

Contents

Preface (v)

Chapter 1

Electromechanical Energy Conversion

1.1	Electromechanical Energy Conversion Devices	1
1.1.1	Generator Action	1
1.1.2	Motor Action	2
1.2	Principle of Electromechanical Energy Conversion	2
1.3	Electromechanical Force	3
1.4	Energy Flow in Electromechanical Systems	4
1.5	Energy Balance in Electromechanical Systems	4
1.5.1	Singly Excited System (without a Rotor)	5
1.5.2	Singly Excited System (with Rotor)	6
1.6	Static Energization	8
1.7	Dynamic Energization	8
1.7.1	Slow Movement of Rotor	9
1.7.2	Fast Movement of Rotor	10
1.7.3	Transient Rotor Movement	11
1.8	Doubly Excited System	12
1.9	Physical Concept of Force and Torque Production	14
1.9.1	DC Machines	14
1.9.2	Synchronous Machines	15
1.9.3	Induction Machines	16
1.9.4	Summary	16
	<i>Review Questions</i>	17
	<i>Problems</i>	17

Chapter 2

Single Phase Transformer

2.1	Introduction	19
2.2	Principle of Operation	19

(viii) | Contents

2.3	Constructional Features	20
2.4	Core Type Construction	20
2.5	Shell Type Construction	21
2.6	Types of Transformer Stampings	21
2.7	EMF Equation	22
2.8	Equivalent Circuit and Phasor Diagram on No Load	24
2.9	Magnetizing Current v/s Magnetizing Inrush Current	26
2.10	Equivalent Circuit and Phasor Diagram on Load	28
2.11	Power Flow Analysis	32
2.12	Per Unit (pu) Value	33
2.13	Voltage Regulation	34
2.13.1	Voltage Regulation by Approximate Method	35
2.14	Losses in a Transformer	38
2.15	Efficiency	39
2.16	All Day Efficiency	43
2.17	Tests on Transformers	45
2.17.1	Open Circuit Test	46
2.17.2	Short Circuit Test	47
2.17.3	Polarity Test	48
2.17.4	Sumpner's Back to Back Test	49
2.18	Merits of Transformer	52
2.19	Test for Separation of Hysteresis and Eddy Current Losses	53
Review Questions		56
Problems		57

CHAPTER 3

Three Phase Transformer

3.1	Construction	59
3.2	Three Phase Core Type Transformer	59
3.3	Three-Phase Shell Type Transformer	60
3.4	Three Phase Unit Transformer versus Bank of 3 Single-Phase Transformers	62
3.5	Three Phase Transformer Connections	63
3.5.1	Delta-Star Connection	63
3.5.2	Star-Delta Connection	64

3.5.3	Star-Star Connection	64
3.5.4	Delta-Delta Connection	66
3.6	Three Phase Transformer Phasor Groups (Vector Groups)	66
3.6.1	Zero Phase Displacement Yy0 Connection	67
3.6.2	Zero Phase Displacement Dd0 Connection	68
3.6.3	180° Phase Displacement Yy6 Connection	69
3.6.4	180° Phase Displacement Dd6 Connection	70
3.6.5	-30° Phase Displacement Dy1 Connection	70
3.6.6	-30° Phase Displacement Yd1 Connection	71
3.6.7	30° Phase Displacement Dy11 Connection	72
3.6.8	30° Phase Displacement Yd11 Connection	73
3.7	Effect of Connections on Parallel Operation of Transformers	74
3.8	Open Delta (V-V) Connection	74
3.9	Open Star Connection	76
3.10	Three Phase to Two Phase (Scott-Connected) Transformation	77
3.11	Three Phase to Six Phase Connections	82
3.11.1	Star or Delta/Double Star Connection	82
3.11.2	Star or Delta / Double Delta Connection	85
3.11.3	Delta/Diametral Connection	86
3.11.4	Zigzag Connected Transformer	87
3.12	Phasor Groups with Zigzag Connected Transformers	88
3.13	3 Phase to 6 Phase Conversion using Double Zigzag Connection	88
3.14	3 Phase to 12 Phase Conversion using Two Times Double Zigzag Connection	89
3.15	3 Phase to 12 Phase Conversion using Double Diametral Connection	89
3.16	Application of 3 Phase to 12 Phase Conversion	89
3.17	Excitation Phenomenon and Harmonics in Transformers	89
3.18	Excitation Phenomenon with Zero Hysteresis Loss	91
3.18.1	Unsaturated Magnetic Circuit	91
3.18.2	Saturated Magnetic Circuit	92
3.19	Harmonics in Delta Connected Transformer	92
3.20	Grounding of Transformer Neutral	92
3.21	Grounding Transformer	92
3.22	Effect of Core Construction on Harmonic Voltages	93
3.22.1	Transformer with Interlinked Magnetic Circuit	93

(x) | Contents

3.22.2	Transformers with Independent Magnetic Circuits	93
3.23	Effect of Harmonic Currents	94
3.24	Effect of Harmonic Voltages	94
3.25	Tertiary Winding (3 Winding Transformer)	94
3.26	Stabilization by Tertiary Winding	96
3.27	Equivalent Circuit of 3 Winding Transformer	97
3.28	Parallel Operation of Transformers	98
3.29	Parallel Operation of Single Phase Transformers	98
3.30	Per Unit System	99
3.31	Parallel Operation of 3 Phase Transformers	99
3.31.1	Essential Conditions	99
3.31.2	Desirable Conditions	100
3.32	Load sharing by Two Transformers with Equal Voltage Ratio	100
3.33	Load sharing by Two Transformers with Unequal Voltage Ratio	103
3.34	Auto-Transformer	106
3.34.1	Single-phase Auto-Transformer	106
3.34.2	Ratio of Weight of Copper in Auto-Transformer to Two Winding Transformer	107
3.34.3	Power Transferred by Transformer Action in Auto-Transformer	108
3.35	Three Phase Auto-Transformer	109
3.36	Two Winding Transformer as Auto-Transformer	110
3.37	Efficiency	110
3.38	Merits	110
3.39	Applications	110
	Review Questions	111
	Problems	111

CHAPTER 4

DC Generators

4.1	Introduction to DC Machines	115
4.2	Construction of DC Machines	115
4.3	Principle of Operation of DC Machines	115
4.4	Types of DC Machines	116

4.5	Circuit Models	117
4.5.1	Generating Mode	117
4.5.2	Motoring Mode	118
4.6	Methods of Excitation	118
4.6.1	Circuit Models of various types of DC Machines	118
4.7	Armature Winding of DC Machines	121
4.8	Equalizer Rings	127
4.9	Armature Reaction	128
4.9.1	Shifting of Magnetic Neutral Plane (MNP)	129
4.10	Mitigation of Adverse Effects of Armature Reaction	133
4.11	Commutation	134
4.12	Characteristics of DC Generators	136
4.13	Open Circuit Characteristic of DC Generators	137
4.13.1	Separately Excited DC Generator	137
4.13.2	Self-Excited DC Shunt Generator	138
4.13.3	Self-Excited DC Series Generator	141
4.14	External and Internal Characteristics of DC Generators	141
4.14.1	Separately Excited DC Generators	141
4.14.2	Self-Excited DC Shunt Generators	142
4.14.3	Self Excited DC Series Generators	143
4.14.4	DC Compound Generators	144
4.15	Losses and Efficiency of DC Generators	146
4.15.1	Copper Loss (I^2R Loss)	146
4.15.2	Iron Loss	146
4.15.3	Mechanical Loss	146
4.15.4	Efficiency	147
4.16	Voltage Regulation of DC Generators	147
4.17	Parallel Operation of DC Generators	148
4.17.1	Parallel Operation of DC Shunt Generators	148
4.17.2	Parallel Operation of DC Series Generators	151
4.18	Applications of DC Generators	151
	Review Questions	152
	Problems	152

CHAPTER 5

Dc Motors

5.1	Working Principle of DC Motors	155
5.1.1	Production of Torque	155
5.2	Production of Torque	156
5.3	Counter or Back EMF	158
5.4	Types of DC Motors	158
5.4.1	Separately Excited DC Motors	159
5.4.2	Self Excited DC Shunt Motors	159
5.4.3	Self Excited DC Series Motors	160
5.4.4	DC Compound Motors – Short Shunt Cumulative	160
5.4.5	DC Compound Motors – Short Shunt Differential	161
5.4.6	DC Compound Motors-Long Shunt Cumulative	161
5.5	Operating Characteristics of DC Motors	162
5.5.1	Characteristics of Separately Excited DC Motors	162
5.5.2	Characteristics of Shunt Motors	166
5.5.3	Characteristics of DC Series Motors	167
5.5.4	Characteristics of DC Compound Motors	169
5.6	Comparison of Different Types of DC Motors	170
5.7	Applications of DC Motors	172
5.8	Necessity of DC Motor Starters	172
5.8.1	Three-Point DC Shunt Motor Starters	173
5.8.2	Four-Point DC Shunt Motor Starters	175
5.8.3	DC Series Motor Starters	176
5.8.4	Calculation of Step Resistors for DC Shunt Motor Starters	177
5.9	Introduction to Soft Starting of DC Shunt and Series Motors	181
5.9.1	Controlled Rectifier Circuit	181
5.9.2	Chopper Circuit	183
5.10	Speed Control of DC Motors	184
5.10.1	Field Control Method	185
5.10.2	Armature Control Method	186
5.10.3	Ward Leonard Method (Voltage Control)	188
5.11	Losses and Efficiency	189
5.11.1	Iron Loss	189

5.11.2	Copper Loss	189
5.11.3	Mechanical Loss	190
5.11.4	Efficiency	190
5.12	Tests on DC Motors	191
5.12.1	Brake Test (Direct Method)	191
5.12.2	Swinburne's Test (Indirect Method)	192
5.12.3	Regenerative/Hopkinson' Test (Indirect Method)	193
5.13	Concept of Braking of DC Motors	195
5.13.1	Rheostatic (Dynamic) Braking	196
5.13.2	Regenerative Braking	198
5.13.3	Plugging (Reverse Current Braking)	199
5.14	Applications of DC Motors	200
	<i>Review Questions</i>	200
	<i>Problems</i>	201