



Short-circuit Currents

J Schlabbach

Contents

List of figures	xiii
List of tables	xxiii
Foreword	xxvii
1 Introduction	1
1.1 Objectives	1
1.2 Importance of short-circuit currents	1
1.3 Maximal and minimal short-circuit currents	3
1.4 Norms and standards	4
2 Theoretical background	11
2.1 General	11
2.2 Complex calculations, vectors and phasor diagrams	11
2.3 System of symmetrical components	14
2.3.1 Transformation matrix	14
2.3.2 Interpretation of the system of symmetrical components	18
2.3.3 Transformation of impedances	19
2.3.4 Measurement of impedances of the symmetrical components	20
2.4 Equivalent circuit diagram for short-circuits	24
2.5 Series and parallel connection	27
2.6 Definitions and terms	30
2.7 Ohm-system, p.u.-system and %/MVA-system	32
2.7.1 General	32
2.7.2 Correction factor using %/MVA- or p.u.-system	34
2.8 Examples	34
2.8.1 Vector diagram and system of symmetrical components	34

2.8.2	Calculation of impedances of a three-winding transformer in %/MVA	37
2.8.3	Conversion of impedances (Ω ; %/MVA; p.u.)	40
2.8.4	Impedances in %/MVA-system based on measurement	41
2.8.5	Representation of a line in the RYB-system and in the system of symmetrical components	42
3	Calculation of impedance of electrical equipment	45
3.1	General	45
3.2	Equipment in a.c. systems	45
3.2.1	General	45
3.2.2	Impedance calculation	46
3.3	Equipment in d.c. systems	50
3.3.1	General	50
3.3.2	Impedance calculation	58
3.4	Examples for calculation	63
3.4.1	a.c. equipment	63
3.4.2	d.c. equipment	64
4	Calculation of short-circuit current in a.c. three-phase HV-systems	67
4.1	Types of short-circuits	67
4.2	Methods of calculation	68
4.3	Calculation of parameters of short-circuit currents	70
4.3.1	General	70
4.3.2	Calculation of short-circuit current parameters according to IEC 60909-0	72
4.4	Influence of motors	84
4.5	Minimal short-circuit currents	85
4.6	Examples	86
4.6.1	Three-phase near-to-generator short-circuit	86
4.6.2	Line-to-earth (single-phase) short-circuit	87
4.6.3	Calculation of peak short-circuit current	88
4.6.4	Short-circuit currents in a meshed 110-kV-system	89
4.6.5	Influence of impedance correction factors on short-circuit currents	91
4.6.6	Short-circuit currents in a.c. auxiliary supply of a power station	94
5	Influence of neutral earthing on single-phase short-circuit currents	97
5.1	General	97
5.2	Power system with low-impedance earthing	98
5.3	Power system having earthing with current limitation	102
5.4	Power system with isolated neutral	105

5.5	Power system with resonance earthing (Petersen-coil)	108
5.5.1	General	108
5.5.2	Calculation of displacement voltage	112
5.5.3	Tuning of the Petersen-coil	115
5.6	Handling of neutrals on HV-side and LV-side of transformers	116
5.7	Examples	119
5.7.1	Increase of displacement voltage for systems with resonance earthing	119
5.7.2	Limitation of single-phase short-circuit current by earthing through impedance	123
5.7.3	Design of an earthing resistor connected to an artificial neutral	124
5.7.4	Resonance earthing in a 20-kV-system	124
5.7.5	Calculation of capacitive earth-fault current and residual current	125
5.7.6	Voltages at neutral of a unit transformer	126
6	Calculation of short-circuit currents in low-voltage systems	131
6.1	General	131
6.2	Types of faults	131
6.3	Method of calculation	132
6.4	Calculation of short-circuit parameters	132
6.4.1	Impedances	132
6.4.2	Symmetrical short-circuit breaking current I_b	133
6.4.3	Steady-state short-circuit current I_k	134
6.5	Minimal short-circuit currents	134
6.6	Examples	135
7	Double earth-fault and short-circuit currents through earth	139
7.1	General	139
7.2	Short-circuit currents during double earth-faults	139
7.2.1	Impedances and initial symmetrical short-circuit current I_k''	139
7.2.2	Power system configurations	140
7.2.3	Peak short-circuit current i_p	143
7.2.4	Symmetrical short-circuit breaking current I_b and steady-state short-circuit current I_k	143
7.3	Short-circuit currents through earth	143
7.3.1	Introduction	143
7.3.2	Short-circuit inside a switchyard	144
7.3.3	Short-circuit at overhead-line tower	145
7.4	Examples	146
7.4.1	Double earth-fault in a 20-kV-system	146
7.4.2	Single-phase short-circuit in a 110-kV-system	148

8 Factors for the calculation of short-circuit currents	151
8.1 General	151
8.2 Correction using %/MVA- or p.u.-system	152
8.3 Impedance correction factors	154
8.4 Factor κ for peak short-circuit current	156
8.5 Factor μ for symmetrical short-circuit breaking current	158
8.6 Factor λ for steady-state short-circuit current	160
8.7 Factor q for short-circuit breaking current of asynchronous motors	162
9 Calculation of short-circuit currents in d.c. auxiliary installations	165
9.1 General	165
9.2 Short-circuit currents from capacitors	169
9.3 Short-circuit currents from batteries	170
9.4 Short-circuit currents from rectifiers	172
9.5 Short-circuit currents from d.c. motors with independent excitation	174
9.6 Total short-circuit current	178
9.7 Example	182
9.7.1 Calculation of the impedances of cables and busbar conductors	184
9.7.2 Calculation of the short-circuit currents of the individual equipment	185
9.7.3 Calculation of the correction factors and corrected parameters	190
9.7.4 Calculation of partial short-circuit currents	191
9.7.5 Calculation of total short-circuit current	193
10 Effects of short-circuit currents	195
10.1 General	195
10.2 a.c. systems	195
10.2.1 Thermal effects and thermal short-circuit strength	195
10.2.2 Mechanical short-circuit strength of rigid conductors	201
10.3 d.c. auxiliary installations	209
10.3.1 Substitute rectangular function	209
10.3.2 Mechanical short-circuit strength of rigid conductors	212
10.3.3 Thermal short-circuit strength	215
10.4 Calculation examples (a.c. system)	216
10.4.1 Calculation of thermal effects	216
10.4.2 Electromagnetic effect	217
10.5 Calculation examples (d.c. system)	218
10.5.1 Thermal effect	218
10.5.2 Electromagnetic effect	220

11 Limitation of short-circuit currents	225
11.1 General	225
11.2 Measures	226
11.2.1 Measures in power systems	226
11.2.2 Measures in installations and switchgear arrangement	232
11.2.3 Measures concerning equipment	236
11.3 Structures of power systems	240
11.3.1 General	240
11.3.2 Radial system	241
11.3.3 Ring-main system	241
11.3.4 Meshed systems	241
12 Special problems related to short-circuit currents	245
12.1 Interference of pipelines	245
12.1.1 Introduction	245
12.1.2 Calculation of impedances for inductive interference	247
12.1.3 Calculation of induced voltage	252
12.1.4 Characteristic impedance of the pipeline	253
12.1.5 Voltage pipeline-to-earth	254
12.2 Considerations on earthing	257
12.2.1 General	257
12.2.2 Resistance of human body	257
12.2.3 Soil conditions	258
12.2.4 Relevant currents through earth	259
12.2.5 Earthing impedance	261
12.3 Examples	262
12.3.1 Interference of pipeline from 400-kV-line	262
12.3.2 Calculation of earthing resistances	264
13 Data of equipment	267
13.1 Three-phase a.c. equipment	267
13.1.1 System feeders	267
13.1.2 Transformers	267
13.1.3 Generators	270
13.1.4 Overhead lines	271
13.1.5 Cables	276
13.1.6 Reactors and resistors	278
13.1.7 Asynchronous motors	281
13.2 d.c. equipment	281
13.2.1 Conductors	281
13.2.2 Capacitors	283
13.2.3 Batteries	283

xii *Contents*

Symbols, superscripts and subscripts	287
References	293
Index	299