



BSI Standards Publication

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

National foreword

This Published Document is the UK implementation of IEC/TR 62271-306:2012+A1:2018.

The UK participation in its preparation was entrusted to Technical Committee PEL/17, High voltage switchgear, controlgear and assemblies.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© The British Standards Institution 2018
Published by BSI Standards Limited 2018

ISBN 978 0 580 75297 1

ICS 29.130.10

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 30 September 2018.

Amendments/corrigenda issued since publication

Date	Text affected
------	---------------



TECHNICAL REPORT



**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**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.130.10

ISBN 978-2-83220-558-7

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

FOREWORD.....	14
INTRODUCTION to the Amendment.....	16
1 General.....	17
1.1 Scope.....	17
1.2 Normative references.....	17
2 Evolution of IEC standards for high-voltage circuit-breaker.....	18
3 Classification of circuit-breakers.....	22
3.1 General.....	22
3.2 Electrical endurance class E1 and E2.....	22
3.3 Capacitive current switching class C1 and C2.....	23
3.4 Mechanical endurance class M1 and M2.....	23
3.5 Class S1 and S2.....	24
3.6 Conclusion.....	24
4 Insulation levels and dielectric tests.....	25
4.1 General.....	25
4.2 Longitudinal voltage stresses.....	29
4.3 High-voltage tests.....	29
4.4 Impulse voltage withstand test procedures.....	30
4.5 Correction factors.....	38
4.6 Background information about insulation levels and tests.....	42
4.7 Lightning impulse withstand considerations of vacuum interrupters.....	45
5 Rated normal current and temperature rise.....	46
5.1 General.....	46
5.2 Load current carrying requirements.....	46
5.3 Temperature rise testing.....	50
5.4 Additional information.....	53
6 Transient recovery voltage.....	54
6.1 Harmonization of IEC and IEEE transient recovery voltages.....	54
6.2 Initial Transient Recovery Voltage (ITRV).....	63
6.3 Testing.....	66
6.4 General considerations regarding TRV.....	68
6.5 Calculation of TRVs.....	79
7 Short-line faults.....	81
7.1 Short-line fault requirements.....	81
7.2 SLF testing.....	86
7.3 Additional explanations on SLF.....	89
7.4 Comparison of surge impedances.....	94
7.5 Test current and line length tolerances for short-line fault testing.....	94
7.6 TRV with parallel capacitance.....	95
8 Out-of-phase switching.....	98
8.1 Reference system conditions.....	98
8.2 TRV parameters introduced into Tables 1b and 1c of the first edition of IEC 62271-100.....	100
9 Switching of capacitive currents.....	103
9.1 General.....	103

9.2	General theory of capacitive current switching	104
9.3	Capacitor bank switching.....	110
9.4	No-load cable switching.....	113
9.5	No-load transmission line switching	127
9.6	Voltage factors for capacitive current switching tests	133
9.7	General application considerations	135
9.8	Considerations of capacitive currents and recovery voltages under fault conditions	153
9.9	Explanatory notes regarding capacitive current switching tests.....	157
10	Gas tightness	159
10.1	Specification	159
10.2	Testing	160
10.3	Cumulative test method and calibration procedure for type tests on closed pressure systems	168
11	Miscellaneous provisions for breaking tests.....	172
11.1	Energy for operation to be used during demonstration of the rated operating sequence during short-circuit making and breaking tests.....	172
11.2	Alternative operating mechanisms	173
12	Rated and test frequency	178
12.1	General.....	178
12.2	Basic considerations	179
12.3	Applicability of type tests at different frequencies	180
13	Symmetrical and asymmetrical currents	183
13.1	General.....	183
13.2	Arcing time.....	183
13.3	Symmetrical currents.....	183
13.4	Asymmetrical currents	190
13.5	Double earth fault.....	196
13.6	Break time	201
14	Synthetic making and breaking tests	202
14.1	General.....	202
14.2	Current injection methods.....	203
14.3	Duplicate transformer circuit.....	206
14.4	Voltage injection methods	208
14.5	Current distortion	211
14.6	Step-by-step method to prolong arcing	226
14.7	Examples of the application of the tolerances on the last current loop based on 4.1.2 and 6.109 of IEC 62271-101:2012	227
15	Transport, storage, installation, operation and maintenance.....	228
15.1	General.....	228
15.2	Transport and storage	228
15.3	Installation	229
15.4	Commissioning.....	229
15.5	Operation.....	231
15.6	Maintenance	231
15.7	Corrosion: Information regarding service conditions and recommended test requirements.....	231
15.8	Electromagnetic compatibility on site	232

16	Inductive load switching	233
16.1	General.....	233
16.2	Shunt reactor switching	234
16.3	Motor switching	247
16.4	Unloaded transformer switching.....	251
16.5	Shunt reactor characteristics	255
16.6	System and station characteristics.....	257
16.7	Current chopping level calculation	258
16.8	Application of laboratory test results to actual shunt reactor installations	263
16.9	Statistical equations for derivation of chopping and re-ignition overvoltages	270
17	Information and technical requirements relevant for enquiries, tenders and orders	271
17.1	General.....	271
17.2	Normal and special service conditions (refer to Clause 2 of IEC 62271-1:2007)	271
17.3	Ratings and other system parameters (refer to Clause 4 IEC 62271-1:2007).....	271
17.4	Design and construction (refer to Clause 5 of IEC 62271-1:2007).....	272
17.5	Documentation for enquiries and tenders	273
Annex A (informative) Consideration of DC time constant of the rated short-circuit current in the application of high-voltage circuit-breakers.....		274
A.1	General.....	274
A.2	Basic theory	274
A.3	Network reduction	278
A.4	Special case time constants	278
A.5	Guidance for selecting a circuit-breaker	279
A.6	Discussion regarding equivalency.....	289
A.7	Current and TRV waveshape adjustments during tests	291
A.8	Conclusions	297
Annex B (informative) Interruption of currents with delayed zero crossings.....		298
B.1	General.....	298
B.2	Faults close to major generation	298
B.3	Conditions for delayed current zeros on transmission networks	314
Annex C (informative) Parallel switching.....		318
Annex D (informative) Application of current limiting reactors.....		319
D.1	General.....	319
D.2	Pole factor considerations	320
D.3	Oscillatory component calculation.....	321
D.4	Series reactors on shunt capacitor banks.....	326
Annex E (informative) Guidance for short-circuit and switching test procedures for metal-enclosed and dead tank circuit-breakers		327
E.1	General.....	327
E.2	General description of special features and possible interactions	327
Annex F (informative) Current and test-duty combination for capacitive current switching tests		330
F.1	General.....	330
F.2	Combination rules	330
F.3	Examples	331
Annex G (informative) Grading capacitors		343
G.1	Grading capacitors	343

Annex H (informative) Circuit-breakers with opening resistors	347
H.1 General.....	347
H.2 Background of necessity of overvoltage limitation	347
H.3 Basic theory on the effect of opening resistors	348
H.4 Review of TRV for circuit-breakers with opening resistors for various interrupting duties	356
H.5 Performance to be verified	364
H.6 Time sequence of main and resistor interrupters	367
H.7 Current carrying performance	368
H.8 Dielectric performance during breaking tests.....	368
H.9 Characteristics of opening resistors	368
Annex I (informative) Circuit-breaker history	370
Bibliography	372
 Figure 1 – Probability of acceptance (passing the test) for the 15/2 and 3/9 test series.....	32
Figure 2 – Probability of acceptance at 5 % probability of flashover for 15/2 and 3/9 test series.....	33
Figure 3 – User risk at 10 % probability of flashover for 15/2 and 3/9 test series	33
Figure 4 – Operating characteristic curves for 15/2 and 3/9 test series	36
Figure 5 – α risks for 15/2 and 3/9 test methods	37
Figure 6 – β risks for 15/2 and 3/9 test methods	38
Figure 7 – Ideal sampling plan for AQL of 10 %	38
Figure 8 – Disruptive discharge mode of external insulation of switchgear and controlgear having a rated voltage above 1 kV up to and including 52 kV	42
Figure 9 – Temperature curve and definitions	52
Figure 10 – Evaluation of the steady state condition for the last quarter of the test duration shown in Figure 9	52
Figure 11 – Comparison of IEEE, IEC and harmonized TRVs, example for 145 kV at 100 % I_{SC} with $k_{pp} = 1,3$	57
Figure 12 – Comparison of IEEE, IEC and harmonized TRVs with compromise values of u_1 and t_1 , example for 145 kV at 100 % I_{SC} with $k_{pp} = 1,3$	60
Figure 13 – Comparison of TRV's for cable-systems and line-systems	62
Figure 14 – Harmonization of TRVs for circuit-breakers < 100 kV	63
Figure 15 – Representation of ITRV and terminal fault TRV	65
Figure 16 – Typical graph of line side TRV with time delay and source side with ITRV.....	67
Figure 17 – Effects of capacitor size on the short-line fault component of recovery voltage with a fault 915 m from circuit-breaker.....	91
Figure 18 – Effect of capacitor location on short-line fault component of transient recovery voltage with a fault 760 m from circuit-breaker.....	92
Figure 19 – TRV obtained during a L_{g0} test duty on a 145 kV, 50 kA, 60 Hz circuit- breaker.....	93
Figure 20 – TRV vs. ωIZ as function of t/t_{dL} when $t_L/t_{dL} = 4,0$	98
Figure 21 – Typical system configuration for out-of-phase breaking for case A	99
Figure 22 – Typical system configuration for out-of-phase breaking for Case B	99
Figure 23 – Voltage on both sides during CO under out-of-phase conditions	102
Figure 24 – Fault currents during CO under out-of-phase.....	102
Figure 25 – TRVs for out-of-phase clearing (enlarged).....	102

Figure 64 – Comparison of reference and alternative mechanical characteristics	174
Figure 65 – Closing operation outside the envelope	175
Figure 66 – Mechanical characteristics during a T100s test	176
Figure 75 – General case for shunt reactor switching	234
Figure 76 – Current chopping phenomena	235
Figure 77 – General case first-pole-to-clear representation	236
Figure 78 – Single phase equivalent circuit for the first-pole-to-clear	237
Figure 79 – Voltage conditions at and after current interruption	238
Figure 80 – Shunt reactor voltage at current interruption	239
Figure 81 – Re-ignition at recovery voltage peak for a circuit with low supply side capacitance	241
Figure 82 – Field oscillogram of switching out a 500 kV 135 Mvar solidly earthed shunt reactor	242
Figure 83 – Single-phase equivalent circuit	243
Figure 84 – Motor switching equivalent circuit	248
Figure 87 – Arc characteristic	259
Figure 88 – Rizk's equivalent circuit for small current deviations from steady state	259
Figure 89 – Single phase equivalent circuit	260
Figure 90 – Circuit for calculation of arc instability	261
Figure 91 – Initial voltage versus arcing time	266
Figure 92 – Suppression peak overvoltage versus arcing time	266
Figure 93 – Calculated chopped current levels versus arcing time	266
Figure 94 – Calculated chopping numbers versus arcing time	266
Figure 95 – Linear regression for all test points	267
Figure 96 – Representation of a four-parameter TRV and a delay line	69
Figure 97 – Representation of a specified TRV by a two-parameter reference line and a delay line	70
Figure 98 – Single-phase equivalent circuit for capacitive current interruption	104
Figure 99 – Voltage and current shapes at capacitive current interruption	105
Figure 100 – Voltage and current wave shapes in the case of a restrike	106
Figure 101 – Voltage build-up by successive restrikes	107
Figure 102 – Example of an NSDD during capacitive current interruption	108
Figure 103 – Recovery voltage of the first-pole-to-clear at interruption of a three-phase non-effectively earthed capacitive load	109
Figure 104 – General circuit for capacitor bank switching	110
Figure 105 – Typical circuit for no-load cable switching	114
Figure 106 – Individually screened cable with equivalent circuit	115
Figure 107 – Belted cable with equivalent circuit	115
Figure 108 – Cross-section of a high-voltage cable	116
Figure 109 – Equivalent circuit for back-to-back cable switching	120
Figure 110 – Equivalent circuit of a compensated cable	121
Figure 111 – Currents when making at voltage maximum and full compensation	123
Figure 112 – Currents when making at voltage zero and full compensation	124
Figure 113 – Currents when making at voltage maximum and partial compensation	125

Figure 114 – Currents when making at voltage zero and partial compensation	125
Figure 115 – RMS charging current versus system voltage for different line configurations at 60 Hz	127
Figure 116 – General circuit for no-load transmission line switching	128
Figure 117 – Recovery voltage peak in the first-pole-to-clear as a function of C_1/C_0 , delayed interruption of the second phase	129
Figure 118 – Typical current and voltage relations for a compensated line	131
Figure 119 – Half cycle of recovery voltage	131
Figure 120 – Energisation of no-load lines: basic phenomena	132
Figure 121 – Recovery voltage on first-pole-to-clear for three-phase interruption: capacitor bank with isolated neutral.....	134
Figure 122 – Example of the recovery voltage across a filter bank circuit-breaker.....	136
Figure 123 – Typical circuit for back-to-back switching.....	142
Figure 124 – Example of 123 kV system	143
Figure 125 – Voltage and current relations for capacitor switching through interposed transformer.....	147
Figure 126 – Station illustrating large transient inrush currents through circuit-breakers from parallel capacitor banks	149
Figure 127 – Fault in the vicinity of a capacitor bank.....	154
Figure 128 – Recovery voltage and current for first-phase-to-clear when the faulted phase is the second phase-to-clear	155
Figure 129 – Recovery voltage and current for last-phase-to-clear when the faulted phase is the first-phase-to-clear	155
Figure 130 – Basic circuit for shunt capacitor bank switching	156
Figure 131 – Example of a tightness coordination chart, TC, for closed pressure systems.....	161
Figure 132 – Interrupting windows and k_p value for three-phase fault in a non-effectively earthed system.....	185
Figure 133 – Three-phase unearthed fault current interruption	186
Figure 134 – Interrupting windows and k_p values for three-phase fault to earth in an effectively earthed system at 800 kV and below.....	187
Figure 135 – Interrupting windows and k_p values for three-phase fault to earth in an effectively earthed system above 800 kV.....	187
Figure 136 – Simulation of three-phase to earth fault current interruption at 50 Hz	188
Figure 137 – Case 1 with interruption by a first pole (blue phase) after minor loop of current with intermediate asymmetry	192
Figure 138 – Case 2 with interruption of a last pole-to-clear after a major extended loop of current with required asymmetry and longest arcing time.....	193
Figure 139 – Case 3 with interruption of a last pole-to-clear after a major extended loop of current with required asymmetry but not the longest arcing time	194
Figure 140 – Case 4 with interruption by the first pole in the red phase after a major loop of current with required asymmetry and the longest arcing time (for a first-pole-to-clear).....	194
Figure 141 – Representation of a system with a double earth fault.....	197
Figure 142 – Representation of circuit with double-earth fault	198
Figure 143 – Fault currents relative to the three-phase short-circuit current.....	200
Figure 144 – Principle of synthetic testing	202

Figure 145 – Typical current injection circuit with voltage circuit in parallel with the test circuit-breaker	203
Figure 146 – Injection timing for current injection scheme with the circuit given in Figure 145	204
Figure 147 – Examples of the determination of the interval of significant change of arc voltage from the oscillograms	205
Figure 148 – Transformer or Skeats circuit	206
Figure 149 – Triggered transformer or Skeats circuit	208
Figure 150 – Typical voltage injection circuit diagram with voltage circuit in parallel with the auxiliary circuit-breaker (simplified diagram)	209
Figure 151 – TRV waveshapes in a voltage injection circuit with the voltage circuit in parallel with the auxiliary circuit-breaker	210
Figure 152 – Direct test circuit, simplified diagram	212
Figure 153 – Prospective short-circuit current flow	212
Figure 154 – Distortion current flow	212
Figure 155 – Distortion current	213
Figure 156 – Simplified circuit diagram for high-current interval	214
Figure 157 – Current and arc voltage characteristics for symmetrical current and constant arc voltage	216
Figure 158 – Current and arc voltage characteristics for asymmetrical current and constant arc voltage	217
Figure 159 – Reduction of amplitude and duration of final current loop of arcing for symmetrical current and constant arc voltage	218
Figure 160 – Reduction of amplitude and duration of final current loop of arcing for symmetrical current and linearly rising arc voltage	219
Figure 161 – Reduction of amplitude and duration of final current loop of arcing for asymmetrical current and constant arc voltage	220
Figure 162 – Reduction of amplitude and duration of final current loop of arcing for asymmetrical current and linearly rising arc voltage	221
Figure 163 – Typical re-ignition circuit diagram for prolonging arc-duration	226
Figure 164 – Typical waveshapes obtained during a symmetrical test using the circuit in Figure 163	227
Figure 165 – Unloaded transformer switching circuit representation	252
Figure 166 – Transformer side oscillation (left) and circuit-breaker transient recovery voltage (right)	252
Figure 167 – Re-ignition loop circuit	254
Figure A.1 – Simplified single-phase circuit	275
Figure A.2 – Percentage DC component in relation to the time interval from the initiation of the short-circuit for the standard time constants and for the alternative special case time constants (from IEC 62271-100)	276
Figure A.3 – First valid operation in case of three-phase test ($\tau = 45$ ms) on a circuit-breaker exhibiting a very short minimum arcing time	286
Figure A.4 – Second valid operation in case of three-phase test on a circuit-breaker exhibiting a very short minimum arcing time	286
Figure A.5 – Third valid operation in case of three-phase test on a circuit-breaker exhibiting a very short minimum arcing time	287
Figure A.6 – Plot of 60 Hz currents with indicated DC time constants	290
Figure A.7 – Plot of 50 Hz currents with indicated DC time constants	290

Figure A.8 – Three-phase testing of a circuit-breaker with a DC time constant of the rated short-circuit breaking current longer than the test circuit time constant	293
Figure A.9 – Single phase testing of a circuit-breaker with a DC time constant of the rated short-circuit breaking current shorter than the test circuit time constant.....	295
Figure A.10 – Single-phase testing of a circuit-breaker with a DC time constant of the rated short-circuit breaking current longer than the test circuit time constant.....	297
Figure B.1 – Single-line diagram of a power plant substation	299
Figure B.2 – Performance chart (power characteristic) of a large generator.....	300
Figure B.3 – Circuit-breaker currents i and arc voltages u_{arc} in case of a three-phase fault following underexcited operation: non-simultaneous fault inception	300
Figure B.4 – Circuit-breaker currents i and arc voltages u_{arc} in case of a three-phase fault following underexcited operation: Simultaneous fault inception at third phase voltage zero.....	301
Figure B.5 – Circuit-breaker currents i and arc voltages u_{arc} in case of a three-phase fault following underexcited operation: Simultaneous fault inception at third phase voltage crest.....	301
Figure B.6 – Circuit-breaker currents i and arc voltages u_{arc} under conditions of a non-simultaneous three-phase fault, underexcited operation and failure of a generator transformer	302
Figure B.7 – Circuit-breaker currents i and arc voltages u_{arc} under conditions of a non-simultaneous three-phase fault following full load operation.....	303
Figure B.8 – Circuit-breaker currents i and arc voltages u_{arc} under conditions of a non-simultaneous three-phase fault following no-load operation.....	304
Figure B.9 – Circuit-breaker currents i and arc voltages u_{arc} under conditions of unsynchronized closing with 90° differential angle	305
Figure B.10 – Comparison of TRV test curve for out-of-phase (red) and system-source short-circuit (green)	306
Figure B.11 – Prospective (inherent) current.....	307
Figure B.12 – Arc voltage-current characteristic for a SF ₆ puffer type interrupter	308
Figure B.13 – Assessment function $e(t)$	308
Figure B.14 – Network with contribution from generation and large motor load	309
Figure B.15 – Computer simulation of a three-phase simultaneous fault with contribution from generation and large motor load	310
Figure B.16 – Short-circuit at voltage zero of phase A (maximum DC component in phase A) with transition from three-phase to two-phase fault	311
Figure B.17 – Short-circuit at voltage crest of phase B (phase B totally symmetrical) and transition from three-phase to two-phase fault.....	312
Figure B.18 – Comparison of current zero crossing with (green) and without (blue) influence of arc voltage.....	313
Figure B.19 – Recording of delayed current zero on A and B phase in the presence of a line-to-earth fault on C phase	315
Figure B.20 – Influence of arc voltage of SF ₆ vs. air-blast circuit-breaker.....	316
Figure B.21 – Earthing of the shunt reactor using a 100 Ω resistor for 200 ms insertion time.....	317
Figure D.1 – Current limiting reactor location.....	319
Figure D.2 – Circuit for k_{pp} calculation	320
Figure D.3 – Variation of k_{pp} with ratio X_{R}/X_1	321
Figure D.4 – Oscillatory circuit for the circuit arrangement of Figure D.1(a)	321
Figure D.5 – Oscillatory circuit for the circuit arrangement of Figure D.1(b)	322

Figure D.6 – Series reactor application case.....	323
Figure D.7 – TRV calculation circuit	324
Figure D.8 – Circuit-breaker with T30 source and varying values of C_R	324
Figure D.9 – Circuit-breaker TRV with source TRV $k_{af} = 1,4$ p.u. (down from 1,54 p.u.) and t_3 unchanged at 80 μs	325
Figure D.10 – Circuit-breaker TRV with source TRV k_{af} unchanged at 1,54 p.u. and t_3 increased to 110 μs	325
Figure D.11 – Circuit-breaker TRV with source TRV $k_{af} = 1,4$ p.u. and $t_3 = 110 \mu s$	326
Figure F.1 – Test-duty 2 combination for Case 1	332
Figure F.2 – TD1 combination for case a)	333
Figure F.3 – TD1 combination for case b)	333
Figure F.4 – TD1/TD2 combination for Case 1	334
Figure F.5 – TD2 combination for Case 2	337
Figure F.6 – TD1 combination	338
Figure F.7 – TD1/TD2 combination for Case 2	338
Figure F.8 – TD2 combination for Case 3	341
Figure F.9 – TD1 combination for Case 3	341
Figure G.1 – Equivalent circuit of a grading capacitor	343
Figure G.2 – Equivalent circuit for determination of $\tan \delta$, power factor and quality factor	344
Figure G.3 – Vector diagram of capacitor impedances	344
Figure H.1 – Typical system configuration for breaking with opening resistors	347
Figure H.2 – Circuit diagram used for the RLC method, ramp current injection	348
Figure H.3 – Relationship between TRV peak and critical damping	349
Figure H.4 – Approximation by superimposed ramp elements	350
Figure H.5 – Results of calculations done with RLC method	352
Figure H.6 – Example of a calculation of the TRV across the main interrupter for T100 using 700 Ω opening resistors	354
Figure H.7 – Example of a calculation of the TRV across the main interrupter for T10 using 700 Ω opening resistors	355
Figure H.8 – Typical TRV waveshapes in the time domain using the Laplace transform	355
Figure H.9 – TRV plots for resistor interrupter for a circuit-breaker with opening resistor in the case of terminal faults	357
Figure H.10 – Typical waveforms for out-of-phase interruption – Network 1 without opening resistor	358
Figure H.11 – Typical waveforms for out-of-phase interruption – Network 1 with opening resistor (700 Ω)	359
Figure H.12 – Typical waveforms for out-of-phase interruption – Network 2 without opening resistor	360
Figure H.13 – Typical waveforms for out-of-phase interruption – Network 2 with opening resistor (700 Ω)	361
Figure H.14 – Typical recovery voltage waveshape of capacitive current switching on a circuit-breaker equipped with opening resistors	363
Figure H.15 – Recovery voltage waveforms across the resistor interrupter during capacitive current switching by a circuit-breaker with opening resistors	364
Figure H.16 – Timing sequence of a circuit-breaker with opening resistor	365
Figure H.17 – Voltage waveshapes for line-charging current breaking operations	366

Figure I.1 – Manufacturing timelines of different circuit-breaker types	371
---	-----

Table 1 – Classes and shapes of stressing voltages and overvoltages (from IEC 60071-1:2006, Table 1)	28
Table 2 – 15/2 and 3/9 test series attributes	31
Table 3 – Summary of theoretical analysis.....	37
Table 4 – Values for m for the different voltage waveshapes	39
Table 5 – Maximum ambient temperature versus altitude (IEC 60943).....	50
Table 6 – Some examples of the application of acceptance criteria for steady state conditions	51
Table 7 – Ratios of I_a/I_r for various ambient temperatures based on Table 3 of IEC 62271-1:2007	53
Table 8 – Summary of recommended changes to harmonize IEC and IEEE TRV requirements	58
Table 9 – Recommended u_1 values	58
Table 10 – Standard values of initial transient recovery voltage – Rated voltages 100 kV and above	66
Table 11 – Comparison of typical values of surge impedances for a single-phase fault (or third pole to clear a three-phase fault) and the first pole to clear a three-phase fault	94
Table 16 – Results of the calibration of the enclosure	171
Table 17 – Temperature rise tests	181
Table 18 – Short-time withstand current tests	181
Table 19 – Peak withstand current tests	181
Table 20 – Short-circuit making current tests	181
Table 21 – Terminal faults: symmetrical test duties	182
Table 22 – Terminal faults: asymmetrical test duties	182
Table 23 – Short-line faults	182
Table 24 – Capacitive current switching	182
Table 29 – Circuit-breaker chopping numbers.....	240
Table 30 – Chopping and re-ignition overvoltage limitation method evaluation for shunt reactor switching	244
Table 31 – Re-ignition overvoltage limitation method evaluation for motor switching	249
Table 32 – Typical shunt reactor electrical characteristics.....	256
Table 33 – Connection characteristics for shunt reactor installations	257
Table 34 – Capacitance values of various station equipment.....	258
Table 35 – Laboratory test parameters	265
Table 36 – 500 kV circuit-breaker TRVs	269
Table 37 – 1 000 kV circuit-breaker transient recovery voltages	269
Table 38 – 500 kV circuit-breaker: maximum re-ignition overvoltage values.....	269
Table 39 – First-pole-to-clear factors k_{pp}	72
Table 40 – Pole-to-clear factors for each clearing pole.....	73
Table 41 – Pole-to-clear factors for other types of faults in non-effectively earthed neutral systems	74
Table 42 – Actual percentage short-line fault breaking currents	95
Table 43 – Voltage factors for single-phase capacitive current switching tests.....	133
Table 44 – Inrush current and frequency for switching capacitor banks	140

Table 45 – Typical values of inductance between capacitor banks	141
Table 46 – Sensitivity and applicability of different leak-detection methods for tightness tests	162
Table 47 – Results of a calibration procedure prior to a low temperature test	167
Table 48 – Example of comparison of rated values against application ($U_r = 420$ kV)	190
Table A.1 – X/R values	277
Table A.2 – I_{peak} values	277
Table A.3 – Comparison of last major current loop parameters for the first-pole-to-clear, case 1	281
Table A.4 – Comparison of last major current loop parameters for the first-pole-to-clear, case 1: test parameters used for the reference case set at the minimum permissible values	282
Table A.5 – Comparison of last major current loop parameters of the first-pole-to-clear, case 2	284
Table A.6 – Comparison of last major current loop parameters for the first-pole-to-clear, case 2: test parameters used for the reference case set at the minimum permissible values	285
Table A.7 – 60 Hz comparison between the integral method and the " $I \times t$ " product method	288
Table A.8 – 50 Hz comparison between the integral method and the " $I \times t$ " product method	288
Table A.9 – Example showing the test parameters obtained during a three-phase test when the DC time constant of the test circuit is shorter than the DC time constant of the rated short-circuit current	292
Table A.10 – Example showing the test parameters obtained during a single-phase test when the DC time constant of the test circuit is longer than the DC time constant of the rated short-circuit current	294
Table A.11 – Example showing the test parameters obtained during a single-phase test when the DC time constant of the test circuit is shorter than the DC time constant of the rated short-circuit current	296
Table F.1 – Summary of required test-duties for covering the capacitive current switching without any test-duty combination	331
Table F.2 – Case where TD2 covers LC2, CC2 and BC2	332
Table F.3 – Combination values for the case where TD2 covers only CC2 and BC2	332
Table F.4 – Combination values for case a): the combined TD1 covers CC1 and BC1	333
Table F.5 – Combination values for case b): the combined TD1 covers LC1 and CC1	334
Table F.6 – Combination values for a TD2 covering LC2, CC1 and BC1	334
Table F.7 – Summary of the possible test-duty combination for a 145 kV circuit-breaker, tested single-pole according to class C2	335
Table F.8 – Neutral connection prescriptions for three-phase capacitive tests	336
Table F.9 – Summary of required test-duties for covering the capacitive current switching without any test duty combination	336
Table F.10 – Combination values for a TD2 covering LC2, CC2 and BC2	337
Table F.11 – Values for the additional TD2 for covering only BC2	337
Table F.12 – Values for the three a TD1 that shall be performed since no combination is possible	338
Table F.13 – Combination values for a TD2 covering LC2, CC2 and BC1	339
Table F.14 – Summary of the possible test-duty combination for a 36 kV circuit-breaker tested under three-phase conditions according to class C2	339

Table F.15 – Summary of required test-duties for covering the capacitive current switching without any test-duty combination	340
Table F.16 – Combination values for a TD2 covering LC2, CC2 and BC2	341
Table F.17 – Combination values for a TD1 covering LC1, CC1 and BC1	342
Table F.18 – Summary of the possible test-duty combination for a 245 kV circuit-breaker, tested single-phase according to class C1	342
Table H.1 – Summary of TRV between main and resistor interrupters after out-of-phase interruption with/without opening resistor	361
Table H.2 – TRV on main interrupter with opening resistor for T100, T60, T30, T10, OP and SLF $U_r = 1\,100\text{ kV}$, $I_{SC} = 50\text{ kA}$, $R = 700\ \Omega$	362
Table H.3 – TRV on resistor interrupter for T100s, T60, T30, T10, OP2 and SLF with opening resistor of $700\ \Omega$	362
Table H.4 – Example of calculated values on main and resistor interrupter	369

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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****FOREWORD**

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publication(s)”). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC 62271-306, which is a technical report, has been prepared by subcommittee 17A: High-voltage switchgear and controlgear, of IEC technical committee 17: Switchgear and controlgear.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

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 document follows the structure of IEC 62271-1 and IEC 62271-100. The topics addressed appear in the order they appear in IEC 62271-1 and IEC 62271-100.

The committee has decided that the contents of the base publication and its amendment will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

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

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION to the Amendment

At the SC 17A meeting held in Delft (NL) in 2013, the decision was made form a new maintenance team (MT 57) with the task to amend/revise IEC 62271-306. The objective was to update the publication to amendment 2 of IEC 62271-100. Together with MT 34 (IEC 62271-1), MT 36 (IEC 62271-100) and MT 28 (IEC 62271-101) the decision was made to move some of the informative annexes to IEC 62271-306.

This amendment includes the following significant technical changes.

- Annex G of IEC 62271-1:2007 has been included;
- Annexes E, G, H, J, L and Q of IEC 62271-1:2007 have been included;
- I.2 of IEC 62271-100:2008 + A1:2012 has been included;
- Informative parts of Annex O of IEC 62271-100:2008 have been included;
- Former Clause 14 has been added to Clause 13;
- Clause 14 now has heading "Synthetic making and breaking tests". This clause contains annexes A, B, C, D and G of IEC 62271-101;
- Clause 9 has been restructured;
- 16.4 (No-load transformer switching) has been rewritten;
- Annex B has been expanded to include information about fully compensated transmission lines and cables;
- Annex D has been rewritten.

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

1 General

1.1 Scope

This part of IEC 62271 is applicable to a.c. circuit-breakers designed for indoor or outdoor installation and for operation at frequencies of 50 Hz and 60 Hz on systems having voltages above 1 000 V.

NOTE While this technical report mainly addresses circuit-breakers, some clauses (e.g. Clause 5) apply to switchgear and controlgear.

This technical report addresses utility, consultant and industrial engineers who specify and apply high-voltage circuit-breakers, circuit-breaker development engineers, engineers in testing stations, and engineers who participate in standardization. It is intended to provide background information concerning the facts and figures in the standards and provide a basis for specification for high-voltage circuit-breakers. Thus, its scope will cover the explanation, interpretation and application of IEC 62271-100 and IEC 62271-1 as well as related standards and technical reports with respect to high-voltage circuit-breakers.

Rules for circuit-breakers with intentional non-simultaneity between the poles are covered by IEC 62271-302.

This technical report does not cover circuit-breakers intended for use on motive power units of electrical traction equipment; these are covered by the IEC 60077 series.

Generator circuit-breakers installed between generator and step-up transformer are not within the scope of this technical report.

This technical report does not cover self-tripping circuit-breakers with mechanical tripping devices or devices which cannot be made inoperative.

Disconnecting circuit-breakers are covered by IEC 62271-108.

By-pass switches in parallel with line series capacitors and their protective equipment are not within the scope of this technical report. These are covered by IEC 62271-109 and IEC 60143-2.

In addition, special applications (among others parallel switching, delayed current zero crossings) are treated in annexes to this document.

1.2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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