

Contents

Opening notes	11
1. Introduction	13
1.1. Basic concepts and parametrization	15
1.1.1. Failure	15
1.1.2. Outage	16
1.1.3. Reliability	16
1.1.4. Failure rate $\lambda(t)$	18
1.1.5. Instantaneous availability $A(t)$	18
1.1.6. Availability (stationary)	18
1.1.7. MTTF	19
1.1.8. MTTR	19
1.1.9. MTTF	19
1.1.10. MTBF	20
1.1.11. Continuity	20
1.1.12. Dependability	21
1.1.13. Resiliency	21
1.1.14. Recoverability	21
1.1.15. Maintainability	22
1.1.16. Maintenance support performance	22
1.1.17. Durability	22
1.1.18. Redundancy	22
1.1.19. Independence	23
1.1.20. Sparsity	26
1.2. Voltage interruptions and dips	26
1.2.1. Long interruptions	27
1.2.1.1. Causes	28
1.2.1.2. Standards	29
1.2.2. Short interruptions and dips	30
1.2.2.1. Causes	32
1.2.2.2. Standards	35

1.3. Effects	41
1.3.1. Effects on electrical equipment	42
1.3.1.1. IT equipment and control systems	42
1.3.1.2. Contactors and relays	44
1.3.1.3. Induction motors	44
1.3.1.4. Synchronous motors	45
1.3.1.5. Variable speed drives	45
1.3.1.6. High pressure discharge lamps	46
1.4. Dependability calculation	46
1.5. Dependability estimation	49
1.6. Costs	49
2. User side dependability	51
2.1. Load and supply classification	52
2.1.1. Load classification	52
2.1.2. Supply classification	55
2.2. Parameters and standards	55
2.2.1. Parameters	55
2.2.2. Standards	56
2.3. Improving dependability	58
2.4. Distribution schemes	59
2.4.1. Basic schemes	60
2.4.1.1. Shunted	60
2.4.1.2. Simple radial	60
2.4.1.3. Ring	62
2.4.1.4. Double radial	63
2.4.1.5. Meshed	65
2.4.1.6. Compound	65
2.4.2. General criteria for the choice of the scheme	65
2.4.2.1. Parameters and basic conditions	65
2.4.2.2. Scheme of the grid	
as a link between supplies and loads	66
2.4.2.3. The system supply section and end section	68
2.4.2.4. The standard and preferential functions	68
2.4.2.5. Bottlenecks	69
2.4.2.6. Uniform availability and limit of tight	
of the components	70
2.4.2.7. Redundancy of protections	70

2.4.2.8. Resilience and flexibility – capability of replacement	71
2.4.2.9. Power reserve	72
2.5. Supplementary supply	73
2.5.1. Public network	75
2.5.2. Additional power supply line	75
2.5.3. Power electronic fast transfer systems	76
2.5.4. Solid state breakers	77
2.5.5. UPS or absolute continuity systems	78
2.5.5.1. Static UPS	79
2.5.5.2. Voltage and Frequency Independent UPS (VFI)	82
2.5.5.3. Voltage and Frequency Dependent UPS (VFD)	92
2.5.5.4. Voltage Independent UPS (VI)	94
2.5.5.5. DELTA UPS	97
2.5.6. Solutions for increasing the reliability and power scalability of UPS	99
2.5.6.1. A standby UPS	100
2.5.6.2. UPS parallel configuration	102
2.5.6.3. UPS series configuration	106
2.5.6.4. Redundant distributed system and parallel operation of uninterruptible power supply systems	106
2.5.6.5. UPS with spinning reserve	106
2.5.7. Dynamic UPS	108
2.5.7.1. Size selection	109
2.5.7.2. Site location	109
2.5.8. Generator sets	110
2.5.8.1. Primary motor	110
2.5.8.2. Synchronous generator	112
2.5.8.3. Transition	114
2.5.8.4. AMF panel	116
2.5.8.5. Generator set frame	117
2.5.8.6. Size selection	117
2.6. Energy storage systems	118
2.6.1. Superconducting magnetic energy storage systems	124
2.6.2. Supercapacitors	126
2.6.3. Flywheel energy storage systems	127
2.6.4. Battery electrochemical energy storage	129
2.6.4.1. Lead-Acid batteries	129
2.6.4.2. Lithium-ion (Li-ion) batteries	130

2.6.4.3. Nickel-based batteries	131
2.6.4.4. Metal-Air batteries	132
2.6.4.5. Sodium sulfur (NaS) batteries	133
2.6.4.6. Flow batteries	133
2.6.5. Pumped storage power plants	134
2.6.6. The role of energy storage systems in power system	135
2.7. Critical infrastructures	140
2.7.1. Hospitals	141
2.7.1.1. Dependability demand	141
2.7.1.2. Electrical distribution design principles	146
2.7.1.3. Typical solutions	147
2.7.2. Data centers	149
2.7.2.1. Dependability demand	150
2.7.2.2. Electrical distribution design principles	152
2.7.2.3. Typical solutions	153
2.7.3. High buildings	159
2.7.3.1. Dependability demand	160
2.7.3.2. Electrical sources for safety services	161
2.7.3.3. Circuits of safety services	163
2.7.3.4. Emergency escape lighting	164
2.7.3.5. Fire protection applications	166
2.7.3.6. Documentation	167
2.7.3.7. Electrical distribution design principles	167
2.7.3.8. Typical solutions	167
2.7.4. Office building	171
2.7.4.1. Description of existing situation	171
2.7.4.2. Distribution scheme	171
2.7.4.3. Lines	173
2.7.4.4. Load	173
2.7.4.5. Power quality	173
2.7.4.6. Events	175
2.7.4.7. Analysis – initial situation	175
2.7.4.8. Distribution scheme	175
2.7.4.9. Line overheating	175
2.7.4.10. Coordination among protective devices and lines	175
2.7.4.11. Design approach	176
2.7.4.12. Load classification	176

2.7.4.13. Main distribution schemes	176
2.7.4.14. Line sizing	179
2.7.4.15. Cost analysis	180
2.7.4.16. Lesson learned	181
3. Supply side reliability	182
3.1. Parameters and indicators of power supply reliability	183
3.2. Definitions and types of interruptions monitored	184
3.3. The reliability indicators used	190
3.3.1. System Average Interruption Frequency Index – SAIFI	190
3.3.2. Customer Interruption – CI	191
3.3.3. Transformer SAIFI – T-SAIFI	191
3.3.4. System Average Interruption Duration Index – SAIDI	191
3.3.5. Transformer SAIDI – T-SAIDI	191
3.3.6. Customer Minutes Lost – CML	191
3.3.7. Momentary Average Interruption Frequency Index – MAIFI ...	192
3.3.8. Customer Average Interruption Duration Index – CAIDI	192
3.3.9. Customer Average Interruption Frequency Index – CAIFI	192
3.3.10. Customer Total Average Interruption Duration Index – CTAIDI	193
3.3.11. Equivalent Interruption Time Related to the Installed Capacity – TIEPI	193
3.3.12. Equivalent Number of Interruptions – NIEPI	194
3.3.13. Average Service Availability Index – ASAI	194
3.3.14. Average Service Unavailability Index – ASUI	195
3.3.15. Average System Interruption Duration Index – ASIDI	195
3.3.16. Average System Interruption Frequency Index – ASIFI	195
3.3.17. Average Energy Not Supplied – AENS	196
3.3.18. Energy Not Distributed – END	196
3.3.19. Energy Not Supplied – ENS	196
3.3.20. Average Interruption Time – AIT	196
3.3.21. Average Interruption Frequency – AIF	197
3.3.22. Average Interruption Duration – AID	197
3.3.23. System Average Restoration Index – SARI	197
3.4. Standards	197
3.4.1. Technical solutions for CoS topologies	200
3.4.2. Open grids	202
3.4.3. Closed grids	203

3.4.4. Technical methods	208
3.4.5. Organizational and technical methods	210
3.5. Distributed generation	212
4. Combined supply and user side dependability – case studies	218
4.1. Case study no. 1	218
4.1.1. Description of the facility	218
4.1.2. The quality of the supply voltage	220
4.1.3. Air conditioning	220
4.1.4. Installed power capacity	222
4.1.5. Fire protection systems	223
4.1.6. Protection against unauthorized access	223
4.1.7. Reliability of power delivery	224
4.1.7.1 External network	224
4.1.7.2. Distribution of MV in the power plant part	225
4.1.7.3. Distribution of MV in the user part	226
4.1.7.4. Internal network	226
4.1.7.5. Transformers	229
4.1.7.6. Generator	229
4.1.8. The system activating the reserve	229
4.1.9. Static UPS	230
4.1.10. Motor-generator system	231
4.1.11. Power supply system	232
4.1.12. Tests	233
4.1.12.1. Stage 1	233
4.1.12.2. Stage 2	240
4.2. Case study no. 2	250
4.3. Case study no. 3	252
4.4. Case study no. 4	253
4.5. Case study no. 5	256
4.6. Case study no. 6	271
4.6.1. Test A – Dynamic load power variation in the presence of mains supply	275
4.6.2. Test B – Dynamic variation of load power in the absence of mains supply	279
4.6.3. Test C – UPS operating time in the absence of voltage at the UPS input	281

4.6.4. Test D – Assessment of the output voltage parameters.....	286
4.6.5. Test E – Evaluation of the battery charging time after full discharge	291
4.6.6. Test F – Correctness of notification mechanisms of power supply failure.....	294
4.6.7. Test G – Battery depletion signal to switching off the UPS output voltage	298
4.6.8. Tests summary and conclusions	301
References	307