PD IEC/TR 62271-306:2012+A1:2018

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

Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

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

Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

IEC/TR 62271-306

Edition 1.0 2012-12

TECHNICAL REPORT

colour inside

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.

® Registered trademark of the International Electrotechnical Commission

Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

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

AVA Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

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

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62271-306:2012+A1:2018

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

AVA Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

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_{90} 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

AVA Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

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

AVA Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

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

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62271-306:2012+A1:2018

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 (τ = 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

AVA Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

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

AVA Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

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 µs 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 tanδ, 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

AVA Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

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

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62271-306:2012+A1:2018

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

AVA Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

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 kV, I_{sc} = 50 kA, R = 700 Ω 362
Table H.3 – TRV on resistor interrupter for T100s, T60, T30, T10, OP2 and SLF with opening resistor of 700 Ω 362
Table H.4 – Example of calculated values on main and resistor interrupter 369

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62271-306:2012+A1:2018

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.

AVA Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

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.

Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

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.

Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

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*

Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

IEC 60071-1:2006, *Insulation co-ordination – Part 1: Definitions, principles and rules*

IEC 60071-2:1996, *Insulation co-ordination – Part 2: Application guide*

IEC 60376, *Specification of technical grade sulfur hexafluoride (SF_6) for use in electrical equipment*

IEC 60480, *Guidelines for the checking and treatment of sulfur hexafluoride (SF_6) taken from electrical equipment and specification for its re-use*

IEC 62146-1, *Grading capacitors for high-voltage alternating current circuit-breakers*[1]

IEC 62271-1:2007, *High-voltage switchgear and controlgear – Part 1: Common specifications*

IEC 62271-4, *High-voltage switchgear and controlgear – Part 4: Handling procedures for sulphur Hexafluoride (SF_6)* [2]

A1 IEC 62271-100:2008, *High-voltage switchgear and controlgear – Part 100: Alternating-current circuit-breakers*
Amendment 1:2012
Amendment 2:2017 A1

A1 IEC 62271-101:2012, *High-voltage switchgear and controlgear – Part 101: Synthetic testing* A1

IEC 62271-102:2001, *High-voltage switchgear and controlgear – Part 102: Alternating current dosconnectors and earthing switches*

A1 IEC 62271-110:2012, *High-voltage switchgear and controlgear – Part 110: Inductive load switching* A1

IEC 62271-310, *High-voltage switchgear and controlgear – Part 310: Electrical endurance testing for circuit-breakers above a rated voltage of 52 kV*

2 Evolution of IEC standards for high-voltage circuit-breaker

Questions arise frequently concerning the basis and interpretation of standards IEC 62271-100 and IEC 62271-1. In most cases, these questions were due to a lack of background knowledge of the values and requirements laid down in these standards.

A selected number of reference textbooks is listed in the Bibliography. It must be remembered that the technology of high-voltage circuit-breakers is continuously progressing and will continue to do so in the future. Therefore, it is advisable to use such textbooks primarily as a source of information on network behaviour, such as switching conditions, transients, etc., and not for switchgear design.

As the installation of standard equipment in general is more economical than special designs, the application guide will help the utility and industrial engineers in the selection of the appropriate ratings to conform to their needs and specifications. It will enable them to judge which rating is necessary when specifying their circuit-breakers. This should take into account that in future high-voltage networks which will be worked harder and closer to their limits and that high-voltage circuit-breakers of present day technology are designed and procured for a lifetime of several decades. It is recognised that certain conditions may necessitate

[1] To be published.

[2] To be published.

Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

requirements which are outside the circuit-breaker standards. In such cases, the technical report will help to specify the various ratings or possible additional testing to verify the suitability of the circuit-breaker for a specific application or condition.

Standards should be written fit for purpose, i.e. they should reflect general system requirements to ensure that the installed equipment works properly. Although it is recognised that not 100 % of all conditions occurring in service can be covered, long term experience with high-voltage switchgear standards shows that system conditions are generally covered adequately. Nevertheless, the feedback from service and new developments in equipment and networks must be taken into account in their revision, making standardization an ongoing process. This technical report will be a forum to provide the necessary information concerning the background of changes in the standards.

Technical specification aspects are not generally considered in standards. However, this application guide will address such aspects where appropriate.

As high-voltage transmission and distribution systems and high-voltage circuit-breakers developed it was found necessary to provide standards for circuit-breakers, first on national basis. For example, already in 1923 the first edition of the British Standard B.S.S. No. 116 for circuit-breakers was issued.

In the late 1920s it was recognized that an international agreement should be obtained for a specification for high-voltage circuit-breakers, particularly with respect to their behaviour under short-circuit condition. This lead to the establishment of the "IEC Advisory Committee No. 17" which met for the first time in Stockholm in 1930 and drafted some preliminary recommendations on the international standardization of circuit-breakers.

After a series of specially convened meetings the first IEC Specification No. 56 for Alternating-Current Circuit-Breakers, Chapter I, Rules for Short-Circuit Conditions, was issued in the summer of 1937, with international approval and recognition as a basis upon which to establish national specifications. The first edition of IEC 56 was bilingual and consisted of 55 pages.

Also at that time, already, the need was seen to have Certificates of Ratings issued by approved Testing Authorities to confirm the compliance with Standard Specifications.

The second world war interrupted the further work on the IEC circuit-breaker standards. In 1954 the second edition was published which used and continued the concept of the first edition. It was intended that the IEC Specification No. 56 should ultimately incorporate five chapters which were to be discussed in the following order:

Chapter I	Rules for short-circuit conditions.
	First edition of Publication 56 to be revised and enlarged in a second edition.
Chapter II	Rules for normal-load conditions.
	Part 1 – Rules for temperature-rise.
	Part 2 – Rules for operating conditions.
Chapter III	Rules for strength of Insulation.
Chapter IV	Rules for the selection of circuit-breakers for service.
Chapter V	Rules for the maintenance of circuit-breakers in service.

Actually, the second edition, as the first one, did not progress beyond Chapter I. It was bilingual and had a total of 77 pages. According to its scope it covered a.c. circuit-breakers of 1 000 V and above.

Some major features were:

Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

– the breaking capacity was expressed in MVA by 2 values, one for a symmetrical and the other for an asymmetrical breaking current;

– the TRV, defined as "restriking voltage", was of single frequency. The amplitude factor or crest value and the TRV frequency or rate-of-rise were not specified but to be evaluated in the tests;

– the first-pole-to-clear factor in general was 1,5. However, in a note allowance was made to use 1,3 for circuit-breakers for earthed systems;

– 50 Hz and 60 Hz were no problem, as for making and breaking tests the tolerance of the frequency was ±25 %;

– the short-circuit current breaking tests consisted of test-duties 1 to 5 with 10 %, 30 %, 60 % and 100 % of the rated symmetrical and the rated asymmetrical breaking current.

Edition 3 was issued in 1971 with a new structure. It applied to high-voltage a.c. circuit-breakers rated above 1 000 V and had six parts which were published as separate booklets:

Publication 56-1:	Part 1: General and definitions.
Publication 56-2:	Part 2: Rating.
Publication 56-3:	Part 3: Design and construction.
Publication 56-4:	Part 4: Type tests and routine tests.
Publication 56-5:	Part 5: Rules for the selection of circuit-breakers for service.
Publication 56-6:	Part 6: Information to be given with enquiries, tenders and orders and rules for transport, erection and maintenance.

IEC 56 consisted of 294 pages when it was issued, but over the years a large number of amendments was added. Out-of-phase was covered by its own publication, IEC 267.

The third edition was the first comprehensive IEC Standard on high-voltage circuit-breakers meeting the originally intended goals. It included, also, the general requirements which are now compiled in IEC 62271-1.

Compared to the second edition a large number of changes were introduced:

– for the first time mechanical tests, tests on insulation properties, tests on auxiliary and control circuits, temperature rise tests, etc., were specified;

– the R 10 series is used for rated normal and breaking currents;

– the TRV (first time to use this term) representation by two or four parameters and the definitions as used up to today are installed;

– for rated voltages up to 100 kV the first-pole to clear factor is 1,5, for 123 kV and above it is alternatively 1,3 or 1,5;

– the supply side rate-of-rise of TRV for 123 kV and above for terminal fault is 1,0 kV/μs for TD 4, 2,0 kV/μs for TD 3 and 5,0 kV/μs for TD 2;

– the short-line fault is introduced. The specified surge impedance is 480 Ω for lines with 1 conductor/phase (52 – 245 kV < 40 kA), 375 Ω for 2 conductors/phase and 330 Ω for 3 or 4 conductors per phase. The line side peak factor is 1,7, 1,6, or 1,5, respectively. The source side rate-of-rise is 0,67 kV/μs;

– test for capacitive current switching (line and cable charging, single capacitors) are prescribed;

– not only type tests, but also routine test procedures are defined.

Edition 4 of IEC 56, published 1987, followed the scheme of the 3rd edition. However, to avoid a duplication of requirements in the various standards for high-voltage switching equipment, IEC 56 was reduced to those requirements that were specific for high-voltage a.c. circuit-breakers. The "common clauses for high-voltage switchgear and controlgear" was published as a separate standard in 1980 with reference number IEC 694.

AVA Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

Edition 4 of IEC 60056 consisted of one book of 329 pages. To conform with actual service conditions some major changes were incorporated:

– as all systems rated 245 kV and higher are effectively earthed only a first-pole-to-clear factor 1,3 is specified for these voltage levels. For 100 kV to 170 kV alternatives 1,3 and 1,5 are specified;
– based on a large number of network investigations the supply side rate-of-rise of TRV is increased to 2,0 kV/μs for 100 %, 3,0 kV/μs for 60 % and 5,0 kV/μs for 30 % rated breaking current;
– to take into account the clashing of the conductors of a line phase due to the forces of the short-circuit current, which makes it similar to a single conductor, a uniform surge impedance of 450 Ω is specified for all short-line fault tests. The line side peak value is 1,6, the supply side rate-of-rise 2,0 kV/μs;
– the initial Transient Recovery Voltage (ITRV) is introduced for rated voltages of and above 100 kV;
– out-of-phase specifications are included;
– to prove that capacitive current breaking is performed without restrikes the number of tests per duty is increased;
– also, the number of operations during mechanical type tests is increased from 1 000 to 2 000.

And still, IEC 60056 continued to grow. The 4th edition was revised, resulting in the first edition of IEC 62271-100 published in 2001. The first edition of IEC 62271-100 had 575 pages. The structure of the document was retained but its content was revised taking into account service experience and requirements by the utilities:

– classifications of circuit-breaker are introduced with respect to mechanical and (for medium voltage) electrical endurance and restrike behaviour when switching capacitive loads;
– more severe test conditions are prescribed for circuit-breakers to prove a very low probability of restrikes in capacitive current switching;
– for type tests the number of test specimen is limited;
– some test procedures are prescribed in more detail;
– critical current tests and single-phase and double-earth fault tests are treated in particular;
– tolerances are given on practically all test quantities during type tests;
– special cases time constants, longer than 45 ms, are specified for the different levels of rated voltages.

The first edition of IEC 62271-100 was revised and the second edition was published in 2008. The following major changes were made:

– the introduction of harmonised (IEC and IEEE) TRV waveshapes for rated voltages of 100 kV and above (amendment 1 to the first edition);
– the introduction of cable and line systems with their associated TRVs for rated voltages below 100 kV (amendment 2 to the first edition);
– the inclusion of IEC 61633 (Guide for short-circuit and switching tests procedures for metal enclosed and dead tank circuit-breakers) and IEC 62271-308 (Guide for asymmetrical short-circuit breaking test duty T100a).

IEC 60694 covered common matters for equipment falling under the responsibility of subcommittees IEC SC 17A and SC 17C, such as circuit-breakers, disconnectors and earthing switches, switches and their combinations with other equipment, gas-insulated substations, etc. Mainly, these specifications concerned normal and special service conditions, ratings and tests on dielectric withstand, normal and short-circuit current carrying auxiliary and control circuits, and common rules for design and construction. The first edition had 78 pages.

AVA Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

The experience with this standard on common specifications was very positive. Therefore, when the decision was made to revise IEC 694 this was largely to take into account items which had not been covered by standards, so far. Very little had to be changed or updated in the existing clauses of the first edition. This second edition with title "Common specifications for high-voltage switchgear and controlgear" published in 1996 with reference IEC 60694, has, among others, additional chapters which deal with safety aspects of electrical, mechanical, thermal and operational nature. This had, in particular, consequences for the rules for design and construction as well as tests which now, also, covered topics such as interlocking, position indication, degree of protection by enclosures and tightness. A new and important item that was introduced was electromagnetic compatibility (EMC). Naturally, service and test experiences which had been gathered on the basis of the first edition reflected in the revision. For example, the number of test specimen became limited, the conditions for identification of the test object became more pronounced, and the criteria to pass the test were written in a more exact manner.

The second edition of IEC 60694 was revised and published in 2007 as the first edition of IEC 62271-1.

Manufacturers, users and test laboratories recognize that the reliability of high-voltage switchgear is of crucial importance for the safety and availability of the supply of electric energy. The overall high level of reliability and performance which is common today has its roots in the very good quality of the standards for high-voltage switchgear and controlgear. They are continuously updated to reflect the actual status of the respective technologies.

3 Classification of circuit-breakers

3.1 General

IEC 62271-100 defines the following classes of circuit-breakers:

– Class E1 and E2 of electrical endurance are defined in 3.4.112 and 3.4.113 of IEC 62271-100:2008;

– Class C1 and C2 for capacitive current switching are defined in 3.4.114 and 3.4.115 of IEC 62271-100:2008;

– Class M1 and M2 of mechanical endurance are defined in 3.4.116 and 3.4.117 of IEC 62271-100:2008;

– Class S1 and S2 for specific system application are defined in 3.4.119 and 3.4.120 of IEC 62271-100:2008.

The different classes and their specific applications are discussed in detail in this subclause.

3.2 Electrical endurance class E1 and E2

Two classes are defined for circuit-breakers rated ≤ 52 kV:

– Class E1: basic electrical endurance;

– Class E2: electrical endurance covering the expected operating life of the circuit-breaker.

A circuit-breaker class E1 has a basic electrical endurance, whereas a circuit-breaker of class E2 is designed such as not to require maintenance of the interrupting parts of the main circuit during its expected operating life.

There is no mandatory requirement for electrical endurance for circuit-breakers rated > 52 kV in IEC 62271-100.

Class E2 is defined in IEC 62271-310 for circuit-breakers > 52 kV in the same way as for circuit-breakers ≤ 52 kV. This application is restricted to circuit-breakers used for overhead lines. IEC 62271-310 proposes a unified test procedure for this class E2.

AVA Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

Class E2 is intended for a low maintenance circuit-breakers used for applications where frequent fault currents are switched.

3.3 Capacitive current switching class C1 and C2

Two classes are defined:

– Class C1: low probability of restrike;

– Class C2: very low probability of restrike.

IEC 60056 contained a definition of the term "restrike-free circuit-breaker". This definition was removed when the capacitive current switching requirements and test procedures were revised. The revised requirements and test procedures were first published in the first edition of IEC 62271-100 (published in 2001). The reason why the term "restrike-free circuit-breaker" was deleted from the standard was because it did not correspond to a physical reality.

The first edition of IEC 62271-100 introduced the term "restrike probability" during the type tests, corresponding to a certain probability of restrike in service, which depends on several parameters (see 9.4.6). For this reason, the term cannot be quantified in service.

The main differences in restrike performance between class C1 and C2 type tests are the number of tests shots and the allowable number of restrikes. Class C2 tests are performed on a pre-conditioned circuit-breaker. Pre-conditioning is done performing 3 breaking operations at 60 % of the rated short-circuit current. The pre-conditioning was derived based on CIGRE statistics and is considered to create interrupter wear that is broadly representative of long term service conditions.

The choice for the user between class C1 and C2 depends on:

– the service conditions;

– the operating frequency;

– the consequences of a restrike to the circuit-breaker or to the system.

Class C1 is acceptable for medium-voltage circuit-breakers and circuit-breakers applied for infrequent switching of transmission lines and cables.

Class C2 is recommended for capacitor bank circuit-breakers and those used on frequently switched transmission lines and cables.

The above given conditions are essential when choosing the circuit-breaker for a capacitive switching application, the needed performance class and the voltage factor should be known and demonstrated by the relevant type test. It is important to note that the performance class may vary for different capacitive current switching applications. For example, a circuit-breaker used to switch an overhead line may be tested for class C1 whereas the same circuit-breaker is tested in accordance with class C2 for capacitor bank switching.

3.4 Mechanical endurance class M1 and M2

Two classes are defined:

– Class M1, normal mechanical endurance, a circuit-breaker mechanically type tested for 2 000 operations;

– Class M2, extended mechanical endurance, a circuit-breaker mechanically type tested for 10 000 operations).

As a general rule, the number of operations of high-voltage circuit-breakers switching transmission lines is relatively small, and class M1 is sufficient.

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62271-306:2012+A1:2018

For particular applications, such as frequent switching of reactors, capacitor banks, industrial applications, specification of class M2 is recommended.

It should be noted that it is always possible, in the case of a very special use (pumping station, etc.), to request a larger number of operations than that recommended for class M2.

3.5 Class S1 and S2

3.5.1 General

Two classes are defined:

– Class S1, circuit-breakers intended for use in cable systems;

– Class S2, circuit-breakers intended for use in line systems or in a cable system with direct connection (without cable) to overhead lines.

3.5.2 Cable system

A cable system is a system in which the TRV during breaking of terminal fault at 100 % of short-circuit breaking current does not exceed the two-parameter envelope derived from Table 1 of IEC 62271-100:2008.

NOTE 1 This definition is restricted to systems of rated voltages higher than 1 kV and less than 100 kV.

NOTE 2 Circuit-breakers of indoor substations with cable connection are generally in cable-systems.

NOTE 3 A circuit-breaker in an outdoor substation is considered to be in a cable-system if the total length of cable (or equivalent length when capacitors are also present) connected on the supply side of the circuit-breaker is at least 100 m. However if in an actual case with an equivalent length of cable shorter than 100 m a calculation can show that the actual TRV is covered by the envelope defined from Table 1 of IEC 62271-100:2008, then this system is considered as a cable system.

NOTE 4 The capacitance of cable-systems on the supply side of circuit-breakers is provided by cables and/or capacitors and/or insulated bus.

3.5.3 Line system

A line system is a system in which the TRV during breaking of terminal fault at 100 % of short-circuit breaking current is covered by the two-parameter envelope derived from Table 2 of IEC 62271-100:2008 and exceeds the two-parameter envelope derived from Table 1 of IEC 62271-100:2008.

NOTE 1 This definition is restricted to systems of rated voltages equal to or higher than 15 kV and less than 100 kV.

NOTE 2 In line-systems, no cable is connected on the supply side of the circuit-breaker, with the possible exception of a total length of cable less than 100 m between the circuit-breaker and the supply transformer(s).

NOTE 3 Systems with overhead lines directly connected to a busbar (without intervening cable connections) are typical examples of line-systems.

3.6 Conclusion

A circuit-breaker is defined by its complete rating, i.e. the basic short-circuit rating and, for example, with or without out-of-phase switching, with or without overhead line capacitive current switching as well as by the endurance classification such as E1, M2, etc.

It is the technical and economic responsibility of the user to select the type of circuit-breaker and its endurance classes according to:

– the technical needs, derived from the point of application and the proposed usage on the user's system;

– the management of the user's circuit-breaker population;

Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

– the user's maintenance policy, which is increasingly linked to the system availability and life cycle costs;

– the cost of the circuit-breakers, with preference for the purchase of standard circuit-breakers.

4 Insulation levels and dielectric tests

4.1 General

Insulation co-ordination is defined as follows (see 3.1 of IEC 60071-1:2006).

insulation co-ordination
selection of the dielectric strength of equipment in relation to the operating voltages and overvoltages which can appear on the system for which the equipment is intended and taking into account the service environment and the characteristics of the available preventing and protective devices

[SOURCE: IEC 60050-604:1987, 604-03-08, modified]

Dealing with insulation co-ordination, it should be kept in mind the difference between "voltage surges" stressing the insulation in service, and "voltage impulses" used in conventional tests.

TC 28 has classified the different types of overvoltages that can appear in the system and related those to a standardized test voltage. This relationship is given in Table 1 of IEC 60071-1:2006 and is repeated here for convenience (see Table 1).

The current insulating levels for switchgear and controlgear were prepared in 1971 by a joint working group with experts from CIGRE Study Committee A3 and from IEC Subcommittee 17A, when longitudinal and phase-to-phase insulations were not dealt with by the edition of IEC 60071-1 valid at that date. It was considered that the longitudinal insulation might have two very different purposes:

– the working function, that is the separation of two parts of a network;

– the isolating function, to ensure that no voltage is applied on a part of the network where people might be working.

For the isolating function, it was considered that the dielectric withstand of the interrupting gap of a load switch or of a circuit-breaker was not reliable enough, due to its pollution by arc by-products. The isolating function should be provided by a device meeting the requirements of IEC 62271-102 for its expected life.

When an insulation coordination study is made in accordance with the process described in IEC 60071-1, all the electric stresses likely to occur at a given site and with a given probability are taken into account. This is done with respect to the insulation phase-to-earth, phase-to-phase and longitudinal stresses. These are classified according to their front duration whatever their origins. The influence of any voltage protective devices is also considered, see Table 1 of IEC 60071-1:2006. Note that what is called "temporary" overvoltage includes the stresses generated at various frequencies, such as harmonics. The numerous correction factors are applied to each of them to take care of:

– performance criterion: the basis on which the insulation is selected so as to reduce to an economically and operationally acceptable level the probability that the resulting voltage stresses imposed on the equipment will not cause damage to equipment insulation or affect continuity of service;

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62271-306:2012+A1:2018

– statistical distribution: it is normally accepted to disregard those overvoltages which have a probability of occurrence less than 2 %;

– inaccuracy of input;

– effect of the equipment test assembly;

– dispersion in production;

– ageing in service: if not otherwise specified, an ageing factor of 15 % is considered for internal insulation and 5 % for external insulation;

– altitude correction.

To reduce the duration and the costs of the tests, only two types of test voltage shapes are in practical use. These are the power frequency and the standard lightning impulse voltages, for equipment up to and including 245 kV (Range I), and the standard switching and standard lightning impulse voltages, for equipment above 245 kV (Range II). For voltage range I the inherent switching surge strength (in p.u.) is higher than the magnitude of the surges at that voltage. In other words, the amount of insulation that is required to satisfy the lightning impulse and power frequency tests automatically exceed the requirements for the maximum switching surges that can occur on the system. Conversion factors are given in IEC 60071-2 so that "slow-front overvoltages" in range I or short-duration overvoltages of range II be covered by the selected test voltage shapes.

In using this approach, it follows that:

– no overvoltages larger than those used to assess the insulation levels are thought likely to occur on the incoming terminal of a switching device;

– a different probability uncertainty and performance criterion can be applied depending on whether they apply to the working function or to the isolating function. By convention, it was decided that the insulation of the "isolating distance" be the closest value to the IEC 60071-1 value but with a 15 % excess over the phase-to-earth insulation;[3]

– although no power frequency tests are required by IEC 60071-1 for range II it can be agreed that product standards may add them when necessary, which is the case with switchgear and controlgear, due to their elaborated design, and because it is a convenient voltage shape for routine tests (IEC 60071-1 deals only with type tests and does not consider the safety aspects).

There are some differences between the insulation levels stated in IEC 60071-1 and those in IEC 62271-1:

– not all of the insulation levels of IEC 60071-1 are taken into IEC 62271-1. This is because the first standard is designed for every type of equipment and some of its values are not used in the latter for switchgear;

– the switching impulse withstand voltage of longitudinal insulating is lower in IEC 62271-1. It should be noted that there are only two cases where longitudinal insulation stress occurs:

  - when a line crosses another line or a busbar;
  - and the case of switchgear and controlgear.

  In the first case, it is easy and economical to use longer clearances; it is more difficult to increase the longitudinal insulation of switchgear and controlgear, and not really necessary, as explained in 4.6. In fact, the insulation levels specified in IEC 62271-1 have been used successfully for more than twenty years (for rated voltages of 800 kV or less), and IEC TC 28, responsible of IEC 60071, agreed that switchgear standards keep their values (see minutes of meeting RM 3606/TC 28).

The splitting into two voltage ranges is done mainly in consideration of neutral earthing systems: in range II, it is considered usual that the neutrals are solidly earthed. Therefore, the

[3] Nevertheless, the only safe condition to work on a network is to earth it on each side of the work site.

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62271-306:2012+A1:2018

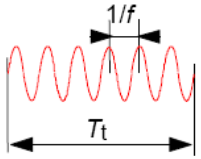
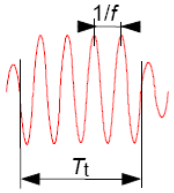
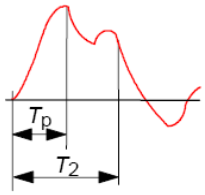
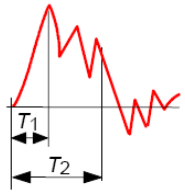
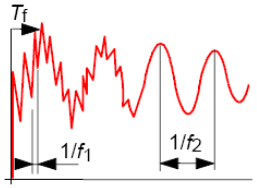
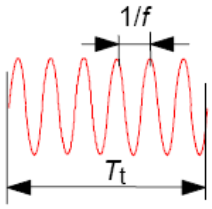
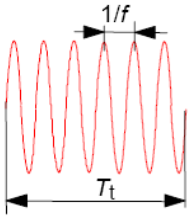
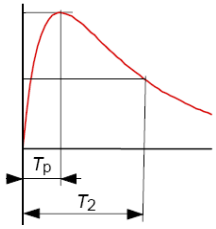
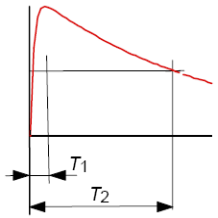
voltage stresses are lower. This explains why the same lightning withstand voltage is required for 245 kV and for 300 kV.

Background information on insulation levels and associated testing is provided in 4.6.

Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

Table 1 – Classes and shapes of stressing voltages and overvoltages (from IEC 60071-1:2006, Table 1)

Class	Low frequency		Transient		
	Continuous	Temporary	Slow-front	Fast-front	Very-fast front
Voltage or overvoltage shapes					
Range of voltage or overvoltage shapes	f = 50 Hz or 60 Hz $T_t \geq$ 3 600 s	10 Hz < f < 500 Hz 0,02 s ≤ T_t ≤ 3 600 s	20 µs < T_p ≤ 5 000 µs T_2 ≤ 20 ms	0,1 µs < T_1 ≤ 20 µs T_2 ≤ 300 µs	T_f ≤ 100 ns 0,3 MHz < f_1 < 100 MHz 30 kHz < f_2 < 300 kHz
Standard voltage shapes	 f = 50 Hz or 60 Hz T_t [a]	 48 Hz ≤ f ≤ 62 Hz T_t = 60 s	 T_p = 250 µs T_2 = 2 500 µs	 T_1 = 1,2 µs T_2 = 50 µs	[a]
Standard withstand voltage test	[a]	Short-duration power frequency test	Switching impulse test	Lightning impulse test	[a]

[a] To be specified by the relevant apparatus committees.

© IEC 2018

Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

4.2 Longitudinal voltage stresses

Normally a circuit-breaker does not have a disconnecting function, this is the duty of the disconnector.

NOTE Circuit-breakers having a disconnecting function are covered by IEC 62271-108.

For its working function, it has firstly to withstand the recovery voltage after having extinguished the arc. In the open position it may be stressed by the power frequency voltage on one terminal with the other stressed by any of the following voltages:

– the D.C voltage resulting from the trapped charge of the overhead line in the case of no-load line or capacitor bank switching;
– power frequency voltage in out-of-phase condition, in the case when busbars or generators are switched;
– a slow-front surge in the case of a switching operation at the remote end;
– a possible fast front surge in the case of a lightning stroke.

The open circuit-breaker is normally isolated by a disconnector and may be stressed only for a short period. That is normally not the case for shunt reactor, capacitor bank, filter and bus tie (busbar) circuit-breakers. For bus tie circuit-breakers the two bus voltages rarely have a large phase shift. Exposed situations where complete out-of-phase voltages will be present for minutes do exist, e.g. in the case of circuit-breakers used for synchronisation purposes, sometimes with a higher component on the generator side.

4.3 High-voltage tests

The standard dealing with high-voltage insulation tests is IEC 60060-1, but the various types and values of dielectric tests are specified in IEC 60071-1, because their statistical meaning is to be taken into account in the process of designing insulation co-ordination. It must be kept in mind that each test voltage shape is a conventional shape to evaluate the behaviour of the insulation when stressed by various voltage stresses, short duration, slow-front or fast front (see Table 1 of IEC 60071-1:2006).

Disruptive discharge voltages are subject to random variations and usually a number of observations must be made in order to obtain a statistically significant value of the withstand voltage. Ideally, the best would be to use a test procedure providing some statistical results. To do that, it is necessary to have an idea of the limit and therefore to have at least one disruptive discharge. But if the test object includes a non-self-restoring part in its insulation system, to reach the limit would mean some destructive effect. In many cases, the insulation is composed of self-restoring parts and of non-self-restoring mixed together. Therefore, several procedures are proposed, supposedly having the same severity, which means that the probability that a "good" specimen is rejected (risk of the manufacturer) is the same as a "bad specimen" being accepted (risk of the user):

– for complete self-restoring insulation (air at atmospheric pressure associated with glass or porcelain), the "up and down" procedure provides the U_{50} value, the critical disruptive level, and an estimate of the standard deviation. It is called "procedure D" in IEC 60060-1:2010;
– for clearly defined non self-restoring insulation, "procedure A" of the same standard assess an assumed withstand voltage (three shots without disruptive discharge);
– for insulation systems composed of mixed self-restoring and non-self-restoring insulation, a compromise was found with procedures B or C, where no disruptive discharges are allowed on the non-self-restoring part of the insulation. Subclause 5.3.4 of IEC 60071-2:1996 shows how procedure B and C give the same probability to pass a test at 90 % of the maximum withstand value. This is with a much better selectivity with procedure B. The question most likely to be raised in the laboratory occurs when the last (or last two) applications of the test voltage leads to disruptive discharges, and whether they are on self-restoring insulation or not. For this reason IEC 62271-1 requires 6 non-

AVA Documents
Document Sharing Hub
Full document details: PD IEC/TR 62271-306:2012+A1:2018

disruptive discharges to conclude the test. This is aimed at giving confidence that the non-self-restoring insulation is likely to be sound.

Another problem may exist when applying atmospheric correction factors for external insulation in the case that the insulation system of the switchgear and controlgear consists of internal and external insulation in parallel. Subclause 4.3.6 of IEC 60060-1:2010 gives some guidance on how to perform the tests.

The following additional concerns may exist:

– the test voltage across longitudinal insulation or phase-to-phase is higher than the test voltage phase-to-earth. Procedures for those cases are given in 6.2.5.2 of IEC 62271-1:2007;
– three-phase switchgear and controlgear in the same enclosure: test voltages are usually applied between phase and earth, across longitudinal insulation of each pole and phase to phase separately.

4.4 Impulse voltage withstand test procedures

4.4.1 General

The purpose of this subclause is to explain the basis for the several impulse voltage withstand test methods used to verify the insulation integrity of high-voltage switching devices.

In 6.2.5 of IEC 62271-1:2007 the application of the test voltage and test conditions are given. This subclause prescribes several test series, such as testing across the open switching device, to earth, and between phases, as well as tests with power frequency and impulses with positive and negative voltage polarity. Each of these test series has to be considered individually as each of them has to show that the individual insulation under test meets the particular requirements. According to the philosophy of insulation coordination these requirements are based on a flashover probability of 10 %. This should be met by each individual insulation, as well as by the whole switching device. Consequently, adding up all tests performed on the switching device is not justified and does not give any information on the withstand probability of the whole device.

4.4.2 Application to high-voltage switching devices

For impulse tests, the following two procedures are given in 6.2.4 of IEC 62271-1:2007:

– Procedure B of IEC 60060-1:2010: 15 consecutive impulses at the rated lightning or switching impulses at the rated withstand voltage for each test condition and each polarity. The test object is considered to have passed the test if the number of disruptive discharges (flashovers) on the self-restoring part of the insulation does not exceed two for each series of 15 impulses and if no disruptive discharge occurs on non-self-restoring insulation. This method is referred to as the 15/2 method;
– As an alternative, procedure C of IEC 60060-1:2010 may be applied. In this case the test consists of three consecutive impulses for each test condition and each polarity. The test has been passed if no disruptive discharge occurs. If one disruptive discharge (flashover) occurs on the self-restoring part of the insulation, then 9 additional impulses may be applied. If no disruptive discharge occurs during these additional impulses the test object is considered to have passed the test. This test procedure is referred to as the 3/9 method. The 3/9 method is accepted only when all three phases are tested.

The theory on which the test procedures are based is described in 4.4.5.

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62271-306:2012+A1:2018

4.4.3 Additional criteria to pass the tests

4.4.3.1 Procedure B

Based on the 15/2 method, IEC 62271-100 states additional criteria to pass the tests. If disruptive discharges occur during the application of 15 test impulses it shall be demonstrated that they did not occur on non-self-restoring insulation (SF_6 gas is considered self-restoring). Evidence that damage has not occurred to non-self-restoring insulation can be confirmed by five consecutive impulse withstands following the last disruptive discharge. If permissible disruptive discharges occur within the last five test impulses sufficient additional verification impulses may be applied in order to achieve five consecutive withstands. A disruptive discharge is permissible during the additional verification impulses if only one such discharge occurred during the first 15 test impulses. This procedure leads to a maximum possible number of 25 impulses per series.

4.4.3.2 Procedure C

The original test method required in ANSI/IEEE C37.09 was the so-called 3/3 method. Three test impulses are applied with the following possibilities:

– all three impulses are withstands, then the test is successful and complete;
– if one disruptive discharge occurs, then three further impulses are applied and all must be withstands for the test to be successful;
– if two disruptive discharges occur, the test is a failure.

This method was later modified to the 3/9 method which simply means a disruptive discharge in the application of the first three impulses shall be followed by 9 withstands. The tolerance on the peak voltage is $^{+3}_{0}$ % in accordance with ANSI/IEEE C37.09, whereas it is ±3 % in accordance with IEC 62271-1.

4.4.4 Review and perspective

The statistical sampling plans on which the various test methods discussed above are based are described in 4.4.5.

Subclause 6.2.4 of IEC 62271-1:2007 states that the 15/2 method is the preferred test procedure and further that procedure C of IEC 60060-1:2010 “may be used when all three poles are tested”. Neither of these statements is of the “mandatory” or “advisory” nature that one expects to find in an IEC standard and presents both the manufacturer and user with a choice to be made. The attributes of both test series are shown in Table 2 and will be discussed from two perspectives, namely, insulation coordination and quality assurance.

Table 2 – 15/2 and 3/9 test series attributes

Test series	Probability of passing the test (%)	Risk (%)	
		Manufacturer (α)	User (β)
15/2	76	4,9	29,2
3/9	82	4,6	53,6
NOTE The values in column 2 are based on a flashover probability of 10 %.			

The principles and practices of insulation coordination are described in IEC 60071-1 and IEC 60071-2. In the context of insulation coordination, withstand voltage is defined as the voltage at which there is a 10 % probability of flashover. Figure 1 is derived from the operating characteristics of the two test series shown in Figure 4. The 15/2 test series has a

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62271-306:2012+A1:2018

76 % probability of passing the test which compares favourably to the 82 % probability for the 3/9 test series. The former test series is thus the more onerous.

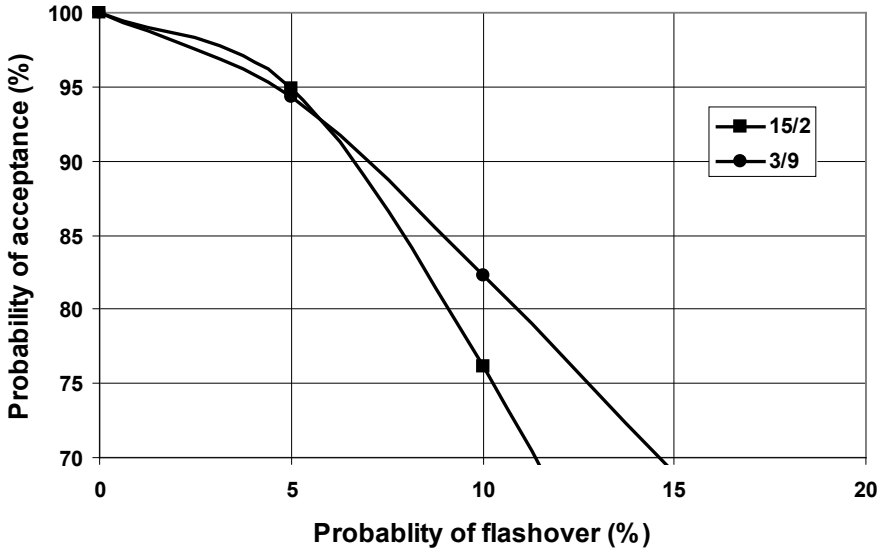


Figure 1 – Probability of acceptance (passing the test) for the 15/2 and 3/9 test series

Taking the quality assurance perspective, it is reasonably argued that a 10 % probability of flashover is too high and that 5 % is a more reasonable and applicable number. Figure 2 shows that the probability of acceptance at 5 % probability of flashover are 94,86 % and 94,7 % for the 15/2 and 3/9 test series, respectively. The corresponding probabilities of rejection are 5,14 % and 5,73 %, respectively, and the argument continues that, on this basis, the two test series are statistically equivalent. However, it is not legitimate to compare two statistical sampling plans at one point only; in fact, equivalent plans would have both similar manufacturer risks at 95 % probability of acceptance (Figure 2) and user risks at 10 % probability of acceptance as shown in Figure 3. With reference to Table 2, the manufacturer risks are near equal but there is a significant difference in the user risks with the 3/9 test series giving the higher risk.

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62271-306:2012+A1:2018

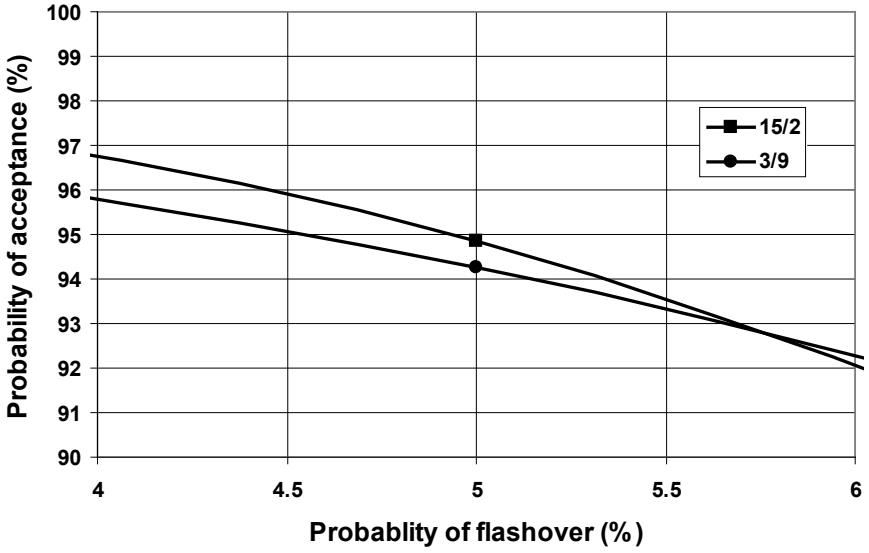


Figure 2 – Probability of acceptance at 5 % probability of flashover for 15/2 and 3/9 test series

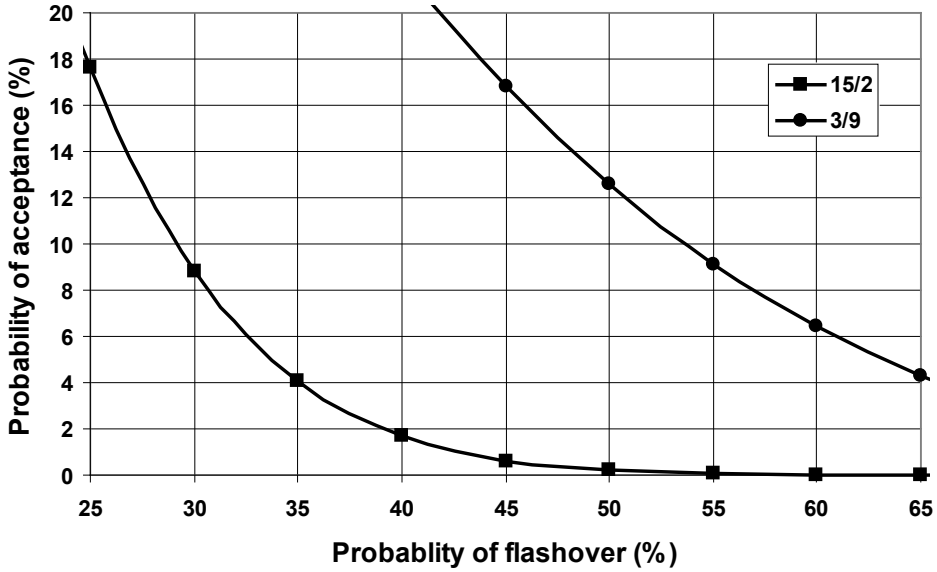


Figure 3 – User risk at 10 % probability of flashover for 15/2 and 3/9 test series

In reality, the 3/9 test series is used and accepted only in the United States and the 15/2 test series is favoured elsewhere.

The purpose of type testing is to demonstrate that the test object meets the requirements. If it does not pass the test, the reason has to be shown, and exactly what has to be improved or changed in order to justify the repetition of the test. For the new test, a new test object should be submitted which should be an improved device. One should not use the same test object or a second one of the same kind in the expectation of success in a second or third attempt.

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62271-306:2012+A1:2018

4.4.5 Theory

4.4.5.1 General

Originally invented to test insulators, and described in IEC 60060-1, the statistical considerations from which the impulse voltage withstand test procedures were derived actually apply to batches (or lots), i.e. to testing of a relatively large number of samples. Therefore, they are suited in a limited way, only, to prove the quality of individual items, such as switchgear.

Nevertheless, as the procedures have been generally accepted for impulse voltage withstand testing of high-voltage switchgear it may be justified to present their mathematical background.

4.4.5.2 Additive probabilities

According to one axiom of probability the probability function for mutually exclusive events is additive [1] [4]. For example the probability of event A or event B is the sum of their individual respective probabilities providing the two events are mutually exclusive.

4.4.5.3 Special law of multiplication

According to the special law of multiplication the probability that a number of independent events will all occur is the product of their individual respective probabilities [1]. For example the probability of event A and event B is the product of their individual respective probabilities providing the two events are independent.

4.4.5.4 Binomial distribution

The relative merit of the individual plans is analysed by means of the binominal probability distribution and two other relations from probability theory. However, the probability theory has a limited applicability when the number of samples is small or, in the extreme case, when this number is down to one. Yet, this analysis may be useful to understand the background of the test procedures defined in IEC 60060-1 and 6.2.4 of IEC 62271-1:2007 and IEC 62271-100.

Impulse tests are statistically a set of repeated trials. Letting "n" represent the number of trials and "r" the number of test failures, the tests can be analysed using the binominal probability distribution on the basis that the following assumptions apply [1]:

a) There are only two possible outcomes for each trial, "success" or "failure". (Textbooks usually assign the outcome associated with "r" as a success, without inferring that success is necessarily a desirable outcome. In our particular case we are designating the outcome associated with "r" a failure because in the context of dielectric testing a disruptive discharge is a failure.);

b) The probability of failure is constant from trial to trial and is denoted as "p"; the probability of success is thus (1 − p);

c) There are "n" trials, where "n" is a given constant;

d) The "n" trials are independent.

The probability of r failures in n trials for a probability of failure p is given by:

$$b(r, n, p) = \binom{n}{r} p^r (1-p)^{n-r}$$

[4] Numbers between square brackets refer to the references in the bibliography.

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62271-306:2012+A1:2018

where $\binom{n}{r} = \frac{n!}{r!(n-r)!}$

It follows from the axiom described above that the cumulative probability of r or fewer failures in n trials is:

$$B(r, n, p) = \sum_{r=0}^{r} \binom{n}{r} p^r (1-p)^{n-r}$$

$B(r,n,p)$ is the probability of acceptance of the test based on a single sampling plan where a maximum of "r" failures are allowed.

In the case of sampling schemes consisting of more than one sampling plan the cumulative probability distributions for the respective plans are combined in accordance with the axiom and law described above to yield the probability of acceptance for various values of "p" using that scheme.

P_a will be denoted as the probability of acceptance using a particular sampling scheme.

To illustrate the application of the theory, the 3/9 method is considered. The acceptable outcomes are 3/0 or (3/1 and 9/0):

$$P_a = \binom{3}{0} p^0 (1-p)^{3-0} + \left[\binom{3}{1} p^1 (1-p)^{3-1} \times \binom{9}{0} p^0 (1-p)^{9-0} \right]$$

$$= \frac{3!}{0!(3-0)!}(1-p)^3 + \left[\frac{3!}{1!(3-1)!} p(1-p)^2 \times \frac{9!}{0!(9-0)!}(1-p)^9 \right] = (1-p)^3 + 3p(1-p)^{11}$$

The plot of P_a as a function of "p" is usually called an operating characteristic curve.

An equation and associated operating characteristic curve can be similarly developed for the 15/2 test series [2].

The operating characteristic curves for the 15/2 and 3/9 test series are plotted in Figure 4.

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62271-306:2012+A1:2018

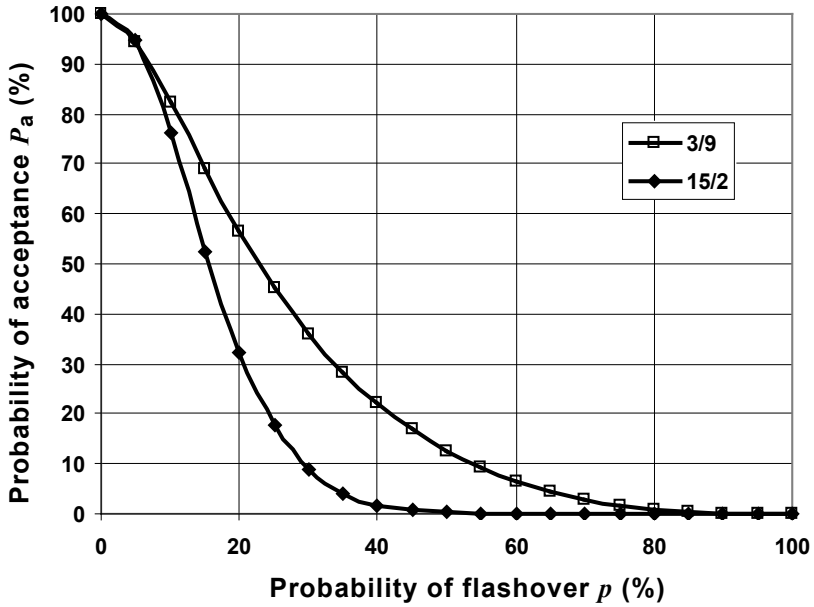


Figure 4 – Operating characteristic curves for 15/2 and 3/9 test series

4.4.5.5 Comparison of the different test methods

4.4.5.5.1 General

The various test methods are actually statistical sampling plans developed to distinguish between "good" and "bad" products out of a larger number of samples, the 15/2 method being a single sampling plan and the 3/9 method being a double sampling plan. The notion of sampling implies risk: the manufacturer's risk is that a "good" product will be rejected (fails the test) and the risk of the user is that a "bad" product will be accepted (passes the test). In reality both risks are mitigated by design safety margins and the ultimate question is which plan gives the best product quality.

To make a comparison between the different methods, two quantities need to be defined (again, it must be remembered that these considerations apply to a large number of samples and not to testing of an individual test object).

4.4.5.5.2 Manufacturer's risk (α risk)

The manufacturer's risk is the probability that a "good" lot will be rejected by the sampling plan. This risk is usually set at 5 % (corresponds to 95 % acceptance) and is stated in conjunction with a numerical definition of "good" quality such as an Acceptable Quality Level (AQL). Ideally the AQL is the value of "p" corresponding to a value of P_a equal to 95 %. The AQL is thus the maximum percent defective that, for the purpose of sampling inspection (testing in this case), can be considered satisfactory as a process average.

4.4.5.5.3 User's risk (β risk)

The user's risk is the probability that a "bad" lot will be accepted by the sampling plan and is stated in conjunction with a numerical definition of "bad" quality such as a Lot Tolerance Percent Defective (LTPD). In quality assurance procedures, when checking and selecting the acceptable samples out of a lot, a user's risk of 10 % is common and LTPD is the lot quality (i.e. value of "p") for which there is a 10 % probability of acceptance, i.e. 10 % of such lots will be accepted.

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62271-306:2012+A1:2018

The α and β risks for the operating characteristic curves of Figure 4 are shown in Figure 5 and Figure 6 and summarized in 4.4.6.

Another measure for comparison of sampling plans is to consider how well the plans discriminate between "good" and "bad" lots. An ideal plan would discriminate absolutely between the "good" and "bad" lots as is shown in Figure 7 for an AQL of 10 %; all lots to the left of the vertical acceptance line will be accepted and those to the right will be rejected. The closer the actual sampling plan comes to the ideal plan, the better its discrimination.

Readers interested in a more detailed description of statistical sampling are referred to the referenced textbooks on quality control [3, 4, 5].

4.4.6 Summary of 15/2 and 3/9 test methods

The theoretical analysis is summarized in Table 3 and in Figure 5, Figure 6 and Figure 7.

Table 3 – Summary of theoretical analysis

Method	Description	Number of acceptable outcomes	AQL (%)	LTPD (%)	Comments
15/2	As for 15/2M except that one (1) disruptive discharge permissible in the verification impulses if only one such discharge occurred in the basic 15 impulses	38	5	29,2	Addresses the disadvantages of the 15/2 and 15/2M while retaining the principle of maximum two (2) disruptive discharges permissible
3/9	Basic 3 impulses, one (1) disruptive discharge permissible in which event nine (9) further impulses applied with no disruptive discharges permissible	3	4,6	53,5	Used only in the United States

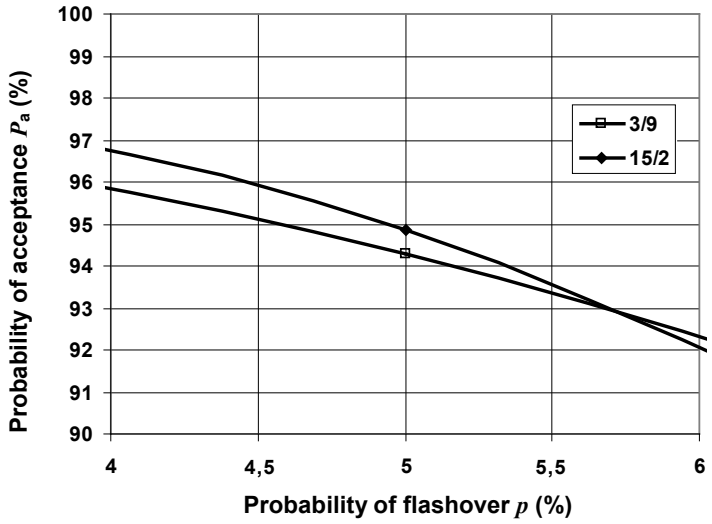


Figure 5 – α risks for 15/2 and 3/9 test methods

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62271-306:2012+A1:2018

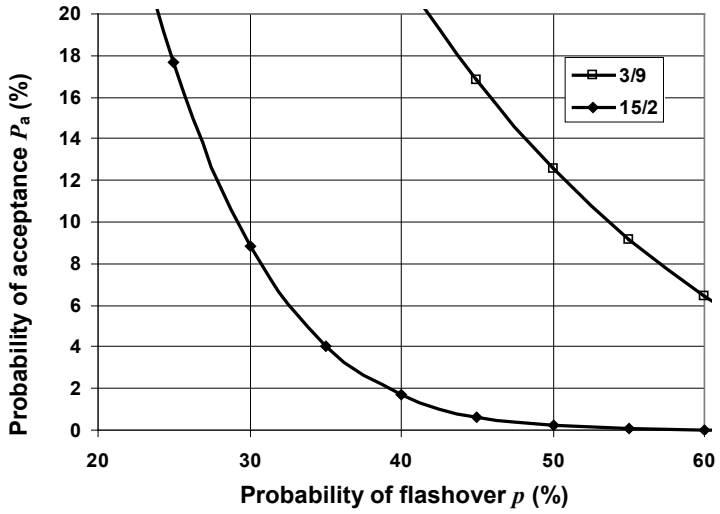


Figure 6 – β risks for 15/2 and 3/9 test methods

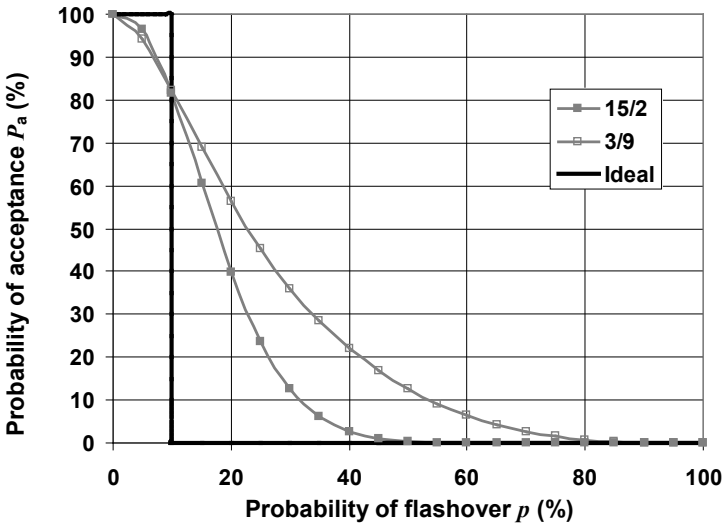


Figure 7 – Ideal sampling plan for AQL of 10 %

4.4.7 Routine tests

It should be noted that routine tests are detailed in the relevant standards. The power frequency test is used because it is most suitable for factory conditions.

4.5 Correction factors

4.5.1 Altitude correction factor

4.5.1.1 General

In the determination of the required withstand voltages, a number of factors have to be taken into account: the atmospheric correction factor k_{at} and a safety factor k_s. These factors are multipliers to be applied to the insulation level (see 4.5.1.2).

An effect of altitude is the reduction of the atmospheric pressure. A reduced atmospheric pressure reduces the disruptive voltage of a given gap in air. Subclause 4.2.2 of IEC 60071-2:1996 provides equations for derating insulation levels according to the voltage

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62271-306:2012+A1:2018

shape and to the electrode configurations based on measurements made in HV laboratories. The difficulty occurs when it comes to switching surges. So, in IEC 62271-1, it was proposed and accepted to simplify the altitude correction factor as shown in Figure 1 of this standard. In addition, these equations are general for any altitude above sea level. But in the process of assessing insulation level in IEC 60071-1, a correction is already included to cover use up to 1 000 m. As a consequence, the insulation levels stated in IEC 62271-1 are valid up to 1 000 m and, for higher altitudes, the equation for the correction factor is modified accordingly.

The altitude correction is applicable to external insulation only and is incorporated into the atmospheric correction factor, since the air density is a function of the altitude. The dielectric strength is dependent on the air density. The altitude dependence on the atmospheric pressure is given in IEC 60721-2-3 in tabular form. IEC TC 28 (Insulation coordination) has transferred the information given in IEC 60721-2-3 into Equation (1) that deviates by no more than 1 % from the information given in IEC 60721-2-3:

$$\frac{b_0}{b} = e^{H/8150} \tag{1}$$

where

b_0 is the standard barometric pressure, 101,3 kPa (or 1 013 mbar);

b is the pressure at altitude H above sea level (Pa);

H is the altitude above sea level (m).

The air density correction factor is given as (IEC 60060-1):

$$k_{\mathrm{d}} = \delta^{m} \tag{2}$$

with $\delta = \frac{b}{b_0} \times \frac{273 + t_0}{273 + t}$

where,

k_{d} is the air density correction factor;

δ is the air density;

t_0 is the standard reference temperature, 20 °C;

t is the actual ambient temperature;

m is an exponent dependent on the minimum discharge path and other attributes. Values of m can be derived from Figure 4 of IEC 60060-1:2010. These values are based on measurements performed at altitudes up to 2 000 m.

The fixed (and conservative) values for m are given for convenience, more detailed values are given in IEC 60071-2. The values are reproduced here from IEC 62271-1 (see Table 4):

Table 4 – Values for *m* for the different voltage waveshapes

m	Power frequency	Switching impulse	Lightning impulse
Phase-to-earth	1	0,75	1
Phase-to-phase	1	1	1
Longitudinal	1	0,9	1

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62271-306:2012+A1:2018

Combining Equations (1) and (2) and assuming standard reference temperature applies, the following equation is obtained for the altitude correction factor:

$$k_{alt} = e^{m\left(\frac{H}{8\,150}\right)} \quad (3)$$

Subclause 2.2.1 of IEC 62271-1:2007 specifies the following altitude correction factor:

a) altitudes up to and including 1 000 m: $k_{alt} = 1$

b) altitudes higher than 1 000 m: $k_{alt} = e^{m\left(\frac{H-1\,000}{8\,150}\right)}$ (4)

where

k_{alt} is the altitude correction factor;

H is the altitude in m above sea level;

m is an exponent.

The specification of the altitude correction factor as given in IEC 62271-1 has been based on the following considerations.

The safety factors used are k_s = 1,05 for external insulation and k_s = 1,15 for internal insulation.

Considering the overall correction k_{total} = ($k_{alt} \times k_s$) as a function of the altitude at constant humidity and temperature, assuming m = 1, the following can be determined:

External insulation: at 0 m k_{total} = 1,05 and at 1 000 m k_{total} = 1,19

Internal insulation: k_{total} = 1,15 (independent of altitude)

For a circuit-breaker having internal and external insulation in parallel (which is frequently the case), the overall correction factors are nearly equal at 1 000 m. This means that the safety factor of 1,15 covers the requirements for both internal and external insulation up to an altitude of 1 000 m.

As the safety factor is included in the required withstand voltages, these voltages are valid up to and including 1 000 m.

4.5.1.2 Examples of application of the altitude correction factor

Example 1: A 245 kV circuit-breaker is going to be installed in a substation at an altitude of 1 800 m above sea level. The user specification for the insulation level is 1 050 kV at site level. Which circuit-breaker will fulfil these requirements?

The required insulation level at standard atmospheric conditions (sea level) will be obtained applying the altitude correction factor (Equation (4)) and the following considerations:

– For lightning impulse and power frequency m = 1, hence k_{alt} = 1,103. This means that the circuit-breaker needs to be tested at sea level with a voltage of 1 050 × k_{alt} = 1 158 kV.

– The nearest standardized impulse voltage is 1 175 kV, which belongs to a system voltage of 362 kV.

– The requirement for the power frequency withstand at sea level is 507 kV (dry and wet). Regarding the test to earth this is not fully covered by the requirements for a 362 kV circuit-breaker. However, a 362 kV circuit-breaker has been tested with switching impulse (dry and wet), which gives higher stresses on the external insulation compared to the

AVA Documents Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

power frequency test, hence one can safely assume that a 362 kV circuit-breaker fulfils the requirements of a 245 kV circuit-breaker used at 1 800 m above sea level.

Conclusion: The 245 kV circuit-breaker fulfilling the requirements for an altitude of 1 800 m will be a circuit-breaker having an insulation level belonging to a system voltage of 362 kV. Application of surge arresters with the intent to lower the insulation level of the substation may result in a more advantageous choice of equipment.

Example 2: A 245 kV circuit-breaker is tested in a testing station that is located at an altitude of 800 m above sea level. What are the correct test values?

Test values and conditions for testing of switchgear and controlgear is referring to standard atmospheric conditions. As the testing station is located at 800 m above sea level, the test values for external insulation need to be corrected to the standard atmospheric conditions. Applying Equation (3) using H = 800 and m = 1 gives k_{alt} = 1,103.

The test values for external insulation in the testing station may be reduced to 1 050/k_{alt} = 952 kV_{peak} for the lightning impulse withstand test and 417 kV r.m.s. for the power frequency test, providing the circuit-breaker has external insulation only. When the circuit-breaker has both internal and external insulation, k_{alt} = 1.

Example 3: The circuit-breaker of Example 2 is tested in the same testing station at an altitude of 800 m for application at an altitude of 1 800 m. What is the correct test voltage?

The testing values at sea level have been derived in Example 1 and are 1 158 kV for the lightning impulse withstand test and 507 kV r.m.s. for the power frequency withstand test.

Application of Equation (3) (calculated in Example 2) to these values give the following result:

– lightning impulse withstand test: 1 050 kV_{peak};
– power frequency withstand test: 460 kV.

Again, this is only valid for the external insulation of the circuit-breaker.

4.5.2 Humidity correction factor

IEC 62271-1 deviates from IEC 60060-1 with respect to the humidity correction factor h to be applied during dry tests of switchgear and controlgear having a rated voltage above 1 kV and up to and including 52 kV.

In fact, the correction factors as defined in IEC 60060-1 do not fully apply to switchgear and controlgear having a rated voltage above 1 kV and up to and including 52 kV in which dielectric stress implies short distances and highly stressed insulating surfaces, and where the location and length of the disruptive discharge are practically impossible to define. The disruptive discharge depends on temperature and humidity as shown in Figure 8:

- in area 3 and 4, the external insulation behaves as an air gap;
- in area 2, due to high absolute moisture content, it is observed that disruptive discharges generally occur along the insulating surface and cannot be considered as if in air. In case of high moisture content with condensation, the weakest point may become the surface instead of the air gap;
- the cases corresponding to area 1 practically do not exist except for the zone near the standard conditions.

In order to avoid varying interpretations and have a practical approach for laboratories, a simplified method to determine w values is preferred to the calculation as given in IEC 60060-1. It was based on the experience of IEC 60694:1981 in which the factor w value equal to 1 had been used for long time by laboratories with satisfactory results especially in

AVA Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

area 3 of Figure 8 ($h \leq 11$ g/m^3), and on recent results in area 2 ($h > 11$ g/m^3) showing that taking $w = 0$ gives good correlation with experimental data.

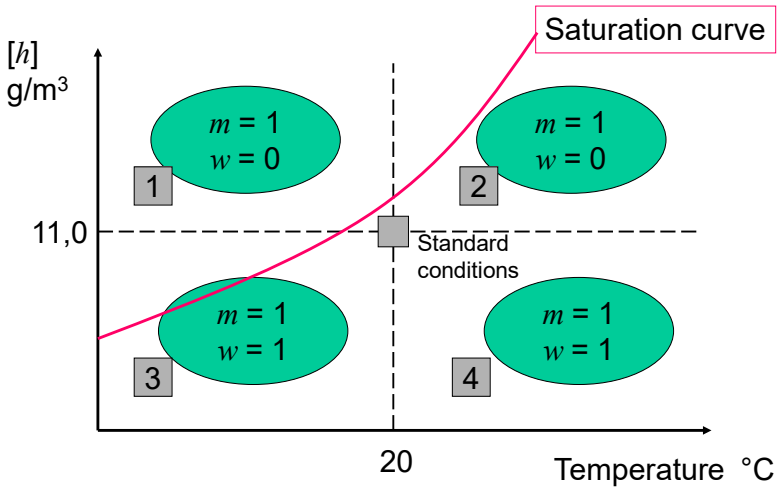


Figure 8 – Disruptive discharge mode of external insulation of switchgear and controlgear having a rated voltage above 1 kV up to and including 52 kV

4.6 Background information about insulation levels and tests

4.6.1 Specification

4.6.1.1 General

The rated insulation levels are mainly based on the requirements of IEC 60071-1. The application guide IEC 60071-2 explains the relationship between the nominal system voltage and the standardized insulation levels. However, these standards are intended to be applied to all types of equipment: insulators, cables, power transformers, etc. Therefore, some related considerations need to be addressed in applying them to high-voltage switchgear and controlgear.

4.6.1.2 Phase-to-earth

The insulation levels have been selected taking into account the values most commonly used for switchgear and controlgear.

In addition to IEC 60071-1, a rated short-duration power-frequency withstand voltage is required for rated voltages higher than 245 kV, in order to verify internal insulation voltage withstand capability with respect to temporary overvoltages.

4.6.1.3 Phase-to-phase

No changes are made to the specifications of IEC 60071-1 for the insulation between poles.

4.6.1.4 Longitudinal insulation

Since no other IEC product standards specify requirements for longitudinal insulation, SC 17A has developed its own set of rated withstand values.

AVA Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

4.6.1.5 Isolating distance

In addition to the requirements of insulation coordination, the standard specifies insulation of the “isolating distance”. This is to cover special conditions which are to be met by disconnectors to provide an additional safety factor (1,15) (see 5.102 of IEC 62271-102:2001).

The intent of the isolating distance is not to provide fundamental-coordination but to require that any disruptive discharge occurs phase-to-earth on the switching device rather than between its open contacts. Exceptions may occur, for example when high creepage distances to earth are required. However, it is generally recognized that when work has to be carried out on a high-voltage conductor, safety is assured only when the conductor is directly connected to earth. Local safety rules should apply.

4.6.1.6 Combined voltage tests

A combined voltage test is one in which two separate sources, generating voltages against earth, are connected to two terminals of the test object (see Clause 9 of IEC 60060-1:2010 and Tables 2a and 2b of IEC 62271-1:2007).

Such tests are required for switchgear and controlgear of 300 kV and above to demonstrate longitudinal voltage withstand capability. They may also be useful for testing where the test voltage between two live parts is specified to be higher than the phase-to-earth value.

The components of the combined voltage tests have been specified based on the following considerations:

a) Short-duration power-frequency withstand voltage

The specified power-frequency withstand voltage values correspond to the most severe situation of full load rejection after disconnection of a generator at full load. The overvoltage on the generator side of the switching device may reach up to 1,5 times the system voltage and may last up to 3 s with a possible phase shift. At the same time, the network side of the switching device is energized at the normal operating voltage. The sum of the two voltages in out-of-phase condition is 2,5 times the system voltage, extended here to 2,5 the rated voltage.

b) Switching impulse withstand voltage

The switching impulse voltage value specified phase to earth in Column 4 of Table 2 of IEC 62271-1:2007 is designed to cover the highest slow-front overvoltage likely to occur at the switching device terminal. This occurs at the remote end of a line after fast reclosing from the other end on a trapped charge. This highest overvoltage is of the same polarity as the power-frequency voltage of the network at this instant and therefore is not to be used when the maximum stress across a switching device is the consideration. The maximum longitudinal stress takes place when an overvoltage occurs on the polarity opposite to the power-frequency voltage of the system. The maximum value for this case occurs on closing from the remote end and is lower than the value occurring on reclosing. Therefore, the values of switching impulse specified in Column 6 of Table 2 of IEC 62271-1:2007 are lower than those of Column 4 of Table 2 of IEC 62271-1:2007.

c) Lightning impulse

In the process of designing insulation coordination, IEC 60071-1 takes into account the probability of occurrence of a particular event in order to determine the performance criteria. The likelihood that the maximum fast-front overvoltage occurs on the terminal of a switching device at the instant when its opposite terminal is energized with the maximum system voltage at opposite polarity is small. Therefore, the specified lightning impulse to be considered in this particular case need not be as high as for the general case. The reduction of about 5 % of the power frequency voltage that appear in IEC 60694 has been changed in IEC 62271-1 to a tolerance on the total test voltage of $^{+3}_{-0}$ %.

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62271-306:2012+A1:2018

4.6.2 Testing

4.6.2.1 Test of the longitudinal insulation with the alternative method

To be strictly in compliance with the preferred method, the voltage between the energized terminal and the base frame U_f should be equal to the rated withstand voltage phase to earth. But it is difficult to control this voltage during the test of the longitudinal insulation. The value of U_f has been fixed considering the following facts:

– the test voltage between any terminal and the base frame cannot exceed the rated phase to earth withstand voltage without risk;

– the electric field stress across open contacts is mainly dependent on the voltage across them, and to a lesser extent on the voltage to earth;

– the determination of the rated withstand voltage of the isolating distance is not that accurate;

– a safety factor is included in the process of insulation coordination (see IEC 60071-1) to account for such testing difficulties.

4.6.2.2 Test between phases for rated voltages above 245 kV

4.6.2.2.1 Voltage sharing between the two switching impulse components of the phase-to-phase test

The actual ratio of the two components may have any value in the network. In order to simplify the tests, IEC 60071-1 decided to specify balanced components (same amplitude with opposite polarities). Since this leads to a less severe condition, the total test voltage was increased to cover any realistic case (see Annex A of IEC 60071-2:1996). Therefore, if the same total test voltage is applied by an unbalanced sharing of the components, the test is more difficult than required.

In reality few laboratories have two impulse generators and the peak of a power-frequency voltage may replace one component. However, this leads to power-frequency voltages higher than specified phase-to-earth and for a rather long duration. Therefore, some compromise is necessary depending on the actual phase-to-earth withstand voltage of the switching device and on the facilities of the laboratory.

4.6.2.2.2 Wet tests

No wet switching impulse tests are normally necessary between phases for the following reasons:

– enclosed insulation does not need wet tests;

– insulation between phases exposed to precipitation is atmospheric air only and is not sensitive to this influence for switchgear and controlgear of rated voltage above 245 kV.

4.6.3 Combined voltage tests of longitudinal insulation

4.6.3.1 Tolerance on the power-frequency voltage component

According to IEC 60060-1, the tolerance of the power-frequency component voltage for a test with a duration longer than 1 min should be maintained within ±3 % of the specified level. This allows for some variations from the main voltage without permanent adjustment. During a combined voltage test, however, the laboratory has also to monitor many other parameters from the impulse voltage source. Therefore a higher tolerance is acceptable for the power frequency component with the understanding that the test voltage to be considered is the actual total voltage across the open contacts or the isolating distance. The tolerance on the total voltage is $^{+3}_{-0}$ %.

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62271-306:2012+A1:2018

4.6.3.2 Atmospheric correction factor

For atmospheric corrections the parameter g (4.3.4.3 of IEC 60060-1:2010) shall be calculated considering combined or composite test voltage value. The parameter $k1$ and k_2 (4.3.4.1 and 4.3.4.2 of IEC 60060-1:2010) shall be calculated for the higher of the two test voltages and be applied to both.

4.7 Lightning impulse withstand considerations of vacuum interrupters

4.7.1 General

The lightning impulse withstand voltage performance of vacuum interrupters has some characteristics that must be considered when testing. The breakdown voltage between the open contacts of a switching device in general depends on two things.

– the gaseous material between the contacts, and

– the contact surfaces.

In cases with high pressure gases at or above the normal atmospheric pressure, the gas exerts a major influence on breakdown in comparison to the contacts. In cases with vacuum gaps the contact surfaces exert the major influence.

Electrical breakdown between the contacts in a gas gap is called avalanche breakdown. The electrons that are accelerated by the electric field between the contacts collide with neutral atoms or molecules and knock off an increasing number of new electrons until a complete breakdown of the gap occurs. A *key* parameter influencing these collisions is the mean free path. The mean free path is the distance between collisions of electrons with neutral atoms or molecules as the electrons are accelerated by the electric field between the contacts. In a gas gap, the mean free path is a very small fraction of a millimetre and hence an even smaller fraction of the contact gap. Hence breakdown between the open contacts of a gas interrupter depends largely on the type of gas and the gas pressure.

In a vacuum gap, the gas pressure is 8 to 10 orders of magnitude less than the normal atmospheric pressure. In contrast, the mean free path in a vacuum gap is 10 or more times greater than the distance between the contacts. Hence breakdown between the open contacts of a vacuum interrupter is determined largely by the condition of the contact surfaces.

4.7.2 Conditioning during vacuum interrupter manufacturing

The procedure used to increase the breakdown voltage of a vacuum gap is called "*conditioning*" or "*seasoning*". Conditioning is of great practical importance to improve the withstand voltage capability and achieve the required lightning impulse withstand voltage performance of vacuum interrupters. At the end of the manufacturing process all vacuum interrupter will go through a conditioning process. The common procedure used by all leading vacuum interrupter manufacturers to condition vacuum interrupters is voltage conditioning where the contacts are blocked in the open position and an a.c.-voltage is applied across the open contact gap. The conditioning voltage level is chosen such that the vacuum interrupter can subsequently be able to pass its rated lightning impulse withstand voltage and can therefore be safely applied at the required voltage rating in circuit-breakers that comply with standards like, e.g., IEC, IEEE.

If the lightning impulse withstand voltage test is done immediately after the seasoning operation when the contacts are still in the blocked open position, the impulse voltage withstand performance is at its best. However, after the contacts are allowed to touch, some microscopic roughness occurs that reduces to a small degree the lightning impulse withstand voltage performance of the interrupter. In addition, mechanical cycling of a switching device once the interrupter is installed can also result in some small reduction of the lightning impulse withstand voltage performance of the interrupter.

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62271-306:2012+A1:2018

4.7.3 De-conditioning in service

Most common causes for de-conditioning in service are:

- high inrush currents during contact closure, for example during the making of an capacitive current with a high peak inrush current;
- interruption of high short-circuit currents (≥ 10 kA);
- passage of high currents (≥ 10 kA) through closed contacts.

The interruption of many high short-circuit currents often reduces the lightning impulse withstand voltage capability. So over time, the impulse withstand voltage capability of the vacuum interrupter may be reduced below the rated value.

4.7.4 Re-conditioning in service

In contrast, various phenomena can improve the lightning impulse voltage withstand performance, such as one or more breakdowns during impulse voltage testing or arcing between the contacts when breaking current. The interruption of load currents or lower fault currents (< 5 kA) can often re-condition the contacts from the effects of inrush currents or high currents passed through the vacuum interrupter contacts.

4.7.5 Performing lightning impulse withstand voltage tests

NOTE 3 of 6.2.4 of IEC 62271-1:2007 may be applied for the preliminary impulse voltage tests. This note does not specify how many preliminary tests nor how many breakdowns are acceptable.

After the completion of the preliminary impulse voltage tests, the official certification tests at the rated withstand voltage are performed in accordance with 6.2.4 of IEC 62271-100:2008.

5 Rated normal current and temperature rise

5.1 General

This section of the guide also applies to other switchgear and controlgear components of similar basic construction to circuit-breakers and hence it is written making reference to switchgear and controlgear rather than circuit-breakers alone.

5.2 Load current carrying requirements

5.2.1 Rated normal current

The switchgear and controlgear is designed for applications where the load current does not exceed the rated normal current under specific conditions. These conditions are:

– the altitude above sea level for the application is 1 000 m or less;

– the ambient temperature does not exceed 40 °C and the average value, measured over a period of 24 h, does not exceed 35 °C.

NOTE 1 No correction factor is applied for altitudes up to 2 000 m. For altitudes higher than 2 000 m refer to 5.2.2.4.

When choosing the switchgear and controlgear for an application the following parameters should be taken into account:

– the expected maximum load current. The rated normal current of the switchgear should be selected from the R10 series, specified in IEC 60059.

NOTE 2 The R10 series is based on the work of a French army engineer (Col. Charles Renard), who proposed in the 1870s a set of preferred numbers for use with the metric system. His system was adopted in 1952 as

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62271-306:2012+A1:2018

international standard ISO 3. Renard's system of preferred numbers divides the interval from 1 to 10 into 5, 10, 20, or 40 steps. The factor between two consecutive numbers in a Renard series is constant (before rounding), namely the 5th, 10th, 20th, or 40th root of 10 (1,58; 1,26; 1,12 and 1,06, respectively), which leads to a geometric sequence. This way, the maximum relative error is minimized if an arbitrary number is replaced by the nearest Renard number multiplied by the appropriate power of 10.

The R10 series is based on the following equation: $R(i) = 10^{\frac{i}{10}}$, where i is the i^{th} element of the series.

– the expected maximum ambient temperature around the switchgear. For ambient temperatures up to 40 °C no special requirements are given.

5.2.2 Load current carrying capability under various conditions of ambient temperature and load

5.2.2.1 General

The rated normal current is based on the maximum permissible total temperature limitations of various parts of the switchgear and controlgear when it is carrying its rated normal current at an ambient temperature of 40 °C. The total temperature of these parts under service conditions depends both on the actual load current and the actual ambient temperature. It is therefore possible to operate at a current higher than the rated normal current when the ambient temperature is less than 40 °C, provided that the allowable temperature limit is not exceeded. Similarly, when the ambient temperature is higher than 40 °C, the current must be reduced to less than the rated normal current to keep the total temperature within the allowable limits.

The methods of calculating the allowable current under various conditions of ambient temperature and load are given in 5.2.2.2 through 5.2.2.4. For some high ambient temperature conditions, it may not be practical to reduce the current sufficiently to keep the total temperatures within their allowable limits. Forced air cooling will help in many cases. Temperature limits of associated equipment such as cables and current transformers must be considered as this heat transfer is not taken into account during type testing. However no advice can be given for these cases or the similar effects of solar radiation which also must be considered.

5.2.2.2 Continuous load current capability based on actual ambient temperature

If the ambient temperature is above 40 °C, parts of the switchgear and controlgear may exceed the specific limits given in Table 3 of IEC 62271-1:2007, when carrying its rated normal current. In this case a higher rated normal current range for the switchgear and controlgear has to be selected. For load currents which are lower than the rated normal current of the circuit-breaker, a permissible maximum ambient temperature for that load current can be calculated with the help of Equation (5):

$$\theta_a = \theta_{max} - \left(\frac{I_a}{I_r}\right)^{1,8} \times (\theta_r) \quad (5)$$

where

I_a is the allowable continuous load current, in A, at actual ambient temperature θ_a (I_a is not to exceed two times I_r);

I_r is the rated normal current, in A;

θ_{max} is the allowable hottest spot total temperature (θ_{max} = θ_r + 40), in °C;

θ_r is the allowable hottest spot temperature rise at rated normal current, in K;

θ_a is the allowable or actual ambient temperature, in °C.

NOTE The exponent would normally be 2, since the heat development in the switchgear and controlgear is proportional to the square of the current. Due to radiation and convection, the exponent may vary. Experience has

AVA Documents Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018

shown that the exponent, depending on switchgear and controlgear design and components within the switchgear and controlgear, generally is in the range of 1,6 to 2,0. A value of 1,8 represents a compromise that covers most cases and is used in this application guide.

If Equation (5) is solved for the current I_a the allowable continuous load current at an actual ambient temperature θ_a can be calculated as given in Equation (6).

$$I_a = I_r \left(\frac{\theta_{max} - \theta_a}{\theta_r} \right)^{1/1,8} \quad (6)$$

The design features of switchgear and controlgear dictate the appropriate values of θ_{max} and θ_r to be used in the calculation. The major components of a circuit-breaker have several different temperature limitations which are specified in Table 3 of IEC 62271-1:2007. The values for θ_{max} and θ_r should be determined as follows:

a) if the actual ambient temperature is less than 40 °C, the component with the highest specified values of allowable temperature limitations should be used for θ_{max} and θ_r;

b) if the actual ambient temperature is greater than 40 °C, the component with the lowest specified values of allowable temperature limitations should be used for θ_{max} and θ_r.

The use of these values in the calculation will result in an allowable continuous current which will not cause the temperature of any part of the switchgear to exceed the permissible limits.

Example: A circuit-breaker that has been tested for 3 150 A rated normal current at an ambient temperature of 40 °C will carry a maximum load current of 2 500 A. What is the highest permissible ambient temperature?

As the estimated load current is less than rated current a higher ambient temperature is permissible. For the calculation θ_{max} and θ_r should be chosen as described under b).

In this case the lowest specified value in Table 3 of IEC 62271-1:2007 is θ_{max} = 90 °C and θ_r = 50 K for the bare bolted connection in air. With Equation (5) the maximum permissible ambient temperature in this example is

$$\theta_a = \theta_{max} - \left(\frac{I_a}{I_r} \right)^{1,8} \times (\theta_{max} - 40) = 57\ °C$$

5.2.2.3 Short-time load current capability

When switchgear and controlgear has been operating at a current level below its allowable continuous load current I_a, it is possible to increase the load current for a short time to a value greater than the allowable current without exceeding the permissible temperature limitations. There are different factors which influence the length of time period t_s of the overcurrent I_s. These are:

– the magnitude of the current I_s itself;
– the magnitude of the initial current I_i carried prior to the application of I_s;
– the thermal time characteristic (thermal time constant) of the switchgear and controlgear;
– the ambient temperature prior to and during application of overcurrent I_s.

The allowable duration of current I_s can be calculated directly by use of the Equation (7) and Equation (8):

AVA Documents
Document Sharing Hub

Full document details: PD IEC/TR 62271-306:2012+A1:2018