

## Contents

	<b>Foreword</b>	<i>XI</i>
<b>1</b>	<b>Introduction</b>	<i>1</i>
1.1	Reliability, Security, Economy	<i>1</i>
1.2	Legal, Political and Social Restrictions	<i>2</i>
1.3	Needs for Power System Planning	<i>4</i>
1.4	Basic, Development and Project Planning	<i>5</i>
1.4.1	Basic Planning	<i>5</i>
1.4.2	System Development Planning	<i>5</i>
1.4.3	Project Planning	<i>7</i>
1.5	Instruments for Power System Planning	<i>7</i>
1.6	Further Tasks of Power System Engineering	<i>10</i>
<b>2</b>	<b>Power System Load</b>	<i>11</i>
2.1	General	<i>11</i>
2.2	Load Forecast with Load Increase Factors	<i>12</i>
2.3	Load Forecast with Economic Characteristic Data	<i>13</i>
2.4	Load Forecast with Estimated Values	<i>14</i>
2.5	Load Forecast with Specific Loads and Degrees of Electrification	<i>14</i>
2.6	Load Forecast with Standardized Load Curves	<i>17</i>
2.7	Typical Time Course of Power System Load	<i>20</i>
<b>3</b>	<b>Planning Principles and Planning Criteria</b>	<i>23</i>
3.1	Planning Principles	<i>23</i>
3.2	Basics of Planning	<i>26</i>
3.3	Planning Criteria	<i>30</i>
3.3.1	Voltage Band According to IEC 60038	<i>30</i>
3.3.2	Voltage Criteria	<i>31</i>
3.3.3	Loading Criteria	<i>33</i>
3.3.4	Stability Criteria	<i>34</i>
<b>4</b>	<b>Economic Consideration and Loss Evaluation</b>	<i>37</i>
4.1	Present Value and Annuity Method	<i>37</i>
4.2	Evaluation of Losses	<i>38</i>

4.2.1	Energy Losses	39
4.2.2	Power Losses	40
<b>5</b>	<b>Topologies of Electrical Power Systems</b>	<b>45</b>
5.1	Development of Power Systems	45
5.2	Recommended Voltage Levels	47
5.3	Topology of Power Systems	48
5.3.1	Radial Systems	48
5.3.2	Ring-Main Systems	50
5.3.3	Meshed Systems at HV and MV Levels	62
5.3.4	Meshed Systems at the LV Level	65
5.4	Special Operating Considerations	67
<b>6</b>	<b>Arrangement in Gridstations and Substations</b>	<b>69</b>
6.1	Busbar Arrangements	69
6.1.1	General	69
6.1.2	Single Busbar without Separation	69
6.1.3	Single Busbar with Sectionalizer	71
6.1.4	Special H-Arrangement	71
6.1.5	Double Busbar Arrangement	72
6.1.6	Double Busbar with Reserve Busbar	73
6.2	Arrangement in Switchyards	74
6.2.1	Breakers and Switches	74
6.2.2	Incoming and Outgoing Feeders	75
6.2.3	Current Transformers	75
6.2.4	Voltage Transformers	78
<b>7</b>	<b>Transformers</b>	<b>81</b>
7.1	General	81
7.2	Utilization and Construction of Transformers	81
7.2.1	Utilization of Transformers	81
7.2.2	Oil-Immersed Transformers and Dry-Type Transformers	83
7.2.3	Characteristic Data of Transformers	86
7.3	Operation of Transformers	86
7.3.1	Voltage Drop	86
7.3.2	Permissible Loading of Transformer Neutral	88
7.4	Thermal Permissible Loading	88
7.4.1	Temperature Models	88
7.4.2	Maximum Permissible Loading of Oil-Immersed Transformers	95
7.4.3	Maximal Permissible Loading of Dry-Type Transformers	102
7.5	Economical Operation of Transformers	105
7.6	Short-Circuit Strength	106
<b>8</b>	<b>Cable Systems</b>	<b>111</b>
8.1	General	111
8.2	Construction Details	112

8.3	Electrical Parameters of Cables	114
8.4	Losses and Permissible Current	115
8.4.1	General	115
8.4.2	Calculation of Losses	118
8.4.3	Soil Characteristics	120
8.4.4	Thermal Resistances of Cables	123
8.4.5	Calculation according to VDE 0276-1000	124
8.4.6	Determination of Maximal Permissible Loading by Computer Programs	126
8.5	Planning and Design of Cable Routes and Trenches	127
8.5.1	Coordination with Other Cables and Pipes	127
8.5.2	Effect of Thermally Unfavorable Areas	129
8.5.3	Influence of Other Parameters	130
8.6	Short-Circuit Withstand Capability	132
8.6.1	General	132
8.6.2	Rating of Cable Screens	134
<b>9</b>	<b>Overhead Lines</b>	<b>137</b>
9.1	General	137
9.2	Permissible Loading (Thermal) Current	137
9.2.1	Design Limits	137
9.2.2	Losses	138
9.2.3	Heating by Solar Radiation	140
9.2.4	Heat Dissipation by Radiation and Convection	142
9.2.5	Examples for Permissible Thermal Loading	145
9.3	Electric Field Strength	145
9.4	Sag, Tensions and Minimum Distances	148
9.4.1	Minimal Length of Insulation	148
9.4.2	Conductor Sag and Span Length	150
9.5	Short-Circuit Thermal Withstand Strength	151
9.6	Right-of-way (ROW) and Tower Arrangement	153
9.7	Cost Estimates	156
<b>10</b>	<b>Flexible AC Transmission Systems (FACTS)</b>	<b>159</b>
10.1	Basics of Transmission of Power through Lines	159
10.2	Parallel Compensation of Lines	163
10.3	Serial Compensation of Lines	165
10.4	Phase-Shifting Equipment	166
10.5	Improvement of Stability	168
<b>11</b>	<b>Load-Flow and Short-Circuit Current Calculation</b>	<b>173</b>
11.1	Load-Flow Calculation	173
11.2	Calculation of Short-Circuit Currents	175
11.2.1	General	175
11.2.2	Initial Short-Circuit Current (AC)	179
11.2.3	Peak Short-Circuit Current	179

11.2.4	Symmetrical Short-Circuit Breaking Current	182
11.2.5	Steady-State Short-Circuit Current	183
11.2.6	Influence of Synchronous and Asynchronous Motors	183
11.3	Short-Circuit Withstand Capability	185
11.4	Limitation of Short-Circuit Currents	187
11.4.1	General	187
11.4.2	Measures in Power Systems	188
11.4.3	Measures in Installations and Switchgear Arrangement	193
11.4.4	Measures Concerning Equipment	199
<b>12</b>	<b>Connection of “Green-Energy” Generation to Power Systems</b>	<b>205</b>
12.1	General	205
12.2	Conditions for System Connection	208
12.2.1	General	208
12.2.2	Short-Circuit Currents and Protective Devices	209
12.2.3	Reactive Power Compensation	209
12.2.4	Voltage Fluctuations and Voltage Increase	210
12.2.5	Harmonic and Interharmonic Currents and Voltages	211
12.2.6	Flicker	213
12.2.7	Voltage Unbalance	214
<b>13</b>	<b>Protection of Equipment and Power System Installations</b>	<b>217</b>
13.1	Faults and Disturbances	217
13.2	Criteria for Operation of Protection Devices	218
13.3	General Structure of Protective Systems; Transducers	220
13.4	Protection of Equipment	222
13.5	Protection of Lines (Overhead Lines and Cables)	223
13.5.1	General	223
13.5.2	Overcurrent Protection	224
13.5.3	Distance (Impedance) Protection	226
13.5.4	Differential Protection of Lines	231
13.5.5	Ground-Fault Protection	231
13.6	Protection of Transformers	233
13.6.1	General	233
13.6.2	Differential Protection	233
13.6.3	Overcurrent Protection, Distance Protection, Ground-Fault Protection	234
13.6.4	Buchholz Protection	235
13.7	Protection of Busbars	236
13.7.1	Current Criteria for Busbar Protection	236
13.7.2	Impedance Criteria for Busbar Protection	237
13.8	Protection of Other Equipment	237
13.9	Reference List of IEC-Symbols and ANSI-Code-Numbers	237

<b>14</b>	<b>Overvoltages and Insulation Coordination</b>	<b>239</b>
14.1	General; Definitions	239
14.2	Procedure of Insulation Coordination	241
14.3	Determination of the Representative Overvoltages	242
14.3.1	Continuous Power-Frequency Voltage and Temporary Overvoltages	242
14.3.2	Slow-Front Overvoltages	243
14.3.3	Fast-Front Overvoltages	245
14.4	Determination of the Coordination Withstand Voltage and the Required Withstand Voltage	252
14.5	Selection of the Rated Voltage	254
14.6	Application Example	257
<b>15</b>	<b>Influence of Neutral Earthing on Single-Phase Short-Circuit Currents</b>	<b>263</b>
15.1	General	263
15.2	Power System with Low-Impedance Earthing	264
15.3	Power System Having Earthing with Current Limitation	268
15.4	Power System with Isolated Neutral	270
15.5	Power System with Resonance Earthing (Petersen Coil)	275
15.5.1	General	275
15.5.2	Calculation of Displacement Voltage	279
15.5.3	Tuning of the Petersen Coil	282
15.6	Earthing of Neutrals on HV Side and LV Side of Transformers	284
<b>16</b>	<b>Tendering and Contracting</b>	<b>289</b>
16.1	General (Project Definition)	289
16.2	Terms of Reference (TOR)	291
16.2.1	Background	291
16.2.2	Objective	291
16.2.3	Scope of Engineering Activities	292
16.3	Project Funding	293
16.4	Form of Tendering	293
16.4.1	International Tendering	294
16.4.2	Prequalification	294
16.4.3	Short Listing	295
16.5	Planning and Design	295
16.6	Tender Structure	297
16.6.1	General	297
16.6.2	Tender Set-up	298
16.6.3	General Technical Specifications	300
16.7	Scope of Work and Supply	308
16.7.1	General	308
16.7.2	380kV Switchgear	308
16.7.3	123kV Switchgear	309

16.7.4	Transformers and Reactors	309
16.7.5	Telecommunication System	310
16.8	Technical Data Sheets	310
16.9	Tendering Period and Evaluation of Tender	312
16.9.1	Tendering Period	312
16.9.2	Bid Evaluation	317
16.10	Contracting	317
	<b>Appendix</b>	<b>321</b>
	<b>References</b>	<b>325</b>
	<b>Index</b>	<b>331</b>