
Contents

1	Fundamentals of Distribution Systems	1
1.1	Primary Distribution Configurations	4
1.2	Urban Networks.....	9
1.3	Primary Voltage Levels.....	12
1.4	Distribution Substations	17
1.5	Subtransmission Systems	20
1.6	Differences between European and North American Systems.....	22
1.7	Loads.....	26
1.8	The Past and the Future	28
	References.....	30
2	Overhead Lines	33
2.1	Typical Constructions.....	33
2.2	Conductor Data.....	38
2.3	Line Impedances	43
2.4	Simplified Line Impedance Calculations.....	51
2.5	Line Impedance Tables.....	57
2.6	Conductor Sizing	57
2.7	Ampacities.....	61
2.7.1	Neutral Conductor Sizing	71
2.8	Secondaries	73
2.9	Fault Withstand Capability	74
2.9.1	Conductor Annealing.....	75
2.9.2	Burndowns.....	77
2.10	Other Overhead Issues.....	83
2.10.1	Connectors and Splices.....	83
2.10.2	Radio Frequency Interference.....	86
	References.....	88
3	Underground Distribution.....	91
3.1	Applications.....	91
3.1.1	Underground Residential Distribution (URD)	92
3.1.2	Main Feeders	94
3.1.3	Urban Systems.....	94
3.1.4	Overhead vs. Underground	95
3.2	Cables.....	98
3.2.1	Cable Insulation	99
3.2.2	Conductors.....	104

3.2.3	Neutral or Shield	104
3.2.4	Semiconducting Shields.....	106
3.2.5	Jacket.....	107
3.3	Installations and Configurations.....	108
3.4	Impedances	111
3.4.1	Resistance.....	111
3.4.2	Impedance Formulas.....	114
3.4.3	Impedance Tables.....	121
3.4.4	Capacitance.....	121
3.5	Ampacity	123
3.6	Fault Withstand Capability	136
3.7	Cable Reliability	139
3.7.1	Water Trees.....	139
3.7.2	Other Failure Modes	142
3.7.3	Failure Statistics	144
3.8	Cable Testing	147
3.9	Fault Location.....	148
	References.....	153

4	Transformers	159
4.1	Basics.....	159
4.2	Distribution Transformers	164
4.3	Single-Phase Transformers	166
4.4	Three-Phase Transformers.....	174
4.4.1	Grounded Wye – Grounded Wye	179
4.4.2	Delta – Grounded Wye.....	183
4.4.3	Floating Wye – Delta.....	183
4.4.4	Other Common Connections	185
4.4.4.1	Delta – Delta	185
4.4.4.2	Open Wye – Open Delta.....	186
4.4.4.3	Other Suitable Connections	189
4.4.5	Neutral Stability with a Floating Wye	189
4.4.6	Sequence Connections of Three-Phase Transformers	191
4.5	Loadings.....	191
4.6	Losses.....	197
4.7	Network Transformers.....	201
4.8	Substation Transformers	202
4.9	Special Transformers	206
4.9.1	Autotransformers.....	206
4.9.2	Grounding Transformers	207
4.10	Special Problems	210
4.10.1	Paralleling	210
4.10.2	Ferroresonance	211
4.10.3	Switching Floating Wye – Delta Banks.....	220
4.10.4	Backfeeds.....	223

4.10.5 Inrush.....	226
References.....	229

5 Voltage Regulation.....	233
5.1 Voltage Standards	233
5.2 Voltage Drop	236
5.3 Regulation Techniques	238
5.3.1 Voltage Drop Allocation and Primary Voltage Limits.....	238
5.3.2 Load Flow Models.....	240
5.3.3 Voltage Problems	242
5.3.4 Voltage Reduction.....	243
5.4 Regulators	245
5.4.1 Line-Drop Compensation.....	249
5.4.1.1 Load-Center Compensation	250
5.4.1.2 Voltage-Spread Compensation	253
5.4.1.3 Effects of Regulator Connections	257
5.4.2 Voltage Override	258
5.4.3 Regulator Placement	258
5.4.4 Other Regulator Issues.....	259
5.5 Station Regulation.....	260
5.5.1 Parallel Operation.....	261
5.5.2 Bus Regulation Settings	262
5.6 Line Loss and Voltage Drop Relationships	262
References.....	266

6 Capacitor Application	269
6.1 Capacitor Ratings.....	273
6.2 Released Capacity	276
6.3 Voltage Support.....	277
6.4 Reducing Line Losses.....	280
6.4.1 Energy Losses	283
6.5 Switched Banks	284
6.6 Local Controls.....	286
6.7 Automated Controls	288
6.8 Reliability	290
6.9 Failure Modes and Case Ruptures.....	291
6.10 Fusing and Protection	295
6.11 Grounding.....	307
References.....	309