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**High-voltage switchgear and controlgear –
Part 37-013: Alternating current generator circuit-breakers**

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CONTENTS

FOREWORD.....	13
1 Scope.....	16
2 Normative references	16
3 Terms and definitions	17
3.1 General terms and definitions	17
3.2 Assemblies of switchgear and controlgear	20
3.3 Parts of assemblies	20
3.4 Switching devices	21
3.5 Parts of switchgear and controlgear	24
3.6 Operational characteristics of switchgear and controlgear.....	27
3.7 Characteristic quantities	31
3.8 Index of definitions.....	45
4 Normal and special service conditions	49
4.1 Normal service conditions	49
4.2 Special service conditions.....	49
4.2.1 General	49
4.2.2 Altitude	49
4.2.3 Exposure to pollution	49
4.2.4 Temperature and humidity	49
4.2.5 Exposure to abnormal vibrations, shock or tilting	49
4.2.6 Wind speed	49
4.2.7 Other parameters	50
5 Ratings.....	50
5.1 General.....	50
5.2 Rated voltage (U_r , U_{rgcb_side} , U_{rsd_side})	50
5.3 Rated insulation level (U_d , U_p)	51
5.4 Rated frequency (f_r).....	52
5.5 Rated continuous current (I_r)	52
5.6 Rated short-time withstand current (I_k)	55
5.7 Rated peak withstand current (I_p)	55
5.8 Rated duration of short circuit (t_k).....	55
5.9 Rated supply voltage of auxiliary and control circuits (U_a)	55
5.9.1 General	55
5.9.2 Rated supply voltage (U_a)	55
5.10 Rated supply frequency of auxiliary and control circuits	56
5.11 Rated pressure of compressed gas supply for controlled pressure systems.....	56
5.101 Rated short-circuit current (I_{sc})	56
5.102 Rated short-circuit making current I_{MC}	61
5.103 Rated load breaking current.....	62
5.104 Rated out-of-phase making and breaking current	62
5.105 Rated transient recovery voltage (TRV)	62
5.106 Rated operating sequence	65

5.107	Mechanical operation endurance capability of generator circuit-breakers, main-disconnectors, starting switches, BTB-switches and braking switches of classes M1, M2 and M3	65
5.108	Rated first-pole-to-clear factor	65
6	Design and construction	65
6.1	Requirements for liquids in switchgear and controlgear	65
6.2	Requirements for gases in switchgear and controlgear	65
6.3	Earthing of switchgear and controlgear	66
6.4	Auxiliary and control equipment and circuits	66
6.5	Dependent power operation	67
6.6	Stored energy operation	67
6.7	Independent unlatched operation (independent manual or power operation)	67
6.8	Manually operated actuators	67
6.9	Operation of releases	67
6.9.1	General	67
6.9.2	Shunt closing release	67
6.9.3	Shunt opening release	67
6.9.4	Capacitor operation of shunt releases	68
6.9.5	Under-voltage release	68
6.9.101	Multiple releases	68
6.9.102	Operation limits of releases	68
6.9.103	Power consumption of releases	68
6.10	Pressure/level indication	68
6.10.1	Gas pressure	68
6.10.2	Liquid level	68
6.11	Nameplates	68
6.11.1	General	68
6.11.2	Application	68
6.12	Locking devices	75
6.13	Position indication	75
6.14	Degrees of protection provided by enclosures	76
6.14.1	General	76
6.14.2	Protection of persons against access to hazardous parts and protection of the equipment against ingress of solid foreign objects (IP coding)	77
6.14.3	Protection against ingress of water (IP coding)	77
6.14.4	Protection against mechanical impact under normal service conditions (IK coding)	77
6.15	Creepage distances for outdoor insulators	77
6.16	Gas and vacuum tightness	77
6.17	Tightness for liquid systems	77
6.18	Fire hazard (flammability)	77
6.19	Electromagnetic compatibility (EMC)	77
6.20	X-ray emission	77
6.21	Corrosion	77
6.22	Filling levels for insulation, switching and/or operation	77
6.101	Requirements for simultaneity of poles during single closing and single opening operations	78
6.102	General requirement for operation	78
6.103	Pressure limits of fluids for operation	78
6.104	Vent outlets of generator circuit-breakers	78

6.105	Warning labels	79
6.106	Instructions	79
6.107	Low-and high-pressure interlocking devices	79
7	Type tests	79
7.1	General.....	79
7.1.1	Basics	79
7.1.2	Information for identification of test objects.....	81
7.1.3	Information to be included in type test reports	81
7.2	Dielectric tests	81
7.2.1	General	81
7.2.2	Ambient air conditions during tests	82
7.2.3	Wet test procedure	84
7.2.4	Arrangement of the equipment.....	84
7.2.5	Criteria to pass the test	85
7.2.6	Application of the test voltage and test conditions.....	85
7.2.7	Tests of switchgear and controlgear of $U_T \leq 245$ kV	85
7.2.8	Tests of switchgear and controlgear of $U_T > 245$ kV	85
7.2.9	Artificial pollution tests for outdoor insulators.....	85
7.2.10	Partial discharge tests	85
7.2.11	Dielectric tests on auxiliary and control circuits.....	86
7.2.12	Voltage test as a condition check	86
7.3	Radio interference voltage (RIV) tests.....	86
7.4	Resistance measurement.....	86
7.4.1	Measurement of the resistance of auxiliary contacts class 1 and class 2	86
7.4.2	Measurement of the resistance of auxiliary contacts class 3	86
7.4.3	Electrical continuity of earthed metallic part tests	86
7.4.4	Resistance measurement of contacts and connections in the main circuit as a condition check.....	86
7.5	Continuous current tests	87
7.5.1	Condition of the test object.....	87
7.5.2	Arrangement of the equipment.....	87
7.5.3	Test current and duration.....	89
7.5.4	Temperature measurement during test	89
7.5.5	Resistance of the main circuit.....	89
7.5.6	Criteria to pass test	89
7.6	Short-time withstand current and peak withstand current tests	90
7.6.1	General	90
7.6.2	Arrangement of the equipment and of the test circuit	90
7.6.3	Test current and duration.....	90
7.6.4	Conditions of the test object after test.....	91
7.7	Verification of the protection	91
7.7.1	Verification of the IP coding.....	91
7.7.2	Verification of the IK coding.....	91
7.8	Tightness tests	91
7.9	Electromagnetic compatibility tests (EMC)	91
7.10	Additional tests on auxiliary and control circuits	91
7.10.1	General	91
7.10.2	Functional tests	91
7.10.3	Verification of the operational characteristics of auxiliary contacts	91

7.10.4	Environmental tests	91
7.10.5	Dielectric tests	92
7.11	X-radiation test for vacuum interrupters	92
7.101	Mechanical and environmental tests	92
7.102	Miscellaneous provisions for making and breaking tests	102
7.103	System-source short-circuit making and breaking tests	135
7.104	Load current breaking tests.....	142
7.105	Generator-source short-circuit current making and breaking tests	143
7.106	Out-of-phase making and breaking tests	158
7.107	Generator circuit-breakers with alternative operating mechanisms	163
8	Routine tests	164
8.1	General.....	164
8.2	Dielectric test on the main circuit	164
8.3	Tests on auxiliary and control circuits	165
8.3.1	Inspection of auxiliary and control circuits, and verification of conformity to the circuit diagrams and wiring diagrams	165
8.3.2	Functional tests	165
8.3.3	Verification of protection against electrical shock.....	165
8.3.4	Dielectric tests.....	165
8.4	Measurement of the resistance of the main circuit.....	166
8.5	Tightness test	166
8.5.1	General	166
8.5.2	Controlled pressure systems for gas.....	166
8.5.3	Closed pressure systems for gas	166
8.5.4	Sealed pressure systems.....	166
8.5.5	Liquid tightness tests	166
8.6	Design and visual checks.....	167
8.101	Mechanical operating tests of generator circuit-breakers.....	167
8.102	Dielectric tests on the enclosure of generator circuit-breaker systems	168
9	Guide to the selection of switchgear and controlgear	168
9.101	General.....	168
9.102	General application conditions	169
9.103	Application consideration	171
10	Information to be given with enquiries, tenders and orders (informative).....	202
10.1	General.....	202
10.2	Information with enquiries and orders	202
10.3	Information with tenders.....	203
11	Transport, storage, installation, operating instructions and maintenance	205
11.1	General.....	205
11.2	Conditions during transport, storage and installation	205
11.3	Installation	205
11.3.1	General	205
11.3.2	Unpacking and lifting	205
11.3.3	Assembly.....	206
11.3.4	Mounting	206
11.3.5	Connections	206
11.3.6	Information about gas and gas mixtures for controlled and closed pressure systems	206
11.3.7	Final installation inspection.....	206

11.3.8	Basic input data by the user	207
11.3.9	Basic input data by the manufacturer	207
11.4	Operating instructions	211
11.5	Maintenance	211
11.5.1	General	211
11.5.2	Information about fluids and gas to be included in maintenance manual	211
11.5.3	Recommendations for the manufacturer	211
11.5.4	Recommendations for the user	213
11.5.5	Failure report	213
12	Safety	214
12.1	General	214
12.2	Precautions by manufacturers	215
12.3	Precautions by users	215
13	Influence of the product on the environment	216
Annex A (normative) Tolerances on test quantities during type tests		217
Annex B (normative) Records and reports of type tests specified in 7.6, 7.103, 7.104, 7.105 and 7.106		224
B.1	Information and results to be recorded	224
B.2	Information to be included in type test reports	224
B.2.1	General	224
B.2.2	Apparatus tested	224
B.2.3	Rated characteristics of generator circuit-breaker, including its operating devices and auxiliary equipment	224
B.2.4	Test conditions (for each series of tests)	225
B.2.5	Short-circuit making and breaking tests	225
B.2.6	Short-time withstand current test	226
B.2.7	No-load operation	226
B.2.8	Out-of-phase making and breaking tests	226
B.2.9	Load current breaking tests	227
B.2.10	Graphical records	227
Annex C (normative) Method for determining the reference travel band closing and the reference travel band opening of the mechanical characteristics		228
C.1	General	228
C.2	Reference travel band closing	228
C.3	Reference travel band opening	228
Annex D (informative) Example of the application of a generator circuit-breaker		230
D.1	General	230
D.2	System characteristics	230
D.3	System-source short-circuit current	232
D.3.1	AC component of the system-source short-circuit breaking current	232
D.3.2	Asymmetrical system-source short-circuit breaking current	233
D.4	Generator-source short-circuit current	235
D.4.1	AC component of the generator-source short-circuit breaking current	235
D.4.2	Asymmetrical generator-source short-circuit breaking current	236
D.5	Transient recovery voltage	239
D.6	Out-of-phase conditions	239
D.7	Continuous current application	242
D.8	Generator circuit-breaker electrical characteristics	243

Annex E (informative) Example of the application of a generator circuit-breaker with multiple generators	245
E.1 General.....	245
E.2 System-source short-circuit current with additional generator contribution	246
E.2.1 General	246
E.2.2 AC component of the system-source short-circuit breaking current	246
E.2.3 Asymmetrical system-source short-circuit breaking current.....	246
E.3 Generator-source short-circuit current.....	246
E.4 Calculation based on power plant layout	247
E.4.1 System-source short-circuit current with additional generator contribution	247
E.4.2 Generator-source short-circuit current	247
E.5 Power plant layout with additional generator circuit-breaker connected at the generator voltage terminals of the step-up transformer	247
E.5.1 General	247
E.5.2 System-source short-circuit breaking current	248
E.5.3 Multiple generator-source short-circuit breaking current.....	248
E.6 Transient recovery voltage.....	248
Annex F (informative) Effects on TRV requirements due to the capacitance added when shielded cables connect generator circuit-breakers to the step-up transformer	249
Annex G (informative) Symbols and related terminology	252
G.1 Comparison of IEEE and IEC electrical terms and symbols	252
G.2 Comparison between TRV terminology and symbols	253
Annex H (informative) Determination of the degree of asymmetry for generator-source short-circuit breaking tests.....	255
Annex I (informative) Faults in circuits with a three-winding step-up transformer.....	257
Annex J (normative) Requirements for testing and application of Tee-OFF generator circuit-breakers in power plant layouts	260
Annex K (normative) Requirements for doubly-fed induction machines (DFIMs) applications	267
K.1 General.....	267
K.2 Transient stator and rotor currents	267
K.3 Stator currents in case of a three-phase fault.....	268
K.4 DC component of the short-circuit current	268
K.5 AC component of the short-circuit current	268
K.6 Influence of rotor's slip.....	269
K.7 Influence of the crowbar resistor	269
K.8 Influence of pre-fault loading conditions	269
K.9 Specific requirements for the application of generator circuit-breakers.....	269
Annex L (normative) Requirements for wind farm applications	271
L.1 General.....	271
L.2 Generators without power electronic converters	271
L.3 Generators with full-scale power electronic converters connected at the stator of the generator	271
L.4 Generators with partial-scale power electronic converters connected at the rotor of the generator	272
L.5 Breaking tests.....	272
L.5.1 General	272
L.5.2 Low frequency breaking tests	272
L.5.3 High frequency breaking tests	275

Annex M (normative) Assessment of TRV test parameters for out-of-phase current breaking in the case of generator circuit-breakers equipped with capacitors	279
Annex N (normative) Assessment of TRV test parameters for load current breaking in the case of generator circuit-breakers equipped with capacitors	281
Annex O (normative) Requirements for pumped-storage applications	283
O.1 General.....	283
O.2 Phase-reversal-disconnector.....	285
O.3 Starting switch and BTB-switch.....	285
O.4 Braking switch	285
O.5 Breaking tests.....	287
O.5.1 General	287
O.5.2 Low frequency breaking tests	287
Annex P (informative) Derivation of the humidity exponent w	288
Bibliography.....	292
Figure 1 – Example of a graphical record of a three-phase short-circuit make-break test	40
Figure 2 – Generator circuit-breaker without resistors – Opening operation	41
Figure 3 – Generator circuit-breaker without resistors – Close-open cycle	41
Figure 4 – Generator circuit-breaker with opening resistors – Opening operation.....	42
Figure 5 – Generator circuit-breaker with opening resistors – Close-open cycle.....	43
Figure 6 – Example of a three-phase asymmetrical current.....	43
Figure 7 – Examples of possible interruptions in a phase with intermediate level of asymmetry after a major loop and a corresponding time t_1	44
Figure 8 – Examples of possible interruptions in a phase with intermediate level of asymmetry after a minor loop and a corresponding time t_2	44
Figure 9 – Effect of various cooling failures and subsequent load reductions on generator circuit-breaker (system) temperature.....	54
Figure 10 – Typical asymmetrical system-source short-circuit current.....	58
Figure 11 – Degree of asymmetry as a function of time after fault initiation	59
Figure 12 – Typical asymmetrical generator-source short-circuit current with a strong decrement of the AC component.....	60
Figure 13 – Two-parameter representation of prospective TRV waveform for interrupting three-phase symmetrical faults.....	63
Figure 14 – Typical continuous current test setup for single-phase enclosed generator circuit-breaker systems (top view).....	88
Figure 15 – Test sequences for low and high temperature tests.....	102
Figure 16 – Reference travel curve measured during the three-phase breaking test (idealised curve)	107
Figure 17 – Reference travel curve measured during the three-phase breaking test (idealised curve) with the specified envelopes centred over the reference travel curve	108
Figure 18 – Reference travel curve measured during the three-phase breaking test (idealised curve) with the specified envelopes fully displaced upward from the reference travel curve	108
Figure 19 – Reference travel curve measured during the three-phase breaking test (idealised curve) with the specified envelopes fully displaced downward from the reference travel curve	109
Figure 20 – Equivalent testing set-up for unit testing of generator circuit-breakers with more than one separate interrupters	110

Figure 21 – Two valid three-phase symmetrical breaking operations	118
Figure 22 – Three-phase asymmetrical breaking operation – Minimum arcing time in a phase with intermediate level of asymmetry after a major loop ($t_{arc\ asym\ min\ 1}$)	120
Figure 23 – Three-phase asymmetrical breaking operation – Maximum arcing time for a first-pole-to-clear at maximum asymmetry criteria after a major loop ($t_{arc\ asym\ max\ 1}$)	121
Figure 24 – Three-phase asymmetrical breaking operation – Minimum arcing time in a phase with intermediate level of asymmetry after a minor loop ($t_{arc\ asym\ min\ 2}$)	122
Figure 25 – Three-phase asymmetrical breaking operation – Maximum arcing time for a last-pole-to-clear at maximum asymmetry criteria after a major extended loop ($t_{arc\ asym\ max\ 2}$)	123
Figure 26 – Single-phase asymmetrical breaking operation – Minimum arcing time in a phase with intermediate level of asymmetry after a major loop ($t_{arc\ asym\ min\ 1}$)	127
Figure 27 – Single-phase asymmetrical breaking operation – Maximum arcing time for a first-pole-to-clear at maximum asymmetry criteria after a major loop ($t_{arc\ asym\ max\ 1}$)	128
Figure 28 – Single-phase asymmetrical breaking operation – Minimum arcing time in a phase with intermediate level of asymmetry after a minor loop ($t_{arc\ asym\ min\ 2}$)	130
Figure 29 – Single-phase asymmetrical breaking operation – Maximum arcing time for a last-pole-to-clear at maximum asymmetry criteria after a major extended loop ($t_{arc\ asym\ max\ 2}$)	130
Figure 30 – Earthing of test circuits for three-phase short-circuit tests, first-pole-to-clear factor 1,5	136
Figure 31 – Earthing of test circuits for single-phase short-circuit tests, first-pole-to-clear factor 1,5	136
Figure 32 – Example of a valid prospective test current for test-duty 5	147
Figure 33 – Example of a valid test for test-duty 5	148
Figure 34 – Example of a valid test with a subsequent minor loop for test-duty 5	148
Figure 35 – Example of an invalid test for test-duty 5	149
Figure 36 – Example of an invalid test with a subsequent minor loop for test-duty 5	149
Figure 37 – Second example of a valid test for test-duty 5	150
Figure 38 – Second example of a valid test with a subsequent minor loop for test-duty 5	150
Figure 39 – Example of a valid prospective test current for test-duties 6A and 6B	151
Figure 40 – Example of a valid test for test-duties 6A and 6B	152
Figure 41 – Example of a valid test for test-duties 6A and 6B	153
Figure 42 – Example of a valid test with a subsequent minor loop for test-duties 6A and 6B	153
Figure 43 – Example of an invalid test for test-duties 6A and 6B	154
Figure 44 – Example of an invalid test with a subsequent minor loop for test-duties 6A and 6B	154
Figure 45 – Example of a valid test for test-duties 6A and 6B after adapting the contact separation compared to Figure 43 or Figure 44	155
Figure 46 – Test circuit for single-phase out-of-phase tests	161
Figure 47 – Test circuit for out-of-phase tests using two voltages separated by 120 electrical degrees	161
Figure 48 – Test circuit for out-of-phase tests with one terminal of the generator circuit-breaker earthed (subject to agreement of the manufacturer)	161

Figure 49 – General circuit diagram of a power plant	173
Figure 50 – Generator-source short-circuit current	176
Figure 51 – Generator-source short-circuit current in the case of generator delivering power with lagging or leading power factor prior to fault initiation	177
Figure 52 – Short-circuit current for generator-source fault	178
Figure 53 – Short-circuit current with circuit-breaker arc voltage after contact separation	180
Figure 54 – Single-line diagram of a power plant with two generators connected to the high-voltage system by means of a three-winding step-up transformer	189
Figure 55 – Single-line diagram of unit generator system	191
Figure 56 – Single-line diagram of half-sized transformer unit system	191
Figure 57 – Single-line diagram of system with half-sized generators	192
Figure 58 – Single-line diagram of power system	196
Figure 59 – Equivalent circuit of power system	196
Figure 60 – Voltage diagram for lagging power factor load	197
Figure 61 – Voltage diagram for unity power factor load	197
Figure 62 – Recovery voltage across the generator circuit-breaker	197
Figure 63 – TRV curve for the first-pole-to-clear	198
Figure C.1 – Reference travel band closing	229
Figure C.2 – Reference travel band opening	229
Figure D.1 – Single-line power plant diagram	230
Figure D.2 – Asymmetrical generator-source short-circuit current with no arc at the fault location	238
Figure D.3 – Asymmetrical generator-source short-circuit current with arc at the fault location	238
Figure D.4 – Schematic diagram of power plant (single-line diagram as in Figure 55)	240
Figure D.5 – Prospective fault current considering the moment of inertia of the synchronous machine and resulting from synchronising under out-of-phase conditions	241
Figure D.6 – Generator circuit-breaker temperature and load current with loss of coolant	243
Figure E.1 – Single-line power plant diagram with two generators	245
Figure E.2 – Single-line power plant diagram with two generators and three GCBs	247
Figure F.1 – TRV rate-of-rise for system-source faults: transformers rated from 65,5 MVA to 100 MVA	250
Figure F.2 – TRV peak (u_c) multipliers for system-source faults: transformers rated from 65,5 MVA to 100 MVA	250
Figure F.3 – TRV rate-of-rise for system-source faults: transformers rated from 10 MVA to 50 MVA	251
Figure F.4 – TRV peak (u_c) multipliers for system-source faults: transformers rated from 10 MVA to 50 MVA	251
Figure G.1 – Two-parameter TRV envelope representation of 1-cosine TRV when interrupting three-phase symmetrical fault currents	254
Figure H.1 – Prospective generator-source short-circuit current (fault initiation at voltage zero)	256
Figure I.1 – Single-line diagram of a power plant with two generators connected to the high-voltage system by means of a three-winding step-up transformer	257
Figure I.2 – Prospective fault current to be interrupted by Generator circuit-breaker #1	258

Figure I.3 – Prospective fault current to be interrupted by Generator circuit-breaker #2	259
Figure J.1 – Single-line diagram of a power plant with Tee-OFF generator circuit-breaker and generator circuit-breaker.....	260
Figure J.2 – Power plant electrical layout with Tee-OFF generator circuit-breaker – fault locations considered for setting the requirements for the application of the Tee-OFF generator circuit-breaker.....	261
Figure K.1 – Equivalent circuit of a DFIM.....	267
Figure K.2 – Example of influence of crowbar resistor on generator-source short-circuit current.....	270
Figure O.1 – Pumped-storage power plant – Typical single line diagram	284
Figure O.2 – Braking switch single line diagram.....	286
Figure P.1 – Humidity exponent w	289
Figure P.2 – Humidity correction factor k_2 (example 1)	290
Figure P.3 – Humidity correction factor k_2 (example 2)	291
Table 1 – Rated insulation levels for generator circuit-breakers and generator circuit-breaker systems	52
Table 2 – Preferred values of supply voltages and their ranges for auxiliary and control circuits of generator circuit-breakers and generator circuit-breaker systems	56
Table 3 – TRV parameters for system-source short-circuit tests.....	64
Table 4 – TRV parameters for generator-source short-circuit tests.....	64
Table 5 – TRV parameters for load current tests	64
Table 6 – TRV parameters for out-of-phase tests	65
Table 7 – Nameplate information for generator circuit-breakers	69
Table 8 – General nameplate information for generator circuit-breaker systems.....	71
Table 9 – Nameplate information for generator circuit-breakers, being part of a generator circuit-breaker system.....	72
Table 10 – Nameplate information for main-disconnector, switches and short-circuiting connections, being part of a generator circuit-breaker system.....	74
Table 11 – Type tests	81
Table 12 – Conditions during continuous current test.....	89
Table 13 – Number of operating sequences	96
Table 14 – Operations to be performed before and after the test programme	97
Table 15 – Test parameters for 50 Hz asymmetrical system-source fault test-duties for the first-pole-to-clear	131
Table 16 – Test parameters for 60 Hz asymmetrical system-source fault test-duties for the first-pole-to-clear	132
Table 17 – Test parameters for 50 Hz asymmetrical system-source fault test-duties for the last-pole-to-clear.....	133
Table 18 – Test parameters for 60 Hz asymmetrical system-source fault test-duties for the last-pole-to-clear.....	134
Table 19 – Test parameters for commutation tests at 50 Hz and 60 Hz.....	140
Table 20 – Test-duties to demonstrate the system-source short-circuit making and breaking current capability for three-phase tests.....	141
Table 21 – Test-duties to demonstrate the system-source short-circuit making and breaking current capability for single-phase tests.....	142

Table 22 – Test-duties to demonstrate the generator-source short-circuit making and breaking current capability for three-phase tests	156
Table 23 – Test-duties to demonstrate the generator-source short-circuit making and breaking current capability for single-phase tests.....	157
Table 24 – Test-duties to demonstrate the out-of-phase current making and breaking capability for three-phase tests	159
Table 25 – Test-duties to demonstrate the out-of-phase current making and breaking capability for single-phase tests	160
Table A.1 – Tolerances on test quantities for type tests	218
Table D.1 – System characteristics	231
Table G.1 – Comparison of IEEE and IEC electrical terms and symbols.....	252
Table G.2 – Comparison between the TRV terminology and symbols used in this document and those used in older IEEE/ANSI standards	254
Table I.1 – Comparison between prospective system-source short-circuit currents to be interrupted by Generator circuit-breaker #1 in the case of a three-phase earthed fault occurring at location F in Figure I.1	258
Table J.1 – TRV parameters related to the breaking of the Tee-OFF generator circuit-breaker short-circuit current	263
Table J.2 – Nameplate information for Tee-OFF generator circuit-breakers.....	265
Table L.1 – TRV parameters for low frequency generator-source faults	273
Table L.2 – Test-duties to demonstrate the low frequency breaking capability for three-phase tests.....	274
Table L.3 – Test-duties to demonstrate the low frequency breaking capability for single-phase tests	275
Table L.4 – TRV parameters for high frequency generator-source faults.....	276
Table L.5 – Test-duties to demonstrate the high frequency breaking capability for three-phase tests.....	277
Table L.6 – Test-duties to demonstrate the high frequency breaking capability for single-phase tests	278
Table M.1 – Reference values for MVA classes	280

INTERNATIONAL ELECTROTECHNICAL COMMISSION

HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

Part 37-013: Alternating current generator circuit-breakers

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IEC/IEEE 62271-37-013 was prepared by subcommittee 17A: High-voltage switchgear and controlgear, of IEC technical committee 17: Switchgear and controlgear, in cooperation with the Switchgear Committee of the IEEE Power and Energy Society¹, under the IEC/IEEE Dual Logo Agreement between IEC and IEEE. It is an International Standard.

This document is published as an IEC/IEEE Dual Logo standard.

The IEEE Std C37.013™-1997 (R2008) was revised and converted into the first edition of the IEC/IEEE Dual Logo International Standard IEC/IEEE 62271-37-013 published in 2015.

This second edition cancels and replaces the first edition published in 2015. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) content has been added to address the requirements of the other components of the generator circuit breaker system;
- b) requirements for the application of generator circuit-breakers in power plants with multiple generators connected to one step-up transformer have been added;
- c) requirements for testing and application of Tee-OFF generator circuit-breakers have been added;
- d) requirements for application of generator circuit-breakers in power plants with doubly-fed induction machines, pumped-storage power plants, and wind farms have been added;
- e) the clause numbering has been aligned with the numbering in IEC 62271-1:2017;
- f) the topic of reference mechanical characteristics has been revised to improve clarity;
- g) the modifying effects of capacitors on the prospective TRVs for out-of-phase and load current switching has been addressed in Annex M and in Annex N with use of the tool named "GenCB TRV calculator". This tool provides the values of K_{E2} , $RRRV_0$, K_{RRRV-U} , K_{RRRV-I} , t_{d0} , K_{td-U} , K_{td-I} , as well as the values of the parameters of the prospective TRV modified by the capacitors of the generator circuit-breaker.

The text of this International Standard is based on the following IEC documents:

FDIS	Report on voting
17A/1318/FDIS	17A/1327/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with the rules given in the ISO/IEC Directives, Part 2, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

¹ A list of IEEE participants can be found at the following address:
http://standards.ieee.org/downloads/62271/62271-37-013-2015/62271-37-013-2015_wg-participants.pdf.

This document is to be read in conjunction with IEC 62271-1, to which it refers and which is applicable unless otherwise specified. In order to simplify the indication of corresponding requirements, the same numbering of clauses and subclauses is used as in IEC 62271-1. Amendments to these clauses and subclauses are given under the same numbering, while additional subclauses are numbered from 101.

This document contains attached files in the form of Excel spreadsheets ("GenCB TRV calculator"). These files are intended to be used as a complement and do not form an integral part of the document.

A list of all parts in the IEC 62271 series, published under the general title *High-voltage switchgear and controlgear*, can be found on the IEC website.

The IEC Technical Committee and IEEE Technical Committee have decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

Part 37-013: Alternating current generator circuit-breakers

1 Scope

This part of IEC 62271 is applicable to three-phase AC high-voltage generator circuit-breakers, hereafter called generator circuit-breakers, designed for indoor or outdoor installation and for operation at frequencies of 50 Hz and 60 Hz on systems having voltages above 1 kV and up to 38 kV.

It is applicable to generator circuit-breakers that are installed between the generator and the transformer terminals. Requirements relative to generator circuit-breakers intended for use with generators and transformers rated 10 MVA or more are covered specifically. Generator circuits rated less than 10 MVA and pumped-storage installations are considered special applications, and their requirements are not completely covered by this document.

This document is also applicable to the operating mechanisms of generator circuit-breakers and to their auxiliary equipment.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

If not otherwise specified throughout this document, the relevant IEC or IEEE standards for the particular components or functions of a generator circuit-breaker system apply.

IEC 60050-441, *International Electrotechnical Vocabulary (IEV) – Part 441: Switchgear, controlgear and fuses* (available at <http://www.electropedia.org>)

IEC 60060-1:2010, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60071-1:2019, *Insulation co-ordination – Part 1: Definition, principles and rules*

IEC 60071-2:2018, *Insulation co-ordination – Part 2: Application guidelines*

IEC 60296, *Fluids for electrotechnical applications – Mineral insulating oils for electrical equipment*

IEC 60480, *Specifications for the re-use of sulphur hexafluoride (SF₆) and its mixtures in electrical equipment*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 60664-1, *Insulation co-ordination for equipment within low-voltage supply systems – Part 1: Principles, requirements and tests*

IEC 62262, *Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK code)*

IEC 62271-1, *High-voltage switchgear and controlgear – Part 1: Common specifications for alternating current switchgear and controlgear*

IEC IEEE 62271-37-082, *High-voltage switchgear and controlgear – Part 37-082: Standard practice for the measurement of sound pressure levels on alternating current circuit-breakers*

IEC 62271-100:2021, *High-voltage switchgear and controlgear – Part 100: Alternating current circuit-breakers*

IEC 62271-101:2021, *High-voltage switchgear and controlgear – Part 101: Synthetic testing*

IEC 62271-102:2018, *High-voltage switchgear and controlgear – Part 102: Alternating current disconnectors and earthing switches*

IEC TR 62271-306, *High-voltage switchgear and controlgear – Part 306: Guide to IEC 62271-100, IEC 62271-1 and other IEC standards related to alternating current circuit-breakers*

IEEE Std C37.011™, *IEEE Guide for the Application of Transient Recovery Voltage for AC High-Voltage Circuit Breakers with Rated Maximum Voltage above 1000 V²*

IEEE Std C37.59™, *IEEE Standard Requirements for Conversion of Power Switchgear Equipment*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-441 and IEC 62271-1 and the following apply.

For definitions not specifically called out in this document, the following references could be useful:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>
- IEEE Standards Online Dictionary: available at <http://dictionary.ieee.org>

NOTE Additional definitions are classified to be aligned with the classification used in IEC 60050-441.

3.1 General terms and definitions

3.1.101

switchgear and controlgear

general term covering switching devices and their combination with associated control, measuring, protective and regulating equipment, also assemblies of such devices and equipment with associated interconnections, accessories, enclosures and supporting structures

[SOURCE: IEC 60050-441:1984, 441-11-01]

² The IEEE standards or products referred to in this clause are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

3.1.102**short-circuit current**

over-current resulting from a short circuit due to a fault or an incorrect connection in an electric circuit

[SOURCE: IEC 60050-441:1984, 441-11-07]

3.1.103**moment of inertia**

sum (integral) of the products of the mass elements of a body and the squares of their distances (radii) from a given axis

3.1.104**out-of-phase conditions**

abnormal circuit conditions of loss or lack of synchronism between the parts of an electrical system on either side of a generator circuit-breaker in which, at the instant of operation of the generator circuit-breaker, the phase angle between rotating vectors, representing the generated voltages on either side, exceeds the normal value

3.1.105**out-of-phase**

<as prefix to a characteristic quantity> qualifying term indicating that the characteristic quantity is applicable to operation of the generator circuit-breaker in out-of-phase conditions

3.1.106**unit test**

test made on a making or breaking unit or group of units at the making current or the breaking current, specified for the test on the complete pole of a generator circuit-breaker and at the appropriate fraction of the applied voltage, or the recovery voltage, specified for the test on the complete pole of the generator circuit-breaker

3.1.107**loop**

<of an AC current wave> part of the wave of the AC current between two successive current zero crossings

SEE: Figure 1 *n* and *p*.

Note 1 to entry: When a DC component (see Figure 1 *d*) is present, a distinction is made between a major loop (see Figure 1 *n*) and a minor loop (see Figure 1 *p*) depending on the time interval between two successive current zero crossings being longer or shorter, respectively, than the half-period of the alternating component of the current.

3.1.108**power factor**

<of a circuit> ratio of the resistance to the impedance at power frequency of an equivalent circuit supposed to be formed by a reactance and a resistance in series

3.1.109**external insulation**

distances in air and along the surfaces in contact with atmospheric air of solid insulation of the equipment, which are subject to dielectric stresses and to the effects of atmospheric and other environmental conditions from the site

Note 1 to entry: Examples of environmental conditions are pollution, humidity, vermin, etc.

[SOURCE: IEC 60050-614:2016, 614-03-02, modified – replacement of "atmospheric air" by "air".]

3.1.110
disruptive discharge

phenomenon associated with the failure of insulation under electric stress, in which the discharge completely bridges the insulation under test, reducing the voltage between the electrodes to zero or nearly to zero

Note 1 to entry: This term applies to discharges in solid, liquid and gaseous dielectrics and to combinations of these.

Note 2 to entry: A disruptive discharge in a solid dielectric produces permanent loss of dielectric strength (non-self-restoring insulation); in a liquid or gaseous dielectric, the loss may be only temporary (self-restoring insulation).

Note 3 to entry: The term "sparkover" is used when a disruptive discharge occurs in a gaseous or liquid dielectric. The term "flashover" is used when a disruptive discharge occurs over the surface of a solid dielectric in a gaseous or liquid medium. The term "puncture" is used when a disruptive discharge occurs through a solid dielectric.

3.1.111
non-sustained disruptive discharge
NSDD

disruptive discharge associated with current interruption that does not result in the resumption of power-frequency current or, in the case of capacitive current interruption, does not result in current in the main load circuit

Note 1 to entry: Oscillations following NSDDs are associated with the parasitic capacitance and inductance local to or of the circuit-breaker itself. NSDDs may also involve the stray capacitance to earth of nearby equipment.

3.1.112
effectively earthed neutral system

system earthed through a sufficiently low impedance such that for all system conditions the ratio of the zero-sequence reactance to the positive-sequence reactance (X_0/X_1) is positive and less than 3, and the ratio of the zero-sequence resistance to the positive-sequence reactance (R_0/X_1) is positive and less than 1

Note 1 to entry: Normally such systems are solidly earthed (neutral) systems or low impedance earthed (neutral) systems.

Note 2 to entry: For the correct assessment of the earthing conditions not only the physical earthing conditions around the relevant location but the total system is to be considered.

3.1.113
non-effectively earthed neutral system

system other than effectively earthed neutral system, not meeting the conditions given in 3.1.112

Note 1 to entry: Normally such systems are isolated neutral systems, high impedance earthed (neutral) systems or resonant earthed (neutral) systems.

Note 2 to entry: For the correct assessment of the earthing conditions not only the physical earthing conditions around the relevant location but the total system is to be considered.

3.1.114
re-ignition

<of an AC mechanical switching device> resumption of current between the contacts of a mechanical switching device during a breaking operation with an interval of zero current of less than a quarter cycle of power frequency

[SOURCE: IEC 60050-441:1984, 441-17-45]

3.1.115
restrike

<of an AC mechanical switching device> resumption of current between the contacts of a mechanical switching device during a breaking operation with an interval of zero current of a quarter cycle of power frequency or longer

[SOURCE: IEC 60050-441:1984, 441-17-46]

3.1.116
isolated-phase bus
IPB

bus in which each phase conductor is enclosed by an individual earthed metal housing separated from adjacent conductor housings by an air space

Note 1 to entry: The bus may be self-cooled or may be forced-cooled by means of circulating gas or liquid.

3.1.117
internal insulation

internal distances of the solid, liquid or gaseous insulation of equipment which are protected from the effects of atmospheric and other external conditions

[SOURCE: IEC 60050-614:2016, 614-03-03]

3.2 Assemblies of switchgear and controlgear**3.2.101**
generator circuit-breaker system

assembly, utilising a generator circuit-breaker as one of the components

Note 1 to entry: Examples are assemblies which are not covered by IEC 62271-200 [17], IEEE C37.20.2 [18], or IEEE C37.20.3 [19].

Note 2 to entry: Generator circuit-breaker systems are covered in this document to ensure harmonization of requirements of the various components which form part of the system.

3.3 Parts of assemblies**3.3.101**
component

<of a generator circuit-breaker system> essential part of a generator circuit-breaker system which serves one or several specific functions

Note 1 to entry: If not otherwise specified throughout this document, the relevant IEC or IEEE standards for the particular components or functions apply.

Note 2 to entry: The following are examples of components or functions of a generator circuit-breaker system:

- generator circuit-breaker;
- main-disconnector;
- phase-reversal-disconnector;
- starting switch;
- ET-switch (3.4.121);
- Tee-OFF-switch (3.4.122);
- Tee-OFF generator circuit-breaker (3.4.132);
- BTB-switch (3.4.123);
- earthing switch;
- braking switch;
- short-circuiting connection;
- capacitor;
- instrument transformer;

- surge arrester;
- sensor/monitoring device;
- enclosure;
- cable.

3.4 Switching devices

3.4.101

switching device

device designed to make or break the current in one or more electric circuits

[SOURCE: IEC 60050-441:1984, 441-14-01]

3.4.102

mechanical switching device

switching device designed to close and open one or more electric circuits by means of separable contacts

Note 1 to entry: Any mechanical switching device may be designated according to the medium in which its contacts open and close, e.g. air, SF₆, oil.

[SOURCE: IEC 60050-441:1984, 441-14-02]

3.4.103

circuit-breaker

mechanical switching device, capable of making, carrying and breaking currents under normal circuit conditions and also making, carrying for a specified duration and breaking currents under specified abnormal circuit conditions such as those of short circuit

[SOURCE: IEC 60050-441:1984, 441-14-20]

3.4.104

generator circuit-breaker

circuit-breaker installed between generator and associated step-up transformer

3.4.105

oil circuit-breaker

circuit-breaker in which the contacts open and close in oil

Note 1 to entry: Typical examples of oil circuit-breakers are live tank minimum oil circuit-breakers and dead tank bulk oil circuit-breakers.

[SOURCE: IEC 60050-441:1984, 441-14-28]

3.4.106

vacuum generator circuit-breaker

generator circuit-breaker in which the contacts open and close within a highly evacuated envelope

[SOURCE: IEC 60050-441:1984, 441-14-29 modified – Addition of "generator" before circuit-breaker.]

3.4.107**gas-blast circuit-breaker**

circuit-breaker in which the arc develops in a blast of gas

Note 1 to entry: Where the gas is moved by a difference in pressure established by mechanical means during the opening operation of the circuit-breaker, it is termed a single pressure gas-blast circuit-breaker. Where the gas is moved by a difference in pressure established before the opening operation of the circuit-breaker, it is termed a double pressure gas-blast circuit-breaker.

[SOURCE: IEC 60050-441:1984, 441-14-30]

3.4.108**air-blast circuit-breaker**

gas-blast circuit-breaker in which the gas used is air

[SOURCE: IEC 60050-441:1984, 441-14-32]

3.4.109**generator circuit-breaker class M1**

generator circuit-breaker with normal mechanical endurance

3.4.110**generator circuit-breaker class M2 and class M3**

frequently operated generator circuit-breaker for special service requirements and designed to require only limited maintenance as demonstrated by specific type tests

3.4.111**generator circuit-breaker class G1**

generator circuit-breaker having a rated generator-source short-circuit breaking current characterised at contact separation by a degree of asymmetry of 110 % with the assigned AC component of the rated generator-source short-circuit breaking current and a degree of asymmetry of 130 % with a current having an AC component equal to 74 % of the assigned AC component of the rated generator-source short-circuit breaking current

3.4.112**generator circuit-breaker class G2**

generator circuit-breaker having a rated generator-source short-circuit breaking current characterised at contact separation by a degree of asymmetry of 130 % with the assigned AC component of the rated generator-source short-circuit breaking current

3.4.113**disconnecter**

mechanical switching device which provides, in the open position, an isolating distance in accordance with specified requirements.

Note 1 to entry: A disconnecter is capable of opening and closing a circuit when either negligible current is broken or made, or when no significant change in the voltage across the terminals of each of the poles of the disconnecter occurs. It is also capable of carrying currents under normal circuit conditions and carrying for a specified time currents under abnormal conditions such as those of short circuit.

[SOURCE: IEC 60050-441:1984, 441-14-05]

3.4.114**main-disconnector**

disconnecter, being a component or a function of a generator circuit-breaker system and part of the main current path

3.4.115**main-disconnector class M1**

main-disconnector with normal mechanical endurance

3.4.116

main-disconnector class M2 and class M3

frequently operated main-disconnector for special service requirements and designed so as to require only limited maintenance as demonstrated by specific type tests

3.4.117

starting switch

mechanical switching device, with or without fuse, being a component or a function of a generator circuit-breaker system, to connect the main circuit in order to start up the rotating machine

3.4.118

starting switch class M1

starting switch with normal mechanical endurance

3.4.119

starting switch class M2 and class M3

frequently operated starting switch for special service requirements and designed so as to require only limited maintenance as demonstrated by specific type tests

3.4.120

ET-switch

mechanical switching device, being a component or a function of a generator circuit-breaker system, to connect the main circuit to the excitation transformer

3.4.121

Tee-OFF-switch

mechanical switching device, being a component or a function of a generator circuit-breaker system, to connect the main circuit to the unit auxiliary transformer

3.4.122

BTB-switch

mechanical switching device, with or without fuse, being a component or a function of a generator circuit-breaker system, to connect the main circuit of a rotating machine in order to be used for starting up another rotating machine (back-to-back start-up)

3.4.123

BTB-switch class M1

BTB-switch with normal mechanical endurance

3.4.124

BTB-switch class M2 and class M3

frequently operated BTB-switch for special service requirements and designed so as to require only limited maintenance as demonstrated by specific type tests

3.4.125

earthing switch

mechanical switching device for earthing parts of a circuit, capable of withstanding for a specified time currents under abnormal conditions such as those of short circuit, but not required to carry current under normal conditions of the circuit

3.4.126

short-circuiting connection

busbar which is connected to the three main conductors of a generator circuit-breaker system

3.4.127

manually mounted short-circuiting connection

short-circuiting connection where the connection to the main conductors of the generator circuit-breaker system is made manually (for example by the use of bolts) and which is removed before the generator circuit-breaker system is put back in its normal operational mode

3.4.128

motor operated short-circuiting connection

short-circuiting connection that is connected to the main conductors of the generator circuit-breaker system by closing a motor operated switch

3.4.129

phase-reversal-disconnector

main-disconnector with at least two additional poles used to interchange two phases of the system in the aim of changing the direction of rotation of an electrical rotating machine

3.4.130

braking switch

mechanical switching device, used to establish a three-phase short-circuit in the aim of electrically slowing down a rotating machine already disconnected from the power grid

3.4.131

Tee-OFF generator circuit-breaker

generator circuit-breaker, being a component or a function of a generator circuit-breaker system, to connect the main circuit to the unit auxiliary transformer

3.5 Parts of switchgear and controlgear

3.5.101

pole

portion of a switching device associated exclusively with one electrically separated conducting path of its main circuit and excluding those portions which provide a means for mounting and operating all poles together

Note 1 to entry: A switching device is called single-pole if it has only one pole. If it has more than one pole, it may be called multipole (two-pole, three-pole, etc.) provided the poles are or can be coupled in such a manner as to operate together.

[SOURCE: IEC 60050-441:1984, 441-15-01]

3.5.102

main circuit

all the conductive parts of a switching device included in the circuit which it is designed to close or open

[SOURCE: IEC 60050-441:1984, 441-15-02]

3.5.103

control circuit

<of a switching device> all the conductive parts (other than the main circuit) of a switching device which are included in a circuit used for the closing operation or opening operation, or both, of the device

[SOURCE: IEC 60050-441:1984, 441-15-03]

3.5.104
auxiliary circuit

<of a switching device> all the conductive parts of a switching device which are intended to be included in a circuit other than the main circuit and the control circuits of the device

Note 1 to entry: Some auxiliary circuits fulfil supplementary functions such as signalling, interlocking, etc., and, as such, they may be part of the control circuit of another switching device.

[SOURCE: IEC 60050-441:1984, 441-15-04]

3.5.105
contact

<of a mechanical switching device> conductive parts designed to establish circuit continuity when they touch and which, due to their relative motion during an operation, open or close a circuit or, in the case of hinged or sliding contacts, maintain circuit continuity

[SOURCE: IEC 60050-441:1984, 441-15-05]

3.5.106
main contact

contact included in the main circuit of a mechanical switching device, intended to carry, in the closed position, the current of the main circuit

[SOURCE: IEC 60050-441:1984, 441-15-07]

3.5.107
arcing contact

contact on which the arc is intended to be established

Note 1 to entry: An arcing contact may serve as a main contact; it may be a separate contact so designed that it opens after and closes before another contact which it is intended to protect from injury.

[SOURCE: IEC 60050-441:1984, 441-15-08]

3.5.108
control contact

contact included in a control circuit of a mechanical switching device and mechanically operated by this device

[SOURCE: IEC 60050-441:1984, 441-15-09]

3.5.109
auxiliary contact

contact included in an auxiliary circuit and mechanically operated by the switching device

[SOURCE: IEC 60050-441:1984, 441-15-10]

3.5.110
auxiliary switch

<of a mechanical switching device> switch containing one or more control and/or auxiliary contacts mechanically operated by a switching device

[SOURCE: IEC 60050-441:1984, 441-15-11]

3.5.111

**"a" contact
make contact**

control or auxiliary contact which is closed when the main contacts of the mechanical switching device are closed and open when they are open

[SOURCE: IEC 60050-441:1984, 441-15-12]

3.5.112

**"b" contact
break contact**

control or auxiliary contact which is open when the main contacts of a mechanical switching device are closed and closed when they are open

[SOURCE: IEC 60050-441:1984, 441-15-13]

3.5.113

release

<of a mechanical switching device> device, mechanically connected to a mechanical switching device, which releases the holding means and permits the opening or the closing of the switching device

[SOURCE: IEC 60050-441:1984, 441-15-17]

3.5.114

connection

<bolted or equivalent> two or more conductors designed to ensure permanent circuit continuity when forced together by means of screws, bolts or the equivalent

3.5.115

terminal

component provided for the connection of a device to external conductors

3.5.116

making or breaking unit

part of a generator circuit-breaker which in itself acts as a circuit-breaker and which, operated simultaneously with one or more identical parts in series, forms the complete generator circuit-breaker

Note 1 to entry: Making units and breaking units may be separate or combined. Each unit may have several contacts.

Note 2 to entry: The means controlling the voltage distribution between units may differ from unit to unit.

3.5.117

module

assembly which generally comprises making or breaking units, post-insulators and mechanical parts and which is mechanically and electrically connected to other identical assemblies to form a pole of a generator circuit-breaker

3.5.118
enclosure

component of a generator circuit-breaker system, not intended for use in equipment defined by any other standard, providing a specified degree of protection of equipment against external influences and a specified degree of protection against approach to or contact with live parts and against contact with moving parts

Note 1 to entry: For generator circuit-breakers applied in switchgear and controlgear assemblies, the enclosure requirements are defined by the applicable standard.

Note 2 to entry: A three-phase enclosed generator circuit-breaker system has all three phases in a common enclosure.

Note 3 to entry: A single-phase enclosed generator circuit-breaker system has each phase in a single independent enclosure.

Note 4 to entry: For degrees of protection specified by protection provided by enclosures (IP coding) see IEC 60529 and for degrees of protection specified by external mechanical impact (IK coding) see IEC 62262.

[SOURCE: IEC 60050-441:1984, 441-13-01, modified – "part of an assembly" has been replaced by "component of generator circuit-breaker system", "not intended...other standard" and notes to entry have been added.]

3.5.119
operating mechanism

part of the generator circuit-breaker that actuates the main contacts

3.5.120
power kinematic chain

mechanical connecting system from and including the operating mechanism up to and including the moving contacts

3.5.121
alternative operating mechanism

mechanism obtained when a change in the power kinematic chain of the original operating mechanism or the use of an entirely different operating mechanism leads to the same mechanical characteristics

Note 1 to entry: Mechanical characteristics are defined in 7.101.1.1.

Note 2 to entry: An alternative operating mechanism can utilise an operating principle different from the original one (for example the alternative mechanism can be spring-operated and the original hydraulic).

Note 3 to entry: A change in the secondary equipment does not lead to an alternative operating mechanism. However, changes in the opening time can entail differences for asymmetrical breaking conditions.

3.6 Operational characteristics of switchgear and controlgear

3.6.5 Terms and definitions relative to pressure (or density)

3.6.5.1
filling pressure p_{re} for insulation and/or making and breaking
filling density ρ_{re} for insulation and/or making and breaking

pressure (in Pa), for insulation and/or for making and breaking, referred to the standard atmospheric air conditions of 20 °C and 101,3 kPa (or density), which may be expressed in relative or absolute terms, to which the assembly is filled before being put into service, or automatically replenished

3.6.5.2**filling pressure p_{rm} for operation****filling density ρ_{rm} for operation**

pressure (in Pa), for operation, referred to the standard atmospheric air conditions of 20 °C and 101,3 kPa (or density), which may be expressed in relative or absolute terms, to which the energy storage device is filled before being put into service or automatically replenished

3.6.5.3**alarm pressure p_{ae} for insulation and/or making and breaking****alarm density ρ_{ae} for insulation and/or making and breaking**

pressure (in Pa), for insulation and/or for making and breaking, referred to the standard atmospheric air conditions of 20 °C and 101,3 kPa (or density), which may be expressed in relative or absolute terms, at which a monitoring signal may be provided

3.6.5.4**alarm pressure p_{am} for operation****alarm density ρ_{am} for operation**

pressure (in Pa), for operation, referred to the standard atmospheric air conditions of 20 °C and 101,3 kPa (or density), which may be expressed in relative or absolute terms, at which a monitoring signal from the energy storage device may be provided

3.6.5.5**minimum functional pressure p_{me} for insulation and/or making and breaking****minimum functional density ρ_{me} for insulation and/or making and breaking**

pressure (in Pa), for insulation and/or for making and breaking, referred to the standard atmospheric air conditions of 20 °C and 101,3 kPa (or density), which may be expressed in relative or absolute terms, at which and above which rated characteristics of switchgear and controlgear are maintained

Note 1 to entry: For generator circuit-breakers with a sealed pressure system (also termed sealed-for-life), the minimum functional pressure for insulation and/or making and breaking is the one at which the rated characteristics of the generator circuit-breaker are maintained taking into account the pressure drop at the end of the expected operating life.

3.6.5.6**minimum functional pressure p_{mm} for operation****minimum functional density ρ_{mm} for operation**

pressure (in Pa), for operation, referred to the standard atmospheric air conditions of 20 °C and 101,3 kPa (or density), which may be expressed in relative or absolute terms, at which and above which rated characteristics of switchgear and controlgear are maintained and at which a replenishment of the energy storage device becomes necessary

Note 1 to entry: This pressure is often designated as interlocking or lockout pressure.

3.6.101**operation**

<of a mechanical switching device> transfer of the moving contact(s) from one position to an adjacent position

Note 1 to entry: For a generator circuit-breaker, this can be a closing operation or an opening operation.

Note 2 to entry: If distinction is necessary, an operation in the electrical sense, e.g. make or break, is referred to as a switching operation, and an operation in the mechanical sense, e.g. close or open, is referred to as a mechanical operation.

[SOURCE: IEC 60050-441:1984, 441-16-01, modified – In Note 1 to entry, addition of the word "generator" to "circuit-breaker".]

3.6.102

operating cycle

<of a mechanical switching device> succession of operations from one position to another and back to the first position through all other positions, if any

[SOURCE: IEC 60050-441:1984, 441-16-02]

3.6.103

operating sequence

<of a mechanical switching device> succession of specified operations with specified time intervals

[SOURCE: IEC 60050-441:1984, 441-16-03]

3.6.104

closing operation C

<of a mechanical switching device> operation by which the device is brought from the open position to the closed position

[SOURCE: IEC 60050-441:1984, 441-16-08, modified – C has been added.]

3.6.105

opening operation O

<of a mechanical switching device> operation by which the device is brought from the closed position to the open position

[SOURCE: IEC 60050-441:1984, 441-16-09, modified – O has been added.]

3.6.106

stored energy operation

operation by means of energy stored in the mechanism itself prior to the completion of the operation and sufficient to complete it under predetermined conditions

Note 1 to entry: This kind of operation may be subdivided according to:

- a) The manner of storing the energy (spring, weight, etc.);
- b) The origin of the energy (manual, electric, etc.);
- c) The manner of releasing the energy (manual, electric, etc.).

[SOURCE: IEC 60050-441:1984, 441-16-15]

3.6.107

closed position

<of a mechanical switching device> position in which the predetermined continuity of the main circuit of the device is secured

[SOURCE: IEC 60050-441:1984, 441-16-22]

3.6.108

open position

<of a mechanical switching device> position in which the predetermined clearance between open contacts in the main circuit of the device is secured

[SOURCE: IEC 60050-441:1984, 441-16-23]

3.6.109

trip-free mechanical switching device

mechanical switching device, the moving contacts of which return to and remain in the open position when the opening operation is initiated after the initiation of the closing operation, even if the closing command is maintained

Note 1 to entry: To ensure proper breaking of the current which may have been established, it may be necessary that the contacts momentarily reach the closed position.

Note 2 to entry: If the release circuit is completed through an auxiliary switch, electrical release will not take place until such auxiliary switch is closed.

[SOURCE: IEC 60050-441:1984, 441-16-31, modified – Addition of a second note to entry.]

3.6.110

shunt release

release energized by a source of voltage

Note 1 to entry: The source of voltage can be independent of the voltage of the main circuit.

[SOURCE: IEC 60050-441:1984, 441-16-41]

3.6.111

anti-pumping device

device which prevents reclosing after a close-open operation as long as the device initiating closing is maintained in the position for closing

[SOURCE: IEC 60050-441:1984, 441-16-48]

3.6.112

interlocking device

device which makes the operation of a switching device dependent upon the position or operation of one or more other pieces of equipment

[SOURCE: IEC 60050-441:1984, 441-16-49]

3.6.113

making operation

closing operation while power is applied to the main circuit

SEE: Figure 1.

3.6.114

breaking operation

opening operation while power is applied to the main circuit

SEE: Figure 1.

3.6.115

close-open operation

CO

closing operation followed by an opening operation

3.6.116

make-break operation

close-open operation while power is applied to the main circuit

SEE: Figure 1.

3.7 Characteristic quantities

Figure 1 to Figure 5 illustrate some definitions of this subclause.

Time quantities, see terms and definitions 3.7.122 to 3.7.130, are expressed in milliseconds or in cycles of the rated power frequency. When expressed in cycles, the power frequency should be stated in brackets. In the case of generator circuit-breakers incorporating breaking resistors, a distinction is made, where applicable, between time quantities associated with the contacts breaking the full current and the contacts breaking the current limited by breaking resistors.

Unless otherwise stated, the time quantities referred to are associated with the contacts making and breaking the full current.

3.7.101 rated value

quantity value assigned, generally by a manufacturer, for a specified operating condition of component, device or equipment

3.7.102 prospective current

<of a circuit and with respect to a switching device or a fuse> current that would flow in the circuit if each pole of the switching device or the fuse were replaced by a conductor of negligible impedance

Note 1 to entry: The method to be used to evaluate and to express the prospective current is to be specified in the relevant publications.

[SOURCE: IEC 60050-441:1984, 441-17-01]

3.7.103 prospective peak current

peak value of the first major loop of the prospective current during the transient period following initiation

Note 1 to entry: The definition assumes that the current is made by an ideal generator circuit-breaker, i.e. with instantaneous and simultaneous transition of its impedance across the terminals of each pole from infinity to zero. The peak value may differ from one pole to another; it depends on the instant of current initiation relative to the voltage wave across the terminals of each pole.

3.7.104 peak current

peak value of the first major loop of current during the transient period following initiation

SEE: Figure 1 *a*.

3.7.105 prospective symmetrical current

<of an AC circuit> prospective current when it is initiated at such an instant that no transient phenomenon follows the initiation

Note 1 to entry: For polyphase circuits, the condition of non-transient period can only be satisfied for the current in one pole at a time.

Note 2 to entry: The prospective symmetrical current is expressed by its RMS.

[SOURCE: IEC 60050-441:1984, 441-17-03]

3.7.106

maximum prospective peak current

<of an AC circuit> prospective peak current when initiation of the current takes place at the instant which leads to the highest possible value

Note 1 to entry: For a multiple device in a polyphase circuit, the maximum prospective peak current refers to a single pole only.

[SOURCE: IEC 60050-441:1984, 441-17-04]

3.7.107

prospective making current

<for a pole of a switching device> prospective current when initiated under specified conditions

Note 1 to entry: The specified conditions may relate to the method of initiation, e.g. by an ideal switching device, or to the instant of initiation, e.g. leading to the maximum prospective peak current in an AC circuit, or to the highest rate of rise. The specification of these conditions is found in the relevant publications.

[SOURCE: IEC 60050-441:1984, 441-17-05]

3.7.108

making current

peak value of the first major loop of the current in a pole of a generator circuit-breaker during the transient period following the initiation of current during a making operation

Note 1 to entry: The peak value may differ from one pole to another and from one operation to another as it depends on the instant of current initiation relative to the wave of the applied voltage.

Note 2 to entry: Where, for a polyphase circuit, a single value of making current is referred to, this is, unless otherwise stated, the highest value in any phase.

SEE: Figure 1 *a*.

3.7.109

prospective breaking current

<for a pole of a switching device> prospective current evaluated at the instant corresponding to the initiation of the arc during a breaking process

3.7.110

breaking current

<of a switching device or a fuse> current in a pole of a switching device or in a fuse at the instant of initiation of the arc during a breaking process

[SOURCE: IEC 60050-441:1984, 441-17-07]

3.7.111

short-circuit making current

making current for which the prescribed conditions include a short circuit at the terminals of the switching device

SEE: Figure 1 *a*.

[SOURCE: IEC 60050-441:1984, 441-17-10, modified – Replacement of "capacity" by "current" and a reference to Figure 1 has been added.]

3.7.112

short-circuit breaking current

breaking current for which the prescribed conditions include a short circuit at the terminals of the switching device

SEE: Figure 1 *b*.

[SOURCE: IEC 60050-441:1984, 441-17-11, modified – Replacement of "capacity" by "current" and a reference to Figure 1 has been added.]

3.7.113

short-time withstand current

current that a circuit or a switching device in the closed position can carry during a specified short time under prescribed conditions of use and behaviour

Note 1 to entry: depending on whether the source of the short-circuit current is from the generator through no transformation or from the power system through at least one transformation, it can be referred to as generator-source short-time withstand current or system-source short-time withstand current respectively

[SOURCE: IEC 60050-441:1984, 441-17-17, modified – The note has been added.]

3.7.114

peak withstand current

value of peak current that a circuit or a switching device in the closed position can withstand under prescribed conditions of use and behaviour

[SOURCE: IEC 60050-441:1984, 441-17-18]

3.7.115

applied voltage

<for a switching device> voltage which exists across the terminals of a pole of a switching device just before the making of the current

[SOURCE: IEC 60050-441:1984, 441-17-24]

3.7.116

recovery voltage

voltage which appears across the terminals of a pole of a switching device or a fuse after the breaking of the current

Note 1 to entry: This voltage may be considered in two successive intervals of time, one during which a transient voltage exists, followed by a second one during which the power-frequency or the steady-state recovery voltage alone exists.

[SOURCE: IEC 60050-441:1984, 441-17-25]

3.7.117

transient recovery voltage

TRV

recovery voltage during the time in which it has a significant transient character

Note 1 to entry: The transient recovery voltage may be oscillatory or non-oscillatory or a combination of these depending on the characteristics of the circuit and the switching device. It includes the voltage shift of the neutral of a polyphase circuit.

Note 2 to entry: The transient recovery voltage in three-phase circuits is, unless otherwise stated, that across the first-pole-to-clear, because this voltage is generally higher than that which appears across each of the other two poles.

[SOURCE: IEC 60050-441:1984, 441-17-26]

3.7.118**prospective transient recovery voltage**

<of a circuit> transient recovery voltage following the breaking of the prospective symmetrical current by an ideal switching device

Note 1 to entry: The definition assumes that the switching device or the fuse, for which the prospective transient recovery voltage is sought, is replaced by an ideal switching device, i.e. having instantaneous transition from zero to infinite impedance at the very instant of zero current, i.e. at the "natural" zero. For circuits where the current can follow several different paths, e.g. a polyphase circuit, the definition further assumes that the breaking of the current by the ideal switching device takes place only in the pole considered.

[SOURCE: IEC 60050-441:1984, 441-17-29]

3.7.119**power-frequency recovery voltage**

recovery voltage after the transient voltage phenomena have subsided

[SOURCE: IEC 60050-441:1984, 441-17-27]

3.7.120**clearance**

distance between two conductive parts along a string stretched the shortest way between these conductive parts

[SOURCE: IEC 60050-441:1984, 441-17-31]

3.7.121**clearance between open contacts**

total clearance between the contacts, or any conductive parts connected thereto, of a pole of a mechanical switching device in the open position

[SOURCE: IEC 60050-441:1984, 441-17-34]

3.7.122**opening time**

interval of time between the instant of energising the opening release, the generator circuit-breaker being in the closed position, and the instant when the arcing contacts have separated in all poles

SEE: Figure 1 *j*.

Note 1 to entry: The opening time may vary with the breaking current.

Note 2 to entry: For generator circuit-breakers with more than one interrupting unit in series per pole the following applies: for each pole the contact separation is determined by the contact separation of the first unit in that pole. The contact separation of the three-pole generator circuit-breaker is the longest of the three contact separations of the three poles.

Note 3 to entry: For generator circuit-breakers with more than one interrupting unit in parallel per pole the following applies: for each pole the contact separation is determined by the contact separation of the last unit in that pole. The contact separation of the three-pole generator circuit-breaker is the longest of the three contact separations of the three poles.

Note 4 to entry: The opening time includes the operating time of any auxiliary equipment necessary to open the generator circuit-breaker and forming an integral part of the generator circuit-breaker.

3.7.123
arcing time

<of a pole> interval of time between the instant of the initiation of the arc in a pole and the instant of final arc extinction (of that pole)

SEE: Figure 1 *k*.

[SOURCE: IEC 60050-441:1984, 441-17-37, modified – "or a fuse" has been deleted, "in that pole" has been replaced by "(of that pole)" and a reference to Figure 1 has been added.]

3.7.124
break-time

<of a pole> interval of time between the beginning of the opening time of a mechanical switching device and the end of the arcing time (of that pole)

SEE: Figure 1 *l*.

[SOURCE: IEC 60050-441:1984, 441-17-39, modified – "(or the pre-arcing time of a fuse)" has been deleted and "(of that pole)" and a reference to Figure 1 have been added.]

3.7.125
closing time

interval of time between energising the closing circuit, the generator circuit-breaker being in the open position, and the instant when the contacts touch in all poles

Note 1 to entry: The closing time includes the operating time of any auxiliary equipment necessary to close the generator circuit-breaker and forming an integral part of the generator circuit-breaker.

3.7.126
make-time

interval of time between the beginning of the closing time and the instant when the current begins to flow in the first pole

SEE: Figure 1 *m*.

[SOURCE: IEC 60050-441:1984, 441-17-40, modified – The definition has been rephrased and a reference to Figure 1 has been added.]

3.7.127
pre-arcing time

interval of time between the initiation of current flow in the first pole during a closing operation and the instant when the contacts touch in all poles for three-phase conditions and the instant when the contacts touch in the arcing pole for single-phase conditions

Note 1 to entry: The pre-arcing time depends on the instantaneous value of the applied voltage during a specific closing operation and therefore may vary considerably.

3.7.128
close-open time

interval of time between the instant when the contacts touch in the first pole during a closing operation and the instant when the arcing contacts have separated in all poles during the subsequent opening operation

Note 1 to entry: Unless otherwise stated, it is assumed that the opening release incorporated in the generator circuit-breaker is energised at the instant when the contacts touch in the first pole during closing. This represents the minimum close-open time.

[SOURCE: IEC 60050-441:1984, 441-17-42, modified – Note 1 to entry has been added.]

3.7.129**minimum trip signal duration**

minimum time the auxiliary power is applied to the opening release to ensure complete opening of the generator circuit-breaker

3.7.130**minimum close signal duration**

minimum time the auxiliary power is applied to the closing device to ensure complete closing of the generator circuit-breaker

3.7.131**first-pole-to-clear factor**

<in a three-phase system> ratio of the power-frequency voltage across the first interrupting pole before current interruption in the other poles, to the power-frequency voltage occurring across the pole or the poles after interruption in all three poles (when interrupting any symmetrical three-phase current)

3.7.132**amplitude factor**

ratio between the maximum excursion of the transient recovery voltage to the crest value of the power-frequency recovery voltage

3.7.133**insulation level**

set of withstand voltages specified which characterise the dielectric strength of the insulation

[SOURCE: IEC 60050-614:2016, 614-03-23]

3.7.134**power-frequency withstand voltage**

RMS value of sinusoidal power-frequency voltage that the insulation of the given equipment can withstand during tests made under specified conditions and for a specified duration

[SOURCE: IEC 60050-614:2016, 614-03-22]

3.7.135**impulse withstand voltage**

peak value of the standard impulse voltage wave which the insulation of the generator circuit-breaker withstands under specified test conditions

3.7.136**degree of asymmetry**

<of a current at any time> ratio (expressed as a percentage) of the DC component to the peak value of the AC component determined from the envelope of the current wave at that time

Note 1 to entry: This value is 100 % when the DC component equals the peak value of the AC component.

3.7.137**generator-source short-circuit current**

short-circuit current when the source of the short-circuit current is entirely from a generator through no transformation

3.7.138**system-source short-circuit current**

short-circuit current when the source of the short-circuit current is from the power system through at least one transformation

3.7.139

intermediate level of asymmetry

level of asymmetry in the two phases having an intermediate (reduced) level of asymmetry, when in a three-phase system the short-circuit current is initiated simultaneously in all phases and maximum asymmetry is obtained in one of the phases

SEE: Figure 6.

3.7.140

earliest possible interruption in a phase with intermediate level of asymmetry after a major loop

interruption with the shortest time (t_1) from fault current initiation to the first current zero after a major loop in the phase with intermediate level of asymmetry, taking into account:

- the minimum relay time (0,5 cycle of power frequency);
- the minimum opening time;
- the minimum arcing time;
- and that the subsequent current zero crossing of the prospective three-phase current occurs in the other phase with maximum level of asymmetry after a major loop

SEE: Figure 7

Note 1 to entry: This definition is to be used only for the determination of the test parameters during asymmetrical short-circuit breaking tests. (TD2 – System-source fault)

Note 2 to entry: Typically, the minimum opening time will occur when the opening release is energised at upper limit of the supply voltage and if applicable at maximum functional pressure for operation.

3.7.141

earliest possible interruption in a phase with intermediate level of asymmetry after a minor loop

interruption with the shortest time (t_2) from fault current initiation to the first current zero after a minor loop in the phase with intermediate level of asymmetry, taking into account:

- the minimum relay time (0,5 cycle of power frequency);
- the minimum opening time;
- the minimum arcing time;
- and that the subsequent current zero crossing of the prospective three-phase current occurs in the other phase with intermediate level of asymmetry after a major loop

SEE: Figure 8.

Note 1 to entry: This definition is to be used only for the determination of the test parameters during asymmetrical short-circuit breaking tests. (TD2 – System-source fault)

Note 2 to entry: Typically, the minimum opening time will occur when the opening release is energised at upper limit of the supply voltage and if applicable at maximum functional pressure for operation.

3.7.142**three-phase break-time**

<of a generator circuit-breaker> maximum interval between the energising of the trip circuit and the interruption of the current in all poles in the main circuit during test-duty 1 of Table 20 (see 7.103.12) under the following conditions:

- rated auxiliary supply voltage and frequency;
- filling pressures for operation, insulation and/or making and breaking;
- an ambient air temperature of $(20 \pm 5) \text{ }^\circ\text{C}$

Note 1 to entry: According to 7.102.3.1, the breaking tests, shall be carried out at the minimum auxiliary supply voltage, at the minimum pressure for operation and at the minimum pressure for insulation and/or making and breaking. In order to verify the three-phase break-time during these test-duties, the lower auxiliary supply voltage and pressures should be taken into account as follows:

$$t_{b \text{ cal}} = t_1 + t_{\text{arc sym min}} + T \cdot 132^\circ/360^\circ$$

where

- $t_{b \text{ cal}}$ is the calculated three-phase break-time;
- t_1 is the opening time at rated supply voltage of the opening device, rated supply frequency of the opening device, specified pressure for operation, insulation and/or making and breaking and at ambient air temperature of $20 \pm 5 \text{ }^\circ\text{C}$;
- $t_{\text{arc sym min}}$ is the minimum arcing time recorded during test-duty 1;
- T is one period of the power frequency (20 ms for 50 Hz, 16,7 ms for 60 Hz);

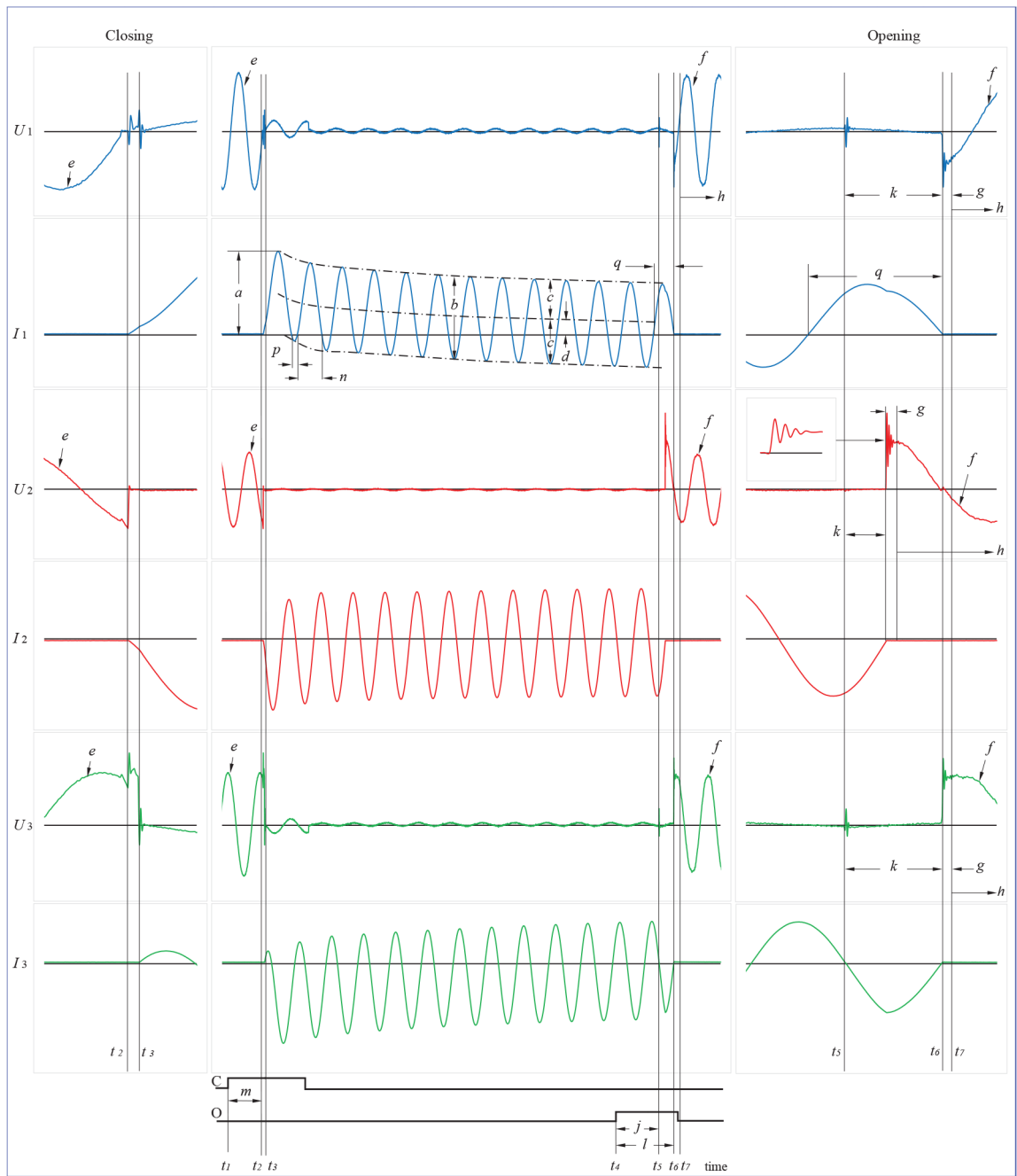
Note 2 to entry: The three-phase break-time can also be referred to as rated interrupting time.

Note 3 to entry: Typical values are approximately 60 ms to 90 ms with the actual time being dependent on the rated system-source short-circuit breaking current.

Note 4 to entry: The three-phase break-time can slightly differ from the calculated three-phase break-time as the minimum arcing time can additionally be slightly influenced by the pressure for operation and the pressure for insulation and/or making and breaking. In order to show this influence, the test to show the three-phase break-time can be repeated at rated auxiliary supply voltage, specified pressure for operation and specified pressure for insulation and/or making and breaking.

Note 5 to entry: For single-phase tests simulating a three-phase operation, the recorded break-time can exceed the three-phase break-time by 30 electrical degrees because in these cases the current zeros occur less frequently than in the three-phase case.

Note 6 to entry: For generator circuit-breakers equipped with resistors, the time until final extinction of the resistor current will be longer.



U_2	voltage across the terminals of the first-pole-to-clear	a	making current
I_2	current in the first-pole-to-clear	b	peak-to-peak value of the AC component
U_1, U_3	voltage across the terminals of the two other poles	c	peak value of the AC component
I_1, I_3	current in the two other poles	d	DC component
C	closing command, e.g. voltage across the terminals of the closing circuit	e	applied voltage
O	opening command, e.g. voltage across the terminals of the opening release	f	recovery voltage
t_1	the instant of initiation of the closing operation	g	transient recovery voltage
t_2	the instant when the current begins to flow in the main circuit (voltage breakdown in phases 1 and 2)	h	power-frequency recovery voltage
t_3	the instant when the current is established in all poles (voltage breakdown in phase 3)	j	opening time
t_4	the instant of energising the opening release	k	arcing time
t_5	the instant when the arcing contacts have separated (or instant of initiation of the arc) in all poles	l	three-phase break-time
t_6	the instant of final arc extinction in all poles	m	make time
t_7	the instant when the transient voltage phenomena have subsided in the last-pole-to-clear	n	major loop
		p	minor loop
		q	major extended loop

NOTE 1 Indicators i and o are not used.

NOTE 2 The RMS value of the AC component of the breaking current is $c/\sqrt{2}$.

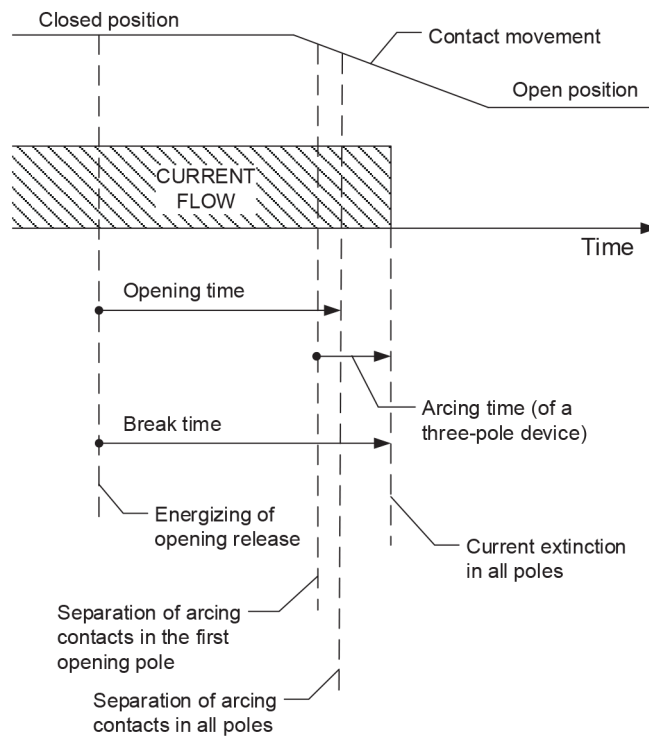
NOTE 3 Different scale factors for voltage and current traces in each phase are used.

Figure 1 – Example of a graphical record of a three-phase short-circuit make-break test

The following notes apply to Figure 2 to Figure 5:

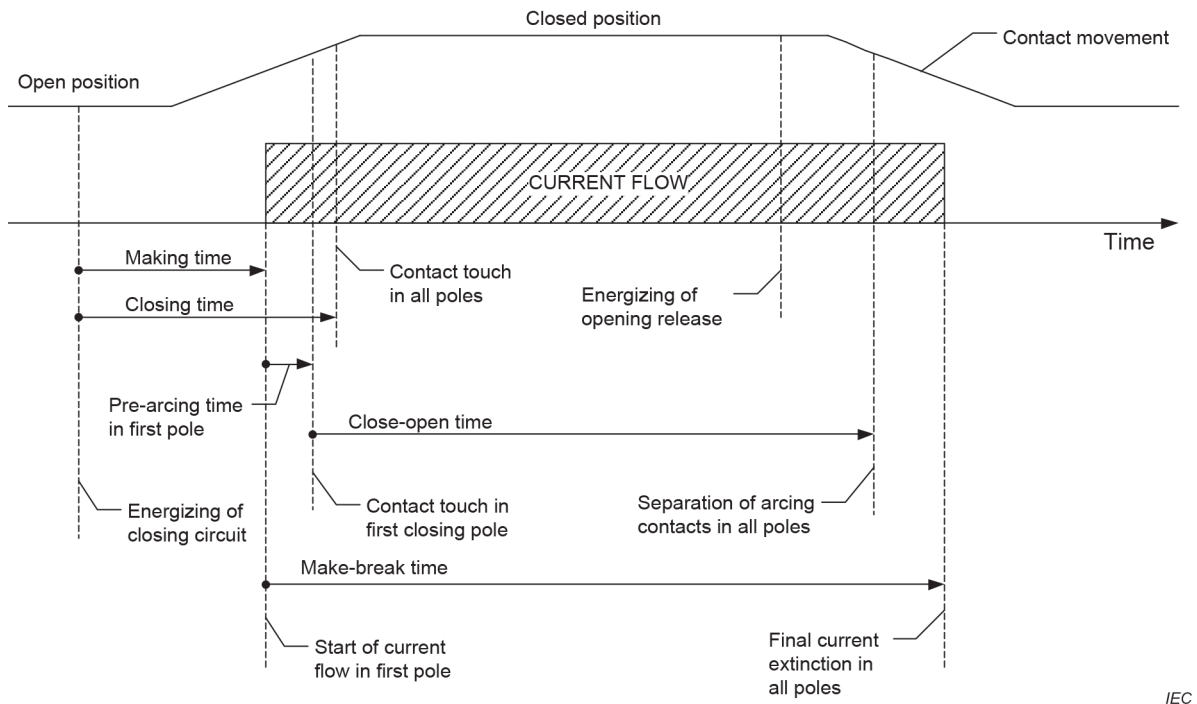
NOTE 1 In practice, there will be a time spread between the travel of the contacts of the three poles. For clarity the travel of the contacts is indicated with a single line for all three poles.

NOTE 2 In practice, there will be a time spread between both the start and end of current flow in the three poles. For clarity, both the start and end of current flow is indicated with a single line for all three poles.



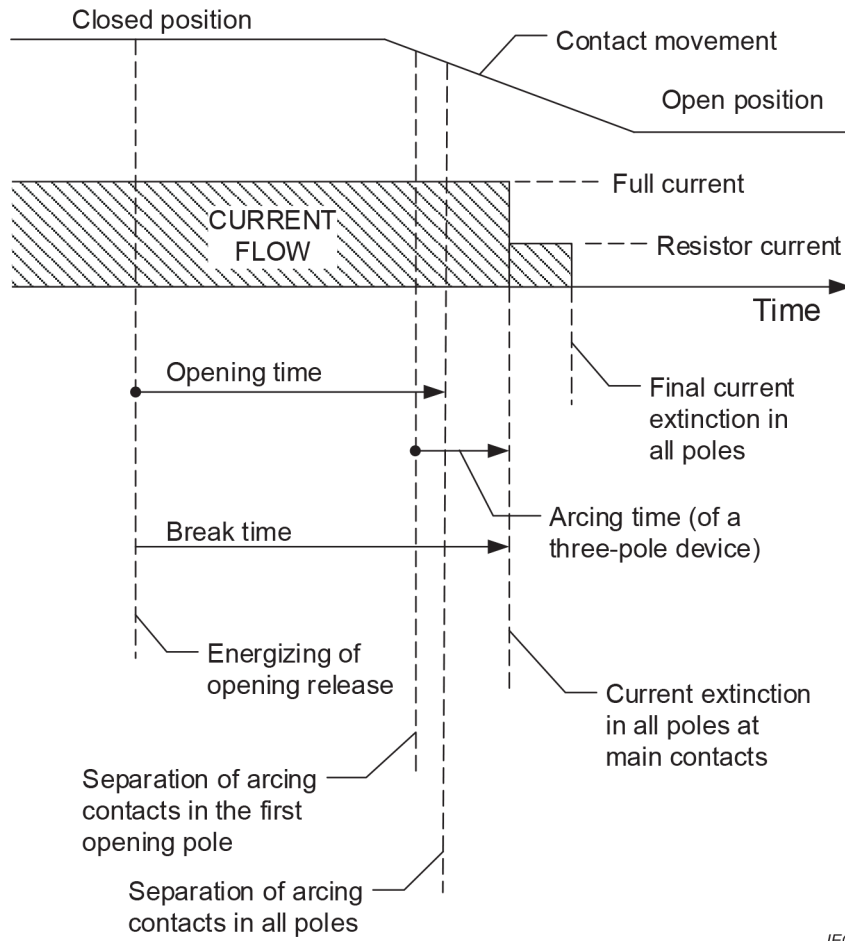
IEC

Figure 2 – Generator circuit-breaker without resistors – Opening operation



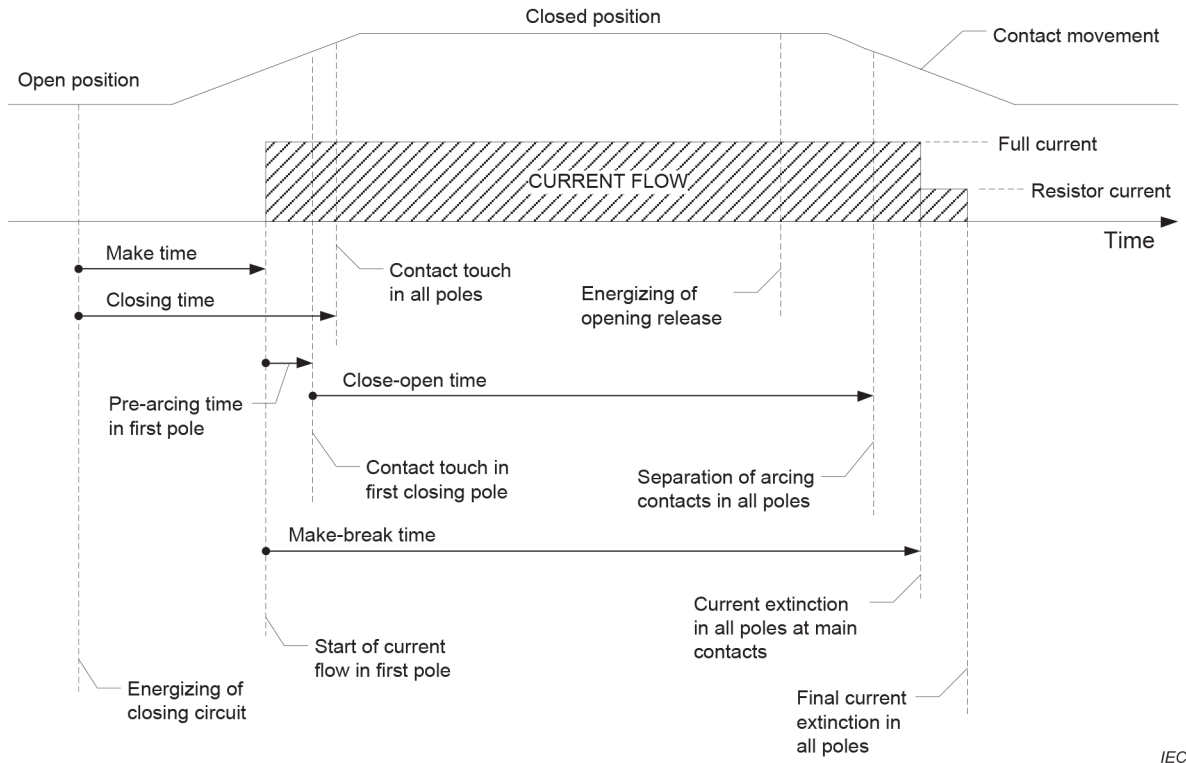
IEC

Figure 3 – Generator circuit-breaker without resistors – Close-open cycle



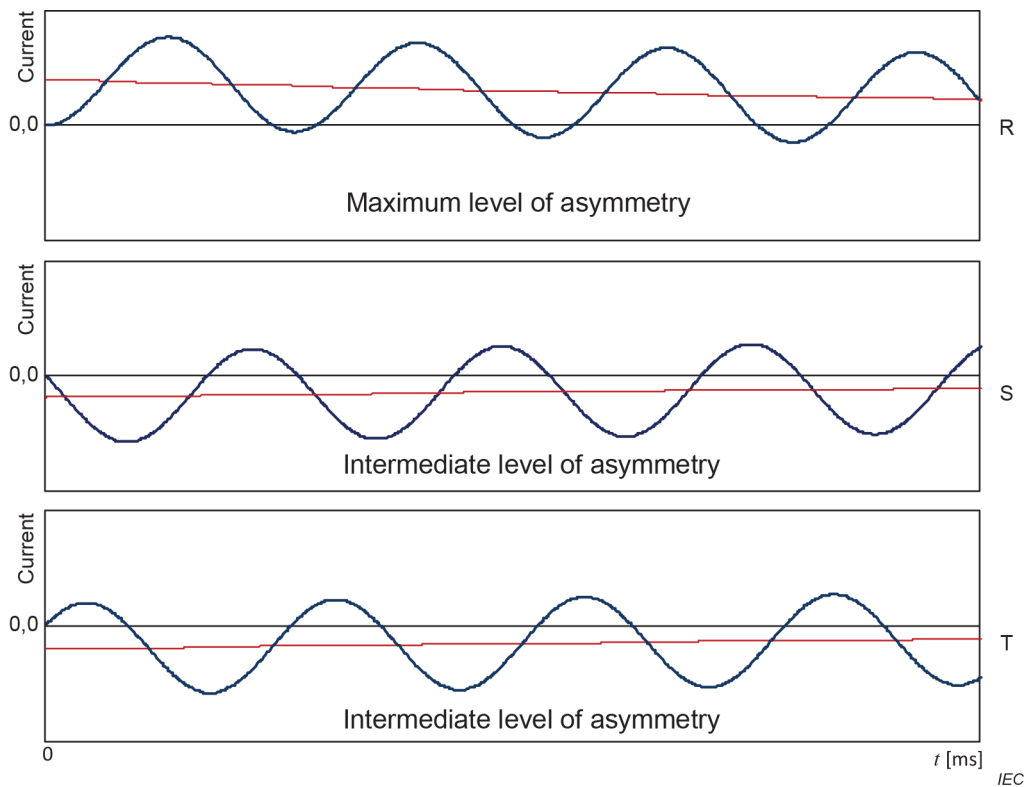
IEC

Figure 4 – Generator circuit-breaker with opening resistors – Opening operation



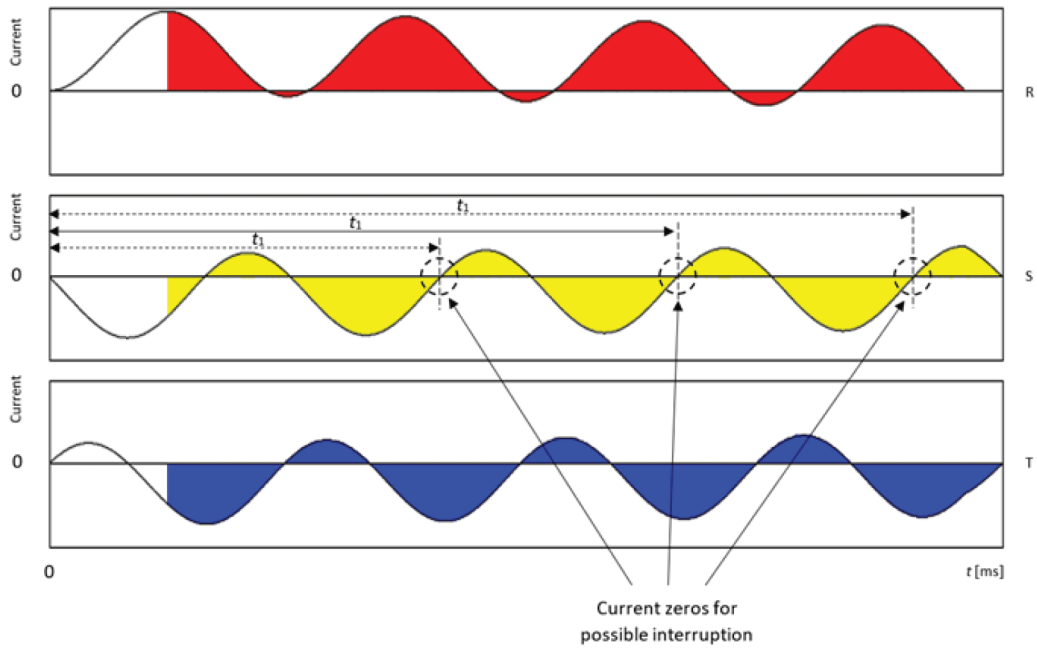
IEC

Figure 5 – Generator circuit-breaker with opening resistors – Close-open cycle



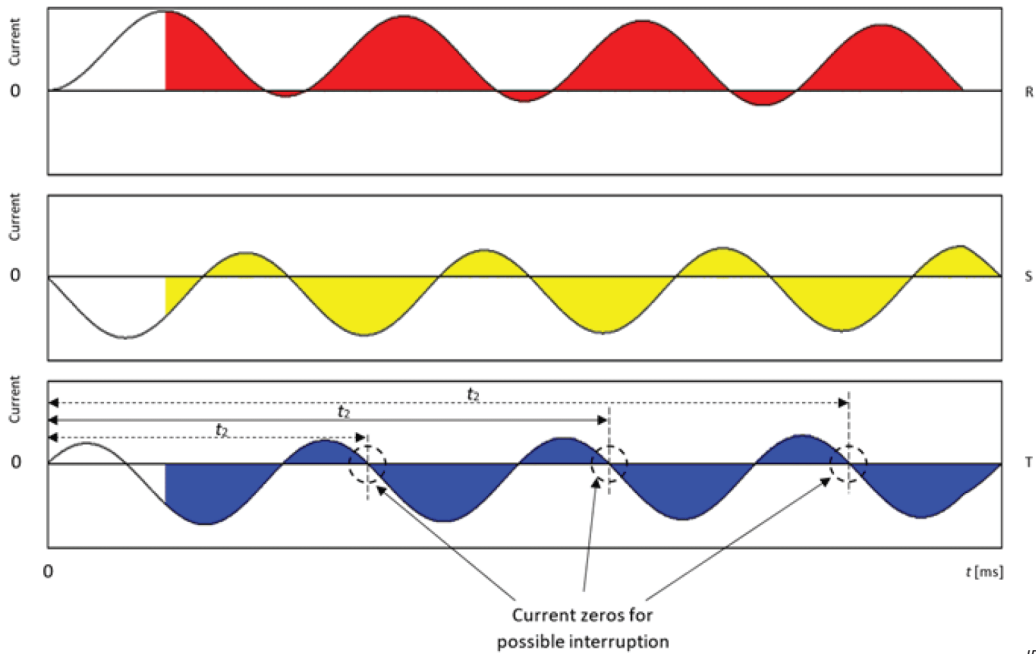
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Figure 6 – Example of a three-phase asymmetrical current



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Figure 7 – Examples of possible interruptions in a phase with intermediate level of asymmetry after a major loop and a corresponding time t_1



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Figure 8 – Examples of possible interruptions in a phase with intermediate level of asymmetry after a minor loop and a corresponding time t_2

3.8 Index of definitions

A

"a" contact, make contact	3.5.111
Air-blast circuit-breaker	3.4.108
Alarm pressure for insulation and/or making and breaking	3.6.5.3
Alarm pressure for operation	3.6.5.4
Alternative operating mechanism	3.5.121
Amplitude factor	3.7.132
Anti-pumping device	3.6.111
Applied voltage (for a switching device)	3.7.115
Arcing contact	3.5.107
Arcing time (of a pole)	3.7.123
Auxiliary circuit	3.5.104
Auxiliary contact	3.5.109
Auxiliary switch	3.5.110

B

"b" contact, break contact	3.5.112
Braking switch	3.4.130
Break contact	3.5.112
Breaking current (of a switching device or a fuse)	3.7.110
Breaking operation	3.6.114
Breaking unit	3.5.116
Break-time	3.7.124
BTB-switch	3.4.122
BTB-switch class M1	3.4.123
BTB-switch class M2 and class M3	3.4.124

C

Circuit-breaker	3.4.103
Class G1 generator circuit-breaker	3.4.111
Class G2 generator circuit-breaker	3.4.112
Class M1 generator circuit-breaker	3.4.109
Class M2 and class M3 generator circuit-breaker	3.4.110
Clearance	3.7.120
Clearance between open contacts	3.7.121
Closed position	3.6.107
Close-open operation (CO)	3.6.115
Close-open time	3.7.128
Closing operation (C)	3.6.104
Closing time	3.7.125
Component	3.3.101
Connection (bolted or the equivalent)	3.5.114

Contact	3.5.105
Control circuit	3.5.103
Control contact	3.5.108

D

Disconnecter	3.4.113
Degree of asymmetry (of a current at any time)	3.7.136
Disruptive discharge	3.1.110

E

Earliest possible interruption in a phase with intermediate level of asymmetry after a major loop	3.7.140
Earliest possible interruption in a phase with intermediate level of asymmetry after a minor loop	3.7.141
Earthing switch	3.4.125
Effectively earthed neutral system	3.1.112
Enclosure	3.5.118
ET-switch	3.4.120
External insulation	3.1.109

F

Filling pressure for insulation and/or making and breaking	3.6.5.1
Filling pressure for operation	3.6.5.2
First-pole-to-clear factor (in a three-phase system)	3.7.131

G

Gas-blast circuit-breaker	3.4.107
Generator circuit-breaker	3.4.104
Generator circuit-breaker class G1	3.4.111
Generator circuit-breaker class G2	3.4.112
Generator circuit-breaker class M1	3.4.109
Generator circuit-breaker class M2 and class M3	3.4.110
Generator-source short-circuit current	3.7.137
Generator circuit-breaker system	3.2.101

I

Impulse withstand voltage	3.7.135
Insulation level	3.7.133
Interlocking device	3.6.112
Intermediate level of asymmetry	3.7.139
Internal insulation	3.1.117
Isolated-phase bus (IPB)	3.1.116

L

Loop	3.1.107
------	---------

M

Main circuit	3.5.102
Main contact	3.5.106
Main-disconnector	3.4.114
Main-disconnector class M1	3.4.115
Main-disconnector class M2 and class M3	3.4.116
Make-break operation	3.6.116
Make contact	3.5.111
Make-time	3.7.126
Making current	3.7.108
Making operation	3.6.113
Making unit	3.5.116
Manually mounted short-circuiting connection	3.4.127
Maximum prospective peak current (of an AC circuit)	3.7.106
Mechanical switching device	3.4.102
Minimum close signal duration	3.7.130
Minimum functional pressure for insulation and/or making and breaking	3.6.5.5
Minimum functional pressure for operation	3.6.5.6
Minimum trip signal duration	3.7.129
Module	3.5.117
Moment of inertia	3.1.103
Motor operated short-circuiting connection	3.4.128

N

Non-effectively earthed neutral system	3.1.113
Non-sustained disruptive discharge (NSDD)	3.1.111
NSDD	3.1.111

O

Oil circuit-breaker	3.4.105
Opening operation (O)	3.6.105
Opening time	3.7.122
Open position	3.6.108
Operating cycle	3.6.102
Operating mechanism	3.5.119
Operating sequence	3.6.103
Operation	3.6.101
Out-of-phase (as prefix to a characteristic quantity)	3.1.105
Out-of-phase conditions	3.1.104

P

Peak current	3.7.104
Peak withstand current	3.7.114
Phase-reversal-disconnector	3.4.129

Pole	3.5.101
Power factor (of a circuit)	3.1.108
Power-frequency recovery voltage	3.7.119
Power-frequency withstand voltage	3.7.134
Power kinematic chain	3.5.120
Pre-arcing time	3.7.127
Prospective breaking current (for a pole of a switching device)	3.7.109
Prospective current (of a circuit and with respect to a switching device or a fuse)	3.7.102
Prospective making current (for a pole of a switching device)	3.7.107
Prospective peak current	3.7.103
Prospective symmetrical current (of an AC circuit)	3.7.105
Prospective transient recovery voltage (of a circuit)	3.7.118

R

Rated value	3.7.101
Recovery voltage	3.7.116
Re-ignition (of an AC mechanical switching device)	3.1.114
Release	3.5.113
Restrike (of an AC mechanical switching device)	3.1.115

S

Short-circuit current	3.1.102
Short-circuit breaking current	3.7.112
Short-circuit making current	3.7.111
Short-circuiting connection	3.4.126
Short-time withstand current	3.7.113
Shunt release	3.6.110
Starting switch	3.4.117
Starting switch class M1	3.4.118
Starting switch class M2 and class M3	3.4.119
Stored energy operation	3.6.106
Switchgear and controlgear	3.1.101
Switching device	3.4.101
System-source short-circuit current	3.7.138

T

Tee-OFF generator circuit-breaker	3.4.131
Tee-OFF-switch	3.4.121
Terminal	3.5.115
Three-phase break-time	3.7.142
Transient recovery voltage (TRV)	3.7.117
Trip-free mechanical switching device	3.6.109
TRV	3.7.117

U

(Making or breaking) Unit	3.5.116
Unit test	3.1.106

V

Vacuum generator circuit-breaker	3.4.106
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4 Normal and special service conditions

NOTE Normal and special service conditions are sometimes called usual and unusual service conditions respectively.

4.1 Normal service conditions

Subclause 4.1 of IEC 62271-1:2017 is applicable.

4.2 Special service conditions

4.2.1 General

Subclause 4.2.1 of IEC 62271-1:2017 is applicable.

4.2.2 Altitude

Subclause 4.2.2 of IEC 62271-1:2017 is not applicable and is replaced by the following:

For installations at an altitude higher than 1 000 m, the insulation withstand level of external insulation at the service location shall be determined by multiplying the rated insulation levels by a factor:

$$K_a = e^{(H-1000)/8150}$$

NOTE The equation from 6.2.2 of IEC 60071-2:2018 has been modified to reflect that no correction is required up to 1 000 m.

For internal insulation, the dielectric characteristics are identical at any altitude and no special precautions need to be taken. For external and internal insulation, IEC 60071-2 shall apply.

For low-voltage auxiliary and control equipment, no special precautions need to be taken if the altitude is lower than 2 000 m. For higher altitudes, IEC 60664-1 shall apply.

4.2.3 Exposure to pollution

Subclause 4.2.3 of IEC 62271-1:2017 is applicable.

4.2.4 Temperature and humidity

Subclause 4.2.4 of IEC 62271-1:2017 is applicable.

4.2.5 Exposure to abnormal vibrations, shock or tilting

Subclause 4.2.5 of IEC 62271-1:2017 is applicable.

4.2.6 Wind speed

Subclause 4.2.6 of IEC 62271-1:2017 is applicable.

4.2.7 Other parameters

Subclause 4.2.7 of IEC 62271-1:2017 is applicable.

5 Ratings

5.1 General

Subclause 5.1 of IEC 62271-1:2017 is replaced by the following:

The ratings and required capabilities of a generator circuit-breaker or of a generator circuit-breaker system are the designated limits of operating characteristics based on definite conditions and shall include the following items, where applicable:

- a) rated voltage;
- b) rated insulation level;
- c) rated frequency;
- d) rated continuous current;
- e) rated short-time withstand current;
- f) rated peak withstand current;
- g) rated duration of short-circuit;
- h) rated supply voltage of auxiliary and control circuits;
- i) rated supply frequency of auxiliary and control circuits;
- j) rated pressure of compressed gas supply for controlled pressure systems;
- k) rated system-source short-circuit breaking current;
- l) rated short-circuit making current;
- m) rated load breaking current;
- n) rated transient recovery voltage;
- o) rated operating sequence;
- p) rated time quantities.

The following characteristics are not mandatory but shall be given on request if assigned.

- q) rated out-of-phase making and breaking current;
- r) rated generator-source short-circuit breaking current.

5.2 Rated voltage (U_r , U_{rgcb_side} , U_{rsd_side})

Subclause 5.2 of IEC 62271-1:2017 is replaced by the following:

The rated voltage U_r of a generator circuit-breaker or a generator circuit-breaker system is the highest phase-to-phase RMS voltage for which the generator circuit-breaker or the generator circuit-breaker system is designed and is the upper limit for operation.

Components or functions which are not used at the rated voltage of the generator may have lower voltage ratings, for example the starting device side of the starting switch for gas turbines.

When the starting switch is in the open position, the rated voltage of the generator circuit-breaker side of a starting switch U_{rgcb_side} is the highest phase-to-phase RMS voltage for which that side of the starting switch has been designed.

When the starting switch is in the open or closed position, the rated voltage of the starting device side of a starting switch U_{rsd_side} is the highest phase-to-phase RMS voltage for which that side of the starting switch has been designed.

NOTE 1 The rated voltage can also be referred to as rated maximum voltage.

NOTE 2 The rated voltage is equal to the maximum operating voltage of the generator (usually equal to 1,05 times the rated voltage of the generator) to which the generator circuit-breaker is applied.

NOTE 3 Any numerical value above 1 kV and up to 38 kV can be chosen as the rated voltage of a generator circuit-breaker or of any of the individual components of a generator circuit-breaker system.

5.3 Rated insulation level (U_d , U_p)

Subclause 5.3 of IEC 62271-1:2017 is replaced by the following:

The rated insulation level of a generator circuit-breaker or of a generator circuit-breaker system shall be selected from the values given in Table 1.

NOTE The rated insulation level can also be referred to as rated dielectric strength.

Withstand values given in Table 1 cover the application of generator circuit-breakers and generator circuit-breaker systems under normal service conditions defined in 4.1 including altitudes from sea level up to 1 000 m. However, for testing purposes to verify a rating or capability, they shall be considered as insulation values at the standardised reference atmosphere temperature (20 °C), pressure (101,3 kPa) and humidity (11 g/m³) specified in IEC 60071-1:2019. For special service conditions, refer to IEC TR 62271-306.

The "common values" used in Table 1 apply to phase-to-earth, between phases and across open switching devices, if not otherwise specified in this document. The insulation levels "across the isolating distance" apply to the clearance between open contacts of the main-disconnector of a generator circuit-breaker system.

Regarding the insulation level across the open starting switch, the "common value" of U_{rsd_side} is applicable to the starting device side with the generator circuit-breaker side grounded and the "common value" of U_{rgcb_side} is applicable to the generator circuit-breaker side with the starting device side grounded.

Table 1 – Rated insulation levels for generator circuit-breakers and generator circuit-breaker systems

Rated voltage $U_r, U_{rgcb_side}, U_{rsd_side}$ kV (RMS value)	Rated power-frequency withstand voltage U_d kV (RMS value)		Rated lightning impulse withstand voltage U_p kV (peak value)	
	Common value	Across the isolating distance	Common value	Across the isolating distance
(1)	(2)	(3)	(4)	(5)
$U_r \leq 7,2$	20	22	60	66
$7,2 < U_r \leq 12$	28	31	75	83
$12 < U_r \leq 15$	38	42	95	105
$15 < U_r \leq 17,5$	50	55	110	121
$17,5 < U_r \leq 27$	60	66	125	138
$27 < U_r \leq 38$	80	88	150	165

These values are applicable for indoor and outdoor generator circuit-breakers and for indoor and outdoor generator circuit-breaker systems.

5.4 Rated frequency (f_r)

Subclause 5.4 of IEC 62271-1:2017 is applicable with the following modifications:

The standard values for the rated frequency of generator circuit-breakers and generator circuit-breaker systems are 50 Hz and 60 Hz.

If rated for both 50 Hz and 60 Hz, the nameplate may be marked 50/60 Hz.

Applications at other frequencies require special considerations.

NOTE The rated frequency can also be referred to as rated power frequency.

5.5 Rated continuous current (I_r)

Subclause 5.5 of IEC 62271-1:2017 is applicable with the following addition:

Values from the R 10 series are preferred values only. Manufacturers and users are free to choose any other values.

NOTE The term "rated continuous current" as used in this edition is equivalent to the term "rated normal current" used in the previous edition of this document.

5.5.101 Emergency current ratings during loss of cooling

The operating considerations for generator circuit-breakers and generator circuit-breaker systems require that emergency ratings are established to enable the generator circuit-breaker or the generator circuit-breaker system to remain in service following loss of normally required cooling systems.

The following provisions shall be observed:

- a) it is possible to operate the generator circuit-breaker or the generator circuit-breaker system for limited time periods with generator circuit-breaker or generator circuit-breaker system parts at a higher total temperature than the limits specified for the continuous current rating;
- b) the difference between the emergency temperature limits and the normal operating temperatures provide a definite allowable time period during which full load may be carried before the reduction in load current shall be accomplished;
- c) the generator circuit-breaker or the generator circuit-breaker system may remain in service at a reduced load current, the value of which will depend on the type of emergency condition prevailing;
- d) where the generator circuit-breaker or the generator circuit-breaker system continuous current rating is affected by several independent systems (e.g. interrupting medium, cooling medium, forced air cooling of isolated-phase bus), the effect of losing each system individually and in combination should be established;
- e) in addition to a) through d), certain power plant designs (e.g. single generator output connected by two generator circuit-breakers or generator circuit-breaker systems to two unit step-up transformers) may also require special emergency operating conditions and ratings.

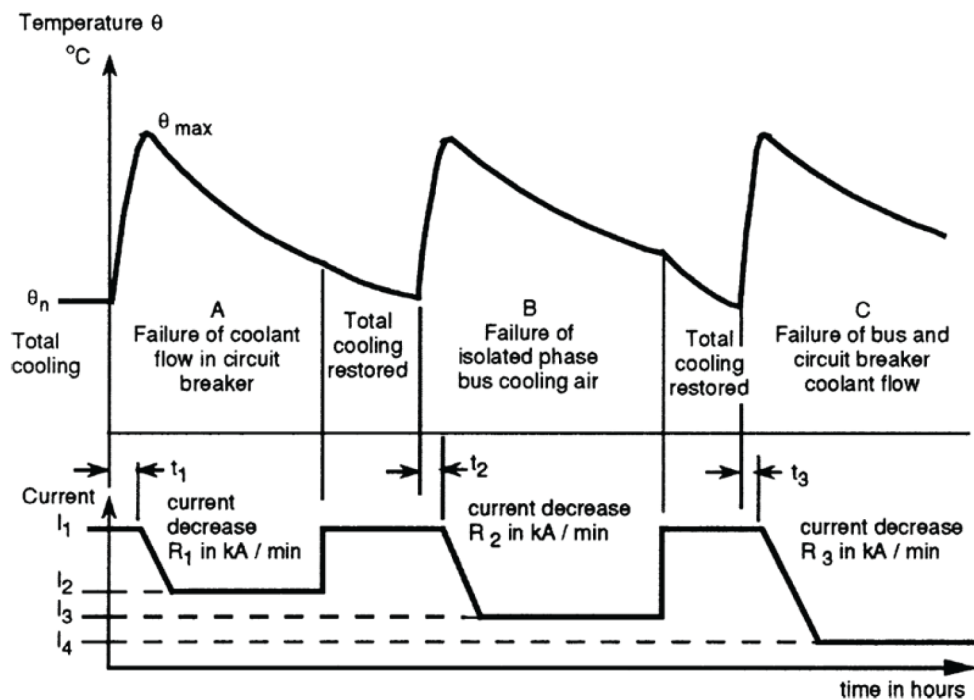
For each emergency condition the following parameters shall be given:

t_e the time available at rated continuous current before the load shall be reduced;

R_e the rate at which the continuous current shall be reduced in kA/min;

I_e the emergency current assigned to the generator circuit-breaker or to the generator circuit-breaker system for operating under each emergency condition for an unlimited period of time.

Figure 9 illustrates typical emergency conditions in which the loss of two cooling systems, that of the generator circuit-breaker or of the generator circuit-breaker system and that of the bus, have been studied separately and simultaneously.



IEC

Key

- I_1 is the rated continuous current with all cooling systems in operation
- I_2 is the allowable continuous current if failure (A) of coolant in the generator circuit-breaker (system) occurs
- I_3 is the allowable continuous current if failure (B) of isolated phase bus cooling air occurs
- I_4 is the allowable continuous current if failure (C) of isolated bus and generator circuit-breaker (system) coolant flow occurs
- θ_{max} is the allowable hottest spot total temperature in °C
- θ_n is the hottest spot total temperature at rated continuous current
- t_1, t_2, t_3 are the allowable times without a reduction in rated continuous current and without exceeding θ_{max}
- R_1, R_2, R_3 are the rates at which the load current shall be reduced in kA/min

Figure 9 – Effect of various cooling failures and subsequent load reductions on generator circuit-breaker (system) temperature

The following are the parameters that are required for correct operation under each type of emergency condition and for which values shall be determined by the manufacturer:

- t_1, t_2, t_3 are the times available at rated current before the load shall be reduced.
- R_1, R_2, R_3 are the rates at which the load current shall be reduced in kA/min.
- I_2, I_3, I_4 are the emergency currents assigned to the generator circuit-breaker or the generator circuit-breaker system for operating under each emergency condition for an unlimited period of time.

5.6 Rated short-time withstand current (I_k)

Subclause 5.6 of IEC 62271-1:2017 is applicable with the following modifications:

The rated short-time withstand current of the main current path is either the rated system-source short-time withstand current or the rated generator-source short-time withstand current, whichever is the higher.

Starting switches for gas turbines need to withstand the rated generator-source short-time withstand current.

Starting switches and BTB-switches for pumped-storage applications (see Annex O), ET-switches, Tee-OFF-switches and Tee-OFF generator circuit-breakers need to withstand the sum of the rated generator-source short-time withstand current and the rated system-source short-time withstand current.

5.7 Rated peak withstand current (I_p)

Subclause 5.7 of IEC 62271-1:2017 is applicable with the following modifications:

The rated peak withstand current of the main current path is either the rated system-source peak withstand current or the rated generator-source peak withstand current, whichever is higher.

A DC time constant of 133 ms covers the majority of system-source short-circuit currents and corresponds to a rated system-source peak withstand current equal to 2,74 times the rated system-source short-circuit current.

Starting switches for gas turbines need to withstand the rated generator-source peak withstand current.

Starting switches and BTB-switches for pumped-storage applications, ET-switches, Tee-OFF-switches and Tee-OFF generator circuit-breakers need to withstand the sum of the rated generator-source peak withstand current and the rated system-source peak withstand current.

5.8 Rated duration of short circuit (t_k)

Subclause 5.8 of IEC 62271-1:2017 is applicable with the following modification.

The minimum value of t_k shall be 1 s.

5.9 Rated supply voltage of auxiliary and control circuits (U_a)

5.9.1 General

Subclause 5.9.1 of IEC 62271-1:2017 is applicable with the following addition:

In general the supply voltage is measured at the control power terminals of the operating mechanism at the peak operating current.

5.9.2 Rated supply voltage (U_a)

Subclause 5.9.2 of IEC 62271-1:2017 is not applicable and is replaced by the following:

Preferred values of supply voltages and their ranges are given in Table 2.

Table 2 – Preferred values of supply voltages and their ranges for auxiliary and control circuits of generator circuit-breakers and generator circuit-breaker systems

Direct current voltage ranges ^{a, b, c, d, g, h}			Alternating current voltage ranges ^{a, b, c, g}	
Preferred supply voltage	Closing and auxiliary functions	Tripping functions	Preferred supply voltage	Closing and auxiliary functions
U_a			U_a	
V	V	V	V	V
			Single-phase	
48 ^e	36 to 56	28 to 56	120	104 to 127 ^f
110 to 125	90 to 140	70 to 140	240	208 to 254 ^f
220 to 250	180 to 280	140 to 280	Three-phase	
			208 Y/120	180 Y/104 to 220 Y/127
			240	208 to 254
<p>^a Relays, motors, or other auxiliary equipment that function as part of the control for a device shall be subject to the voltage limits imposed by this document, whether mounted at the device or at a remote location.</p> <p>^b Mechanism devices in some applications may be exposed to supply voltages exceeding those specified here due to abnormal conditions, such as abrupt changes in line loading. Such applications require study, and the manufacturer should be consulted. Also, application of devices containing solid-state control exposed continuously to control voltages approaching the upper limits of ranges specified herein require specific attention, and the manufacturer should be consulted before application is made.</p> <p>^c Includes supply for pump or compressor motors. Note that rated voltages for motors and their operating ranges are covered in the related standards.</p> <p>^d It is recommended that the coils of closing, auxiliary, and tripping devices that are connected continually to one DC potential should be connected to the negative control bus so as to minimise electrolytic deterioration.</p> <p>^e 48 V tripping, closing, and auxiliary functions are recommended only when the device is located near the battery or where special effort is made to ensure the adequacy of conductors between battery and control terminals.</p> <p>^f Includes heater circuits.</p> <p>^g Extended voltage ranges apply to all closing and auxiliary devices when cold. Mechanisms utilising standard auxiliary relays for control functions may not comply at lower extremes of voltage ranges when relay coils are hot, as after repeated or continuous operation.</p> <p>^h DC supply voltage sources, such as those derived from rectified alternating current, may contain sufficient inherent ripple to modify the operation of control devices to the extent that they may not function over the entire specified voltage ranges.</p>				

5.10 Rated supply frequency of auxiliary and control circuits

Subclause 5.10 of IEC 62271-1:2017 is applicable.

5.11 Rated pressure of compressed gas supply for controlled pressure systems

Subclause 5.11 of IEC 62271-1:2017 is applicable.

5.101 Rated short-circuit current (I_{sc})

5.101.1 General

The rated short-circuit current of a generator circuit-breaker is the RMS value of the three-phase earthed short-circuit current to which all required short-circuit capabilities are related. Procedures for determining the symmetrical short-circuit current duties that compare with ratings and related required capabilities are found in Clause 9. It is to be noted that, if the performance capability of a generator circuit-breaker design has been demonstrated for a certain generator short-circuit current rating or transformer short-circuit current rating, then that performance capability is automatically demonstrated for a generator or a transformer of lower short-circuit current rating respectively.

5.101.2 Rated system-source short-circuit breaking current (I_{sc})

5.101.2.1 General

The rated system-source short-circuit breaking current is the highest system-source short-circuit current at contact separation, which the generator circuit-breaker shall be capable of breaking under the conditions of use and behaviour specified in this document. Such a current is found in a circuit having a power-frequency recovery voltage corresponding to the rated voltage of the generator circuit-breaker and having a transient recovery voltage equal to the value specified in 5.105. For three-pole generator circuit-breakers, the AC component relates to a three-phase earthed short-circuit. The source of the short-circuit current is from the power system through at least one transformation.

The rated system-source short-circuit breaking current is characterised by two values:

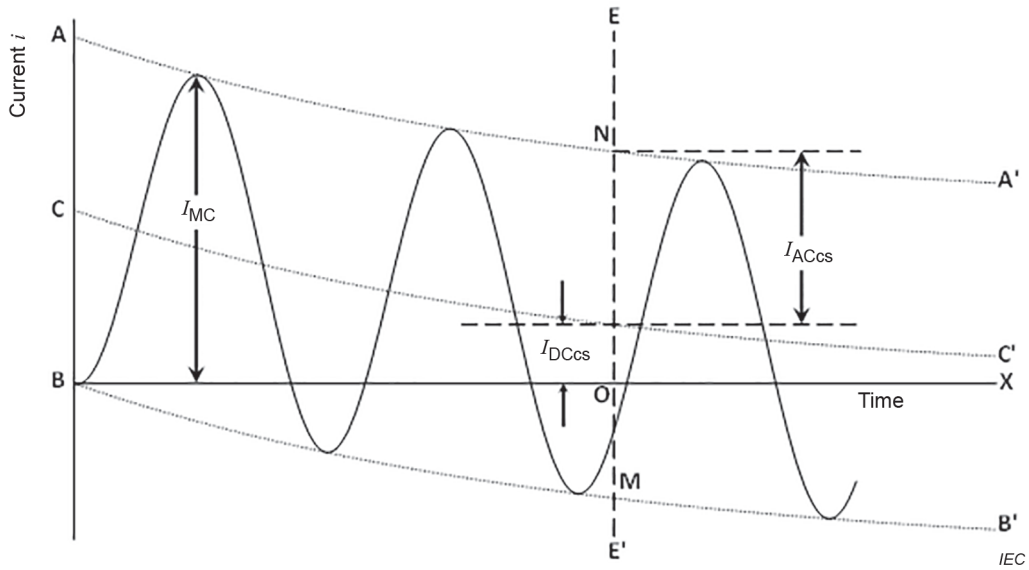
- a) the RMS value of its AC component I_{sc} ;
- b) the DC time constant of the rated system-source short-circuit breaking current which results in a certain degree of asymmetry at contact separation.

NOTE 1 If the degree of asymmetry at contact separation does not exceed 20 %, the rated system-source short-circuit breaking current is characterised only by the RMS value of its AC component.

NOTE 2 The degree of asymmetry is a function of the DC time constant of the rated system-source short-circuit breaking current (see 5.101.2.3) and of the instant of initiation of the system-source short-circuit current.

NOTE 3 In the case of rated system-source short-circuit breaking current the degree of asymmetry does not exceed 100 %.

For determination of the AC component, the DC component and the degree of asymmetry at any time following current initiation, see Figure 10 and Figure 11.



Key

- AA' and BB' define the envelope of current-wave
- BX is the current zero line
- CC' is the centre line of the envelope of current-wave
- EE' is the instant of contact separation (initiation of the arc)
- I_{MC} is the peak value of making current
- I_{ACcs} is the peak value of AC component of current at instant of contact separation, EE'
- I_{DCcs} is the DC component of current at instant of contact separation, EE'

Figure 10 – Typical asymmetrical system-source short-circuit current

The RMS value of the AC component of current I_{SC} at instant of contact separation is

$$\frac{I_{ACcs}}{\sqrt{2}}$$

The degree of asymmetry at instant of contact separation is

$$.Asy_{cs} = 100\% \times \frac{I_{DCcs}}{I_{ACcs}} = 100\% \times \frac{\overline{ON} - \overline{OM}}{\overline{MN}} = 100\% \times \left(\frac{2 \times \overline{ON}}{\overline{MN}} - 1 \right)$$

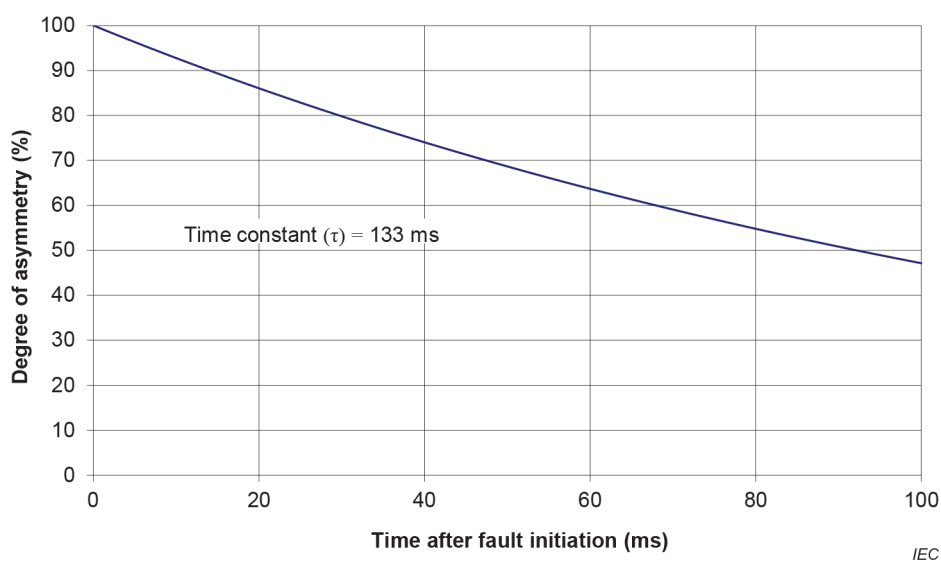


Figure 11 – Degree of asymmetry as a function of time after fault initiation

The generator circuit-breaker shall be capable of breaking any short-circuit current up to its rated system-source short-circuit breaking current containing any AC component up to the rated value and, associated with it, any degree of asymmetry corresponding to the DC time constant up to that specified, under the conditions mentioned above.

The following applies:

- a) at voltages below and equal to the rated voltage, the generator circuit-breaker shall be capable of breaking its rated short-circuit breaking current;
- b) at voltages above the rated voltage, no short-circuit breaking current is guaranteed.

5.101.2.2 RMS value of the AC component of the rated system-source short-circuit breaking current I_{sc}

The standard RMS value of the AC component of the rated system-source short-circuit breaking current should be selected from the R10 series specified in IEC 60059 [1]³. Values from the R 10 series are preferred values only. Manufacturers and users are free to choose any other values.

5.101.2.3 DC time constant of the rated system-source short-circuit breaking current τ

The standard DC time constant is 133 ms.

³ Numbers in square brackets refer to the Bibliography.

5.101.2.4 Rated generator-source short-circuit breaking current

5.101.2.4.1 General

The rated generator-source short-circuit breaking current is the highest generator-source short-circuit current at contact separation, which the generator circuit-breaker shall be capable of breaking under the conditions of use and behaviour specified in this document. Such a current is found in a circuit having a power-frequency recovery voltage corresponding to the rated voltage of the generator circuit-breaker and having a transient recovery voltage equal to the value specified in 4.105. For three-pole generator circuit-breakers, the AC component relates to a three-phase earthed short-circuit. The source of the short-circuit current is entirely from a generator through no transformations.

The rated generator-source short-circuit breaking current is characterised by two values:

- a) the RMS value of its AC component at contact separation I_{scg} ;
- b) the degree of asymmetry at contact separation Asy_{cs} .

If the degree of asymmetry exceeds 100 % then this leads to delayed current zero crossings.

NOTE If the degree of asymmetry at contact separation does not exceed 20 %, the rated generator-source short-circuit breaking current is characterised only by the RMS value of its AC component.

A typical generator-source short-circuit current wave form including the AC component, the DC component and the degree of asymmetry as a function of time after fault initiation is depicted in Figure 12.

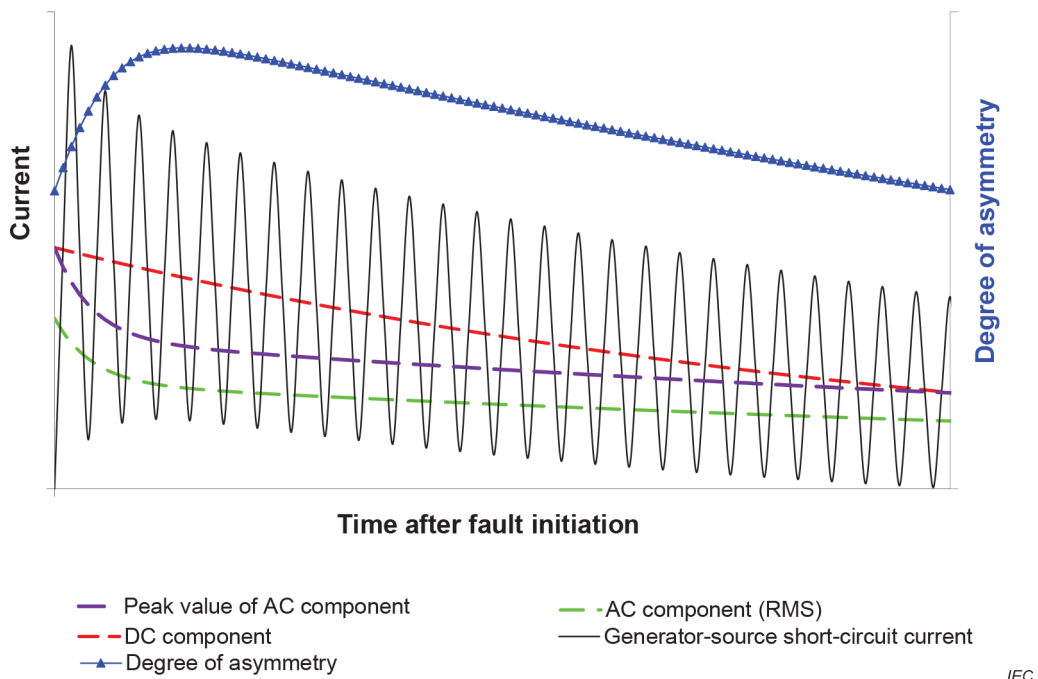


Figure 12 – Typical asymmetrical generator-source short-circuit current with a strong decrement of the AC component

For determination of the AC component and the degree of asymmetry at any time following current initiation, see Annex D.

The following applies:

- a) at voltages below and equal to the rated voltage, the generator circuit-breaker shall be capable of breaking its rated generator-source short-circuit breaking current;
- b) at voltages above the rated voltage, no short-circuit breaking current is guaranteed.

It should be noted that the AC component of this short-circuit current can decay rapidly, depending on the subtransient and transient time constants of the generator while the DC component decays with the armature time constant. The AC component and the degree of asymmetry of the generator-source short-circuit current can vary depending on whether the generator is unloaded or delivering power prior to fault.

The capability of a generator circuit-breaker to interrupt short-circuit currents with delayed current zero crossings occurring in actual service conditions, may be difficult to demonstrate in high power test laboratories. Therefore, the capability of a generator circuit-breaker to interrupt a short-circuit current with delayed current zero crossings shall be ascertained by calculations (see 9.103.6.3.6.4) taking into account results derived from test-duties in 7.105.11.

5.101.2.4.2 RMS value of the AC component of the rated generator-source short-circuit breaking current I_{scg}

This document does not give preferred values for the AC component of the generator-source short-circuit breaking current because its maximum value is usually less than the AC component of the short-circuit breaking current from the power system. If a rating is assigned by the manufacturer, then the generator circuit-breaker shall be tested for the related capabilities (see 7.105).

5.101.2.4.3 Degree of asymmetry of the rated generator-source short-circuit breaking current

For a generator circuit-breaker of class G1 the degree of asymmetry is 110 % with the assigned AC component of the rated generator-source short-circuit breaking current and 130 % with a current having an AC component equal to 74 % of the assigned AC component of the rated generator-source short-circuit breaking current irrespectively of the time that contact separation occurs (see Annex H).

For a generator circuit-breaker of class G2 the degree of asymmetry is 130 % with the assigned AC component of the rated generator-source short-circuit breaking current irrespectively of the time that contact separation occurs (see Annex H).

5.101.3 Rated single-phase-to-earth fault breaking current

No specific rating is assigned to cover the single-phase-to-earth fault breaking current because generator circuit-breakers are designed for use on systems earthed through a high-impedance where the single-phase-to-earth fault current will not exceed 50 A. In no case are the capabilities for single-phase-to-earth faults required to exceed this value. Generator circuit-breakers can easily break this current.

5.102 Rated short-circuit making current I_{MC}

The rated short-circuit making current (see Figure 10) of a generator circuit-breaker having simultaneity of poles is based on a DC time constant of 133 ms. This is 2,74 times the RMS value of the AC component of its rated system-source short-circuit breaking current.

If a generator-source short-circuit current rating is assigned and its making current is higher than the value above, then the rated making current shall be assigned by the manufacturer.

This value is applicable both for 50 Hz and 60 Hz.

NOTE The short-circuit making current can also be referred to as closing current.

5.103 Rated load breaking current

The rated load breaking current is the highest load current which the generator circuit-breaker shall be capable of making and breaking under the conditions of use and behaviour specified in this document. Such a current is found in a circuit having a power-frequency recovery voltage corresponding to the rated voltage of the generator circuit-breaker and having a transient recovery voltage equal to the value specified in 5.105.

The capability of the generator circuit-breaker to interrupt the load current shall be demonstrated by tests in accordance with 7.104.

5.104 Rated out-of-phase making and breaking current

The rated out-of-phase making and breaking current is the highest out-of-phase current which the generator circuit-breaker shall be capable of making and breaking under the conditions of use and behaviour specified in this document. Such a current is found in a circuit having a power-frequency recovery voltage corresponding to the rated voltage of the generator circuit-breaker and having a transient recovery voltage equal to the value specified in 5.105. The RMS value of the assigned out-of-phase current making and breaking rating I_d shall be 50 % of the RMS value of the AC component of the rated system-source short-circuit breaking current.

5.105 Rated transient recovery voltage (TRV)

5.105.1 Representation of TRV waves

The waveform of transient recovery voltages approximates a damped single frequency oscillation. Two straight lines adequately represent the upper and lower bounds of the rising part of the TRV waveform. The upper line begins at the origin, rises up and to the right and is tangent to the TRV curve, with a slope equal to the TRV rate of rise. The lower line has the same slope as the upper, and begins on the time axis at the point of the time delay t_d and ends at the point with coordinates (t', u') as illustrated in Figure 13. The upper line ends where it intersects a horizontal line drawn tangent to the highest point, u_c , of the TRV waveform. The time at the point where these two lines intersect, t_3 , is called the rise time, and the coordinates of this point are (t_3, u_c) . It is clear from Figure 13 that this time, t_3 , is earlier than the time when the TRV waveform actually reaches its peak. Methods of drawing TRV envelopes are given in 9.103.7.3.

The influence of local capacitance produces a slower rate of rise of the voltage during the first few microseconds of the TRV. This is taken into account by introducing the time delay.

The two parameters used for the representation of TRV are u_c and t_3 .

u_c is the reference voltage (the TRV peak value), and is calculated as follows

$$u_c = k_{pp} \times k_{af} \times \frac{U_r \sqrt{2}}{\sqrt{3}}$$

where

k_{pp} is the first-pole-to-clear factor with a value of 1,5 (see 9.103.7.4);

k_{af} is the amplitude factor with a value of 1,5 (see 9.103.7.5);

t_3 is the time to the intersection point of the upper line and the horizontal reference line. The method for determining the value for the time t_3 for a given TRV waveform is described in 9.103.7.3.

The preferred value of u' is chosen to be $u_c/3$ and t' is chosen to be $t_d + t_3/3$.

The ratio of u_c/t_3 is called the "Rate-of-Rise-of-Recovery-Voltage" (RRRV).

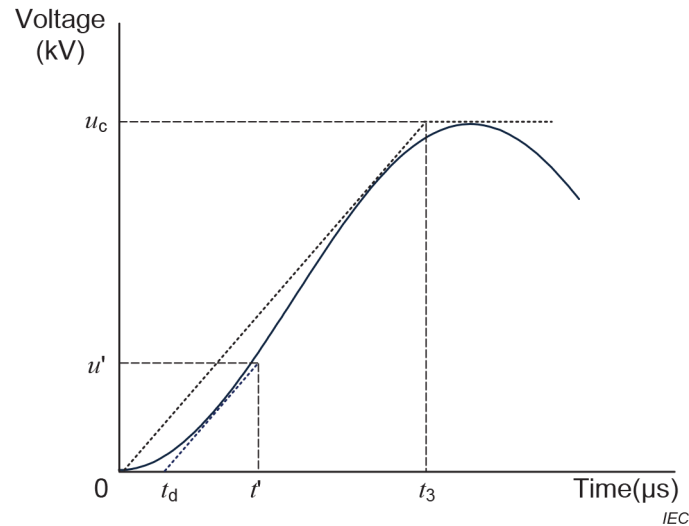


Figure 13 – Two-parameter representation of prospective TRV waveform for interrupting three-phase symmetrical faults

5.105.2 Rated values of TRV

Standard values for TRV parameters are listed in Table 3, Table 4, Table 5, and Table 6. The equation and method for determining the time t_3 are given in 9.103.7.3 and Figure 13. Table 3, Table 4, Table 5, and Table 6 provide the values of the prospective TRV parameters. U_r is expressed in kV (RMS value). For out-of-phase and load current breaking, the values of the prospective TRV parameters modified by the capacitors of the generator circuit-breaker are available in Annex M and in Annex N respectively.

The values for the TRV parameters t_3 and u_c given in Table 3 through Table 6 are expressed in microseconds and kV (peak value) respectively, and are calculated as functions of U_r , which is expressed in units of kV (RMS value). The ratings given in Table 3 and Table 4 are determined for the first-pole-to-clear and for symmetrical current interruption in the case of three-phase earthed faults. If the generator circuit-breaker requires that the prospective TRV be modified by the addition of capacitors, then the amount of equivalent capacitance required shall be given in the test report and on the nameplate.

Table 3 – TRV parameters for system-source short-circuit tests

Transformer rating MVA	Prospective TRV		
	Time t_3 μs	TRV peak value u_c kV	RRRV kV/ μs
10 to 50	$0,58 U_r$	$1,84 U_r$	3,2
51 to 100	$0,53 U_r$	$1,84 U_r$	3,5
101 to 200	$0,46 U_r$	$1,84 U_r$	4,0
201 to 400	$0,41 U_r$	$1,84 U_r$	4,5
401 to 600	$0,37 U_r$	$1,84 U_r$	5,0
601 to 1 000	$0,34 U_r$	$1,84 U_r$	5,5
1 001 or more	$0,31 U_r$	$1,84 U_r$	6,0
The time delay t_d shall be equal to $1 \mu\text{s}$.			

Table 4 – TRV parameters for generator-source short-circuit tests

Generator rating MVA	Prospective TRV		
	Time t_3 μs	TRV peak value u_c kV	RRRV kV/ μs
10 to 50	$1,23 U_r$	$1,84 U_r$	1,5
51 to 100	$1,15 U_r$	$1,84 U_r$	1,6
101 to 400	$1,02 U_r$	$1,84 U_r$	1,8
401 to 800	$0,92 U_r$	$1,84 U_r$	2,0
801 or more	$0,84 U_r$	$1,84 U_r$	2,2
The time delay t_d shall be equal to $0,5 \mu\text{s}$.			

Table 5 – TRV parameters for load current tests

Generator rating MVA	Prospective TRV		
	Time t_3 μs	TRV peak value u_c kV	RRRV kV/ μs
10 to 50	$1,03 U_r$	$0,92 U_r$	0,9
51 to 100	$0,92 U_r$	$0,92 U_r$	1,0
101 to 400	$0,77 U_r$	$0,92 U_r$	1,2
401 to 800	$0,66 U_r$	$0,92 U_r$	1,4
801 or more	$0,58 U_r$	$0,92 U_r$	1,6
The time delay t_d shall be equal to $1 \mu\text{s}$.			

Table 6 – TRV parameters for out-of-phase tests

Generator rating MVA	Prospective TRV		
	Time t_3 μs	TRV peak value u_c kV	RRRV kV/ μs
10 to 50	$0,87 U_r$	$2,6 U_r$	3,0
51 to 100	$0,79 U_r$	$2,6 U_r$	3,3
101 to 400	$0,64 U_r$	$2,6 U_r$	4,1
401 to 800	$0,56 U_r$	$2,6 U_r$	4,7
801 or more	$0,50 U_r$	$2,6 U_r$	5,2
The time delay t_d shall be equal to $1 \mu\text{s}$.			

5.106 Rated operating sequence

The rated operating sequence of a generator circuit-breaker shall be CO – 30 min – CO (without any intentional delay between C and O).

5.107 Mechanical operation endurance capability of generator circuit-breakers, main-disconnectors, starting switches, BTB-switches and braking switches of classes M1, M2 and M3

A generator circuit-breaker as well as the main-disconnector, the starting switch and the BTB-switch of a generator circuit-breaker system shall be able to perform the following number of mechanical operations taking into account the programme of maintenance specified by the manufacturer:

Standard generator circuit-breaker, main-disconnector, starting switch, BTB-switch and braking switch (normal mechanical endurance) class M1	1 000 operating cycles
Generator circuit-breaker, main-disconnector, starting switch, BTB-switch and braking switch for special service requirements (extended mechanical endurance) class M2	3 000 operating cycles
Generator circuit-breaker, main-disconnector, starting switch, BTB-switch and braking switch for special service requirements (extended mechanical endurance) class M3	10 000 operating cycles

NOTE Class M3 can be considered also for pumped-storage applications (see Annex O).

5.108 Rated first-pole-to-clear factor

The rated value of the first-pole-to-clear factor is 1,5.

6 Design and construction

6.1 Requirements for liquids in switchgear and controlgear

Subclause 6.1 of IEC 62271-1:2017 is applicable.

6.2 Requirements for gases in switchgear and controlgear

Subclause 6.2 of IEC 62271-1:2017 is applicable.

6.3 Earthing of switchgear and controlgear

Subclause 6.3 of IEC 62271-1:2017 is applicable with the following modifications:

For non-enclosed generator circuit-breakers, non-enclosed generator circuit-breaker systems, three-phase enclosed generator circuit-breakers or three-phase enclosed generator circuit-breaker systems, 6.3 of IEC 62271-1:2017 is applicable.

For single-phase enclosed generator circuit-breakers or single-phase enclosed generator circuit-breaker systems the earthing connection is typically made by connecting the enclosures of the generator circuit-breaker system to the earthed enclosures of the busbar.

6.4 Auxiliary and control equipment and circuits

Subclause 6.4 of IEC 62271-1:2017 is applicable with the following modifications:

- a) the voltage variations shall be according to Table 2;
- b) where shunt opening and closing releases are used, appropriate measures shall be taken in order to avoid damage to the releases when a continuous or sustained closing or opening command signal is applied. For example, those measures may include the use of series control contacts arranged so that:
 - when the generator circuit-breaker is closed, the close release control contact ("b" contact or break contact) is open and the open release control contact ("a" contact or make contact) is closed, and
 - when the generator circuit-breaker is open, the open release control contact ("a") is open and the close release control contact ("b") is closed;

NOTE Systems other than contacts are possible and can be used.

- c) for shunt closing releases the protective measures mentioned in the first dashed item of item b) above shall operate no sooner than the minimum close signal duration (3.7.130) provided by the generator circuit-breaker and no later than the rated closing time. If the current of the shunt closing release is interrupted by the control contact, the closing command shall be positively longer than the rated closing time.
- d) for shunt opening releases the protecting measures mentioned in the second dashed item of item b) above shall operate no sooner than the minimum trip signal duration (3.7.129) required by the generator circuit-breaker and no later than 20 ms after separation of the main contacts;
- e) for short close-open time requirements the protective measures for the shunt releases as mentioned in item b) above shall operate no sooner than when main contacts close and no later than one half-cycle after main contacts close;
- f) where auxiliary switches are used as position indicators, they shall indicate the end position of the generator circuit-breaker at rest, open or closed. The signalling shall be sustained;
- g) connections shall withstand the stresses imposed by the generator circuit-breaker, especially those due to mechanical forces during operations;
- h) in the case of outdoor generator circuit-breakers, all auxiliary equipment including the wiring shall be adequately protected against rain and humidity;
- i) where special items of control equipment are used, they shall operate within the limits specified for supply voltages of auxiliary and control circuits, interrupting and/or insulating and operating media, and be able to switch the loads which are stated by the generator circuit-breaker manufacturer;
- j) special items of auxiliary equipment such as liquid indicators, pressure indicators, relief valves, filling and draining equipment, heating and interlock contacts shall operate within the limits specified for supply voltages of auxiliary and control circuits and/or within the limits of use of interrupting and/or insulating and operating media;
- k) the power consumption of heaters at rated voltage shall be within the tolerance of $\pm 10\%$ of the value specified by the manufacturer;

- l) where anti-pumping devices are part of the generator circuit-breaker control scheme, they shall act on each control circuit, if more than one is installed.

6.5 Dependent power operation

For generator circuit-breakers 6.5 of IEC 62271-1:2017 is not applicable.

For the main-disconnector and the switches of a generator circuit-breaker system 6.5 of IEC 62271-102:2018 is applicable.

6.6 Stored energy operation

Subclause 6.6 of IEC 62271-1:2017 is applicable.

6.7 Independent unlatched operation (independent manual or power operation)

For generator circuit-breakers 6.7 of IEC 62271-1:2017 is not applicable.

For the main-disconnector and the switches of a generator circuit-breaker system, 6.7 of IEC 62271-102:2018 is applicable.

6.8 Manually operated actuators

Subclause 6.8 of IEC 62271-1:2017 is applicable.

6.9 Operation of releases

6.9.1 General

Subclause 6.9.1 of IEC 62271-1:2017 is not applicable and is replaced by the following:

See 5.9.2 for the basis of operation limits with respect to supply voltage.

6.9.2 Shunt closing release

For generator circuit-breakers 6.9.2 of IEC 62271-1:2017 is not applicable.

A shunt closing release shall be able to operate within a voltage range of the power supply, measured at the input terminals, according to Table 2.

For the main-disconnector and the switches of a generator circuit-breaker system, 6.9.2 of IEC 62271-1:2017 is applicable.

6.9.3 Shunt opening release

For generator circuit-breakers 6.9.3 of IEC 62271-1:2017 is not applicable.

A shunt opening release shall be able to operate within a voltage range of the power supply, measured at the input terminals, according to Table 2.

The operating mechanism shall be trip-free as defined in 3.6.109 of this document. That is, whenever an opening command is given it shall have priority over a closing command.

For the main-disconnector and the switches of a generator circuit-breaker system, 6.9.3 of IEC 62271-1:2017 is applicable.

6.9.4 Capacitor operation of shunt releases

Subclause 6.9.4 of IEC 62271-1:2017 is applicable.

6.9.5 Under-voltage release

Subclause 6.9.5 of IEC 62271-1:2017 is not applicable.

6.9.101 Multiple releases

If a generator circuit-breaker is fitted with more than one release for the same function, a defect in one release shall not disturb the function in the others. Releases used for the same function shall be physically separated, i.e. magnetically decoupled.

6.9.102 Operation limits of releases

For shunt opening releases of generator circuit-breakers the minimum trip duration and for shunt closing releases the minimum command duration at rated supply voltage shall not be less than 2 ms.

The minimum supply voltage for operation of shunt releases of generator circuit-breakers shall not be less than 20 % of the rated supply voltage.

6.9.103 Power consumption of releases

The power consumption of shunt closing or opening releases of a three-pole generator circuit-breaker should not exceed 1 200 VA. For certain generator circuit-breaker designs higher values may be required.

6.10 Pressure/level indication

6.10.1 Gas pressure

Subclause 6.10.1 of IEC 62271-1:2017 is applicable.

6.10.2 Liquid level

Subclause 6.10.2 of IEC 62271-1:2017 is applicable.

6.11 Nameplates

6.11.1 General

Subclause 6.11.1 of IEC 62271-1:2017 is applicable.

6.11.2 Application

For generator circuit-breakers 6.11.2 of IEC 62271-1:2017 is applicable with the following modifications:

The nameplate(s) of a generator circuit-breaker and its operating devices shall include the items listed in Table 7 below.

Additional information may be given.

The nameplate(s) shall be visible when the generator circuit-breaker is in the position of normal service and installation.

Coils of operating devices and releases shall be marked with the manufacturer's name and part number.

Table 7 – Nameplate information for generator circuit-breakers

Information to be listed on nameplates	Condition: Marking only required if	Abbreviation	Unit	Generator circuit-breaker	Operating device
(1)	(2)	(3)	(4)	(5)	(6)
Manufacturer				X	X
Type designation and serial number				X	X
Rated voltage		U_r	kV	X	
Rated power-frequency withstand voltage		U_d	kV	X	
Rated lightning impulse withstand voltage		U_p	kV	X	
Rated frequency		f_r	Hz	X	
Rated continuous current	external forced cooling is not required	I_r	A	Y	
Rated continuous current with external forced cooling	external forced cooling is required	$I_{r, efc}$	A	Y	
Rated short-time withstand current		I_k	kA	X	
Rated duration of short-circuit		t_k	s	X	
Rated short-circuit making current		I_{MC}	kA	X	
RMS value of the AC component of the rated system-source short-circuit breaking current		I_{SC}	kA	X	
Rated rate-of-rise-of-recovery-voltage		$RRRV$	kV/ μ s	X	
Minimum opening time			ms	X	
RMS value of the AC component of the rated out-of-phase breaking current		I_d	kA	(X)	
Filling pressure for operation at 20 °C		p_{rm}	MPa [psi] absolute		(X)
Kind and mass of fluid for insulation and/or making and breaking	sealed tank contains fluid		kg [lb]	Y	
Filling pressure for insulation and/or making and breaking at 20 °C		p_{re}	MPa [psi] absolute	(X)	
Rated supply voltage of control circuits			V		(X)
Rated supply frequency of control circuits			Hz		(X)
Current of control circuits			A		(X)
Rated supply voltage of auxiliary circuits		U_a	V		(X)
Rated supply frequency of auxiliary circuits			Hz		(X)

Information to be listed on nameplates	Condition: Marking only required if	Abbreviation	Unit	Generator circuit-breaker	Operating device
(1)	(2)	(3)	(4)	(5)	(6)
Current of auxiliary circuits			A		(X)
Mass (including fluids)		<i>M</i>	kg [lb]	X	X
Rated operating sequence				X	
Three-phase break-time			ms	X	
Required capacitance value per phase at the generator side	non zero		nF	Y	
Capacitance value per phase provided at the generator side	different from required capacitance value		nF	Y	
Required capacitance value per phase at the transformer side	non zero		nF	Y	
Capacitance value per phase provided at the transformer side	different from required capacitance value		nF	Y	
Opening resistor value	equipped with opening resistor in parallel to the interrupting chamber		Ω	Y	
Mechanical endurance class				X	X
Year of manufacture				X	X
Minimum and maximum ambient air temperature			°C	X	
Instruction book number				X	X
Relevant standard with date of issue				X	X
<p>Key</p> <p>X = the marking of these values is mandatory; blanks indicate the value zero.</p> <p>(X) = if a rating is assigned the marking of these values is mandatory.</p> <p>Y = the marking of these values is mandatory if the conditions in column (2) are met.</p> <p>NOTE 1 The abbreviation in column (3) can be used instead of the terms in column (1). When terms in column (1) are used, the word "rated" need not appear.</p> <p>NOTE 2 If the values for the control circuits (closing and opening) are different, additional lines may be required.</p>					

For generator circuit-breaker systems 6.11.2 of IEC 62271-1:2017 is applicable with the following modifications:

The nameplate(s) of a generator circuit-breaker system and its operating devices shall include the items listed in Table 8 to Table 10 below.

Additional information may be given.

- Table 8: general information;
- Table 9: information for a generator circuit-breaker, being part of a generator circuit-breaker system;

- Table 10: information for the main-disconnector, switches and short-circuiting connections, being part of a generator circuit-breaker system.

The nameplate(s) shall be visible when the generator circuit-breaker system is in the position of normal service and installation. Each stand-alone object shall be equipped with its own nameplate.

Coils of operating devices and releases shall be marked with the manufacturer's name and part number.

Table 8 – General nameplate information for generator circuit-breaker systems

Information to be listed on nameplates	Condition: Marking only required if	Abbreviation	Unit	System
(1)	(2)	(3)	(4)	(5)
Manufacturer				X
Type designation and serial number				X
Rated voltage		U_r	kV	X
Rated power-frequency withstand voltage		U_d	kV	X
Rated lightning impulse withstand voltage		U_p	kV	X
Rated frequency		f_r	Hz	X
Rated continuous current	external forced cooling is not required	I_r	A	Y
Rated continuous current with external forced cooling	external forced cooling is required	$I_{r, efc}$	A	Y
Rated short-time withstand current		I_k	kA	X
Rated duration of short-circuit		t_k	s	X
Minimum and maximum ambient air temperature			°C	X
Year of manufacture				X
Instruction book number(s)				X
Relevant standard with date of issue				X
Total mass (including fluids)		M	kg [lb]	X
Key				
X = the marking of these values is mandatory; blanks indicate the value zero.				
Y = the marking of these values is mandatory if the conditions in column (2) are met.				
NOTE The abbreviation in column (3) can be used instead of the terms in column (1). When terms in column (1) are used, the word "rated" need not appear.				

Table 9 – Nameplate information for generator circuit-breakers, being part of a generator circuit-breaker system

Information to be listed on nameplates	Condition: Marking only required if	Abbreviation	Unit	Generator circuit-breaker	Operating device
(1)	(2)	(3)	(4)	(5)	(6)
Manufacturer	different from general information for generator circuit-breaker system			Y	Y
Type designation and serial number				Y	Y
Rated voltage		U_r	kV	Y	
Rated power-frequency withstand voltage		U_d	kV	Y	
Rated lightning impulse withstand voltage		U_p	kV	Y	
Rated frequency		f_r	Hz	Y	
Rated continuous current		I_r	A	Y	
Rated continuous current with external forced cooling		$I_{r, efc}$	A	Y	
Rated short-time withstand current		I_k	kA	Y	
Rated duration of short-circuit		t_k	s	Y	
Rated short-circuit making current			I_{MC}	kA	X
RMS value of the AC component of the rated system-source short-circuit breaking current		I_{SC}	kA	X	
Rated rate-of-rise-of-recovery-voltage		$RRRV$	kV/ μ s	X	
Minimum opening time			ms	X	
RMS value of the AC component of the rated out-of-phase breaking current		I_d	kA	(X)	
Filling pressure for operation at 20 °C		p_{rm}	MPa [psi] absolute		(X)
Kind and mass of fluid for insulation and/or making and breaking	sealed tank contains fluid		kg [lb]	Y	
Filling pressure for insulation and/or making and breaking at 20 °C		p_{re}	MPa [psi] absolute	(X)	
Rated supply voltage of control circuits			V		(X)
Rated supply frequency of control circuits			Hz		(X)
Current of control circuits			A		(X)
Rated supply voltage of auxiliary circuits		U_a	V		(X)
Rated supply frequency of auxiliary circuits			Hz		(X)
Current of auxiliary circuits			A		(X)
Rated operating sequence				X	
Three-phase break-time			ms	X	
Required capacitance value per phase at the generator side	non zero		nF	Y	
Capacitance value per phase provided at the generator side	different from required capacitance value		nF	Y	

Information to be listed on nameplates	Condition: Marking only required if	Abbreviation	Unit	Generator circuit-breaker	Operating device
(1)	(2)	(3)	(4)	(5)	(6)
Required capacitance value per phase at the transformer side	non zero		nF	Y	
Capacitance value per phase provided at the transformer side	different from required capacitance value		nF	Y	
Opening resistor value	equipped with opening resistor in parallel to the interrupting chamber		Ω	Y	
Mechanical endurance class				X	X
Year of manufacture	different from general information for generator circuit-breaker system			Y	Y
Instruction book number(s)				Y	Y
Relevant standard with date of issue				Y	Y
Key					
X = the marking of these values is mandatory; blanks indicate the value zero.					
(X) = if a rating is assigned the marking of these values is mandatory.					
Y = the marking of these values is mandatory if the conditions in column (2) are met.					
NOTE 1 The abbreviation in column (3) can be used instead of the terms in column (1). When terms in column (1) are used, the word "rated" need not appear.					
NOTE 2 If the values for the control circuits (closing and opening) are different, additional lines may be required.					

Information to be listed on nameplates	Condition: Marking only required if	Abbreviation	Unit	Main-disconnector	starting switch	ET-switch	Tee-OFF-switch	BTB-switch	Braking switch	Earthing switch	Short-circuiting connection	Operating device(s)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Filling pressure for operation at 20 °C		p_{rm}	MPa [psi] absolute									(X)
Kind and mass of fluid for insulation	sealed tank contains fluid		kg [lb]	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	
Filling pressure for insulation		p_{re}	MPa [psi] absolute	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	
Rated supply voltage of auxiliary and control circuits			V									X
Year of manufacture	different from general information for generator circuit-breaker system			Y	Y	Y	Y	Y	Y	Y	Y	Y
Instruction book number(s)				Y	Y	Y	Y	Y	Y	Y	Y	Y
Relevant standard with date of issue				Y	Y	Y	Y	Y	Y	Y	Y	Y
Key												
X = the marking of these values is mandatory; blanks indicate the value zero.												
(X) = if a rating is assigned the marking of these values is mandatory.												
Y = the marking of these values is mandatory if the conditions in column (2) are met.												
NOTE The abbreviation in column (3) can be used instead of the terms in column (1). When terms in column (1) are used, the word "rated" need not appear.												

Additional components of a generator circuit-breaker system, other than those quoted in Table 10, if any, shall have separate nameplates, but these nameplates need only be legible when the additional components are in the removed position.

6.11.101 Modification of generator circuit-breakers

Revised nameplates shall be furnished when modification is involved. IEEE Std C37.59™ provides guidance regarding nameplates for modified generator circuit-breakers.

6.12 Locking devices

Subclause 6.12 of IEC 62271-1:2017 is applicable.

6.13 Position indication

Subclause 6.13 of IEC 62271-1:2017 is applicable.

6.14 Degrees of protection provided by enclosures

6.14.1 General

Subclause 6.14.1 of IEC 62271-1:2017 is replaced by the following:

Degrees of protection provided by enclosures of generator circuit-breaker systems:

- against allowing penetration from outside for the (IP coding) assigned according to IEC 60529,

and

- against external mechanical impacts for the (IK coding) assigned according to IEC 62262,

shall be specified for all enclosures containing parts of the main circuit of the generator circuit-breaker system, as well as for enclosures containing appropriate low-voltage control and/or auxiliary circuits and for enclosures containing mechanical operating mechanisms.

The degrees of protection apply to the service conditions of the generator circuit-breaker system.

NOTE The degrees of protection can be different for other conditions such as maintenance, testing.

Being connected on each side to the isolated-phase bus (IPB), the enclosure of the generator circuit-breaker system contains air whose dryness and cleanliness depend on the atmosphere inside the IPB. In order to ensure the long-term dielectric withstand of the IPB and generator circuit-breaker system, it is necessary to keep these pieces of equipment with the lowest possible level of dust or humidity during their whole service life.

The IPB and generator circuit-breaker system being similar toward this issue, the atmosphere of both pieces of equipment shall be controlled using similar solutions. Because these solutions are closely dependent on power plant service load and environmental conditions, their design and implementation are usually handled by IPB engineering.

Long term worldwide experience shows that dedicated solutions shall be applied to reach the requested atmosphere quality whatever the circumstances.

To avoid dust penetration, IP5x or more is usually sufficient to reach the goal. However, if IPx5 or IPx6 do efficiently prevent liquid water from penetrating the enclosures, they do not prevent water vapours from penetrating the enclosure due to breathing phenomenon in the case of atmospheric pressure variation, temperature variation, or load variation.

Depending on power plant exploitation and climate conditions these variations can generate water condensation in the IPB and generator circuit-breaker system enclosures. Specifically, in case of applications where load current is far from being sufficient to continuously heat the conductors and the inner surfaces of the enclosures (or in case of long periods of power shutdown), the external atmospheric variations may create a condensation situation on a regular basis. The repetition of these conditions may lead to liquid water accumulation in the enclosures, making the situation worse as long time goes, leading to possible insulation issues and corrosion of the equipment.

IPB engineering should ensure a safe atmosphere inside the IPB enclosure for all climatic and service conditions, and that the atmosphere inside the generator circuit-breaker system benefits from measures against condensation risks such as:

- IPB and generator circuit-breaker system enclosures pressurisation, with a slight pressure of dry air (0,5 kPa to 2 kPa above atmospheric pressure);
- IPB and generator circuit-breaker system enclosures heating by appropriate equipment to maintain the surface temperature above the dew point of the air inside the IPB.

If the IPB and generator circuit-breaker system have two separate atmospheres, appropriate measures shall be subject to agreement between the user and generator circuit-breaker system manufacturer.

6.14.2 Protection of persons against access to hazardous parts and protection of the equipment against ingress of solid foreign objects (IP coding)

Subclause 6.14.2 of IEC 62271-1:2017 is applicable.

6.14.3 Protection against ingress of water (IP coding)

Subclause 6.14.3 of IEC 62271-1:2017 is applicable.

6.14.4 Protection against mechanical impact under normal service conditions (IK coding)

Subclause 6.14.4 of IEC 62271-1:2017 is applicable.

6.15 Creepage distances for outdoor insulators

Subclause 6.15 of IEC 62271-1:2017 is applicable.

6.16 Gas and vacuum tightness

Subclause 6.16 of IEC 62271-1:2017 is applicable.

6.17 Tightness for liquid systems

Subclause 6.17 of IEC 62271-1:2017 is applicable.

6.18 Fire hazard (flammability)

Subclause 6.18 of IEC 62271-1:2017 is applicable.

6.19 Electromagnetic compatibility (EMC)

Subclause 6.19 of IEC 62271-1:2017 is applicable.

6.20 X-ray emission

Subclause 6.20 of IEC 62271-1:2017 is applicable.

6.21 Corrosion

Subclause 6.21 of IEC 62271-1:2017 is applicable.

6.22 Filling levels for insulation, switching and/or operation

Subclause 6.22 of IEC 62271-1:2017 is applicable.

6.101 Requirements for simultaneity of poles during single closing and single opening operations

The following requirements are applicable under rated conditions of the auxiliary and control voltage and pressure for operation:

The maximum difference between the instances of contact touch during closing in the three poles shall not exceed one quarter of a cycle of rated frequency. If one pole consists of more than one interrupter connected in series, the maximum difference between the instances of contact touch within these series connected interrupters shall not exceed one sixth of a cycle of rated frequency.

The maximum difference between the instances of contact separation during opening in the three poles shall not exceed one sixth of a cycle of rated frequency. If one pole consists of more than one interrupter connected in series, the maximum difference between the instances of contact separation within these series connected interrupters shall not exceed one eighth of a cycle of rated frequency.

6.102 General requirement for operation

A generator circuit-breaker, including its operating devices, shall be capable of completing its rated operating sequence (5.106) in accordance with the relevant provisions of 6.6 to 6.12 and 6.103 for the applicable range(s) of ambient temperatures as defined in Clause 4 of IEC 62271-1:2017.

This requirement is not applicable to auxiliary manual operating devices; where provided, these shall be used only for maintenance and for emergency operation on a dead circuit.

Generator circuit-breakers provided with heaters shall be designed to permit an opening operation at the assigned minimum ambient temperature when the heaters are not operational for a minimum time of 2 h.

6.103 Pressure limits of fluids for operation

The manufacturer shall state the maximum and minimum pressures of the fluid for operation at which the generator circuit-breaker is capable of performing according to its ratings and at which the appropriate low- and high-pressure interlocking devices shall be set (see 6.107). The manufacturer shall state the minimum functional pressure for operation and the minimum functional pressure for insulation and/or making and breaking (see 3.6.5.6 and 3.6.5.5).

The manufacturer may specify pressure limits at which the generator circuit-breaker is capable of each of the following performances:

- a) breaking its rated short-circuit breaking current, i.e. an "O" operation;
- b) making its rated short-circuit making current immediately followed by breaking its rated short-circuit breaking current, i.e. a "CO" operating cycle.

The generator circuit-breakers shall be provided with energy storage of sufficient capacity for satisfactory performance of the appropriate operations at the corresponding minimum pressures stated.

6.104 Vent outlets of generator circuit-breakers

Vent outlets are devices which allow a deliberate release of pressure in a generator circuit-breaker during operation.

NOTE These are normally associated with air, air-blast and oil generator circuit-breakers.

Vent outlets of generator circuit-breakers shall be situated such that a discharge of oil or gas or both will not cause electrical breakdown and is directed away from any location where persons are likely to be present. The necessary safety distance shall be stated by the manufacturer.

The construction shall be such that gas cannot collect at any point where ignition can be caused, during or after operation, by sparks arising from normal operation of the generator circuit-breaker or its auxiliary equipment.

6.105 Warning labels

Markings and warning labels shall be provided to identify possible dangerous conditions related to the generator circuit-breaker or the generator circuit-breaker system and its operating devices and to call special attention to the appropriate precautions.

6.106 Instructions

Instructions essential for maintenance and the safe operation of the generator circuit-breaker or the generator circuit-breaker system shall be provided.

6.107 Low-and high-pressure interlocking devices

All generator circuit-breakers having an energy storage in gas receivers or hydraulic accumulators (see 6.6.2 of IEC 62271-1:2017) and all generator circuit-breakers except sealed pressure devices, using compressed gas for insulation and/or making and breaking (see 6.103) shall be fitted with a low-pressure or low-density interlocking device, and can also be fitted with a high-pressure or high-density interlocking device, set to operate at, or within, the appropriate limits of pressure or density stated by the manufacturer.

7 Type tests

7.1 General

7.1.1 Basics

Subclause 7.1.1 of IEC 62271-1:2017 is applicable with the following modifications:

Type tests are made to determine the adequacy of the design of a particular type, style, or model generator circuit-breaker to meet its assigned ratings and to operate satisfactorily under the specified service conditions. Type tests are made only on representative generator circuit-breakers of basically the same design, i.e., the same interrupters operating at the same contact speeds, and having at least the same dielectric strength. These tests are not intended to be used as a part of normal production. The applicable portions of these type tests may also be used to evaluate modifications of a previous design and to ensure that performance has not been adversely affected. Test data from previous similar designs may be used for current designs, where appropriate.

The type tests for generator circuit-breakers are listed in Table 11. For the type tests, the tolerances on test quantities are given in Annex A. The individual type tests shall, in principle, be performed on a generator circuit-breaker in a new and clean condition. In case of generator circuit-breakers using SF₆ for insulation and/or making and breaking and/or operation, the quality of the gas shall at least comply with the acceptance levels of IEC 60480.

The responsibility of the manufacturer is limited to the declared rated values and not to those values achieved during the type tests.

The uncertainty of each measurement of the quantities which determine the ratings (for example short-circuit current, applied voltage and recovery voltage) shall be within ±5 %.

For generator circuit-breaker systems additional type tests are needed. The relevant standards, which are valid for the individual components, with the following modifications apply:

- Dielectric tests shall be performed for the entire generator circuit-breaker system, according to 7.2.
- Continuous current tests on the main current path (generator circuit-breaker, main-disconnector) shall be performed for the entire generator circuit-breaker system, according to 7.5.
- Continuous current tests on fully energised voltage and current transformers or other components not being part of the main circuit can be performed in separate stand alone tests with the individual components. For components, the highest ambient temperature inside the enclosure seen by the component shall be considered (for example typically 80 °C when carrying continuous current).
- Short-time withstand current and peak withstand current tests with the main-disconnector, the earthing switches, the starting switch, the Tee-OFF-switch, the BTB-switch, the ET-switch, and the short-circuiting connection shall be performed with a peak factor according to 5.7 and a duration of short-circuit according to 5.8. The duration of short-circuit for the test with the main-disconnector shall be the same as for the generator circuit-breaker.
- If the main-disconnector is part of a single-phase enclosed generator circuit-breaker system then the short-time withstand current and peak withstand current tests shall be performed according to 7.6.
- The mechanical endurance tests with the main-disconnector and the earthing switch shall be performed according to their applicable standard. For the main-disconnector the mechanical endurance classes according to 5.107 are applicable.
- The mechanical endurance tests with the starting switch, BTB-switch, Tee-OFF-switch, ET-switch and motor operated short-circuiting connections shall be performed according to the standard applicable for disconnectors, with the following modification: For the starting switch and BTB-switch the mechanical endurance classes according to 5.107 are applicable.
- The Tee-OFF generator circuit-breaker shall be tested in accordance with Annex J.

Some components of a generator circuit-breaker systems (such as starting switch, BTB-switch, braking switch, or short-circuiting connection) need to carry current for a limited time, typically for a few minutes up to a few tens of minutes. The manufacturer shall provide values for temporary current and current carrying time. No temperature limits are given for these components, provided that they remain in good condition after their temporary current carrying and do not cause any damage to the surrounding components. In addition the manufacturer shall provide the duty cycle (such as cooling time needed between temporary current carrying cycles).

Table 11 – Type tests

Mandatory type tests		Subclauses
Dielectric tests		7.2
Measurement of the resistance of the main circuit		7.4
Continuous current tests		7.5
Short-time withstand current and peak withstand current tests		7.6
Additional tests on auxiliary and control circuits		7.10
Mechanical operation test at ambient temperature		7.101.2.1 to 7.101.2.3
Sound pressure level tests		7.101.4
System-source short-circuit current making and breaking tests		7.103
Load current breaking tests		7.104
Type tests dependent upon application, rating or design	Condition requiring type test	Subclauses
Verification of the degree of protection	Assigned IP coding	7.7.1
	Assigned IK coding	7.7.2
Tightness test	Controlled, sealed or closed pressure systems	7.8
EMC tests	Electronic equipment or components are included in the secondary system	7.9
Extended mechanical endurance tests on generator circuit-breakers for special service conditions	Assigned class M2 or class M3	7.101.2.4
Low and high temperature tests	In accordance with 7.101.3.1	7.101.3
Generator-source short-circuit current making and breaking tests	Assigned generator-source short-circuit current	7.105
Out-of-phase making and breaking tests	Assigned out-of-phase current	7.106
Mandatory type tests, shown in the upper part of the table, are required for all generator circuit-breakers. Other type tests, shown in the lower part of the table, are required for all generator circuit-breakers where the associated rating is specified.		

7.1.2 Information for identification of test objects

Subclause 7.1.2 of IEC 62271-1:2017 is applicable.

7.1.3 Information to be included in type test reports

Subclause 7.1.3 of IEC 62271-1:2017 is applicable with the following addition:

Further details relating to records and reports of type tests for making, breaking and short-time current performance are given in Annex B.

7.2 Dielectric tests

7.2.1 General

Subclause 7.2.1 of IEC 62271-1:2017 is applicable.

7.2.2 Ambient air conditions during tests

Subclause 7.2.2 of IEC 62271-1:2017 is replaced by the following:

7.2.2.101 General

For test objects where external insulation (see 3.1.109) is of principle concern, the correction factor K_t shall be applied, in order to achieve similar results, as if the tests were performed under standard reference atmospheric conditions:

$$U = U_0 \times K_t$$

where

U is the voltage to be applied during test of external insulation;

U_0 is the test voltage as specified in Table 1;

K_t is the correction factor.

7.2.2.102 Standard reference atmosphere

The standard reference atmosphere is:

$t_0 = 20 \text{ °C}$ reference temperature

$p_0 = 101,3 \text{ kPa}$ reference pressure

$h_0 = 11 \text{ g/m}^3$ reference (absolute) humidity

7.2.2.103 Correction factor K_t

The external insulation of generator circuit-breakers or generator circuit-breaker systems in free air shall be tested by applying the correction factor K_t .

$$K_t = k_1 \times k_2$$

where

K_t is the correction factor;

k_1 is the air density correction factor;

k_2 is the humidity correction factor.

7.2.2.104 Air density correction factor

When the temperatures t and t_0 are expressed in degrees Celsius and the atmospheric pressures p and p_0 are expressed in the same units, the air density correction factor is:

$$k_1 = \delta^m$$

$$\delta = \frac{p}{p_0} \times \frac{273+t_0}{273+t}$$

where

k_1 is the air density correction factor;

δ is the relative air density;

m is an exponent;

p_0 is the reference pressure;
 p is the ambient pressure;
 t_0 is the reference temperature;
 t is the ambient temperature.

According to IEC 62271-1:2017, subclause 7.2.2, it can be assumed that $m = 1$. Hence:

$$k_1 = \frac{p}{p_0} \cdot \frac{273+t_0}{273+t}$$

7.2.2.105 Humidity correction factor for power-frequency withstand voltage tests

$$k_2 = k^w$$

$$k = 1 + 0,012(h/\delta - 11)$$

$$w = 0,5 - \tan^{-1}((h - 11 \times \delta) \times 100)/\pi \quad (\text{see Annex P})$$

where

k_2 is the humidity correction factor;
 k is the humidity parameter;
 w is the humidity exponent;
 h is the absolute humidity in g/m^3 ;
 δ is the relative air density.

7.2.2.106 Humidity correction factor for lightning impulse voltage tests

$$k_2 = k^w$$

$$k = 1 + 0,010(h/\delta - 11)$$

$$w = 0,5 - \tan^{-1}((h - 11 \times \delta) \times 100)/\pi \quad (\text{see Annex P})$$

where

k_2 is the humidity correction factor;
 k is the humidity parameter;
 w is the humidity exponent;
 h is the absolute humidity in g/m^3 ;
 δ is the relative air density.

7.2.2.107 Internal insulation

To test the internal insulation of generator circuit-breakers or generator circuit-breaker systems the correction factor K_t shall not be applied as the internal insulation is not influenced by the ambient air conditions.

7.2.2.108 Combination of external insulation in free air and internal insulation

Most generator circuit-breakers or generator circuit-breaker systems have both external insulation and internal insulation. By applying the correction factor K_t (refer to 7.2.2.102 for calculation), the internal insulation could be either overstressed or understressed during the dielectric tests. By not applying the correction factor K_t , the external insulation could be either overstressed or understressed during the dielectric tests. Additional steps may be necessary to prevent such overstressing. Some methods are discussed in IEC 60060-1.

Therefore, during the dielectric tests, the following three cases shall be distinguished:

- a) If the correction factor K_t is below 0,95 one of the following two test procedures is possible:
 - To avoid overstress of the external insulation, the effective correction factor K_t shall be applied. Additional tests, where the correction factor K_t is not applied, shall be performed to show the correct dielectric performance of the internal insulation.
 - With the consent of the manufacturer, it is also permissible to test with any correction factor K_t between 0,95 and 1,00.
- b) If the correction factor K_t is between 0,95 and 1,00 it shall be applied during the dielectric type tests. With the consent of the manufacturer it is also permissible to test without applying the correction factor K_t .
- c) If the correction factor K_t is above 1,00 one of the following two test procedures is possible:
 - To avoid overstress of the internal insulation, the correction factor K_t may be set to 1,00. Additional tests, where the effective correction factor K_t is applied, shall be performed to show the correct dielectric performance of the external insulation.
 - With the consent of the manufacturer, the correction factor K_t shall be applied during the dielectric tests.

7.2.3 Wet test procedure

Subclause 7.2.3 of IEC 62271-1:2017 is applicable.

7.2.4 Arrangement of the equipment

Subclause 7.2.4 of IEC 62271-1:2017 is applicable with the following additions:

With the generator circuit-breaker, additional power-frequency voltage tests shall be performed with the insulating gas at atmospheric pressure to simulate the loss of this gas, with a voltage corresponding to 1,5 times the following voltages:

- a) the phase opposition voltage across the open contacts;
- b) the phase-to-earth voltage between the conductor and earth;
- c) the phase-to-phase voltage between phases, if applicable.

If vacuum interrupters are used in enclosures filled with an insulating gas the additional power-frequency voltage tests are performed with the insulating gas at atmospheric pressure.

If vacuum interrupters are not used in enclosures filled with an insulating gas, the additional power-frequency voltage tests are not required.

It may be difficult to carry out the dielectric tests on generator circuit-breakers equipped with resistors or capacitors. In such cases, they may be replaced by dummy resistors or dummy capacitors. Dummy resistors and dummy capacitors shall have the same outer dimensions and selection of materials as the real resistors and real capacitors. In addition, resistors or capacitors shall be tested separately in accordance with their standards and the values of Table 1.

It may be difficult to carry out the dielectric tests on generator circuit-breaker systems equipped with surge arresters or instrument transformers. In such cases, they may be replaced by dummy surge arresters or dummy instrument transformers. Dummy surge arresters and dummy instrument transformers shall have the same outer dimensions and selection of materials as the real surge arresters and real instrument transformers. In addition, surge arresters or instrument transformers shall be tested separately in accordance with their standards.

7.2.5 Criteria to pass the test

Subclause 7.2.5 of IEC 62271-1:2017 is applicable with the following addition:

If disruptive discharges occur and evidence cannot be given during testing that the disruptive discharges were on self-restoring insulation, the generator circuit-breaker or the generator circuit-breaker system shall be dismantled and inspected after the completion of the dielectric test series. If damage (for example tracking, puncture) to non-self-restoring insulation is observed, the generator circuit-breaker or the generator circuit-breaker system has failed the test.

7.2.6 Application of the test voltage and test conditions

Subclause 7.2.6 of IEC 62271-1:2017 is applicable.

7.2.7 Tests of switchgear and controlgear of $U_r \leq 245$ kV

7.2.7.1 General

The test voltages specified in Table 1 apply.

7.2.7.2 Power-frequency withstand voltage tests

Subclause 7.2.7.2 of IEC 62271-1:2017 is applicable.

7.2.7.3 Lightning impulse voltage test

Subclause 7.2.7.3 of IEC 62271-1:2017 is applicable.

7.2.8 Tests of switchgear and controlgear of $U_r > 245$ kV

These are not applicable for generator circuit-breakers or generator circuit-breaker systems.

7.2.9 Artificial pollution tests for outdoor insulators

Subclause 7.2.9 of IEC 62271-1:2017 is applicable.

7.2.10 Partial discharge tests

Subclause 7.2.10 of IEC 62271-1:2017 is applicable with the following addition.

Partial discharge tests are not normally required to be performed on the complete generator circuit-breaker or generator circuit-breaker system. However, in the case of generator circuit-breaker systems using components for which a relevant IEC or IEEE standard exists, including partial discharge measurements (for example, bushings, see IEC 60137 [2]), evidence shall be produced by the manufacturer showing that those components have passed the partial discharge tests as laid down in the relevant IEC or IEEE standard.

7.2.11 Dielectric tests on auxiliary and control circuits

Subclause 7.2.11 of IEC 62271-1:2017 is not applicable and is replaced with the following:

The dielectric tests on auxiliary and control circuits are covered under 7.10.5.

7.2.12 Voltage test as a condition check

Subclause 7.2.12 of IEC 62271-1:2017 is not applicable; the tests specified there are replaced with the following:

After mechanical or environmental tests (see 7.101.1.4), if the insulating properties of a generator circuit-breaker across open contacts, to earth or between adjacent poles cannot be verified by visual inspection with sufficient reliability, a power-frequency withstand voltage test in dry condition according to 7.2.7.2 at 80 % of the value in column (2) of Table 1 shall be applied.

After making and breaking tests a 1 min power-frequency withstand voltage test shall be performed as a condition check across the open contacts. If there are any other dielectric gaps subject to the arcing medium (e.g. operating rod), they shall be evaluated either by this test or if that is not practical, then by a separate test. The test voltage shall be 80 % of the value in column (2) of Table 1.

7.3 Radio interference voltage (RIV) tests

Subclause 7.3 of IEC 62271-1:2017 is not applicable.

7.4 Resistance measurement

7.4.1 Measurement of the resistance of auxiliary contacts class 1 and class 2

Subclause 7.4.1 of IEC 62271-1:2017 is applicable.

7.4.2 Measurement of the resistance of auxiliary contacts class 3

Subclause 7.4.2 of IEC 62271-1:2017 is applicable.

7.4.3 Electrical continuity of earthed metallic part tests

Subclause 7.4.3 of IEC 62271-1:2017 is applicable.

7.4.4 Resistance measurement of contacts and connections in the main circuit as a condition check

7.4.4.1 Resistance measurement test procedure

Subclause 7.4.4.1 of IEC 62271-1:2017 is applicable with the following modification:

The current during the measurement shall be specified by the manufacturer, but shall not be less than 100 A DC.

7.4.4.2 Making and breaking tests

Subclause 7.4.4.2 of IEC 62271-1:2017 is not applicable and is replaced with the following:

After making and breaking tests the test object shall comply with the conditions specified in 7.102.9.

7.4.4.3 Other tests

Subclause 7.4.4.3 of IEC 62271-1:2017 is not applicable and is replaced with the following:

During and after mechanical and environmental tests the test object shall comply with the conditions specified in 7.101.1.4.

7.5 Continuous current tests

7.5.1 Condition of the test object

Subclause 7.5.1 of IEC 62271-1:2017 is applicable.

7.5.2 Arrangement of the equipment

Subclause 7.5.2 of IEC 62271-1:2017 is applicable with the following additions and modifications according to a), b) or c):

- a) For non-enclosed or three-phase enclosed generator circuit-breakers or generator circuit-breaker systems the following apply.

Because of the thermal effects of the magnetic influence on the neighbouring poles of the generator circuit-breaker or generator circuit-breaker system, three-phase tests shall be performed.

During tests with generator circuit-breaker systems, additional components, according to 3.3.101, shall be mounted in their regular positions.

The inductive heating of adjacent supporting structures such as pole frames shall be taken into account and shall be measured.

- b) For single-phase enclosed generator circuit-breakers or generator circuit-breaker systems the following apply.

Single-phase tests are permissible for single-phase enclosed generator circuit-breakers or generator circuit-breaker systems

- if the single-phase enclosed generator circuit-breaker system is connected to a single-phase enclosed isolated phase bus (IPB) system whose enclosures carry the rated current;
- if the tests are made at the phase having the most unfavourable position, which in most cases is the middle phase;
- if there is no possibility of magnetic influence;
- if the influence of the neighbouring phases can be simulated by means of heaters, heat insulation or equivalent.

Single-phase enclosed generator circuit-breaker systems which are not connected to single-phase enclosed IPBs or where the enclosure of the single-phase enclosed IPB does not carry the rated continuous current shall be tested three-phase.

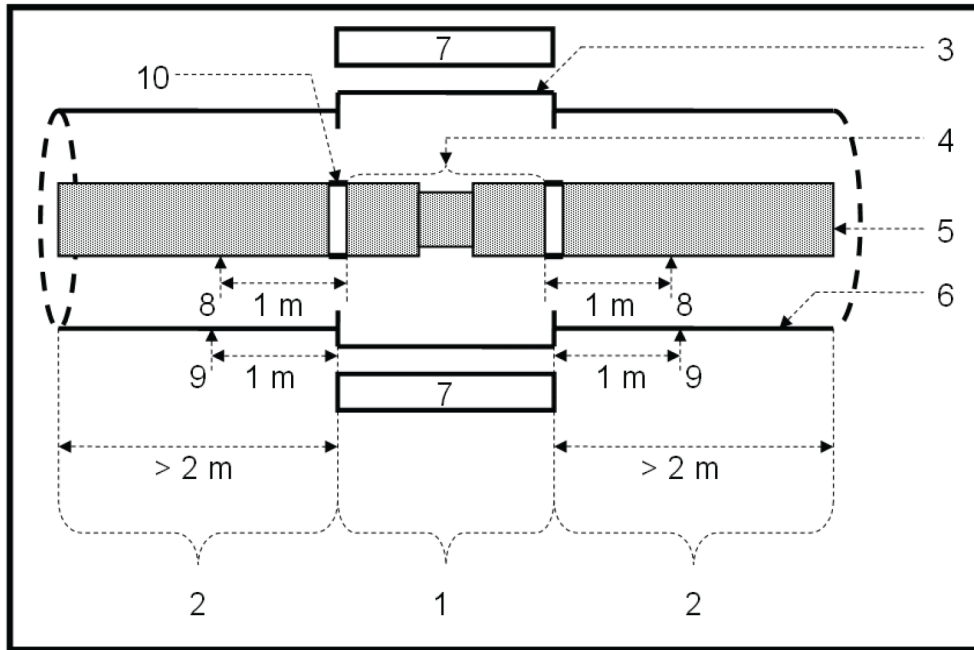
When single-phase enclosed generator circuit-breaker systems are single-phase tested, the current in the enclosure of the generator circuit-breaker system shall be the rated continuous current.

During tests with generator circuit-breaker systems, additional components, according to 3.3.101, shall be mounted in their regular positions.

If a generator circuit-breaker system consists of more than one stand-alone object, these objects may be tested independently.

As the continuous current-carrying capability of a generator circuit-breaker or generator circuit-breaker system is influenced by the temperature of the connected IPB, the tests shall be performed with an IPB attached to the generator circuit-breaker or generator circuit-breaker system. The minimum length of the IPB shall be 1,5 times its enclosure's outer diameter, or 2 m, whichever of the two numbers is larger.

A typical continuous current test setup for single-phase enclosed generator circuit-breakers is illustrated in Figure 14.



IEC

Key

- | | |
|---|--|
| 1 Single-phase enclosed generator circuit-breaker system | 6 Enclosure of the IPB |
| 2 Single-phase enclosed IPB | 7 Means to simulate the neighbouring phases of the generator circuit-breaker system |
| 3 Enclosure of the generator circuit-breaker system | 8 Position at which the temperature of the conductor of the IPB shall be kept at the values indicated in Table 12 |
| 4 Components in the main current path of the generator circuit-breaker system (e.g. interrupting chamber and main disconnector) | 9 Position at which the temperature of the enclosure of the IPB shall be kept at the values indicated in Table 12 |
| 5 Conductor of the IPB | 10 Connections between the terminals of the generator circuit-breaker system and the terminals of the conductor of the IPB |

Figure 14 – Typical continuous current test setup for single-phase enclosed generator circuit-breaker systems (top view)

- c) For generator circuit-breakers or generator circuit-breaker systems with forced cooling the following apply.

When testing a generator circuit-breaker or generator circuit-breaker system with a forced-cooled rating, the continuous current-carrying capability shall be determined with the forced cooling system operating. The temperatures in the current-carrying path shall be measured during these tests.

The entrance temperature and the quantity of the coolant (m³/s) (e.g. air, water) shall be adjusted to the prevailing rated service conditions and recorded.

If an isolated phase bus is used and is forced-cooled, the temperatures of the IPB – as defined in Table 12 – are not applicable since the temperatures of the IPB are dependent on quantity and temperature of the coolant.

7.5.3 Test current and duration

7.5.3.1 Test on main circuit

Subclause 7.5.3.1 of IEC 62271-1:2017 is applicable.

7.5.3.2 Test of the auxiliary and control equipment

Subclause 7.5.3.2 of IEC 62271-1:2017 is applicable.

7.5.4 Temperature measurement during test

7.5.4.1 Ambient air temperature

Subclause 7.5.4.1 of IEC 62271-1:2017 is applicable.

7.5.4.2 Temperature of test object

Subclause 7.5.4.2 of IEC 62271-1:2017 is applicable with the following modifications:

Typically, an IPB is operated at one of the two pairs of temperatures, defined in Table 12.

The manufacturer shall select one or both of the two options of Table 12 and the results shall be recorded in the continuous current test report.

The temperature rise of the IPB – measured at a distance of 1 m from the terminals of the generator circuit-breaker or generator circuit-breaker system – shall be kept at the temperatures indicated in Table 12. For tolerances on the temperature values reference is made to Annex A. The temperature shall be measured at a minimum of two points for each of the four positions (see positions number 8 and 9 in Figure 14). The measuring points shall be distributed equally around the circumference of the IPB conductor and the IPB enclosure. There is no limit on the difference between the temperature rise at the terminals of the generator circuit-breaker or generator circuit-breaker system and the IPB at a distance of 1 m from the terminals as specified in IEC 62271-1.

In the case where the generator circuit-breaker is attached to the IPB by means of connections, those connections shall not be considered part of the generator circuit-breaker.

NOTE Different values of rated continuous current can be assigned for option 1 and option 2.

Table 12 – Conditions during continuous current test

Part	Ranges of average temperature rise of the IPB at ambient air temperature not exceeding 40 °C	
	K	
	Option 1	Option 2
IPB conductor at position 8 on each side	50	65
IPB enclosure at position 9 on each side	30	40
NOTE Position 8 and position 9 are shown in Figure 14.		

7.5.5 Resistance of the main circuit

Subclause 7.5.5 of IEC 62271-1:2017 is applicable.

7.5.6 Criteria to pass test

Subclause 7.5.6 of IEC 62271-1:2017 is applicable.

7.5.101 Demonstrations of emergency conditions

Emergency conditions shall be demonstrated by tests. These tests shall include, if applicable, the following conditions:

- a) failure of cooling (loss of cooling fluid, failure of cooling in the IPB, failure of fans, pumps, air circulators, etc.);
- b) loss of insulating medium.

Conditions a) and b) shall be tested individually. If the cooling system consists of different independent subsystems, individual failure of each cooling subsystem and simultaneous failure of all subsystems shall be tested.

For each type of test, the following data (refer to Figure 9) shall be determined based on the temperature limits set by the manufacturer:

- a) maximum time the emergency condition can persist (t_1 , t_2 , etc.);
- b) a rate of decrease of the continuous current (R_1 , R_2 , etc.);
- c) the lower value of current so that the temperature rise in the generator circuit-breaker or generator circuit-breaker system will not exceed the values specified in 7.5.6 (I_2 , I_3 , etc.).

The IPB, which is used during the continuous current tests, may require individual heating or cooling to maintain the temperatures stated in Table 12. If this is the case this individual heating or cooling shall remain unchanged during the tests to establish the emergency data t_1 , t_2 , etc., R_1 , R_2 , etc., I_2 , I_3 , etc. During the tests to establish the lower value of the current (I_2 , I_3 , etc.) the IPB temperatures will most probably stabilise at values below those stated in Table 12.

If the forced-cooling systems of the isolated-phase bus and the generator circuit-breaker or generator circuit-breaker system use the same air, the phenomenon becomes complicated when the cooling air is lost, because the temperature of the isolated-phase bus will also rise.

- To establish the maximum time the emergency condition can persist, the cooling system shall be simply switched off. Additional cooling of the IPB is not allowed.
- To establish the lower value of current at which the temperature rise in the generator circuit-breaker or generator circuit-breaker system will not exceed the values specified in 7.5.6, the temperature rise of the IPB – measured at a distance of 1 m from the terminals of the generator circuit-breaker or generator circuit-breaker system – shall be kept at the temperatures stated in at least one of the options of Table 12.

7.6 Short-time withstand current and peak withstand current tests

7.6.1 General

Subclause 7.6.1 of IEC 62271-1:2017 is applicable.

7.6.2 Arrangement of the equipment and of the test circuit

Subclause 7.6.2 of IEC 62271-1:2017 is applicable with the following addition:

Single-phase enclosed generator circuit-breaker systems may be tested single-phase or three-phase. In the case of single-phase testing the enclosure shall carry the full return current. In the case of three-phase testing the return current in the three enclosures can be simulated by short-circuiting both ends of the three enclosures.

7.6.3 Test current and duration

Subclause 7.6.3 of IEC 62271-1:2017 is applicable.

7.6.4 Conditions of the test object after test

Subclause 7.6.4 of IEC 62271-1:2017 is applicable with the following addition:

The no-load operations of the generator circuit-breaker after the short-time withstand current and peak withstand current tests shall be carried out at 100 % of the rated value of control voltage and/or pressure for operation.

7.7 Verification of the protection

7.7.1 Verification of the IP coding

Subclause 7.7.1 of IEC 62271-1:2017 is applicable.

7.7.2 Verification of the IK coding

Subclause 7.7.2 of IEC 62271-1:2017 is applicable.

7.8 Tightness tests

Subclause 7.8 of IEC 62271-1:2017 is applicable with the following addition:

In the case of a vacuum generator circuit-breaker, the tightness verification of the vacuum insulation shall be carried out by means of a power-frequency withstand voltage test according to 7.2.12 or an equivalent test.

7.9 Electromagnetic compatibility tests (EMC)

Subclause 7.9 of IEC 62271-1:2017 is applicable.

7.10 Additional tests on auxiliary and control circuits

7.10.1 General

Subclause 7.10.1 of IEC 62271-1:2017 is applicable.

7.10.2 Functional tests

Subclause 7.10.2 of IEC 62271-1:2017 is applicable with the following addition:

If the mechanical operation tests at ambient air temperature in accordance with 7.101.2 are performed on the complete generator circuit-breaker or generator circuit-breaker system equipped with its entire control unit, then the intent of the functional tests according to 7.10.2 of IEC 62271-1:2017 has been demonstrated and additional tests are not required. When testing of the complete generator circuit-breaker or generator circuit-breaker system is not practicable, component tests in accordance with 7.101.1.2 are acceptable.

7.10.3 Verification of the operational characteristics of auxiliary contacts

Subclause 7.10.3 of IEC 62271-1:2017 is applicable.

7.10.4 Environmental tests

Subclause 7.10.4 of IEC 62271-1:2017 is applicable with the following addition:

If the mechanical operation tests at ambient air temperature in accordance with 7.101.2, the low and high temperature tests in accordance with 7.101.3 are performed on the complete circuit-breaker or generator circuit-breaker system equipped with its entire control unit, then the intent of the environmental tests according to 7.10.4 of IEC 62271-1:2017 has been demonstrated and additional tests are not required. When testing of the complete circuit-breaker is not practicable, subassembly tests in accordance with 7.101.1.2 are acceptable.

NOTE Seismic tests are not covered. If a seismic test is requested, it is performed by agreement between manufacturer and user.

7.10.5 Dielectric tests

Subclause 7.10.5 of IEC 62271-1:2017 is not applicable and is replaced by the following:

Type tests are not required. The related requirements are covered by routine tests in 8.3.4.

7.11 X-radiation test for vacuum interrupters

Subclause 7.11 of IEC 62271-1:2017 is applicable.

7.101 Mechanical and environmental tests

7.101.1 Miscellaneous provisions for mechanical and environmental tests

7.101.1.1 Mechanical characteristics

Before the start of the type tests, the mechanical characteristics of the generator circuit-breaker shall be established by the manufacturer.

The mechanical characteristics will serve as the reference for the purpose of characterising the mechanical behaviour of the generator circuit-breaker. Furthermore, the mechanical characteristics shall be used to confirm that the different test samples used during the mechanical, making and breaking tests behave mechanically in a similar way. The mechanical characteristics are also used to confirm that production units behave mechanically in a similar way as the test objects used during type tests.

The mechanical characteristics shall be defined for operations at rated supply voltage of operating devices and of auxiliary and control circuits and at filling pressure for operation, insulation and/or making and breaking or, for convenience of testing, at the minimum functional pressure for insulation and/or making and breaking.

Typically, the mechanical characteristics consist of

- reference travel band closing;
- reference travel band opening.

Each reference travel band consists of two curves, having a vertical distance of 10 % of the total stroke. In case of generator circuit-breakers with a total stroke of 40 mm or less the distance between the two envelopes is 4 mm.

All test objects shall have their respective no-load travel curves within the reference travel band closing and reference travel band opening. The type and location of the sensor used for the record of the no-load travel curves shall be stated in the test report. The no-load travel curves, which can be measured at any part of the power kinematic chain, may be recorded continuously or discretely. In case of discrete measurement, at least 20 discrete values should be given for the complete stroke. If the no-load travel curves are measured with different methods at the different test laboratories and production sites, transfer functions shall be used for the interpretation of the no-load travel curves.

Each no-load travel curve used to confirm the mechanical behaviour of the generator circuit-breaker may be shifted in horizontal and vertical direction in order to fit into the reference travel band closing and reference travel band opening.

Annex C describes a method on how to gain the reference travel band closing and the reference travel band opening.

It is recognised that for some designs of generator circuit-breakers, this method may be unsuitable, as for example for vacuum generator circuit-breakers. In such cases the manufacturer shall define an appropriate method to verify the proper operation of the generator circuit-breaker. The following parameters may be used to characterise the vacuum generator circuit-breaker:

- stroke, with a maximum tolerance width of 4 mm or 10 %, as assigned by the manufacturer;
- closing time, with a tolerance assigned by the manufacturer;
- opening time, with a tolerance assigned by the manufacturer;
- momentary closing speed at a certain stroke, with a maximum tolerance of ± 10 %, as assigned by the manufacturer;
- momentary opening speed at a certain stroke, with a maximum tolerance of ± 10 %, as assigned by the manufacturer.

7.101.1.2 Subassembly tests

When testing of a generator circuit-breaker is not practicable, subassembly tests may be accepted as type tests. The manufacturer should determine the subassemblies which are suitable for testing.

Subassemblies are separate functional parts of the complete generator circuit-breaker (for example, pole, breaking unit, operating mechanism).

When subassembly tests are made, the manufacturer shall prove that the mechanical and environmental stresses on the subassembly during the tests are not less than those applied to the same subassembly when the complete generator circuit-breaker is tested. Subassembly tests shall cover all different types of subassemblies of the complete generator circuit-breaker, provided that the particular test is applicable to the subassembly. The conditions for the subassembly type tests shall be the same as those which could be employed for the complete generator circuit-breaker.

Parts of auxiliary and control equipment shall comply with the relevant standards by which they have been manufactured, as applicable. The proper function of such parts in connection with the function of the other parts of the generator circuit-breaker or generator circuit-breaker system shall be verified.

7.101.1.3 Characteristics and settings to be recorded before and after the tests

Before and after the tests and in accordance with the provisions of 7.101.2.5, the following operating characteristics or settings shall be recorded and evaluated:

- a) closing time;
- b) opening time;
- c) maximum difference between closing times and maximum difference between opening times for units of one pole, if applicable;
- d) maximum difference among closing times and maximum difference among opening times for the poles of a three-pole operated generator circuit-breaker;
- e) recharging time of the operating device;
- f) power consumption of the control circuit;

- g) power consumption of the tripping devices, possible recording of the current of the releases;
- h) duration of opening and closing command impulse;
- i) tightness, if applicable;
- j) gas densities or pressures, if applicable;
- k) resistance of the main circuit;
- l) time-travel chart;
- m) other important characteristics or settings as specified by the manufacturer.

7.101.1.4 Condition of the generator circuit-breaker during and after the tests

During and after the tests, the generator circuit-breaker shall be in such a condition that it is capable of operating normally, carrying its rated continuous current, making and breaking its rated short-circuit current and withstanding the voltage values for 1 min at 80 % of the value in column (2) of Table 1.

In general, these requirements are fulfilled if:

- during the tests, the generator circuit-breaker operates on command and does not operate without command;
- the no-load closing operation and the no-load opening operation after the test series, performed at rated supply voltage and at filling pressure for operation shall be compared with the corresponding operations before the test series. The requirements of 7.101.1.1 shall be fulfilled;
- during the no-load operations of the generator circuit-breaker, which is a part of a generator circuit-breaker system, which also contains a main-disconnecting function and/or other switches mounted on the same frame, the main-disconnecting function is in its closed position and the other switches are in their open position;
- after the tests, all parts do not show undue wear or if the generator circuit-breaker is one component of a generator circuit-breaker system, also all other components of the generator circuit-breaker system do not show undue wear;
- the main contacts shall be in such a condition, in particular with regard to wear, contact area, pressure and freedom of movement that they are capable of carrying the rated continuous current without their temperature rise exceeding by more than 10 K the values specified in Table 14 of IEC 62271-1:2017.

Coated contacts are such that a layer of coating material remains at the contact area. If this is not the case, the contacts shall be regarded as bare and the test requirements are fulfilled only if the temperature rise of the contacts during the continuous current test (according to 7.5) does not exceed the value permitted for bare contacts.

For other than sealed-for-life interrupters, visual inspection is usually sufficient for verification of the capability of the generator circuit-breaker to carry the rated continuous current.

NOTE Experience shows that an increase of the voltage drop across the generator circuit-breaker cannot alone be considered as reliable evidence of an increase in temperature rise.

For sealed-for-life generator circuit-breakers, procedures A or B of 7.102.9.1 indent b) apply.

- during and after the tests, any distortion of mechanical parts is not such that it adversely affects the operation of the generator circuit-breaker or prevents the proper fitting of any replacement part;
- after the tests the insulating properties of the generator circuit-breaker in the open position shall be in essentially the same condition as before the tests. Visual inspection of the generator circuit-breaker after the tests is usually sufficient for verification of the insulating properties. In the case of generator circuit-breakers with sealed-for-life interrupters, a voltage test as a condition check in accordance with 7.2.12 shall be performed.

If interrupters are placed in an insulating fluid with different characteristics, that also might withstand the test voltages when replacing the original arc extinguishing medium (for example a vacuum interrupter in an enclosure filled with SF₆) the voltage test as a condition check, as requested in 7.2.12 may not be adequate to verify the integrity of the device. In such cases the integrity of the device shall be demonstrated by the methods according to 7.102.9.1 item c) fourth paragraph.

7.101.1.5 Condition of the auxiliary and control equipment during and after the tests

During and after the tests, the following conditions for the auxiliary and control equipment shall be fulfilled:

- during the tests, care should be taken to prevent undue heating;
- during the tests, a set of contacts (both make and break auxiliary contacts) shall be arranged to switch the current of the circuits to be controlled (see 6.4);
- during and after the tests, the auxiliary and control equipment shall fulfil its functions, including the trip-free and anti-pumping functions;
- during and after the tests, capability of the auxiliary circuits of the auxiliary switches and of the control equipment shall not be impaired. In case of doubt, the tests specified in 8.3.4 shall be performed;
- during and after the tests, the contact resistance of the auxiliary switches shall not be adversely affected. The temperature rise when carrying the rated continuous current shall not exceed the specified values (see Table 14 of IEC 62271-1:2017).

7.101.2 Mechanical operation test at ambient air temperature

7.101.2.1 General

The mechanical operation test shall be made at the ambient air temperature of the test location. The ambient air temperature should be recorded in the test report. Auxiliary equipment forming part of the operating devices shall be included.

The application of voltage or current in the main circuit is not required for this test.

NOTE A generator circuit-breaker design can be fitted with several variants of auxiliary equipment (shunt releases and motors) in order to accommodate the various rated control voltages and frequencies as stated in 5.9 and 5.10. These variants do not need to be tested if they are of similar designs and if the resulting no-load travel curves are within the reference travel bands of the mechanical characteristics as defined in 7.101.1.1.

7.101.2.2 Condition of the generator circuit-breaker before the test

The generator circuit-breaker for test shall be mounted on its own support and its operating mechanism shall be operated in the specified manner. It shall be tested according to its type as follows:

A three-pole operated generator circuit-breaker, or a single-pole operated generator circuit-breaker with all poles mounted on a common frame, shall be tested as a complete unit.

Tests shall be conducted at the filling pressure/density for insulation and/or making and breaking.

A single-pole operated generator circuit-breaker with the poles mounted on individual frames should be tested preferably as a complete three-pole generator circuit-breaker. However, for convenience, or owing to limitations of the dimensions of the test bay, one single-pole unit of the generator circuit-breaker may be tested, provided that it is equivalent to, or not in a more favourable condition than, the complete three-pole generator circuit-breaker over the range of tests, for example in respect of:

- mechanical characteristics;

- power, energy and force of closing and opening mechanism;
- rigidity of structure.

If a generator circuit-breaker is one component of a generator circuit-breaker system, the mechanical operation tests with the generator circuit-breaker shall be performed with the other components of the generator circuit-breaker system installed.

7.101.2.3 Description of the test on class M1 generator circuit-breakers

The mechanical operation test shall consist of 1 000 operating cycles.

The generator circuit-breaker shall be tested in accordance with Table 13.

7.101.2.4 Description of the test on class M2 and class M3 generator circuit-breakers

The mechanical operation test for M2 shall consist of 3 000 operating cycles.

The mechanical operation test for M3 shall consist of 10 000 operating cycles.

The generator circuit-breaker shall be tested in accordance with Table 13.

Table 13 – Number of operating sequences

Operating sequence	Supply voltage	Number of operating sequences at filling pressure for operation		
		Class M1 generator circuit-breakers ^{a, b}	Class M2 generator circuit-breakers ^{a, c}	Class M3 generator circuit-breakers ^{a, c}
C – t_a – O – t_a	Minimum	250	750	2 500
	Rated	250	750	2 500
	Maximum	250	750	2 500
CO – t_a	Rated	250	750	2 500
<p>Key</p> <p>O opening</p> <p>C closing</p> <p>CO a closing operation followed immediately (i.e. without any intentional time-delay) by an opening operation</p> <p>t_a time between two operations which is necessary to restore the initial conditions and/or to prevent undue heating of parts of the generator circuit-breaker (this time can be different according to the type of operation)</p> <p>It is allowed to test M1, M2, and M3 in a consecutive way. If so, first perform the number of operations required for M1, then add the number of operations to cover M2, and then add the number of operations to cover M3. After each 1 000 operating cycles cleaning, tightening, adjusting, lubricating, as recommended by the manufacturer, is allowed.</p> <p>^a No functional part shall have been replaced prior to completion of the specified number of operations.</p> <p>^b After 500 operating cycles cleaning, tightening, adjusting, lubricating, as recommended by the manufacturer, is allowed. Any visual inspection, cleaning, tightening, adjusting, and/or lubricating carried out during the test shall be mentioned in the test report.</p> <p>^c After each 1 000 operating cycles cleaning, tightening, adjusting, lubricating, as recommended by the manufacturer, is allowed. Any visual inspection, cleaning, tightening, adjusting, and/or lubricating carried out during the test shall be mentioned in the test report.</p>				

7.101.2.5 Acceptance criteria for the mechanical operation tests

The criteria given below apply for mechanical operation tests on class M1, class M2 and class M3 generator circuit-breakers.

Before and after the total test programme, the operations specified in Table 14 shall be performed.

Table 14 – Operations to be performed before and after the test programme

		Operating pressure		
		Minimum if applicable	Filling pressure	Maximum if applicable
Supply voltage	Minimum	1 × C	1 × C	1 × C
		1 × O	1 × O	1 × O
		1 × CO	1 × CO	1 × CO
	Rated	1 × C	1 × C	1 × C
		1 × O	1 × O	1 × O
		1 × CO	1 × CO	1 × CO
Maximum	1 × C	1 × C	1 × C	
	1 × O	1 × O	1 × O	
	1 × CO	1 × CO	1 × CO	
Key				
O opening operation				
C closing operation				
CO a closing operation followed immediately (i.e. without any intentional time-delay) by an opening operation				

During these operations, the operating characteristics (see 7.101.1.3) shall be recorded and evaluated. After the total test programme the condition of the generator circuit-breaker shall be in accordance with 7.101.1.4.

7.101.3 Low and high temperature tests

7.101.3.1 General

The two tests need not be performed in succession, and the order in which they are made is of no importance. If the minimum ambient air temperature of indoor and outdoor generator circuit breakers is greater than or equal to $-5\text{ }^{\circ}\text{C}$, no low temperature test is required. If the maximum ambient air temperature of indoor and outdoor circuit breakers is greater than $+40\text{ }^{\circ}\text{C}$, a high temperature test is required.

For generator circuit-breakers with a common operating device, three-phase tests shall be made. Generator circuit-breakers with independent poles, testing of only one complete pole is permitted.

Owing to limitations of the testing facilities, multi-enclosure type generator circuit-breaker systems may be tested using one or more of the following alternatives provided that the generator circuit-breaker system in its testing arrangement is not in a more favourable condition than the normal condition for mechanical operation (see 7.101.2.2):

- a) reduced length of phase-to-earth insulation;
- b) reduced pole spacing;
- c) reduced number of modules.

If heat sources are required, they shall be in operation with the exception of the conditions identified in item f) of 7.101.3.3.

Liquid or gas supplies for generator circuit-breaker operation shall be at the test air temperature unless the generator circuit-breaker design requires a heat source for these supplies.

If a generator circuit-breaker is one component of a generator circuit-breaker system, the low and high temperature tests with the generator circuit-breaker shall be performed with the other components of the generator circuit-breaker system installed.

No maintenance, replacement of parts, lubrication or readjustment of the generator circuit-breaker is permissible during the tests.

NOTE 1 In order to determine the material temperature characteristics, ageing, etc., tests of longer duration than those specified in 7.101.3.3 and 7.101.3.4 can apply.

The generator circuit-breaker has passed the test if the conditions stated in 7.101.1.4 and 7.101.1.5 are fulfilled. Furthermore, the conditions in 7.101.3.3 and 7.101.3.4 shall be fulfilled and the leakage rates recorded shall not exceed the limits given in Table 15 of IEC 62271-1:2017. In the test report the testing conditions and the condition of the generator circuit-breaker before, during and after the test shall be reported. The recorded quantities shall be presented in an appropriate way and the graphical record taken shall be shown. To reduce the number of graphical records in the test report, it is allowed to show a single representative graphical record of every relevant type of operation under each specified testing condition.

Vacuum generator circuit-breakers are excluded from the tightness verification tests during the high and low temperature tests. The integrity of the vacuum will be verified by a power-frequency voltage (or equivalent) test after the high and low temperature tests. However, if the vacuum generator circuit-breaker system is used in an enclosure filled with an insulating gas, for example SF₆, the tightness verification tests during the high and low temperature tests shall be performed on this enclosure.

NOTE 2 A generator circuit-breaker design can be fitted with several variants of auxiliary equipment (shunt releases and motors) in order to accommodate the various rated control voltages and frequencies as stated in 5.9 and 5.10. These variants do not need to be tested if they are of similar designs and if the resulting no-load travel curves are within the reference travel bands of the mechanical characteristics as defined in 7.101.1.1.

7.101.3.2 Measurement of ambient air temperature

The ambient air temperature in three locations at the distance of 1 m from the generator circuit-breaker shall be measured and reported:

- at the level of the top of the generator circuit-breaker;
- at half the height of the generator circuit-breaker. This is the ambient temperature to be reported;
- at the bottom of the generator circuit-breaker but not less than 0,25 m from the floor.

The maximum temperature deviation over the height of the generator circuit-breaker shall not exceed 5 K.

7.101.3.3 Low temperature test

The diagram of the test sequences and identification of the application points for the tests specified are given in Figure 15 a).

If the low temperature test is performed immediately after the high temperature test, the low temperature test can proceed after completion of item u) of the high temperature test. In this case items a) and b) are omitted.

- a) The test generator circuit-breaker shall be adjusted in accordance with the manufacturer's instructions.
- b) Characteristics and settings of the generator circuit-breaker shall be recorded in accordance with 7.101.1.3 and at an ambient air temperature T_A of $20\text{ °C} \pm 5\text{ °C}$. The tightness test shall be performed according to 7.8, if gases are used for insulation and/or making and breaking and/or operation.

- c) With the generator circuit-breaker in the closed position, the air temperature shall be decreased to the appropriate, minimum ambient air temperature T_L , according to the value chosen from 4.1.2, 4.1.3 or 4.2.4 of IEC 62271-1:2017. The generator circuit-breaker shall be kept in the closed position for 24 h after the ambient air temperature stabilises at T_L .
- d) During the 24 h period with the generator circuit-breaker in the closed position at temperature T_L , a tightness test shall be performed if gases are used for insulation and/or making and breaking and/or operation. An increased leakage rate is acceptable, provided that it returns to the original value when the generator circuit-breaker is restored to the ambient air temperature T_A and is thermally stable. The increased temporary leakage rate shall not exceed the permissible temporary leakage rate of Table 15 of IEC 62271-1:2017. For vacuum generator circuit-breakers no tightness test is required. However, if the vacuum generator circuit-breaker system is used in an enclosure filled with an insulating gas, for example SF₆, the tightness verification tests shall be performed on this enclosure.
- e) After 24 h at temperature T_L , an opening and closing operation at rated supply voltage and at filling pressure for operation shall be performed and the results of these operations shall be compared with the results of the corresponding operations before the low temperature test. The measurements shall comply with the mechanical characteristics, as defined in 7.101.1.1, for example no-load travel curves are within the reference travel bands.
- f) The low temperature behaviour of the generator circuit-breaker and its alarms and lock-out systems shall be verified by disconnecting the supply of all heating devices, including also the anti-condensation heating elements, for a duration t_x . During this interval, occurrence of the alarm is acceptable but lock-out is not. At the end of the interval t_x , an opening order, at rated values of supply voltage and filling pressure for operation, shall be given. The generator circuit-breaker shall then open. The opening time shall be recorded (and the no-load travel curve measured, if feasible) to allow assessment of the interrupting capability. The manufacturer shall state the value of t_x (not less than 2 h) up to which the generator circuit-breaker is still operable without auxiliary power to the heaters.
- g) The generator circuit-breaker shall be left in the open position for 24 h.
- h) During the 24 h period with the generator circuit-breaker in the open position at temperature T_L , a tightness test shall be performed according to 7.8, if gases are used for insulation and/or making and breaking and/or operation. An increased leakage rate is acceptable, provided that it returns to the original value when the generator circuit-breaker is restored to the ambient air temperature T_A and is thermally stable. The increased temporary leakage rate shall not exceed the permissible temporary leakage rate of Table 15 of IEC 62271-1:2017.
- i) At the end of the 24 h period, 50 closing and 50 opening operations shall be made at rated values of supply voltage and filling pressure for operation with the generator circuit-breaker at temperature T_L . An interval of least a 3 min shall be allowed for each cycle or sequence. The results of the first closing and opening operation shall be recorded and compared with the results of the corresponding operation before the low temperature test. The measurements shall comply with the mechanical characteristics, as defined in 7.101.1.1, for example no-load travel curves are within the reference travel bands.

Following the first closing operation C and the first opening operation O three CO operating cycles (no intentional time delay between the C and O) shall be performed. The additional operations shall be made by performing C – t_a – O – t_a operating sequences (t_a is defined in Table 13).

- j) After completing the 50 opening and 50 closing operations, the air temperature shall be increased to ambient air temperature T_A at a rate of change of approximately 10 K per hour. During the temperature transition period the generator circuit-breaker shall be subjected to alternate C – t_a – O – t_a – C and O – t_a – C – t_a – O operating sequences at rated values of supply voltage and filling pressure for operation. The alternate operating sequences should be made at 30 min intervals so that the generator circuit-breaker will be in open and closed positions for 30 min periods between the operating sequences.
- k) After the generator circuit-breaker has stabilised thermally at ambient air temperature T_A , a recheck shall be made of the generator circuit-breaker settings, operating characteristics and tightness as in items a) and b) for comparison with the initial characteristics.

The accumulated leakage during the complete low temperature test sequence from item b) to item j) shall not be such that lock-out pressure is reached (reaching alarm pressure is allowed).

7.101.3.4 High temperature test

The diagram of the test sequence and identification of the application points for the tests specified are given in Figure 15 b).

If the high temperature test is performed immediately after the low temperature test, the high temperature test can proceed after completion of item j) of the low temperature test. In this case, items l) and m) below are omitted.

- l) The test generator circuit-breaker shall be adjusted in accordance with the manufacturer's instructions.
- m) Characteristics and settings of the generator circuit-breaker shall be recorded in accordance with 7.101.1.3 and at an ambient air temperature T_A of $20\text{ °C} \pm 5\text{ °C}$. The tightness test shall be performed according to 7.8, if gases are used for insulation and/or making and breaking and/or operation.
- n) With the generator circuit-breaker in the closed position, the air temperature shall be increased to the appropriate, maximum ambient air temperature (T_H), according to the upper limit of ambient air temperature chosen from 4.1.2, 4.1.3 or 4.2.4 of IEC 62271-1:2017 at a rate of change of approximately 10 K per hour. The generator circuit-breaker shall be kept in the closed position for 24 h after the ambient air temperature stabilises at T_H .

For applications where the generator circuit-breakers are installed outdoors, the effects of solar radiation should be considered. Refer to IEEE Std C37.24™ [3].

- o) During the 24 h period with the generator circuit-breaker in the closed position at the temperature T_H , a tightness test shall be performed if gases are used for insulation and/or making and breaking and/or operation. An increased leakage rate is acceptable, provided that it returns to the original value when the generator circuit-breaker is restored to the ambient air temperature T_A and is thermally stable. The increased temporary leakage rate shall not exceed the permissible temporary leakage rate of Table 15 of IEC 62271-1:2017. For vacuum generator circuit-breakers no tightness test is required. However, if the vacuum generator circuit-breaker system is used in an enclosure filled with an insulating gas, for example SF₆, the tightness verification tests shall be performed on this enclosure.
- p) After 24 h at the temperature T_H , an opening and closing operation at rated supply voltage and at filling pressure for operation shall be performed and the results of these operations shall be compared with the results of the corresponding operations before the high temperature test. The measurements shall comply with the mechanical characteristics, as defined in 7.101.1.1, for example no-load travel curves are within the reference travel bands.

- q) The generator circuit-breaker shall be opened and left open for 24 h at the temperature T_H .
- r) During the 24 h period with the generator circuit-breaker in the open position at the temperature T_H , a tightness test shall be performed according to 7.8, if gases are used for insulation and/or making and breaking and/or operation. An increased leakage rate is acceptable, provided that it returns to the original value when the generator circuit-breaker is restored to the ambient air temperature T_A and is thermally stable. The increased temporary leakage rate shall not exceed the permissible temporary leakage rate of Table 15 of IEC 62271-1:2017.
- s) At the end of the 24 h period, 50 closing and 50 opening operations shall be made at rated values of supply voltage and filling pressure for operation with the generator circuit-breaker at the temperature T_H . An interval of at least 3 min shall be allowed for each cycle or sequence. The results of the first closing and opening operation shall be recorded and compared with the results of the corresponding operations before the high temperature test. The measurements shall comply with the mechanical characteristics, as defined in 7.101.1.1, for example no-load travel curves are within the reference travel bands.

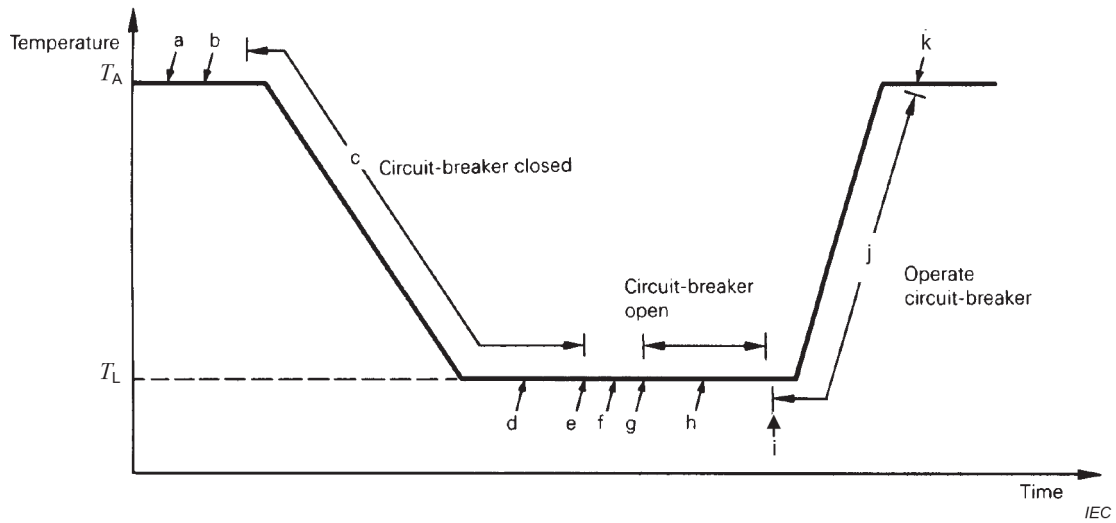
Following the first closing operation C and the first opening operation O three CO operation cycles (no intentional time delay between the C and O) shall be performed. The additional operations shall be made by performing C – t_a – O – t_a operating sequences (t_a is defined in Table 13).

- t) After completing the 50 opening and 50 closing operations, the air temperature shall be decreased to ambient air temperature T_A , at a rate of change of approximately 10 K per hour.

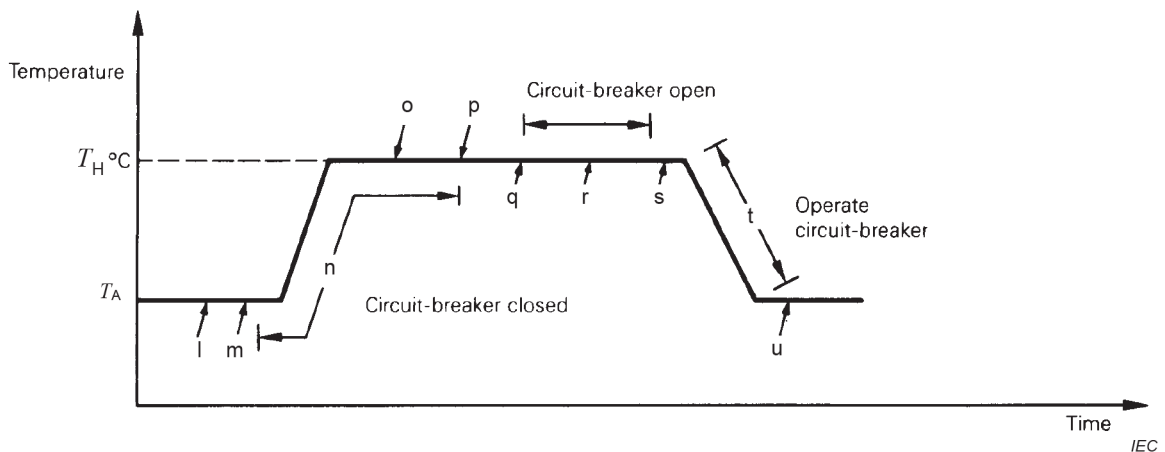
During the temperature transition period, the generator circuit-breaker shall be subjected to alternate C – t_a – O – t_a – C and O – t_a – C – t_a – O operating sequences at rated values of supply voltage and filling pressure for operation. The alternate operating sequences should be made at 30 min intervals so that the generator circuit-breaker will be in the open and closed positions for 30 min periods between the operating sequences.

- u) After the generator circuit-breaker has stabilised thermally at ambient air temperature T_A , a recheck shall be made of the generator circuit-breaker settings, operating characteristics and tightness as in items l) and m) for comparison with the initial characteristics.

The accumulated leakage during the complete high temperature test sequence from item l) to item t) shall not be such that lock-out pressure is reached (reaching alarm pressure is allowed).



a) Low temperature test



b) High temperature test

NOTE Letters a to u identify application points of tests specified in 7.101.3.3 and 7.101.3.4.

Figure 15 – Test sequences for low and high temperature tests

7.101.4 Sound level tests

Sound level tests can either be performed under three-phase or single-phase no-load conditions. The peak instantaneous sound pressure level at any location accessible to personnel including above and below the generator circuit-breaker shall be measured and reported.

A sufficient number of measurement locations shall be chosen to identify and monitor the highest sound level locations. The test should be made at the site, if feasible, rather than in the laboratory. The tests shall be made taking into account IEC/IEEE 62271-37-082.

7.102 Miscellaneous provisions for making and breaking tests

7.102.1 General

Subclauses 7.102.2 to 7.102.11 are applicable to all making and breaking tests unless otherwise specified in 7.103, 7.104, 7.105 and 7.106.

Where applicable, prior to the commencement of the tests, the manufacturer shall declare the values of

- minimum conditions of the operating mechanism guaranteeing the rated operating sequence (for example the minimum functional pressure for operation in the case of a hydraulic operating mechanism);
- minimum conditions of the interrupting device guaranteeing the rated operating sequence (for example the minimum functional pressure for insulation and/or making and breaking).

Generator circuit-breakers shall be capable of making and breaking system-source short-circuit currents. This is demonstrated by the tests as described in 7.103.

In addition, generator circuit-breakers shall be capable of breaking load currents. This is demonstrated by the tests as described in 7.104.

Generator circuit-breakers with an assigned generator-source short-circuit current rating shall be capable of making and breaking generator-source short-circuit currents. This is demonstrated by the tests as described in 7.105.

Generator circuit-breakers with an assigned out-of-phase current rating shall be capable of making and breaking out-of-phase currents. This is demonstrated by the tests as described in 7.106.

It is preferred that three-phase making and breaking capabilities be demonstrated on a complete three-pole generator circuit-breaker in a three-phase test circuit.

If the tests are carried out in a laboratory, the applied voltage, current, transient and power-frequency recovery voltages may all be obtained from a single power source (direct tests) or from several sources where all of the current, or a major portion of it, is obtained from one source, and the transient recovery voltage is obtained wholly or in part from one or more separate sources (synthetic tests).

If, owing to limitations of the testing facilities, the short-circuit performance of the generator circuit-breaker cannot be proved in the above way, several methods employing either direct or synthetic test methods may be used either singly or in combination, depending on the generator circuit-breaker type:

- a) single-phase testing (see 7.102.4.1);
- b) unit testing (see 7.102.4.2).

7.102.2 Number of test objects

No limitation on the number of test objects is set for making and breaking tests.

All test objects used for making and breaking tests shall comply with the mechanical characteristics, as defined in 7.101.1.1, for example no-load travel curves are within the reference travel bands.

The expendable parts or parts subject to wear may be replaced or refitted between any test-duty, but no parts can be replaced or refitted within each test-duty.

7.102.3 Arrangement of generator circuit-breaker for tests

7.102.3.1 General

The generator circuit-breaker under test shall be mounted on its own support or on an equivalent support. A generator circuit-breaker supplied as a component of a generator circuit-breaker system shall be assembled on its own supporting structure and enclosure, complete with any disconnecting features, with vent outlets forming part of the unit and, where practicable, with main connections and busbars.

Capacitors can be installed between the step-up transformer and the generator circuit-breaker, or between the generator and the generator circuit-breaker, or at both sides, or capacitors can be part of the generator circuit-breaker assembly. In these cases the tests shall be carried out with the capacitors connected or if these capacitors are not installed during these tests the influence of the capacitors on the prospective TRV shall be taken into account and the modified TRV applied accordingly. For out-of-phase and load current breaking, the parameters of the prospective TRV modified by these capacitors shall be derived from Annex M and Annex N respectively. For system-source and generator-source short-circuit current breaking tests, computer simulations may be necessary to establish the modified TRV.

The interrupting capability demonstrated by these tests is valid only if capacitors of the same capacitance value as used during the tests are installed in service according to the tested configuration.

The operating time of some generator circuit-breakers may vary when the supply voltage to the coils is at the minimum value specified in Table 2, while the operating times are reasonably constant at their rated supply voltages. Performing a test-duty with correct arcing times can be difficult to achieve in such a case, especially where steps of 18 electrical degrees need to be made to prove the arcing window. Additionally, the scattering of the closing time may prevent the possibility to perform the making test with the rated short-circuit making current.

For generator circuit-breakers where the operation of the coils does not affect the travel curve, it is permitted to increase the supply voltage of the coils from the minimum value to the maximum supply voltage. No-load operations performed at the rated and minimum supply voltage shall be included in the test report to show that the travel curve is not affected by the increased voltage of the coil.

At least one making and one breaking operation shall be performed at rated system-source short-circuit current with minimum supply voltage to prove the ability of the circuit-breaker to operate correctly up to its rated short-circuit current under minimum control voltage conditions.

Operating devices having a minimum operating condition (i.e. pressure, energy, etc.) shall be operated at the minimum condition for operation at the commencement of the rated operating sequence.

The close-open time shall remain as close as possible to the minimum close-open time (see Note of 3.7.132), but it is permissible to delay the circuit-breaker opening such that the degree of asymmetry at contact separation is within the permissible limits.

Interlocking devices associated with pressure interlocks shall be made inoperative during the tests, if they interfere with the intent of the test.

It shall be shown that the generator circuit-breaker will operate satisfactorily under the above conditions at no-load as specified in 7.102.6. The pressure of the compressed gas for insulation and/or making and breaking, if any, shall be set at its minimum functional value as specified in 3.6.5.5.

The generator circuit-breaker shall be tested according to its type as specified in 7.102.3.2 and 7.102.3.3.

7.102.3.2 Common enclosure type

A three-pole generator circuit-breaker having all its arcing contacts supported within a common enclosure shall be tested as a complete three-pole generator circuit-breaker in three-phase circuits.

The reasons are as follows:

- possibility of disruptive discharge between poles or to earth due to the influence of exhaust gases;
- possible differences in the conditions of the extinguishing medium (pressures, temperatures, pollution levels, etc.);
- greater influence between phases due to electrodynamic forces in the case of a three-phase fault;
- possible different stresses on the operating mechanism.

7.102.3.3 Multi-enclosure type

A three-pole generator circuit-breaker consisting of three independent single-pole switching devices can be tested single-phase according to 7.102.4.1. The manufacturer shall give testing evidence to show compliance with 6.101.

A three-pole generator circuit-breaker not having completely independent switching devices should be tested as a complete three-pole generator circuit-breaker. However, owing to limitation of available testing facilities, one single-pole of the generator circuit-breaker may be tested, provided that mechanical and electrical conditions applied during the tests are equivalent to, or not more favourable than, the complete three-pole generator circuit-breaker over the range of tests with respect to:

- mechanical behaviour in a making operation (for the evaluation method, see 7.102.4.1);
- mechanical behaviour in a breaking operation (for the evaluation method, see 7.102.4.1);
- availability of arc-extinguishing medium;
- power, energy and force of closing and opening devices;
- rigidity of structure.

7.102.4 General considerations concerning testing methods

7.102.4.1 Single-phase testing of one pole of a generator circuit-breaker with a common operating mechanism

According to this method, one pole of a generator circuit-breaker with a common operating mechanism is tested single-phase, applying to the pole the same current and substantially the same power-frequency voltage which would be impressed upon the most highly stressed pole during three-phase making and breaking by the complete generator circuit-breaker with a common operating mechanism under corresponding conditions.

In those cases where the generator circuit-breaker design permits single-phase testing to simulate three-phase conditions and the generator circuit-breaker is equipped with one operating mechanism for all poles, a complete three-pole assembly shall be supplied for the tests.

For short-circuit tests, in order to establish whether the generator circuit-breaker permits single-phase tests to simulate three-phase conditions, verification tests consisting of a three-phase making operation and a three-phase symmetrical breaking operation shall be performed.

During the verification tests for making and breaking, the travel curve shall be recorded. The sensor used for the record of the travel curve shall be mounted at a suitable location, in order to optimally record the contact travel, either directly or indirectly.

The type and location of the sensor used for the record of the mechanical characteristics shall be stated in the test report. The travel curves, which can be measured at any part of the power kinematic chain, may be recorded continuously or discretely.

The verification tests for making and breaking shall be performed as follows:

- a) The verification test for making shall be performed in a three-phase test circuit which can provide a prospective value of the making current equal to at least I_{MC} .

Owing to limitations of testing facilities, it is not always possible to perform the verification test for making at rated voltage and rated short-circuit current. The making operation at reduced voltage with a minimum of not less than 50 % of the rated voltage is permissible if the pre-arcing time during making at rated voltage in any phase is not more than 1/10 cycle of power frequency with a tolerance of 20 %.

The pre-arcing time at rated voltage shall be determined by performing making tests at reduced current. The reduced current shall be low enough to avoid contact erosion.

The verification test for making consists of a three-phase making test at the rated short-circuit current. Tests performed at 50 Hz are also valid for 60 Hz applications and tests performed at 60 Hz are also valid for 50 Hz applications, as long as for both cases the test circuit is such that a prospective value of the making current of at least I_{MC} can be provided.

The three-phase verification test for making is valid independent from the actual closing angle. As a result the peak current value will be at least 93 % of I_{MC} in one of the three phases.

The generator circuit-breaker shall reach the fully closed position and the duration of the current shall last at least until the generator circuit-breaker has reached its fully closed position.

- b) The verification test for breaking consists of a three-phase breaking test at the rated short-circuit breaking current and with the maximum arcing time in the last-pole-to-clear. The breaking operation may be performed at any convenient test voltage. Tests performed at 50 Hz are also valid for 60 Hz applications and tests performed at 60 Hz are also valid for 50 Hz applications, as long as for both cases the maximum arcing time in the last-pole-to-clear of the respective application is covered. The travel curve during the three-phase breaking test (see Figure 16) shall be used as a reference curve for the following procedure:
- Two envelope curves shall be drawn from the instant of contact separation to the end of the travel curve. The distance between the two envelopes from the original course shall be ± 5 % of the total travel or ± 2 mm whichever is larger evaluated from the three-phase verification test (see Figure 17).
 - During a single-phase test under the same conditions (breaking test at the rated short-circuit breaking current with the maximum arcing time) the travel curve shall be recorded. If the travel curve of the single-phase test is within the envelope curves, single-phase testing to represent three-phase conditions is permitted.
 - The envelope curves can be moved in the vertical direction until one of the envelope curves covers the reference curve. This gives maximum tolerances over the reference travel curve of -0 % or -0 mm, $+10$ % or $+4$ mm and $+0$ % or $+0$ mm, -10 % or -4 mm respectively (see Figure 18 and Figure 19). The displacement of the envelope curves can be done only once for the complete procedure in order to get a maximum total deviation from the reference curve of 10 % or 4 mm.

Special attention should be paid to the emission of arc products. If it is considered that such emission would, for example, be likely to impair the insulation distance to adjacent poles, then this shall be checked, using earthed metallic screens (see 7.102.8).

The series of Figure 16 through Figure 19 are idealised, and do not show the variation in profile caused by the friction effect of the contacts or the end of travel damping. In particular, it is important to note that the effects of damping are not shown in these diagrams. The oscillations produced at the end of travel are dependent upon the efficiency of the damping of the drive system. The shape of these oscillations may be a deliberate function of the design and may slightly vary from one test object to another. Therefore, it is important that any variations in the curve at the end of the stroke, which are outside the tolerance margin given by the envelope, are fully explained and understood before they are rejected or accepted as showing equivalence with the reference curves. In general, all curves should fall within the envelopes for acceptance.

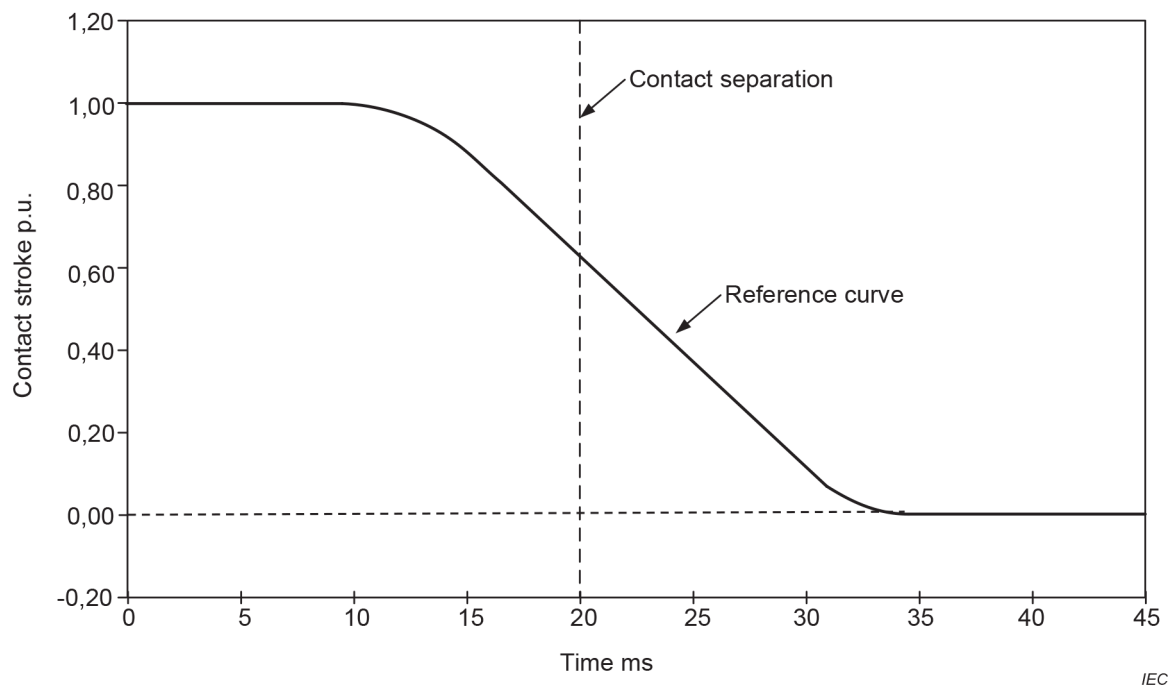


Figure 16 – Reference travel curve measured during the three-phase breaking test (idealised curve)

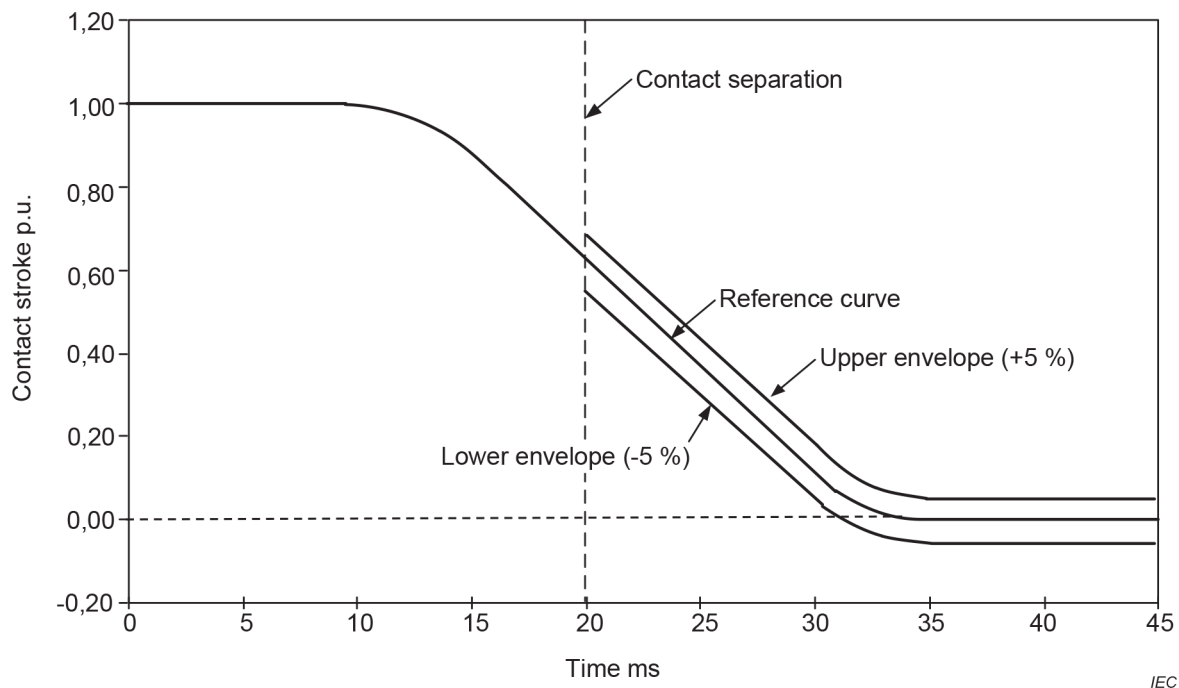


Figure 17 – Reference travel curve measured during the three-phase breaking test (idealised curve) with the specified envelopes centred over the reference travel curve

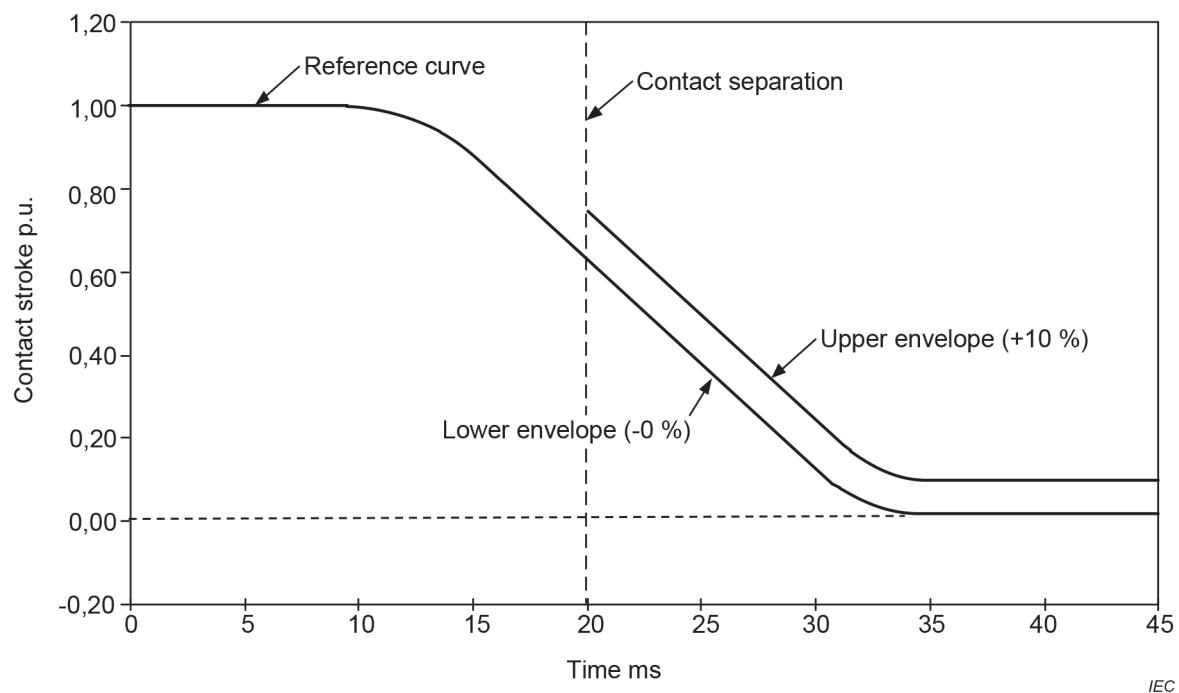


Figure 18 – Reference travel curve measured during the three-phase breaking test (idealised curve) with the specified envelopes fully displaced upward from the reference travel curve

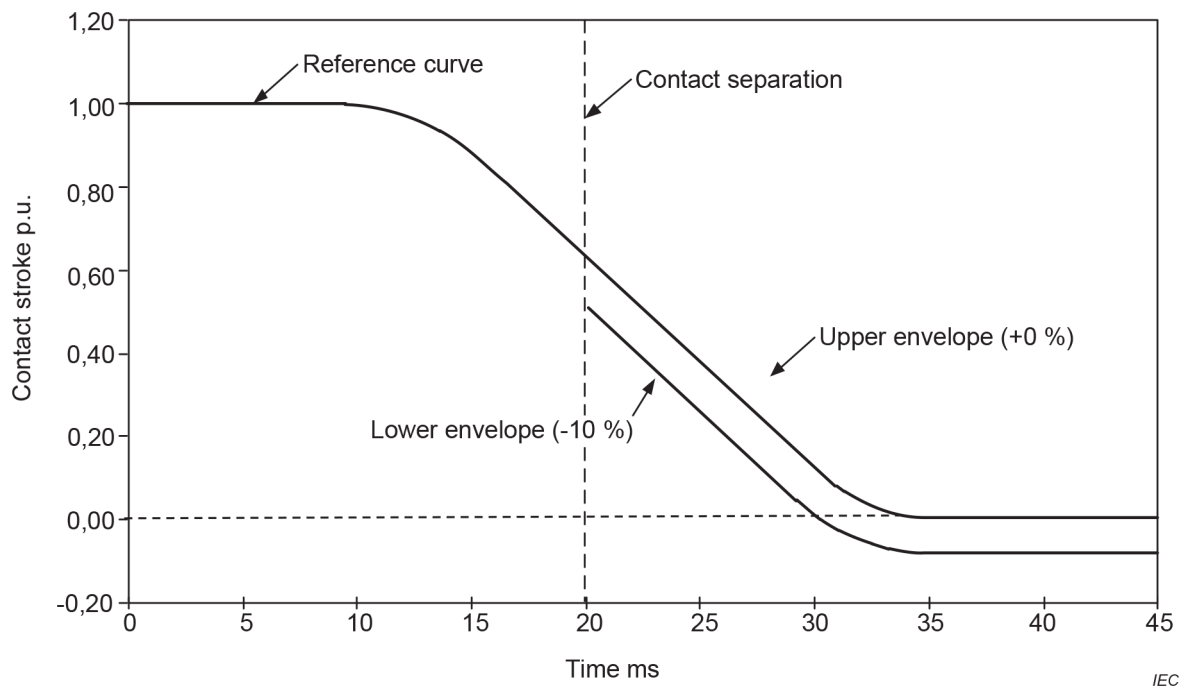


Figure 19 – Reference travel curve measured during the three-phase breaking test (idealised curve) with the specified envelopes fully displaced downward from the reference travel curve

7.102.4.2 Unit testing

7.102.4.2.1 General

Certain generator circuit-breakers are constructed by assembling identical making or breaking units in series, the voltage distribution between the units of each pole often being improved by the use of parallel impedances.

This type of design enables the making or breaking performance of a generator circuit-breaker to be tested by carrying out tests on one or more units.

The requirements of 7.101.1.1, 7.102.3 and 7.102.4.1 also apply for unit testing. Since, therefore, at least a complete pole assembly has to be made available for the verification tests on one or more units, the test results relate only to this specific pole design.

The following situations can be distinguished:

- a) The generator circuit-breaker pole consists of units (or assemblies of units) which are separately operated and which have no mutual connections for the arc extinguishing medium. In this case unit testing is acceptable. However, the mutual influence through the electrodynamic forces of the current on the units and the arc in the units should be taken into account (see Figure 20). This may be done by substitution of the second interrupter by a conductor with equivalent shape.
- b) The generator circuit-breaker pole consists of units (or assemblies of units) which are separately operated but which have a mutual connection for the arc extinguishing medium. In this case, unit testing is only acceptable if the units not under test arc during the test (e.g. used as auxiliary circuit-breaker in synthetic tests).

- c) The generator circuit-breaker pole consists of units (or assemblies of units) which are not separately operated. In this case, unit testing is only acceptable if the mechanical characteristics for single-unit testing and full-pole testing are the same. The procedure as given in 7.102.4.1 for single-phase testing of a three-pole generator circuit-breaker shall be applied accordingly. Moreover, the influence of electrodynamic forces (see also item a) above) shall be covered. However, if the units not under test arc during the test (for example, used as auxiliary circuit-breaker in synthetic tests), the requirements related to the mechanical characteristics are considered to be covered. In this case, the requirement for generator circuit-breakers, which have mutual connections for the extinguishing medium between units (see also item b) above) is covered at the same time.

The mechanical characteristics for single-unit testing and for full-pole testing shall be the same. The procedure given in 7.102.4.1 for single-phase testing of a three-pole generator circuit-breaker shall be applied accordingly.

When carrying out unit tests it is essential that the units are identical and that the static voltage distribution for the type of test is known.

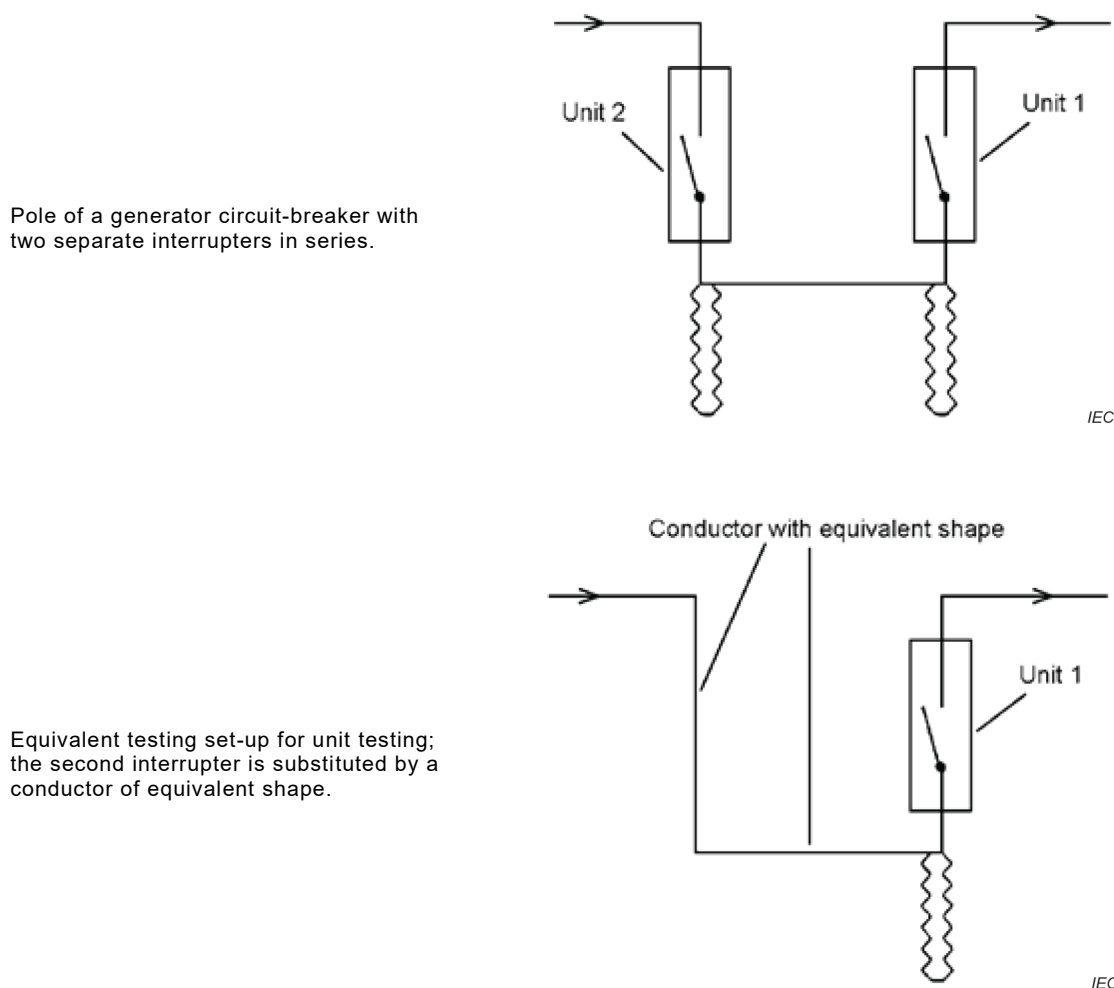


Figure 20 – Equivalent testing set-up for unit testing of generator circuit-breakers with more than one separate interrupters

7.102.4.2.2 Identical nature of the units

The units of the generator circuit-breaker shall be identical in their shape, in their dimensions and in their operating conditions; only the devices for controlling the voltage distribution among units may be different. In particular, the following conditions shall be fulfilled.

a) Operation of contacts

In making tests the closing of the contacts of one pole shall be such that the time interval between the closing of the contacts of the first unit to close and the closing of the contacts of the last unit to close is not more than one-sixth of a cycle of rated frequency. In breaking tests the opening of the contacts of one pole shall be such that the time interval between the opening of the contacts of the first unit to open and the opening of the contacts of the last unit to open is not more than one-eighth of a cycle of rated frequency. Filling pressure for operation and rated supply voltages shall be used to determine this time interval.

b) Supply of the arc-extinguishing medium

For a generator circuit-breaker using a supply of arc-extinguishing medium from a source external to the units, the supply to each unit shall, for all practical purposes, be independent of the supply to the other units, and the arrangement of the supply pipes shall be such as to ensure that all units are fed essentially together and in an identical manner.

7.102.4.2.3 Voltage distribution

The test voltage is determined by analysing the voltage distribution between the units of the pole.

The voltage distribution between units of a pole, as affected by the influence of earth, shall be determined for the relevant test conditions laid down for tests on one pole.

Where the units are not symmetrically arranged, the voltage distribution shall be determined also with reverse connections.

The voltage distribution is determined either by measurement or by calculation. Values used in the calculations shall be supported by measurements of the stray capacitances of the generator circuit-breaker. Such calculations and supporting measurements verifying the assumptions used in the calculations are the responsibility of the manufacturer.

If the generator circuit-breaker is fitted with parallel resistors, the voltage distribution shall be calculated or measured statically at the frequency of the TRV.

If only capacitors are used, the voltage distribution may be calculated or measured at power frequency.

The manufacturing tolerances for resistors and capacitors shall be taken into account. The manufacturer shall state the value of these tolerances.

NOTE 1 It can be taken into account that the voltage distribution is more favourable during the out-of-phase and load current breaking tests than during the short-circuit fault tests.

NOTE 2 The influence of pollution is not considered in determining voltage distribution. In some cases, pollution can affect this voltage distribution.

7.102.4.2.4 Requirements for unit testing

When testing a single unit, the test voltage shall be the voltage of the most highly stressed unit of the complete pole of the generator circuit-breaker, determined in accordance with 7.102.4.2.3.

When testing a group of units, the voltage appearing at the terminals of the most highly stressed unit of the group shall be equal to the voltage of the most highly stressed unit of the pole, both determined in accordance with 7.102.4.2.3.

During unit testing, the insulation to earth is not stressed with the full voltage occurring during a breaking operation of the complete generator circuit-breaker. It is therefore necessary to prove that the insulation to earth is capable of withstanding this full voltage, after interruption of the rated short-circuit current in all units with maximum arcing time. The influence of exhaust gases should also be taken into account.

7.102.5 Synthetic tests

Synthetic testing methods can be applied for making and breaking tests as required in 7.103 to 7.106.

NOTE For synthetic testing techniques and methods IEC 62271-101 can be used as a reference.

7.102.6 No-load operations before tests

Before commencing making and breaking tests, an opening and closing operation at rated supply voltage and at filling pressure for operation shall be recorded. The measurements shall comply with the mechanical characteristics, as defined in 7.101.1.1, for example no-load travel curves are within the reference travel bands.

After a change of contacts or any kind of maintenance, these mechanical characteristics shall be reconfirmed by repeating these no-load tests.

The pressure of the fluid for insulation and/or making and breaking shall be set at its minimum functional value as specified in 3.6.5.6. This does not apply to sealed-for-life generator circuit-breakers.

For electrically or spring-operated generator circuit-breakers, the operations shall be made with the closing solenoid or shunt closing releases and with the shunt opening release energised at rated maximum and minimum supply voltages as specified in Table 2.

7.102.7 Alternative operating mechanisms

Subclause 7.107 of this document applies.

7.102.8 Behaviour of generator circuit-breaker during tests

During making and breaking tests, the generator circuit-breaker shall not

- show signs of distress;
- show harmful interaction between poles and to earth;
- show harmful interaction with adjacent laboratory equipment;
- exhibit behaviour which could endanger an operator.

The generator circuit-breaker shall close and latch satisfactorily.

For generator circuit-breakers which are designed to have discharge of interrupting medium to atmosphere during the making and breaking tests, the above requirements are considered to have been met, provided

- for oil generator circuit-breakers, there is no outward emission of flame, and the gases produced, together with the oil carried with the gases, shall be conducted from the generator circuit-breaker and directed away from all live conductors and locations where persons may be present;

- for other types of generator circuit-breakers, such as air blast or air break, there is an outward emission of flame, gas and/or metallic particles. If such emissions are appreciable, the tests may be performed with metallic screens placed in the vicinity of the live parts and separated from them by a safety clearance which the manufacturer shall specify. The screens shall be insulated from earth but connected thereto by a suitable device to indicate any significant leakage current to earth. There shall be no indication of significant leakage currents to the generator circuit-breaker earthed structure, or screens when fitted, during the tests.

If no other devices are available, the earthed parts, etc. can be connected to earth through a fuse consisting of a copper wire of 0,1 mm diameter and 5 cm long. No significant leakage is assumed to have occurred if this fuse wire is intact after the test.

If faults occur which are neither persistent nor due to defect in design, but rather are due to errors in assembly or maintenance, the faults can be rectified and the test-duty repeated. In those cases, the test report shall include reference to the invalid tests.

NSDDs may occur during the recovery voltage period following a breaking operation. However, their occurrence is not a sign of distress of the switching device under test. Therefore, their number is of no significance to interpreting the performance of the device under test. They shall be reported in the test report in order to differentiate them from restrikes.

NOTE It is not the intent to require the installation of special measuring circuits to detect NSDDs. They are only reported when seen on a graphical record.

7.102.9 Condition of generator circuit-breaker after tests

7.102.9.1 General

The generator circuit-breaker may be inspected after any test-duty. Its mechanical parts and insulators shall be in essentially the same condition as before the test-duty.

After each test-duty the generator circuit-breaker shall be in the following condition:

- a) The generator circuit-breaker shall be capable of withstanding a voltage test as a condition check according to 7.2.12.
- b) The main contacts shall be in such a condition, in particular with regard to wear, contact area, pressure and freedom of movement that they are capable of carrying the rated continuous current without their temperature rise exceeding the values specified in Table 14 of IEC 62271-1:2017 by more than 10 K.

Contacts shall be considered as "silver-faced" only if there is still a layer of silver at the contact points after any of the short-circuit test-duties; otherwise, they shall be treated as "not silver-faced" (see 7.5.6.2, point 6 of IEC 62271-1:2017).

For other than sealed-for-life interrupters, visual inspection is usually sufficient for verification of the capability of the generator circuit-breaker to carry the rated continuous current.

NOTE Experience shows that an increase of the voltage drop across the generator circuit-breaker cannot alone be considered as reliable evidence of an increase in temperature rise.

For generator circuit-breakers with sealed-for-life interrupters either procedure A or B below applies:

Procedure A

This procedure is applicable, when a continuous current test has been carried out in accordance with 7.5 and the manufacturer has provided the test results to the testing laboratory.

- 1) The manufacturer shall make available the results of the appropriate continuous current test together with drawings illustrating the circuit-breaker tested. The drawings shall show the configuration and dimensions of the conductors and interrupter together with details and dimensions of the enclosure, if any. The testing laboratory shall ensure that the circuit-breaker submitted for short-circuit tests is identical in all significant details likely to affect the continuous current rating of the circuit-breaker on which the continuous current test was carried out.
- 2) The resistance across the generator circuit-breaker shall be measured before the making and breaking tests. Three measurements of resistance shall be made on each interrupting unit with intervening no-load operations to establish an average value. The measurements shall be made with DC at any convenient value of current between 100 A and the rated continuous current.
- 3) Provided that the average increase of the resistance for each interrupting unit is not greater than 20 % of the highest resistance value recorded for the interrupting units submitted to the continuous current test, then the making and breaking tests can proceed. In the event of the increase of the resistance measurements exceeding the 20 %, then procedure B shall be applied.
- 4) After the completion of the making and breaking tests the resistance across each interrupting unit shall be measured again. The measurement procedure shall be identical to that used for the resistance measurements made prior to the making and breaking tests.
- 5) The condition of the contacts after completion of the making and breaking tests is considered to be satisfactory, if the average resistance increase for each interrupting unit is not greater than 100 % of the maximum value recorded for the interrupting units submitted to the continuous current tests.
- 6) In the event of the average value of resistance increase for any interrupting unit exceeding 100 % of the maximum value recorded for the original continuous current test, then the testing laboratory shall request a continuous current test to be performed (see assessment for procedure B).

Procedure B

This procedure is applicable either when a manufacturer has not carried out a continuous current test on the type of generator circuit-breaker submitted for making and breaking tests, or alternatively, when the testing laboratory is not satisfied that there is a satisfactory relationship between the generator circuit-breaker for test and the generator circuit-breaker on which a continuous current test was performed.

- 1) A continuous current test shall be performed after the no-load operations completing the making and breaking tests prior to the replacement of any interrupting units.
 - 2) The condition of the contacts after the making and breaking tests is considered acceptable if the maximum temperature rise recorded at the terminals of any interrupting unit does not exceed by more than 10 K the values specified in Table 14 of IEC 62271-1:2017.
- c) The generator circuit-breaker shall be capable of making and breaking load currents according to 7.104, although its short-circuit making and breaking performance may be impaired.

For other than sealed-for-life interrupters, visual inspection is usually sufficient for verification of the capability of the generator circuit-breaker to make and break load currents according to 7.104.

For sealed-for-life generator circuit-breakers verifications according to a) and b) are normally sufficient for verification of the capability of the generator circuit-breaker to make and break load currents according to 7.104.

If interrupters are placed in an insulating fluid with different characteristics that also might withstand the test voltages when replacing the original arc extinguishing medium (for example a vacuum interrupter in an enclosure filled with SF₆), the voltage test as a condition check, as requested in 7.2.12, may not be adequate to verify the integrity of the device. In such cases the integrity of the device shall be demonstrated by one of the following:

- appropriate methods as stated by the manufacturer (for example by removing the interrupter and testing it in the interrupter factory with the same procedure as for a new interrupter);
- short-circuit current breaking tests in a circuit which supplies at least 10 % of the rated short-circuit breaking current and at least 50 % of the rated voltage irrespectively of the TRV. One of the three following tests shall be performed:
 - 1) in a three-phase solidly earthed test circuit, one breaking operation;
 - 2) in a three-phase isolated neutral test circuit, three breaking operations. Each pole shall be the first to clear once;
 - 3) in a single-phase test circuit, one breaking operation on each pole.

The requirements mentioned above also apply to synthetic tests.

A successful interruption in each pole demonstrates that the interrupter integrity is maintained.

7.102.9.2 No-load operations after a test-duty

After a test-duty no-load operations shall be repeated under the same condition as the corresponding operations before the test-duty. Additionally, an opening and closing operation at rated supply voltage and at filling pressure for operation shall be recorded. The measurements shall comply with the mechanical characteristics, as defined in 7.101.1.1, for example no-load travel curves are within the reference travel bands. If the test continues on the same test object without maintenance, then the no-load operations are not required at this stage.

7.102.9.3 No-load operations after a series of tests

After the completion of a test series of making and breaking tests, the no-load operations performed at the beginning of the test series shall be repeated under the same condition as the corresponding operations before the test series. Additionally, an opening and closing operation at rated supply voltage and at filling pressure for operation shall be recorded. The measurements shall comply with the mechanical characteristics, as defined in 7.101.1.1, for example no-load travel curves are within the reference travel bands.

7.102.10 Demonstration of the most severe breaking conditions

7.102.10.1 General

The procedures described in 7.102.10 are relevant for the system-source short-circuit current breaking tests, generator-source short-circuit current breaking test-duty 4, and for the out-of-phase current breaking tests. Each test-duty is demonstrated with a minimum of two tests on one test sample.

The current to be interrupted by a generator circuit-breaker shall be determined at the instant of contact separation in accordance with Figure 10, and shall be stated in terms of the following two values:

- the RMS value of the AC component averaged over all phases;
- the degree of asymmetry in each phase.

The RMS value of the AC component in any phase shall not vary from the average by more than 10 %.

Although the breaking current is measured at the instant corresponding to contact separation, the breaking performance of the generator circuit-breaker is determined, among other factors, by the current which is finally interrupted in the last loop of arcing. The decrement of the AC component of the current is therefore very important, particularly when testing those generator circuit-breakers which arc for several loops of current. To obviate an easement of duty, the decrement of the AC component of the current should be such that at a time corresponding to the final extinction of the main arc in the last-pole-to-clear, the AC component of the prospective current is not less than 90 % of the appropriate value for the test-duty. This shall be proven by a record of the prospective current before commencing the tests.

If the characteristics of the generator circuit-breaker are such that it reduces the current value below the prospective breaking current, or if the graphical record is such that the current wave envelope cannot be drawn successfully, the average prospective breaking current in all phases shall be used as the breaking current and shall be measured from the graphical record of prospective current at a time corresponding to the instant of contact separation.

The instant of contact separation can be determined according to the experience of the test laboratory and the type of apparatus under test by various methods, for instance, by recording the contact travel during the test, by recording the arc voltage or by a test on the generator circuit-breaker at no-load.

7.102.10.2 Three-phase tests

7.102.10.2.1 General

The procedures given below are for direct tests. Where synthetic tests are performed it is necessary to establish the minimum arcing time for the first-pole-to-clear before starting the sequences. The method of establishing the minimum arcing time is given in 7.102.10.3.

7.102.10.2.2 Three-phase symmetrical breaking operations

The most severe breaking conditions are considered satisfactory if the following conditions are met:

- a) in one of the two opening operations, where in the first-pole-to-clear arc extinction occurs at minimum arcing time;
- b) in one of the two opening operations, where in the first-pole-to-clear arc extinction occurs at maximum arcing time;
- c) the degree of asymmetry at contact separation during the breaking operations shall not exceed 20 % in any phase;
- d) during synthetic tests the following additional requirements shall be met: the peak short-circuit current during the last loop prior to interruption shall not deviate by more than 10 % from the peak value of the AC component of the rated current. In cases, where the applied voltage from the high current source is at least 50 % of the rated voltage, a higher deviation of the last current loop is accepted provided that the prospective current loop with the auxiliary circuit-breaker arcing is within the tolerances specified in Annex A.

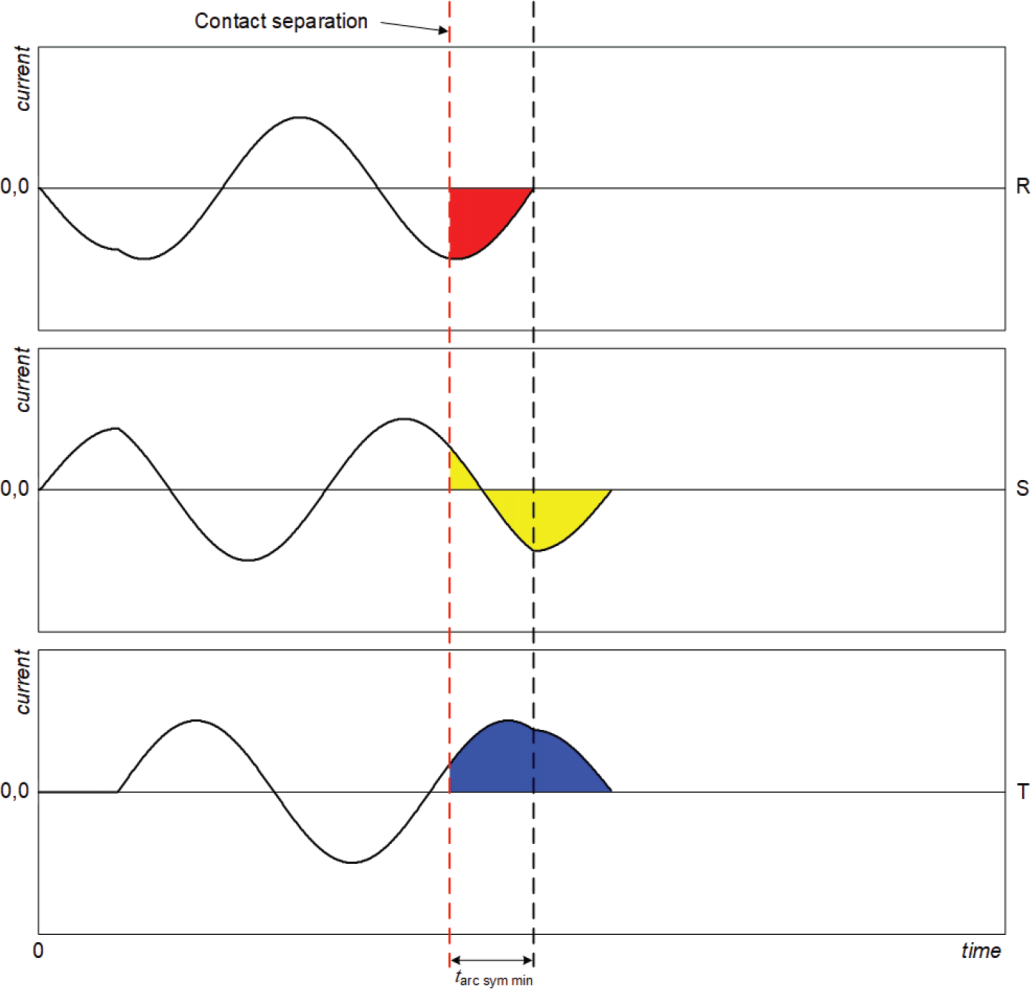
The recommended procedure to achieve these two valid operations is as follows.

First it is necessary to establish the minimum arcing time $t_{\text{arc sym min}}$. The minimum arcing time may be known from experience. However, tests illustrated in Figure 21 are needed to confirm the minimum and the maximum arcing times. The minimum arcing time $t_{\text{arc sym min}}$ is established when any delay in the contact separation with respect to the current waveform results in interruption at the next current zero in another phase, resulting in a valid test with maximum arcing time.

The minimum arcing time is found by changing the setting of the tripping command by steps of 18° ($d\alpha$).

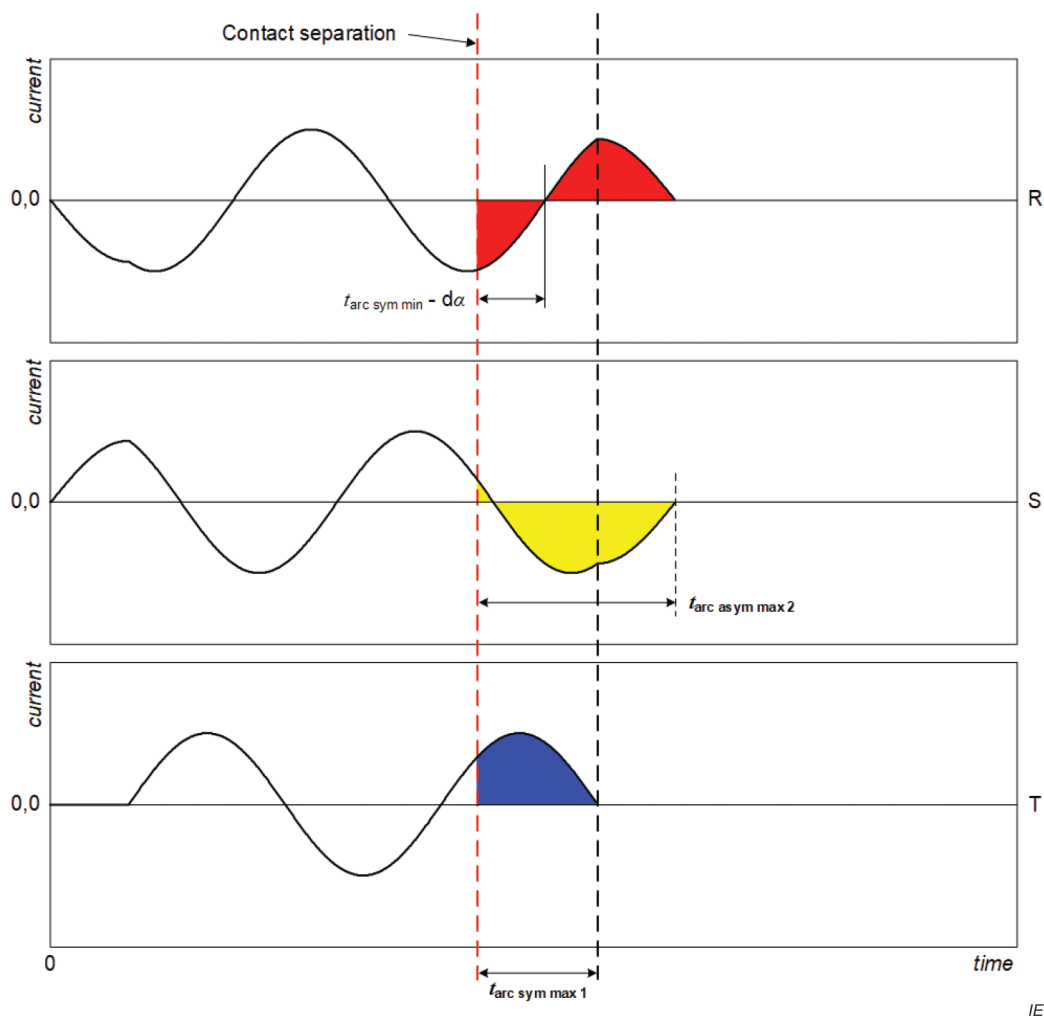
A graphical representation of the two valid breaking operations is given in Figure 21.

As an alternative to the above, three CO-operations could be applied where the tripping command shall be advanced or delayed by 40 electrical degrees (40°) between the three opening operations.



IEC

a) Minimum arcing time (in phase R)



IEC

b) Maximum arcing time for the first-pole-to-clear (in phase T) and maximum arcing time for the last-pole-to-clear (in phase S)

Figure 21 – Two valid three-phase symmetrical breaking operations

7.102.10.2.3 Three-phase asymmetrical breaking operations

Since the severity of the tests under asymmetrical breaking conditions can vary widely depending on the moment of contact separation, a procedure has been developed in order to prove the most severe breaking conditions.

The following asymmetry criteria shall be fulfilled by the prospective current waveform when performing test-duty 2 and test-duty OP2:

- last current loop peak;
- last current loop duration;
- DC component at current zero (parameter controlling the di/dt and the resulting TRV parameters).

The breaking operations are valid if the prospective current, of the pole with maximum asymmetry, meets the following asymmetry criteria:

- the peak current during the last loop prior to the intended interruption is between 90 % and 110 % of the required value;

- the duration of the current loop prior to the intended interruption is between 90 % and 110 % of the required value;
- the product of the peak and the duration of the current during the last loop prior to the intended interruption is between 90 % and 110 % of the required value.

With the consent of the manufacturer, values of more than 110 % of the above are acceptable.

During synthetic tests the breaking operations are valid if during the test the following additional requirements are met:

- the peak of the current during the last loop prior to the interruption is between 90 % and 110 % of the required value;
- the duration of the current loop prior to the interruption is between 90 % and 110 % of the required value;
- the product of the peak and the duration of the current during the last loop prior to the interruption is between 90 % and 110 % of the required value.

With the consent of the manufacturer, values of more than 110 % of the above are acceptable.

NOTE These conditions apply only provided that the instant of current initiation is within 10° during both the prospective current calibration and breaking tests.

The intention is to prove the most severe breaking conditions as follows:

- a) In one breaking operation arc extinction in the first-pole-to-clear shall occur at the end of a major current loop with the maximum arcing time and with the required maximum asymmetry criteria. This operation shall comply with the TRV requirements for the first-pole-to-clear condition.
- b) In one breaking operation arc extinction in one of the last-poles-to-clear shall occur at the end of a major extended current loop with the maximum arcing time and with the required maximum asymmetry criteria. This operation shall comply with the TRV requirements for the last pole-to-clear condition.

Some generator circuit-breakers will not clear at the end of a major loop. Arcing then continues during the subsequent minor current loop and becomes a last pole-to-clear. However, this test is considered valid if during a subsequent test it is proven that the maximum arcing time was achieved.

A test where the circuit-breaker clears at the end of a reduced major current loop or a minor loop in the phase meeting the asymmetry criteria is invalid with the exception of the situation described above.

The sequence is of no consequence as long as the tests fulfil the conditions in a) and b). Between the condition a) and the condition b) tests the initiation of the short-circuit should be changed by 60° in order to transfer the required asymmetry criteria to another phase and to equalise the contact erosion of the poles.

The preferred procedure to demonstrate the conditions a) and b) in four operations on one generator circuit-breaker without reconditioning is as follows:

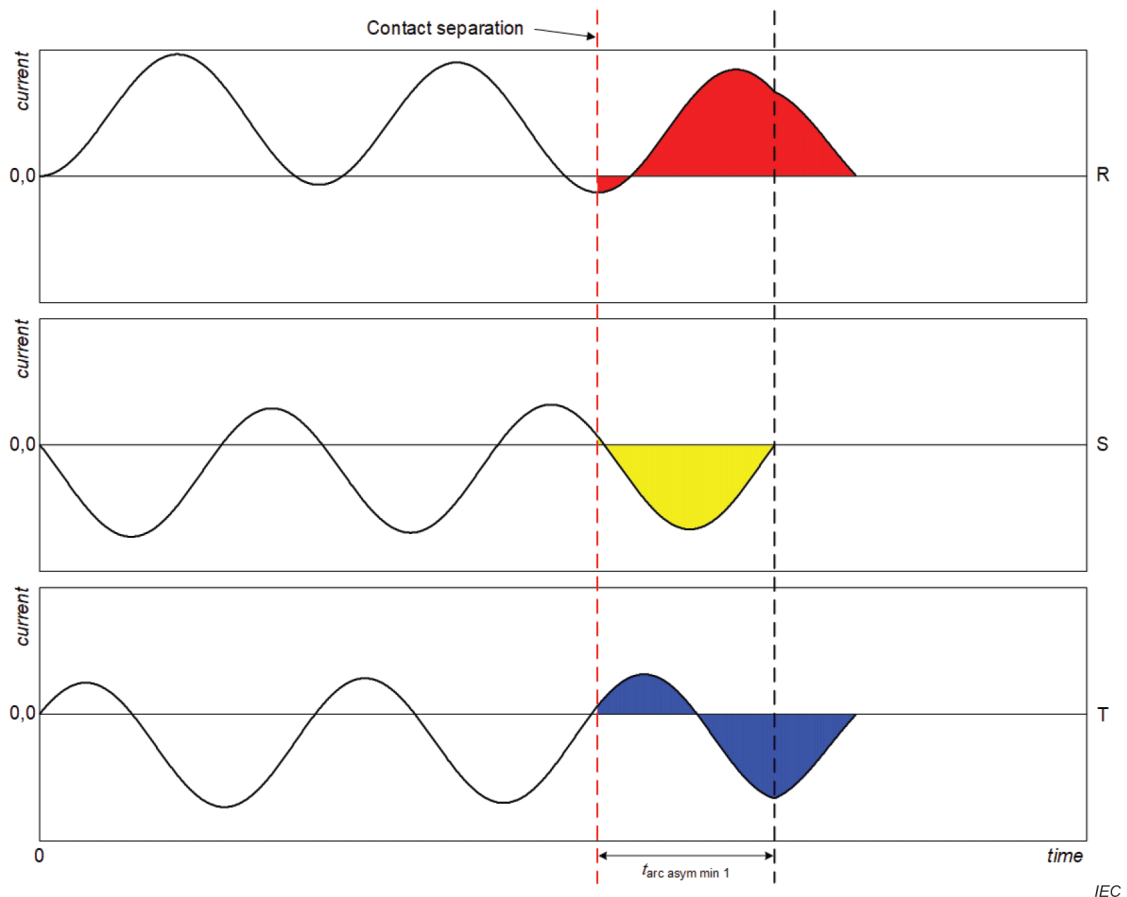
Demonstration of condition a)

Two breaking operations are required, one according to Figure 22 and one according to Figure 23.

- Figure 22 shows the contact separation to achieve the minimum arcing time $t_{\text{arc asym min 1}}$ in phase S with intermediate level of asymmetry after a major loop. Parameters for this intermediate asymmetrical major loop are given in Table 15 for 50 Hz and in Table 16 for 60 Hz.

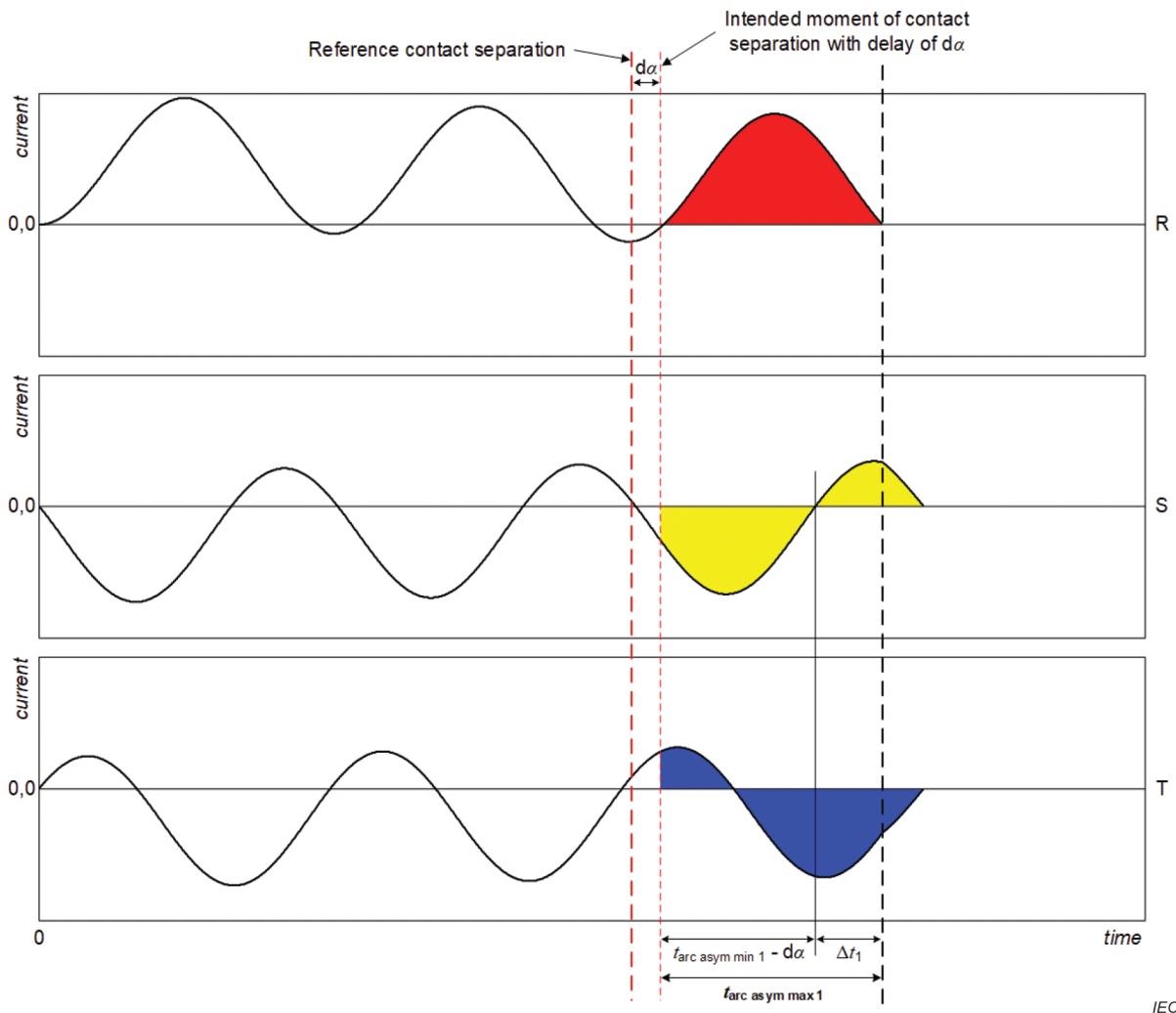
- Figure 23 shows the contact separation delayed by $d\alpha$ (18°) with respect to the current waveform of Figure 22 resulting in a first-pole-to-clear interruption after a major loop in phase R with the required maximum asymmetry criteria and the maximum arcing time $t_{\text{arc asym max } 1} = t_{\text{arc asym min } 1} - T \times d\alpha/360^\circ + \Delta t_1$. Parameters for this maximum asymmetrical major loop and values for the time interval Δt_1 are given in Table 15 for 50 Hz and in Table 16 for 60 Hz.

The minimum arcing time may be known from experience. However tests illustrated in Figure 22 and Figure 23 are needed to confirm the minimum and the maximum arcing times.



Contact separation is set such as to achieve the minimum arcing time in phase S with intermediate level of asymmetry after a major loop.

Figure 22 – Three-phase asymmetrical breaking operation – Minimum arcing time in a phase with intermediate level of asymmetry after a major loop ($t_{\text{arc asym min } 1}$)



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Contact separation is delayed by $d\alpha$ with respect to Figure 22 in order to achieve the maximum arcing time for a first-pole-to-clear (phase R) at maximum asymmetry criteria after a major loop.

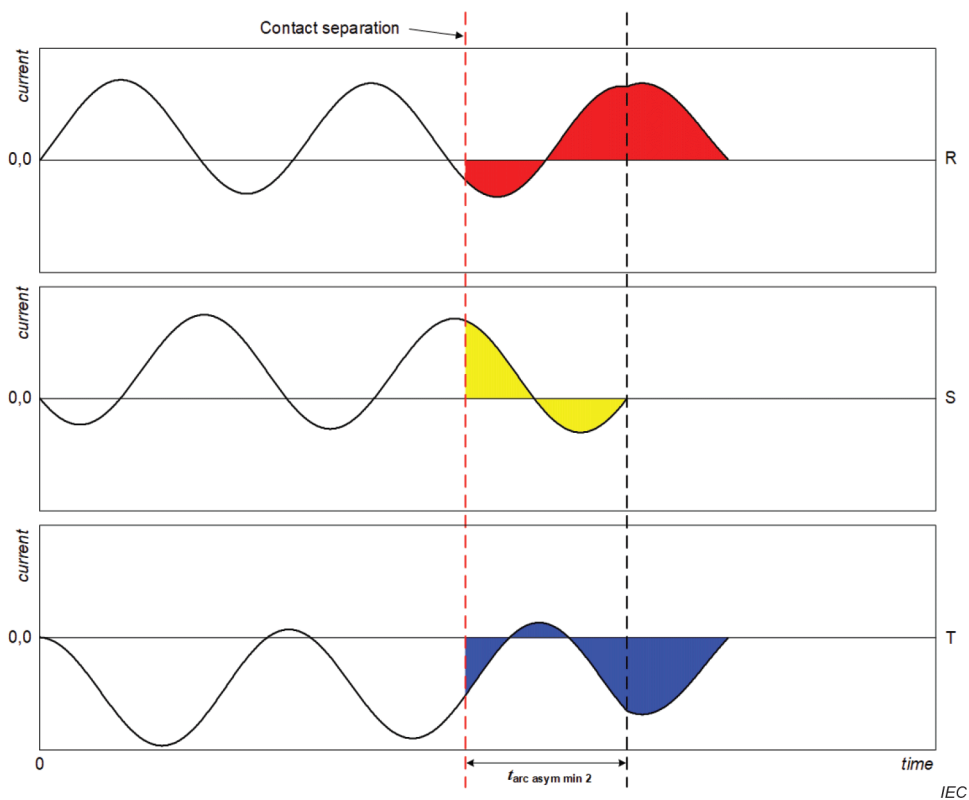
Figure 23 – Three-phase asymmetrical breaking operation – Maximum arcing time for a first-pole-to-clear at maximum asymmetry criteria after a major loop ($t_{\text{arc asym max 1}}$)

Demonstration of condition b)

Two breaking operations are required, one according to Figure 24 and one according to Figure 25.

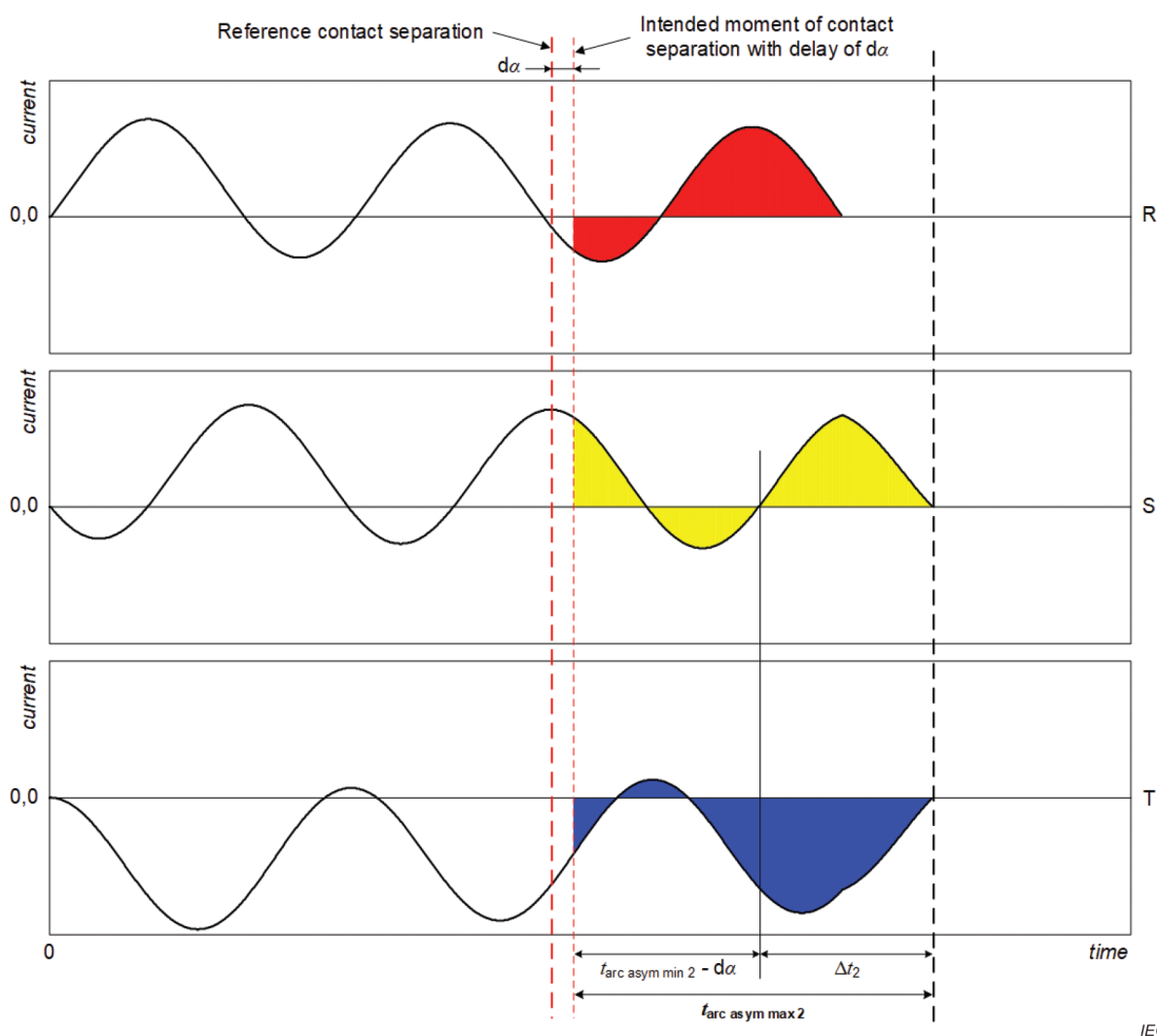
- Figure 24 shows the contact separation such as to achieve the minimum arcing time $t_{\text{arc asym min 2}}$ in phase S with intermediate level of asymmetry after a minor loop. Parameters for this intermediate asymmetrical minor loop are given in Table 17 for 50 Hz and in Table 18 for 60 Hz.
- Figure 25 shows the contact separation delayed by $d\alpha$ (18°) with respect to the current waveform of Figure 24 resulting in a last-pole-to-clear interruption after a major extended loop in phase T with the required maximum asymmetry criteria and the maximum arcing time $t_{\text{arc asym max 2}} = t_{\text{arc asym min 2}} - T \times d\alpha/360^\circ + \Delta t_2$. Parameters for this maximum asymmetrical major extended loop and values for the time interval Δt_2 are given in Table 17 for 50 Hz and in Table 18 for 60 Hz.

The minimum arcing time may be known from experience. However tests illustrated in Figure 24 and Figure 25 are needed to confirm the minimum and the maximum arcing times.



Contact separation is set such as to achieve the minimum arcing time in phase S with intermediate level of asymmetry after a minor loop.

Figure 24 – Three-phase asymmetrical breaking operation – Minimum arcing time in a phase with intermediate level of asymmetry after a minor loop ($t_{arc\ asym\ min\ 2}$)



Contact separation is delayed by $d\alpha$ with respect to Figure 24 in order to achieve the maximum arcing time for a last-pole-to-clear (phase T) at maximum asymmetry criteria after a major extended loop.

**Figure 25 – Three-phase asymmetrical breaking operation –
 Maximum arcing time for a last-pole-to-clear at maximum asymmetry
 criteria after a major extended loop ($t_{\text{arc asym max 2}}$)**

If it is not possible to achieve the requirements a) and b) because of the characteristics of the generator circuit-breaker, the number of breaking operations shall be extended to prove that, in this particular case, the most severe test conditions have been achieved. With the consent of the manufacturer two options to perform additional breaking operations are suggested.

Option 1: Additional breaking operations shall be carried out without reconditioning on the same generator circuit-breaker:

- If during the first four breaking operations according to the preferred procedure neither condition a) nor condition b) were achieved, at least two more breaking operations shall be carried out. The test-duty is fulfilled, if among all the six breaking operations each of the two conditions a) and b) are met at least once, while taking into account an enlarged tolerance of ± 2 ms to the required arcing times.

- If during the first four breaking operations according to the preferred procedure only one of the conditions a) and b) was achieved, at least one more breaking operation shall be carried out. If during this additional breaking operation the remaining condition is met, the test-duty is fulfilled. If a second additional breaking operation is necessary to prove the remaining condition, then, if among all the six breaking operations the remaining condition was met at least once, while taking into account an enlarged tolerance of ± 2 ms to the required arcing times, the test-duty is fulfilled.

Option 2: The preferred procedure as described above shall be repeated with a reconditioned or a new generator circuit-breaker:

During repetition of the preferred procedure the required conditions a) and b) shall be fulfilled taking into account an enlarged tolerance of ± 2 ms to the required arcing times.

7.102.10.3 Single-phase tests to substitute for three-phase conditions

7.102.10.3.1 General

This procedure may be used instead of three-phase tests, except where single-phase testing is not permitted according to 7.102.3.2 or 7.102.3.3.

The procedures given below are partly derived from synthetic test methods. Where direct tests are performed the procedure for establishing a minimum arcing time might result in a valid test with maximum arcing time or with an arcing time in excess of the maximum arcing time.

The aim of the following single-phase tests is to satisfy the conditions of the first-pole-to-clear and the last-pole-to-clear for each test-duty in one test circuit.

It is recognised that single-phase tests in substitution of three-phase conditions are more severe than three-phase tests because the arcing time of the last-pole-to-clear is used together with the prospective TRV of the first-pole-to-clear. As an alternative, the manufacturer may choose to split each test-duty into two separate test series, each test series demonstrating a successful interruption with the minimum and maximum arcing times for each pole-to-clear with its associated prospective TRV.

The following procedures are applicable if all operations of the rated operating sequence fulfil the requirements of 6.101.

7.102.10.3.2 Single-phase symmetrical breaking operations

The intention to achieve the most severe breaking conditions is considered satisfactory if the following conditions are met:

- a) In one of the two opening operations, arc extinction shall occur with the maximum arcing time and with TRV requirements for the first-pole-to-clear condition. The maximum arcing time for the first-pole-to-clear condition is determined as follows:

$$t_{\text{arc sym max 1}} = t_{\text{arc sym min}} + T \times 42^\circ/360^\circ$$

where

$t_{\text{arc sym min}}$ is the minimum arcing time obtained from one or more additional tests;

T is one period of the power frequency;

42° is the arcing window of the first-pole-to-clear – $d\alpha = 60^\circ - 18^\circ$

- b) In one of the two open operations, arc extinction shall occur with the maximum arcing time and with TRV requirements for the last-pole-to-clear condition. The maximum arcing time for the last-pole-to-clear condition is determined as follows:

$$t_{\text{arc sym max 2}} = t_{\text{arc sym min}} + T \times 132^\circ/360^\circ$$

where

$t_{\text{arc sym min}}$ is the minimum arcing time obtained from one or more additional tests;

T is one period of the power frequency;

132° is the arcing window of last-pole-to-clear – $d\alpha = (60^\circ + 90^\circ) - 18^\circ$.

- c) The degree of asymmetry at contact separation during the breaking operations shall not exceed 10 %.

During synthetic tests the following additional requirements shall be met:

- d) The peak short-circuit current during the last loop prior to interruption shall not deviate by more than 10 % from the peak value of the AC component of the rated current. In cases where the applied voltage from the high current source is at least 50 % of the rated voltage, higher deviations of the last current loop parameters are accepted provided that the prospective current loop parameters with the auxiliary circuit-breaker arcing are within the tolerances specified in Annex A.

It is necessary to establish the minimum arcing time $t_{\text{arc sym min}}$ before starting the above sequence. The minimum arcing time may be known from previous testing by using an additional test object clearly identified as the same type or may be found as part of the test. The minimum arcing time is established when any extra delay in the contact separation with respect to the current waveform results in interruption at the next current zero. This minimum arcing time is found by changing the setting of the tripping command by steps of 18° . In case of synthetic testing, visual inspection shall show that re-ignition occurred between arcing contacts only. Thorough inspection of screens, arcing and main contacts, etc. should be made to verify a correct behaviour. For sealed-for-life generator circuit-breakers without separate arcing and main contact systems, for example vacuum generator circuit-breakers, 7.102.9.1 indent b) procedures A or B apply.

7.102.10.3.3 Single-phase asymmetrical breaking operations

The aim of the following single-phase tests is to satisfy the conditions of the first-pole-to-clear and the last pole-to-clear as per a) and b) in 7.102.10.2.3. The recommended test procedure for single-phase testing is derived from the three-phase test procedure.

The following asymmetry criteria shall be fulfilled by the prospective current waveform when performing test-duty 2 and test-duty OP2:

- last current loop peak;
- last current loop duration (for the first-pole-to-clear conditions only);
- DC component at current zero (parameter controlling the di/dt and the resulting TRV parameters).

The breaking operations are valid if the prospective current meets the following asymmetry criteria:

- the peak current during the last loop prior to the intended interruption is between 100 % and 110 % of the required value, and
- the duration of the current loop prior to the intended interruption is between 90 % and 110 % of the required value (for first-pole-to-clear conditions only).

or if the above tolerances cannot be fulfilled:

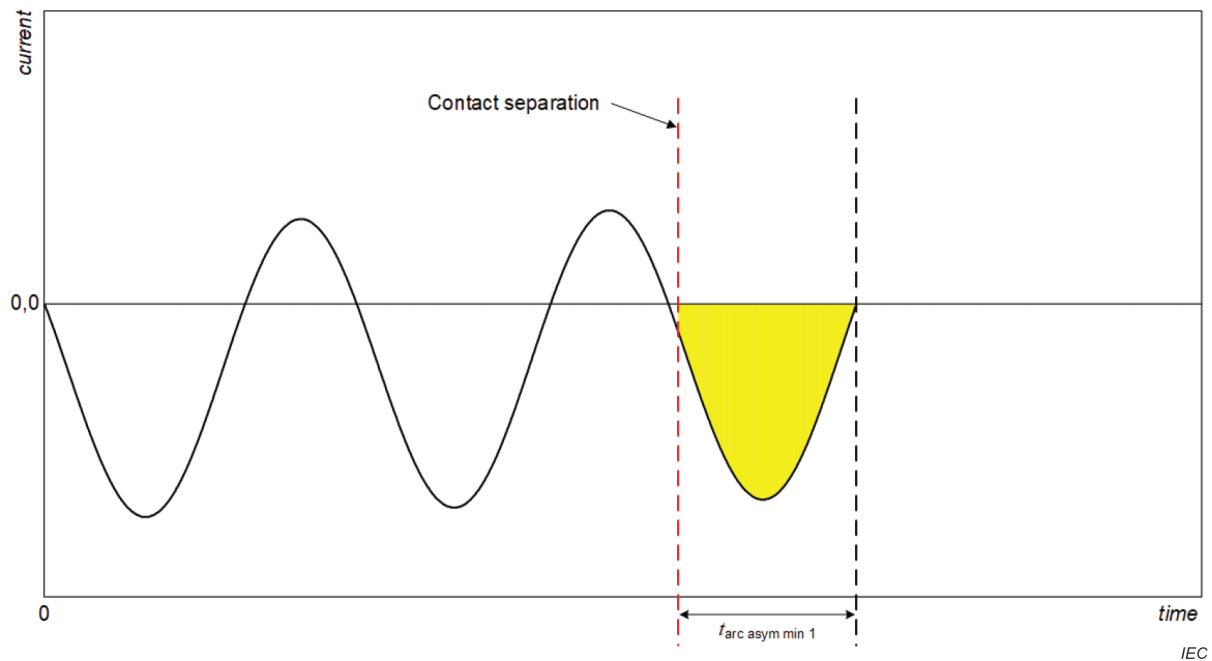
- the product of the peak and the duration of the current during the last loop prior to the intended interruption is between 100 % and 110 % of the required value (for first-pole-to-clear conditions only).

During synthetic tests the following additional requirements shall be met:

- the peak of the current during the last loop prior to the interruption is between 90 % and 110 % of the required value,
- the duration of the current loop prior to the interruption is between 90 % and 110 % of the required value (for first-pole-to-clear conditions only), and
- the product of the peak and the duration of the current during the last loop prior to the interruption is between 90 % and 110 % of the required value (for first-pole-to-clear conditions only).
- in cases where the applied voltage from the high current source is at least 50 % of the rated voltage, higher deviations of the last current loop parameters are accepted provided that the prospective current loop parameters with the auxiliary circuit-breaker arcing are within the tolerances specified above.

NOTE 1 These conditions apply only provided that the instant of current initiation is within 10° during both the prospective current calibration and breaking tests.

Before the first valid opening operation it is necessary to establish the minimum arcing time $t_{\text{arc asym min 1}}$ derived from a phase with intermediate asymmetry level after a major loop in a three-phase system (Figure 22). Parameters for this intermediate major loop are given in Table 15 for 50 Hz and in Table 16 for 60 Hz. This minimum arcing time may be known from previous testing by using an additional test object clearly identified as the same type or may be found as part of the tests. The minimum arcing time $t_{\text{arc asym min 1}}$ is established when any delay in the contact separation with respect to the current waveform results in interruption at the next current zero. This minimum arcing time is found by changing the setting of the tripping command by steps of 18° ($d\alpha$) (Figure 26). In case of synthetic testing, visual inspection shall show that re-ignition occurred between arcing contacts only. Thorough inspection of screens, arcing and main contacts, etc., should be made to verify a correct behaviour. For sealed-for-life generator circuit-breakers without separate arcing and main contact systems, for example vacuum generator circuit-breakers, 7.102.9.1 indent b) procedures A or B apply.

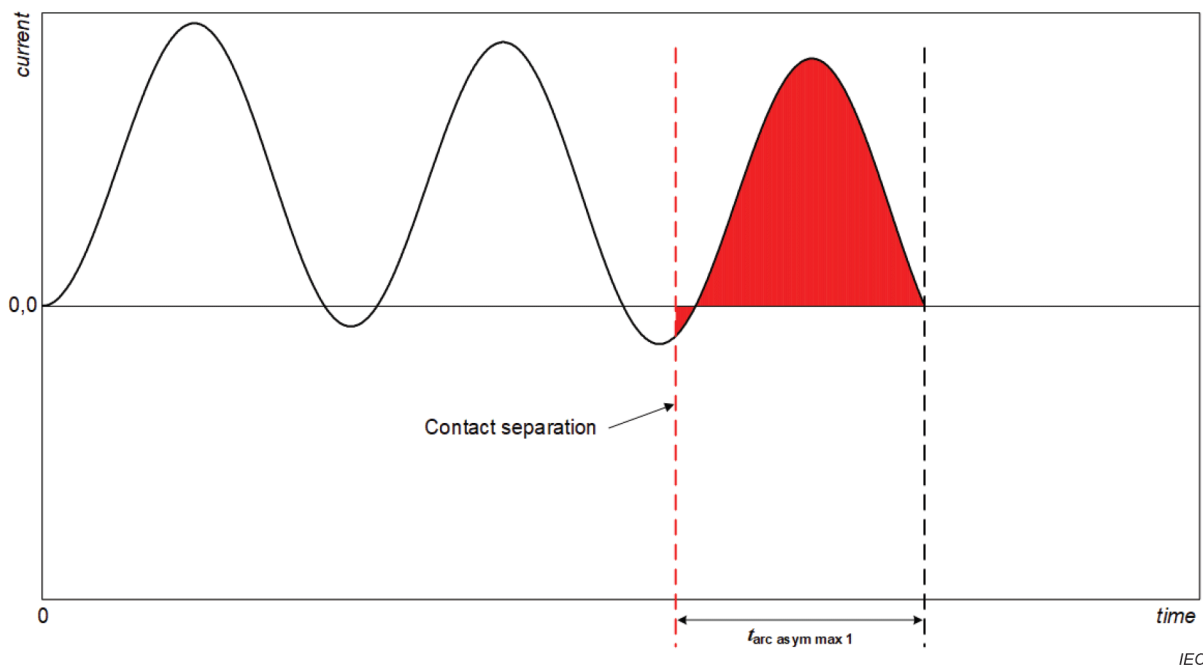


Contact separation is set to achieve the minimum arcing time after a major loop with intermediate asymmetry level.

Figure 26 – Single-phase asymmetrical breaking operation – Minimum arcing time in a phase with intermediate level of asymmetry after a major loop ($t_{\text{arc asym min 1}}$)

For the first valid opening operation, the initiation of short-circuit and the setting of the control of the tripping command shall be such that:

- the required asymmetry criteria for the appropriate major loop are obtained (Figure 27);
- arc extinction occurs with the required asymmetry criteria after a major loop with the maximum arcing time $t_{\text{arc asym max 1}} = t_{\text{arc asym min 1}} - T \times d\alpha/360^\circ + \Delta t_1$, with the time interval Δt_1 as given in Table 15 for 50 Hz and in Table 16 for 60 Hz, and with the required maximum asymmetry criteria in order to comply with the TRV requirements for the first-pole-to-clear condition;
- loop parameters of the prospective current as given in Table 15, columns 6, 7 and 9, for 50 Hz and in Table 16, columns 6, 7 and 9, for 60 Hz are fulfilled;
- interruption occurs after a subsequent minor loop if the generator circuit-breaker failed to interrupt after the required major loop.



Contact separation is set to achieve the longest possible arc duration for a first-pole-to-clear at maximum asymmetry criteria after a major loop.

Figure 27 – Single-phase asymmetrical breaking operation – Maximum arcing time for a first-pole-to-clear at maximum asymmetry criteria after a major loop ($t_{\text{arc asym max 1}}$)

Before the second valid opening operation it is necessary to establish the minimum arcing time $t_{\text{arc asym min 2}}$ derived from a phase with intermediate asymmetry level after a minor loop in a three-phase system (Figure 28). Parameters for this intermediate minor loop are given in Table 17 for 50 Hz and in Table 18 for 60 Hz. This minimum arcing time may be known from previous testing by using an additional test object clearly identified as the same type or may be found as part of the tests. The minimum arcing time $t_{\text{arc asym min 2}}$ is established when any delay in the contact separation with respect to the current waveform results in interruption at the next current zero. This minimum arcing time is found by changing the setting of the tripping command by steps of 18° ($d\alpha$) (Figure 28). In case of synthetic testing, visual inspection shall show that re-ignition occurred between arcing contacts only. Thorough inspection of screens, arcing and main contacts, etc., should be made to verify a correct behaviour. For sealed-for-life generator circuit-breakers without separate arcing and main contact systems, for example vacuum generator circuit-breakers, 7.102.9.1 indent b) procedures A or B apply.

For the second valid opening operation, the initiation of short-circuit and the setting of the control of the tripping command shall be such that:

- the required asymmetry criteria for the appropriate major loop are obtained (Figure 29);
- arc extinction occurs with the required asymmetry criteria after a major loop with the maximum arcing time $t_{\text{arc asym max 2}} = t_{\text{arc asym min 2}} - T \times d\alpha/360^\circ + \Delta t_2$, with the time interval Δt_2 as given in Table 17 for 50 Hz and in Table 18 for 60 Hz, and with the required maximum asymmetry criteria in order to comply with the TRV requirements for the last-pole-to-clear condition;
- loop parameters of the prospective current as given in Table 17, columns 6 and 9, for 50 Hz and in Table 18, columns 6 and 9, for 60 Hz are fulfilled;
- interruption occurs after a subsequent minor loop if the generator circuit-breaker failed to interrupt after the required major loop.

NOTE 2 It is recognised that single-phase testing in a direct test circuit to prove the last-pole-to-clear conditions is more severe than in a three-phase test circuit because the arcing time of the last-pole-to-clear is used together with the current of the first-pole-to-clear.

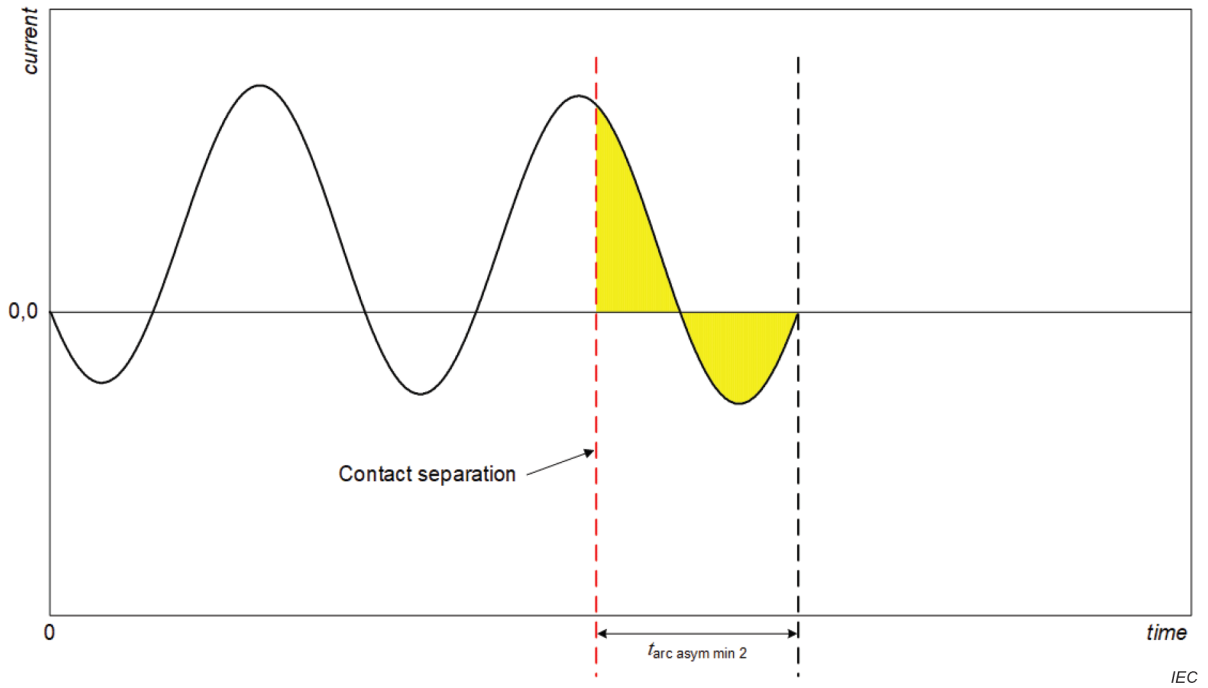
If it is not possible to achieve the requirements a) and b) in 7.102.10.2.3 because of the characteristics of the generator circuit-breaker, the number of breaking operations shall be extended to prove that, in this particular case, the most severe test conditions have been achieved. There are two options to perform additional breaking operations.

Option 1: With the consent of the manufacturer additional breaking operations shall be carried out without reconditioning on the same generator circuit-breaker:

- If during the first two breaking operations according to the preferred procedure neither condition a) nor condition b) were achieved, at least two more breaking operations shall be carried out. The test-duty is fulfilled if, among all the four breaking operations, each of the two conditions a) and b) are met at least once, while taking into account an enlarged tolerance of ± 2 ms to the required arcing times.
- If during the first two breaking operations according to the preferred procedure only one of the conditions a) and b) was achieved, at least one more breaking operation shall be carried out. If during this additional breaking operation the remaining condition is met, the test-duty is fulfilled. If a second additional breaking operation is necessary to prove the remaining condition, then, if among all the four breaking operations the remaining condition was met at least once, while taking into account an enlarged tolerance of ± 2 ms to the required arcing times, the test-duty is fulfilled.

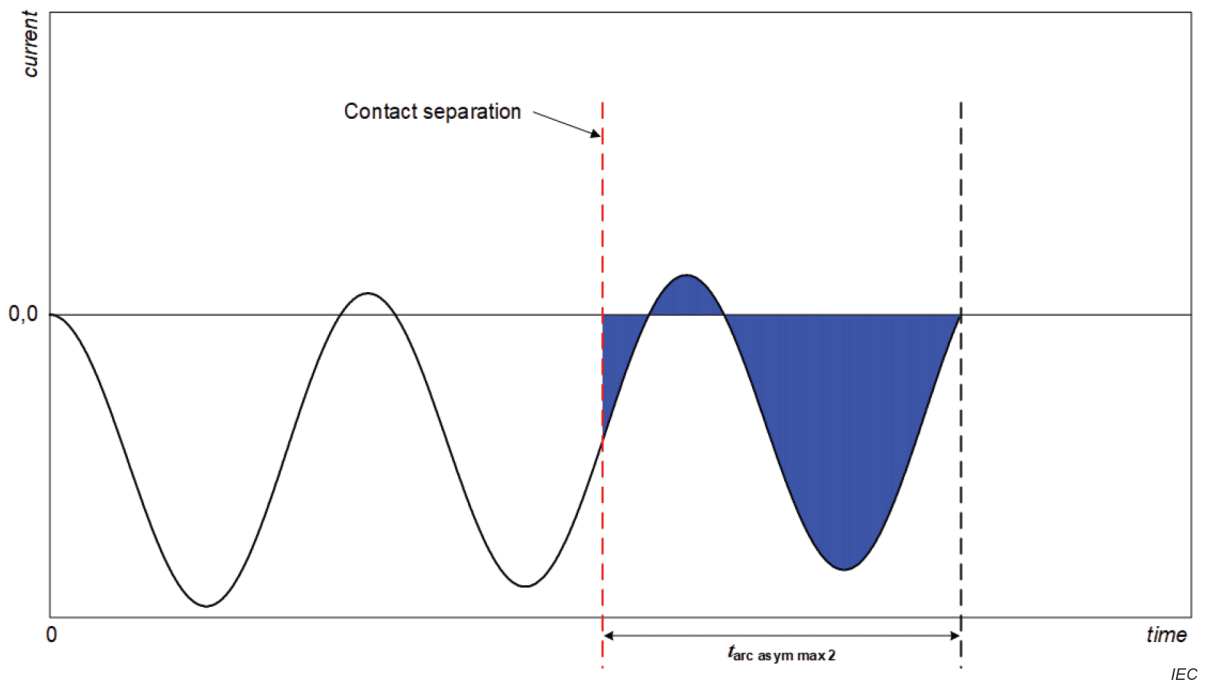
Option 2: The preferred procedure as described above shall be repeated with a reconditioned or a new generator circuit-breaker:

During repetition of the preferred procedure the required conditions a) and b) shall be fulfilled taking into account an enlarged tolerance of ± 2 ms to the required arcing times.



Contact separation is set to achieve the minimum arcing time after a minor loop with intermediate asymmetry level.

Figure 28 – Single-phase asymmetrical breaking operation – Minimum arcing time in a phase with intermediate level of asymmetry after a minor loop ($t_{arc\ asym\ min\ 2}$)



Contact separation is set to achieve the maximum arcing time for a last-pole-to-clear at maximum asymmetry criteria after a major loop.

Figure 29 – Single-phase asymmetrical breaking operation – Maximum arcing time for a last-pole-to-clear at maximum asymmetry criteria after a major extended loop ($t_{arc\ asym\ max\ 2}$)

Table 15 – Test parameters for 50 Hz asymmetrical system-source fault test-duties for the first-pole-to-clear

		Intermediate major loop				Subsequent major loop in first-pole-to-clear				Time interval	
t_1	I_{peak}	Loop duration	Degree of asymmetry at current zero	Corresponding di/dt at current zero	I_{peak}	Loop duration	Degree of asymmetry at current zero	Corresponding di/dt at current zero	Δt_1		
ms	p.u.	Δt ms	%	%	p.u.	ms	%	%	ms		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)		
32,8	1,39	12,6	37,4	93,6	1,80	15,9	75,3	67,6	4,8		
52,6	1,34	12,2	32,3	95,4	1,69	14,9	65,0	77,5	4,5		
72,5	1,29	11,9	27,8	96,7	1,59	14,0	56,1	84,1	4,3		
92,4	1,25	11,6	23,9	97,7	1,51	13,4	48,4	88,7	4,2		
112	1,22	11,4	20,6	98,4	1,44	12,9	41,7	91,9	4,0		
132	1,19	11,2	17,7	98,8	1,38	12,5	35,9	94,2	3,9		
152	1,16	11,0	15,3	99,2	1,32	12,1	31,0	95,8	3,8		
172	1,14	10,9	13,2	99,5	1,28	11,8	26,7	97,0	3,8		

Key

t_1 earliest possible interruption in a phase with intermediate level of asymmetry after a major loop (see 3.7.140)

I_{peak} p.u. value of the peak current related to the peak value of the symmetrical short-circuit current

Δt duration of the applicable loop

Δt_1 time interval from current zero in the phase with intermediate degree of asymmetry after a major loop to the subsequent current zero at arc extinction in the appropriate asymmetrical phase resulting in a first-pole-to-clear and major loop

NOTE The test-duties to demonstrate the system-source short-circuit making and breaking current capability are described in Table 20 and Table 21.

Table 16 – Test parameters for 60 Hz asymmetrical system-source fault test-duties for the first-pole-to-clear

		Intermediate major loop				Subsequent major loop in first-pole-to-clear				Time interval
t_1	I_{peak}	Loop duration	Degree of asymmetry at current zero	Corresponding di/dr at current zero	I_{peak}	Loop duration	Degree of asymmetry at current zero	Corresponding di/dr at current zero		
ms	p.u.	Δt ms	%	%	p.u.	Δt ms	%	%	Δt_1 ms	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
27,4	1,41	10,6	39,3	92,8	1,83	13,6	78,9	63,0	4,1	
43,9	1,36	10,3	34,7	94,5	1,73	12,7	69,8	73,0	3,9	
60,5	1,32	10,1	30,6	95,8	1,65	12,1	61,7	79,9	3,7	
77,1	1,28	9,84	27,0	96,8	1,57	11,6	54,5	84,9	3,6	
93,6	1,25	9,66	23,9	97,6	1,50	11,1	48,2	88,6	3,5	
110	1,22	9,50	21,1	98,2	1,44	10,8	42,6	91,3	3,4	
127	1,19	9,36	18,6	98,6	1,39	10,5	37,6	93,4	3,3	
143	1,17	9,24	16,4	99,0	1,35	10,2	33,2	95,0	3,3	

Key

t_1 earliest possible interruption in a phase with intermediate level of asymmetry after a major loop (see 3.7.140)

I_{peak} p.u. value of the peak current related to the peak value of the symmetrical short-circuit current

Δt duration of the applicable loop

Δt_1 time interval from current zero in the phase with intermediate degree of asymmetry after a major loop to the subsequent current zero at arc extinction in the appropriate asymmetrical phase resulting in a first-pole-to-clear and major loop

NOTE The test-duties to demonstrate the system-source short-circuit making and breaking current capability are described in Table 20 and Table 21.

Table 17 – Test parameters for 50 Hz asymmetrical system-source fault test-duties for the last-pole-to-clear

		Intermediate minor loop				Subsequent major extended loop in last-pole-to-clear				Time interval
t_2	I_{peak}	Loop duration	Degree of asymmetry at current zero	Corresponding di/dr at current zero	I_{peak}	Loop duration	Degree of asymmetry at current zero	Corresponding di/dr at current zero	Δt_2	
ms	p.u.	Δt ms	%	%	p.u.	ms	%	%	ms	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
26,9	0,56	7,12	42,5	89,5	1,80	17,2	56,8	66,8	12,0	
47,1	0,64	7,55	36,5	92,2	1,69	16,2	49,0	72,6	11,4	
67,2	0,68	7,90	31,4	94,2	1,59	15,4	42,2	76,6	11,0	
87,4	0,72	8,20	27,0	95,6	1,51	14,8	36,4	79,5	10,6	
108	0,76	8,46	23,2	96,7	1,44	14,4	31,4	81,5	10,3	
128	0,79	8,69	19,9	97,5	1,38	14,0	27,0	82,9	10,0	
148	0,82	8,87	17,2	98,1	1,32	13,6	23,3	84,0	9,8	
168	0,85	9,03	14,7	98,6	1,28	13,4	20,0	84,7	9,5	
188	0,87	9,16	12,7	98,9	1,24	13,1	17,3	85,3	9,3	

Key

t_2 earliest possible interruption in a phase with intermediate level of asymmetry after a minor loop (see 3.7.141)

I_{peak} p.u. value of the peak current related to the peak value of the symmetrical short-circuit current

Δt duration of the applicable loop

Δt_2 time interval from current zero in the phase with intermediate degree of asymmetry after a minor loop to the subsequent current zero at arc extinction in the appropriate asymmetrical phase resulting in a last-pole-to-clear and major extended loop

NOTE The test-duties to demonstrate the system-source short-circuit making and breaking current capability are described in Table 20 and Table 21.

Table 18 – Test parameters for 60 Hz asymmetrical system-source fault test-duties for the last-pole-to-clear

		Intermediate minor loop				Subsequent major extended loop in last-pole-to-clear				Time interval
t_2		I_{peak}	Loop duration	Degree of asymmetry at current zero	Corresponding di/dr at current zero	I_{peak}	Loop duration	Degree of asymmetry at current zero	Corresponding di/dr at current zero	Δt_2
ms		p.u.	Δt ms	%	%	p.u.	ms	%	%	ms
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
22,4	0,55	5,88	43,7	89,1	1,83	14,6	59,4	64,2	10,2	
39,2	0,61	6,18	38,5	91,5	1,73	13,8	52,5	69,9	9,7	
56,0	0,65	6,45	34,0	93,4	1,65	13,2	46,4	74,0	9,4	
72,8	0,69	6,68	29,9	94,8	1,57	12,7	41,0	77,1	9,1	
89,5	0,73	6,88	26,4	95,9	1,50	12,3	36,2	79,4	8,8	
106	0,76	7,05	23,3	96,8	1,44	12,0	32,0	81,1	8,5	
123	0,79	7,21	20,5	97,5	1,39	11,7	28,2	82,4	8,4	
140	0,81	7,34	18,1	98,0	1,35	11,5	24,9	83,4	8,2	
157	0,84	7,46	16,0	98,4	1,30	11,3	22,0	84,2	8,0	

Key

t_2 earliest possible interruption in a phase with intermediate level of asymmetry after a minor loop (see 3.7.141)

I_{peak} p.u. value of the peak current related to the peak value of the symmetrical short-circuit current

Δt duration of the applicable loop

Δt_2 time interval from current zero in the phase with intermediate degree of asymmetry after a minor loop to the subsequent current zero at arc extinction in the appropriate asymmetrical phase resulting in a last-pole-to-clear and major extended loop

NOTE The test-duties to demonstrate the system-source short-circuit making and breaking current capability are described in Table 20 and Table 21.

7.102.11 Methods of determining prospective transient recovery voltage waves

Assessing the prospective transient recovery voltage characteristics of the circuit shall be done as described in Annex D of IEC 62271-100:2021.

7.103 System-source short-circuit making and breaking tests

7.103.1 Power factor of test circuit

There is no requirement for the power factor of test circuit.

7.103.2 Frequency of test circuit

System-source short-circuit breaking tests shall be performed at rated frequency.

System-source short-circuit making tests performed at 60 Hz are valid for 50 Hz and vice versa.

7.103.3 Earthing of test circuit

The connections to earth of the test circuit for system-source short-circuit making and breaking tests shall be in accordance with the following requirements and shall, in all cases, be indicated in the diagram of the test circuit included in the test report.

a) Three-phase tests:

The generator circuit-breaker (with its structure earthed as in service) shall be connected in a test circuit having the neutral point of the supply isolated and the short-circuit point earthed as shown in Figure 30 a), or vice versa as shown in Figure 30 b), if the test can only be made in the latter way.

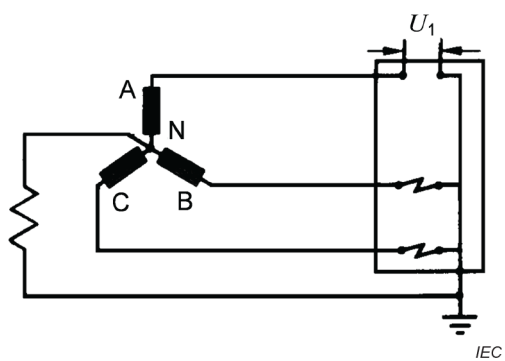
In accordance with Figure 30 a), the neutral of the supply source may be earthed through a resistor, the resistance of which is as high as possible and, expressed in ohms, in no case less than $U/10$, where U is the numerical value in volts of the voltage between lines of the test circuit.

When a test circuit according to Figure 30 b) is used, it is recognised that in case of an earth fault at one terminal of the test generator circuit-breaker, the resulting earth current could be dangerous. It is consequently permitted to connect the supply neutral to earth through appropriate impedance.

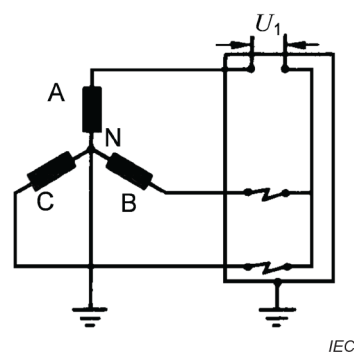
b) Single-phase tests:

The test circuit and the generator circuit-breaker structure shall be connected as in Figure 31 a), so that the voltage conditions between live parts and the structure after arc extinction are the same as those which would exist in the first-pole-to-clear of a three-pole generator circuit-breaker if tested in the test circuit shown in Figure 30 a).

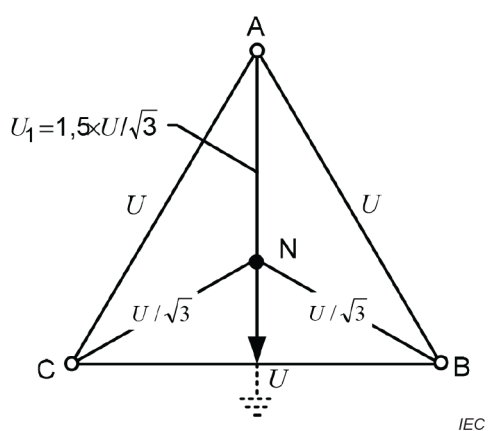
The preferred test circuit is shown in Figure 31 a). Where there are limitations on test laboratory equipment, the circuit shown in Figure 31 b) may be used if the insulation between phases and/or to earth is not critical.



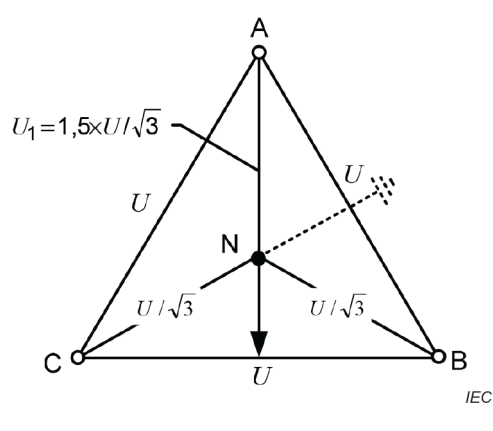
a) Preferred circuit



b) Alternative circuit

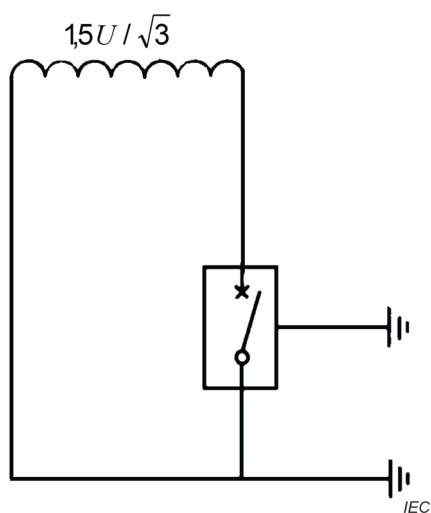


c) Voltage diagram for preferred circuit

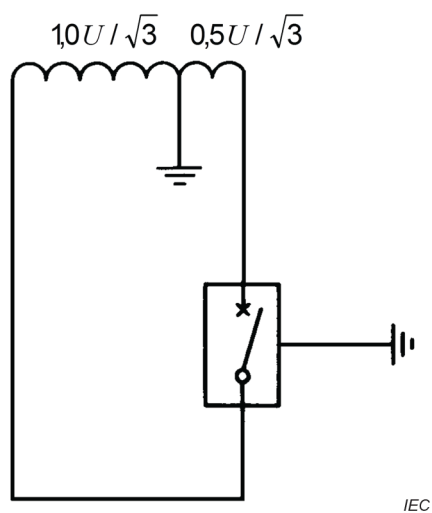


d) Voltage diagram for alternative circuit

Figure 30 – Earthing of test circuits for three-phase short-circuit tests, first-pole-to-clear factor 1,5



a) Preferred circuit



b) Alternative circuit not applicable for generator circuit-breakers where the insulation between phases and/or to earth is critical

Figure 31 – Earthing of test circuits for single-phase short-circuit tests, first-pole-to-clear factor 1,5

7.103.4 Connection of test circuit to generator circuit-breaker

For testing, the generator circuit-breaker shall be connected to that side which gives the more severe conditions with respect to voltage to earth, as identified and declared by the manufacturer, unless the generator circuit-breaker is especially designed for feeding from one side only.

When the manufacturer does not declare the more severe conditions with respect to voltage to earth, either of the following applies:

- a) if no generator-source short-circuit current rating is assigned, test-duties 1 and 2 shall be made with opposite connections;
- b) if a generator-source short-circuit current rating is assigned, test-duties 1 and 2 can be made with the connections at the same side. In such a case, the test-duties 3, 4, 5, 6A and 6B shall be made with the opposite connection compared to the connection used during test-duties 1 and 2.

7.103.5 Applied voltage for system-source short-circuit making tests

The applied voltage, listed in Table 20 and Table 21, shall be as follows:

- a) For three-phase tests on a three-pole generator circuit-breaker, the average value of the applied phase-to-phase voltages shall not be less than the rated voltage U_r and shall not exceed this value by more than 10 % without the consent of the manufacturer. The differences between the average value and the applied voltages of each pole shall not exceed 5 %.
- b) For single-phase tests on a three-pole generator circuit-breaker, the applied voltage shall be not less than the phase-to-earth value $U_r/\sqrt{3}$ and shall not exceed this value by more than 10 % without the consent of the manufacturer.

NOTE With the manufacturer's consent, for convenience of testing, a voltage equal to the product of the phase-to-earth voltage and the first-pole-to-clear factor (1,5) of the generator circuit-breaker can be applied.

Owing to limitations of testing facilities, it is not always possible to perform the short circuit making tests at rated voltage and rated short-circuit current. Making operations at reduced voltage with a minimum of not less than 50 % of the rated voltage are permissible if the pre-arcing time during making at rated voltage in any phase is not more than 1/10 cycle of the power frequency with a tolerance of 20 %.

The pre-arcing time at rated voltage shall be determined by performing two making tests, one at each polarity, at reduced current. The reduced current shall be low enough to avoid contact erosion.

7.103.6 System-source short-circuit making and breaking current

Making and breaking tests are required with both symmetrical and asymmetrical currents.

The test quantities are listed in Table 20 and Table 21 with the following additions.

The short-circuit current to be interrupted by a generator circuit-breaker shall be determined at the instant of contact separation and shall be stated in terms of the following two values:

- the RMS value of the AC component averaged over all phases;
- the degree of asymmetry in each phase.

a) Symmetrical breaking current

Any breaking test in which the degree of asymmetry of the current in all phases at contact separation is less than or equal to 20 % is considered a symmetrical test.

b) Asymmetrical breaking current

The test parameters (last current loop parameters as detailed in 7.102.10) used for test-duty 2 are based on the maximum possible degree of asymmetry, which is determined by the following equation:

$$Asy_{cs} = 100\% \times e^{\frac{-(t_{opmin} + t_r)}{\tau}}$$

where

Asy_{cs} is the maximum possible degree of asymmetry at the earliest possible contact separation (this value is given for informative purposes only);

t_{opmin} is the minimum opening time declared by the manufacturer;

t_r is the relay time (0,5 cycle; 10 ms for 50 Hz and 8,3 ms for 60 Hz);

τ is the standard DC time constant (133 ms, see Figure 11).

7.103.7 Transient recovery voltage (TRV) for system-source short-circuit breaking tests

The prospective circuit TRV (unmodified by the generator circuit-breaker) shall meet the values as listed in Table 3.

For direct testing asymmetrical current-interrupting capabilities shall be demonstrated using test circuits capable of producing the rated TRV envelopes unmodified by the generator circuit-breaker when a symmetrical current is interrupted.

For synthetic testing refer to IEC 62271-101.

7.103.8 Measurement of transient recovery voltage during test

The actual TRV measured during the test may differ from the prospective TRV of the test circuit measured before the test without the generator circuit-breaker present. This is because the generator circuit-breaker itself can influence the TRV due to its resistors and/or capacitors, or other reasons.

The transient recovery voltage during the test shall be recorded.

7.103.9 Power-frequency recovery voltage

The test quantities listed in Table 20 and Table 21 are the phase-to-earth values.

The power-frequency recovery voltage of the test circuit shall not be less than 95 % of the specified value and shall be maintained for at least 0,3 s.

For synthetic test circuits, guidance about details and tolerances is given in IEC 62271-101.

During the single-phase tests, the specified value of $1,5U_r/\sqrt{3}$ shall be maintained for one cycle of the power frequency and thereafter may be reduced to $U_r/\sqrt{3}$.

7.103.10 System-source short-circuit test operating sequence

The time intervals between individual operations of a test sequence shall be the time intervals of the rated operating sequence of the generator circuit-breaker, given in 5.106.

With the consent of the manufacturer, it is permissible to reduce the time interval to a shorter time than 30 min.

Owing to limitations of the testing facilities, it may not be possible to achieve the time interval of the rated operating sequence. In such cases the time interval may be extended and the reason for such a delay shall be recorded in the test report. Prolonged time intervals shall not be due to faulty operation of the generator circuit-breaker.

7.103.11 System-source short-circuit test-duties

The basic short-circuit test series shall consist of test-duties 1 and 2 as specified in Table 20 and Table 21.

7.103.12 Demonstration of the most severe commutation conditions

This subclause is only applicable for generator circuit-breakers with a separate main and arcing contact system.

During breaking operations of generator circuit-breakers with a separate main and arcing contact system, the current shall be fully commutated from the main to the arcing contact system before separating the arcing contact system. The commutation time typically depends on the current parameters at the instant of main-contact separation and the time difference between the main-contact separation and the arcing-contact separation.

During the verification of the short-circuit breaking capability at least one test shall show that the generator circuit-breaker can successfully commutate asymmetrical currents from the main-contact system to the arcing-contact system. This test shall fulfil the following conditions:

- The current value at the instant of main-contact separation shall be at least 90 % of the current value of the first possible peak of a major loop after the earliest possible main-contact separation during breaking of a current with maximum degree of asymmetry. Current peak values for different main-contact separation times are given in Table 19.
- The test may be part of one of the two breaking operations of test-duty 2.
- If the successful commutation is not proved during test-duty 2, then the verification of successful commutation shall be performed as a separate test on the same or a second test object of the same type. The test shall be a successful breaking operation with correct TRV parameters to show the verification of a successful commutation.

The verification of a successful commutation at 50 Hz is also valid for 60 Hz applications and vice versa, as long as the current value at the instant of the main-contact separation is covered within the given tolerance.

The instant of main-contact separation can be determined by various methods, for instance, by recording the arc voltage or by a no-load test on the generator circuit-breaker combined with a resistance measurement across the generator circuit-breaker.

Table 19 – Test parameters for commutation tests at 50 Hz and 60 Hz

50 Hz		60 Hz	
<i>t</i> ms	<i>I</i> _{peak} p.u.	<i>t</i> ms	<i>I</i> _{peak} p.u.
10,1 to 30,0	1,80	8,4 to 25,0	1,83
30,1 to 50,0	1,69	25,1 to 41,6	1,73
50,1 to 70,0	1,59	41,7 to 58,3	1,65
70,1 to 90,0	1,51	58,4 to 75,0	1,57
90,1 to 110,0	1,44	75,1 to 91,6	1,50
110,1 to 130,0	1,38	91,7 to 108,3	1,44
130,1 to 150,0	1,32	108,4 to 125,0	1,39
150,1 to 170,0	1,28	125,1 to 141,6	1,35

Key

t earliest possible main-contact separation (including 0,5 cycle relay time)

*I*_{peak} p.u. value of the peak current of the first major loop after the earliest possible main-contact separation related to the peak value of the symmetrical short-circuit current

Table 20 – Test-duties to demonstrate the system-source short-circuit making and breaking current capability for three-phase tests

Test-duty ^{a,b,c}	Operating sequence	Applied voltage	Making current	System-source short-circuit breaking current at contact separation		Power-frequency recovery voltage ⁱ
				Magnitude	Degree of asymmetry	
1 ^{d,e,f,g}	C – 0,25 s – O _{sym} 30 min CO _{sym}	$U_r/\sqrt{3}$	1 st C: $2,74I_{sc}$ 2 nd C: -	I_{sc}	≤ 20 %	$U_r/\sqrt{3}$
1-A ^g	C + 0,25 s	$U_r/\sqrt{3}$	$2,74I_{sc}$	-	-	-
1-B ^f	C _{no-load} O _{sym} 30 min CO _{sym}	$U_r/\sqrt{3}$	-	I_{sc}	≤ 20 %	$U_r/\sqrt{3}$
2 ^h	C _{no-load} O _{asym} 30 min C _{no-load} O _{asym}	-	-	I_{sc}	Asy_{cs}^j	$U_r/\sqrt{3}$

Key

U_r rated voltage of the generator circuit-breaker

I_{sc} RMS value of the AC component of the rated system-source short-circuit current of the generator circuit-breaker

Asy_{cs} maximum possible degree of asymmetry of the short-circuit current at the earliest possible contact separation, see Figure 11.

^a The test-duty sequence is only a suggested sequence. The test-duties can be performed in any sequence desired.

^b No refitting or replacement of parts to the generator circuit-breaker is permitted during each test-duty.

^c If the generator circuit-breaker has an auxiliary resistor chamber and an auxiliary switch, tests should be performed with the auxiliary resistor and switch in the circuit, or, for convenience of testing, the tests may be performed on both interrupters separately by using equivalent TRVs.

^d The operating sequence can also be reversed to CO_{sym} – 30 min – C – 0,25 s – O_{sym}.

^e Test-duty 1 can be replaced by test-duties 1-A and 1-B.

^f The making operation shall occur within ±20° of the peak value of the applied voltage in one of the three phases.

^g Higher values can be tested if agreed by the manufacturer.

^h To facilitate consistent control of the opening operation, the releases may be supplied at the maximum operating voltage.

ⁱ This value applies after current interruption in the last pole.

^j The degree of asymmetry at contact separation is for reference only. The parameters to be met are I_{peak} , Δt and di/dt . The required values for these parameters are given in Table 15, Table 16, Table 17 and Table 18.

Table 21 – Test-duties to demonstrate the system-source short-circuit making and breaking current capability for single-phase tests

Test-duty ^{a,b,c}	Operating sequence	Applied voltage	Making current	System-source short-circuit breaking current at contact separation		Power-frequency recovery voltage ⁱ
				Magnitude	Degree of Asymmetry	
1 ^{d,e,f,g}	C _{asym} – 0,25 s – O _{sym} 30 min C _{sym} O _{sym}	$U_r/\sqrt{3}$	1 st C: $2,74I_{sc}$ 2 nd C: -	I_{sc}	≤ 10 %	$(1,5)U_r/\sqrt{3}$
1-A ^g	C _{asym} + 0,25 s	$U_r/\sqrt{3}$	$2,74I_{sc}$	–	–	–
1-B ^f	C _{no-load} O _{sym} 30 min C _{sym} O _{sym}	$U_r/\sqrt{3}$	–	I_{sc}	≤ 10 %	$(1,5)U_r/\sqrt{3}$
2 ^h	C _{no-load} O _{asym} 30 min C _{no-load} O _{asym}	–	–	I_{sc}	Asy _{cs} ^j	$(1,5)U_r/\sqrt{3}$

Key

U_r rated voltage of the generator circuit-breaker

I_{sc} RMS value of the AC component of the rated system-source short-circuit current of the generator circuit-breaker

Asy_{cs} maximum possible degree of asymmetry of the short-circuit current at the earliest possible contact separation, see Figure 11.

^a The test-duty sequence is only a suggested sequence. The test-duties can be performed in any sequence desired.

^b No refitting or replacement of parts to the generator circuit-breaker is permitted during each test-duty.

^c If the generator circuit-breaker has an auxiliary resistor chamber and an auxiliary switch, tests should be performed with the auxiliary resistor and switch in the circuit, or, for convenience of testing, the tests may be performed on both interrupters separately by using equivalent TRVs.

^d The operating sequence can also be reversed to C_{sym}O_{sym} – 30 min – C_{asym} – 0,25 s – O_{sym}.

^e Test-duty 1 can be replaced by test-duties 1-A and 1-B.

^f The making operation shall occur within ±20° of the peak value of the applied voltage.

^g Higher values can be tested if agreed by the manufacturer.

^h To facilitate consistent control of the opening operation, the releases may be supplied at the maximum operating voltage.

ⁱ For first-pole-to-clear conditions the recovery voltage is $1,5U_r/\sqrt{3}$. For last-pole-to-clear conditions the recovery voltage is $U_r/\sqrt{3}$.

^j The degree of asymmetry at contact separation is for reference only. The parameters to be met are I_{peak} , Δt and di/dt . The required values for these parameters are given in Table 15, Table 16, Table 17 and Table 18.

7.104 Load current breaking tests

7.104.1 General

Tests are made to determine the ability of the generator circuit-breaker to switch load currents up to the rated continuous current of the generator, such as load currents that may be encountered in normal service.

When disconnecting the generator from the system, both generator circuit-breaker terminals remain energised. The power-frequency recovery voltage appearing across the generator circuit-breaker is equal to the sum of voltage drops on the reactances of the generator and transformer and the corresponding short-circuit reactance of the high-voltage system. Since the voltage drops are caused by the load current, the recovery voltage will always have a phase displacement of 90° to the load current and will be independent of the load phase angle of the generator. When breaking the rated load current, the voltage drops of a generator-transformer bank generally do not reach 50 % of rated voltage. Therefore, the load breaking capability of a generator circuit-breaker could be tested using an inductive short-circuit test circuit as recommended. The test results are valid for any lagging or leading power factors.

7.104.2 Conditions of test severity

Load current breaking tests shall be made under the following conditions:

- a) The test current shall be the rated continuous current I_r .
- b) The test circuit shall be similar to the usual short-circuit test arrangement.
- c) Power-frequency and transient recovery test voltages shall be based on the rated voltage, U_r .
 - If three-phase tests are made, they shall be made with phase-to-phase voltage equal to $0,5U_r$.
 - If single-phase tests are made, the test voltage shall be equal to $0,5 \times 1,5 \times U_r / \sqrt{3} = 0,44U_r$.
- d) The TRV rate of the first-pole-to-clear in three-phase tests and for the case of single-phase test circuits shall be as specified in Table 5.
- e) The normally earthed parts of the generator circuit-breaker shall be earthed.
- f) Either three-phase or single-phase tests can be made.

If three-phase tests are made, either the neutral of the supply or the short-circuit point shall be earthed, but not both. If single-phase tests are made, the test circuit shall be earthed.
- g) The degree of asymmetry at contact separation shall be $\leq 20\%$.
- h) Tests made at 60 Hz are also valid for 50 Hz and vice versa.
- i) Tests shall be made at the minimum interrupting and operating medium pressure and minimum control voltage specified by the manufacturer.

7.104.3 Number of tests

If three-phase tests are made, the test-duty shall comprise three breaking tests with random uncontrolled times. For single-phase tests, the test-duty shall comprise six breaking tests where the tripping times are controlled and distributed in steps of approximately 30° with respect to the current wave.

The time interval between two tests shall take into account thermal limitations of parts such as resistors.

7.105 Generator-source short-circuit current making and breaking tests

7.105.1 Power factor of test circuit

There is no requirement for the power factor of test circuit.

7.105.2 Frequency of test circuit

Generator-source short-circuit breaking tests shall be performed at rated frequency. However for test-duties 5, 6A and 6B, tests made at 50 Hz are also valid for 60 Hz but not vice versa.

Generator-source short-circuit making tests performed at 60 Hz are valid for 50 Hz and vice versa.

7.105.3 Earthing of test circuit

The connections to earth of the test circuit for generator-source short-circuit making and breaking tests shall be in accordance with the following requirements and shall, in all cases, be indicated in the diagram of the test circuit included in the test report.

a) Three-phase tests:

The generator circuit-breaker (with its structure earthed as in service) shall be connected in a test circuit having the neutral point of the supply isolated and the short-circuit point earthed as shown in Figure 30 a), or vice versa as shown in Figure 30 b), if the test can only be made in the latter way.

In accordance with Figure 30 a), the neutral of the supply source may be earthed through a resistor, the resistance of which is as high as possible and, expressed in ohms, in no case less than $U/10$, where U is the numerical value in volts of the voltage between lines of the test circuit.

When a test circuit according to Figure 30 b) is used, it is recognised that in case of an earth fault at one terminal of the test generator circuit-breaker, the resulting earth current could be dangerous. It is consequently permitted to connect the supply neutral to earth through appropriate impedance.

b) Single-phase tests:

The test circuit and the generator circuit-breaker structure shall be connected as in Figure 31 a), so that the voltage conditions between live parts and the structure after arc extinction are the same as those which would exist in the first-pole-to-clear of a three-pole generator circuit-breaker if tested in the test circuit shown in Figure 30 a).

The preferred test circuit is shown in Figure 31 a). Where there are limitations on test laboratory equipment, the circuit shown in Figure 31 b) may be used if the insulation between phases and/or to earth is not critical.

7.105.4 Connection of the test circuit to the generator circuit-breaker

For testing, the generator circuit-breaker shall be connected to that side which gives the more severe conditions with respect to voltage to earth, as identified and declared by the manufacturer, unless the generator circuit-breaker is especially designed for feeding from one side only.

When the manufacturer does not declare the more severe conditions with respect to voltage to earth, either of the following shall be made:

- a) in case test-duties 1 and 2 according to 7.103 have been made with opposite connections, any side can be connected to perform the test-duties 3, 4, 5, 6A and 6B according to 7.105;
- b) in case test-duties 1 and 2 according to 7.103 have been made with the same connection, the test-duties 3, 4, 5, 6A and 6B according to 7.105 shall be made with the opposite connection compared to the connection made during test-duties 1 and 2 according to 7.103.

7.105.5 Applied voltage for generator-source short-circuit making tests

The applied voltage listed in Table 22 and Table 23 shall be as follows:

- a) For three-phase tests on a three-pole generator circuit-breaker, the average value of the applied phase-to-phase voltages shall not be less than the rated voltage U_r and shall not exceed this value by more than 10 % without the consent of the manufacturer. The differences between the average value and the applied voltages of each pole shall not exceed 5 %.

- b) For single-phase tests on a three-pole generator circuit-breaker, the applied voltage shall be not less than the phase-to-earth value $U_p/\sqrt{3}$ and shall not exceed this value by more than 10 % without the consent of the manufacturer.

NOTE With the manufacturer's consent, for convenience of testing, a voltage equal to the product of the phase-to-earth voltage and the first-pole-to-clear factor (1,5) of the generator circuit-breaker can be applied.

Owing to limitations of testing facilities, it is not always possible to perform the short circuit making tests at rated voltage and rated short-circuit current. Making operations at reduced voltage with a minimum of not less than 50 % of the rated voltage are permissible if the pre-arcing time during making at rated voltage in any phase is not more than 1/10 cycle of the power frequency with a tolerance of 20 %.

The pre-arcing time at rated voltage shall be determined by performing two making tests, one at each polarity, at reduced current. The reduced current shall be low enough to avoid contact erosion.

7.105.6 Generator-source short-circuit making current

The test quantities are listed in Table 22 and Table 23.

It is recognised that the peak value of the generator-source short-circuit making current is usually considerably lower than the peak value of the system-source short-circuit making current.

If the peak value of the generator-source short-circuit making current is higher than the peak value of the system-source short-circuit making current then test-duty 3 is required.

7.105.7 Generator-source short-circuit breaking current

7.105.7.1 General

The test quantities are listed in Table 22 and Table 23.

The generator-source short-circuit current to be interrupted by a generator circuit-breaker shall be determined at the instant of contact separation and shall be stated in terms of the following two values:

- the RMS value of the AC component averaged over all phases;
- the percentage value of the maximum degree of asymmetry in any phase.

7.105.7.2 AC component of generator-source short-circuit breaking current

The RMS value of the AC component in any phase shall not vary from the average by more than 10 %.

7.105.7.3 Degree of asymmetry of generator-source short-circuit breaking current

Breaking tests are required with both symmetrical and asymmetrical currents. Any breaking test in which the degree of asymmetry of the current in all phases at contact separation is less than or equal to 20 % is considered a symmetrical test. The arc voltage shall be recorded during the asymmetrical tests.

NOTE It is generally accepted that the generator circuit-breaker will experience, during its life, short-circuit currents from the generator-source with delayed current zeros. The capability of the generator circuit-breaker to interrupt the current with delayed zero crossings is verified by computations that consider the effect of the arc voltage on the prospective short-circuit current. The arc voltage model is derived from these tests with comparable magnitudes of current (see 9.103.6.3.6.3).

7.105.8 Transient recovery voltage (TRV) for generator-source short-circuit breaking tests

7.105.8.1 General

The prospective circuit TRV (unmodified by the generator circuit-breaker) shall meet the values as listed in Table 4.

7.105.8.2 Measurement of transient recovery voltage during test

The actual TRV measured during the test may differ from the prospective TRV of the test circuit measured before the test without the generator circuit-breaker present. This is because the generator circuit-breaker itself can influence the TRV due to its resistors and/or capacitors, or other reasons.

The transient recovery voltage during the test shall be recorded.

7.105.9 Power-frequency recovery voltage

The test quantities are listed in Table 22 and Table 23.

The power-frequency recovery voltage of the test circuit shall not be less than 95 % of the specified value and shall be maintained for at least 0,3 s.

For synthetic test circuits, guidance about details and tolerances is given in IEC 62271-101.

During the single-phase tests, the specified values shall be maintained for one cycle of the power frequency and thereafter may be reduced to the equivalent single-phase-to-earth voltage.

7.105.10 Generator-source short-circuit test operating sequence

The time intervals between individual operations of a test sequence shall be the time intervals of the rated operating sequence of the generator circuit-breaker, given in 5.106.

Owing to limitations of the testing facilities, it may not be possible to achieve the 30 min time interval of the rated operating sequence. In such cases the time interval may be extended and the reason for such a delay shall be recorded in the test report. Prolonged time intervals shall not be due to faulty operation of the generator circuit-breaker.

7.105.11 Generator-source short-circuit making and breaking test-duties

7.105.11.1 General

The test series shall include test-duties as specified in Table 22 and Table 23.

7.105.11.2 Making test-duty

The making test shall be performed according to test-duty 3. Tests made at 60 Hz are also valid for 50 Hz and vice versa.

7.105.11.3 Symmetrical current breaking test-duty

The symmetrical current breaking tests shall be performed according to test-duty 4. For testing purposes 7.102.10 is applicable.

If during system-source fault test-duty 1, the time delay t_d of the prospective TRV is equal to or less than $0,5 \mu\text{s}$, then test-duty 4 is covered by test-duty 1 provided that the AC component of the rated generator-source short-circuit breaking current does not exceed the AC component of the rated system-source short-circuit breaking current.

7.105.11.4 Asymmetrical current breaking test-duties

The asymmetrical current breaking tests shall be performed according to test-duties 5 and 6A for class G1 generator circuit-breakers or according to test-duty 6B for G2 class generator circuit-breakers.

For test-duty 5 the test procedure shall include a prospective test current waveform where the RMS value of the AC component of this current is I_{scg} and current peaks and relative minimums until the first current zero crossing shall be recorded. The prospective test current waveform shall have a minimum of three full cycles before the first current zero occurs in order to show two relative minimums without zero crossing (see Figure 32).

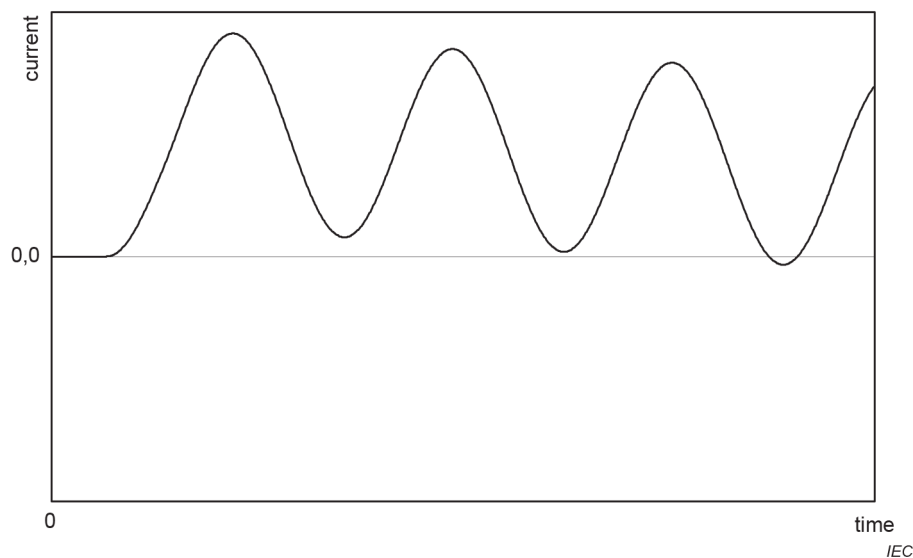


Figure 32 – Example of a valid prospective test current for test-duty 5

The contact separation shall occur not later than 1,5 cycles before the first current zero of the prospective current. This setting shall result in the required degree of asymmetry at contact separation and in an arcing time of at least one full cycle. Figure 33 shows an example of a valid test and Figure 35 shows an example of an invalid test.

Some generator circuit-breakers will not clear at the end of a major loop. Arcing then continues during a subsequent minor loop. If the current is interrupted at the end of this subsequent minor loop and the arcing time is at least 1,25 cycles, then this test is still considered valid. Figure 34 shows an example of a valid test in this case whereas Figure 36 shows an example of an invalid test.

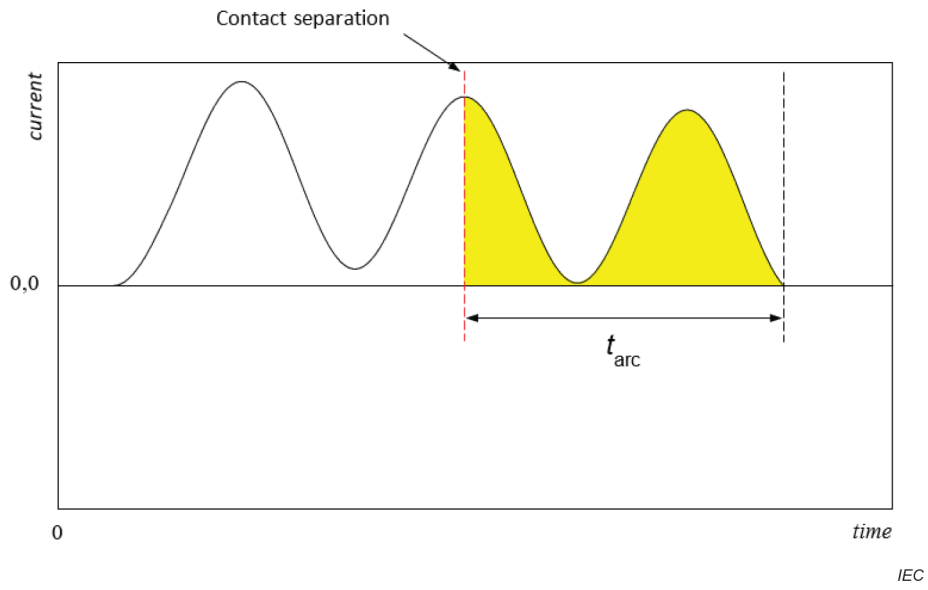


Figure 33 – Example of a valid test for test-duty 5

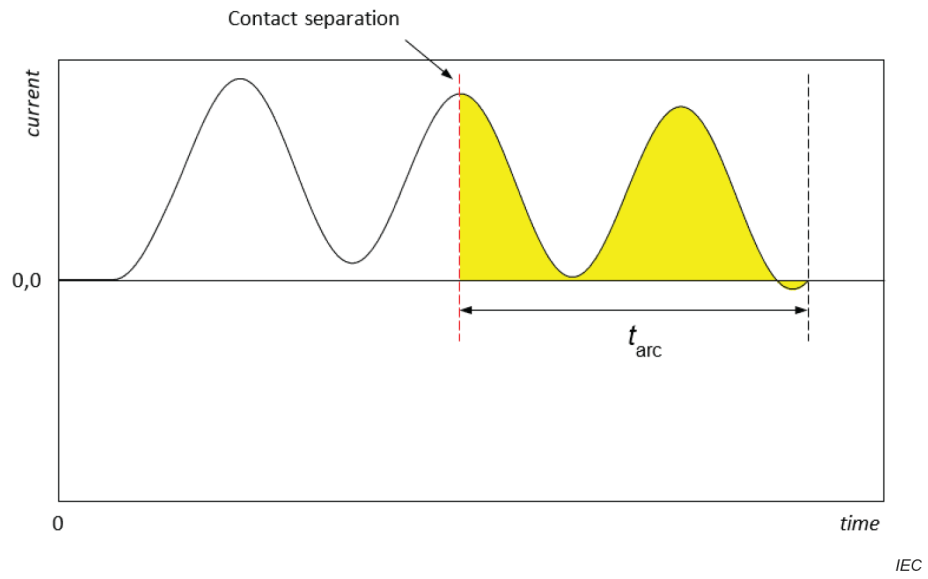


Figure 34 – Example of a valid test with a subsequent minor loop for test-duty 5

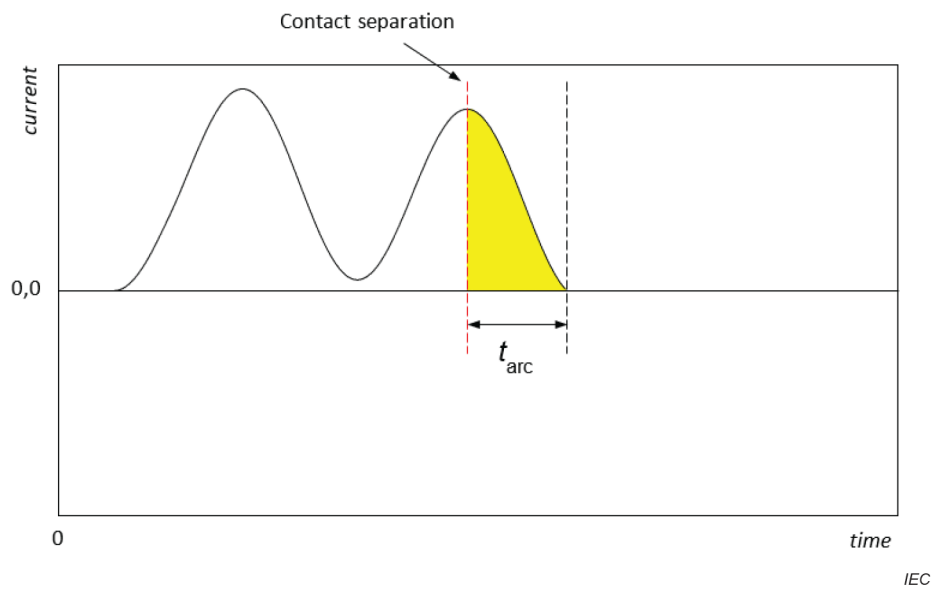


Figure 35 – Example of an invalid test for test-duty 5

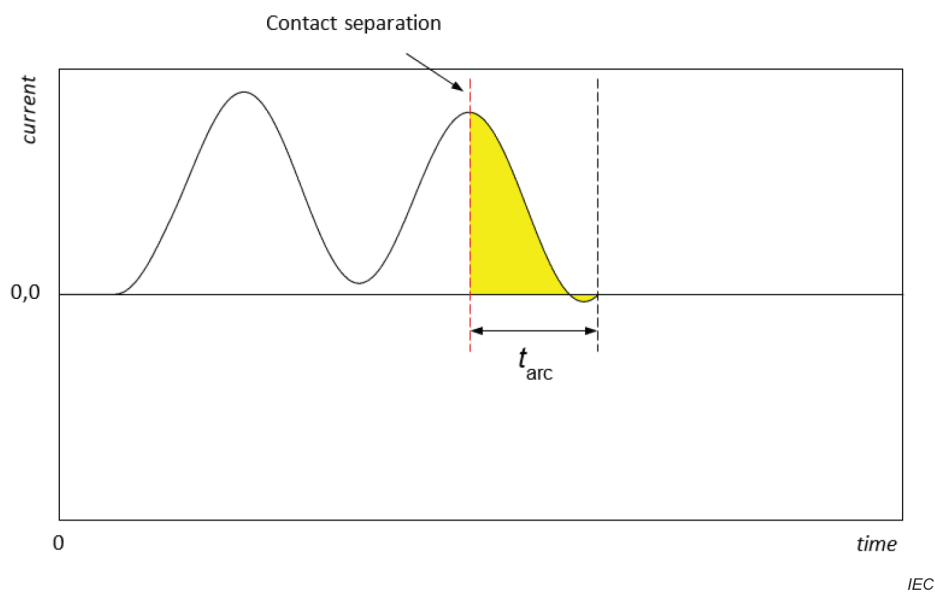


Figure 36 – Example of an invalid test with a subsequent minor loop for test-duty 5

In the case of an invalid test as per Figure 35 or Figure 36, contact separation shall be advanced by 180 electrical degrees. The resulting arcing time shall be at least one full cycle. Figure 37 and Figure 38 show an example of a valid test in this case.

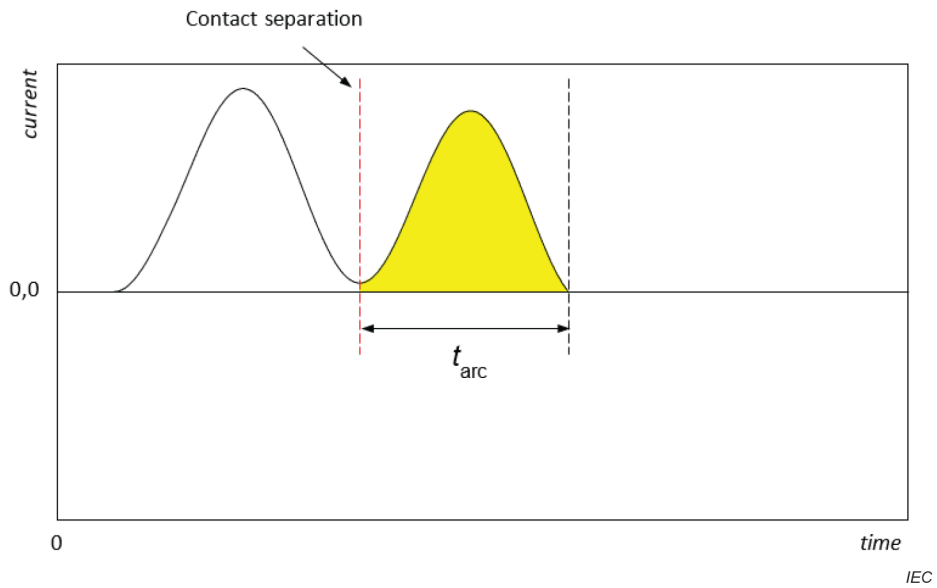


Figure 37 – Second example of a valid test for test-duty 5

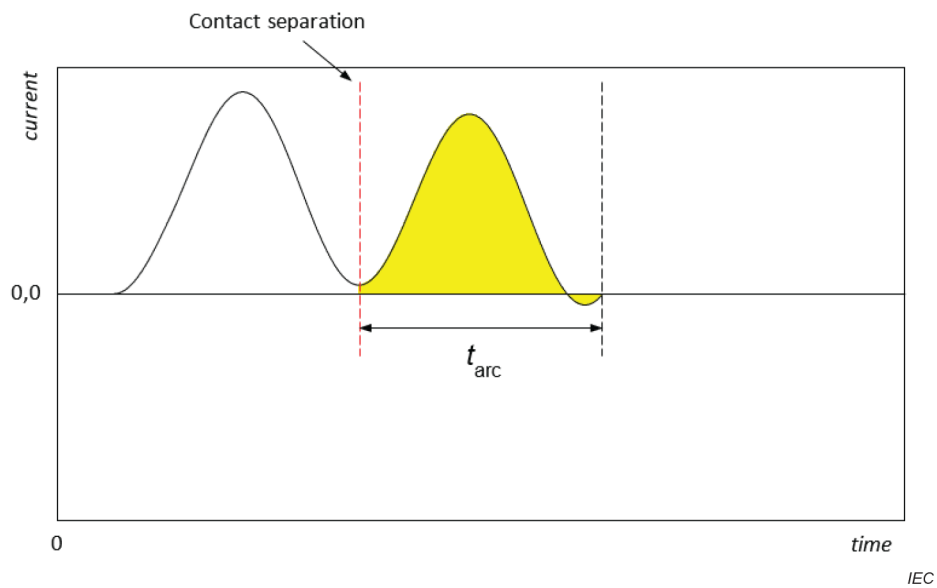


Figure 38 – Second example of a valid test with a subsequent minor loop for test-duty 5

For test-duties 6A and 6B the test procedure shall include a prospective test current waveform where the RMS value of the AC component of this current is $0,74 I_{scg}$ for test-duty 6A and I_{scg} for test-duty 6B respectively and current peaks and relative minimums until the first current zero crossing shall be recorded. The prospective test current waveform shall have three full cycles before the first current zero occurs in order to show two relative minimums without zero crossing (see Figure 39).

NOTE With the manufacturer's consent the number of full cycles before the first current zero occurs can be increased.

For the test the contact separation shall be set 2 ms before the first current peak of the prospective current. This setting shall result in the required degree of asymmetry at contact separation and in an arcing time of at least 1,5 cycles. Figure 40 a), Figure 40 b), Figure 41 and Figure 42 show examples of valid tests.

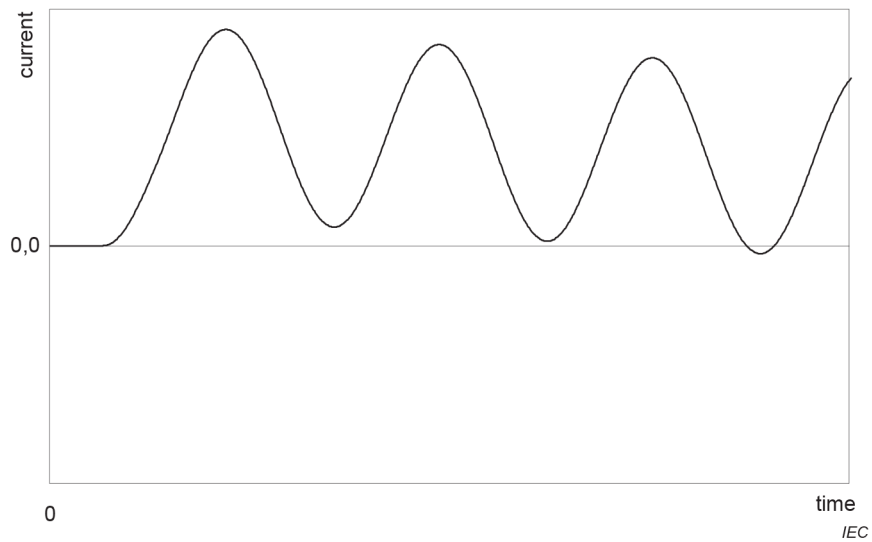
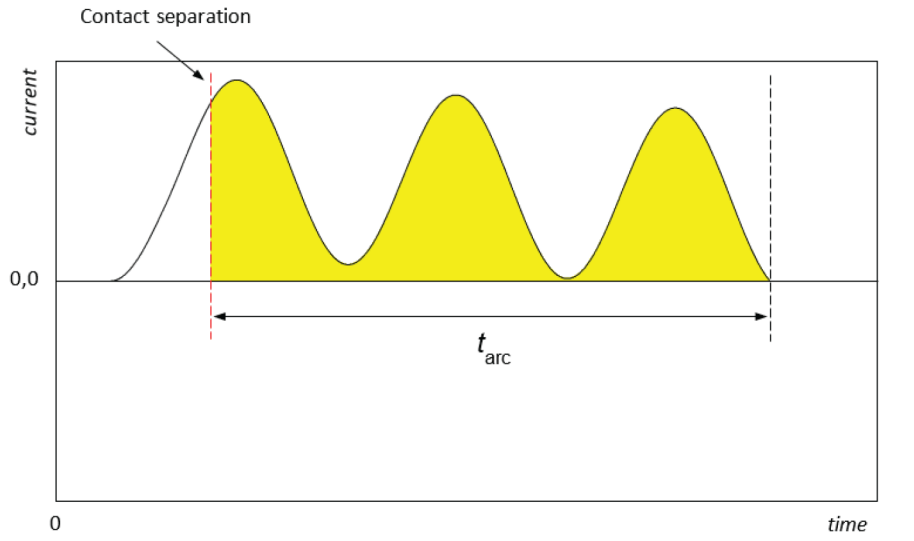
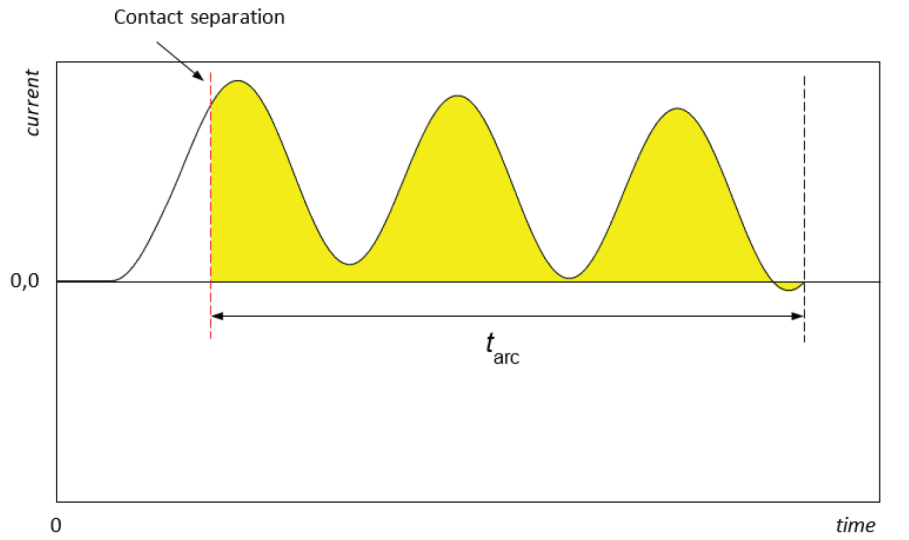


Figure 39 – Example of a valid prospective test current for test-duties 6A and 6B



IEC

a) valid test for test-duties 6A and 6B



IEC

b) valid test with a subsequent minor loop for test-duties 6A and 6B

Figure 40 – Example of a valid test for test-duties 6A and 6B

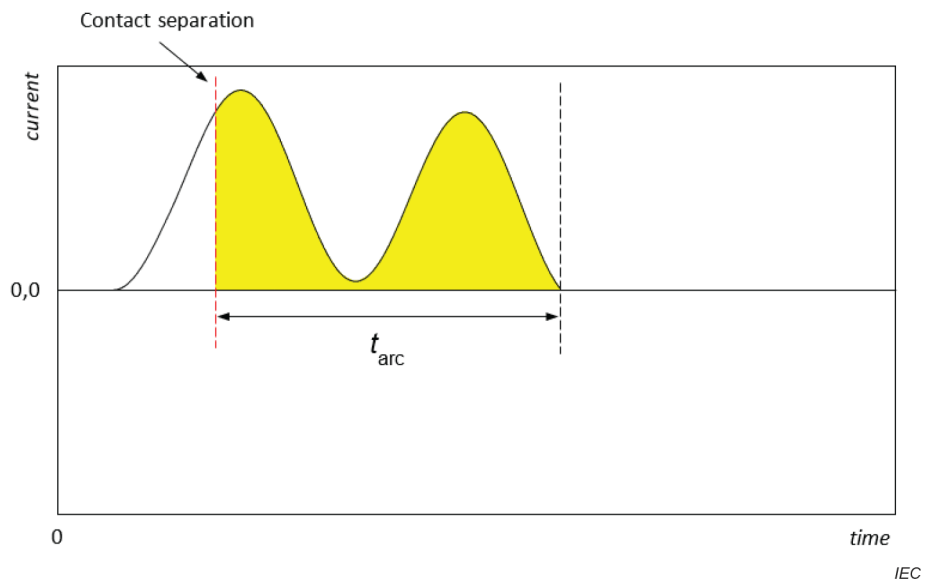


Figure 41 – Example of a valid test for test-duties 6A and 6B

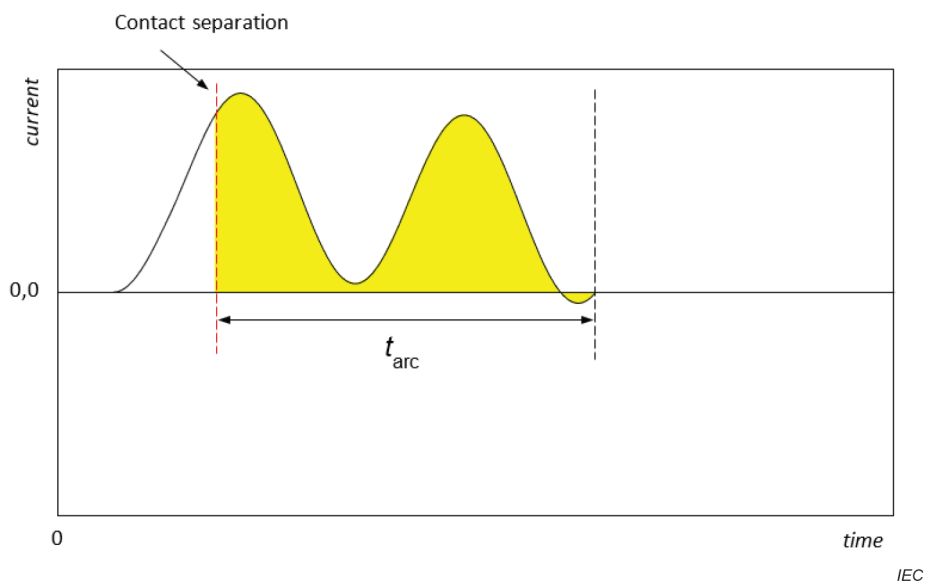


Figure 42 – Example of a valid test with a subsequent minor loop for test-duties 6A and 6B

In the case of an invalid test according to Figure 43 or Figure 44, contact separation shall be delayed by 54 electrical degrees. The resulting arcing time shall be 1,5 cycles. Figure 45 a) and Figure 45 b) show an example of a valid test in this case.

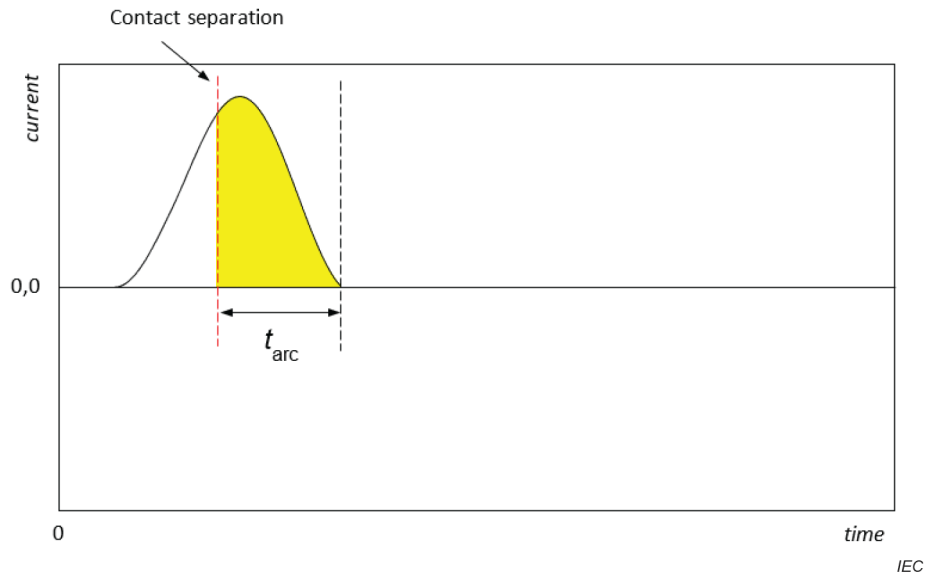


Figure 43 – Example of an invalid test for test-duties 6A and 6B

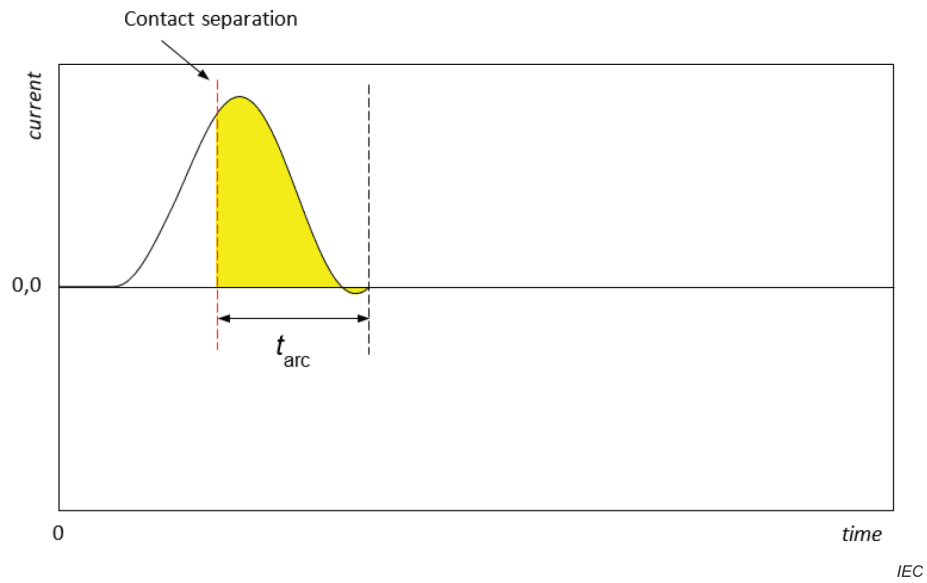
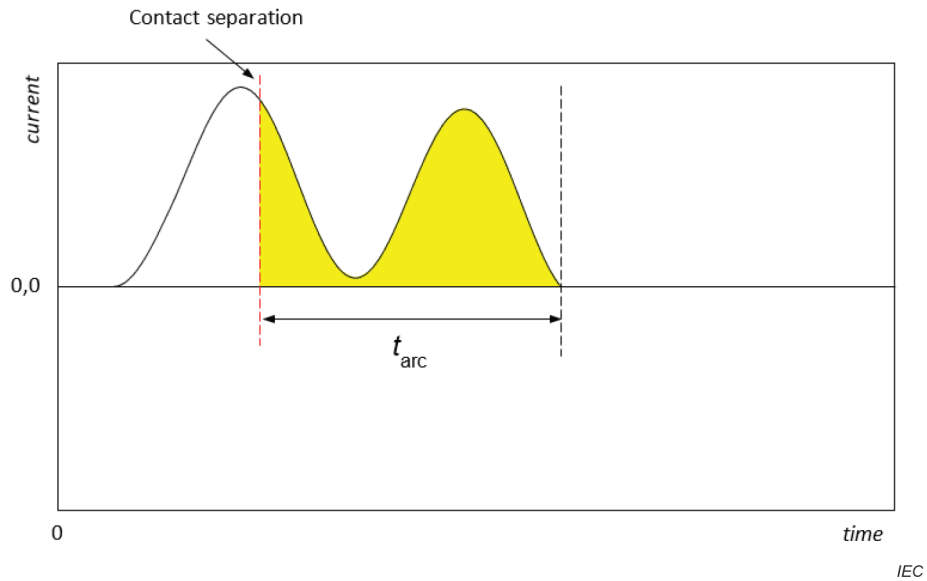
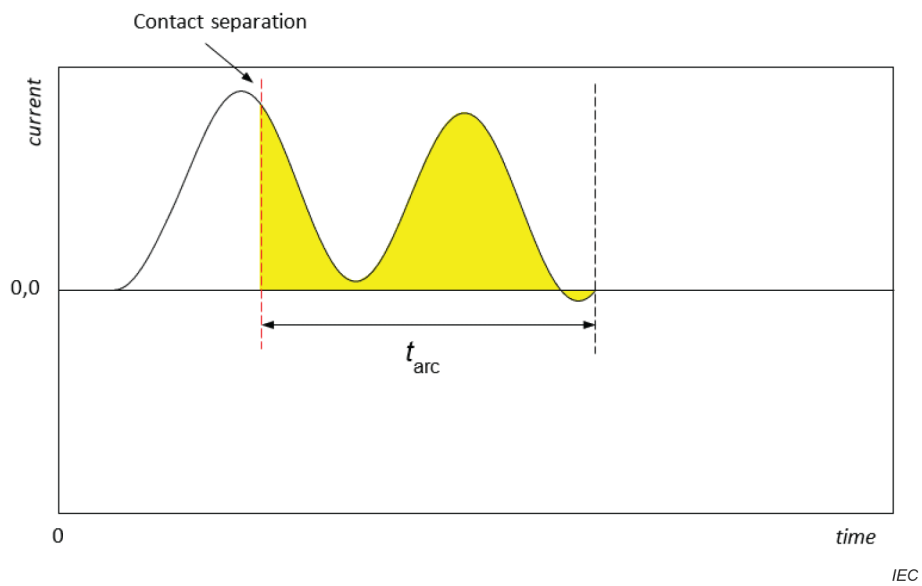


Figure 44 – Example of an invalid test with a subsequent minor loop for test-duties 6A and 6B



a) valid test for test-duties 6A and 6B after adapting the contact separation compared to Figure 43 or Figure 44



b) valid test for test-duties 6A and 6B with a subsequent minor loop after adapting the contact separation compared to Figure 43 or Figure 44

Figure 45 – Example of a valid test for test-duties 6A and 6B after adapting the contact separation compared to Figure 43 or Figure 44

The degree of asymmetry at contact separation shall be recorded.

Table 22 – Test-duties to demonstrate the generator-source short-circuit making and breaking current capability for three-phase tests

Test- duty ^{a,b,c}	Operating sequence	Applied voltage	Making current	Generator-source short-circuit breaking current at contact separation		Power-frequency recovery voltage ⁿ
				Magnitude	Degree of asymmetry	
3 ^d	C + 0,25 s	$U_r/\sqrt{3}$	I_{MC}	–	–	–
4	$C_{no-load}O_{sym}$ and $C_{no-load}O_{sym}$	–	–	I_{scg}	≤ 20 %	$U_r/\sqrt{3}$
5 ^{f, h, j, m}	$C_{no-load}O_{asym}$	–	–	I_{scg}	110 % ^g	$U_r/\sqrt{3}$ ^e
6A ^{f, i, k, m}	$C_{no-load}O_{asym}$	–	–	$0,74I_{scg}$	130 % ^g	$U_r/\sqrt{3}$ ^e
6B ^{f, h, l, m}	$C_{no-load}O_{asym}$	–	–	I_{scg}	130 % ^g	$U_r/\sqrt{3}$ ^e

Key

U_r rated voltage of the generator circuit-breaker

I_{scg} RMS value of the AC component of the rated generator-source short-circuit breaking current of the generator circuit-breaker

^a The test-duty sequence is only a suggested sequence. The test-duties can be performed in any sequence desired.

^b No refitting or replacement of parts to the generator circuit-breaker is permitted during each test-duty.

^c If the generator circuit-breaker has an auxiliary resistor chamber and an auxiliary switch, tests should be performed with the auxiliary resistor and switch in the circuit, or, for convenience of testing, the tests may be performed on both interrupters separately by using equivalent TRVs.

^d Test-duty 3 is not required if I_{MC} has already been proven in test-duty 1 or 1-A.

^e Owing to limitations of testing facilities, it is not always possible to perform the breaking operations at rated voltage and rated short-circuit current. Breaking operation at reduced recovery voltage with a minimum of not less than 50 % of the rated voltage is permissible.

^f For practical reasons this test is normally performed as a single-phase test.

^g This value is determined from the prospective current.

^h A prospective test is required at 100 % of I_{scg} .

ⁱ A prospective test is required at 74 % of I_{scg} .

^j Test-duty 5 is mandatory for class G1 generator circuit-breakers but not mandatory for class G2 generator circuit-breakers as it is covered by test-duty 6B.

^k Test-duty 6A is mandatory only for class G1 generator circuit-breakers.

^l Test-duty 6B is mandatory only for class G2 generator circuit-breakers.

^m To facilitate consistent control of the opening operation, the releases may be supplied at the maximum operating voltage.

ⁿ This value applies after current interruption in the last pole.

Table 23 – Test-duties to demonstrate the generator-source short-circuit making and breaking current capability for single-phase tests

Test-duty ^{a,b,c}	Operating duty	Applied voltage	Making current	Generator-source short-circuit breaking current at contact separation		Power-frequency recovery voltage
				Magnitude	Degree of asymmetry	
3 ^d	C + 0,25 s	$U_r/\sqrt{3}$	I_{MC}	–	–	–
4	$C_{no-load}O_{sym}$ and $C_{no-load}O_{sym}$	$U_r/\sqrt{3}$	–	I_{scg}	≤ 10 %	$(1,5)U_r/\sqrt{3}$ ^m
5 ^{g, i, l}	$C_{no-load}O_{asym}$	–	–	I_{scg}	110 % ^f	$U_r/\sqrt{3}$ ^e
6A ^{h, j, l}	$C_{no-load}O_{asym}$	–	–	$0,74I_{scg}$	130 % ^f	$U_r/\sqrt{3}$ ^e
6B ^{g, k, l}	$C_{no-load}O_{asym}$	–	–	I_{scg}	130 % ^f	$U_r/\sqrt{3}$ ^e

Key

U_r rated voltage of the generator circuit-breaker

I_{scg} RMS value of the AC component of the rated generator-source short-circuit current of the generator circuit-breaker

^a The test-duty sequence is only a suggested sequence. The test-duties can be performed in any sequence desired.

^b No refitting or replacement of parts to the generator circuit-breaker is permitted during each test-duty.

^c If the generator circuit-breaker has an auxiliary resistor chamber and an auxiliary switch, tests should be performed with the auxiliary resistor and switch in the circuit, or, for convenience of testing, the tests may be performed on both interrupters separately by using equivalent TRVs.

^d Test-duty 3 is not required if I_{MC} has already been proven in test-duty 1 or 1-A.

^e Owing to limitations of testing facilities, it is not always possible to perform the breaking operations at rated voltage and rated short-circuit current. Breaking operation at reduced recovery voltage with a minimum of not less than 50 % of the rated voltage is permissible.

^f This value is determined from the prospective current.

^g A prospective test is required at 100 % of I_{scg} .

^h A prospective test is required at 74 % of I_{scg} .

ⁱ Test-duty 5 is mandatory for class G1 generator circuit-breakers but not mandatory for class G2 generator circuit-breakers as it is covered by test-duty 6B.

^j Test-duty 6A is mandatory only for class G1 generator circuit-breakers.

^k Test-duty 6B is mandatory only for class G2 generator circuit-breakers.

^l To facilitate consistent control of the opening operation, the releases may be supplied at the maximum operating voltage.

^m For first-pole-to-clear conditions the recovery voltage is $1,5U_r/\sqrt{3}$. For last-pole-to-clear conditions the recovery voltage $U_r/\sqrt{3}$.

7.106 Out-of-phase making and breaking tests

7.106.1 General

The out-of-phase conditions are abnormal circuit conditions due to loss or lack of synchronism between generator and power system at the instant of operation of the generator circuit-breaker. The phase angle difference between rotating phasors representing the generated voltages on each side of the generator circuit-breaker may exceed the normal value and may be as much as 180° . The out-of-phase current resulting from this condition is dependent on this phase angle and attains its maximum value at 180° (phase opposition). If the sum of the short-circuit reactances of transformer and network on the transformer side of the circuit-breaker is less than the generator short-circuit reactance, the out-of-phase current at full phase opposition would exceed the generator subtransient short-circuit current I''_d resulting from a terminal short-circuit. The resulting electrodynamic overstress for the generator windings shall be prevented from occurring by adequate measures such as preventing incorrect synchronisation.

The majority of generator circuit-breakers are expected to close but not to interrupt under full phase opposition conditions. Only generator circuit-breakers having full interrupting capability (to clear short-circuit currents on either side of the circuit-breaker) could have an assigned out-of-phase current rating. The rating is limited as outlined in Table 24 and Table 25 and as described in 7.106.2 and 7.106.3.

When out-of-phase current making and breaking is a matter of special importance and the user specifies the generator circuit-breaker for full-phase opposition capability, a special generator circuit-breaker may be required with an interrupting rating often exceeding rated short-circuit current interrupting capability, especially with the following:

- a) power-frequency recovery voltage of U_r and with transient recovery voltage to be computed for the first-pole-to-clear;
- b) phase opposition current having a magnitude between the system-source short-circuit current and generator-source short-circuit current. The value shall be computed for each individual installation.

7.106.2 Out-of-phase current making and breaking capability

Out-of-phase current making and breaking capability is specified in terms of the following:

- a) The maximum value of the out-of-phase recovery voltage for the first-pole-to-clear. This value implicitly defines the maximum out-of-phase angle at which the generator circuit-breaker shall be capable of breaking under certain specified conditions. If a generator circuit-breaker has an assigned out-of-phase current rating, it is based on an out-of-phase angle of 90° at rated voltage.
- b) The maximum out-of-phase current that the generator circuit-breaker shall be capable of making and breaking at the maximum out-of-phase voltage specified. The RMS value of the assigned out-of-phase current rating shall be 50 % of the symmetrical system-source short-circuit current. With the consent of the manufacturer higher values of out-of-phase current can be tested whereby the TRV parameters remain as assigned for the out-of-phase current rating of 50 % of the symmetrical system-source short-circuit current.

7.106.3 Conditions of test severity

The out-of-phase current making and breaking tests shall be carried out under the following conditions of severity:

- a) opening and closing operations carried out in conformity with the instructions given by the manufacturer for the operation and proper use of the generator circuit-breaker and its auxiliary equipment;
- b) earthing condition of generator neutral: not effectively earthed, thus, the recovery voltage for the first-pole-to-clear will be $\sqrt{2} \times 1,5 \times U_r / \sqrt{3} = 1,22 U_r$ corresponding to an out-of-phase angle of 90° ;

- c) absence of a fault on either side of the generator circuit-breaker;
- d) tests performed at 60 Hz are acceptable for 50 Hz, provided the arcing window for 50 Hz is covered.
- e) synthetic tests performed at 50 Hz, but where the injection current of the synthetic circuit represents 60 Hz, are acceptable for 50 Hz and for 60 Hz applications;
- f) tests and further conditions of severity are outlined in Table 24 and Table 25.

Table 24 – Test-duties to demonstrate the out-of-phase current making and breaking capability for three-phase tests

Test-duty ^{a,b,c}	Operating duty	Applied voltage	Out-of-phase breaking current at contact separation		Power-frequency recovery voltage ^h
			Magnitude	Degree of asymmetry	
OP1 ^{d, f}	CO _{sym} – 30 min – CO _{sym}	$\sqrt{2}U_r/\sqrt{3}$	I_d	≤ 20 %	$\sqrt{2}U_r/\sqrt{3}$
OP2 ^{e, g}	C _{no-load} O _{asym} – 30 min – C _{no-load} O _{asym}	-	I_d	75 % ⁱ	$\sqrt{2}U_r/\sqrt{3}$

Key

U_r rated voltage of the generator circuit-breaker

I_d RMS value of the AC component of the rated out-of-phase breaking current of the generator circuit-breaker

^a The test-duty sequence is only a suggested sequence. The test-duties can be performed in any sequence desired.

^b No refitting or replacement of parts to the generator circuit-breaker is permitted during each test-duty. Refitting or replacement of parts to the generator circuit-breaker is permitted between test-duties 1 and 2.

^c If the generator circuit-breaker has an auxiliary resistor chamber and an auxiliary switch, tests should be performed with the auxiliary resistor and switch in the circuit, or, for convenience of testing, the tests may be performed on both interrupters separately by using equivalent TRVs.

^d Procedure is given in 7.102.10.2.2.

^e Procedure is given in 7.102.10.2.3.

^f In one of the two operations making shall occur within ±20° of the peak value of the applied voltage in one phase of the three-phase tests.

^g To facilitate consistent control of the opening operation, the releases may be supplied at the maximum operating voltage.

^h This value applies after current interruption in the last pole.

ⁱ 75 % is for reference only (see 7.106.8). The parameters to be met are I_{peak} , Δt and di/dt . The required values for these parameters are given in the second rows of Table 15, Table 16, Table 17 and Table 18.

Table 25 – Test-duties to demonstrate the out-of-phase current making and breaking capability for single-phase tests

Test-duty ^{a,b,c}	Operating duty	Applied voltage	Out-of-phase breaking current at contact separation		Power-frequency recovery voltage ^d
			Magnitude	Degree of asymmetry	
OP1 ^{e, g}	CO _{sym} – 30 min – CO _{sym}	$\sqrt{2}U_r/\sqrt{3}$	I_d	≤ 10 %	$(1,5)\sqrt{2}U_r/\sqrt{3}$
OP2 ^{f, h}	C _{no-load} O _{asym} – 30 min – C _{no-load} O _{asym}	–	I_d	75 % ⁱ	$(1,5)\sqrt{2}U_r/\sqrt{3}$

Key

U_r rated voltage of the generator circuit-breaker

I_d RMS value of the AC component of the rated out-of-phase breaking current of the generator circuit-breaker

^a The test-duty sequence is only a suggested sequence. The test-duties can be performed in any sequence desired.

^b No refitting or replacement of parts to the generator circuit-breaker is permitted during each test-duty. Refitting or replacement of parts to the generator circuit-breaker is permitted between test-duties 1 and 2.

^c If the generator circuit-breaker has an auxiliary resistor chamber and an auxiliary switch, tests should be performed with the auxiliary resistor and switch in the circuit, or, for convenience of testing, the tests may be performed on both interrupters separately by using equivalent TRVs.

^d For first-pole-to-clear conditions the recovery voltage is $1,5\sqrt{2}U_r/\sqrt{3}$. For last-pole-to-clear conditions the recovery voltage $\sqrt{2}U_r/\sqrt{3}$.

^e Procedure is given in 7.102.10.3.2.

^f Procedure is given in 7.102.10.3.3.

^g In one of the two operations making shall occur within ±20° of the peak value of the applied voltage.

^h To facilitate consistent control of the opening operation, the releases may be supplied at the maximum operating voltage.

ⁱ 75 % is for reference only (see 7.106.8). The parameters to be met are I_{peak} , Δt and di/dt . The required values for these parameters are given in the second rows of Table 15, Table 16, Table 17 and Table 18.

7.106.4 Test circuit

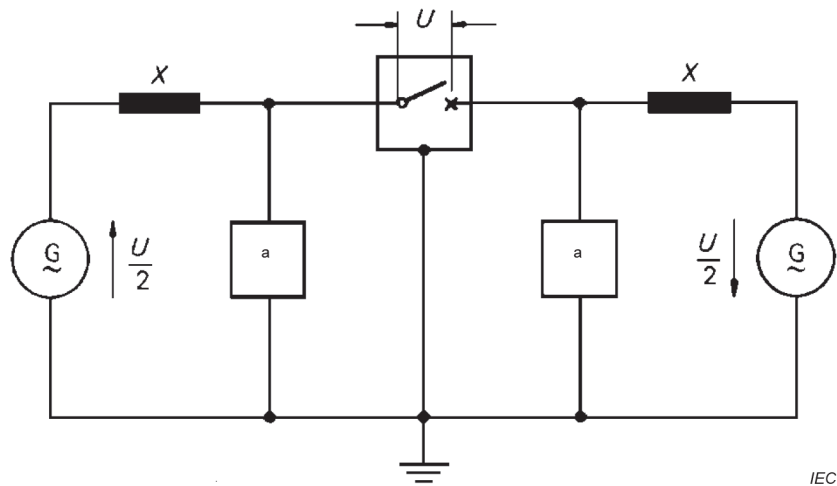
Out-of-phase testing is normally performed with a single-phase test circuit.

The following condition shall be satisfied:

For single-phase tests, the test circuit shall be arranged so that approximately one-half of the applied voltage and the recovery voltage is on each side of the generator circuit-breaker (see Figure 46).

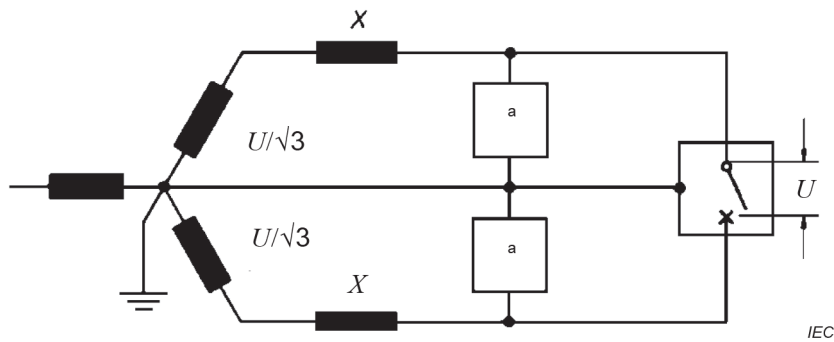
If it is not feasible to use this circuit in the test laboratory, it is permissible to use either of the following circuits shown in Figure 47 and Figure 48 at the option of the manufacturer:

- 1) Two identical voltages separated in phase by 120° instead of 180° may be used provided that the total voltage across the generator circuit-breaker is as stated in Table 25 (see Figure 47).
- 2) Tests with one terminal of the generator circuit-breaker earthed may be used (see Figure 48).



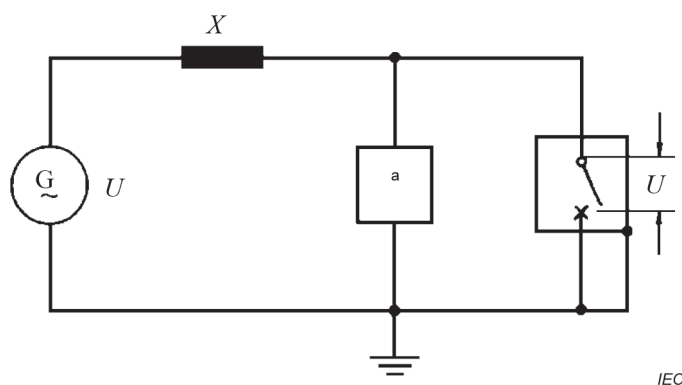
^a The squares represent combinations of capacitances and resistances.

Figure 46 – Test circuit for single-phase out-of-phase tests



^a The squares represent combinations of capacitances and resistances.

Figure 47 – Test circuit for out-of-phase tests using two voltages separated by 120 electrical degrees



^a The square represents combinations of capacitances and resistances.

Figure 48 – Test circuit for out-of-phase tests with one terminal of the generator circuit-breaker earthed (subject to agreement of the manufacturer)

7.106.5 Applied voltage before out-of-phase making tests

The test quantities are listed in Table 24 and Table 25 where the applied voltage shall be as follows:

- a) For three-phase tests on a three-pole generator circuit-breaker, the average value of the applied voltages phase-to-phase shall not be less than $\sqrt{2} U_r$ and shall not exceed this value by more than 10 % without the consent of the manufacturer.
- b) For single-phase tests on a three-pole generator circuit-breaker, the applied voltage shall not be less than the phase-to-earth value $\sqrt{2} U_r/\sqrt{3}$ and shall not exceed this value by more than 10 % without the consent of the manufacturer.

NOTE For convenience of testing the applied voltage can be increased with the agreement of the manufacturer to $1,5 U_r/\sqrt{2/\sqrt{3}}$.

Owing to limitations of testing facilities, it is not always possible to perform the making operations at appropriate voltage and rated out-of-phase current. Making operations at reduced applied voltage with a minimum of not less than 50 % of the appropriate voltage are permissible if the pre-arcing time during making at appropriate voltage in any phase is not more than 1/10 cycle of power frequency with a tolerance of 20 %. The pre-arcing time at appropriate voltage shall be determined by performing two making tests, one at each polarity, at reduced current. The reduced current shall be low enough to avoid contact erosion.

7.106.6 Transient recovery voltage (TRV) for out-of-phase breaking tests

The prospective circuit TRV (unmodified by the generator circuit-breaker) shall meet the values as listed in Table 6.

7.106.7 Demonstration of the most severe making and breaking conditions during test-duty OP1

The procedure given in 7.102.10.2.2 (three-phase tests) and in 7.102.10.3.2 (single-phase tests) is applicable.

7.106.8 Demonstration of the most severe breaking conditions during test-duty OP2

For testing purposes asymmetrical breaking current capability test-duty OP2 is based on a time constant of 133 ms.

The procedure given in 7.102.10.2.3 (three-phase tests) and in 7.102.10.3.3 (single-phase tests) is applicable with the following addition:

- the earliest possible interruption is independent from the relay time and the opening time;
- the degree of asymmetry at contact separation is independent from the relay time and the opening time;
- for testing purposes the earliest possible interruption in a phase with intermediate level of asymmetry after a major loop is considered as 52,6 ms for 50 Hz and as 43,9 ms for 60 Hz. The applicable loop parameters are specified in the second row of Table 15 for 50 Hz and in the second row of Table 16 for 60 Hz;
- for testing purposes the earliest possible interruption in a phase with intermediate level of asymmetry after a minor loop is considered as 47,1 ms for 50 Hz and as 39,2 ms for 60 Hz. The applicable loop parameters are specified in the second row of Table 17 for 50 Hz and in the second row of Table 18 for 60 Hz.

7.107 Generator circuit-breakers with alternative operating mechanisms

This subclause applies to generator circuit-breakers that are already completely type tested using an original operating mechanism. Other versions, differing in the operating mechanism are referred to as generator circuit-breakers with an alternative operating mechanism (see definition 3.5.123). The alternative operating mechanism(s) of a three-pole operated generator circuit-breaker may be either three-pole or single-pole operating and the alternative operating mechanism(s) of a single-pole operated generator circuit-breaker may also be either three-pole or single-pole operating.

The tests to be performed are limited to the following:

- a) A no-load opening operation and a no-load closing operation at rated supply voltage and at filling pressure for operation shall be recorded. The measurements shall comply with the mechanical characteristics, as defined in 7.101.1.1, for example no-load travel curves are within the reference travel bands.
- b) If the main contact system of the generator circuit-breaker is of the butt type then the tests according to 7.6 shall be fully repeated on the generator circuit-breaker with an alternative operating mechanism.

NOTE 1 A butt contact is a contact in which relative movement of the contact pieces is substantially in a direction perpendicular to the contact surface (IEC 60050-441:2000, 441-15-14).

- c) On the generator circuit-breaker with an alternative operating mechanism all tests according to 7.101 shall be repeated.
- d) On the generator circuit-breaker with an alternative operating mechanism a verification test for breaking and a verification test for making, both under short-circuit conditions, shall be performed. For three-pole operated generator circuit-breakers the verification tests shall be performed three-phase, for single-pole operated generator circuit-breakers the verification tests can be performed single-phase.

The three-phase verification test for making shall be performed according to 7.102.4.1 a). After this making operation a no-load opening operation at rated supply voltage and at filling pressure for operation shall be recorded. The measurements shall comply with the mechanical characteristics, as defined in 7.101.1.1, for example no-load travel curves are within the reference travel bands.

The single-phase verification test for making consists of a single-phase making test at the rated short-circuit current. The peak current value shall be at least $2,74I_{sc}$. The duration of the current shall be long enough for the generator circuit-breaker to reach its fully closed position. After this making operation a no-load opening operation at rated supply voltage and at filling pressure for operation shall be recorded. The measurements shall comply with the mechanical characteristics, as defined in 7.101.1.1, for example no-load travel curves are within the reference travel bands.

Both the three-phase and the single-phase verification test for breaking consist of a symmetrical breaking test at the rated short-circuit current with the maximum arcing time for the last-pole-to-clear. The breaking operation may be performed at any convenient test voltage.

Typically, the following procedure applies:

The course of the travel of the completely tested generator circuit-breaker during a breaking test under the same conditions shall be used as a reference travel curve for the following procedure:

- Two envelope curves shall be drawn from the instant of contact separation to the end of the reference travel curve of the completely tested generator circuit-breaker. The distance between the two envelopes from the original course shall be $\pm 5\%$ of the total travel or ± 2 mm whichever is larger (see Figure 17).
- The travel curve of the generator circuit-breaker with an alternative operating mechanism during its verification test for breaking shall be recorded. If the travel curve during the verification test for breaking is within the envelope curves of the completely tested generator circuit-breaker, the verification test is a valid operation.

- The envelope curves can be moved in the vertical direction until one of the envelope curves covers the reference curve. This gives maximum tolerances over the reference travel curve of -0% or 0 mm , $+10\%$ or $+4\text{ mm}$ and $+0\%$ or $+0\text{ mm}$, -10% or -4 mm respectively (see Figure 18 and Figure 19). The displacement of the envelope curves can be done only once for the complete procedure in order to get a maximum total deviation from the reference curve of 10% or 4 mm .

It is recognised that for some designs of generator circuit-breakers, this method may be unsuitable, as for example for vacuum generator circuit-breakers. In such cases the manufacturer shall define an appropriate method to verify the proper operation of the vacuum generator circuit-breaker. The following parameters may be used to characterise the vacuum generator circuit-breaker:

- stroke, with a maximum tolerance width of 4 mm or 10% , as assigned by the manufacturer;
- closing time, with a tolerance assigned by the manufacturer;
- opening time, with a tolerance assigned by the manufacturer;
- momentary closing speed at a certain stroke, with a maximum tolerance of $\pm 10\%$, as assigned by the manufacturer;
- momentary opening speed at a certain stroke, with a maximum tolerance of $\pm 10\%$, as assigned by the manufacturer.

During the verification test of breaking all the parameters shall be within the tolerances as assigned by the manufacturer.

- e) In the particular case, where the variation in opening times of the alternative operating mechanism causes the generator circuit-breaker to fall into a different category of earliest possible interruption (see Table 15, Table 16, Table 17 and Table 18), test-duty 2 of Table 20 or Table 21 shall be performed on the generator circuit-breaker with an alternative operating mechanism.

If requirements a) to e) are met, the reference mechanical characteristics of the completely tested generator circuit-breaker shall apply also for the generator circuit-breakers with alternative operating mechanisms.

8 Routine tests

8.1 General

Subclause 8.1 of IEC 62271-1:2017 is applicable with the following modifications:

Routine tests shall be made on the complete generator circuit-breaker or generator circuit-breaker system. However, when generator circuit-breakers or generator circuit-breaker systems are assembled and shipped as separate units, the routine tests shall be performed on site.

The mechanical routine tests with the main-disconnector and the earthing switch shall be performed according to their applicable standard.

The mechanical routine tests with the starting switch, BTB-switch, braking switch, Tee-OFF-switch, ET-switch and motor operated short-circuiting connections shall be performed according to the standard applicable for disconnectors.

8.2 Dielectric test on the main circuit

Subclause 8.2 of IEC 62271-1:2017 is applicable with the following modifications:

The test voltage shall be the one specified in column (2) of Table 1 of this document.

For generator circuit-breakers having interrupters with one interrupting medium, enclosed in a different insulating fluid, the power-frequency withstand voltage test alone may be insufficient to show whether or not either interrupting medium or the insulating medium, has been compromised by a leak that may have developed in the enclosure of the interrupter.

For example, suppose a generator circuit-breaker system has vacuum interrupters that are enclosed in an SF₆ filled enclosure. If a leak were to develop allowing SF₆ gas to enter the vacuum interrupter chamber, it could be possible for the interrupters to withstand a power-frequency withstand voltage test, but still be unable to clear the rated short-circuit current. In this case, the manufacturer shall advise the user what would be an appropriate way to verify that integrity of the vacuum chamber has not been compromised.

If the generator circuit-breaker or generator circuit-breaker system is equipped with resistors, capacitors, surge arresters or instrument transformers, then those components can be disconnected or removed prior to the dielectric test, provided that these components have been routine tested separately in accordance with their standards.

8.3 Tests on auxiliary and control circuits

8.3.1 Inspection of auxiliary and control circuits, and verification of conformity to the circuit diagrams and wiring diagrams

Subclause 8.3.1 of IEC 62271-1:2017 is applicable with the following addition:

All resistors and heaters shall be checked either by operation or resistance measurements. All closing, tripping, control valve, and relay coils shall be checked by resistance measurement and shall be within specified manufacturing limits.

8.3.2 Functional tests

Subclause 8.3.2 of IEC 62271-1:2017 is applicable with the following addition:

The tests shall be performed with the maximum, minimum and rated values of the supply voltage defined in Table 2.

8.3.3 Verification of protection against electrical shock

Subclause 8.3.3 of IEC 62271-1:2017 is applicable.

8.3.4 Dielectric tests

Subclause 8.3.4 of IEC 62271-1:2017 is not applicable and is replaced with the following:

All secondary wiring of conventional instrument transformers shall receive a power-frequency withstand voltage test of 2 500 V for 1 min. All other wiring shall receive a power-frequency withstand voltage test of 1 500 V for 1 min.

If the control circuit of a generator circuit-breaker or any other component of a generator circuit-breaker system includes a motor, the motor may be disconnected during dielectric tests on the control circuit and subsequently tested, in place, at its specified dielectric withstand voltage, but at not less than 900 V.

The test voltage of other devices such as electronic equipment used in the auxiliary and control circuits shall be the same as the test voltage of those circuits. If such apparatus has already been tested in accordance with the appropriate specification, it may be disconnected for these tests.

8.4 Measurement of the resistance of the main circuit

Subclause 8.4 of IEC 62271-1:2017 is not applicable and is replaced with the following:

The DC resistance of the current-carrying circuit from terminal to terminal of each pole unit in the closed position shall be measured with at least 100 A flowing in the circuit and shall not exceed the limit set for the rating of the generator circuit-breaker or the generator circuit-breaker system by the manufacturer.

8.5 Tightness test

8.5.1 General

Subclause 8.5.1 of IEC 62271-1:2017 is applicable.

8.5.2 Controlled pressure systems for gas

Subclause 8.5.2 of IEC 62271-1:2017 is applicable.

8.5.3 Closed pressure systems for gas

Subclause 8.5.3 of IEC 62271-1:2017 is not applicable and is replaced with the following:

The purpose of tightness tests is to demonstrate that the absolute leakage rate F does not exceed the specified value of the permissible leakage rate F_p (refer to 6.16).

The tightness tests shall be performed with the same fluid or with helium and under the same conditions as used in service. Where possible, the tests should be performed on a complete system at the filling pressure (density) for insulation and/or making and breaking. If this is not practical, the tests may be performed on subassemblies. In such cases, the leakage rate of the total system shall be determined by summation of the subassemblies leakage rates. The possible leakages between subassemblies of different pressures shall also be taken into account.

Only cumulative leakage measurements allow calculation of leakage rates. For this reason, sniffing is not acceptable because it is not cumulative.

The routine test report should include such information as:

- an indication of the calibration of the meters used to detect leakage rates;
- the results of the measurements;
- the test gas.

In general, for the application of an adequate test method, reference is made to IEC 60068-2-17[4].

8.5.4 Sealed pressure systems

Subclause 8.5.4 of IEC 62271-1:2017 is applicable.

8.5.5 Liquid tightness tests

Subclause 8.5.5 of IEC 62271-1:2017 is applicable.

8.6 Design and visual checks

Subclause 8.6 of IEC 62271-1:2017 is not applicable and is replaced with the following:

The generator circuit-breaker or the generator circuit-breaker system shall be checked to verify its compliance with the order specification.

For example the following items shall be checked if applicable:

- the language and data on the nameplates;
- the values of the resistors and capacitors connected to the main circuit;
- identification of any auxiliary equipment;
- the colour and quality of paint and corrosion protection of metallic surfaces.

8.101 Mechanical operating tests of generator circuit-breakers

Mechanical operating tests shall be performed at filling pressure for insulation and/or making and breaking and shall include the following:

- a) at maximum supply voltage of operating devices and of auxiliary and control circuits and maximum functional pressure for operation of the mechanism (if applicable):
 - five closing operations;
 - five opening operations.
- b) at minimum supply voltage of operating devices and of auxiliary and control circuits and minimum functional pressure for operation of the mechanism (if applicable):
 - five closing operations;
 - five opening operations.
- c) at rated supply voltage of operating devices and of auxiliary and control circuits and filling pressure for operation of the mechanism (if applicable):
 - five close-open operating cycles with the opening mechanism energised by the closing of the main contacts; during these tests, the close control switch shall be held to maintain the close signal to demonstrate that both the anti-pumping and the (electrically) trip-free functions of the control circuit of the generator circuit-breaker are working properly.

Mechanical operating tests shall be made on the complete generator circuit-breaker. However, when generator circuit-breakers are assembled and shipped as separate units, routine tests may be performed on subassemblies according to 7.101.1.2. In such cases, the routine mechanical operating tests shall be performed on site to confirm the compatibility of such separate units and subassemblies when assembled as a complete generator circuit-breaker.

For all required operating sequences the following values shall be measured and recorded:

- closing time of each pole, the time spread of the poles (see 6.101) and when possible time spread of the breaking units or groups of units of each pole;
- opening time of each pole, time spread of the poles (see 6.101) and when possible time spread of the breaking units or groups of units of each pole;
- where applicable, measurement of fluid consumption during opening and closing operations, for example pressure difference;
- when the circuit-breaker is provided with resistor closing or opening units, the resistor insertion times shall be recorded.

In the case of multiple trip coils, one additional opening operation shall be performed and the time recorded for each.

Proof shall be given that the mechanical behaviour conforms to that of the test object used for type testing. This shall be done by confirming the mechanical characteristics as described in 7.101.1.1 at the end of the routine tests.

The measurement of additional parameters, like momentary speed at a certain stroke, may also be part of the routine tests.

Tolerances on the opening time, closing time, and additional parameters like momentary speed shall be given by the manufacturer.

After completion of the required operating sequences, the following tests and inspections shall be performed (if applicable):

- connections shall be checked;
- the control and/or auxiliary switches shall correctly indicate the open and closed positions of the generator circuit-breaker;
- all auxiliary equipment shall operate correctly at the limits of supply voltage of operating devices and of auxiliary and control circuits and/or pressures for operation.

Furthermore, the following tests and inspections shall be made (if applicable):

- measurement of the resistance of heaters (if fitted) and of the control coils;
- inspections of the wiring of the control, heater and auxiliary equipment circuits and checking of the number of auxiliary contacts, in accordance with the order specification;
- inspection of control cubicle (electrical, mechanical, pneumatic and hydraulic systems);
- recharging duration(s);
- functional performance of pressure relief valve;

NOTE A valve is not a rupture disc, but is resettable, so this is not a destructive test.

- operation of electrical, mechanical, pneumatic or hydraulic interlocks and signalling devices;
- where applicable, on rising pressure for insulation and/or making and breaking: disappearance of the low-pressure or low-density alarm;
- where applicable, on dropping pressure for insulation and/or making and breaking: appearance of low-pressure or low-density alarm;
- operation of anti-pumping device;
- general performance of equipment within the required tolerance of the supply voltage;
- inspection of earthing terminals of the generator circuit-breaker.

If adjustments are required during the mechanical operating tests, the complete test sequence shall be repeated following the adjustments.

8.102 Dielectric tests on the enclosure of generator circuit-breaker systems

In the case where the enclosure is insulated from the pole frame, it shall be subjected to a power-frequency withstand voltage test of 1 500 V for 1 min.

9 Guide to the selection of switchgear and controlgear

Clause 9 of IEC 62271-1:2017 is replaced by the following:

9.101 General

Clause 9 is intended for general use as a guide in the application of AC high-voltage generator circuit-breakers or generator circuit-breaker systems. Familiarity with other standards applying to generator circuit-breakers or other components of generator circuit-breaker systems is assumed, and provisions of those standards are indicated herein only when necessary for clarity in describing application requirements. A typical application example is presented in Annex D. More information on application in pumped-storage power plants are given in Annex O.

The complete list of rated characteristics is given in Clause 5. The following individual ratings are dealt with in this clause.

<i>Type of rating and characteristic</i>	<i>Subclause</i>
Rated voltage	9.103.2
Rated insulation level	9.103.3
Rated frequency	9.103.4
Rated continuous current	9.103.5
Short-circuit current rating	9.103.6
TRV rating for system-source and generator-source short-circuits	9.103.7
Rated load breaking current	9.103.8
Rated out-of-phase making and breaking current	9.103.9
Excitation breaking current	9.103.10
Capacitive making and breaking current	9.103.11

For rated characteristics not dealt with in Clause 9, reference should, if applicable, be made to Clause 5.

When selecting a generator circuit-breaker or a generator circuit-breaker system, due allowance should be made for the likely future development of the system as a whole, so that the generator circuit-breaker or the generator circuit-breaker system may be suitable not merely for immediate needs but also for the requirements of the future.

9.102 General application conditions

9.102.1 Normal service conditions

9.102.1.1 General

Normal service conditions for generator circuit-breakers or generator circuit-breaker systems are defined in 4.1.

9.102.1.2 Provisions for system growth

Power system facilities can be increased from time to time to serve larger loads. Although the generator is unlikely to be replaced with a larger generator, system growth usually results in higher values of short-circuit current. Therefore, liberal allowance in the system-source short-circuit current rating of the generator circuit-breaker or the generator circuit-breaker system for possible future increases is advisable.

9.102.1.3 System design

Methods for limiting the magnitude of short-circuit currents or reducing the probability of high-current short-circuits by system design are outside the scope of this document. Such methods should be considered where short-circuit currents approach the maximum capability of the generator circuit-breaker or the generator circuit-breaker system.

9.102.2 Special service conditions

9.102.2.1 General

Special service conditions are listed in 4.2. Special specification, installation, operation, and maintenance provisions should be considered where these conditions are encountered, and should be called to the attention of the manufacturer as necessary.

9.102.2.2 Application at abnormal temperatures

The use of apparatus in ambient temperatures outside the limits of those specified in 4.1 is considered special. In most applications, the generator circuit-breaker or the generator circuit-breaker system is installed as an integral part of the isolated phase bus. Under these conditions, the isolated phase bus cooling directly affects the temperature inside of the enclosed generator circuit-breaker or the enclosed generator circuit-breaker system. The ambient temperature and the thermal time-constant of the generator circuit-breaker or the generator circuit-breaker system govern the continuous current application described in 5.5.

9.102.2.3 Application at altitudes above 1 000 m

The normal service conditions specified in 4.1 are intended for use at altitudes not exceeding 1 000 m.

For installation at altitudes above 1 000 m, 4.2.2 is applicable.

The rated short-circuit breaking current at rated voltage, related required capabilities and the three-phase break-time are not affected by altitude. The rated continuous current may have to be corrected and the manufacturer should be consulted.

9.102.2.4 Exposure to damaging fumes or vapours, steam, salt spray, oil spray, excessive moisture, dripping water, and other similar conditions

Equipment subject to such conditions may require the following special construction or protective features:

- a) provisions to avoid condensation on all electrical insulation and current-carrying parts;
- b) bushings with extra creepage distance;
- c) special maintenance, including insulator cleaning in cases where particulate exposure represents a hazard to insulation integrity;
- d) the use of materials resistant to fungus growth.

9.102.2.5 Exposure to excessive or abrasive, magnetic or metallic dust

Equipment subject to such conditions may require the following special construction or protective features:

- a) totally enclosed equipment or compartments and provision for conditioned ventilating air;
- b) derating where current-carrying equipment designed for ventilated operation is enclosed in a non-ventilated compartment.

9.102.2.6 Exposure to explosive mixtures of dust or gases

Generator circuit-breakers or generator circuit-breaker systems are not designed for use in explosive atmospheres. For this type of service, special consideration should be given so that acceptable equipment is selected.

9.102.2.7 Exposure to abnormal vibration, shock or tilting

Generator circuit-breakers or generator circuit-breaker systems are designed for mounting on substantially level structures free from excessive vibration, shock or tilting. Where any of these abnormal conditions exist, recommendations for the particular application should be obtained from the manufacturer.

9.102.2.8 Seasonal or infrequent use

Equipment stored or de-energised for long periods, such as during generator maintenance, should be protected against accelerated deterioration. Before energising for service, operating performance and insulation integrity should be checked.

9.102.2.9 Application of unusual forces

During normal operation, the generator circuit-breaker or the generator circuit-breaker system may be subjected to abnormal thermal and seismic forces, in addition to normal short-circuit current and thermal forces.

Abnormal thermal forces are due to the thermal cycling of connections to the generator circuit-breaker or the generator circuit-breaker system. The application of a generator circuit-breaker or a generator circuit-breaker system, as part of a long rigid bus system, may produce severe compression and tensile forces on the connections of the generator circuit-breaker or the generator circuit-breaker system. Consult the manufacturer for this application.

Applications where seismic forces exceed 0,5 g should be checked with the manufacturer.

9.102.2.10 Application effects of magnetic fields

Occasionally, the busbars in power plants are not enclosed and in general, effects of magnetic fields for generator normal (continuous) current below 6 300 A is usually of no concern. However, the magnetic field in the vicinity of the bus between generator and transformer may have adverse effects on equipment and building steel if the bus current exceeds 6 300 A. For such a case, the manufacturer should be consulted for values of magnetic fields outside of the housing of the generator circuit-breaker or the generator circuit-breaker system because induced voltages and currents could produce undesired heating effects. For this reason, and to avoid electromagnetic forces between the current-carrying busbars, isolated-phase bus is usually used.

Precautions need to be observed for the following conditions:

- a) The difference in the return current through the enclosure of the generator circuit-breaker system and the current flow in the busbar is above 6 300 A .
- b) The magnetic field outside the enclosure of the generator circuit-breaker system plus the magnetic field caused by the difference in current flowing through the enclosure and the active part of the generator circuit-breaker system is higher than the magnetic field of a 6 300 A current.

These precautions include avoidance of metal connections and/or the placement of metal support structures adjacent to and between the poles of a generator circuit-breaker or a generator circuit-breaker system and bus phases.

9.103 Application consideration

9.103.1 General

In usual applications, the principal function of the generator circuit-breaker is to carry the generator rated load current and provide means for the interruption of the short-circuit currents from the generator as well as from the power system. However, the generator circuit-breaker can also be used for load, transformer excitation, or out-of-phase current making and breaking. In some cases, these requirements may be the determining factor in the selection of a generator circuit-breaker rather than the short-circuit current interruption requirements. Generator circuit-breaker systems include additional functions which are provided by the components as listed in 3.3.101.

9.103.2 Rated voltage

The maximum operating voltage of the generator cannot exceed the rated voltage of the generator circuit-breaker or the generator circuit-breaker system since this is the generator circuit-breaker's or the generator circuit-breaker system's upper limit for operation.

NOTE The operating voltages of generators with ratings of 200 MVA to 1 500 MVA vary widely, from approximately 10 kV to 27 kV. Consequently, when defining short-circuit duties, the rated voltage is the maximum operating voltage of the generator to which the generator circuit-breaker or the generator circuit-breaker system is connected.

9.103.3 Rated insulation level

The preferred withstand voltage levels for generator circuit-breakers or generator circuit-breaker systems are specified in Table 1. The dielectric performance is required down to the minimum functional pressure for insulation and/or making and breaking.

In the event of pressure loss of the insulating medium, the loss of dielectric withstand is progressive. If the insulating medium is a gas other than compressed air, the inner parts of the generator circuit-breaker may remain filled with the gas at atmospheric pressure that has higher dielectric properties than the ambient atmospheric air. For a certain time under this circumstance, the generator circuit-breaker is able to withstand more than the operating voltage, even in phase opposition conditions. This time should be used to remove the generator circuit-breaker from service by complete electrical isolation, preferably by automatic means, before any ingress of humidity, dust, or both, has taken place. This electrical isolation should be completed within 1 h of the loss of insulation medium pressure.

Unusual circumstances may exist where, due to operational conditions, a time longer than 1 h is desirable before the generator circuit-breaker is isolated from the source. If such a situation exists, the generator circuit-breaker should be prevented from operating. To provide for this unusual circumstance, the following data should be requested from the manufacturer:

- a) withstand voltage-to-earth and across contacts with the insulating medium at atmospheric pressure;
- b) the current-carrying capability of the generator circuit-breaker with the insulating medium at atmospheric pressure.

9.103.4 Rated frequency

The rated frequency for generator circuit-breakers or generator circuit-breaker systems is 50 Hz or 60 Hz, depending on the system power frequency in which the generator circuit-breaker is installed.

9.103.5 Rated continuous current

9.103.5.1 Application considerations for normal operation

Generator circuit-breakers or generator circuit-breaker systems are usually designed as an integral part of the bus between the generator and transformer. The generator circuit-breaker or the generator circuit-breaker system shall be able to carry the rated continuous current of the generator. The metal enclosed bus is usually phase-isolated. In many cases, the generator circuit-breaker or the generator circuit-breaker system is equipped with a cooling system using air or water.

Current-carrying capabilities of generator circuit-breakers or generator circuit-breaker systems under various conditions of ambient temperature and load vary from other high-voltage circuit-breakers. Generator circuit-breaker systems have two current-carrying parts that have to be considered, i.e. the active part with the interrupting device, and the metal enclosure.

Various parts of the generator circuit-breaker or the generator circuit-breaker system and the connected bus have different temperature limits that are detailed in 7.5.6.

9.103.5.2 Continuous load current-carrying capability based on actual ambient and connected bus temperature

Both the ambient temperature and the temperature of the connected bus influence the continuous current-carrying capability of the generator circuit-breaker or the generator circuit-breaker system. As a result, the continuous current-carrying capability may be different to the one recorded during the type tests according to 7.5. For power plant-specific applications, the temperature rise limits laid down in 7.5 may be exceeded provided that the absolute temperature limit is not exceeded.

Consult the manufacturer to determine the maximum value of continuous current-carrying capability under the specific ambient conditions.

9.103.5.3 Emergency conditions

Following the loss of cooling systems, the temperature of the parts of the generator circuit-breaker or the generator circuit-breaker system will increase. For generator circuit-breakers or generator circuit-breaker systems, 5.5.101 establishes the parameters involved. In 7.5.101 the tests for such emergency conditions are explained.

In case of cooling system failure, the current shall be reduced to the lowest allowable continuous current of the IPB, generator circuit-breaker system and other components without cooling.

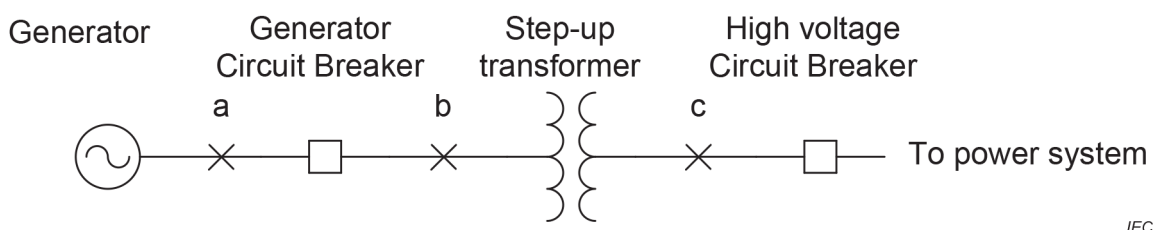
9.103.6 Short-circuit current rating

9.103.6.1 Background of short-circuit current rating

The short-circuit current, which a generator circuit-breaker or a generator circuit-breaker system can experience, is explained by Figure 49, a general diagram of a power plant, with a short-circuit shown in the following different locations:

- the system-source short-circuit current (location a, Figure 49);
- the generator-source short-circuit current (locations b and c, Figure 49);

Location b has a higher short-circuit current than location c; therefore, location c is disregarded.



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Figure 49 – General circuit diagram of a power plant

In most applications, the AC component of the system-source short-circuit current is higher than that of the generator-source case because the sum of the short-circuit reactance of the transformer and the system is lower than the subtransient and transient reactances of the generator.

For special power plant layouts where two (or more) generators are connected to one two-winding step-up transformer the maximum short-circuit current, which a generator circuit-breaker or a generator circuit-breaker system can experience, shall be determined as the sum of the generator-source and system-source short-circuit current when the fault is located near one of the generators.

The determination of the AC component and the degree of asymmetry of the total short-circuit current and its dependency on the fault locations is described in Annex D.

9.103.6.2 Short-circuit current rating

The definition for short-circuit current rating given in 5.101.1 states that it is the RMS value of the AC component of the three-phase short-circuit current to which all required short-circuit capabilities are related.

It is to be noted that, if the short-circuit performance capability of a generator circuit-breaker or a generator circuit-breaker system has been demonstrated for a certain generator-source fault rating, or for a certain system-source fault rating, then that proven short-circuit performance capability also serves to demonstrate the capability for less severe generator-source faults, or for less severe system-source faults. However, it is important to remember that parameters for generator circuit faults include short-time current withstand, transient recovery voltage (TRV), making current, degree of asymmetry and most severe making and breaking conditions, as well as the symmetrical current, for both system-source faults and generator-source faults. Proven capabilities for all of these parameters shall be demonstrated to meet or exceed the respective requirements for the intended application.

9.103.6.3 Related capabilities

9.103.6.3.1 General

The following are related capabilities concerning the short-circuit current:

- a) System-source short-circuit currents:
 - symmetrical breaking current;
 - asymmetrical breaking current;
 - short-time current-carrying capability.
- b) Generator-source short-circuit currents:
 - symmetrical breaking current;
 - asymmetrical breaking current;
 - asymmetrical breaking current for maximum degree of asymmetry.
- c) Generator-source or system-source: making capability.

9.103.6.3.2 Symmetrical breaking current for three-phase system-source faults

This capability is based on the RMS value of the AC component of the rated system-source short-circuit breaking current.

9.103.6.3.3 Asymmetrical breaking current for three-phase system-source faults

This capability is based on the rated system-source short-circuit breaking current. Its DC component decays with a time constant of 133 ms and depends on the instant contact separation occurs, which is the sum of 1/2 cycle tripping delay plus the minimum opening time of the generator circuit-breaker. It is calculated with the equation below and illustrated by Figure 10. The numerical values are shown in Figure 11.

The degree of asymmetry $A_{sy_{cs}}$ at the time t_{cs} is determined by the following equation:

$$A_{sy_{cs}} = \frac{I_{DCcs}}{I_{ACcs}}$$

is the degree of asymmetry at contact separation (usually expressed in per cent)

where

I_{ACcs} is the peak value of the AC component of the rated system-source short-circuit breaking current at contact separation;

I_{DCcs} is the DC component of the system-source short-circuit breaking current at contact separation and can be calculated as follows:

$$I_{DCcs} = I_{ACcs} e^{-t_{cs}/\tau}$$

where

τ is 133 ms.

The asymmetrical breaking current is calculated as follows:

$$I_{asymcs} = \sqrt{I_{sc}^2 + I_{DCcs}^2} = \sqrt{I_{sc}^2 + (I_{ACcs} \times e^{-t_{cs}/\tau})^2} = \sqrt{I_{sc}^2 + (I_{sc} \times Asy_{cs} \times \sqrt{2})^2} = I_{sc} \sqrt{1 + 2Asy_{cs}^2}$$

This formula is not used for testing purposes but for the evaluation of the suitability of generator circuit-breakers for plant-specific applications. In order to assess the capability of the generator circuit-breaker to interrupt a plant-specific short-circuit current, provided that the making current does not exceed the rated making current capability, any combination of plant-specific AC and DC components (due to e.g. DC time constants different from 133 ms or relay times different from 0,5 cycle) is permissible provided that the following conditions are met at the instant of contact separation:

- a) the project-specific AC component does not exceed the tested AC component of the rated system-source short-circuit breaking current;
- b) the project-specific asymmetrical short-circuit current does not exceed the value

$$I_{ACcs} \sqrt{0,5 + \left(e^{-\frac{t_{cs}}{\tau}} \right)^2}$$

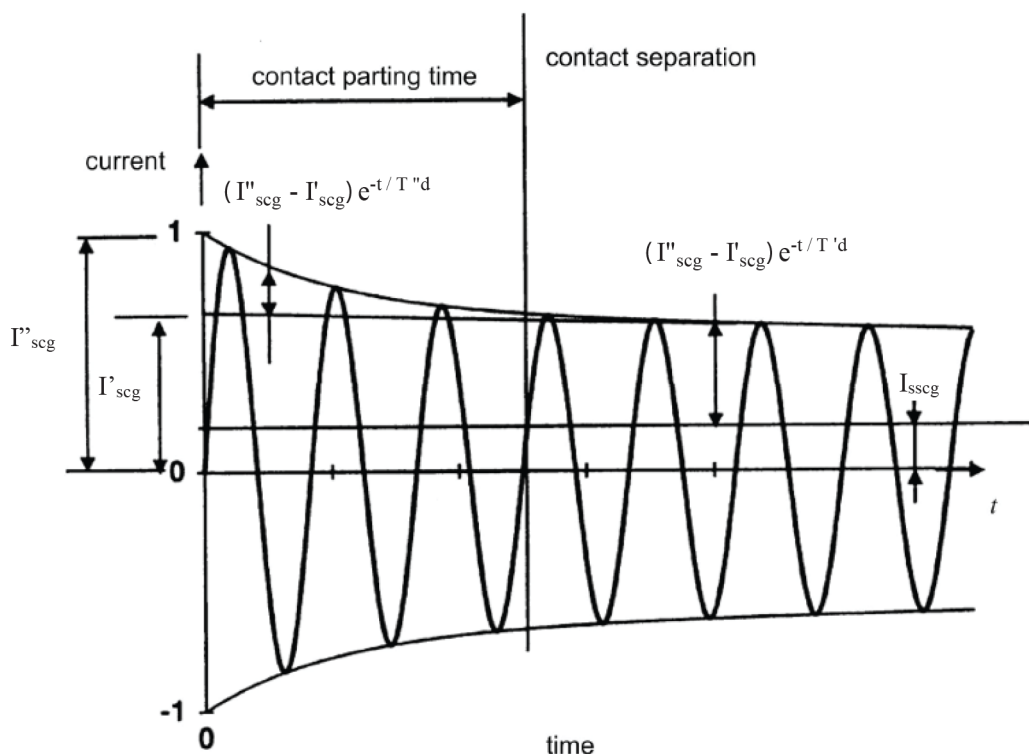
where I_{ACcs} is the peak value of the AC component of the rated

system-source short-circuit breaking current at contact separation, t_{cs} is the time of contact separation equal to the sum of relay time of 0,5 cycle and minimum opening time of the generator circuit-breaker; τ is the DC time constant of the rated system-source short-circuit breaking current equal to 133 ms;

- c) the project-specific degree of asymmetry does not exceed 100 %.

9.103.6.3.4 Symmetrical breaking current for three-phase generator-source faults

The AC component of the generator-source short-circuit breaking current can be significantly lower than the system-source short-circuit breaking current. Its value is measured from the envelope of the current excursion at the moment of contact separation when the source of the current is entirely from a generator without transformation. This envelope shall be calculated from a full-load rated power factor condition taking the generator constants into account. It shall be recognised that the AC component of this short-circuit current decays with the subtransient and transient time constants of the generator and is illustrated by Figure 50.



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Key

- I''_{scg} subtransient component of the generator-source short-circuit
- I'_{scg} transient component of the generator-source short-circuit
- I_{sscg} steady state component of the generator-source short-circuit
- T''_d subtransient time constant of the generator
- T'_d transient time constant of the generator

Figure 50 – Generator-source short-circuit current

9.103.6.3.5 Asymmetrical breaking current for three-phase generator-source faults

The AC component of the short-circuit current, when the source is from a generator without transformation, may decay faster than the DC component. The decay of the AC component is governed by the subtransient and transient time constants τ'_d , τ''_d , τ'_q , τ''_q of the generator and the decay of the DC component by the short-circuit time constant, $\tau_a = X''_d/\omega R_a$, where X''_d is the direct axis subtransient reactance and R_a represents the armature DC resistance. As a consequence, the DC component at contact separation can be higher than the peak value of the AC component. A survey of many generators with different ratings revealed that at full load and with the generator operating in the overexcited mode with a lagging power factor the degree of asymmetry could be even higher than 110 %. This value varies very little within a practical range of contact separation times.

In order to assess the capability of the generator circuit-breaker to interrupt a project-specific short-circuit current, provided that the making current does not exceed the rated making current capability, any combination of project-specific AC and DC components is permissible provided that the following conditions are met at the instant of contact separation:

- a) the project-specific AC component does not exceed the tested AC component of the rated generator-source short-circuit breaking current;

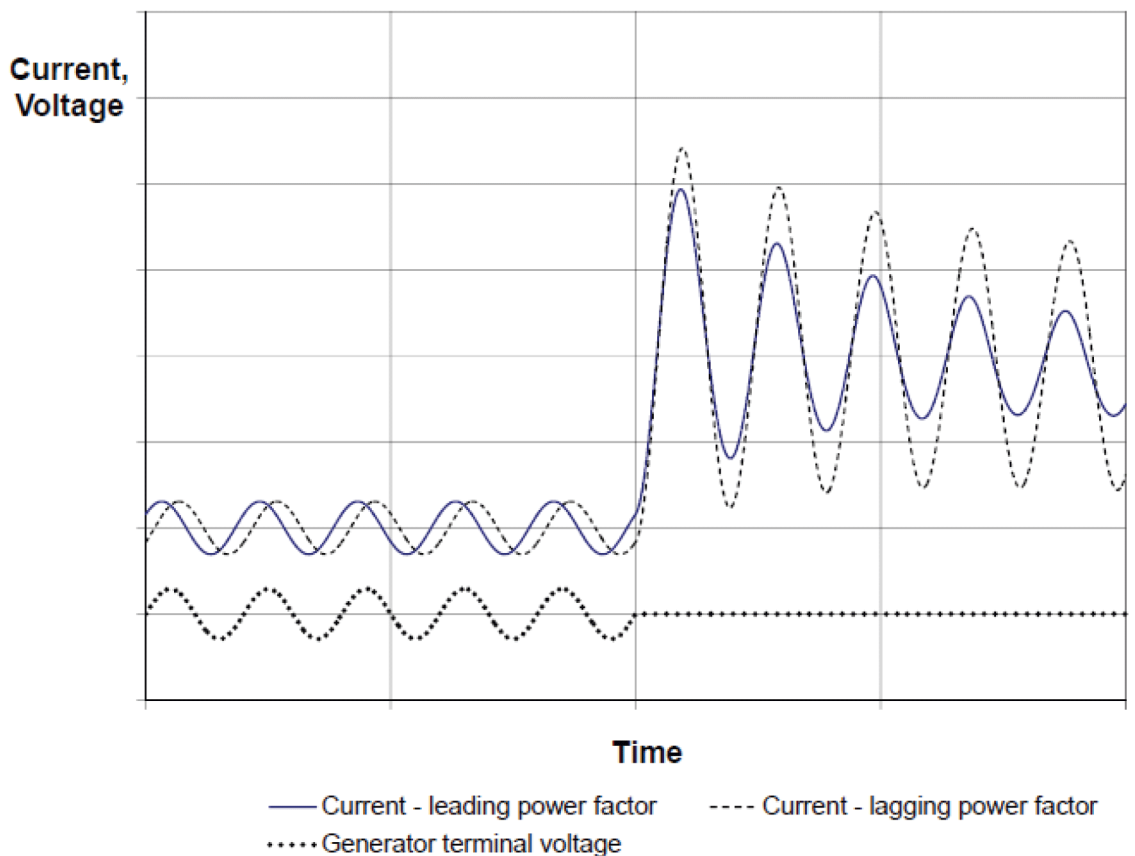
- b) the project-specific asymmetrical short-circuit current does not exceed the tested asymmetrical generator-source short-circuit breaking current;
- c) the project-specific degree of asymmetry from the generator-source might exceed 100 % provided that it is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum tested arcing time.

The capability of the generator circuit-breaker to force current to zero shall be ascertained by calculations in accordance with 9.103.6.3.6.3.

9.103.6.3.6 Asymmetrical breaking current for three-phase generator-source faults for maximum degree of asymmetry

9.103.6.3.6.1 General

The highest value of asymmetry occurs when, prior to the fault, the generator is operating in the underexcited mode with a leading power factor. Under this condition, the DC component may be higher than the peak value of the AC component of the short-circuit current and may lead to delayed current zeros. This principle is illustrated in Figure 51 and explained in 9.103.6.3.6.2 to 9.103.6.3.6.4.



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Figure 51 – Generator-source short-circuit current in the case of generator delivering power with lagging or leading power factor prior to fault initiation

When a short-circuit occurs, but prior to the fault the generator is carrying load with lagging power factor, the short-circuit current excursion is similar to the dashed curve, whereas for a leading power factor its excursion follows the solid curve in Figure 51.

The analysis of a large number of generators resulted in a degree of asymmetry in the order of 130 %. The AC component of the short-circuit current for this case is only 74 % of the assigned AC component of the rated generator-source short-circuit breaking current. It is recognised that the degree of asymmetry in some cases can reach very high values and exceed 130 %.

9.103.6.3.6.2 Origin of high asymmetries with delayed current zeros

A short-circuit current will flow if the generator circuit-breaker is closed into a short-circuit or as a consequence of a flashover in at least two phases to earth or between phases. If a short-circuit is initiated at voltage zero in one phase, this implies that the current in the corresponding phase exhibits the maximum degree of asymmetry.

The AC component of the short-circuit current will decrease exponentially in time with the short-circuit subtransient and transient time constants $\tau'_d, \tau''_d, \tau'_q, \tau''_q$ of the generator, depending on the specific case (often only the open circuit time constants $\tau'_{d0}, \tau''_{d0}, \tau'_{q0}, \tau''_{q0}$ are known. For computation of the short-circuit currents, the short-circuit time constants $\tau'_d, \tau''_d, \tau'_q, \tau''_q$ can be calculated using relatively simple equations). The DC component of the short-circuit current decays exponentially in time, with the short-circuit time constant $\tau_a = X''_d / (2\pi f \times R_a)$. Depending on the value of these time constants, which may vary in a relatively wide range for different sizes and designs of generators, the AC component of the short-circuit current may decrease faster than the DC component, leading to delayed current zeros for a certain period of time.

Typical values for time constants mentioned in the preceding paragraph are τ''_d and $\tau''_q = 25$ ms to 45 ms, $\tau'_d = 0,8$ s to 1,5 s, $\tau'_q = 250$ ms to 400 ms, $\tau_a = 150$ ms to 400 ms.

Figure 52 shows an example of a calculation of short-circuit current for a generator-source fault.

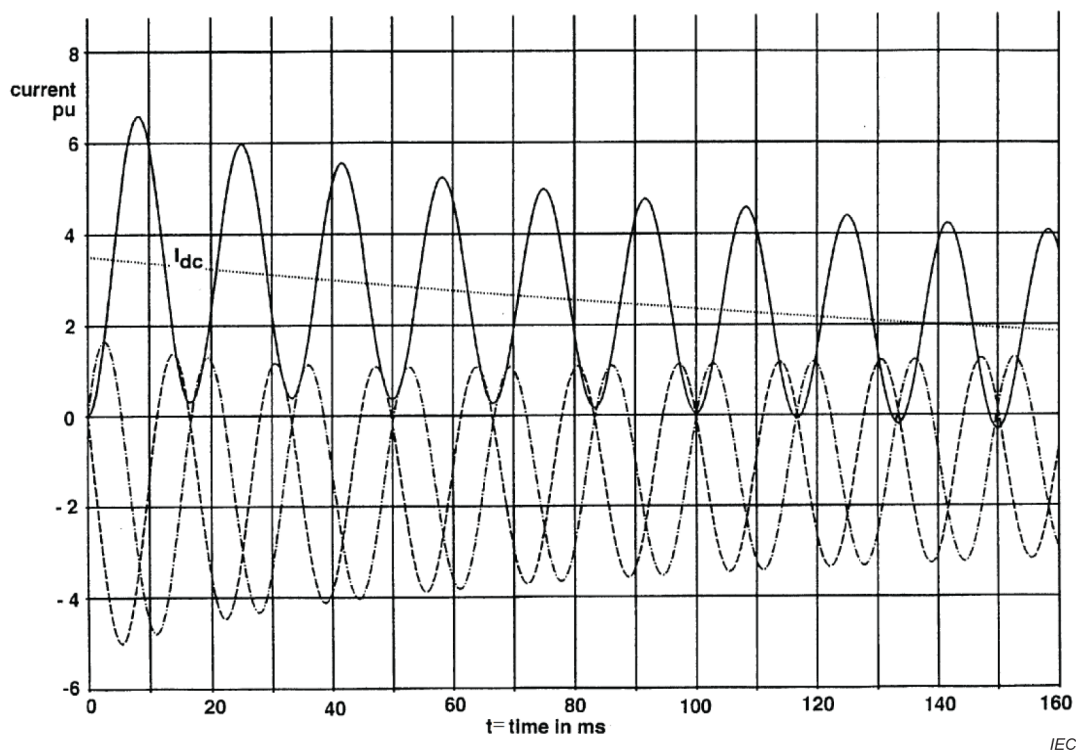


Figure 52 – Short-circuit current for generator-source fault

As described in 9.103.6.3.6, the highest value of asymmetry occurs when, prior to the fault, the generator is operating in the underexcited mode with a leading power factor. Under such a condition, the AC component of short-circuit current is lower than the assigned AC component of the rated generator-source short-circuit breaking current. In the case where the generator is carrying load with a lagging power factor prior to the fault, the asymmetry will be lower but the AC component will be higher.

Also circuits with doubly-fed induction machines can produce delayed current zeros and requirements for this case are given in Annex K. Wind farm applications can also produce similar requirements as given in Annex L.

9.103.6.3.6.3 Interruption of short-circuit currents with delayed current zeros

Additional resistance in series with the armature resistance, $R_a = X''_d / (2\pi f \tau_a)$, forces the DC component of the short-circuit current to decay faster. If R_{add} is the additional resistance, the DC component decreases more quickly with the time constant $\tau_a = X''_d / [2\pi f \times (R_a + R_{add})]$. Such additional resistance may be the connection from the generator to the fault location, but especially the arc resistance of the fault and the circuit-breaker arc resistance after contact separation. If there is an arc at the fault location, this arc resistance further reduces the time constant of the DC component from the beginning of the fault and the generator circuit-breaker arc resistance after contact separation. The values of these additional series resistances are normally high enough to force a fast decay of the DC component of the short-circuit current so that current zeros are produced.

Figure 53 shows the effect of the arc voltage on the current from the example shown in Figure 52, in the phase with the highest asymmetry. At the moment of contact separation, the decay of the DC component changes suddenly due to the influence of the arc voltage of the generator circuit-breaker. The DC component of the current does not decrease exponentially because arc resistance due to arc voltage is not constant. Arc resistance at the fault location was not taken into account in this example. However, within one cycle after contact separation, current zeros occur.

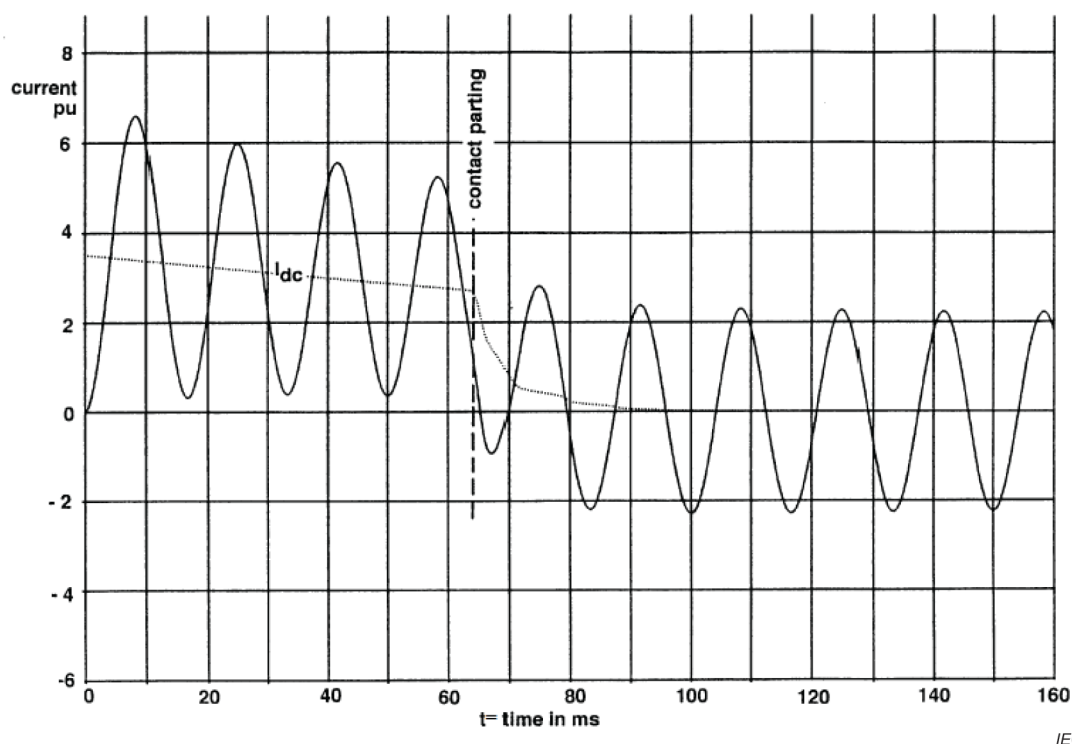


Figure 53 – Short-circuit current with circuit-breaker arc voltage after contact separation

9.103.6.3.6.4 Proof of the capability of the generator circuit-breaker

The capability of a generator circuit-breaker to interrupt short-circuit currents with delayed current zero crossings occurring in actual service conditions, may be difficult to demonstrate in high power test laboratories.

If, in some cases, three-phase tests in power test laboratories are possible, the conditions described in 7.105 shall be observed.

When the current exhibits delayed current zeros (i.e. degree of asymmetry > 100 %) the capability of the generator circuit-breaker to force current zeros shall be demonstrated by means of a calculation considering the effect of the arc voltage of the generator circuit-breaker on the prospective current. The arc voltage versus current characteristic of the generator circuit-breaker can be derived from test-duties 5, 6A and 6B. The developed model can be improved taking into account the test results (current, arc-voltage) measured during other tests like for example test-duty 4, system-source short-circuit and out-of-phase current breaking tests. The arc voltage versus current characteristic can be used as described in [5] to model the generator circuit-breaker. To be able to investigate the behaviour of the circuit-breaker during the interruption of currents with delayed current zeros the arc voltage characteristic shall be transferred into a mathematical model. From the arc voltage $u_{arc}(i,t)$ and the current $i(t)$ the arc resistance $R_{arc}(i,t)$ can be obtained. In order to model the behaviour of the generator circuit-breaker a non-linear time-varying resistance of the value $R_{arc}(i,t)$ shall be inserted into the simulation at the time of the separation of the contacts of the generator circuit-breaker.

Typically, every generator circuit-breaker type is represented by its own model for the purpose of these studies.

The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:

- 1) Fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry.
- 2) Fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

For each of the situations 1 and 2 the following two cases shall be investigated:

- a) Generator at no-load with the generator circuit-breaker closing into a three-phase fault. In the computation, the arc voltage of the generator circuit-breaker after contact separation shall be taken into account.
- b) Generator in service with leading power factor. An arcing fault is assumed in at least two phases. For the computation, arc voltage at the fault location starting at the initiation of the fault, and the arc voltage of the generator circuit-breaker starting at contact separation shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum tested arcing time).

9.103.6.3.7 Guide for the selection of the class of the generator circuit-breaker

9.103.6.3.7.1 General

In order to select the class of the generator circuit-breaker which is required for a specific application, the following steps shall be followed and the requirements laid down in 9.103.6.3.7.2, 9.103.6.3.7.3 and 9.103.6.3.7.4 shall be met simultaneously.

The asymmetrical breaking current is calculated in the same manner as for the system-source short-circuit current, see formula in 9.103.6.3.3. In case of generator-source short-circuit breaking currents, this formula is used with degrees of asymmetry which could exceed 100 %. This formula is not used for testing purposes but for the evaluation of the suitability of generator circuit-breakers for plant-specific applications.

9.103.6.3.7.2 Case of generator delivering power with lagging power factor prior to fault

Calculate the RMS value of the AC component of the prospective generator-source short-circuit current I_{scg_lagg} and the asymmetrical current in the case of a three-phase fault occurring between the generator-circuit-breaker and the associated step-up transformer with the generator delivering power with lagging power factor prior to fault. Fault initiation shall be assumed at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry. These two values shall be calculated at the instant of intended contact separation in the phase exhibiting the maximum degree of asymmetry.

Select a generator circuit-breaker class G1 or G2 with the RMS value of the AC component of the rated generator-source short-circuit breaking current I_{scg} not less than I_{scg_lagg} .

- a) For a generator circuit-breaker class G1 the asymmetrical short-circuit current calculated at the instant of intended contact separation shall not exceed the asymmetrical generator-source short-circuit breaking current of the generator circuit-breaker equal to

$$I_{scg} \sqrt{1 + 2 \times (1,1)^2} .$$

- b) For a generator circuit-breaker class G2 the asymmetrical short-circuit current calculated at the instant of intended contact separation shall not exceed the asymmetrical generator-source short-circuit breaking current of the generator circuit-breaker equal to

$$I_{scg} \sqrt{1 + 2 \times (1,3)^2} .$$

9.103.6.7.7.3 Case of generator unloaded prior to fault

Calculate the RMS value of the AC component I_{scg_unl} and the degree of asymmetry of the prospective generator-source short-circuit current in the case of a three-phase fault occurring between the generator-circuit-breaker and the associated step-up transformer with the generator unloaded prior to fault. No fault arc voltage shall be taken into consideration for the calculations. Fault initiation shall be assumed at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry. The RMS value of the AC component and the degree of asymmetry of this prospective generator-source short-circuit current shall be calculated at the instant of intended contact separation in the phase exhibiting the maximum degree of asymmetry.

- If the calculated degree of asymmetry does not exceed 110 %, a generator circuit-breaker having I_{scg} not less than I_{scg_unl} with either class G1 or class G2 is adequate for the application provided that it is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum tested arcing time. The following two situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:
 - fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;
 - fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

In the computation, the arc voltage of the generator circuit-breaker after contact separation shall be taken into account. No fault arc voltage shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum tested arcing time).

- If the calculated degree of asymmetry is between 110 % and 130 %, one of the following conditions shall be met:
 - 1) Select a generator circuit-breaker class G1 with the RMS value of the AC component of the rated generator-source short-circuit breaking current I_{scg} not less than I_{scg_unl} provided that the following conditions are met:
 - i) The asymmetrical short-circuit current calculated at the instant of intended contact separation does not exceed the asymmetrical generator-source short-circuit breaking current of the generator circuit-breaker.
 - ii) It is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum tested arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:
 - fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;
 - fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

In the computation, the arc voltage of the generator circuit-breaker after contact separation shall be taken into account. No fault arc voltage shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum tested arcing time).

- 2) Select a generator circuit-breaker class G1 with $0,74 I_{scg}$ not less than I_{scg_unl} provided that it is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum tested arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:

- fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;
- fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

In the computation, the arc voltage of the generator circuit-breaker after contact separation shall be taken into account. No fault arc voltage shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum tested arcing time).

- 3) Select a generator circuit-breaker with class G2 and I_{scg} not less than I_{scg_unl} provided that it is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum tested arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:

- fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;
- fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

In the computation, the arc voltage of the generator circuit-breaker after contact separation shall be taken into account. No fault arc voltage shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum tested arcing time).

- If the calculated degree of asymmetry exceeds 130 %, one of the following conditions shall be met:

- 1) Select a generator circuit-breaker class G1 with the RMS value of the AC component of the rated generator-source short-circuit breaking current I_{scg} higher than I_{scg_unl} provided that the following conditions are met:

- i) The asymmetrical short-circuit current calculated at the instant of intended contact separation does not exceed the asymmetrical generator-source short-circuit breaking current of the generator circuit-breaker.

- ii) It is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum tested arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:

- fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;
- fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

In the computation, the arc voltage of the generator circuit-breaker after contact separation shall be taken into account. No fault arc voltage shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum tested arcing time).

- 2) Select a generator circuit-breaker class G1 with $0,74 I_{scg}$ higher than I_{scg_unl} provided that the following conditions are met:
 - i) The asymmetrical short-circuit current calculated at the instant of intended contact separation does not exceed $0,74 \times I_{scg} \sqrt{1 + 2 \times (1,3)^2}$.
 - ii) It is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum tested arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:
 - fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;
 - fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

In the computation, the arc voltage of the generator circuit-breaker after contact separation shall be taken into account. No fault arc voltage shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum tested arcing time).

- 3) Select a generator circuit-breaker with class G2 and I_{scg} higher than I_{scg_unl} so that the following conditions are met:
 - i) The asymmetrical short-circuit current calculated at the instant of intended contact separation does not exceed the asymmetrical generator-source short-circuit breaking current of the generator circuit-breaker.
 - ii) It is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum tested arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:
 - fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;
 - fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

In the computation, the arc voltage of the generator circuit-breaker after contact separation shall be taken into account. No fault arc voltage shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum tested arcing time).

9.103.6.7.7.4 Case of generator delivering power with leading power factor prior to fault

Calculate the RMS value of the AC component I_{scg_lead} and the degree of asymmetry of the prospective generator-source short-circuit current in the case of a three-phase fault occurring between the generator-circuit-breaker and the associated step-up transformer with the generator loaded with leading power factor prior to fault. Fault initiation shall be assumed at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry. The RMS value of the AC component and the degree of asymmetry of this prospective generator-source short-circuit current shall be calculated at the instant of intended contact separation in the phase exhibiting the maximum degree of asymmetry.

- If the calculated degree of asymmetry does not exceed 110 %, a generator circuit-breaker having I_{scg} not less than I_{scg_lead} with either class G1 or class G2 is adequate for the application provided that it is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum tested arcing time. The following two situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:
 - fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;
 - fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

In the computation an arcing fault is assumed in at least two phases. For the computation, arc voltage at the fault location starting at the initiation of the fault, and the arc voltage of the generator circuit-breaker starting at contact separation shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum tested arcing time).

- If the calculated degree of asymmetry is between 110 % and 130 %, one of the following conditions shall be met:
 - 1) Select a generator circuit-breaker class G1 with the RMS value of the AC component of the rated generator-source short-circuit breaking current I_{scg} not less than I_{scg_lead} provided that the following conditions are met:
 - i) The asymmetrical short-circuit current calculated at the instant of intended contact separation does not exceed the asymmetrical generator-source short-circuit breaking current of the generator circuit-breaker.
 - ii) It is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum tested arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:
 - fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;
 - fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

In the computation an arcing fault is assumed in at least two phases. For the computation, arc voltage at the fault location starting at the initiation of the fault, and the arc voltage of the generator circuit-breaker starting at contact separation shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum tested arcing time).

- 2) Select a generator circuit-breaker class G1 with $0,74 I_{scg}$ not less than I_{scg_lead} provided that it is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum tested arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:

- fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;
- fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

In the computation an arcing fault is assumed in at least two phases. For the computation, arc voltage at the fault location starting at the initiation of the fault, and the arc voltage of the generator circuit-breaker starting at contact separation shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum tested arcing time).

- 3) Select a generator circuit-breaker with class G2 and I_{scg} not less than I_{scg_lead} provided that it is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum tested arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:

- fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;
- fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

In the computation an arcing fault is assumed in at least two phases. For the computation, arc voltage at the fault location starting at the initiation of the fault, and the arc voltage of the generator circuit-breaker starting at contact separation shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum tested arcing time).

- If the calculated degree of asymmetry exceeds 130 %, one of the following conditions shall be met:
 - 1) Select a generator circuit-breaker class G1 with the RMS value of the AC component of the rated generator-source short-circuit breaking current I_{scg} higher than I_{scg_lead} provided that the following conditions are met:
 - i) The asymmetrical short-circuit current calculated at the instant of intended contact separation does not exceed the asymmetrical generator-source short-circuit breaking current of the generator circuit-breaker.

- ii) It is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum tested arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:

- fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;
- fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

In the computation an arcing fault is assumed in at least two phases. For the computation, arc voltage at the fault location starting at the initiation of the fault, and the arc voltage of the generator circuit-breaker starting at contact separation shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum tested arcing time).

- 2) select a generator circuit-breaker class G1 with $0,74 I_{scg}$ higher than I_{scg_lead} provided that the following conditions are met:

- i) The asymmetrical short-circuit current calculated at the instant of intended contact separation does not exceed $0,74 \times I_{scg} \sqrt{1+2 \times (1,3)^2}$.

- ii) It is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum tested arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:

- fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;
- fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

In the computation an arcing fault is assumed in at least two phases. For the computation, arc voltage at the fault location starting at the initiation of the fault, and the arc voltage of the generator circuit-breaker starting at contact separation shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum tested arcing time).

- 3) Select a generator circuit-breaker with class G2 and I_{scg} higher than I_{scg_lead} so that the following conditions are met:

- i) The asymmetrical short-circuit current calculated at the instant of intended contact separation does not exceed the asymmetrical interrupting capability of the generator circuit-breaker.

- ii) It is shown with calculations that the generator circuit-breaker by means of its arc voltage is capable of forcing the current to zero within its maximum tested arcing time. The following two typical situations shall be considered for a particular generator-source short-circuit current for a three-phase fault:

- fault initiation at voltage zero in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;

- fault initiation at voltage maximum in one phase which implies that the current in the corresponding phase is symmetrical.

In the computation an arcing fault is assumed in at least two phases. For the computation, arc voltage at the fault location starting at the initiation of the fault, and the arc voltage of the generator circuit-breaker starting at contact separation shall be taken into account.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum tested arcing time).

9.103.6.7.7.5 Case of synchronous compensators

Subclauses 9.103.6.3.7.2, 9.103.6.3.7.3 and 9.103.6.3.7.4 are applicable with the following modifications: for the cases of machine delivering power prior to fault, a power factor equal to 0 shall be taken into account for the computations. Special attention shall be paid to these cases because the degree of asymmetry of the fault current might attain values higher than those observed in conventional generator applications.

9.103.6.7.8 Making current capability

The short-circuit current into which the generator circuit-breaker shall close is determined by the higher value of either the system-source short-circuit current or the generator-source short-circuit current. In the majority of applications the system-source short-circuit current is higher than the generator-source short-circuit current.

The ratio of the peak value of the short-circuit current to the RMS value of the AC component of the rated system-source short-circuit breaking current of the generator circuit-breaker is determined by the following equation:

$$\frac{I_{mc}}{I_{sc}} = \sqrt{2} \left(e^{-\frac{t}{133}} + 1 \right) = 2,74$$

where t is approximately 1/2 cycle in ms.

In cases where the generator-source short-circuit current might be higher than the system-source short-circuit current special considerations are necessary. The required generator-source symmetrical breaking current at contact separation depends on the decay of the AC current with the generator time constants τ'_d , τ''_d , τ'_q , and τ''_q varies from one application to another. The required making current shall be established by calculation. The equation in D.4.2 could be used for an estimation.

9.103.6.7.9 Faults in the case of three-winding step-up transformers

When two generators are connected to the high-voltage system by means of a three-winding step-up transformer, special attention should be paid to the system-source short-circuit current. In the case of a three-phase earthed fault occurring at location F in Figure 54, both the AC component and the degree of asymmetry of the system-source short-circuit current which should be interrupted by the Generator circuit-breaker #1 can attain very high values because of the additional contribution to the current of the Generator #2.

Because the AC component of the fault current fed by the Generator #2 is not constant, the ratio of the peak value of the short-circuit current seen by Generator circuit-breaker #1 to the RMS value of the AC component of the short-circuit breaking current (at contact separation of Generator circuit-breaker #1) could exceed the standard value of 2,74 (refer to Annex I).

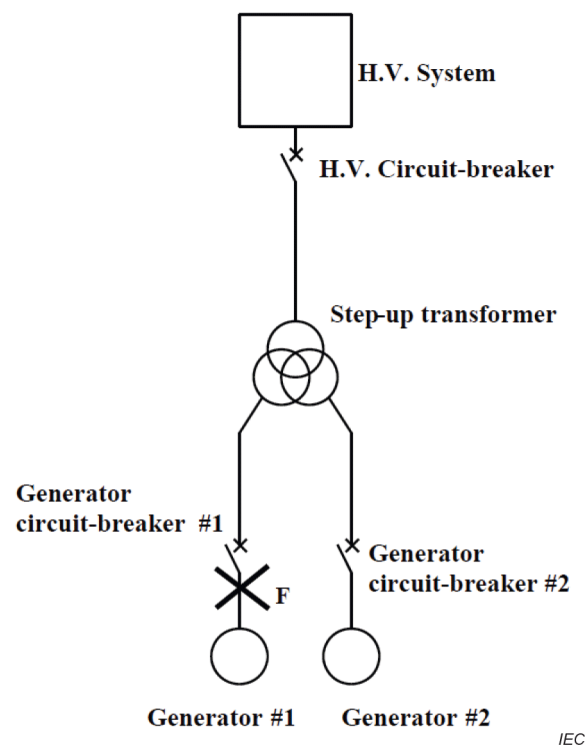


Figure 54 – Single-line diagram of a power plant with two generators connected to the high-voltage system by means of a three-winding step-up transformer

In addition the fault current fed by Generator #2 in the case of a fault occurring at location F generally features a relatively small magnitude and a very high degree of asymmetry and it often exhibits several cycles without natural zero crossing (refer to Annex I). These delayed current zeros have totally different causes and are extremely dissimilar in comparison with the currents associated with generator terminal faults and out-of-phase synchronising. The waveform of this current is obtained as the superposition of two contributions, i.e. one oscillating at power frequency and a transient one whose course is dictated by the time constants of the circuit. The transient component consists of two decaying exponential functions: this waveform is over-damped as the damping contribution prevails over the oscillating one. If the Generator circuit-breaker #2 has to interrupt this current, the capability of the generator circuit-breaker to force current zeros shall be demonstrated by means of calculations considering the effect of the arc voltage of the generator circuit-breaker on the prospective short-circuit current.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum tested arcing time).

9.103.7 TRV rating for system-source and generator-source short-circuits

9.103.7.1 Background

The principles in IEEE Std C37.011™ are applicable when TRV problems are considered during the interruption process of short-circuit currents by a generator circuit-breaker. An exception is that the short-line fault rating does not apply.

The generator circuit-breaker is a special application because it is installed between a generator and step-up transformer, the characteristics of which largely dictate the waveshape of the prospective TRV for various duties. Therefore, the TRV ratings are defined for the generator-source and the system-source faults, depending on the generator or transformer ratings (see Table 3 and Table 4). These ratings are determined for the first-pole-to-clear and for symmetrical current interruption in case of three-phase earthed faults. Rated TRVs are prospective values assuming an ideal generator circuit-breaker. These values may be modified by the generator circuit-breaker characteristics or by the asymmetry of the current.

A system with a TRV that exceeds the rated values shall be modified in such a way as to mitigate the TRV. This is achieved by placing a low ohmic resistor in parallel with the main interrupting device of the generator circuit-breaker or by connecting capacitors to its terminals. Capacitors can be installed between the step-up transformer and the generator circuit-breaker, or between the generator and the generator circuit-breaker, or at both sides, or capacitors can be part of the generator circuit-breaker assembly. The interrupting capability demonstrated by relevant type tests is valid only if capacitors of the same capacitance value as taken into account during the tests are installed according to the tested configuration. An interrupting capability different than that tested cannot be confirmed for the generator circuit-breaker with a different capacitance value of the capacitors used to mitigate the TRV.

9.103.7.2 Basis of standardised TRV parameters for the interrupting of short-circuit currents

9.103.7.2.1 General

Several cases should be considered based on the following:

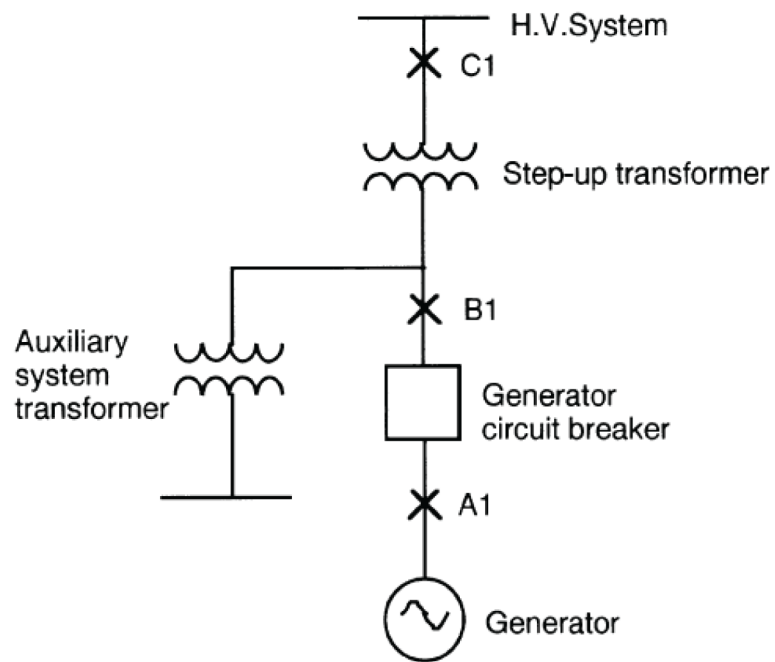
- a) system-source faults where the short-circuit is located on the generator side of the generator circuit-breaker;
- b) generator-source faults where the short-circuit is located on the transformer side of the generator circuit-breaker.

The neutral of the generator is not-effectively earthed, thus the single-phase to earth fault current is not significant. A three-phase fault is the most severe case and gives the maximum short-circuit current and the maximum TRV rate.

9.103.7.2.2 Influence of the power plant configuration

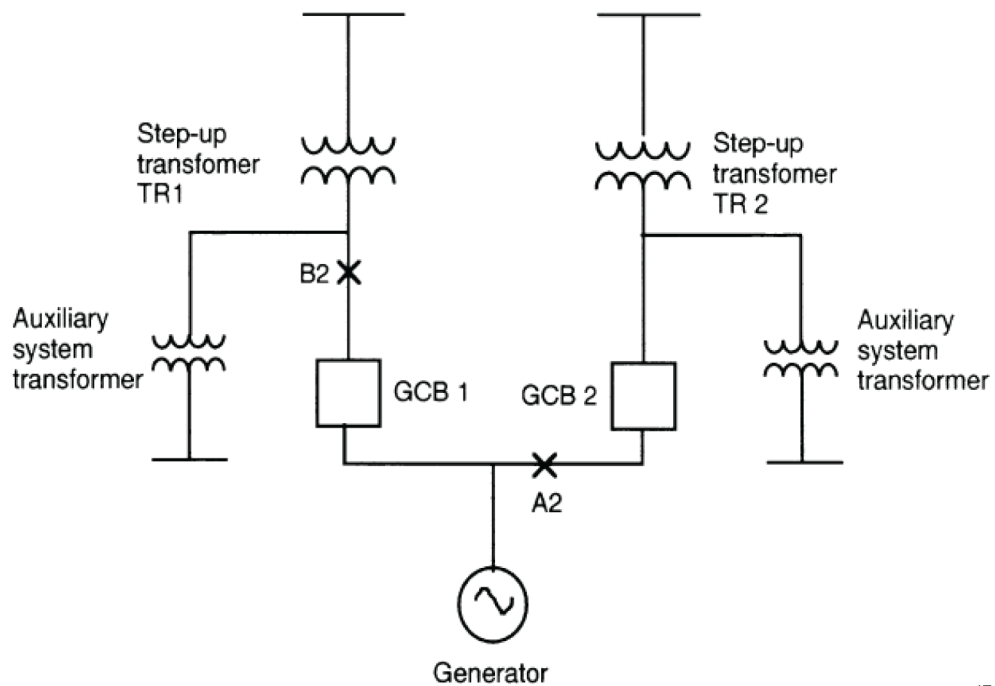
9.103.7.2.2.1 General

The most commonly used power plant single-line configuration is shown in Figure 55, where the generator and the step-up transformer have essentially the same rating. Other arrangements having the same total rating as in Figure 55 are shown in Figure 56 and Figure 57. In each case, the auxiliary transformer is a minor source of short-circuit current and can be neglected.



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Figure 55 – Single-line diagram of unit generator system



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Figure 56 – Single-line diagram of half-sized transformer unit system

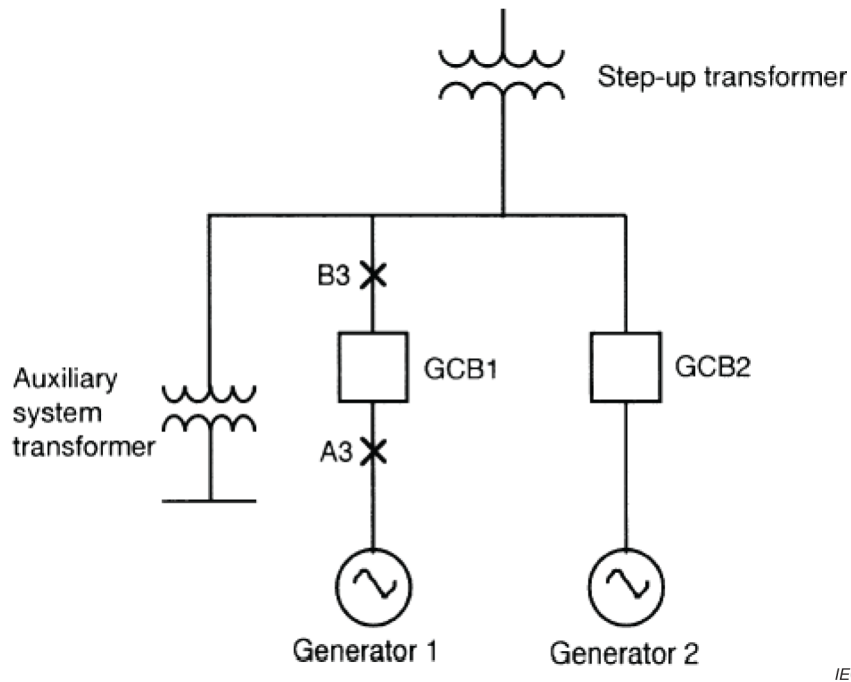


Figure 57 – Single-line diagram of system with half-sized generators

9.103.7.2.2.2 System-source faults

For a system-source fault at A1 in Figure 55, the short-circuit current is determined by the sum of the transformer short-circuit reactance, X_T and the high-voltage (HV) system reactance, X_S . The maximum value of short-circuit current is obtained for a given transformer when X_S is minimum or assumed to be zero.

The natural frequency of the transformer is much higher than the natural frequency of the HV system. Therefore, the TRV first oscillates at the value of voltage drop in the transformer, $I_{sc} \times X_T \sqrt{2}$ to the prospective value of $1,5 I_{sc} \times X_T \sqrt{2}$, where I_{sc} is the RMS value of the available symmetrical short-circuit current.

The voltage drop in the transformer is equal to the total power-frequency recovery voltage for $X_S = 0$. Therefore, the TRV rate is maximum when the short-circuit current is maximum. This is contrary to what is observed in HV systems, where the TRV rate increases when the short-circuit current decreases.

Practically, the maximum observed TRV rate is 75 % to 90 % of the theoretical value determined from the natural frequency of the step-up transformer, taking into account the capacitance of the low-voltage side, including the auxiliary transformer.

A larger reduction in TRV rate is observed if capacitors are installed on the low voltage side of the step-up transformer. The TRV rate is reduced from 6 kV/ μ s to a value of 4 kV/ μ s with the addition of 0,1 μ F to 0,2 μ F of capacitance per phase. The standardised values of TRV rate do not take into account this capacitance.

For a system-source fault at A2 in Figure 56, the situation is the same as for a fault at A1 in Figure 55, except that the short-circuit current and the TRV parameters seen by the individual circuit-breakers are related to a step-up transformer of lower rating.

For a system-source fault at A3 in Figure 57, the short-circuit current is higher because the fault is also fed by the generator, G2. However, the TRV rate is lower because of the capacitance of the G2 generator windings. If the generator G2 is out of service, the situation is the same as for a fault at A1 in Figure 55, except that the generator G1 is approximately half the rating.

In the special case where the generator circuit-breaker is connected to the step-up transformer by shielded cables, the additional capacitance of the cables modifies the prospective TRV, as illustrated in Annex F.

9.103.7.2.2.3 Generator-source faults

For a generator-source fault at B1 in Figure 55, the short-circuit current is usually lower than for the system-source fault at A1, because of the higher reactance of the generator windings.

Although the short-circuit current and TRV rate are lower for generator-source faults than for system-source faults, generator-source faults cannot be ignored because of the high degree of asymmetry of the short-circuit current (see 9.103.6.3.5), thus the corresponding TRV parameters shall be specified.

For a generator-source fault at C1 in Figure 55, on the HV side of the transformer, the short-circuit current is lower when compared to a fault at B1. This fault location can usually be ignored because the resulting stresses on the generator circuit-breaker are much lower than for faults at A1 and B1.

The TRV results from transformer and generator voltage oscillations. The magnitude of each oscillation is approximately proportional to the transformer and generator reactances, respectively.

For a generator-source fault at B2 in Figure 56, if the transformer TR2 is out of service, the oscillation is the same as for a fault at B1 in Figure 55 with the short-circuit current and TRV parameters determined by the rating of the generator. If the transformer TR2 is in service and the generator circuit-breaker GCB1 is the first to open, the short-circuit current is higher than for a fault at B1 in Figure 55, and TRV parameters are intermediate in value, between TRV parameters for the full-sized generator and TRV parameters for the half-sized transformer. This case needs special consideration to determine the required TRV parameters.

An example of how to apply generator circuit-breakers in power stations with multiple generators is given in Annex E.

9.103.7.2.2.4 Faults in the presence of current limiting reactors

Owing to the very small inherent capacitance of a number of current limiting reactors, the natural frequency of transients involving these reactors can be very high. A generator circuit-breaker installed immediately in series with such type of reactor will face a high frequency TRV when clearing a terminal fault (reactor at supply side of generator circuit-breaker) or clearing a fault behind the reactor (reactor at load side of generator circuit-breaker). The resulting TRV frequency can exceed the standardised TRV values.

In these cases, it is necessary to take mitigation measures, such as the application of capacitors in parallel to the reactors or connected to earth. The available mitigation measures are very effective and cost efficient. It is strongly recommended to use them, unless it can be demonstrated by tests that a generator circuit-breaker can successfully clear faults with the required high frequency TRV.

The mitigation method should be such that the rate-of-rise of TRV for the fault current, as limited by the series reactor, is reduced to a value lower than the standard values, depending on the generator circuit-breaker ratings.

Based on the preceding considerations, no rated values of TRV and no special test-duty are specified for this fault case.

9.103.7.3 Rated prospective transient recovery voltage

The rated voltages of generators and associated step-up transformers are not standardised. The short-circuit currents therefore will vary widely.

After reviewing available equipment data, TRV parameters were standardised based on the power rating of the step-up transformer and generator, respectively.

Table 3 gives the parameters of the rated TRV applicable when the fault is located on the generator side of the generator circuit-breaker and the source of the short-circuit current is the power system through a step-up transformer. The values are applicable to the interrupting operation of the AC component of rated system-source short-circuit breaking current according to 5.101.2 and symmetrical interrupting capability for three-phase faults according to 9.103.6.3.2. For the asymmetrical interrupting capability for three-phase faults according to 9.103.6.3.3, the same prospective TRV parameters shall be used but the actual TRV will be less severe due to the asymmetry. At the instant of current interruption at current zero, the power-frequency recovery voltage is shifted in phase due to the DC component of the current and the TRV oscillates around a lower instantaneous power-frequency recovery voltage value than for the symmetrical case.

Table 4 gives the parameters of the rated TRV applicable when the fault is located on the transformer side of the generator circuit-breaker and the source of the short-circuit current is the generator. The values are applicable to the interrupting operation of the AC component of rated generator-source short-circuit breaking current according to 5.101.3 and generator-source symmetrical interrupting capability for three-phase faults according to 9.103.6.3.4. For the generator-source asymmetrical interrupting capability for three-phase faults according to 9.103.6.3.5, and the generator-source asymmetrical interrupting capability for maximum degree of asymmetry according to 9.103.6.3.6, the same prospective TRV parameters are to be used but the actual TRV will be less severe due to the asymmetry for the same reason stated above. At the interruption of the short-circuit current with maximum asymmetry, the transient oscillation of the recovery voltage will be very small or even non-existent since at the moment of short-circuit current interruption, the power-frequency voltage value may be very small or zero.

TRV parameters listed in Table 3 and Table 4 apply to the first-pole-to-clear for a three-phase earthed fault, with a first-pole-to-clear factor equal to 1,5. The TRV oscillates as shown in Figure 13.

If the generator circuit-breaker requires that the prospective TRV be modified by the addition of capacitors, then the amount of equivalent capacitance required shall be given in the test report and on the nameplate. It is recognised that connecting a shielded cable or a cable bus between the generator and the circuit-breaker may provide this capacitance.

The curve rises to the crest value, u_c equal to $1,84U_r$ where U_r is the RMS value of the rated voltage in kV and the value 1,84 is equal to

$$\sqrt{\frac{2}{3}} \times 1,5 \text{ (= first-pole-to-clear factor)} \times 1,5 \text{ (= amplitude factor)}$$

The rising part of the TRV curve is bounded by two lines. One line goes through the origin and tangent to the TRV curve with a slope equal to the rate-of-rise of the TRV (RRRV). The other line has the same slope and goes through the point t_d , time delay.

For more information about symbols and terminology related to TRV waveforms, see Table G.2 and Figure G.1 in Annex G.

The reference lines for the prospective transient recovery voltage wave of the test circuit shall at no time be below the specified reference lines required for the application.

The manufacturer shall approve the extent by which the TRV envelope of the test circuit exceeds the specified reference line.

9.103.7.4 First-pole-to-clear factor

The first-pole-to-clear factor is 1,5 and corresponds to the worst condition of a three-phase earthed fault on a non-effectively earthed system.

9.103.7.5 Amplitude factor

Analysis of the available data gives 1,5 as a realistic value, with no capacitance connected to the terminals of the generator circuit-breaker.

9.103.8 Rated load breaking current

9.103.8.1 General

During normal service of the generator, the load current is reduced to zero before an opening operation of the generator circuit-breaker is initiated. However, the interruption of full load current may be required occasionally for emergency circumstances. Prospective transient recovery voltages are shown in Table 5 for this situation.

9.103.8.2 Power-frequency recovery voltage

The single-line diagram, Figure 58, and the equivalent circuit, Figure 59, show a generator supplying a load having an impedance Z_L through a transformer T with a reactance, X_t and a transmission line with a reactance X_L . The generator is synchronised with the rest of the system symbolised by a single generator E''_{Gn} , a single transformer X_{tn} , and a single load, Z_n .

In comparison with the sum of reactances from the generator G1 to the load Z_L , the short-circuit reactance of the HV network is small and can be neglected. Thus, when I_L is interrupted and the network only serves the load Z_L , there is no voltage drop in the HV network.

The magnitude of the load current I_L determines voltage drops through the reactances of generator G1 and transformer T.

These voltage drops have a phase shift of 90° leading, to the current I_L , irrespective of the load phase angle ϕ , as shown on the vector diagrams of Figure 60 and Figure 61, the latter corresponding to an almost pure resistive load.

After the interruption of I_L , these voltage drops are zero. The voltage on the transformer side of the generator circuit-breaker decreases from U_p to U_{np} , with the natural frequency of the transformer side circuit. The voltage on the generator side of the generator circuit-breaker increases from U_p to E''_{G1} with the natural frequency of the generator side circuit. The amplitude of the voltage across the transformer, which was $\sqrt{2}I_L X_t$ before interruption of I_L , drops to zero.

For rapid changes in load conditions of the generator, the subtransient reactance X''_d shall be taken into account and the amplitude of the voltage drop U_s is equal to $\sqrt{2}I_L X''_d$.

The power-frequency recovery voltage appearing across the generator circuit-breaker terminals (see Figure 62) consists of the sum of the voltage variations on each side of the generator circuit-breaker, following load interruption, i.e., $I_L(X''_d + X_t)$, in kV RMS, and for the first-pole-to-clear in a three-phase system the voltage is equal to $1,5I_L(X''_d + X_t)$. The power-frequency recovery voltage across the generator circuit-breaker terminals expressed in p.u. (per unit) of the rated voltage is equal to

$$1,5 \frac{U_r}{\sqrt{3}} \times (x''_d + x_t)$$

where

U_r is the rated voltage in p.u.;

x''_d is the per unit reactance value of the generator;

x_t is the per unit reactance value of the transformer.

In practice, even for the larger units, the sum of $x''_d + x_t$ does not exceed 0,5 p.u., therefore the recovery voltage across the generator circuit-breaker during a full load interruption will not exceed 50 % of the recovery voltage value which appears after a short-circuit interruption and consequently is standardised at

$$1,5 \frac{U_r}{\sqrt{3}} \times 0,5 = 0,43U_r$$

for interruption of the rated normal current of the generator.

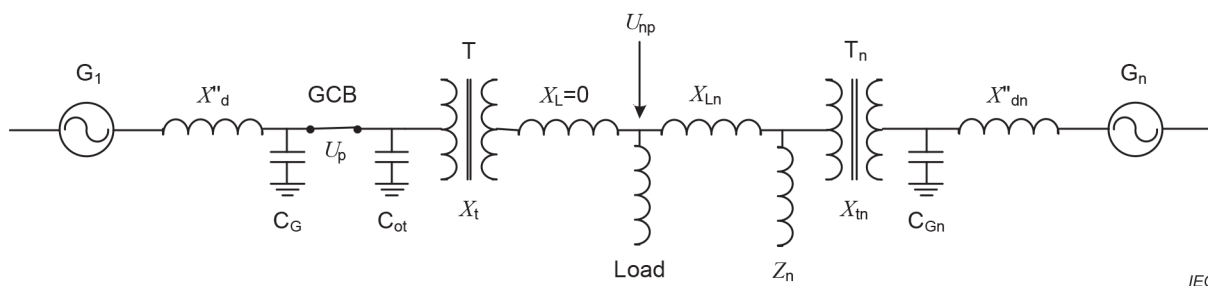


Figure 58 – Single-line diagram of power system

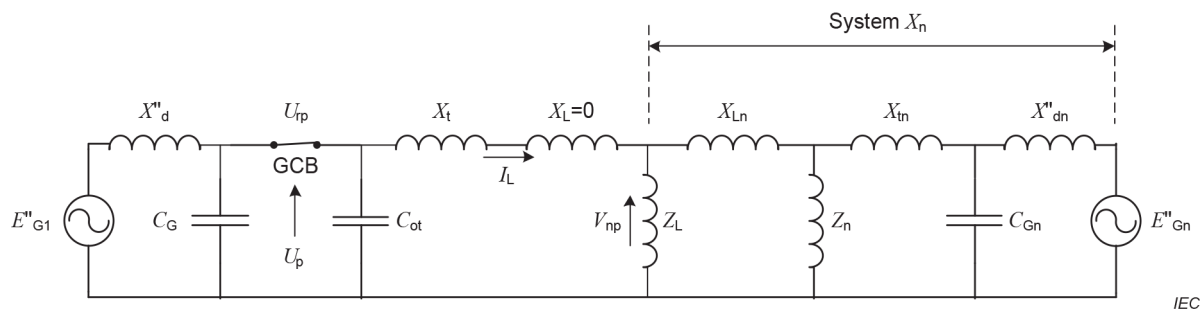


Figure 59 – Equivalent circuit of power system

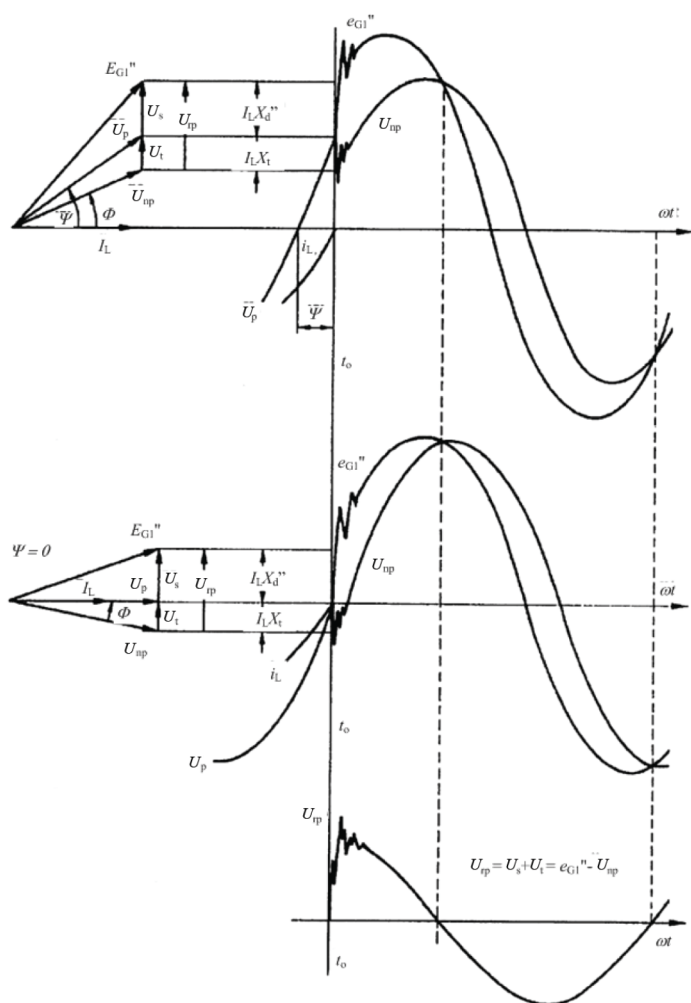


Figure 60 – Voltage diagram for lagging power factor load

Figure 61 – Voltage diagram for unity power factor load

Figure 62 – Recovery voltage across the generator circuit-breaker

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The following Key applies to Figure 58, Figure 59, Figure 60, Figure 61 and Figure 62

C_G	capacitance on generator side	X_n	HV system short-circuit reactance = $X_{dn} + X_{tn} + X_{Ln}$
C_{ot}	capacitance on transformer side	X_t	transformer reactance
$E_{G1}'' (e_{G1}'')$	generator voltage at the generator circuit-breaker terminals after time t_o	Z_L	load impedance
$I_L (i_L)$	load current	G1	generator (load current I_L)
U_{np}	system voltage (at the load terminals)	GCB	generator circuit-breaker
$U_p (u_p)$	operating voltage at the circuit-breaker terminals before time t_o	T	transformer
$U_{rp} (u_{rp})$	recovery voltage across the switch	ψ	phase angle at the generator circuit-breaker location
X_d''	subtransient generator reactance	ϕ	load phase angle
X_L	line reactance (from transformer to load)	ω	angular system frequency

9.103.8.3 Prospective transient recovery voltage

The TRV across the first-pole-to-clear for load current breaking is normally a dual frequency oscillatory curve, as shown in Figure 63; the natural frequency of the transformer being higher than the natural frequency of the generator. Also, the first peak of the transformer side voltage is smaller than the first peak of the generator side voltage because X_t is always smaller than X_d .

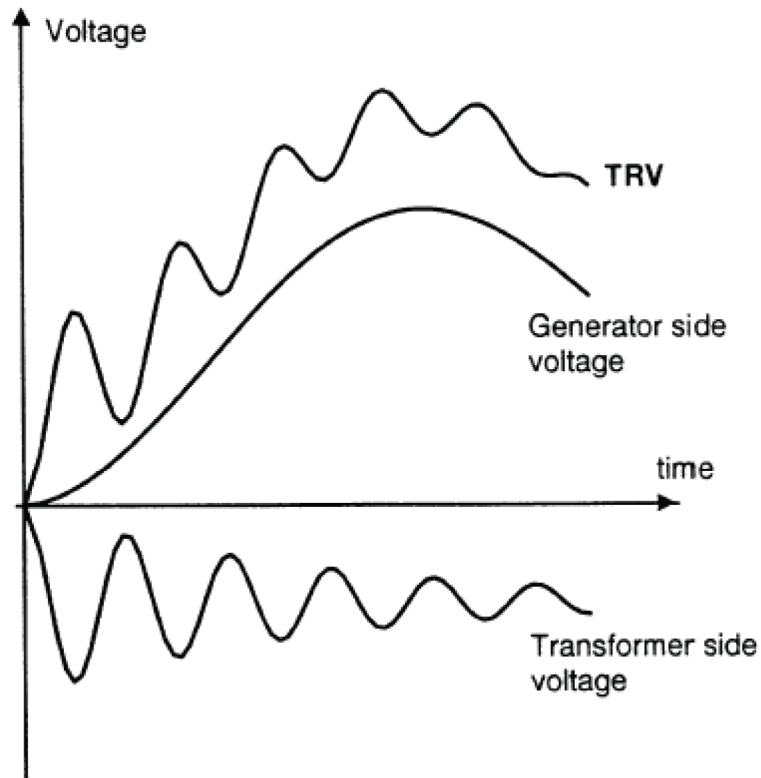


Figure 63 – TRV curve for the first-pole-to-clear

Theoretical calculations prove to be difficult and yield pessimistic results. Measurements at the site by injecting current at low voltage with the high-voltage side of the transformer short-circuited (representing a fault on the high-voltage side by neglecting the HV system reactances) are preferable.

Standardised TRV rate values have been selected by reviewing available results of measurements. Standardised values do not consider the use of capacitors, which would reduce the TRV rate.

The interrupting capability of the generator circuit-breaker demonstrated by relevant type tests is valid only if capacitors of the same capacitance value as used during the tests are installed according to the tested configuration. An interrupting capability different than that tested cannot be confirmed for the generator circuit-breaker equipped with a different capacitance value of the capacitors used to mitigate the TRV.

9.103.8.4 Endurance capability

The endurance capability can also be referred to as service capability. It gives the user some guidance for the servicing and maintenance of generator circuit-breakers. Several subclauses in this document deal with service and endurance capability (see 5.107, 7.101.2.3 and 7.101.2.4).

The endurance capability consists of the following two types of requirements:

- a) Electrical endurance that essentially is a measure of contact wear and gives guidance as to when to replace arcing contacts or other parts of the generator circuit-breaker, which are exposed to the arc or stressed electrically during making and breaking.
- b) Mechanical endurance, to ensure that the minimum number of operations can be performed without the need for servicing or overhaul. The number of operations is specified in 5.107. If a greater number is desired, it is subject to agreement between the user and the manufacturer.

9.103.9 Rated out-of-phase making and breaking current

9.103.9.1 Out-of-phase current

During out-of-phase conditions with the generator operating at rated voltage, the RMS value of the AC component of the out-of-phase current (I_{oph}) through the generator, the generator circuit-breaker, the transformer, and the HV system at $t = 0$, i.e., at the moment of initiation of the out-of-phase condition, can be calculated using the following equation, provided that the single-line diagram of the power plant is as shown in Figure 55 and Figure 56.

$$I_{\text{oph}} = \frac{1}{\sqrt{3}} \times \frac{U_{\text{oph}}}{X_{\text{d}}'' + X_{\text{t}} + X_{\text{s}}} = \frac{1}{\sqrt{3}} \times \frac{\delta \times U_{\text{oG}}}{X_{\text{d}}'' + X_{\text{t}} + X_{\text{s}}}$$

where

U_{oph} is the out-of-phase voltage;

U_{oG} is the generator line-to-line operating voltage;

δ is $\sqrt{2}$ for a 90° out-of-phase angle, and 2 for a 180° out-of-phase angle;

X_{d}'' is the subtransient reactance of the generator in Ω ;

X_{t} is the transformer short-circuit reactance in Ω ;

X_{s} is the short-circuit system reactance in Ω .

The ultimate out-of-phase current is lower than the initial out-of-phase current at $t = 0$ because it decreases based on the time constants of the generator, the transformer and the system. The calculation of the current excursion shall be performed by computer programs that simulate the generator behaviour correctly. The current resulting from out-of-phase synchronising might show delayed current zeros whose causes are totally different compared to generator terminal faults [6]. The rapid movement of the rotor from initial out-of-phase angle φ_0 to $\varphi = 0$ results in a very small AC component of the fault current and a dominant DC component when the condition of $\varphi = 0$ is reached. The current resulting from out-of-phase synchronising shall be assessed by the aid of computer simulations which allow modelling power plant equipment with a high level of accuracy, especially the synchronous machine. The moment of inertia of the turbine, the rotor and excitation equipment of the generator is of special importance. This is because the instant when the $\varphi = 0$ condition is reached is determined by the angular velocity of the rotor.

In case the fault current shows delayed current zeros the capability of the generator circuit-breaker to force current zeros shall be demonstrated by means of a calculation considering the effect of arc voltage. The procedure described in 9.103.6.3.6.3 applies.

The following two typical situations shall be considered for a particular out-of-phase current for a three-phase fault:

- a) initiation of the out-of-phase condition at voltage zero across the open contacts of the generator circuit-breaker in one phase which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;

- b) initiation of the out-of-phase condition at voltage maximum across the open contacts of the generator circuit-breaker in one phase which implies that the current in the corresponding phase is symmetrical.

For each of the above situations a) and b) the following two cases shall be investigated:

- 1) Generator at no-load with the generator circuit-breaker closing with the phase angle difference between phasors representing the voltages on each side of the generator circuit-breaker. The case of generator voltage leading the system voltage referred to the LV-side of the step-up transformer shall be investigated. In the computation, the arc voltage of the generator circuit-breaker after contact separation shall be taken into account. Contact separation occurs at the minimum opening time of the generator circuit-breaker after initiation of the out-of-phase condition plus tripping delay of the protection system. The tripping delay is generally equal to 0,5 cycles at power frequency.
- 3) Generator at no-load with the generator circuit-breaker closing with the phase angle difference between phasors representing the voltages on each side of the generator circuit-breaker. The case of generator voltage lagging the system voltage referred to the LV-side of the step-up transformer shall be investigated. In the computation, the arc voltage of the generator circuit-breaker after contact separation shall be taken into account. Contact separation occurs at the minimum opening time of the generator circuit-breaker after initiation of the out-of-phase condition plus tripping delay of the protection system. The tripping delay is generally equal to 0,5 cycles at power frequency.

The technical data of the actual generator shall be used for these computations.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum tested arcing time).

If the generator is connected to the system in full phase opposition, $\delta = 2$, I_{oph} will in general exceed the generator terminal short-circuit current, which is not acceptable for the safety of the generator. Therefore, to avoid this situation automatic synchronisation or other precautions should be taken.

A generator circuit-breaker is not required to interrupt the full phase opposition current with a recovery voltage twice the maximum operating voltage, thus the assigned out-of-phase current rating will not exceed 50 % of the rated short-circuit current of the generator circuit-breaker, which corresponds to a maximum out-of-phase angle of 90° .

9.103.9.2 TRV parameters

Circuits involved in out-of-phase current breaking have the same configuration as for load current breaking. Therefore, the TRV is standardised in the same manner according to 9.103.8.2 taking into account a power-frequency recovery voltage equal to $\sqrt{2}$ times the maximum operating voltage of the generator. The TRV parameters are given in Table 6.

The interrupting capability of the generator circuit-breaker demonstrated by relevant type tests is valid only if capacitors of the same capacitance value as used during the tests are installed according to the tested configuration. An interrupting capability different than that tested cannot be confirmed for the generator circuit-breaker equipped with a different capacitance value of the capacitors used to mitigate the TRV.

9.103.10 Excitation breaking current

During routine operation, a generator step-up transformer is seldom switched in an unloaded condition. However, consideration should be given to breaking of transformer excitation current. The excitation current is typically 10 A to 50 A, depending on the rating and no-load characteristics of the transformer. Excitation current breaking is not so much a matter of the generator circuit-breaker capability, but a question of whether overvoltages are produced due to current chopping.

The value of chopped current, and consequently the overvoltages produced, are dependent on the generator circuit-breaker, system configuration, and also the various system parameters. Modern transformers have a low no-load current value compared to older designs, and their magnetic characteristics are such that a relatively low amount of energy is released when current chopping occurs during breaking, leading to moderate chopping overvoltages. Furthermore, the transformer LV side is usually protected by additional capacitance and by surge arresters.

Chopping overvoltages are produced only on the transformer side of the generator circuit-breaker. No overvoltages occur on the generator side because the inductance of the generator is much lower than the magnetising impedance of the transformer, and the energy content is low and not of sufficient magnitude to produce overvoltages.

Air-blast generator circuit-breakers are usually shunted by low-ohmic damping resistors in series with an auxiliary interrupter. This auxiliary interrupter interrupts these small inductive currents, thus, current chopping levels are in the order of those of air-blast distribution circuit-breakers. Some air-blast generator circuit-breakers may be equipped with voltage-dependent resistors connected across the magnetising current interrupter.

Experience indicates that the current chopping level of SF₆ self-blast generator circuit-breakers is low and should not produce overvoltages of concern.

In general, no difficulties should be expected due to making and breaking of excitation currents. If tests and/or calculations are to be carried out for a specific application, they should be performed based on agreement between the user and the manufacturer.

Therefore, a detailed test procedure for breaking unloaded transformers, i.e. breaking transformer excitation currents, is not considered in this document. The reasons for this are as follows:

- a) Owing to the non-linearity of the transformer core, it is not possible to correctly model the breaking of the transformer excitation current by using linear components in a test laboratory. Tests conducted using an available transformer, such as a test transformer, will only be valid for the transformer tested and cannot be representative for other transformers.
- b) As detailed in IEC TR 62271-306, the characteristics of this duty are usually less severe than any other inductive current breaking duty. It should be noted that such a duty may produce severe overvoltages within the transformer winding(s) depending on the circuit-breaker re-ignition behaviour and transformer winding resonance frequencies.

9.103.11 Capacitive making and breaking current

The generator circuit-breaker is not normally called on to make and break capacitive currents. Therefore, capacitive making and breaking is considered a special application and is not addressed in this document. And if the generator circuit-breaker is required to have a capacitive current making and breaking capability, the manufacturer should be consulted.

NOTE In case a surge capacitor is connected to the circuit, its capacitance value is usually in the order of 200 nF. The resulting current is less than 4 A and generator circuit-breakers are capable of making and breaking such capacitive currents.

10 Information to be given with enquiries, tenders and orders (informative)

10.1 General

Subclause 10.1 of IEC 62271-1:2017 is replaced by the following:

The intention of Clause 10 is to define information, which is necessary to enable the user to make an appropriate enquiry for equipment and to enable the supplier to give an adequate tender.

Furthermore, it enables the user to make a comparison and evaluation of offers from different suppliers.

NOTE The supplier can either be a manufacturer or a contractor.

When enquiring about or ordering an installation of a generator circuit-breaker or a generator circuit-breaker system the following information as a minimum should be supplied by the enquirer.

10.2 Information with enquiries and orders

Subclause 10.2 of IEC 62271-1:2017 is replaced by the following:

The following information listed below, if applicable, should be given by the enquirer or user.

a) Particulars of systems:

- 1) single-line diagram of the power plant;
- 2) rated, minimum and maximum operating voltages;
- 3) rated frequency;
- 4) generator data (ratings, decrement curve, reactances, time constants, armature resistance, moment of inertia and operating capability curve showing MW and MVAR limits);
- 5) earthing method of the generator;
- 6) power transformers' data (ratings, reactances, resistances or time constant);
- 7) power transformers' tap changer steps, if any, and change of impedance with tap-changer operation;
- 8) maximum system short-circuit current on high-voltage side of main transformer (including future requirements);
- 9) high-voltage system DC time constant;
- 10) value of surge capacitors, if any.

b) Application:

- 1) type of power plant (e.g. fossil, hydro, nuclear, base-load, or peaking power plant);
- 2) service conditions including minimum and maximum ambient air temperatures, altitude if over 1 000 m and any special conditions likely to exist or arise, for example unusual exposure to water vapour, moisture, fumes, explosive gases, excessive dust or salt air (see 8.102.2);
- 3) indoor or outdoor installation of the generator circuit-breaker;
- 4) limiting dimensions at generator circuit-breaker location;
- 5) minimum and maximum phase spacings;
- 6) interlocks and key coordination system;
- 7) type of bus between generator and generator step-up transformer (e.g. isolated phase bus, segregated phase bus, cable bus, cables). Note that if cables are used, the type of cable construction should be given;

- 8) bus conductor temperatures at the terminals of generator circuit-breakers and bus conductor and enclosure temperatures at the terminals of generator circuit-breaker systems;
 - 9) cooling of bus (if forced air cooling, air flow rate and inlet air temperature at each pole of the generator circuit-breaker);
 - 10) overpressure of air for enclosed buses;
 - 11) expected frequency of operations.
- c) Required characteristics of generator circuit-breaker:
- 1) operating voltage;
 - 2) insulation level;
 - 3) power frequency;
 - 4) continuous current;
 - 5) short-time withstand current;
 - 6) peak withstand current;
 - 7) duration of short-circuit;
 - 8) short-circuit making current;
 - 9) system-source short-circuit breaking current (RMS value of the AC component and time constant);
 - 10) if applicable, generator-source short-circuit breaking current (RMS value of the AC component and degree of asymmetry);
 - 11) load breaking current;
 - 12) if applicable, out-of-phase making and breaking conditions;
 - 13) transient recovery voltages (TRV) for the breaking conditions according to items 9), 10), 11) and 12) above;
 - 14) mechanical operation endurance capability;
 - 15) number of allowed load current making and breaking operations.
- d) Characteristics of the operating mechanism of generator circuit-breaker and associated equipment, in particular:
- 1) number and type of spare auxiliary switches;
 - 2) rated supply voltage and rated supply frequency;
 - 3) number of releases for tripping, if more than one;
 - 4) number of releases for closing, if more than one.
- e) Requirements or restrictions concerning the use of compressed gas and requirements for design and tests of pressure vessels.
- f) Requirements for any other component of a generator circuit-breaker system as listed in 3.3.101.
- g) Information of any special conditions not included above, that might influence the tender or order (see also Clause 9).

10.3 Information with tenders

Subclause 10.3 of IEC 62271-1:2017 is replaced by the following:

The following information listed below, if applicable, should be given by the manufacturer with descriptive material and drawings.

- a) Rated values and characteristics of the generator circuit-breaker or of the generator circuit-breaker system:
- 1) voltage;

- 2) insulation level;
 - 3) power frequency;
 - 4) continuous current;
 - 5) short-time withstand current;
 - 6) peak withstand current;
 - 7) duration of short-circuit;
 - 8) short-circuit making current;
 - 9) system-source short-circuit breaking current (RMS value of the AC component and time constant or degree of asymmetry at contact separation);
 - 10) generator-source short-circuit breaking current (RMS value of the AC component and degree of asymmetry at contact separation);
 - 11) load breaking current;
 - 12) out-of-phase making and breaking conditions;
 - 13) transient recovery voltages (TRV) for the breaking conditions according to items 9), 10), 11) and 12) above;
 - 14) operating times;
 - 15) type of gas for insulation and/or making and breaking;
 - 16) specified filling pressure for insulation and/or making and breaking;
 - 17) minimum functional pressure for insulation and/or making and breaking;
 - 18) specified filling pressure for operation;
 - 19) minimum functional pressure for operation;
 - 20) mechanical operation endurance capability.
- b) Particulars of the installation:
- 1) minimum and maximum phase spacings;
 - 2) cooling of the generator circuit-breaker or the generator circuit-breaker system (if forced air cooling, air flow rate and inlet air temperature at each pole of the generator circuit-breaker);
 - 3) rated values of components (e.g. for VTs, CTs or SAs in an assembly, for individual functional units of an assembly) and means of protection (e.g. VTs with fuses);
 - 4) degree of protection for the enclosure and partitions;
- c) Characteristics of the operating mechanisms of components of the generator circuit-breaker system and associated equipment, where applicable:
- 1) type of operating devices;
 - 2) number and type of spare auxiliary switches;
 - 3) rated supply voltage and rated supply frequency;
 - 4) number of releases for tripping;
 - 5) number of releases for closing;
- d) Overall dimensions and other information:
- 1) dimensions of the generator circuit-breaker or the generator circuit-breaker system and details necessary for the design of the foundation;
 - 2) seismic qualification level.
- e) General information regarding installation of the generator circuit-breaker or of the generator circuit-breaker system and its connections should be given.

11 Transport, storage, installation, operating instructions and maintenance

11.1 General

Subclause 11.1 of IEC 62271-1:2017 is not applicable and is replaced with the following:

It is essential that the transport, storage and installation of generator circuit-breakers or generator circuit-breaker systems, as well as their operation and maintenance in service, be performed in accordance with instructions given by the manufacturer.

In addition, commissioning tests shall be performed as part of the installation according to 11.3.101 taking into consideration the routine tests to be performed after final assembly.

Consequently, the manufacturer should provide the appropriate version of the instruction manual for the transport, storage, installation including any routine tests to be performed during commissioning as well as for the operation and maintenance of the generator circuit-breaker or the generator circuit-breaker system. The instructions for the transport and storage should be given at a convenient time before delivery, and the instructions for the installation, commissioning, operation and maintenance should be given by the time of delivery at the latest. It is preferable that the operation manual be a separate document from the installation, commissioning and maintenance manual.

It is impossible, here, to cover in detail the complete rules for the installation, commissioning, operation and maintenance of each one of the different types of generator circuit-breakers or generator circuit-breaker systems manufactured; however, the following information is given relative to the most important points to be considered for the instructions provided by the manufacturer.

NOTE Refer also to IEEE Std C37.12.1™ [7].

11.2 Conditions during transport, storage and installation

Subclause 11.2 of IEC 62271-1:2017 is not applicable and is replaced with the following:

A special agreement should be made between manufacturer and user if the service conditions of temperature and humidity defined in the order cannot be guaranteed during transport, storage and installation.

Protection of insulation during transport, storage and installation, and prior to energising, to prevent moisture absorption due, for instance, to rain, snow or condensation shall be considered. Appropriate instructions should be given.

Vibrations during transport shall be considered. Shock recorders with the appropriate measuring characteristics should be installed during the shipment. Appropriate instructions should be given.

11.3 Installation

11.3.1 General

Subclause 11.3.1 of IEC 62271-1:2017 is applicable.

11.3.2 Unpacking and lifting

Subclause 11.3.2 of IEC 62271-1:2017 is replaced by the following:

Each complete equipment shall be provided with adequate lifting facilities and labelled (externally) to show the correct method of lifting. The equipment shall be labelled (externally) to indicate its shipping mass in kg or in "kg and [weight lb]", when fully equipped. Special lifting devices shall be capable of lifting the mass of each transport unit and special precautions shall be detailed in the installation manual (for example lifting brackets or bolts that are intended to be used only temporarily shall be removed at site).

Required information for unpacking should be given.

11.3.3 Assembly

Subclause 11.3.3 of IEC 62271-1:2017 is replaced by the following:

When the generator circuit-breaker or the generator circuit-breaker system is not fully assembled for transport, all transport units should be clearly marked. Drawings showing assembly of these parts should be provided with the generator circuit-breaker or the generator circuit-breaker system.

11.3.4 Mounting

Subclause 11.3.4 of IEC 62271-1:2017 is replaced by the following:

Instructions for the mounting of the generator circuit-breaker or the generator circuit-breaker system, the operating device(s) and the auxiliary equipment should include sufficient details of locations and foundations to enable site preparation to be completed.

These instructions should also indicate

- the total mass of the apparatus inclusive of extinguishing or insulating fluids;
- the mass of extinguishing or insulating fluids;
- the mass of the heaviest part of the apparatus to be lifted separately if it exceeds 100 kg [weighs more than 220 lb].

11.3.5 Connections

Subclause 11.3.5 of IEC 62271-1:2017 is replaced by the following.

Instructions should include information on

- a) connection of conductors, comprising the necessary advice to prevent overheating and unnecessary strain on the generator circuit-breaker or the generator circuit-breaker system and to provide adequate clearance;
- b) connection of auxiliary circuits;
- c) connection of liquid or gas systems, if any, including size and arrangement of piping;
- d) connection for earthing.

11.3.6 Information about gas and gas mixtures for controlled and closed pressure systems

Subclause 11.3.6 of IEC 62271-1:2017 is applicable.

11.3.7 Final installation inspection

Subclause 11.3.7 of IEC 62271-1:2017 is replaced by the following:

Instructions should be provided for inspection and tests which should be made after the generator circuit-breaker or the generator circuit-breaker system has been installed and all connections have been completed.

These instructions should include

- a schedule of recommended site tests to establish correct operation;
- procedures for carrying out any adjustment that may be necessary to obtain correct operation;
- recommendations for any relevant measurements that should be made and recorded to help with future maintenance decisions;
- instructions for final inspection and putting into service.

11.3.8 Basic input data by the user

Subclause 11.3.8 of IEC 62271-1:2017 is replaced by the following:

- a) specific pressure vessel rules and procedures that may apply during installation and commissioning tests;
- b) interface requirements for high-voltage cables and transformers;
- c) in-service conditions or operating restrictions that shall be respected;
- d) safety regulations that shall be adhered to;

NOTE The following information is rarely provided in the instructions relating to the generator circuit-breaker or the generator circuit-breaker system; however, it is usually given as part of the work plan for the site.

- e) access limitations to the local site;
- f) local working conditions and any restrictions that may apply (for example, safety equipment, normal working hours, union requirements for supervisor, manufacturer's and local installation crew);
- g) availability and capacity of lifting and handling equipment;
- h) availability, number and experience of local personnel.

11.3.9 Basic input data by the manufacturer

Subclause 11.3.9 of IEC 62271-1:2017 is replaced by the following:

- a) space necessary for installation and assembly;
- b) size and mass [weight] of components and testing equipment;
- c) site conditions regarding cleanliness and temperature for clean installation and preparation area;
- d) number and experience of local personnel required for installation;
- e) time and activity schedules for installation and commissioning;
- f) electric power, lighting, water and other needs for installation and commissioning;
- g) proposed training of installation and service personnel;
- h) in case of extension to existing generator circuit-breaker
 - out-of-service requirements of existing components related to the installation schedule;
 - safety precautions.

11.3.101 Commissioning tests

After a generator circuit-breaker or a generator circuit-breaker system has been installed and all connections have been completed, commissioning tests shall be performed.

The purpose of commissioning tests is for confirmation of

- absence of damage, due to transport and storage;
- compatibility of separate units;
- correct assembly;

- correct performance of the assembled generator circuit-breaker.

The manufacturer shall specify a programme of site commissioning checks and tests.

When generator circuit-breakers or generator circuit-breaker systems are shipped as complete units the commissioning tests shall include, but are not limited to, the programme given in 11.3.102. The results of the tests shall be recorded in a test report. Repetition of the full programme of routine tests, already performed in the factory, shall be avoided.

When generator circuit-breakers or generator circuit-breaker systems are assembled and shipped as separate units, the commissioning tests shall additionally include the full set of routine tests as given in Clause 8. Possible exceptions according to 11.3.102.5.3 shall be regarded.

11.3.102 Commissioning checks and test programme

11.3.102.1 General checks

The following general checks shall be performed:

- assembly conforms to manufacturer's drawings and instructions;
- tightness of the generator circuit-breaker or, if applicable, any other component of a generator circuit-breaker system, their fastenings, fluid systems and control devices ;
- external insulation and, where applicable, internal insulation are undamaged and clean;
- paint and other corrosion protection are sound;
- operating devices, especially operating releases, are free from contamination;
- adequacy and integrity of the earth connection up to and including the interface with the substation earthing system;

and, where applicable:

- record the number on the operations counter(s) at delivery;
- record the number on the operations counter(s) at completion of all site testing.

11.3.102.2 Checks of electrical circuits

The following electrical circuits checks shall be performed:

- conformity to the wiring diagram;
- correct operation of signalling (position, alarms, lockouts, etc.);
- correct operation of heating and lighting.

11.3.102.3 Checks of the insulation and/or making and breaking fluid(s)

The following checks shall be performed as applicable:

- oil type;
- oil dielectric strength (IEC 60296);
- oil level.
- filling pressure (density) for insulation and/or making and breaking;
- gas quality checks, to confirm the manufacturer's acceptance levels.

The quality checks are not required on sealed generator circuit-breakers or sealed components of generator circuit-breaker systems or if generator circuit-breakers or the components of generator circuit-breaker systems are filled on site by using new gas from sealed bottles.

11.3.102.4 Checks on operating fluid(s), where filled or added on site

The following checks shall be performed as applicable:

- hydraulic oil level;
- unless otherwise agreed, confirmation that the moisture content of the hydraulic oil is sufficiently low to prevent internal corrosion or other damage to the hydraulic system;
- gas filling pressure;
- gas purity (for example oxygen free or 1 % tracer gas).

11.3.102.5 Mechanical tests and measurements

11.3.102.5.1 Measurements of the characteristic insulating and/or making and breaking fluid pressures (where applicable)

11.3.102.5.1.1 General

The following measurements shall be taken in order to compare them with the values both recorded during the routine tests and guaranteed by the manufacturer. These values serve as the reference for future maintenance and other checks and will enable any drift in operating characteristics to be detected.

These measurements involve a check of the operation of the alarm and lockout devices (pressure switches, relays, transducers, etc.) where applicable.

11.3.102.5.1.2 Verifications of alarm function

Where applicable, on rising pressure: disappearance of the low-pressure or low-density alarm.

11.3.102.5.2 Measurements of characteristic operating fluid pressures (if applicable)

11.3.102.5.2.1 General

The following measurements (list to be adapted as necessary) shall be taken, in order to compare them with the values both recorded during routine tests and guaranteed by the manufacturer. These values may serve as a reference during later checks (maintenance) and will enable any drift in operating characteristics to be detected.

The measurements involve a check of the operation of the lockout or alarm devices (pressure switches, relays, etc.).

11.3.102.5.2.2 Verifications

The following verifications shall be made as applicable:

- a) On a rise in pressure with the pumping device (pump, compressor, controlled valve, etc.) in service:
 - disappearance of the low-pressure alarm;
 - cut-off of the pumping device;
 - opening of the safety valve (if applicable).

NOTE The measurements can be combined with the measurements of the recharging time of the operating mechanism (see 11.3.102.5.2.4).

- b) On a drop in pressure with the pumping device switched off:
 - closing of the safety valve (if applicable);
 - starting of the pumping device;
 - appearance of the low-pressure alarm.

11.3.102.5.2.3 Verification of the rated operating sequence of the generator circuit-breaker

The mechanical ability of the generator circuit-breaker to perform its rated operating sequence should be verified under de-energised conditions. The tests should be performed with the recharging device in service, with site supply voltage.

The site supply voltage is the on-load voltage available at the generator circuit-breaker from the normal site supply and should be compatible with the rated supply voltage of auxiliary and control circuits.

11.3.102.5.2.4 Verification of recharging time of the operating mechanism of the generator circuit-breaker

The following recharging time shall be verified as applicable:

a) Fluid-operated mechanism

The operation time of the pumping device (pump, compressor, control valve, etc.) should be measured:

- between minimum and maximum pressure (cut-in and cut-off of the pumping device);
- during the following operations or operating sequence, starting each time with minimum pressure (cut-in of the pumping device):
 - C three-pole;
 - O three-pole;
 - CO three-pole.

b) Other mechanisms

The recharging time after a closing operation and, if applicable, after an opening operation and after a close-open operation should be measured at the site supply voltage.

11.3.102.5.2.5 Record of travel curve of the generator circuit-breaker

If the generator circuit-breaker has been assembled as a complete generator circuit-breaker for the first time on site or where all or part of the routine tests are performed on site, then proof shall be given that the mechanical behaviour conforms to that of the test object used for type testing. This shall be done by confirming the mechanical characteristics as defined in 7.101.1.1, for example no-load travel curves are within the reference travel bands.

If the generator circuit-breaker has been assembled as a complete circuit-breaker at the factory and the travel curve recorded and confirmed according to 8.101 no further record on site is required.

11.3.102.5.2.6 Simulation of fault-making operation and check of anti-pumping device of the generator circuit-breaker

A CO operation shall be performed with the trip circuit energised by the closing of the auxiliary contact. The closing command shall be maintained for at least 1 s in order that the anti-pumping device can be checked for effective operation.

The test also verifies the proper function during the rapid application of the opening command.

NOTE A simplified anti-pumping test can also be executed, using the local control. In this case, a closing command is applied and maintained, while a consecutive opening command is applied.

11.3.102.5.2.7 Mechanical tests and measurements with any other component of a generator circuit-breaker system

The main-disconnector and the earthing switch shall be tested according to their applicable standard.

The starting switch, BTB-switch, Tee-OFF-switch, ET-switch and motor operated short-circuiting connections shall be tested according to the standard applicable for disconnectors.

11.3.102.5.3 Electrical tests and measurements

11.3.102.5.3.1 Dielectric tests

Power-frequency withstand voltage tests on the main circuits according to 8.2 are required only if the interrupting units have been assembled on site.

If the generator circuit-breaker or generator circuit-breaker system is equipped with resistors, capacitors, surge arresters or instrument transformers, then those components can be disconnected or removed prior to the dielectric test, provided that these components have been routine tested separately in accordance with their standards.

11.3.102.5.3.2 Measurement of the resistance of the main circuit

Measurements of the resistance of the main circuits need only be made if the interrupting units and any other component within the main circuit have been assembled on site. The measurement shall be made with a direct current in accordance with 8.4.

11.4 Operating instructions

The instructions given by the manufacturer should contain the following information:

- a general description of the equipment with particular attention to the technical description of its characteristics and operation so that the user has an adequate understanding of the main principles involved;
- a description of the safety features of the equipment and the operation of the interlocks and padlocking facilities;
- as relevant, a description of the action to be taken to manipulate the equipment for operation isolation, earthing, maintenance, and testing;
- as relevant, measures against corrosion should be given.

11.5 Maintenance

11.5.1 General

The effectiveness of maintenance depends mainly on the way instructions are prepared by the manufacturer and implemented by the user.

11.5.2 Information about fluids and gas to be included in maintenance manual

Where applicable, the following information shall be provided by the manufacturer:

- a) type and required quantity and quality of liquid to be used in generator circuit-breaker or generator circuit-breaker system;
- b) type and required quantity and quality of gas to be used in generator circuit-breaker or generator circuit-breaker system.

11.5.3 Recommendations for the manufacturer

- a) The manufacturer's maintenance manual should include the following information.
 - 1) Extent and frequency of maintenance. For this purpose the following factors should be considered:
 - number of making and breaking operations as a function of current;
 - total number of operations;
 - time in service (periodic intervals);

- environmental conditions;
 - measurements and diagnostic tests, (if any).
- 2) Detailed description of the maintenance work:
- recommended place for the maintenance work (indoor, outdoor, in factory, on site, etc.);
 - procedures for inspection, diagnostic tests, examination, overhaul;
 - reference to drawings;
 - reference to part numbers;
 - use of special equipment or tools;
 - precautions to be observed (for example cleanliness and possible effects of harmful arcing by-products);
 - lubrication procedures.
- 3) Comprehensive drawings of the details of the generator circuit-breaker or the generator circuit-breaker system that are important for maintenance, with clear identification (part number and description) of assemblies, subassemblies and significant parts.

NOTE Expanded detail drawings which indicate the relative position of components in assemblies and subassemblies are a recommended illustration method.

- 4) Limits of values and tolerances which, when exceeded, make corrective action necessary, for example,
- pressures, density levels, gas mixtures tolerance;
 - resistors and capacitors (of the main circuit);
 - operating times;
 - resistance of the main circuits;
 - insulating liquid or gas characteristics;
 - quantities and quality of liquid or gas (see IEC 60480 for SF₆ and IEC 62271-4 [8]);
 - dew point inside gas-filled switchgear compartment according to 11.3.6;
 - permissible erosion of parts subject to wear;
 - torques;
 - important dimensions.
- 5) Specifications for auxiliary maintenance materials, including warning of known non-compatibility of materials:
- grease;
 - oil;
 - fluid;
 - cleaning and degreasing agents.
- 6) List of special tools, lifting and access equipment.
- 7) Tests after the maintenance work.
- 8) List of the recommended spare parts (description, reference number, quantities) and advice for storage.
- 9) Estimate of active scheduled maintenance time.
- 10) How to proceed with the equipment at the end of its operating life, taking into consideration environmental requirements.
- b) The manufacturer should inform the purchasers of a particular type of generator circuit-breaker or generator circuit-breaker system about corrective actions required by systematic defects and failures detected in service.

c) Availability of spares:

The manufacturer should be responsible for ensuring the continued availability of spare parts required for maintenance for a period of not less than 10 years from the date of final manufacture of the generator circuit-breaker or the generator circuit-breaker system.

11.5.4 Recommendations for the user

- a) The user should prepare maintenance plans based on the maintenance manual of the manufacturer.
- b) The user should record the following information:
 - the serial number and the type of generator circuit-breaker or generator circuit-breaker system;
 - the date when the generator circuit-breaker or the generator circuit-breaker system is put in service;
 - the results of all measurements and tests including diagnostic tests carried out during the life of the generator circuit-breaker or the generator circuit-breaker system;
 - dates and extent of the maintenance work carried out;
 - the history of service, periodical records of the operation counters and other indications (for example short-circuit operations);
 - references to any failure report.
- c) In the case of failure and defects, the user should make a failure report and should inform the manufacturer by stating the special circumstances and measures taken. Depending upon the nature of the failure, an analysis of the failure should be made in collaboration with the manufacturer.

11.5.5 Failure report

NOTE Refer also to IEEE Std C37.10™-2011 [9].

The purpose of the failure report is to standardise the recording of the failures of the generator circuit-breaker or the generator circuit-breaker system with the following objectives:

- to describe the failure using a common terminology;
- to provide data for the user statistics;
- to provide a meaningful feedback to the manufacturer.

The following gives guidance on how to make a failure report.

A failure report should include

- a) identification of the generator circuit-breaker or the generator circuit-breaker system which failed:
 - power plant name;
 - identification of the generator circuit-breaker or the generator circuit-breaker system (manufacturer, type, serial number, ratings);
 - generator circuit-breaker family (air blast, minimum oil, SF₆, vacuum);
 - location (indoor, outdoor);
 - enclosure;
 - operating mechanism, if applicable (hydraulic, pneumatic, spring, motor).
- b) history of the generator circuit-breaker or the generator circuit-breaker system:
 - date of commissioning of the equipment;
 - date of failure or defect;
 - total number of operating cycles, if applicable;

- date of last maintenance;
 - details of any changes made to the equipment since manufacture;
 - total number of operating cycles since last maintenance;
 - condition of the generator circuit-breaker or the generator circuit-breaker system when the failure or defect was discovered (in service, maintenance, etc.).
- c) identification of the subassembly or component responsible for the primary failure or defect
- high-voltage stressed components;
 - electrical control and auxiliary circuits;
 - operating mechanism, if applicable;
 - other components.
- d) stresses presumed to contribute to the failure or defect:
- environmental conditions (temperature, wind, rain, snow, ice, pollution, lightning, etc.).
- e) classification of the failure or defect:
- major failure;
 - minor failure;
 - defect.
- f) origin and cause of the failure or defect:
- origin (mechanical, electrical, tightness if applicable);
 - cause (design, manufacture, inadequate instructions, incorrect mounting, incorrect maintenance, stresses beyond those specified, etc.).
- g) consequences of the failure or defect:
- generator circuit-breaker (system) down-time;
 - time consumption for repair;
 - labour cost;
 - cost of spare parts.

A failure report may include the following information:

- drawings, sketches;
- photographs of defective components;
- single-line power plant diagram;
- operation and timing sequences;
- records or plots;
- references to maintenance or operating manuals.

12 Safety

12.1 General

Subclause 12.1 of IEC 62271-1:2017 is replaced by the following:

Generator circuit-breakers or generator circuit-breaker systems can be considered safe when installed in accordance with the relevant installation rules including those provided by the manufacturers and used and maintained in accordance with the manufacturer's instructions (see Clause 11).

A generator circuit-breaker or a generator circuit-breaker system is normally only accessible by qualified persons. It shall be operated and maintained by skilled persons. When unrestricted access is available to the generator circuit-breaker or the generator circuit-breaker system, additional safety features may be required.

Generator circuit-breakers or generator circuit-breaker systems in accordance with this document offer a high level of safety with regard to external effects that might harm personnel. Nevertheless, high power equipment can present some potential risks, some examples are:

- the enclosures, if any, may be pressurised with gas;
- opening of pressure-relief devices due to an internal arc, originated by exceptional conditions. In extreme circumstances, the arc can burn through the enclosures. Both result in the sudden release of hot gas;
- sudden events, which are in themselves with low risk to humans, may alarm personnel and lead to accidents (for example, a fall);
- commissioning, maintenance and extension activities may require special attention due to the complexity of the equipment and its internal parts which are mostly not visible.

Experience has shown that human error is a factor that shall be considered (for example, closing an earthing switch on an energised conductor).

12.2 Precautions by manufacturers

Subclause 12.2 of IEC 62271-1:2017 is replaced by the following:

The following list provides examples of precautions that may be taken by manufacturers.

- Design and test of pressurised enclosures, pressure relief devices and relevant elements to international electrical standards such as IEC, ASME, CENELEC, and JIS.
- Provide adequate and easy means to check interlocking systems (the most reasonable way to avoid human error).
- Explain safe operation of the generator circuit-breaker or the generator circuit-breaker system clearly in instruction manuals. Explain precautions to prevent improper operation and the consequences of improper operation.
- Provide the user and/or contractor with appropriate information related to the design of the surrounding area. In the case of a gas insulated generator circuit-breaker or generator circuit-breaker system, which is installed in a building, provide the user and/or contractor with appropriate information needed for ventilation and gas detection, to minimise personnel risks in case a failure occurs.

12.3 Precautions by users

Subclause 12.3 of IEC 62271-1:2017 is replaced by the following:

The following list provides examples of precautions that may be taken by users.

- Limit access to the installation to people who are trained and authorised.
- Keep operators and other personnel instructed regarding risks and safety requirements including local regulations.
- Keep generator circuit-breaker maintained and up to date in terms of technical standards, especially interlocking and protection devices.
- Use remote control and have the interlocking system working as intended.
- Select equipment that minimises the risk to personnel from improper operation (for example, fast acting earthing switches on lines, motor operators to allow remote operation).
- Coordinate the protection system with product properties (for example, do not reclose on internal faults).

- Prepare earthing procedures considering the difficulty of referring to and understanding the complex arrangement and operation of the generator circuit-breaker or generator circuit-breaker system.
- Label equipment clearly for easy identification of individual devices and gas compartments.

Especially during maintenance, repair or extension work:

- Ensure that maintenance, repair and extension work is carried out only by qualified and trained personnel.
- Prepare a safety and protection plan for the work. Indicate who is responsible for planning, implementing and enforcing safety and protection measures.
- Check interlocking and protection devices before starting.
- Pay special attention to manual operations, especially when the generator circuit-breaker or the generator circuit-breaker system is energised.
- Inform personnel who may be near the generator circuit-breaker or the generator circuit-breaker system before operating the equipment (for example, a horn or flashing light).
- Mark emergency exits and keep passages clear of obstructions.
- Instruct the people involved on how to work safely in a generator circuit-breaker or generator circuit-breaker system environment and what to do in an emergency.

13 Influence of the product on the environment

Clause 13 of IEC 62271-1:2017 is replaced by the following:

The manufacturer shall be prepared to provide on request, the following relevant information about the environmental impact of the generator circuit-breaker or the generator circuit-breaker system.

When fluids are used in the generator circuit-breaker or generator circuit-breaker system, as far as is practicable, instructions should be provided in order to allow the user to

- minimise the leakage rate;
- control the handling of the new and used fluids.

The manufacturer shall give guidance on request, concerning disassembly and end-of-life procedures for the different materials of the equipment and indicate the possibility to recycle.

Annex A (normative)

Tolerances on test quantities during type tests

During type tests, the following types of tolerances may normally be distinguished:

- tolerances on test quantities which directly determine the stress of the test object;
- tolerances concerning features or the behaviour of the test object before and after the test;
- tolerances on test conditions;
- tolerances concerning parameters of measurement devices to be applied.

In the following Table A.1, only tolerances on test quantities are considered.

A tolerance is defined as the range of the test value specified in this document within which the measured test value should lie for a test to be valid.

Any deviation of the measured test value and the true test value caused by the uncertainty of the measurement are not taken into account in this respect.

The basic rules for application of tolerances on test quantities during type tests are as follows:

- a) Test laboratories shall aim wherever possible for the test values specified.
- b) The tolerances on test quantities specified shall be observed by the test laboratory. Higher stresses of the circuit-breaker exceeding those tolerances are permitted only with the consent of the manufacturer. Lower stresses render the test invalid.
- c) Where, for any test quantity, no tolerance is given within this document, or the standard to be applied, the type test shall be performed at values not less severe than specified. The upper stress limits are subject to the consent of the manufacturer.
- d) If, for any test quantity, only one limit is given, the other limit shall be considered to be as close as possible to the specified value.

Table A.1 – Tolerances on test quantities for type tests

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/limits of test values	Reference to values
7.2	Dielectric tests				
7.2.7.2	Power-frequency withstand voltage tests	Test voltage (RMS value)	Rated short-duration power-frequency withstand voltage	±1 %	IEC 62271-1, IEC 60060-1
		Frequency	–	45 Hz to 65 Hz	
		Wave shape	Peak value / RMS value = $\sqrt{2}$	±5 %	
7.2.7.3	Lightning impulse voltage test	Peak value	Rated lightning impulse voltage	±3 % for procedure B –0 % to +3 % for procedure C	IEC 60060-1
		Front time	1,2 µs	±30 %	
		Time to half-value	50 µs	±20 %	
7.4.4.1	Resistance measurement test procedure	DC test current I_{DC}	–	100 A ≤ I_{DC} ≤ rated continuous current	IEC 62271-1
7.5	Continuous current tests	Ambient air velocity	–	≤ 0,5 m/s	IEC 62271-1
		Test current frequency	Rated frequency	±2 %	
		Test current	Rated continuous current	+2 % / 0 %	
		Temperature rises of IPB conductor and enclosure	see Table 12	±5 K Test tolerances and limits shall be applied only for the last two hours of the testing period.	
		Ambient air temperature T	–	+10 °C < T < 40 °C	

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/limits of test values	Reference to
7.6	Short-time withstand current and peak withstand current tests	Test frequency	Rated frequency	±10 % except as provided in 7.6.3	IEC 62271-1
		Peak current (in one of the outer phases)	Rated peak withstand current	+5 % / 0 %	
		Average of AC component of three-phase test current	Rated short-time withstand current	See tolerances for I^2t in 7.6.3	
		The ratio of the AC component of test current in any phase to the average	1	± 10 %	
		Duration of short-circuit	Rated duration of short-circuit	See tolerances for I^2t in 7.6.3	
7.101.3	Low and high temperature tests	Value of I^2t	Rated value I^2t	+10 % / 0 %	
		Variation in ambient air temperature	–	≤ 5 K	
		Ambient air temperature for recording characteristics before test	20 °C	±5 K	
7.102.10	Demonstration of the most severe breaking conditions, valid for <ul style="list-style-type: none"> • system-source short-circuit current • generator-source short-circuit current (symmetrical breaking operations only) • out-of-phase current 	Minimum and maximum ambient air temperature during tests	According to class of generator circuit-breaker (see Clause 4)	±3 K	
		Maximum arcing time to be controlled	Specified test value	±1 ms	
		Average of the AC components of the prospective current of all phases at the intended contact separation	Specified breaking current for the relevant test-duty	0 % / +10 %	
7.102.10.1	System-source short-circuit breaking current Generator-source short-circuit breaking current Out-of-phase breaking current	AC component of the prospective current of any phase / average of the AC components of the prospective current of all phases	1	±10 %	
		AC component of the prospective current at intended final arc extinction in last-pole-to-clear	Specified breaking current for the relevant test-duty	≥ 90 %	

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/limits of test values	Reference to
7.102.10.2.2 or 7.102.10.3.2	Three-phase or single-phase symmetrical breaking operations, valid for: <ul style="list-style-type: none"> • system-source short-circuit current • generator-source short-circuit current • out-of-phase current 	Degree of asymmetry at contact separation during the breaking operations of symmetrical currents in any phase		For three-phase tests: $\leq 20\%$ For single-phase tests: $\leq 10\%$	
7.102.10.2.2 or 7.102.10.3.2	Additional requirements for symmetrical breaking operations during synthetic tests, valid for <ul style="list-style-type: none"> • system-source short-circuit current • generator-source short-circuit current • out-of-phase current 	Deviation of the peak of the short-circuit current during the last loop prior to the interruption from the peak of the prospective current		$\pm 10\%$	
7.102.10.2.3	Three-phase asymmetrical breaking operations, valid for <ul style="list-style-type: none"> • system-source short-circuit current • out-of-phase current 	Peak of the prospective current during the last loop prior to the intended interruption of the phase with the maximum asymmetry Duration of the last loop of the prospective current prior to the intended interruption of the phase with the maximum asymmetry Or if the above tolerances cannot be fulfilled: product of the peak and the duration of the prospective current during the last loop prior to the intended interruption of the phase with the maximum asymmetry	See Table 15 to Table 18	$\pm 10\%$	
			See Table 15 to Table 18	$\pm 10\%$	

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/limits of test values	Reference to
7.102.10.3.3	Single-phase asymmetrical breaking operations, valid for <ul style="list-style-type: none"> • system-source short-circuit current • out-of-phase current 	Peak of the prospective current during the last loop prior to the intended interruption of the phase with the maximum asymmetry	See Table 15 to Table 18	0 % / +10 %	
		Duration of the last loop of the prospective current prior to the intended interruption of the phase with the maximum asymmetry (for first-pole-to-clear conditions only)	See Table 15 to Table 18	±10 %	
7.102.10.2.3. or 7.102.10.3.3	Additional requirements for asymmetrical breaking operations during synthetic tests, valid for <ul style="list-style-type: none"> • system-source short-circuit current • out-of-phase current 	Or if the above tolerances cannot be fulfilled: product of the peak and the duration of the prospective current during the last loop prior to the intended interruption of the phase with the maximum asymmetry (for first-pole-to-clear conditions only)		0 % / +10 %	
		Peak of the short-circuit current during the last loop prior to the interruption	See Table 15 to Table 18	±10 %	
7.103.2	Frequency of test circuit	Duration of the short-circuit current loop prior to the interruption	See Table 15 to Table 18	±10 %	
		Product of the peak and the duration of the short-circuit current during the last loop prior to the interruption		±10 %	
7.103.5	Applied voltage before system-source short-circuit making tests	Frequency	Rated frequency	–2 % to +5 %	
		Applied voltage	See 7.103.5	+10 % / 0 %	
7.103.6	System-source short-circuit making current	Applied phase voltage / average (three-phase)	1	±5 %	
		Making current	See Table 20 and Table 21	0 % / +10 %	
7.103.7	Transient recovery voltage (TRV) for system-source short-circuit breaking tests	Peak value of TRV:	See Table 3	+10 % / 0 %	
		Rate of rise of TRV:	See Table 3	+15 % / 0 %	
7.103.9	Power-frequency recovery voltage	Time delay	See Table 3	±20 %	
		Power-frequency recovery voltage	See Table 20 and Table 21	±5 %	

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/limits of test values	Reference to
7.104	Load current breaking tests	Peak value of TRV:	See Table 5	+10 % / 0 %	
		Peak value of TRV:	According to calculations in Annex N	+10 % / 0 %	
		Rate of rise of TRV:	See Table 5	+15 % / 0 %	
		Rate of rise of TRV:	According to calculations in Annex N	+15 % / 0 %	
		Time delay	See Table 5	±20 %	
7.105.2	Frequency of test circuit	Time delay	According to calculations in Annex N	±30 %	
		Frequency	Rated frequency	-2 % to +5 %	
7.105.5	Applied voltage before generator-source short-circuit making tests	Applied voltage	See 7.105.5	0 % / +10 %	
		Applied phase voltage / average (three-phase)	1	±5 %	
7.105.6	Generator-source short-circuit making current	Making current	See Table 22 and Table 23	0 % to +10 %	
7.105.8	Transient recovery voltage (TRV) for generator-source short-circuit breaking tests	Peak value of TRV:	See Table 4	+10 % / 0 %	
		Rate of rise of TRV:	See Table 4	+15 % / 0 %	
		Time delay	See Table 4	±20 %	

Subclause	Designation of the test	Test quantity	Specified test value	Test tolerances/limits of test values	Reference to
7.105.9	Power-frequency recovery voltage	Power-frequency recovery voltage	See Table 22 and Table 23	±5 %	
7.105.11.4	Asymmetrical current breaking test-duties	Arcing time for test-duty 5	≥ 1 cycle	≥ 1 cycle – 2 ms	
7.105.11.4	Asymmetrical current breaking test-duties	Arcing time for test-duties 6A and 6B	≥ 1,5 cycles	≥ 1,5 cycles – 4 ms	
7.105.11.4	Asymmetrical current breaking test-duties	Degree of asymmetry for test-duty 5	110 %	≥ 110 %	
7.105.11.4	Asymmetrical current breaking test-duties	Degree of asymmetry for test-duties 6A and 6B	130 %	≥ 130 % – 5 %	
7.106	Out-of-phase making and breaking tests	Frequency	Rated frequency	–2 % to +5 %	
		Applied voltage and power-frequency recovery voltage	See Table 24 and Table 25	±5 %	
		Peak value of TRV:	See Table 6	+10 % / 0 %	
		Peak value of TRV:	According to calculations in Annex M	+10 % / 0 %	
		Rate of rise of TRV:	See Table 6	+15 % / 0 %	
		Rate of rise of TRV:	According to calculations in Annex M	+15 % / 0 %	
		Time delay	See Table 6	±20 %	
		Time delay	According to calculations in Annex M	±30 %	
		Instant of closing in one of the operations of test-duty OP1	At crest of applied voltage in one pole	±20°	

Annex B

(normative)

Records and reports of type tests specified in 7.6, 7.103, 7.104, 7.105 and 7.106

B.1 Information and results to be recorded

All relevant information and results of type tests shall be included in the type test report.

Graphical records according to Clause B.2 shall be made of all operations.

The type test report shall include a statement concerning the uncertainty of the measurement systems used for the tests. This statement shall refer to internal procedures of the laboratory through which traceability of the measuring uncertainty is established.

The type test report shall include a statement of the performance of the generator circuit-breaker during each test-duty and of the condition of the generator circuit-breaker after each test-duty, in so far as an examination is made, and at the end of the series of test-duties. The statement shall include the following particulars:

- a) condition of generator circuit-breaker or generator circuit-breaker systems, giving details of any replacements or adjustments made and condition of contacts, oil (including any quantity lost), statement of any damage to arc shields, enclosures, insulators and bushings;
- b) description of performance during test-duty, including observations regarding emission of oil, gas or flame.

B.2 Information to be included in type test reports

B.2.1 General

The following information shall be included in the type test reports:

- a) date of tests;
- b) reference of report number;
- c) test numbers;
- d) graphical record numbers.

B.2.2 Apparatus tested

Subclause 7.1.3 and Clause A.3 of IEC 62271-1:2017 are applicable with the following additions:

Reference drawing numbers given in the test report shall indicate the manufacturer's reference number, revision number and corresponding contents.

The mechanical characteristic, if applicable, shall be included or reference shall be made in the test report by the use of a drawing number or in an equivalent way.

B.2.3 Rated characteristics of generator circuit-breaker, including its operating devices and auxiliary equipment

The values of rated characteristics specified in Clause 5 and the minimum opening time shall be given by the manufacturer.

B.2.4 Test conditions (for each series of tests)

The following information shall be included in the type test reports:

- a) number of poles;
- b) frequency, in Hz;
- c) generator neutral (earthed or isolated);
- d) transformer neutral (earthed or isolated);
- e) short-circuit point or load side neutral (earthed or isolated);
- f) diagram of test circuit including connection(s) to earth;
- g) details of connection of generator circuit-breaker to the test circuit (e.g. orientation);
- h) pressure of fluid for insulation and/or making and breaking;
- i) pressure of fluid for operation.

B.2.5 Short-circuit making and breaking tests

The following information shall be included in the type test reports:

- a) operating sequence and time intervals;
- b) applied voltage, in kV;
- c) making current (peak value), in kA;
- d) prospective current for test-duties 2, 5, 6A and 6B:
 - 1) RMS value of AC component in kA for each phase and average;
 - 2) degree of asymmetry at intended contact separation (applicable to test-duties 5, 6A and 6B);
 - 3) peak current in the expected last current loop (applicable only to test-duty 2 for the phase having the highest degree of asymmetry);
 - 4) loop duration of the expected last current loop (applicable only to test-duty 2 for the phase having the highest degree of asymmetry and first-pole-to-clear);
 - 5) the number of current peaks and relative minimums until the first current zero crossing (applicable to test-duties 5, 6A and 6B only);
- e) breaking current:
 - 1) RMS value of AC component in kA for each phase and average;
 - 2) degree of asymmetry at contact separation;
 - 3) peak current in the last current loop;
 - 4) loop duration of the last current loop;
- f) power-frequency recovery voltage, in kV;
- g) transient recovery voltage:
 - 1) prospective transient recovery voltage in accordance with requirements of 7.103.8 and 7.105.8;
 - 2) transient recovery voltage during the actual test;
- h) arc parameters:
 - 1) arcing time, in ms;
- i) opening time, in ms;
- j) break-time, in ms;
where applicable, break-times up to the instant of extinction of the main arc and up to the instant of the breaking of resistor current shall be given.
- k) closing time, in ms;

- l) make time, in ms;
- m) behaviour of generator circuit-breaker during tests, including, where applicable, emission of flame, gas, oil, etc.; the occurrence of NSDDs shall be noted;
- n) condition after tests;
- o) parts renewed or reconditioned during the tests.

B.2.6 Short-time withstand current test

The following information shall be included in the type test reports:

- a) current
 - 1) RMS value, in kA;
 - 2) value of the first major peak, in kA;
- b) duration in s;
- c) equivalent duration in s based on the specified short-time current;
- d) behaviour of generator circuit-breaker during tests;
- e) condition after tests;
- f) resistance of the main circuit before and after tests, in $\mu\Omega$.

B.2.7 No-load operation

The following information shall be included in the type test reports:

- a) before making and breaking tests (see 7.102.6);
- b) after making and breaking tests (see 7.102.9.2 and 7.102.9.3).

B.2.8 Out-of-phase making and breaking tests

The following information shall be included in the type test reports:

- a) prospective current for test-duties OP1 and OP2:
 - 1) RMS value of AC component in kA for each phase and average;
 - 2) peak current in the expected last current loop (applicable only to test-duty OP2 for the phase having the highest degree of asymmetry);
 - 3) loop duration of the expected last current loop (applicable only to test-duty OP2 for the phase having the highest degree of asymmetry and first-pole-to-clear).
- b) applied voltage, in kV;
- c) making current (peak value), in kA;
- d) breaking current:
 - 1) RMS value of AC component in kA for each phase and average;
 - 2) degree of asymmetry at contact separation;
 - 3) peak current in the last current loop;
 - 4) loop duration of the last current loop;
- e) power-frequency recovery voltage, in kV;
- f) transient recovery voltage:
 - 1) prospective transient recovery voltage in accordance with requirements of 7.106.6;
 - 2) transient recovery voltage during the actual test;
- g) arcing time, in ms;
- h) opening time, in ms;
- i) break-time, in ms;

- j) closing time, in ms;
- k) make-time, in ms;
- l) duration of resistor current (where applicable), in ms;
- m) behaviour of generator circuit-breaker during tests, including, where applicable, emission of flame, gas, oil, etc.; the occurrence of NSDDs shall be noted;
- n) condition after tests;
- o) parts renewed or reconditioned during the tests.

B.2.9 Load current breaking tests

The following information shall be included in the type test reports:

- a) RMS value of AC component of the breaking current in A for each phase and average;
- b) power-frequency recovery voltage, in kV;
- c) transient recovery voltage:
 - 1) prospective transient recovery voltage according to requirements of 7.104.2;
 - 2) transient recovery voltage during the actual test;
- d) arcing time, in ms;
- e) opening time, in ms;
- f) break-time, in ms;
- g) behaviour of generator circuit-breaker during tests, including, where applicable, emission of flame, gas, oil, etc.; the occurrence of NSDDs shall be noted;
- h) condition after tests;
- i) parts renewed or reconditioned during the tests.

B.2.10 Graphical records

Graphical records shall include all quantities listed in a) through h) below, as applicable, recorded as a function of time for all tests, including prospective pre-tests. Certain quantities can be recorded separately, as well as in various groupings and records can be made using several different time scales to show all required results.

The following quantities shall be recorded as applicable:

- a) applied voltage(s);
- b) current in each pole;
- c) recovery voltage(s);
- d) arc voltage (applicable to test-duties 5, 6A and 6B only);
- e) current and/or voltage in closing release circuit;
- f) current and/or voltage in opening release circuit;
- g) amplitude scales and timing scales appropriate for the required accuracy;
- h) mechanical travel characteristics (where applicable).

All cases in which the requirements of this document are not strictly complied with and all deviations shall be explicitly mentioned at the beginning of the test report.

Annex C

(normative)

Method for determining the reference travel band closing and the reference travel band opening of the mechanical characteristics

C.1 General

The mechanical characteristics shall be available at the beginning of the type tests. They can be either defined during a separate test before the beginning of the type tests or as part of the first type test being either a mechanical type test or a making or breaking type test. Here below a method is described on how the typical mechanical characteristics, consisting of a reference travel band closing and a reference travel band opening, can be defined.

C.2 Reference travel band closing

First, a no-load travel curve during a closing operation at rated supply voltage of operating devices and of auxiliary and control circuits and at filling pressure for operation, insulation and/or making and breaking or, for convenience of testing, at the minimum functional pressure for insulation and/or making and breaking shall be recorded. The type and location of the sensor used for the record of the travel curve can be positioned at any part of the power kinematic chain with the following addition: in case the power kinematic chain comprises an intentionally deformable element, for example spring, or mechanical gap, the sensor shall be located between the operating device and the deformable element or mechanical gap. The travel curve may be recorded continuously or discretely. In the case of discrete measurement, at least 20 discrete values should be measured for the complete stroke.

In a second step two envelope curves from the beginning of contact travel to the instant of contact touch, being parallel to the no-load curve shall be drawn. The distance between the two envelope curves shall be 10 % of the total stroke of the travel curve or 4 mm in case the total stroke is below 40 mm. The area between the two envelope curves is called reference travel band closing.

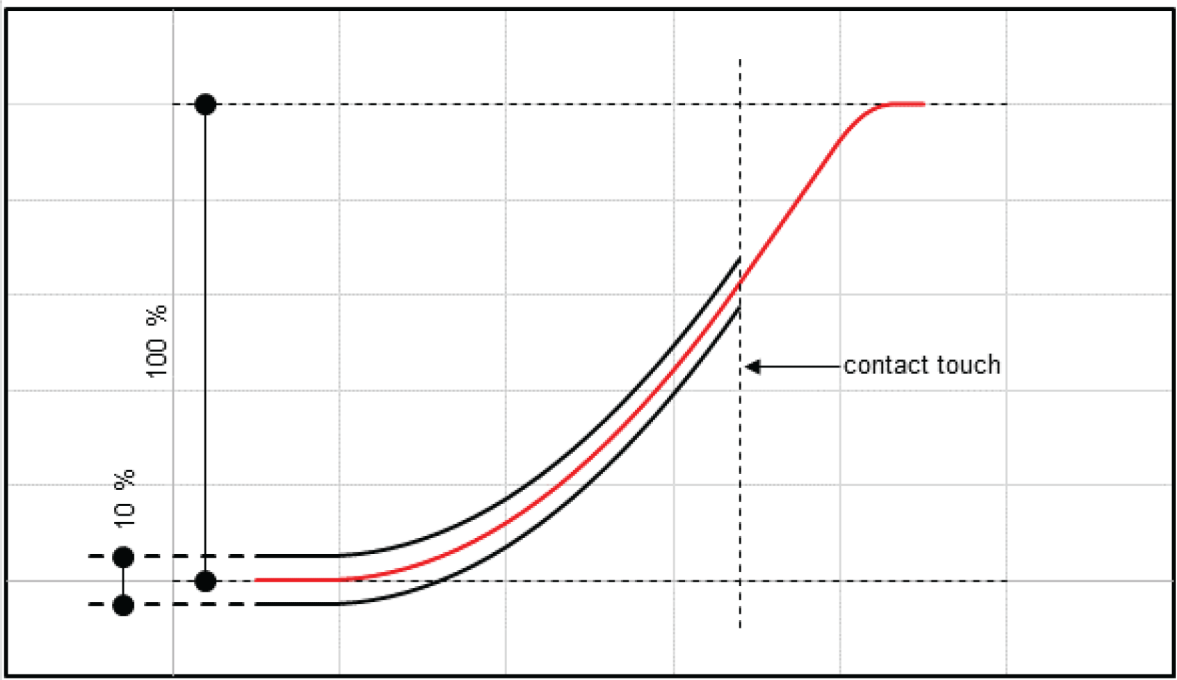
Figure C.1 shows an example of a typical no-load curve during a closing operation (bold red curve), its two envelope curves (bold black curves) and the reference travel band closing (area between the two bold black curves).

C.3 Reference travel band opening

First, a no-load travel curve during an opening operation at rated supply voltage of operating devices and of auxiliary and control circuits and at filling pressure for operation, insulation and/or making and breaking or, for convenience of testing, at the minimum functional pressure for insulation and/or making and breaking shall be recorded. The type and location of the sensor used for the record of the travel curve can be positioned at any part of the power kinematic chain with the following addition: in case the power kinematic chain comprises an intentionally deformable element, for example spring, or mechanical gap, the sensor shall be located between the operating device and the deformable element or mechanical gap. The travel curve may be recorded continuously or discretely. In the case of discrete measurement, at least 20 discrete values should be measured for the complete stroke.

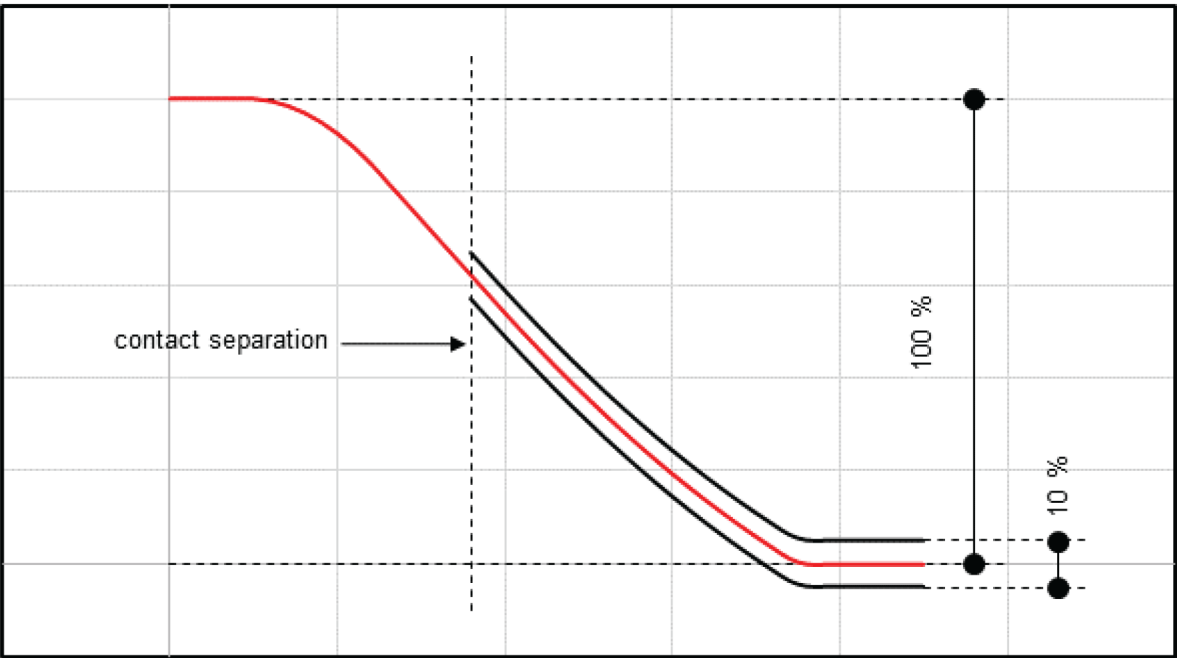
In a second step two envelope curves from the instant of contact separation to the end of contact travel, being parallel to the no-load curve shall be drawn. The distance between the two envelope curves shall be 10 % of the total stroke of the travel curve or 4 mm in case the total stroke is below 40 mm. The area between the two envelope curves is called reference travel band opening.

Figure C.2 shows an example of a typical no-load curve during an opening operation, its two envelope curves and the reference travel band opening.



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Figure C.1 – Reference travel band closing



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Figure C.2 – Reference travel band opening

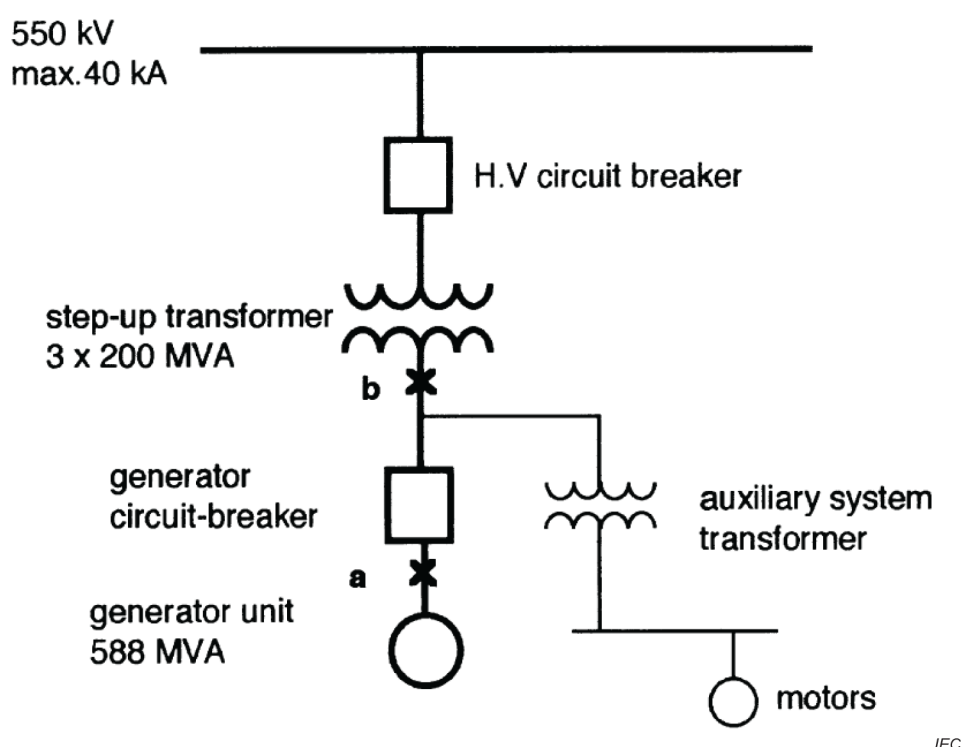
Annex D (informative)

Example of the application of a generator circuit-breaker

D.1 General

The application guide given in Clause 9 was used in developing this example.

When requesting proposals for AC generator circuit-breakers, it is important that the purchaser provide the manufacturer with a specification containing the information outlined in Clause 10. This information alerts the manufacturer to the application conditions in 9.102 and 9.103.



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Figure D.1 – Single-line power plant diagram

The example given in Clause D.2 describes an actual indoor generator circuit-breaker application for a 588 MVA, coal-fired, continuous-load power plant. The generator circuit-breaker is forced-air-cooled.

D.2 System characteristics

System characteristics are described in Table D.1.

Table D.1 – System characteristics

Item	Corresponding IEC (IEEE) Symbol	Value
a) Single-line diagram		See Figure D.1
b) Maximum generator line-to-line voltage (kV)	U_{mG}	22,05
c) Rated frequency (Hz)	f_r	60
d) Generator data (rated values):		
1) Rated power (MVA)	S_{rG}	588
2) Rated voltage (kV)	U_{rG} (in IEEE called V_{nG})	21
3) Reactance values in p.u.:		At rated voltage (saturated)
i) Synchronous direct axis	$x_{d \text{ sat}}$ (in IEEE called X_{dv})	2,0
ii) Transient direct axis	$x'_{d \text{ sat}}$ (in IEEE called X'_{dv})	0,31
iii) Subtransient direct axis	$x''_{d \text{ sat}}$ (in IEEE called X''_{dv})	0,24
iv) Synchronous quadrature axis	$x_{q \text{ sat}}$ (in IEEE called X_{qv})	2,04
v) Transient quadrature axis	$x'_{q \text{ sat}}$ (in IEEE called X'_{qv})	0,5
vi) Subtransient quadrature axis	$x''_{q \text{ sat}}$ (in IEEE called X''_{qv})	0,25
vii) Negative sequence	$x_{2 \text{ sat}}$ (in IEEE called X_{2v})	0,24
viii) Zero sequence	$x_{0 \text{ sat}}$ (in IEEE called X_{0v})	0,1
4) Time constants in seconds:		
i) Transient open-circuit	τ'_{do} (in IEEE called T'_{do})	5,63
ii) Transient short-circuit	τ'_d (in IEEE called T'_d)	0,84
iii) Subtransient open-circuit	τ''_{do} (in IEEE called T''_{do})	0,034
iv) Subtransient short-circuit	τ''_d (in IEEE called T''_d)	0,025
v) Transient open-circuit quadrature	τ'_{qo} (in IEEE called T'_{qo})	–
vi) Transient short-circuit quadrature	τ'_q (in IEEE called T'_q)	0,255
vii) Subtransient open-circuit quadrature	τ''_{qo} (in IEEE called T''_{qo})	–
viii) Subtransient short-circuit quadrature	τ''_q (in IEEE called T''_q)	0,025
ix) Armature short-circuit	τ_a (in IEEE called T_a)	0,31
5) Generator earthing		Earthed with high resistance through distribution transformer
6) Moment of inertia (kgm ²)	J	28 300
7) Capacitance of armature winding-to-earth (all phases tied together) (µF)		0,9
e) Generator step-up transformer data (rated values):		
1) Rated voltage (kV)	U_{rTHV}/U_{rTLV}	550/21
2) Rated power (MVA)	S_{rT}	3 × 200
3) Connection		Wye Star effectively earthed/delta
4) Short-circuit reactance at rated voltage (p.u.)	u_{krT}	0,14

Item	Corresponding IEC (IEEE) Symbol	Value
5) Tap changer range on HV side (1,25 % steps)		–10 % /+5 %
Change in short-circuit reactance		–5 % /+2,5 %
6) Time constant $X/\omega R$ (ms)	τ_T	160
f) System-source initial symmetrical short-circuit current on high-voltage side of generator step-up transformer (future requirement) (kA)	$I''_{k\text{ sys}}$	40
g) Time constant $X/\omega R$ of the high-voltage system (ms)	τ_{sys}	45
h) Maximum service voltage of the high-voltage system (kV)	$U_{m\text{ sys}}$	577,5
i) Unit auxiliary transformer data (rated values):		
1) Rated voltage (kV)	$U_{r\text{ aux transf HV}}/U_{r\text{ aux transf LV}}$	21/6,3
2) Rated power (MVA)	$S_{r\text{ aux transf}}$	35
3) Short-circuit reactance at rated voltage (p.u.)	$u_{kr\text{ aux transf}}$	0,08
4) Time constant $X/\omega R$ (ms)	$\tau_{\text{aux transf}}$	100

D.3 System-source short-circuit current

D.3.1 AC component of the system-source short-circuit breaking current

The following example is based on a fault at location "a" (see Figure D.1).

The RMS value of the AC component of the system-source short-circuit breaking current is the highest RMS value of the symmetrical component of the polyphase short-circuit current that the generator circuit-breaker has to interrupt at rated voltage and rated duty cycle.

For a 40 kA system-source short-circuit current contribution on the 550 kV side, the required system short-circuit reactance seen from the 21 kV low-voltage side is as follows:

$$X_{\text{sys}} \cong \frac{550}{40\sqrt{3}} \left(\frac{21}{550} \right)^2 = 11,57 \times 10^{-3} \Omega$$

The short-circuit reactance of the main transformer with a rated power of 600 MVA and a short-circuit reactance of 0,14 p.u. yields a reactance of the following:

$$X_t \cong 0,14 \times \frac{21^2}{600} = 102,9 \times 10^{-3} \Omega$$

The calculation of the system-source short-circuit breaking current shall be based on the maximum service voltage of the high-voltage system. Therefore, the short-circuit contribution from the system side is as follows:

$$I_{\text{SC}_{\text{sys}+t}} = \frac{22,05}{\sqrt{3} \left((11,57 + 102,9) \times 10^{-3} \right)} = 111,21 \text{ kA}$$

The contribution to the short-circuit current from the auxiliary system motors is a small fraction of the current from the high-voltage system. It can be determined as follows if the motors are connected through two auxiliary transformers each rated 35 MVA, 0,08 p.u. short-circuit reactance, and with a time constant of 100 ms (X/R ratio of 37,7). The maximum rating of all motors combined is 60 MVA with the conservative assumption that all are in service at the same time. The rated voltage of the motors U_{rM} in this example is assumed to be equal to the rated voltage of the LV-winding of the unit auxiliary transformer.

The motor short-circuit impedance is as follows:

$$Z_M = \frac{I_{rM}}{I_{LR}} \times \frac{U_{rM}^2}{S_{sM}} \times \left(\frac{U_{r \text{ aux transf HV}}}{U_{r \text{ aux transf LV}}} \right)^2 = 0,2 \times \frac{6,3^2}{60} \left(\frac{21}{6,3} \right)^2 \cong X_M = 1,47 \Omega$$

with I_{rM}/I_{LR} being the ratio of rated motor current to the locked rotor motor current and equal to approximately 0,2 in the given example.

$$X_{\text{aux transf}} \cong 0,08 \times \frac{21^2}{70} = 0,504 \Omega$$

The initial symmetrical RMS short-circuit current contribution from the auxiliary system is as follows:

$$I''_{k \text{ aux sys}} \times \frac{22,05}{\sqrt{3} (1,47 + 0,504)} = 6,45 \text{ kA}$$

This initial current decays and the current interrupted at a contact separation time of 40 ms to 80 ms can be estimated as being equal to 0,7 to 0,85 times the initial current $I''_{k \text{ aux sys}}$. If the factor is 0,8, which is based on the selected generator circuit-breaker having a 58,3 ms (opening time 50 ms plus a tripping delay of 0,5 cycles) contact separation time, the contribution from the auxiliary system to the RMS value of the AC component of the system-source short-circuit breaking current will be 5,16 kA.

The RMS value of the AC component of the total system-source short-circuit breaking current seen by the generator circuit-breaker is as follows:

$$I_{\text{sc tot cs}} = 111,21 + 5,16 = 116,37 \text{ kA}$$

D.3.2 Asymmetrical system-source short-circuit breaking current

The following example is based on a fault at location "a" (see Figure D.1), and on the calculations in D.3.1. The DC component of the system-source short-circuit current is equal to the following:

$$I_{\text{DC}} = \left(\sqrt{2} I''_k \right) e^{-t/\tau}$$

where

I''_k is the system-source initial symmetrical short-circuit current. Assuming that the RMS value of the AC component of the system-source short-circuit current is constant with time I''_k is equal to the RMS value of the AC component of the system-source short-circuit breaking current $I_{sc\ sys + t}$ that was determined to be 111,21 kA through the step-up transformer for a 40 kA system short-circuit current contribution on the high-voltage side of the step-up transformer;

I_{DC} is the DC component of the system-source short-circuit current;

τ is $\left(\frac{1}{\omega} \times \frac{X}{R}\right)$;

X is the short-circuit reactance of system elements;

R is the resistance of system elements;

ω is the angular frequency corresponding to the rated frequency.

As for the AC component of the system-source short-circuit current the DC component is composed of the contribution from the high-voltage system through the step-up transformer and the DC component of the auxiliary system. It shall be determined at contact separation.

The high-voltage system time constant is 45 ms, and its short-circuit reactance is determined as follows: $X_{sys} = 11,57 \times 10^{-3} \Omega$ (see D.3.1).

It follows that:

$$R_{sys} = \frac{11,57 \times 10^{-3}}{377 \times 45 \times 10^{-3}} = 0,682 \times 10^{-3} \Omega$$

The time constant of the generator step-up transformer is 160 ms and the transformer short-circuit reactance was calculated to be $X_t = 102,9 \times 10^{-3} \Omega$.

This leads to the following step-up transformer resistance:

$$R_t = \frac{102,9 \times 10^{-3}}{377 \times 160 \times 10^{-3}} = 1,706 \times 10^{-3} \Omega$$

The total reactance and resistance which have to be considered for the calculation of the high-voltage system contribution to the system-source short-circuit current through the step-up transformer are:

$$X_{sys+t} = X_{sys} + X_t = 11,57 \times 10^{-3} + 102,9 \times 10^{-3} = 114,47 \times 10^{-3} \Omega$$

$$R_{sys+t} = R_{sys} + R_t = 0,682 \times 10^{-3} + 1,706 \times 10^{-3} = 2,39 \times 10^{-3} \Omega$$

Therefore, the time constant τ_{sys+t} of the decay of the DC component of the short-circuit current from the high-voltage system through the step-up transformer is as follows:

$$\tau_{sys+t} = \frac{114,47 \times 10^{-3}}{377 \times 2,39 \times 10^{-3}} = 127,04 \text{ ms}$$

The auxiliary system transformer's short-circuit reactance was evaluated to be 0,504 Ω and is assumed to have a time constant of 100 ms $[(X/R)_{\text{aux transf}} = 37,7]$. Therefore, the resistance is as follows:

$$R_{\text{aux transf}} = 0,0134 \Omega$$

For the motors a reactance of $X_M = 1,47 \Omega$ was calculated. The resistance R_M for motors greater than 1 MW rated power is approximately 0,1 times X_M . Therefore,

$$R_M = 0,147 \Omega$$

The time constant of the decrement of the DC component from the auxiliary system is as follows:

$$\tau_{\text{aux sys}} = \frac{X_{\text{aux transf}} + X_M}{\omega \times (R_{\text{aux transf}} + R_M)} = \frac{0,504 + 1,47}{377 \times (0,0134 + 0,147)} = 32,64 \text{ ms}$$

The DC component of the total system-source short-circuit current (including the DC component of the auxiliary system contribution), at a contact separation of the generator circuit-breaker of 58,3 ms (opening time 50 ms plus a tripping delay of 0,5 cycles), is the sum of the contribution from the high-voltage system through the step-up transformer and the auxiliary system contribution.

$$I_{\text{DC sys + t cs}} = 111,21 \times \sqrt{2} \times e^{-58,3/127,04} = 99,39 \text{ kA}$$

$$I_{\text{DC aux sys cs}} = 6,45 \times \sqrt{2} \times e^{-58,3/32,64} = 1,53 \text{ kA}$$

$$I_{\text{DC tot cs}} = 99,39 + 1,53 = 100,92 \text{ kA}$$

The degree of asymmetry at contact separation is therefore 61,3 %.

The asymmetrical short-circuit breaking current can be calculated using the equation described in 9.103.6.3.3 thus resulting in

$$I_{\text{scasymtotcs}} = \sqrt{I_{\text{sctotcs}}^2 + I_{\text{DCtotcs}}^2} = 154,04 \text{ kA}$$

D.4 Generator-source short-circuit current

D.4.1 AC component of the generator-source short-circuit breaking current

This current is measured from the envelope of the current excursion at the moment of contact separation when the source of the short-circuit current is entirely from a generator without transformation.

As mentioned in 9.103.6.3.4 this envelope shall be calculated from a full-load rated power factor condition taking the generator constants into account. Calculations are generally complex and are often performed with computer simulations.

Consequently, the equations displayed below shall not be considered as exhaustive but they can be used to estimate the magnitude of the fault current when the generator is unloaded prior to fault.

The RMS value of the AC component of the generator-source short-circuit breaking current as a function of time t can be calculated using the following equation for no-load conditions:

$$I_{\text{gen sym}} = \frac{U_{\text{mG}} S_{\text{rG}}}{\sqrt{3} U_{\text{rG}}^2} \left[\left(\frac{1}{x''_{\text{d}}} - \frac{1}{x'_{\text{d}}} \right) e^{-t/\tau''_{\text{d}}} + \left(\frac{1}{x'_{\text{d}}} - \frac{1}{x_{\text{d}}} \right) e^{-t/\tau'_{\text{d}}} + \frac{1}{x_{\text{d}}} \right]$$

where

- U_{mG} is the maximum generator line-to-line voltage;
- S_{rG} is the rated power of the generator;
- U_{rG} is the rated voltage of the generator;
- x''_{d} is the saturated value of the direct axis subtransient reactance in p.u.;
- x'_{d} is the saturated value of the direct axis transient reactance in p.u.;
- τ''_{d} is the direct axis subtransient short-circuit time constant;
- τ'_{d} is the direct axis transient short-circuit time constant.

Using the data given for the generator in this example, the RMS value of the AC component of the generator-source short-circuit breaking current at a contact separation equal to 58,3 ms results in the following when the generator is unloaded prior to fault:

$$I_{\text{scg cs}} = 53,2 \text{ kA.}$$

D.4.2 Asymmetrical generator-source short-circuit breaking current

The asymmetrical generator-source short-circuit current as a function of time t for the phase with the highest asymmetry, the generator being in the no-load mode, can be calculated by the following equation:

$$I_{\text{gen asym}} = \frac{\sqrt{2} U_{\text{mG}} S_{\text{rG}}}{\sqrt{3} U_{\text{rG}}^2} \left\{ \left[\left(\frac{1}{x''_{\text{d}}} - \frac{1}{x'_{\text{d}}} \right) e^{-t/\tau''_{\text{d}}} + \left(\frac{1}{x'_{\text{d}}} - \frac{1}{x_{\text{d}}} \right) e^{-t/\tau'_{\text{d}}} + \frac{1}{x_{\text{d}}} \right] \cos(\omega t) \right\}$$

$$- \frac{\sqrt{2} U_{\text{mG}} S_{\text{rG}}}{\sqrt{3} U_{\text{rG}}^2} \left[\frac{1}{2} \left(\frac{1}{x''_{\text{d}}} + \frac{1}{x'_{\text{q}}} \right) e^{-t/\tau_{\text{a}}} + \frac{1}{2} \left(\frac{1}{x''_{\text{d}}} - \frac{1}{x'_{\text{q}}} \right) e^{-t/\tau_{\text{a}}} \cos(\omega t) \right]$$

where

- U_{mG} is the maximum generator line-to-line voltage;
- S_{rG} is the rated power of the generator;
- U_{rG} is the rated voltage of the generator;
- x''_{d} is the saturated value of the direct axis subtransient reactance in p.u.;
- x''_{q} is the saturated value of the quadrature axis subtransient reactance in p.u.;
- x'_{d} is the saturated value of the direct axis transient reactance in p.u.;
- τ''_{d} is the direct axis subtransient short-circuit time constant;
- τ'_{d} is the direct axis transient short-circuit time constant;
- τ_{a} is the armature time constant.

Since x''_d is approximately equal to x''_q for turbo generators, the equation can be written as follows:

$$I_{\text{gen asym}} = \frac{\sqrt{2}U_{\text{mG}}S_{\text{rG}}}{\sqrt{3}U_{\text{rG}}^2} \left\{ \left[\left(\frac{1}{x''_d} - \frac{1}{x'_d} \right) e^{-t/\tau''_d} + \left(\frac{1}{x'_d} - \frac{1}{x_d} \right) e^{-t/\tau'_d} + \frac{1}{x_d} \right] \cos(\omega t) - \left(\frac{1}{x''_d} \right) e^{-t/\tau_a} \right\}$$

Figure D.2 shows the three-phase asymmetrical short-circuit current for the example in this annex obtained by calculation, assuming that the pre-fault voltage is the generator rated voltage and the fault occurs with the generator in the no-load mode. This case may occur when the generator circuit-breaker is closed into a bolted fault such as a closed earthing switch. At the location of the fault therefore, no arcing is taken into account. The asymmetry at the contact separation of the generator circuit-breaker is 110,1 %.

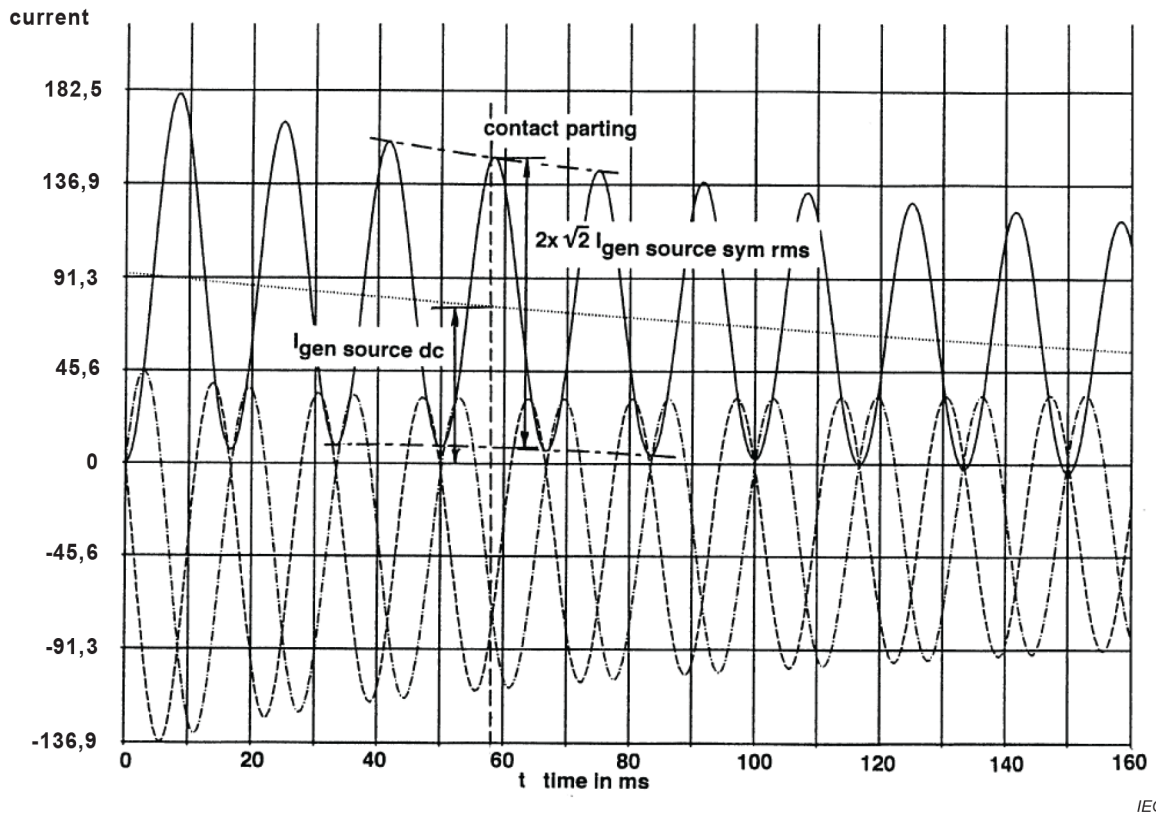
The asymmetrical short-circuit breaking current can be calculated using the equation described in 9.103.6.3.3 thus resulting in 98,5 kA.

Figure D.3 exhibits for comparison the calculated asymmetrical three-phase short-circuit current but with the assumption of an arc at the fault location influencing the asymmetry of the short-circuit current. Owing to the arc voltage, the asymmetry is reduced to 68 % in comparison to Figure D.2 with an asymmetry of 110,1 %.

A free-burning arc in air has an arc voltage of 10 V/cm, which means that the arc voltage of a fault in the bus is at least 300 V. In the case of a failure occurring in a transformer, an arc would burn in oil with a considerably higher arc voltage.

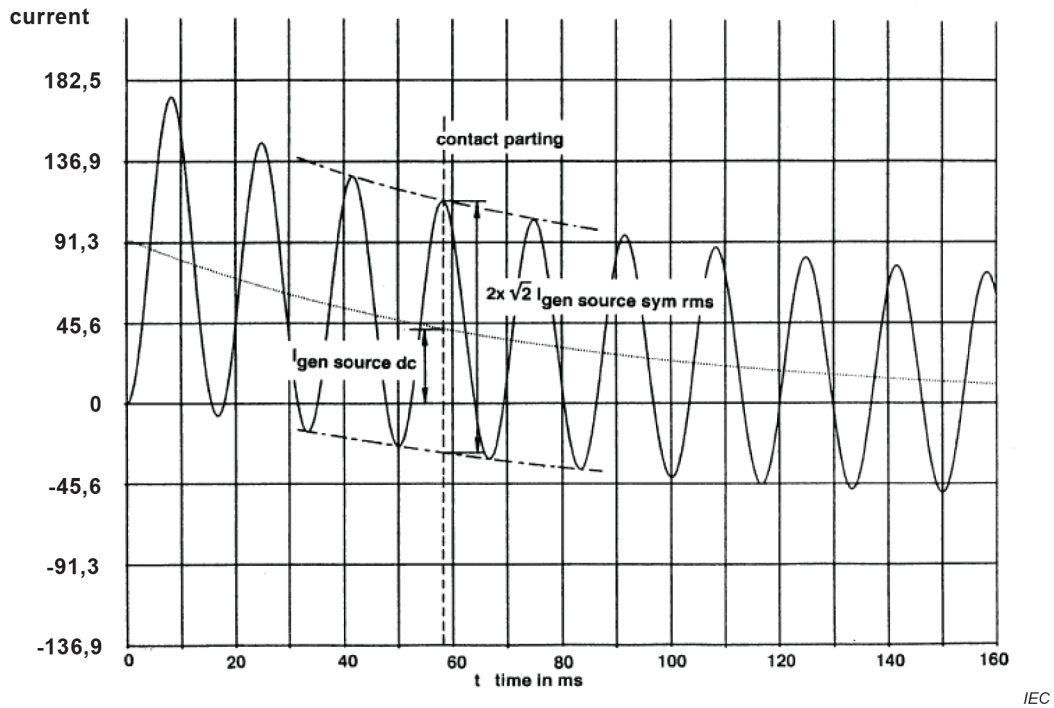
The influence of the generator circuit-breaker arc on the phase with the maximum asymmetry is illustrated in the computer calculation in Figure 53.

The asymmetrical generator-source short-circuit current is normally calculated by using appropriate computer programs. For the generator-source short-circuit current with maximum degree of asymmetry and with the generator in an underexcited or overexcited mode, no approximate equation can be given so the short-circuit current is calculated using appropriate computer programs.



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Figure D.2 – Asymmetrical generator-source short-circuit current with no arc at the fault location



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Figure D.3 – Asymmetrical generator-source short-circuit current with arc at the fault location

D.5 Transient recovery voltage

The prospective TRV for the system-source fault can be determined in the same manner as a transformer fed fault. The natural frequency of the transformer in the short-circuit mode has to be known. This frequency can be measured by means of a low-voltage injection method. When capacitors are used, they shall be accounted for in the actual TRV.

The TRV parameters given in this document are the result of data from a large number of transformers and generators, normally from measurements, and they cover the most severe cases. See [10] and [11].

A calculation of the TRV for the system-source fault, as well as for the generator-source fault, may be inaccurate because the appropriate modelling is complicated and the necessary accurate data, which are partially frequency dependent, may not be available.

D.6 Out-of-phase conditions

An out-of-phase condition can occur under the following two conditions:

- a) Instability in a high-voltage transmission system where the high-voltage circuit-breakers are tripped by the relevant protective scheme before a maximum 180° phase opposition is reached. This case can be disregarded for generator circuit-breakers.
- b) Synchronising with the generator circuit-breaker, if performed incorrectly, can result in an out-of-phase condition if the generator circuit-breaker has to be tripped.

The RMS value of the AC component of the out-of-phase current (I_{oph}) for the latter case at the moment of current initiation ($t = 0$), can be estimated using the following expressions:

$$I_{\text{oph}} = \frac{1}{\sqrt{3}} \times \frac{U_{\text{oph}}}{X_{\text{d}}'' + X_{\text{t}} + X_{\text{s}}} = \frac{1}{\sqrt{3}} \times \frac{\delta \times U_{\text{oG}}}{X_{\text{d}}'' + X_{\text{t}} + X_{\text{s}}}$$

where

U_{oph} is the out-of-phase voltage;

U_{oG} is the generator line-to-line operating voltage prior to synchronisation;

δ is $\sqrt{2}$ for a 90° out-of-phase angle, and 2 for a 180° out-of-phase angle;

X_{d}'' is the subtransient reactance of the generator in Ω ;

X_{t} is the transformer short-circuit reactance in Ω ;

X_{s} is the short-circuit system reactance in Ω .

NOTE The synchronisation is generally performed with the generator voltage at its rated value.

This equation is valid for system diagrams such as Figure 55 or schematic diagram, Figure D.4, with generator and generator step-up transformer in series.

The ultimate out-of-phase current is lower than the initial out-of-phase current at $t = 0$ because it decreases based on the time constants of the generator, the transformer and the system.

As a better approach, for power plant single-line diagrams such as Figure 55, the out-of-phase current as a function of time t can be approximately calculated using the following equation when the generator is in a no-load situation prior to the out-of-phase condition (see Figure D.4).

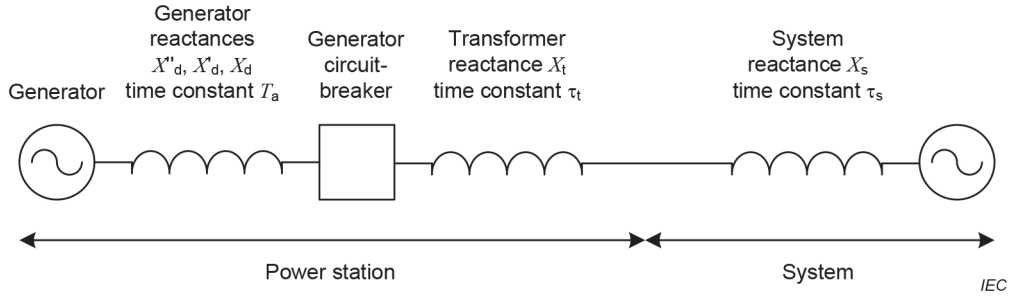


Figure D.4 – Schematic diagram of power plant (single-line diagram as in Figure 55)

$$I_{\text{oph}} = \frac{\sqrt{2}U_{\text{oph}}S_{rG}}{\sqrt{3}U_{rG}^2} \left\{ \left[\left(\frac{1}{x''_d + x_s + x_t} - \frac{1}{x'_d + x_s + x_t} \right) e^{-t/\tau''} \left(\frac{1}{x'_d + x_s + x_t} - \frac{1}{x_d + x_s + x_t} \right) e^{-t/\tau'} + \frac{1}{x_d + x_s + x_t} \right] \cos(\omega t) \right\} - \frac{\sqrt{2}U_{\text{oph}}S_{rG}}{\sqrt{3}U_{rG}^2} \left(\frac{1}{x''_d + x_s + x_t} \right) e^{-t/\tau}$$

where

$$\tau'' = \tau''_{d0} \left(\frac{x''_d + x_s + x_t}{x'_d + x_s + x_t} \right) = \tau''_d \left(\frac{x''_d}{x'_d} \times \frac{x'_d + x_s + x_t}{x'_d + x_s + x_t} \right) \text{ because } \tau''_{d0} \cong \tau''_d \left(\frac{x''_d}{x'_d} \right)$$

$$\tau' = \tau'_{d0} \left(\frac{x'_d + x_s + x_t}{x_d + x_s + x_t} \right) = \tau'_d \left(\frac{x'_d}{x_d} \times \frac{x'_d + x_s + x_t}{x'_d + x_s + x_t} \right) \text{ because } \tau'_{d0} \cong \tau'_d \left(\frac{x'_d}{x_d} \right)$$

$$\tau = \frac{x''_d + x_s + x_t}{\frac{x''_d}{\tau_a} + \frac{x_s}{\tau_s} + \frac{x_t}{\tau_t}} = \frac{x''_d + x_s + x_t}{\frac{x''_d}{\tau_a} + x_s \times \frac{\omega}{(X/R)_s} + x_t \times \frac{\omega}{(X/R)_t}}$$

U_{oph} is the out-of-phase voltage which is equal to $\delta \times$ generator operating voltage prior to synchronisation;

δ is the out-of-phase factor and it is the ratio of the RMS value of the voltage across the open contacts of the generator circuit-breaker and the relating generator operating voltage prior to synchronisation;

the reactances x''_d , x'_d , x_d , x_t , and x_s are p.u. values on generator MVA base;

$\tau_s = (X/R)_s/\omega$ is the time constant of the high-voltage system;

$\tau_t = (X/R)_t/\omega$ is the time constant of the step-up transformer.

For a 180° out-of-phase condition, δ is equal to 2. Under this condition for the phase with full asymmetry one-half cycle after current initiation, the peak current is 234 kA plus some percentage contribution from the auxiliary system. This current peak is considerably higher than the generator terminal fault peak short-circuit current of 190 kA (calculated according to D.4.2). Such a high out-of-phase short-circuit current would damage the generator, taking into account that the mechanical forces increase as the square of the current. Consequently, the 180° out-of-phase condition shall be avoided by appropriate relay protection.

The contribution of the auxiliary system to the out-of-phase making and breaking current should be taken into consideration depending upon power plant operation.

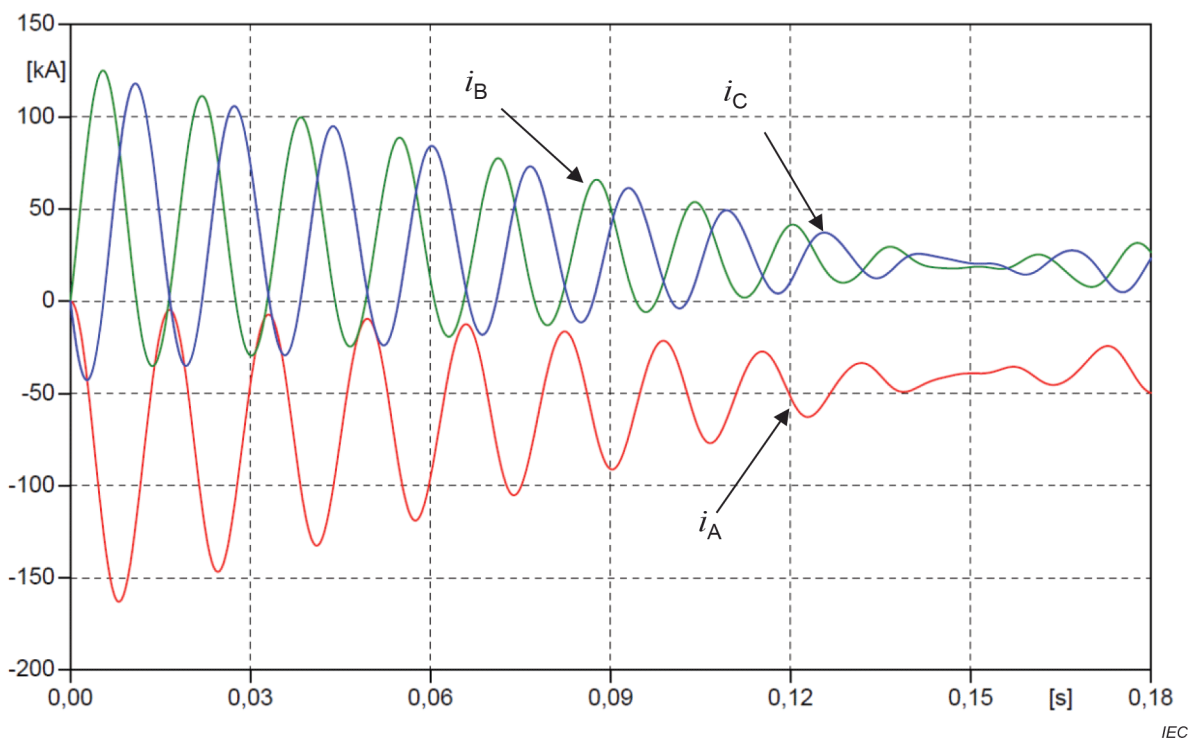
For the 90° out-of-phase condition, δ is equal to $\sqrt{2}$; the out-of-phase asymmetrical peak current after one-half cycle is 166 kA, which is lower than the generator terminal fault peak short-circuit current.

The calculated out-of-phase current at the contact separation for this example is 51 kA.

For the out-of-phase TRV calculation, the same considerations apply as in Clause D.5. The TRV requirements are given in Table 6.

The calculation of the out-of-phase current waveshape shall be performed by computer programs that simulate the generator behaviour more completely. The current resulting from out-of-phase synchronising can result in delayed current zeros whose causes are totally different compared to generator terminal faults (see 9.103.9.1). The rapid movement of the rotor from initial out-of-phase angle φ_0 to $\varphi = 0$ results in a very small AC component of the fault current and a dominant DC component when the condition of $\varphi = 0$ is reached. The current resulting from out-of-phase synchronising shall include an accurate description of the behaviour of the synchronous machine. The instant when the $\varphi = 0$ condition is reached is determined by the movement of the rotor. Therefore, the moment of inertia of turbine, rotor and excitation equipment of the generator are of special importance. Figure D.5 shows a computer simulation of the fault current resulting from synchronising under out-of-phase conditions. In this example the synchronisation occurs when the voltage across the open contacts of pole A (U_A) of the generator circuit-breaker is zero. From Figure D.5 it is evident that at the time when $\varphi = 0$ (about 150 ms after synchronisation) the fault current is dominated by a DC component.

In case the out-of-phase current shows delayed current zeros the capability of the generator circuit-breaker to force current zeros shall be demonstrated by means of a calculation considering the effect of arc voltage. The procedure described in 9.103.9.1 applies.



Out-of-phase angle $\varphi_0 = 90^\circ$

Fault initiation at $U_A = 0$

Figure D.5 – Prospective fault current considering the moment of inertia of the synchronous machine and resulting from synchronising under out-of-phase conditions

D.7 Continuous current application

The rated continuous current of the generator at the rated voltage of 21 kV is as follows:

$$588 \text{ MVA} / (21 \sqrt{3} \text{ kV}) = 16\,200 \text{ A}$$

Assuming a minimum operating voltage of 19,95 kV (i.e. $0,95 \times 21 \text{ kV}$) the maximum RMS value of the current which shall be carried continuously by the generator circuit-breaker is as follows:

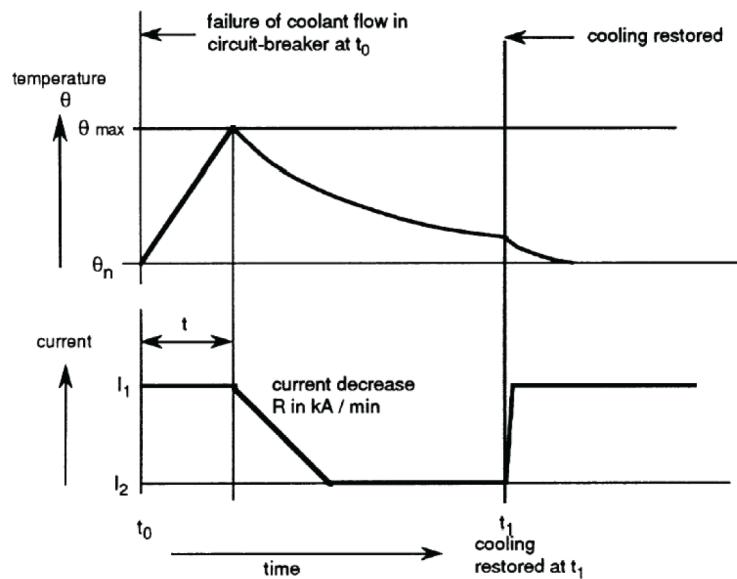
$$588 \text{ MVA} / (0,95 \times 21 \times \sqrt{3} \text{ kV}) = 17\,020 \text{ A}$$

The generator circuit-breaker in this example is forced-air-cooled. Figure D.6 illustrates the procedure for calculating the continuous current rating of the generator circuit-breaker when the forced-air-cooling fails.

With the forced-air-cooling in operation, the generator circuit-breaker can carry the rated current of the generator. If a failure occurs in the cooling system, the current shall be reduced, starting after the time t , with a decreasing rate R in kA/min, in order that the temperature of the circuit-breaker does not exceed the allowable hottest spot total temperature, θ_{\max} . The allowable total temperature is limited by the materials used in the generator circuit-breaker (see Table 14 of IEC 62271-1:2017) so that there is no deterioration of any parts of the generator circuit-breaker.

The temperature decreases due to the lower current, tending toward the allowable hottest spot temperature, θ_n . The cooling is restored at a time t_1 , and the current is increased to the rated current of the generator. Consequently, the temperature decreases to the allowable hottest spot temperature, θ_n . This emergency procedure shall be established with the manufacturer.

A similar procedure is used when the cooling system is more complicated (e.g. the generator circuit-breaker is water-cooled and the bus is forced-air-cooled). The emergency schedule contains, in such a case, the procedure for a failure in each of the cooling systems as indicated in Figure 9.



IEC

Key

- θ_{max} allowable hottest spot total temperature
- θ_n allowable hottest spot temperature at generator rated current
- t allowable time without reduction of current and without exceeding θ_{max}
- I_1 rated current of the generator
- I_2 allowable current with failure of coolant flow

Figure D.6 – Generator circuit-breaker temperature and load current with loss of coolant

D.8 Generator circuit-breaker electrical characteristics

The following are minimum electrical characteristics to be specified for the generator circuit-breaker in the example:

Rated voltage	22,05 kV
Rated insulation level:	
Rated power-frequency withstand voltage (RMS value)	60 kV
Rated lightning impulse withstand voltage (peak value)	125 kV
Rated continuous current	17 020 A
Rated making current	321 kA
Rated system-source short-circuit breaking current	
RMS value of the AC component	116,4 kA
degree of asymmetry	61,3 %

The following electrical characteristics have been estimated by using the equations in Clauses D.4 and D.6.

Generator-source short-circuit breaking current

RMS value of the AC component	53,2 kA
degree of asymmetry	110,1 %

Out-of-phase breaking current

RMS value of the AC component	51,0 kA
degree of asymmetry	89,4 %

In order to select the proper generator circuit-breaker for the application the calculations shall be performed by computer programs that simulate the generator behaviour correctly. The results of the last simulation in Clause D.6 (see Figure D.5) take into account the moment of inertia of the synchronous machine and show the following:

Out-of-phase breaking current

Generator terminal voltage lagging system voltage referred to the LV-side of the step-up transformer

RMS value of the AC component	37,9 kA
degree of asymmetry	120,6 %

Generator terminal voltage leading system voltage referred to the LV-side of the step-up transformer

RMS value of the AC component	34,9 kA
degree of asymmetry	128,3 %

From the above results it is evident the decrement of the AC component of the out-of-phase fault current which in turns leads to a degree of asymmetry at contact separation higher than 100 % and hence to delayed current zeros. Specifically, the AC component of the fault current is higher for a generator terminal voltage lagging the system voltage than for a generator terminal voltage leading the system voltage. On the other hand, the degree of asymmetry is higher for a generator terminal voltage leading the system voltage than for a generator terminal voltage lagging the system voltage.

Annex E (informative)

Example of the application of a generator circuit-breaker with multiple generators

E.1 General

The application guide appearing in Clause 9 also introduced power plant layouts different from Figure D.1. The purpose of this example is to provide guidance on how to select an appropriate generator circuit-breaker for power plant layouts employing several generators connected to one two-winding step-up transformer by following the guidelines of Annex D.

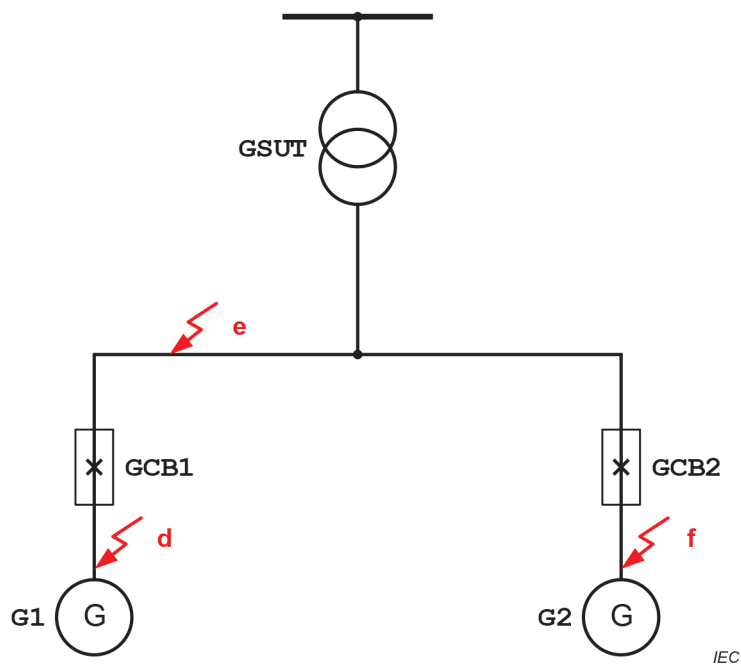


Figure E.1 – Single-line power plant diagram with two generators

The example given in Figure E.1 illustrates a power plant layout consisting of two generators connected to one two-winding step-up transformer. It indicates the two fault locations where the maximum short-circuit current will occur. Based on the type of power plant, the generator combinations can be as follows:

- The capacity of generator G1 is equal to the capacity of generator G2.
- The capacity of generator G1 differs from the capacity of generator G2.

This guideline strictly follows the equations and calculations described in Clauses D.3 and D.4.

E.2 System-source short-circuit current with additional generator contribution

E.2.1 General

The calculation of the short-circuit current for a power plant layout with two or more generators requires the inclusion of additional short-circuit current contribution, which is fed from the adjacent generators towards the fault location. This additional current contribution results in a higher RMS value of the AC component of the system-source short-circuit current and an increased degree of asymmetry.

E.2.2 AC component of the system-source short-circuit breaking current

The following example is based on a fault at location "d" (see Figure E.1).

The calculation of the system-source short-circuit breaking current arises from the system and the generator G2 contributions. The RMS value of the AC component of the short-circuit breaking current fed by HV grid is calculated according to D.3.1 and the RMS value of the AC component of the short-circuit breaking current fed by the generator is calculated according to D.4.1.

The calculation of the RMS value of the total symmetrical component of the short-circuit breaking current is equal to the sum of the RMS value of the AC component of the short-circuit breaking current fed by the HV grid and the RMS value of the AC component of the short-circuit breaking current fed by generator G2.

E.2.3 Asymmetrical system-source short-circuit breaking current

The following example is based on a fault at location "d" (see Figure E.1) and on the calculations in E.2.2.

The DC component of the short-circuit breaking current fed by the HV grid is calculated according to D.3.2 and the DC component of the short-circuit breaking current fed by the generator is calculated according to D.4.2.

The calculation of the DC component of the total asymmetrical short-circuit breaking current is equal to the sum of the DC component of the short-circuit breaking current fed by the HV grid and the DC component of the short-circuit breaking current fed by generator G2.

The total asymmetrical short-circuit current seen by the generator circuit-breaker GCB1 is calculated as the square root of the sum of the squares of:

- the RMS value of the AC component of the system-source short-circuit breaking current;
- the DC component of the system-source short-circuit breaking current.

E.3 Generator-source short-circuit current

The following example is based on a fault at location "e" (see Figure E.1).

The calculation of the RMS values of the AC component of the generator-source short-circuit breaking current and the generator-source asymmetrical short-circuit current can be done according to D.4.1 and D.4.2 respectively. This approach is valid for both generators, G1 and G2.

E.4 Calculation based on power plant layout

E.4.1 System-source short-circuit current with additional generator contribution

Reference is made to Figure E.1.

The corresponding short-circuit current is calculated as follows:

- Fault location "d": The generator circuit-breaker GCB1 will experience the total short-circuit breaking current contribution fed by the HV grid and the generator G2. The calculation shall be done according to Clause E.2.
- Fault location "f": The generator circuit-breaker GCB2 will experience the total short-circuit breaking current contribution fed by the HV grid and the generator G1. The calculation shall be done according to Clause E.2.

E.4.2 Generator-source short-circuit current

Each generator circuit-breaker GCB1 or GCB2 will experience the short-circuit breaking current contribution from generator G1 or G2 respectively. The calculation shall be done according to Clause E.3.

E.5 Power plant layout with additional generator circuit-breaker connected at the generator voltage terminals of the step-up transformer

E.5.1 General

As the configuration of power plant layouts may differ in various power plants this example modifies the power plant layout given in Figure E.1 by adding an additional generator circuit-breaker (GCB3) at the generator voltage terminals of the step-up transformer.

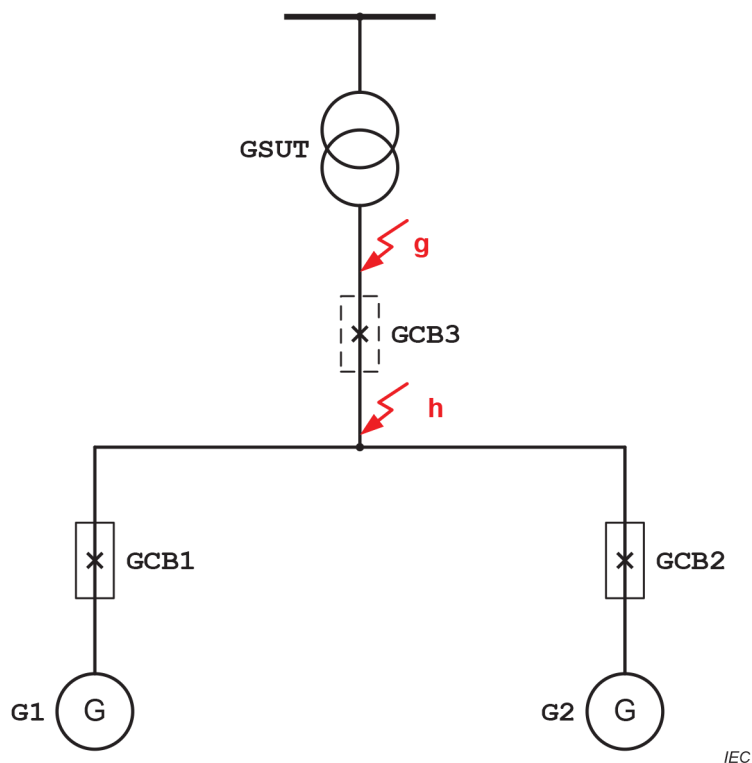


Figure E.2 – Single-line power plant diagram with two generators and three GCBs

The example given in Figure E.2 indicates two fault locations with the maximum short-circuit current, which can be experienced by the generator circuit-breaker GCB3:

- a) short-circuit fault at the generator voltage terminals of the step-up transformer (fault location "g"), which is fed by generator G1 and generator G2 simultaneously;
- b) short-circuit fault on the busbar connecting both generators (fault location "h"), which is fed by the HV grid.

E.5.2 System-source short-circuit breaking current

The system-source short-circuit breaking current is calculated according to Clause D.3.

E.5.3 Multiple generator-source short-circuit breaking current

The AC component of the short-circuit breaking current fed by each generator is calculated according to D.4.1.

The AC component of the total short-circuit breaking current is the sum of the AC component of the short-circuit breaking current fed by each generator.

The DC component of the short-circuit breaking current fed by each generator is calculated according to D.4.2.

The DC component of the total short-circuit breaking current is the sum of the DC component of the short-circuit breaking current fed by each generator.

The total asymmetrical short-circuit breaking current fed by all the generators is calculated as the square root of the sum of the squares of:

- the RMS value of the AC component of the total short-circuit breaking current,
- the DC component of the total short-circuit breaking current.

E.6 Transient recovery voltage

The transient recovery voltage shall be calculated taking into account plant-specific equipment parameters and operating conditions. For further information, refer to 9.103.7.

Annex F (informative)

Effects on TRV requirements due to the capacitance added when shielded cables connect generator circuit-breakers to the step-up transformer

The prospective transient recovery voltage (TRV) requirements for generator circuit-breakers under system-source fault conditions are listed in Table 3. They are based on the assumption that the step-up transformer will be connected to the generator circuit-breaker by bus. Although this assumption is true for many applications, several smaller installations also exist where the connection is made with shielded cables. One way of determining the effects of the capacitance added by shielded cables on the TRV that the generator circuit-breaker would experience while trying to clear a three-phase fault current, fed from a non-effectively earthed source, has been described by Dufournet and Montillet [12]. This method illustrates that the added capacitance of shielded cables used to connect the transformer to the generator circuit-breaker can have two significant effects on the TRV, as follows:

- a) The rate of rise of the recovery voltage (RRRV), or "TRV rate," is reduced.
- b) The TRV peak (called u_c in Figure F.2 and in Figure F.4) is increased.

The significance of these effects can be illustrated in the following four figures:

- Figure F.1 shows the effect on the TRV rate-of-rise, associated with breaking faulted transformers rated in the range of 65,5 MVA to 100 MVA.
- Figure F.2 shows the effect on the TRV peak, u_c , associated with breaking faulted transformers rated in the range of 65,5 MVA to 100 MVA.
- Figure F.3 shows the effect on the TRV rate-of-rise, associated with breaking faulted transformers rated in the range of 10 MVA to 50 MVA.
- Figure F.4 shows the effect on the TRV peak, u_c , associated with breaking faulted transformers rated in the range of 10 MVA to 50 MVA.

These calculations are illustrative of a method to evaluate the effects of capacitance associated with cable connections. Certain other assumptions, such as the transformer short-circuit impedance of 14 %, although consistent with the other illustrative calculations in this document, are not intended to be completely representative of all applications. The user should carefully consider all the parameters of the particular circuit and determine the appropriate TRV values based on the actual parameters of the circuit under consideration.

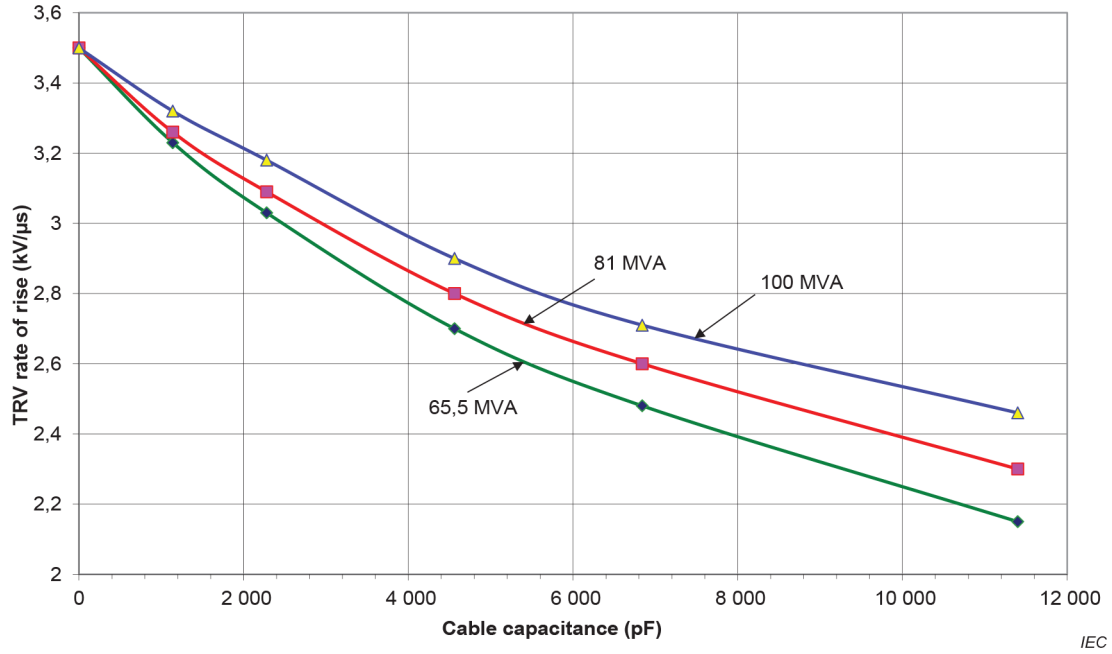


Figure F.1 – TRV rate-of-rise for system-source faults: transformers rated from 65,5 MVA to 100 MVA

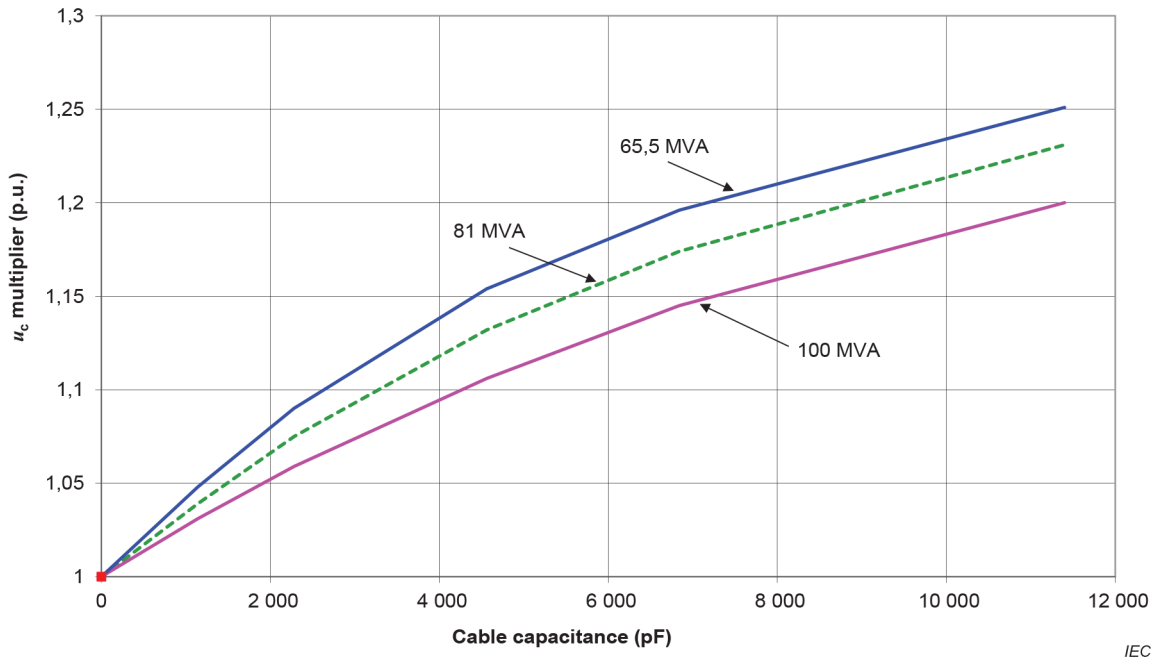


Figure F.2 – TRV peak (u_c) multipliers for system-source faults: transformers rated from 65,5 MVA to 100 MVA

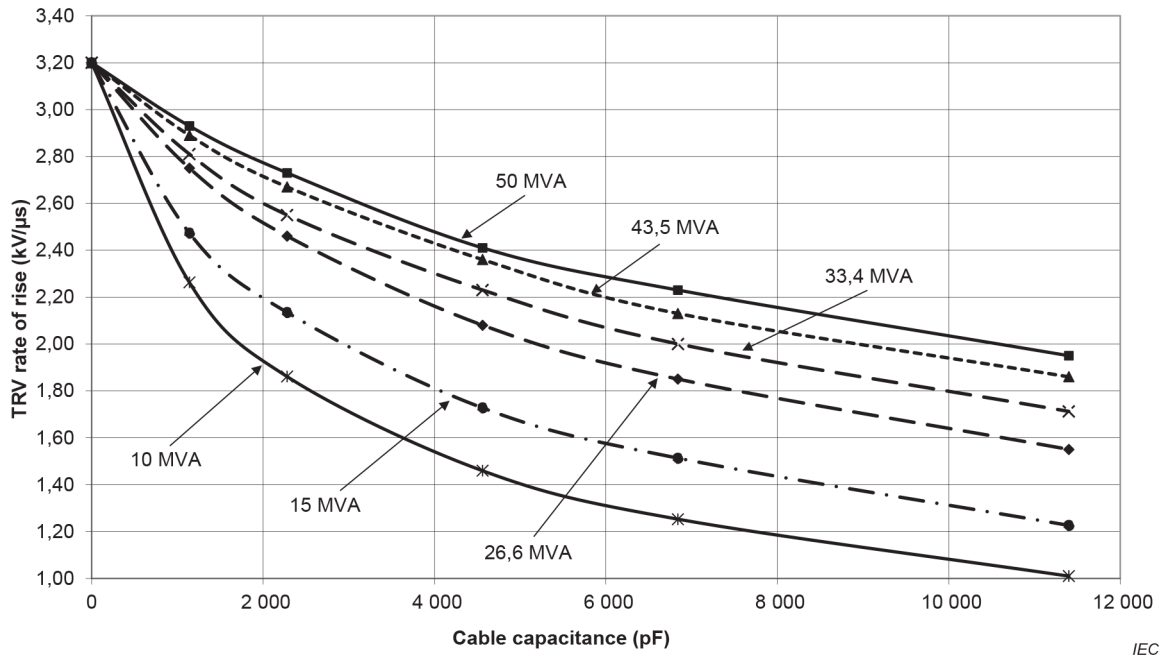


Figure F.3 – TRV rate-of-rise for system-source faults: transformers rated from 10 MVA to 50 MVA

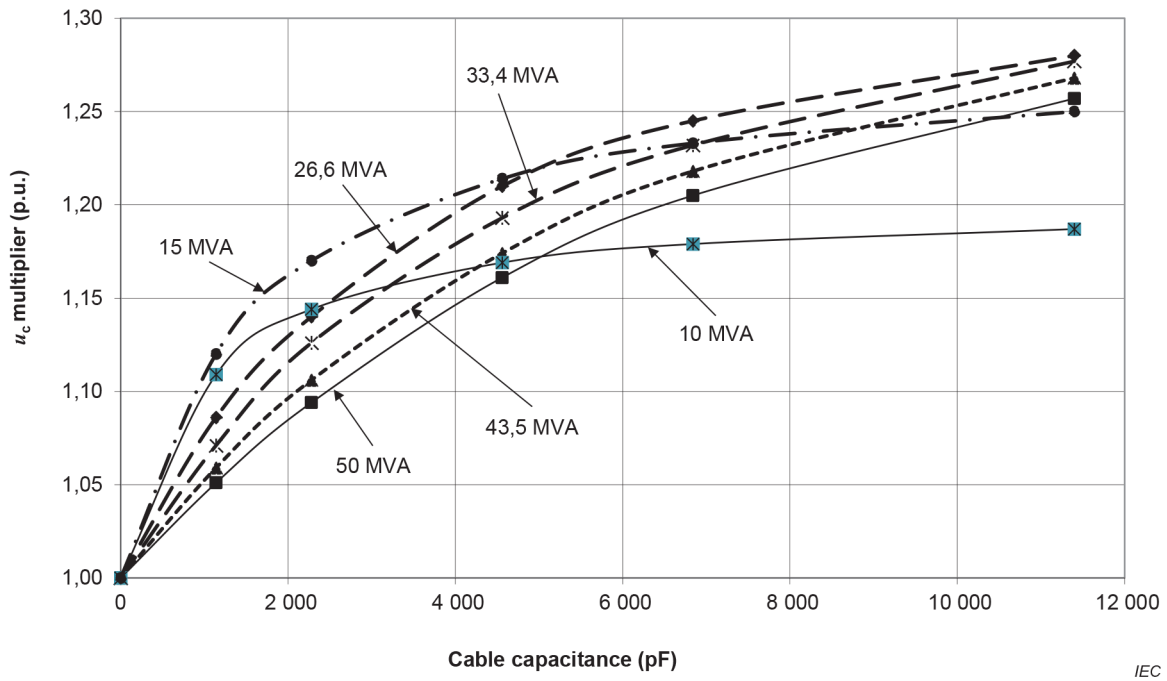


Figure F.4 – TRV peak (u_c) multipliers for system-source faults: transformers rated from 10 MVA to 50 MVA

Annex G (informative)

Symbols and related terminology

G.1 Comparison of IEEE and IEC electrical terms and symbols

Table G.1 provides a listing of the most common terms and their respective abbreviations as used in IEEE and IEC.

NOTE Some of the terms are very similar but have slightly different definitions between IEEE and IEC.

Table G.1 – Comparison of IEEE and IEC electrical terms and symbols

Abbreviation		Definition	Customary units	Appearing first in
IEEE	IEC			
V	U_r	Rated maximum voltage (IEEE); Rated voltage (IEC)	V RMS	5.2
None	U_p	Rated lightning impulse withstand voltage	V peak	5.3
None	I_r	Rated continuous current	A RMS	5.5
None	Not used	Rated momentary withstand current	kA asymmetrical	Not used
None	I_p	Rated peak withstand current	kA peak	5.7
None	I_k	Rated short-time withstand current	kA symmetrical	5.6
None	t_k	Rated duration of short circuit	s	5.8
None	U_a	Rated supply voltage of auxiliary circuits	V RMS	5.9
None	U_d	Rated power-frequency withstand voltage	V RMS	5.3
Grounded	Effectively earthed	System neutral is effectively connected to ground or earth		3.1.112
Ungrounded	Non-effectively earthed	System neutral is not connected to ground or earth, that is, the neutral is isolated or connected to ground or earth through a high impedance		3.1.113
		Rated dielectric strength (IEEE) Rated insulation level (IEC)		5.3
None	f_r	Rated power-frequency (IEEE) Rated frequency (IEC)	Hz	5.4
		Rated short-circuit current duty cycle (IEEE) Rated operating sequence (IEC)		5.106
V_{nG}	U_{rG}	Rated voltage of the generator	kV	Clause D.2
X_{dv}	$x_{d \text{ sat}}$	Synchronous reactance direct axis – saturated value	per unit (p.u.)	Clause D.2
X'_{dv}	$x'_{d \text{ sat}}$	Transient reactance direct axis – saturated value	per unit (p.u.)	Clause D.2
X''_{dv}	$x''_{d \text{ sat}}$	Subtransient reactance direct axis – saturated value	per unit (p.u.)	Clause D.2
X_{qv}	$x_{q \text{ sat}}$	Synchronous reactance quadrature axis – saturated value	per unit (p.u.)	Clause D.2
X'_{qv}	$x'_{q \text{ sat}}$	Transient reactance quadrature axis – saturated value	per unit (p.u.)	Clause D.2

Abbreviation		Definition	Customary units	Appearing first in
IEEE	IEC			
X_{qv}''	$x_{q\text{ sat}}''$	Subtransient reactance quadrature axis – saturated value	per unit (p.u.)	Clause D.2
X_{2v}	$x_{2\text{ sat}}$	Negative sequence reactance – saturated value	per unit (p.u.)	Clause D.2
X_{0v}	$x_{0\text{ sat}}$	Zero sequence reactance – saturated value	per unit (p.u.)	Clause D.2
T_{do}'	τ_{do}'	Transient open-circuit time constant direct axis	s	Clause D.2
T_d'	τ_d'	Transient short-circuit time constant direct axis	s	Clause D.2
T_{do}''	τ_{do}''	Subtransient open-circuit time constant direct axis	s	Clause D.2
T_d''	τ_d''	Subtransient short-circuit time constant direct axis	s	Clause D.2
T_{qo}'	τ_{qo}'	Transient open-circuit time constant quadrature axis	s	Clause D.2
T_q'	τ_q'	Transient short-circuit time constant quadrature axis	s	Clause D.2
T_{do}''	τ_{qo}''	Subtransient open-circuit time constant quadrature axis	s	Clause D.2
T_d''	τ_q''	Subtransient short-circuit time constant quadrature axis	s	Clause D.2
T_a	τ_a	Armature short-circuit time constant	s	Clause D.2
	I_{MC}	Closing, latching and carry current (IEEE) Short-circuit making current (IEC)		5.102
		Out-of-phase switching current (IEEE) Out-of-phase making and breaking current (IEC)		5.104
		Rated Interrupting time (IEEE) Three-phase break-time (IEC)		3.7.142
		Usual service condition (IEEE) Normal service condition (IEC)		4.1
		Unusual service condition (IEEE) Special service condition (IEC)		4.2
		Design test (IEEE) Type test (IEC)		Clause 7
		Production test (IEEE) Routine test (IEC)		Clause 8
		Phase – A, B, C (IEEE) Phase – R, S, T (IEC)		Figure 6

G.2 Comparison between TRV terminology and symbols

Table G.2 and Figure G.1 provide a comparison between the TRV terminology and symbols used in this document and those used in older IEEE/ANSI standards.

Table G.2 – Comparison between the TRV terminology and symbols used in this document and those used in older IEEE/ANSI standards

No.	Terms	Symbol per this document	Symbol per older IEEE/ANSI standards
1	Rated maximum voltage (IEEE); Rated voltage (IEC)	U_r	V
2	Voltages, general – some are uppercase and some are lowercase	u	v, e or u
3	Times, general – some are upper case and some are lower case	t	t
4	Rate of rise of recovery voltage	u/t or RRRV	R or RRRV
5	u_c = TRV peak	u_c	$E2$
6	T2 = time to reach the peak voltage of the 1-cosine TRV curve, E2 NOTE For the two-parameter construction lines, the line from the origin to point u_c, t_3 , and the horizontal line at u_c , is tangent to the ANSI/IEEE undamped 1-cosine TRV, and then $T2 = 1,138 \times t_3$ or $t_3 = 0,88 \times T2$ (see Figure G.1)		$T2$
7	first-pole-to-clear factor (k_{pp})	k_{pp}	k_f
8	amplitude factor (k_{af}) [the term "transient amplitude factor (k_a)" is replaced by amplitude factor (k_{af})]	k_{af}	k_a
9	Time delay t_d	t_d	t_d
10	Delay line, a line from 0, t_d to u', t' that is parallel to the line from 0,0 to u_c, t_3 (see Figure G.1). Provides a lower limit to TRV.	Delay line	
11	Rated TRV wave shape	Two-parameter reference line	1-cosine envelope
12	t_3 , time to reach u_c for two-parameter TRVs. Time t_3 is derived from u_c and the specified value of the rate of rise u_c/t_3 .	t_3	

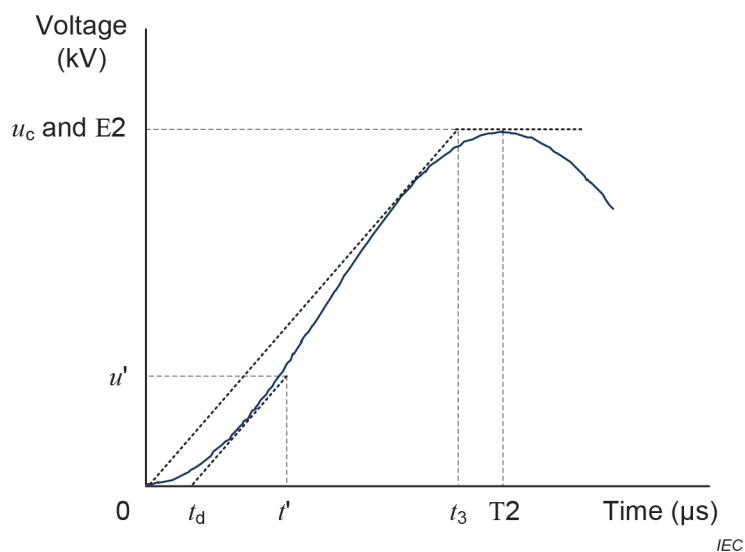


Figure G.1 – Two-parameter TRV envelope representation of 1-cosine TRV when interrupting three-phase symmetrical fault currents

Annex H (informative)

Determination of the degree of asymmetry for generator-source short-circuit breaking tests

The degree of asymmetry of a current is defined as the ratio of the DC component to the peak value of the AC component determined from the envelope of the current wave at that time (see 3.7.136). The AC component of the generator-source short-circuit current may decay faster than the DC component. The decay of the AC component is governed by the subtransient and transient time constants of the generator and the decay of the DC component by the armature time constant. As a consequence, the DC component at contact separation can be higher than the peak value of the AC component. In such a case the degree of asymmetry of the fault current is higher than 100 %, thus leading to delayed current zeros. In addition, the magnitude of the AC component of the generator-source short-circuit current and its degree of asymmetry can vary if the generator is unloaded or delivering power with lagging or leading power factor prior to fault. If fault initiation takes place when the voltage in one phase passes through zero the resulting fault current in that phase exhibits the maximum degree of asymmetry. A survey of many generators with different ratings revealed that the degree of asymmetry can be very high and exceed 130 %.

A typical wave shape of generator-source short-circuit current in the case of fault initiation at voltage zero is shown in Figure H.1. The degree of asymmetry initially increases due to the rapid decay of the AC component, it reaches a value of approximately 148 % and it subsequently decays when the AC component is approaching its steady state.

Reproducing such a current wave shape and especially the decay of the AC component can be very difficult in high power test laboratories. In addition, depending on the pre-loading of the generator in a power plant the degree of asymmetry may be far higher than the one being adjustable in a laboratory. Therefore, in order to reproduce interrupting conditions which are similar to the ones observed in power plant applications, the test requirement for the degree of asymmetry is set to a constant value irrespectively of the instant of contact separation. The dotted line in Figure H.1 represents a degree of asymmetry of 130 % which is set as a requirement for test-duties 6A and 6B (see Table 23 and Table 24).

Considering that various designs of generators behave differently, it may not be possible to simulate the required current shape in the test laboratory. Therefore the capability of a generator circuit-breaker to interrupt a short-circuit current with delayed current zero crossings shall be ascertained by calculations (see 9.103.6.3.6.3) taking into account results derived from a limited number of appropriate tests (see 7.105).

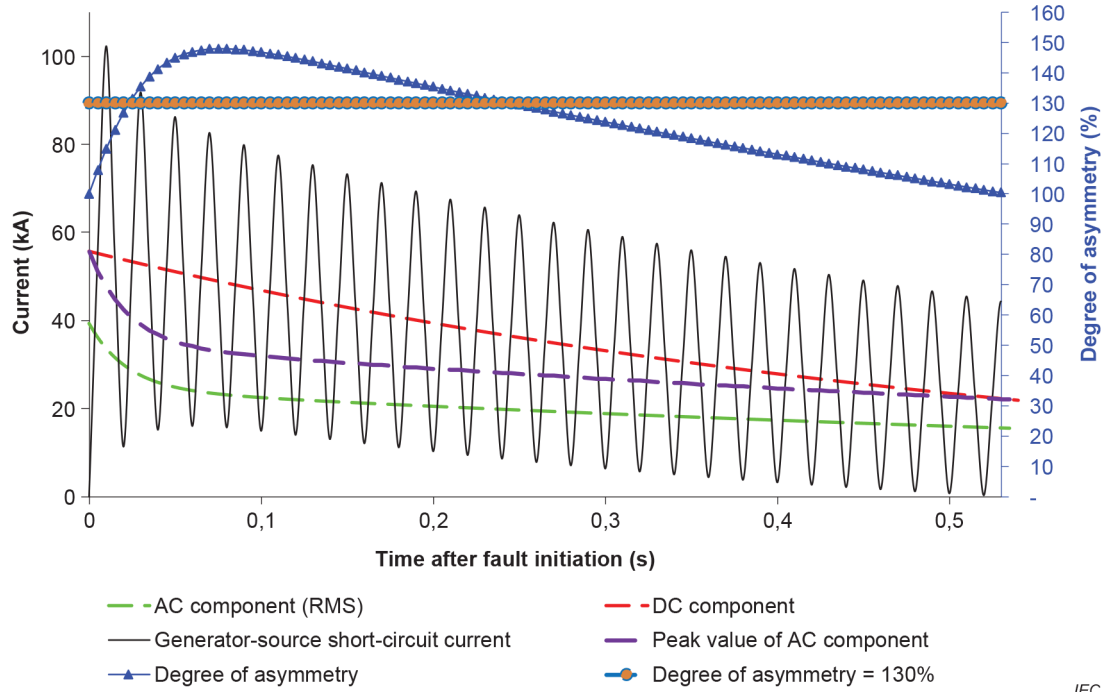


Figure H.1 – Prospective generator-source short-circuit current (fault initiation at voltage zero)

Annex I (informative)

Faults in circuits with a three-winding step-up transformer

When two generators are connected to the high-voltage system by means of a three-winding step-up transformer, special attention should be paid to the system-source short-circuit current. In the case of a three-phase earthed fault occurring at location F in Figure I.1, both the AC component and the degree of asymmetry of the system-source short-circuit current which should be interrupted by Generator circuit-breaker #1 can attain very high values because of the additional contribution to the current of Generator #2.

Because the AC component of the fault current fed by Generator #2 is not constant, the ratio of the peak value of the short-circuit current seen by Generator circuit-breaker #1 to the RMS value of the AC component of the short-circuit breaking current (at contact separation of Generator circuit-breaker #1) could exceed the standard value of 2,74.

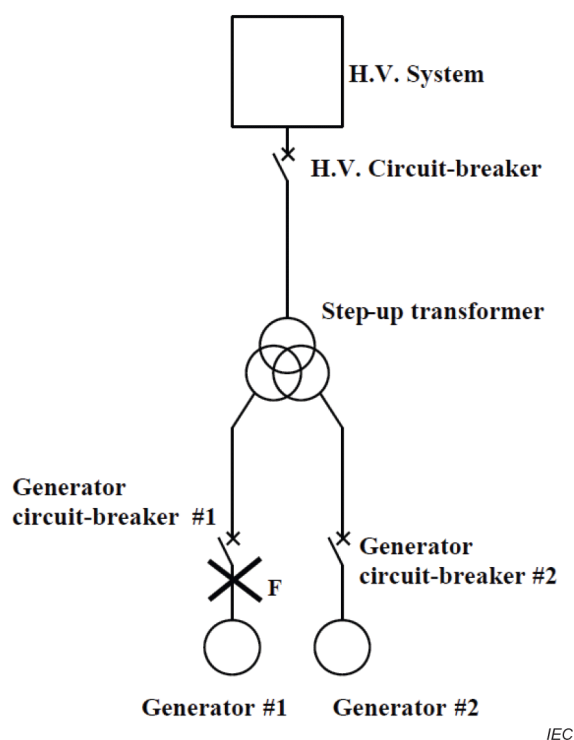
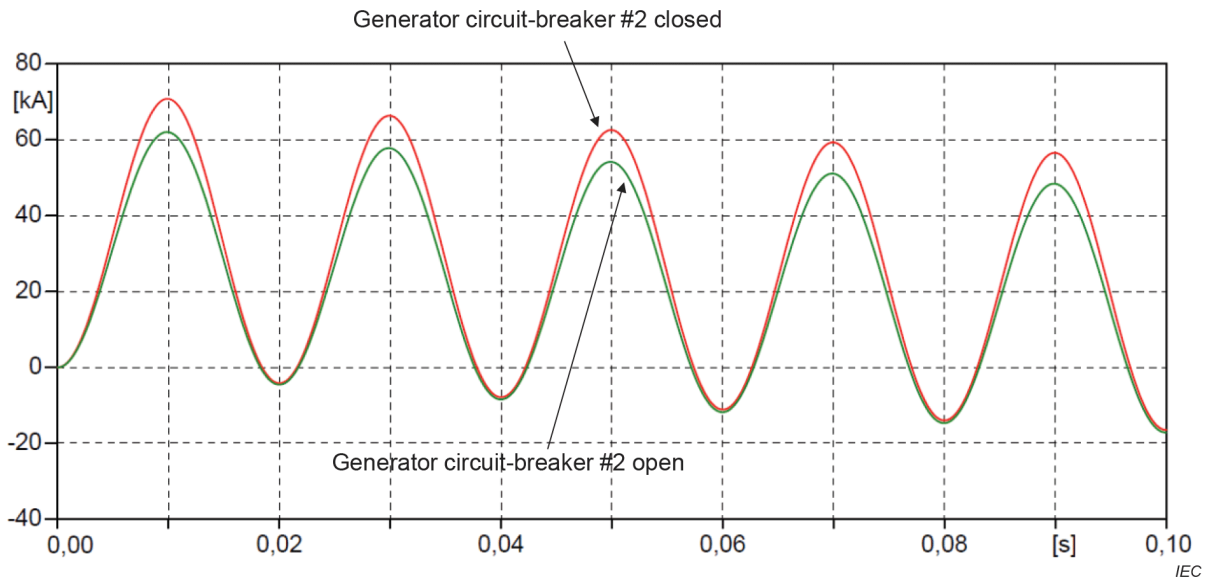


Figure I.1 – Single-line diagram of a power plant with two generators connected to the high-voltage system by means of a three-winding step-up transformer

The system-source short-circuit in the case of a three-phase earthed fault occurring at location F in Figure I.1, has been calculated considering Generator circuit-breaker #2 either open or closed. In the latter case the contribution of Generator #2 to the fault current to be interrupted by Generator circuit-breaker #1 has been taken into account. It has been assumed that fault initiation occurs at voltage zero in one phase. The resulting short-circuit current waveform is depicted in Figure I.2. Only the current in the phase with the highest degree of asymmetry is shown. The upper and the lower curves refer to the case of Generator circuit-breaker #2 closed and open respectively. The results are summarised in Table I.1.



Three-phase earthed fault occurring at location F in Figure I.1 (only the current in the phase with the highest degree of asymmetry is shown – fault initiation at voltage = 0)

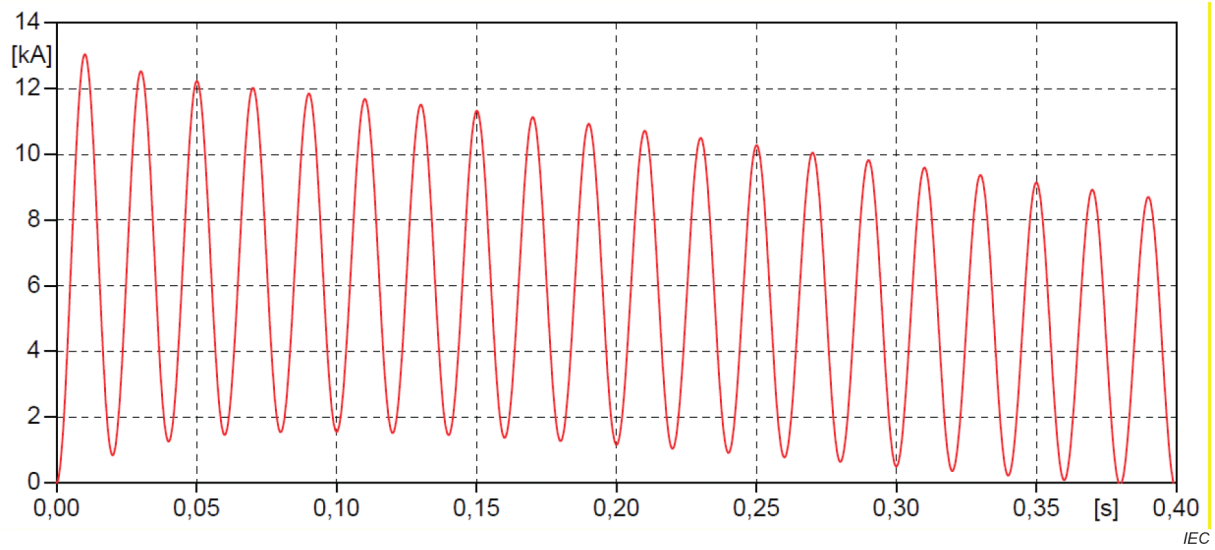
Figure I.2 – Prospective fault current to be interrupted by Generator circuit-breaker #1

Table I.1 – Comparison between prospective system-source short-circuit currents to be interrupted by Generator circuit-breaker #1 in the case of a three-phase earthed fault occurring at location F in Figure I.1

Terms	Generator circuit-breaker #2 opened	Generator circuit-breaker #2 closed
Making current (kA)	62,1	70,8
RMS value of the AC component of the system-source short-circuit current at intended contact separation (kA)	22,7	25,5
Degree of asymmetry of the system-source short-circuit current at intended contact separation	68,5 %	73,6 %
Ratio of making current to RMS value of the AC component of the system-source short-circuit current at intended contact separation	2,74	2,78

The case of Generator circuit-breaker #2 closed leads to higher current magnitudes because of the additional contribution of Generator #2. The fault current fed by Generator #2 features a relatively small magnitude and a very high degree of asymmetry and it exhibits several cycles without natural zero crossing. These delayed current zeros have totally different causes and are extremely dissimilar in comparison with the currents associated with generator terminal faults and out-of-phase synchronising. The waveform of this current is obtained as the superposition of two contributions, i.e. one oscillating at power frequency and a transient one whose course is dictated by the time constants of the circuit. The transient component consists of two decaying exponential functions: this waveform is over-damped as the damping contribution prevails over the oscillating one as it can be seen in Figure I.3. If the Generator circuit-breaker #2 has to interrupt this current, the capability to force current to zero shall be demonstrated by means of calculations considering the effect of the arc voltage of the generator circuit-breaker on the prospective short-circuit current.

The capability of a generator circuit-breaker to interrupt a given short-circuit current which shows delayed current zeros can be considered as being demonstrated if the generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum tested arcing time).



Three-phase earthed fault occurring at location F in Figure I.1 (only the current in the phase with the highest degree of asymmetry is shown – fault initiation at voltage = 0)

Figure I.3 – Prospective fault current to be interrupted by Generator circuit-breaker #2

Annex J (normative)

Requirements for testing and application of Tee-OFF generator circuit-breakers in power plant layouts

Power plant layouts can be equipped with a generator circuit-breaker (Tee-OFF generator circuit-breaker) installed at the higher voltage side of the unit auxiliary transformer (see Figure J.1).

NOTE At the Tee-OFF location, sometimes switches, which only need to handle short-time withstand and peak withstand currents, are used. This annex describes Tee-OFF generator circuit-breakers also having a short-circuit breaking capability.

Owing to its installation location, a Tee-OFF generator circuit-breaker has to handle currents of very high magnitude which can also exhibit delayed zero crossings. Moreover, these currents are associated to very steep transient recovery voltages which often exceed the tested capability of conventional general purpose circuit-breakers. Moreover, because of the simultaneous contribution of the HV grid and of the generator, the requirements for the application of Tee-OFF generator circuit-breakers can exceed those of the associated generator circuit-breakers.

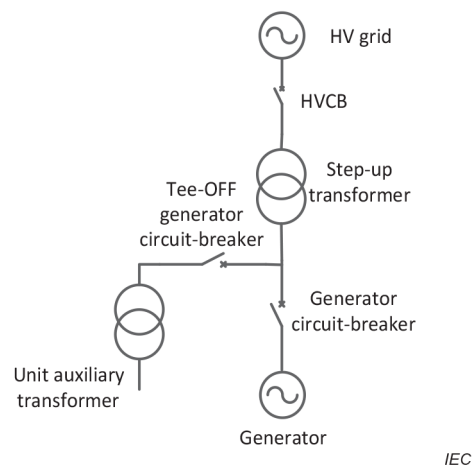


Figure J.1 – Single-line diagram of a power plant with Tee-OFF generator circuit-breaker and generator circuit-breaker

In order to set the requirements for the application of the Tee-OFF generator circuit-breaker, short-circuit current and transient recovery voltage shall be thoroughly assessed.

For this purpose, two fault locations shall be considered, namely F1 and F2 depicted in Figure J.2. Three-phase grounded faults have been investigated. The current to be interrupted by the Tee-OFF generator circuit-breaker in the case of a fault in F2 is normally fed by asynchronous motors and its magnitude is much smaller than that associated to faults in F1. Therefore, this case can be disregarded in the analysis. On the other hand, the current to be interrupted in the case of faults in F1 is fed by both the HV grid and by the generator.

Assuming that both the HVCB and the generator circuit-breaker remain in the closed position, the current to be interrupted by the Tee-OFF generator circuit-breaker would have both high magnitude and high degree of asymmetry.

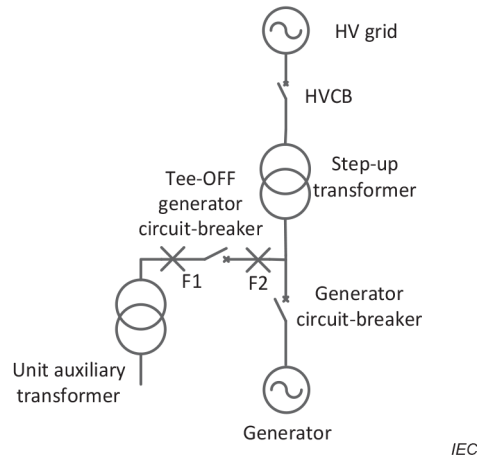


Figure J.2 – Power plant electrical layout with Tee-OFF generator circuit-breaker – fault locations considered for setting the requirements for the application of the Tee-OFF generator circuit-breaker

The short-circuit requirements for the application shown in Figure J.2 shall be assessed by means of studies.

For short-circuit current studies, the generator shall be modelled with armature time constant, direct-axis and quadrature-axis subtransient and transient short-circuit time constants and direct-axis and quadrature-axis subtransient, transient and synchronous inductances. The inertia constant of the rotating mass shall be taken into account as well.

The power transformers shall be modelled with winding resistance and series inductance. The equivalent winding parameters shall be obtained from the short-circuit impedances. The windings of each power transformer shall be connected according to the vector group of the machine.

The HV grid can be modelled as equivalent voltage source and sequence impedances. The equivalent impedance is determined by the maximum short-circuit power of the HV grid.

The Tee-OFF generator circuit-breaker short-circuit current is related to the requirements imposed on the generator circuit-breaker: it is the sum of the system-source and of the generator-source short-circuit currents of the generator circuit-breaker, with the HVCB and the generator circuit-breaker being in the closed position. The current to be handled by the Tee-OFF generator circuit-breaker can therefore be described by the following expressions:

$$I_{SCsys_gen} = I_{SCsys} \times (1 + I_{SCgen}/I_{SCsys})$$

$$DOA_{sys_gen} = (DOA_{sys} \times I_{SCsys} + DOA_{gen} \times I_{SCgen}) / (I_{SCsys} + I_{SCgen}) =$$

$$= [DOA_{sys} + DOA_{gen} \times (I_{SCgen}/I_{SCsys})] / (1 + (I_{SCgen}/I_{SCsys}))$$

$$I_{Psys_gen} = I_{Psys} + I_{Pgen} = I_{SCsys} \times (I_{Psys}/I_{SCsys}) \times (1 + I_{Pgen}/I_{Psys})$$

where:

I_{SCsys}	is the AC component of the system-source short-circuit breaking current of the generator circuit-breaker;
I_{SCgen}	is the AC component of the generator-source short-circuit breaking current of the generator circuit-breaker;
I_{Psys}	is the peak value of the system-source short-circuit current of the generator circuit-breaker;
I_{Pgen}	is the peak value of the generator-source short-circuit current of the generator circuit-breaker;
DOA_{sys}	is the degree of asymmetry of the system-source short-circuit current of the generator circuit-breaker at contact separation;
DOA_{gen}	is the degree of asymmetry of the generator-source short-circuit current of the generator circuit-breaker at contact separation;
I_{SCsys_gen}	is the AC component of the current to be handled by the Tee-OFF generator circuit-breaker at contact separation;
DOA_{sys_gen}	is the degree of asymmetry of the current to be handled by the Tee-OFF generator circuit-breaker at contact separation;
I_{Psys_gen}	is the peak value of the current to be handled by the Tee-OFF generator circuit-breaker.

Taking into consideration the above equations, the ratings for the Tee-OFF generator circuit-breaker can be obtained.

The degree of asymmetry can be higher than 100 %, which means that delayed current zeros can be expected. When the current exhibits delayed zeros, the capability of the Tee-OFF generator circuit-breaker to force current zeros shall be demonstrated by means of a calculation considering the effect of the arc-voltage of the circuit-breaker on the prospective current.

The following two situations shall be considered for a three-phase short-circuit current:

- fault initiation at voltage zero in one phase, which implies that the current in the corresponding phase exhibits the maximum degree of asymmetry;
- fault initiation at voltage maximum in one phase, which implies that the current in the corresponding phase is symmetrical.

The capability of a Tee-OFF generator circuit-breaker to interrupt a given current which shows delayed zeros can be considered as being demonstrated if the Tee-OFF generator circuit-breaker is capable of forcing the current to zero within the time interval in which it is able to interrupt a current (i.e. within the maximum tested arcing time). Subclauses 9.103.6.3.6 and 9.103.6.3.7 apply.

The transient recovery voltage requirements for the application shall be derived by the parameters laid down in Table 3 and Table 4 of this document. For this assessment the generator circuit-breaker and the Tee-OFF generator circuit-breakers have been modelled as ideal circuit-breakers (i.e. neither the arc-voltage nor the wave-slowing capacitors have been taken into account). The prospective TRV (i.e. the TRV not influenced by the arc-voltage and the capacitors of the circuit-breakers) appearing across the contacts of the Tee-OFF generator circuit-breaker immediately after the interruption of the fault current has been calculated. The TRV is determined for the first-pole-to-clear in the case of a three-phase current. The TRV resulting from interruption of a symmetrical current has been calculated.

The resulting TRV is displayed in Table J.1.

Table J.1 – TRV parameters related to the breaking of the Tee-OFF generator circuit-breaker short-circuit current

Generator rating MVA	Prospective TRV		
	Time t_3 μs	TRV peak value u_c kV	RRRV kV/ μs
10 to 50	$0,81 U_r$	$1,7 U_r$	2,1
51 to 100	$0,77 U_r$	$1,7 U_r$	2,2
101 to 200	$0,68 U_r$	$1,7 U_r$	2,5
201 to 400	$0,65 U_r$	$1,7 U_r$	2,6
401 to 800	$0,59 U_r$	$1,7 U_r$	2,9
801 to 1 000	$0,55 U_r$	$1,7 U_r$	3,1
above 1 001	$0,53 U_r$	$1,7 U_r$	3,2

The time delay t_d shall be equal to 0,6 μs . In case the associated generator circuit-breaker is equipped with capacitors of at least 100 nF/phase installed phase-to-ground, the time delay t_d will be longer than 1,0 μs .

The ratings and required capabilities of a Tee-OFF generator circuit-breaker are the designated limits of operating characteristics based on definite conditions and shall include the following items, where applicable:

- a) rated voltage;
- b) rated insulation level;
- c) rated frequency;
- d) rated continuous current;
- e) rated short-time withstand current;
- f) rated peak withstand current;
- g) rated duration of short-circuit;
- h) rated supply voltage of auxiliary and control circuits;
- i) rated supply frequency of auxiliary and control circuits;
- j) filling pressures of compressed gas supply and/or of hydraulic supply for operation, insulation and/or making and breaking, as applicable;
- k) rated system-source short-circuit breaking current;
- l) rated generator-source short-circuit breaking current;
- m) rated Tee-OFF generator circuit-breaker short-circuit breaking current;
- n) rated Tee-OFF generator circuit-breaker short-circuit making current;
- o) rated load breaking current;
- p) rated transient recovery voltage (TRV);
- q) rated operating sequence;
- r) rated time quantities.

For items a), b), c), k), l) and q), the ratings and the testing procedure of the Tee-OFF generator circuit-breaker shall be the same as for the associated generator circuit-breaker.

For items d) and o) the magnitude of the current is typically lower than that of the associated generator circuit-breaker and it is dictated by the load connected to the secondary side of the unit auxiliary transformer. The testing procedure of the Tee-OFF generator circuit-breaker shall be the same as for the associated generator circuit-breaker.

For items e), f), m) and n) the magnitude of the current shall be the sum of the generator-source and system-source short-circuit currents of the associated generator circuit-breaker. The testing procedure of the Tee-OFF generator circuit-breaker shall be the same as for the associated generator circuit-breaker.

For items g), h), i), j) and r) 5.8, 5.9, 5.10, 5.11 and 5.107 apply respectively.

For item p), the parameters of the rated TRV are given in Table 3, Table 4, Table 5 and Table J.1.

The testing procedure of the Tee-OFF generator circuit-breaker shall be the same as for the associated generator circuit-breaker.

Special requirements, for example out-of-phase making and breaking capability, are not covered in this document and, when required, shall be agreed by the user and manufacturer.

The nameplate of a Tee-OFF generator circuit-breaker and its operating devices shall include the items listed in Table J.2 below.

Additional information may be given.

The nameplate shall be visible when the Tee-OFF generator circuit-breaker is in the position of normal service and installation.

Coils of operating devices and releases shall be marked with the manufacturer's name and part number.

Table J.2 – Nameplate information for Tee-OFF generator circuit-breakers

Information to be listed on nameplates	Condition: Marking only required if	Abbreviation	Unit	Tee-OFF generator circuit-breaker	Operating device
(1)	(2)	(3)	(4)	(5)	(6)
Manufacturer				X	X
Type designation and serial number				X	X
Rated voltage		U_r	kV	X	
Rated lightning impulse withstand voltage		U_p	kV	X	
Rated frequency		f_r	Hz	X	
Rated continuous current	external forced cooling is not required	I_r	A	Y	
Rated continuous current with external forced cooling	external forced cooling is required	$I_{r, efc}$	A	Y	
Rated short-time withstand current		I_k	kA	X	
Rated duration of short-circuit		t_k	s	X	
Rated Tee-OFF generator circuit-breaker short-circuit making current		I_{MC}	kA	X	
RMS value of the AC component of the rated Tee-OFF generator circuit-breaker short-circuit breaking current		I_{SC}	kA	X	
Rated rate-of-rise-of-recovery-voltage		$RRRV$	kV/ μ s	X	
Minimum opening time			ms	X	
Filling pressure for operation at 20 °C		p_{rm}	MPa [psi] absolute		(X)
Kind and mass of fluid for insulation and/or interruption	sealed tank contains fluid		kg [weight lb]	Y	
Filling pressure for insulation and/or making and breaking at 20 °C		p_{re}	MPa [psi] absolute	(X)	
Rated supply voltage of control circuits			V		(X)
Rated supply frequency of control circuits			Hz		(X)
Current of control circuits			A		(X)
Rated supply voltage of auxiliary circuits		U_a	V		(X)
Rated supply frequency of auxiliary circuits			Hz		(X)
Current of auxiliary circuits			A		(X)
Mass (including fluids)		M	kg [weight lb]	X	X
Rated operating sequence				X	
Three-phase break-time			ms	X	

Information to be listed on nameplates	Condition: Marking only required if	Abbreviation	Unit	Tee-OFF generator circuit-breaker	Operating device
(1)	(2)	(3)	(4)	(5)	(6)
Required capacitance value per phase at the generator step-up transformer side	non zero		nF	Y	
Capacitance value per phase provided at the generator step-up transformer side	different from required capacitance value		nF	Y	
Opening resistor value	equipped with opening resistor in parallel to the interrupting chamber		Ω	Y	
Mechanical endurance class				X	X
Year of manufacture				X	X
Minimum and maximum ambient air temperature			°C	X	
Instruction book number				X	X
Relevant standard with date of issue				X	X
<p>Key</p> <p>X = the marking of these values is mandatory; blanks indicate the value zero.</p> <p>(X) = if a rating is assigned the marking of these values is mandatory.</p> <p>Y = the marking of these values is mandatory if the conditions in column (2) are met.</p> <p>NOTE 1 The abbreviation in column (3) can be used instead of the terms in column (1). When terms in column (1) are used, the word "rated" need not appear.</p> <p>NOTE 2 If the values for the control circuits (closing and opening) are different, additional lines may be required.</p>					

Annex K (normative)

Requirements for doubly-fed induction machines (DFIMs) applications

K.1 General

Variable-speed machines have gained increasing importance in pumped-storage power plant and in wind farm applications. For the former application variable-speed machines are of particular interest as they present big advantages compared to the classical topology with a synchronous generator, such as the possibility to vary the power absorbed in pumping mode over a certain range by means of the speed of the pump and the ability to respond much more dynamically to changes in power set point values. Within the variable speed-solutions, the one employing a doubly-fed induction machine (DFIM) has become the preferred solution for large installations since it provides the advantages of variable-speed operation and four-quadrant active and reactive power capabilities using converters rated only a small fraction (ca. 20 % to –30 %) of the rated power.

The characteristics of the current fed by a DFIM after a three-phase short-circuit at its terminals is of utmost importance to define the requirements of the generator circuit-breaker installed between the generator and the step-up transformer. In the case of terminal faults, since the main flux-linkage cannot follow sudden supply voltage variations, a three-phase fault at the DFIM's stator terminals induces very large currents in the rotor windings. To protect the rotor-side converter, the rotor is short-circuited via crowbar resistors once the maximum current permissible by the converter is exceeded. Large rotor currents flow through the crowbar instead of the converter and the thermal breakdown of the power electronic converter is avoided. The different operating parameters of the machine (such as rotor's slip, pre-fault loading of the generator and crowbar resistance value) have a considerable impact on the current waveform.

For more detailed information on the application of generator circuit-breakers in conjunction with DFIMs, refer to [13] and [14].

K.2 Transient stator and rotor currents

The transient stator and rotor current can be derived from the equivalent circuit of a DFIM as shown in Figure K.1 and can be expressed as a function of the fluxes. The parameters are referred to the stator side.

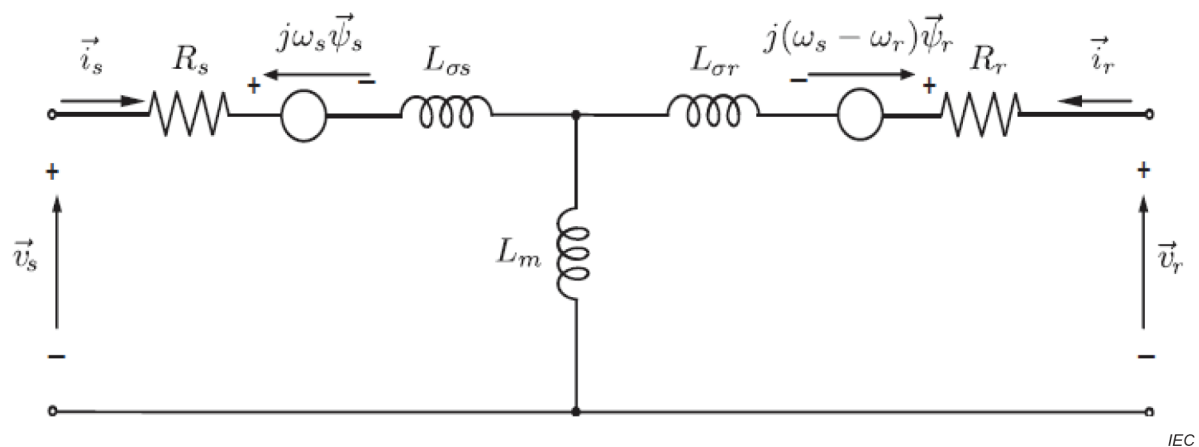


Figure K.1 – Equivalent circuit of a DFIM

K.3 Stator currents in case of a three-phase fault

Since the main flux-linkage cannot follow sudden supply voltage variations, a three-phase fault at the DFIM's stator terminals induces very large currents in the rotor windings. To protect the rotor-side converter, the rotor is short-circuited via crowbar resistors once the maximum current permissible by the converter is exceeded. Since this operation occurs immediately after the fault, it can be assumed, without any loss of generality, that both stator and rotor are short-circuited at $t = 0$. Large rotor currents flow through the crowbar instead of the converter and the thermal breakdown of the power electronic converter is avoided.

Under steady-state operation the stator flux rotates with synchronous speed, and thus is constant in a synchronously rotating reference frame.

In a fixed reference frame this flux does not rotate (DC flux), and decays exponentially with a time constant dictated by the DFIM's stator parameters, given by:

$$T'_s = \frac{L'_s}{R_s}$$

The rotor flux is fixed to the rotor windings, and decays exponentially with a time constant dictated by the DFIM's rotor parameters, given by:

$$T'_r = \frac{L'_r}{R_r}$$

From a fixed reference frame, this flux will rotate with the rotor mechanical angular velocity, $\omega_m(t)$. For a short period of time mechanical transients can be neglected, therefore the mechanical angular velocity can be considered constant: $\omega_m(t) = \omega_{m0} = \omega_m$.

The analytical expression for the stator three-phase short-circuit current can be obtained as follows:

$$\vec{i}_s = \frac{\vec{v}_{s0}}{j\omega_s L'_s} e^{-\frac{t}{T'_s}} - \frac{k_r}{L'_s} \vec{\psi}_{r0} \times e^{-\frac{t}{T'_r}} \times e^{-j\omega_m t}$$

K.4 DC component of the short-circuit current

The initial DC component of the short-circuit current depends only upon the magnitude of the stator flux at the moment the short-circuit occurs, and then decays exponentially with the time constant given by the machine technical parameters. For a DFIM, the initial value of the DC component will be maximum when the short-circuit occurs at voltage zero in one phase, and will be independent of the specific operating point of the DFIM prior to the fault.

K.5 AC component of the short-circuit current

The magnitude of the AC component of the short-circuit current depends only upon the magnitude of the rotor flux at the moment the short-circuit occurs. The rotor flux will depend only upon the power output and power factor of the DFIM prior to the fault. Specifically, the higher the reactive power generated by the DFIM, the higher the magnitude of the AC component of the short-circuit current; on the other hand the higher the reactive power absorbed, the lower the magnitude of the AC component of the short-circuit current.

K.6 Influence of rotor's slip

The higher the positive slip, the lower the frequency of the current; the higher the negative slip, the higher the frequency of the current.

K.7 Influence of the crowbar resistor

The crowbar resistance R_{cb} has only an impact on the time constant of the AC component since it adds to the rotor's resistance R_r (both values of R_r and R_{cb} are referred to the stator side):

$$T'_r = \frac{L'_r}{R_r + R_{cb}}$$

With a higher crowbar resistance, the AC component decays faster and hence the short-circuit current becomes more asymmetrical. For typical applications, the symmetrical component of the short-circuit current decays to zero within two to three cycles, thus leading to a current which is almost purely DC.

K.8 Influence of pre-fault loading conditions

In accordance with what is stated in Clause K.4, the higher the reactive power generated by the DFIM, the higher the magnitude of the AC component of the short-circuit current; on the other hand the higher the reactive power absorbed, the lower the magnitude of the AC component of the short-circuit current.

The initial DC component of the short-circuit current depends only upon the magnitude of the stator voltage at the moment the short-circuit occurs; the initial value of the DC component will be maximum when the short-circuit occurs at voltage zero in one phase, and will be independent of the specific pre-fault loading condition.

K.9 Specific requirements for the application of generator circuit-breakers

The requirements laid down in Clause 9 apply.

As the crowbar resistor decreases the time constant of the decay of the AC component of the short-circuit current, upon insertion of the crowbar the symmetrical component of the current will therefore decay faster, and depending on the crowbar's resistance value, can decay much faster than the DC component. When this occurs, the resulting current waveform can exhibit delayed current zeros. Furthermore, typical values of crowbar resistance can lead to a very small symmetrical component within a few milliseconds, thus leading to a short-circuit current which is almost purely DC (see Figure K.2).

Under these circumstances the current has no natural zero crossing for several hundred milliseconds. These conditions shall be thoroughly investigated when assessing the suitability of a generator circuit-breaker for a given application.

When the current exhibits delayed current zeros (i.e. degree of asymmetry > 100 %) the capability of the generator circuit-breaker to force current zeros shall be demonstrated by means of a calculation considering the effect on the prospective current of the crowbar resistor and of the arc voltage of the generator circuit-breaker. The requirements and conditions laid down in 9.103.6.3.6.4 apply.

Subclauses 9.103.6.3.6.4, 9.103.6.3.7.2, 9.103.6.3.7.3 and 9.103.6.3.7.4 are applicable with the following addition: the short-circuit currents shall be calculated assuming that the crowbar resistor is inserted and summed up to the rotor's resistance to reduce the time constant of decay of the AC component. Special attention shall be paid to these cases because the degree of asymmetry of the fault current might attain values much higher than those observed in conventional synchronous generator applications.

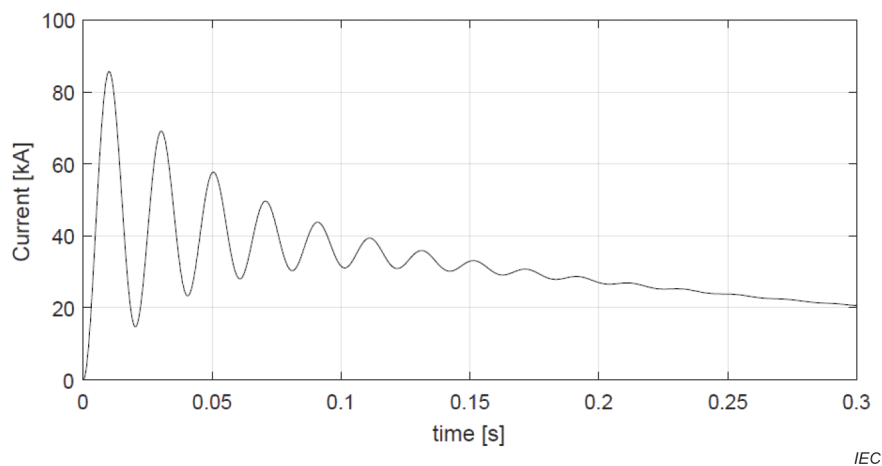


Figure K.2 – Example of influence of crowbar resistor on generator-source short-circuit current

Annex L (normative)

Requirements for wind farm applications

L.1 General

Wind farms can employ generators with or without power electronic converters. In case power electronic converters are used, they can be either full-scale converters connected at the stator of the generator or partial-scale converters connected at the rotor of the generator. The requirements imposed on generator circuit-breakers by the various types of generators used in wind farms are covered in Clauses L.2 to L.4.

L.2 Generators without power electronic converters

A typical wind tower layout consists in the following components connected in series: generator, generator circuit-breaker, and step-up transformer. These applications are considered as conventional generator circuit-breaker applications. In order to assess the requirements imposed on the generator circuit-breaker Clause 9 applies.

L.3 Generators with full-scale power electronic converters connected at the stator of the generator

A typical wind tower layout consists in the following components connected in series: generator, first generator circuit-breaker, full-scale converter, second generator circuit-breaker, and step-up transformer.

In order to assess the requirements imposed on the generator circuit-breaker installed between the full-scale converter and the step-up transformer (second generator circuit-breaker) Clause 9 applies. The generator-source short-circuit current shall be assessed taking into consideration the effect of the full-scale converter in case of a three-phase earth fault between generator circuit-breaker and step-up transformer. The system-source short-circuit current shall be assessed considering a three-phase earth fault between full-scale converter and generator circuit-breaker.

In order to assess the requirements imposed on the generator circuit-breaker installed between the generator and the full-scale converter (first generator circuit-breaker), Clause 9 applies. The system-source short-circuit current shall be assessed taking into consideration the effect of the full-scale converter in case of a three-phase earth fault between generator and generator circuit-breaker. The generator-source short-circuit current shall be assessed considering a three-phase earth fault between generator circuit-breaker and full-scale converter.

In this case all the requirements laid down in Clause 9 for generator-source short-circuit current apply with the addition that all the calculations shall be performed also for the minimum and for the maximum frequency of the current which can be attained by the generator. In the case of high frequency, in the current interruption process the time derivative of the current (di/dt) at the last current zero is of special concern. The generator circuit-breaker can be considered as suitable for the application if it can extinguish the arc at the current zero crossing and withstand the subsequent transient recovery voltage. Test evidence shall be provided for the capability of the generator circuit-breaker to handle the last current loop parameters (time, peak and di/dt at current zero) required for the project-specific application.

In the case of lower frequency, the arcing time can be very long. A longer arcing time means higher arc-energy input. The generator-circuit breaker shall withstand the resulting arc-energy and extinguish the arc at the current zero crossing. The generator circuit-breaker can be considered as suitable for the application if it can extinguish the arc at the current zero crossing and withstand the subsequent transient recovery voltage. Test evidence shall be provided for the capability of the generator circuit-breaker to withstand the arc energy and extinguish the arc after the long arcing time required for the project-specific application.

L.4 Generators with partial-scale power electronic converters connected at the rotor of the generator

A typical wind tower layout consists in the following components connected in series: generator, generator circuit-breaker, and step-up transformer. In order to assess the requirements imposed on the generator circuit-breaker Annex K applies.

L.5 Breaking tests

L.5.1 General

Assigning low frequency or high frequency breaking capability to the generator circuit-breaker is not mandatory, but if such a capability is assigned by the manufacturer, then the following test requirements shall be met. The generator circuit-breaker might need to break short-circuit currents at frequencies lower or higher than the rated one. Such short-circuit currents are fed by the generator and are based on the generator ratings of the wind farm. Short-circuit currents are possible at any frequency between 0 Hz and up to possibly three times the rated frequency of the wind farm.

L.5.2 Low frequency breaking tests

If required, low frequency breaking tests shall be made under the following conditions:

- a) The test current shall be the rated generator-source short-circuit current I_{scg} .
- b) The test circuit shall be similar to the usual short-circuit test arrangement (see 7.105);
- c) The tests shall be performed at a power frequency of 20 Hz \pm 3 Hz.
- d) For testing purposes, the asymmetrical current breaking capability is based on a time constant of 350 ms.
- e) Either three-phase or single-phase tests can be made. If three-phase tests are made, either the neutral of the supply or the short-circuit point shall be earthed, but not both. If single-phase tests are made, the test circuit shall be earthed.
- f) The test voltages shall be based on the rated voltage, U_r and a rated frequency of 50 Hz.
 - If three-phase tests are made, they shall be made with phase-to-phase voltage equal to $U_{test} = 20 \text{ Hz} / 50 \text{ Hz} \times U_r = 0,4 U_r$.
 - If single-phase tests are made, the test voltage shall be equal to $U_{test} = 20 \text{ Hz} / 50 \text{ Hz} \times k_{pp} \times U_r / \sqrt{3} = 0,346 U_r$.
- g) The TRV parameters of the first-pole-to-clear in three-phase tests and for the case of single-phase test circuits shall be as specified in Table L.1.

Table L.1 – TRV parameters for low frequency generator-source faults

Generator rating MVA	Prospective TRV		
	Time t_3 μs	TRV peak value u_c kV	RRRV kV/ μs
10 to 50	$1,23 U_r$	$0,73 U_r$	0,60
51 to 100	$1,15 U_r$	$0,73 U_r$	0,64
101 to 400	$1,02 U_r$	$0,73 U_r$	0,72
401 to 800	$0,92 U_r$	$0,73 U_r$	0,80
801 or more	$0,84 U_r$	$0,73 U_r$	0,88
The time delay t_d shall be equal to 0,5 μs .			

- h) The normally earthed parts of the generator circuit-breaker shall be earthed.
- i) Tests shall be made at the minimum functional pressure for insulation and/or making and breaking and at the minimum functional pressure for operating. To facilitate consistent control of the opening operation, the shunt opening releases may be supplied at the maximum operating voltage.
- j) Symmetrical breaking operations shall show the breaking behaviour after maximum arcing times under first-pole-to-clear and last-pole-to-clear conditions. In order to achieve this, the minimum arcing time $t_{\text{arc sym min LF}}$ shall be established. The same procedure as given in 7.102.10.2.2 for three-phase tests and 7.102.10.3.2 for single-phase tests shall apply.
- k) Asymmetrical breaking operations shall show the behaviour after the second major loop of the phase with maximum asymmetry. The last loop parameters of the prospective current of the phase with maximum asymmetry shall be based on a time constant of 350 ms. The maximum arcing times under first-pole-to-clear and last-pole-to-clear conditions shall be tested. For simplicity and contrary to the procedure described in 7.102.10.2.3 $t_{\text{arc sym min LF}}$ instead of $t_{\text{arc asym min 1 LF}}$ and $t_{\text{arc asym min 2 LF}}$ may also be used to calculate the maximum arcing times for asymmetrical breaking operations.
- l) Tests and further conditions of severity are outlined in Table L.2 and Table L.3.
- m) The arcing times given in Table L.2 and Table L.3 are prospective values for an exact power frequency of 20 Hz and a perfect setting of the trip-signal. The arcing time during the test may be modified by the tolerance of the power frequency, the tolerance of the trip-signal and the behaviour of the test object. Therefore, a tolerance on the setting of the contact separation is given and shall be within $\pm 18^\circ$ of its theoretical position, calculated during a prospective test.

Table L.2 – Test-duties to demonstrate the low frequency breaking capability for three-phase tests

Test-duty	Operating duty	Applied voltage	Current magnitude	Last loop parameters of prospective current (20 Hz)				Power-frequency recovery voltage
				I_{peak} p.u.	Duration of loop ms	Corresponding di/dr at current zero %	Arcing time set to ms	
a,b,c								
LF1 e	O_{sym} 30 min	$0,4 U_r/\sqrt{3}$	I_{scg}	1,00	25,0	100	$t_{arc\ sym\ min\ LF} + 5,8$	$0,4 U_r/\sqrt{3}$
	O_{sym}			1,00	29,2	86,6	$t_{arc\ sym\ min\ LF} + 18,3$	
LF2 e	O_{asym} 30 min	$0,4 U_r/\sqrt{3}$	I_{scg}	1,81	40,1	66,3	$t_{arc\ sym\ min\ LF} + 9,6$	$0,4 U_r/\sqrt{3}$
	O_{asym}			1,81	43,1	66,0	$t_{arc\ sym\ min\ LF} + 27,5$	

Key

U_r rated voltage of the generator circuit-breaker

I_{scg} RMS value of the AC component of the rated generator-source short-circuit breaking current of the generator circuit-breaker

a The test-duty sequence is only a suggested sequence. The test-duties can be performed in any sequence desired.

b No refitting or replacement of parts to the generator circuit-breaker is permitted during each test-duty. Refitting or replacement of parts to the generator circuit-breaker is permitted between test-duties LF1 and LF2.

c If the generator circuit-breaker has an auxiliary resistor chamber and an auxiliary switch, tests should be performed with the auxiliary resistor and switch in the circuit, or, for convenience of testing, the tests may be performed on both interrupters separately by using equivalent TRVs.

d 100 % corresponds to a symmetrical current with a power frequency of 20 Hz.

e The upper line corresponds to first-pole-to-clear conditions, the lower line corresponds to last-pole-to-clear conditions.

Table L.3 – Test-duties to demonstrate the low frequency breaking capability for single-phase tests

Test-duty a,b,c	Operating duty	Applied voltage	Current magnitude	Last loop parameters of prospective current (20 Hz)				Power-frequency recovery voltage
				I_{peak} p.u.	Duration of loop ms	Corresponding di/dt at current zero %	Arcing time set to ms	
LF1	O_{sym} 30 min	$0,4 U_r/\sqrt{3}$	I_{scg}	1,00	25,0	100	$t_{arc\ sym\ min\ LF}^+ + 5,8$	1,5 (0,4 $U_r/\sqrt{3}$)
	O_{sym}			1,00	25,0	86,6	$t_{arc\ sym\ min\ LF}^+ + 18,3$	0,4 $U_r/\sqrt{3}$
LF2	O_{asym} 30 min	$0,4 U_r/\sqrt{3}$	I_{scg}	1,81	40,1	66,3	$t_{arc\ sym\ min\ LF}^+ + 9,6$	1,5 (0,4 $U_r/\sqrt{3}$)
	O_{asym}			1,81	40,1	66,0	$t_{arc\ sym\ min\ LF}^+ + 27,5$	0,4 $U_r/\sqrt{3}$

Key

U_r rated voltage of the generator circuit-breaker

I_{scg} RMS value of the AC component of the rated generator-source short-circuit breaking current of the generator circuit-breaker

^a The test-duty sequence is only a suggested sequence. The test-duties can be performed in any sequence desired.

^b No refitting or replacement of parts to the generator circuit-breaker is permitted during each test-duty. Refitting or replacement of parts to the generator circuit-breaker is permitted between test-duties LF1 and LF2.

^c If the generator circuit-breaker has an auxiliary resistor chamber and an auxiliary switch, tests should be performed with the auxiliary resistor and switch in the circuit, or, for convenience of testing, the tests may be performed on both interrupters separately by using equivalent TRVs.

^d 100 % corresponds to a symmetrical current with a power frequency of 20 Hz.

L.5.3 High frequency breaking tests

If required, high frequency symmetrical breaking tests shall be made under the following conditions:

- The test current shall be the rated generator-source short-circuit current I_{scg} .
- The test circuit shall be similar to the usual short-circuit test arrangement (see 7.105).
- The tests shall be performed at the maximum frequency $f_{max} \pm 10\%$. Synthetic tests with a current circuit at any other power frequency are valid provided that di/dt fulfils the required value for maximum frequency f_{max} .
- Either three-phase or single-phase tests can be made. If three-phase tests are made, either the neutral of the supply or the short-circuit point shall be earthed, but not both. If single-phase tests are made, the test circuit shall be earthed.
- The test voltages shall be based on the rated voltage, U_r and a rated frequency of 50 Hz.
- If three-phase tests are made, they shall be made with phase-to-phase voltage equal to $U_{test} = f_{max} / 50 \times U_r$, where f_{max} is expressed in Hz.
- If single-phase tests are made, the test voltage shall be equal to $f_{max} / 50 \times k_{pp} \times U_r / \sqrt{3}$, where f_{max} is expressed in Hz.
- The TRV parameters of the first-pole-to-clear in three-phase tests and for the case of single-phase test circuits shall be as specified in Table L.4.

Table L.4 – TRV parameters for high frequency generator-source faults

Prospective TRV			
Time t_3 μs	TRV peak value u_c kV	RRRV kV/ μs	Time delay t_d μs
$1,23 U_r$	$f_{\max} / 50 \times 1,84 U_r$	$f_{\max} / 50 \times 1,5$	0,5

- i) The normally earthed parts of the generator circuit-breaker shall be earthed.
- j) Tests shall be made at the minimum functional pressure for insulation and/or making and breaking and at the minimum functional pressure for operation. To facilitate consistent control of the opening operation, the shunt opening releases may be supplied at the maximum operating voltage.
- k) The breaking operations shall show the behaviour after maximum arcing times under first-pole-to-clear and last-pole-to-clear conditions. In order to achieve this, the minimum arcing time $t_{\text{arc sym min HF}}$ shall be established. The same procedure as given in 7.102.10.2.2 for three-phase tests and 7.102.10.3.2 for single-phase tests shall apply.
- l) Tests and further conditions of severity are outlined in Table L.5 and Table L.6.
- m) The arcing times given in Table L.5 and Table L.6 are prospective values for an exact power frequency of f_{\max} and a perfect setting of the trip-signal. The arcing time during the test may be modified by the tolerance of the power frequency, the tolerance of the trip-signal and the behaviour of the test object. Therefore, a tolerance on the setting of the contact separation is given and shall be within $\pm 18^\circ$ of its theoretical position, calculated during a prospective test.

High frequency asymmetrical breaking tests are not required. They are covered by system-source and generator-source short-circuit asymmetrical breaking current tests (see 7.103 and 7.105) and the di/dt is covered by the high-frequency symmetrical breaking tests.

Table L.5 – Test-duties to demonstrate the high frequency breaking capability for three-phase tests

Test-duty a,b	Operating duty	Applied voltage	Current magnitude	Last loop parameters of prospective current (f_{max})				Power-frequency recovery voltage
				I_{peak} p.u.	Duration of loop ms	Corresponding di/dt at current zero %	Arcing time set to ms	
HF ^d	O_{sym}	$f_{max}/50 \times U_r/\sqrt{3}$	I_{scg}	1,00	$500/f_{max}$	100	$t_{arc\ sym\ min\ HF}^+ + 117/f_{max}$	$f_{max}/50 \times U_r/\sqrt{3}$
	O_{sym}			1,00	$583/f_{max}$	86,6	$t_{arc\ sym\ min\ HF}^+ + 367/f_{max}$	

Key

U_r rated voltage of the generator circuit-breaker

I_{scg} RMS value of the AC component of the rated generator-source short-circuit breaking current of the generator circuit-breaker

In this table f_{max} is already accounted for in Hz; the user only needs to use the number in the formulas in the table.

- a No refitting or replacement of parts to the generator circuit-breaker is permitted during the test-duty.
- b If the generator circuit-breaker has an auxiliary resistor chamber and an auxiliary switch, tests should be performed with the auxiliary resistor and switch in the circuit, or, for convenience of testing, the tests may be performed on both interrupters separately by using equivalent TRVs.
- c 100 % corresponds to a symmetrical current with a power frequency of f_{max} .
- d The upper line corresponds to first-pole-to-clear conditions, the lower line corresponds to last-pole-to-clear conditions.

Table L.6 – Test-duties to demonstrate the high frequency breaking capability for single-phase tests

Test-duty	Operating duty	Applied voltage	Current magnitude	Last loop parameters of prospective current (f_{max})				Power-frequency recovery voltage
				I_{peak} p.u.	Duration of loop ms	Corresponding di/dt at current zero %	Arcing time set to ms	
a,b						c		
HF ^d	O_{sym}	$f_{max} / 50 \times U_r / \sqrt{3}$	I_{scg}	1,00	$500 / f_{max}$	100	$t_{arc\ sym\ min\ HF}^+ / 117 / f_{max}$	$1,5 (f_{max} / 50 \times U_r / \sqrt{3})$
	30 min							
	O_{sym}			1,00	$500 / f_{max}$	86,6	$t_{arc\ sym\ min\ HF}^+ / 367 / f_{max}$	$f_{max} / 50 \times U_r / \sqrt{3}$

Key

U_r rated voltage of the generator circuit-breaker

I_{scg} RMS value of the AC component of the rated generator-source short-circuit breaking current of the generator circuit-breaker

In this table f_{max} is already accounted for in Hz; the user only needs to use the number in the formulas in the table.

^a No refitting or replacement of parts to the generator circuit-breaker is permitted during the test-duty.

^b If the generator circuit-breaker has an auxiliary resistor chamber and an auxiliary switch, tests should be performed with the auxiliary resistor and switch in the circuit, or, for convenience of testing, the tests may be performed on both interrupters separately by using equivalent TRVs.

^c 100 % corresponds to a symmetrical current with a power frequency of f_{max} .

^d The upper line corresponds to first-pole-to-clear conditions, the lower line corresponds to last-pole-to-clear conditions.

Annex M (normative)

Assessment of TRV test parameters for out-of-phase current breaking in the case of generator circuit-breakers equipped with capacitors

Capacitors can be installed between the step-up transformer and the generator circuit-breaker, or between the generator and the generator circuit-breaker, or both, or capacitors can be part of the generator circuit-breaker. If the test circuit comprises one voltage source only (with the other side of the generator circuit-breaker being earthed), then the tests shall be carried out without these capacitors installed. The influence of the capacitors on the prospective TRV shall be taken into account by using the "GenCB TRV calculator" tool to determine the values for the modified TRV parameters to be used as the TRV requirements for the out-of-phase current breaking.

This tool is included as a downloadable part of this document.

The modified prospective TRV parameters given by the "GenCB TRV calculator" tool are derived using the following formulas:

$$u_{cm} = K_{E2} \times U_r$$

$$RRRV_m = RRRV_0 + K_{RRRV-U} \times (U_r - U_{class}) + K_{RRRV-I} \times (I_{sc} - I_{class})$$

$$t_{dm} = td_0 + K_{td-U} \times (U_r - U_{class}) + K_{td-I} \times (I_{sc} - I_{class})$$

where

u_{cm} [kV], $RRRV_m$ [kV/ μ s], and t_{dm} [μ s]	are respectively the peak value, the rate-of-rise and the time delay of the prospective TRV for out-of-phase current breaking modified by the capacitors of the generator circuit-breaker;
U_r	is the rated voltage of the generator circuit-breaker expressed in kV;
I_{sc}	is the RMS value of the AC component of the system-source short-circuit breaking current expressed in kA;
U_{class} [kV] and I_{class} [kA]	are parameters depending on the classes listed in Table M.1.

Table M.1 – Reference values for MVA classes

MVA class	Generator rating
	MVA
1	10 to 50
2	51 to 100
3	101 to 200
4	201 to 400
5	401 to 600
6	601 to 800
7	801 to 1 000
8	≥ 1 001

NOTE The generator rating has been split into more classes compared to Table 5 and Table 6 in order to coordinate the generator ratings according to Table 4 with the step-up transformer ratings according to Table 3.

The values for the parameters K_{E2} , $RRRV_0$ [kV/ μ s], K_{RRRV-U} [1/ μ s], K_{RRRV-I} [kV/ μ s \times 1/kA], t_{d0} [μ s], K_{td-U} [μ s/kV], K_{td-I} [μ s/kA] are calculated by the GenCB TRV calculator tool. They depend on the value of the capacitors at the generator side (C_g) and at the transformer side (C_s) of the generator circuit-breaker, where K_{E2} is used to calculate the value of the TRV first peak.

The prospective TRV modified by the capacitors of the generator circuit-breaker has been assessed in accordance with the approach described below for a three-phase circuit consisting of generator, step-up transformer and HV grid.

- The value of the equivalent reactance of the step-up transformer and the HV grid has been derived from the RMS values of the rated voltage and AC component of the rated system-source short-circuit breaking current of the generator circuit-breaker.
- The value of the equivalent reactance of the step-up transformer, the HV grid, and the generator has been derived from the RMS value of the rated voltage of the generator circuit-breaker multiplied by $\sqrt{2}$ and the AC component of the rated out-of-phase breaking current of the generator circuit-breaker (see 5.104).
- The value of the equivalent reactance of the generator has been calculated by subtracting the value of the equivalent reactance of the step-up transformer and the HV grid from the value of the equivalent reactance of the step-up transformer, the HV grid, and the generator.

NOTE The value of the equivalent reactance of the generator model calculated as described above is not related to the rated generator-source short-circuit breaking current.

- The value of the parameters used to control the TRV (resistors in parallel with the reactances, capacitors phase-to-ground and capacitors between the primary winding and the secondary winding of the step-up transformer) have been calculated so that the three-phase circuit of the step-up transformer, the HV grid, and the generator provides the prospective TRV parameters defined in Table 6 in case of 90° out-of-phase breaking current conditions. This part of the calculation has been performed by means of electromagnetic transient simulations.
- To the circuit obtained, capacitors connected phase-to-ground have been added in each phase at the transformer-side or at both the generator-side and transformer-side of the generator circuit-breaker.
- Calculations of the TRV have been repeated with the modified circuit to obtain the parameters of the prospective TRV modified by the additional capacitors.

The modified TRV parameters form the TRV requirements for out-of-phase current breaking tests of the generator-circuit breaker including its capacitors.

Annex N (normative)

Assessment of TRV test parameters for load current breaking in the case of generator circuit-breakers equipped with capacitors

Capacitors can be installed between the step-up transformer and the generator circuit-breaker, or between the generator and the generator circuit-breaker, or both, or capacitors can be part of the generator circuit-breaker. If the test circuit comprises one voltage source only (with the other side of the generator circuit-breaker being earthed), then the tests shall be carried out without these capacitors installed. The influence of the capacitors on the prospective TRV shall be taken into account by using the "GenCB TRV calculator" tool to determine the values for the modified TRV parameters to be used as the TRV requirements for the load current breaking.

This tool is included as a downloadable part of this document.

The modified prospective TRV parameters given by the "GenCB TRV calculator" tool are derived using the following formulas:

$$u_{cm} = K_{E2} \times U_r$$

$$RRRV_m = RRRV_0 + K_{RRRV-U} \times (U_r - U_{class}) + K_{RRRV-I} \times (I_{sc} - I_{class}), \text{ if } I_{load}/I_{sc} \times 5,656\ 854 < 1$$

$$RRRV_m = \frac{RRRV_0 + K_{RRRV-U} \times (U_r - U_{class}) + K_{RRRV-I} \times (I_{sc} - I_{class})}{1 - \frac{\frac{I_{load}}{I_{sc}} \times 5,656854 - 1}{3}}, \text{ if } I_{load}/I_{sc} \times 5,656\ 854 \geq 1$$

$$t_{dm} = t_{d0} + K_{td-U} \times (U_r - U_{class}) + K_{td-I} \times (I_{sc} - I_{class}), \text{ if } I_{load}/I_{sc} \times 5,656854 < 1$$

$$t_{dm} = \left(t_{d0} + K_{td-U} \times (U_r - U_{class}) + K_{td-I} \times (I_{sc} - I_{class}) \right) \times \left(1 - \left(\frac{I_{load}}{I_{sc}} \times 5,656854 - 1 \right) \times 0,383 \right), \text{ if}$$

$$I_{load}/I_{sc} \times 5,656\ 854 \geq 1$$

where

u_{cm} [kV], $RRRV_m$ [kV/ μ s], and t_{dm} [μ s]	are respectively the peak value, the rate-of-rise and the time delay of the prospective TRV for load current breaking modified by the capacitors of the generator circuit-breaker;
U_r	is the rated voltage of the generator circuit-breaker expressed in kV;
I_{sc}	is the RMS value of the AC component of the system-source short-circuit breaking current expressed in kA;
I_{load}	is the RMS value of the AC component of the load breaking current expressed in kA;
U_{class} [kV] and I_{class} [kA]	are parameters depending on the classes listed in Table M.1.

The values for the parameters K_{E2} , $RRRV_0$ [kV/ μ s], K_{RRRV-U} [1/ μ s], K_{RRRV-I} [kV/ μ s \times 1/kA], t_{d0} [μ s], K_{td-U} [μ s/kV], K_{td-I} [μ s/kA] are calculated by the GenCB TRV calculator tool. They depend on the value of the capacitors at the generator side (C_g) and at the transformer side (C_s) of the generator circuit-breaker, where K_{E2} is used to calculate the value of the TRV first peak.

The prospective TRV modified by the capacitors of the generator circuit-breaker has been assessed according to the approach described below for a three-phase circuit consisting of generator, step-up transformer and HV grid.

- The value of the equivalent reactance of the step-up transformer and the HV grid has been derived from the RMS values of the rated voltage and AC component of the rated system-source short-circuit breaking current of the generator circuit-breaker.
- The value of the equivalent reactance of the step-up transformer, the HV grid, and the generator has been derived from the RMS value of the rated voltage of the generator circuit-breaker multiplied by 0,5 and the AC component of the rated load breaking current of the generator circuit-breaker (see 5.103, 7.104.1 and 9.103.8.2).
- The value of the equivalent reactance of the generator has been calculated by subtracting the value of the equivalent reactance of the step-up transformer and the HV grid from the value of the equivalent reactance of the step-up transformer, the HV grid, and the generator.

NOTE The value of the equivalent reactance of the generator model calculated as described above is not related to the rated generator-source short-circuit breaking current.

- The values of the parameters used to control the TRV (resistors in parallel with the reactances, capacitors phase-to-ground and capacitors between the primary winding and the secondary winding of the step-up transformer) have been calculated so that the three-phase circuit of the step-up transformer, the HV grid, and the generator provides the prospective TRV parameters defined in Table 5 in case of load breaking current conditions. This part of the calculation has been performed by means of electromagnetic transient simulations.
- To the circuit obtained, capacitors connected phase-to-ground have been added in each phase at the transformer-side or at both the generator-side and transformer-side of the generator circuit-breaker.
- Calculations of the TRV have been repeated with the modified circuit to obtain the parameters of the prospective TRV modified by the additional capacitors.

The modified TRV parameters form the TRV requirements for load current breaking tests of the generator-circuit breaker including its capacitors.

Annex O (normative)

Requirements for pumped-storage applications

O.1 General

Pumped-storage applications are considered special applications, and their requirements are not completely covered by this document. Nevertheless, a detailed description on the functions of a pumped-storage generator circuit-breaker system and low frequency test requirements and procedures are specifically covered in this annex.

Pumped-storage power plants are of great importance for the economical operation of a power system as they make use of electrical energy during off-peak hours to pump water from a lower reservoir to a higher reservoir for use in the generation of electrical energy during system peak periods. Generator circuit-breakers are widely used in pumped-storage power plants because the use of such circuit-breakers allows the electrical scheme (Figure O.1) to be greatly simplified, which provides operational advantages and increased power plant reliability.

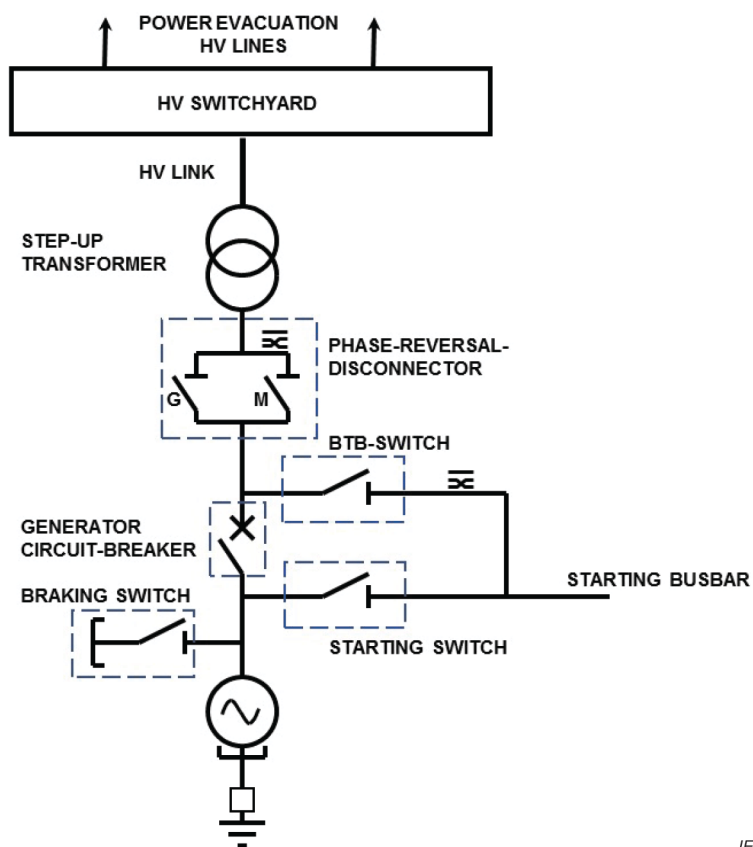
Pumped-storage power plants employ specific components dedicated to allow the unit to operate in turbine, pumping, and intermediate modes. These components are also used in the transition phase between two operating modes.

The most common specific components are:

- phase-reversal-disconnector;
- starting switches and BTB-switches;
- braking switch.

For layout reasons, these components may be located in separates enclosures.

A typical single line diagram is given in Figure O.1.



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Figure O.1 – Pumped-storage power plant – Typical single line diagram

When a machine is started-up in the motor mode, it has to be accelerated to its rated speed before it can be connected to the system (unless asynchronous starting is used). The two most common methods used for starting-up machines in the motor mode are the static frequency converter (SFC) and the "back-to-back" starting arrangements. Both are synchronous starting modes. In the SFC starting arrangement the machine is connected to a converter which provides at the machine side voltage and frequency of variable magnitude; by increasing the frequency and voltage of the converter the machine is accelerated [15]. At about 95 % of the synchronous speed, the synchronising equipment will take over control of the SFC and after reaching the conditions necessary for synchronisation it will give a closing command to the generator circuit-breaker and block the SFC impulses. Therefore there is no current flow caused by the SFC after synchronisation. When the generator circuit-breaker has been closed, the SFC will be disconnected.

In the "back-to-back" starting arrangement another machine in the station, acting as a generator, is employed. The generator and the motor to be started-up are connected together electrically. The wicket gate of the generator turbine is opened and both machines are accelerated to synchronous speed.

In asynchronous starting, the unexcited machine is connected to full or reduced voltage at system frequency and is acting as an asynchronous motor during the starting period.

Another important issue in all hydro power plants and therefore also in pumped-storage power plants, is the braking of the machine after it has been disconnected from the system. Electrical braking by short-circuiting the stator and re-excitation of the rotor is attractive because it assists hydraulic braking at lower speed and allows to substantially reduce the wear of the mechanical braking system and hence to increase the maintenance intervals and to decrease the associated costs [16]. The current used for the electrical braking is typically in the range of 1,0 to 1,3 times the rated current of the machine. The current will remain at this value nearly to full standstill of the unit, because both the voltage and the reactance decrease proportionally with the speed of the unit.

The high number of transitions between the generator and motor operating modes in a pumped-storage power plant typically require increased mechanical and electrical endurance of generator circuit-breakers. Also, these generator circuit-breakers could experience additional operations from a failed starting procedure or perform breaking of short-circuit currents at off nominal frequencies.

O.2 Phase-reversal-disconnector

A phase-reversal-disconnector consists of at least five poles, operated by groups, to serve the purpose of:

- isolating the unit from the system;
- interchanging two phases to reverse the rotation of the machine to use it alternatively in generator mode or motor mode, corresponding respectively to the turbine mode and the pumping mode of the unit.

The electrical ratings of a phase-reversal-disconnector are those of a main-disconnector of a generator circuit-breaker system, as described in this document.

The phase-reversal-disconnector shall have capacitive current interruption capability when capacitors are installed between the generator circuit-breaker and the phase-reversal-disconnector.

O.3 Starting switch and BTB-switch

Starting and BTB-switches are used during the starting process of rotating machines in pumping mode, when generators or static frequency converters are used to provide power with voltage at variable amplitude and frequency from 0 Hz to power frequency.

Starting switches are typically connected to the main busbar at a point situated between generator and generator circuit -breaker, while BTB-switches are connected at a point between generator circuit-breaker and phase-reversal-disconnector.

The insulation levels shall be the same as for the generator circuit-breaker, as specified in Table 1.

Current carrying capability is defined by the manufacturer as described in 7.1.1.

Rated short-time withstand current and peak withstand current are defined in 5.6 and 5.7.

Mechanical endurance classes M1, M2, M3 defined in 5.107 are applicable.

O.4 Braking switch

The braking switch is typically mounted in a cubicle, and is typically connected to the generator main busbar between the terminals of the generator and the generator circuit-breaker.

The braking switch shall withstand the insulation levels of the generator circuit-breaker system when the contacts are open. In addition, the braking switch shall have a making capability and a temporary current carrying capability, as described in 7.1.1, and in accordance with the required braking process.

For practical reasons, making capability shall be demonstrated at 50 Hz or 60 Hz.

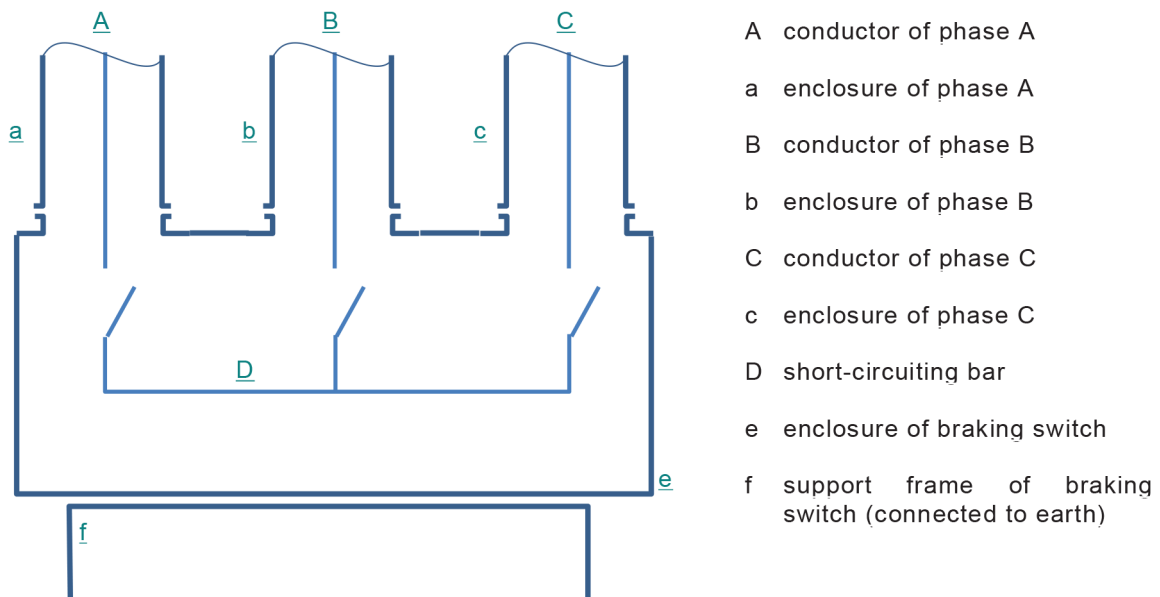
Short-time withstand current and peak withstand current capabilities as defined in 5.6 and 5.7 do not apply.

A braking switch is not intended for protection purposes, therefore, no interrupting capability is required.

Mechanical endurance classes M1, M2, M3 defined in 5.107 are applicable.

With reference to Figure O.2, the insulation levels of the braking switch are as follows:

- the common values of Table 1 are applicable between A, B, C and e;
- where the short-circuiting bar D is at a floating potential by design, the insulation level D-e shall be at least 1 500 V. The short-circuiting bar shall be subjected to a power-frequency withstand voltage test of 1 500 V for 1 min.



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Figure O.2 – Braking switch single line diagram

Typically, the enclosure e is electrically isolated from the enclosures a, b and c to avoid return currents through the enclosure e. The earthing concept of the plant shall be respected.

O.5 Breaking tests

O.5.1 General

Assigning low frequency breaking capability to the generator circuit-breaker is not mandatory, but if such a capability is assigned by the manufacturer, then the following test requirements shall be met. During start-up procedures the generator circuit-breaker might need to break short-circuit currents at low frequencies. Such short-circuit currents are fed by the generator and are based on the generator ratings of the pumped storage power plant. Short-circuit currents are possible at any frequency between 0 Hz and the rated frequency of the pumped storage power plant. Typically, the time spent operating within the frequency range of 0 Hz to 20 Hz is limited. Therefore, the tests should be performed at a power frequency of 20 Hz.

O.5.2 Low frequency breaking tests

Subclause L.5.2 is applicable.

Annex P (informative)

Derivation of the humidity exponent w

According to 4.3.4.2 of IEC 60060-1:2010 no humidity correction can be specified for rated voltages below 72,5 kV. This is equivalent to $k_2 = 1$ or $w = 0$.

On the other hand, 6.2.1 of IEC 60694:1996⁴, introduced a step function for the humidity exponent, being $w = 0$ for an absolute humidity $h > 11 \text{ g/m}^3$ and $w = 1$ for an absolute humidity $h < 11 \text{ g/m}^3$. No value for w is given for $h = 11 \text{ g/m}^3$.

This step function is still found in the latest edition of IEC 62271-1 from 2017.

This step function leads to a discontinuous behaviour of the humidity correction factor k_2 . To avoid the discontinuous behaviour around a humidity value of 11 g/m^3 , the following mathematical approximation has been introduced:

$$w = 0,5 - \tan^{-1} \left(\frac{(h - 11 \times \delta) 100}{\pi} \right)$$

Figure P.1 shows a graph of the function w for two different ambient air conditions and – as comparison – for the step function according to IEC 62271-1.

⁴ Withdrawn.

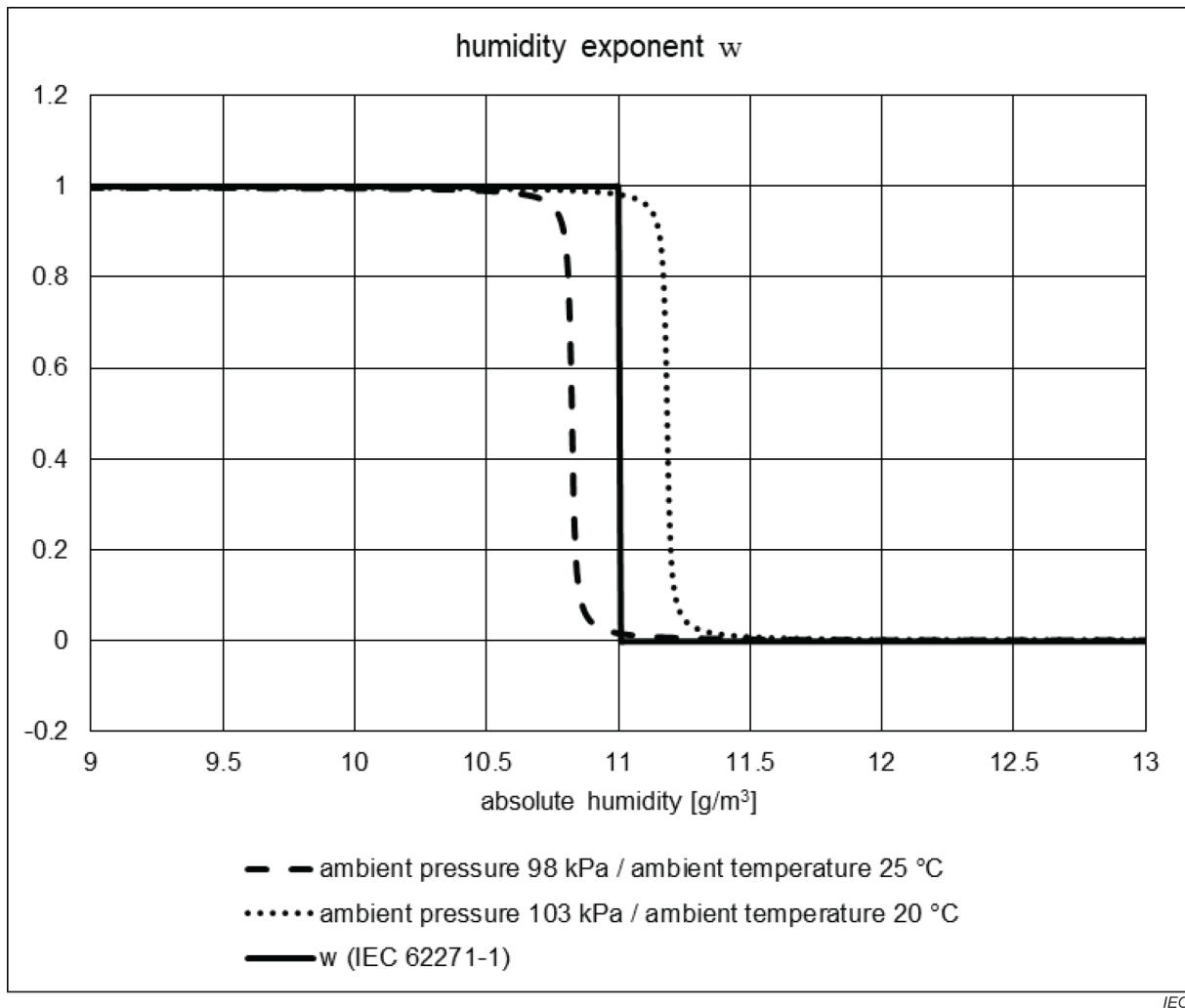
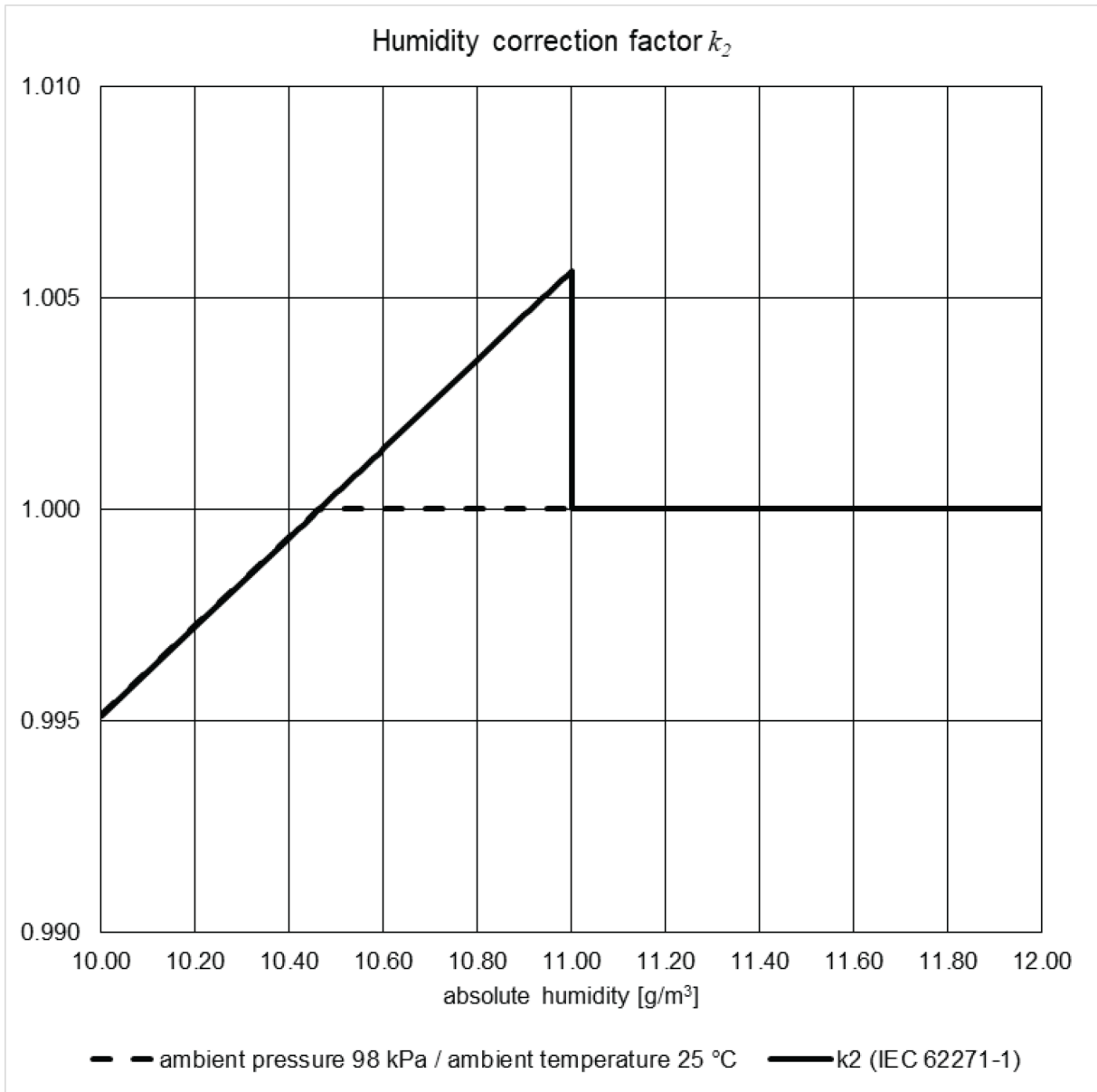


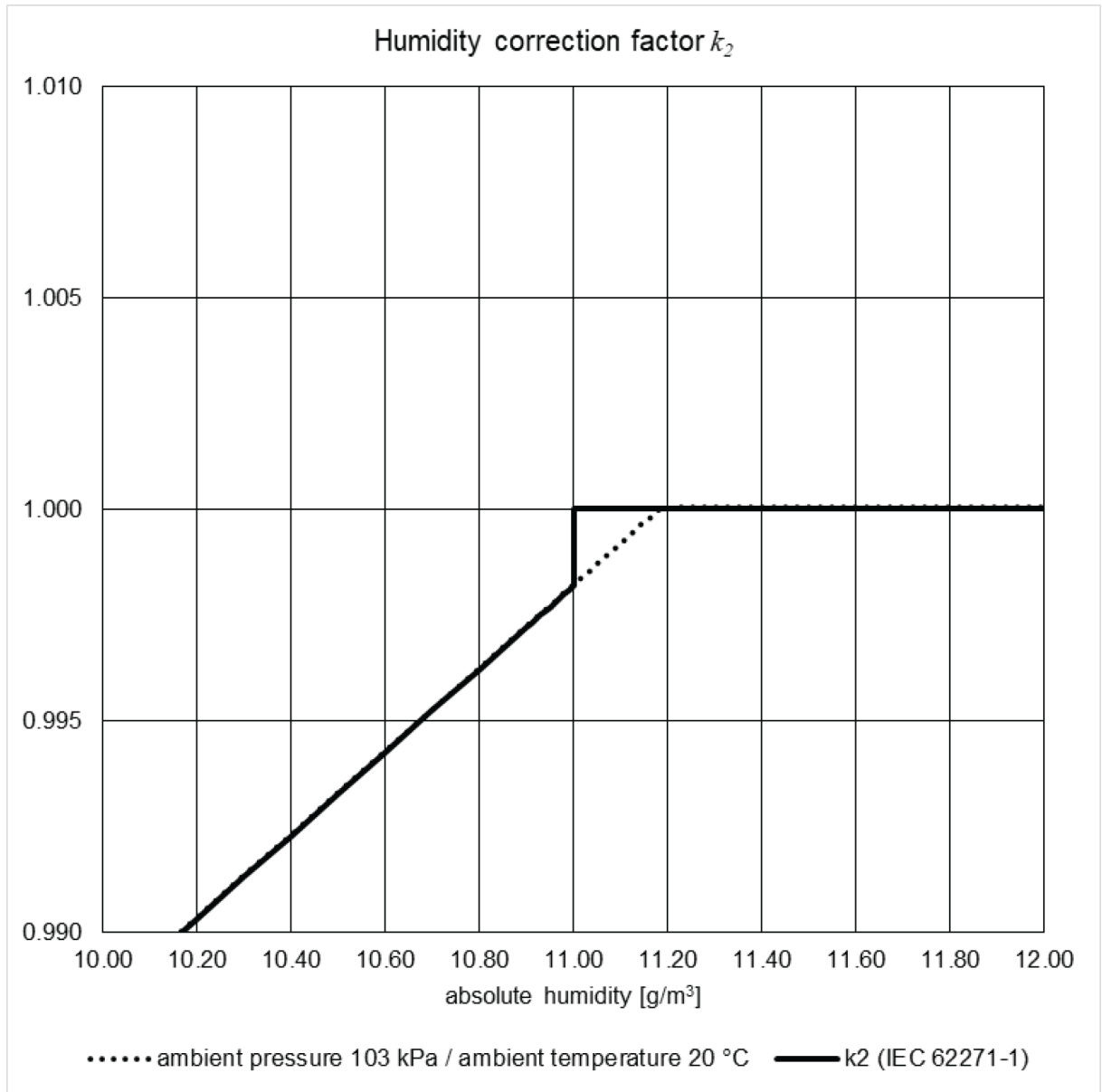
Figure P.1 – Humidity exponent w

Figure P.2 and Figure P.3 show the respective humidity correction factors for the same ambient air conditions as in Figure P.1 and – as comparison – calculated according to IEC 62271-1, where an unnatural discontinuous behaviour appears at a humidity of 11 g/m^3 .



IEC

Figure P.2 – Humidity correction factor k_2 (example 1)



IEC

Figure P.3 – Humidity correction factor k_2 (example 2)

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