

**Unit – I**

**Chapter 1 : Basics of Electric Drives 1-1 to 1-24**

**Syllabus :** Electric drive, Types and choice of electric drives, Parts of electrical drive-source, Power modulator, Electric motor and control unit, Motor duty class, Classification – Continuous, Short time, Intermittent period, Motor power rating for continuous, Short time and intermittent duty, Equivalent torque current and power methods for fluctuating and intermittent loads (Simple numerical), Speed-torque characteristics of DC motors, Speed-torque characteristics of three phase induction motor.

1.1	Introduction .....	1-2
1.1.1	Introduction to Electric Drives .....	1-2
1.1.2	Advantages of Electric Drives .....	1-2
1.1.3	Disadvantages .....	1-2
1.2	Types of Electric Drives .....	1-2
1.2.1	Merits and Demerits of Individual Drive .....	1-3
1.2.2	Group - Drive .....	1-3
1.2.3	Advantages and Disadvantages of Group Drive System .....	1-3
1.2.4	Comparison of Individual Drive and Group Drive .....	1-3
1.3	Factors Considered For Drive Selection .....	1-4
1.4	Parts of Electric Drives .....	1-5
1.4.1	Requirements of Adjustable Speed Drives .....	1-6
1.5	Motor Duty Class .....	1-6
1.5.1	Classification of Duty Cycle .....	1-6
1.5.2	Continuous Duty .....	1-6
1.5.3	Short Time Intermittent Duty .....	1-7
1.5.4	Periodic Intermittent Duty .....	1-8
1.6	Torque Rating of Motors .....	1-8
1.7	Power Rating of a Motor .....	1-9
1.8	Thermal Model of a Motor .....	1-10
1.9	Calculation of Motor Power Rating .....	1-11
1.9.1	Continuous Duty .....	1-11
1.9.2	Equivalent Current, Torque and Power Method for Fluctuating and Intermittent Loads .....	1-12
1.9.3	Short Time Duty .....	1-13
1.9.4	Intermittent Periodic Duty .....	1-14
1.10	Speed-Torque Characteristics .....	1-15

1.10.1	DC Shunt Motor .....	1-16
1.10.2	DC Series Motor .....	1-16
1.10.3	Torque Speed Characteristics of DC Compound Motors .....	1-17
1.11	Torque Slip Characteristics of Induction Motor ..	1-17
1.11.1	Analysis of the Torque-Slip Characteristics .....	1-18
1.11.2	Pull Out Torque or Breakdown Torque .....	1-19
1.11.3	Other Regions of Operation .....	1-19
1.11.4	Torque Speed Characteristics of Synchronous Motor .....	1-20
1.12	Solved Examples .....	1-20
	• <b>Review Questions .....</b>	<b>1-24</b>

**Unit – II**

**Chapter 2 : DC Drives using Converters 2-1 to 2-38**

**Syllabus :** Single phase SCR drives : Half wave converter, Full wave converter, Semiconductor, Dual converter, Three phase SCR drives : Half wave converter, Full wave converter, Semiconductor, Dual converter, Power factor in SCR motor drives, Reversible SCR drives.

2.1	Introduction .....	2-2
2.1.1	Classification of Converter Drives .....	2-2
2.1.2	Motor Performance Parameters .....	2-2
2.1.3	Input Supply Performance Parameters .....	2-3
2.2	Characteristics of DC Motors .....	2-3
2.2.1	Speed Control Techniques of DC Motors .....	2-4
2.2.2	Characteristics of Separately Excited DC Motor (Two Zone Operation) .....	2-4
2.3	Basic Setup for Converter based DC Drives .....	2-5
2.4	Operating Modes of DC Drives .....	2-5
2.4.1	Motoring .....	2-5
2.4.2	Dynamic Braking .....	2-5
2.4.3	Plugging .....	2-6
2.4.4	Regenerative Braking .....	2-7
2.4.5	Four Quadrants of Operation .....	2-8
2.5	Block Diagram of a DC Drive .....	2-8
2.6	Principle of Speed Control of DC Motors .....	2-9
2.6.1	Armature Voltage Control .....	2-9
2.6.2	Field Current Control .....	2-9
2.7	Single Phase DC Drives .....	2-9



<p>2.8 Single Phase Half Wave Converter Drive ..... 2-10</p> <p>2.8.1 Operation with Discontinuous <math>I_a</math> ..... 2-10</p> <p>2.8.2 Operation with Continuous <math>I_a</math> ..... 2-12</p> <p>2.8.3 Features of Half Wave Converter Drive ..... 2-12</p> <p>2.8.4 Drawbacks of Half Wave Converter Drive ..... 2-13</p> <p>2.9 Single Phase Semiconverter Drives ..... 2-13</p> <p>2.9.1 Semiconverter Drive in the Continuous Conduction Mode ..... 2-13</p> <p>2.9.2 Operation with Discontinuous Armature Current ..... 2-14</p> <p>2.9.3 Semiconverter Drive with Discontinuous Armature Current ..... 2-15</p> <p>2.9.4 Quadrant of Operation ..... 2-16</p> <p>2.9.5 Features of Semiconverter Drive ..... 2-16</p> <p>2.9.6 Advantages of Semiconverter Drive ..... 2-16</p> <p>2.9.7 Drawbacks of Semiconverter Drive ..... 2-16</p> <p>2.10 Single Phase Full Converter Drive ..... 2-16</p> <p>2.10.1 Full Converter Drive in the Continuous Conduction Mode ..... 2-16</p> <p>2.10.2 Full Converter Drive with Discontinuous Armature Current ..... 2-19</p> <p>2.10.3 Features of Full Converter Drive ..... 2-19</p> <p>2.10.4 Advantages of Full Converter Drive ..... 2-19</p> <p>2.10.5 Drawbacks of Full Converter Drive ..... 2-19</p> <p>2.10.6 Comparison between the Semi and Full Converter Drives ..... 2-19</p> <p>2.11 Single Phase Dual Converter Drives ..... 2-20</p> <p>2.11.1 Single Phase Dual Converter ..... 2-20</p> <p>2.11.2 Features of a Dual Converter Drive ..... 2-22</p> <p>2.11.3 Advantages of Dual Converter Drive ..... 2-22</p> <p>2.12 Three Phase Drives for DC Motors ..... 2-22</p> <p>2.12.1 Advantages of Three Phase Drives ..... 2-22</p> <p>2.12.2 Types of Three Phase Drives ..... 2-22</p> <p>2.13 Three Phase Half Wave Controlled DC Drives ..... 2-23</p> <p>2.14 Three Phase Semiconverter DC Drive ..... 2-24</p> <p>2.14.1 Features of Semiconverter Drive ..... 2-27</p> <p>2.14.2 Advantages of Semiconverter Drive ..... 2-27</p> <p>2.14.3 Drawbacks of Semiconverter Drive ..... 2-27</p> <p>2.15 Three Phase Full Converter Drives (Continuous Motor Current Mode) ..... 2-27</p> <p>2.15.1 Features of Full Converter Drive ..... 2-29</p> <p>2.15.2 Advantages of Full Converter Drive ..... 2-29</p> <p>2.15.3 Drawbacks of Full Converter Drive ..... 2-30</p>	<p>2.16 Three Phase Dual Converter Drives ..... 2-30</p> <p>2.16.1 Practical Dual Converters ..... 2-30</p> <p>2.16.2 Dual Converter with Circulating Current ..... 2-30</p> <p>2.16.3 Features of a Dual Converter Drive ..... 2-31</p> <p>2.16.4 Advantages of Dual Converter Drive ..... 2-31</p> <p>2.16.5 Disadvantage ..... 2-31</p> <p>2.17 Power Factor in SCR Motor Drives ..... 2-31</p> <p>2.18 Reversible Drives ..... 2-31</p> <p>2.18.1 Armature Current Reversal ..... 2-32</p> <p>2.18.2 Speed Reversal using Changeover Contactors ..... 2-32</p> <p>2.18.3 Speed Reversal using Dual Converter ..... 2-33</p> <p>2.19 Closed Loop DC Drive ..... 2-34</p> <p>2.20 Control of DC Series Motor ..... 2-35</p> <p>2.20.1 Characteristics of DC Series Motor ..... 2-35</p> <p>2.20.2 DC Series Motor Control using <math>1-\phi</math> Semiconverter ..... 2-35</p> <p>2.20.3 Control of DC Series Motor using <math>1-\phi</math> Full Converter ..... 2-37</p> <p>• <b>Review Questions</b> ..... <b>2-38</b></p>
--	--

**Unit – III**
**Chapter 3 : DC Drives using Choppers      3-1 to 3-24**

**Syllabus :** Basic chopper circuit using SCR, Classification based on output voltage and quadrant of operation, Chopper controlled DC drives : Class A chopper drive, Class B chopper drive, Class C chopper drive, Class D chopper drive, Class E chopper drive, Application of chopper control drive in solar and battery powered vehicles.

3.1	Basic Chopper Circuit using SCR ..... 3-2
3.2	Classification of Chopper Based on the Output Voltage ..... 3-2
3.3	Classification of Choppers Base on Quadrant of Operation ..... 3-3
3.4	DC Motor Drives Using Choppers ..... 3-4
3.5	Class A Chopper Drive ..... 3-5
3.5.1	Operation with Discontinuous Armature Current ..... 3-6
3.5.2	Features of Class A Chopper Drive ..... 3-7
3.5.3	Drawbacks of Class A Chopper Drive ..... 3-7
3.6	Class B Chopper Drive ..... 3-7
3.6.1	Features of Class B Chopper Drive ..... 3-8
3.6.2	Drawbacks of Class B Chopper Drive ..... 3-8



3.7	Class C Chopper Drive .....3-9	4.1.1	Introduction to AC Motor Control .....4-2
3.7.1	Operation in First Quadrant .....3-9	4.2	Two / Four Quadrant Operation of Induction Motor .....4-2
3.7.2	Operation in Second Quadrant .....3-10	4.2.1	Two Quadrant Operation .....4-2
3.7.3	Features of Class C Chopper Drive .....3-10	4.2.2	Four Quadrant Operation .....4-2
3.8	Class D chopper Drive .....3-12	4.3	Operating Modes of the Induction Motor .....4-3
3.8.1	First Quadrant Operation (Motoring Mode) .....3-13	4.3.1	Speed Control of Induction Motors .....4-4
3.8.2	Fourth Quadrant Operation of Type D Chopper .....3-13	4.4	Stator Voltage Control .....4-4
3.8.3	Features of Class D Chopper Drive .....3-14	4.4.1	Implementation of Stator Voltage Control using AC Voltage Controller .....4-5
3.9	Class E Chopper Drive .....3-16	4.5	Stator Voltage and Frequency Control [V/f Control] .....4-6
3.9.1	Operation in the First Quadrant .....3-16	4.5.1	Implementation of Variable Voltage Variable Frequency Control .....4-6
3.9.2	Operation of Type E Chopper in the Fourth Quadrant .....3-17	4.5.2	Square Wave Inverter Based Drive .....4-7
3.9.3	Operation of Type E Chopper in the Third Quadrant .....3-17	4.5.3	Constant V/f Control using PWM Inverter (PWM Based VSI Drive) .....4-9
3.9.4	Operation of Type E Chopper in the Second Quadrant .....3-18	4.5.4	Closed Loop Control using PWM Inverter .....4-10
3.9.5	Merits and Demerits of a Four Quadrant Chopper .....3-19	4.6	Cycloconverter Based Induction Motor Drives .....4-10
3.9.6	Applications of Type E Chopper .....3-19	4.6.1	Scherbius Scheme with Cycloconverters .....4-10
3.10	DC Series Motor Control using Choppers .....3-19	4.7	Current Source Inverter Control of Induction Motor .....4-11
3.10.1	DC Series Motor Control using a Step Down Chopper .....3-19	4.7.1	Advantages .....4-13
3.10.2	Step Down Chopper Drive with Discontinuous Armature Current .....3-20	4.7.2	Disadvantages .....4-13
3.10.3	DC Series Motor Control using a Step Up Chopper .....3-20	4.8	Speed Control of Induction Motor using Rotor Resistance Control .....4-13
3.10.4	Advantages of Chopper Drives .....3-22	4.8.1	Implementation of Rotor Resistance Control .....4-13
3.11	Application of Chopper Drive in Battery Powered Vehicles .....3-22	4.9	Slip Power Controlled Induction Motor Drives .....4-14
3.12	Application of Chopper Control Drive in Solar Powered Vehicles .....3-24	4.9.1	Basic Kramer System .....4-15
3.13	Comparison of Converter and Chopper Drives .....3-24	4.9.2	Static Kramer System .....4-15
	• <b>Review Questions</b> .....3-24	4.9.3	Scherbius System .....4-17
		4.9.4	Scherbius Scheme with Cycloconverters .....4-18
		4.9.5	Closed Loop Slip Power Control .....4-18
		4.10	Comparisons .....4-19
		4.10.1	Comparison of Various Speed Control Techniques .....4-19
		4.10.2	Comparison of DC and AC Drives .....4-19
		4.11	Solar Powered Pump Drives .....4-20
		4.11.1	A Simple Solar Pump Drive .....4-20
		4.11.2	Solar Pump Drive with a Chopper .....4-21
4.1	Introduction .....4-2		

### Unit – IV

#### Chapter 4 : AC Drives 4-1 to 4-28

**Syllabus :** Stator voltage control method using thyristor circuit, Variable frequency control method using square wave inverter, Constant V/F control method, Rotor resistance control using chopper, Slip power recovery system, Solar powered pump drives, Drives required at each stage for following applications : Textile mills, Steel rolling mills, Paper mills, Sugar mills.

4.1 Introduction .....4-2



4.11.3	Solar Pump Drive with a PWM Inverter .....	4-21	5.8	Control of DC Motors using Microprocessor .....	5-4
4.11.4	Solar Power Drive with an Intermediate Battery .....	4-21	5.8.1	Other Applications of Microprocessors in DC Drives .....	5-7
4.12	Drives Required for Various Applications .....	4-21	5.8.2	Selection of Microprocessor .....	5-7
4.13	Textile Mills .....	4-22	5.9	Microcomputer Control of DC Drives .....	5-7
4.13.1	AC Motor Control to Exercise Torque Control .....	4-23	5.10	Microcomputer Control of DC Drives .....	5-9
4.14	Steel Rolling Mills .....	4-23	5.11	Phase Locked Loop (PLL) Control of DC Drives .....	5-10
4.14.1	Classification .....	4-23	5.12	Speed Control Techniques for Synchronous Motor .....	5-10
4.14.2	Reversing Hot Rolling Mills .....	4-24	5.13	Variable Frequency Control (True Synchronous Mode) .....	5-10
4.14.3	Continuous Hot Rolling Mills .....	4-24	5.13.1	Modes of Operation .....	5-11
4.14.4	Reversing Cold Rolled Mills .....	4-24	5.13.2	Operation of the VSI Drive (True Synchronous Mode) .....	5-11
4.14.5	Continuous Cold Rolling Mills .....	4-24	5.14	Self Controlled Drive Employing Load Commutated Inverter .....	5-12
4.14.6	Motors used for Mill Drive .....	4-25	5.14.1	Closed Loop Control of Load Commutated Inverter Sync. Motor .....	5-14
4.15	Paper Mills .....	4-25	5.15	Self Controlled Drive Employing Cycloconverter .....	5-15
4.16	Sugar Mills .....	4-26	5.15.1	Merits / Advantages .....	5-15
	<b>Review Questions .....</b>	<b>4-27</b>	5.15.2	Demerits / Disadvantages .....	5-16
			5.15.3	Applications .....	5-16

**Unit – V**

**Chapter 5 : Advanced Techniques of Motor Control**

**5-1 to 5-20**

**Syllabus :** Microcontroller / Microprocessor based control for drives, Phase locked loop control of DC motor, AC /DC drive using Microprocessor control, AC /DC drive using microcontroller control, Synchronous Motor drives, Ratings & specifications of stepper motor, Stepper motor drives employing microcontroller (No programming).

5.1	Introduction .....	5-2	5.16	Important Definitions Related to Stepper Motors .....	5-16
5.1.1	Disadvantages of Discrete Drives .....	5-2	5.17	Stepper Motor Characteristics .....	5-16
5.2	Advantages of Microprocessor / Microcomputer Controlled Drives .....	5-2	5.17.1	Static Characteristics .....	5-16
5.3	Comparison of Discrete Analog and Microprocessor Control .....	5-2	5.17.2	Dynamic Characteristics .....	5-17
5.4	Disadvantages of Microprocessor Control .....	5-3	5.17.3	Limitations of Stepper Motor .....	5-17
5.5	Application Areas of Microprocessor Based Control .....	5-3	5.17.4	Ratings and Specifications of Stepper Motors .....	5-17
5.6	Functions of Microprocessors in Drives .....	5-3	5.18	Drive Requirements for a Step Motor .....	5-18
5.7	Speed Detection Using Optical Encoders .....	5-3	5.19	Open Loop Control of Stepper Motor .....	5-18
5.7.1	Incremental Rotary Encoder .....	5-3	5.19.1	Closed Loop Control of Stepper Motors .....	5-19
5.7.2	Absolute Encoders .....	5-4	5.20	Microprocessor Based Control of Stepper Motor .....	5-19
				<b>Review Questions .....</b>	<b>5-20</b>
				<b>Appendix-A : Power Factor in SCR Drives .....</b>	<b>A-1 to A-10</b>

