SUMMER – 2022 EXAMINATION

Subject Name: Industrial Drives & Control **Model Answer:** **22629: IDC**

Important Instructions to examiners:

1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given more Importance (Not applicable for subject English and Communication Skills).
4) While assessing figures, examiner may give credit for principal components indicated in the figure. The figures drawn by candidate and model answer may vary. The examiner may give credit for any equivalent figure drawn.
5) Credits may be given step wise for numerical problems. In some cases, the assumed constant values may vary and there may be some difference in the candidate's answers and model answer.
6) In case of some questions credit may be given by judgement on part of examiner of relevant answer based on candidate's understanding.
7) For programming language papers, credit may be given to any other program based on equivalent concept.

Q. No.	Sub Q. N.	Answer	Marking Scheme
1.		**Attempt any FIVE of the following:**	**10 Marks**

a) State the need of electric drives.

Ans:

Need of Electric Drives:

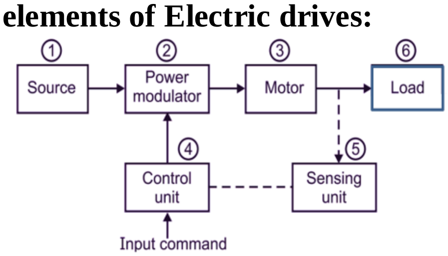
1) Electrical energy is the most versatile form of energy. So to produce mechanical movement or motion in industry, electric (motor) drive is needed.
2) The conversion efficiency of electrical energy converter is comparatively high, so in most of the applications where mechanical energy is required, electric (motor) drive is used.
3) In many industrial applications, speed control of electric motors is required, which can be done with the help of electric drive.
4) In many industrial applications, along with speed control of electric motors, torque and power control is also necessary, which can be done with the help of electric drive.
5) For precise control of electric motor, electric drive is needed.
6) For reliable control of electric motor, electric drive is needed.
7) For remote control of electric motor, electric drive is needed.
8) To match the characteristics of motor with load, electric drive is needed.
9) To obtaining optimum performance of motor, electric drive is needed.
10) For energy saving, electric drive is needed.
11) To implement the modern technologies, electric drive is the best option.
12) For automation and smart applications, electric drive is the best option.

1 Mark for each of any two points = 2 Marks

b) Draw block diagram of the basic elements of electric drives.

Ans:

Block diagram of the basic elements of Electric drives:



2 Marks for correct diagram

c) List the advantages of converter controlled drives.

Ans:

Advantages of Converter controlled drives:

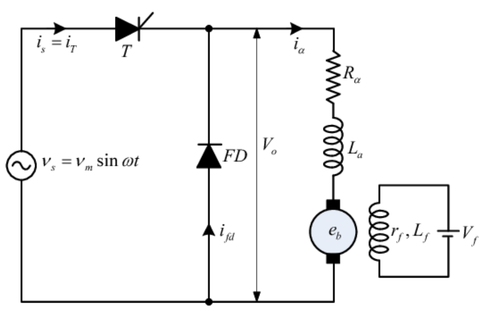
1) Highly efficient: The conduction losses and switching losses in converters are less, hence they are highly efficient.
2) Highly reliable: The converters do not have moving parts, there are very less failure chances and hence has a very rugged performance and long life, provided it is operated under rated conditions.
3) Faster dynamic response: Due to static converter, they exhibit faster dynamic response.
4) Negligible maintenance: Due to absence of mechanical moving parts, the power electronic converters require almost nil maintenance.
5) Small size: These power electronic converters are very small in size and hence less weight, less floor space, less handling issues, less installation cost, less packing and transportation prices and many more.
6) Smooth and precise control: Control over acceleration, deceleration, speed control, starting, stopping etc.
7) Power factor control: Effective control over power factor can be implemented.
8) Energy saving: Efficient operation finally results in energy saving.

1 Mark for each of any two advantages = 2 Marks

d) Draw the circuit diagram of single phase half wave controlled converter drive.

Ans:

Circuit diagram of single phase half wave controlled converter drive:



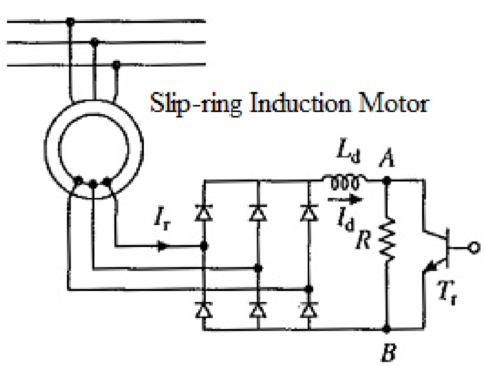
Single phase half wave converter drive

2 Marks for correct circuit diagram

e) Draw the circuit diagram of rotor resistance control method of Induction motor.

Ans:

Circuit diagram of rotor resistance control method of Induction motor:



2 Marks for correct circuit diagram

OR Equivalent Circuit

f) State the advantages of microcontroller based system over electronic speed control systems.

Ans:

Advantages of microcontroller based system over electronic speed control systems:

1. Use of microcontroller reduces the complexity of the system.
2. Software supported control using microcontrollers result in the least hardware, making the system economically viable or cost effective.
3. Number of parts in control system is reduced.
4. Reliability of the control of the drives is higher.
5. Control is free from drift and parameter variations due to temperature.
6. The information can flow in both forward (in) and backward (out) directions.
7. Proper shielding may minimise the EMI problems.
8. Control may be extended as it is compatible with the host computer.
9. Speed detection schemes are completely digital, avoiding the errors of measurement. This improves the accuracy even at very low speeds.
10. Control efficiency is more.
11. Concepts of modern control theory can be used in the control.
12. Control is capable of performing the control functions, such as decision making, complicated computations, etc.
13. Control also permits several other functions, such as data acquisition, monitoring and warning, diagnosis, etc.
14. Fault diagnosis of digital control systems is easier than that of a dedicated Hardware Systems.
15. It is easy to maintain the system.

1 Mark for each of any two advantages = 2 Marks

g) State the functions of microprocessor in drives.

Ans:

Functions of microprocessor in drives:

1. Generating and providing firing pulses to the converters
2. Generation of necessary waveforms to feed the motors
3. Nonlinear function generation. Estimation of feedback signals. Implementation of software supported controllers in the feedback control, such as current controllers, speed controllers, etc. The limiters are also implemented to limit the control variables to safe values
4. Processing the measured signals, such as voltage, current and speed.
5. Storing and processing the information of controlled quantities.
6. Estimation of feedback signals and computation of reference quantities which cannot be directly measured, such as torque and flux.
7. Adaptive control and optimization
8. General sequencing control.
9. Monitoring and warnings.
10. Diagnostics and tests.

1 Mark for each of any two functions = 2 Marks

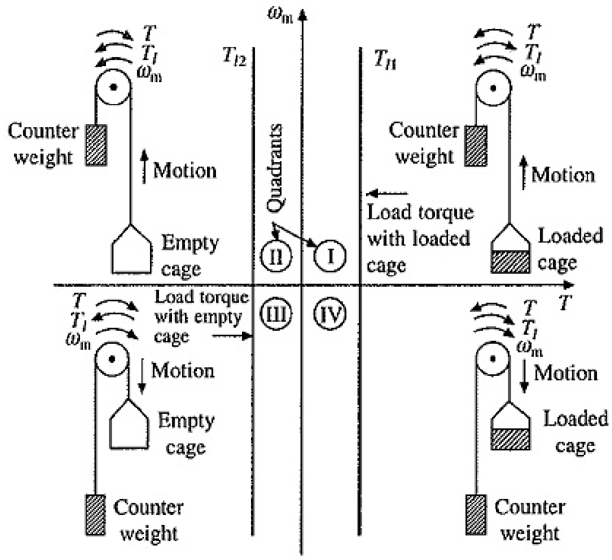
2. Attempt any THREE of the following: **12 Marks**

a) Describe the four quadrant operation of a hoist with speed torque characteristics?

Ans:

Four quadrant operation of a hoist:

The hoist drive system operates in four quadrants such as, in quadrant one – forward motoring, in quadrant two – forward braking, in quadrant three – reverse motoring, and in quadrant four – reverse braking.



Four quadrant operation of a motor driving a hoist load

2 Marks for diagram

Quadrant I Operation: In quadrant one, the weight of loaded cage is greater than the weight of counterweight, the load torque produced by loaded cage may cause rotation in clockwise direction which is opposite to that of actual rotation. In order to pull up the loaded cage, a motor must produce the torque to rotate motor in the anti-clockwise direction. Here, the speed is positive, the power developed is also positive and the operation is forward motoring.

2 Marks for explanation

Quadrant II Operation: In quadrant two, the weight of the cage is less than the weight of the counterweight. So the cage is pulled up naturally and in order to limit the speed to the safe value, the motor must produce braking torque to oppose anticlockwise rotation. The load torque causes rotation in an anticlockwise direction. Here, the speed is positive whereas the power developed is negative and operation is forward braking.

Quadrant III Operation: In quadrant three, the weight of the empty cage is less than the counter weight. In order to lower the empty cage i.e pull up the counterweight, the motor must produce torque to cause rotation in a clockwise direction. The load torque produced by counter weight is opposite to motor torque causing clockwise rotation. Here, the speed is negative and power developed is positive. The operation is reverse motoring.

Quadrant IV Operation: In quadrant four, the weight of the cage is more than the weight of the counterweight. Here the loaded cage is pulled down naturally and in order to limit the speed to a safe level, the motor must produce the torque to oppose clockwise rotation. Here, both speed and power developed are negative, hence the operation is reverse braking.

b) Compare single phase and three phase full converter drives (Any four points).

Ans:

Sr. no.	Single phase full converter drive	Three phase full converter drive
1	The output ripple (peak to peak) is large compared to three phase drive.	The output ripple is small.
2	They are used for low power application	They are used for high power applications, up to megawatt power level
3	The ripple frequency is small.	The ripple frequency is large.

1Marks for each of any 4 points = 4 Marks

4	Filter requirement is high compared to three phase drives.	Filtering requirement is less as peak to peak ripple content is less.
5	Peak/average and rms/average current ratios are comparatively high.	Peak/average and rms/average current ratios are comparatively less.
6	The commutating capability of single-phase drives is inferior.	The commutating capability of three-phase drives is better.
7	The armature current is not continuous.	The armature current is mostly continuous.
8	Motor heating at given torque is more due to large harmonics.	Motor heating is comparatively less due to less harmonics.
9	Motor performance is good.	Motor performance is better.
10	The power factor improvement is possible in single phase drives over complete range of firing angles.	The power factor improvement is possible in three phase drives only in a certain range of firing angles.

c) State the role of drives in sugar mills.

Ans:

Role of drives in sugar mills:

1. To drive the centrifuge in the speed range of 50 rpm to 1000 rpm.
2. To drive the centrifuge at 200 rpm during charging of syrup.
3. To drive the centrifuge at speeds of 500 rpm & 1000 rpm for separation of crystals from syrup.
4. To drive the centrifuge by lowering the speed in steps to 50 rpm at which the ploughing takes place.
5. To reduce energy loss during starting and braking of motor.
6. To employ the regenerative braking.
7. To employ soft starting of motor.

1 Mark for each of any four = 4 Marks

d) Draw labelled block diagram of Phase Lock Loop (PLL) control DC motor drive. State the function of each block.

Ans:

Phase Lock Loop (PLL) control DC motor drive:

The Phase Locked Loop block diagram is shown in fig. (a).

Phase Detector: It compares two pulse trains: Reference pulse train of frequency f^* and the feedback pulse train of frequency f. Output of the phase detector produces a pulse-width modulated output V_c. Pulse-width of V_c depends on the phase difference between the two input pulse trains and polarity depends on the sign of phase difference (i.e. lag or load) between them.

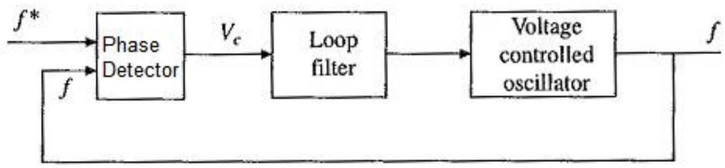
Loop Filter: The output of the phase detector is filtered by the loop filter to obtain a dc signal and applied as control voltage to a voltage controlled oscillator (VCO).

Voltage Controlled Oscillator (VCO): It is an oscillator which produces pulse train of frequency f, which is also the feedback signal f. Because of the closed-loop, VCO output frequency f changes in a direction that reduces the phase difference. When steady state is reached, f becomes exactly equal to f* and the loop is said to be locked.

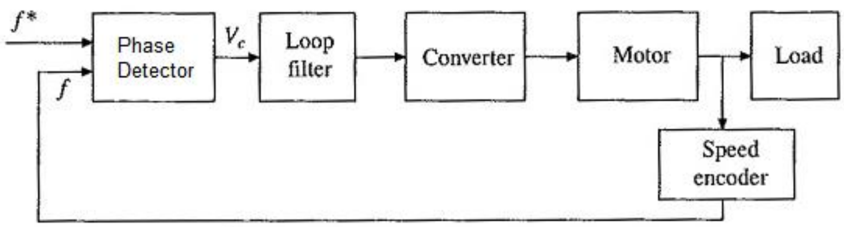
Control voltage required by VCO to produce f equal to f* comes from the phase difference between the two input signals. If now f* is altered, f will follow the change and control voltage required by VCO will be obtained by the adjustment of phase difference between the two input signals.

½ Mark for Explanation of each of 4 blocks = 2 Marks

2 Marks for diagram in Fig.(b)



(a) Phase-Locked-Loop (PLL)



(b) Closed-loop speed control using PLL

Phase Locked Loop (PLL) Control

An electrical drive employing Phase Locked Loop Control is shown in Fig.(b).
The VCO is replaced by converter, motor and speed encoder.
Output of the loop-filter forms the control signal for the converter. It alters the converter operation such that the motor speed adjusts to make the frequency (f) of speed encoder output signal equal to the frequency of reference signal (f^*). By changing f^* the motor speed can be changed.
Speed Encoder: It senses the motor speed and generates the pulse train of frequency (f).
The Phase Locked Loop Control (PLL) can achieve a speed regulation as low as 0.002% which can be useful in conveyers for material handling, paper and textile mills, and computer peripherals. The Phase Locked Loop Control are available as inexpensive integrated circuits.

3. Attempt any THREE of the following: 12 Marks

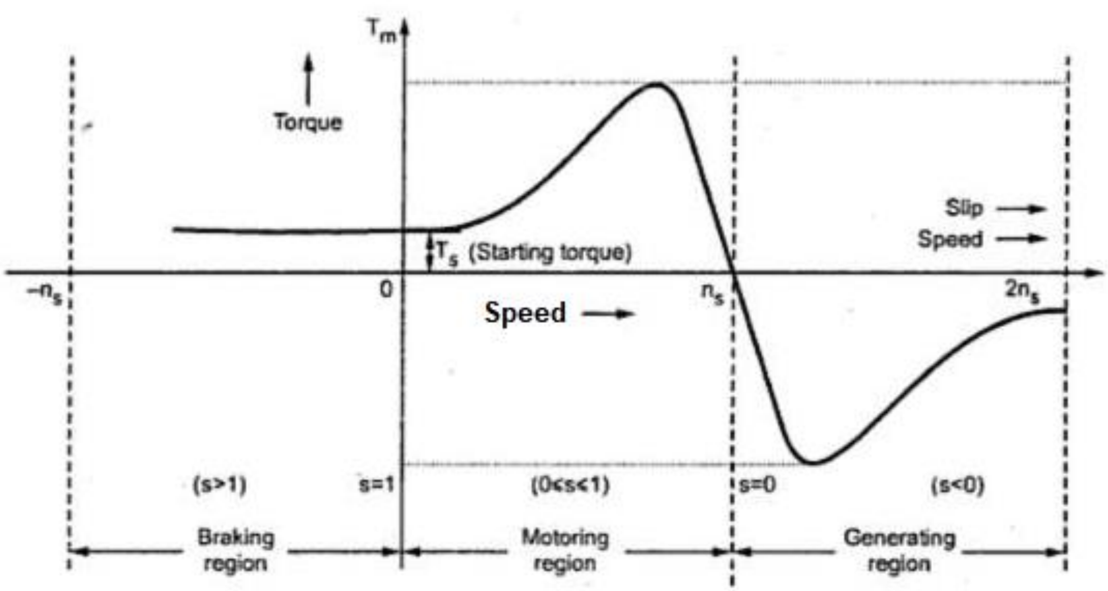
a) Draw speed torque characteristics of Induction motor showing all regions.

Ans:

Speed torque characteristics of Induction motor:

1 Mark for diagram

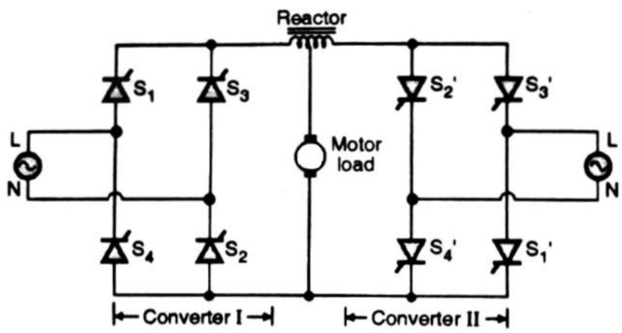
1 Mark for showing each of 3 region = 3 Marks



b) Draw the circuit diagram of single phase dual converter drive and explain its operation.

Ans:

Single phase Dual Converter Drive:



Circuit Diagram of a Single Phase Dual Converter Drive

2 Marks for circuit diagram

Operation:

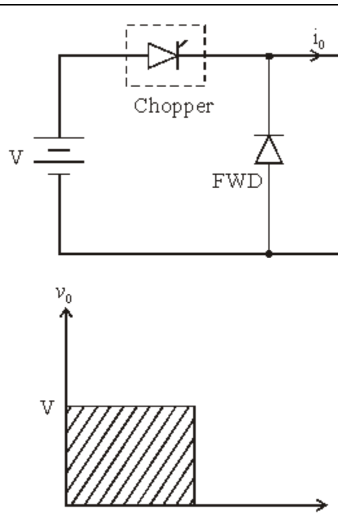
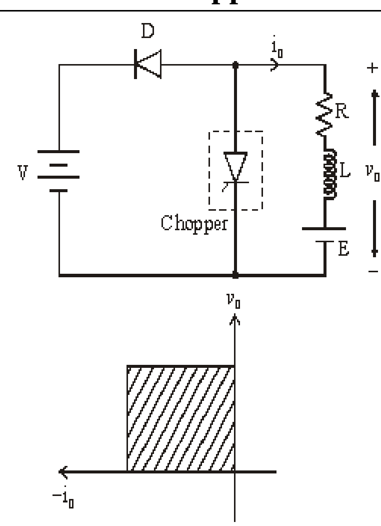
A single-phase dual converter drive feeding a DC motor is shown in the figure. This dual converter drive is basically a combination of two full-wave converters – Converter I and Converter II, as shown. When only converter I operates, positive voltage is supplied to armature and motor runs in the forward direction. When only converter II operates, negative voltage is supplied to armature and motor runs in the reverse direction. During these modes i.e forward and reverse motoring, the opposite polarity voltage can appear across the armature due to its large inductance and absence of free-wheeling diode. Hence this drive works in four quadrants. In the absence of free-wheeling diode, during forward or reverse motoring, when load drives motor to over-speed it, the motor can be operated in regenerative braking mode. In regenerative braking mode, the load drives motor and motor returns the energy back to electric supply to reduce the speed (braking operation). In this way, the motor can be operated in total four modes: Forward motoring, forward braking (regenerative), reverse motoring, reverse braking (regenerative).

2 Marks for explanation

c) Compare Class A and Class B chopper drive (Any four points).

Ans:

Class A and Class B chopper drive:

Class A chopper drive	Class B chopper drive
	
It is step down chopper drive, it means that	It is step up chopper drive, it means that the

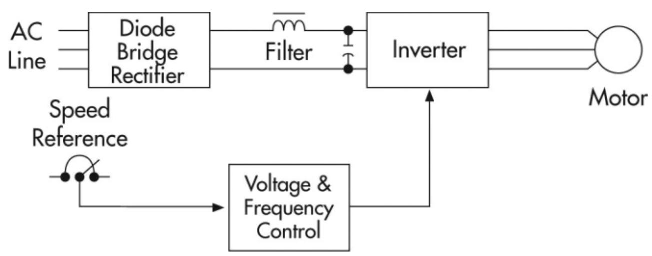
1 Mark for each of any four points = 4 Marks

the output DC voltage is less than the input DC voltage.	output DC voltage is greater than the input DC voltage.
It is first quadrant chopper drive, it means that the output voltage as well as output current is positive.	It is second quadrant chopper drive, it means that the output voltage is positive but output current is negative.
It is called as forward motoring drive.	It is called as regenerative braking drive.
The power flows from supply side to load side.	The power flows from load side to supply side.

d) Describe the working of V/F control method for speed control of Induction motor with neat block diagram.

Ans:

V/F control method for speed control of Induction motor:



2 Marks for block diagram

OR any other equivalent block diagram

The speed of rotating magnetic field produced by stator winding is given by,

Synchronous speed $N_s = \frac{120f}{P}$ rpm.

where, f is the frequency in hz and P is the no. of poles of rotating magnetic field.

The rotor rotates slightly slower than the synchronous speed of the motor. This is because the magnetic field is cut by rotor conductors and induced emf causes currents to flow in the rotor windings, producing a torque which turns the rotor; so if the rotor turns at the same speed as the magnetic field, there would be no relative motion between the rotor and the magnetic field, no flux cutting, no emf induction, no current and no torque would be produced. Therefore, rotor speed is always less than the synchronous speed. When load increases, the speed drops down. However, the change in speed from no load condition to full load condition is small. So the induction motor is considered as fixed or constant speed drive. Thus when operated from a constant frequency power source (typically 50Hz), AC induction motors are fixed speed devices.

2 Marks for explanation

A variable frequency drive controls the speed of an AC motor by varying the frequency supplied to the motor. The drive also regulates the output voltage in proportion to the output frequency to provide a relatively constant ratio of voltage to frequency (V/f), as required by the characteristics of the AC motor to produce adequate torque.

The first step in this process is to convert the AC supply voltage into DC by the use of a rectifier. DC power contains voltage ripples which are smoothed using filter capacitors. This section of the VFD is often referred to as the DC link.

This DC voltage is then converted back into AC. This conversion is typically achieved through the use of power electronic devices such as IGBT, power transistors etc. using a technique called Pulse Width Modulation (PWM). The output voltage is turned on and off at a high frequency, with the duration of on-time, or width of the pulse, controlled to

approximate a sinusoidal waveform. The frequency of such approximate sinusoidal waveform is also controlled so as to obtain the desired speed.
The entire process can controlled by a microprocessor which monitors the:

- incoming voltage supply,
- speed set-point,
- DC link voltage,
- output voltage and current to ensure operation of the motor within established parameters.

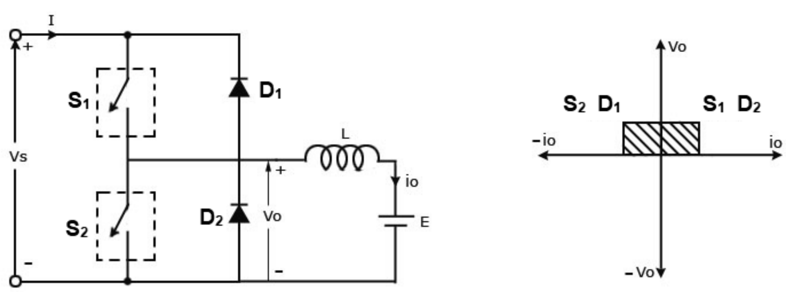
Many alternative approaches are available to implement the V/f control.

4. Attempt any THREE of the following: **12 Marks**

a) Identify type of chopper for forward motoring and forward braking of DC motor. Justify your answer with neat sketch.

Ans:
The Class C (Type-C) chopper is used for forward motoring and forward braking.

Class C (Type C) chopper:



Class C or Type C Chopper

1 Mark for Identifying the chopper

The circuit configuration of Class C (Type C) chopper is shown in the fig. It is essentially a two-quadrant chopper in the sense that the load current can be either positive or negative but the load voltage is always positive, as shown in fig. It is a combination of class A and class B chopper. Keeping chopper S_2 inoperative, the circuit behaves as Class A chopper and keeping chopper S_1 inoperative, the circuit behaves as Class B chopper.

3 marks for justification

(i) **Class A operation (Forward Motoring):**
In this operation the chopper S_1 is turned on and turned off alternately. When the chopper S_1 is turned on, the DC source voltage gets applied across the load and supplies load current. When the chopper S_1 is turned off, the load inductance forces current through free-wheeling diode D_2 which makes the load voltage zero. Thus the load voltage is either positive or zero and the load current is positive. Thus the chopper is operated in first quadrant.

(ii) **Class B operation (Regenerative Braking)**:

In this operation, the load current (i_0) is opposite to that shown in the fig. When the chopper S_2 is turned on, the load voltage becomes zero, the emf E drives load current i_0 through load parameters R-L and S_2. When chopper S_2 is turned off (opened), the load inductive voltage reverses its polarity and aids the emf E to force current through D_1 and V_s. The load voltage thus becomes equal to Vs. Thus the load voltage is either zero or positive and the load current is negative. Thus the chopper is operated in second quadrant. The class C chopper can operate either as a rectifier or as an inverter. This chopper is thus used for controlling the motoring and regenerative braking of DC motors.

b) State the sequence of stages involved in textile mill and the types of drives used for it.

Ans:

Various stages involved in textile mill and its speed ratings at each stage are:

1. **Ginning**: The process of separating seeds from raw cotton is called ginning. The ginning motors have speed ranges of 250-1450 rpm. The load speeds are fairly constant and no speed control is required. Commercially available squirrel cage induction motors may be employed
2. **Blowing**: The ginned cotton in the form of bales is opened up and cleaned in the blowing room. The normal induction motors having synchronous speed of 1000 or 1500 rpm may be employed. No speed control is required.
3. **Cording**: The process of converting cleaned cotton into laps is done by lap machines. These machines are normal squirrel cage induction motors. These laps are converted to slivers by a process called "Cording". A motor used for cording is required to accelerate a drum having a large moment of inertia and to withstand prolonged accelerating periods. The motor must have a very high starting torque and low starting current. Therefore, three-phase totally enclosed and /or fan cooled squirrel cage induction motor with high starting torque or slip-ring induction motor with rotor resistance starter may be employed.
4. **Straightening**: The thick fibers called slivers are converted to uniform straight fibers. Speed range is up to 1000 rpm. Normal standard squirrel cage induction motors can be employed.
5. **Combing/Lap operation**: This process upgrades the fiber. Speed range is 1000 rpm and normal squirrel cage induction motors can be employed.
6. **Spinning**: The thread is thinned down in two or three stages. Speed range is 500 rpm and motor having smooth acceleration is employed. The spinning motor must be capable of drawing, twisting and winding operations. Two speed pole change induction motor can be employed.
7. **Winding, warping and sizing**: For these operations speed range is 100 rpm and normal squirrel cage induction motor can be employed..
8. **Looms**: The weaving of yarn into cloth is done in looms. Speed range is 600-750 rpm and three-phase totally enclosed induction motor with high starting torque are employed.

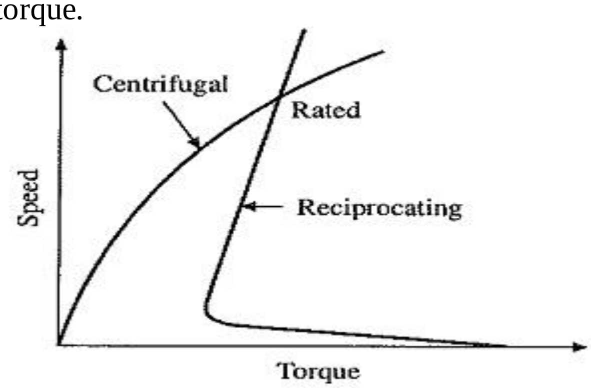
1 Mark for each of any 4 stages and corresponding drive = 4 Marks

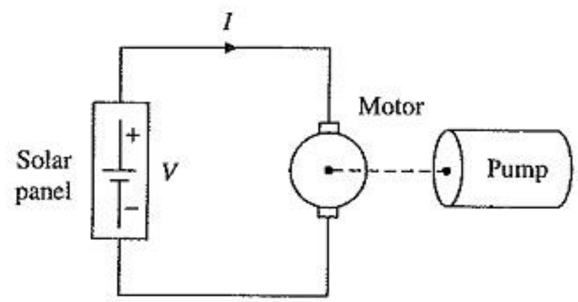
c) Describe with diagram the operation of centrifugal solar powered pump drives.

Ans:

Solar Powered Pump Drives:

Solar powered pump drives can be centrifugal and reciprocating. Their speed-torque characteristics are shown in Fig. Centrifugal pump requires only a small torque to start whereas reciprocating pump owing to stiction may require as much as three times the rated torque.

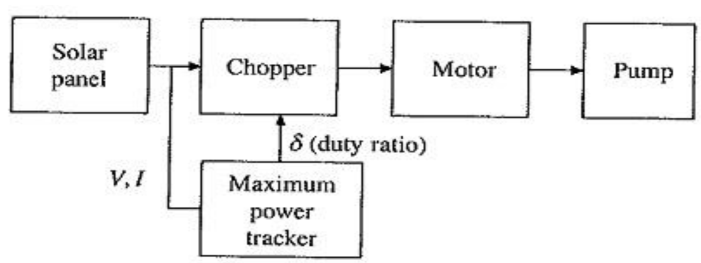




2 Marks for diagram

2 Marks for description

A simple scheme of Solar Powered Pump Drives using a permanent magnet dc motor is shown in Fig. The solar panel directly feeds the motor. One can connect the solar cells to form a low-voltage-high-current or low-current-high-voltage unit. A low current-high-voltage arrangement is preferred because of lower proportion of losses in the motor and solar panel. However, a dc voltage more than 80 volts may present a serious electrocution hazard and should be avoided. Since the solar cells themselves regulate the maximum output current no starter is required for the dc motor.



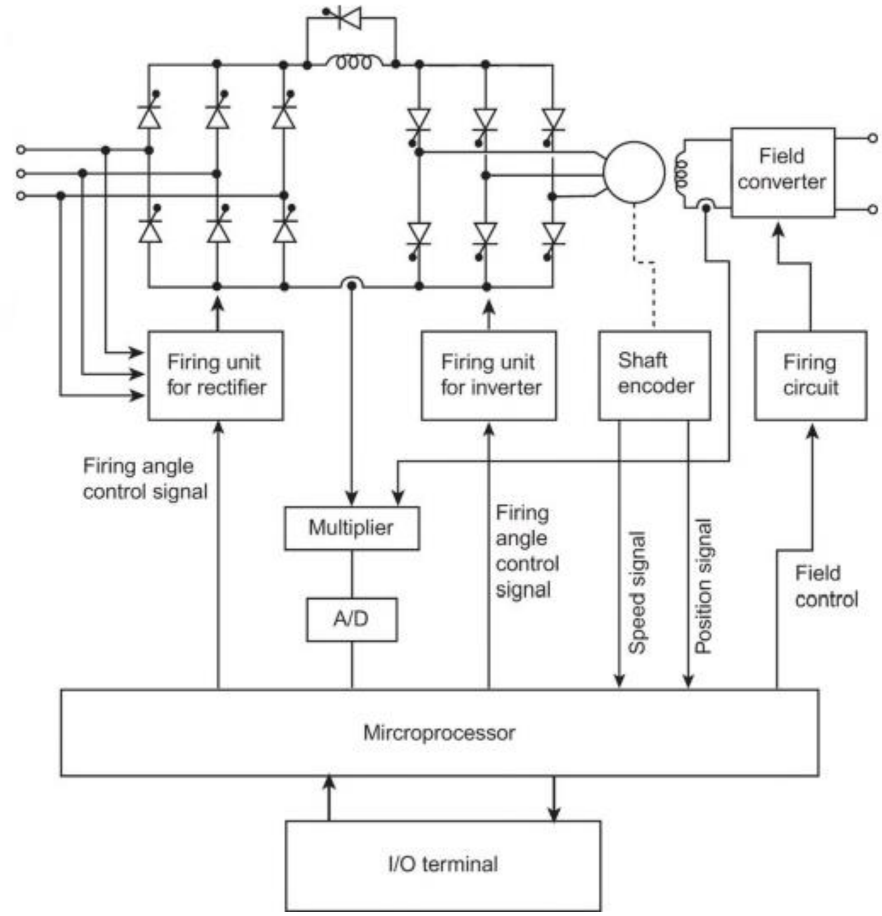
For better matching a step-down chopper is inserted between the solar panel and the motor. With the help of the maximum-power point tracker, the duty ratio of the chopper is varied to obtain the solar panel operation at the maximum power-points for all insolation levels. The circuit for this is shown in Fig. It should, however, be noted that the addition of one more power stage (i.e. chopper) increases the losses.

d) Draw and explain microprocessor based control of synchronous motor drives.

Ans:

Microprocessor based control of synchronous motor drives:

A typical block diagram implementation of a microprocessor for the control of a CSI fed synchronous motor is shown in the Figure. The system consists of a dc link converter which is made up of two six pulse bridge converters interconnected by a high smoothing inductance. The dc link inverter feeds a synchronous motor whose field may be controlled by a chopper or a phase controlled rectifier. In the normal operation, the line side converter operates as a rectifier and the machine side converter acts as an inverter.



2 Marks for diagram

The control pulses to the rectifier are provided by the microprocessor with proper interface between the ac lines and microprocessor, to provide the proper interrupt signal, to synchronize the firing pulses with frequency and to vary the firing angle with respect to the natural firing instant. The synchronous motor is fitted with a shaft encoder. This is an aluminium disc with slots on the periphery mounted on the shaft. A combination of phototransistor and light emitting diode aligned across the slots provides the necessary train of pulses. These pulses are processed to obtain the rotor position as well as the speed. The forced, commutation is available during starting until the machine accelerates to a speed where natural commutation can take over. The stator and field currents are also sensed and converted to digital form before they are fed to the microprocessor for further processing.

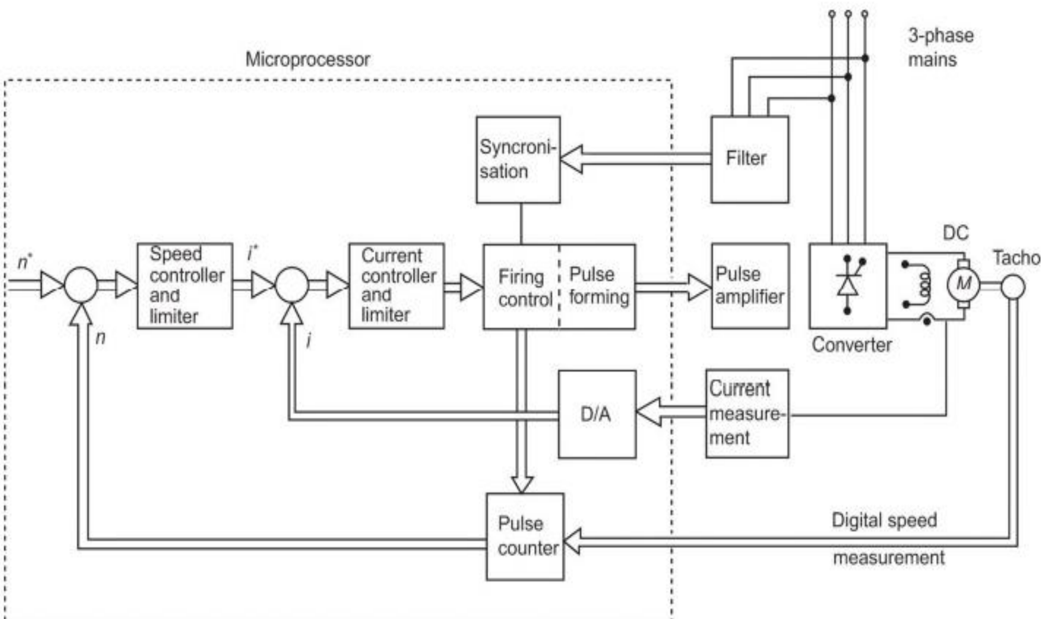
2 Marks for explanation

The functions of the microprocessor can be listed as under:

1. The microprocessor should perform the main functions of monitoring and control of the system variables to obtain the desired performance.
2. It must be supported by proper software to ensure the necessary commutation of the inverter at low speeds.
3. It receives the data concerning the system variables, stator and field currents, and processes them to issue the desired control signals to the rectifier and inverter to achieve the desired performance at all operating conditions.

4. The link current control is obtained by controlling the firing angle of the line side converter. The firing angle control with proper synchronisation with line voltage and with respect to the natural firing instant may be obtained by implementing the method described above with the control of dual converters. Another scheme using phase locked loop can be employed.
5. The microprocessor receives the information regarding the rotor position and processes it to control the firing of the inverter.
6. It must be software supported and have necessary hardware to accomplish the feedback configurations of the control. It must perform the generation of necessary feedback signals, necessary controllers, limiters and function generators using look-up tables. The controllers must be software oriented so that they can be readily modified.
7. It processes the information from the rotor position sensor to determine the speed, which is one of the feedback signals.

e) Draw block diagram of microprocessor based control of DC motor.
Ans:



4 Marks for relevant diagram with labels

5 Attempt any TWO of the following: 12 Marks

5 a) A separately excited dc motor is fed from 230 V, 50 Hz supply via a 1ϕ half controlled bridge rectifier. Armature parameters are L = 0.06 H, R = 0.3 Ω, K_a = 0.9 V/A rad/s and R_f = 104 Ω. The field current is also controlled by a semiconverter and is set to a maximum possible value. T_L = 50 N-m at 800 rpm. The inductances of armatures and field circuits are sufficient enough to make the armature and field currents continuous and ripple free. Compute:

(i) Field current I_f,

(ii) Firing angle of the converter in the armature circuit

Ans:

Data given:

Separately excited DC motor: Armature parameters: L = 0.06 H, R = 0.3 Ω,
K_a = 0.9 V/A rad/sec, R_f = 104 Ω, T_L = 50 N-m at 800 rpm
AC Input condition: V_S = 230V, f = 50 Hz, Single-phase half-controlled bridge rectifier

I) For single-phase semi converter controlled d.c. drive, the expression for field supply voltage is,

$$V_f = \frac{V_m}{\pi}(1 + cos\alpha_f)$$

1 Mark for equation of semiconverter output

The field current is controlled by a semiconverter and is set to a maximum possible value. The maximum field current can flow only when maximum possible voltage is supplied by semiconverter to the field winding. It is obtained only when semiconverter firing angle $\boldsymbol{\alpha_f = 0°}$

1 mark for α_f

$$\therefore V_{fmax} = \frac{V_m}{\pi}(1 + \cos 0°) = \frac{2V_m}{\pi} = \frac{2 \times \sqrt{2} \times V_s}{\pi} = \frac{2 \times \sqrt{2} \times 230}{\pi} = \mathbf{207.07\ V}$$

1 Mark

Maximum field current is given by, $I_f = \frac{V_{fmax}}{R_f} = \frac{207.07}{104} = \mathbf{1.99 A}$

1 Mark for I_f

II) Since the proportionality constant K_a is given as 0.9 V/A rad/s, the equation for back emf get modified as,

$E_b = K_a I_f \omega \qquad \therefore \frac{E_b}{\omega} = K_a I_f$

For DC motor, torque can be expressed as $T = K_a I_f I_a$

Under steady-state condition, T = T_L

Armature current is given by,

$$I_a = \frac{T}{K_a I_f} = \frac{50}{0.9 \times 1.99} = 27.92A$$

1 mark for I_a

The speed in rad/s is given by, $\omega = N\frac{2\pi}{60} = 800\frac{2\pi}{60} = 83.76\ rad/s$

The back emf is given by,

$$E_b = K_a I_f \omega = 0.9 \times 1.99 \times 83.76 = 150.01\ V$$

Armature voltage is given by, $V_a = E_b + I_a R_a = 150.01 + (27.92 \times 0.3) = 158.39\ V$

1 Mark for E_b

Since the armature is supplied from the semiconverter, the armature voltage can be expressed as, $V_a = \frac{V_m}{\pi}(1 + cos\alpha_a) = \frac{\sqrt{2}\times V_s}{\pi}(1 + cos\alpha_a) = 158.39$

$$\frac{\sqrt{2} \times 230}{\pi}(1 + cos\alpha_a) = 103.54(1 + cos\alpha_a) = 158.39$$

$$(1 + cos\alpha_a) = 1.53$$

$$cos\alpha_a = 0.53$$

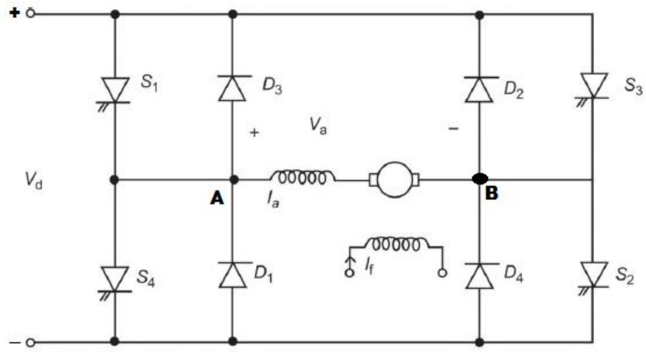
$$\therefore \textbf{Firing angle } \boldsymbol{\alpha_a = 58°}$$

1 mark for α_a

5 b) Draw and describe four Quadrant Chopper Drive.

Ans:

Four Quadrant Chopper Drive:



2 Marks for circuit diagram

OR any other equivalent diagram

Four quadrant chopper drive allows reversal of both voltage and current at the motor terminals, so that reversing and regenerative braking in both directions of rotation can be achieved. The circuit configuration of four-quadrant chopper feeding separately excited DC motor is shown in the figure. The drive operates in four modes corresponding to four quadrant operation.

I) **Forward motoring (Quadrant I operation)**: In this mode, the choppers S_1 and S_2 are ON, making A positive w. r. t. B, the motor current flows from A to B. The source V_d supplies power to motor and the motor drives the load and runs in the forward direction. Depending upon load condition and motor operation, the motor may accelerate or runs at constant speed. However, during this forward motoring, if the chopper S_1 is turned off, then the energy stored in motor inductance is utilized to drive load by maintaining current in the same direction (from A to B) through S_2 and D_1. Since S_2 and D_1 conduct, the motor terminal voltage is almost zero. The motor decelerate and speed drops down.

1 Marks for description of each quadrant operation = 4 Marks

II) **Forward Braking (Regenerative) (Quadrant II operation):** During forward motoring, usually motor drives the load. However, it may happen that under special conditions, the load may drive the motor in the same direction and over-speeding may take place. In order to limit the speed, the braking need to be applied. This is done by simply turning off the choppers S_1 and S_2. Due to over-speeding, the back emf is more than the supply voltage, so the diodes D_3 and D_4 get forward biased and conduct. The polarity of motor voltage remains same (A positive w. r. t. B). However, reversal of motor current takes place (from B to A) and load drives motor and motor returns energy to the DC source. Therefore, this mode is referred as regenerative braking. During this braking operation, depending upon driving load power, the motor may run at constant speed or decelerate. If the chopper S_4 is turned ON, the energy stored in motor inductance is utilized to maintain the current in the same direction (from B to A) through S_4 and D_4. Since S_4 and D_4 conduct, the motor voltage is almost zero and motor decelerates.

III) **Reverse Motoring (Quadrant III operation):** In this mode, the choppers S_3 and S_4 are ON, making B positive w. r. t. A, the motor current flows from B to A. The source V_d supplies power to motor and the motor drives the load and runs in the reverse direction. Depending upon load condition and motor operation, the motor may accelerate or runs at constant speed. However, during this reverse motoring, if the chopper S_3 is turned off, then the energy stored in motor inductance is utilized to drive load by maintaining current in the same direction (from B to A) through S_4 and D_4. Since S_4 and D_4 conduct, the motor terminal voltage is almost zero. The motor decelerate and speed drops down.

IV) **Reverse Braking (Regenerative) (Quadrant IV operation):** During reverse motoring, when the load drives the motor in the same direction and over-speeding is likely to occur, then in order to limit the speed, the braking need to be applied. This is done by simply turning off the choppers S_3 and S_4. Due to over-speeding, the back emf is more than the supply voltage, so the diodes D_2 and D_1 get forward biased and conduct. The polarity of motor voltage remains same (B positive w. r. t. A). However, reversal of motor current takes place (from A to B) and load drives motor and motor returns energy to the DC source. Therefore, this mode is referred as reverse regenerative braking. During this braking operation, depending upon driving load power, the motor may run at constant speed or decelerate. If the chopper S_2 is turned ON, the energy stored in motor inductance is utilized to maintain the current in the same direction (from A to B) through S_2 and D_1. Since S_2 and D_2 conduct, the motor voltage is almost zero and motor decelerates.

5 c) State the rating and specification of stepper motor. If there are 4 pairs of stator phases and 6 teeth on rotor, calculate step angle.

Ans:

Rating and specification of stepper motor:

1. Amps per phase: This is the maximum current that the motor windings can handle without overheating.
2. Resistance per phase: This is the resistance of each phase. — 2 marks for 2 ratings
3. Voltage rating: V = Amps per phase x Resistance per phase.
4. Frame size: NEMA 8 to NEMA 66
5. No. of leads: 4, 6, or 8 lead configurations for bipolar or unipolar operation
6. Shaft type: — 2 Marks for 2 specifications
7. Holding torque:
8. Steps per revolution:
9. Step angle:

Calculation of Step angle:

Data Given:

There are 4 pairs of stator phases — 2 Marks for stepwise solution

$\therefore$ No. of stator phases = m = 4

And No. of stator teeth (poles) = Ts = 8 (as 4 pairs of phases means 8 coils = 8 poles)

No. of rotor teeth = Tr = 6

Step angle = $\frac{T_s - T_r}{T_s T_r} \times 360°$

$= \frac{8-6}{48} \times 360° = 15°$

OR

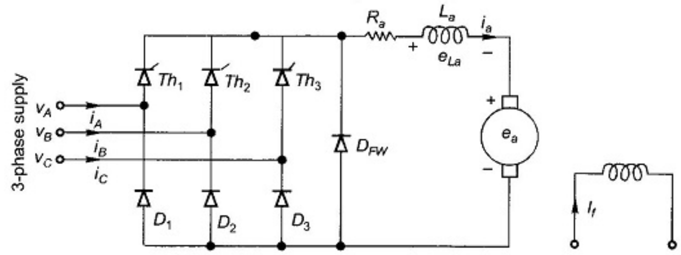
Step angle = $\frac{360°}{m.Tr} = \frac{360°}{4 \times 6} = 15°$

6 Attempt any TWO of the following: 12 Marks

6 a) Draw the circuit diagram and waveforms of 3ϕ semiconverter drive. State the equation of average armature voltage.

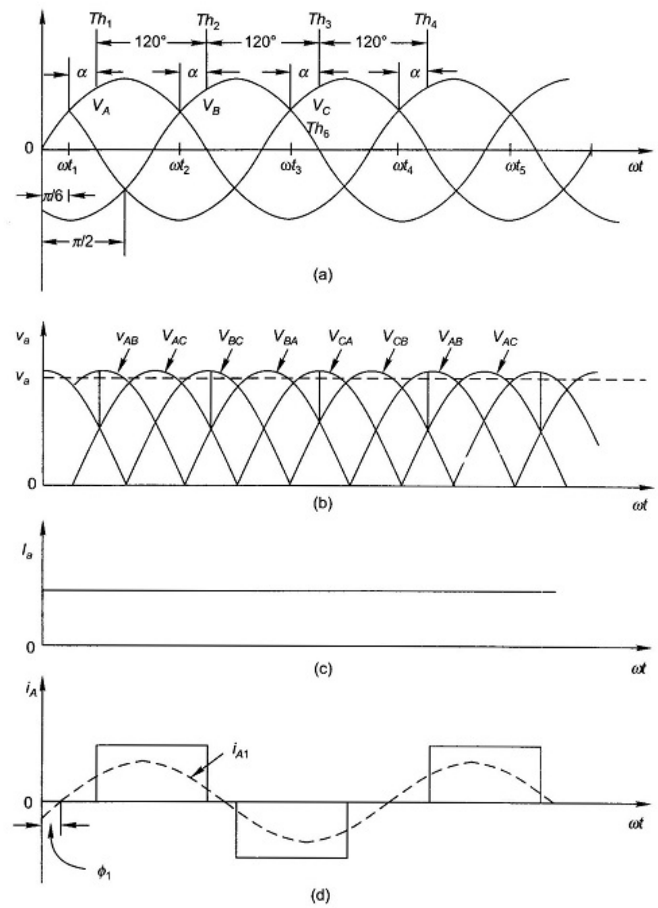
Ans:

3ϕ Semiconverter Drive:



Three-phase semi-converter feeding separately excited dc motor

2 Marks for circuit diagram



Voltage and current waveforms of 3-phase semi-converter feeding separately excited dc motor

3 Marks for waveforms

Average armature Voltage under continuous output condition is given by,

$$V_{dc} = \frac{3\sqrt{3}}{2\pi} V_m (1 + \cos\alpha)$$

1 Mark for equation

Where, V_m is the maximum value of the phase voltage,

α is the firing angle.

6 b) Classify choppers based on quadrant of operation. With neat diagram and waveform, explain the operation of basic chopper circuit using SCR.

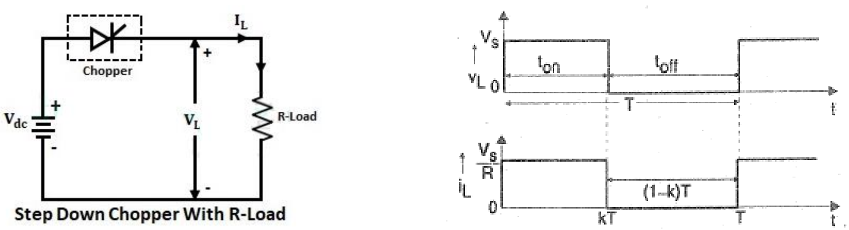
Ans:

Classification of choppers based on quadrant of operation:

1. Class A or type A chopper (Single-quadrant chopper)
2. Class B or type B chopper (Single-quadrant chopper)
3. Class C or type C chopper (Two-quadrant chopper)
4. Class D or type D chopper (Two-quadrant chopper)
5. Class E or type E chopper (Four-quadrant chopper)

1 Mark for classification

Basic Chopper:



(a) Circuit Diagram (b) Waveforms

1 Mark for circuit diagram

2 marks for Waveforms

A chopper is a high-speed On/Off semiconductor switch. During period t_{on}, the chopper is on and the load voltage is equal to the source voltage. During period t_{off}, the chopper is off and the load voltage is zero. In this manner, chopped DC voltage is produced at the load terminals. The average load voltage is given by,

2 marks for explanation

$$V_{Lav} = \frac{1}{T}\int_0^T v_L dt = \frac{1}{T}\left[\int_0^{t_{on}} v_L dt\right] = \frac{1}{T}\int_0^{t_{on}} V_s dt = \frac{V_s (t)_0^{t_{on}}}{T}$$

$$= \frac{t_{on}}{T} V_s = k\, V_s$$

where k is the duty cycle.

Duty cycle of chopper is defined as the ratio of the on time t_{on} of chopper to the period T (= $t_{on} + t_{off}$) of the on-off cycle of chopper.

6 c) Compare between the stator voltage control, constant V/F control and Rotor resistance control (Any four points).

Ans:

Comparison between the stator voltage control, constant V/F control and Rotor resistance control:

Sr. No.	Particulars	Stator voltage control	Constant V/F control	Rotor resistance control
1	Controlling quantity	Stator voltage	Ratio of stator voltage to frequency	External resistance in rotor circuit
2	Control Side	Stator side control	Stator side control	Rotor side control
3	Effect on magnetic condition of motor	Since air-gap flux depends upon stator voltage, magnetic condition is seriously affected.	Air-gap flux is maintained constant, so magnetic condition is not affected.	Magnetic condition is not affected.

1 ½ mark for each of any four points = 6 Marks

4	Suitability	Usually employed for Squirrel cage IM	Usually employed for Squirrel cage IM	Usually employed for Slip-ring IM
5	Implementation	By using auto-transformer or using external resistance in stator circuit or using power electronic converter interface	By using Pulse-width-modulation (PWM) converter interface	By using external resistance in rotor circuit or using chopper controlled resistance in rotor circuit.
6	Power loss	Power loss is more which affect the efficiency if external resistance is used in stator circuit for voltage control. Otherwise when auto-transformer or converter control is used, power loss is less and efficiency is more.	Power loss is less and efficient operation	Power loss is more and efficiency is affected.
7	Range of speed control	Narrow speed control range.	Wide speed control range limited by resistance	Wide speed control range
8	Effect on torque	Since torque α V^2, during speed control torque is affected. Low starting torque.	Since voltage is controlled according to frequency, constant torque operation is possible.	Torque is affected during speed control but high torque can be obtained at any speed.
9	Economy	Economical	Costlier	Economical
10	Simplicity	Simple	Complicated	Simple when 3-ph resistance is externally inserted. Complicate when chopper control of resistance is employed.