

SYLLABUS

Malla Reddy Engineering College (Autonomous)

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Course Code: 50226

Credits: 4

B.Tech-VII Semester

SOLID STATE DRIVES

Objective: To expose the students from the basic idea of electric drives and its characteristics with different loads, control of DC & AC motors with different methods.

Module I: Electric Drives**[14 Periods]**

Type of electric drives, choice of motor, starting and running characteristics, speed control, temperature rise, particular applications of electric drives, types of industrial loads, continuous, intermittent and variable loads, load equalization.

Control of DC motors by Single phase Converters

Introduction to Thyristor controlled Drives, Single Phase Semi and Fully controlled converters connected to D.C separately excited and D.C series motors – continuous current operation – output voltage and current waveforms – Speed and Torque expressions – Speed – Torque Characteristics- Problems on Converter fed D.C motors.

Module II: Control of DC motors by three phase Converters**[10 Periods]**

Three phase semi and fully controlled converters connected to D.C separately excited and D.C series motors – output voltage and current waveforms – Speed and Torque expressions – Speed – Torque characteristics – Problems.

Module III: Four Quadrant operations of DC Drives**[14 Periods]**

Introduction to Four quadrant operation – Motoring operations, Electric Braking – Plugging, Dynamic and Regenerative Braking operations. Four quadrant operation of D.C motors by dual converters.

Control of DC motors by Choppers

Single quadrant, Two –quadrant and four quadrant chopper fed dc separately excited and series excited motors – Continuous current operation – Output voltage and current wave forms – Speed torque expressions – speed torque characteristics – Problems on Chopper fed D.C Motors

Module IV: Control of Induction Motor through Stator voltage and Stator Frequency**[12 Periods]**

Variable voltage characteristics-Control of Induction Motor by AC Voltage Controllers – Waveforms – speed torque characteristics.

Variable frequency characteristics- control of induction motor by Voltage source inverter and current source inverter - cyclo converters- PWM control – Introduction to CSI and VSI – Comparison of VSI and CSI operations – Speed torque characteristics – numerical problems on induction motor drives

Module V: Control of Induction motor of Rotor side**[12 Periods]**

Static rotor resistance control – Slip power recovery – Static Scherbius drive – Static Kramer Drive – their performance and speed torque characteristics – advantages applications – problems

Control of Synchronous Motors

Separate control & self control of synchronous motors – Operation of self controlled synchronous motors by VSI.

CONTENTS

UNIT-I: ELECTRIC DRIVES

UNIT-II: CONTROL OF DC MOTORS

UNIT-III: OPERATION OF DC DRIVES

UNIT-IV: CONTROL OF INDUCTION MOTORS

UNIT-V: CONTROL OF SYNCHRONOUS MOTORS

UNIT-I

Electrical Drives:

Motion control is required in large number of industrial and domestic applications like transportation systems, rolling mills, paper machines, textile mills, machine tools, fans, pumps, robots, washing machines etc.

Systems employed for motion control are called DRIVES, and may employ any of prime movers such as diesel or petrol engines, gas or steam turbines, steam engines, hydraulic motors and electric motors, for supplying mechanical energy for motion control. Drives employing electric motors are known as Electrical Drives.

An Electric Drive can be defined as an electromechanical device for converting electrical energy into mechanical energy to impart motion to different machines and mechanisms for various kinds of process control.

Classification of Electric Drives

According to Mode of Operation

- ✓ Continuous duty drives
- ✓ Short time duty drives
- ✓ Intermittent duty drives

According to Means of Control

- ✓ Manual
- ✓ Semi-automatic
- ✓ Automatic

According to Number of machines

- ✓ Individual drive
- ✓ Group drive
- ✓ Multi-motor drive

According to Dynamics and Transients

- ✓ Uncontrolled transient period
- ✓ Controlled transient period

According to Methods of Speed Control

- ✓ Reversible and non-reversible uncontrolled constant speed.
- ✓ Reversible and non-reversible step speed control.
- ✓ Variable position control.

Reversible and non-reversible smooth speed control.

Advantages of Electrical Drive

They have flexible control characteristics. The steady state and dynamic characteristics of electric drives can be shaped to satisfy the load requirements.

1. Drives can be provided with automatic fault detection systems. Programmable logic controller and computers can be employed to automatically control the drive operations in a desired sequence.
2. They are available in wide range of torque, speed and power.
3. They are adaptable to almost any operating conditions such as explosive and radioactive environments
4. It can operate in all the four quadrants of speed-torque plane
5. They can be started instantly and can immediately be fully loaded
6. Control gear requirement for speed control, starting and braking is usually simple and easy to operate.

Choice (or) Selection of Electrical Drives

Choice of an electric drive depends on a number of factors. Some of the important factors are.

- ✓ Steady State Operating conditions requirements:

Nature of speed torque characteristics, speed regulation, speed range, efficiency, duty cycle, quadrants of operation, speed fluctuations if any, ratings etc

- ✓ Transient operation requirements:

Values of acceleration and deceleration, starting, braking and reversing performance.

- ✓ Requirements related to the source:

Types of source and its capacity, magnitude of voltage, voltage fluctuations, power factor, harmonics and their effect on other loads, ability to accept regenerative power

- ✓ Capital and running cost, maintenance needs life.

- ✓ Space and weight restriction if any.

- ✓ Environment and location.

- ✓ Reliability.

Group Electric Drive

This drive consists of a single motor, which drives one or more line shafts supported on bearings. The line shaft may be fitted with either pulleys and belts or gears, by means of which a group of machines or mechanisms may be operated. It is also sometimes called as SHAFT DRIVES.

Advantages

A single large motor can be used instead of number of small motors

Disadvantages

There is no flexibility. If the single motor used develops fault, the whole process will be stopped.

Individual Electric Drive

In this drive each individual machine is driven by a separate motor. This motor also imparts motion to various parts of the machine.

Multi Motor Electric Drive

In this drive system, there are several drives, each of which serves to actuate one of the working parts of the drive mechanisms.

E.g. Complicated metal cutting machine tools

Paper making industries, rolling machines etc.

Classification of Electrical Drives

Another main classification of electric drive is

- ✓ DC drive
- ✓ AC drive

Applications

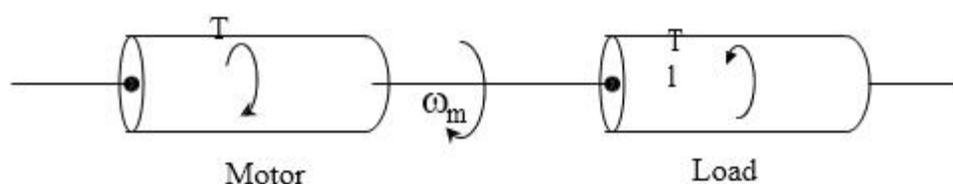
- ✓ Paper mills
- ✓ Cement Mills
- ✓ Textile mills
- ✓ Sugar Mills
- ✓ Steel Mills
- ✓ Electric Traction
- ✓ Petrochemical Industries
- ✓ Electrical Vehicles

Dynamics of Motor Load System

A motor generally drives a load (Machines) through some transmission system. While motor always rotates, the load may rotate or undergo a translational motion.

Load speed may be different from that of motor, and if the load has many parts, their speed may be different and while some parts rotate others may go through a translational motion.

Equivalent rotational system of motor and load is shown in the figure.



J = Moment of inertia of motor load system referred to the motor shaft kg / m^2

ω_m = Instantaneous angular velocity of motor shaft, rad/sec.

T = Instantaneous value of developed motor torque, N-m

T_1 = Instantaneous value of load torque, referred to the motor shaft N-m

Load torque includes friction and wind age torque of motor. Motor-load system shown in figure can be described by the following fundamental torque equation.

$$T - T_1 = \frac{d}{dt} (J \omega_m) = J \frac{d}{dt} (\omega_m) + \omega_m \frac{dJ}{dt} \dots\dots\dots (1)$$

Equation (1) is applicable to variable inertia drives such as mine winders, reel drives, Industrial robots.

For drives with constant inertia

$$\frac{dJ}{dt} = 0$$

$$T = T_1 + J \frac{d}{dt} (\omega_m) \dots\dots\dots (2)$$

Equation (2) shows that torque developed by motor

Classification of Load Torques:

Various load torques can be classified into broad categories.

- ✓ Active load torques
- ✓ Passive load torques

Load torques which has the potential to drive the motor under equilibrium conditions are called active load torques. Such load torques usually retain their sign when the drive rotation is changed (reversed)

Eg:

- ✓ Torque due to force of gravity
- ✓ Torque due tension
- ✓ Torque due to compression and torsion etc

Load torques which always oppose the motion and change their sign on the reversal of motion are called passive load torques

Eg:

- ✓ Torque due to friction, cutting etc.

Components of Load Torques:

The load torque T_1 can be further divided in to following components

✓ Friction Torque (TF):

Friction will be present at the motor shaft and also in various parts of the load. TF is the equivalent value of various friction torques referred to the motor shaft.

✓ Windage Torque (TW)

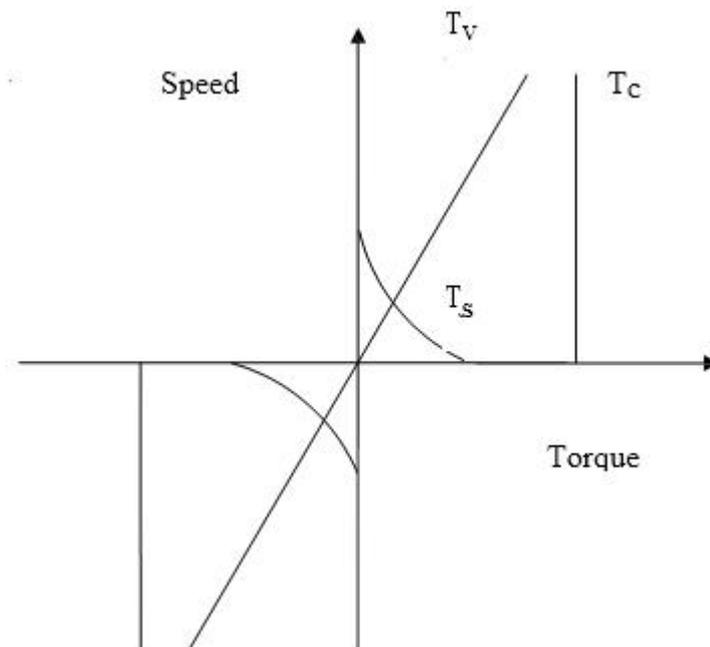
When motor runs, wind generates a torque opposing the motion. This is known as windage torque.

✓ Torque required to do useful mechanical work

Nature of this torque depends upon particular application. It may be constant and independent of speed. It may be some function of speed, it may be time invariant or time variant, its nature may also change with the load's mode of operation.

Friction at zero speed is called diction or static friction. In order to start the drive the motor should at least exceeds diction.

Friction torque can also be resolved into three components



Component T_v varies linearly with speed is called VISCOUS friction and is given by

$$T_v = B \omega_m$$

Where B is viscous friction co-efficient.

Another component T_c , which is independent of speed, is known as COULOMB friction. Third component T_s accounts for additional torque present at stand still. Since T_s is present only at stand still it is not taken into account in the dynamic analysis. Wind age torque, T_w which is proportional to speed Squared is given by

$$T_w = C \omega_m^2$$

From the above discussions, for finite speed

$$T_1 = T_L + B \omega_m + T_C + C \omega_m^2$$

Characteristics of Different types of Loads

One of the essential requirements in the selection of a particular type of motor for driving a machine is the matching of speed-torque characteristics of the given drive unit and that of the motor. Therefore the knowledge of how the load torque varies with speed of the driven machine is necessary. Different types of loads exhibit different speed torque characteristics. However, most of the industrial loads can be classified into the following four categories.

Constant torque type load

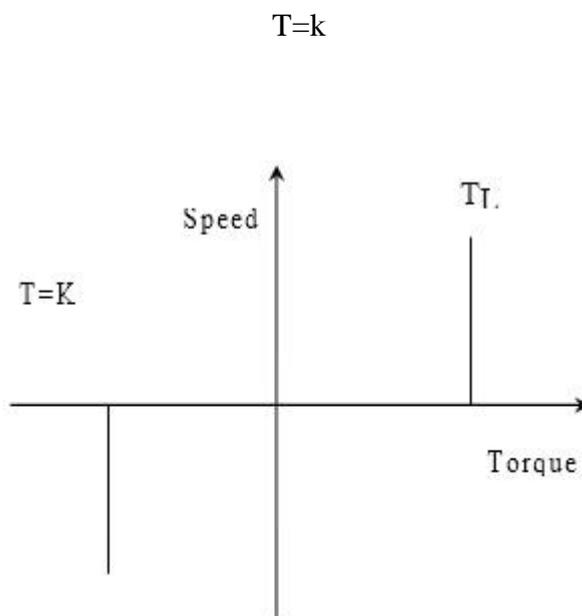
- ✓ Torque proportional to speed (Generator Type load)
- ✓ Torque proportional to square of the speed (Fan type load)
- ✓ Torque inversely proportional to speed (Constant power type load)

Constant Torque characteristics:

Most of the working machines that have mechanical nature of work like shaping, cutting, grinding or shearing, require constant torque irrespective of speed. Similarly cranes during the hoisting and conveyors handling constant weight of material per unit time also exhibit this type of Characteristics

Torque Proportional to speed:

Separately excited dc generators connected to a constant resistance load, eddy current brakes have speed torque characteristics given by

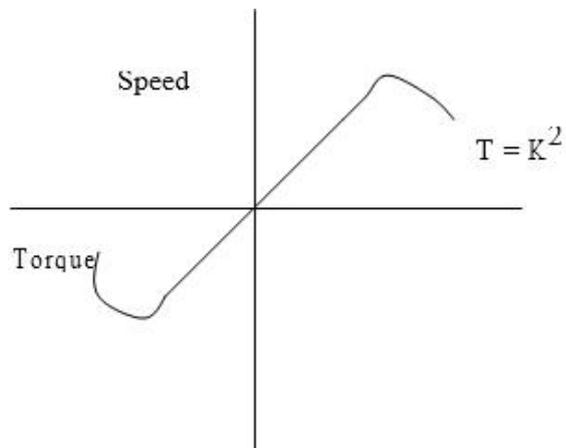
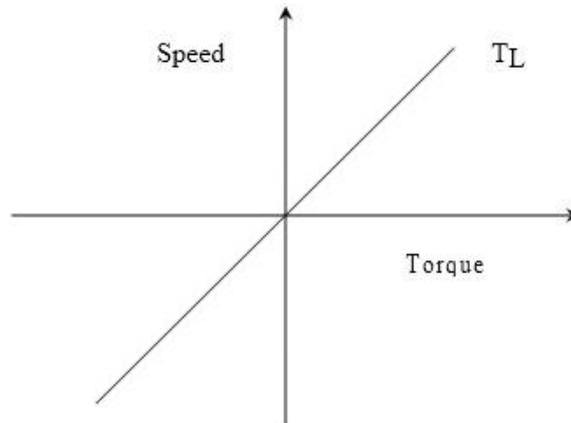


Torque proportional to square of the speed:

Another type of load met in practice is the one in which load torque is proportional to the square of the speed.

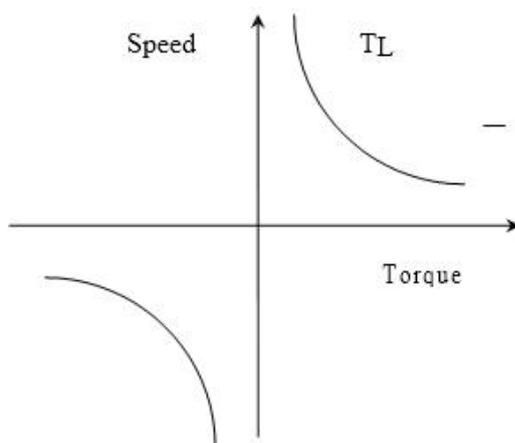
Examples:

- ✓ Fans rotary pumps,
- ✓ Compressors
- ✓ Ship propellers



Torque Inversely proportional to speed:

Certain types of lathes, boring machines, milling machines, steel mill coiler and electric traction load exhibit hyperbolic speed-torque characteristics



Multi quadrant Operation:

For consideration of multi quadrant operation of drives, it is useful to establish suitable conventions about the signs of torque and speed.

A motor operates in two modes – Motoring and braking. In motoring, it converts electrical energy into mechanical energy, which supports its motion. In braking it works as a generator converting mechanical energy into electrical energy and thus opposes the motion.

Now consider equilibrium point B which is obtained when the same motor drives another load as shown in the figure. A decrease in speed causes the load torque to become greater than the motor torque, electric drive decelerates and operating point moves away from point B.

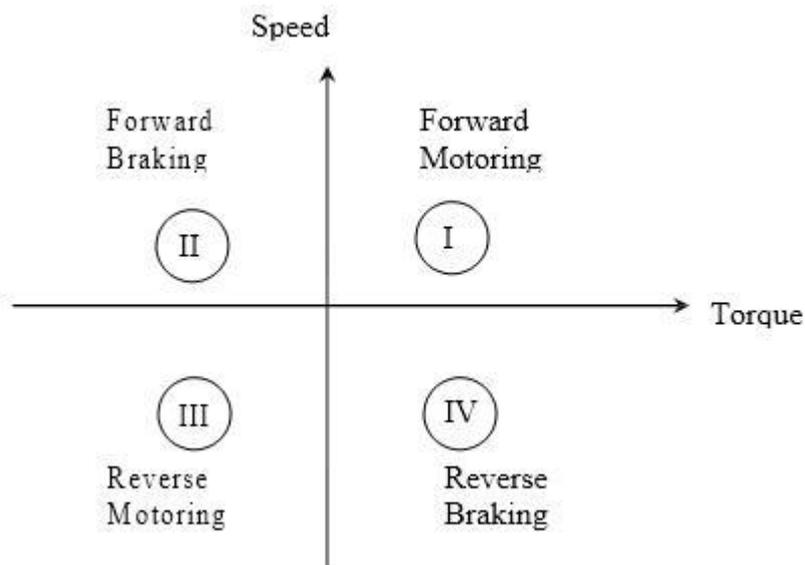
Similarly when working at point B and increase in speed will make motor torque greater than the load torque, which will move the operating point away from point B.

Similarly operation in quadrant III and IV can be identified as reverse motoring and reverse braking since speed in these quadrants is negative.

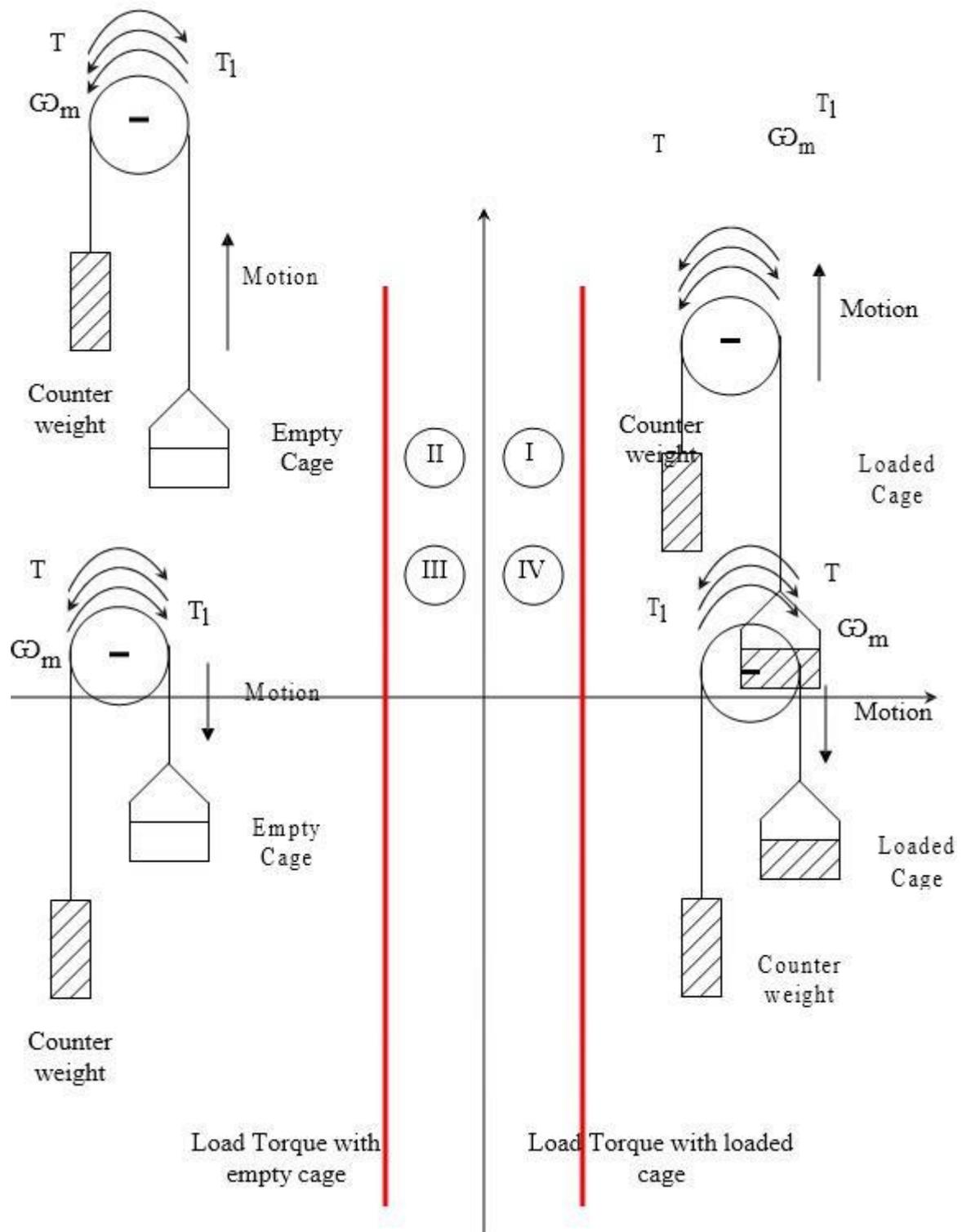
For better understanding of the above notations, let us consider operation of hoist in four quadrants as shown in the figure. Direction of motor and load torques and direction of speed are marked by arrows.

The figure at the right represents a DC motor attached to an inertial load. Motor can provide motoring and braking operations for both forward and reverse directions.

Figure shows the torque and speed co-ordinates for both forward and reverse motions. Power developed by a motor is given by the product of speed and torque. For motoring operations Power developed is positive and for braking operations power developed is negative.



For better understanding of the above notations, let us consider operation of hoist in four quadrants as shown in the figure. Direction of motor and load torques and direction of speed are marked by arrows.



A hoist consists of a rope wound on a drum coupled to the motor shaft one end of the rope is tied to a cage which is used to transport man or material from one level to another level . Other end of the rope has a counter weight. Weight of the counter weight is chosen to be higher than the weight of empty cage but lower than of a fully loaded cage.

Forward direction of motor speed will be one which gives upward motion of the cage. Load torque line in quadrants I and IV represents speed-torque characteristics of the loaded hoist. This torque is the difference of torques due to loaded hoist and counter weight. The load torque in quadrants II and III is the speed torque characteristics for an empty hoist.

This torque is the difference of torques due to counter weight and the empty hoist. Its sign is negative because the counter weight is always higher than that of an empty cage. The quadrant I operation of a hoist requires movement of cage upward, which corresponds to the positive motor speed which is in counter clockwise direction here. This motion will be obtained if the motor produces positive torque in CCW direction equal to the magnitude of load torque T_{L1} .

Since developed power is positive, this is forward motoring operation. Quadrant IV is obtained when a loaded cage is lowered. Since the weight of the loaded cage is higher than that of the counter weight. It is able to overcome due to gravity itself.

In order to limit the cage within a safe value, motor must produce a positive torque T equal to T_{L2} in anticlockwise direction. As both power and speed are negative, drive is operating in reverse braking operation. Operation in quadrant II is obtained when an empty cage is moved up. Since a counter weight is heavier than an empty cage, its able to pull it up.

In order to limit the speed within a safe value, motor must produce a braking torque equal to T_{L2} in clockwise direction. Since speed is positive and developed power is negative, it's forward braking operation.

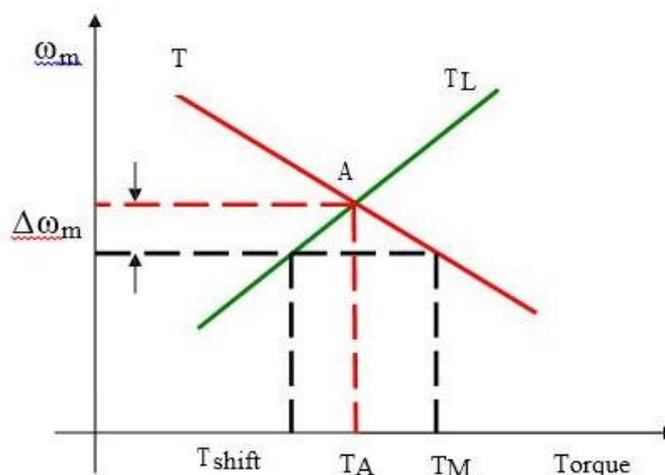
Operation in quadrant III is obtained when an empty cage is lowered. Since an empty cage has a lesser weight than a counter weight, the motor should produce a torque in CW direction. Since speed is negative and developed power is positive, this is reverse motoring operation. During transient condition, electrical motor can be assumed to be in electrical equilibrium implying that steady state speed torque curves are also applicable to the transient state operation.

Steady State Stability:

Equilibrium speed of motor-load system can be obtained when motor torque equals the load torque. Electric drive system will operate in steady state at this speed, provided it is the speed of stable state equilibrium.

Concept of steady state stability has been developed to readily evaluate the stability of an equilibrium point from the steady state speed torque curves of the motor and load system. In most of the electrical drives, the electrical time constant of the motor is negligible compared with the mechanical time constant. During transient condition, electrical motor can be assumed to be in electrical equilibrium implying that steady state speed torque curves are also applicable to the transient state operation.

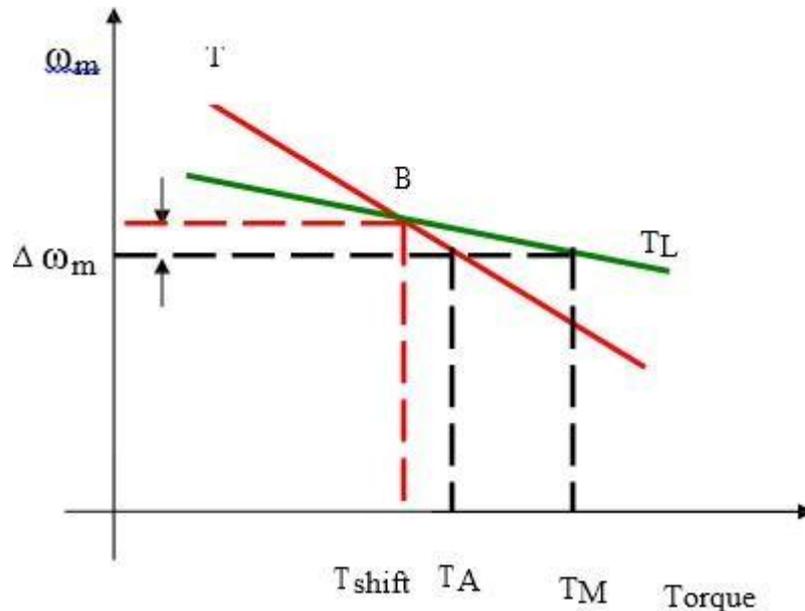
Now, consider the steady state equilibrium point A shown in figure below



Now consider equilibrium point B which is obtained when the same motor drives another load as shown in the figure.

A decrease in speed causes the load torque to become greater than the motor torque, electric drive decelerates and operating point moves away from point B.

Similarly when working at point B and increase in speed will make motor torque greater than the load torque, which will move the operating point away from point B



Basics of Regenerative Braking

In the regenerative braking operation, the motor operates as generator, while it is still connected to the supply. Here, the motor speed is greater than the synchronous speed.

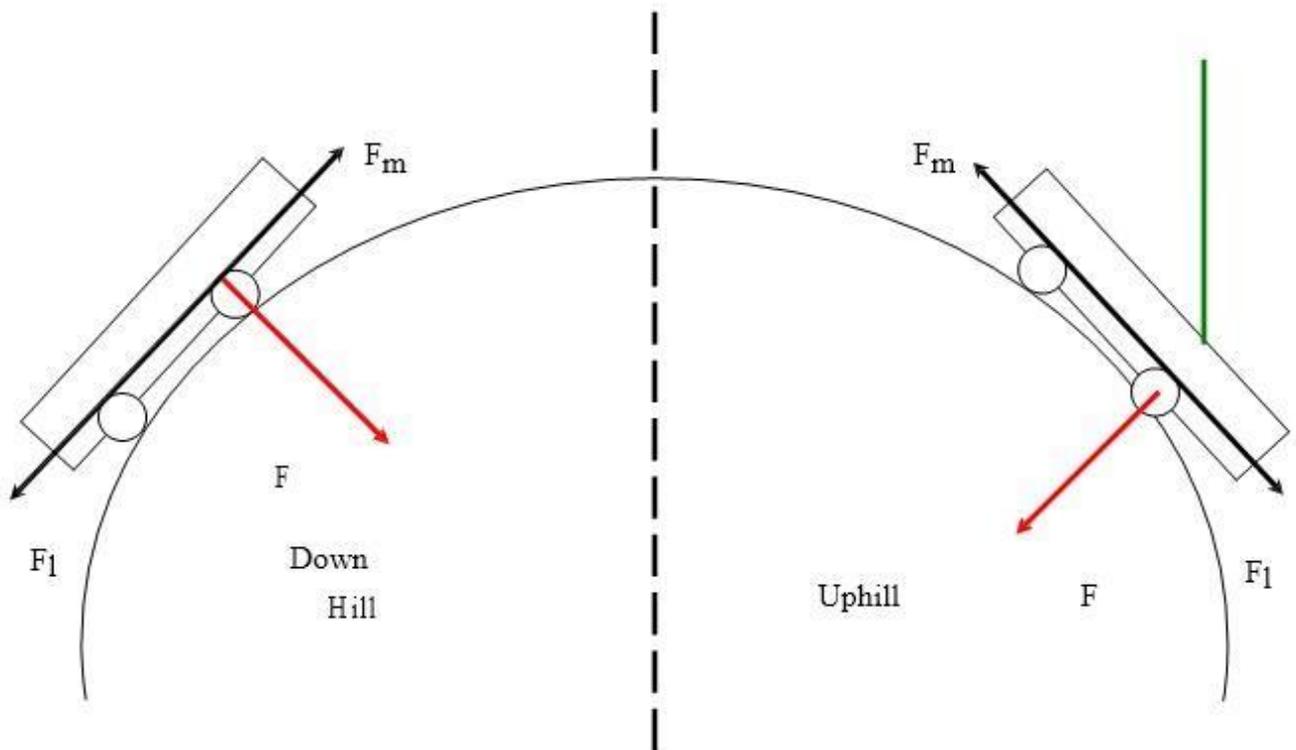
Mechanical energy is converted into electrical energy, part of which is returned to the supply and rest of the energy is lost as heat in the winding and bearings of electrical machines pass smoothly from motoring region to generating region, when over driven by the load.

An example of regenerative braking is shown in the figure below. Here an electric motor is driving a trolley bus in the uphill and downhill direction. The gravity force can be resolved into two components in the uphill direction.

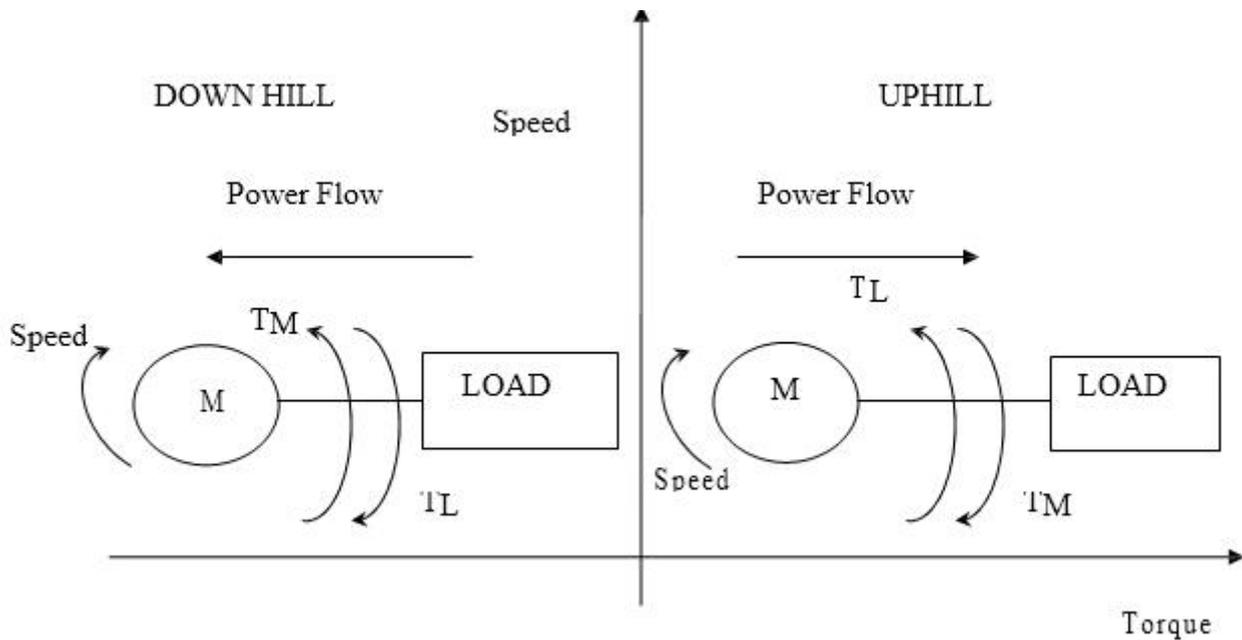
One is perpendicular to the load surface (F) and another one is parallel to the road surface F_1 . The parallel force pulls the motor towards bottom of the hill.

If we neglect the rotational losses, the motor must produce force F_m opposite to F_1 to move the bus in the uphill direction.

Here the motor is still in the same direction on both sides of the hill. This is known as regenerative braking. The energy exchange under regenerative braking operation is power flows from mechanical load to source.



This operation is indicated as shown in the figure below in the first quadrant. Here the power flow is from the motor to load.



Now we consider that the same bus is traveling in down hill, the gravitational force doesn't change its direction but the load torque pushes the motor towards the bottom of the hill. The motor produces a torque in the reverse direction because the direction of the motor torque is always opposite to the direction of the load torque.

Here the motor is still in the same direction on both sides of the hill. This is known as regenerative braking. The energy exchange under regenerative braking operation is power flows from mechanical load to source. Hence, the load is driving the machine and the machine is generating electric power that is returned to the supply.

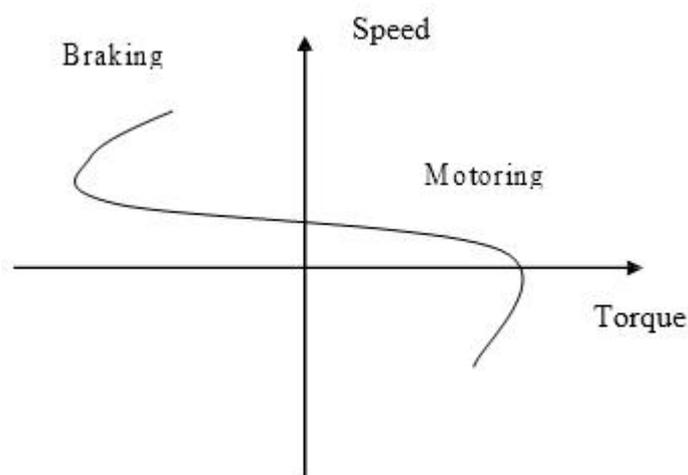
Regenerative braking of Induction motor:

An induction motor is subjected to regenerative braking, if the motor rotates in the same direction as that of the stator magnetic field, but with a speed greater than the synchronous speed. Such a state occurs during anyone of the following process.

- ✓ Downward motion of a loaded hoisting mechanism
- ✓ During flux weakening mode of operation of IM.

Under regenerative braking mode, the machine acts as an induction generator. The induction generator generates electric power and this power is fed back to the supply. This machine takes only the reactive power for excitation.

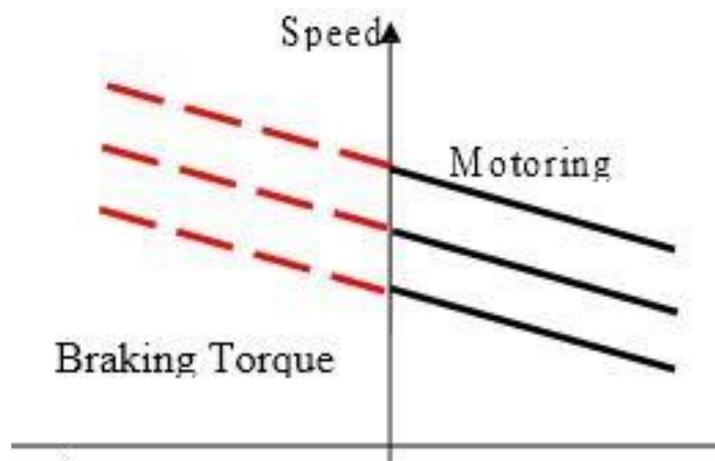
The speed torque characteristic of the motor for regenerative braking is shown in the figure.



Regenerative Braking for DC motor:

In regenerative braking of dc motor, generated energy is supplied to the source. For this the following condition is to be satisfied.

$E > V$ and I_a should be negative



Modes of Operation:

An electrical drive operates in three modes

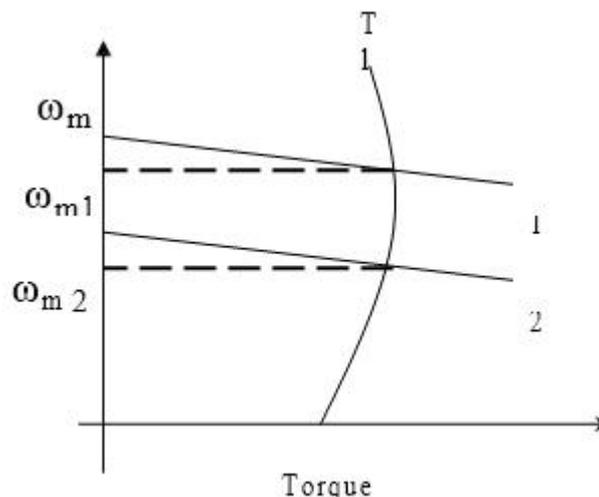
- ✓ Steady state
- ✓ Acceleration including Starting
- ✓ Deceleration including Stopping

We know that

$$T = T_1 + J \frac{d}{dt} (\omega_m)$$

According to the above expression the steady state operation takes place when motor torque equals the load torque. The steady state operation for a given speed is realized by adjustment of steady state motor speed torque curve such that the motor and load torques are equal at this speed. Change in speed is achieved by varying the steady state motor speed torque curve so that motor torque equals the load torque at the new desired speed. In the figure shown below when the motor parameters are adjusted to provide speed torque curve 1, drive runs at the desired speed ω_{m1} .

Speed is changed to ω_{m2} when the motor parameters are adjusted to provide speed torque curve 2. When load torque opposes motion, the motor works as a motor operating in quadrant I or III depending on the direction of rotation. When the load is active it can reverse its sign and act to assist the motion. Steady state operation for such a case can be obtained by adding a mechanical brake which will produce a torque in a direction to oppose the motion. The steady state operation is obtained at a speed for which braking torque equal the load torque. Drive operates in quadrant II or IV depending upon the rotation.



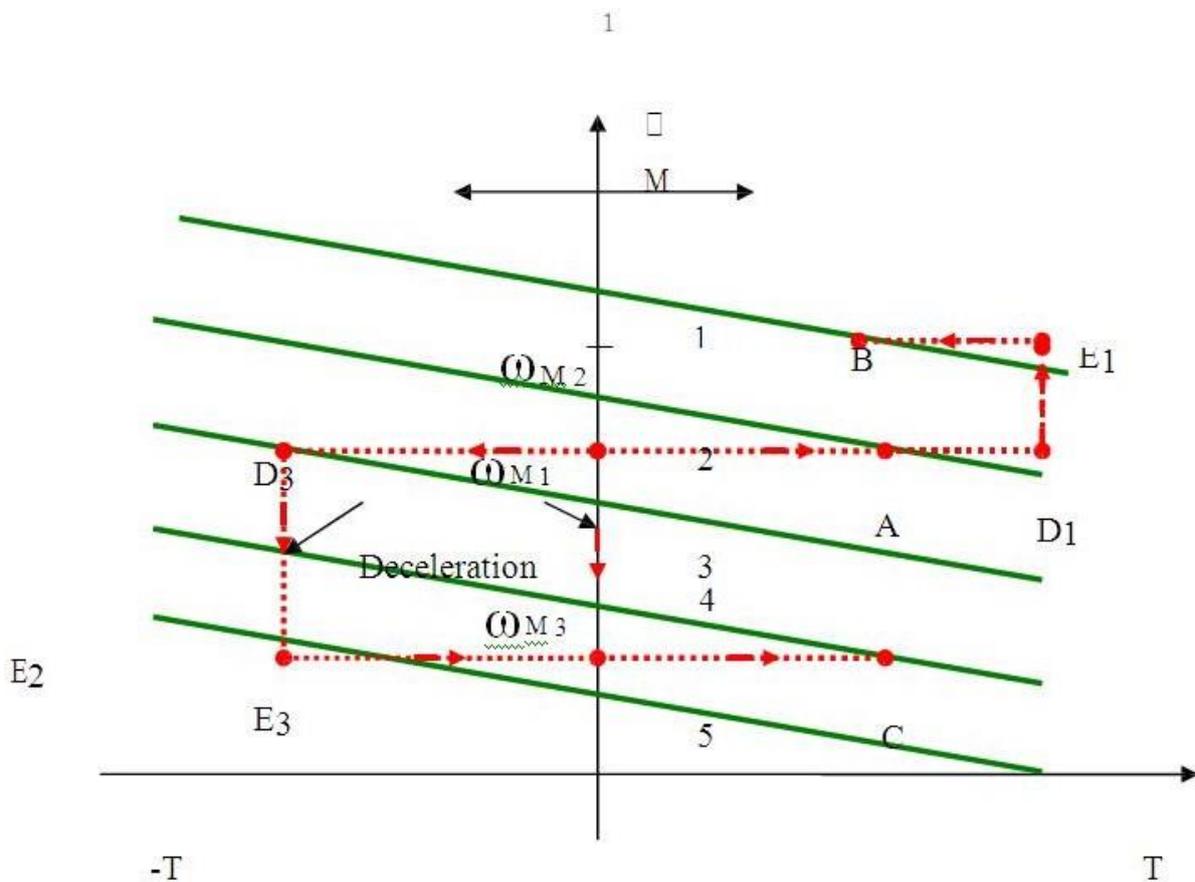
Acceleration and Deceleration modes are transient modes. Drive operates in acceleration mode whenever an increase in its speed is required. For this motor speed torque curve must be changed so that motor torque exceeds the load torque. Time taken for a given change in speed depends on inertia of motor load system and the amount by which motor torque exceeds the load torque.

Increase in motor torque is accompanied by an increase in motor current. Care must be taken to restrict the motor current within a value which is safe for both motor and power modulator. In applications involving acceleration periods of long duration, current must not be allowed to exceed the rated value. When acceleration periods are of short duration a current higher than the rated value is allowed during acceleration.

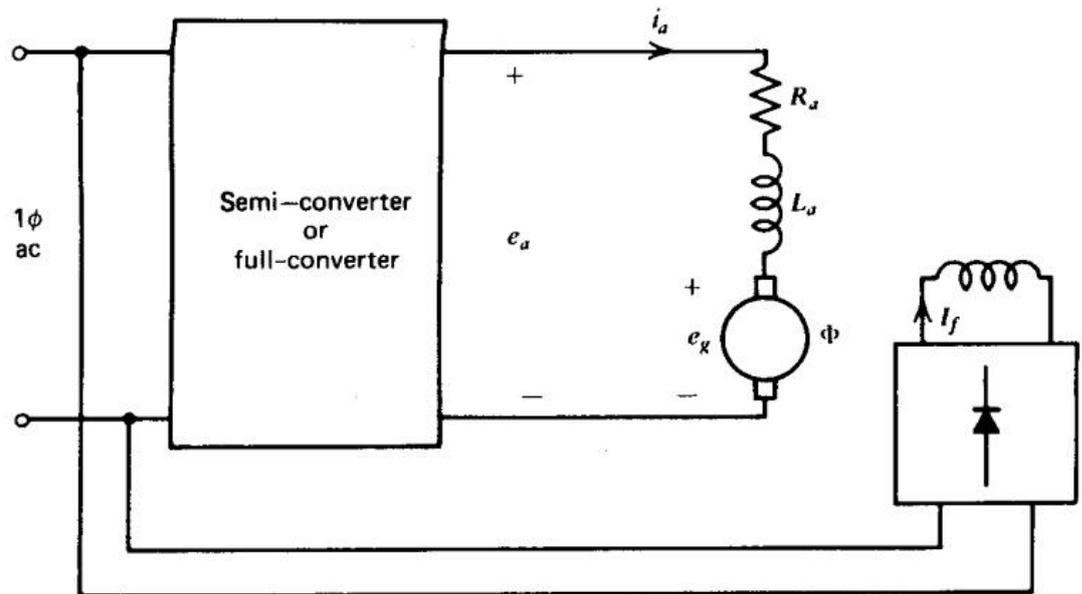
In closed loop drives requiring fast response, motor current may be intentionally forced to the maximum value in order to achieve high acceleration. Figure shown below shows the transition from operating point A at speed.

Point B at a higher speed ω_{m2} , when the motor torque is held constant during acceleration. The path consists of AD1E1B. In the figure below, 1 to 5 are motor speed torque curves. Starting is a special case of acceleration where a speed change from 0 to a desired speed takes place. All points mentioned in relation to acceleration are applicable to starting.

The maximum current allowed should not only be safe for motor and power modulator but drop in source voltage caused due to it should also be in acceptable limits. In some applications the motor should accelerate smoothly, without any jerk. This is achieved when the starting torque can be increased step lessly from its zero value. Such a start is known as soft start.



UNIT II

Single Phase Fully Controlled Converter Fed Separately Excited D.C Motor Drive**Fig 2.1**

The basic circuit for a single-phase separately excited dc motor drive is shown in Fig. 2.1. The armature voltage is controlled by a semi-converter or full-converter and the field circuit is fed from the ac supply through a diode bridge. The motor current cannot reverse due to the thyristors in the converters. If semi-converters are used, the average output voltage (E_a) is always positive. Therefore power flow ($E_a I_a$) is always positive, that is, from the ac supply to the dc load. In drive system semi-converters, regeneration or reverse power flow from motor to ac supply is not possible. In semi-converters free-wheel (i.e., dissipation of armature inductance energy through the free-wheeling path) takes place when the thyristor blocks.

Single-phase full-wave drives are used for low and medium-horsepower applications as indicated in Fig. 2.1. Such drives have poor speed regulation on open-loop firing angle control. However, with armature voltage or tachometer feedback, good regulation can be achieved.

Basic Equation I

The armature circuit of the dc motor is represented by its back voltage e_g , armature resistance R_a , and armature inductance L_a as shown in Fig. 2.1.

Back voltage:

$$e_g = K_a \Phi n \quad (1)$$

Average Back Voltage

$$E_g = K_a \Phi N \quad (2)$$

Developed torque:

$$t = K_a \Phi i_a \quad (3)$$

Average developed torque:

$$T = K_a \Phi I_a \quad (4)$$

The armature circuit voltage equation is

$$e_a = R_a i_a + L_a \frac{di_a}{dt} + e_g \quad (5)$$

In terms of average values,

$$E_a = R_a I_a + E_g \quad (6)$$

Note that the inductance L_a does not absorb any average voltage. From equations 2 and 6, the average speed is

$$N = \frac{E_a - R_a I_a}{K_a \Phi}$$

In single-phase converters, the armature voltage e_a and current t , change with time. This is unlike the M-G set drive in which both e_a and t , are essentially constant. In phase-controlled converters, the armature current i_a may not even be continuous. In fact, for most operating conditions, t , is discontinuous. This makes prediction of performance difficult. Analysis is simplified if continuity of armature current can be assumed. Analysis for both continuous and discontinuous current is presented in the following sections

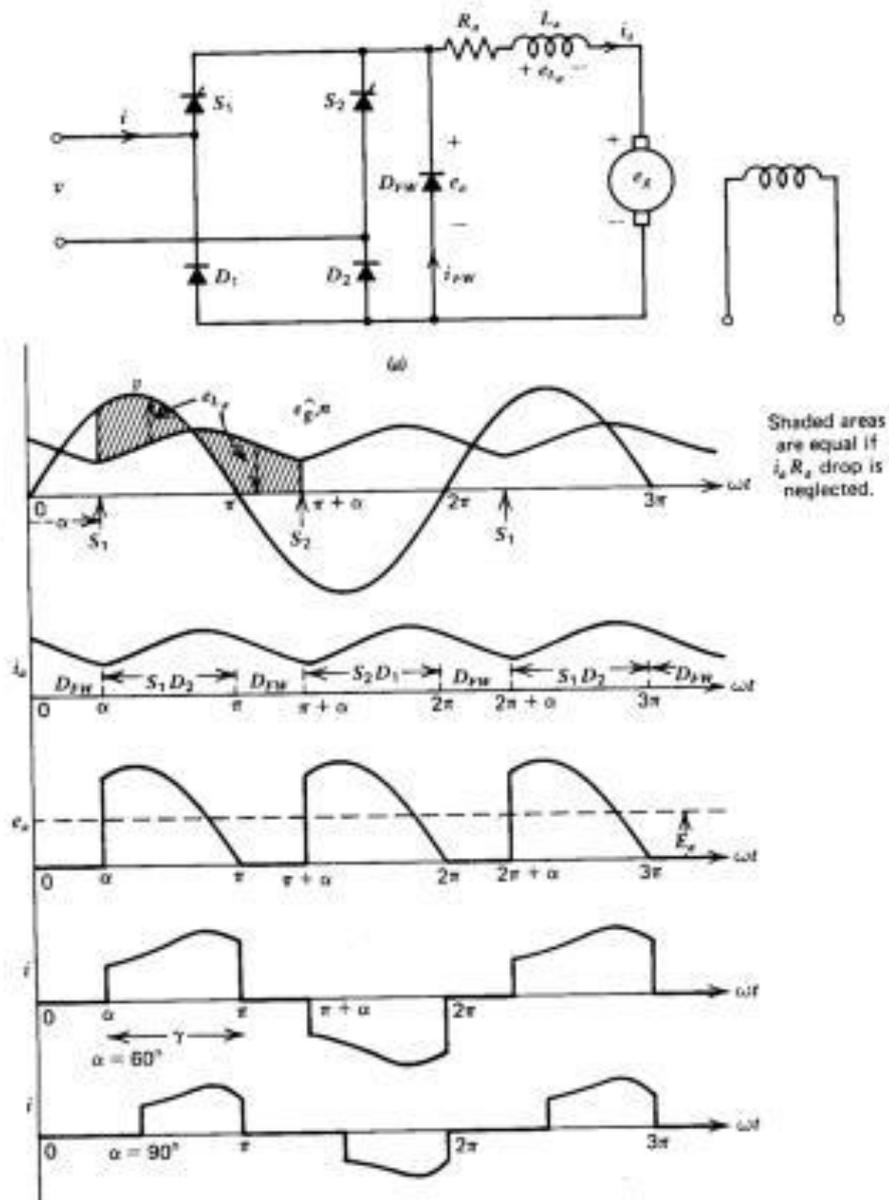
Continuous Armature Current

Let us assume that the armature current is continuous over the whole range of operation. Typical voltage and current waveforms are shown in Figs.2.2 and 2.3 for semi-converter and full-converter systems, respectively. The thyristors are symmetrically triggered. In the semi-converter system shown in Fig.2.2, thyristor S1 is triggered at an angle α and S2 at an angle $\alpha + \pi$ with respect to the supply voltage v . In the full-converter system shown in Fig.2.3, thyristors S1 and S3 are simultaneously triggered at α , thyristors S2 and S4 are triggered at $\pi + \alpha$.

In Fig. 2.2, the motor is connected to the input supply for the period $\alpha < \omega t < \pi$ through S1 and D2, and the motor terminal voltage e_a is the same as the supply input voltage v . Beyond π , e_a tends to reverse as the input voltage changes polarity. This will forward-bias the free-wheeling diode and DFW will start

conducting. The motor current i_a , which was flowing from the supply through $S1'$ is transferred to DFW (i.e., $S1$ commutates). The motor terminals are shorted through the free-wheeling diode during $7T < \omega t < (7T + a)$, making e_o zero. Energy from the supply is therefore delivered to the armature

Circuit when the thyristor conducts (a to $7T$). This energy is partially stored in the inductance, partially stored in the kinetic energy (K.E.) of the moving system, and partially used to supply the mechanical load. During the free-wheeling period, $7T$ to $7T + a$, energy is recovered from the inductance and is converted to mechanical form to supplement the K.E. in supplying the mechanical load. The free-wheeling armature current continues to produce electromagnetic torque in the motor. No energy is feedback to the supply during this period.



In Fig.2.3, the motor is always connected to the input supply through the thyristors. Thyristors $S1$ and $S3$ conduct during the interval $a < \omega t < (7T + a)$ and connect the motor to the supply. At $7T + a$, thyristors $S2$ and $S4$ are triggered. Immediately the supply voltage appears across the thyristors $S1$ and $S3$ as a reverse-bias voltage and turns them off. This is called natural or line commutation. The motor current i_a , which was flowing from the supply through $S1$ and $S3$ is transferred to $S2$ and $S4$. During a to $7T$, energy flows from

the input supply to the motor (both v and i_a re positive, and e_o and i_o are positive, signifying positive power flow). However, during $7T$ to $7T + a$, some of the motor system energy is feedback to the input supply(v and I have opposite polarities and likewise e_a and i_o' signifying reverse power flow).

In Fig.2.3c voltage and current waveforms are shown for a firing angle greater than 90° . The average motor terminal voltage E_o is negative. If the motor back emf E_g is reversed, it will behave as a de-generator and will feed power back to the ac supply. This is known as the inversion operation of the converter, and this mode of operation is used in the regenerative braking of the motor.

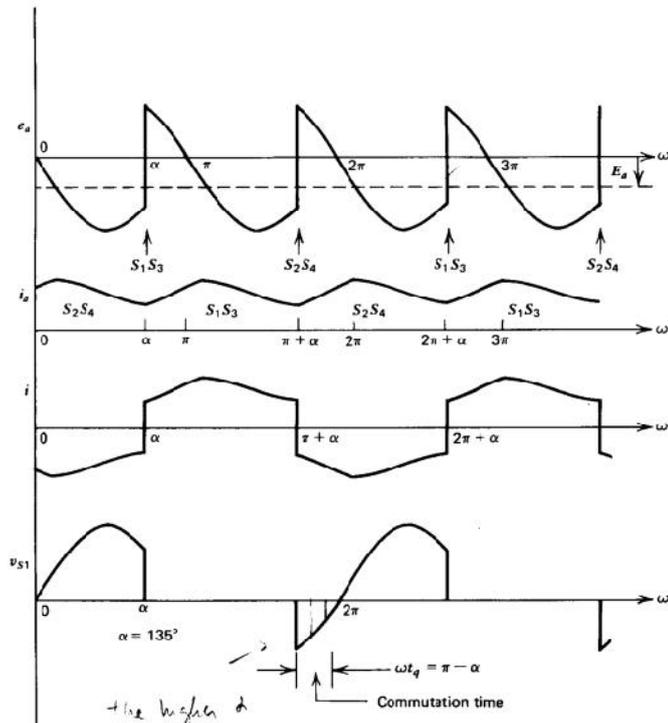


Fig. 2.3 (Continued)

Torque Speed Characteristics

For a semi-converter with free-wheeling action the armature circuit equations are:

$$e_a = v = R_a i_a + L_a \frac{di_a}{dt} + e_g \quad \alpha < \omega t < \pi$$

$$e_a = 0 = R_a i_a + L_a \frac{di_a}{dt} + e_g \quad \pi < \omega t < \pi + \alpha$$

Single-Phase Separately Excited DC Motor Drives

The armature circuit equation for a full-converter is:

$$e_a = v = R_a i_a + L_a \frac{di_a}{dt} + e_g \quad \alpha < \omega t < \pi + \alpha$$

$$E_a = \frac{1}{\pi} \int_{\alpha}^{\pi} \sqrt{2} V \sin \theta d\theta = \frac{\sqrt{2} V}{\pi} (1 + \cos \alpha)$$

With a full-converter:

$$E_a = \frac{1}{\pi} \int_{\alpha}^{\pi+\alpha} \sqrt{2} V \sin \theta d\theta = \frac{2\sqrt{2} V}{\pi} \cos \alpha$$

DISCONTINUOUS ARMATURE CURRENT

The torque-speed characteristics shown in Fig.2.4b are drawn on the crude assumption that the armature current is continuous over the whole range of operation. It is very doubtful that the armature current will be continuous at high values of the firing angle α , high speed, and low values of torque. In fact, armature current is discontinuous for these operating conditions. If the armature current is discontinuous, the no-load speeds will be higher than those shown in Fig.2.4b, and the speed regulation will be significantly poor in the region of discontinuous armature current. The motor performance

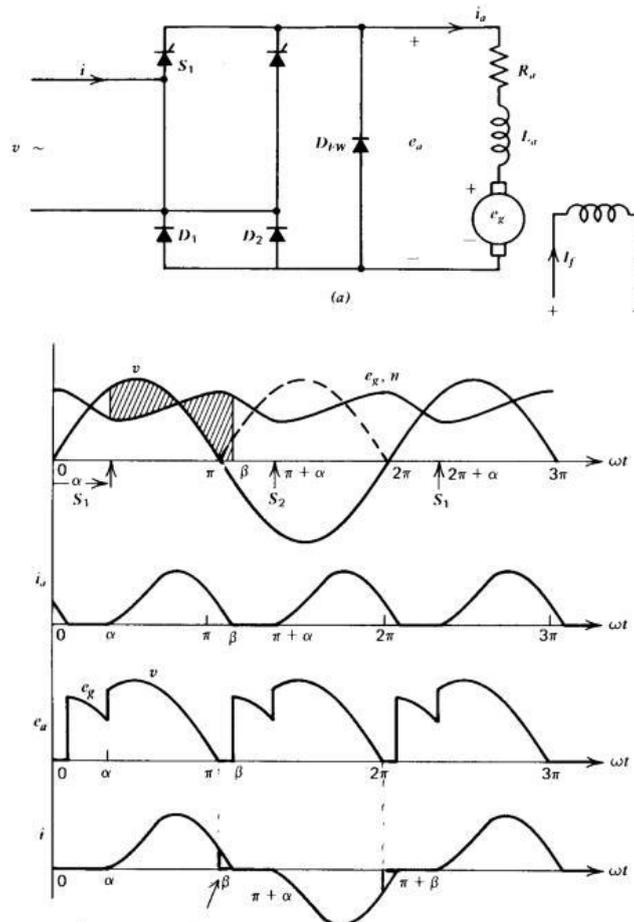
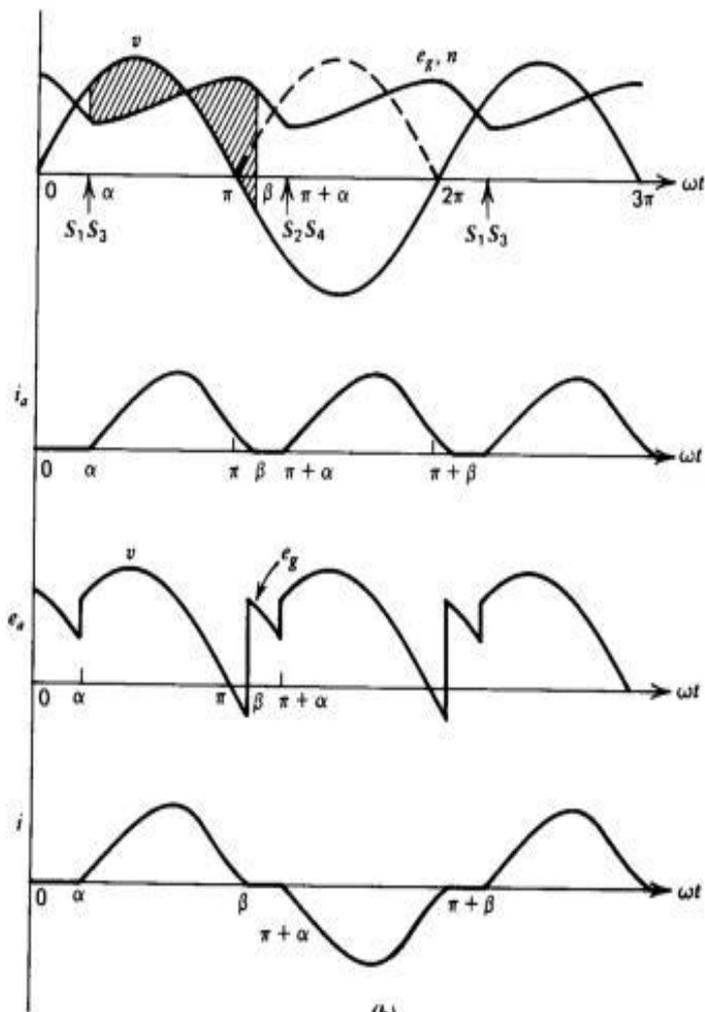
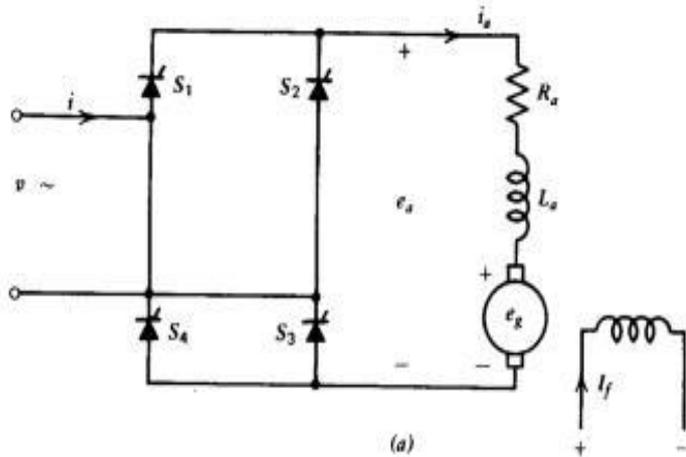


Fig. 2.5 Effects of discontinuous motor current in semi-converter operation. (a) Power circuit. (b) Voltage and current waveforms.

The waveforms with semi-converter and full-converter with discontinuous armature current are shown in Fig. 2.5 and Fig. 2.6, respectively.



In Fig. 2.5, the motor is connected to the input supply for the period $\alpha < \omega t < \pi + \alpha$ through S_1 and S_4 . Beyond $\pi + \alpha$, the motor terminal is shorted through the free-wheeling diode DFW. The armature current decays to zero before the thyristor S_2 is triggered at $\pi + \alpha$, thereby making the armature current discontinuous. During α to $\pi + \alpha$ (i.e., the conduction period of the thyristor S_1), motor terminal voltage e_a is the same as the supply voltage v . However, during the motor current free-wheels through DFW and so e_a is zero. The motor coasts and the motor terminal voltage e_a is the same as the back voltage. In Fig. 2.6, the

motor is connected to the supply during $\omega t < \pi/3$ and it Coasts during $\pi/3 < \omega t < \pi/2 + \alpha$. As long as the motor is connected to the supply, its terminal voltage is the same as the input supply voltage.

If the armature current can be assumed to be continuous, the torque-speed characteristics can be calculated merely from average values of the motor terminal voltage and current. In the discontinuous current mode, these calculations are cumbersome. The difficulty arises in the calculation of the average motor terminal voltage E_a , because (called the extinction angle, the instant at which the thyristor or motor current becomes zero) depends on, the average speed N , average armature current I_a and the firing angle α . A general approach, valid for both continuous and discontinuous armature current, is therefore necessary.

Three Phase Fully Controlled Converter Fed Separately Excited D.C Motor Drive

Three phase controlled rectifiers are used in large power DC motor drives. Three phase controlled rectifier gives more number of voltage per cycle of supply frequency. This makes motor current continuous and filter requirement also less.

The number of voltage pulses per cycle depends upon the number of thyristors and their connections for three phase controlled rectifiers. In three phase drives, the armature circuit is connected to the output of a three phase controlled rectifier.

Three phase drives are used for high power applications up to megawatts power level. The ripple frequency of armature voltage is greater than that of the single phase drives and its requires less inductance in the armature circuit to reduce the armature current ripple

Three phase full converter are used in industrial application up to 1500KW drives. It is a two quadrant converter.

Principle of Operation

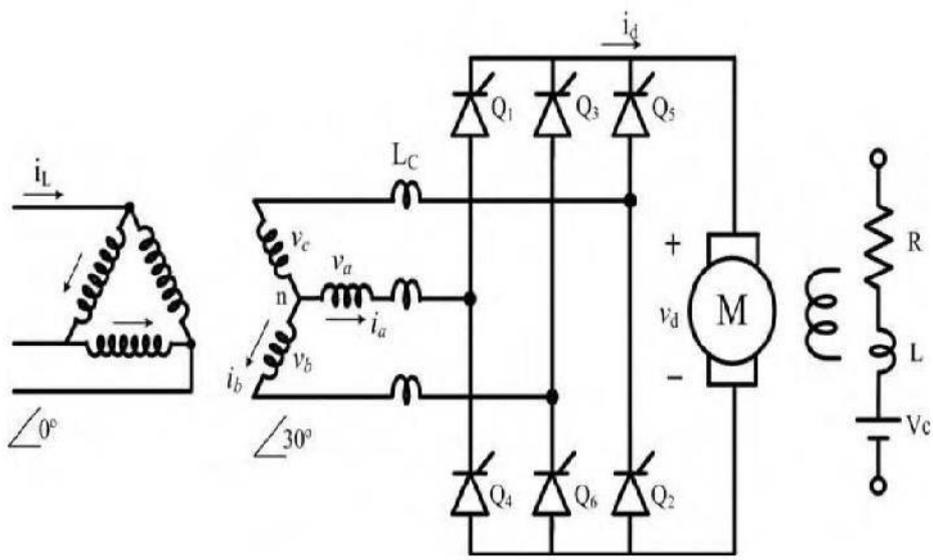


Figure 2.13

Three phase full converter bridge circuit connected across the armature terminals is shown fig. The voltage and current waveforms of the converter. The circuit works as a three AC to DC converter for firing angle delay $0^\circ < \alpha < 90^\circ$ and as a line commutated inverter for $90^\circ < \alpha < 180^\circ$. A three full converter fed DC motor is performed where generation of power is required.

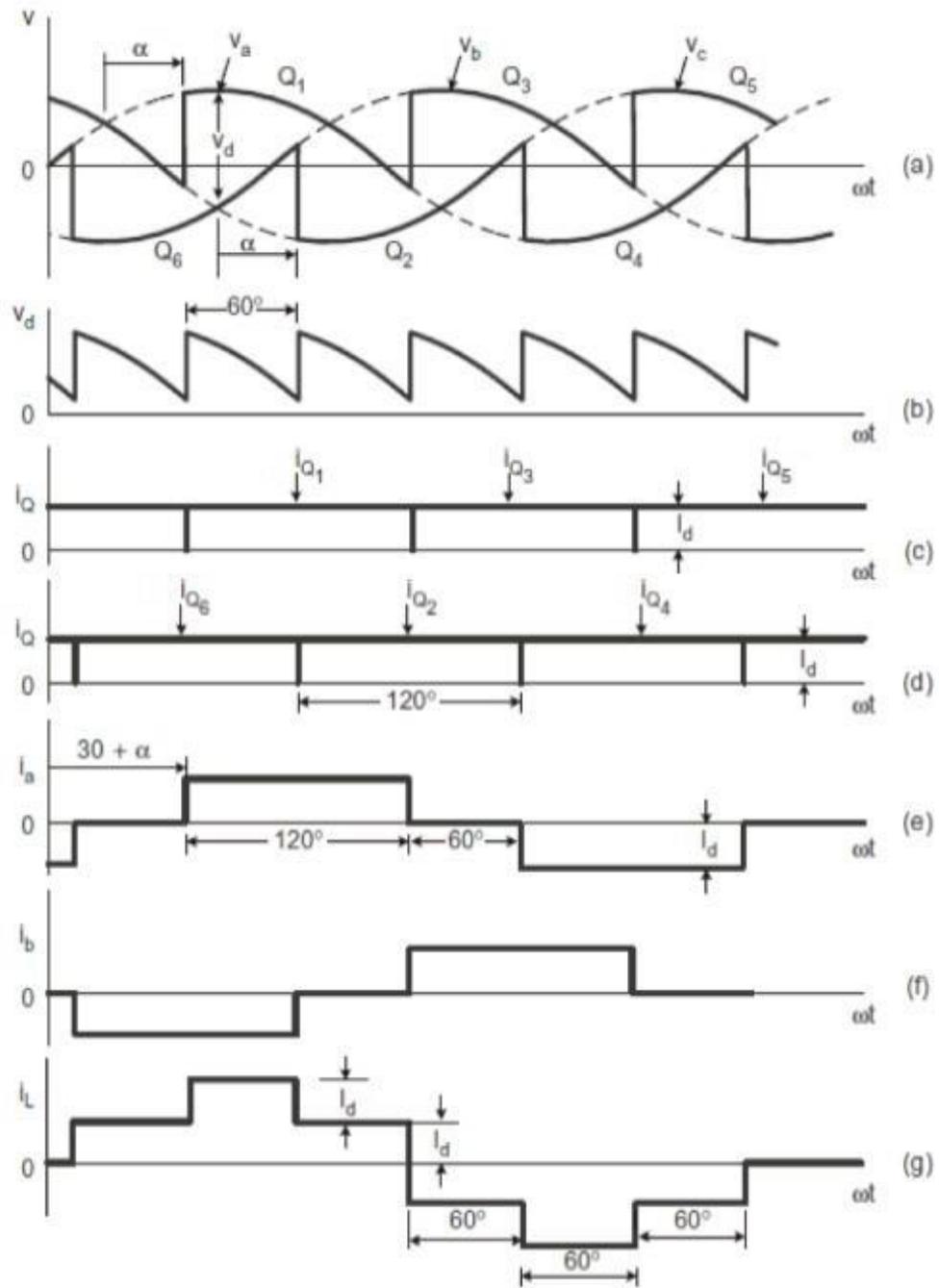


Fig 2.14 Three-phase thyristor bridge waveforms in rectification mode ($\alpha = 40^\circ$)

The average motor armature voltage is given by

$$V_a = \frac{3}{\pi} \int_{\frac{\pi}{6} + \alpha}^{\frac{\pi}{2} + \alpha} V_{ab} d(\omega t) \quad (2.49)$$

$$\text{In the above substitute } V_{ab} = \sqrt{3}V_m \sin\left(\omega t + \frac{\pi}{6}\right) d(\omega t) \quad (2.50)$$

$$\text{We have } V_a = \frac{3\sqrt{3}}{\pi} V_m \cos \alpha \quad (2.51)$$

2.4.3.2 Speed Torque Relations:

The drive speed is given by

$$V_a = E_b + I_a R_a \quad \text{Where } E_b = K_a \phi \omega$$

$$\text{Then } V_a = K_a \phi \omega_m + I_a R_a$$

$$\omega_m = \frac{V_a - I_a R_a}{K_a \phi} \quad (2.52)$$

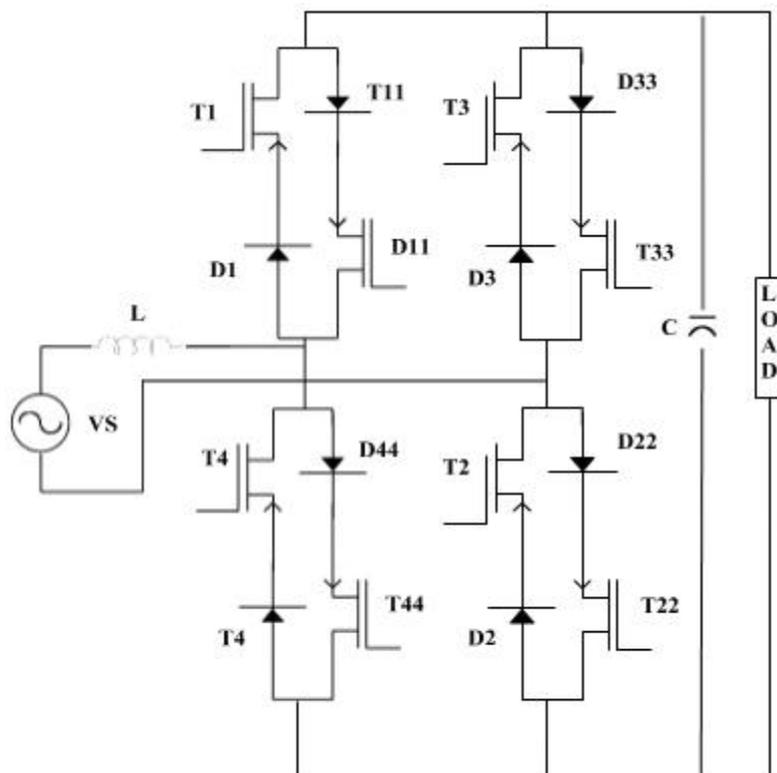
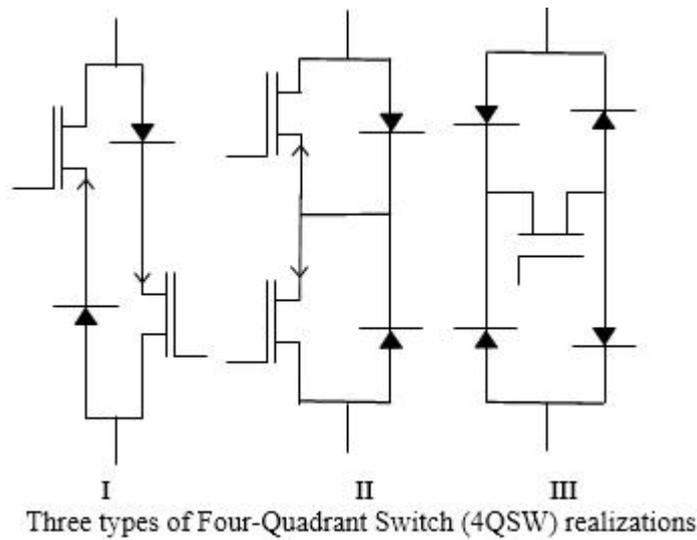
In separately excited DC motor $K_a \phi I_a = T$ therefore (2.52) becomes

$$\omega_m = \frac{V_a}{K_a \phi} - \frac{R_a}{(K_a \phi)^2} T \quad (2.53)$$

Four Quadrant Operation of a Converters

The bi-directional boost converter is the IPQC version of the conventional thyristor dual converters. Their topology is derived from ac-ac matrix converters using four quadrant switches (4QSWs). Since no four-quadrant switch is currently commercially available the realized by embedding a transistor inside a diode bridge or by inverse parallel connections of transistors as shown in Fig (1). Power IGBT employed because they have the advantage so high switching frequency and small pulse and notch widths. Topology of a single-phase bi-directional boost converter using typeI 4QSWsis shown in Fig(2).

In the circuit shown in Fig (2), here are four4QSWs, two in each limb. Each 4QSW comprises two 2QSWs (two quadrant switches), each two-quadrant switch consisting of a IGBTT with series diode, connected in inverse-parallel. The operation of the bi-directional boost converter in boost mode and in a particular quadrant in the V-I plane shown in Fig (3) is determined by the conditioning of the switching states of two sets (IandII) of devices. In the single-phase version each set comprises four IGBTs; set(A) IGBTs–T11,T22,T33,T44 and set(B)I GBTTs–T1,T2,T3,T4.corresponding to the four quadrants in the buck and boost modes pertaining to the rectification and inversion operations



The power circuit diagram of a single phase bi-direction boost rectifier

Time Ratio Control (TRC)

In this control scheme, time ratio T_{on}/T (duty ratio) is varied. This is realized by two different ways called Constant Frequency System and Variable Frequency System as described below:

Constant Frequency System

In this scheme, on-time is varied but chopping frequency f is kept constant. Variation of T_{on} means adjustment of pulse width, as such this scheme is also called pulse-width-modulation scheme.

Variable Frequency System

In this technique, the chopping frequency f is varied and either (i) on-time T_{On} is kept constant or (ii) off-time T_{Off} is kept constant. This method of controlling duty ratio is also called Frequency-modulation scheme.

Current- Limit Control

In this control strategy, the on and off of chopper circuit is decided by the previous set value of load current. The two set values are maximum load current and minimum load current.

When the load current reaches the upper limit, chopper is switched off. When the load current falls below lower limit, the chopper is switched on. Switching frequency of chopper can be controlled by setting maximum and minimum level of current.

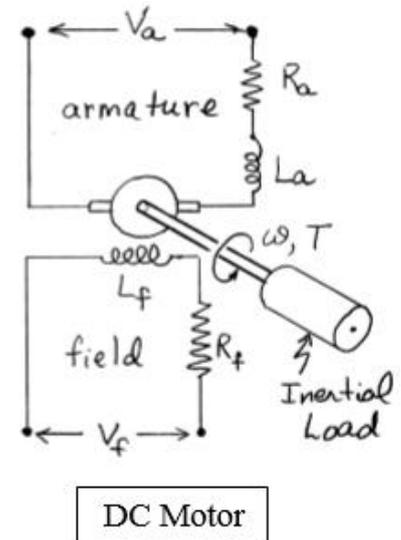
Current limit control involves feedback loop, the trigger circuit for the chopper is therefore more complex. PWM technique is the commonly chosen control strategy for the power control in chopper circuit

UNIT III

3.1 Transfer Function For DC Motor

The figure at the right represents a DC motor attached to an inertial load. The voltages applied to the field and armature sides of the motor are represented by V_f and V_a . The resistances and inductances of the field and armature sides of the motor are represented by R_f , L_f , R_a , and L_a . The torque generated by the motor is proportional to i_f and i_a the currents in the field and armature sides of the motor.

$$\boxed{T_m = K i_f i_a} \quad (1.1)$$



Field-Current Controlled:

In a field-current controlled motor, the armature current i_a is held constant, and the field current is controlled through the field voltage V_f . In this case, the motor torque increases linearly with the field current. We write

$$T_m = K_{mf} i_f$$

By taking Laplace transforms of both sides of this equation gives the transfer function from the input current to the resulting torque.

$$\boxed{\frac{T_m(s)}{I_f(s)} = K_{mf}} \quad (1.2)$$

For the field side of the motor the voltage/current relationship is

$$\begin{aligned} V_f &= V_R + V_L \\ &= R_f i_f + L_f \left(\frac{di_f}{dt} \right) \end{aligned}$$

The transfer function from the input voltage to the resulting current is found by taking Laplace transforms of both sides of this equation.

$$\boxed{\frac{I_f(s)}{V_f(s)} = \frac{(1/L_f)}{s + (R_f/L_f)}} \quad (1^{\text{st}} \text{ order system}) \quad (1.3)$$

The transfer function from the input voltage to the resulting motor torque is found by combining equations (1.2) and (1.3).

$$\boxed{\frac{T_m(s)}{V_f(s)} = \frac{T_m(s)}{I_f(s)} \frac{I_f(s)}{V_f(s)} = \frac{(K_{mf}/L_f)}{s + (R_f/L_f)}} \quad (1^{\text{st}} \text{ order system}) \quad (1.4)$$

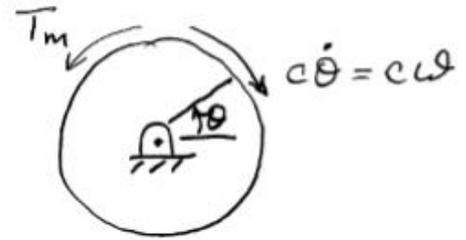
So, a step input in field voltage results in an exponential rise in the motor torque.

An equation that describes the rotational motion of the inertial load is found by summing moments

$$\sum M = T_m - c\omega = J\dot{\omega} \quad (\text{counterclockwise positive})$$

or

$$\boxed{J\dot{\omega} + c\omega = T_m}$$



$$\boxed{\frac{\omega(s)}{T_m(s)} = \frac{(1/J)}{s + (c/J)}} \quad (1^{\text{st}} \text{ order system}) \quad (1.5)$$

Combining equations (1.4) and (1.5) gives the transfer function from the input field voltage to the resulting speed change

$$\boxed{\frac{\omega(s)}{V_f(s)} = \frac{\omega(s)}{T_m(s)} \frac{T_m(s)}{V_f(s)} = \frac{(K_{mf}/L_f J)}{(s + c/J)(s + R_f/L_f)}} \quad (2^{\text{nd}} \text{ order system}) \quad (1.6)$$

Finally, since $w = dq/dt$, the transfer function from input field voltage to the resulting rotational position change is

$$\boxed{\frac{q(s)}{V_f(s)} = \frac{q(s)}{\omega(s)} \frac{\omega(s)}{V_f(s)} = \frac{(K_{mf}/L_f J)}{s(s + c/J)(s + R_f/L_f)}} \quad (3^{\text{rd}} \text{ order system}) \quad (1.7)$$

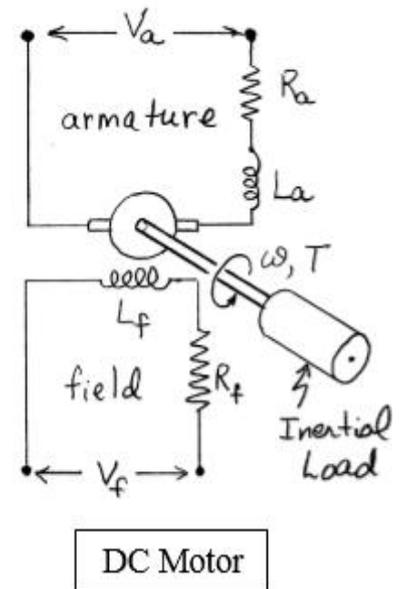
Armature-Current Controlled:

In a armature-current controlled motor, the field current i_f is held constant, and the armature current is controlled through the armature voltage V_a . In this case, the motor torque increases linearly with the armature current. We write

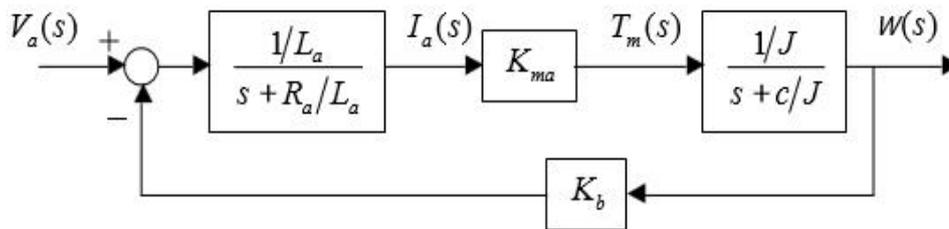
$$T_m = K_{ma} i_a$$

The transfer function from the input armature current to the resulting motor torque is

$$\frac{T_m(s)}{I_a(s)} = K_{ma} \tag{1.8}$$



Equations (1.8), (1.11) and (1.12) together can be represented by the closed loop block diagram shown below.



Block diagram reduction gives the transfer function from the input armature voltage to the resulting speed change.

$$\frac{W(s)}{V_a(s)} = \frac{(K_{ma}/L_a J)}{(s + R_a/L_a)(s + c/J) + (K_b K_{ma}/L_a J)} \tag{1.13}$$

(2nd order system)

The transfer function from the input armature voltage to the resulting angular position change is found by multiplying Equation (1.13) by 1/s .

The voltage/current relationship for the armature side of the motor is

$$V_a = V_R + V_L + V_b \tag{1.9}$$

where V_b represents the "back EMF" induced by the rotation of the armature windings in a magnetic field. The back EMF V_b is proportional to the speed w , i.e. $V_b(s) = K_b w(s)$. Taking Laplace transforms of Equation (1.9) gives

$$\boxed{V_a(s) - V_b(s) = (R_a + L_a s) I_a(s)} \tag{1.10}$$

or

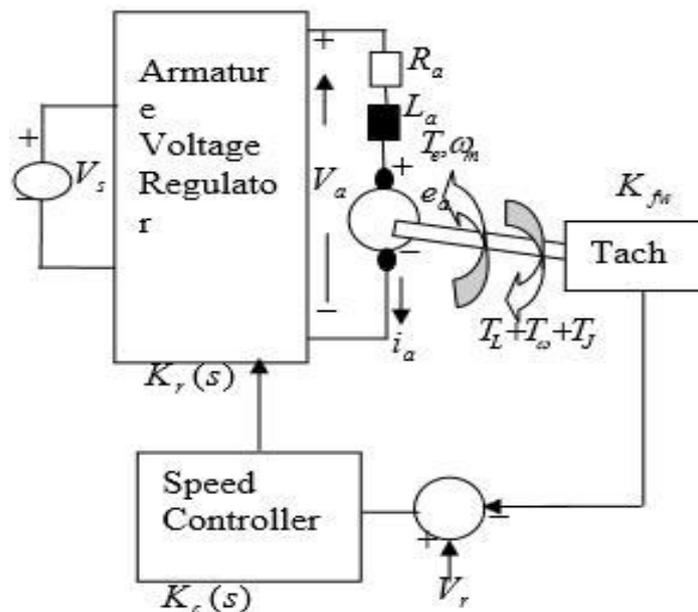
$$\boxed{V_a(s) - K_b w(s) = (R_a + L_a s) I_a(s)} \tag{1.11}$$

As before, the transfer function from the input motor torque to rotational speed changes is

$$\boxed{\frac{w(s)}{T_m(s)} = \frac{(1/J)}{s + (c/J)}} \quad (1^{st} \text{ order system}) \tag{1.12}$$

3.3 Closed Loop Control With Current And Speed Feedback

Closed loop control improves on the drives performance by increasing speed of response and improving on speed regulation. So the functions of closed loop control is that ω_n is increased, ϵ is reduced, t_s is reduced, and Speed Regulation (SR) is reduced. A closed loop speed control scheme is shown below



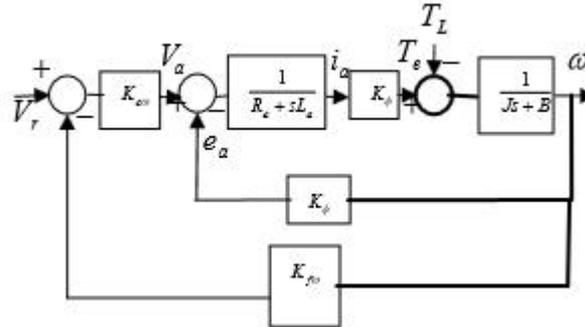
Schematic Diagram of the Closed Loop Speed Control

Where, $K_{f\omega}$ is the tachometer feedback gain

$K_c(s)$ is the speed controller gain

$K_r(s)$ is the armature voltage regulator gain

The block diagram representation of the control configuration is shown below.



Block Diagram of the Closed Loop Speed Control.

The dynamic equation by mason's rule is,

$$\begin{pmatrix} \omega_m \\ i_a \end{pmatrix} = \frac{\begin{pmatrix} K_\phi K_{v\omega}(s) & -(R_a + sL_a) \\ (Js + B)K_{v\omega}(s) & K_\phi K_{f\omega}(s)K_{v\omega}(s) \end{pmatrix} \begin{pmatrix} V_r \\ T_L \end{pmatrix}}{D_o(s)} \quad (23)$$

Where,

$$D_o(s) = s^2 J L_a + (R_a J + B L_a) s + R_a B + K_\phi^2 + K_\phi K_{f\omega}(s) K_{v\omega}(s) \quad (24)$$

$$D_o(s) = J L_a [s^2 + \left(\frac{R_a J + B L_a}{J L_a}\right) s + \frac{R_a B + K_\phi^2 + K_\phi K_{f\omega}(s) K_{v\omega}(s)}{J L_a}] \quad (25)$$

If the tachometer loop does not contain a filter, the feedback gain can be a constant designated as $K_{f\omega}$

$$K_{cw}(s) = K_{cwp} + \frac{K_{cwl}}{s} + s K_{cwd}$$

Where,

K_{cwd} is the proportional gain component of $K_{cw}(s)$

K_{cwp} is the integral gain component of $K_{cw}(s)$ & K_{cwl}

Three possible controller configurations are possible:

1. For K_{cwl} & K_{cwd} zero $K_{cw}(S) = K_{cwp}$ Which is a Proportional Controller
2. For K_{cwp} & K_{cwd} zero $K_{cw}(S) = K_{cwl}/S$ Which is an Integral Controller

3. For K_{cwi} zero $K_{cw}(S) = K_{cwp} + K_{cwi}/S$ Which is a Proportional Integral Controller

Now taking the Proportional Controller as a case study, with $K_{cw}(S) = K_{cwp}$, the dynamic equation is,

$$\begin{pmatrix} \omega_m \\ i_a \end{pmatrix} = \frac{\begin{pmatrix} K_\phi K_{cwp} & -(R_a + sL_a) \\ (Js + B)K_{cwp} & K_\phi K_{f\omega} K_{cwp} \end{pmatrix} \begin{pmatrix} V_r \\ T_L \end{pmatrix}}{D_o(s)}$$

Where,

$$D_o(s) = s^2 J L_a + (R_a J + B L_a) s + R_a B + K_\phi^2 + K_\phi K_{f\omega} K_{cwp}$$

$$D_o(s) = J L_a [s^2 + \left(\frac{R_a J + B L_a}{J L_a}\right) s + \frac{R_a B + K_\phi^2 + K_\phi K_{f\omega} K_{cwp}}{J L_a}]$$

$$D_o(s) = J L_a [s^2 + 2\varepsilon \omega_n s + \omega_n^2]$$

Last Equation is a second order system

The Natural Frequency of Oscillation, ω_n is,

$$\omega_n = \sqrt{\frac{R_a B + K_\phi^2 + K_\phi K_{f\omega} K_{cwp}}{J L_a}}$$

This is always higher than the open loop case due to the factor $K_\phi, K_{f\omega}, K_{cwp}$

The Damping Ratio, ε , is

$$\varepsilon = \frac{R_a J + B L_a}{2 \omega_n J L_a}$$

This is lower than in the open loop case due to the increase in ω_n

Speed Regulation (SR) is also derived as

$$SR = \frac{-R_a}{R_a B + K_\phi^2 + K_\phi K_{f\omega} K_{c\omega p}}$$

SR is also lower than in the open loop case due to the factor $K_\phi, K_{f\omega}, K_{c\omega p}$. This is an indication of a better drive performance.

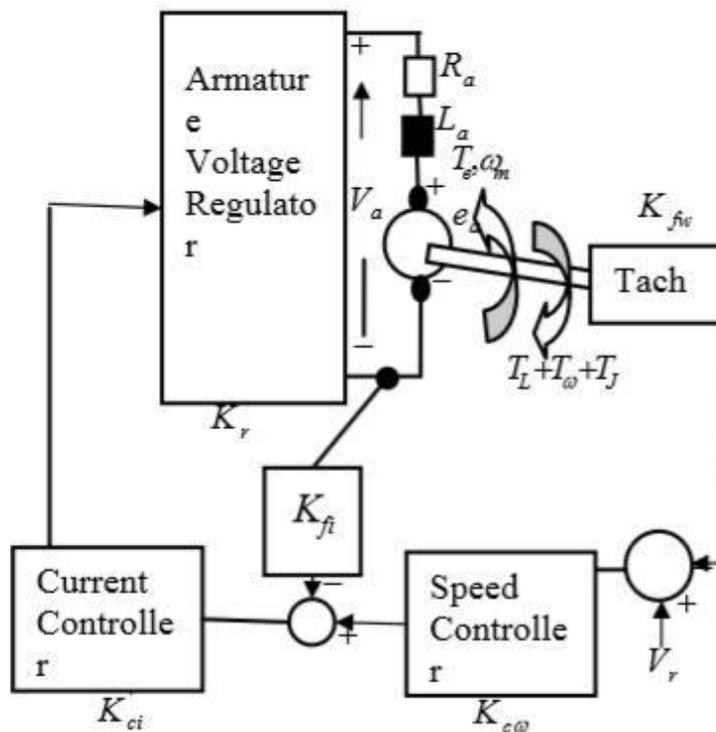
Inner Current Loop Control

Improvement in speed control can be obtained with Inner Current Loop Control method, whereby armature current is fed back to the input. A closed loop speed control scheme with inner current control is shown in Figure.

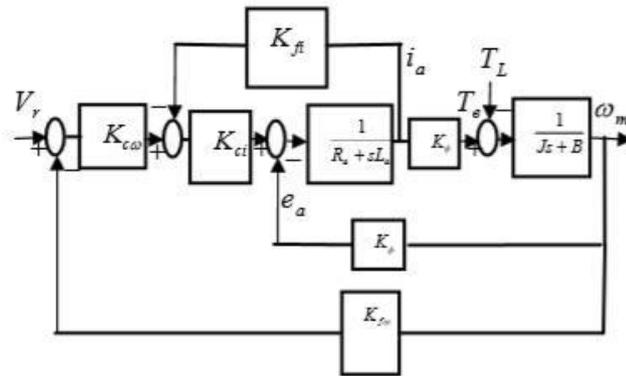
Designating $K_{ci} + K_r = K_{ci}$ the block diagram representation of the control configuration is shown in Figure.

The dynamic equation is,

$$\begin{pmatrix} \omega_m \\ i_a \end{pmatrix} = \frac{\begin{pmatrix} K_\phi K_{ci} K_{c\omega} & -(R_a + sL_a + K_{ci} K_{fi}) \\ (Js + B) K_{c\omega} K_{ci} & K_\phi + K_{f\omega} K_{c\omega} K_{ci} \end{pmatrix} \begin{pmatrix} V_r \\ T_L \end{pmatrix}}{D_o}$$



Schematic Diagram of the Inner Current Loop Control.

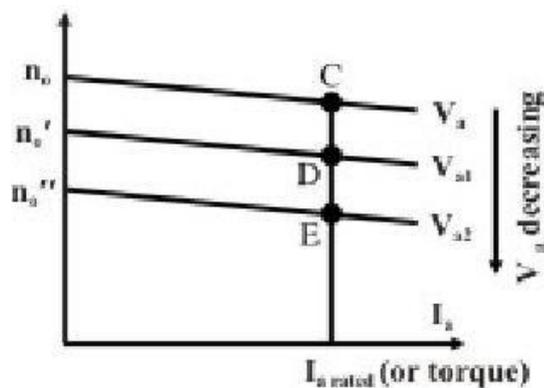
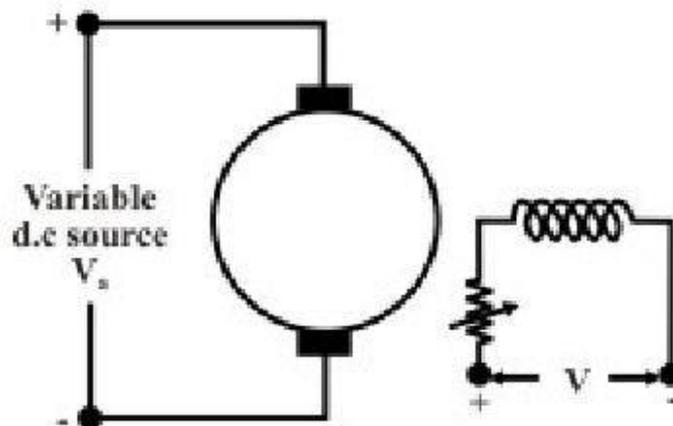


Block Diagram of the Inner Current Loop Control

Speed control by armature voltage variation

In this method of speed control, armature is supplied from a separate variable Ac voltage source, while the field is separately excited with fixed rate dc voltage as shown in figure. Here the armature resistance and field current are not varied. Since the no load speed the speed versus I_a characteristic will shift parallel as shown in figure for different values of V_a .

$$n_0 = \frac{V_a}{k\phi}$$



As flux remains constant, this method is suitable for constant torque loads. In a way armature voltage control method dissimilar to that of armature resistance control method except that the former

one is much superior as next re-power loss takes place in the armature circuit. Armature voltage control method is adopted for controlling speed from base speed down to very small speed, as one should not apply across the armature a voltage, which is higher than the rated voltage.

Flux-Weakening Control Design and Analysis

In order to produce the maximum torque, which main component is proportional to q-axis component of the armature current, it is convenient to control the inverter-fed PMSM by keeping the direct, *d-axis*, current component to be i_d as long as the inverter output voltage doesn't reach its limit.

At that point, the motor reaches its maximum speed, so-called *rated speed* (called also *base speed* when talking about flux-weakening). Beyond that limit, the motor torque decreases rapidly toward its minimum value, which depends on a load torque profile. To expand the speed above the rated value, the motor torque is necessary to be reduced. A common method in the control of synchronous motors is to reduce the magnetizing current, which produces the magnetizing flux. This method is known as *field-weakening*. With PM synchronous motors it is not possible, but, instead, the air gap flux is weakened by producing a negative d-axis current component, i_d .

Because nothing has happened to the excitation magnetic field and the air gap flux is still reduced, so is the motor torque, this control method is called *flux-weakening*. As a basis for this analysis, the PMSM current and voltage d-q vector diagrams from the previous section Fig are used. During flux-weakening, because the demagnetizing (negative) i_d current increases, a phase current vector i_s rotates toward the *negative d-semi-axis*. The rotation of the phase voltage vector is determined by a chosen flux weakening strategy, but at the end of flux-weakening it always rotates toward the *positive q-semi axis* because of i_q current, i.e. v_d voltage magnitude decrease.

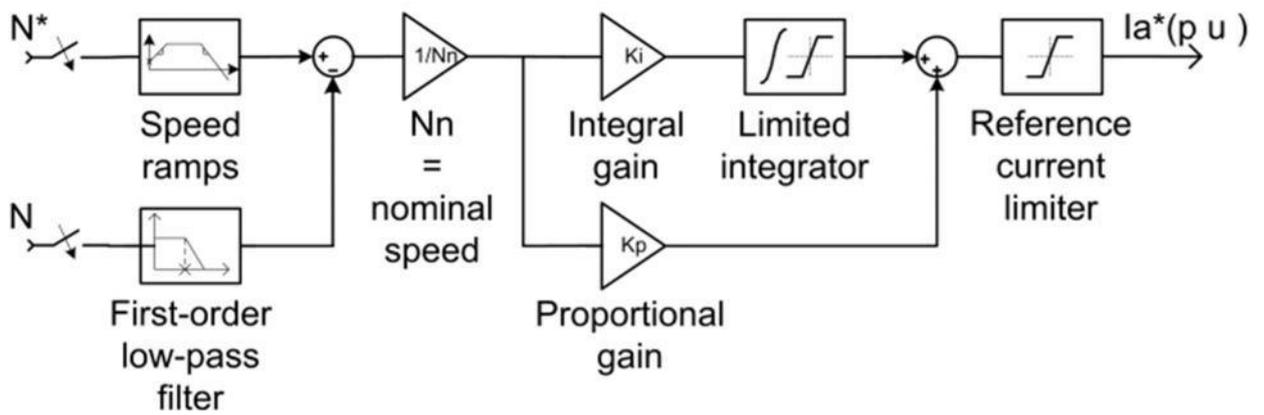
Hence, the voltage-to-current phase shift decreases to zero and increases in negative direction either to the inverter phase shift limit (usually 30°), or a load torque dictated steady-state (zero acceleration), or to the zero motor torque condition (no load or generative load). A big concern of flux-weakening control is a danger of permanent demagnetization of magnets. However, large materials such as Samarium-Cobalt, allows significant i_d current which can extend the motor rated speed up to two times. Three commonly used flux-weakening control strategies are:

- 1) constant-voltage-constant-power(CVCP)control;
- 2) constant-current-constant-power(CCCP)control;and
- 3) optimum-current-vector(OCV or CCCV-constant-current-constant-voltage)control.

Speed Controller

The speed regulator in the following figure uses a PI controller. The controller outputs the armature current reference (in pu) used by the current controller in order to obtain the electromagnetic torque needed to reach the desired speed. During torque regulation, the speed controller is disabled.

The controller takes the speed reference (in rpm) and the rotor speed of the DC machine as inputs. The speed reference change rate will follow user-defined acceleration and deceleration ramps in order to avoid sudden reference changes that could cause armature over-current and destabilize the system. The speed measurement is filtered by a first-order low-pass filter.

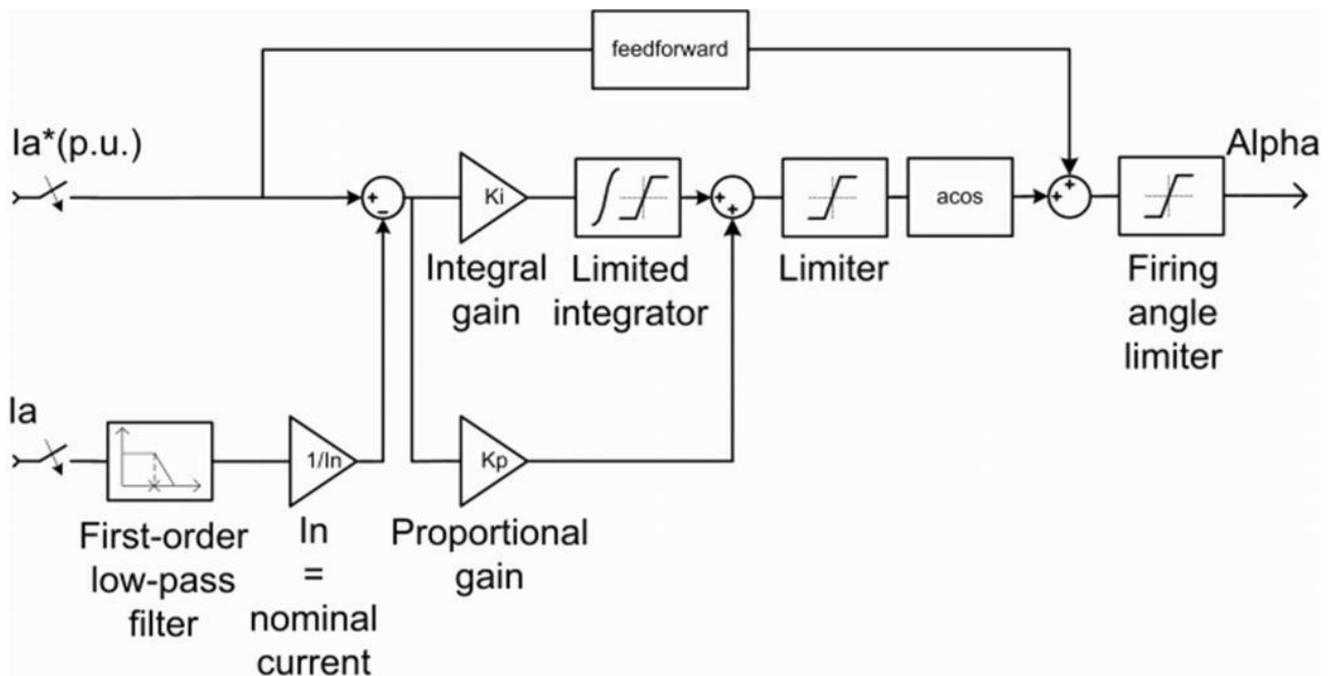


Current Controller

The armature current regulator in the following figure is based on a second PI controller. The regulator controls the armature current by computing the appropriate thyristor firing angle. This generates the rectifier output voltage needed to obtain the desired armature current and thus the desired electromagnetic torque.

The controller takes the current reference (in pu) and the armature current flowing through the motor as inputs. The current reference is either provided by the speed controller during speed regulation or computed from the torque reference provided by the user during torque regulation. This is managed by the "regulation switch" block.

The armature current input is filtered by a first-order low-pass filter. An arccosine function is used to linearize the control system during continuous conduction. To compensate nonlinearities appearing during discontinuous conduction, a feed forward term is added to the firing angle.



UNIT IV

Stator Voltage Control

In this method of control, back-to-back thyristors are used to supply the motor with variable ac voltage. The analysis implies that the developed torque varies inversely as the square of the input RMS voltage to the motor. This makes such a drive suitable for fan- and impeller-type loads for which torque demand rises faster with speed. For other types of loads, the suitable speed range is very limited. Motors with high rotor resistance may offer an extended speed range. It should be noted that this type of drive with back-to-back thyristors with firing-angle control suffers from poor power and harmonic distortion factors when operated at low speed. If unbalanced operation is acceptable, the thyristors in one or two supply lines to the motor may be bypassed. This offers the possibility of dynamic braking or plugging, desirable in some applications.

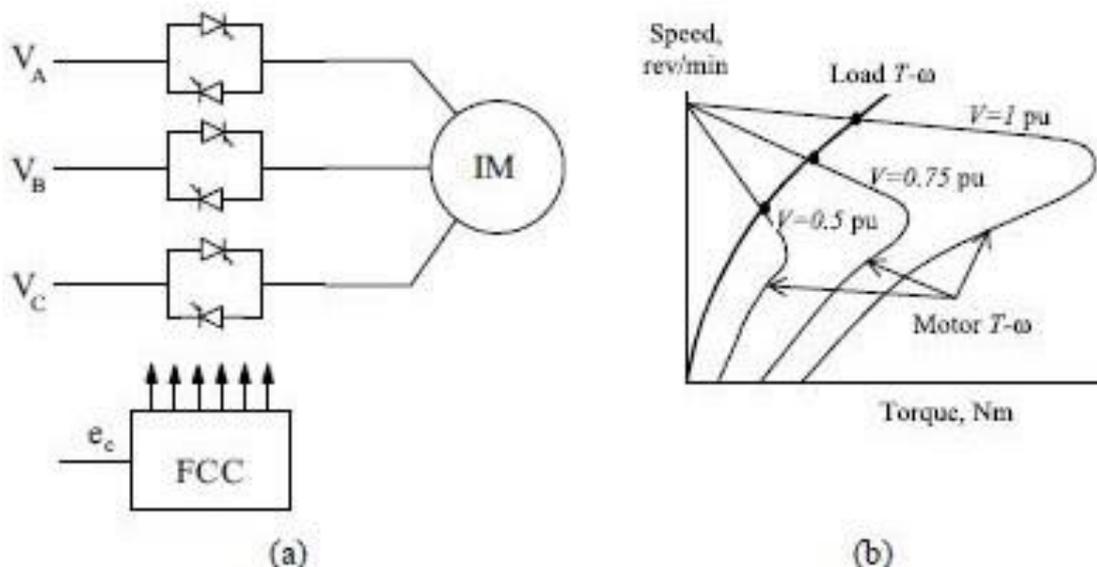
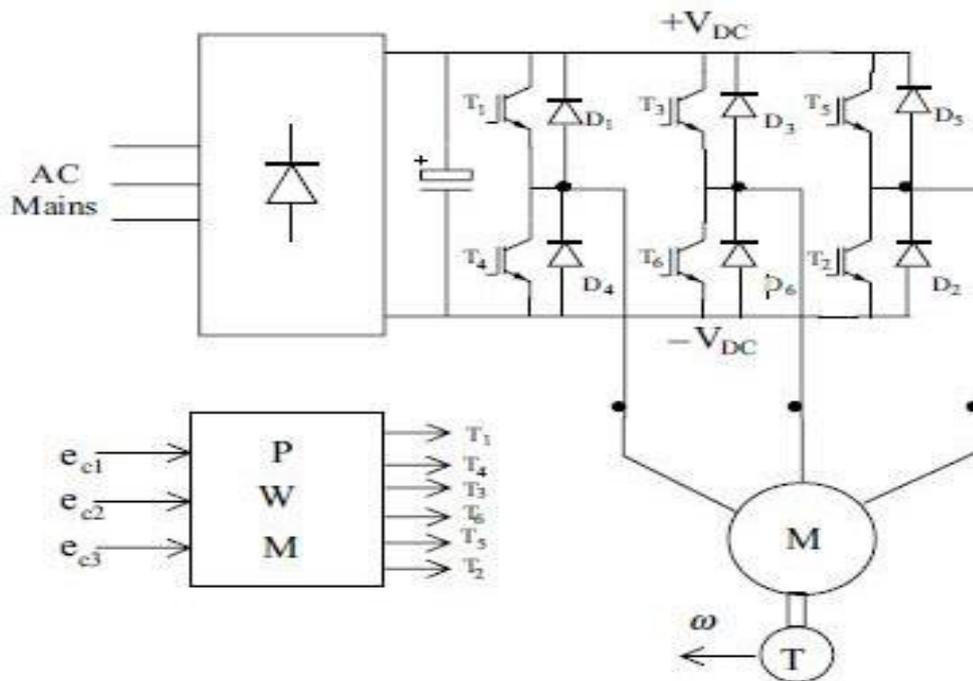


FIGURE (a) Stator voltage controller. (b) Motor and load torque–speed characteristics under voltage control.

The induction motor speed variation can be easily achieved for a short range by either stator voltage control or rotor resistance control. But both of these schemes result in very low efficiencies at lower speeds. The most efficient scheme for speed control of induction motor is by varying supply frequency. This not only results in scheme with wide speed range but also improves the starting performance. If the machine is operating at speed below base speed, then v/f ratio is to be kept constant so that flux remains constant. This retains the torque capability of the machine at the same value. But at lower frequencies, the torque capability decrease and this drop in torque has to be compensated for increasing the applied voltage.



V/F Control

Open Loop V/F Control

The open loop V/F control of an induction motor is the most common method of speed control because of its simplicity and these types of motors are widely used in industry. Traditionally, induction motors have been used with open loop 50Hz power supplies for constant speed applications. For adjustable speed drive applications, frequency control is natural. However, voltage is required to be proportional to frequency so that the stator flux

$$\Psi_s = V_s / \omega_s$$

Remains constant if the stator resistance is neglected. The power circuit consists of a diode rectifier with a single or three-phase ac supply, filter and PWM voltage-fed inverter. Ideally no feedback signals are required for this control scheme.

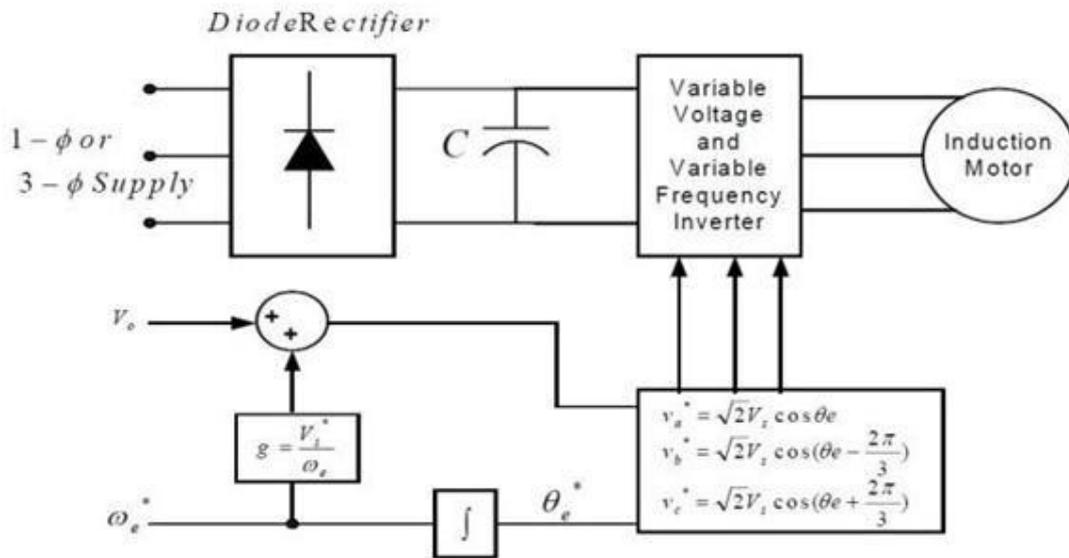
The PWM converter is merged with the inverter block. Some problems encountered in the operation of this open loop drive are the following:

The speed of the motor cannot be controlled precisely, because the rotor speed will be slightly less than the synchronous speed and that in this scheme the stator frequency and hence the synchronous speed is the only control variable.

The slip speed, being the difference between the synchronous speed and the electrical rotor speed, cannot be maintained, as the rotor speed is not measured in this scheme. This can lead to operation in the unstable region of the torque-speed characteristics.

The effect of the above can make the stator currents exceed the rated current by a large amount thus endangering the inverter- converter combination

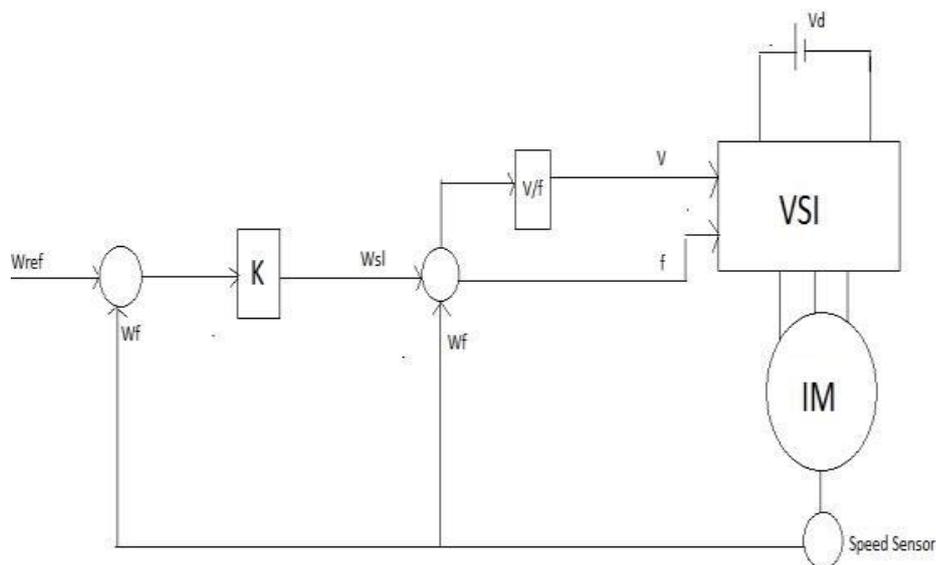
These problems are to be suppress by having an outer loop in the induction motor drive, in which the actual rotor speed is compared with its commanded value, and the error is processed through a controller usually a PI controller and a limiter is used to obtain the slip-speed command



Block diagram of open loop V/F Control for an IM

Closed Loop V/F Control

The basis of constant V/F speed control of induction motor is to apply a variable magnitude and variable frequency voltage to the motor. Both the voltage source inverter and current source inverters are used in adjustable speed ac drives. The following block diagram shows the closed loop V/F control using a VSI



Block diagram for closed loop V/F control for an IM

A speed sensor or a shaft position encoder is used to obtain the actual speed of the motor. It is then compared to a reference speed. The difference between the two generates an error and the error so obtained is processed in a Proportional controller and its output sets the inverter frequency. The

synchronous speed, obtained by adding actual speed ω_f and the slip speed ω_{sl} , determines the inverter frequency. The reference signal for the closed-loop control of the machine terminal voltage ω_f is generated from frequency.

Field Weakening Mode

In the field of closed loop controlled voltage source inverter-fed induction motors the rotor flux oriented control scheme can be regarded as the state of the art for various applications [6]. In some applications as spindles, traction and electric vehicle drives the availability of constant power operation is very important. A field-oriented induction motor drive is a suitable candidate for such applications because the flux of the induction machine can be easily weakened. In this case the drive operates close to the voltage limit and the reference flux has to be carefully selected to achieve the maximum torque. Control of an induction motor with weakened flux has been investigated by many authors and three methods for establishing the flux were suggested.

- 1) The flux reference can be set according to a fixed flux- speed characteristic
- 2) it can be calculated from simplified motor equations, which can be improved through consideration of additional variables
- 3) it can be provided by a voltage controller, which sets the flux in such a way that the voltage required by the motor matches the voltage capability of the inverter

The third strategy seems to be optimal because it is not sensitive to parameter variations in a middle speed region. At high speed the current has to be reduced for matching the maximum torque and for avoiding a pull-out. In this is done with a fixed current-speed characteristic which is sensitive to parameter and DC link voltage variations. A remedy is possible if a parameter insensitive feature of the induction machine is used for the current reduction. Such a criterion is presented and an extension of the voltage control is presented in this paper which allows an operation with maximum torque in the whole field weakening region.

THE STEADY STATE TORQUE CAPABILITY

The investigation starts with the dynamic model of the induction motor in the rotor flux oriented frame

$$\frac{d}{dt} \begin{pmatrix} i_{sd} \\ i_{sq} \\ \psi_{rd} \end{pmatrix} = \begin{pmatrix} -\frac{K_R}{K_L} & \omega_{FS} & \frac{L_m}{L_R K_L T_R} \\ -\omega_{FS} & -\frac{K_R}{K_L} & \frac{L_m}{-p \omega_m L_R K_L} \\ \frac{L_m}{T_R} & 0 & -\frac{1}{T_R} \end{pmatrix} \cdot \begin{pmatrix} i_{sd} \\ i_{sq} \\ \psi_R \end{pmatrix} + \begin{pmatrix} \frac{1}{K_L} & 0 \\ 0 & \frac{1}{K_L} \\ 0 & 0 \end{pmatrix} \cdot \begin{pmatrix} u_{sd} \\ u_{sq} \end{pmatrix} \quad (1)$$

$$T_m = \frac{3}{2} p \frac{L_m}{L_R} i_{sq} \psi_R \quad (2)$$

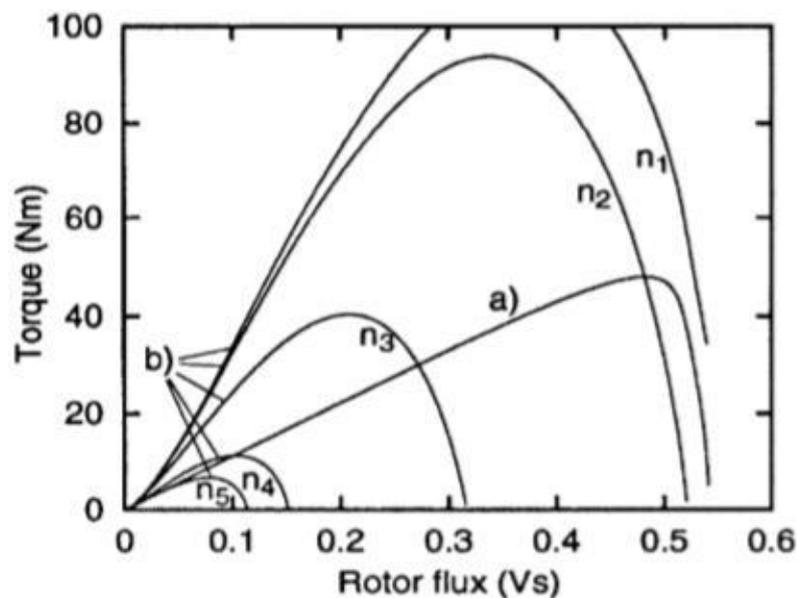
$$T_m = \frac{3}{2} p \frac{L_m}{L_R} i_{Sq} \Psi_R \quad (2)$$

$$\omega_{FS} = \omega_{FR} + p\omega_m \quad (3)$$

$$\omega_{FR} = \frac{L_m}{T_R} \cdot \frac{i_{Sq}}{\Psi_R} \quad (4)$$

$$L_m = f(i_m) \quad \text{with } i_m = i_{Sd} \sqrt{1 + \left(\frac{i_{Sq}}{i_{Sd}} \left(1 - \frac{L_m}{L_R} \right) \right)^2} \quad (5)$$

The voltage limitation curves depend on rotor speed. For every rotor speed any operation point below the voltage and the current limitation curve is possible and permissible. Obviously three speed regions have to be distinguished Basic speed region: At low speeds the peak of the current limit curve is situated below the voltage limit curve (e. g. curve b) with 1000 rpm). The maximum torque is determined by the peak of the current limitation curve and the corresponding rotor flux Root has to chosen.



Lower flux weakening region: At medium speeds the maximum torque is indicated by the crossing of both limitation curves (e. g. curve a) and b) with 2500 rpm). The induction machine has to run with minimum current and maximum voltage.

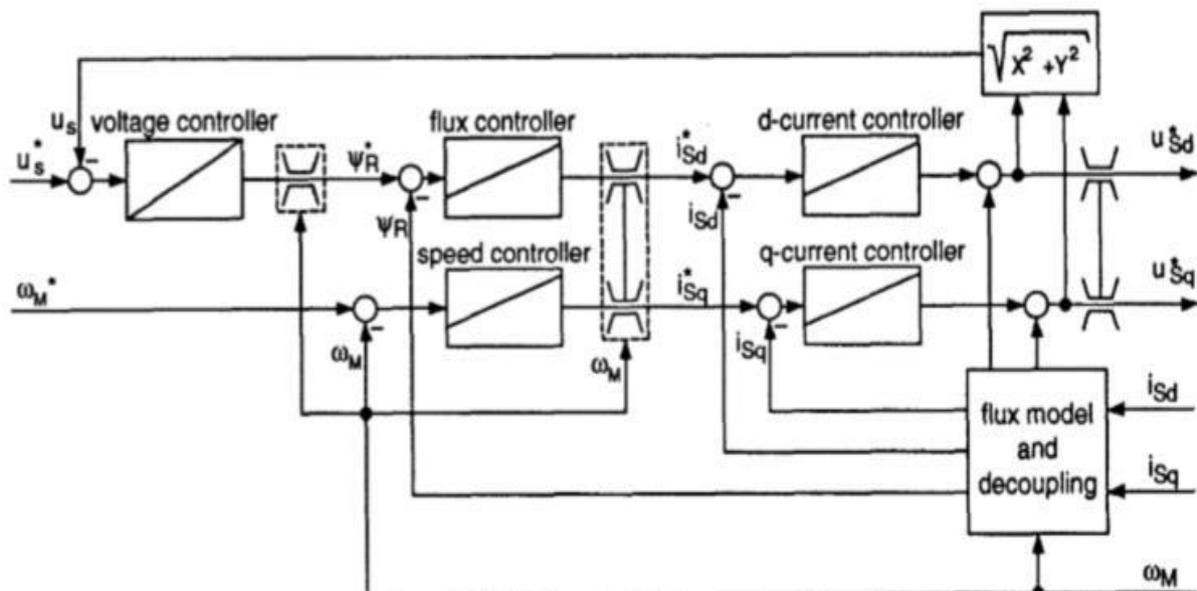
Upper flux weakening region: At high speeds the maximum torque is fixed by the maxima of the voltage limitation curves only. The machine has to run only with maximum voltage but the current has to be reduced.

In the lower flux weakening region the optimum operating point can be adjusted independently of the electrical parameters if the control scheme makes sure that the induction machine runs with maximum current and voltage.

Fig. 2 shows a scheme that keeps these two conditions ([3], [10]). The voltage controller increases the flux of the induction motor until the voltage matches the reference value u_s that is nearly the same as the voltage maximum

At the basic speed region the induction motor must not run at the voltage limit. The missing condition to adjust the operating point is replaced by the limitation of the reference flux. This is chosen as that determined the peak of the current limitation curve.

At the upper flux weakening region the limitation of the reference q-current is carried out with a speed depending function is $\max(\omega_M)$ that is calculated offline in such a way that the reduced current limitation curve crosses the voltage limitation curves at their maxima in Fig



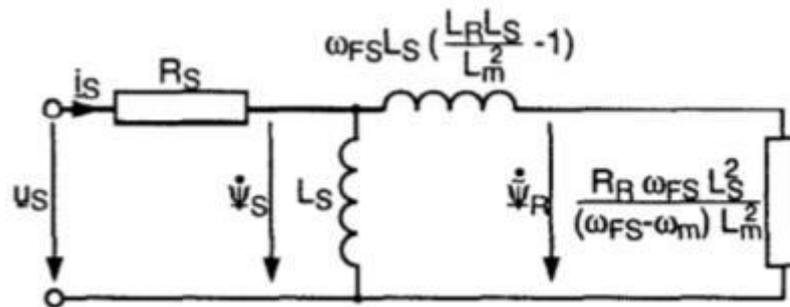
Scheme of rotor flux oriented control with voltage controller

CURRENT REDUCTION IN THE UPPER FLUX WEAKENING REGION

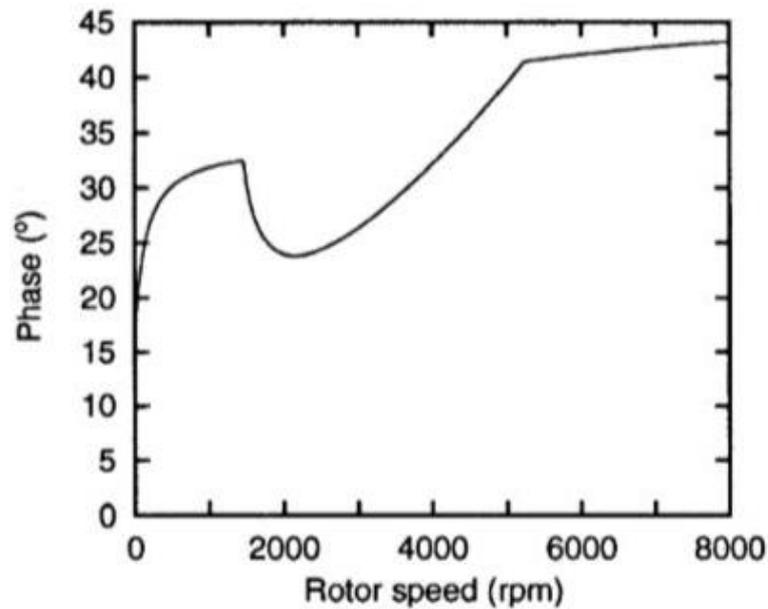
The function $I_q \max(\omega_M)$ depends on the electrical parameters as well as the DC link voltage. If the uncertainties of the electrical parameters and the variations of u_d are taken into account the optimum operating point can be missed. This problem can be solved, if there is a second condition that describes the optimum operating point in the upper flux weakening region independently of the critical parameters. A condition that describes the optimum operating point independent of the electrical parameters can only depend on the measured values of current, voltage and speed. Since the torque has to be optimized for a given speed the measured value of the speed delivers no information.

The amplitudes of the remaining voltage and current values are analyzed by means of Fig. 1 but additional information can be extracted from the angle between these quantities. The angle can be gathered from Fig. 3 that shows the locus of apparent power depends on speed if the motor runs with maximum torque. The three speed regions can be separated in this diagram as well as in Fig Basic speed region (0 rpm ... 1457 rpm): The stator voltage increases with speed and also the active and reactive power. Lower flux weakening region (1457 rpm...5240 rpm): The motor runs with maximum voltage and current. This results in $\omega_M = \text{const}$. Upper flux weakening region (5240 rpm.. .8000 rpm): The current is reduced and also the apparent power.

Remarkable is the phenomenon that the angle Ψ between u_s and I_s is nearly 45° and constant at the upper flux weakening region. This is also true for machines with other parameters. The reason can be deduced from the equivalent circuit of the induction motor at steady state (Fig.). In the upper flux weakening region with the corresponding high excitation frequencies the magnetizing current as well as the influence of the stator resistance can be neglected. The maximum active power for a given voltage and excitation frequency is achieved if leakage reactance and rotor resistance are equal and



Equivalent circuit for induction machine with all leakage on rotor side.



Angle between stator voltage and stator current ϕ .

$\phi = 45^\circ$. This results in:

$$\omega_{FS} - \omega_{RS} = \frac{R_R}{K_L} \cdot \quad (6)$$

A more exact solution can be found by searching the maximum of

$$P_m(i_{Sd}, i_{Sq}) = T_m \cdot \omega_m = \frac{3L_m^2}{2L_R} \cdot \omega_{RS} \cdot i_{Sd} \cdot i_{Sq} \quad (7)$$

with the constraints:

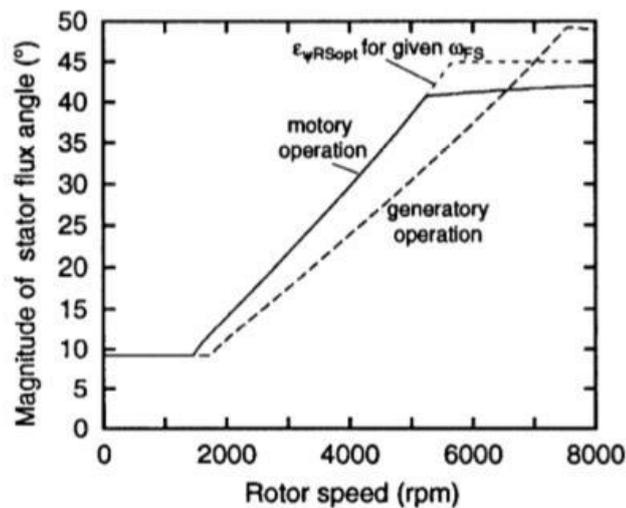
$$L_m = f(i_{Sd}, i_{Sq}) \quad (8)$$

$$u_{max}^2 = u_{Sd}^2 + u_{Sq}^2 \quad (9)$$

with

$$u_{Sd} = R_S i_{Sd} - K_L \omega_{RS} i_{Sq} - \frac{K_L R_R}{L_R} \cdot \frac{i_{Sq}^2}{i_{Sd}}, \quad (10)$$

With these equations the torque is maximized for a given rotor speed and not for a given excitation frequency as with equ. (6) And in some papers.



Optimal angle of stator flux in the rotor flux frame

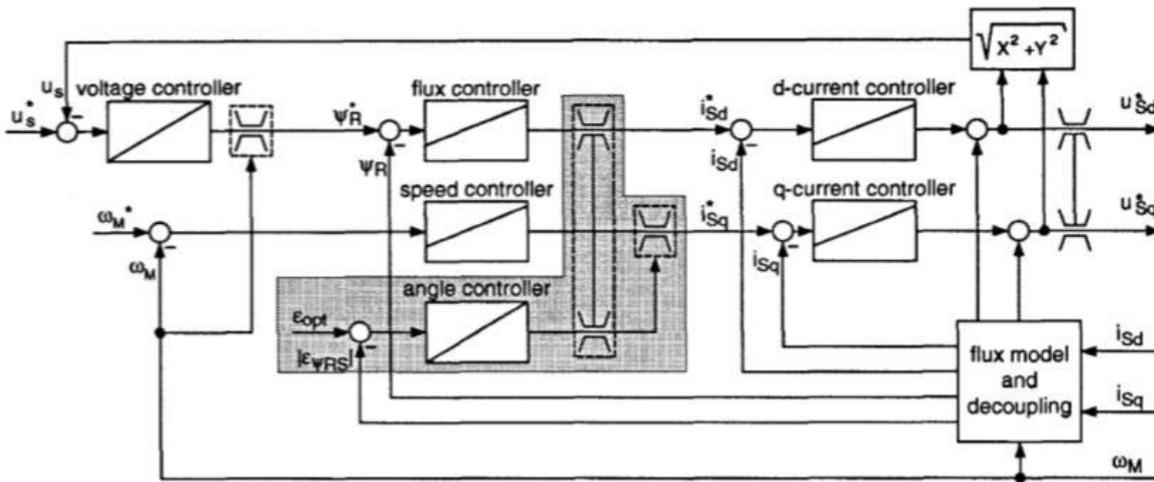
The different operation areas are characterized by different behavior

In the basic speed region E_{VRSOPT} is small and constant.

In the lower flux weakening region the angle is characterized by a monotonous increase with a large gradient.

In the upper flux weakening region $E_{\Psi_{RS}OPT}$ increases monotonously as well but the gradient is very small. As proposed $E_{\Psi_{RS}OPT}$ is just a few degrees below 45° and nearly the same as Ψ in this speed range. These quantity can be utilized advantageously as a criterion for the optimum operating point.

During generatory operation the upper flux weakening region is very small; the angle is negative and its magnitude runs above 45°



Scheme of rotor flux oriented control with voltage and with angle controller

The result of the simplified optimization for the upper flux weakening region is also presented in Fig. This curve runs just below 45° (exactly 45° if $R_S = 0$) and the corresponding operation points are identical to the well-known pullout torque of the induction machine which characterizes the maximum torque if the machine is excited with a fixed voltage and frequency. But these operation points represents not the maximum torque for excitation with variable frequency and constant voltage. A larger torque can be attained for a given rotor speed if the machine runs with a smaller slip and excitation frequency and a therefore larger flux amplitude.

Table I: Loss of torque due to parameter variations (7000 rpm)

$\frac{L_m}{L_{mN}}$	$\frac{L_{R,SO}}{L_{R,SON}}$	$\frac{R_S}{R_{SN}}$	$\frac{R_R}{R_{RN}}$	$\frac{\epsilon_{\Psi_{RS}opt}}{\text{degree}}$	$\frac{\Delta T_m}{T_{mmax}}$
0.8	0.8	1.2	1.2	40.26	-1.3 %e
1	0.8	1.2	1.2	40.27	-1.3 %e
1.2	0.8	1.2	1.2	40.28	-1.2 %e
...
1	1.2	1.2	1.2	41.67	~ 0
1	1	1	1	41.67	0
1.2	1.2	1.2	1.2	41.67	~ 0
...
0.8	1.2	0.8	0.8	42.68	-0.65 %e
1	1.2	0.8	0.8	42.69	-0.67 %e
1.2	1.2	0.8	0.8	42.69	-0.67 %e

The robustness of the stator flux angle $E_{\Psi_{RSPOT}}$ is demonstrated with Table I. In this table the results of $E_{\Psi_{RSPOT}}$ for a fixed rotor speed are listed which can be obtained if variations of the electrical parameters (factor: 0.8, 1.0, 1.2) are allowed and all 81 combinations are examined. The rows are sorted to increasing $E_{\Psi_{RSPOT}}$. In spite of the large variations the maximum and the minimum of $E_{\Psi_{RSPOT}}$ differ only little from the correct value 41.67° . For these calculations the saturation of the mutual inductance was neglected and in this case $E_{\Psi_{RSPOT}}$ is independent of the stator voltage. The last column shows the loss of torque if the induction machine runs with $E_{\Psi_{RSPOT}}$ calculated from the detuned parameters. An extreme robustness to parameter uncertainties can be realized.

Table II: Data of investigated drive

Unit	Parameter	
Inverter:	DC link voltage	300 V
	maximum phase voltage u_{max}	173 V
	maximum phase current	38 A
	switching frequency	10 kHz
Motor:	rated power (name plate data)	3 kW
	rated current (amplitude)	21 A
	maximum speed	8000 rpm
	stator resistance	0.22 Ω
	rotor resistance	0.231 Ω
	stray inductance	1.204 mH
	$L_m = \frac{62.9 \text{ mH}}{e^{i_m/141\text{A}}} - \frac{30 \text{ mH}}{e^{i_m/13\text{A}}} + 10 \text{ mH}$	
	inertia (load included)	0.04 kgm ²
number of pole pairs	2	

The current reduction by means of the stator flux angle can be easily implemented in the control scheme. One solution with little expense is shown in Fig. 7. The flux model delivers additionally an estimated value of the difference to $E_{\Psi_{RSPOT}}$ is applied to an integrator which operates as an angle controller. Its regulating quantity is the limit of the reference q-current. If ($E > E_{\Psi_{RSPOT}}$) the q-current will be reduced until the regulated quantity meets its reference value $E_{\Psi_{RSPOT}}$.

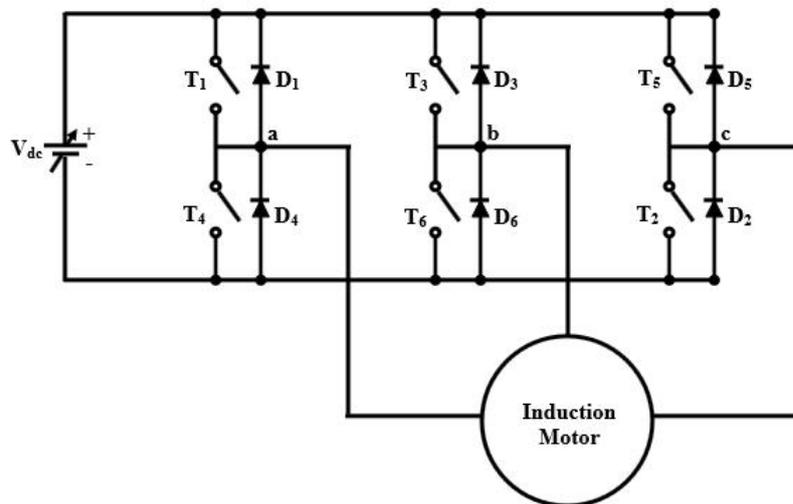
The quality of the operation point adjustment depends apparently on the quality of the flux estimation but at the relevant large rotor speeds a robust flux estimation is not difficult and uncritical. Furthermore, $E_{\Psi_{RS}}$ coupled closely to the measurable angle Ψ in this speed range.

Voltage-source Inverter-driven Induction Motor

A three-phase variable frequency inverter supplying an induction motor is shown in Figure. The power devices are assumed to be ideal switches. There are two major types of switching schemes for the inverters, namely, **square wave switching and PWM switching**.

Square wave inverters

The gating signals and the resulting line voltages for square wave switching are shown in Figure. The phase voltages are derived from the line voltages assuming a balanced three-phase system.

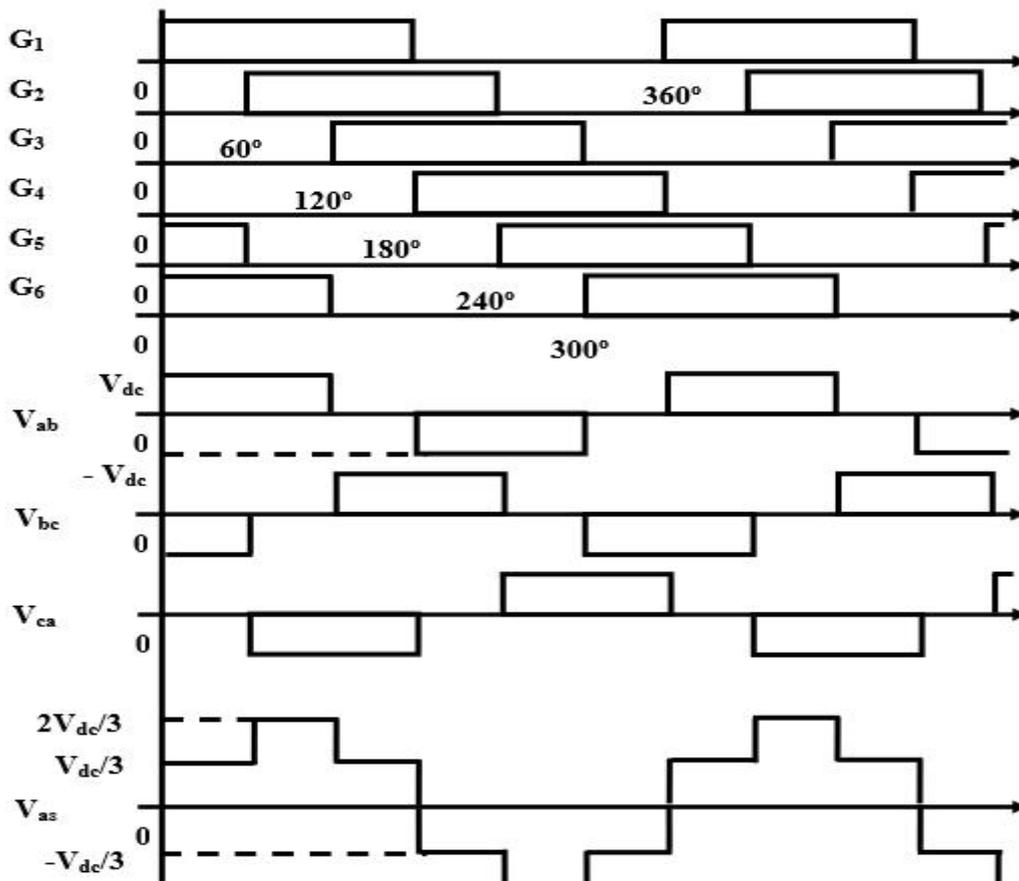


A schematic of the generic inverter-fed induction motor drive.

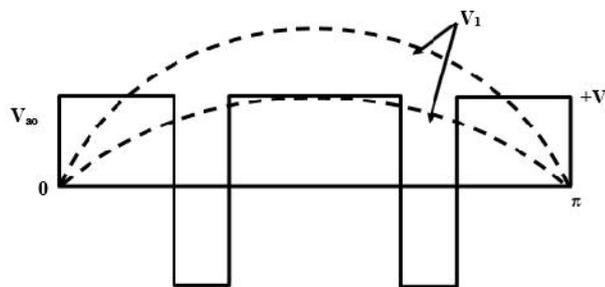
The square wave inverter control is simple and the switching frequency and consequently, switching losses are low. However, significant energies of the lower order harmonics and large distortions in current wave require bulky low-pass filters. Moreover, this scheme can only achieve frequency control. For voltage control a controlled rectifier is needed, which offsets some of the cost advantages of the simple inverter.

PWM Principle

It is possible to control the output voltage and frequency of the PWM inverter simultaneously, as well as optimize the harmonics by performing multiple switching within the inverter major cycle which determines frequency. For example, the fundamental voltage for a square wave has the maximum amplitude ($4V_d/\pi$) but by intermediate switching, as shown in Fig. 34.12, the magnitude can be reduced. This determines the principle of simultaneous voltage control by PWM. Different possible strategies for PWM switching exist. They have different harmonic contents. In the following only a sinusoidal PWM is discussed.



Inverter gate (base) signals and line-and phase-voltage waveforms



PWM principle to control output voltage.

Sinusoidal PWM

Figure explains the general principle of SPWM, where an isosceles triangle carrier wave of frequency f_c is compared with the sinusoidal modulating wave of fundamental frequency f , and the points of intersection determine the switching points of power devices. For example, for phase-a, voltage (V_{a0}) is obtained by switching ON Q1 and Q4 of half-bridge inverter, as shown in the figure. Assuming that $f \ll f_c$, the pulse widths of v_{a0} wave vary in a sinusoidal manner. Thus, the fundamental frequency is controlled by varying f and its amplitude is proportional to the command modulating voltage. The Fourier analysis of the v_{a0} wave can be shown to be of the form

$$V_{a0} = 0.5mV_d \sin(2\pi ft + \pi\phi) + \text{harmonic frequency terms}$$

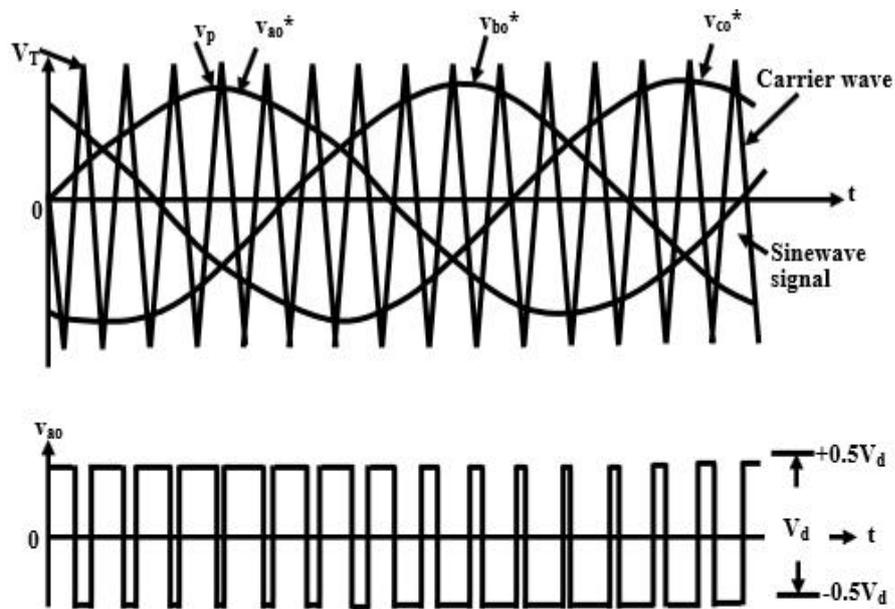
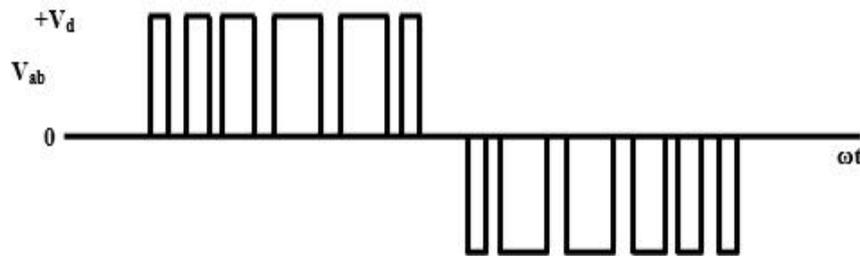


Fig. 34.13(a) Principle of sinusoidal PWM for three-phase bridge inverter.



Line voltage waves of PWM inverter

Where $m =$ modulation index and $\phi =$ phase shift of output, depending on the position of the modulating wave. The modulation index m is defined as

$$m = V_p / V_T$$

Where $V_p =$ peak value of the modulating wave and $V_T =$ peak value of the carrier wave. Ideally, m can be varied between 0 and 1 to give a linear relation between the modulating and output wave. The inverter basically acts as a linear amplifier. The line voltage waveform is shown in Fig.

Current Fed Inverters

CSI classification is based on the structure of the front-end power converter, which could be either a phase-controlled thyristor rectifier or a PWM current-source rectifier.

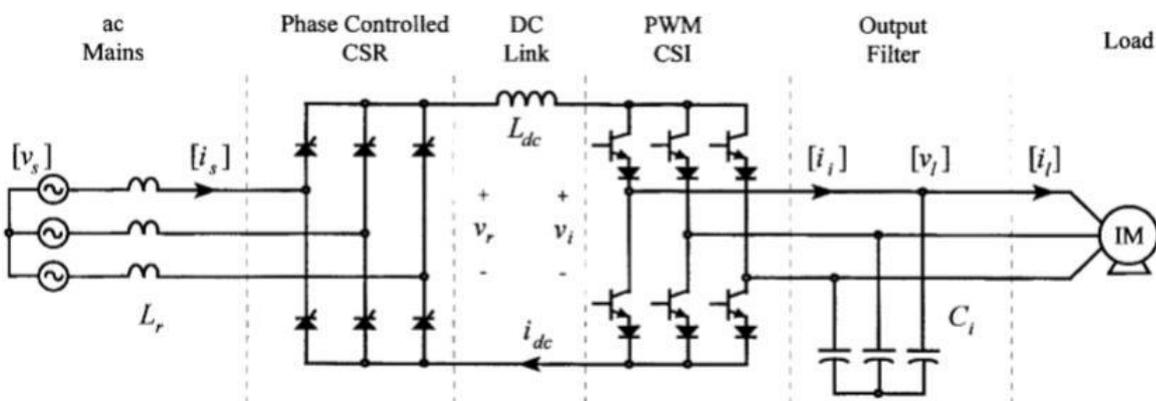
A. Phase-Controlled Front-End Rectifiers

These drives use a front-end rectifier based on thyristor-type power switches (Fig. 1), which can be operated with either variable or fixed dc-link current. The performance of the drive converter depends on this last feature.

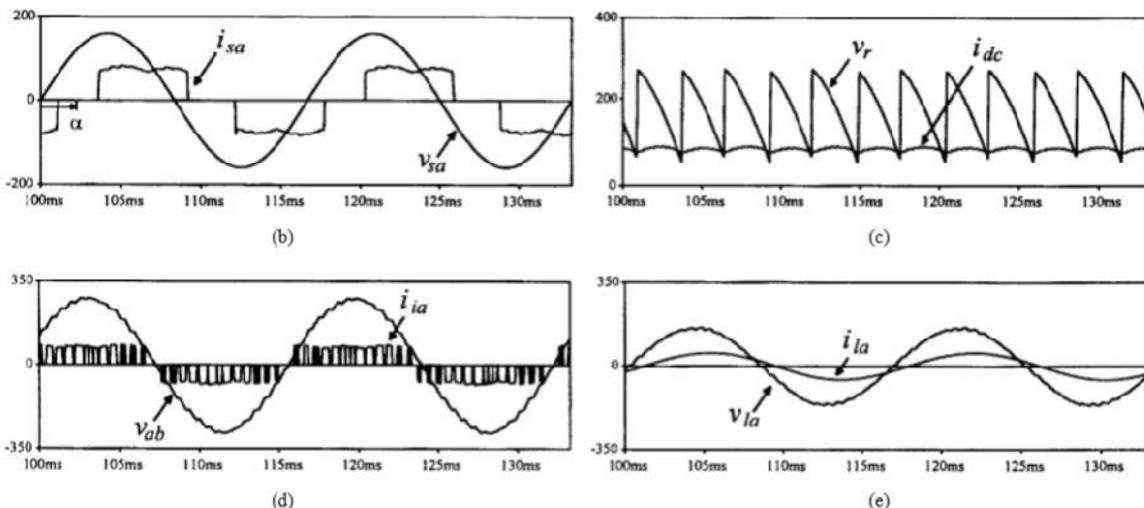
Variable DC-Link Current Scheme

The CSI is operated with a fixed pattern, which is usually optimized in terms of harmonic spectrum and switching frequency. Thus, the load voltage harmonic distortion is minimum and constant (Table I). However, the dc-link current must be adjusted through transient changes in firing angle to meet the requirements of the load. The dc voltage, on the other hand, is practically constant and independent of the load torque.

This last feature leads to a constant input current displacement factor and, thereby, a constant overall PF. Also, since the dc-link current tracks the output current, the dc-bus and switch conduction losses are kept to a minimum. Usually, the dc-link inductor is designed to have an acceptable current ripple (5%). In order to achieve this value and due to the low-order harmonics produced by the thyristor rectifier (sixth, 12th, etc.), the size of the dc inductor becomes quite bulky. This results in a slow system transient response. Also, the supply current has a high distortion factor % due to the low-order harmonics (fifth, seventh, etc.) injected by the thyristor rectifier. Fig shows typical waveforms of the converter. The rectifier phase angle is only adjusted during transient conditions occurring under load speed and torque variations.



(a)



AC drive CSI based on a phase-controlled front-end rectifier

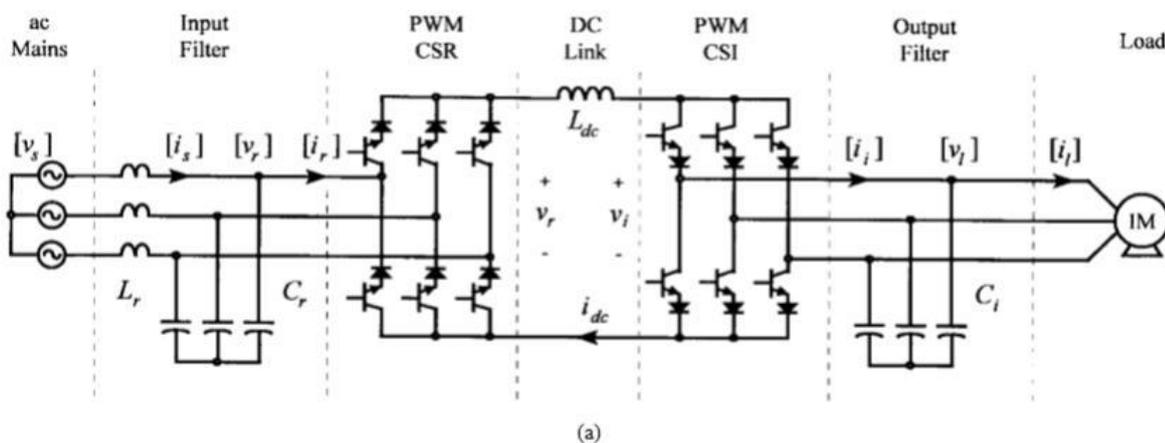
(a) Power topology. (b) Supply phase voltage and supply line current. (c) DC rectifier voltage and dc-link current. (d) CSI line current and load line voltage. (e) Load phase voltage and load line current.

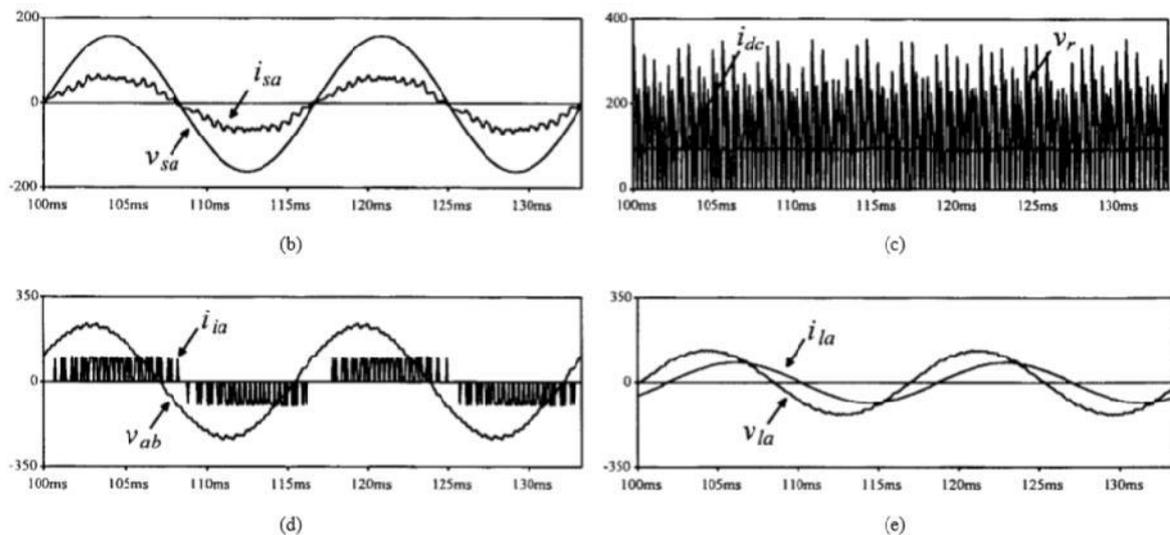
Fixed DC-Link Current Scheme

Unlike the above control scheme, the CSI is operated with a PWM pattern, which varies as a function of the CSI modulation index. Therefore, the load voltage harmonic distortion is variable and depends upon the speed and load torque (Table I). Since the dc-link current is fixed, the different load power requirements are obtained by varying the dc-link voltage. To achieve this, the input current displacement factor is continuously adjusted and, thereby, the input PF becomes variable and close to zero for light loads. Contrary to the variable dc-link current scheme, the dc-bus and switch conduction losses are always maximum, due to the fact that the dc-link current is always maximum (Table I). Although the dc-link inductor size is as big as the one used in the above scheme, the dynamic response of the load current is improved, due to the variable PWM pattern approach with time responses to modulation index changes of the order of a sampling period. This scheme also presents a high supply current harmonic distortion, due to the thyristor rectifier operation (Table I). Typical waveforms shown in Fig are also applicable in this case; however, in this mode of operation, the rectifier phase angle is continuously adjusted to maintain a constant dc-link current, regardless of the load speed and torque.

B. PWM Front-End Rectifiers

Unlike phase-controlled rectifier topologies, this topology uses a PWM rectifier. This allows a reduction in the harmonics injected into the ac supply. The rectifier is operated with a fixed dc-link current. Fig. 2 shows typical waveforms of the converter. The PWM pattern is adjusted on a continuous basis to keep a constant dc-link current. In contrast to topologies based on thyristor front-end rectifiers, the overall drive input PF is always greater than 0.95, and the total input current harmonic distortion, which depends on the sampling frequency, is typically lower than 10% (Table I). Also, since the output inverter is PWM modulated, the system has time responses close to the sampling period. However, the dc-bus losses and switch conduction losses are maximum, since the dc-link current is always equal to its maximum value, regardless of the load speed and torque.





AC drive CSI based on a PWM front-end rectifier

- (a) Power topology. (b) Supply phase voltage and supply line current. (c) DC rectifier voltage and dc-link current. (d) CSI line current and load line voltage. (e) Load phase voltage and load line current.

Vector Control of AC Induction Machines

Vector control is the most popular control technique of AC induction motors. In special reference frames, the expression for the electromagnetic torque of the smooth-air-gap machine is similar to the expression for the torque of the separately excited DC machine. In the case of induction machines, the control is usually performed in the reference frame (d-q) attached to the rotor flux space vector. That's why the implementation of vector control requires information on the modulus and the space angle (position) of the rotor flux space vector. The stator currents of the induction machine are separated into flux- and torque-producing components by utilizing transformation to the d-q coordinate system, whose direct axis (d) is aligned with the rotor flux space vector. That means that the q-axis component of the rotor flux space vector is always zero:

$$\Psi_{rq} = 0 \text{ and also } \frac{d}{dt}\Psi_{rq} = 0$$

The rotor flux space vector calculation and transformation to the d-q coordinate system require the high computational power of a microcontroller. The digital signal processor is suitable for this task. The following sections describe the space vector transformations and the rotor flux space vector calculation.

Block Diagram of the Vector Control

Shows the basic structure of the vector control of the AC induction motor. To perform vector control, it is necessary to follow these steps:

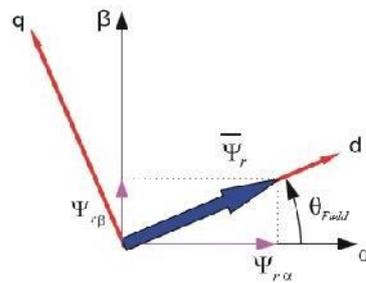
- Measure the motor quantities (phase voltages and currents)
- Transform them to the 2-phase system (α, β) using a Clarke transformation
- Calculate the rotor flux space vector magnitude and position angle
- Transform stator currents to the d-q coordinate system using a Park transformation

The inverse Clarke transformation goes back from a 2-phase (α, β) to a 3-phase i_{sa}, i_{sb}, i_{sc} system. For constant $k=2/3$, it is given by the following equations:

$$\begin{aligned}i_{sa} &= i_{s\alpha} \\i_{sb} &= -\frac{1}{2}i_{s\alpha} + \frac{\sqrt{3}}{2}i_{s\beta} \\i_{sc} &= -\frac{1}{2}i_{s\alpha} - \frac{\sqrt{3}}{2}i_{s\beta}\end{aligned}$$

Forward and Inverse Park Transformation (α, β to d-q and backwards)

The components $i_{s\alpha}$ and $i_{s\beta}$, calculated with a Clarke transformation, are attached to the stator reference frame α, β . In vector control, it is necessary to have all quantities expressed in the same reference frame. The stator reference frame is not suitable for the control process. The space vector $i_{s\beta}$ is rotating at a rate equal to the angular frequency of the phase currents. The components $i_{s\alpha}$ and $i_{s\beta}$ depend on time and speed. We can transform these components from the stator reference frame to the d-q reference frame rotating at the same speed as the angular frequency of the phase currents. Then the i_{sd} and i_{sq} components do not depend on time and speed. If we consider the d-axis aligned with the rotor flux, the transformation is illustrated in Figure where θ_{field} is the rotor flux position.



Park Transformation

The inverse Park transformation from the d-q to α, β coordinate system is given by the following equations:

$$\begin{aligned}i_{s\alpha} &= i_{sd}\cos\theta_{Field} - i_{sq}\sin\theta_{Field} \\i_{s\beta} &= i_{sd}\sin\theta_{Field} + i_{sq}\cos\theta_{Field}\end{aligned}$$

Rotor Flux Model

Knowledge of the rotor flux space vector magnitude and position is key information for the AC induction motor vector control. With the rotor magnetic flux space vector, the rotational coordinate system (d-q) can be established. There are several methods for obtaining the rotor magnetic flux space vector. The implemented flux model utilizes monitored rotor speed and stator voltages and currents. It is calculated in the stationary reference frame (α, β) attached to the stator. The error in the calculated value of the rotor flux, influenced by the changes in temperature, is negligible for this rotor flux model.

The rotor flux space vector is obtained by solving the differential equations (EQ 4-2) and (EQ 4-3), which are resolved into the α and β components. The equations are derived from the equations of the AC induction motor model

$$[(1 - \sigma)T_s + T_r] \frac{d\psi_{r\alpha}}{dt} = \frac{L_m}{R_s} u_{s\alpha} - \psi_{r\alpha} - \omega T_r \psi_{r\beta} - \sigma L_m T_s \frac{di_{s\alpha}}{dt}$$

$$[(1 - \sigma)T_s + T_r] \frac{d\psi_{r\beta}}{dt} = \frac{L_m}{R_s} u_{s\beta} + \omega T_r \psi_{r\alpha} - \psi_{r\beta} - \sigma L_m T_s \frac{di_{s\beta}}{dt}$$

where:

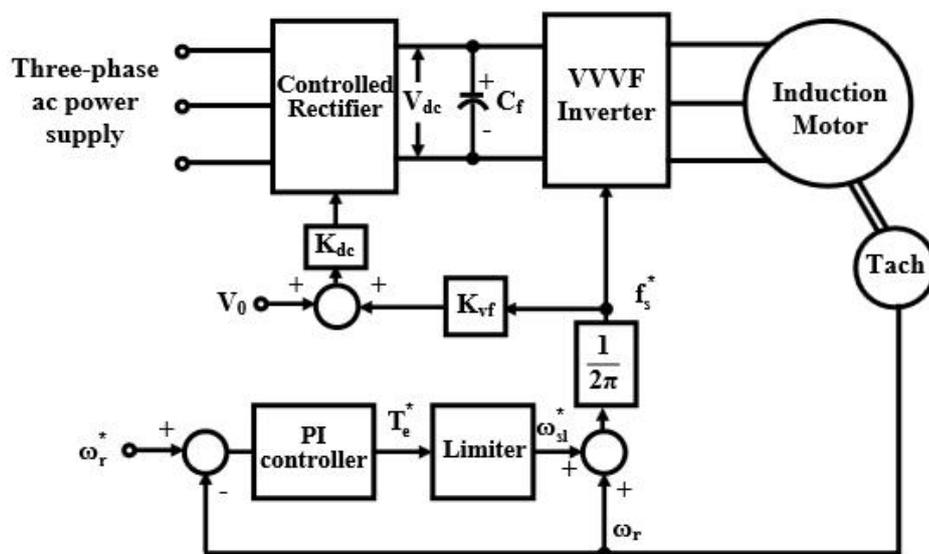
L_s	self-inductance of the stator	[H]
L_r	self-inductance of the rotor	[H]
L_m	magnetizing inductance	[H]
R_r	resistance of a rotor phase winding	[Ohm]
R_s	resistance of a stator phase winding	[Ohm]
ω	angular rotor speed	[rad.s ⁻¹]
p_p	number of motor pole-pairs	

$$T_r = \frac{L_r}{R_r} \quad \text{rotor time constant} \quad [s]$$

$$T_s = \frac{L_s}{R_s} \quad \text{stator time constant} \quad [s]$$

$$\sigma = 1 - \frac{L_m^2}{L_s L_r} \quad \text{resultant leakage constant} \quad [-]$$

Closed-loop control of induction motor



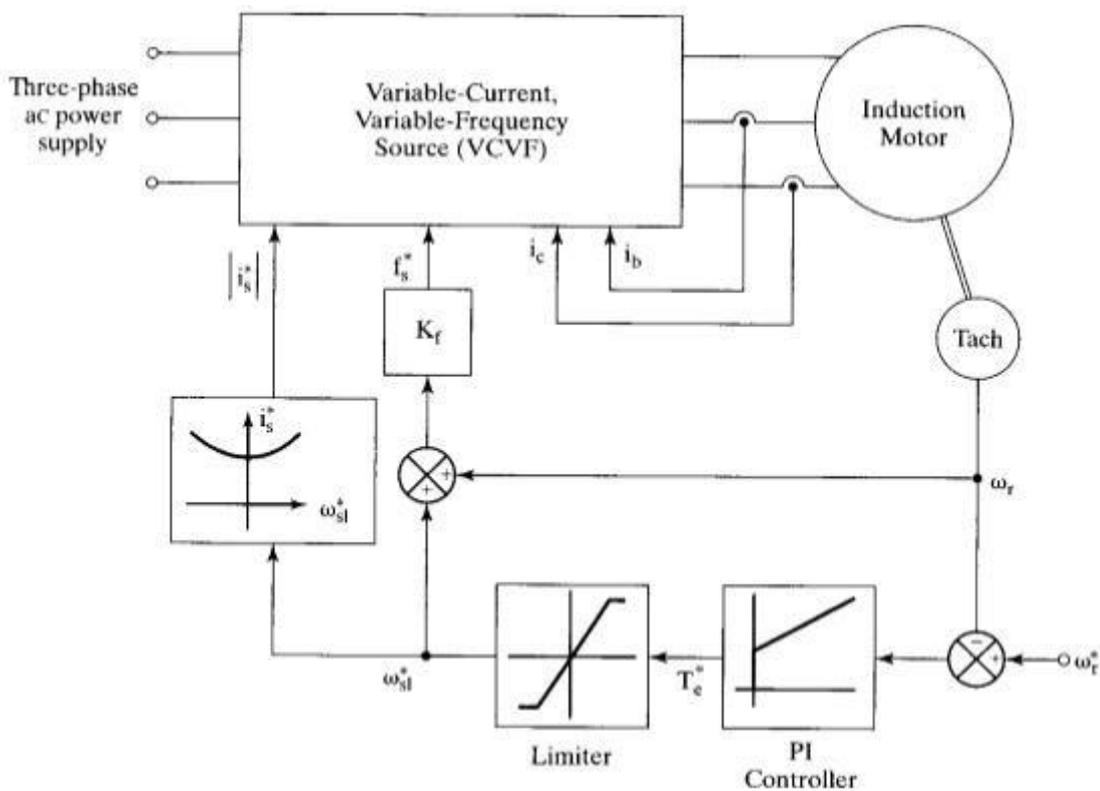
Closed-loop induction motor drive with constant volts/Hz control strategy

An outer speed PI control loop in the induction motor drive, shown in Figure computes the frequency and voltage set points for the inverter and the converter respectively. The limiter ensures that the slip-speed command is within the maximum allowable slip speed of the induction motor. The slip-speed command is added to electrical rotor speed to obtain the stator frequency command. Thereafter, the stator frequency command is processed in an open-loop drive. K_{dc} is the constant of proportionality between the dc load voltage and the stator frequency.

Constant air gap flux control:

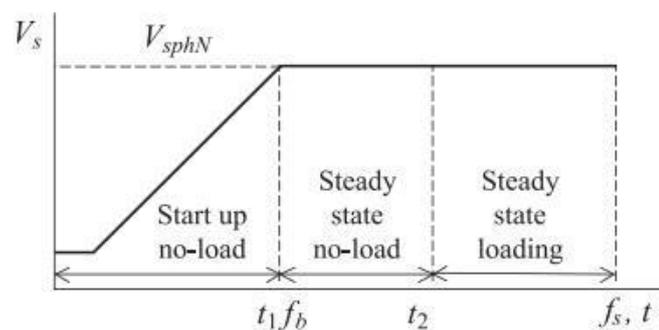
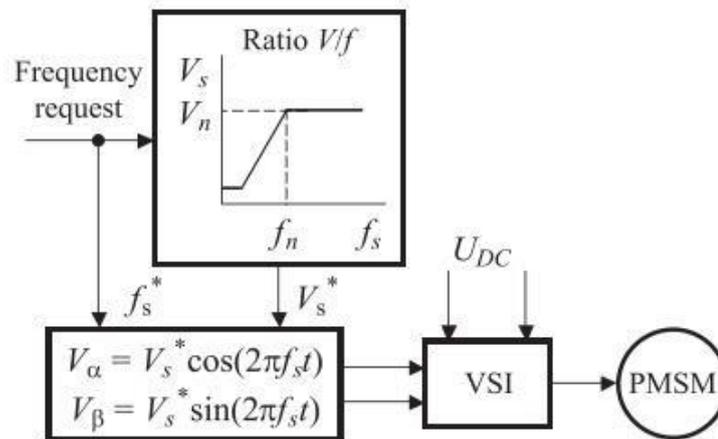
1. Equivalent separately-excited dc motor in terms of its speed but not in terms of decoupling of flux and torque channel.
2. Constant air gap flux linkages

$$\lambda_m = L_m i_m = E_1 / \omega_s$$



The rotor flux magnitude and position is key information for the AC induction motor control. With the rotor magnetic flux, the rotational coordinate system (d-q) can be established. There are several methods for obtaining the rotor magnetic flux. The implemented flux model utilizes monitored rotor speed and stator voltages and currents. It is calculated in the stationary reference frame (α, β) attached to the stator. The error in the calculated value of the rotor flux, influenced by the changes in temperature, is negligible for this rotor flux model

UNIT V

V/F OF PERMANENT MAGNETS SYNCHRONOUS MOTORS

Constant volt per hertz control in an open loop is used more often in the squirrel cage IM applications. Using this technique for synchronous motors with permanent magnets offers a big advantage of sensor less control. Information about the angular speed can be estimated indirectly from the frequency of the supply voltage. The angular speed calculated from the supply voltage frequency according to (1) can be considered as the value of the rotor angular speed if the external load torque is nothing her than the break down torque.

The mechanical synchronous angular speed ω_s is proportional to the frequency f_s of the supply voltage

$$\omega_s = \frac{2\pi f_s}{p},$$

Where p is the number of pole pairs.

The RMS value of the induced voltage of AC motors is given as

$$E_f = \sqrt{2}\pi f_s N_s k_w \phi.$$

By neglecting the stator resistive voltage drop and as sum- in steady state conditions, the stator voltage is identical to the induced one and the expression of magnetic flux can be written as

$$\phi = \frac{V_{sph}}{\sqrt{2}\pi f_s N_s k_w} = c \frac{V_{sph}}{f_s}.$$

To maintain the stator flux constant at its nominal value in the base speed range, the voltage-to-frequency ratio is kept constant, hence the name V/f control. If the ratio is different from the nominal one, the motor will become overexcited around excited. The first case happens when the frequency value is lower than the nominal one and the voltage is kept constant or if the voltage is higher than that of the constant ratio V/f. This condition is called over excitation, which means that the magnetizing flux is higher than its nominal value.

An increase of the magnetizing flux leads to arise of the magnetizing current. In this case the hysteresis and eddy current losses are not negligible. The second case represents under excitation. The motor becomes under excited because the voltage is kept constant and the value of stator frequency is higher than the nominal one. Scalar control of the synchronous motor can also be demonstrated via the torque equation of SM, similar to that of an induction motor. The electromagnetic torque of the synchronous motor, when the stator resistance R_s is not negligible, is given

$$T_e = -\frac{m}{\omega_s} \left[\frac{V_{sph} E_f}{Z_d} \sin(\vartheta_L - \alpha) - \frac{E_f^2 R_s}{Z_d} \right]$$

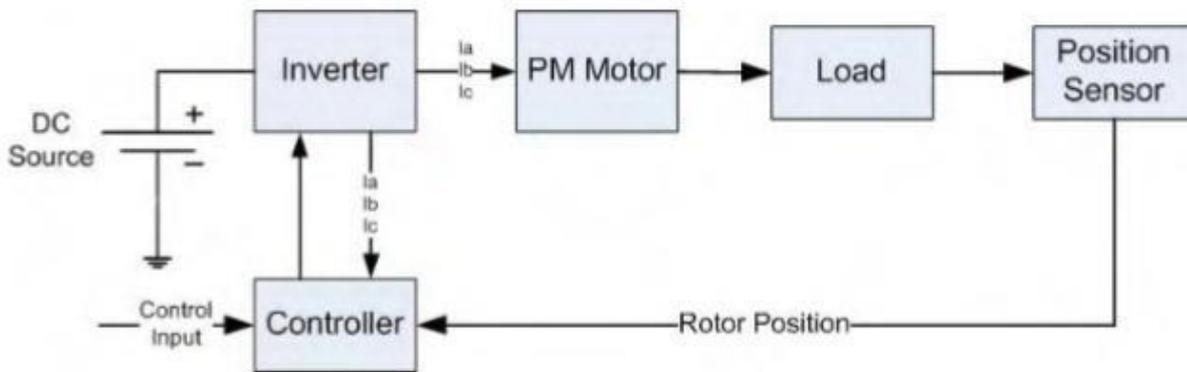
$$T_m = \frac{3p}{2\pi f_s} \frac{V_{sph} E_{PM}}{2\pi f_s L_d} = \frac{3p}{2\pi f_s} \frac{V_{sph} 2\pi f_s \Psi_{PM}}{2\pi f_s L_d}.$$

The torque will be constant in a wide speed range up to the nominal speed if the ratio of stator voltage and frequency is kept constant

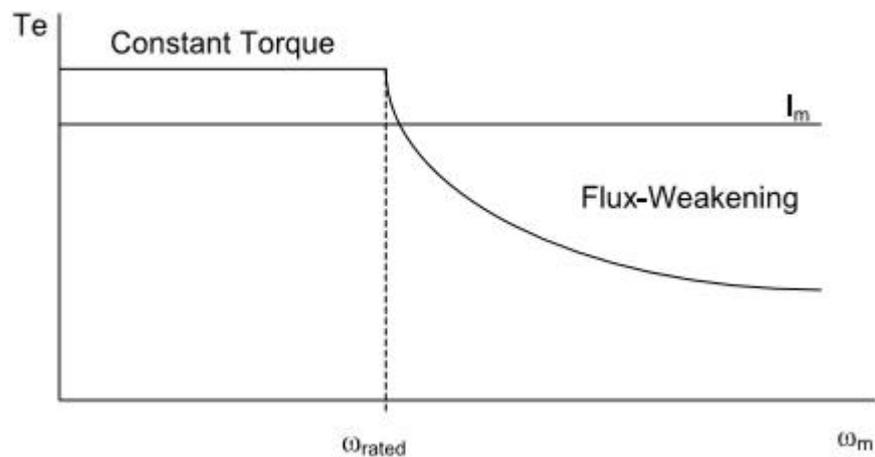
$$\frac{V_{sph}}{f_s} = \text{const.}$$

Self-Control Synchronous Motor

Control of PM motors is performed using field oriented control for the operation of synchronous motor as a dc motor. The stator windings of the motor are fed by an inverter that generates a variable frequency variable voltage. Instead of controlling the inverter frequency independently, the frequency and phase of the output wave are controlled using a position sensor as shown in figure.



Field oriented control was invented in the beginning of 1970s and it demonstrates that an induction motor or synchronous motor could be controlled like a separately excited dc motor by the orientation of the stator mmf or current vector in relation to the rotor flux to achieve a desired objective. In order for the motor to behave like DC motor, the control needs knowledge of the position of the instantaneous rotor flux or rotor position of permanent magnet motor. This needs a resolver or an absolute optical encoder. Knowing the position, the three phase currents can be calculated. Its calculation using the current matrix depends on the control desired. Some control options are constant torque and flux weakening. These options are based in the physical limitation of the motor and the inverter. The limit is established by the rated speed of the motor.



Steady State Torque versus Speed

Field Oriented Control of PM Motors:

The PMSM control is equivalent to that of the dc motor by a decoupling control known as field oriented control or vector control. The vector control separates the torque component of current and flux channels in the motor through its stator excitation.

The vector control of the PM synchronous motor is derived from its dynamic model. Considering the currents as inputs, the three currents are:

$$i_a = I_m \sin(\omega_r t + \alpha)$$

$$i_b = I_m \sin(\omega_r t + \alpha - \frac{2\pi}{3})$$

$$i_c = I_m \sin(\omega_r t + \alpha + \frac{2\pi}{3})$$

$$\begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} = \begin{pmatrix} \cos(\omega_r t + \alpha) \\ \cos(\omega_r t + \alpha - \frac{2\pi}{3}) \\ \cos(\omega_r t + \alpha + \frac{2\pi}{3}) \end{pmatrix} (I_m)$$

Where α is the angle between the rotor field and stator current phasor, $r \omega$ is the electrical rotor speed

The previous currents obtained are the stator currents that must be transformed to the rotor reference frame with the rotor speed $r \omega$, using Park's transformation. The q and d axis currents are constants in the rotor reference frames since α is a constant for a given load torque. As these constants, they are similar to the armature and field currents in the separately excited dc machine. The q axis current is distinctly equivalent to the armature current of the dc machine; the d axis current is field current, but not in its entirety. It is only a partial field current; the other part is contributed by the equivalent current source representing the permanent magnet field. For this reason the q axis current is called the torque producing component of the stator current and the d axis current is called the flux producing component of the stator current.

Substituting equation above and obtain i_d and i_q in terms of I_m as follows

$$\begin{pmatrix} i_q \\ i_d \end{pmatrix} = I_m \begin{pmatrix} \sin \alpha \\ \cos \alpha \end{pmatrix}$$

Using equations the electromagnetic torque equation is obtained as given below.

$$T_e = \frac{3}{2} \cdot \frac{P}{2} \left[\frac{1}{2} (L_d - L_q) I_m^2 \sin 2\alpha + \lambda_f I_m \sin \alpha \right]$$

Constant Torque Operation:

Constant torque control strategy is derived from field oriented control, where the maximum possible torque is desired at all times like the dc motor. This is performed by making the torque producing current i_q equal to the supply current I_m . That results in selecting the α angle to be 90° degrees according to equation. By making the i_d current equal to zero the torque equation can be rewritten as:

$$T_e = \left(\frac{3}{2}\right) \left(\frac{P}{2}\right) \lambda_f \cdot i_q$$

Assuming that:

$$k_t = \left(\frac{3}{2}\right) \left(\frac{P}{2}\right) \lambda_f$$

The torque is give by

$$T_e = k_t \cdot i_q$$

Flux-weakening:

Flux weakening is the process of reducing the flux in the d axis direction of the motor which results in an increased speed range.

The motor drive is operated with rated flux linkages up to a speed where the ratio between the induced emf and stator frequency (V/f) is maintained constant. After the base frequency, the V/f ratio is reduced due to the limit of the inverter dc voltage source which is fixed. The weakening of the field flux is required for operation above the base frequency.

This reduces the V/f ratio. This operation results in a reduction of the torque proportional to a change in the frequency and the motor operates in the constant power region.

The rotor flux of PMSM is generated by permanent magnet which cannot be directly reduced as induction motor. The principle of flux-weakening control of PMSM is to increase negative direct axis current and use armature reaction to reduce air gap flux, which equivalently reduces flux and achieves the purpose of flux-weakening control.

This method changes torque by altering the angle between the stator MMF and the rotor d axis. In the flux weakening region where $\omega_r > \omega_{\text{rated}}$ angle α is controlled by proper control of i_d and i_q for the same value of stator current. Since i_q is reduced the output torque is also reduced. The angle α can be obtained as:

$$\alpha = \tan^{-1} \left(\frac{i_q}{i_d} \right)$$

The current I_m is related to i_d and i_q by:

$$I_m = \sqrt{i_d^2 + i_q^2}$$

Flux-weakening control realization

The realization process of equivalent flux-weakening control is as follows,

- 1) Measuring rotor position and speed ω_r from a sensor which is set in motor rotation axis.
- 2) The motor at the flux weakening region with a speed loop, T_e^* is obtained from the PI controller.
- 3) Calculate I_q^*

$$i_q = \frac{T_e^*}{\left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\lambda_f}$$

4) Calculate I_d^* using equation:

$$i_d^* = \frac{\lambda_d - \lambda_f}{L_d}$$

5) Calculate α using equation

$$\alpha = \tan^{-1}\left(\frac{i_q}{i_d}\right)$$

6) Then the current controller makes use of the reference signals to control the inverter for the desired output currents.

7) The load torque is adjusted to the maximum available torque for the reference speed

$$T_L = T_{e(\text{rated})} \frac{\omega_{\text{rated}}}{\omega_r}$$

Power Factor Correction Of Permanent Magnet Synchronous Motor Drive With Field Oriented Control Using Space Vector Modulation

Field oriented control demonstrates that, a synchronous motor could be controlled like a separately excited dc motor by the orientation of the stator mmf or current vector in relation to the rotor flux to achieve a desired objective. The aim of the FOC method is to control the magnetic field and torque by controlling the d and q components of the stator currents or relatively flux. With the information of the stator currents and the rotor angle a FOC technique can control the motor torque and the flux in a very effective way.

The main advantages of this technique are the fast response and reduced torque ripple. The implementation of this technique will be carried out using two current regulators, one for the direct-axis component and another for the quadrature-axis component, and one speed regulator. There are three PI regulators in the control system. One is for the mechanical system (speed) and two others for the electrical system (d and q currents). At first, the reference speed is compared with the measured speed and the error signal is fed to the speed PI controller.

This regulator compares the actual and reference speed and outputs a torque command. Once is obtained the torque command, it can be turned into the quadrature-axis current reference, $I_{q,\text{ref}}$. There is a PI controller to regulate the d component of the stator current. The reference value, $I_{d,\text{ref}}$, is zero since there is no flux weakening operation. The d component error of the current is used as an input for the PI regulator. Moreover, there is another PI controller to regulate the q component of the current. The reference value is

compared with the measured and then fed to the PI regulator. The performance of the FOC block diagram can be summarized in the following steps

The performance of the FOC block diagram can be summarized in the following steps:

1. The stator currents are measured as well as the rotor angle.
2. The stator currents are converted into a two-axis reference frame with the Clark Transformation.
3. The α, β currents are converted into a rotor reference frame using Park Transformation
4. With the speed regulator, a quadrature-axis current reference is obtained. The d-current controls the air gap flux, the q-current control the torque production.
5. The current error signals are used in controllers to generate reference voltages for the inverter.
6. The voltage references are turned back into abc domain.
7. With these values are computed the PWM signals required for driving the inverter.

SPACE VECTOR MODULATION

The basis of SVPWM is different from that of sine pulse width modulation (SPWM). SPWM aims to achieve symmetrical 3-phase sine voltage waveforms of adjustable voltage and frequency, while SVPWM takes the inverter and motor as a whole, using the eight fundamental voltage vectors to realize variable frequency of voltage and speed adjustment. SVPWM aims to generate a voltage vector that is close to the reference circle through the various switching modes of inverter. Fig is the typical diagram of a three-phase voltage source inverter model. For the on- off state of the three-phase inverter circuit, every phase can be considered as a switch S . Here, $S_A(t)$, $S_B(t)$ and $S_C(t)$ are used as the switching functions for the three phases, respectively.

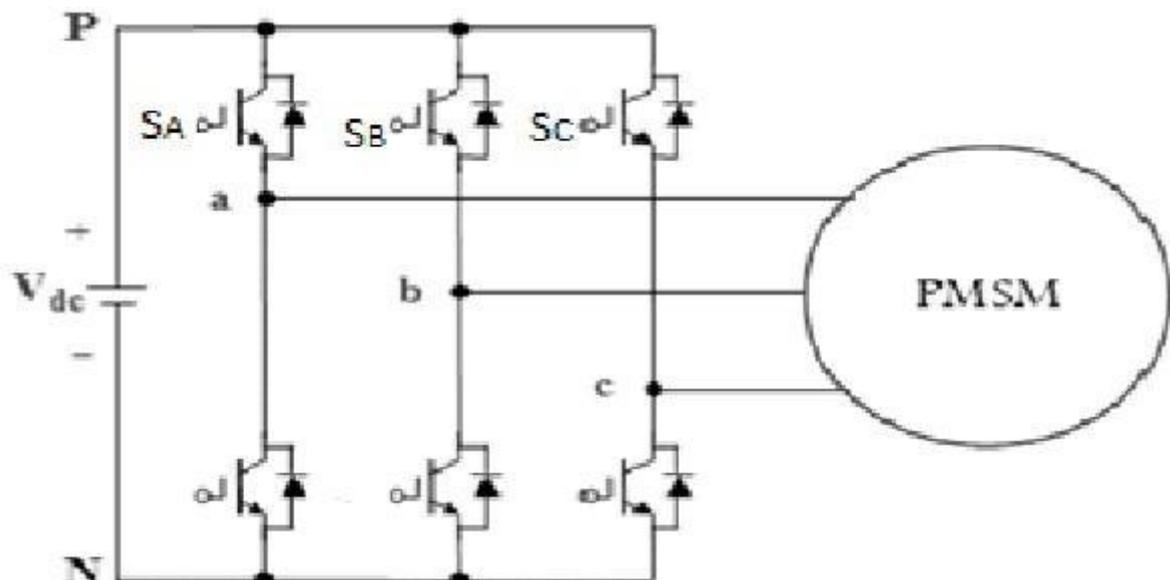
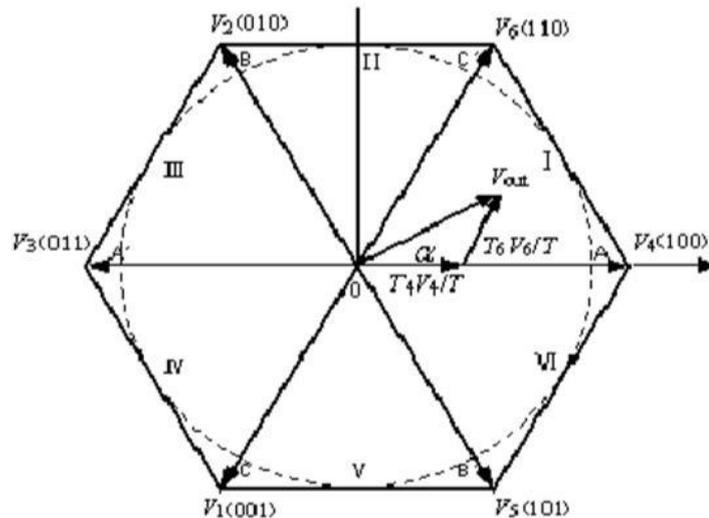


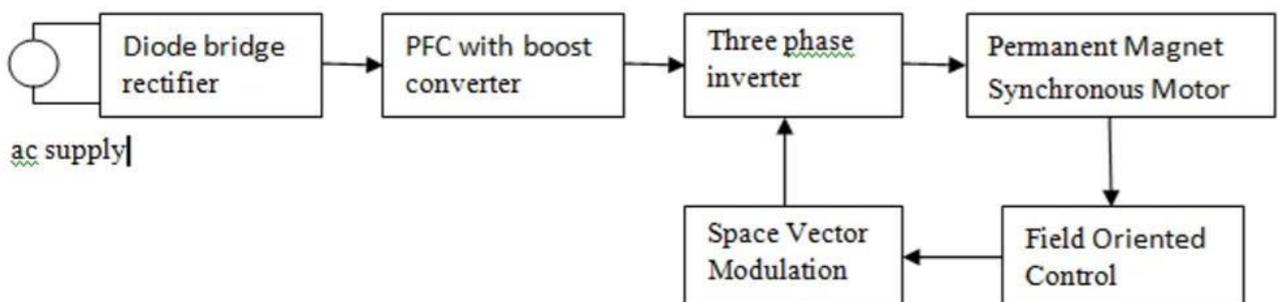
Diagram of a three phase inverter

The space vector of output voltage of inverter can be expressed as

$$V(S_A, S_B, S_C) = \frac{2 * V_{dc} (S_A + \alpha S_B + \alpha^2 S_C)}{3}$$



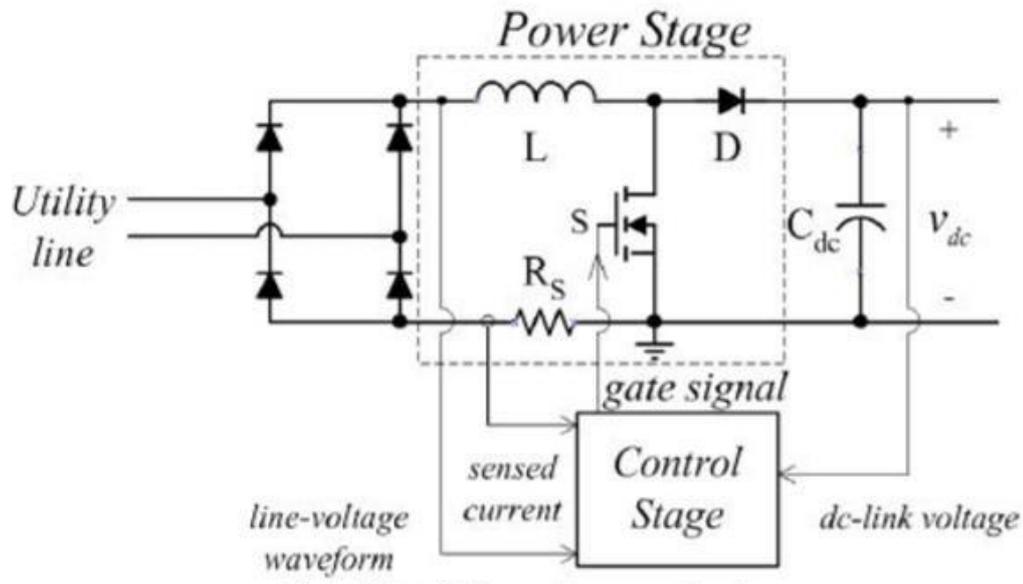
PMSM Drive with Active Power Factor Correction (Apfc):



PMSM drive with PFC

The above figure shows the block diagram of PMSM drive with Active power Factor Correction. The APFC consists of an energy stored element, switching device and control module. It is commonly installed between the power rectifier and the dc link bus. The main purpose of APFC is to make the input of the power supply look like a pure resistor. In other words, it is to make the input current waveform in phase with the input voltage waveform so that there is no phase displacement between them. The operation of APFC is basically based on a controller that can output the signal to a switching device to control the energy being stored or released in the reactive elements. In such a way, the input current waveform can be adjusted. The magnitude and phase of the input current waveforms by proper control can follow that of the input voltage waveform. Consequently, the power factor improvement can be achieved and further, the voltage stability can be obtained as well. The dc link voltage for the inverter is obtained from PFC block. The stator currents and rotor position of PMSM are given to the FOC, which controls the flux and torque components.

The current error signals are used in controllers to generate reference voltages V_α and V_β , which are the inputs of SVM. Space Vector modulation gives signals required for driving the inverter. By using inverter three phase supply is given to the PMSM



PFC with Boost Converter Circuit

The above Figure shows the circuit of power factor correction circuit with boost converter. An uncontrolled diode rectifier with a boost converter is used to convert the single phase AC voltage into a constant DC link voltage, which is fed to the three phase inverter supplying a PMSM.

The boost converter is the widely used topology for achieving power factor correction. This converter draws nearly unity power factor current from the AC mains and eliminates a harmonic current which regulates the DC link voltage even under fluctuating voltage conditions of AC mains.

This circuit uses a diode bridge rectifier, an inductor which is connected in series with the supply, a switch MOSFET and an output capacitor. The bulk energy storage capacitor sits on the output side of the converter rather than just after the diode rectifier bridge. The average inductor current which charges the bulk capacitor is proportional to the utility line voltage.

For proper operation, the output voltage must be higher than the peak line voltage and current drawn from the line must be proportional to the line voltage. In circuit operation, it is assumed that the inductance of boost inductor is large so that it can be represented by constant current source and that the output ripple voltage is negligible so that the voltage across the output filter capacitor can be represented by constant voltage source.

DESIGN EQUATIONS OF BOOST POWER FACTOR CORRECTION CIRCUIT

The AC input voltage given to the power factor correction circuit is 100V and input frequency is 50Hz. The selection of boost converter components is based on the following equations Maximum input power,

Maximum input power,

$$P_{in(max)} = \frac{P_{o(max)}}{\eta_{min}}$$

Maximum rms input current,

$$I_{in(rms)max} = \frac{P_{in(max)}}{V_{in(rms)max}}$$

Maximum peak input current,

$$I_{in(pk)max} = I_{in(rms)max}$$

Average input current,

$$I_{in(avg)max} = \frac{2 * I_{in(pk)max}}{\Pi}$$

Boost capacitor,

$$C_{in} = K_{\Delta} I_L \frac{I_{in(rms)max}}{2 * \Pi * f_{sw} * r * V_{in(rms)max}}$$

Switching frequency, $f_{sw} = 100\text{KHz}$

Minimum input peak voltage,

$$V_{in(pk)min} = \sqrt{2} V_{in(pk)min}$$

Peak boost transistor duty cycle

$$D_{pk} = 1 - \frac{V_{in(pk)}}{V_o}$$

Inductor ripple current

$$\Delta I_L = 0.2 * I_{in(pk)max}$$

ΔI_L is based on the assumption of 20% ripple current

Peak inductor current,

$$I_{L(pk)max} = I_{in(pk)max} + \frac{\Delta I_L}{2}$$

Inductance,

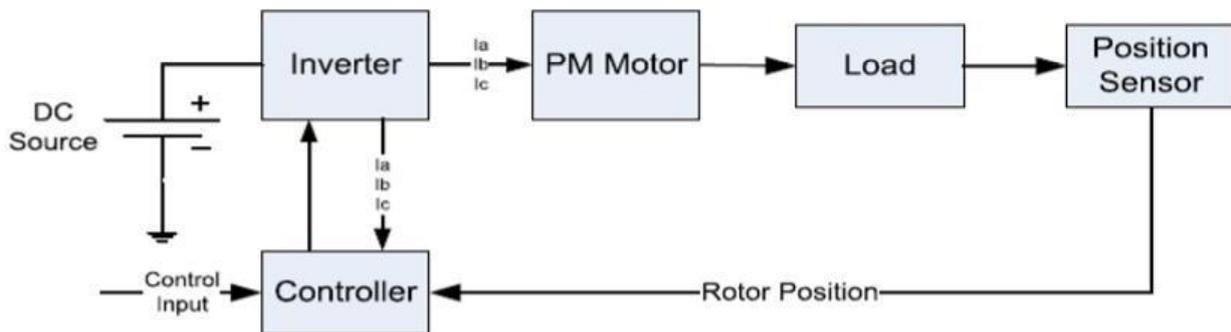
$$L = \frac{V_{in(pk)min} * D_{pk}}{f_{sw} * \Delta I_L}$$

Output Capacitor

$$C_{out} = \frac{I_{out(max)}}{f_{sw} * \Delta V}$$

Permanent Magnet Synchronous Motor Block Diagram Of Closed Loop Control

The basic block-diagram of PMSM drive system shown in figure in this figure basic four part divided in this circuit. All part discuss in briefly in this below section. The below figure shown it is one type of closed-loop block diagram.

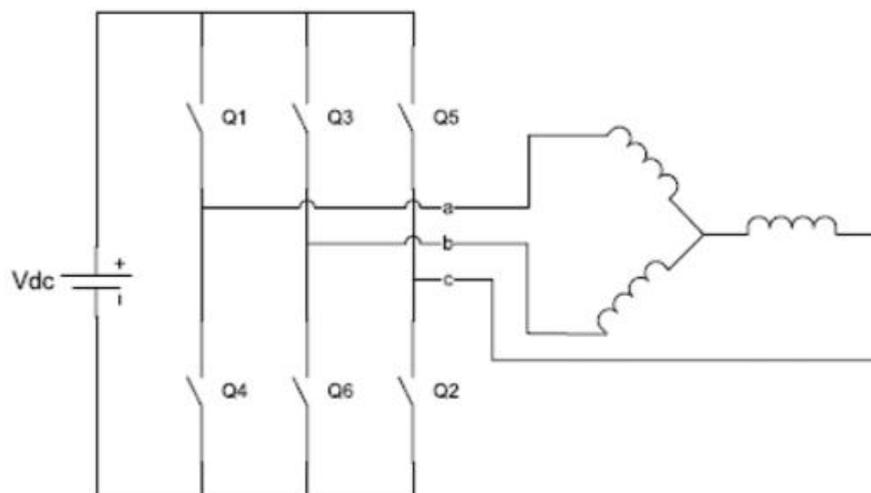


There are four basic component

1. Voltage Source Inverter
2. Pm Synchronous Motor
3. Current Controller
4. Position Sensor

Voltage Source Inverter

Voltage Source Inverters are devices that convert a DC voltage to AC voltage of variable frequency and magnitude. They are very commonly used in adjustable speed drives and are characterized by a well-defined switched voltage wave form in the terminals. The ac voltage frequency can be variable or constant depends on the application. Three phase inverters consist of six power switches connected as shown in figure to dc voltage source. An inverter switches must be carefully selected based on the requirements of operation, ratings and the application.



Voltage Source Inverter

PM Synchronous Motor

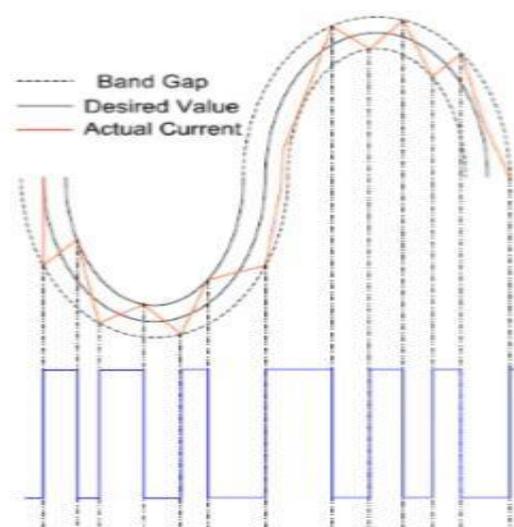
A permanent magnet synchronous motor (PMSM) is a motor that uses permanent magnets to produce the air gap magnetic field rather than using electromagnets. These motors have significant advantages, attracting the interest of researchers and industry for use in many applications. The properties of the permanent magnet material will affect directly the performance of the motor and proper knowledge is required for the selection of the materials and for understanding PM motors. Permanent magnet (PM) synchronous motors are widely used in low and mid power applications such as computer peripheral equipment's, robotics, adjustable speed drives and electric vehicles.

HYSTERESIS Current Controller

Current regulators for AC drives are complex because an AC current regulator must control both the amplitude and phase of the stator current. The AC drive current regulator forms the inner loop of the overall motion controller. As such, it must have the widest bandwidth in the system and must, by necessity, have zero or nearly zero steady-state error both current source inverters (CSI) and voltage source inverters (VSI) can be operated in controlled current modes. The current source inverter is a "natural" current supply and can readily be adapted to controlled current operation.

The voltage source inverter requires more complexity in the current regulator but offers much higher bandwidth and elimination of current harmonics as compared to the CSI and is almost exclusively used for motion control applications. Hysteresis current controller can also be implemented to control the inverter currents. The controller will generate the reference currents with the inverter within a range which is fixed by the width of the band gap. In this controller the desired current of a given phase is summed with the negative of the measured current. The error is fed to a comparator having a hysteresis band.

When the error crosses the lower limit of the hysteresis band, the upper switch of the inverter leg is turned on but when the current attempts to become less than the upper reference band, the bottom switch is turned on. The hysteresis band with the actual current and the resulting gate signals. This controller does not have a specific switching frequency and changes continuously but it is related with the band width shown in figure.



Hysteresis Current Controller

Position Sensor

Operation of permanent magnet synchronous motors requires position sensors in the rotor shaft when operated without damper winding. The need of knowing the rotor position requires the development of devices for position measurement. There are four main devices for the measurement of position, the potentiometer, linear variable differential transformer, optical encoder and resolvers. The ones most commonly used for motors are encoders and resolvers. Depending on the application and performance desired by the motor a position sensor with the required accuracy can be selected.

VECTOR CONTROL TECHNIQUE

The PMSM control is equivalent to that of the dc motor by a decoupling control known as field oriented control or vector control. The vector control separates the torque component of current and flux channels in the motor through its stator excitation. The vector control strategy is somewhat similar to that of the induction motor vector control, except for the following:

1. The slip frequency is zero because the machine always runs at synchronous speed.
2. The magnetizing current $I_{ds} = 0$ because the rotor flux is supplied by the PM.
3. The unit vector generated from an absolute position sensor because, the unlike slipping poles of an induction motor, the poles are fixed on the rotor.

Two Marks Question Bank

UNIT – I

1. What is meant by electrical drives?

Systems employed for motion control are called drives and they employ any of the prime movers such as diesel or petrol engines, gas or steam turbines, hydraulic motors and electric motors for supplying mechanical energy for motion control. Drives employing electric motion are called electric drives.

2. What are the requirements of an electric drive?

Stable operation should be assured.

The drive should have good transient response

3. Specify the functions of power modulator.

Power modulator performs one or more of the following four functions.

- a. Modulates flow of power from the source to the motor in such a manner that motor is imparted speed-torque characteristics required by the load.
- b. During transient operations, such as starting, braking and speed reversal, it restricts source and motor currents within permissible values; excessive current drawn from source may overload it or may cause a voltage dip.

4. Mention the different types of drives.

- 1) Group drive
- 2) Individual drive
- 3) Multimotor drive

5. List the different types of electrical drives.

- 1) dc drives
- 2) ac drives

6. What are the advantages of electric drives?

They have flexible control characteristics. the steady state and dynamic characteristics of electrical drives can be shaped to satisfy load requirements.

- 1) Drives can be provided with automatic fault detection systems, programmable logic controllers and computers can be employed to automatically ctrl the drive operations in a desired sequence.
- 2) They are available in which range of torque, speed and power.
- 3) It can operate in all the four quadrants of speed-torque plane. Electric braking gives smooth deceleration and increases life of the equipment compared to other forms of braking.
- 4) Control gear required for speed control, starting and braking is usually simple and easy to operate.

7. What are the functions performed by electric drives?

Various functions performed by electric drives include the following.

- a. Driving fans, ventilators, compressors and pumps etc.
- b. Lifting goods by hoists and cranes
- c. Imparting motion to conveyors in factories, mines and warehouses and
- d. Running excavators and escalators, electric locomotives, trains, cars, trolley buses, lifts and drums winders etc.

8. What are the disadvantages of electric drives?

The disadvantages of electric drives are

- a. Electric drives system is tied only up to the electrified area.

- b. The condition arising under the short circuits, leakage from conductors and breakdown of overhead conductor may lead to fatal accidents.
- c. Failure in supply for a few minutes may paralyse the whole system.

9. What are the advantages of group drive over individual drive?

The advantages of group drive over individual drive are

- a. Initial cost: Initial cost of group drive is less as compared to that of the individual drive.
- b. Sequence of operation: Group drive system is useful because all the operations are stopped simultaneously.
- c. Space requirement: Less space is required in group drive as compared to individual drive.
- d. Low maintenance cost: It requires little maintenance as compared to individual drive.

10. What the group drive is not used extensively.

Although the initial cost of group drive is less but yet this system is not used extensively because of following disadvantages.

- a. Power factor: Group drive has low power factor
- b. Efficiency: Group drive system when used and if all the machines are not working together the main motor shall work at very much reduced load.
- c. Reliability: In group drive if the main motor fails whole industry will come to stand still.
- d. Flexibility: Such arrangement is not possible in group drive i.e., this arrangement is not suitable for the place where flexibility is the prime factor.
- e. Speed: Group drive does not provide constant speed.
- f. Types of machines: Group drive is not suitable for driving heavy machines such as cranes, lifts and hoists etc.

11. Write short notes on individual electric drives.

In individual drive, each individual machine is driven by a separate motor. This motor also imparts motion to various other parts of the machine. Examples of such machines are single spindle drilling machines (Universal motor is used) and lathes. In a lathe, the motor rotates the spindle, moves the feed and also with the help of gears, transmits motion to lubricating and cooling pumps. A three phase squirrel cage induction motor is used as the drive. In many such applications the electric motor forms an integral part of the machine.

12. Mention the different factors for the selection of electric drives?

- 1) Steady state operation requirements.
- 2) Transient operation requirements.
- 3) Requirements related to the source.
- 4) Capital and running cost, maintenance needs life.
- 5) Space and weight restriction.
- 6) Environment and location.
- 7) Reliability.

13. Mention the parts of electrical drives.

- 1) Electrical motors and load.
- 2) Power modulator
- 3) Sources
- 4) Control unit
- 5) Sensing unit

14. Mention the applications of electrical drives

- Paper mills
- Electric traction Cement mills
- Steel mills

15. Mention the types of enclosures

Screen projected type
Drip proof type
Totally enclosed type

16. Mention the different types of classes of duty

Continuous duty, Discontinuous duty, Short time duty, intermittent duty.

17. What is meant by regenerative braking?

Regenerative braking occurs when the motor speed exceeds the synchronous speed. In this case the IM runs as the induction m/c is converting the mechanical power into electrical power which is delivered back to the electrical system. This method of braking is known as regenerative braking.

18. What is meant by dynamic braking?

Dynamic braking of electric motors occurs when the energy stored in the rotating mass is dissipated in an electrical resistance. This requires a motor to operate as a gen. to convert the stored energy into electrical.

19. What is meant by plugging?

It is one method of braking of IM. When phase sequence of supply of the motor running at the speed is reversed by interchanging connections of any two phases of stator with respect to supply terminals, operation shifts from motoring to plugging region.

20. What is critical speed?

It is the speed that separates continuous conduction from discontinuous conduction mode.

21. Which braking is suitable for reversing the motor?

Plugging is suitable for reversing the motor.

22. Define equivalent current method

The motor selected should have a current rating more than or equal to the current. It is also necessary to check the overload of the motor. This method of determining the power rating of the motor is known as equivalent current method.

23. Define cooling time constant

It is defined as the ratio between C and A. Cooling time constant is denoted as Tau.

$$\text{Tau} = C/A$$

Where C=amount of heat required to raise the temp of the motor body by 1 degree Celsius

A=amount of heat dissipated by the motor per unit time per degree Celsius.

24. What are the methods of operation of electric drives?

Steady state
Acceleration including starting
Deceleration including starting

25. Define four quadrant operations.

The motor operates in two mode: motoring and braking. In motoring, it converts electrical energy into mechanical energy which supports its motion. In braking, it works as a generator, converting mathematical energy into electrical energy and thus opposes the motion. Motor can provide motoring and braking operations for both forward and reverse directions.

26. What is meant by mechanical characteristics?

The curve is drawn between speed and torque. This characteristic is called mechanical characteristics.

27. Mention the types of braking

Regenerative braking Dynamic braking
Plugging

28. What are the advantage and disadvantages of D.C. drives?

The advantages of D.C. drives are,

- a. Adjustable speed
- b. Good speed regulation
- c. Frequent starting, braking and reversing.

The disadvantage of D.C. drives is the presence of a mechanical commutator which limits the maximum power rating and the speed.

29. Give some applications of D.C. drives.

The applications of D.C. drives are,

- | | | | |
|------------------|----------------|---------------------|---------------|
| a. Rolling mills | b. Paper mills | c. Mine winders | d. Hoists |
| e. Machine tools | f. Traction | g. Printing presses | h. Excavators |
| i. Textile mills | j. Cranes | | |

30. Why the variable speed applications are dominated by D.C. drives?

The variable speed applications are dominated by D.C. drives because of lower cost, reliability and simple control.

UNIT – II**TWO MARKS****1. What is the use of flywheel? Where it is used?**

It is used for load equalization. It is mounted on the motor shaft in compound motor.

2. What are the advantages of series motor?

The advantages of series motors are,

- a. High starting torque
- b. Heavy torque overloads.

3. Define and mention different types of braking in a dc motor?

In braking the motor works as a generator developing a negative torque which opposes the motion. Types are regenerative braking, dynamic or rheostat braking and plugging or reverse voltage braking.

4. How the D.C. motor is affected at the time of starting?

A D.C. motor is started with full supply voltage across its terminals, a very high current will flow, which may damage the motor due to heavy sparking at commutator and heating of the winding. Therefore, it is necessary to limit the current to a safe value during starting.

5. List the drawbacks of armature resistance control?

In armature resistance control speed is varied by wasting power in external resistors that are connected in series with the armature. since it is an inefficient method of speed control it was used in intermittent load applications where the duration of low speed operations forms only a small proportion of total running time.

6. What is static Ward-Leonard drive?

Controlled rectifiers are used to get variable d.c. voltage from an a.c. source of fixed voltage controlled rectifier fed dc drives are also known as static Ward-Leonard drive.

7. What is a line commutated inverter?

Full converter with firing angle delay greater than 90 deg. is called line commutated inverter. Such an operation is used in regenerative braking mode of a dc motor in which case a back emf is greater than applied voltage.

8. Mention the methods of armature voltage controlled dc motor?

When the supplied voltage is ac,

Ward-Leonard schemes

Transformer with taps and uncontrolled rectifier bridge

Static Ward-Leonard scheme or controlled rectifiers

when the supply is dc:

Chopper control

9. How is the stator winding changed during constant torque and constant horsepower operations?

For constant torque operation, the change of stator winding is made from series - star to parallel - star, while for constant horsepower operation the change is made from series-delta to parallel-star. Regenerative braking takes place during changeover from higher to lower speeds.

10. Define positive and negative motor torque.

Positive motor torque is defined as the torque which produces acceleration or the positive rate of change of speed in forward direction. Positive load torque is negative if it produces deceleration.

11. Write the expression for average o/p voltage of full converter fed dc drives?

$V_m = (2V_m/\pi) \cos \alpha$ continuous conduction

$V_m = [V_m(\cos \alpha - \cos \beta) + (\pi + \alpha + \beta)]/\pi$ discontinuous conduction

12. What are the disadvantages of conventional Ward-Leonard schemes?

Higher initial cost due to use of two additional

m/c's. Heavy weight and size.

Needs more floor space and proper foundation. Required frequent maintenance

13. Mention the drawbacks of rectifier fed dc drives?

Distortion of supply. Low power factor.

Ripple in motor current

14. What are the advantages in operating choppers at high frequency?

The operation at a high frequency improves motor performance by reducing current ripple and eliminating discontinuous conduction.

15. Why self commutated devices are preferred over thyristors for chopper circuits?

Self commutated devices such as power MOSFETs power transistors, IGBTs, GTOs and IGCTs are preferred over thyristors for building choppers because they can be commutated by a low power control signal and don't need commutation circuit.

16. State the advantages of dc chopper drives?

DC chopper device has the advantages of high efficiency, flexibility in control, light weight, small size, quick response and regeneration down to very low speed.

17. What are the advantages of closed loop c of dc drives?

Closed loop control system has the adv. of improved accuracy, fast dynamic response and reduced effects of disturbance and system non-linearities.

18. What are the types of control strategies in dc chopper?

- Time ratio control.
- Current limit control.

19. What are the adv. of using PI controller in closed loop ctrl. of dc drive?

Stabilize the drive

- Adjust the damping ratio at the desired value
- Makes the steady state speed error close to zero by integral action and filters out noise again due to the integral action.

20. What are the different methods of braking applied to the induction motor?

Regenerative braking Plugging, Dynamic braking.

21. What are the different methods of speed control of IM?

Stator voltage control, Supply frequency control, Rotor resistance control, Slip power recovery control.

22. What is meant by stator voltage control.?

The speed of the IM can be changed by changing the stator voltage. Because the torque is proportional to the square of the voltage.

23. Mention the application of stator voltage control.

This method is suitable for applications where torque demand reduced with speed, which points towards its suitability for fan and pump drives.

24. Mention the applications of ac drives.

AC drives are used in a no. of applications such as fans, blowers, mill run-out tables, cranes, conveyors, traction etc.

25. What are the three regions in the speed-torque characteristics in the IM?

Motoring region ($0 \leq s \leq 1$)

Generating region ($s < 0$)

Plugging region ($1 < s \leq 2$) where s is the slip.

26. What are the advantages of stator voltage control method?

- The control circuitry is simple
- Compact size
- Quick response time
- There is considerable savings in energy and thus it is economical method as compared to other methods of speed ctrl.

27. What is meant by soft start?

The ac voltage controllers show a stepless control of supply voltage from zero to rated voltage they are used for soft start for motors.

28. List the adv of squirrel cage IM?

- Cheaper
- light in weight
- Rugged in construction
- More efficient
- Require less maintenance
- It can be operated in dirty and explosive environment

29. Define slip

The difference between the synchronous speed (N_s) and actual speed (N) of the rotor is known as slip speed. the % of slip is given by,

$$\% \text{ slip } s = \frac{(N_s - N)}{N_s} \times 100$$

30. Define base speed.

The synchronous speed corresponding to the rated frequency is called the base speed.

UNIT – III**TWO MARKS****1. What is meant by frequency control of IM?**

The speed of IM can be controlled by changing the supply frequency because the speed is directly proportional to supply frequency. This method of speed control is called frequency control.

2. What is meant by V/F control?

When the frequency is reduced the input voltage must be reduced proportionally so as to maintain constant flux otherwise the core will get saturated resulting in excessive iron loss and magnetizing current. This type of IM behavior is similar to the working of dc series motor.

3. What are the advantages of V/F control?

- Smooth speed control
- Small input current and improved power factor at low frequency start
- Higher starting torque for low case resistance

3. What is meant by stator current control?

The 3 phase IM speed can be controlled by stator current control. The stator current can be varied by using current source inverter.

5. What are the 3 modes of region in the adjustable-frequency IM drives characteristics?

- Constant torque region
- Constant power region
- High speed series motoring region

6. What are the two modes of operation in the motor?

The two modes of operation in the motor are, motoring and braking. In motoring, it converts electrical energy to mechanical energy, which supports its motion. In braking, it works as a generator converting mechanical energy to electrical energy and thus opposes the motion.

7. How will you select the motor rating for a specific application?

When operating for a specific application motor rating should be carefully chosen that the insulation temperature never exceed the prescribed limit. Otherwise either it will lead to its immediate thermal breakdown causing short circuit and damage to winding, or it will lead to deterioration of its quality resulting into thermal breakdown in near future.

8. What is braking? Mention its types.

The motor works as a generator developing a negative torque which opposes the motion is called braking.

It is of three types. They are,

- a. Regenerative braking.
- b. Dynamic or rheostat braking.
- c. Plugging or reverse voltage braking.

9. What are the three types of speed control?

The three types of speed control are,

- a. Armature voltage control
- b. Field flux control
- c. Armature resistance control.

10. What are the advantages of armature voltage control?

The advantages of armature voltage control are,

- a. High efficiency
- b. Good transient response
- c. Good speed regulation.

11. What are the methods involved in armature voltage control?

When the supply is A.C.

- a. Ward-Leonard schemes
- b. Transformer with taps and an uncontrolled rectifier bridge.
- c. Static ward Leonard scheme or controlled rectifiers when the supply is D.C.
- d. Chopper control.

12. Give some drawbacks and uses of Ward-Leonard drive.

The drawbacks of Ward . Leonard drive are.

- a. High initial cost
- b. Low efficiency

The Ward-Leonard drive is used in rolling mills, mine winders, paper mills, elevators, machine tools etc.

13. Give some advantages of Ward-Leonard drive.

The advantages of Ward-Leonard drive are,

- a. Inherent regenerative braking capability
- b. Power factor improvement.

14. What is the use of controlled rectifiers?

Controlled rectifiers are used to get variable D.C. Voltage from an A.C. Source of fixed voltage.

15. What is known as half-controlled rectifier and fully controlled rectifier?

The rectifiers provide control of D.C. voltage in either direction and therefore, allow motor control in quadrants I and IV. They are known as fully-controlled rectifiers.

The rectifiers allow D.C. Voltage control only in one direction and motor control in quadrant I only. They are known as half-controlled rectifiers.

16. What is called continuous and discontinuous conduction?

A D.C. motor is fed from a phase controlled converter the current in the armature may flow in discrete pulses in called continuous conduction.

A D.C. motor is fed from a phase controlled converter the current in the armature may flow continuously with an average value superimposed on by a ripple is called discontinuous conduction.

17. What are the three intervals present in discontinuous conduction mode of single phase half and fully controlled rectifier?

The three intervals present in half controlled rectifier are,

- a. Duty interval
- b. Free, wheeling interval
- c. Zero current intervals.

The two intervals present in fully controlled rectifier are

- a. Duty interval
- b. Zero current intervals.

18. What is called inversion?

Rectifier takes power from D.C. terminals and transfers it to A.C. mains is called inversion.

19. What are the limitations of series motor? Why series motor is not used in traction applications now a days?

1. The field of series cannot be easily controlled. If field control is not employed, the series motor must be designed with its base speed equal to the highest desired speed of the drive.
2. Further, there are a number of problems with regenerative braking of a series motor. Because of the limitations of series motors, separately excited motors are now preferred even for traction applications.

20. What are the advantages of induction motors over D.C. motors?

The main drawback of D.C. motors is the presence of commutate and brushes, which require frequent maintenance and make them unsuitable for explosive and dirty environments. On the other hand, induction motors, particularly squirrel-cage are rugged, cheaper, lighter, smaller, more efficient, require lower maintenance and can operate in dirty and explosive environments.

21. Give the applications of induction motors drives.

Although variable speed induction motor drives are generally expensive than D.C. drives, they are used in a number of applications such as fans, blowers, mill run-out tables, cranes, conveyors, traction etc., because of the advantages of induction motors. Other applications involved are underground and underwater installations, and explosive and dirty environments.

22. How is the speed controlled in induction motor?

The induction motor speed can be controlled by supplying the stator a variable voltage, variable frequency supply using static frequency converters. Speed control is also possible by feeding the slip power to the supply system using converters in the rotor circuit, basically one distinguishes two different methods of speed control.

- a. Speed control by varying the slip frequency when the stator is fed from a constant voltage, constant frequency mains.

- b. Speed control of the motor using a variable frequency variable voltage motor operating a constant rotor frequency.

23. How is the speed control by variation of slip frequency obtained?

Speed control by variation of slip frequency is obtained by the following ways.

- a. Stator voltage control using a three-phase voltage controller.
- b. Rotor resistance control using a chopper controlled resistance in the rotor circuit.
- c. Using a converter cascade in the rotor circuit to recover slip energy.
- d. Using a cycloconverter in the rotor circuit.

24. Mention the effects of variable voltage supply in a cage induction motor.

When a cage induction motor is fed from a variable voltage for speed control the following observations may be made.

- a. The torque curve beyond the maximum torque point has a negative shape. A stable operating point in this region is not possible for constant torque load.
- b. The voltage controlled must be capable of withstanding high starting currents. The range of speed control is rather limited.
- c. The motor power factor is poor.

25. Classify the type of loads driven by the motor.

The type of load driven by the motor influences the current drawn and losses of the motor as the slip varies. The normally occurring loads are

- a. Constant torque loads.
- b. Torque varying proportional to speed.
- c. Torque varying preoperational to the square of the speed.

26. What are the disadvantages of constant torque loads?

The constant torque loads are not favored due to increase in the losses linearly with slip and becoming maximum at $s = 1.0$. This is obvious from the variation of flux as the voltage is varied for speed control. To maintain constant torque the motor draws heavy current resulting in poor torque/ampere, poor efficiency and poor power factor at low speeds.

27. In which cases, torque versus speed method is suitable.

Torque versus speed method is suitable only for the following cases.

- a. For short time operations where the duration of speed controls is defined.
- b. For speed control of blowers or pumps having parabolic or cubic variations of torque with speed. This is not suitable for constant torque loads due to increases and heating.

28. How is the speed of a squirrel cage induction motor controlled?

The speed of a squirrel cage induction motor can be controlled very effectively by varying the stator frequency. Further the operation of the motor is economical and efficient, if it operates at very small slips. The speed of the motor is therefore, varied by varying the supply frequency and maintaining the rotor frequency at the rated value or a value corresponding to the required torque on the linear portion of the torque-speed curve.

29. Why the control of a three-phase induction motor is more difficult than D.C. motors.

The control of a three-phase induction motor, particularly when the dynamic performance involved is more difficult than D.C. motors. This is due to a. Relatively large internal resistance of the converter causes voltage fluctuations following load fluctuations because the capacitor cannot be ideally large.

- b. In a D.C. motor there is a decoupling between the flux producing magnetizing current and torque producing armature current. They can be independently controlled. This is not the case with induction motors.
- c. An induction motor is very poorly damped compared to a D.C. motor.

30. Where is the V/f control used?

The V/f control would be sufficient in some applications requiring variable torque, such as centrifugal pumps, compressors and fans. In these, the torque varies as the square of the speed. Therefore at small speeds the required torque is also small and V/f control would be sufficient to drive these loads with no compensation required for resistance drop. This is true also for the case of the liquid being pumped with minimal solids.

UNIT – IV

TWO MARKS

1. What are the components of the applied voltage to the induction motor?

The applied voltage to the induction motor has two components at low frequencies. They are

- a. Proportional to stator frequency.
- b. To compensate for the resistance drop in the stator.

The second component deepens on the load on the motor and hence on rotor frequency.

2. What is indirect flux control?

The method of maintaining the flux constant by providing a voltage boost proportional to slip frequency is a kind of indirect flux control. This method of flux control is not desirable if very good dynamic behaviour is required.

3. What is voltage source inverter?

Voltage source inverter is a kind of D.C. link converter, which is a two stage conversion device.

4. What is the purpose of inductance and capacitance in the D.C. link circuit?

The inductance in the D.C. link circuit provides smoothing whereas the capacitance maintains the constancy of link voltage. The link voltage is a controlled quantity.

5. What are the disadvantages of square wave inverter in induction motor drive?

Square wave inverters have commutation problems at very low frequencies, as the D.C. link voltage available at these frequencies cannot charge the commutating capacitors sufficiently enough to commutate the thyristors. This puts a limit on the lower frequency of operation. To extend the frequency towards zero, special charging circuits must be used.

6. What is slip controlled drive?

When the slip is used as a controlled quantity to maintain the flux constant in the motor the drive is called slip controlled drive. By making the slip negative (i.e., decreasing the output frequency of the inverter) the machine may be made to operate as a generator and the energy of the rotating parts fed back to the mains by an additional line side converter or dissipated in a resistance for dynamic braking. By keeping the slip frequency constant, braking at constant torque and current can be achieved. Thus braking is also fast.

7. What are the effects of harmonics in VSI fed induction motor drive?

The motor receives square wave voltages. These voltages have harmonic components. The harmonics of the stator current cause additional losses and heating. These harmonics are also responsible for torque pulsations. The reaction of the fifth and seventh harmonics with the fundamental

gives rise to the seventh harmonic pulsations in the torque developed. For a given induction motor fed from a square wave inverter the harmonic content in the current tends to remain constant independent of input frequency, with the range of operating frequencies of the inverter.

8. What is a current source inverter?

In a D.C. link converter, if the D.C. link current is controlled, the inverter is called a current source inverter. The current in the D.C. link is kept constant by a high inductance and the capacitance of the filter is dispensed with. A current source inverter is suitable for loads which present a low impedance to harmonic currents and have unity p.f.

9. Explain about the commutation of the current source inverter.

The commutation of the inverter is load dependent. The load parameters form a part of the commutation circuit. A matching is therefore required between the inverter and the motor. Multimotor operation is not possible. The inverter must necessarily be a force commutated one as the induction motor cannot provide the reactive power for the inverter. The motor voltage is almost sinusoidal with superimposed spikes.

10. Give the features from which a slip controlled drive is developed.

The stator current of an induction motor operating on a variable frequency, variable voltage supply is independent of stator frequency if the air gap flux is maintained constant. However, it is a function of the rotor frequency. The torque developed is also a function of rotor frequency. The torque developed is also a function of rotor frequency only. Using these features a slip controlled drive can be developed employing a current source inverter to feed an induction motor.

11. How is the braking action produced in plugging?

In plugging, the braking torque is produced by interchange any two supply terminals, so that the direction of rotation of the rotating magnetic field is reversed with respect to the rotation of the motor. The electromagnetic torque developed provides the braking action and brings the rotor to a quick stop.

12. Where is rotor resistance control used?

Where the motors drive loads with intermittent type duty, such as cranes, ore or coal unloaders, skip hoists, mine hoists, lifts, etc. slip-ring induction motors with speed control by variation of resistance in the rotor circuit are frequently used. This method of speed control is employed for a motor generator set with a flywheel (Inger set) used as an automatic slip regulator under shock loading conditions.

13. What are the advantages and disadvantages of rotor resistance control?

Advantage of rotor resistance control is that motor torque capability remains unaltered even at low speeds. Only other method which has this advantage is variable frequency control. However, cost of rotor resistance control is very low compared to variable frequency control.

Major disadvantage is low efficiency due to additional losses in resistors connected in the rotor circuit.

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16. How is the resistance in the output terminals of a chopper varied?

The resistance connected across the output terminals of a chopper can be varied from 0 to R by varying the time ratio of the chopper. When the chopper is always OFF, the supply is always connected to the resistance R. The time ratio in this case is zero and the effective resistance connected is R. Similarly when the chopper is always ON, the resistance is short circuited. The time ratio in the case is unity and the effective resistance connected is 0. Hence by varying the time ratio from 0 to 1, the value of resistance can be varied from R to 0.

17. What is the function of inductance L and resistance R in the chopper resistance circuit?

A smoothing inductance L is used in the circuit to maintain the current at a constant value. Any short circuit in the chopper does not become effective due to L.

The value of R connected across the chopper is effective for all phases and its value can be related to the resistance to be connected in each phase if the conventional method has been used. The speed control range is limited by the resistance.

18. What are the disadvantages and advantages of chopper controlled resistance in the rotor circuit method?

The method is very inefficient because of losses in the resistance. It is suitable for intermittent loads such as elevators. At low speeds, in particular the motor has very poor efficiency. The rotor current is non-sinusoidal. The harmonics of the rotor current produce torque pulsations. These have a frequency which is six times the slip frequency.

Because of the increased rotor resistance, the power factor is better.

19. How is the range of speed control increased?

The range of speed control can be increased if a combination of stator voltage control and rotor resistance control is employed. Instead of using a high resistance rotor, a slip ring rotor with external rotor resistance can be used when stator voltage control is used for controlling the speed.

20. Why the static scherbius drive has a poor power factor?

Drive input power is difference between motor input power and the power fed back. Reactive input power is the sum of motor and inverter reactive power. Therefore, drive has a poor power factor throughout the range of its options.

21. How is super synchronous speed achieved?

Super synchronous speed can be achieved if the power is fed to the rotor from A.C. mains. This can be made possible by replacing the converter cascade by a cycloconverter. A cycloconverter allows power flow in either direction making the static scherbets drive operate at both sub and super synchronous speeds.

22. Give the features of static scherbius drive

The torque pulsations and other reactions are minimal. The performance of the drive improves with respect to additional losses and torque pulsations. A smooth transition is possible from sub to super synchronous speeds without any commutation problems. Speed reversal is not possible. A step up transformer may be interposed between the lines and the converter, to reduce the voltage rating of the converter.

23. Where is Kramer electrical drive system used?

Some continuous rolling mills, large air blowers, mine ventilators, centrifugal pumps and any other mechanisms including pumps drives of hydraulic dredgers require speed adjustment in the range from 15 to 30% below or above normal. If the induction motor is of comparatively big size (100 to 200 KW) it becomes uneconomical to adjust speed by means of external resistances due to copper losses as slip power is wasted as heat in the rotor circuit resistance. In these cases, the Kramer electrical drive system is used, where slip power recovery takes place.

24. What is the use of sub synchronous converter cascades?

Sub synchronous converter cascades have been used, till now, in applications requiring one quadrant operation. These can be employed for drives where at least one electrical braking

is required. A four quadrant operation can also be made possible in these cascades, using suitable switching.

25. How is the speed control obtained in static Kramer drive?

For speed control below synchronous speed, the slip power is pumped back to the supply, whereas for the case of speed above synchronous speed, additional slip power is injected into the rotor circuit.

26. What is static Kramer drive?

Instead of wasting the slip power in the rotor circuit resistance, it can be converted to 60 Hz A.C. and pumped back to the line. The slip power controlled drive that permits only a sub synchronous range of speed control through a converter cascade is known as static Kramer drive.

27. What is the use and functions of step down transformer in static Kramer drive?

For a restricted speed range closer to synchronous speed, the system power factor can be further improved by using a step-down transformer.

The step-down transformer has essentially two functions: besides improving the line power factor, it also helps to reduce the converter power ratings.

28. What are the advantages of static Kramer drive?

The static Kramer drive has been very popular in large power pump and fan-type drives, where the range of speed control is limited near, but below the synchronous speed. The drive system is very efficient and the converted power rating is low because it has to handle only the slip power. In fact, the power rating becomes lower with a more restricted range of speed control. The additional advantages are that the drive system has D.C. machine like characteristics and the control is very simple.

29. What are the causes of harmonic currents in static Kramer drive?

The rectification of slip power causes harmonic currents in the rotor, and these harmonics are reflected to the stator by the transformer action of the machine. The harmonic currents are also injected into the A.C. line by the inverter. As a result, the machine losses are increased and some amount of harmonic torque is produced. Each harmonic current in the rotor will create a rotating magnetic field and its direction of rotation will depend on the order of the harmonic.

UNIT – V**TWO MARKS****1. Give the four modes of operation of a Scherbius drive**

The four modes of operation of static Scherbius drive are,

Sub synchronous motoring.

Sub synchronous regeneration

Super synchronous motoring
Super synchronous regeneration

2. Give the use of synchronous motors.

Synchronous motors were mainly used in constant speed applications. The development of semiconductor variable frequency sources, such as inverters and cycloconverters, has allowed their use in draft fans, main line traction, servo drives, etc.

3. How are the stator and rotor of the synchronous motor supplied?

The stator of the synchronous motor is supplied from a thyristor power converter capable of providing a variable frequency supply. The rotor, depending upon the situation, may be constructed with slip rings, where it conforms to a conventional rotor. It is supplied with D.C. through slip rings. Sometimes rotor may also be free from sliding contacts (slip rings), in which case the rotor is fed from a rectifier rotating with rotor.

4. What is the difference between an induction motor and synchronous motor?

An induction motor operates at lagging power factor and hence the converter supplying the same must invariable is a force commutated one. A synchronous motor, on the other hand, can be operated at any power factor by controlling the field current.

5. List out the commonly used synchronous motors.

Commonly used synchronous motors are,

- a. Wound field synchronous motors.
- b. Permanent magnet synchronous motors
- c. Synchronous reluctance synchronous motors.
- d. Hysteresis motors.

6. Mention the main difference between the wound field and permanent magnet motors.

When a wound field motor is started as an induction motor, D.C. field is kept off. In case of a permanent magnet motor, the field cannot be 'turned off'.

7. Give the advantages and applications of PMSM.

The advantages of PMSM are,

- a. High efficiency
- b. High power factor
- c. Low sensitivity to supply voltage variations.

The application of PMSM is that it is preferred of industrial applications with large duty cycle such as pumps, fans and compressors.

8. Give the uses of a hysteresis synchronous motor.

Small hysteresis motors are extensively used in tape recorders, office equipment and fans. Because of the low starting current, it finds application in high inertia application such as gyrocompasses and small centrifuges.

9. Mention the two modes employed in variable frequency control

Variable frequency control may employ and of the two modes.

- a. True synchronous mode
- b. Self-controlled mode

10. Define load commutation

Commutation of thyristors by induced voltages pf load is known as load commutation.

11. List out the advantages of load commutation over forced commutation.

Load commutation has a number of advantages over forced commutation

It does not require commutation circuits
 Frequency of operation can be higher
 It can operate at power levels beyond the capability of forced commutation.

12. Give some application of load commutated inverter fed synchronous motor drive.

Some prominent applications of load commutated inverter fed synchronous motor drive are high speed and high power drives for compressors, blowers, conveyers, steel rolling mills, main-line traction and aircraft test facilities.

13. How the machine operation is performed in self-controlled mode?

For machine operation in the self-controlled mode, rotating field speed should be the same as rotor speed. This condition is realised by making frequency of voltage induced in the armature. Firing pulses are therefore generated either by comparison of motor terminal voltages or by rotor position sensors.

14. What is meant by margin angle of commutation?

The difference between the lead angle of firing and the overlap angle is called the margin angle of commutation. If this angle of the thyristor, commutation failure occurs. Safe commutation is assured if this angle has a minimum value equal to the turn off angle of the thyristor.

15. What are the disadvantages of VSI fed synchronous motor drive?

VSI synchronous motor drives might impose fewer problems both on machine as well as on the system design. A normal VSI with 180° conduction of thyristors required forced commutation and load commutation is not possible.

16. How is PNM inverter supplied in VSI fed synchronous motor?

When a PWM inverter is used, two cases may arise the inverter may be fed from a constant D.C. source in which case regeneration is straight forward. The D.C. supply to the inverter may be obtained from a diode rectifier. In this case an additional phase controlled converter is required on the line side.

17. What is D.C. link converter and cycloconverter?

D.C. link converter is a two stage conversion device which provides a variable voltage, variable frequency supply.

Cycloconverter is a single stage conversion device which provides a Variable voltage, variable frequency supply.

18. What are the disadvantages of cycloconverter?

A cycloconverter requires large number of thyristors and its control circuitry is complex. Converter grade thyristors are sufficient but the cost of the converter is high.

19. What are the applications of cycloconverter?

A cycloconverter drive is attractive for low speed operation and is frequently employed in large, low speed reversing mills requiring rapid acceleration and deceleration. Typical applications are large gearless drives, e.g. drives for reversing mills, mine hoists, etc.

20. Give the application of CSI fed synchronous motor.

Application of this type of drive is in gas turbine starting pumped hydro turbine starting, pump and blower drives, etc.

21. What are the disadvantages of machine commutation?

The disadvantages of machine commutation are,

- a. Limitation on the speed range.
- b. The machine size is large

c. Due to overexciting it is underutilized.

22. What is the use of an auxiliary motor?

Sometimes when the power is small an auxiliary motor can be used to run up the synchronous motor to the desired speed.

23. What are the advantages of brushless D.C. motor?

The brushless D.C. motor is in fact an inverter-fed self controlled permanent synchronous motor drive. The advantages of brushless D.C. motor are low cost, simplicity reliability and good performance.

24. When can the synchronous motor be load commutated?

When the synchronous motor operates at a leading power factor thyristors of load side converter can be commutated by the motor induced voltages same way as the thyristors of a line commutated converter are commutated by line voltages.

25. What are the characteristics of self controlled mode operated synchronous motor?

- a) It operates at like dc motor also commutator less motor.
- b) These machines have better stability behavior.
- c) Do not have oscillatory behavior.

26. What are the characteristics of true synchronous mode operated synchronous motor?

The motor behaves like conventional synchronous motor i.e) hunting oscillations exists. The change in frequency is slow enough for rotor to track the changes. Multi motor operation is possible here.

27. What is meant by sub synchronous speed operation?

The sub synchronous speed operation means the SRIM speed can be controlled below the synchronous speed. i.e) the slip power is fed back to the supply.

28. What is meant by super synchronous speed operation?

The super synchronous speed operation means the SRIM speed can be controlled above the synchronous speed. i.e) the supply is fed back to the rotor side.

29. What are the two types of static scherbius system?

- a) DC link static scherbius system
- b) Cyclo converter scherbius system

ASSIGNMENT/ TUTORIAL QUESTIONS

Question No	Questions (Module I)	Bloom's Taxonomy Level	CO
1.	Identify and explain the types of electric drives.	Applying	1
2.	Identify and explain the types of industrial loads.	Applying	1

Question No	Questions (Module II)	Bloom's Taxonomy Level	CO
1.	Explain the operation of a three-phase semi converter fed DC separately excited motor.	Understanding	2
2.	Explain the operation of a three-phase full converter fed DC separately excited motor.	Understanding	2

Question No	Questions (Module III)	Bloom's Taxonomy Level	CO
1.	Explain the types of electric braking.	Understanding	3
2.	Explain about dual converter control of dc separately excited motor.	Understanding	3

Question No	Questions (Module IV)	Bloom's Taxonomy Level	CO
1.	Analyze the operation of AC Voltage Controllers used for control of Induction motor.	Analyzing	4
2.	Compare VSI and CSI operations.	Analyzing	4

Question No	Questions (Module V)	Bloom's Taxonomy Level	CO
1.	Illustrate with suitable figures the working of Static Scherbius drive.	Applying	5

2.	Analyze the operation of self controlled synchronous motor by VSI.	Analyzing	5
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IV B.Tech I Semester II Mid Question Bank 2019-20

Subject: SOLID STATE DRIVES

Branch: EEE

Name of the Faculty: K S S NAGA TEJA

OBJECTIVE QUESTIONS

- 1 For a buck converter to reduce the conduction losses in diode []
- A. A high on - resistance switch can be added in parallel
- B. A low on - resistance switch can be added in parallel
- C. A high on - resistance switch can be added in series
- D. A low on - resistance switch can be added in series
- 2 In a flyback converter, the inductor of the buck-boost converter has been replaced by a []
- A. Flyback capacitor
- B. Flyback resistor
- C. Flyback transformer
- D. Flyback transistor
- 3 A step - down choppers can be used in []
- A. Electric traction
- B. Electric vehicles
- C. Machine tools
- D. All of these
- 4 The output current in PWM DC - DC converters is equal to []
- A. Average value of the output inductor current
- B. Product of an average inductor current and a function of duty ratio
- C. Either (a) or (b)
- D. None of these
- 5 The control method used for PWM dc - dc converter is []
- A. Voltage mode control
- B. Current mode control
- C. Hysteric control
- D. All of these
- 6 The average value of the output voltage in a step - down dc chopper is given by []
- A. $V_0 = V_s$
- B. $V_0 = D V_s$
- C. $V_0 = V_s / D$
- D. $V_0 = V_s / (1 - D)$
- 7 Choppers is a []

- A.AC - DC converters
B.AC - AC converters
C.DC - AC converters
D.DC - DC converters
- 8 Unipolar modulation is generally used in []
- A.AC - AC converters
B.AC - DC converters
C.DC - AC converters
D.DC - DC converters
- 9 In current commutated DC-DC choppers, the voltage spike appears across the load when []
- A.Voltage across the commutating inductances collapses
B.The capacitance voltage adds to the supply voltage
C.Both (a) and (b)
D.None of these
- 10 In a load commutated DC - DC chopper, the capacitor has a []
- A.Symmetric triangular voltage across itself
B.Symmetric rectangular voltage across itself
C.Symmetric trapezoidal voltage across itself
D.Symmetric sinusoidal voltage across itself
- 11 For high frequency choppers the device that is preferred is []
- A.Thyristor
B.TRIAC
C.Transistor
D.GTO.
- 12 Silicon controlled rectifier can be turned on []
- A.By applying a gate pulse and turned off only when current becomes zero
B.And turned off by applying gate pulse
C.By applying a gate pulse and turned off by removing the gate pulse
D.By making current non zero and turned off by making current zero
- 13 TRIAC is a semiconductor power electronic device which contains []
- A.Two SCR's connected in reverse parallel
B.Two SCR's connected in parallel
C.Two SCR's connected in series
D.Two BJT's connected in series
- 14 An SCR can be used []
- A.as static conductor
B.for power control
C.for speed control of dc shunt motor

- D.all of these
- 15 A crowbar is a circuit which is used to protect a []
A.voltage sensitive load from excessive dc power supply output voltages
B.current sensitive load from excessive dc power supply output voltage
C.voltage sensitive load from excessive ac power supply output voltages
D.current sensitive load from excessive ac power supply output voltages
- 16 A full wave rectifier with resistive load produces []
A.Second harmonic
B.Third harmonic
C.Fifth harmonic
D.Do not produce harmonics
- 17 The advantage of using free – wheeling diode in half controlled bridge converter is that []
A.There is always a path for the dc current independent of the ac line
B.There is always a path for the ac current independent of the ac line
C.There is always a path for the dc current dependent of the ac line
D.There is always a path for the ac current independent of the ac line
- 18 The most suited gate pulses given to the AC regulator with R – L load can be in the form of []
A.Continuous signal
B.Large isolating pulse transformer
C.A train of pulses
D.None of these
- 19 With increase in firing angle, []
A.Both harmonic distortion and quality of input current increases
B.Harmonic distortion increases and quality of input current decreases
C.Harmonic distortion decreases and quality of input current increases
D.Both harmonic distortion and quality of input current decreases
- 20 The power MOSFET device is a []
A.Current controlled unipolar device
B.Voltage controlled unipolar device
C.Current controlled bipolar device

- 21 D.Voltage controlled bipolar device
The conduction losses in IGBT is []
A.More than that of MOSFET
B.Lower than that of MOSFET
C.Equal to that of MOSFET
D.Equal to that of BJT
- 22 Very large values of modulation index (greater than 3.24) lead to []
A.Square AC output voltage
B.Sine AC output voltage
C.Triangular AC output voltage
D.Trapezoidal AC output voltage
- 23 Double fourier series analysis of PWM is []
A.Two dimensional functions
B.Three dimensional functions
C.One dimensional functions
D.All of these
- 24 In bipolar modulation, the carrier is symmetric about zero with amplitude equal to C_m , the PWM output []
A.Zero
B.Switches between $-1/2$ and $+1/2$
C.Switches between -1 and $+1$
D.Switches between 0 and $+1$
- 25 In a three phase converter, the number of notches per cycle is []
A.One
B.Three
C.Six
D.Nine
- 26 Harmonics in 3 phase inverters can be reduced by using []
A.Passive filter
B.Active filter
C.Both passive and active filters
D.None of these
- 27 Single phase VSI are mainly used in []
A.Power supplies
B.Ups
C.Multilevel configuration
D.All of these
- 28 In single phase VSI, the harmonic which is not present is []

- A.2nd
B.3rd
C.5th
D.7th
- 29 The square wave operation of 3 phase VSI lines contains the harmonics. The amplitudes are []
A.Directly proportional to their harmonic order
B.Inversely proportional to their harmonic order
C.Not related to their harmonic order
D.None of these
- 30 Under harmonic free load voltages, the 3 phase VSI []
A.Does not contains second harmonic
B.Does not contains third harmonic
C.Does not contains fifth harmonic
D.Does not contains seventh harmonic
- 31 For similar carrier and modulating signals, the line current used in CSI is []
A.Identical to line voltage in a VSI
B.Identical to line current in VSI
C.Identical to phase voltage in VSI
D.Identical to phase voltage in CSI
- 32 In a 3 phase CSI, if the required line output voltages are balanced and 120 degree out of phase, then the chopping angles are used to eliminate only the harmonics at frequencies []
A.5
B.7
C.11
D.All of these
- 33 During the commutation period in 3 phase converter, overlap time is []
A.Dependent on the load current
B.Dependent on the voltage
C.Dependent on both the load current and load voltage behind the short circuit current
D.Independent on both the load current and load voltage
- 34 Between the incoming and outgoing devices in voltage commutation []
A.Large overlapping takes place
B.Small overlapping operation
C.No overlapping operation
D.None of these
- 35 The effects of EMI can be reduced by []
A.Suppressing emissions
B.Reducing the efficiency of the coupling path
C.Reducing the susceptibility of the receptor
D.All of these
- 36 In radiative coupling, the emitter radiation field []
A.Decays as $1 / R$, where R is the separation distance between the emitter and the receptor
B.Decays as R, where R is the separation distance between the emitter and the receptor
C.Decays as $1 / 2 R$, where R is the separation distance between the emitter and the receptor
D.Decays as $2R$, where R is the separation distance between the emitter and the receptor
- 37 In EMC signal, the source delivers maximum power to the input of transmission line when the transmission line input impedance []
A.Is equal to the source resistance
B.Greater than the source resistance
C.Smaller than the source resistance
D.None of these

- 38 For swept frequency measurements, the input impedance of the mismatched transmission line would vary with frequency as the electrical length of the transmission line would []
A. Decrease with frequency
B. Remains same with change in frequency
C. Increase with frequency
D. Either (a) or (b)
- 39 Voltage commutation circuit can be converted into a current commutation by interchanging the positions of []
A. Diode and capacitor
B. Capacitor and SCR
C. Inductor and capacitor
D. Capacitor and load
- 40 LISN is a device used to measure conducted emissions. LISN stands for []
A. Line integrated stabilization network
B. Line impedance stabilization network
C. Line integrated stored network
D. Laser integrated stabilization networking
- 41 The output power of the cascaded amplifier / attenuator system can be determined using []
A. Actual gain of amplifier
B. Actual gain of amplifier and attenuator
C. Gain in dB of amplifier and attenuator
D. Actual gain of attenuator
- 42 An SCR is made up of silicon because []
A. silicon has large leakage current than germanium
B. silicon has small leakage current than germanium
C. silicon has small leakage voltage than germanium
D. silicon has large leakage voltage than germanium
- 43 C power in a load can be controlled by using []
A. two SCR's in parallel opposition
B. two SCR's in series
C. three SCR's in series
D. four SCR's in series
- 44 The switching function of semiconductor devices can be characterized with []
A. Duty ratio only
B. Frequency only
C. Duty ratio and frequency
D. Duty ratio, frequency and time delay
- 45 With gate open, the maximum anode current at which SCR is turned off from ON condition is called []
A. breakdown voltage
B. peak reverse voltage
C. holding current
D. latching current
- 46 The curve between V and I of SCR when anode is positive w.r.t cathode and when anode is negative w.r.t cathode are known as []
A. both as forward characteristics
B. both as reverse characteristics

- C.former as forward characteristics and later as reverse characteristics
 D.former as reverse characteristics and later as forward characteristics
- 47 Form factor of a rectifier is the ratio of []
- A.Root mean square value of voltage and current to its peak value
 B.Root mean square value of voltage and current to its average value
 C.Average value of current and voltage to its root mean square value
 D.Peak value of current and voltage to its root mean square value
- 48 Ripple factor is the ratio of []
- A.Rms value of the ac component of load voltage to the dc voltage
 B.Average value of the ac component of load voltage to the peak value of voltage
 C.Average value of the dc component of load voltage to the ac voltage
 D.Peak value of the dc component of load voltage to the ac voltage
- 49 The Graetz bridge makes excellent use of []
- A.Current transformer
 B.Potential transformer
 C.Power transformer
 D.SCR
- 50 The ac voltage controller can be used for []
- A.Lighting and heating control
 B.On – line transformer tap changing
 C.Soft starting
 D.All of these
- 51 An RC snubber network used in BJT []
- A.Divert the collector current during turn – off
 B.Improves the reverse bias safe operating area
 C.Dissipates a fair amount of switching power
 D.All of these
- 52 A MOSFET, for its conduction uses []
- A.Only minority carriers
 B.Only majority carriers
 C.Both minority and majority carriers
 D.None of these
- 53 The typical value of SCR for modern alternator is []
- A.1.5.
 B.0.5.
 C.1.0.
 D.1.2.
- 54 An SCR has half cycle surge current rating of 3000 A for 50 Hz supply. One cycle surge current will be []
- A.1500 A.
 B.6000 A
 C.2121.32 A
 D.4242.64 A
- 55 Which triggering is the most reliable? []
- A.Forward voltage triggering.
 B.Gate triggering.
 C.dV / dt triggering.

- 56 D.Thermal triggering.
Light triggering mainly used in []
A.low - voltage direct current transmission
B.medium voltage direct current transmission.
C.high voltage direct current transmission
D.all of these
- 57 AC voltage controllers convert []
A.fixed ac to fixed dc
B.variable ac to variable dc
C.fixed ac to variable ac
D.variable ac to fixed ac
- 58 In AC voltage controllers the []
A.variable ac with fixed frequency is obtained
B.variable ac with variable frequency is obtained
C.variable dc with fixed frequency is obtained
D.variable dc with variable frequency is obtained
- 59 Earlier then the semiconductor technology, _____ devices were used for voltage control applications. []
A.cycloconverters
B.vacuum tubes
C.tap changing transformer
D.induction machine
- 60 The AC voltage controllers are used in _____ applications. []
A.power generation
B.electric heating
C.conveyor belt motion
D.power transmission
- 61 In the principle of phase control []
A.the load is on for some cycles and off for some cycles
B.control is achieved by adjusting the firing angle of the devices
C.control is achieved by adjusting the number of on off cycles
D.control cannot be achieved
- 62 A single-phase half wave voltage controller consists of []
A.one SCR is parallel with one diode
B.one SCR is anti parallel with one diode
C.two SCRs in parallel
D.two SCRs in anti parallel
- 63 In voltage source inverters (VSIs), the amplitude of the output voltage is []
A.independent of the load
B.dependent on the load
C.dependent only on L loads
D.none of the mentioned
- 64 In voltage source inverters (VSIs), the output currents _____ []
A.amplitude depends upon the load impedance
B.waveform depends upon the load impedance
C.amplitude as well as the nature of the waveform depends on the load
D.both amplitude and waveform are independent of the load impedance

- 65 In current source inverters (CSIs) []
 A.the amplitude of the output current is independent of the load
 B.the amplitude of the output current depends on the load
 C.the amplitude of the output voltage is independent of the load
 D.none of the mentioned
- 66 In current source inverters (CSIs), the output voltage's []
 A.amplitude depends upon the load impedance
 B.waveform depends upon the load impedance
 C.amplitude as well as the nature of the waveform depends on the load
 D.both amplitude and waveform are independent of the load impedance
- 67 In current source inverters []
 A.L filter is used after the CSI (load side)
 B.L filter is used before the CSI (input side)
 C.C filter is used after the CSI (load side)
 D.C filter is used before the CSI (input side)
- 68 A CSI converters []
 A.the input dc current to an an current at output
 B.the input ac current to dc current at output
 C.the input dc current to amplified dc current at the output
 D.the input ac current to amplified ac current at the output
69. In a 3-phase VSI operating in square-wave mode, the output line voltage is free from []
 A.3rd harmonic
 B.7th harmonic
 C.11th harmonic
 D.13th harmonic
70. Force-commutated CSIs need []
 A.capacitors for their commutation
 B.inductors for their commutation
 C.diodes for their commutation
 D.none of the mentioned
- 71 Which of the following is used as a harmonic reduction technique in inverters? []
 A.Amplitude modulation
 B.Cycloconverter control
 C.Transformer connection
 D.Series connection of two inverters
- 72 For harmonic reduction by transformer connection, the output voltages from the two inverters must be []
 A.similar and in-phase with each other
 B.dissimilar but in-phase with each other
 C.similar but phase shifted from each other
 D.dissimilar and phase shifted from each other
- 73 The output voltage obtained by connecting two inverters through a transformer is a []
 A.square wave
 B.sine wave
 C.quasi-square wave
 D.none of the mentioned
- 74 Pulses of different widths and heights are superimposed in case of _____ harmonic reduction technique. []

- A.transformer connection
B.pulse width modulation
C.stepped-wave inverter
D.none of the mentioned
- 75 In case of stepped wave inverters, []
A.both the transformers have 1:1 turns ratio
B.both the transformers have 1:2 turns ratio
C.both the transformers have different transformer ratio
D.none of the mentioned
- 76 In stepped wave inverters, one of the inverters are gated such as to obtain []
A.one level modulation
B.two level modulation
C.zero level modulation
D.none of the mentioned
- 77 In three-level modulation []
A.the output voltage is zero in the first half cycle.
B.the output voltage either zero or positive in the first half cycle.
C.the output voltage either zero or negative in the first half cycle.
D.the output voltage either zero, positive or negative in the first half cycle.
- 78 In single-phase modulation of PWM inverters, the lowest harmonic can be eliminated if the []
pulse width is made equal to _____
A.30°
B.0°
C.120°
D.60°
- 79 In single-phase modulation of PWM inverters, the 5th order harmonic can be eliminated if the []
pulse width is made equal to _____
A.30°
B.36°
C.72°
D.None of the mentioned
- 80 In single-phase modulation of PWM inverters, the 5th order harmonic can be eliminated if the []
pulse width is made equal to _____
A.30°
B.36°
C.72°
D.None of the mentioned

- 81 In case of multiple pulse width modulation method, if the amplitudes of the reference wave and the carrier wave are made equal then, the pulse width = []
- A. ∞
 - B. 0
 - C. 100°
 - D. none of the mentioned
- 82 In an inverter, if the fundamental output frequency is 45 Hz, then the frequency of the second lowest order harmonic will be []
- A. 45 Hz
 - B. 135 Hz
 - C. 225 Hz
 - D. 9 Hz
- 83 In an inverter, if the fundamental output frequency is 45 Hz, then the frequency of the lowest order harmonic will be []
- A. 45 Hz
 - B. 225 Hz
 - C. 15 Hz
 - D. 135 Hz
- 84 A VSI will have a better performance if its []
- A. load inductance is small and source inductance is large
 - B. both load inductance and source inductance are small
 - C. both load inductance and source inductance are large
 - D. none of the mentioned
- 85 A single-phase bridge inverter has a square wave output voltage waveform, with odd harmonics present. What is the percentage of the fifth harmonic component to the fundamental component? []
- A. 50 %
 - B. 25 %
 - C. 20 %
 - D. 5 %
- 86 Control of frequency and control of voltage in 3-phase inverters is []
- A. possible only through inverter control circuit
 - B. possible through the control circuit of inverter and converter
 - C. possible through inverter control of frequency and through converter control for voltage
 - D. none of the mentioned
- 87 Control of frequency and control of voltage in 3-phase inverters is []
- A. possible only through inverter control circuit
 - B. possible through the control circuit of inverter and converter
 - C. possible through inverter control of frequency and through converter control for voltage
 - D. none of the mentioned
- 88 A single-phase bridge inverter, fed from a 230 V dc is connected to the load $R = 10 \Omega$ and $L =$ []

0.03 H. Determine the fundamental component of rms output current. Fundamental output frequency of the square wave output = 50 Hz.

- A.30 A
- B.15 A
- C.2.3 A
- D.20.7 A

89 A single-phase bridge inverter, fed from a 230 V dc is connected to the load $R = 10 \Omega$ and $L = 0.03$ H. The output is a quasi-square wave with an on period of 0.5 of a cycle. Determine the fundamental component of rms output voltage. []

- A.207.10 V
- B.146.42 V
- C.265.4 V
- D.129 V

90 In pulse width modulated inverters, the output voltage is controlled by controlling the []

- A.input frequency
- B.modulating index
- C.amplification factor
- D.none of the mentioned

91 In case of sinusoidal pulse width modulation with $MI < 1$, if the number of pulses per half cycle (N) = 5, then []

- A.harmonics of order 5 and 7 become significant
- B.harmonics of order 5 and 7 are eliminated
- C.harmonics of order 9 and 11 become significant
- D.harmonics of order 9 and 11 are eliminated

92 In case of sinusoidal pulse width modulation with $MI < 1$, the order of the dominate harmonic can be raised by []

- A.increasing the number of pulses
- B.reducing the number of pulses
- C.lowering the input voltage frequency
- D.raising the input voltage frequency

93 In case of sinusoidal pulse width modulation with $MI < 1$, if the number of pulses per half cycle (N) = 6, then []

- A.harmonics of order 7 and 9 become significant
- B.harmonics of order 7 and 9 are eliminated
- C.harmonics of order 11 and 13 become significant
- D.harmonics of order 11 and 13 are eliminated

94 Increasing the number of pulses (N), _____ []

- A.reduces the output voltage amplitude
- B.reduces the inverter efficiency
- C.improves the inverter efficiency

- D.none of the mentioned
- 95 In single-phase modulation of PWM inverters, the pulse width is 120° . For an input voltage of 220 V dc, the rms value of output voltage is []
- A.185 V
B.254 V
C.127 V
D.179 V
- 96 In MPM the amplitudes of square wave and triangular wave are respectively 1 V and 2 V. For generating 5 pulses per half cycle, the pulse width should be _____ []
- A. 36°
B. 24°
C. 12°
D. 18°
- 97 In an inverter, if the fundamental output frequency is 50 Hz, then the frequency of the lowest order harmonic will be []
- A.50 Hz
B.150 Hz
C.250 Hz
D.350 Hz
- 98 In constant frequency TRC or pulse width modulation scheme, _____ is varied. []
- A. V_s
B. T_{on}
C.T
D.F
- 99 Calculate the pulse width in case of MPM, if the amplitudes of square wave and triangular wave are respectively 2 V and 3 V respectively. 16 pulses per cycle are generated. []
- A. 18°
B. 7.5°
C. 6.4°
D. 9°
- 100 In the multiple pulse width modulation method, the firing pulses are generate during the interval when the []
- A.triangular wave exceeds the square modulating wave
B.square modulating wave exceeds the triangular wave
C.square wave amplitude is same as the triangular wave's amplitude
D.none of the mentioned
- 101 In MPM, _____ order harmonics can be eliminated by a proper choice of _____ and _____ []

- A.higher, d, γ
 B.lower, d, γ
 C.higher and lower, d, γ
 D.none of the mentioned
- 102 In _____ type of modulation method, the pulse width is not equal for all the pulses. []
- A.multiple pulse width modulation
 B.single pulse width modulation
 C.sinusoidal pulse width modulation
 D.none of the mentioned
- 103 In sinusoidal pulse width modulation, _____ wave is compared with a _____ type of wave. []
- A.square, sinusoidal
 B.sinusoidal, triangular
 C.sinusoidal, quasi-square
 D.none of the mentioned
- 104 A cycloconverter is a _____ []
- A.one stage power converter
 B.one stage voltage converter
 C.one stage frequency converter
 D.none of the mentioned
- 105 Applications of cycloconverters include []
- A.speed control of ac drives
 B.induction heating
 C.static VAr compensation
 D.all of the mentioned
- 106 The single phase mid-point type cycloconverter uses _____ number of SCRs. []
- A.4
 B.8
 C.6
 D.none of the mentioned
- 107 The single phase bridge type cycloconverter uses _____ number of SCRs. []
- A.4
 B.8
 C.6
 D.none of the mentioned
- 108 The principle of three phase cycloconverter is to []
- A.add and remove number of SCRs

- B.vary progressively the firing angle of the devices
 C.keep the firing angle as 0° for all the devices
 D.none of the mentioned
- 109 In three phase cycloconverters, the reduction factor is given by []
 A.input frequency/output frequency
 B.(input frequency/output frequency) $^{-1}$
 C.(input frequency/output frequency) $^{-1/2}$
 D.(input frequency/output frequency) $^{1/2}$
- 110 In a three phase half-wave cycloconverter _____ []
 A.both inverting and converting action takes place
 B.only inversion action takes place
 C.only converting action takes place
 D.none of the mentioned
- 111 Sequence control of ac voltage controllers is employed for the improvement of _____ []
 A.output frequency
 B.input frequency
 C.commutation
 D.system power factor
- 112 A two stage sequence control is []
 A.two SCRs in anti parallel
 B.two voltage controllers in parallel
 C.two voltage controllers in series
 D.a voltage controller having two voltage level
- 113 A single-phase two stage sequence controller is designed to work on 230 V supply, and upper and lower current ratings must be 20 A and 21 A respectively. The transformer rating is ____ []
 A.230 VA
 B.4600 VA
 C.9430 VA
 D.9200 VA
- 114 In a N-stage sequence controller, each secondary is rated for _____ []
 A.n x V_s
 B. V_s
 C. V_s/n
 D. $V_s \times (n-1)$
- 115 A single-phase sinusoidal voltage controller has []
 A.one primary and n secondary windings
 B.one primary and (n-1) secondary windings
 C.n primary and n secondary windings
 D.(n-1) primary and n secondary windings

- 116 What is the expression for load voltage when the chopper is operated in the second quadrant? []
- A. V_s
 B. E
 C. 0
 D. $E + L \frac{di}{dt}$
- 117 For a type E chopper operating in the first quadrant, find the expression for average output voltage. []
- A. V_s
 B. $E + L \frac{di}{dt}$
 C. $E - L \frac{di}{dt}$
 D. 0
- 118 For a type D chopper operating in the first quadrant, find the expression for average output voltage. []
- A. V_s
 B. $E - L \frac{di}{dt}$
 C. 0
 D. $E + L \frac{di}{dt}$
- 119 A type D chopper is a []
- A. two quadrant type-B chopper
 B. two quadrant type-A chopper
 C. two quadrant type-C chopper
 D. none of the mentioned
- 120 In a type-D chopper []
- A. current can flow in both the directions of the load
 B. current cannot flow in both the directions of the load
 C. voltage can only be positive
 D. voltage can only be negative
- 121 For a type D chopper, the average value of output voltage will be positive when []
- A. $T_{on} = T_{off}$
 B. $T_{on} < T_{off}$
 C. $T_{off} = 0$
 D. $T_{on} > T_{off}$
- 122 For a type D chopper, if duty cycle = 0.5 then the []
- A. average voltage is positive
 B. average voltage is negative
 C. average voltage is zero
 D. chopper cannot be operated with duty cycle = 0.5
- 123 For a type D chopper, if duty cycle $\alpha < 0.5$ then the

- A.average voltage is positive
- B.average voltage is negative
- C.average voltage is zero
- D.none of the mentioned

[]

124 Find the average output voltage for a type D chopper if it is given a dc supply of 220 V. Chopper frequency is 2 kHz and both the chopper switches are operated for 0.3 ms.

- A.220 V
- B.108 V
- C.98 V
- D.44 V

[]

125 Find the average output voltage for a type D chopper if it is given a dc supply of 220 V. Chopper frequency is 2 kHz and both the chopper switches are operated for 0.3 ms.

- A.220 V
- B.108 V
- C.98 V
- D.44 V

[]

SOLID STATE DRIVES

MALLA REDDY ENGINEERING COLLEGE (AUTONOMOUS)

B.Tech – VII Sem II Mid Examination Subjective Question Bank

Q.No.	Question	Bloom's Taxonomy Level	CO
<u>Module III</u>			
1.	Explain with a neat diagram, the concept of Plugging.	Understanding	3
OR			
2.	Explain with a neat diagram, the concept of Dynamic Braking.	Understanding	3
OR			
3.	Analyze the operation of chopper fed dc separately excited motor.	Analyzing	3
OR			
4.	Analyze the operation of chopper fed dc series motor.	Analyzing	3
<u>Module IV</u>			
1.	Explain the operation of cycloconverters.	Understanding	4
OR			
2.	Explain the concept of PWM control.	Understanding	4
OR			
3.	Compare VSI and CSI operations.	Analyzing	4
OR			
4.	Compare various methods of control used in induction motor drives.	Analyzing	4
OR			
5.	Construct and explain the control of induction motor by AC voltage controller.	Applying	4
OR			
6.	Construct and explain the control of induction motor by Voltage Source Inverter.	Applying	4
OR			
7.	Construct and explain the speed-torque characteristics of an induction motor controlled by an AC voltage controller.	Applying	4
OR			
8.	Construct and explain the operation of AC Voltage Controllers used for control of Induction motor.	Applying	4
<u>Module V</u>			
1.	Explain the concept of static rotor resistance control.	Understanding	5

OR			
2.	Explain the concept of slip power recovery.	Understanding	5
OR			
3.	Illustrate with suitable figures the working of Static Scherbius drive.	Applying	5
OR			
4.	Illustrate with suitable figure the operation of Static Kramer Drive.	Applying	5
OR			
5.	Explain the advantages and applications of Static Scherbius drive.	Understanding	5
OR			
6.	Explain the advantages and applications of Static Kramer drive.	Understanding	5
OR			
7.	Construct and explain the separate control of synchronous motors.	Applying	5
OR			
8.	Construct and explain the self control of synchronous motors.	Applying	5

MALLA REDDY ENGINEERING COLLEGE (AUTONOMOUS)

B.Tech – VII Sem I Mid Examination Subjective Question Bank

Q.No.	Question	Bloom's Taxonomy Level	CO
1.	Identify and explain the types of electric drives.	Applying	1
OR			
2.	Identify and explain the types of industrial loads.	Applying	1
3.	Analyze the operation of a single-phase semi converter fed DC separately excited motor in continuous current mode with suitable waveforms.	Analyzing	1
OR			
4.	Analyze the operation of a single-phase full converter fed DC series motor in continuous current mode with suitable waveforms.	Analyzing	1
5.	Explain about choice of motor in electric drives.	Understanding	1
OR			
6.	Explain about temperature rise in electric drives.	Understanding	1
7.	A 200 V, 875 rpm, 150 A separately excited dc motor has an armature resistance of 0.06 Ω . It is fed from a single phase fully-controlled rectifier with an ac source voltage of 220 V, 50 Hz. Assuming continuous conduction, Solve and obtain (i) Firing angle for rated motor torque and 750 rpm. (ii) Firing angle for rated motor torque and (-500) rpm. Motor speed for firing angle $\alpha=160^\circ$ and rated torque.	Applying	1
OR			
8.	Solve and obtain the expression for armature voltage of a single-phase full converter fed DC separately excited motor in continuous current mode.	Applying	1
<u>Module II</u>			
1.	Explain the operation of a three-phase semi converter fed DC separately excited motor.	Understanding	2
OR			

2.	Explain the operation of a three-phase full converter fed DC separately excited motor.	Understanding	2
OR			
3.	Solve and obtain the expression for armature voltage for three-phase full converter fed DC separately excited motor.	Applying	2
OR			
4.	Construct and explain the speed-torque characteristics of a three-phase full converter fed DC separately excited motor.	Applying	2
OR			
5.	Explain the operation of a three-phase semi converter fed DC series motor.	Understanding	2
OR			
6.	Explain the operation of a three-phase full converter fed DC series motor.	Understanding	2
OR			
7.	Solve and obtain the expression for armature voltage for three-phase semi converter fed DC separately excited motor.	Applying	2
OR			
8.	A 220V, 1500rpm, 50A separately excited motor with armature resistance of 0.5Ω , is fed from a 3-phase fully-controlled rectifier. Assume $V_m=230.4V$. Solve and obtain the value of firing angle when: (a) Motor is running at 1200 rpm and rated torque. (b) Motor is running at (-800) rpm and twice the rated torque. Assume continuous conduction.	Applying	2
Module III			
1.	Explain the types of electric braking.	Understanding	3
OR			
2.	Explain about dual converter control of dc separately excited motor.	Understanding	3
OR			
3.	Analyze the motoring operation of DC drives.	Analyzing	3
OR			
4.	Analyze the braking operation of DC drives.	Analyzing	3

CODE: 50226

MALLA REDDY ENGINEERING COLLEGE (AUTONOMOUS)

IV B.Tech I Semester I Mid Question Bank 2019-20

Subject: SOLID STATE DRIVES

Branch: EEE

Name of the Faculty: K S S NAGA TEJA

1	For controlling the speeds below the rated value, -----is controlled in case of a DC motor.	A
	armature voltage	
	Field current	
	Both armature voltage and field currents	
	None	
2	DC series motor is a	B
	constant flux machine	
	variable flux machine	
	doesn't have any effect of flux	
	none of these	
3	Speed torque characteristic of a DC series motor before saturation	B
	Linear	
	Rectangular hyperbola	
	both linear and rectangular hyperbola	
	none of these	
4	Which type of machine is used in cranes, lifts, hoists etc	B
	DC shunt motor	
	DC series motor	
	synchronous machine	
	none of these	
5	In a single phase semi converters the number of SCRs are	C
	4	
	6	
	2	
	3	
6	In single phase Full converters the SCR are triggered at an interval of	A
	$\alpha, \pi + \alpha$	
	$\alpha, \pi/2$	
	α, π	
	none of these	
7	A single phase semiconverter is operates in which quadrant	A
	First quadrant	
	second quadrant	

	Third quadrant	
	Fourth quadrant	
8	Freewheeling action play its role for	
	resistive load	D
	heater load	
	motor load	
	battery load	
9	A single phase Full converter operates in which quadrants	D
	1 st and 2 nd quadrant	
	2 nd and 3 rd quadrant	
	3 rd and 4 th quadrant	
	1 st and 4 th quadrant	
10	Which of the following motors has high starting torque	B
	DC shunt motor	
	DC series motor	
	3 phase induction machine	
	None	
11	The consideration involved in the selection of the type of electric drive for a particular application depends on	D
	Speed control range and its nature	
	Starting torque	
	Environmental conditions	
	All of the above	
12	Which of the following is preferred for automatic drives?	C
	Synchronous motors	
	Squirrel cage induction motor	
	Ward Leonard controlled dc motors	
	Any of the above	
13	Which type of drive can be used for hoisting machinery	D
	AC slip ring motor	
	Ward Leonard controlled DC shunt motor	
	DC compound motor	
	Any of the above	
14	The motor normally used for crane travel is	A
	AC slip ring motor	
	Ward Leonard controlled DC shunt motor	
	Synchronous motor	
	DC differentially compound motor	
15	A wound rotor induction motor is preferred over squirrel cage induction motor when the major	D

	consideration involved is	
	high starting torque	
	low starting current	
	speed control over limited range	
	all of the above	
16	When smooth and precise speed control over a wide range is desired, the motor preferred is	D
	synchronous motor	
	squirrel cage induction motor	
	wound rotor induction motor	
	dc motor	
17	When quick speed reversal is a consideration, the motor preferred is	D
	synchronous motor	
	squirrel cage induction motor	
	wound rotor induction motor	
	dc motor	
18	Stator voltage control for speed control of induction motors is suitable for	A
	fan and pump drives	
	drive of a crane	
	running it as generator	
	constant load drive.	
19	The selection of control gear for a particular application is based on the consideration of	D
	Duty	
	starting torque	
	limitations on starting current	
	all of the above	
20	As compared to squirrel cage induction motor, a wound rotor induction motor is preferred when the major consideration is	A
	high starting torque	
	low windage losses	
	slow speed operation	
	all of the above	

21	A synchronous motor is found to be more economical when the load is above	D
	1 kW	
	10 kW	
	20 kW	
	100kW	
22	The advantage of a synchronous motor in addition to its constant speed is	A
	high power factor	
	better efficiency	
	lower cost	
	all of the above	
23	In motor circuit static frequency changers are used for	D
	power factor improvement	
	improved cooling	
	reversal of direction	
	speed regulation	
24	In case of traveling cranes, the motor preferred for boom hoist is	A
	AC slip ring motor	
	Ward Leonard controlled DC shunt motor	
	Synchronous motor	
	Single phase motor	
25	The characteristics of drive for. crane hoisting and lowering is	D
	smooth movement	
	precise control	
	fast speed control	
	all of the above	
26	The capacity of a crane is expressed in terms of	C
	Span	
	Type of drive	
	Tonnes	
	Any of the above.	
27	The traveling speed of cranes varies from	A
	1 to 2.5 m/s	

	5 to 15 m/s	
	20 to 22.5 m/s	
	25 to 40 m/s.	
28	In overhead traveling cranes	C
	continuous duty motors are used	
	slow speed motors are preferred	
	short time rated motors are preferred	
	none of the above	
29	15 minute rated motors are suitable for	A
	light duty cranes	
	medium duty cranes	
	heavy duty cranes	
	all of the above	
30	Light duty cranes are generally used in	D
	automobile workshops	
	pumping stations	
	power houses	
	All of the above	
31	Heavy duty cranes are used in	D
	Heavy engineering workshops	
	Steel plants	
	Ore handling plants	
	All of the above	
32	1/2 hour rated motors are used for	B
	light duty cranes	
	medium duty cranes	
	heavy duty cranes	
	none of the above	

33	Which of the following drive can be used for derricks and winches?	D
	AC slip-ring motors with variable resistance	
	Pole changing squirrel cage motors	
	DC motors with Ward Leonard control	
	Any of the above	
34	The number of sets used in pole changing type squirrel cage motors for derricks and winches, is	B
	2	
	3	
	4	
	6	
35	A pole changing type squirrel cage motor used in derricks has four, eight and twenty four poles. In this the medium speed is used for	A
	Lifting	
	Hoisting	
	Lowering	
	landing the load	
36	A pole changing type squirrel cage motor used in derricks has four, eight and twenty four poles. In this the lowest speed is used for	D
	Lifting	
	Hoisting	
	Lowering	
	landing the load	
37	For handling fragile articles in a crane	A
	low speed is preferred	
	medium speed is preferred	
	high speed is preferred	
	None of the above	
38	The range of horse power of electric motor drives for rolling mills is of the order of	D

	1 to 10 HP	
	15 to 25 HP	
	50 to 100 HP	
	100 to 500 HP	
39	Motors preferred for rolling mill drive is	C
	dc motors	
	ac slip ring motors with speed control	
	any of the above	
	none of the above	
40	Themotors, because of their inherent characteristics, are best suited for the rolling mills	A
	dc motors	
	slip ring induction motors	
	squirrel cage induction motors	
	single phase motors	
41	Motor preferred for kiln drives is usually	D
	slip ring induction motor	
	three phase shunt wound commutator motor	
	cascade controlled ac motor	
	any of the above	
42	Belt conveyors offer	D
	zero starting torque	
	low starting torque	
	medium starting torque	
	high starting torque	
43	In case belt conveyors	A
	squirrel cage motors with direct-on-line starters are used	
	single phase induction motors are used	
	dc shunt motors are used	

	Induction motors with star-delta starters are used.	
44	Which of the following motor is preferred for blowers?	B
	wound rotor induction motor	
	squirrel cage induction motor	
	dc shunt motor	
	dc series motor.	
45.	Centrifugal pumps are usually driven by	C
	dc shunt motors	
	dc series motors	
	squirrel cage induction motors	
	Any of the above.	
46	In case of centrifugal pumps the starting torque is generally	D
	double the running torque	
	slightly more than running torque	
	same as running torque	
	less than running torque	
47	In a centrifugal pump if the liquid to be pumped has density twice that of water, then the horse power required (as compared to that while pumping water) will be	C
	Half	
	Same	
	Double	
	four times	
48	Wound rotor and squirrel-cage motors with high slip which develop maximum torque at stand still are used for	B
	machine tools	
	presses and punches	
	Elevators	
	all of the above	
49	Belted slip ring induction motor is almost invariably used for	B

	centrifugal blowers	
	jaw crushers	
	water pumps	
	screw pumps	
50	In jaw crushers, a motor has to often start against	D
	low load	
	medium load	
	normal load	
	heavy load	
51	Motor used for elevators is generally	B
	synchronous motor	
	induction motor	
	capacitor start single phase motor	
	any of the above	
52	In synthetic fibre mills motor with	A
	constant speeds are preferred	
	high starting torque are preferred	
	variable speed are preferred	
	low starting torque are preferred	
53	Which of the following motor is preferred for synthetic fibre mills?	B
	series motor	
	reluctance motor	
	shunt motor	
	synchronous motor	
54	Reluctance motor is a	A
	self-starting type synchronous motors	
	low torque variable speed motor	

	variable torque motor	
	low noise, slow speed motor	
55	A reluctance motor	A
	is compact	
	has high cost	
	requires starting gear	
	is provided with slip rings	
56	Power factor in case of reluctance motor is	D
	nearly unity	
	always leading	
	0.8	
	None	
57	The efficiency of reluctance motor is around	D
	95%	
	90%	
	75 to 85%	
	60 to 75%.	
58	A reluctance motor on over-load runs as	B
	synchronous motor	
	induction motor	
	either of the two	
	None	
59	The size of a excavator is usually expressed in terms of	A
	cubic meters	
	travel in meters	
	angle of swing	
	'crowd' motion	
60	Ward-Leonard controlled dc drives are generally used for	C

	light duty excavators	
	medium duty excavators	
	heavy duty excavators	
	all of the above	
61	In case of contactors, the contacts are generally made of	D
	Copper	
	Silver	
	cadmium copper	
	any of the above	
62	Which electromagnet is preferred for noiseless operation?	A
	DC operated	
	AC operated	
	Any of the above	
	None	
63	For high frequency choppers the device that is preferred is	C
	Thyristor	
	TRIAC	
	Transistor	
	GTO	
64	The number of operations per hour in case of class IV contactor will be around	D
	100	
	600	
	900	
	1200.	
65	In case of contactors, the duty in which the main contacts remain closed for a period bearing a definition relation to the no-load periods, is known as	B
	Standard duty	
	Intermittent duty	

	Temporary duty	
	Un-interrupted duty	
66	In case of contactors the ratio of the in service period to the entire period, expressed as a percentage is known as	B
	Duty	
	load factor	
	class of contact	
	none of the above	
67	A class I contactor should be mechanically sound to withstand	B
	0.05 million times	
	0.25 million times	
	1.2 million times	
	5.0 million times	
68	Heat control switches find applications on	D
	three phase induction motors	
	single phase motors	
	Transformers	
	cooling ranges	
69.	A saturable core reactor is basically a	D
	variable resistor	
	step down transformer	
	thermal relay	
	variable impedance	
70.	In a rotary converter	C
	armature currents are dc only	
	armature currents are ac only	
	partly ac and partly dc	
	All of the above	

71	In a rotary converter I^2R losses as compared to a dc generator of the same size will be	D
	four times more	
	Double	
	Same	
	less.	
72	In a synchronous converter, the I^2R losses are less as compared to dc generator of the same size because	B
	dc currents are negligible	
	ac components neutralize the dc	
	cyclic fluctuations have low frequency	
	operating speed is low.	
73	A rotary converter can be started	D
	from dc side as dc motor	
	from ac side as induction motor	
	by means of a small auxiliary motor	
	any of the above methods	
74	When a rotor converter is started by means of a small auxiliary motor, the power of motor must be	D
	more than the dc output of converter	
	more than ac input of converter	
	half of dc output of converter	
	slightly more than the value of friction and windage losses at rated speed.	
75	In a mercury arc rectifier positive ions are attracted towards	C
	mercury pool	
	shell bottom	
	Cathode	
	anode.	
76	Maximum current rating of a glass bulb mercury arc rectifier is usually restricted to	C
	50 A	

	100 A	
	500 A	
	1000 A	
77	Which of the following rectifiers can withstand maximum voltage on dc side	C
	Mercury arc rectifier	
	Glass bulb rectifier	
	Steel tank rectifier	
	None of the above	
78	In an arc rectifier the drop in voltage at the cathode is approximately	B
	1 volt	
	6 to 7 volts	
	60 to 70 volts	
	1.2 V7 volts	
79	In arc rectifiers mercury is chosen as the liquid for rectifier because	D
	it has low specific heat	
	it has low ionization potential	
	it has high atomic weight	
	All of the above.	
80	Ionization potential of mercury is approximately	C
	1 V	
	2 V	
	10.4 V	
	104 V.	
81	Least undulating current will be delivered by which mercury arc rectifier	D
	1-phase	
	2 phase	
	3 phase	
	6 phase	
82	In a mercury arc rectifier the cathode voltage drop is due to	B
	surface resistance	
	expenditure of energy in liberating electrons from the mercury	
	expenditure of energy in ionization	
	expenditure of energy in overcoming the electrostatic field	
83	In mercury arc rectifier, voltage drop at anode is due to	A
	energy spent in overcoming the electrostatic field	
	high temperature inside the rectifier	
	self-restoring property of mercury	
	high ionization potential	
84	The average life of the glass bulb rectifier is	C

	100 to 150 hours	
	1000 to 1500 hours	
	10,000 to 15,000 hours	
	100,000 to 150,000 hours.	
85	The vacuum inside the glass bulb of a mercury arc rectifier is of the order of	C
	5×10^{-3} cm of Hg	
	5×10^{-4} cm of Hg	
	5×10^{-5} cm of Hg	
	5×10^{-8} cm of Hg.	
86	For mercury arc rectifiers, the anode is usually made of	D
	Aluminium	
	Copper	
	Tungsten	
	Graphite.	
87	Essential requirement of the anode material in mercury arc rectifier is that	A
	it should not be wetted by mercury	
	it should be light	
	it should be cheap	
	it should be black in color	
88	The advantage of mercury arc rectifier is	D
	it is noiseless in operation	
	it responds quickly to varying load demands	
	it has high efficiency	
	all of the above	
89	A 3 anode mercury arc rectifier has an anode current of overlap 30° . Neglecting arc drop, the regulation will be approximately	C
	1%	
	2%	
	7%	
	17%	
90	As compared to mercury arc rectifiers, metal rectifiers	C
	can operate on high loads	
	can operate on high voltages	
	operate on low temperatures	
	give poor regulation	
91	The current carried by the cathode spot of the mercury arc rectifier is of the order of	C
	400 A/sq-cm	
	4000 A/sq-cm	
	40,000 A/sq-cm	
	40 A/sq-cm	

92	Which of the following is the loss within the mercury arc rectifier chamber?	D
	Voltage drop at the anode	
	Voltage drop at the cathode	
	Voltage drop in arc	
	All of the above	
93	The voltage drop at the cathode is of the order of	C
	0.1 to 0.5 V	
	1 to 1.5 V	
	7 to 9 V	
	70 to 90 V.	
94	The voltage drop in arc primarily depends on	A
	arc length	
	arc temperature	
	purity of mercury	
	all of the above	
95	As the output voltage of a single anode mercury arc rectifier increases, the variation of internal efficiency:	A
	Efficiency increases to a certain level and remains constant	
	Efficiency is always constant	
	Efficiency decreases	
	Efficiency is zero	
96	The voltage drop across the electrodes of a mercury pool rectifier	B
	varies exponentially with the load current	
	is almost independent of load current	
	is directly proportional to load	
	is inversely proportional to load	
97	In a mercury arc rectifier	D
	ion stream moves from cathode to anode	
	current flows from cathode to anode	
	electron stream moves from anode to cathode	
	ion stream moves from anode to cathode.	
98	In a mercury arc rectifier if cathode and anode connections are interchanged	D
	internal losses will be reduced	
	both ion and electron streams will move in the same direction	
	the rectifier will operate at reduced efficiency	
	the rectifier will not operate	
99	In mercury arc rectifier, mercury is used as	D

	conducting medium	
	ionization medium	
	electron accelerator	
	a cathode	
100	The mean value of half wave rectified sine wave is	D
	0.707 i_m	
	0.66 i_m	
	0.5 i_m	
	0.318 i_m .	
101	The form factor for half wave rectified sine wave is	D
	1.0	
	1.11	
	1.44	
	1.57	
102	Assume i_m =peak current value, then for full-wave rectified sine wave, rms current value is	B
	0.707 i_m	
	0.6036 i_m	
	0.5 i_m	
	0.318 i_m	
103	For full-wave rectified sine wave, mean value is	B
	0.70 i_m	
	0.636 i_m	
	0.5 i_m	
	0.318 i_m	
104	For full-wave rectified sine wave, form factor is	D
	1.5	
	1.41	
	1.28	
	1.11.	
105	A half-wave rectifier circuit with a capacitive filter is connected to 200 volts, 50 Hz ac line. The output voltage across the capacitor should be approximately.	B
	300 volts	
	280 volts	
	180 volts	
	80 volts	
106	The ripple factor of a full-wave rectifier circuit compared to that of a half wave rectifier circuit without filter is	B

	half of that for a half 'wave rectifier	
	less than half that for a half-wave rectifier circuit	
	equal to that of a half wave rectifier	
	none of the above	
107	A thyatron is a	C
	vacuum tube with four electrodes	
	gas-filled diode	
	gas-filled triode	
	none of the above.	
108	A thyristor equivalent of a thyatron tube is a	A
	Silicon controlled rectifier (SCR)	
	Triac	
	Diac	
	None of the above.	
109	A silicon controlled rectifier is a	B
	Unijunction device	
	Device with three junction	
	Device with four junctions	
	None of the above	
110	The RMS value of a half wave rectifier current is 10 A. Its value for full wave rectification would be	B
	10 A	
	14.14 A	
	$(20/\pi)$ A	
	20 A	
111	For single phase supply frequency of 50 Hz, ripple frequency in full wave rectifier is	C
	25	
	50	
	100	
	200	
112	The aim of introducing reactor in the ignition circuit of mercury arc rectifier is to limit	A
	the current in the circuit	
	wave ripple	
	voltage of the circuit	
	the rate of change of flux	
113	A mercury vapor discharge tube used for domestic lighting	C
	does not have a filament	
	has one filament	

	has two filaments	
	has two main and one auxiliary filament	
114	For a waveform more peaky than a sine wave, the form factor will be	A
	more than 1.11	
	less than 1.11	
	1.11	
	0	
115	Harmonics in 3 phase inverters can be reduced by using	C
	Passive filter	
	Active filter	
	Both passive and active filters	
	None of these	
116	The advantage of using free - wheeling diode in half controlled bridge converter is that	A
	There is always a path for the dc current independent of the ac line	
	There is always a path for the ac current independent of the ac line	
	There is always a path for the dc current dependent of the ac line	
	There is always a path for the ac current independent of the ac line	
117	The Graetz bridge makes excellent use of	C
	Current transformer	
	Potential transformer	
	Power transformer	
	SCR	
118	If the firing angle becomes negative, then the rectifier begins to work as	B
	A rectifier	
	An inverter	
	A chopper	
	A regulator	
119	In a 3 phase half wave rectifier, when firing angle is less than 90 degree, then the average dc output voltage becomes	A
	Positive	
	Negative	
	Zero	
	None of these	
120	In dual converters,	A
	Both rectifiers provides positive current to the load	
	Both rectifiers provide negative current to the load	
	One rectifiers provide positive current to the load and the other negative current	
	One rectifier provide positive current to the source and the other negative current to the	

121	Advantages of HVDC transmission over AC system is / are	D
	Reversal of power can be controlled by firing angle	
	Very good dynamic behavior	
	They can link two AC system operating unsynchronized	
	All of these	
122	For power output higher than 15 kW, the suitable rectifier is	D
	Single phase	
	3 phase	
	Poly phase	
	Only single phase and 3phase	
123	In a 3 phase bridge rectifier the ripple frequency is	D
	Equal to the input frequency	
	Twice the input frequency	
	Three times the input frequency	
	Six times the input frequency	
124	The sum of all phase current in a star connected primary winding with no neutral connection is equal to	D
	Phase current	
	Three times the phase current	
	Three times the line current	
	Zero at all times	
125	In a 3 phase VSI out of eight valid states, the number of valid states that produce zero ac line voltages is/are	B
	One	
	Two	
	Three	
	Four	

QUESTION BANK – ALL UNITS

Question No	Questions (Module I)	Bloom's Taxonomy Level	CO
1.	Identify and explain the types of electric drives.	Applying	1
2.	Identify and explain the types of industrial loads.	Applying	1
3.	Analyze the operation of a single-phase semi converter fed DC separately excited motor in continuous current mode with suitable waveforms.	Analyzing	1
4.	Analyze the operation of a single-phase full converter fed DC series motor in continuous current mode with suitable waveforms.	Analyzing	1
5.	Explain about choice of motor in electric drives.	Understanding	1
6.	Explain about temperature rise in electric drives.	Understanding	1
7.	A 200 V, 875 rpm, 150 A separately excited dc motor has an armature resistance of 0.06Ω . It is fed from a single phase fully-controlled rectifier with an ac source voltage of 220 V, 50 Hz. Assuming continuous conduction, Solve and obtain (iii) Firing angle for rated motor torque and 750 rpm. (iv) Firing angle for rated motor torque and (-500) rpm. Motor speed for firing angle $\alpha=160^\circ$ and rated torque.	Applying	1
8.	Solve and obtain the expression for armature voltage of a single-phase full converter fed DC separately excited motor in continuous current mode.	Applying	1
9.	Explain the concept of load equalization.	Understanding	1
10.	Explain the types of thyristor controlled drives.	Understanding	1

Question No	Questions (Module II)	Bloom's Taxonomy Level	CO
11.	Explain the operation of a three-phase semi converter fed DC separately excited motor.	Understanding	2

12.	Explain the operation of a three-phase full converter fed DC separately excited motor.	Understanding	2
13.	Solve and obtain the expression for armature voltage for three-phase full converter fed DC separately excited motor.	Applying	2
14.	Construct and explain the speed-torque characteristics of a three-phase full converter fed DC separately excited motor.	Applying	2
15.	Explain the operation of a three-phase semi converter fed DC series motor.	Understanding	2
16.	Explain the operation of a three-phase full converter fed DC series motor.	Understanding	2
17.	Solve and obtain the expression for armature voltage for three-phase semi converter fed DC separately excited motor.	Applying	2
18.	A 220V, 1500rpm, 50A separately excited motor with armature resistance of 0.5Ω , is fed from a 3-phase fully-controlled rectifier. Assume $V_m=230.4V$. Solve and obtain the value of firing angle when: (c) Motor is running at 1200 rpm and rated torque. (d) Motor is running at (-800) rpm and twice the rated torque. Assume continuous conduction.	Applying	2
19.	Compare the three-phase semi converter fed DC series motor with the three-phase semi converter fed DC separately excited motor.	Analyzing	2
20.	Compare the three-phase full converter fed DC series motor with the three-phase full converter fed DC separately excited motor.	Analyzing	2

Question No	Questions (Module III)	Bloom's Taxonomy Level	CO
21.	Explain the types of electric braking.	Understanding	3
22.	Explain about dual converter control of dc separately excited motor.	Understanding	3
23.	Analyze the motoring operation of DC drives.	Analyzing	3
24.	Analyze the braking operation of DC drives.	Analyzing	3
25.	Explain with a neat diagram, the concept of Plugging.	Understanding	3
26.	Explain with a neat diagram, the concept of Dynamic	Understanding	3

	Braking.		
27.	Explain with a neat diagram, the concept of Regenerative Braking.	Understanding	3
28.	Explain the concept of Chopper controlled DC motors.	Understanding	3
29.	Analyze the operation of chopper fed dc separately excited motor.	Analyzing	3
30.	Analyze the operation of chopper fed dc series motor.	Analyzing	3

Question No	Questions (Module IV)	Bloom's Taxonomy Level	CO
31.	Analyze the operation of AC Voltage Controllers used for control of Induction motor.	Analyzing	4
32.	Compare VSI and CSI operations.	Analyzing	4
33.	Explain the operation of cycloconverters.	Understanding	4
34.	Explain the concept of PWM control.	Understanding	4
35.	Compare various methods of control used in induction motor drives.	Analyzing	4
36.	Analyze the speed-torque characteristics of an induction motor controlled by an AC voltage controller.	Analyzing	4
37.	Explain about control of induction motor by AC voltage controller.	Understanding	4
38.	Explain about control of induction motor by Voltage Source Inverter.	Understanding	4
39.	Explain about control of induction motor by Current Source Inverter.	Understanding	4
40.	Explain the difference between control of induction motor through Stator voltage and Stator Frequency.	Understanding	4

Question No	Questions (Module V)	Bloom's Taxonomy Level	CO
41.	Illustrate with suitable figures the working of Static Scherbius drive.	Applying	5

SOLID STATE DRIVES

42.	Analyze the operation of self controlled synchronous motor by VSI.	Analyzing	5
43.	Explain the concept of static rotor resistance control.	Understanding	5
44.	Explain the concept of slip power recovery.	Understanding	5
45.	Analyze the operation of Static Kramer Drive.	Analyzing	5
46.	Compare Static Scherbius drive and Static Kramer Drive.	Analyzing	5
47.	Explain the advantages and applications of Static Scherbius drive.	Understanding	5
48.	Explain the advantages and applications of Static Kramer drive.	Understanding	5
49.	Explain about separate control of synchronous motors.	Understanding	5
50.	Explain about self control of synchronous motors.	Understanding	5

Code No.: 50226

MR15-2015-16 Batch

MALLA REDDY ENGINEERING COLLEGE (AUTONOMOUS)(Affiliated to JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY HYDERABAD)
Gundlupochampally (H), Maisammaguda (V), Medchal (M), Medchal-Malkajgiri (Dist), Hyderabad**IV B.TECH I SEMESTER REGULAR END EXAMINATIONS, NOVEMBER-2018**Subject: Solid State Drives

Branch: EEE

Time: 3 hours

Max. Marks: 60

PART – A

Answer ALL questions of the following

5x2Mark=10 Marks

1. What are the different types of AC-DC converters?
2. A three phase Full converter is connected to 400V, 50Hz AC supply is delivering 20A to dc motor, If the firing angle 30° . Compute power input to the motor?
3. What are the advantages of Freewheeling diode?
4. What is pulse width modulation technique?
5. How control the power factor of synchronous motor.

PART-B

Answer any FIVE Questions of the following

5x10 Marks= 50Marks

1. a) Derive and plot the speed torque equation for DC series motor.
b) Explain Steady state Stability.
2. Draw the relation between speed-torque of a three phase full wave converter feeding a separately excited D.C motor for continuous mode of operation and draw its speed-torque characteristics.
3. Draw the circuit diagram of 3-phase dual converter? Explain the Four Quadrant operation of DC motor by a dual converter in circulating current mode.
4. Explain the closed loop slip controlled PWM inverter with block diagram.
5. A three phase 400v,6 pole, 50 Hz,delta connected slip ring induction motor has rotor resistance of 0.2Ω /phase and leakage reactance of 1Ω /phase referred to stator when driving a fan load it runs at full load of 4% slip what resistance must be inserted in the rotor circuit to obtain a speed of 850 rpm neglect stator impedance and magnetizing branch stator to rotor turns ratio is 2.2.
6. a) Explain in detail the problems on rectifier fed DC motor drives with remedies.
b) A 220V, 1500rpm, 10A Separately Excited DC motor is fed from a single phase fully controlled rectifier with an AC source voltage of 230V, 50Hz, $R_a=2\Omega$. Conduction can be assumed to be continuous. Calculate firing angle for rated motor torque and 500rpm.
7. Explain the operation of three phase semiconverter connected with separately excited DC motor drive and their speed torque characteristics.
8. Write short notes on any two of the following
 - a) Explain the operation of two quadrant dc chopper drive for separately excited dc motor.
 - b) Advantages of electric drives.
 - c) Explain dynamic braking with neat diagram.

MALLA REDDY ENGINEERING COLLEGE (AUTONOMOUS)**SAMPLE MODEL QUESTION PAPER**

I/II/III/IV B.Tech I-Sem (MR 18, MR 17 AND MR 15 (2016-17 BATCH) & M.Tech/ MBA REGULAR EXAMINATION

Subject Name: Solid State Drives

Branch:EEE

Duration : 3 Hours

Max Marks:

Answer all questions

ALL Questions carries equal marks

Question No.	Questions	Bloom's Taxonomy Level	CO
1.	Explain about choice of motor in electric drives.	Understanding	1
	OR		
2.	Explain about temperature rise in electric drives.	Understanding	1
3.	Explain the operation of a three-phase semi converter fed DC series motor.	Understanding	2
	OR		
4.	Explain the operation of a three-phase semi converter fed DC separately excited motor.	Understanding	2
5.	Analyze the motoring operation of DC drives.	Analyzing	3
	OR		
6.	Analyze the braking operation of DC drives.	Analyzing	3
7.	Analyze the operation of AC Voltage Controllers used for control of Induction motor.	Analyzing	4
	OR		
8.	Compare VSI and CSI operations.	Analyzing	4
9.	Illustrate with suitable figures the working of Static Scherbius drive.	Applying	5
	OR		
10.	Analyze the operation of self controlled synchronous motor by VSI.	Analyzing	5

CASE STUDY

Due to their generally prohibitive cost versus HDD's at the time, until 2009, SSDs were mainly used in those aspects of mission critical applications where the speed of the storage system needed to be as high as possible. Since flash memory has become a common component of SSDs, the falling prices and increased densities have made it more cost-effective for many other applications. For instance, in the distributed computing environment, SSDs can be used as the building block for a distributed cache layer that temporarily absorbs the large volume of user requests to the slower HDD based backend storage system. This layer provides much higher bandwidth and lower latency than the storage system, and can be managed in a number of forms, such as distributed key-value database and distributed file system. On the supercomputers, this layer is typically referred to as burst buffer. With this fast layer, users often experience shorter system response time. Organizations that can benefit from faster access of system data include equity trading companies, telecommunication corporations, and streaming media and video editing firms. The list of applications which could benefit from faster storage is vast.

Flash-based solid-state drives can be used to create network appliances from general-purpose personal computer hardware. A write protected flash drive containing the operating system and application software can substitute for larger, less reliable disk drives or CD-ROMs. Appliances built this way can provide an inexpensive alternative to expensive router and firewall hardware.

SSDs based on an SD card with a live SD operating system are easily write-locked. Combined with a cloud computing environment or other writable medium, to maintain persistence, an OS booted from a write-locked SD card is robust, rugged, reliable, and impervious to permanent corruption. If the running OS degrades, simply turning the machine off and then on returns it back to its initial uncorrupted state and thus is particularly solid. The SD card installed OS does not require removal of corrupted components since it was write-locked though any written media may need to be restored.

Hard drives caching

In 2011, Intel introduced a caching mechanism for their Z68 chipset (and mobile derivatives) called Smart Response Technology, which allows a SATA SSD to be used as a cache (configurable as write-through or write-back) for a conventional, magnetic hard disk drive. A similar technology is available on HighPoint's Rocket Hybrid PCIe card.

Solid-state hybrid drives (SSHDs) are based on the same principle, but integrate some amount of flash memory on board of a conventional drive instead of using a separate SSD. The flash layer in these drives can be accessed independently from the magnetic storage by the host using ATA-8 commands, allowing the operating system to manage it. For example, Microsoft's Ready Drive technology explicitly stores portions of the hibernation file in the cache of these drives when the system hibernates, making the subsequent resume faster.

Dual-drive hybrid systems are combining the usage of separate SSD and HDD devices installed in the same computer, with overall performance optimization managed by the computer user, or by the computer's operating system software. Examples of this type of system are bcache and dm-cache on Linux, and Apple's Fusion Drive.