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

© 2018 Wiley-VCH Verlag GmbH & Co. KGaA. Published 2018 by Wiley-VCH Verlag GmbH & Co. KGaA.
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
### Index

**Index**

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

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

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
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
### Index

**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
<table>
<thead>
<tr>
<th>Term</th>
<th>Page Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y-Y transformer, equivalent circuit</td>
<td>109</td>
</tr>
<tr>
<td>wind turbines</td>
<td></td>
</tr>
<tr>
<td>asynchronous generator</td>
<td>99, 100</td>
</tr>
<tr>
<td>DFAG</td>
<td>101</td>
</tr>
<tr>
<td>full converter</td>
<td>101</td>
</tr>
<tr>
<td>high-voltage power network</td>
<td>99</td>
</tr>
<tr>
<td>synchronous generators</td>
<td>99, 100</td>
</tr>
<tr>
<td>wind farm, see wind farm</td>
<td>99</td>
</tr>
<tr>
<td>wound rotor motors</td>
<td>161</td>
</tr>
<tr>
<td>zero-sequence short circuit impedance</td>
<td>2</td>
</tr>
</tbody>
</table>