

# *Contents*

<b>1 History and Future of Power Systems</b>	1
1.1 Thomas A. Edison (1847–1931)	4
1.2 Nikola Tesla (1856–1943)	6
1.3 The Battle of ac versus dc	8
1.4 Today's Power Systems	14
1.5 Future Power Systems	15
1.5.1 Less Polluting Power Plants	15
1.5.2 Alternative Resources	16
1.5.3 Distributed Generation	16
1.5.4 Power Electronics	17
1.5.5 Enhanced Reliability	17
1.5.6 Monitoring and Control of Power Systems	18
1.5.7 Space Power Plants	18
1.5.8 Intelligent Operation, Maintenance, and Training	19
<b>2 Basic Components of Power Systems</b>	21
2.1 Power Plants	22
2.1.1 Turbines	23
2.1.2 Generators	23
2.2 Transformers	24
2.3 High-Voltage Transmission Lines	24
2.4 Medium-Voltage Distribution Lines	26
2.5 Worldwide Standards for Household Voltage and Frequency	27
2.5.1 Voltage Standard	28
2.5.2 Frequency Standard	28
2.5.2.1 Frequency of a Generating Plant	29
2.5.2.2 Frequency of Power Grids	29
<b>3 Energy Resources</b>	31
3.1 Fossil Fuel	34
3.1.1 Oil	35
3.1.2 Natural Gas	37
3.1.3 Coal	38
3.2 Nuclear Fuel	40
<b>4 Power Plants</b>	43
4.1 Hydroelectric Power Plants	43
4.1.1 Types of Hydroelectric Power Plants	44
4.1.2 Impoundment Hydroelectric Power Plants	45

4.1.3	Analysis of Impoundment Hydroelectric Power Plant	48
4.1.3.1	Reservoir	48
4.1.3.2	Penstock	49
4.1.3.3	Turbine	50
4.2	Fossil Fuel Power Plants	53
4.2.1	Thermal Energy Constant	54
4.2.2	Description of a Thermal Power Plant	55
4.3	Nuclear Power Plants	58
4.3.1	Nuclear Fuel	59
4.3.2	Fission Process	60
4.3.3	Fission Control	62
4.3.4	Boiling Water Reactor (BWR)	62
4.3.5	Pressurized Water Reactor (PWR)	64
4.3.6	Safety Features in Nuclear Power Plants	65
4.3.7	Disposal of Nuclear Waste	66
4.3.7.1	Wet Storage	66
4.3.7.2	Dry Storage	67
4.3.7.3	Permanent Storage	67
5	<b>Environmental Impact of Power Plants</b>	71
5.1	Environmental Concerns of Fossil Fuel Power Plants	72
5.1.1	Sulfur Oxides	74
5.1.2	Nitrogen Oxides	75
5.1.3	Ozone	75
5.1.4	Acid Rain	76
5.1.5	Carbon Dioxide	77
5.1.6	Ashes	78
5.2	Environmental Concerns Related to Hydroelectric Power Plants	79
5.3	Environmental Concerns Related to Nuclear Power Plants	80
6	<b>Renewable Energy</b>	85
6.1	Solar Energy	86
6.1.1	Types of Solar Energy Systems	89
6.1.1.1	Passive Solar Energy System	90
6.1.1.2	Active Solar Energy System (Photovoltaic)	91
6.1.2	Daily Power Profile of the Solar Array	94
6.1.3	Photovoltaic System	95
6.1.4	Assessment of Photovoltaic Systems	98
6.2	Wind Energy	100
6.2.1	Kinetic Energy of Wind	101
6.2.2	Wind Turbine	103
6.2.3	Wind Farm Performance	106
6.2.4	Wind Energy and the Environment	107
6.3	Fuel Cell	110
6.3.1	Hydrogen Fuel	111
6.3.2	Generation of Electricity by Fuel Cells	111

6.3.3	Types of Fuel Cells	113
6.3.4	Evaluation of Fuel Cells	114
6.3.5	Environmental Effect of Fuel Cells	115
6.3.6	Safety of Fuel Cells	116
6.4	Small Hydroelectric Systems	116
6.4.1	Reservoir-Type Small Hydroelectric System	117
6.4.2	Diversion-Type Small Hydroelectric System	122
6.5	Geothermal Energy	124
6.5.1	Heat Pump	124
6.5.2	Geothermal Power Plant	125
6.5.3	Types of Geothermal Power Plants	127
6.5.4	Evaluation of the Geothermal Energy	128
6.6	Tidal Energy	128
6.6.1	Tidal Energy Systems	129
6.6.2	Evaluation of Tidal Energy	131
6.7	Biomass Energy	131
7	<b>Alternating Current Circuits</b>	135
7.1	Alternating Current Waveform	136
7.2	Root Mean Square	136
7.3	Phase Shift	139
7.4	Concept of Phasors	141
7.5	Complex Number Analysis	142
7.6	Complex Impedance	146
7.6.1	Series Impedance	146
7.6.2	Parallel Impedance	150
7.7	Electric Power	152
7.7.1	Real Power	155
7.7.2	Reactive Power	155
7.7.3	Complex Power	156
7.7.4	Summary of ac Phasors	157
7.7.5	Power Factor	159
7.7.6	Problems Related to Reactive Power	159
7.7.7	Power Factor Correction	164
7.8	Electric Energy	169
8	<b>Electric Safety</b>	175
8.1	Electric Shock	175
8.1.1	Current Limits of Electric Shocks	176
8.1.2	Factors Determining the Severity of Electric Shocks	178
8.1.2.1	Effect of Voltage	178
8.1.2.2	Effect of Current	179
8.1.2.3	Effect of Body Resistance	179
8.1.2.4	Effect of Current Pathway	180
8.1.2.5	Effect of Shock Duration	180
8.1.2.6	Effect of Frequency	180

8.2	Ground Resistance	182
8.2.1	Measuring Ground Resistance	186
8.2.2	Ground Resistance of People	187
8.3	Touch and Step Potentials	188
8.3.1	Touch Potential	189
8.3.2	Step Potential	193
8.4	Electric Safety at Home	196
8.4.1	Neutral versus Ground	197
8.4.2	Ground Fault Circuit Interrupter (GFCI)	202
8.5	Safety of Personnel Working on Power Lines	203
8.5.1	Live-Line Work	204
8.5.2	De-Energized Line Work	207
<b>9</b>	<b>Three-Phase Systems</b>	<b>219</b>
9.1	Generation of Three-Phase Voltages	219
9.2	Connections of Three-Phase Circuits	222
9.2.1	Wye-Connected Source	223
9.2.2	Delta-Connected Source	227
9.2.3	Wye-Connected Load	228
9.2.4	Delta-Connected Load	232
9.2.5	Circuits with Mixed Connections	234
9.2.6	Wye–Delta Transformation	238
9.3	Power Calculations of Three-Phase Circuits	241
9.3.1	Three-Phase Power of Wye Loads	242
9.3.2	Three-Phase Power of Delta Loads	242
<b>10</b>	<b>Power Electronics</b>	<b>247</b>
10.1	Power Electronic Devices	248
10.1.1	Solid-State Diodes	249
10.1.2	Transistors	250
10.1.2.1	Bipolar junction transistor	250
10.1.2.2	Metal Oxide Semiconductor Field Effect Transistor (MOSFET)	256
10.1.3	Thyristors	257
10.1.3.1	Silicon Controlled Rectifier	257
10.1.3.2	SIDAC	259
10.1.4	Hybrid Power Electronic Devices	259
10.1.4.1	Darlington Transistor	259
10.1.4.2	Insulated Gate Bipolar Transistor (IGBT)	261
10.2	Solid-State Switching Circuits	262
10.2.1	ac/dc Converters	262
10.2.1.1	Fixed-voltage Circuits	263
10.2.1.2	Voltage-Controlled Circuits	267
10.2.1.3	Constant-Current Circuits	271
10.2.2	dc/dc Converters	274
10.2.2.1	Buck Converter	274

10.2.2.2 Boost converter	276
10.2.2.3 Buck–Boost converter	279
10.2.3 dc/ac Converters	282
10.2.3.1 Single-Phase dc/ac Converter	282
10.2.3.2 Three-Phase dc/ac Converter	283
10.2.4 ac/ac Converters	287
<b>11 Transformers</b>	<b>293</b>
11.1 Theory of Operation	295
11.1.1 Voltage Ratio	296
11.1.2 Current Ratio	298
11.1.3 Reflected Load Impedance	299
11.1.4 Transformer Ratings	300
11.2 Multi-Winding Transformer	300
11.3 Autotransformer	304
11.4 Three-Phase Transformer	308
11.4.1 Three-Phase Transformer Ratings	308
11.4.1.1 Y-Y Transformer	309
11.4.1.2 Δ-Δ Transformer	311
11.4.1.3 Y-Δ Transformer	312
11.4.2 Transformer Bank	315
11.5 Actual Transformer	316
11.5.1 Analysis of Actual Transformer	320
11.5.2 Transformer Efficiency	323
11.5.3 Voltage Regulation	325
<b>12 Electric Machines</b>	<b>329</b>
12.1 Rotating Magnetic Field	330
12.2 Rotating Induction Motor	334
12.2.1 Rotation of Induction Motor	336
12.2.2 Equivalent Circuit of Induction Motor	339
12.2.3 Power Analysis	343
12.2.4 Speed–Torque Relationship	347
12.2.5 Starting Torque and Current	349
12.2.6 Maximum Torque	351
12.2.7 Starting Methods	352
12.2.7.1 Voltage Reduction	352
12.2.7.2 Insertion of Resistance	354
12.3 Linear Induction Motor	356
12.3.1 Wheeled Linear Induction Motor	357
12.3.2 Magnetically Levitated (Maglev) Induction Motor	365
12.4 Synchronous Generator	366
12.4.1 Synchronous Generator Connected to an Infinite Bus	374
12.4.1.1 Real Power of a Synchronous Generator	375
12.4.1.2 Reactive Power of Synchronous Generator	378
12.4.2 Synchronous Generator Connected to an Infinite Bus through a Transmission Line	380

12.4.3	Increasing Transmission Capacity	385
12.4.3.1	Increasing Transmission Capacity by Series Capacitor	386
12.4.3.2	Increasing Transmitted Capacity by Using Parallel Lines	387
12.5	Synchronous Motor	389
12.5.1	Reactive Power Control	392
12.5.2	Real Power	394
12.6	Stepper Motor	396
12.6.1	Variable Reluctance Stepper Motor (VRSM)	397
12.6.2	Permanent Magnet Stepper Motor (PMSM)	400
12.6.3	Hybrid Stepper Motor (HSM)	401
12.6.4	Holding State of the Stepper Motor	401
12.6.5	Rotating Stepper Motor	404
<b>13</b>	<b>Power Distribution and Blackouts</b>	<b>411</b>
13.1	Topology of Power Systems	414
13.1.1	Enhancing Power System Reliability by Adding Transmission Lines	415
13.1.2	Enhancing Power System Reliability by Adding Generation	416
13.2	Analysis of Power Networks	416
13.3	Electric Energy Demand	421
13.4	Electric Energy Trade	425
13.5	World Wide Web of Power	427
13.6	Anatomy of Blackouts	430
13.6.1	Balance of Electric Powers	430
13.6.2	Balance of Electrical and Mechanical Powers	431
13.6.3	Control Actions for Decreased Demand	434
13.6.4	Control Actions for Increased Demand	435
13.7	Blackout Scenarios	437
13.7.1	The Great Northeast Blackout of 1965	438
13.7.2	The Great Blackout of 1977	439
13.7.3	The Great Blackout of 2003	439
<b>Appendix</b>		<b>443</b>
<b>Index</b>		<b>447</b>