KKR & KSR INSTITUTE OF TECHNOLOGY & SCIENCES

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Department of Electrical and Electronics Engineering

Academic year: 2017-18 **Year/Semester: III/II** **Regulation: R13**

Name of the subject: POWER SEMICONDUCTOR DRIVES

This course is an extension of power electronics applications to electric drives. This course covers in detail the basic and advanced speed control techniques using power electronic converters that are used in industry. It is equally important to understand the four quadrant operation of electric drives and slip power recovery schemes in induction motors.

LEARNING OBJECTIVES:

- To learn the fundamentals of electric drive and different electric braking methods.
- To analyze the operation of three phase converter controlled dc motors and four quadrant operation of dc motors using dual converters.
- To discuss the converter control of dc motors in various quadrants.
- To understand the concept of speed control of induction motor by using AC voltage controllers and voltage source inverters.
- To learn the principles of static rotor resistance control and various slip power recovery schemes.
- To understand the speed control mechanism of synchronous motors

SYLLABUS

UNIT–I:

Fundamentals of Electric Drives

Electric drive – Fundamental torque equation – Load torque components –Nature and classification of load torques – Steady state stability – Load equalization– Four quadrant operation of drive (hoist control) – Braking methods**:** Dynamic – Plugging – Regenerative methods.

UNIT–II:

Three phase converter controlled DC motors

Revision of speed control techniques – Separately excited and series motors controlled by full converters – Output voltage and current waveforms –Speed-torque expressions – Speed-torque characteristics – Numerical problems – Four quadrant operation using dual converters.

UNIT–III:

Control of DC motors by DC–DC converters (Type C & Type D)

Single quadrant – Two quadrant and four quadrant chopper fed separately excited and series excited motors – Continuous current operation– Output voltage and current waveforms – Speed–torque expressions – Speed–torque characteristics –Four quadrant operations – Closed loop operation (Block diagrams only).

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UNIT–IV:

Induction motor control – Stator side

Variable voltage characteristics–Control of Induction Motor by AC Voltage Controllers – Waveforms –Speed torque characteristics– Variable Voltage Variable Frequency control of induction motor by voltage source inverter –PWM control – Closed loop operation of induction motor drives (Block Diagram Only).

UNIT–V:

Control of Induction motor – Rotor side

Static rotor resistance control – Slip power recovery schemes – Static Scherbius drive – Static Kramer drive – Performance and speed torque characteristics – Advantages –Applications.

UNIT–VI:

Control of Synchronous Motors

Separate control &self control of synchronous motors – Operation of self controlled synchronous motors by VSI– Closed Loop control operation of synchronous motor drives (Block Diagram Only) –Variable frequency control–Pulse width modulation.

PREREQUISITE COURSES

S.no	Name of the course	Year/Semester
1	Electrical Circuit Analysis-I	I/II
2	Electrical Machines-I	II/I
3	Electrical Machines-II	II/II
4	Power Electronics	III/I

COURSE OUTCOMES

Co. No	Course Outcome	Taxonomy Level
C325.1	Explain the fundamentals of electrical drives	Comprehension
C325.2	Explain control of DC motors by three phase converters and four quadrant operation using dual converters	Comprehension
C325.3	Compare chopper control of DC separately and self excited motors	Analysis
C325.4	Compare different stator side controls of Induction Motor	Analysis
C325.5	Explain static rotor resistance control and slip power recovery schemes of Induction Motor	Comprehension
C325.6	Distinguish between self and separate control of synchronous motors	Analysis

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CO-PO MAPPING

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
C325.1	1	2										
C325.2		2	1	2								
C325.3		2	1	2								
C325.4		2	1	2								
C325.5	1	1		2								
C325.6	1	1		2								

LESSON PLAN

L /T No.	Topics covered	Teaching Aid	Textbook /Reference Number	Page Numbers
UNIT I: FUNDAMENTALS OF ELECTRIC DRIVES				
L-01	Introduction	GB&CP	T3	1.1-1.3
L-02	Electric Drive System	GB&CP	T3	1.4-1.6
L-03	Classification and comparision of electric drives,Applications	GB&CP	T3	1.6-1.7
L-03	Fundamental torque equation,Classification of load torques	GB&CP	T3	1.8-1.9
L-04	Components of load torque	GB&CP	T3	1.9-1.12
L-05	Nature and classification of load torques	GB&CP	T1	19-20
L-06	Steady state stability	GB&CP	T1	23-24
L-07	Steady state stability	GB&CP	T1	23-24

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Name of the subject: POWER SEMICONDUCTOR DRIVES

T-01	Problems	GB&CP	T1	24
L-08	Load equalization	GB&CP	T1	24-27
L-09	Four quadrant operation of drive (hoist control)	GB&CP	T1	12-14
L-10	Four quadrant operation of drive (hoist control)	GB&CP	T1	12-14
L-11	Braking methods: Dynamic – Plugging – Regenerative methods	GB&CP	T1	68-74
UNIT II: THREE PHASE CONVERTER CONTROLLED DC MOTORS				
L-12	Introduction	GB&CP	T1	87-89
L-13	Revision of speed control techniques	GB&CP	T1	87-89
L-14	Three phase full converter fed with separately excited DC motor	GB&CP	T1	111-112
L-15	Three phase full converter fed with separately excited DC motor	GB&CP	T1	111-112
L-16	Derivation of output voltage and speed torque characteristics	GB&CP	T1	111-112
T-02	Problems on Three phase full converter fed with separately excited DC motor	GB&CP	T1	113
L-17	Three phase full converter fed with DC series motor	GB&CP	T1	118-119
L-18	Three phase full converter fed with DC series motor	GB&CP	T1	118-119
L-19	Derivation of output voltage and speed torque characteristics	GB&CP	T1	118-119
T-03	Problems on Three phase full converter fed with DC series motor	GB&CP	T1	126-127
L-20	Four quadrant operation using dual converters	GB&CP	T1	114-118
L-21	Four quadrant operation using dual converters(field reversal)	GB&CP	T1	114-118
UNIT–III:Control of DC motors by DC–DC converters (Type C & Type D)				

L-22	Introduction	GB&CP	T1	122-126
L-23	Chopper fed DC motor drive	GB&CP	T1	122-126
L-24	Single quadrant fed separately excited motor	GB&CP	T1	127-128
L-25	Two quadrant fed separately excited motor	GB&CP	T1	127-128
L-26	Four quadrant fed separately excited motor	GB&CP	T1	128-131
T-04	Problems on chopper fed separately excited motor	GB&CP	T1	128-131
L-27	Single quadrant fed series excited motor	GB&CP	T1	128-131
L-28	Two quadrant fed series excited motor	GB&CP	T1	128-131
L-29	Four quadrant fed series excited motor	GB&CP	T1	128-131
T-05	Problems on chopper fed series excited motor	GB&CP	T1	128-131
L-30	Closed loop operation (Block diagrams only)	GB&CP	T1	131-133
L- 31	Closed loop operation (Block diagrams only)	GB&CP	T1	131-133
UNIT–IV:Induction motor control – Stator side				
L-32	Introduction	GB&CP	T1	183
L-33	Stator voltage control(variable voltage characteristics)	GB&CP	T1	183
L-34	Control of Induction Motor by AC Voltage Controllers , Waveforms ,Speed torque characteristics	GB&CP	T1	184
L-35	Control of Induction Motor by AC Voltage Controllers , Waveforms ,Speed torque characteristics	GB&CP	T1	184
T-06	Problems	GB&CP	T1	184-185
L-36	variable frequency characteristics	GB&CP	T1	187
L-37	Variable Frequency control of induction motor	GB&CP	T1	186-194

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Name of the subject: POWER SEMICONDUCTOR DRIVES

L-38	Variable voltage and Variable Frequency control of induction motor by VSI	GB&CP	T1	186-194
L-39	PWM control	GB&CP	T1	209
L-40	Closed loop operation of induction motor drives (Block Diagram Only)	GB&CP	T1	208
T-07	Problems	GB&CP	T1	210-211
UNIT–V:Control of Induction motor – Rotor side				
L-41	Introduction	GB&CP	T1	214
L-42	Static rotor resistance control	GB&CP	T1	214-217
L-43	Closed loop control with static rotor resistance control	GB&CP	T1	214-217
L-44	Static Scherbius drive	GB&CP	T1	218-221
L-45	Static Scherbius drive	GB&CP	T1	218-221
T-08	Problems	GB&CP	T1	223-227
L-46	Static Kramer drive	GB&CP	T1	221-223
L-47	Static Kramer drive	GB&CP	T1	221-223
T-09	Problems	GB&CP	T1	223-227
L-48	Advantages –Applications	GB&CP	T1	218-219
UNIT–VI:Control of Synchronous Motors				
L-49	Introduction	GB&CP	T1	256
L-50	Separate control of synchronous motors	GB&CP	T1	256
L-51	Self control of synchronous motors	GB&CP	T1	256
L-52	Operation of self controlled synchronous motors by VSI	GB&CP	R3	12-14

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Name of the subject: POWER SEMICONDUCTOR DRIVES

L-53	Operation of self controlled synchronous motors by VSI	GB&CP	R3	12-14
T-10	Problems	GB&CP	T1	257-259
L-54	Closed Loop control operation of synchronous motor drives (Block Diagram Only)	GB&CP	R3	131-133
L-55	Closed Loop control operation of synchronous motor drives (Block Diagram Only)	GB&CP	R3	131-133
L-56	Variable frequency control	GB&CP	R3	68-75
L-57	Pulse width modulation	GB&CP	R3	68-75
T-11	Problems	GB&CP	T1	257-259
Total No of Lectures required = 57,Tutorials=11.			**Total**	**68**

Learning Resourses:GB&CP: Glass board & Chalk Piece, **T: Tutorial, L: Lecture**

TEXTBOOK:

T1. Fundamentals of Electric Drives – by G K Dubey Narosa Publications

T2. Power Semiconductor Drives, by S.B. Dewan, G.R.Slemon, A.Straughen, Wiley-India Edition.

REFERENCES:

R1. Electric Motors and Drives Fundamentals, Types and Apllications, by Austin Hughes and Bill Drury, Newnes.

R2. Thyristor Control of Electric drives – Vedam Subramanyam Tata McGraw Hill Publications.

R3. Power Electronic Circuits, Devices and applications by M.H. Rashid, PHI.

R4. Power Electronics handbook by Muhammad H.Rashid, Elsevier.

FACULTY **HOD**

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EXPERIMENTS RELATED TO COURSE

S.No.	Experiment
1.	Performance & speed control of D.C. drive using 3-phase full Converter.
2.	Performance & Operation of a four quadrant Chopper on D.C. Drive
3.	Performance & speed control of 3 phase slip ring Induction motor by Static Rotor Resistance controller.

QUESTION BANK

UNIT-I

S.No.	Question	Taxonomy Level	Related to CO	Marks
1.a)	Explain the different components of basic electrical drive system.	Comprehension	C325.1	5
b)	Describe different braking methods employed for electrical motors.	Comprehension	C325.1	5
2.a)	Explain the four quadrant operation of a motor drive in general.	Comprehension	C325.1	5
b)	Describe different braking methods employed for D.C. motors.	Comprehension	C325.1	5
3.a)	what do you mean by regenerative braking of motor? Explain.	Comprehension	C325.1	5
b)	Explain about nature and classification of different load torques.	Comprehension	C325.1	5
4.a)	Explain the different components of basic electrical drive system.	Comprehension	C325.1	5
b)	Explain the four quadrant operation of a motor drive in general.	Comprehension	C325.1	5
5.a)	Explain about fundamental torque equation.	Comprehension	C325.1	5
b)	What are advantages of electrical drive?	Comprehension	C325.1	5
6.a)	what are the advantages of Electric drives?	Comprehension	C325.1	5
b)	State the essential parts of Electric drives? What are the functions of a power modulator?	Comprehension	C325.1	3
c)	How do you define the active and passive load torques? What are the differences between the two?	Comprehension	C325.1	2

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UNIT-II

S.No.	Question	Taxonomy Level	Related to CO	Marks
1.a)	Explain the operation of a separately excited dc motor supplied from 3-phase fully Controlled rectifier with necessary diagrams. Assume Continuous conduction.	Comprehension	C325.2	5
b)	A 220V, 1440rpm, 120A separately excited DC motor with armature resistance of 0.7 is fed from 3-phase fully controlled converter with an ac source line voltage 440V, 50 Hz supply. A star connected transformer is used to feed the armature so that motor terminal voltage equals rated voltage when converter firing angle is Zero. Calculate the value of firing angle when motor is running at 1200 rpm at rated Torque.	Analysis	C325.2	5
2.a)	Explain the operation of 3-phase six pulse converter feeding DC series motor with neat diagram and relevant waveforms	Comprehension	C325.2	5
b)	A 200V, 875rpm, 150A separately excited dc motor has an armature resistance of 0.06ohm. It is fed from a three phase fully controlled rectifier with an ac source of 220V, 50Hz. Assuming continuous conduction, calculate (i) Firing angle for rated motor torque and 750rpm. (ii) Motor speed for α=160 and rated torque.	Analysis	C325.2	5
3.a)	Explain the operation of dual converter controlling the separately excited dc motor.	Comprehension	C325.2	5
b)	A 220 V, 1500 rpm, 11.6 A separately excited motor is controlled by a 3-phase fully controlled rectifier with an ac source voltage of 230 V, 50 Hz. Enough filter inductance is added to ensure continuous conduction for any torque greater than 25 percent of rated torque, Ra = 2 ohm. (i)What should be the value of the firing angle to get the rated torque at 1000 rpm? (ii)Ca1culate the firing angle for the rated braking torque and –1500 rpm. (iii)Ca1culate the motor speed at the rated torque and α = 160 for the regenerative braking in the second quadrant.	Analysis	C325.2	5
4	Explain the operation of a separately excited dc motor supplied from 3-Φ full controlled rectifier.	Comprehension	C325.2	10

5	A 12.2 kW, 230 V, 850 rpm, 56 A dc separately exited motor is controlled by a 3-phase fully-controlled rectifier fed from 460 V, 60 Hz ac supply through a transformer. It has an armature resistance of 0.284and sufficient inductance to assure continuous conduction for all operating points with torques greater than 20 percent of the rated. The transformer and the source impedance can be neglected. (A) A rated dc voltage across the motor at full load is desired. Choose a suitable transformer from the following three available: (i) 460/460 V(ii) 460/230 V(iii) 460/ 180 V (B) Having chosen the transformer find the following (i) The rectifier firing angle for the rated torque and speed.(ii) The rectifier firing angle for the rated braking torque and the speed of 600 rpm in the reverse direction.	Analysis	C325.2	10
6	Briefly explain different speed control techniques for D.C. motor.	Comprehension	C325.2	10

UNIT-III

S.No.	Question	Taxonomy Level	Related to CO	Marks
1	Explain with circuit and waveforms of four quadrant chopper fed separately excited DC motor.	Comprehension	C325.3	10
2	A 230V, 960rpm and 200A separately excited dc motor has an armature resistance of 0.02 ohm. The motor is fed from a chopper, which is capable of providing both motoring and braking operations. The source has a voltage of 230V. Assuming continuous conduction: When motor is operated in dynamic braking, with Braking resistance of 2 ohm. (i) Calculate Duty ratio of chopper for a motor speed of 600 rpm and braking torque of twice the rated value. (ii) What will be the motor speed for a duty ratio of 0.6 and motor torque equal to twice its rated value?	Analysis	C325.3	10
3	Explain with circuit and waveforms of two quadrant chopper fed separately excited DC motor.	Comprehension	C325.3	10

4	A 230V, 960 rpm and 200A separately excited dc motor has R_a=0.02ohm. The motor is fed from a chopper which provides both motoring and braking operations. Assume continuous conduction. Calculate duty ratio of chopper for motoring and braking operations at rated torque and 350 rpm.	Analysis	C325.3	10
5	A 230 V, 960 rpm and 200A separately excited dc motor has an armature resistance of 0.02Ω. The motor is fed from a chopper, which is capable of providing both motoring and braking operations. The source has a voltage of 230 V.Assuming continuous conduction: (i) Calculate the time ratio of chopper for the motoring action at rated torque and 350 rpm. (ii) Determine the maximum possible speed, if maximum value of time ratio is 0.95 and maximum permissible motor current is twice the rated value	Analysis	C325.3	10
6	Explain the operation of a four quadrant chopper fed to the D.C series motor and also draw the current and voltage wave forms for continuous current operation.	Comprehension	C325.3	10

UNIT-IV

S.No.	Question	Taxonomy Level	Related to CO	Marks
1.a)	Discuss speed control of induction motor from stator side with speed-torque curves.	Comprehension	C325.4	5
b)	The parameters of a three phase 400 Volts, 50 Hz, 6 pole, 960 rpm, and star connected induction motor has the following parameters per phase referred to the stator. R1= 0.4 Ohm. R2 = 0.20 Ohm, X1 = X2 =1.5 Ohm, Xm = 30 Ohms. If the motor is controlled by variable frequency control at a constant flux of rated value,determine the motor speed and the stator current at half the rated torque and 25Hz	Analysis	C325.4	5
2.a)	Explain why stator voltage control is suitable for speed control of Induction motors in fan and pump drives. Draw and explain speed control of 3 phase Induction motor using AC Voltage Controller.	Comprehension	C325.4	5

b)	The rotor resistance and stand still reactance referred to stator of a 3 phase, 4 pole, 50Hz Squirrel cage Induction motor is 0.2 ohm and 0.8 ohm per phase respectively. The full load slip of the motor is 4 percent. Neglect stator resistance and leakage reactance. Determine how much stator voltage should be reduced in order to get a speed of 1200rpm if the load torque remains constant.	Analysis	C325.4	5
3.a)	Show that variable frequency control of induction motor is more efficient than stator voltage control.	Comprehension	C325.4	5
b)	A 440V, 3 phase, 50 Hz, 6 pole, 945 rpm, delta connected Induction Motor has the following parameters referred to the stator.Rs = 2Ω, Rr = 2Ω, Xs= 3Ω, Xr = 4Ω.When driving a fan load at rated voltage it runs at rated speed. The motor speed is controlled by stator voltage control. Determine motor terminal voltage, current and torque at 800 RPM.	Analysis	C325.4	5
4.a)	Explain speed control of induction motor by AC Voltage Controllers.	Comprehension	C325.4	5
b)	A 3 phase, 4 pole, 50 Hz squirrel cage Induction motor has the following circuit parameters:r1 = 0.05ohm, r2 = 0.09ohm, X1 + X2 = 0.55ohm.The motor is star connected and rated voltage is 400V. It drives a load whose torque is proportional to the speed and is given as Tl = 0.05ω N-m. Determine the speed and torque of the motor for a firing angle of 450 of the AC Voltage Controller on a 400V,50 Hz supply.	Analysis	C325.4	5
5.a)	Discuss how v/f speed control scheme of a induction motor is similar to the armature voltage control method of a DC motor.	Comprehension	C325.4	5
b)	Why stator voltage control is an inefficient method of induction motor speed control.	Comprehension	C325.4	5
6.a)	Explain why stator voltage control is suitable for speed control of induction motors in fan and pump drives.	Comprehension	C325.4	5
b)	Variable frequency control of induction motor has higher efficiency and better low speed performance when fed from a PWM inverter instead of 6-step inverter. Explain	Comprehension	C325.4	5

UNIT-V

S.No.	Question	Taxonomy Level	Related to CO	Marks
1.a)	Draw a suitable circuit diagram and explain the working of slip-power recovery scheme using commutator-less Kramer drive.	Comprehension	C325.5	5

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b)	A 3-phase, 440 V, 50 Hz, 6-pole, 970 rpm, Y-connected induction motor has the following parameters referred to stator: Rs=0.2 Ω, Rr'=0.15 Ω, Xs=Xr'=0.4 Ω, stator to rotor turns ratio is 3.5. Motor is controlled by static Scherbius drive. The drive is designed for a speed range of 30% below the synchronous speed. The maximum value of firing angle is 170. Calculate turns ratio of transformer and torque for a speed of 750rpm and α=140 .	Analysis	C325.5	5
2.a)	Draw the circuit diagram and explain the working of a slip power recovery system using Static Kramer drive for a three phase induction motor.	Comprehension	C325.5	5
b)	Explain with circuit and waveforms for speed control of induction motor by Static rotor resistance method.	Comprehension	C325.5	5
3.a)	Explain static Scherbius drive control for speed control of induction motor. Draw speed -torque characteristics.	Comprehension	C325.5	5
b)	Explain with circuit and waveforms for speed control of induction motor by Static rotor resistance.	Comprehension	C325.5	5
4.a)	Draw the circuit diagram and explain the working of a slip power recovery system using static Scherbius system for a three phase induction motor.	Comprehension	C325.5	5
b)	Explain Static Kramer drive for a three phase induction motor	Comprehension	C325.5	5
5.a)	Draw the circuit diagram and explain the operation of rotor- resistance control of Induction motor. Mention the advantages and disadvantages of the above method of control	Comprehension	C325.5	5
b)	Explain Static Kramer drive for a three phase induction motor.	Comprehension	C325.5	5
6.a)	Draw the circuit diagram and explain the working of a slip power recovery system using Solid - State Scherbius system for a three-phase induction motor.	Comprehension	C325.5	5
b)	A 3 Phase, 400V, 50 Hz, 10 KW 960 rpm, 6 pole star connected slip ring Induction motor has the following constants referred to the stator. Rs = 0.4 Ω, Rr' = 0. 6 Ω, Xs = Xr' = 1.4 Ω. The motor drives a fan load at 960 rpm. The Stator to rotor turns ratio is 2.When the motor is controlled by a static rotor resistance control, calculate the value of external resistance so that motor runs at 800 rpm for duty ratio of 0.5.	Analysis	C325.5	5

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UNIT-VI

S.No.	Question	Taxonomy Level	Related to CO	Marks
1	Describe separate controlled and self-controlled modes of operation of a synchronous motor drive in detail and compare them.	Comprehension	C325.6	10
2.a)	Describe self-controlled and load-commutated inverter controlled synchronous motor drives in detail.	Comprehension	C325.6	5
b)	Draw the block diagram of a closed loop synchronous motor drive fed from VSI	Comprehension	C325.6	5
3.a)	Explain the operation of Load commutated CSI fed Synchronous motor drive.	Comprehension	C325.6	5
b)	In variable frequency control of a synchronous motor why (V/f) ratio is maintained constant up to base speed and V constant above the base speed. Explain briefly with necessary waveforms.	Comprehension	C325.6	5
4.a)	Describe the operation of self-controlled Synchronous Motor drives in detail.	Comprehension	C325.6	5
b)	Describe the open-loop and closed loop methods of speed control of a synchronous motor using VSI.	Comprehension	C325.6	5
5.a)	How is the output voltage of a VSI improved by PWM techniques? Explain how you will use this converter for speed control of a synchronous motor.	Comprehension	C325.6	5
b)	Discuss in detail with suitable circuit diagram the principle of operation of selfcontrolled Synchronous motor drive employing load commutated thyristor inverter	Comprehension	C325.6	5
6.a)	Describe self-controlled and separate controlled mode of operation of a synchronous motor drive in detail and compare them.	Comprehension	C325.6	5
b)	A 500KW, 3-ph, 3.3KV, 50Hz, 0.8(lag) pf, 4 pole star connected synchronous motor has following parameters. Xs=15 ohm, Rs=0, rated field current is 10A.calculate (i)Armature current and power factor at half the rated torque & rated field current. (ii)Field current to get unity power factor at the rated torque.	Analysis	C325.6	5