ELECTRIC DRIVES

(NEE-701)

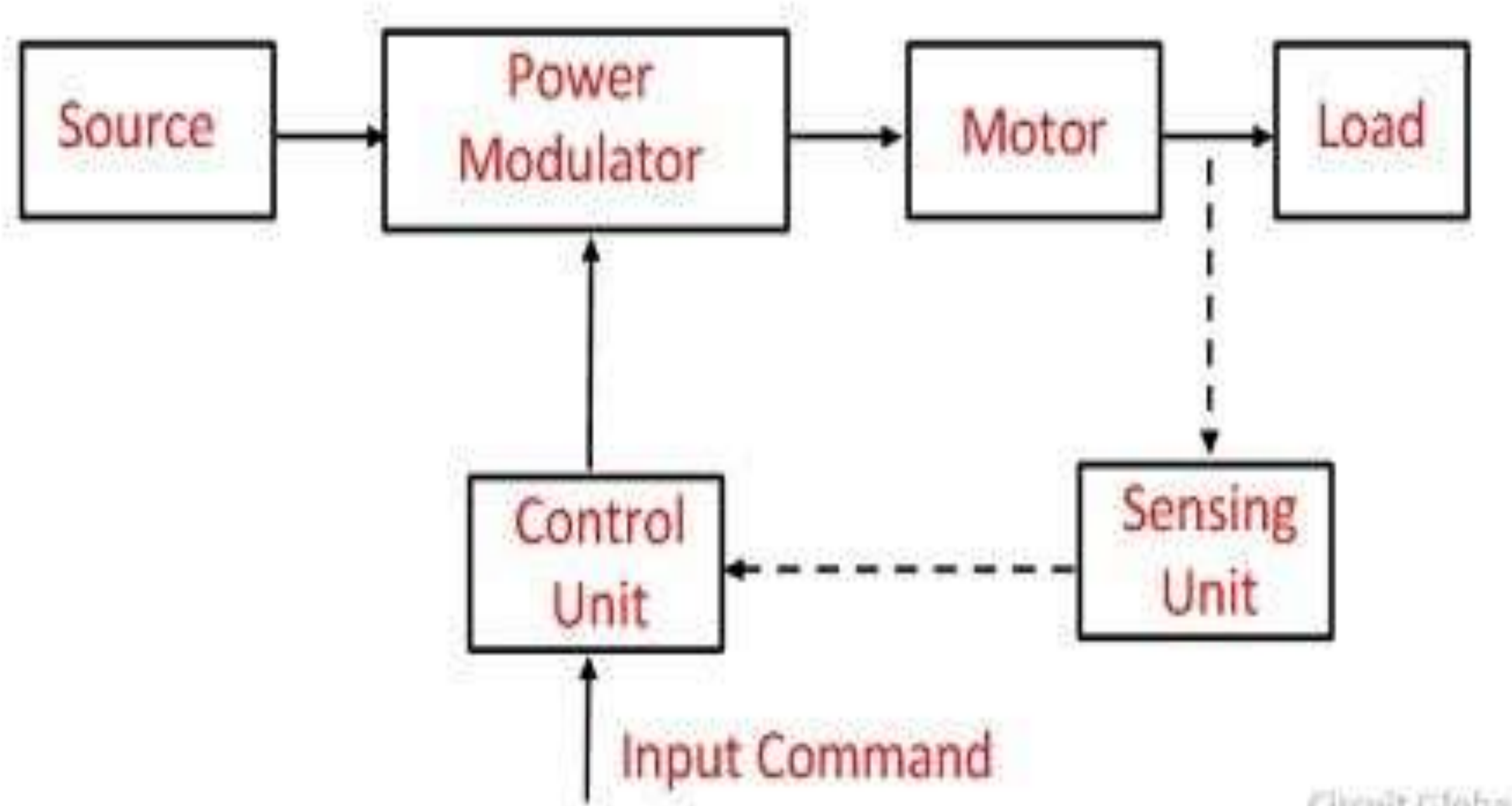
Electric Drives

- Systems employed for motion control are called as **Drives**.

- It 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 called as **Electrical Drives**.

Parts Of Electric Drives



Description of Parts of Electric Drives

Power Modulator :

- The power modulator regulates the output power of the source.

- It controls the power from the source to the motor in such a manner that motor transmits the speed torque characteristic required by the load.

POWER MODULATOR(Cont'd)

- During the transient operations like starting, braking and speed reversing the excessive current drawn from the source.

This excessive current drawn from the source may overload it or may cause a voltage drop. Hence the power modulator restricts the source and motor current.

POWERMODULATOR(Cont'd)

- The power modulator converts the energy according to the requirement of the motor
- e.g. if the source is DC and an induction motor is used then power modulator convert DC into AC.
- It also selects the mode of operation of the motor, i.e., motoring or braking.

CONTROL UNIT

Control Unit :

- The control unit controls the power modulator which operates at small voltage and power levels. The control unit also operates the power modulator as desired.

- It also generates the commands for the protection of power modulator and motor. An input command signal which adjusts the operating point of the drive, from an input to the control unit.

SENSING UNIT

Sensing Unit :

- It senses the certain drive parameter like motor current and speed.

- It mainly required either for protection or for closed loop operation.

ADVANTAGE OF ELECTRIC DRIVES

Advantages of Electrical Drive:

- The electrical drives are available in a wide range of torque, speed and power.

- They are adaptable to almost any operating conditions such as explosive and radioactive environment, submerged in liquids, vertical mounting and so on.

- The electrical drive does not pollute the environment.

ADVANTAGE OF ELECTRIC DRIVES(Cont'd)

- It can operate in all four quadrants of speed torque plane.

- They can be started instantly and can immediately be fully loaded. i.e., there is no need to refuel or warm up the motor.

- They have flexible control characteristic and can be employed to automatically control the drive.

ADVANTAGE OF ELECTRIC DRIVES(Cont'd)

- They have flexible control characteristic and can be employed to automatically control the drive.

- Because of the following advantages, the mechanical energy already available from a non-electrical prime mover is sometimes first converted into electrical energy by a generator and back to a mechanical energy of an electrical motor.

- Electrical link thus provides between the non-electrical prime mover and the load impact to the drive flexible control characteristic.

Disadvantage Of Electric Drives

Disadvantages of Electrical Drive:

- The power failure completely disabled the whole of the system.
- The application of the drive is limited because it cannot use in a place where the power supply is not available.
- It can cause noise pollution.
- The initial cost of the system is high.

CLASSIFICATION OF ELECTRIC DRIVES

Classification of Electric Drive:

Generally classified into 3 categories:

- Group drive
- Individual Drive
- Multimotor Drive

Group Drive :

- If several group of mechanisms or machines are organized on one shaft and driven or actuated by one motor, the system is called a group drive or shaft drive.

CLASSIFICATION OF ELECTRIC DRIVES(Cont'd)

Advantage :

Most Economical

Disadvantage :

- Any Fault that occurs in the driving motor renders all the driving equipment idle.
- Efficiency low because of losses occurring in the energy transmitting mechanisms (Power loss).
- Not safe to operate.Also Noise level at the working spot is high.

CLASSIFICATION OF ELECTRIC DRIVES(Cont'd)

Individual Drive:

- If a single motor is used to drive or actuate a given mechanism and it does all the jobs connected with this load , the drive is called individual drive.

- All the operations connected with operating a lathe may be performed by a single motor.

- Each motor is driven by its own separated motor with the help of gears , pulleys etc.

CLASSIFICATION OF ELECTRIC DRIVES(Cont'd)

Disadvantage:

- Power loss occurs.

Multi Motor Drive:

- Each operation of the mechanism is taken care of by a separate drive motor.

- The System contains several individual drives each of which is used to operate its own mechanism.

CLASSIFICATION OF ELECTRIC DRIVES

Separate motors are provided for actuating different parts of the driven mechanism.

Advantage :

- Each Machine is driven by a separated motor it can be run and stopped as desired.
- Machines not required can be shut down and also replaced with a minimum of dislocation.
- There is a flexibility in the installation of different machines.

CLASSIFICATION OF ELECTRIC DRIVES(Cont'd)

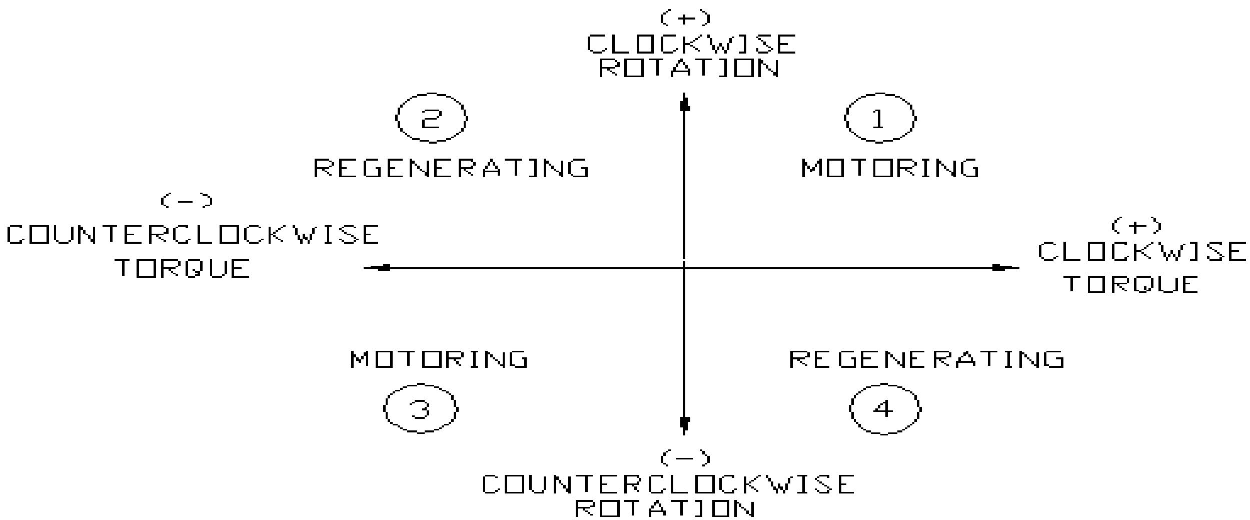
- In the case of motor fault, only its connected machine will stop where as others will continue working undisturbed.

- Absence of belts and line shafts greatly reduces the risk of a accidents to the operating personnel.

Disadvantage:

- Initial high cost

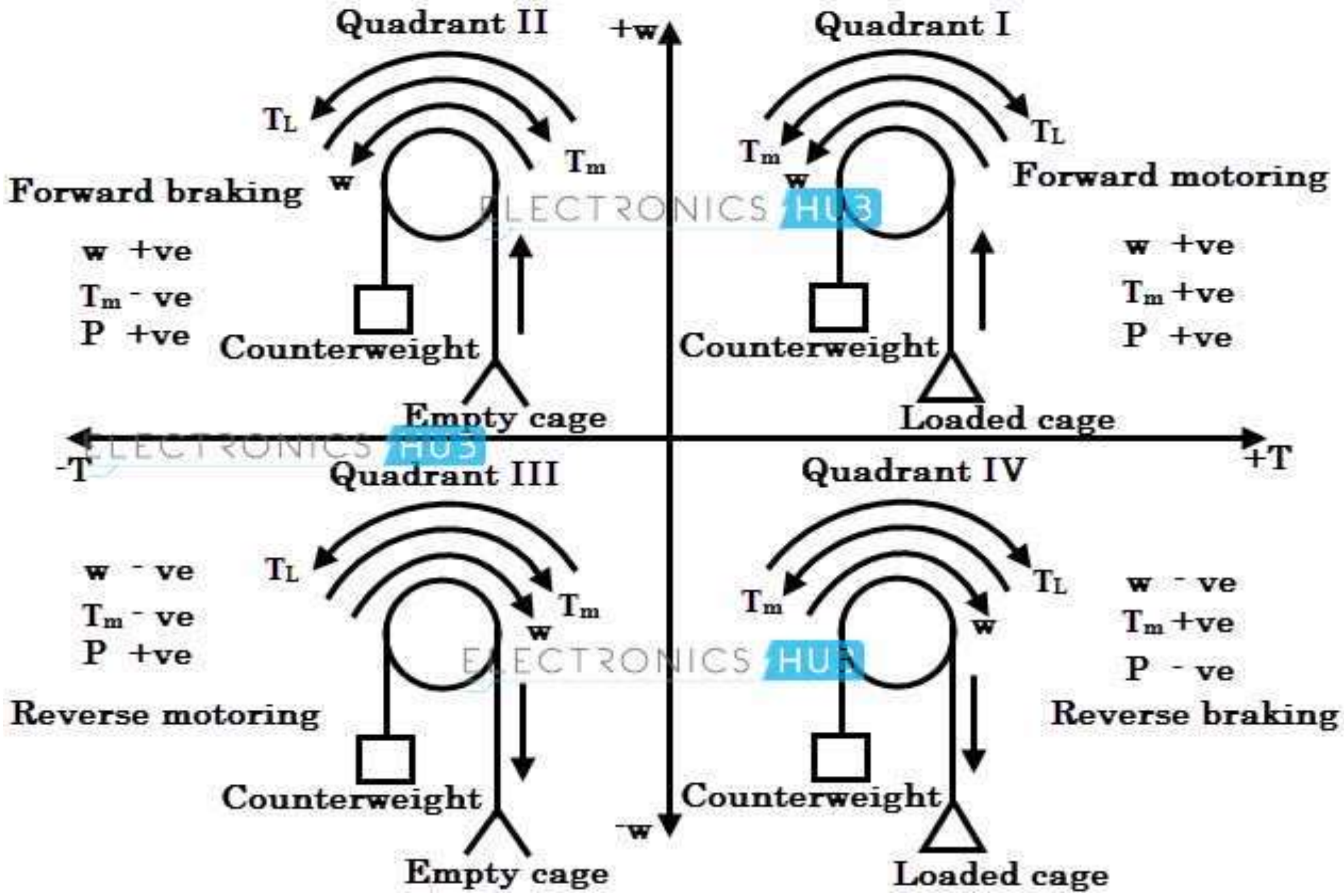
TORQUE-SPEED SIGN CONVENTON



QUADRANT	ROTATION	TORQUE	MOTORING OR REGENERATING
1	(+)	(+)	MOTORING
2	(+)	(–)	REGENERATING
3	(–)	(–)	MOTORING
4	(–)	(+)	REGENERATING

FIGURE D.4 FOUR QUADRANT OPERATION

FOUR QUADRANT OPERATION



FOUR QUADRANT OPERATION

- Motor is driving a hoist consisting of a cage with or without load, a rope wound on to a drum to hoist the cage and a balance weight of magnitude greater than that of the empty cage but less than that of the loaded cage.

- The arrow in the figure indicates the actual directions of the motor torque, load torque and motion in four quadrants.

- The load torque of the hoisting mechanism is of active type and assumed to be constant due to negligible friction and windage for low speed hoist.

FOUR QUADRANT OPERATION(Cont'd)

- Speed torque curve of the hoist is represented by vertical line passing through two quadrants. Loaded hoist characteristics in first and fourth and unloaded in second and third quadrants

- In the first quadrant the load torque acts in the opposite direction to that of rotation. Hence to drive the loaded hoist up, the motor developed torque must be in the direction of the rotation or must be positive.

- The power will also be positive so, this quadrant is known as **'forward motoring quadrant'.**

FOUR QUADRANT OPERATION(Cont'd)

- The hoisting up of the unloaded cage is represented in the second quadrant. As the counterweight is heavier than the empty cage, the speed at which hoist moves upwards may reach a very high value.

- To avoid this, the motor torque must act in the opposite direction of rotation or motor torque must be negative.

- The power will be negative though the speed is positive, so this quadrant is known as **'forward braking quadrant'**.

FOUR QUADRANT OPERATION(Cont’d)

- The third quadrant represents the downward motion of the empty cage. Downward journey will be opposed by torque due to counterweight and friction at the transmitting parts, move cage downwards the motor torque should must be in the direction of the rotation.

- Electric machine acts as a motor but in the reverse direction compared to first quadrant.

- The torque is negative as speed is increased in the negative direction, but the power is positive, this quadrant is known as **‘Reverse motoring quadrant’**.

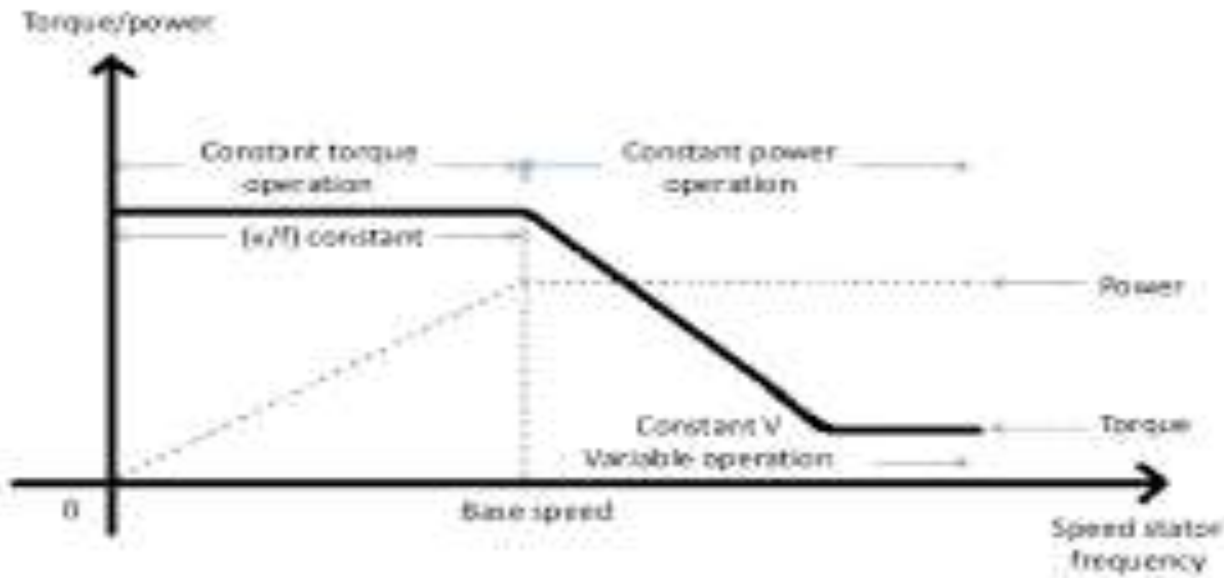
FOUR QUADRANT OPERATION (Cont'd)

- Fourth quadrant has the downward motion of the loaded cage.

- As loaded cage has more weight than the balanced weight to limit the speed of the motion, motor torque must have opposite polarity with respect to rotation and acts as a brake.

- The motor torque sign is positive, but as speed has negative direction; the power will be negative, this quadrant is designated as 'Reverse braking quadrant.

CONSTANT TORQUE AND CONSTANT POWER OPERATION



Torque–speed characteristics

CLASSIFICATION OF LOAD TORQUE

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.

CLASSIFICATION OF LOAD TORQUE(Cont’d)

- Eg: Torque due to force of gravity
- Torque due tension.
- 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 TORQUE

- The load torque TL can be further divided in to following components:
- (i) 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.

COMPONENTS OF LOAD TORQUE(Cont'd)

- **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.

COMPONENTS OF LOAD TORQUE(Cont'd)

- 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 ofoperation.

- **Friction torque can also be resolved into three component:**

COMPONENTS OF LOAD TORQUE(Cont'd)

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

$$v\ m\ T = B\omega$$

Where B is viscous friction co-efficient.

- Another component TC, which is independent of speed, is known as COULOMB friction.

COMPONENTS OF LOAD TORQUE(Cont'd)

- Third component Ts accounts for additional torque present at stand still. Since Ts is present only at stand still it is not taken into account in the dynamic analysis.

Windage torque:

- TW which is proportional to speed squared is given by

NATURE OF LOAD TORQUE

- The nature of load torque depends upon particular application.
- A low speed hoist is an example of load when the torque is constant and independent of speed.
- At low speeds ,windage torque is negligible therefore net torque is mainly due to gravity which is constant and independent of speed.

NATURE OF LOAD TORQUE

- There are drives where coulomb friction dominates over other torque components.

  conesquently torque is independent of speed.

- Example : Paper mill drive.
- Fans , Compressors,Aeroplanes ,Centrifugal pumps ,ship propellors,High speed hoists,traction are the example of the case where load torque is a function of speed.

UNIT-2

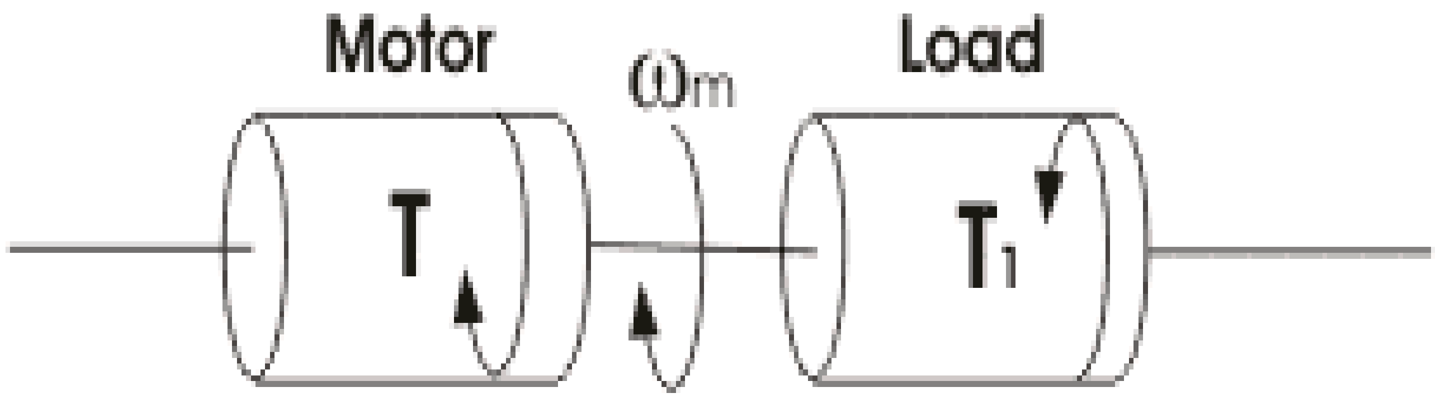
Dynamics of Electric Drive

Dynamics of motor-load combination Drive

- When an electric motor rotates, it is usually connected to a load which has a rotational or translational motion.

- The speed of the motor may be different from that of the load. To analyze the relation among the drives and loads, the concept of **dynamics of electrical drives** is introduced.

Dynamics of motor-load combination Drive



Motor Load System

Dynamics of motor-load combination Drive

- We can describe the dynamics of electrical drive easily by the following instant.
-

J = Polar moment of inertia of motor load
W_m = Instantaneous angular velocity
T = Instantaneous value of developed motor torque
T_1 = Instantaneous value of load torque referred to motor shaft

Dynamics of motor-load combination Drive

- Now, from the fundamental torque equation –

$$T - T1 = d/dt(jwm) = Jdwm/dt + wmdJ/dt$$

For drives with constant inertia,

$$dJ/dt = 0$$

Therefore

$$T = T1 + Jdwm/dt$$

Dynamics of motor-load combination Drive

- So, the above equation states that the motor torque is balanced by load torque and a dynamic torque $J(d\omega_m/dt)$.
- This torque component is termed as dynamic torque as it is only present during the transient operations.
- From this equation, we can determine whether the drive is accelerating or decelerating.

Dynamics of motor-load combination Drive

- Such as during accelerating motor supplies load torque and additional torque component essentially.

- So, the torque, balancing the **Dynamics of electrical braking** is very helpful.

Steady and Transient state stability of Electric Drive

- The drive is said to be in equilibrium if the torque developed by the motor is exactly equal to the load torque

- If the drive comes out of the state of equilibrium due to some disturbance, it comes back to steady state for stable equilibrium but for unstable equilibrium the speed of the drive increases uncontrollably or decreases to zero.

Steady and Transient stability of Electric Drive

- When the drive coming out of the state of equilibrium preserves it steady state at different speed (lying in small range), it is said to be in neutral range.

- The stability of the motor load combination is defined as the capacity of the system which enables it to develop forces of such a nature as to restore equilibrium after any small departure.

Steady and Transient state stability of Electric Drive

- Changes from the state of equilibrium takes place slowly and the effect of either the inertia or the inductance is insignificant – **Steady state stability.**

  Sudden and fast changes from the equilibrium state so effect of both inertia and inductance can not be neglected- **Dynamic or transient stability.**

Steady and Transient state stability of Electric Drive

- **Criteria for steady state stability:-**
- Let the equilibrium of the torques and speed is TM ,TL and ω the small deviations are ΔTM,ΔTL and Δω After the displacement from equilibrium state the torque equation becomes

Steady and Transient state stability of Electric Drive

$$J\frac{d\omega}{dt}+J\frac{d\left(\Delta\omega\right)}{dt}+T_L+\Delta T_L-T_M-\Delta T_M=0$$

$$\text{but, }\; J\frac{d\omega}{dt}+T_L-T_M=0,\;\; \text{so}$$

$$J\frac{d\left(\Delta\omega\right)}{dt}+\Delta T_L-\Delta T_M=0$$

Steady and Transient state stability of Electric Drive

- Considering the small deviation, changes can be expressed as a linear function of change in speed.

- From the torque equation, where all quantities are expressed in terms of their deviations from the equilibrium,

Steady and Transient state stability of Electric Drive

$$\Delta T_M = \frac{dT_M}{d\omega}\Delta\omega, \qquad \Delta T_L = \frac{dT_L}{d\omega}\Delta\omega$$

Steady and Transient state stability of Electric Drive

$$J\frac{d(\Delta\omega)}{dt}+\left[\frac{dT_L}{d\omega}-\frac{dT_M}{d\omega}\right]\Delta\omega=0$$

Steady and Transient state stability of Electric Drive

$$\Delta\omega = (\Delta\omega)_0 \, e^{-1/J\left[\frac{dT_L}{d\omega} - \frac{dT_M}{d\omega}\right]t}$$

Steady and Transient state stability of Electric Drive

$$\Delta\omega = (\Delta\omega)_0 \, e^{-1/J\left[\frac{dT_L}{d\omega} - \frac{dT_M}{d\omega}\right]t}$$

Steady and Transient state stability of Electric Drive

Where,$(\Delta\omega)_0$ is the initial value of the deviation in speed. For the stable system the exponent must be negative, so speed increment will disappear with time. The exponent will always be negative if,

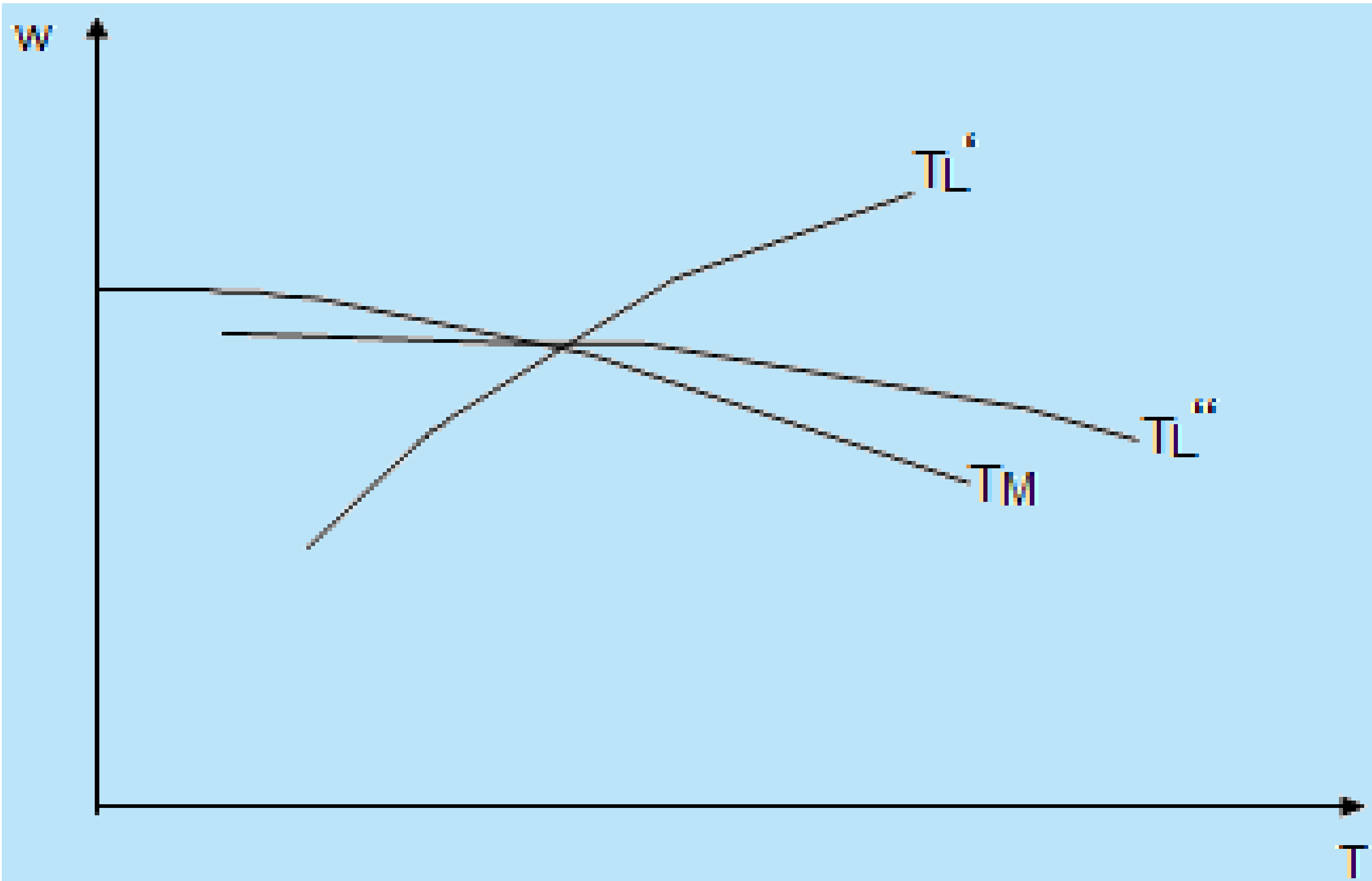
Steady and Transient state stability of Electric Drive

$$\frac{dT_L}{d\omega} - \frac{dT_M}{d\omega} > 0$$

Steady and Transient state stability of Electric Drive

- Criteria for the steady state stability is for a decrease in the speed the motor torque must exceeds the load torque and for increase in speed the motor torque must be less than the load torque.
- Load torque TL results in a stable equilibrium point, and the load torque TL” results in an unstable situation.

Steady and Trasient state stability of Electric Drive



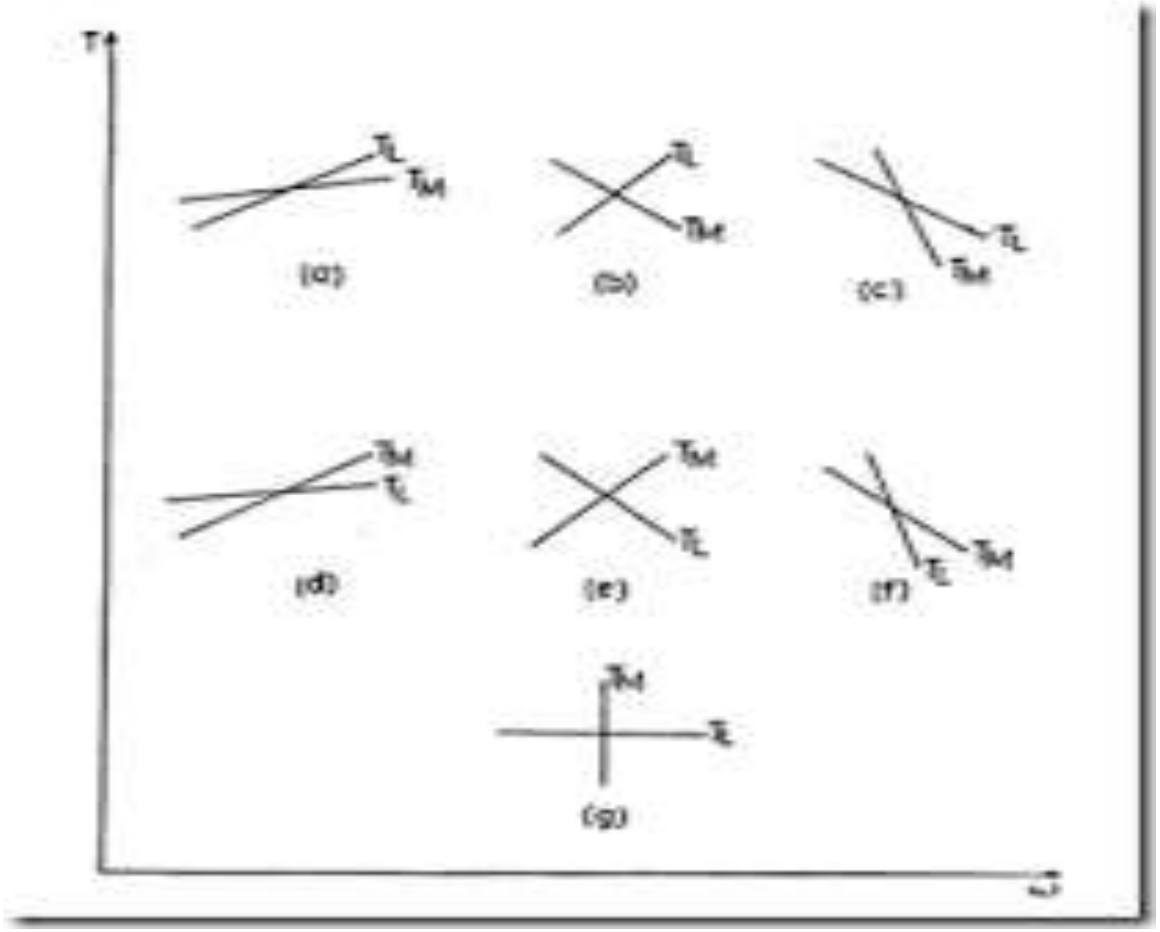
Steady and Transient state stability of Electric Drive

To check the stability at an operating point of the motor, if an increase in speed brings greater

increase in load torque than the motor torque, the speed will tend to decrease and return to its

original value, so operating point will be a stable point else operating point will be an unstable point.

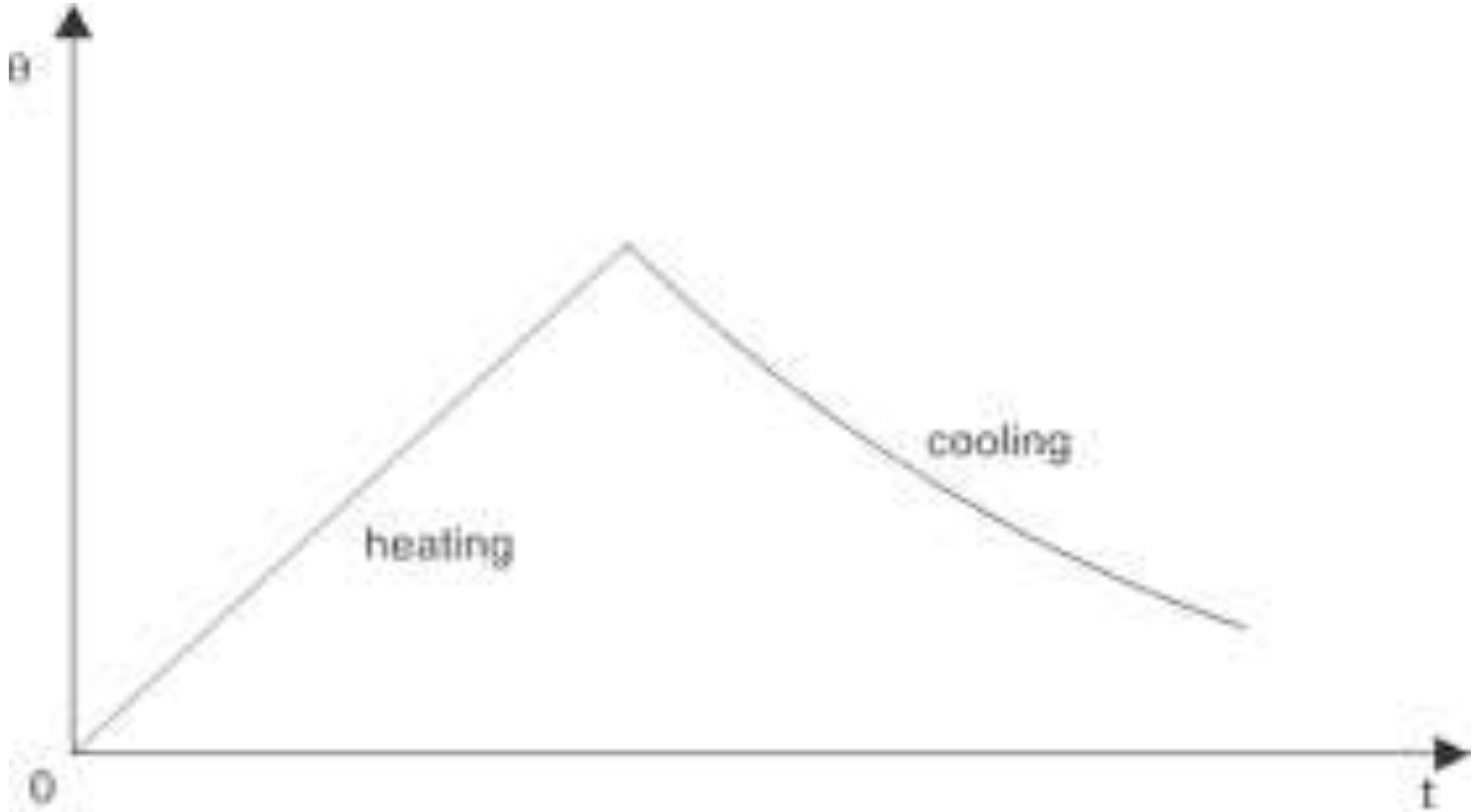
Steady and Transient state stability of Electric Drive



ELECTRIC DRIVE

Selection of Motor Power rating

Thermal model of motor for heating and cooling

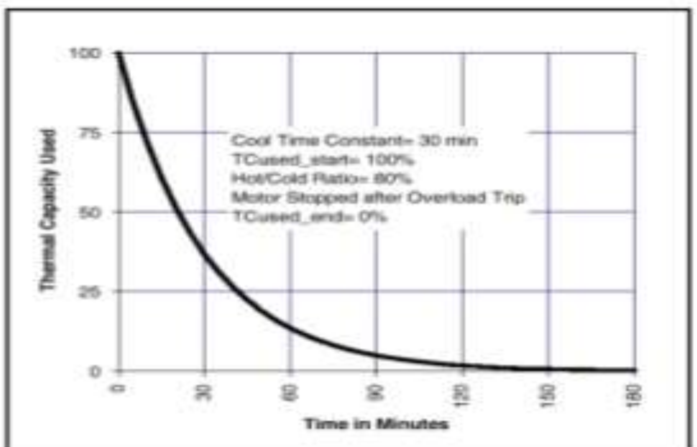


Heating and Cooling curves

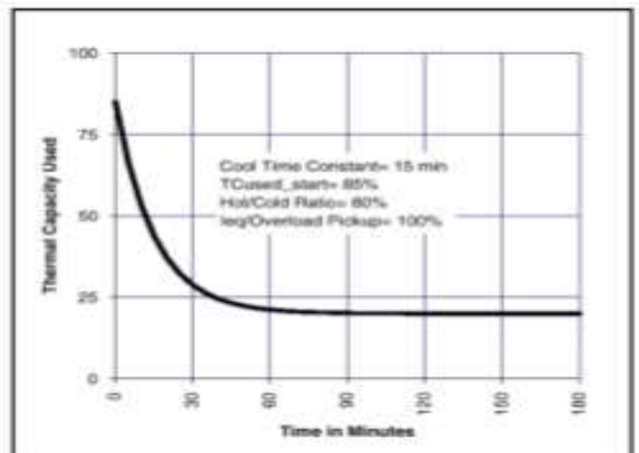
Thermal Model - Motor Cooling

- Motor cooling is characterized by separate cooling time constants (CTC) for running and stopped motor states. Typical ratio of the stopped to running CTC is 2/1
- It takes the motor typically 5 time constants to cool.

Thermal Model Cooling Motor Tripped



Thermal Model Cooling100% load - Running



Thermal model of motor for heating and cooling

- An electrical motor and drive operates, there is a generation of heat inside the motor. The amount of heat generated inside the motor should be known as accurately as possible. That's why **thermal modeling of motor** is necessary.

- The material of the motors and the shapes and size of the motors are not unique but the generation of heat does not alter very much depending on these characteristics.

Thermal model of motor for heating and cooling

- So, a **simple thermal model** of any motor can be obtained assuming it to be a homogeneous body.

- The main aim of this modeling is to choose the appropriate rating of a motor so that the electric motor does not exceed its safe limit during operation.

Thermal model of motor for heating and cooling

- At time ‘t’, let the motor has following parameters

  p_1 = Heat developed, Joules/sec or watts.

- p_2 = Heat dissipated to the cooling medium

- , watts

- W = Weight of the active parts of the machine.

Thermal model of motor for heating and cooling

- h = Specific heat, Joules per Kg per ^oC.

  A=Cooling Surface, m^2

  d = Co-efficient of heat transfer,

  Joules/Sec/m^2/^oC

  θ = Mean temperature rise ^oC

Thermal model of motor for heating and cooling

- Now, if time dt, let the temperature rise of the machine be $d\theta$

- Therefore, heat absorbed in the machine = (Heat generated inside the machine – Heat dissipated to the surrounding cooling medicine)
- Where, $d\theta = p_1 dt - p_2 dt$................(i)

Thermal model of motor for heating and cooling

- Since, $p_2 = \theta dA$................(ii)
- Substituting (ii) in (i), we get,

$$C d\theta/dt = P1 - D\theta$$

Here, C is called the thermal capacity of the machine in watts/^{o}C and D is the heat dissipation constant in watts/^{o}C.

Thermal model of motor for heating and cooling

- When we acquire the first order differential equation of the equation –

$C d\theta/dt = P1 - D\theta$ we get,

$\theta = \theta ss + K e^{-t/\tau}$

where $\theta ss = p1/D$ and $T = C/D$

Thermal model of motor for heating and cooling

- We obtain the value of K by putting $t = 0$ in
- equation (iii) and get the solution as

$$\theta=\theta ss(1-Ke\hat{}-t/\tau +\theta 1e\hat{}-t/\tau)$$

Thermal model of motor for heating and cooling

- So, from the above equation we can find out the rise in temperature inside a working machine, which is very near to being accurate and if we plot a graph for the variation of temperature risk with time during heating and cooling and thus the **thermal modeling of a motor** gets completed.

Thermal model of motor for heating and cooling

- electric motors are used, and to control themelectrical drives are employed. But the operating time for all motors are not the same.
- Some of the motors runs all the time, and some of the motor's run time is shorter than the rest period.
- Depending on this, concept of **motor duty class** is introduced and on the basis of this duty cycles of the motor can be divided in eight categories such as

Classes of motor duty.

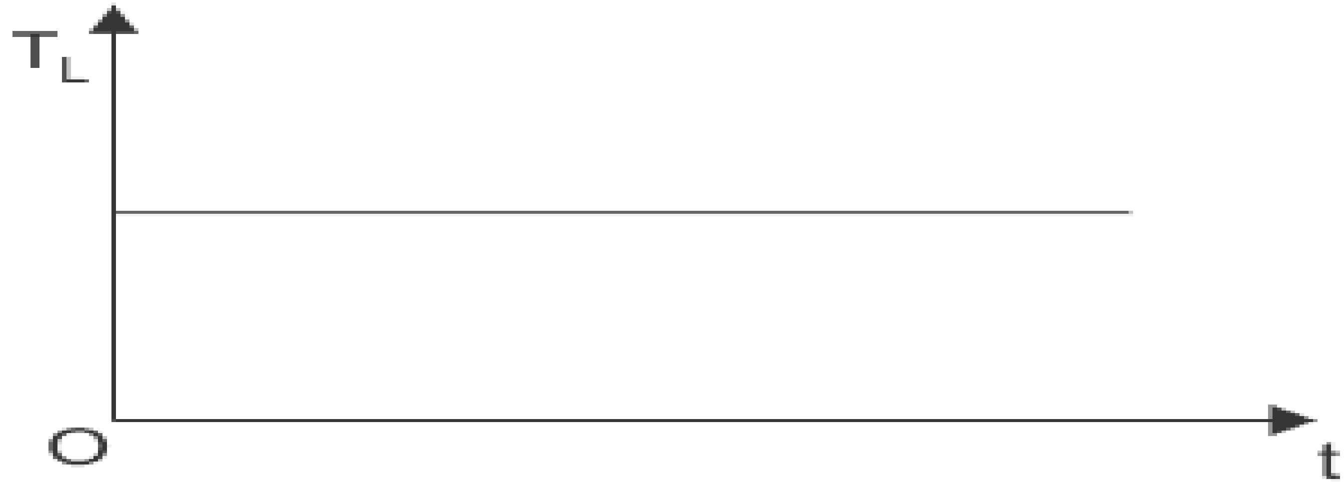
- Continuous duty
- Short time duty
- Intermittent periodic duty
- Intermittent periodic duty with starting
- Intermittent periodic duty with starting and braking
- Continuous duty with intermittent periodic loading
- Continuous duty with starting and braking
- Continuous duty with periodic speed changes
- **Continuous Duty**

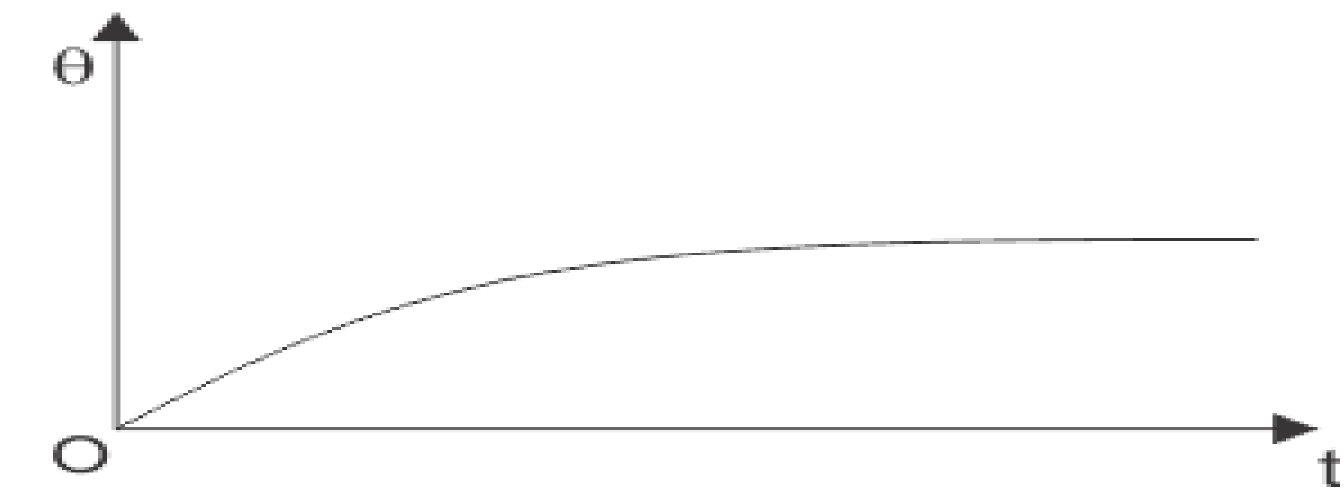
Classes of motor duty.

- **Continuous Duty**
- This duty denotes that, the motor is running long enoug and the electric motor temperature reaches the steady state value.

- These motors are used in paper mill drives, compressors, conveyors etc.

Classes of motor duty.





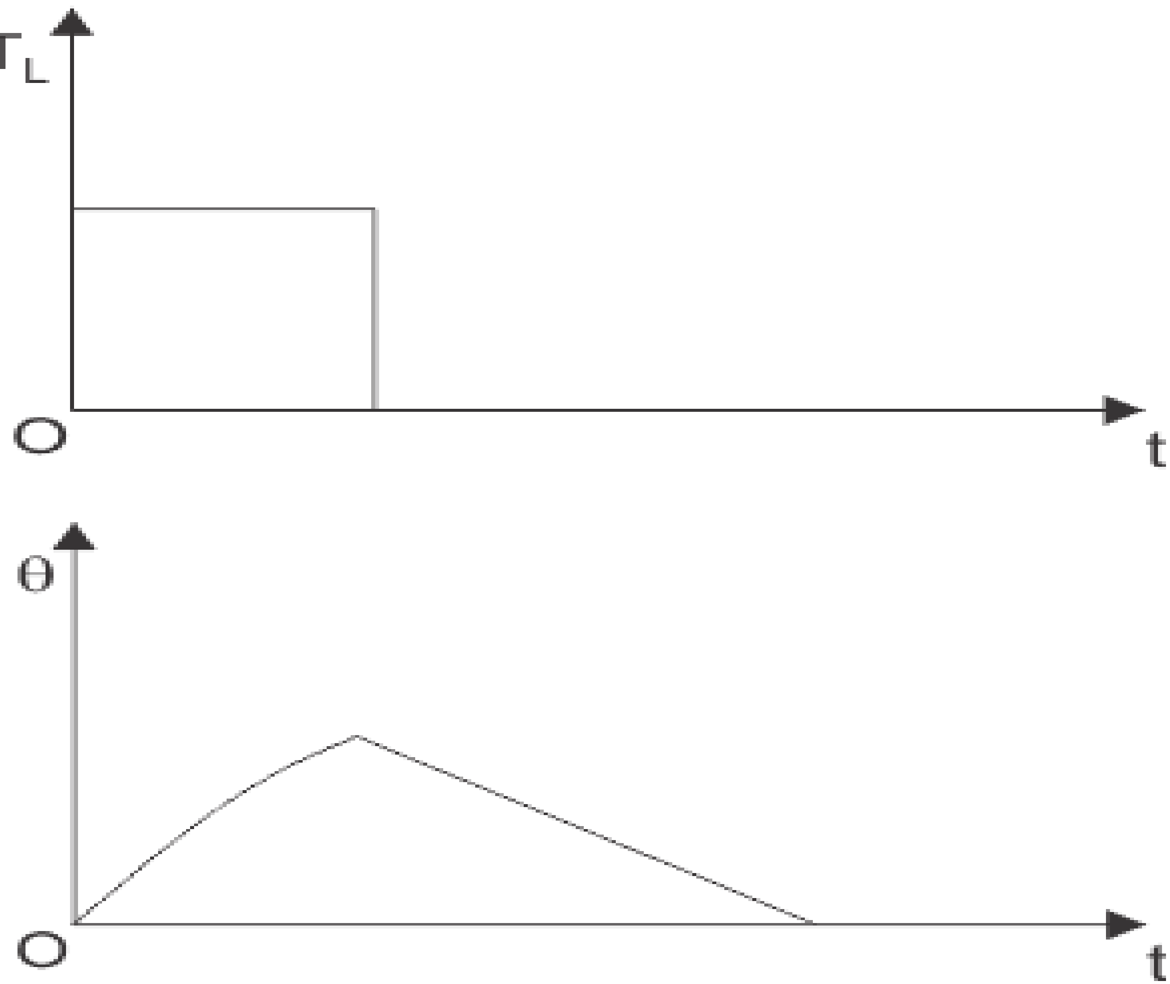
Classes of motor duty.

- **Short Time Duty:**

In these motors, the time of operation is very low and the heating time is much lower than the cooling time.

So, the motor cooks off to ambient temperature before operating again. These motors are used in crane drives, drives for house hold appliances, valve drives etc.

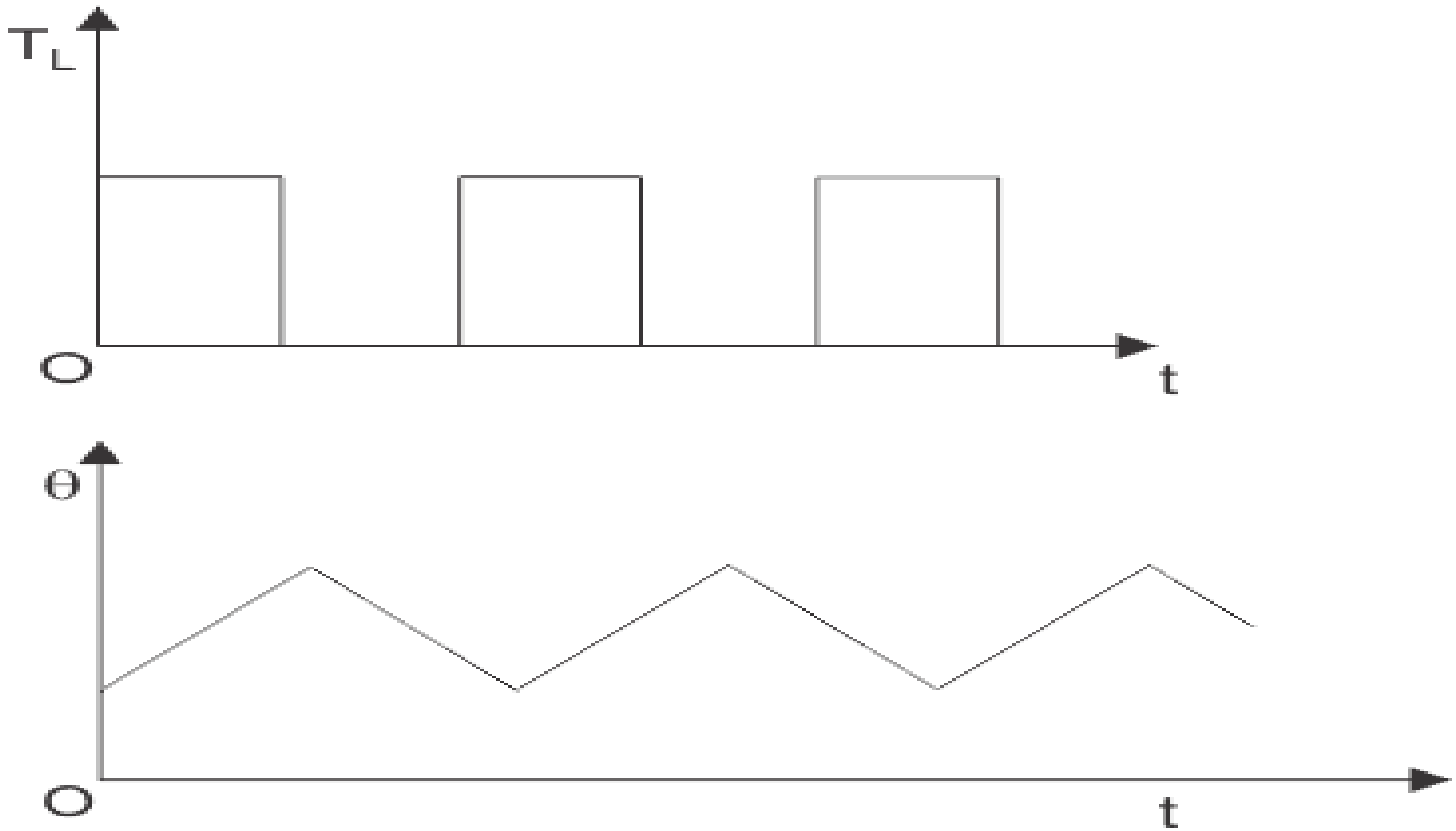
Classes of motor duty.



Classes of motor duty.

- **Intermittent Periodic Duty**
  Here the motor operates for some time and then there is rest period.
- In both cases, the time is insufficient to raise the temperature to steady state value or cool it off to ambient temperature.
- This is seen at press and drilling machine drives.

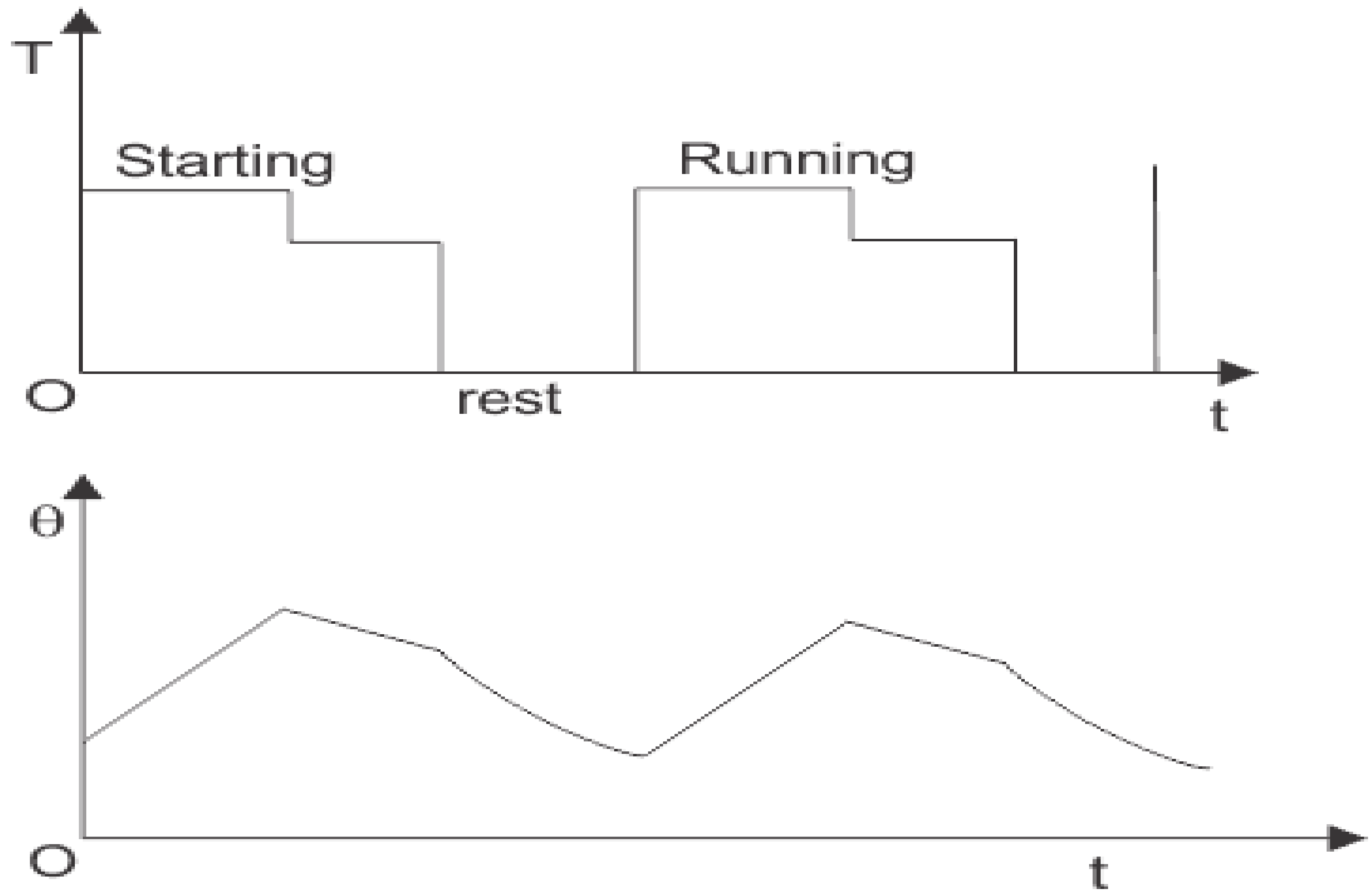
Classes of motor duty.



Classes of motor duty.

- **Intermittent Period Duty with Starting**
  In this type of duty, there is a period of starting, which cannot be ignored and there is a heat loss at that time.
- After that there is running period and rest period which are not adequate to attain the steady state temperatures.
- This motor duty class is widely used in metal cutting and drilling tool drives, mine hoist etc

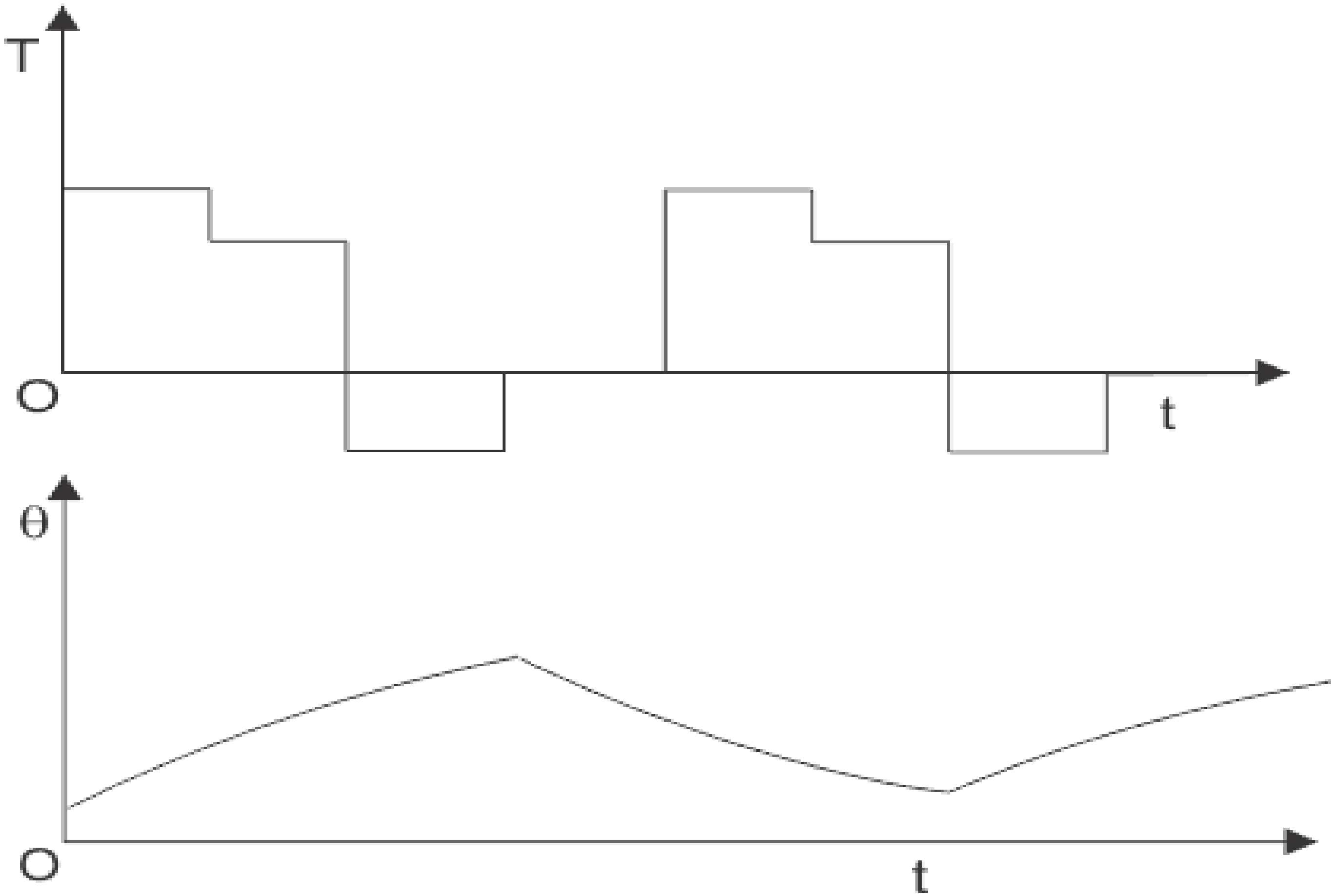
Classes of motor duty.



Classes of motor duty.

- **Intermittent Periodic Duty with Starting and Braking**
  In this type of drives, heat loss during starting and braking cannot be ignored.
- So, the corresponding periods are starting period, operating period, braking period and resting period.

Classes of motor duty.



Classes of motor duty.

- **Continuous Duty with Intermittent Periodic Loading**
  In this type of motor duty, everything is same as the periodic duty but here a no load running period occurs instead of the rest period.

- Pressing, cutting are the examples of this system.

Classes of motor duty.

- **Continuous Duty with Starting and Braking:** It is also a period of starting, running and braking and there is no resting period. The main drive of a blooming mill is an example.
- **Continuous Duty with Periodic Speed Changes:** In this type of motor duty, there are different running periods at different loads and speeds. But there is no rest period and all the periods are too short to attain the steady state temperatures.

Load equalization.

- Load equalisation is the process of smoothing the fluctuating load. The fluctuate load draws heavy current from the supply during the peak interval and also cause a large voltage drop in the system due to which the equipment may get damage.

  In load equalisation, the energy is stored at light load, and this energy is utilised when the peak load occurs. Thus, the electrical power from the supply remains constant.

Load equalization

- The load fluctuation mostly occurs in some of the drives. For example, in a pressing machine, a large torque is required for a short duration.

- Otherwise, the torque is zero. Some of the other examples are a rolling mill, reciprocating pump, planning machines, electrical hammer, etc.

Load equalization

- In electrical drives, the load fluctuation occurs in the wide range. For supplying the peak torque demand to electrical drives the motor should have high ratings, and also the motor will draw pulse current from the supply.

- The amplitude of pulse current gives rise to a line voltage fluctuation which affected the other load connected to the line.

Load equalization

- The problem of load fluctuation can be overcome by using the flywheel.The flying wheel is mounted on a motor shaft in non-reversible drives.

- In variable speed and reversible drive, a flywheel cannot be mounted on the motor shaft as it will increase the transient time of the drive.

Load equalization

- If the motor is fed from the motor generator set, then flywheel mounted on the motor generator shaft and hence equalises the load on the source but not load on the motor.

Load equalization

- When the load is light, the flywheel accelerated and stored the excess energy drawn from the supply. During the peak load, the flying wheel decelerates and supply the stored energy to the load along with the supply energy.

- Hence the power remains constant, and the load demand is reduced.

Load equalization

- Moment of inertia of the flying wheel required for load equalisation is calculated as follows.
- Consider the linear motor speed torque curve as shown in the figure below.

$$\omega m=[(\omega m0-\omega mr)/Tr]*T$$

- Assumed the response of the motor is slow due to large inertia and hence applicable for transient operation. Differentiate the equation (1) and multiply both sides by J (moment of inertia).

Load equalization

$$J\frac{d_{\omega m}}{dt} = \frac{J(\omega_{m0} - \omega_{mr})}{T_r}\frac{dT}{dt} \ldots\ldots\ldots\ldots equ(2)$$

$$J\frac{d_{\omega m}}{dt} = -T_m\frac{dT}{dt} \ldots\ldots\ldots\ldots equ(3)$$

$$T_m = \frac{(\omega_{m0} - \omega_{mr})}{T_r} \ldots\ldots\ldots\ldots\ldots\ldots equ(4)$$

Load equalization

- TmdT/dt +T=Tl

  Consider a periodic load torque a cycle which consists of one high load period with torque T_{lh} and duration the, and one light load period with torque T_{ll} and duration t_l

- T=Tlh(1-e^-t/τm)+Tmaxe^-t/τm for 0 <=t<=th

  Tmax =Tlh(1-e^-t/τm+Tmaxe^-t/τm

  Where t'=t-th

  Tmin=Tll(1-e^-t/τm)+Tmaxe^-t/τm

  τm=th/loge[(Tlh-Tmin)/(Tlh-Tmax)

  J=[Tr/ωm0-ωmr]*Th/loge[(Tlh-Tmin)]/[(Tlh-Tmax)]

  τm=t1/loge[(Tlh-Tmin)/(Tlh-Tmax)

  J=Tr/(ωm0-ωmr)*t1/loge(Tlh-Tmin/Tlh-Tmax)

  J=WR^2

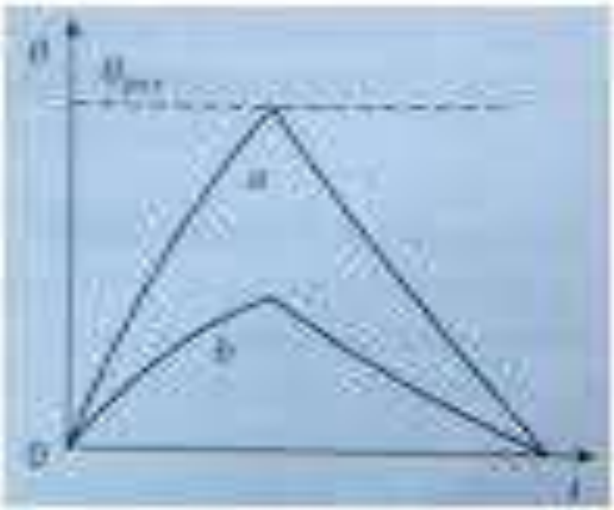
Determination of motor power rating for continuous duty

- Maximontinuous power demand of the load is ascertained.
- A motor with next higher power rating from commercially available rating is selected.
- Motor speed should also match load's speed requirements .

- It is also necessary to check whether the motor can fulfill starting torque requirements and continue to drive load in the face of normal disturbances in power supply system;the latter is generally assured by the transient and steady state reserve torque capacity of the motor.

Determination of motor power rating for Short time duty

Short Time Duty



- In short time duty, time of motor operation considerably less than the heating time constant & motor is allowed to cool down to ambient temperature.

- If a motor with continuous duty power rating of Pr is subjected to a short time duty load of magnitude Pr , then motor temp rise will be far below the maximum permissible value & motor can be overloaded by a factor K (K>1).

Determination of motor power rating for intermittent duty

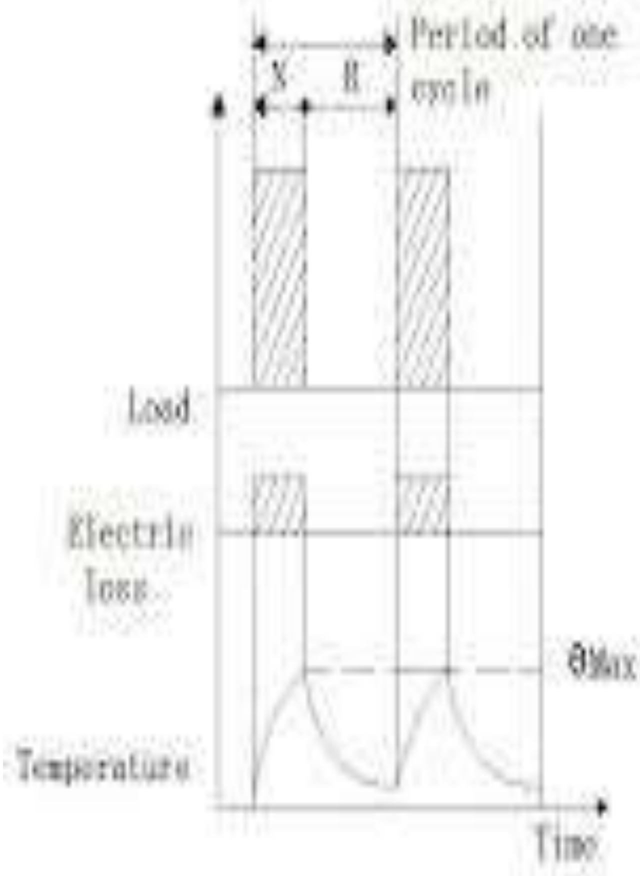


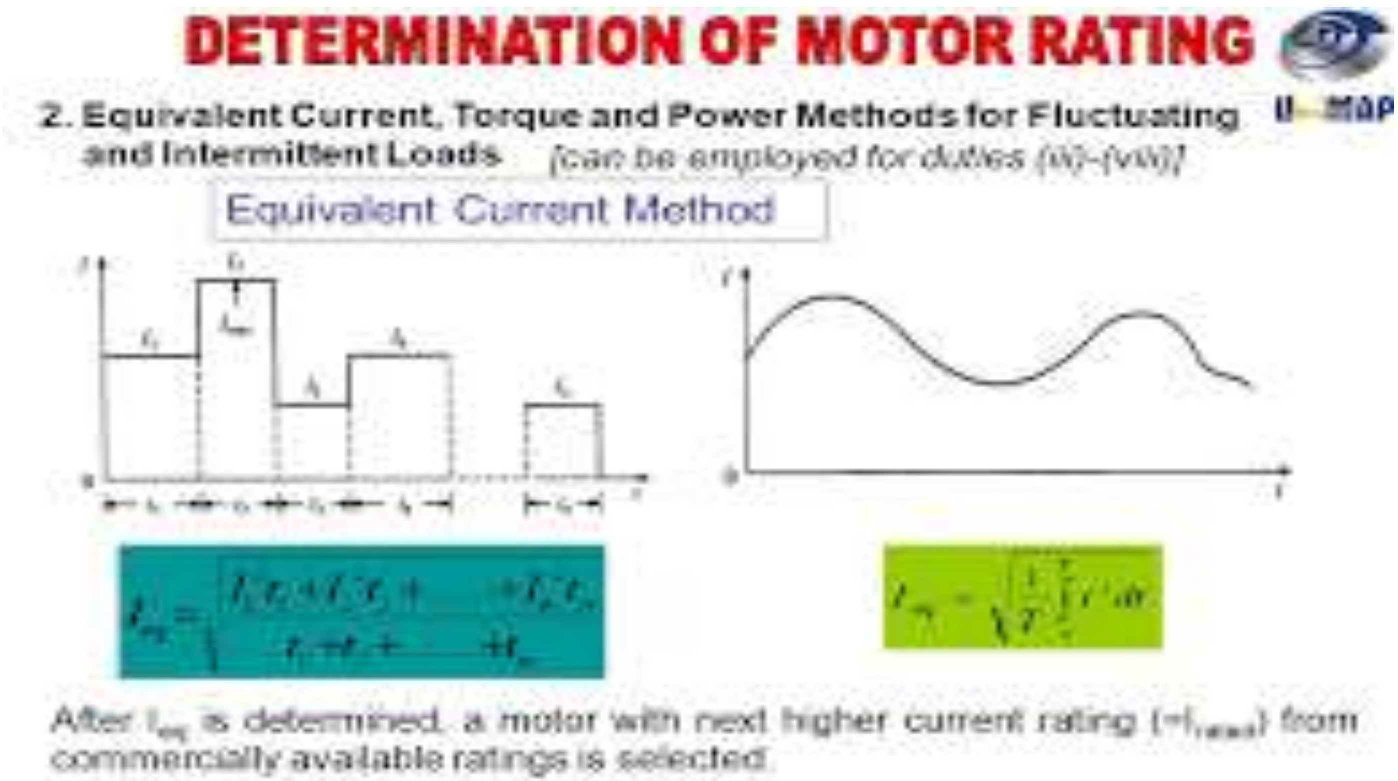
Fig.1: Intermittent Periodic Duty Type S3

X= Operation under rated condition

R= At rest and de-energized

θ Max= Maximum temperature attained during the duty cycle

Determination of motor power rating for intermittent duty



UNIT-3

Electric Braking

Purpose of Electric Breaking

- The process of applying brakes can be termed as braking. Now coming to the term or question**what is braking**.
- we can classify the term braking in two parts:
- Mechanical Braking
- Electrical Braking

- Mechanical braking is left out here because as it is an electrical engineering site, we should only focus on electrical braking here:

Purpose of Electric Breaking

- In mechanical braking the speed of the machine is reduced solely by mechanical process but electrical braking is far more interesting than that because the whole process is depended on the flux and torque directions. We will further see through the various **types of braking** but the main idea behind each type of barking is the reversal of the direction of the flux.

- It is the process of reducing speed of any rotating machine.

- Brakes are used to reduce or cease the speed of motors. We know that there are various types of motors available (DC motors, induction motors, synchronous motors, single phase motors etc.) and the specialty and properties of these motors are different from each other, hence this braking methods also differs from each other

Type Of Electric Breaking

- But we can divide braking in to three parts mainly, which are applicable for almost every type of motors.
- Regenerative Braking.
- Plugging type braking.
- Dynamic braking.
- **Regenerative Braking**
- **Regenerative braking** takes place whenever the speed of the motor exceeds the synchronous speed. This baking method is called regenerative baking because here the motor works as generator and supply itself is given power from the load, i.e. motors.

Type Of Electric Breaking

- The main criteria for regenerative braking is that the rotor has to rotate at a speed higher than synchronous speed, only then the motor will act as a generator and the direction of currentflow through the circuit and direction of the torque reverses and braking takes place.

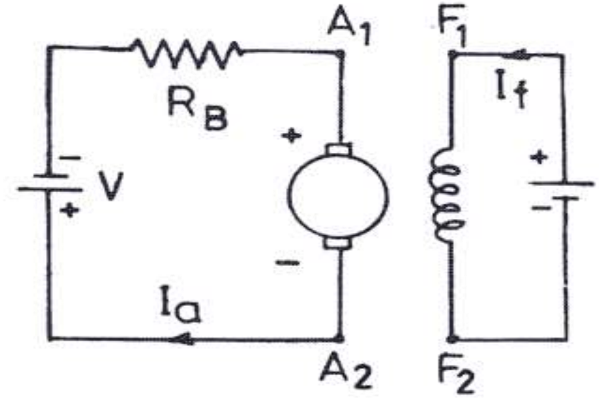
- The only disadvantage of this **type of braking** is that the motor has to run at super synchronous speed which may damage the motor mechanically and electrically, but regenerative braking can be done at sub synchronous speed if the variable frequency source is available.

Type Of Electric Breaking

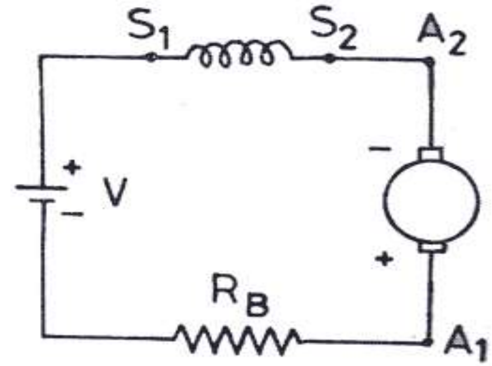
- **Plugging Type Braking**
- Another type of braking is **Plugging type braking**. In this method the terminals of supply are reversed, as a result the generator torque also reverses which resists the normal rotation of the motor and as a result the speed decreases.

- During plugging external resistance is also introduced into the circuit to limit the flowing current. The main disadvantage of this method is that here power is wasted.

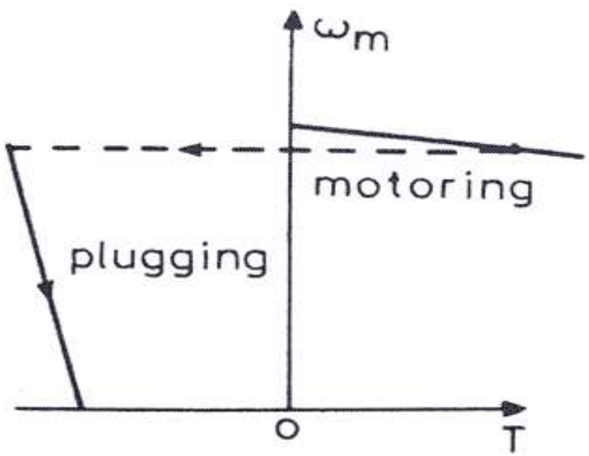
Type Of Electric Breaking



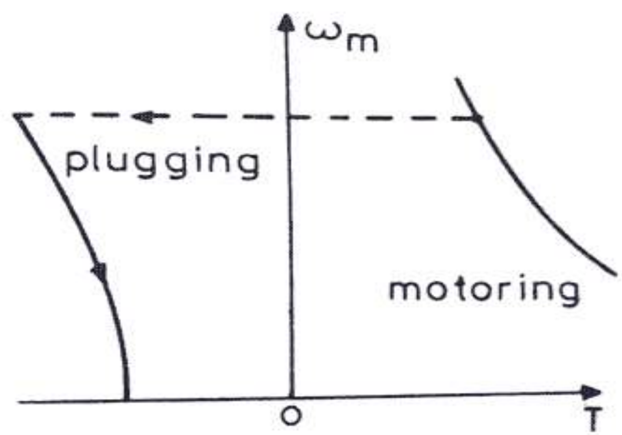
Separately excited



Series



Separately excited



Series

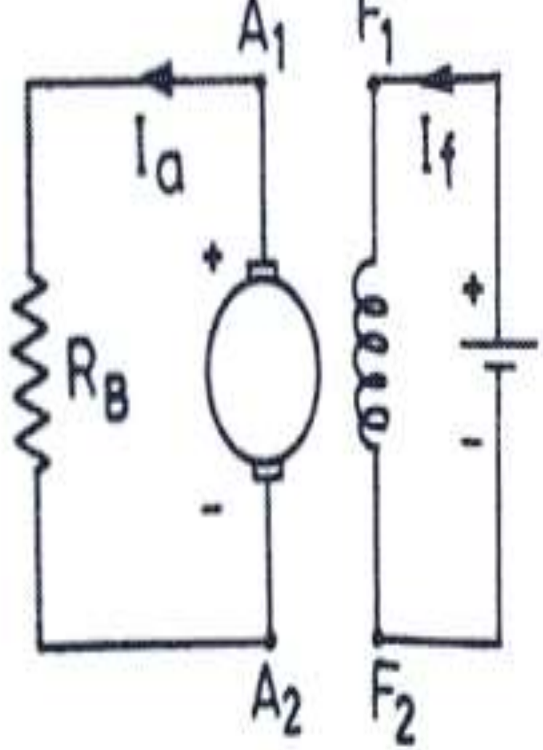
Type Of Electric Breaking

- **Dynamic Braking**

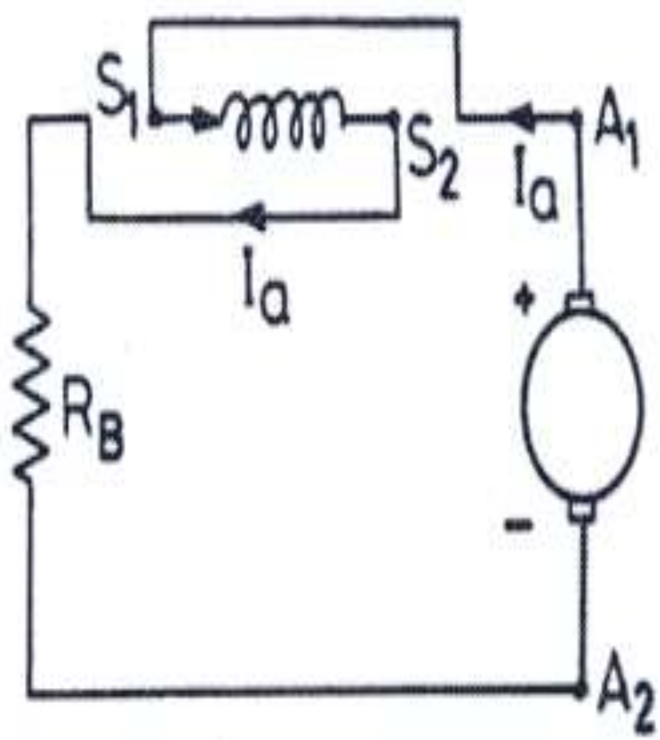
Another method of reversing the direction of torque and braking the motor is **dynamic braking**. In this method of braking the motor which is at a running condition is disconnected from the source and connected across a resistance.

When the motor is disconnected from the source, the rotor keeps rotating due to inertia and it works as a self-excited generator. When the motor works as a generator the flow of the current and torque reverses. During braking to maintain the steady torque sectional resistances are cut out one by one.

Type Of Electric Breaking



Separately excited motor



Series motor

Braking Of DC Motor

- Basically, there are three types of electrical braking done in a DC Motor:-
- **Regenerative Braking**
- **Dynamic Braking**
- **Plugging**
- **Regenerative Braking**

- It is a form of braking in which the kinetic energy of the motor is returned to the power supply system. This type of braking is possible when the driven load forces the motor to run at a speed higher than its no-load speed with a constant excitation

Braking Of DC Motor

- The motor back emf E_b is greater than the supply voltage V, which reverses the direction of the motor armature current. The motor begins to operate as an electric generator.

It is very interesting to note that regenerative braking cannot be used to stop a motor but to control its speed above the no-load speed of the motor driving the descending loads.

Braking Of DC Motor

- **Dynamic Braking**
- It is also known as Rheostatic braking. In this type of braking, the DC motor is disconnected from the supply and a braking resistor R_b is immediately connected across the armature. The motor will now work as a generator, and produces the braking torque.

  During electric braking when the motor works as a generator, the kinetic energy stored in the rotating parts of the motor and a connected load is converted into electrical energy.

Braking Of DC Motor

- It is dissipated as heat in the braking resistance R_b and armature circuit resistance.

Dynamic Braking is an inefficient method of braking as all the generated energy is dissipated as heat in resistances

Braking Of DC Motor

- **Plugging**
- It is also known as reverse current braking. The armature terminals or supply polarity of aseparately excited DC motor or shunt DC motor when running are reversed. Therefore, the supply voltage V and the induced voltage E_b i.e. back emf will act in the same direction.

- The effective voltage across the armature will be $V + E_b$ which is almost twice the supply voltage.

Braking Of DC Motor

- Thus, the armature current is reversed and a high braking torque is produced. Plugging is a highly inefficient method of braking because, in addition to the power supplied by the load, power supplied by the source is wasted in resistances.

Braking Of 3Φ Induction Motor

- The braking is the process of reducing the speed of an induction motor. In braking, the motor works as a generator developing a negative torque which opposes the motion of a motor. The braking of an induction motor is mainly classified into three types. They are:
- Regenerative Braking
- Plugging or reverse voltage braking
- Dynamic Breaking
- AC dynamic braking
- Self-dynamic braking
- DC dynamic braking
- Zero Sequence Braking

Braking Of 3Φ Induction Motor

- **Regenerative Braking:**

The input power of the induction motor drive is given by the formula shown below:

$$P_{in} = 3VI_s\cos\Phi_s$$

Where ϕ_s is the phase angle between stator phase voltage and the stator phase current I_s. For motoring operation, the phase angle is always less than the 90º. If the rotor speed becomes greater than synchronous speed, then the relative speed between the rotor conductor and air gap rotating field reverse.

Braking Of 3Φ Induction Motor

- This reverse the rotor induces emf, rotor current and component of stator current which balances the rotor ampere turns.

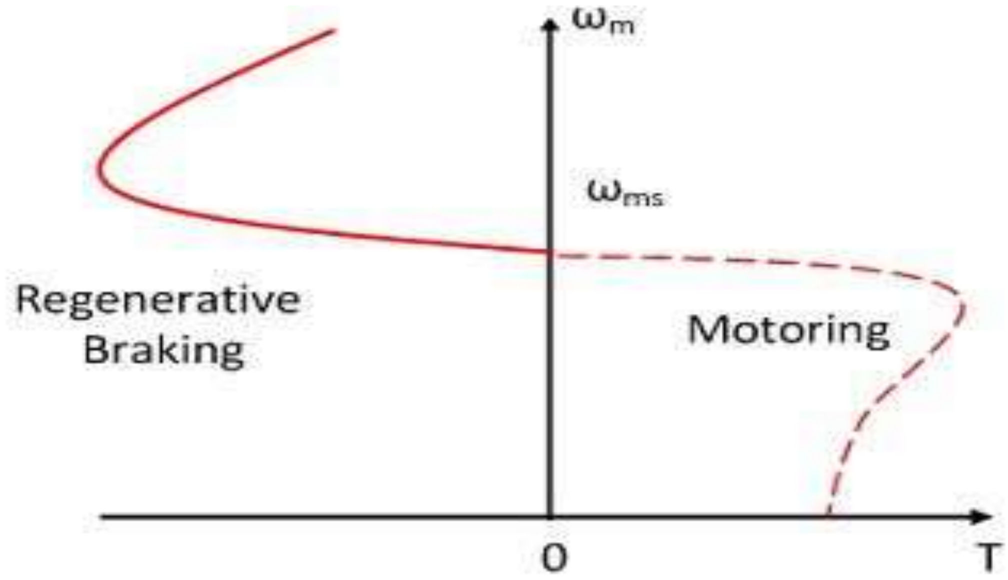
- When the ϕ_s is greater than the 90º, then the power flow to reverse and gives the regenerative braking. The magnetising current produced the air gap flux.

- The nature of the speed torque curve is shown in the figure above. When the supply frequency is fixed, the regenerative braking is possible only for speeds greater than synchronous speed.

.

With a variable frequency speed, it cannot be obtained for speed below synchronous speedThe main advantage of regenerative braking is that the generated power is fully used. And the main drawback is that when fed from a constant frequency source the motor can not employ below synchronous speed.

Braking Of 3Φ Induction Motor



Regenerative Braking

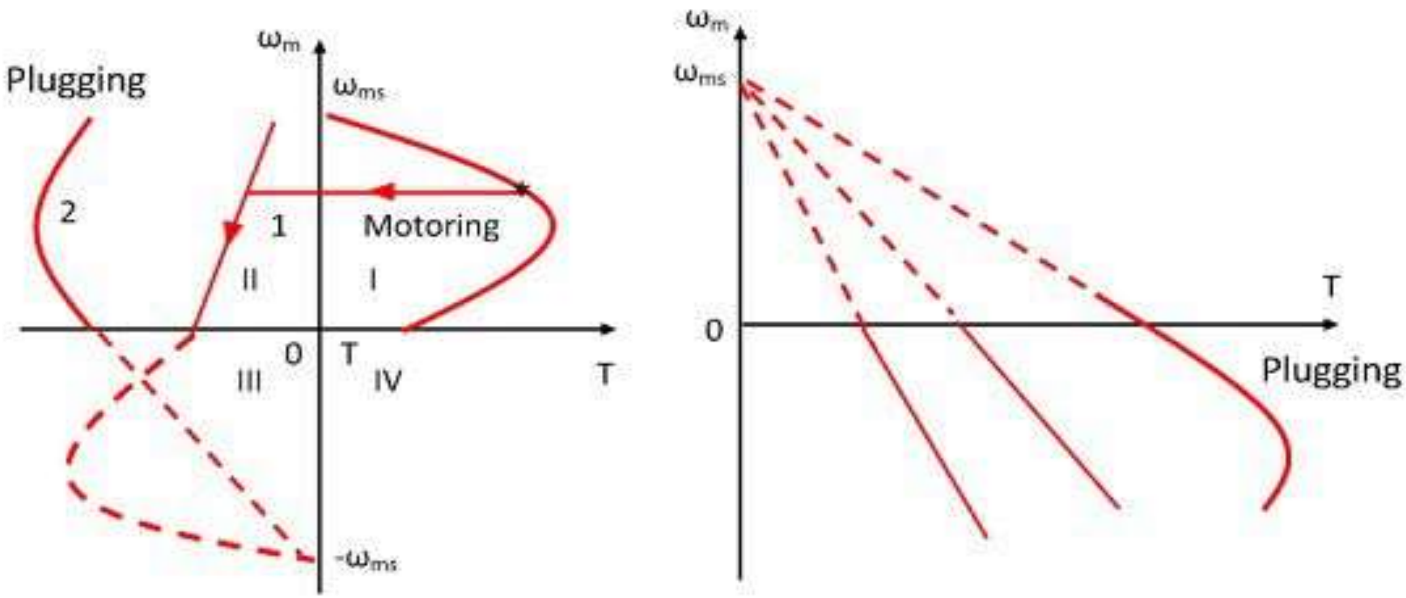
Braking Of 3Φ Induction Motor

- **Plugging:**

What speed en the phase sequence of supply of the motor running is reversed by interchanging the connection of any two phases of the stator on the supply terminal, operation change from motoring to plugging as shown in the figure below.

- Plugging is the extension of motoring characteristic for a negative phase sequence from quadrant third to second. The reversal of phase sequence reverses the direction of a rotating field.

Braking Of 3Φ Induction Motor



1 : Natural Characteristic
2 : With External Resistance in rotor

Plugging in fourth quadrant with extra large external resistance in rotor

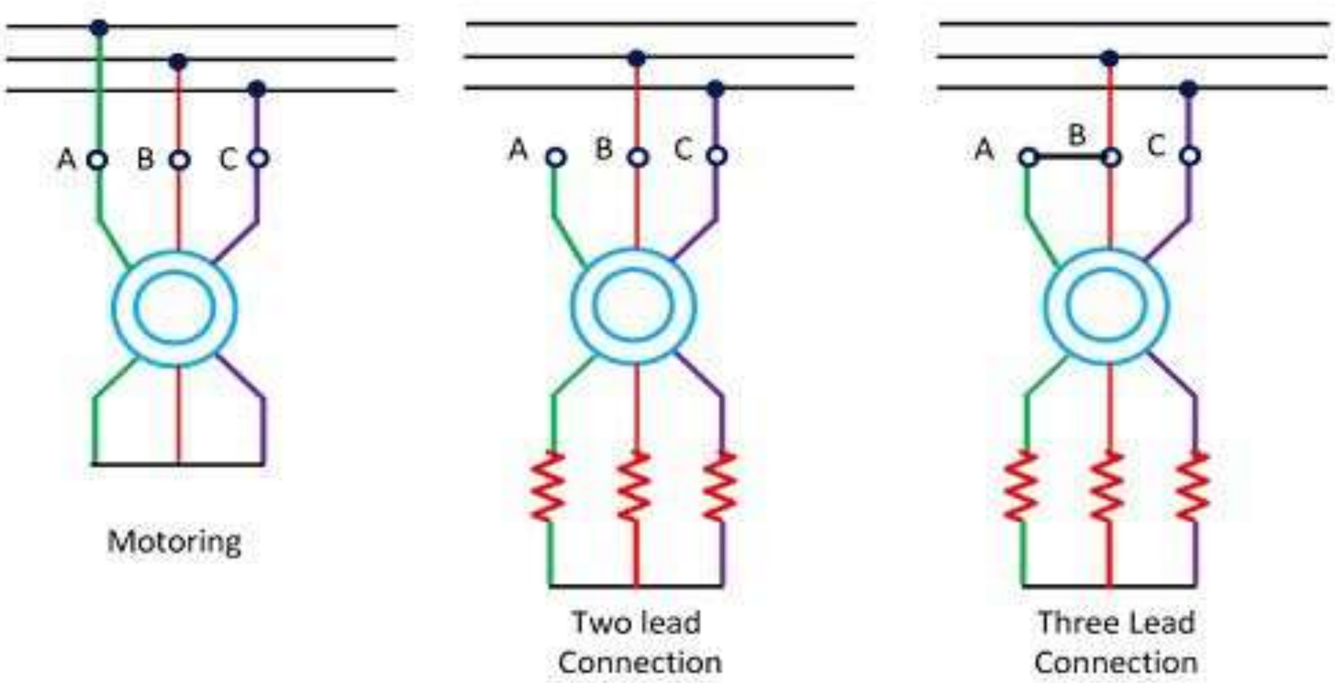
Plugging

Braking Of 3Φ Induction Motor

- **Dynamic Braking**
- **AC Dynamic Braking –** The dynamic braking is obtained when the motor is run on the single phase supply by disconnecting the one phase from the source and either leaving it open or connecting it with another phase.

- The two connections are respectively known as two and three lead connection.

Braking Of 3Φ Induction Motor



AC dynamic Braking of a Wound Rotor Motor

Braking Of 3Φ Induction Motor

- When connected to a one phase supply the motor can be considered as to be fed by positive and negative sequence three phase set of voltage. The total torque produced by the machine is the sum of torque due to positive and negative sequence voltage. When the rotor has high resistance, then the net torque is negative, and the braking operation is obtained.

- Assume the phase A of the star connected motor is open circuited. Then the current flow through the phase A becomes zero, i.e., $I_a = 0$ and current through the other two phases is $I_B = – I_C$.

- The positive and negative sequence component I_p and I_n are represented by the equation.

Braking Of 3Φ Induction Motor

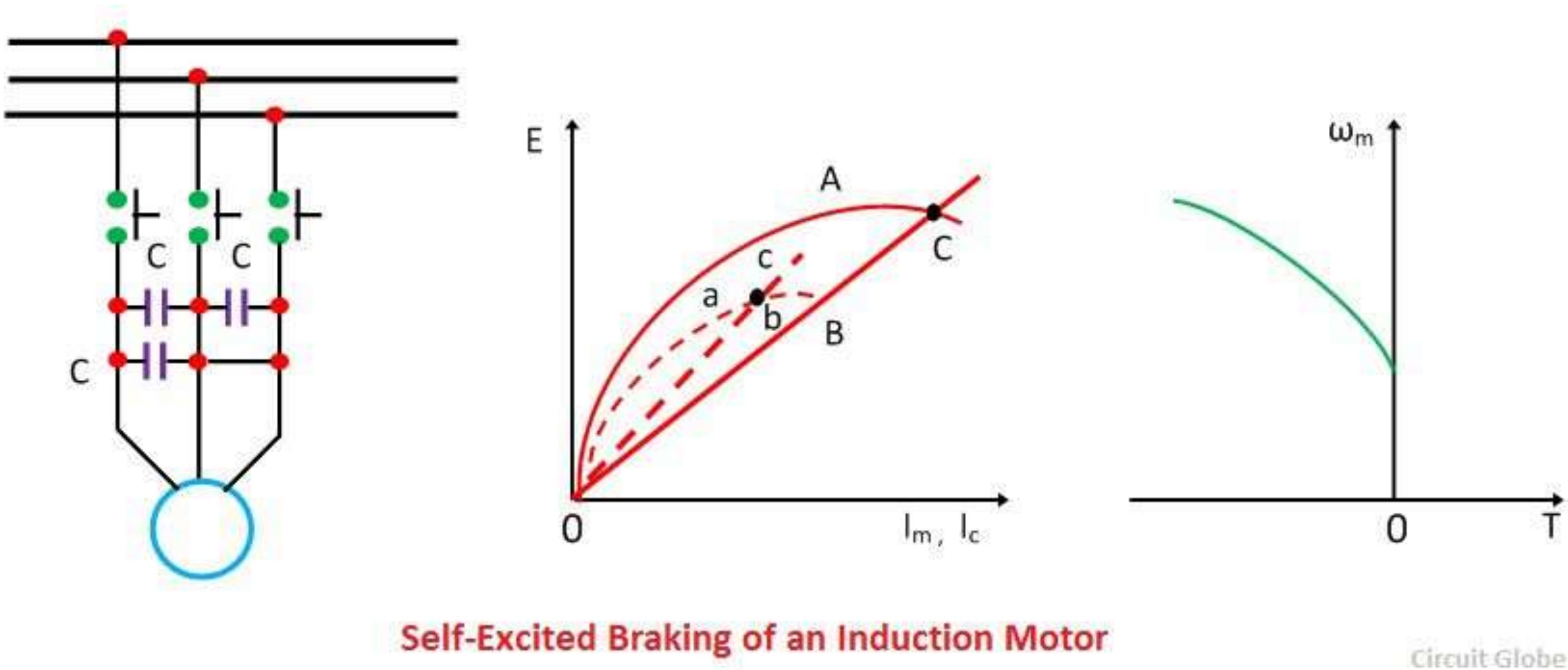
$$I_p = \frac{1}{3}(\bar{I}_A + \alpha\bar{I}_B + \alpha^2\bar{I}_C) = \frac{1}{3}(0 + \alpha\bar{I}_B - \alpha^2\bar{I}_B) = j\bar{I}_B/\sqrt{3}$$

$$I_p = \frac{1}{3}(\bar{I}_A + \alpha^2\bar{I}_B + \alpha\bar{I}_C) = \frac{1}{\sqrt{3}}(0 + \alpha\bar{I}_B - \alpha^2\bar{I}_B) = -j\bar{I}_B/\sqrt{3}$$

Where $\alpha = e^{j20^\circ}$

Braking Of 3Φ Induction Motor

Self Excited Braking Using Capacitor



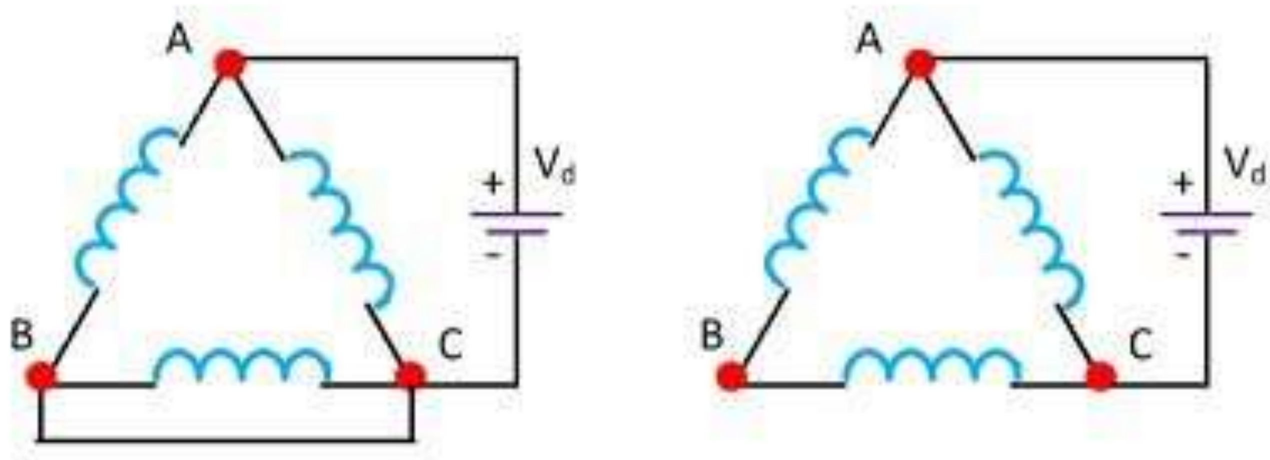
Self-Excited Braking of an Induction Motor

Braking Of 3Φ Induction Motor

- **DC Dynamic Braking –**
- In this method, the stator of induction is connected across the DC supply. The method for getting DC supply with the help of a diode bridge is shown in figure

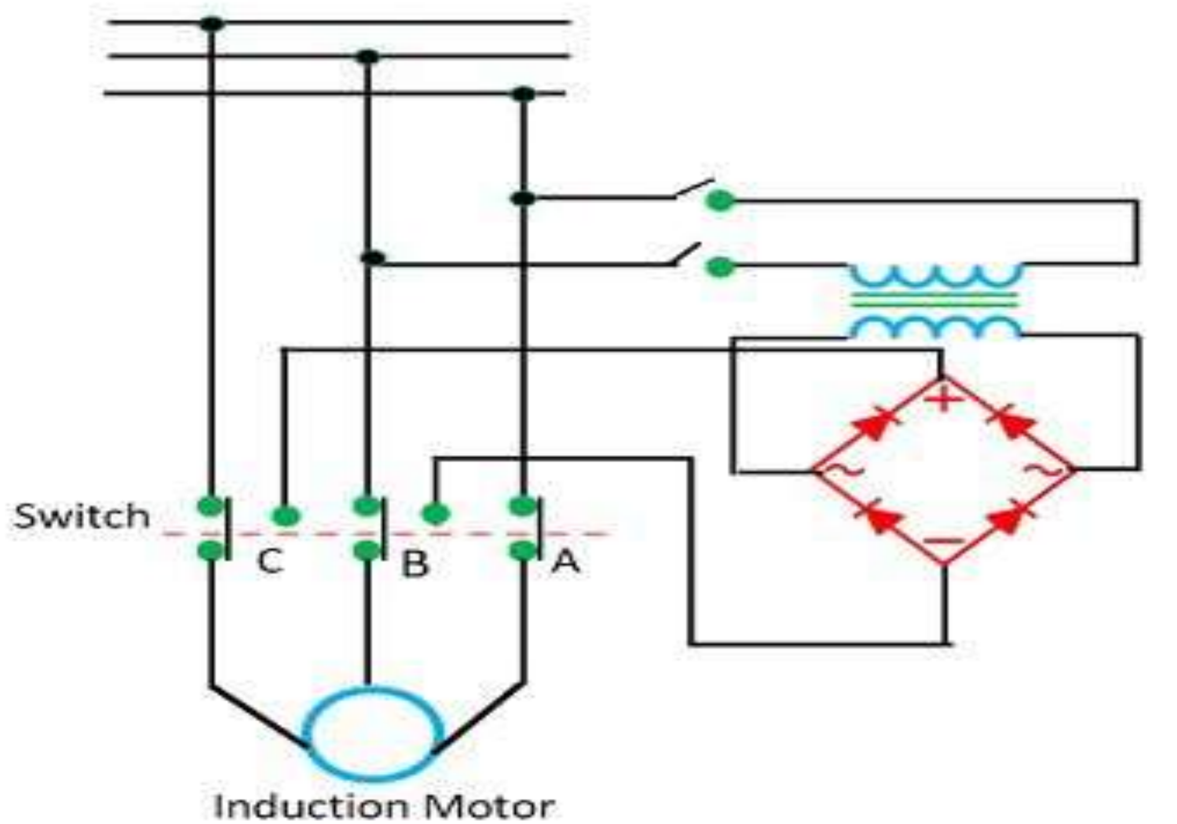
- The direct current flow through the stator produces a stationary magnetic field, and the motion of the rotor in this field produces induces voltage in the stationary windings. The machine therefore works as a generator and the generated energy is dissipated in the rotor circuit resistance, thus giving the dynamic winding.

Braking Of 3Φ Induction Motor



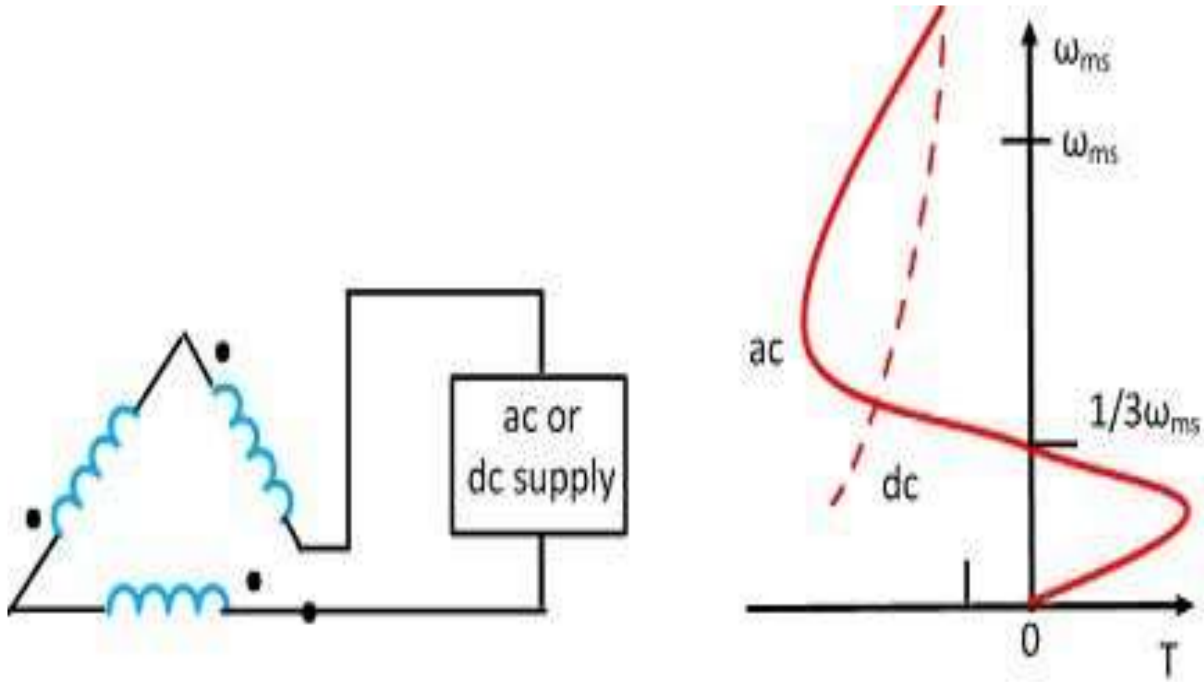
Three Lead Connection of DC Dynamic Braking

Braking Of 3Φ Induction Motor



Two Lead DCdynamic Braking Connection

Braking Of 3Φ Induction Motor



Zero-Sequence Braking

Breaking Of Synchronous Motor

- As we know, there are three types of braking i.e, regenerative, dynamic and plugging type braking. But for **synchronous motor drives** only dynamic braking can be applied though plugging can be applied theoretically.

- Regenerative braking cannot be applied to them as they need higher speed than synchronous speed. Dynamic braking is done by disconnecting the motor from supply and connecting it across a three phase resistor.

Breaking Of Synchronous Motor

- At that time the motor works as a synchronous generator and energy is dissipated at the resistors.

- Plugging is not used for synchronous motors as high plugging current can cause severe disturbance and damage in line.

Energy Relation During Braking

- It has been noted that the most common brakes employ friction to transform .
- the braked system's mechanical energy, irreversibly into heat which is then transferred to the surrounding environment .
- • Kinetic energy is absorbed during slippage of either a clutch or brake, and this energy appears as heat.
- If the heat generated is faster than it is dissipated, then the temperature rises

Energy Relation During Braking

- Thorough design of a brake therefore requires a detailed transient thermal analysis of the interplay between heat generated by friction, heat transferred through the lining and the surrounding metalwork to the environment, and the instantaneous temperature of the surface of the drum as well as the lining.

- For a given size of brake there is a limit to the mechanical power that can be transformed into heat and dissipated without lthe temperatures reaching

Energy Relation During Braking

- damaging levels. Temperature of the lining is more critical and the brake size is characterized by lining contact area, A.

- Heat Generated In Braking During deceleration, the system is subjected to an essentially constant torque

T exerted by the brake, and in the usual situation this constancy implies constant deceleration too.

- Application of the work or energy principle to the system enables the torque exerted by the brake and the work done by the brake, U, to be calculated from:-

Energy Relation During Braking

- $U = \Delta E = T\,\Delta\theta$ ………………………………………………….. (2)

  Where ΔE is the loss of system total energy which is absorbed by the brake
- during deceleration, transformed into heat, and eventually dissipated.

- The elementary equations of constant rotational deceleration apply, thus when the brake drum is brought to rest from an initial speed ωo :-

  Deceleration = $\omega o^2/ 2$ (1) $\Delta\theta = \omega m.\Delta t$; $\omega m = \omega o/2 = \Delta\theta/\Delta t$ where ωm is the mean drum speed over the deceleration period.

- The mean rate of power transformation by the brake over the braking period is :-
- $Pm = U / \Delta t = T\,\omega m$
- (3) which forms a basis for the selection or the design of the necessary brake .

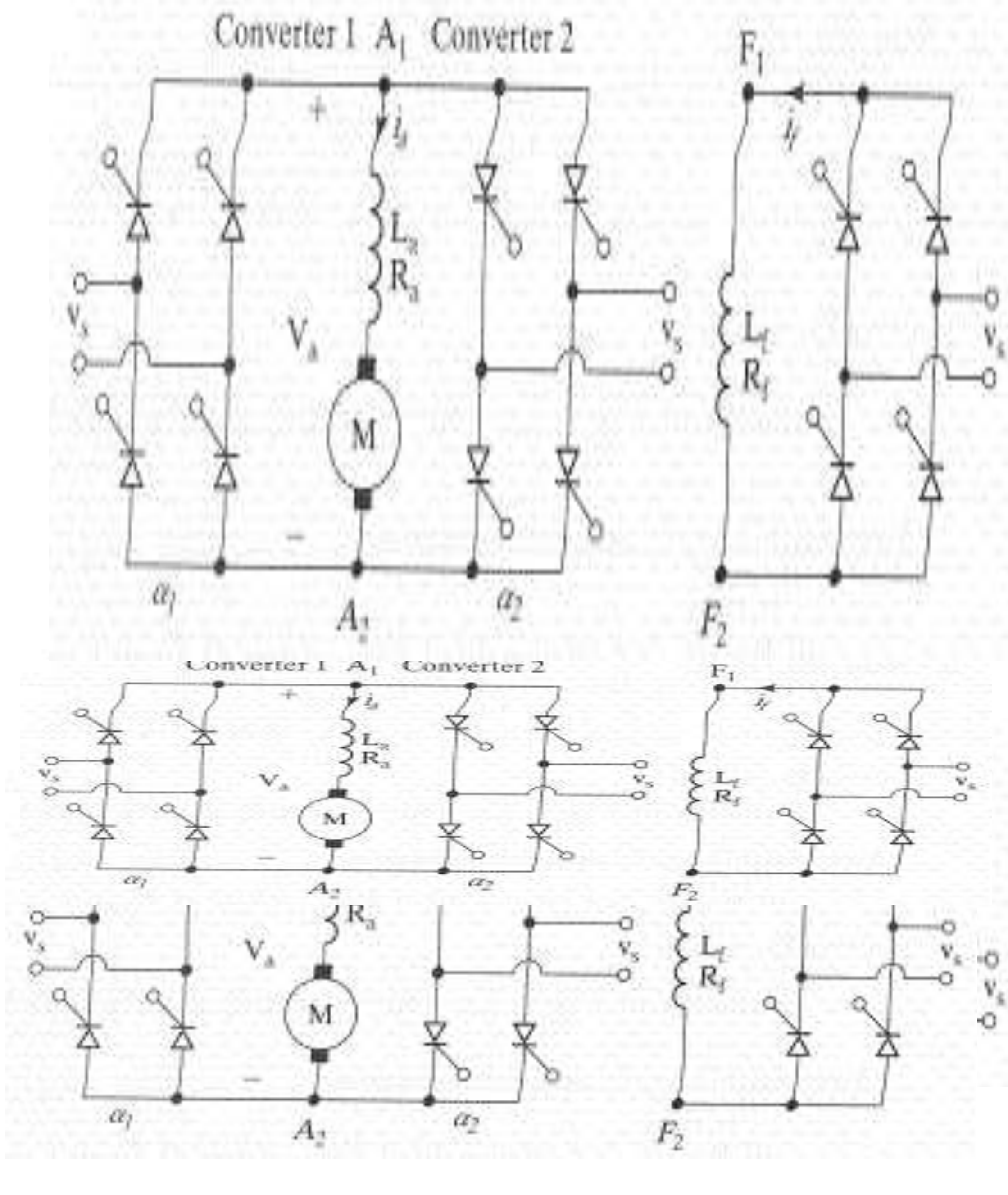
UNIT-4

(Power Electronic Control of DC Drives)

Single-Phase Dual-Converter Drives

- Two single-phase full-wave converters are connected.
- Either converter 1 operates to supply a positive armature voltage, V_a, or converter 2 operates to supply a negative armature voltage, $-V_a$.
- Converter 1 provides operation in the first and fourth quadrants, and converter 2, in the second and third quadrants.
- It is a four-quadrant drive and permits four modes of operation: forward powering, forward braking (regeneration), reverse powering, and reverse braking (regeneration).
- It is limited to applications up to 15 kW. The field converter could be a full-wave or a dual converter.

Single-Phase Dual-Converter Drives



Single-Phase Dual-Converter Drives

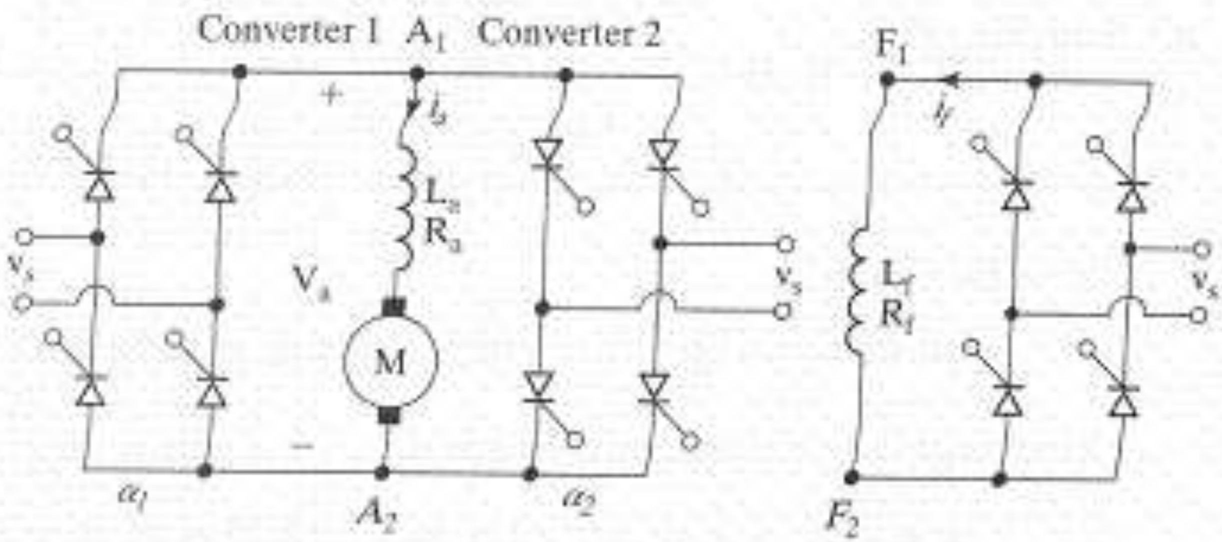


FIGURE 15.15

Single-phase dual-converter drive.

If converter 2 operates with a delay angle of α_{a2}, Eq. (10.16) gives the armature voltage as

$$V_a = \frac{2V_m}{\pi} \cos \alpha_{a2} \qquad \text{for } 0 \le \alpha_{a2} \le \pi \tag{15.20}$$

where $\alpha_{a2} = \pi - \alpha_{a1}$. With a full converter in the field circuit, Eq. (10.5) gives the field voltage as

$$V_f = \frac{2V_m}{\pi} \cos \alpha_f \qquad \text{for } 0 \le \alpha_f \le \pi \tag{15.21}$$

Chopper Control Of Sepatately Excited Dc DRIVES

- **Motoring Control**
- The transistor chopper controlled separately excited DC motor is shown in the figure below. The transistor T_r is operated periodically with period T_r and remains open for a duration T_{on}.

- The waveforms of motor terminal voltage and armature current are shown in the figure below. During on the motor terminal voltage is V and operation of the motor is described as

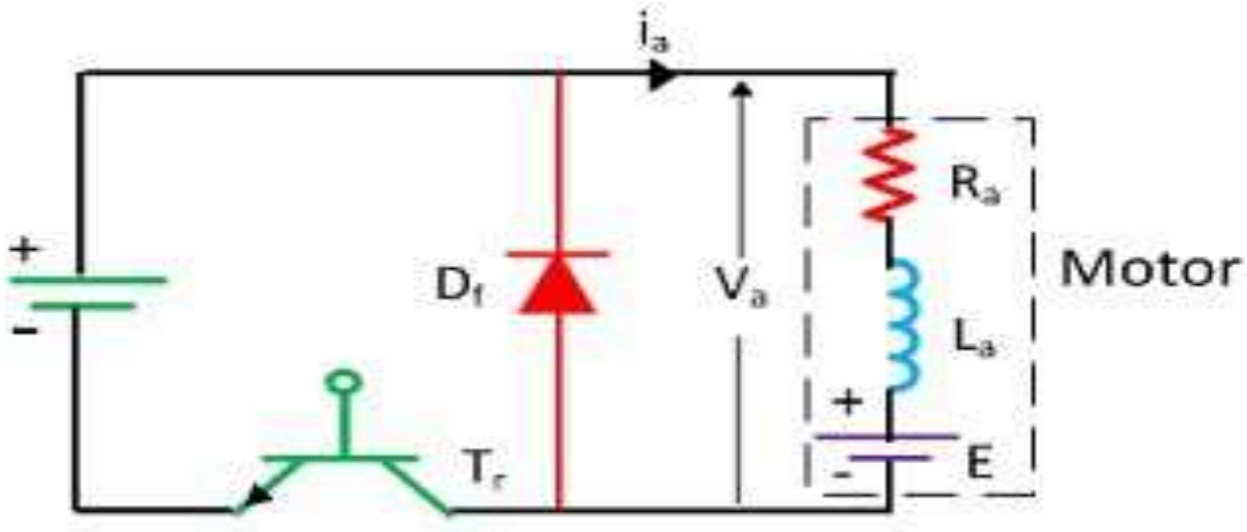
Chopper Control Of Sepatately Excited Dc DRIVES

$$R_a i_a + L_a \frac{di_a}{dt} + E = V, \quad 0 \leq t \leq t_{on}$$

Chopper Control Of Sepatately Excited Dc DRIVES

$$R_a i_a + L_a \frac{di_a}{dt} + E = 0, \quad t_{on} \leq t \leq 0$$

Chopper Control Of Sepatately Excited Dc DRIVES

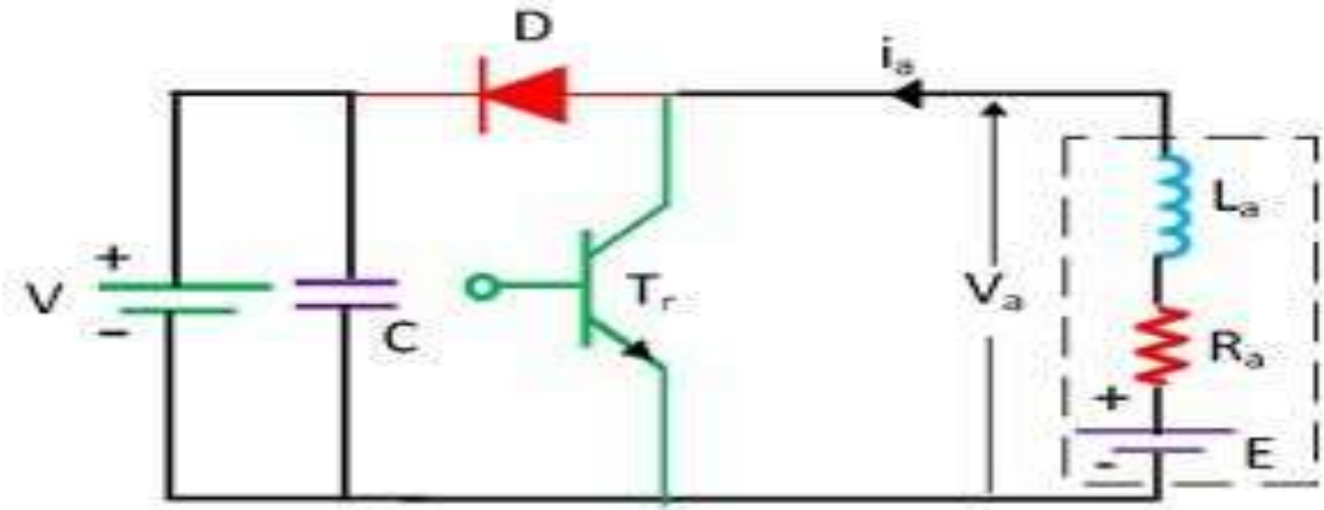


Chopper Control of Seprately Excited Motor

Chopper Control Of Sepatately Excited Dc DRIVES

- Regenerative Braking
- Chopper for regenerative braking operation is shown in the figure below. The transistor T_r is operated periodically with a period T and on-period of t_{on}.
- The waveform of motor terminal voltage v_a and armature current i_a for continuous conduction is shown in the figure below. The external inductance is added to increase the value of L_a. When the transistor is on, i_a increased from i_{a1} to i_{a2}.

Chopper Control Of Sepatately Excited Dc DRIVES



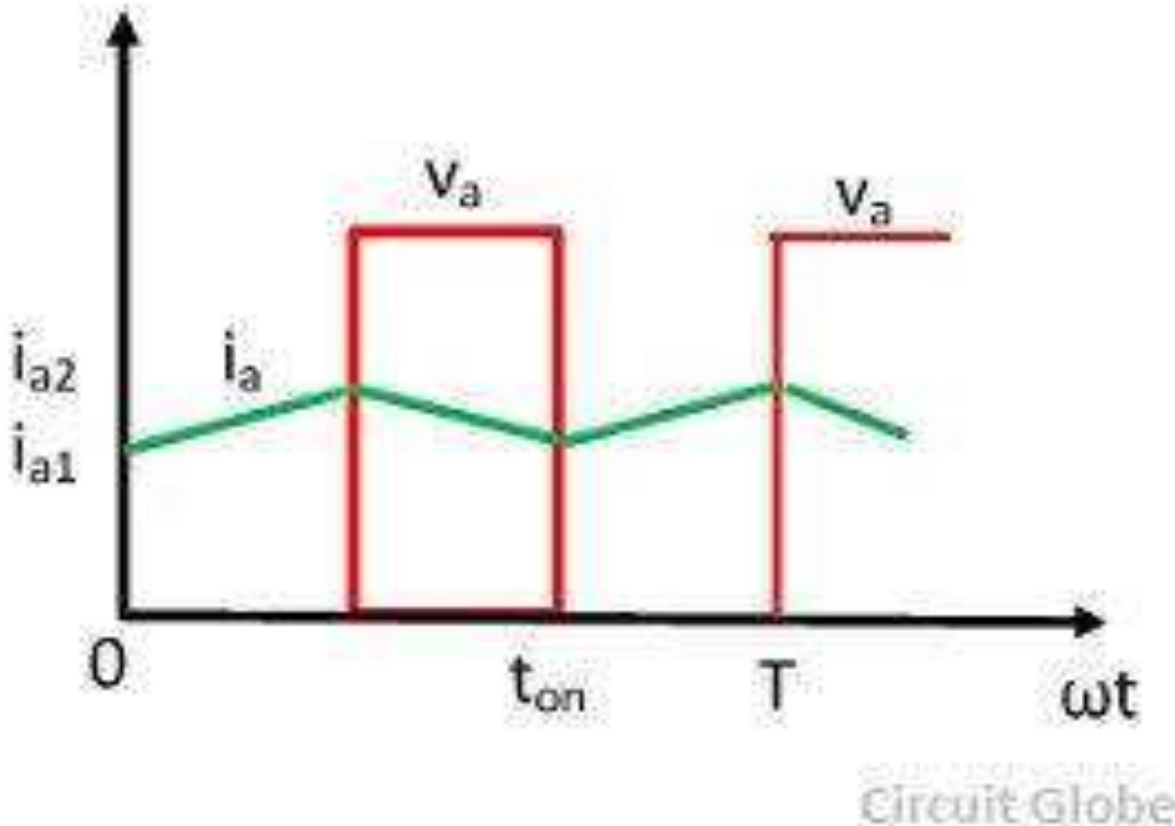
Regenerative Braking of Separately Excited Motor by Chopper Control

Chopper Control Of Sepatately Excited Dc DRIVES

- The mechanical energy is converted into electrical energy by the motor, now working as a generator, partly increased the stored magnetic energy in the armature circuit inductance and the remainder is dissipated in armature and transistors.

When the transistor is turned off, the armature current flows through diode D and the source V and reduces from i_{a2} to i_{a1}. The stored electromagnetic energy and the energy supplied by the machine are fed to the source. The interval $0 \le t \le t_{on}$ is called energy storage interval and the interval $t_{on} \le t \le T$ called the duty interval.

Chopper Control Of Sepatately Excited Dc DRIVES

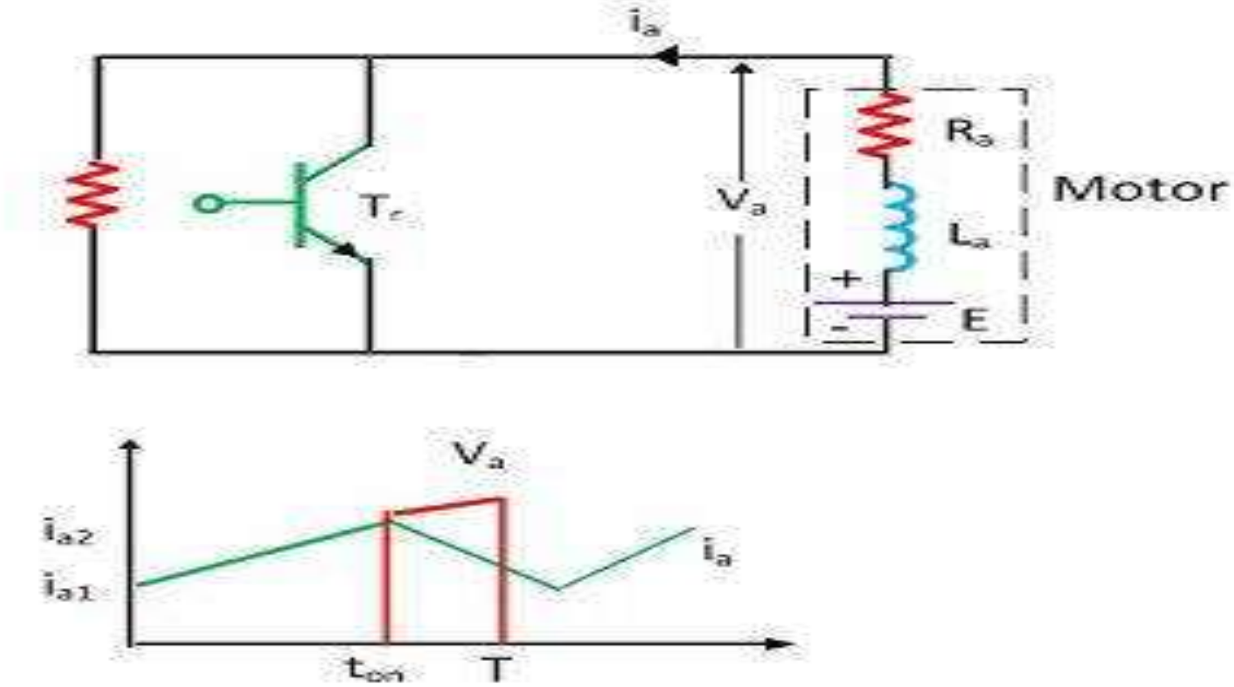


Chopper Control Of Sepatately Excited Dc DRIVES

- Forward Motoring and Braking Control
- The forward motoring operation of the chopper is obtained by the transistor T_{r1} with the diode D_1.The transistor T_{r2} and diode D_2 provide the control for forward regenerative braking operation.

- For the motoring operation, transistor T_{r1} is controlled, and for braking operation, the transistor T_{r2} is controlled. Shifting of control from T_{r1} to T_{r2} shift the operation from motoring to braking and vice versa.

Chopper Control Of Sepatately Excited Dc DRIVES



Dynamic Braknig of Separately Excited Motor by Chopper Control

Circuit Globe

Chopper Control Of Sepatately Excited Dc DRIVES

- **Dynamic Control :**

- The dynamic braking circuit and its waveform are shown in the figure below. During the interval between $0 \leq t \leq T_{on}$, i_a increases from i_{a1} to i_{a2}. The part of the energy is stored in inductance and rest is dissipated in R_a and T_R.

static frequency control scheme (VSI, CSI, and cyclo – converter based)

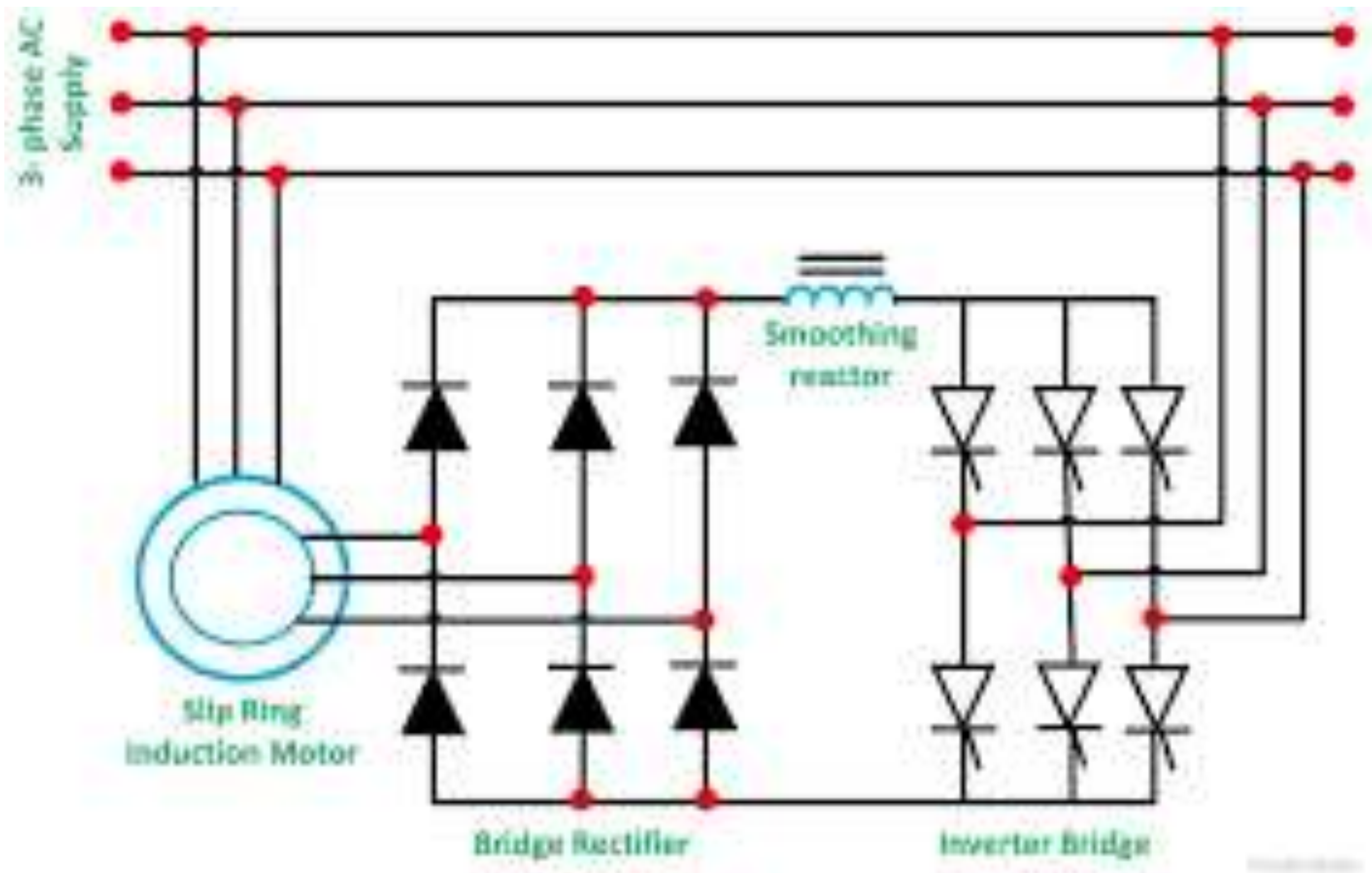
Slip Recovery Scheme

Slip power recovery

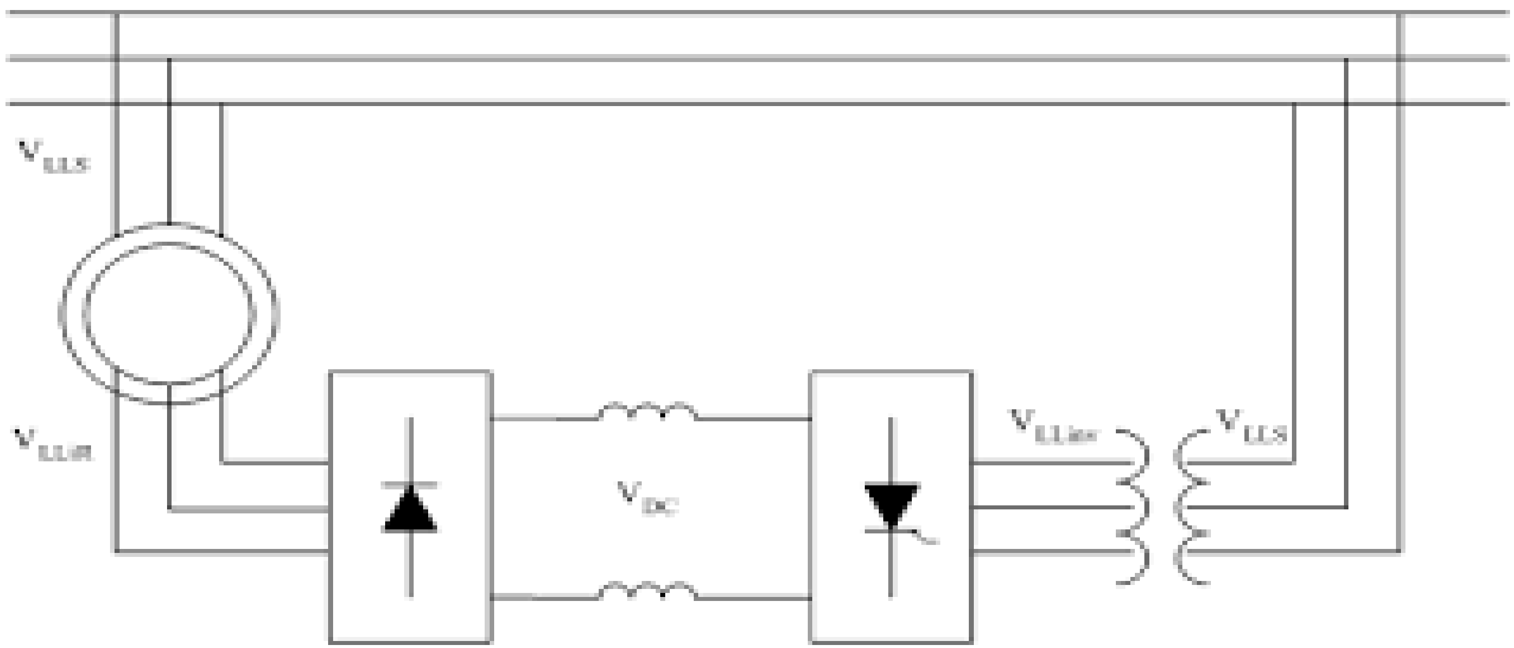
- Instead of wasting the slip power in the rotor circuit resistance, a better approach is to convert it to ac line power and return it back to the line. Two types of converter provide this approach:

1) Static Kramer Drive - only allows operation at sub-synchronous speed.
2) Static Scherbius Drive - allows operation above and below synchronous speed

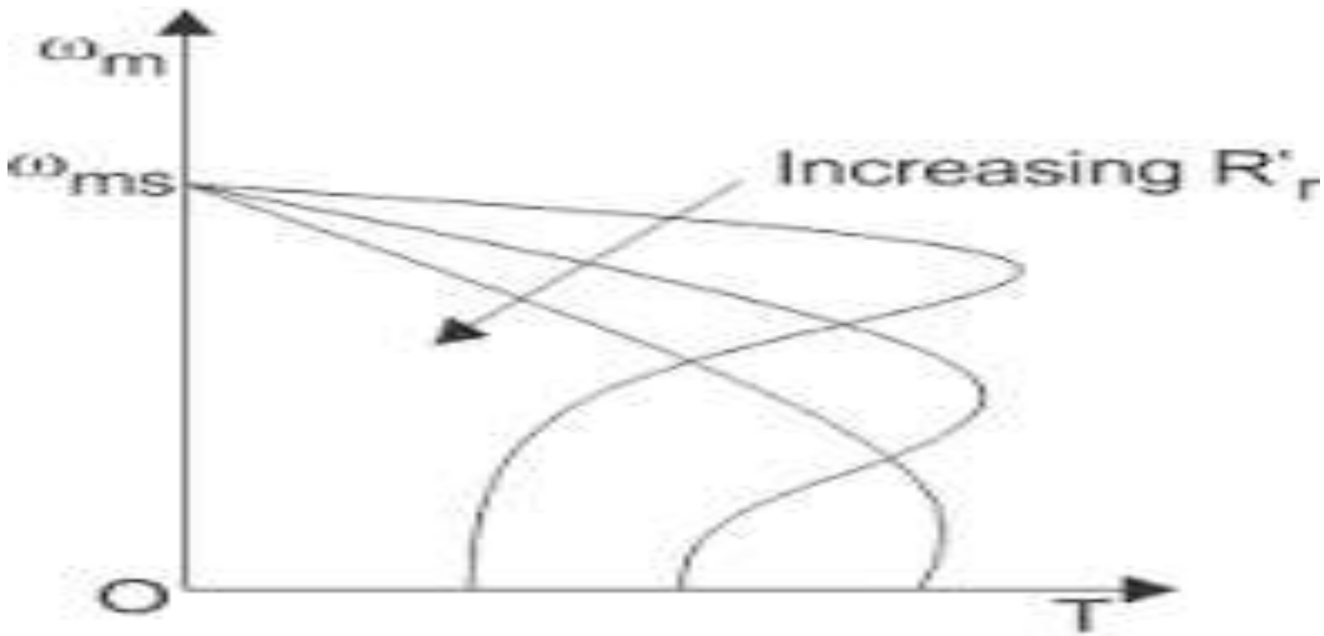
Slip Recovery Scheme



Slip Recovery Scheme

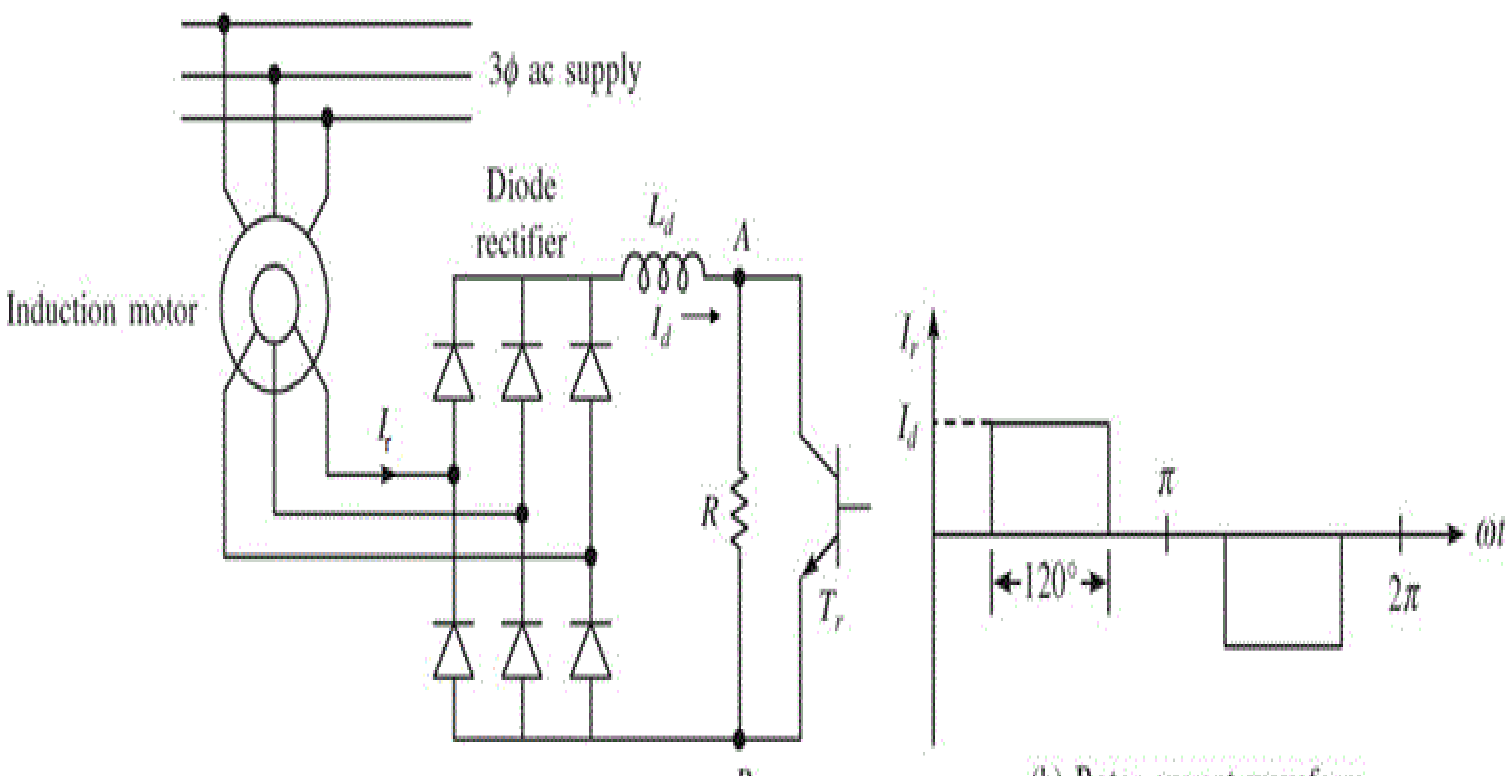


Static Resistance Control



Rotor resistance control

Static Resistance Control



(a) Circuit diagram

(b) Rotor current waveform

Switched Reluctance Motor

- The **switched reluctance motor** (SRM) is a type of a stepper motor, an electric motor that runs by reluctance torque.
- Unlike common DC motor types, power is delivered to windings in the stator (case) rather than the rotor.
- his greatly simplifies mechanical design as power does not have to be delivered to a moving part, but it complicates the electrical design as some sort of switching system needs to be used to deliver power to the different windingstator (case) rather than the rotor.

Switched Reluctance Motor(Cont'd)

- This greatly simplifies mechanical design as power does not have to be delivered to a moving part, but it complicates the electrical design as some sort of switching system needs to be used to deliver power to the different windings.

- With modern electronic devices, precisely timed switching is not a problem, and the SRM is a popular design for modern stepper motors. Its main drawback is torque ripple.

- The SRM has wound field coils as in a DC motor for the stator windings. The rotor however has no magnets or coils attached. It is a solid salient-pole rotor (having projecting magnetic poles) made of soft magnetic material (often laminated-steel).

Switched Reluctance Motor(Cont'd)

- When power is applied to the stator windings, the rotor's magnetic reluctance creates a force that attempts to align the rotor pole with the nearest stator pole. In order to maintain rotation, an electronic control system switches on the windings of successive stator poles in sequence so that the magnetic field of the stator "leads" the rotor pole, pulling it forward.

- Rather than using a troublesome high-maintenance mechanical commutator to switch the winding current as in traditional motors, the switched-reluctance motor uses an electronic position sensor to determine the angle of the rotor shaft and solid state electronics to switch the stator windings, which also offers the opportunity for dynamic control of pulse timing and shaping.

Switched Reluctance Motor(Cont'd)

- This differs from the apparently similar induction motor which also has windings that are energised in a rotating phased sequence, in that the magnetization of the rotor is static (a salient pole that is made 'North' remains so as the motor rotates) while an induction motor has slip, and rotates at slightly less than synchronous speed.

- This absence of slip makes it possible to know the rotor position exactly, and the motor can be stepped arbitrarily slowly.

- **Simple switching**
- If the poles A0 and A1 are energised then the rotor will align itself with these poles.

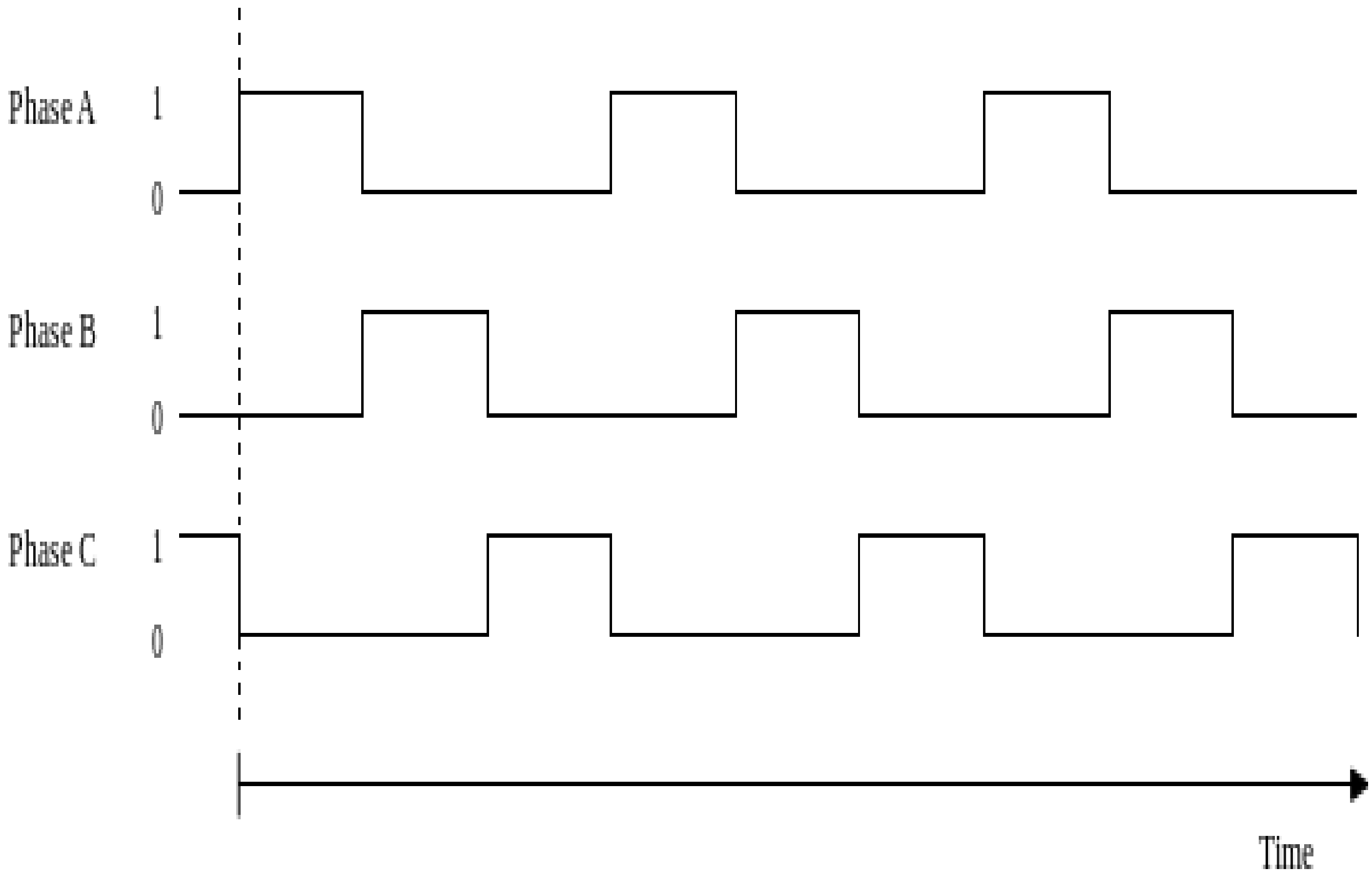
Switched Reluctance Motor(Cont’d)

- Once this has occurred it is possible for the stator poles to be de-energised before the stator poles of B0 and B1 are energized. The rotor is now positioned at the stator poles b. This sequence continues through c before arriving back at the start.

- This sequence can also be reversed to achieve motion in the opposite direction.

- This sequence can be found to be unstable[*clarification needed*] while in operation, under high load, or high acceleration or deceleration, a step can be missed, and the rotor jumps to wrong angle, perhaps going back one instead of forward three.

Switched Reluctance Motor(Cont'd)



Switched Reluctance Motor(Cont'd)

Improved sequence:

A much more stable system can be found by using the following "quadrature" sequence. First, stator poles like A0 and A1 are energized. Then stator poles of B0 and B1 are energized which pulls the rotor so that it is aligned in between the stator poles of A and B.

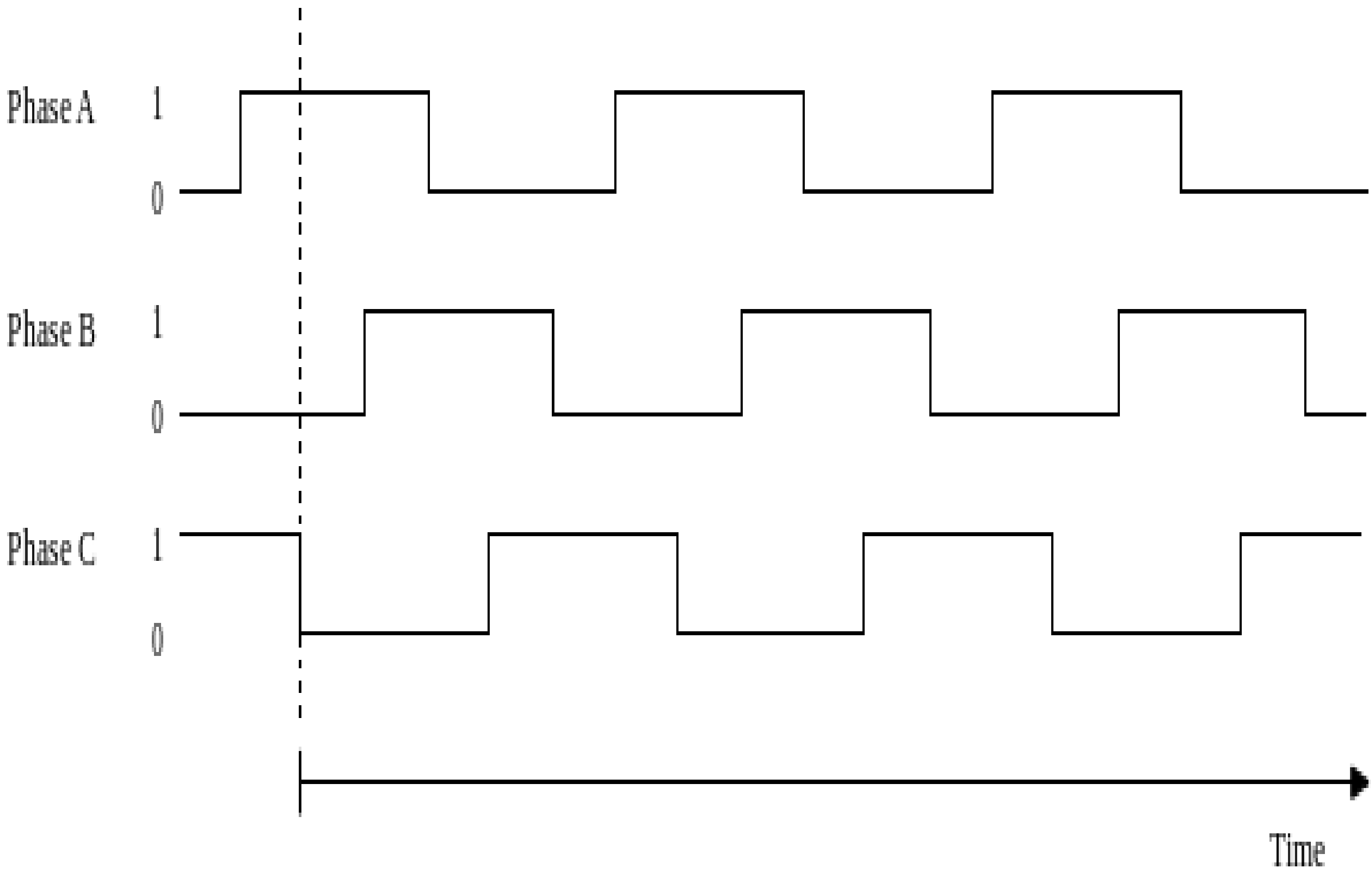
Following this the stator poles of A are de-energized and the rotor continues on to be aligned with the stator poles of B, this sequence continues through BC, C and CA before a full rotation has occurred. This sequence can also be reversed to achieve motion in the opposite direction.

Switched Reluctance Motor(Cont'd)

- As at any time two coils are energised, and there are more steps between positions with identical magnetisation, so the onset of missed steps occurs at higher speeds or loads.

- The control system is responsible for giving the required sequential pulses to the power circuitry in order to activate the phases as required. While it is possible to do this using electro-mechanical means such as commutators or simple analog or digital timing circuits, more control is possible with more advanced methods.

Switched Reluctance Motor(Cont'd)_



Brushless Dc Motor(Cont'd)

- **Brushless DC motor** may be described as electronically commuted motor which do not have brushes. These types of motors are highly efficient in producing large amount of torque over a vast speed range.
- In brushless motors, permanent magnets rotate around a fixed armature and overcome the problem of connecting current to the armature. Commutation with electronics has large scope of capabilities and flexibility. They known for smooth operation, and holding torque when stationary.
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Brushless Dc Motor(Cont'd)

- The brushes change the polarity of the pole to keep the rotation on of the armature. The basic principles for the brushed DC motor and for brushless DC motor are same i.e., internal shaft position feedback. **Brushless DC motor** has only two basic parts: rotor and the stator.

- The rotor is the rotating part and has rotor magnets whereas stator is the stationary part and contains stator windings. In BLDC permanent magnets are attached in the rotor and move the electromagnets to the stator.

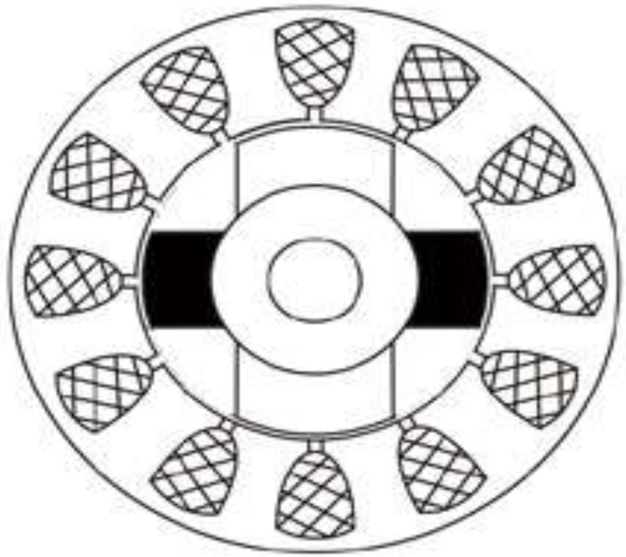
- The high power transistors are used to activate electromagnets for the shaft turns. The controller performs power distribution by using a solid-state circuit.

Brushless Dc Motor(Cont'd)

- **Types of Brushless DC Motors**
- Basically, BLDC are of two types, one is **outer rotor motor** and other is **inner rotor motor**. The basic difference between the two are only in designing, their working principles are same.

- **Inner Rotor Design**
- In an inner rotor design, the rotor is located in the center of the motor and the stator winding surround the rotor. As rotor is located in the core, rotor magnets does not insulate heat inside and heat get dissipated easily. Due to this reason, inner rotor designed motor produces a large amount of torque and validly used.

Brushless Dc Motor(Cont’d)



Inner Motor

Brushless Dc Motor(Cont'd)

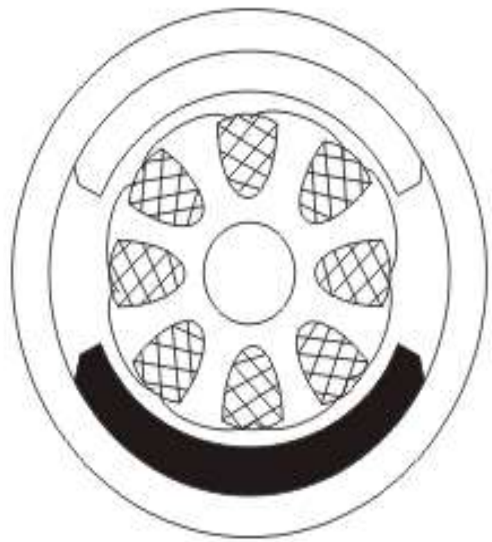
- **Outer Rotor Design**

  In outer rotor design, the rotor surrounds the winding which is located in the core of the motor.

  The magnets in the rotor traps the heat of the motor inside and does not allow to dissipate from the motor. Such type of designed motor operates at lower rated current and has low clogging torque.

- **Advantages of Brushless DC Motor**
- Brushless motors are more efficient as its velocity is determined by the frequency at which current is supplied, not the voltage.
- As brushes are absent, the mechanical energy loss due to friction is less which enhanced efficiency.

Brushless Dc Motor(Cont’d)



Outer Motor

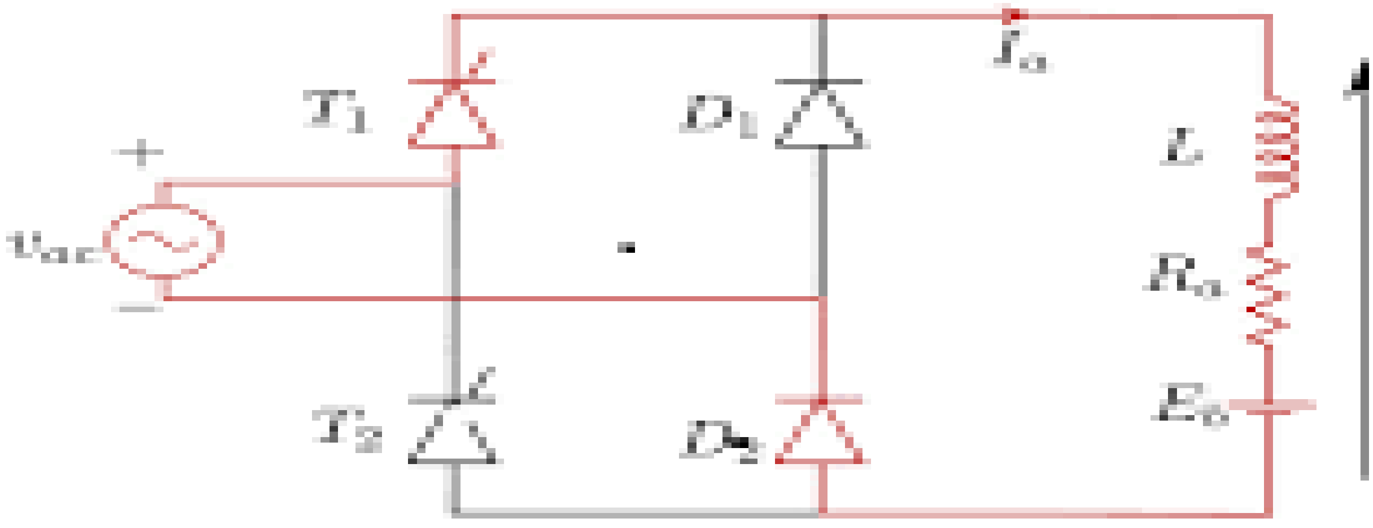
Selection of motor for particular applications

- Economical Operation: can work continuously and take the place of 2 or more laborers
- Dependable: always ready to work
- Efficient: efficiency ranges from 65 to 95 percent
- Long Life: 20 to 30 years with proper care
- Ease of Operation: special skills not required
- Safe: if properly used

Selection of motor for particular applications

- Low Service Requirement: minimum amount of attention required
- Quiet Operation: when properly applied and installed
- Automation: can be automatically and remotely controlled
- Adaptable: light, compact, easily moved
- Available: throughout the country; standard bases, sizes, wiring equipment, etc.

Rectifier Control of Dc Series motor



Rectifier Control of Dc Series motor

- Vmsinωt=Raiaω+Ladia/dt+f(ia)ωm ,α<=ω<=π
- 0=Raia+Ladia/dt+f(ia)ωm, for π<=wt<=(π+α)
- Ea=Kaωm
- Ka=f(Ia)
- Va=Ea+IaRa
- Ωm=(Va-IaRa)/ka
- T=kaIa

Supply harmonics, power factor and ripples in motor current

- Rectified fed dc drives have the following drawbacks:
- Distortion of supply:
- source current of rectifier has harmonics.In a weak AC source
- ,with high internal impedance, current harmonics distort source voltage.

Supply harmonics, power factor and ripples in motor current

- Low Power Factor:

  Assuming sinusoidal supply voltage,power factor of rectifier can be defined as

  PF=REAL POWER/Apparent power

  $=VICOS\phi 1/Vim$

  therefore

  $(I1/Irms)\cos\phi 1$

Supply harmonics, power factor and ripples in motor current

μ is called the distortion factor and cosϕ1 is the displacement factor.

Ripple in motor current:

The rectifier o/p voltage is not perfect dc but Consists of harmonics in additions to dc component.Therefore , motore current value of also has harmonics in addition to dc component.

The presence of harmonics,makes rms and peak values of motor current higher than average value.

Three Phase Synchronous motor:
Self controlled scheme

- **Self – Controlled synchronous motor drive employing load commucated Thyristor Inverter**:

A self –controlled synchronous motor drive employing a load commutated thyristor inverter is shown below:

In large power drives wound field synchronous motor is used.

Medium power drives also employ permanent magnet synchronous motor.

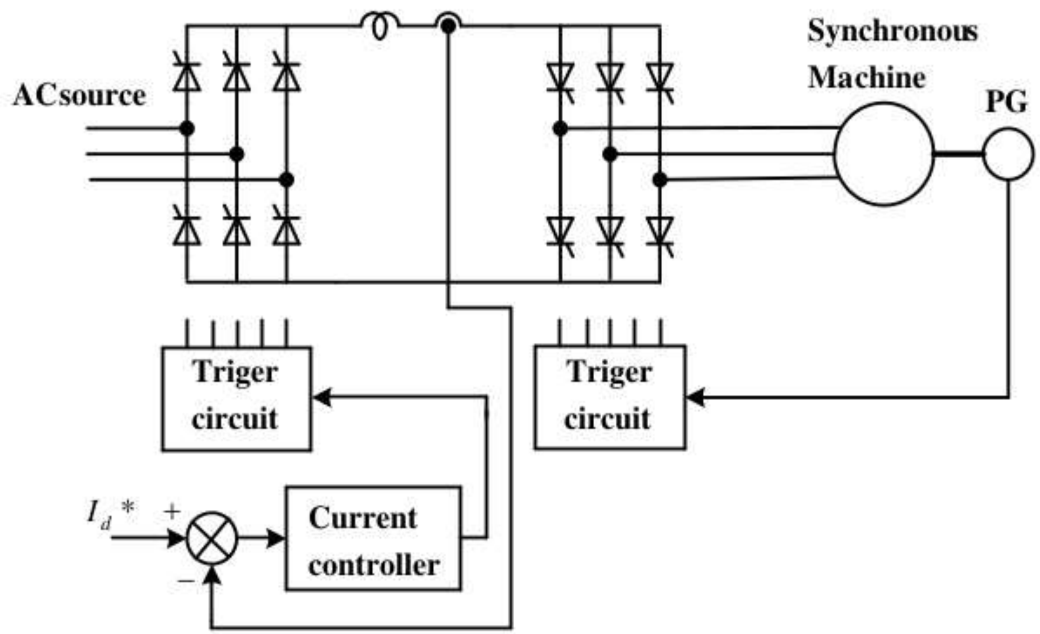
The source side converter is a 6- pulse line commutated thyristor converter.

Three Phase Synchronous motor:
Self controlled scheme

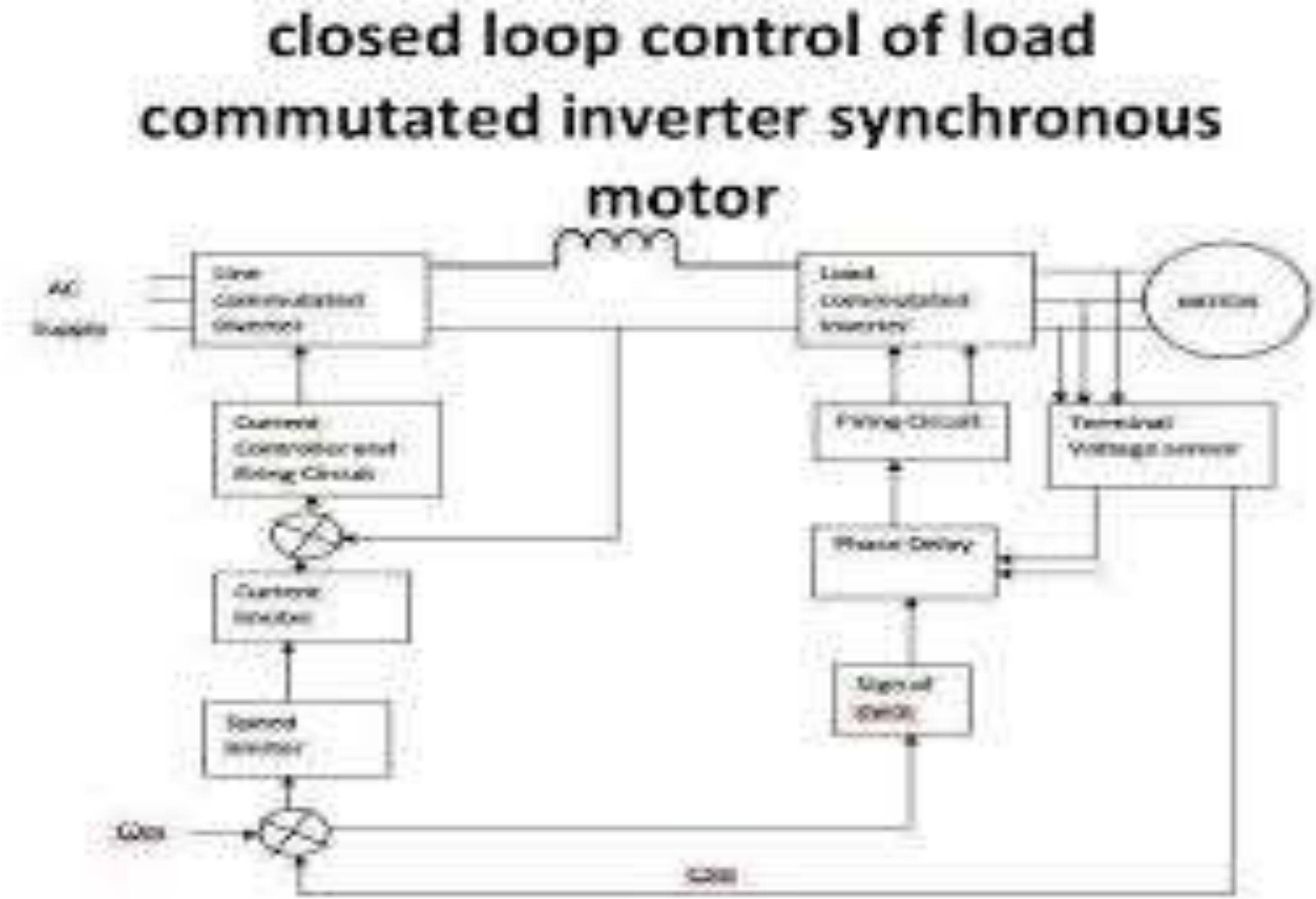
For a firing angle range 0<=αs=<=90 ,it works as a line commutated fully controlled rectifierdelivering positive vds andpositive Id and for the range of firing angle 90<=αs<=180 ,it works as aline commutated inverter delivering negatives and positive Id.

Three Phase Synchronous motor: Self controlled scheme

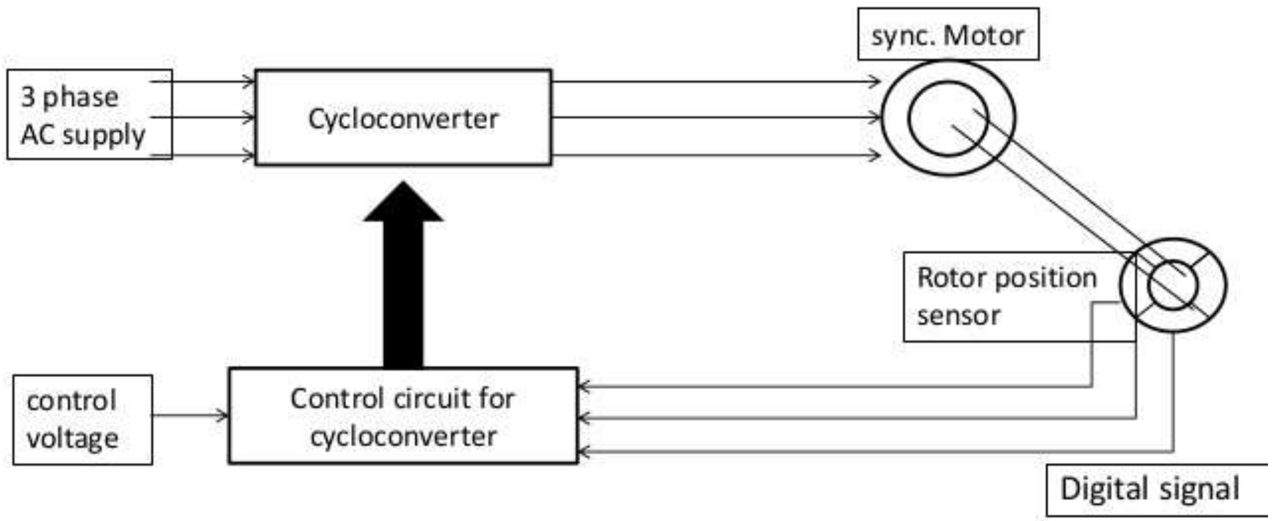
Synchronous Motor Drives



Closed loop control of load commutated inverter synchronous



Self –Controlled synchronous motor Drive employing a cycloconverter



Self controlled sync. Motor drive using a cycloconverter

Dynamics During Breaking

- **Dynamic braking** is the use of the electric traction motors of a railroad vehicle as generators when slowing the locomotive. It is termed*rheostatic* if the generated electrical power is dissipated as heat in brake grid resistors, and *regenerative* if the power is returned to the supply line.

- Dynamic braking lowers the wear of friction-based braking components, and additionally regeneration can also lower energy consumption. Dynamic braking can also be used on railcars with multiple units, light rail vehicles, trams and PCC streetcars.

Dynamics During Breaking

- When braking, the motor fields are connected across either the main traction generator (diesel-electric locomotive) or the supply (electric locomotive) and the motor armatures are connected across either the brake grids or supply line. The rolling locomotive wheels turn the motor armatures, and if the motor fields are now excited, the motors will act as generators.

- During dynamic braking, the traction motors, which are now acting as generators, are connected to the braking grids (large resistors), which put a large load on the electrical circuit. When a generator circuit is loaded down with resistance, it causes the generators to slow their rotation. MPH).

Dynamics During Breaking

- By varying the amount of excitation in the traction motor fields and the amount of resistance imposed on the circuit by the resistor grids, the traction motors can be slowed down to a virtual stop (approximately 3-5 MPH).

Dynamics During Breaking

- For permanent magnet motors, dynamic braking is easily achieved by shorting the motor terminals, thus bringing the motor to a fast abrupt stop.

- This method, however, dissipates all the energy as heat in the motor itself, and so cannot be used in anything other than low-power intermittent applications due to cooling limitations.

- It is not suitable for traction applications.

Single Phase Half controlled rectifier control of dc separately excited motor

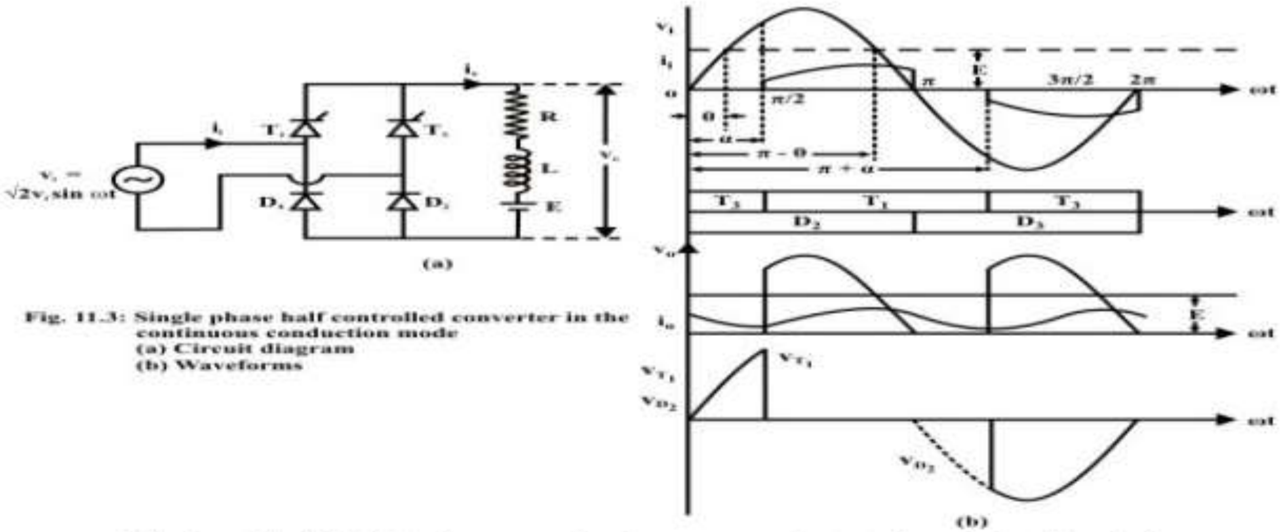


Fig. 11.3: Single phase half controlled converter in the continuous conduction mode
(a) Circuit diagram
(b) Waveforms

Referring to Fig 11.3 (b) T_1 D_2 starts conduction at $\omega t = \alpha$. Output voltage during this period becomes equal to v_i. At $\omega t = \pi$ as v_i tends to go negative D_4 is forward biased and the load current commutates from D_2 to D_4 and freewheels through D_4 and T_1. The output voltage remains clamped to zero till T_3 is fired at $\omega t = \pi + \alpha$. The T_3 D_4 conduction mode continues upto $\omega t = 2\pi$. Where upon load current again free wheels through T_3 and D_2 while the load voltage is clamped to zero.

From the discussion in the previous paragraph it can be concluded that the output voltage (hence the output current) is periodic over half the input cycle. Hence

$$V_{oav} = \frac{1}{\pi}\int_{\alpha}^{\pi} v_o \, d\omega t = \frac{1}{\pi}\int_{\alpha}^{\pi} \sqrt{2} V_i \sin \omega t \, d\omega t = \frac{\sqrt{2} V_i}{\pi}(1 + \cos\alpha) \quad (11.1)$$

$$I_{oav} = \frac{V_{oav} - E}{R} = \frac{\sqrt{2} V_i}{\pi R}(1 + \cos\alpha - \pi \sin\theta) \quad (11.2)$$

Single Phase fully controlled rectifier control of dc separately excited motor

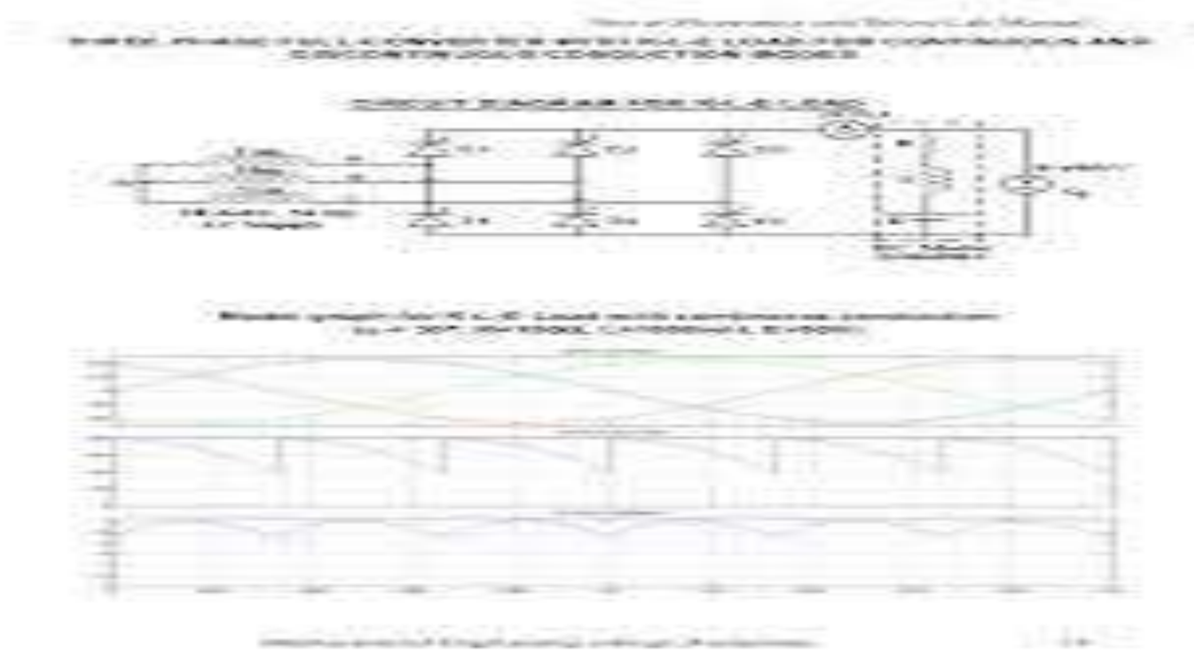
- **Conduction mode**:
- $$V_a = \frac{1}{\pi}\int_{\pi}^{\pi+\alpha} V_m \sin\omega t \, d(\omega t) = (2V_m/\pi)\cos\alpha$$

$$\omega_m = \frac{2V_m}{\pi K}\cos\alpha - (R_a/K^2)T$$

$$\omega_{m0} = V_m/K \quad , 0 <= \alpha <= \pi/2$$

$$V_m \sin\alpha / K , \quad \pi/2 <= \alpha <= \pi$$

Three Phase fully controlled rectifier control of dc separately excited motor



UNIT-5

(Power Electronic Control of AC Drives)

Introduction: AC Motor Drives

- These power controllers, which are relatively complex and more expensive, require advanced feed-back control techniques such as model reference, adaptive control, sliding mode control, and field-oriented control.
- However, the advantages of ac drives outweigh the disadvantages. There are two types of ac drives:
  - Induction motor drives
  - Synchronous motor drives
- Ac drives are replacing dc drives and are used in many industrial and domestic applications.

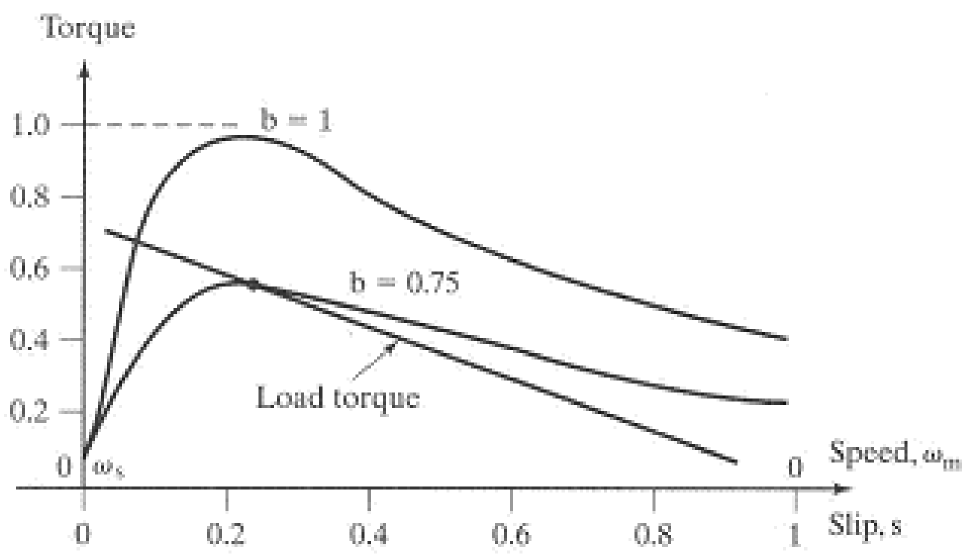
Induction Motor Drives: Stator Voltage Control

Equation (16.18) indicates that the torque is proportional to the square of the stator supply voltage and a reduction in stator voltage can produce a reduction in speed. If the terminal voltage is reduced to bV_s, Eq. (16.18) gives the developed torque

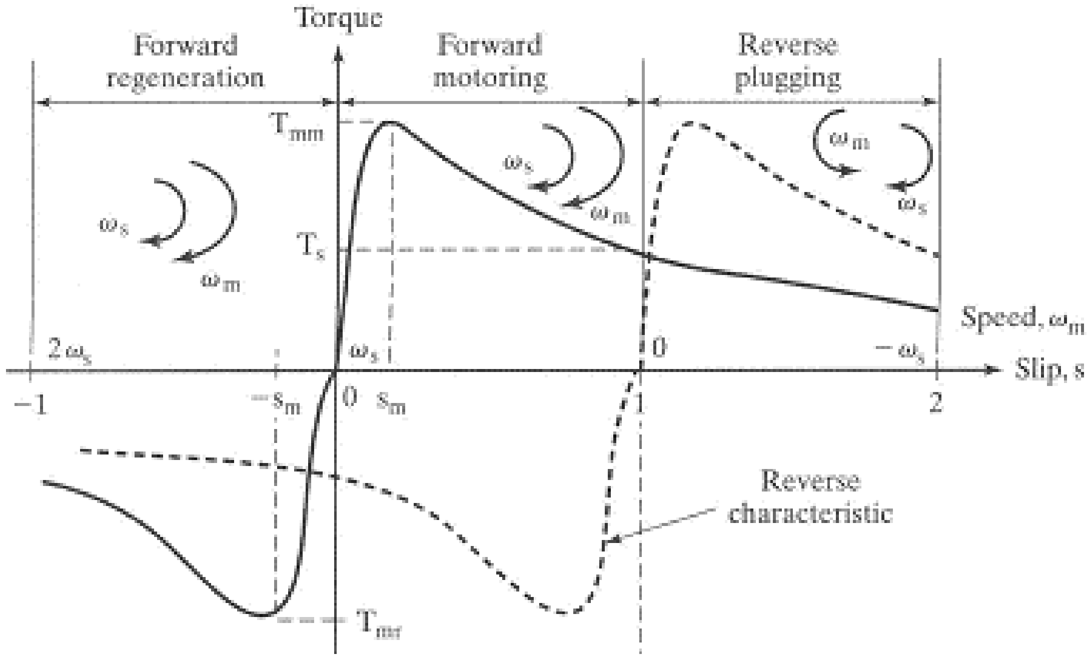
$$T_d = \frac{3R_r'(bV_s)^2}{s\omega_s[(R_s + R_r'/s)^2 + (X_s + X_r')^2]}$$

where $b \le 1$.

Figure 16.4 shows the typical torque–speed characteristics for various values of b. The points of intersection with the load line define the stable operating points.



Induction Motor Drives



- The speed and torque of induction motors can be controlled by
  - Stator voltage control
  - Rotor voltage control
  - Frequency control
  - Stator voltage and frequency control
  - Stator current control
- To meet the torque-speed duty cycle of a drive, the voltage, current, and frequency control are normally used.

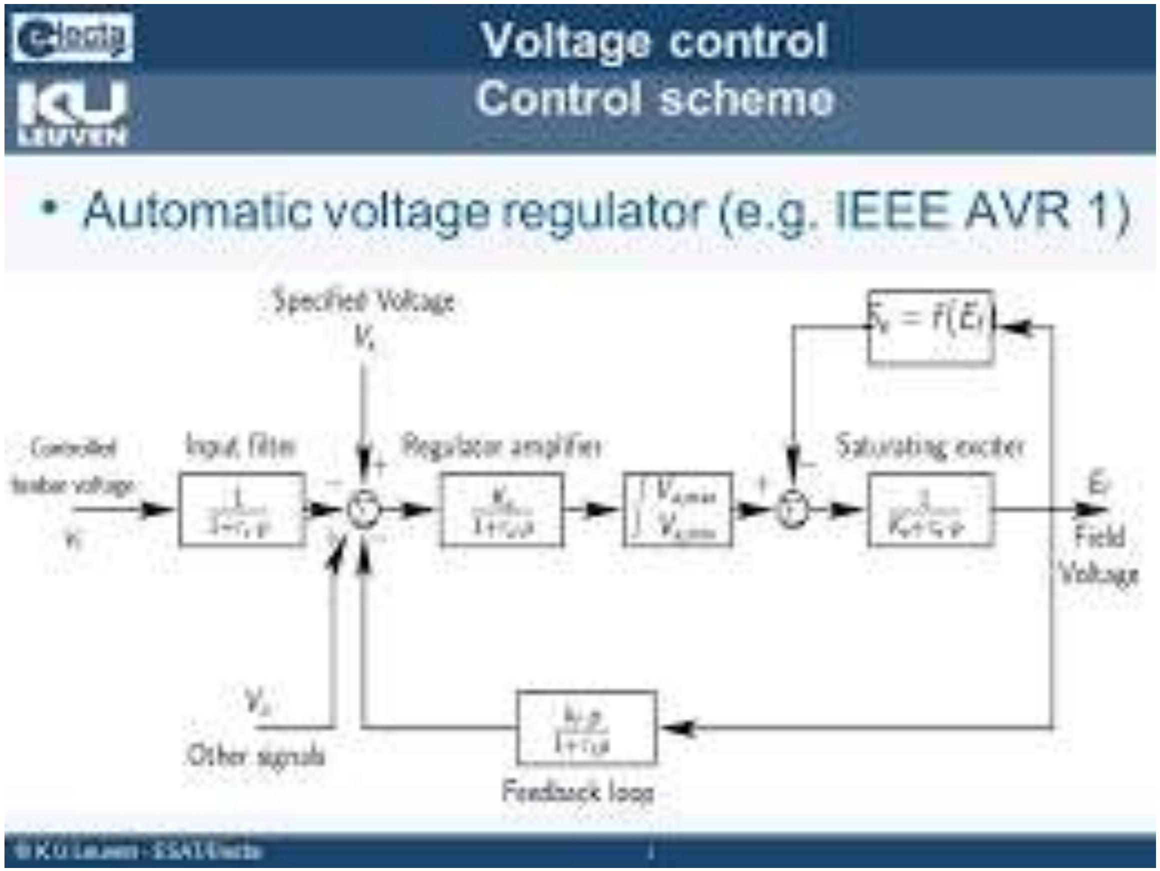
Introduction: AC Motor Drives

- Ac motors exhibit highly coupled, nonlinear, and multivariable structures as opposed to much simpler decoupled structures of separately excited dc motors.
- The control of ac drives generally requires complex control algorithms that can be performed by microprocessors or microcomputers along with fast-switching power converters.
- The ac motors have a number of advantages; they are lightweight (20 to 40% lighter than equivalent dc motors), are inexpensive, and have low maintenance compared with dc motors.
- They require control of frequency, voltage, and current for variable-speed applications.
- The power converters, inverters, and ac voltage controllers can control the frequency, voltage, or current to meet the drive requirements.

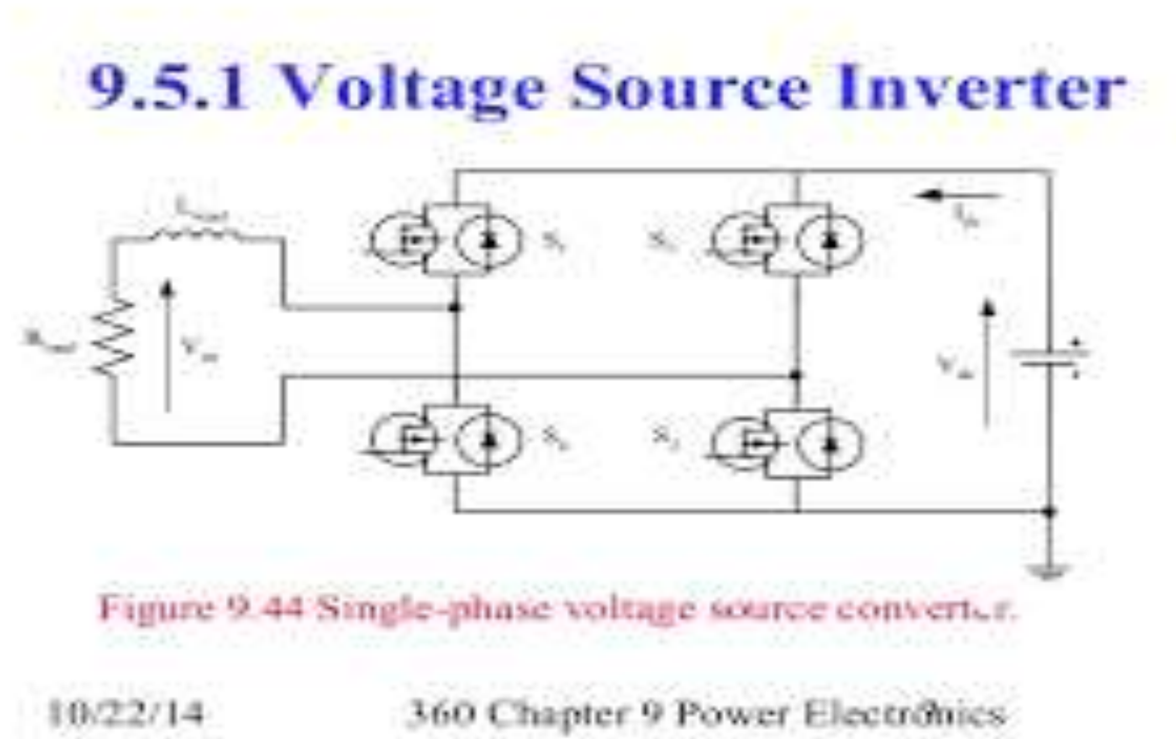
Induction Motor Drives: Rotor Voltage Control

- This method increases the starting torque while limiting the starting current.
- However, this is an inefficient method and there would be imbalances in voltages and currents if the resistances in the rotor circuit are not equal.
- A wound-rotor induction motor is designed to have a low-rotor resistance so that the running efficiency is high and the full-load slip is low.
- The increase in the rotor resistance does not affect the value of maximum torque but increases the slip at maximum torque.
- The wound-rotor motors are widely used in applications requiring frequent starting and braking with large motor torques (e.g., crane hoists).
- Because of the availability of rotor windings for changing the rotor resistance, the wound rotor offers greater flexibility for control.
- However, it increases the cost and needs maintenance due to slip rings and brushes.
- The wound-rotor motor is less widely used as compared with the squirrel-case motor.

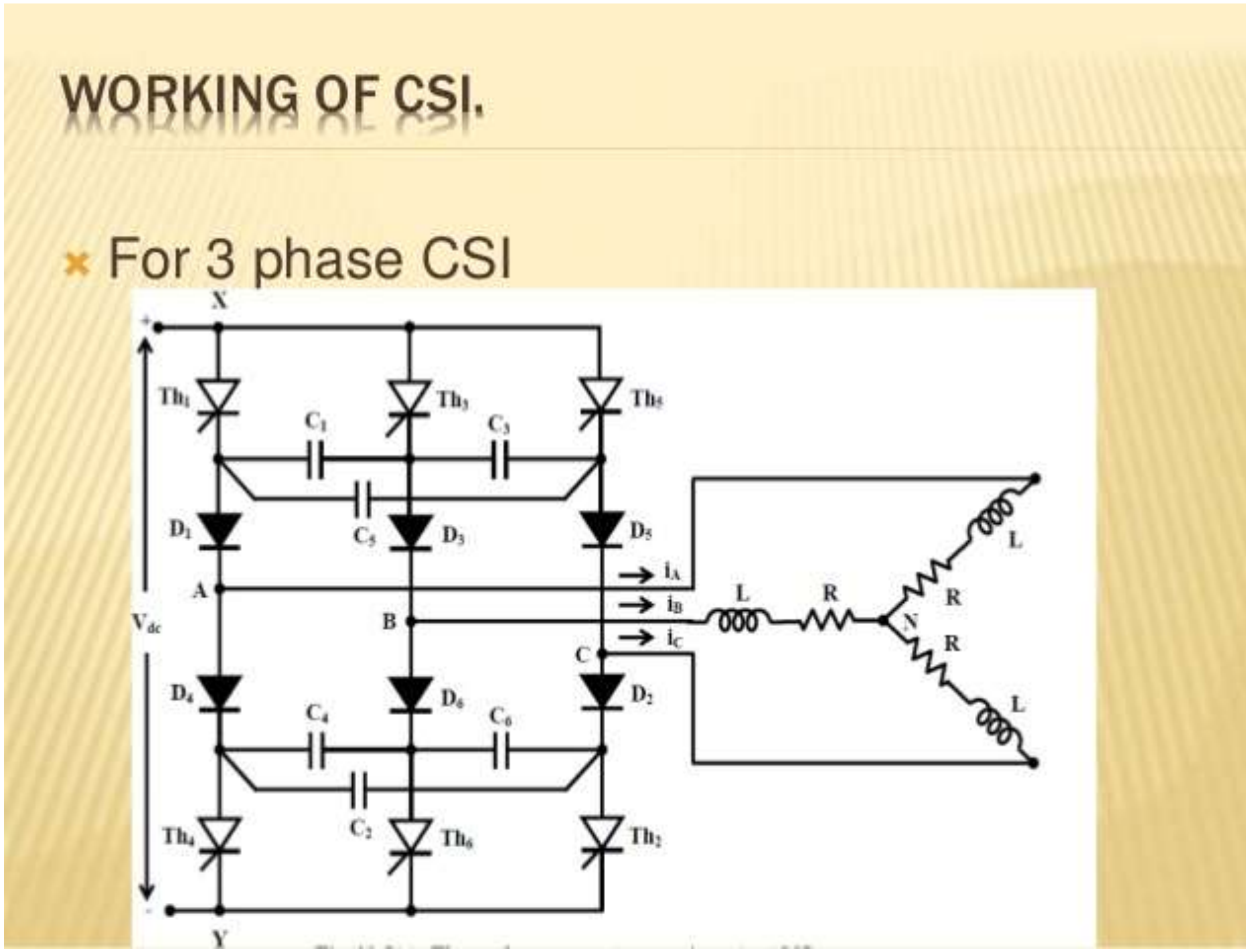
Voltage control Scheme



Frequency control Scheme



Static Frequency control scheme



Static Frequency control Scheme