

Index

a

- admittance matrix 212–213
- asymmetrical short circuits 152, 153
- asynchronous generators (AG) 99–101
- asynchronous machine 71, 101, 105
 - impedance 106
- asynchronous motors
 - equivalent circuit 98
 - overview of 97
 - in plant engineering 97
 - short circuit currents 161–163
- automatic disconnection
 - TN system 56
 - TT systems 57

b

- batteries 147
- Bending moment 180
- breaking current 127
- busbar configuration 183
- busbar systems 45

c

- cables and overhead lines 58
 - average geometrical distance between conductors 86
 - calculation of 105
 - copper cables and conductors
 - resistances per unit length 93
 - resistance values at 20°C 91
 - resistance values at 80°C 90
 - double line 85
 - equivalent capacitive reactance 86
 - equivalent circuit 86

- equivalent radius 86
- 4x conductor bundle line 86
- inductive load reactance 85
- length-specific values 85
- mast diagram 86
- NAYY and NYY cables, resistances
 - and inductive reactances 92
- outgoing and return lines, impedance
 - for 93
- permeability 86
- positive-sequence system 85
 - inductive reactances per unit length 92
 - resistances per unit length 91
- PVC-insulated cables
 - impedance 87
 - resistance values 88–90
- 2x conductor bundle line 86
- XLPE-insulated cables
 - effective capacitances of 95
 - ground fault currents of 96
 - inductances of 95
 - resistances of conductors 94
 - resistances per unit length 94
 - zero-sequence resistances 85
- calculation tools 197
- capacitors 98, 148
- central earthing point (CEP) 47
- choke coils 96–97
- circuit breakers 112, 132, 186, 187
- computer programs 151
- controllable-power transformers 83
- Cramer's rule, application of 229–230

current converters 146
 current limiting 70
 cut-off energy 131

d

DC aperiodic component 2, 3, 49
 DC motors 149
 DC systems 143
 DC systems, short circuit currents
 batteries 203–4
 calculation procedure 200
 capacitors 204–205
 current converters 202
 DC motors 205
 equivalent circuit 201
 IEC 61660–1, 199
 largest short circuit current 199
 resistances of line sections 201
 smallest short circuit current 199
 standardized approximation
 functions 200
 three-phase synchronous generator
 199
 typical paths 200
 delta-star transformation 54
 determinants 209–212
 disconnectors 112
 doubly fed asynchronous generator
 (DFAG) 101

e

earth fault compensation 64–66
 earth-fault relays 24
 earthing systems 48
 electrical system, short circuits 23
 electromagnetic compatibility (EMC)
 47
 EN 50522 60, 125, 126
 equivalent circuit diagrams 36
 equivalent circuits, for power flow
 calculations 227, 228
 equivalent electrical circuit 2
 equivalent voltage source 2, 7, 10–11

f

far-from-generator short circuits 5,
 155, 157

fault current(s) 49–51, 56
 calculation 31
 fault current analysis
 cable selection 26
 distributors 26
 equivalent voltage source 24
 final circuits 26
 high-fault current 24
 IEC 60909-0 23
 load flow condition 24
 medium-voltage networks 24
 multi-phase reclosure 24
 network planning and management
 processes 25
 network's generators 24
 power calculations and system
 planning 25
 reverse feed 24
 selectivity detection 26
 short circuit currents and short
 circuit impedances 27
 three-phase system 25
 transformer
 medium-voltage switchgear 26
 parallel network operation 26
 fuses 112

g

Gauss–Seidel method 224
 generators
 correction factor 106
 impedance correction factor K_G for
 127–129, 131
 impedance of 105
 transient reactance of 50
 ground fault 1
 ground fault tripping 132
 ground loop impedance 30

h

HH fuses 131
 high and low voltage motors
 transformers, with different nominal
 voltages 163–165
 transformers, with two windings
 163

- high voltage power systems
 - generation, transmission and distribution 46
 - high-voltage substation 44
 - 380 kV/110 kV substation 44
 - three-phase high-voltage systems 45
 - transmission line 45
- high-voltage transformers, characteristic values of 85
- hybrid matrix 213, 214
- i**
- IEC 60 909 51, 127, 152
- IEC 60 909-4 85
- IEC 60027 133
- IEC 60364-1 47
- IEC 60364-4-41 30
- IEC 60364-7-710 47
- IEC 60909 11, 12
- IEC 60909-0 1, 23, 27, 109, 130
 - “dead” short circuit 29
 - effective voltage 30
 - medium voltage networks 30
 - neutral point design 30
 - short circuit calculation, range of applicability 31
 - short-circuit current selection 31
 - single-phase equivalent voltage source method 30
 - symmetrical and asymmetrical short circuits 30
 - VDE 0102 29
 - VDE 0670 switchgear regulations 29
- IEC 60947 187
- IEC 61363-1 102
- impedance(s) 54, 235–237
 - asynchronous machines 71
 - capacitors 72
 - network feed-ins 47
 - non-rotating loads 72
 - static converters 73
 - symmetrical components 142, 144–145
 - synchronous machines 49
 - transformers 51
- impedance corrections 75, 193
 - generators 76, 128–129, 131
 - power station 77, 127, 129–130
 - transformers 79, 130–131
- impedance matrix 213
- induction motors 165
- industrial load center network 39, 41
- industrial system, short circuit current 243–244
- in-phase voltage control 83
- insulation, heat transfer 119
- isolated network
 - advantages and disadvantages 64
 - equivalent circuit 63
- IT system
 - circuitry of 53
 - exposed conductive parts, ground resistance of 54
 - hospitals and production, applications in 47
 - indirect contact, protection for 53
 - in industrial sector 53
 - overcurrent protective equipment 53
 - power source, grounding conditions of 53
 - RCDs, use of 48
- j**
- Jacobian method 223–224
- l**
- linear equations 229
- linear equations systems 208–209
- linear load flow equations 218–219
- load-break switches 112
- load circuit 241–243
- load interrupter switches 112
- load nodes 216
- load types and complex power 216–218
- loop impedance 49
- low-resistance grounded network 66–67
- low voltage network
 - radial networks
 - disadvantages 39
 - individual load circuits 40
 - load distribution 40

- low voltage network (*contd.*)
 - meshed network 39, 41
 - with redundant inputs 39, 40
 - TN system 47, 48
 - transformers, equivalent resistances and reactances 84
 - type of connection to earth 47
- low voltage switchgear 186–187
- low-voltage transformers 81, 82

- m**
- magnet wheel 73
- making current 127
- mechanical short circuit strength
 - bending stress 170
 - busbar arrangement 171
 - busbars and parallel conductors, force effects 169
 - circuit breakers 168
 - conductor elements 169
 - correction factor k_{12} 170
 - disconnectors* 168
 - effective spacings 169
 - fuses 168
 - laws of rigidity 170
 - load-break switches 168
 - load interrupter switches* 168
 - moments of resistance and moments of inertia 171
 - natural mechanical oscillating frequency 171
 - operational equipment 168
 - parallel conductors 167
- medium voltage network
 - configuration 43
 - industrial load center network 39, 41
 - with remote station 42
 - ring network 39, 42
 - short circuit current 42, 43
 - supporting structure 42
 - transformers, equivalent resistances and reactances 84
- medium voltage switchgear 185
- mesh diagram 4
- meshed network 19, 37–39, 41, 246
- moments of inertia 171, 181
- moments of resistance 171
- motors
 - asynchronous motor
 - equivalent circuit 98
 - overview of 97
 - in plant engineering 97
 - short circuit currents 161–163
 - energy converters 97
 - high and low voltage motors
 - transformers, with different nominal voltages 163–165
 - transformers, with two windings 163
 - impedance of 106
 - induction motors, short circuits 165
 - LV motor, calculation of 106
 - %/MVA method 14
 - MVA system calculation 19–22

- n**
- near-to-generator short circuits 2, 5, 6, 155–157
- NEC 250 47
- negative-sequence short circuit impedance 2
- NEPLAN 22, 230, 231
- network(s)
 - grounding compensation 43
 - isolated free neutral point 42
 - low impedance neutral point 44
- network feed-in 71–73
- network matrices 212–231
 - admittance matrix 212–213
 - current iteration 223–224
 - equivalent circuits for power flow calculations 227–228
 - examples 228–231
 - Gauss–Seidel method 224
 - hybrid matrix 213–214
 - impedance matrix 213
 - linear load flow equations 218–219
 - Newton–Raphson, load flow calculation by 219–223
 - Newton–Raphson method 224–226
- node voltages and line currents calculation 214–215

- node voltages calculation, at
 - predetermined node power 215
 - power flow analysis, in low voltage
 - power system 226–227
 - power flow calculation 215–218
 - network transformations 54–55
 - network types 21
 - low voltage 21
 - medium voltage 23
 - neutral conductor 30
 - neutral point, arrangement 45
 - neutral-point transformer (NPT)
 - branch with 121, 122
 - branch without 120, 121
 - compensated network 124–125
 - grounding systems 126–127
 - insulated network 125
 - maximal one-phase short circuit
 - currents 121–124
 - Y- Δ winding 120
 - Z-Z winding 119, 120
 - neutral point treatment 39
 - Newton method, application of 228, 229
 - Newton–Raphson, load flow calculation
 - by 219–223
 - Newton–Raphson method 224–226
 - node generator 216
 - nodes, types of 216
 - node voltages and line currents
 - calculation 214–215
 - node voltages calculation, at
 - predetermined node power 215
- O**
- Ohm's law 135
 - operational equipment 189
 - overcurrent protection 131
 - overcurrent protective devices
 - assessment of capacity 189
 - circuit breakers
 - characteristics of 190
 - overloading and short circuit
 - current protection 193
 - uses 197
 - control transformers 193
 - cut-off current 189
 - fuses applications, power systems
 - 194, 197
 - high voltage – high power fuses 189
 - limit switch fuses, time-current
 - characteristics of 189
 - miniature circuit breakers 189
 - motor protection device, tripping
 - curves 196
 - overview of 190
 - principle of current limitation 190
 - protective functions and setting
 - possibilities 193
 - thermal relays, tripping curves 195
 - time-current characteristics
 - circuit breakers 196
 - HH fuses 193
 - limit switch fuses 191, 192
 - miniature circuit breakers 195
 - overcurrent protective equipment 34
 - overhead lines, *see* cables and overhead
 - lines 86
 - overloading 131
 - overload tripping 132
- P**
- parallel circuit 54, 55
 - peak short circuit current 104, 153–155, 244–246
 - peak value 78
 - PE-insulated cables 181
 - PEN conductor 29
 - per unit analysis 12–13
 - phase-angle control transformers 85
 - positive-sequence short circuit
 - impedance 2
 - power flow analysis 207–231
 - determinants 209–212
 - linear equations systems 208–209
 - in low voltage power system
 - 226–227
 - network matrices 212–231
 - power generator 143
 - power plant network, service panel 238
 - protective conductor (PE) 47, 48

protective functions 132
 protective ground conductor 30
 p.u. system 14–19

q

quadrature-control transformers 85

r

radial networks 18, 36, 153, 233–235
 disadvantages 39
 individual load circuits 40
 load distribution 40
 meshed network 39, 41
 with redundant inputs 39, 40
 reactive power, calculation of 228
 reference variables 10
 calculation with 12
 residual current devices (RCDs) 34,
 48, 53, 57
 ring networks 18, 35, 39, 42

s

salient-phase generator 73
 series circuit 54, 55
 series-regulating transformers 83
 short circuit 1, 19
 asynchronous motors 105
 calculation 7, 127
 far-from-generator 5
 impedance 2
 low voltage switchgear 128
 mechanical 111
 near-to-generator 2, 3, 6
 negative-sequence impedance 2
 positive-sequence impedance 2
 positive-sequence system 4
 single-pole 6, 7, 94
 symmetrical breaking current 99
 thermal 111, 112
 three-phase networks 6
 three-pole 4, 6, 7, 91
 two-pole 6, 7, 93
 types 5
 zero-sequence impedance 2
 short-circuit calculation methods
 7–22
 equivalent voltage source 10–11

%/MVA method 14
 MVA system calculation 19–22
 per unit analysis 12–13
 p.u. system 14–19
 reference variables, calculation with
 12
 short-circuit current characteristics
 14
 superposition method 7–10
 switching process calculation 14–15
 transient calculation 11
 short circuit current(s) 1
 asymmetrical short circuits 152, 153
 calculation 21, 151, 153
 capacitors 98
 choke coils 96–97
 initial symmetrical 1, 3
 limitation 120
 nonrotating loads 98
 peak 2, 3, 97
 peak short circuit current 153–154
 power grid 104
 self-quenching 42
 ship and offshore installations
 102–104
 single-phase short circuit
 equivalent circuit 151
 positive, negative and
 zero-sequence systems
 151–152
 static converters 98
 steady state 2, 102
 steady state short circuit current
 157–159
 symmetrical breaking current 2,
 155–157
 three-phase short circuit
 equivalent circuit 148
 fault conditions 147–148
 requirements 147
 time behavior of 2–3
 two-phase short circuit
 with earth contact 148–149
 without earth contact 149–150
 short circuit current calculation
 connection of a motor 240–241
 factory, supply to 249–250

- impedance corrections 250–253, 269–271
- industrial system 243–244
- load circuit calculation 241–243
- low voltage systems, proof of stability 257–259
- medium and high voltage systems
 - current inverter, dimensioning 268
 - different fault locations 261–262
 - network design – single-phase representation 260
 - operational equipment, dimensioning 266–267
 - operational equipment, equivalent circuit 260
 - overvoltage surge arrester, dimensioning 267
 - peak short circuit current* 264
 - positive-sequence short circuit impedances for transformer 260
 - three-pole short circuit, 20 kV bus bar 265
 - three-pole short circuit on transformer bus bar* 262–263
 - transferred short circuit currents 263
 - voltage transformer, dimensioning 268
 - vs. operational equipment stability* 265
- meshed network 246–249
- motors in parallel and contributions 255–257
- power plant network, on-site connection box 237–238
- protective measures proof 235–237
- radial network 233–235
- three-pole short circuit current and peak short circuit current 244
- transformer connection, external network and generator 253
- transformers in parallel 238
- short-circuit impedance 2
- short-circuit path, positive-sequence system 3–5
- short circuit strength
 - choice of switchgear 185
 - low voltage switchgear 186–187
 - medium voltage switchgear 185
- short-circuit types, classification of 5–7
- short-time current 127
- short-time delay release 132
- single-phase short circuit equivalent circuit 151
 - positive, negative and zero-sequence systems 151–152
- single-phase short circuit current 51, 77
 - symmetrical components 140–142
 - TN system 47
- single-phase short circuits between phase and N 6
- single-phase short circuits between phase and PE 6
- single source 17
- slack node 216, 217
- squirrel-cage motors 161
- star-delta transformation 55
- static converters 98
- steady-state condition 9
- steady state short circuit current 157–159
- step voltages 40
- superposition method 2, 7–10
- supply networks 17
 - calculation 34
 - calculation variables 34–35
 - concept finding 33
 - dimensioning 34
 - high-voltage levels 33
 - lines supplied from a single source 35
 - low-voltage levels 33
 - medium-voltage systems 33
 - meshed network 37–38
 - modern dimensioning tools 33
 - power plants and electricity consumer 33

- supply networks (*contd.*)
 - radial network 36
 - ring network 35
- surge arrester 191
- switching process calculation 14–15
- symmetrical breaking current 155–157
- symmetrical components 81, 82
 - impedances 85
- synchronous generators (SG) 99–101
- synchronous machine 49, 99
 - generator 73, 74
 - inner-and outer-phase machines 73
 - nonstationary operation 74
 - positive sequence, equivalent circuit and phasor diagram 74, 75
 - reactances 74–79
 - salient-phase generator 73
 - stationary operation 74
 - turbo generator 73
- systems
 - IT 35
 - TN 29
 - TT 34
- t**
- Terra–Terra (TT) systems
 - automatic disconnection 57
 - circuitry of 52
 - exposed conductive parts, ground resistance of 52
 - overcurrent protective equipment 52
 - RCDs, use of 48
 - in rural supply areas 47
- thermal short circuit strength 181
 - current limitation 176
 - Cu screening 182
 - electrical operational equipment 173
 - high and medium voltage networks 176
 - IEC 76–1 173
 - initial symmetrical short circuit current 173
 - line-protection circuit breakers, house installations 176
 - low voltage systems 176
 - m* and *n* factors 173
 - mechanical short-circuit strength 178–183
 - paper-insulated cables
 - 1–10 kV 177
 - 12/20 kV 178
 - 18/30 kV 179
 - PVC-insulated cables at 1–10 kV 180
 - rated short time current density 174, 175
 - transformer, feeder of 176
- three-phase networks 39
 - short-circuit types in 6–7
- three-phase networks, neutral point treatment
 - earth fault compensation 64–66
 - grounding systems 61
 - isolated network 63–64
 - line interruptions 59
 - low-resistance grounded network 66–68
 - neutral grounding 69
 - neutral point arrangement
 - application of 66
 - high-voltage networks 66
 - surface potential profile 60
 - touch voltage 59, 60
 - transformers 60
 - transverse faults 59
- three-phase power systems
 - standardized method 23
 - superposition method 23
- three-phase short circuit(s) 6, 74
 - current 77
 - equivalent circuit 148
 - fault conditions 147–148
 - requirements 147
- three-phase synchronous generator 143
- three-phase system
 - delta and star connection, neutral point 133, 134
 - symmetrical components
 - asymmetrical faults, calculation of 136

- impedances 142–145
- line-line voltages 134
- line-neutral voltages 134
- one-phase short circuit 140–142
- phase and line currents 135
- phase voltages 133
- positive-, negative-and zero-sequence systems 137–140
- rotational operators 136
- superposition, principle of 142
- three-phase Delta, star source and loads 145
- three-pole short circuit current, 244–246
- TN system
 - automatic disconnection 56
 - circuitry of 49
 - fault current, calculation of 49–51
 - fault protection, requirements on 49
 - in industrial sector 48
 - loop impedance 49
 - low voltage networks 47, 48
 - overcurrent protective equipment 49
 - PEN conductor 48
 - protective ground conductor 48
 - single-phase short-circuit current 47
 - TN-C-S system, circuitry of 48
- touch voltage 39
- transformation ratio 57
- transformers
 - correction factor, calculation of 105
 - correction factor K_T for 130, 131
 - equivalent circuit 80, 82
 - equivalent resistances and reactances 81, 82, 84
 - external network and a generator 253–255
 - high and low voltage motors 163–164
 - impedance calculation 104
 - neutral point treatment 60
 - overview of 80
 - in parallel 238–239
 - positive-sequence impedance 81, 83
 - short-circuit voltage 80–81
 - with three windings 81, 82
 - voltage regulation 83, 85
 - transient calculation 11
 - transient method 10
 - turbo generator 73
 - two-phase short circuit(s) 6–7
 - with earth contact 148–149
 - with ground 6
 - without earth contact 149–150
- U**
 - undelayed release 132
- V**
 - voltage factor 2, 8
 - voltage-regulating transformers 57, 83, 85
- W**
 - watt-metric relays 24
 - wind farm
 - data 107–111
 - grounding arrangement 108
 - negative-sequence impedance 108
 - positive-sequence impedance 108
 - power transformer 108
 - three-legged core transformers 109
 - transformers, correction factor for 109
 - wind energy plant
 - backup protection 116–117
 - data 110–111
 - generator 110
 - maximal three-phase short circuit 111, 115
 - minimal one-phase short circuit 111, 112, 115–116
 - NPT, *see* neutral-point transformer (NPT) 119
 - partial network, one-phase short circuit 113
 - thermal stress of cables 118–119
 - wind power with full converter 106

- Y-Y transformer, equivalent circuit
109
- wind turbines
 - asynchronous generator 99, 100
 - DFAG 101
 - full converter 101
 - high-voltage power network 99

- synchronous generators 99, 100
- wind farm, *see* wind farm 99
- wound rotor motors 161

Z

- zero-sequence short circuit impedance
2