A Course Material on

ELECTRICAL DRIVES & CONTROL

EE6361 ELECTRICAL DRIVES AND CONTROL

Unit-I Introduction

Basic elements-types of electric drives-factors influencing electric drives-heating and cooling curves-loading conditions and classes of duty-Selection of power rating for drive motors with regard to thermal overloading and load variation factors

Unit-II Drive motor characteristics

Mechanical characteristics- speed- torque characteristics of various types of load and drive motors -braking of electrical motors-dc motors: shunt, series, compound motors-single phase and three phase induction motors

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Unit-V Conventional and solid state speed control of AC drives

Speed control of three phase induction motor-Voltage control, voltage/frequency control, slip power recovery scheme-using inverters and AC voltage regulators-applications

TEXT BOOKS

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1		**INTRODUCTION TO ELECTRICAL DRIVES**	

UNIT-I
INTRODUCTION

- Basic elements
- Types of electric drives
- Factors influencing electric drives
- Heating and cooling curves
- Loading conditions and classes of duty
- Selection of power rating for drive motors with regard to thermal overloading and load variation factors

INTRODUCTION

UNIT 1

1. INTRODUCTION

Drive:

A combination of prime mover, transmission equipment and mechanical Working load is called a drive

Electric drive:

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

1.1 BLOCK DIAGRAM OF AN ELECTRICAL DRIVES

The basic block diagram for electrical drives used for the motion control is shown in the following figure1.1

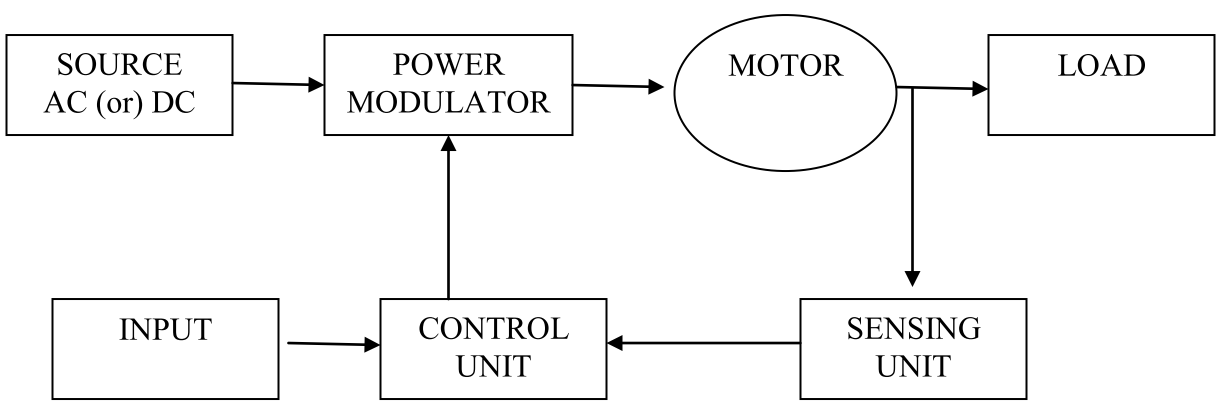


Fig 1.1 Block Diagram for Electrical Drives

The aggregate of the electric motor, the energy transmitting shaft and the control equipment by which the motor characteristics are adjusted and their operating conditions with respect to mechanical load varied to suit practical requirements is called as electric drive.

Drive system=Drive + load

1.1.1 BASIC COMPONENT (or) ELEMENTS OF ELETCRIC DRIVES

Block diagram of electric drive:

1. **Load:** usually a machinery to accomplish a given task. Eg-fans, pumps, washing machine etc.
2. **Power modulator**: modulators (adjust or converter) power flow from the source to the motion
3. **Motor:** actual energy converting machine (electrical to mechanical)
4. **Source:** energy requirement for the operation the system.
5. **Control:** adjust motor and load characteristics for the optimal mode.

Power modulators:

Power modulators regulate the power flow from source to the motor to enable the motor to develop the torque speed characteristics required by the load.

The common function of the power modulator is,

- They contain and control the source and motor currents with in permissible limits during the transient operations such as starting, braking, speed reversal etc.
- They converts the input electrical energy into the form as required by the motors.
- Adjusts the mode of operation of the motor that is motoring, braking are regenerative.

Power modulators may be classified as,

- Converters uses power devices to convert uncontrolled valued to controllable output.
- Switching circuits switch mode of operation
- Variable impedance

Converters

They provide adjustable voltage/current/frequency to control speed, torque output power of the motor.

The various type of converters are,

- AC to DC rectifiers
- DC to DC choppers
- AC to AC choppers
- AC to AC –AC voltage controllers (voltage level is controlled)
- Cyclo converter (Frequency is controlled)
- DC to AC inverters

Switching circuits

Switching circuits are needed to achieve any one of the following.

- Changing motor connection to change its quadrant of operation.
- Changing motor circuits parameters in discrete steps for automatic starting and braking control.
- For operating motors and drives according to a predetermine sequence
- To provide inter locking their by preventing maloperation

- Disconnect under up normal condition

Eg: electromagnetic contacters,
PLC in sequencing and inter locking operation,
solid state relays etc.

Variable impedance

- Variable resisters are commonly used for AC and DC drives and also needed for dynamic braking of drives
- Semiconductors switch in parallel with a fixed resistance is used where stepless variation is needed. inductors employed to limit starting current of ac motors.

1.2 FACTORS INFLUENCING THE CHOICE OF ELECTRICAL DRIVES

(i) Nature of electric supply
- ✓ Whether AC or DC supply is to be used for supply

(ii) Nature of the drive
- ✓ Whether the particular motor is going to drive individual machine or a group of machines

(iii) Capital and running cost

(iv) Maintenance requirement

(v) Space ad weight restrictions

(vi) Environment and location

(vii) Nature of load
- ✓ Whether the load requires light or heavy starting torque
- ✓ Whether load torque increases with speed remain constant
- ✓ Whether the load has heavy inertia which may require longer straight time

(viii) Electrical characteristics of motor
- ✓ Starting characteristics,
- ✓ running characteristics,
- ✓ speed control and
- ✓ Braking characteristics

(ix) Size, rating and duty cycle of motors
- ✓ Whether the motor is going to the operator for a short time or whether it has to run continuously intermittently or on a variable load cycle

(x) Mechanical considerations
- ✓ Type of enclosures, type of bearings, transmission of drive and Noise level.
- ✓ Due to practical difficulties, it may not possible to satisfy all the above considerations.
- ✓ In such circumstances, it is the experience and knowledge background which plays a vital role in the selection of the suitable drive.

The following points must be given utmost important for the selection of motor. The factors are:

- Nature of the mechanical load driven
- Matching of the speed torque characteristics of the motor with that of the load
- Starting conditions of the load.

1.3 CLASSIFICATION OF ELECTRIC DRIVES WITH FACTOR

The choice of the electric drives

There are three classification namely
- ✓ grope drive
- ✓ individual drive
- ✓ multimotor drive

1.3.1 Group drive

One motor is used as a drive for two or more than machines. The motor is connected to a long shaft. All the other machines are connected to this shaft through belt and pulleys**.**

Advantages:

- Grope drive is most economical because, the rating of the motor used may be comparatively less than the aggregate of the individual motors required to drive each equipment, because all of they may not be working simultaneously.
- Grope drive reduces the initial cost of installing a particular industry.
- Cost is less because of investment in one motor which is lesser in HP rating.

Disadvantages:

The use of this kind of drive is restricted due to the following reasons:
- It is not possible to install any machine as per our wish. so, flexibility of lay out is lost.
- The possibility of installation of additional machines in an existing industry is limited.
- In case of any fault to the main driving motor, all the other motors will be stopped immediately.
- so, all systems will remain idle and is not advisable for any industry.
- Level of noise produced at the site is high.
- Because of the restrictions in placing other motors, this kind of drive will result in untidy appearance, and it is also less safe to operate.
- Since all the motors has to be connected through belts and pulleys, large amount of energy is wasted in transmitting mechanisms. Therefore, power loss is high.

1.3.2 Individual drive

In this drive, there will be a separate driving motor for each process equipment.

One motor is used for transmitting motion to various parts or mechanisms belonging to signal equipment.

Ex: Lathe

One motor used in lathe which rotates the spindle, moves feed with the help of gears and imparts motion to the lubricating and cooling pumps).

Advantages:

- Machines can be located at convenient places.
- Continuity in the production of the processing industry is ensured to a high level of reliability.
- If there is a fault in one motor, the effect on the production or output of the industry will not be appreciable.

Disadvantages:

- Initial cost is very high.

1.3.3. Multimotor drive

In this type of drive, separate motors are provided for actuating different parts of the driven mechanism.

Ex: cranes, drives used in paper mills, rolling mills etc.,

In cranes, separate motors are used for hoisting, long travel motion and cross travel motion.

1.4 LOAD CONDITIONS IN MOTOR

The load requirements are in either of

- Speed control
- Torque control

Depending upon the load requirements the motor has to be chosen.

For example in traction system the load (traction network) needs high starting torque (initiali.e.,high current value is needed at t6he start. A series motor provides a high starting torque as .Hence series motor should be chosen for traction system.

1.4.1 Classification of loads

- Torque dependent on speed
  (Ex-hoists, pumping of water or gas against constant pressure)
- Torque linearly dependent on speed
  (Ex- motor driving a DC generator connected to a fixed resistance load [generator field value is kept constant])
- Torque proportional to square of speed
  (Ex- fans, sentrifugal pumps, propellers)
- Torque inversely proportional to speed
  (Ex-milling and boring, machines)

1.4.2 Different type of industrial loads

There are three types of industrial loads under which electric motors are required to work. they are

- Continuous load

- Intermittent load
- Variable or fluctuating load

- **Continuous load**
  - Load is continuous in nature
  - Ex- Pumps or fans require a constant power input to keep them operating**.**

- **Intermittent load**
  - This type classified in to two types
  - Motor loaded for short time and then shunt off for sufficiently longer duration temperature is brought to the room temperature

    Eg: kitchen mixie.

  - The electrical loss is more due to constant ON/OFF delay period
  - Moor loaded for short time and shunt off for short time .
  - Here the motor cannot be cooled down to the room temperature comparison of the two methods it can be Inferred.
  - The temperature level of motor is not brought to the room temperature.

1.5 HEATING AND COOLING CURVES

A machine can be considered as a homogeneous body developing heat internally at uniform rate and dissipating heat proportionately to its temperature rise,

RELATION SHIP BETWEEN TEMPERATURE RISE AND TIME

Let,

P =heat developed, joules/sec or watts
G =weight of active parts of machine, kg
h =specific heat per kg per deg cell
S = cooling surface, m2
λ = specific heat dissipation (or) emissivity, J per sec per m^2 of Surface per deg cell difference between surface and ambient cooling medium
θ = temperature rise, deg cell
θ_m =final steady temperature rise, deg cell
t =time, sec
τ =heating time constant, seconds
τ' =cooling time constant, seconds

Assume that a machine attains a temperature rise after the lapse of time t seconds.
In an element of time "dt" a small temperature rise "d" takes place.

Then,

Heat developed = p.dt
Heat developed = Gh.dθ
Heat dissipated = S$\theta\lambda$.dt

Therefore, total heat developed=heat stored + heat dissipated

$$Ghd\theta + S\,\theta\lambda.dt = p.dt$$

$$\frac{d\theta}{dt} + \theta.\frac{s\lambda}{Gh} = \frac{p}{Gh}$$

This is a differential equation and solution of this equation is,

$$\theta = \frac{p}{s\lambda} + ke^{-(s\lambda/Gh)t}$$

Where k is a constant of integration determined by initial conditions.

Let the initial temperature rise to be zero at t=0.

$$\text{Then, } 0 = \frac{p}{s\lambda} + k$$

$$k = \frac{-p}{s\lambda}$$

Hence, $\theta = \frac{p}{s\lambda}(1 - e^{-(\frac{s\lambda}{Gh}t)})$ - - - - - - - - - - - - - (1)

When t= ∞ , $\theta = \frac{p}{s\lambda} = \theta m$, the final steady temperature rise.

Represent $\frac{p}{s\lambda} = \theta m$ and $\frac{Gh}{s\lambda} = \tau$ - - - - - - - - - - - - - -(2)

Equation 1 can be written as

$\theta = \theta m(1 - e^{-1})$ - - - - - - - - - - -- -(3)

Where is called as heating time constant and it has the dimensions of time.

Heating time constant

Heating time constant is defined as the time taken by the machine to attain 0.623 of its final steady temperature rise.

When t= τ ,

$$\theta = \theta m(1 - e^{-1})$$

$$\theta = 0.632\theta m$$

- The heating time constant of the machine is the index of time taken by the machine to attain its final steady temperature rise.

- We know that $\tau = \dfrac{Gh}{s\lambda}$, therefore, the time constant is inversely proportional to has a larger value for ventilated machines and thus the value of their heating time constant is small.

The value of heating time constant is larger for poorly ventilated machines with large or totally enclosed machines, the heating time constant may reach several hours or even days.

- When a hot body is cooling due to reduction of the losses developed in it, the temperature time curve is again an exponential function

$$\theta = \theta_f + (\theta_i - \theta_f)e^{-\frac{t}{\tau}} \quad \text{- - - - - - - - - - - - - (4)}$$

Where,

θ_f =final temperature drop (the temperature at which whatever heat is generated is dissipated)

$\dfrac{p}{s\lambda'}$ = where, λ is rate of heat dissipation while cooling

θ_i = the temperature rise above ambient in the body at time t=0

τ' = cooling time constant= $\dfrac{Gh}{s\lambda'}$

If motor where disconnected from supply during cooling, there would be no losses taking place and hence, final temperature reached will be the ambient temperature.

There fore, θ_f =0 and hence equation (4) becomes

$$\theta = \theta_i e^{\frac{1}{\tau'}}$$

Cooling time constant

At t= τ' , $\theta = 0.368\theta_i$

Cooling time constant is, therefore, defined as the time required cooling the machine down to 0.368 times the initial temperature rise above ambient temperature.

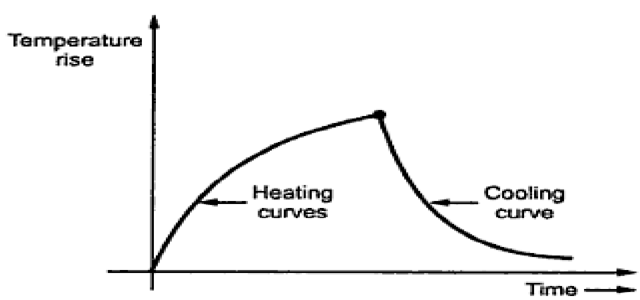


Fig.1.2 Heating and cooling time curves

1.6 CLASSES OF MOTOR DUTY

various load time variations encountered into eight classes as

(i) continuous duty
(ii) short time duty
(iii) intermittent periodic duty
(iv) intermittent periodic duty with starting
(v) intermittent periodic duty with starting & braking
(vi) continuous duty with intermittent periodic loading
(vii) continuous duty with starting & braking
(viii) Continuous duty with periodic speed changes.

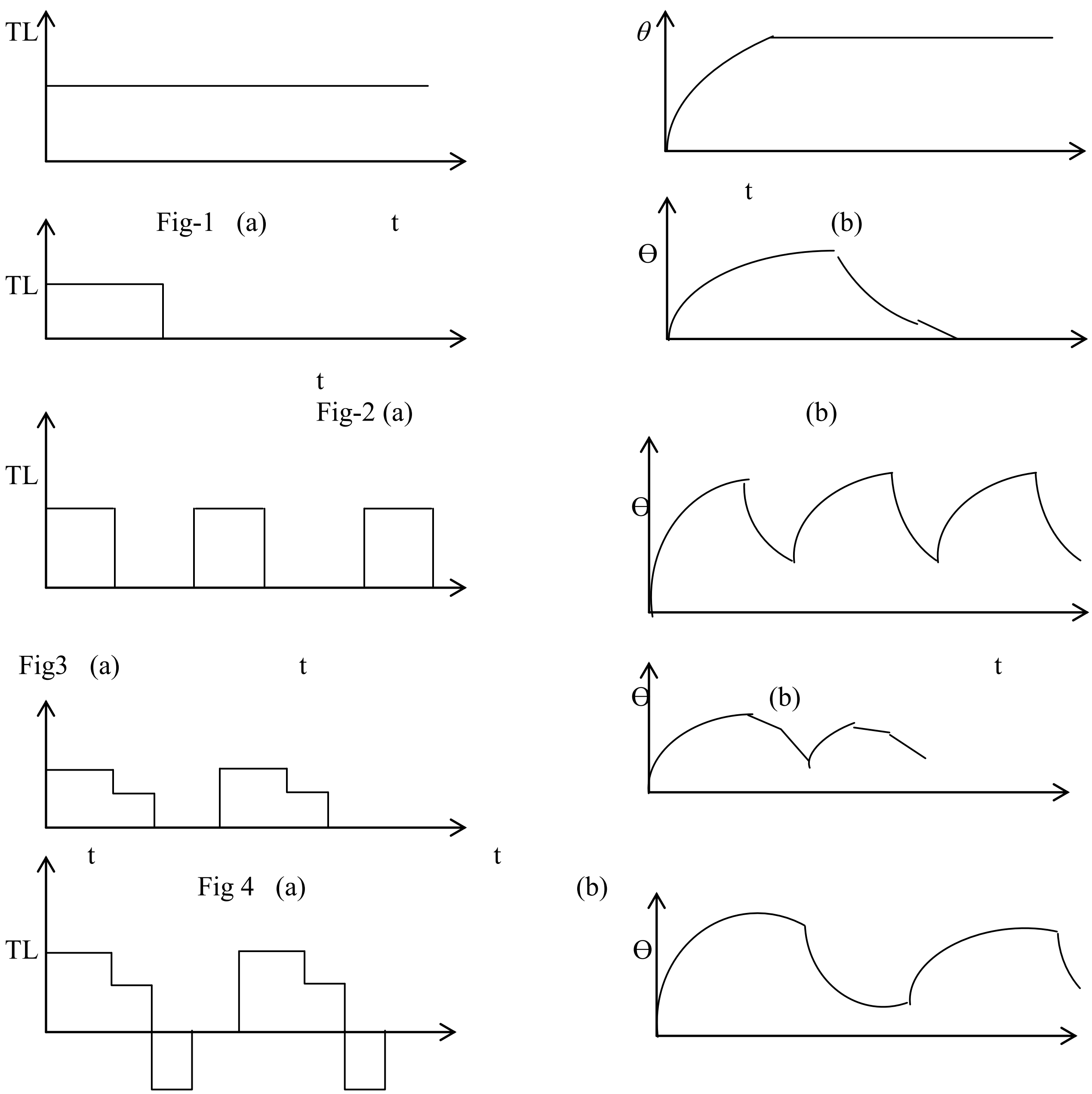


Fig 1.3 Classes of Motor Duty

Where,

TL – Load torque in N-M,
ϴ- Temperature in Deg.centigrade,
t- Time in seconds.

1. Continuous duty:

- This type drive is operated continuously for a duration which is long enough to reach its steady state value of temperature.
- This duty is characterized by constant motor torque and constant motor loss operation. Depicted in fig.1 (a) & (b).
- This type of duty can be accomplished by single phase/ three phase induction motors and DC shunt motors.

Examples:

Paper mill drives ,
Compressors
Conveyors,
Centrifugal pumps and
Fans ,

2. Short time duty:

- In this type drive operation, Time of operation is less than heating time constant and motor is allowed to cool off to room temperature before it is operated again.
- Here the motor can be overloaded until the motor temperature reaches its permissible limit. Depicted in fig.2 (a) & (b).
- This type of duty can be accomplished by single phase/ three phase induction motors and DC shunt motors, DC series motors, universal motors.

Examples:

Crane drives ,
Drives for house hold appliances
Turning bridges
Sluice gate drives
Valve drives and
Machine tool drives.

3. Intermittent periodic duty:

- In this type drive operation, It consists of a different periods of duty cycles
- I.e. a period of rest and a period of running, a period of starting, a period of braking.
- Both a running period is not enough to reach its steady state temperature and a rest period is not enough to cool off the machine to ambient temperature.
- In this type drive operation, heating due to starting and braking is negligible.
- Depicted in fig.3 (a) & (b).
- This type of duty can be accomplished by single phase/ three phase induction motors and DC shunt motors, universal motors.

Examples:

Pressing
Cutting
Drilling machine drives.

4. Intermittent periodic duty with starting:

- This is intermittent periodic duty where heating
- Due to starting can"t be ignored.
- It consists of a starting period; a running period, a braking period & a rest period are being too short to reach their steady state value.
- In this type of drive operation, heating due to braking is negligible.
- Depicted in fig.4 (a) & (b).
- This type of duty can be accomplished by three phase induction motors and DC series motors, DC compound motors, universal motors.

Examples:

Metal cutting,
Drilling tool drives,
Drives for forklift trucks,
Mine hoist etc.

5. Intermittent periodic duty with starting & braking:

- This is an intermittent periodic duty where heating during starting & braking can"t be ignored.
- It consists of a starting period, a running period; a braking period & a rest period are being too short to reach their steady state temperature value.
- Depicted in fig.5 (a) & (b).
- This type of duty can be accomplished by single phase/ three phase induction motors and DC shunt motors, DC series motors, DC compound motors, universal motors.

Examples:

Billet mill drive
Manipulator drive
Ingot buggy drive
Screw down mechanism of blooming mill
Several machine tool drives
Drives for electric suburban trains and
Mine hoist

6. Continuous duty with intermittent periodic loading:

- This type of drive operation consists a period of running at constant load and a period of running at no load with normal voltage to the excitation winding in separately excited machines.
- Again the load and no load periods are not enough to reach their respective temperature limits.
- This duty is distinguished from intermittent periodic duty by running at no load instead of rest period.
- This type of duty can be accomplished by single phase/ three phase induction motors and DC compound motors, universal motors.

Examples:

Pressing
Cutting
Shearing and
Drilling machine drives.

7. Continuous duty with starting & braking:

- It consists a period of starting, a period of running & a period of electrical braking.
- Here period of rest is negligible.
- This type of duty can be accomplished by single phase/ three phase induction motors.

Examples:

The main drive of a blooming mill.

8. Continuous duty with periodic speed changes:

- It consists a period of running in a load with a particular speed and a period of running at different load with different speed which are not enough to reach their respective steady state temperatures.
- Further here is no period of rest.
- This type of duty can be accomplished by single phase/ three phase induction motors and DC series motor in traction.

Examples:

All variable speed drives.

1.7 SELECTION OF POWER RATING OF MOTORS

From the point of view of motor rating for various duty cycles in section 1.6 can be broadly classified as:

- Continuous duty and constant load
- Continuous duty and variable load
- Short time rating

1.7.1 Continuous duty and constant load

If the motor has load torque of T N-m and it is running at ω radians/seconds, if efficiency in η, then power rating of the motor is

$$P = \frac{T\omega}{1000} KW$$

Power rating is calculated and then a motor with next higher power rating from commercially available rating is selected.

Obviously, motor speed should also match load"s speed requirement .It is also necessary to check whether the motor can fulfill starting torque requirement also.

1.7.2 Continuous duty and variable load

- The operating temperature of a motor should never exceed the maximum permissible temperature, because it will result in deterioration and breakdown of insulation and will shorten the service life of motors.
- It is general practice to base the motor power ratings on a standard value of temperature, say 35° c.
- Accordingly, the power given on the name plate of a motor corresponds to the power which the motor is capable of delivering without overheating at an ambient temperature of 35° c. the duty cycle is closely related to temperature and is generally taken to include the environmental factors also.
- The rating of a machine can be determined from heating considerations.
- However the motor so selected should be checked for its overload capacity and starting torque.
- This is because, the motor selected purely on the basis of heating may not be able to meet the mechanical requirements of the basis of heating may not be able to meet the mechanical requirements of the load to be driven by it.
- The majority of electric machines used in drives operate continuously at a constant or only slightly variable load.
- The selection of the motor capacity for these applications is fairly simple in case the approximate constant power input is known
- In many applications, the power input required for a motor is not known before hand and therefore certain difficulties arise in such cases.
- For the determination of ratings of machines whose load characteristics have not been thoroughly studied, it becomes necessary to determine the load diagram i.e., diagram shown the variation of power output versus time.

The temperature of the motor changes continuously when the load is variable. On account of this, it becomes difficult to select the motor rating as per heating.

- The analytical study of heating becomes highly complicated if the load diagram is irregular in shape or when it has a large number of steps.
- Therefore it becomes extremely difficult to select the motor capacity through analysis of the load diagram due to select the motor capacity through analysis of the load diagram due to lack of accuracy of this method.

On the other hand it is not correct to select the motor according to the lowest or highest load because the motor would be overloaded in the first case and under loaded in the second case. Therefore it becomes necessary to adopt suitable methods for the determination of motor ratings.

Methods used

The four commonly used methods are:

- Methods of average losses
- Equivalent current method
- Equivalent torque method
- Equivalent power method

1. Methods of average losses

- The method consists of finding average losses Q_{av} in the motor when it operates according to the given load diagram.
- These losses are then compared with the Q , the losses corresponding to the continuous duty of the machine when operated at its normal rating.
- The method of average losses presupposes that when $Q_{av} = Q_{nomn}$, the motor will operate without temperature rise going above the maximum permissible for the particular class of insulation.
- The figure shows a simple power load diagram and loss diagram for variable load conditions.
- The losses of the motor are calculated for each portion of the load diagram by referring to the efficiency curve of the motor.

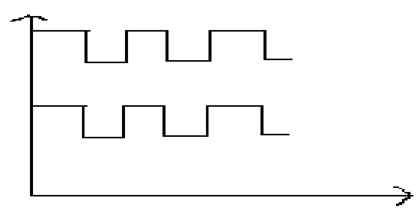


Fig 1.4 Average Load Losses

The average losses are given by

$$Q_{av} = \frac{Q_1 t_1 + Q_2 t_2 + Q_3 t_3 + \ldots\ldots\ldots\ldots + Q_n t_n}{t_{1+} t_2 + \ldots\ldots + t_n}$$

- In case ,the two losses are equal or differ by a small amount ,the motor is selected .if the losses differ considerably ,another motor is selected and the calculations repeated till a motor having almost the same losses as the average losses is found.
- Iit should be checked that the motor selected has a sufficient overload capacity and starting torque.
- The method of average losses dopes not take into account, the maximum temperature rise under variable load conditions .However, this method is accurate and reliable for determining the average temperature rise of the motor during one work cycle.

The disadvantage of this method is that it is tedious to work with and also many a times the efficiency curve is not readily available and the efficiency has to be calculated by means of empirical formula which may not be accurate.

2. Equivalent Current Method

The equivalent current method is based on the assumption that the actual variable current may be replaced by an equivalent current i_{eq} which produces the same losses in the motor as the actual current.

$$I_{eq} = \sqrt{\frac{I_1^2 t_1 + I_2^2 t_2 + I_3^2 t_3 + ...+ I_n^2 t_n}{t_1 + t_2 + t_{3+}..............+ t_n}}$$

The equivalent current is compared with the rated current of the motor selected and the conditions $I_{eq} \leq I_{nom}$ should be met. I_{nom} is the rated current of the machine.

The machine selected should also be checked for its overload capacity,

For DC motors,

$$\frac{I_{\max}}{I_{nom}} \leq 2 to 2.5 and for induction motors, \frac{I_{\max}}{nom} \leq 1.65 to 2.75$$

$I_{\max} = \max imum current during the work cycle.$

$T_{\max} = \max imum load torque$

$T_{nom} = torque of the motor at rated power and speed$

If the over load capacity of the motor selected is not sufficient, it becomes necessary to select a motor of higher power rating.

The equivalent current may not be easy to calculate especially in cases where the current load diagram is irregular .the equivalent current in such cases is calculated from the following expression.

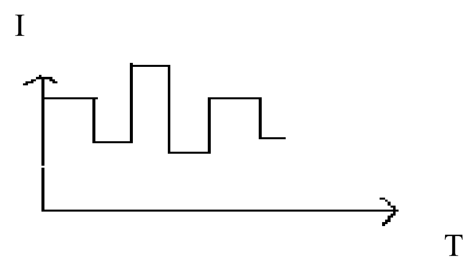


Fig 1.5 Equivalent Current

For a triangular shape diagram,

$$I_{eq} = \sqrt{\frac{I^2}{3}}$$

For a trapezoidal shaped diagram,

$$I_{eq} = \sqrt{\frac{I^2 + I_1 I_2 + I_2^2}{3}}$$

The above method allows the equivalent current values to be calculated with accuracy sufficient for practical purposes.

3. Equivalent torque method

Assuming constant flux and power factor, torque is directly proportional to current.

$$\boxed{T = \sqrt{\frac{T_1^2 t_1 + T_2^2 t_2 + \dots\dots\dots + T_n^2 t_n}{t_1 + t_2 + \dots\dots + t_n}}}$$

4. Equivalent power method

The equation for equivalent power method, power is directly proportional to torque.
At constant speed or where the changes in speed are small, the equivalent power is given by the following relationship,

$$\boxed{P_{eq} = \sqrt{\frac{P_1^2 t_1 + P_2^2 t_2 + \dots\dots\dots + P_n^2 t_n}{t_1 + t_2 + \dots\dots\dots + t_n}}}$$

1.7.3 Short time rating of motor

An electric motor of rated power P_r subjected to its rated load continuously reaches its permissible temperature rise after due to time. If the same motor is to be used for short time duty, it can take up more load for a short period without increasing the maximum permissible temperature of the motor during this period.

$$\theta = \theta_m (1 - e^{\frac{N}{\tau}}) \qquad \theta_m = \theta_m^{'} (1 - e^{-\frac{N}{\tau}})$$

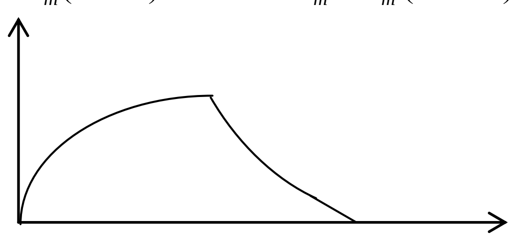


Fig 1.6 Short time motor rating

Where=operating time under rated load

θ_m =maximum permissible temperature which the motor running on short time rating will reach if run continuously at that rating.

θ_m = Maximum permissible temperature rise of the motor run continuously at continuous rating.

If it is assumed that the temperature rise is proportional to losses corresponding to the rating of the motor.

$$\frac{\theta_m'}{\theta_m} = \frac{W_x}{W_r} = \frac{1}{(1-e^{-\frac{N}{\tau}})}$$

The ratings of the motor will be proportional to the losses .If P_x is the short time load P_r is the continuous rating of the motor, losses for continuous rating are,

$$W_r = W_{const} + W_{cu}$$

$$W_x = W_{const+}(\frac{P_x}{P_r})^2 W_{cu}$$

The ratio of $\frac{P_x}{P_r}$ can be determined.

UNIT-II

DRIVE MOTOR CHARACTERISTICS

- Mechanical speed torque characteristics of various types of load and drive motors
- Braking of electrical motors
- Dc motors: shunt, series, compound motors
- Single phase and three phase induction motors

DRIVE MOTOR CHARACTERISTICS

UNIT 2

2.1TYPES OF ELECTRICAL MACHINES

Electrical machines are classified as AC machines and DC machines.

Types of DC machines

1. DC Generator
2. DC Motor

Types of AC machines

1. Transformers
   (a) Single phase (b) three phase
2. Alternators
3. Synchronous motor
4. Induction motor
   (a) Single phase (b) three phase

2.1.1 APPLICATIONS OF DC MOTOR

- **Shunt:** driving constant speed, lathes, centrifugal pumps, machine tools, blowers and fans, reciprocating pumps
- **Series:** electric locomotives, rapid transit systems, trolley cars, cranes and hoists, conveyors
- **Compound:** elevators, air compressors, rolling mills, heavy planners.

2.1.2 CHARACTERISTICS OF DC MOTORS

To select the electric motor for a particular purpose it is necessary to know the characteristics of electric motors. Hence the performance of DC motor can be judged from its characteristics curves.

1. Electrical characteristics

- Torque / Armature current characteristics
- Speed / Armature current characteristics

2. Mechanical characteristics

- Speed / Torque characteristics

2.1.3 TYPES OF ELECTRIC BRAKING

There are three types of electric braking namely,

- Rheostatic or Dynamic braking
- Plugging or counter current braking or reverse current braking
- Regenerative braking

REGENERATIVE BRAKING

- In the regenerative braking operation, the motor operates as a generator, while it is still connected to the supply here, the motor speed is grater that the synchronous speed.
- Mechanical energy is converter into electrical energy, part of which is returned to the supply and rest as heat in the winding and bearing.

DYNAMIC BRAKING

- In this method of breaking, the motor is disconnected from the supply, the field connections are reversed and motor is connected in series with a variable resistance **R.**

PLUGGING

- The plugging operation can be achieved by changing the polarity of the motor there by reversing the direction of rotation of the motor.
- This can be achieved in ac motors by changing the phase sequence and in dc motors by changing the polarity

2.2 DC SHUNT MOTORS

2.2.1 CHARACTERISTICS OF DC SHUNT MOTOR

1. Electrical characteristics

Torque / Armature current characteristics
Speed / Armature current characteristics

2. Mechanical characteristics

Speed / Torque characteristics

Characteristics of dc shunt motor

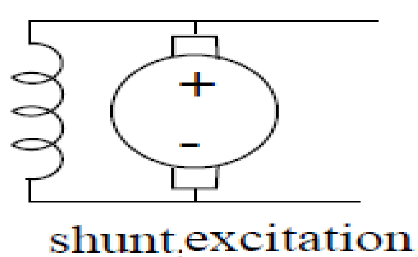


Fig. 2.1 DC Shunt Motor

Torque vs Armature current characteristics.

The torque developed by the dc motor $\boxed{T \alpha Ia}$

In case of dc shunt motors the field excitation current is constant and supply voltage is kept constant. Therefore flux per pole will be constant.

T α Ia

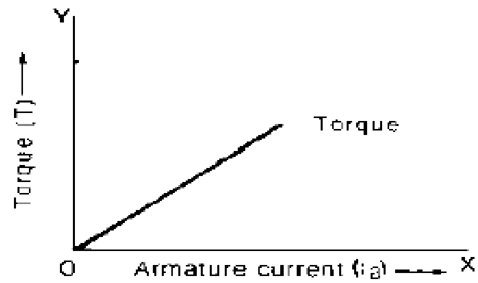


Fig 2.2 T- I Characteristics

- Therefore torque developed in a dc shunt motor will be directly proportional to the armature current. The graph representing the variation of torque with armature current.
- Speed/Armature current characteristics

The back emf equation for dc motor is $\boxed{Eb = PNZ /60A = V- Ia\,Ra}$

Therefore

$$\boxed{N= \frac{V - IaRa}{\phi PZ}60A = \frac{K(V - IaRa)}{\phi}}$$

Where K = 60A/ ZP and it is constant.

- In dc shunt motor, when supply voltage V is kept constant the shunt field current and hence flux per pole will also be constant.

N α V– Ia Ra

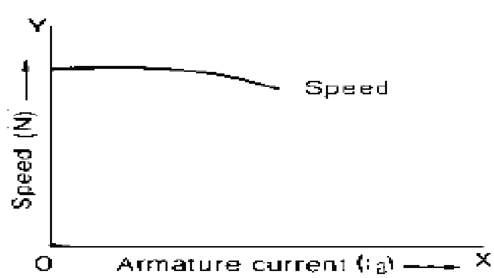


Fig 2.3 N- I Characteristics

- The speeds of the dc shunt motor decreases with increase in armature current due to loading.
- The graph representing variation of speed with armature current is drooping slightly.
- The drop is speed from no load to full load will be about 3 to 6 percent.

- ❖ But the armature reaction effect weakens the field on load and tends to oppose drop in speed so
- ❖ so that the rarely drops by more than about 5 percent from no load to full load.
- ❖ Therefore shunt motor is considered as constant speed motor.

Speed vs Torque characteristics:

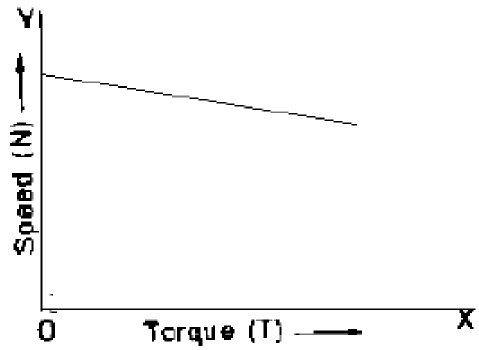


Fig 2.4 N - T Characteristics

- ❖ From the above two characteristics of dc shunt motor, the torque developed and speed at various armature currents of dc shunt motor may be noted.
- ❖ If these values are plotted, the graph representing the variation of speed with torque developed is obtained.

This curve resembles the speed Vs current characteristics as the torque is directly proportional to the armature current.

2.2.2 ELECTRIC BRAKING IN DC SHUNT MOTOR

There are three types of electric braking namely,

- ❖ Rheostatic or Dynamic braking
- ❖ Plugging or counter current braking or reverse current braking
- ❖ Regenerative braking

1. **Electric braking of DC shunt motors**
   - **A. Rheostatic braking**

In this method of braking, the armature is disconnected from the supply and is connected across a variable resistance R.

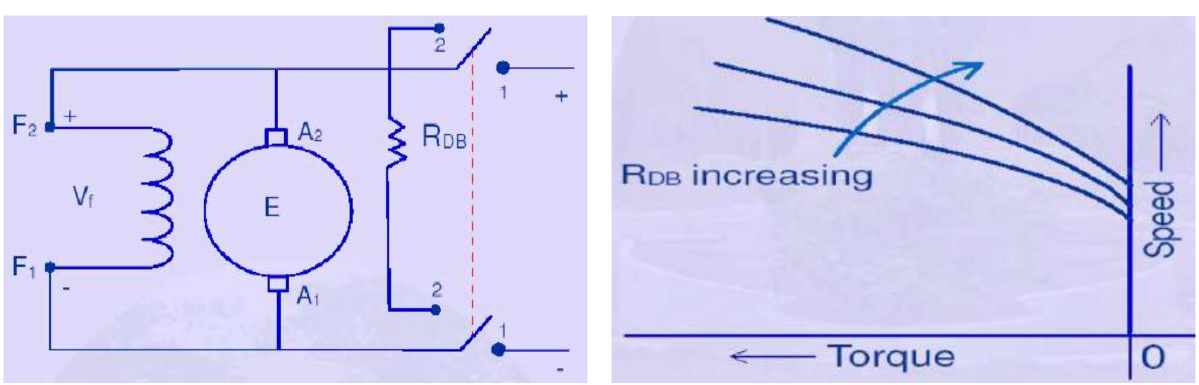


Fig 2.5 Rheostatic braking

The field winding is left connected across the supply and it is undisturbed.
The braking effect is controlled by varying the series resistance R.

Speed-torque characteristics under dynamic braking

- It will be a straight line through the origin in the second quadrant .
- In the first quadrant ,the curve shows that the motor is operating steadily for a given load torque TL at the point A on its natural characteristics.
- The speed no represents ideal no load speed.
- Due to braking the operating point shifts to point B on the characteristics in the II quadrant from point A.
- The motor then decelerates along B O to stand still condition.
- The slope of the braking characteristics in II quadrant can be controlled by varying the braking resistor R.
- Hence, any braking time can be obtained by proper choice of the braking resistor R.

B. Plugging (or) Counter current braking

In this method of breaking, connections to the armature terminals are reversed so that motor tends to run in the opposite direction.

- Due to the reversal of armature connections, both V and E_b start acting in the same direction around the circuit.
- In order to limit the armature current to a safe value, it is essential to insert a resistor in the circuit while reversing the armature connections.
- When compared with rheostat braking, plugging gives better braking torque.
- This method is commonly used for Printing presses, elevators, rolling mills and machine tools.

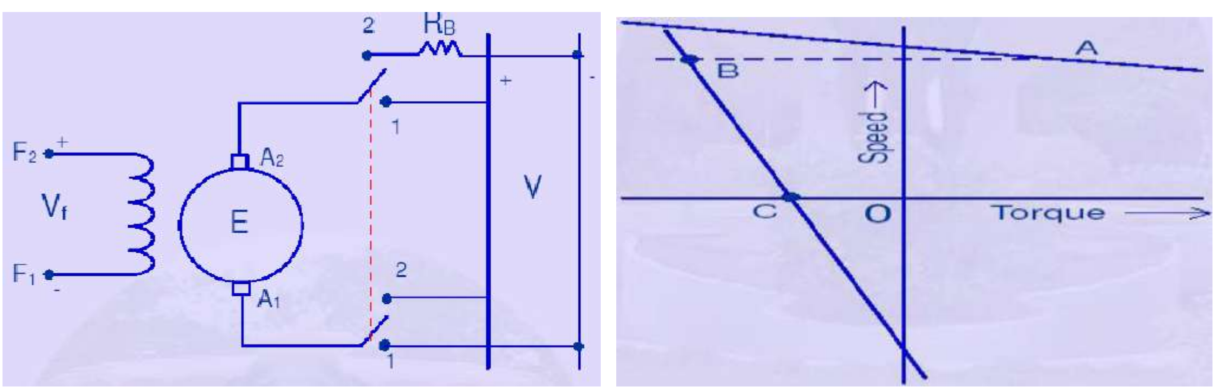


Fig 2.6 Plugging condition and Speed torque characteristics

- Plugging is executed at a time when the motor is operating at the point E characteristics A for a load torque T_L.
- Due to plugging, the operating point shifts to point F on characteristics B as the speed of the motor cannot change instantaneously due to inertia.

- Due to braking torque developed ,the motor decelerates along the characteristics B until the motor stops at GwHEN reversal of rotation is not required, the supply must be switched off when the motor speed becomes very near to zero.
- If the supply is not switched off,the motor will gain speed in the opposite direction along GH on characteristics B .as soon as the direction of the rotation is reversed ,the induced emf in the armature changes its polarity and again acts against the applied voltage so that the drive will rotate in the reverse direction under motoring condition.
- At point H,additional resistance are cut out from the armature circuit and hence the operating point shifts to point I on the natural characteristics C for a load torque,T_L
- If plugging is executed again at the point J,then braking and acceleration in the forward direction will corresponded to J –K-L-M-E.

C. Regenerative braking

This method is used when the load on the motor has overhauling characteristics as in the lowering of the case of a hoist or downgrade motion of electric train.

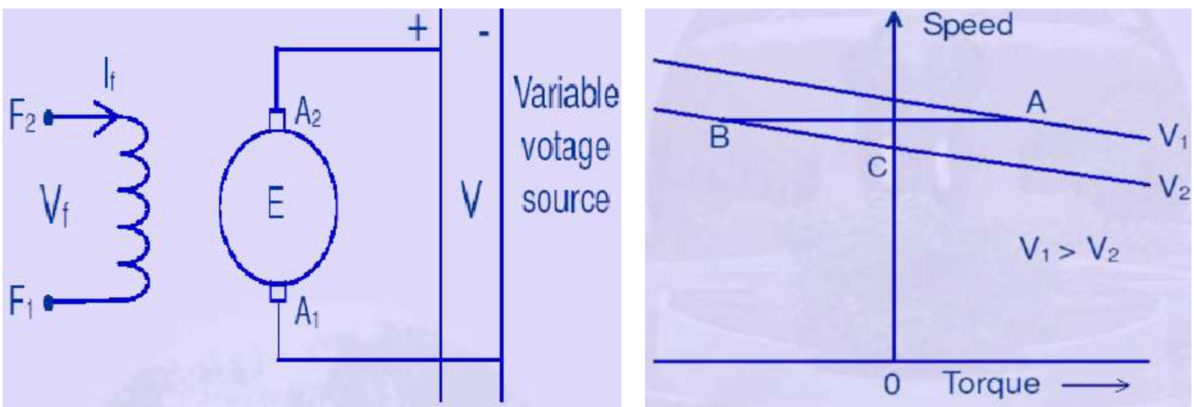


Fig 2.7 Regenerative braking Characteristics and N-T Characteristics

- Regenerative takes place when Eb becomes greater than V.this happens when the overhauling load acts as a prime mover and so drives the machine asa generator.
- Hence ,the direction of Ia and armature torque is reversed and speed falls until eb becomes less than V.
- During slowing down of the motor ,power is returned to the line which may be used for supplying another train on an upgrade motion there by essential to have some type of mechanical braking also in order to hold the load in the event of power failure.

- At zero torque characteristics passes through the point corresponding to ideal no load speed, no as in the case of motoring.
- From the characteristics curves, it is clear that, higher the armature circuit resistance ,the higher is the speed at which the motor has to run for a given braking torque.

2.3 DC SERIES MOTOR

2.3.1 CHARACTERISTICS OF DC SERIES MOTORS

In dc series motors, the load current drawn from the supply passes through both armature and field windings as they are in series.

- Therefore when the load on the motor changes, field flux also changes.
- Hence the characteristics of D.C. series motors entirely differ from the characteristics of D.C. shunt motors.

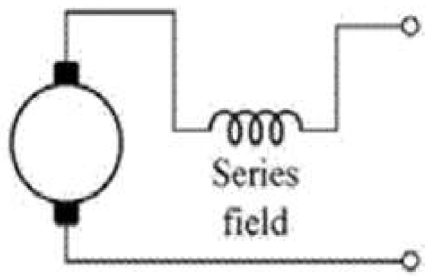


Fig 2.8 DC Series motor

Torque Vs Armature current characteristics

- Torque developed in any dc motor **T α Ia.**

In series motors since field current is equal to armature current.

Therefore,

- When Ia is small, it is proportional to Ia.

Then torque developed in dc series motor **T α Ia^2.**

Therefore

- The torque is proportional to square of the armature current at low values of armature current.

When Ia is large remains constant due to saturation.

Then **T** α **Ia**.

- Therefore torque is proportional to armature current at large values of armature current.

Thus, the torque Vs armature current characteristics begins to rise parabolic ally at low values of armature current and when saturation is reached it becomes a straight line as shown in the following figure.

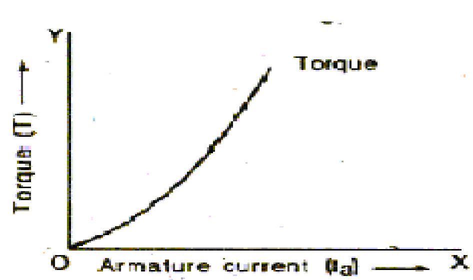


Fig 2.9 T-I characteristics

Speed Vs Armature current characteristics

Consider the speed equation

$$\boxed{\mathbf{N} = \frac{K(V - IaRa)}{\phi}}$$

- When supply voltage V is kept constant, speed of the motor will be inversely proportional to flux.
- In dc series motors field exciting current is equal to armature current which happened to load current.
- Therefore at light loads, when saturation is not attained, flux will be proportional to armature current and hence **speed will be inversely proportional to the armature current**.
- Hence **speed Vs armature current** characteristics of dc series motor will be rectangular hyperbola as shown in the following figure.

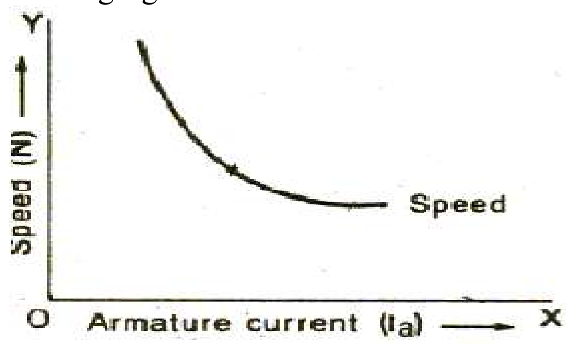


Fig 2.10 N-I characteristics

- As the load on the motor is increased armature current increases and field gets saturated.
- Once field is saturated flux will be constant irrespective of increase in armature current.
- Therefore at heavy loads, speed will be constant.
- This type dc series motor has high starting torque.

Speed Vs Torque characteristics

The speed Vs Torque characteristics of series motor will be similar to the speed Vs armature current characteristics. It will be a rectangular hyperbola as shown in the following figure.

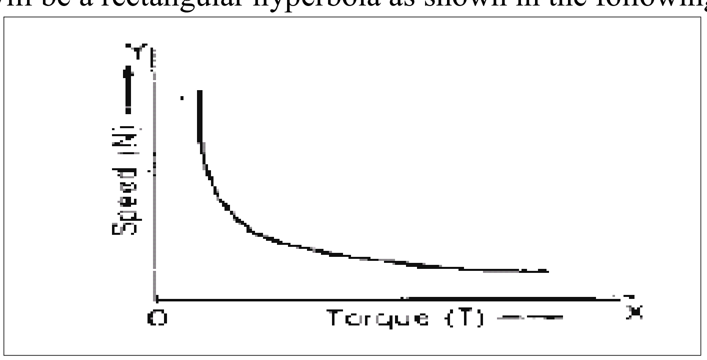


Fig 2.11 N-T characteristics

In dc series motors, torque increases with decrease of speed and they are most suitable for operating cranes, lifts, trains, etc.

2.3.2 ELECTRIC BRAKING IN DC SERIES MOTOR

2. **Electric braking of DC series motor**
   - **D. Rheostatic braking**

In this method of breaking, the motor is disconnected from the supply, the field connections are reversed and motor is connected in series with a variable resistance R as shown in

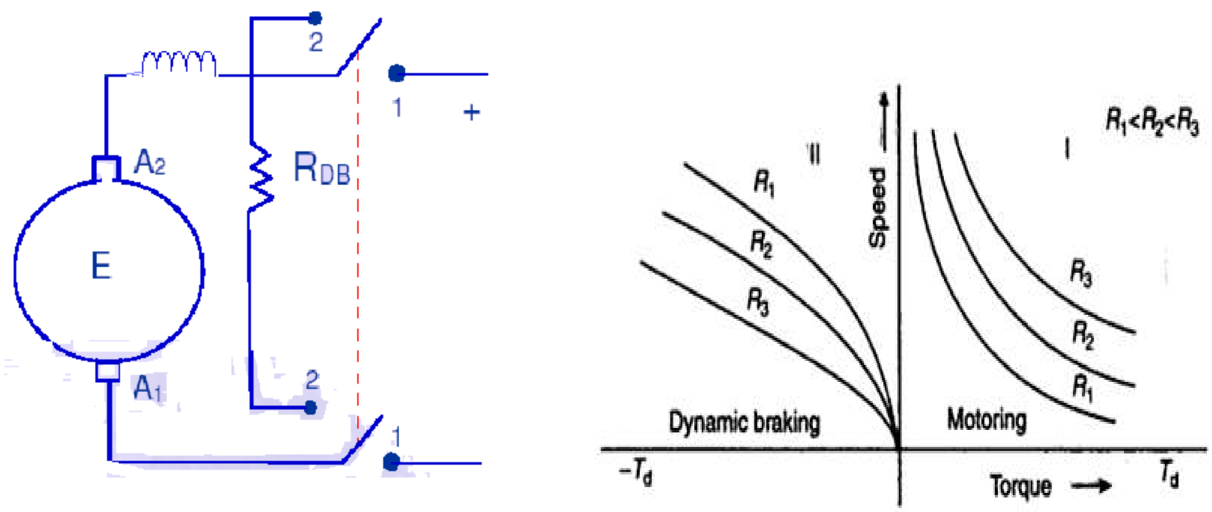


Fig 2.12 Rheostatic braking

- The field connections are reversed to make sure that,the current through the field winding flows in the same direction as before (i.e., from A to B)in order to assist for residual magnetism.
- In practice, the variable resistance used for starting purpose is itself used for braking purposes.
- The speed-torque characteristics of DC series motor during rheostatic braking is shown in the following figure. explanations are similar to rheostatic braking method applied to DC shunt motor.

E. Plugging

In this method of braking, the connections of the armature are reversed and a variable resistance R is put in series with the armature .

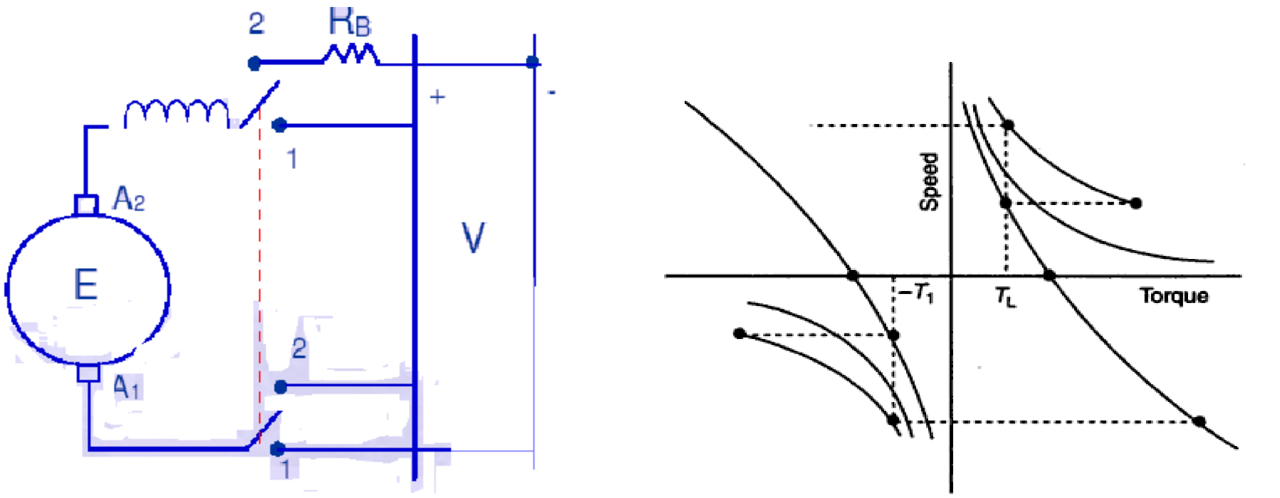


Fig 2.13 Plugging

The above characteristics have been constructed in the same manner as that of plugging conditions applied to DC shunt motor.

F. Regenerative braking

- In DC series motor, regenerative braking is not possible without necessary modifications, because reversal of Ia would result in reversal of field and hence of E_b.
- This method is however used in traction motors with special arrangements.

2.4. COMPOUND DC MOTOR

2.4.1 CHARACTERISTICS OF DC COMPOUND MOTOR

Characteristics of D.C. compound motors:

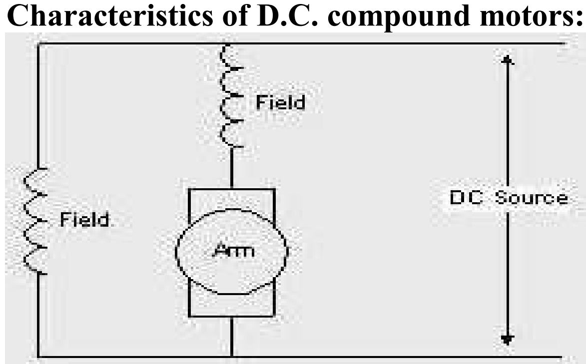


Fig 2.14 Compound DC Motor

- In dc compound motors both shunt field and series field will be acting simultaneously.
- In cumulative compound motors the series field assists the shunt field.
- In such motors when armature current increases the field flux increases.
- So for given armature current the torque developed will be greater and speed lower when compared to a shunt motor.
- In differentially compounded motors the series field opposes the shunt field.
- Therefore when armature current increases the field flux decreases.

- So for given armature current, the torque developed will be lower and the speed greater when compared to shunt motor.

Torque Vs armature current and speed Vs armature current characteristics of dc compound motors are shown in the following figure.

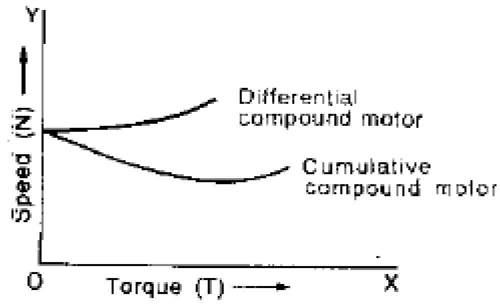


Fig 2.15 speed Vs torque characteristics

The speed Vs torque characteristics are compared with that of shunt motor as shown in the following figure.

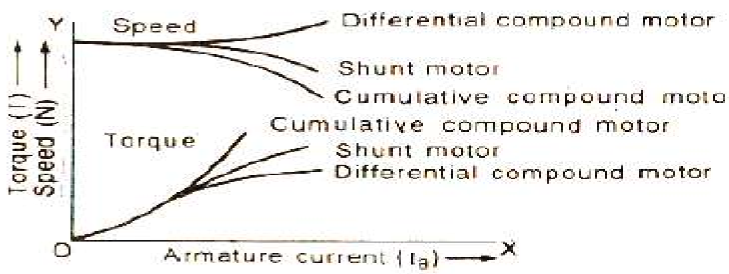


Fig 2.16 speed Vs Current and torque Vs Current characteristics

2.4.2 ELECTRIC BRAKING IN DC COMPOUND

The Dc compound motor has the series as well as the shunt field.

- Regenerative braking
- Dynamic braking
- Counter braking

- In the regenerative braking operation of the compound motor, the direction of the armature and the series field are reversed.
- This may be demagnetized the motor to avoid the demagnetization, the series field winding of the motor is shunt as soon as the speed raises to Wo .

- Therefore the speed torque characteristics of regenerative braking is the straight line.
- The dynamic braking of the compound motor is similar to the dynamic braking of the shunt motor.
- During dynamic braking the armature of the motor is disconnected from the supply and is connected across the braking resister and only the shunt field winding is excited.
- Therefore the field flux is constant.

Counter current braking of the compound motor is similar to the series motor .This is because of the influence of series field winding.

2.5 APPLICATIONS OF DC MOTORS

Type of motor	Characteristics	Applications
shunt	Approximately constant speed. Speed can be controlled. Medium starting torque (Upto 1.5 Full load torque)	For driving constant speed line shafting lathes, centrifugal pumps, machine tools, blowers and fans, reciprocating pumps.
Series	Variable speed. Speed can be controlled. High starting torque.	For traction work i.e. electric locomotives rapid transit systems trolley cars etc. cranes and hoists, conveyors
Cumulative compound	Variable speed Speed can be controlled. High starting torque.	For intermittent high torque loads, for shears and punches, elevators, conveyors, heavy planers, rolling mills, ice machines, printing presses, air compressors

2.6 SINGLE PHASE INDUCTION MOTORS

Why a single phase induction motor does not self start?

- When a single phase supply is fed to the single phase induction motor.
- Its stator winding produces a flux which only alternates along one space axis.
- It is not a synchronously revolving field, as in the case of a 2 or 3phase stator winding, fed from 2 or 3 phase supply.

Types :

The types of single phase induction motors are:

1. Split phase induction motor.
2. Capacitor start induction motor.
3. Capacitor start and capacitor run motor.
4. Shaded pole induction motor.

2.6.1 CONSTRUCTION AND WORKING PRINCIPLE

CONSTRUCTION:

- Similar to a D.C. motor single phase induction motor has basically two main parts one rotating and other stationary.
- The stationary part in single phase induction motors is called stator while the rotating part is called rotor.

- The Stator has laminated construction made up of stampings.
- The stampings are slotted on its periphery to carry the winding called stator winding or main winding. This is excited by a single phase a.c, supply.
- The laminated construction keeps iron losses to minimum.
- The stampings are made up of material like silicon steel which minimizes the hysteresis loss.
- The stator winding is wound for certain definite number of poles means when excited by single phase a.c. supply stator produces the magnetic field which creates the effect of certain definite number of poles.
- The number of poles for which stator winding is wound decides the synchronous speed of the motor.
- The synchronous speed is denoted as N, and it has a fixed relation with supply frequency f and number of poles P. The relation is given by,

$$N_S = \frac{120f}{p} \quad \text{r.p.m}$$

The induction motor never rotates with the synchronous speed but rotates at a speed which is slightly less than synchronous speed.

- The rotor construction is of squirrel cage type.
- In this type rotor consists of un insulated copper or aluminium bars placed in the slots.
- The bars are permanently shorted at both ends with the help of conducting rings called end rings. The entire structure looks like cage hence called squirrel cage rotor.
- The construction and symbol is shown in the Fig. 1
- As the bars are permanently shorted to each other the resistance of the entire rotor is very small.
- The air gap between stator and rotor is kept uniform and as small as possible.
- The main feature of this rotor is that of the stator winding.
- The schematic representation of two pole single phase induction motor is shown in the Fig. 2.

Working Principle:

- For the motoring action there must exists two fluxes which interact with each other to produce the torque.
- In D.C. motors field winding produces the main flux while d.c. supply given to armature is responsible to produce armature flux.
- The main flux and armature flux interact to produce torque.
- In the single phase induction motor single phase a.c. supply is given to the stator winding.
- The stator winding carries an alternating current which produces the flux which is also alternating in nature.
- This flux is called main flux.
- This flux links with the rotor conductors and due to transformer action emf. gets induced in the rotor.
- The induced emf. drives current through the rotor as rotor circuit is closed circuit.
- This rotor current produces another flux called rotor flux required for the motoring action.
- Thus second flux is produced according to induction principle due to induced emf. hence the motor is called induction motor.
- As against this in D.C. motor a separate supply is required to produce armature to flux.
- This is an important difference between d.c motor and an induction motor.

Key Point: Another important difference between the two is that the D.C. motors are self starting while single phase induction motors are not self starting.

2.6.2 TORQUE-SLIP CURVE FOR INDUCTION MOTOR

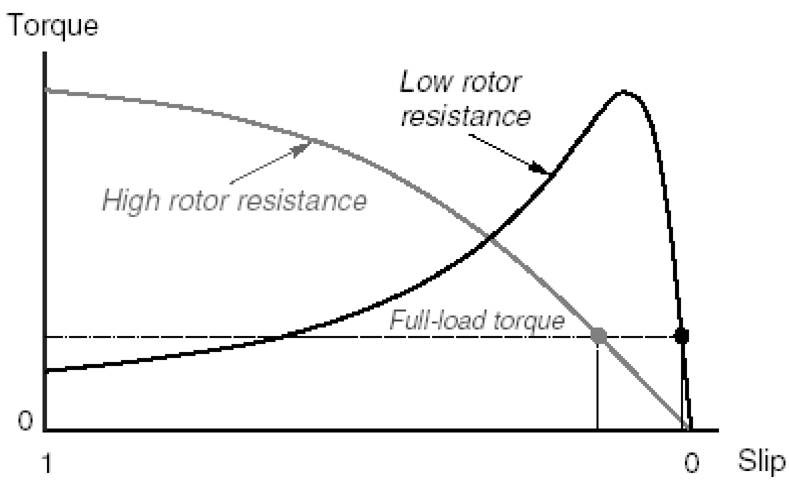


Fig 2.17 T- Slip Characteristics

$$\boxed{\textbf{Torque, T} = \frac{k\phi S E_2^2 R_2}{R_2^2 + (SX_2)^2}}$$

When S = 0, T =0. Hence curve starts from point 0.

At normal speeds, close to synchronism the terms (SX2) is small an hence negligible with respect to R_2.

$$\mathbf{T} \propto \frac{S}{R_2}$$

(Or) $\mathbf{T} \propto \mathbf{S}$. If R_2 is constant.

As slip increases, torque also increases and becomes maximum when

$\mathbf{S} = \frac{R_2}{X_2}$. This torque is known as „Pull out" or „breakdown" torque. Therefore, for large values of slip,

$$\mathbf{T} \propto \frac{S}{(SX_2)^2} \propto \frac{1}{S}$$

Hence, torque/slip curve is a rectangular hyperbola.

2.6.3 ELECTRIC BRAKING IN AC INDUCTION MOTOR

Braking on AC induction motors

- Regenerative braking
- Dynamic braking
- Plugging(op)counter current braking

Regerative braking

In the regerative braking the energy is returned to the supply, is possible if the motor runs faster that its synchronous speed.

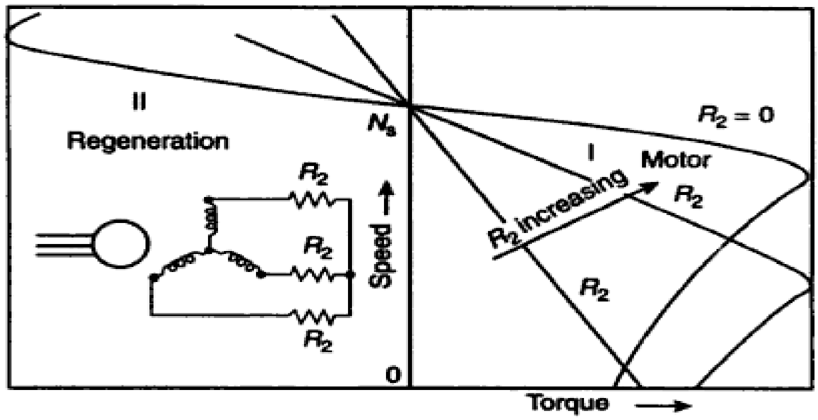


Fig 2.18 Regenerative braking

- The motor torque approach to zero as the motor begins to approach the no load speed i.e the synchronous speed
- The further increase in the motor speed, the motor will acts as a generator ,connected in parallel to the supply and ill return electric energy.
- The regenerative braking operation is represented by the portions of the speed torque characteristics extended into the second quadrant.
- The maximum torque developed on regenerative braking operation will react a higher value than on motoring operation .This can be calculated as below,

$$T_{\max} = \frac{3V^2{}_{ph}}{2\omega_0[R_1 - \sqrt{R_1^{\,2} + (X_1 + X_2)^2}]}$$

The application of this braking are in crane hoists, excavators etc.

Dynamic braking

Dynamic braking of an induction motor is used achieved by switching over its starter to a DC supply and shunting the rotor external resistance.

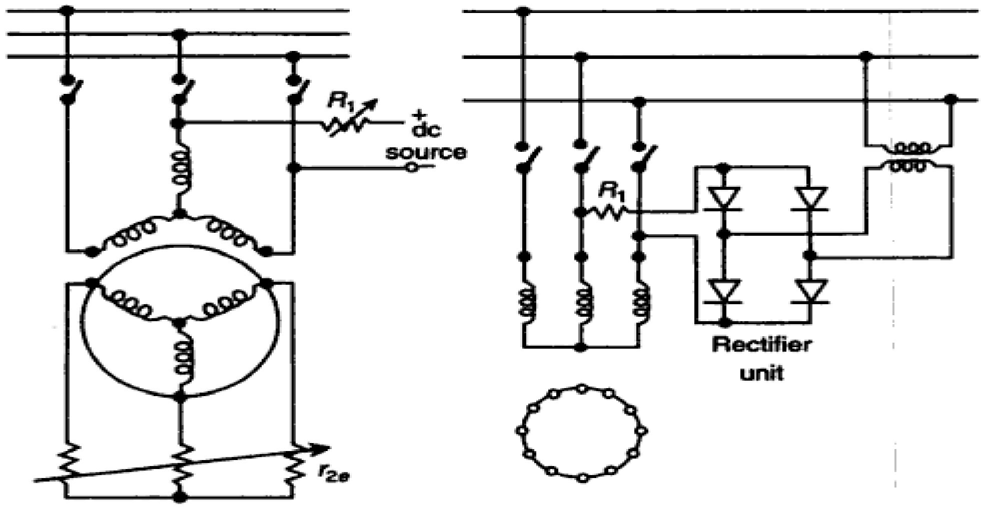
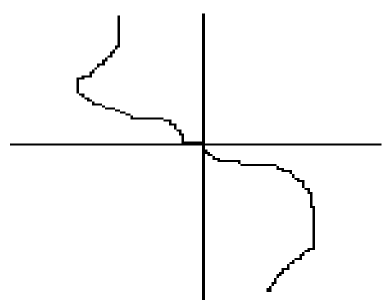


Fig 2.19 Dynamic braking

- To perform dynamic braking the switch Sw1 is opened and cut off a.c apply the DC power. for limiting the current the rotor is connected to a suitable resistor Rb .
- The flow of direct current sent through the starter winding sets up a stationary magnetic flux.
- Rotation of the rotor in this field will produces a flow of induced alternating current in the rotor which also sets up a magnetic field, stationary with respect to the stater.
- Due to the interaction of the resultant magnetic field set up by the stator winding ,the rotor circuit resistance and the speed of the rotor.

Speed torque characteristics of the induction motor under dynamic braking



- The speed torque characteristics of the induction motor under this braking conditions lies in the second quadrant of the speed torque phase.
- If the effect of saturation is neglected, the magnitude of the maximum torque developed will be directly proportional to the square of the voltage applied to the starter.

G. Plugging

The counter braking is widely used in drives .the counter current braking condition can be setup when the torque T_L is greater than Tst‟‟

i.e **T_L>Tst**

where,TL=load torque

Tst=starting torque

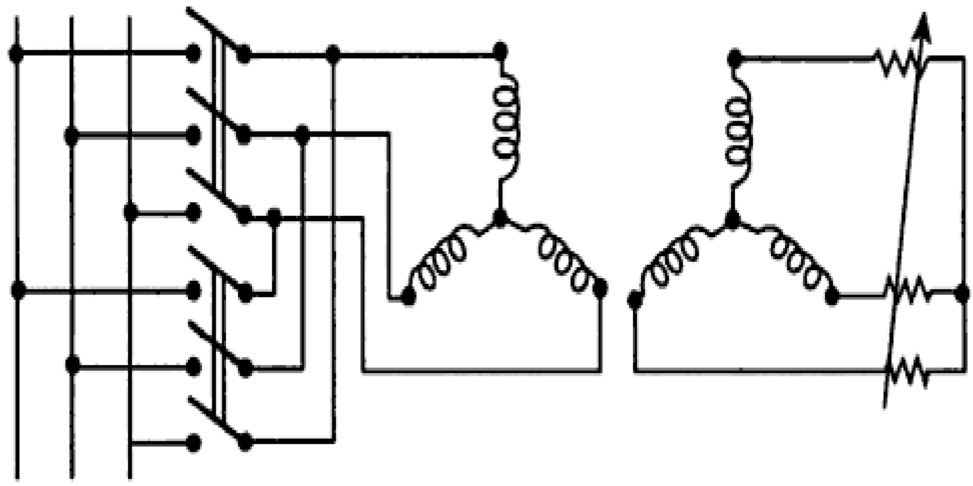


Fig 2.20 Plugging

- To limit the current and develop the braking torque a resistance is introduced in to the rotor circuit.
- Under this counter-current braking the steady-state operation will correspond to the point ()on the characteristics.

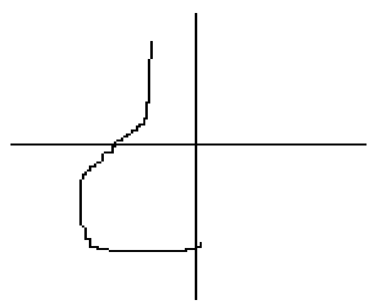


Fig 2.21 N-T Characteristics

Speed torque characteristics of induction motor under counter current braking

- A counter –current braking condition can also be set up by interchanging the supply leads of any two phases of the starter winding to reverse the direction of rotation of the motor field with the rotor still rotation in the initial direction.
- since the rotor rotation is now opposed by a torque acting in the opposite direction, the rotor begins to slow down. when the speed drops to zero, the motor should be de-energized, otherwise, it will again begin motoring and cause the rotor to run in the opposite direction.

2.7 THREE PHASE INDUCTION MOTOR

Types :

There are two types of 3-phase induction motor based on the type of rotor used:

(i) Squirrel cage induction motor.

(ii) Slip ring induction motor.

Slip-ring induction motor over squirrel cage Induction motor

Advantages:

- It is possible to speed control by regulating rotor resistance.
- High starting torque of 200 to 250% of full load voltage.
- Low starting current of the order of 250 to 300% of the full load current.
- Hence slip ring induction motors are used where one or more of the above requirements are to be met.

2.7.1 CONSTRUCTIONAL DETAILS

Conversion of electrical power into mechanical power takes place in the rotating part of an electric motor. In A.C. motors, rotor receives electric power by induction in exactly the same way as the secondary of a two-winding transformer receives its power from the primary. Hence such motors are known as a rotating transformer i.e. one in which primary winding is stationary but the secondary is free to rotate.

An induction motor essentially consists of two main parts:

(a) stator and
(b) Rotor.

(A) Stator:

- The stator of an induction motor is in principle, the same as that of a synchronous motor (or) generator.
- It is made up of a number of stampings, which are slotted to receive the windings.
- The stator carries a 3-phase winding and is fed from a 3-phase supply.
- It is wound for a definite number of poles, the exact number of poles being determined by the requirements of speed.
- The number of poles are higher, lesser the speed and vice-versa.
- The stator winding, when supplied with a 3-phase currents, produce a magnetic flux, which is of constant magnitude but which revolves at synchronous speed ($N_s = 120 \times f / p$).
- This revolving magnetic flux induces emf in rotor by mutual induction.

(B) Rotor:

(i) Squirrel cage Rotor:

Motors employing this type of rotor are known as squirrel cage induction motor.

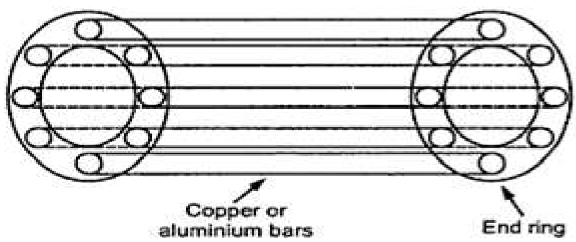
(ii). Phase wound (or) slip-ring Rotor:

Motors employing this type of rotor are widely known as “phase-wound” motors or wound motor or “slip-ring” motors.

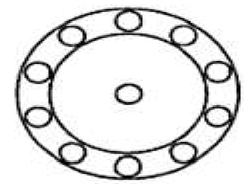
SQUIRREL CAGE ROTOR:

- Almost 90 percentage of induction motors are squirrel-cage type, because this type of rotor has the simplest and most rugged construction imaginable and is almost indestructible.

- The Rotor consists of cylindrical laminated core with parallel slots for carrying the rotor conductors which, it should be noted clearly, are not wires but consists of heavy bars of copper, aluminium or alloys.
- One bar is placed in each slot; rather the bars are inserted from the end when semi-enclosed slots are used.
- The rotor bars are brazed or electrically welded or bolted to two heavy and stout short circuiting end-rings, thus giving us, what is called a squirrel cage construction.



(a) Cage type structure of rotor



(b) Symbolic representation

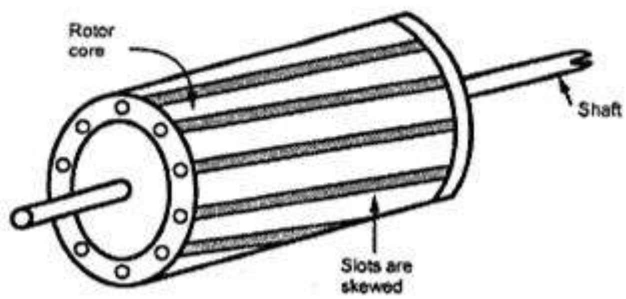


Fig 2.22 Squirrel Cage Rotor

The Rotor bars are permanently short-circuited on themselves; hence it is not possible to add any external Resistance in series with the Rotor circuit for starting purposes.

The rotor slots are not quite parallel to the shaft but are purposely given a slight skew. This is useful in two ways.

A. It helps to make the motor run quietly by reducing the magnetic hum and
B. It helps in reducing the locking tendency of the rotor. i.e. the tendency of the rotor teeth to remain under the stator teeth due to direct magnetic attraction between the two.

PHASE-WOUND ROTOR:

- This type of rotor is provided with 3-phase, double-layer, distributed winding consisting of coils are used in alternators.
- The Rotor is wound for as many poles as the number of stator poles and is always wound 3-phase even when the stator is wound for two-phase.
- The three phases are shorted internally.
- The other three winding terminals are slip-rings mounted on the shaft with brushes resting on them.

- These three brushes are further externally connected to a 3-phase star connected Rheostat.
- This makes possible the introduction of additional resistance in the rotor circuit during the starting period for increasing the starting torque of the motor.
- When running under normal conditions, slip-rings are automatically short circuited by means of a metal collar, which is pushed along the shaft and connects all the rings together.

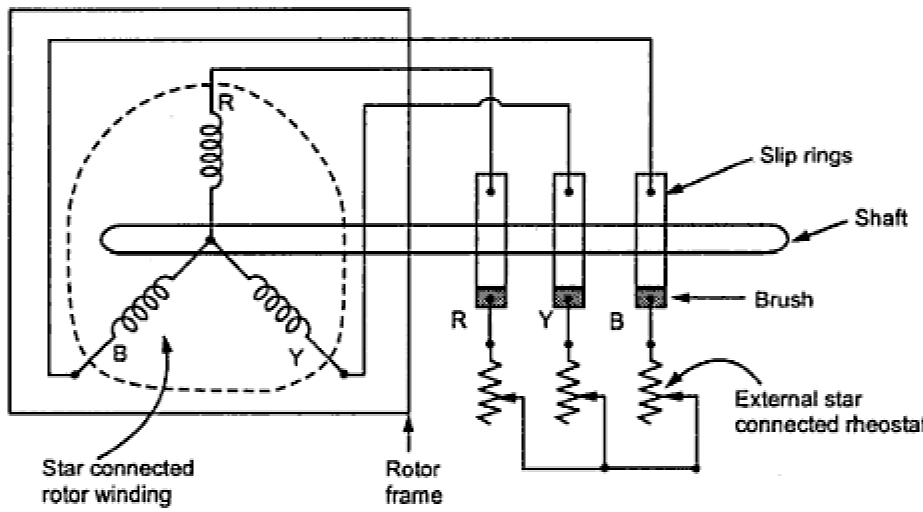


Fig 2.23 Slip ring Rotor

Frame:

Made of close-grained alloy cast iron.

Stator and Rotor core:

Built from high quality low loss silicon steel laminations and flash enameled on both sides.

Stator and Rotor windings:

- Have moisture proof tropical insulation and embodying mica and high quality varnishes.
- Are carefully spaced for most effective air circulation and are rigidly braced to withstand centrifugal forces and any short circuit stresses.

Air gap:

The stator rabbets and bore are machined carefully to ensure uniformity of air gap.

Shaft and Bearings:

Ball and roller bearings are used to suit heavy duty, trouble free running and for enhanced service life.

Fans:

Light aluminium fans are used for adequate circulation of cooling air and are securely keyed onto the Rotor shaft.

<u>Slip-Rings and Slip-Ring Enclosures</u>:

Slip rings are made of high quality phosphor bronze and are of molded construction.

2.7.2 WORKING PRINCIPLE OF THREE PHASE INDUCTION MOTOR

<u>Working principle</u>:

- Induction motor works on the principle of electromagnetic induction.
- When three phase supply is given to the stator winding, a rotating magnetic field of constant magnetic field is produced.
- The speed of rotating magnetic field is synchronous speed, N_S r.p.m.
  - $N_S = \frac{120 f}{P}$ = speed of rotating magnetic field
  - f = supply frequency
- This rotating field produces an effect of rotating poles around a rotor. Let direction of this magnetic field is clockwise as shown.
- Now at this instant rotor is stationary and stator flux R.M.F. is rotating. So its obvious that there exists a relative motion between the R.M.F. and rotor conductors.
- Now the R.M.F. gets cut by rotor conductors as R.M.F. sweeps over rotor conductors.
- Whenever a conductor cuts the flux, emf. gets induced in it. So e.m.f.gets induced in the rotor conductors called rotor induced emf. this is electro – magnetic induction.
- As rotor forms closed circuit, induced emf. circulates current through rotor called rotor current.
- Any current carrying conductor produces its own flux. So rotor produces its flux called rotor flux. For assumed direction of rotor current, the direction of rotor flux is clockwise as shown.
- This direction can be easily determined using right hand thumb rule.
- Now there are two fluxes, one R.M.F. and another rotor flux.
- Both the fluxes interact with each. On left of rotor conductor, two fluxes are in same direction hence added up to get high flux area.
- On right side of rotor conductor, two fluxes are in opposite direction hence they cancel each other to produce low flux area.
- So rotor conductor experiences a force from left to right, due to interaction of the two fluxes.
- As all rotor conductor experiences a force, overall rotor experiences a torque and starts rotating.
- So interaction of the two fluxes is very essential for a motoring action. As seen from the figure, the direction of force is same as that of rotating magnetic field. Hence rotor starts rotating in the same direction as that of R.M.F.

UNIT – III
STARTING METHODS

- Types of d.c motor starters
- Typical control circuits for shunt and series motors
- Three phase squirrel and slip ring induction motors

UNIT 3

STARTING METHODS

3.1 INTRODUCTION

3.1.1 PRIME PURPOSE (or) NECESSITY OF A STARTER FOR MOTORS

The Current drawn by the armature of motor is given by,

$$I_a = (V- E_b) / R_a$$

Where,

V - Supply Voltage
Eb - Back EMF
Ra - Armature Resistance

- When the motor is at rest, there is no back emf developed in the armature. If now full supply voltage is applied across the stationary armature., it will draw a very large current.
- Because armature resistance is very small.
- This excessive current will blow out the fuse and damage the motor.
- To reduce high stating current, a resistance is connected in series with the armature circuit at the time of starting.
- When the motor speed is increased the back emf is also increased.
- Then Ia value is decrease.
- That time external resistance is cut out.

3.1.2 PROTECTIVE DEVICES IN A DC/AC MOTOR STARTER

- Over load Release (O.L.R) or No volt coil
- Hold on Coil
- Thermal Relays
- Fuses (Starting /Running)
- Over load relay

3.1.3 STARTERS FOR DC MOTOR

- Two point Starter
- Three point Starter
- Four point Starter

3.2 THREE POINT STARTER

- The component used and the internal wiring for a three point starter are shown.
- Three terminals L, Z, and A are available in the starter circuit for connecting to the motor.
- The starting resistance R_s provided with tapping and each tapping is connected to a brass stud. The handle of the starter, H is fixed in such a way to move over the brass studs.
- Two protective devices namely over load release and no voltage coil provided to protect the motor during over and during failure of supply.
- To start the motor, the starter handle, full resistance is connected in series with the armature and the armature circuit of the motor is closed through the starting resistance and over load release coil.
- Field circuit of motor is also closed through the no voltage coil.
- Then the handle is moved over the studs against the spring force offered by a spring S_p mounted on the handle.
- As handle movers, the staring resistance is gradually cut out from the motor circuit.
- A soft iron pieces is attached to the handle.
- The no voltage coil, NVC consists of an electro magnet energized by the field current.
- When the handle reaches the ON position, the NVC attracts the soft iron piece and holds the handle firmly.
- Whenever there is a failure of supply, the NVC de-energies and releases the handle.
- The handle position returns to off position due to the spring tension.
- If this arrangement is provided, then when the power supply is restored, the armature alone will be connected to the supply and the current through the armature will be high and it will damage the armature winding.
- Thus the armature is protected against failure of supply by NVC.
- The over load release also has an electromagnet and the line current energizes it.
- When the motor is overloaded, the iron strip P is attracted to the contacts (c and c‟) due to the electromagnetic force produced by the overload release coil and the contacts c and c‟‟ are bridged.
- Thus in this case NVC is de-energized and the handle comes to off position thus the motor is protected against overloading.
- We can see that under normal running of the motor the starting resistance when the handle touches the first stud it also touches the brass arc through which full voltage is supplied to the field coil.

Disadvantage

- This three point starter is not suitable when we have to control the speed of the motor by connecting a variable resistance in series with the field winding.
- When the speed, the no voltage coil will be de-energized and handle will return the off position.
- Due to this disadvantage, four point starters is widely used for starting shunt and compound motors.

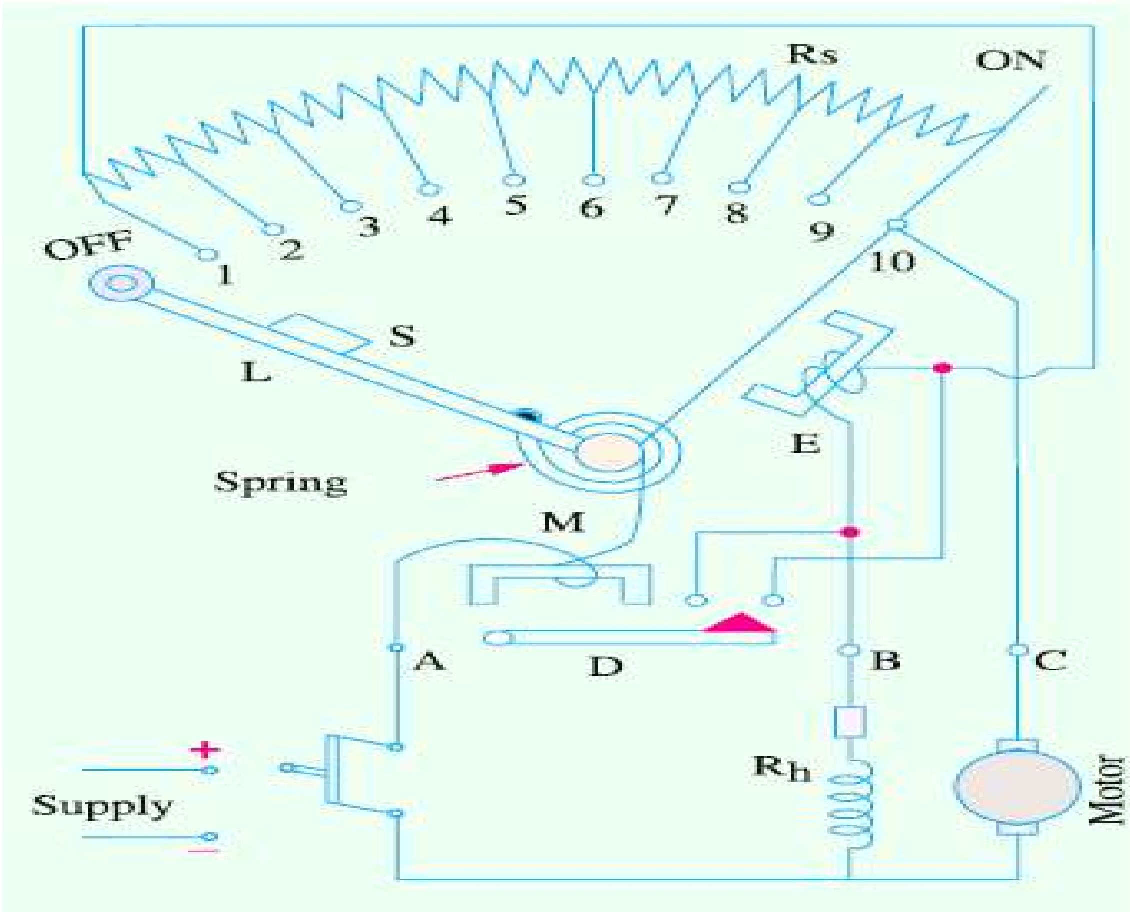


Fig 3.1 Three Point Starter

3.3 FOUR POINT STARTER

- The basic difference between three point and four starters is the connection of NVC.
- In three point, NVC is in series with the field winding while in four point starter NVC is connected independently across the supply through the fourth terminal called „N‟ in addition to the „L‟, „F‟ and „A‟.
- Hence any change in the field current does not affect the performance of the NVC.
- Thus it is ensured that NVC always produce a force which is enough to hold the handle in
- „Run‟position, against forces of the spring, under all the operating conditions.
- Such a current is adjusted through NVC with the help of fixed resistance R connected in series with the NVc using fourth point „N‟ as shown

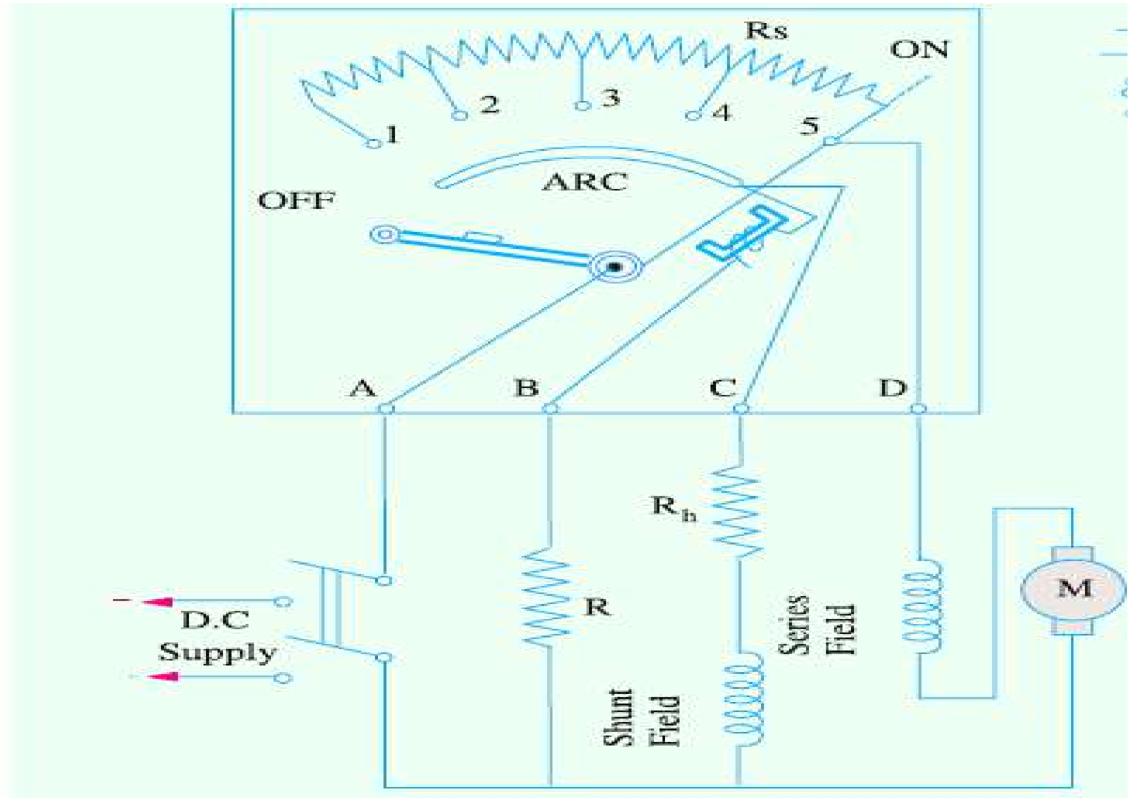


Fig 3.2 Four Point Starter

Disadvantages:

- The only limitation of the four point starter is , it does not provide high speed protection to the motor.
- If under running condition, field gets opened, the field current reduces to zero.
- But there is some residual flux present and $N \alpha \frac{1}{\phi}$ the motor tries to run with dangerously high speed.
- This is called high speeding action of the motion. in three point starter as NVC is in series with the field, under such field failure, NVC releases handle to the OFF position.
- But in four point starter NVC is connected directly across the supply and its current is maintained irrespective of the current through the field winding, hence it always maintains handle in the RUN position, as long as supply is there.
- And thus it does not protect the motor from field failure condition which result into the high speeding of the motor.

3.4 TWO POINT STARTER

- Three point and four point starters are used for d.c. shunt motors.
- In case of series motors, field and armature are inserted and hence starting resistance is inserted in series with the field and armature.
- Such a starter used to limit the star4ting current in case of dc series motor is called two point starters.

- The basic construction of two point starter is similar to that of three point starter the fact that is has only two terminal namely line (L) and field F.
- The terminal is one end of the series combination of field and the armature winding.
- The action of the starter is similar to that of three point starter.
- The handle of the starter is in OFF position.
- When it is moved to on, motor gets the supply and the entire starting resistance is in series with the armature and field. It limits the starting current.
- The current through no volt coil energizes it and when handle reaches to RUN position, the no volt coil holds the handle by attracting the soft iron piece on the handle.
- Hence the no volt coil is also called hold on coil.
- The main problem in case of dc series motor is it over speeding action when the load is less. This can be prevented using two point starters.
- The no volt coil is designed in such a way that it holds the handle in RUN positions only when it carries sufficient current, for which motor can run safely.
- If there is loss of load then current drawn by the motor decreases, due to which no volt coil losses its required magnetism and releases the handle.
- Under spring force, handle comes back to OFF position, protecting the motor from over speeding.
- Similarly if there is any supply problem such that voltage decreases suddenly conditions.

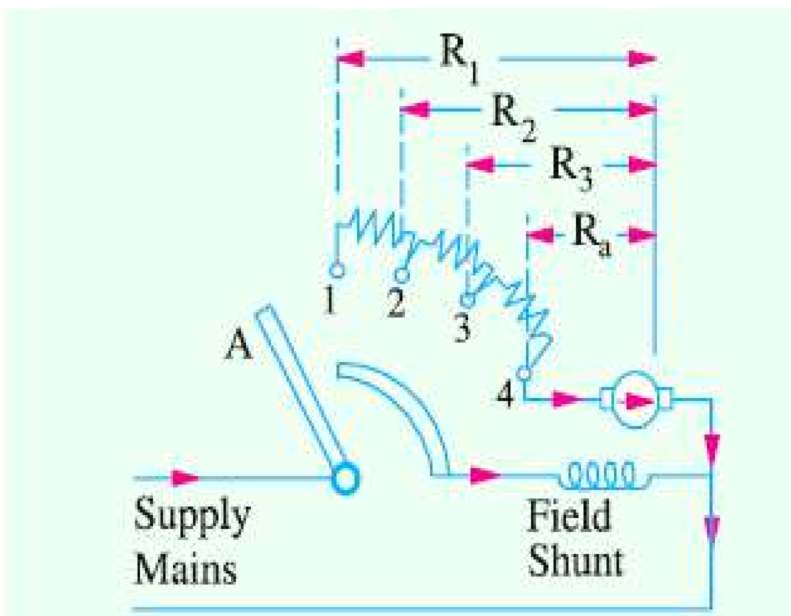


Fig 3.3 Two Point Starter

- The overload condition can be prevented using overload magnet increases.
- This energizes the magnet up to such an extent that it attracts the lever below it.
- When lever is lifted upwards, the triangular piece attached to it touches the two pints, which are the two ends of no volt coil.

- Thus no volt coil gets shorted, loosing its magnetism and releasing the handle back to OFF position.
- This protects the motor from overloading conditions.

3.5 STARTERS FOR AC STARTERS

3.5.1 NECESSITY FOR STARTER

- At starting when full voltage is connected across the stator terminals of an induction motor, large current is drawn by the windings.
- This is because, at starting (i.e before the rotor starts rotating) the induction motor behaves as a short circuited transformer.
- This induced emf of the rotor will circulate a very large current through its windings, due to short.
- The primary will draw very large current nearly 7 times of the rated current from the supply main to balance the rotor ampere turns.
- This current will however be gradually decreasing as the motor will pick up speed.
- Hence if induction motors are started direct-online heavy current is drawn by the motor, such as heavy starting current of short duration may not cause harm to the motor since the construction of induction motors are rugged.
- Moreover, it takes time for intolerable temperature rise to endanger the insulation of the motor windings. But this heavy in high of current will cause a large voltage drop in the lines leading to the motor.
- Other motors and equipment connected to the supply lines will receive reduced voltage.
- In industrial installation, however, it a number of large motors are started direct on-line, the voltage drop will be very high and may be really objectionable for the other types of loads connected to the system.
- The amount of voltage dro0p will not only dependent on the size of the motor but also on factors like the capacity of the power supply system, the size and length of the line leading to the motors, etc.

Types of starters available for induction motors are:

1. Full voltage direct online starting
   a. DOL starter
2. Reduced voltage starting
   a. Star-Delta starter
   b. Auto transformer starter

Stator control

3. Rotor resistance starter → Rotor control

3.5.2 PRIME PURPOSE OF A STARTER FOR MOTORS

- When induction motor is switched on to the supply, it takes about 5 to 8 times full load current at starting.
- This starting current may be of such a magnitude as to cause objectionable voltage drop in the lines.
- So Starters are necessary

3.5.3 NEED FOR STARTER IN AN INDUCTION MOTOR

- At starting when full voltage is connected across the stator terminals of an induction motor, large current is drawn by the windings.
- This is because, at starting (i.e before the rotor starts rotating) the induction motor behaves as short circuited transformer.
- At starting, when the rotor is at stand still emf is induced n the rotor circuit exactly similar to the emf induced in the secondary windings of a transformer.
- This induced emf of the rotor will circulate a very large current through its windings, due to short.
- The primary will draw very large current nearly 5 – 7 times of the rated current from the supply mains to balance rotor ampere turns.
- This current will however be gradually decreasing as motor will pick up speed.
- In order to reduced starting current starters are used.
- Induction motor starter will supply reduced voltage to the stator of induction motors.

3.6 D.O.L STARTER

- It is recommended that large three phase squirrel-case induction motors be started with reduced voltage applied across the stator terminals at starting.
- But small motors up to 5HP ratings may however be started Direct – ON-Line (DOL)

Direct-on-line method of starting of induction motors applicable up to a rating of 5 HP is shown in fig3.4. In the circuit in addition to fuses, thermal motor windings against overload.

Derivation for starting current and torque in case of DOL starters

Rotor input $2\pi N_S T = kT$ (1)

Rotor copper loss $S \times$ rotor input

$\therefore \quad 3I_2{}^2 R_2 = S \times kT$

$\therefore \quad T \propto I_2{}^2 / S$ 9if $R_2$0 is the same

Now $I_2 \propto I_1$

$$\therefore \quad T \propto I_1^2 / S \text{ (or)} \quad T = K I_1^2 / S$$

At starting moment, S = 1

$$\therefore \quad T_{st} = K I_{st}^2$$ where I_{st} = Starting current

If,

I_f = normal full load current and
S_f = Full load slip

3.7 STATOR RESISTANCE (OR) PRIMARY RESISTANCE STARTER

Reduced voltage starting:

- Their purpose is to drop some voltage and hence reduce the voltage applied across the motor terminals.
- In this way, the initial current drawn by the motor is reduced.
- However, it should be noted that whereas current varies directly as the voltage, the torque varies as square of applied voltage.

[Note: When applied voltage is reduced, the rotating flux ϕ is reduced which in turn decreases rotor e.m.f and hence rotor current I_2. Starting torque which depends both on ϕ and I_2 suffers on two counts when impressed voltage is reduced]

For example if voltage applied across motor terminals is reduced by 50%, starting current is reduced by 50%, but torque is reduced to 25% of the full-voltage value.

Then,

$$T_f = KI_f^2 / S_f$$

$$\therefore \quad \frac{T_{st}}{T_f} = \left(\frac{I_{st}}{T_f}\right)^2 .S_f$$

When motor is direct-switched on to normal voltage, then starting current is the short –circuit current I_{sc}.

$$\therefore \quad \frac{T_{st}}{T_f} = \left(\frac{I_{sc}}{T_f}\right)^2 .S_f = a^2 .S_f$$

Where $a = I_{sc} / I_f$ Suppose in a case, $I_{sc} = 7I_f$,

$S_f = 4\% = 0.04$,

Then,

$$\frac{T_{st}}{T_f} = 7^2 \times 0.04 = 1.96$$

$\therefore$ Starting torque = 1.96 x Full load torque.

Hence, even if current is greater than full load current the starting torque is only 1.96 times full-load torque.

If applied voltages/phase can be reduced by fraction „x", then

$$I_{st} = xI_{sc} \quad \text{and} \quad T_{st} = x^2 T_{sc}$$

$$\frac{T_{st}}{T_f} = \left(\frac{I_{st}}{I_f}\right)^2 .S_f = \left(\frac{xI_{sc}}{I_f}\right)^2 .S_f$$

$$= x^2 \left(\frac{xI_{sc}}{I_f}\right)^2 .S_f$$

$$\Rightarrow \quad \frac{T_{st}}{T_f} = x^2 .a^2 .S_f$$

$$\boxed{\frac{T_{st}}{T_f} = x^2 .a^2 .S_f}$$

It is obvious that the ratio of starting torque of full-load torque is x^2 of that obtained with direct switching (or) across the line starting. This method is useful for the smooth starting of small machines only.

3.8 PRIMARY REACTANCE STARTER (or) AUTO TRANSFORMER STARTERS

The working principle of the primary reactance starter is same as that of primary resistance starter except that voltage drop occurs across the reactor, so that i/p voltage applied to the stator of induction motor reduces.

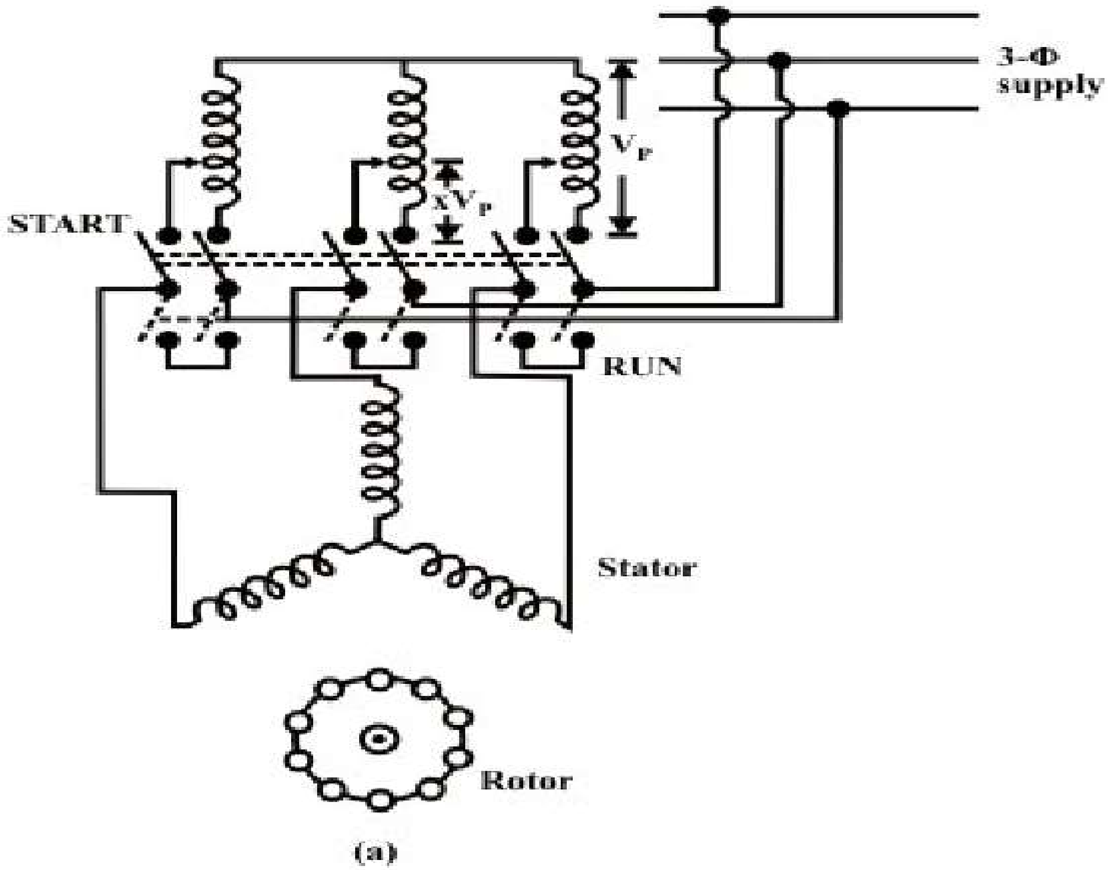


Fig 3.6 Auto transformer starter

- An auto transformer consists of a n auto transformer and a switch as shown in fig.

- When the switch S is put on start position, a reduced voltage is applied across the motor terminals.
- When the motor picks up speed, say to 80 percent of its normal speed, the switch is put to RUN position.
- Then the quato-transformer is cut out of the circuit and full rated voltage gets applied across the motor terminals.
- The switch making these changes from „start" to „run" may be air break (for small motors) or may be oil-increased (for large motors) to reduce sparking.

Derivation for autotransformer starter:

- When full voltage is applied without suing autotransformers say starter, then current taken by the motor is 5 times the full load current. If V is pre line voltage then voltage/phase across the motor is $V/\sqrt{3}$.

$\therefore \quad I_{sc} = S\ I_f = \dfrac{V}{\sqrt{3Z}}$ Where Z is starter impedance /phase

- In the case of autotransformer, if a tapping of transformation ratio k is used, then phase voltage across motor is $kV/\sqrt{3}$

  $\therefore$ Motor starting current $I_2 = \frac{kV}{\sqrt{3Z}} = \frac{kV}{\sqrt{3Z}}$

- The current taken from supply (or) by auto transformer is $I_1 = kI_2 = k^2$ $S_{if} = k.^2 T_{sc}$ if magnetizing current of the transformer is ignored phase is reduced only k times, the direct switching current

  $\because k < 1$, the current taken by the line is reduced to k^2 times.

The torque is proportional to square of the voltage, we get, (i) with direct =switching,

$$T_1 \propto \left(V/\sqrt{3}\right)^2;$$

with auto – transformer,

$$T_2 \propto \left(kV/\sqrt{3}\right)^2$$

$$\therefore \frac{T_2}{T_1} = \frac{\left(kV/\sqrt{3}\right)^2}{\left(V/\sqrt{3}\right)^2}$$

(or)

$$T_2 = k^2 T_{sc}$$

$\therefore$ Torque with quto transformer starter is, = k^2 x Torque with direct – switching.

Relation between starting and full-load torque:

It is seen that voltage across the motor phase on direct –switching is $V/\sqrt{3}$ and starting current is $I_{st} = I_{sc}$. With autotransformer –starter, voltage across the motor phase is $kV/\sqrt{3}$ and $I_{st} = kI_{sc}$

Now,

$$T_{st} \propto I_{st}^{\ 2}(S=1) \text{ and}$$

$$\therefore \frac{T_{st}}{T_f} = \left(\frac{I_{st}}{I_f}\right)^2 .S_f \cdot \quad \text{(Or)}$$

$$\frac{T_{st}}{T_f} = k^2\left(\frac{I_{sc}}{I_f}\right)^2 .S_f \cdot$$

$$\therefore \frac{T_{st}}{T_f} = k^2 9^2 . S_f . \qquad \therefore I_{st} = kI_{sc}$$

From Fig. 1(a) it is seen than for star connection of windings, phase current.

$$I_p = I_{LY} = \frac{V}{\sqrt{3}} \times \frac{1}{Z_P} \text{ Ampere}$$

when I_{LY} is the line current when windings are connected and Z_p is the windings impedance per phase.

For delta connection of windings

$$I_p = \frac{V}{Z_p} \text{ and } \boxed{I_{LD} = \sqrt{3} I_P \text{ Ampere}}$$

The ratio of line currents drawn in star and delta –connection is therefore,

$$\frac{I_{LY}}{I_{L\Delta}} = \frac{V / \sqrt{3} \times Z_p}{\sqrt{3} V / Z_p}$$

$$\Rightarrow \quad \frac{I_{LY}}{I_{LD}} = \frac{1}{3}$$

$$\Rightarrow \quad \boxed{\frac{I_{LY}}{I_{LD}} = \frac{1}{3} IL\Delta}$$

3.9 STAR –DELTA STARTER

- In this method, the stator phase windings are first corrected in star and full voltage is connected across its free terminals.
- As the motor pickup speed, the windings are disconnected through a switch and they are reconnected in delta across the supply terminals.
- The current drawn by the motor from the lines is reduced to 1/3 as compared to the current it would have drawn if connected in delta.

PROOF:

- Thus, by connecting the motor windings, first in star and then in delta, the line current drawn by the motor at starting is reduced to one third as compared to starting with the windings delta connected.

Reduced Torque due to star connection:

- In induction motor, torque developed is proportional to the square of applied voltage. As the phase voltage is reduced to $(1/\sqrt{3})$ times that in star-connection, the starting torque will be reduced to one third. To get full torque in the motor, it must be switched over to delta connection.

- ✶ In making connections for star-delta starting, care should be taken such that sequency of supply connections to the winding terminals does not change wile changing form star-connection to delta-connection. Otherwise the motor will start rotating in opposite direction, when connections are changed from star to delta.
- ✶ Star-delta starters are available for manual operation using push-button control. An automatic star-delta starters uses time-delay relays (TDR) through which star to delta connections take place automatically with some pre-fixed time fixed keeping in view the starting time of the motor.

Derivation:

Relation between starting and full load torque:

I^{st} per phase $= \frac{1}{\sqrt{3}} I_{Sc}$ per phase.

Where I_{Sc} is the current /phase which Δ -connected motor would have taken if switched on to supply directly (however line current at start $= 1/3$ of Line I_{SC}).

Now,

$$T_{st} \propto I_{st}^{\ 2} \qquad (s = 1)$$

$$\therefore \frac{T_{st}}{T_{st}} = \left(\frac{I_{st}}{I_f} \right)^2 .S_f$$

$$= \left(\frac{I_{sc}}{\sqrt{3}} \cdot \frac{1}{I_f} \right)^2 .S_f$$

$$= \frac{1}{3} a^2 .S_f$$

$$\therefore \frac{T_{st}}{T_f} = \frac{1}{3} a^2 .S_f$$

Here, I_{st} and I_{SC} represent phase values.

It is clear that star-Delta switch is equivalent to a n auto-transformer of ratio $1/\sqrt{3}$ (or) 58% approximately.

3.10 ROTOR RESISTANCE STARTERS

- ➢ The easiest method of starting wound rotor (slip-ring) induction motors is to connect some extra resistance in the rotor circuit as shown in fig.
- ➢ Connection of extra resistance in the rotor circuit decreases the starting current and at the same time increases the starting torque.
- ➢ As the motor starts rotating the extra resistance is gradually cut out.

- When the motor attains rated speed the resistance is fully cut out.

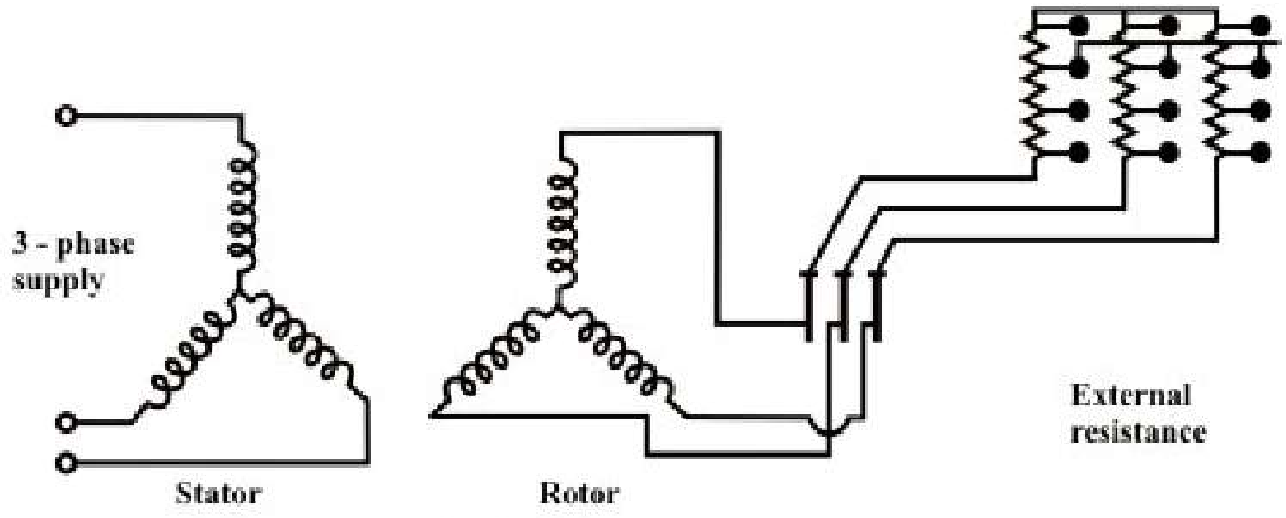


Fig 3.7 Rotor resistance Starter

When the motor attains rated speed the resistance is fully cut out and the slip ring terminals are short circuited.
The motor now operates on its own characteristics which give rise to maximum torque at a low slip.

3.11 COMPARE THE INDUCTION MOTOR STARTERS

Description of Starter	% of line voltage applied	Starting current (I_s)compared with		Starting torque (Ts)compared with	
		D.O.L current(I_{dol})	**Full load current(I)**	**D.O.L Torque(T_{dol})**	**Full load torque(T)**
D.O.L Starter	100%	$I_s = I_{dol}$	$I_s = 6I$	$T_s = T_{dol}$	$T_s = 6T$
Star Delta starter	57.7%	$I_s = (1/\sqrt{3})^2 I_{dol}$	$I_s = 2I$	$T_s = (1/\sqrt{3})^2 T_{dol}$	$T_s = 2/3T$
Auto transformer starter	80%	$I_s =(0.8)^2 I_{dol}$	$I_s = 3.84 I$	$T_s = =(0.8)^2 T_{dol}$	$T_s = 1.28 T$
	60%	$I_s =(0.6)^2 I_{dol}$	$I_s = 2.16 I$	$T_s = =(0.6)^2 T_{dol}$	$T_s = 0.72 T$
	40%	$I_s =(0.4)^2 I_{dol}$	$I_s = 0.96 I$	$T_s = =(0.4)^2 T_{dol}$	$T_s = 0.32 T$
Reactance-resistance starter	64%	$I_s = (0.64)^2 I_{dol}$	$I_s = 2.5 I$	$T_s =(0.425)^2 T_{dol}$	$T_s = 0.35T$

UNIT-IV

CONVENTIONAL AND SOLID STATE SPEED CONTROL OF D.C DRIVES

- Speed control of DC series and shunt motors
- Armature control
- Field control
- Ward-Leonard control system
- Using controlled rectifiers and DC choppers
- Applications

CONVENTIONAL AND SOLID STATE SPEED CONTROL OF D.C DRIVES

UNIT 4

4.1 INTRODUCTION

- ✓ The speed of a given machine (DC) has to be controlled for the required speed variations of an operation.
- ✓ Either armature voltage or field current can be varied or controlled. A separately excited motor is a versatile variable speed motor. The speed control using the variation of the armature voltage can be used for constant torque application in the speed range from zero to base or rated speed.
- ✓ The speed control using the field weakening can be used for constant power application in the speed range from zero to above base or rated speed.

4.2 EXPRESSION FOR SPEED FOR A DC MOTOR

$$\text{Speed } N = \frac{k\,(V - I_a R_a)}{\varphi}$$

Where V = Terminal Voltage in volts
Ia = Armature current in Amps
Ra = Armature resistance in ohms
φ= flux per pole.

4.3 Applications of DC Drives:

- ✓ Electric Traction
- ✓ Steel mills
- ✓ Printing mills
- ✓ Textile mills
- ✓ Paper mills
- ✓ Machine tools
- ✓ Cranes
- ✓ Hoists

4.4 Advantages of DC Drives:

- ✓ Lower cost
- ✓ Reliability
- ✓ Simple control

4.5 Conventional Methods of Speed Control

4.5.1 Speed control of DC Shunt Motors:

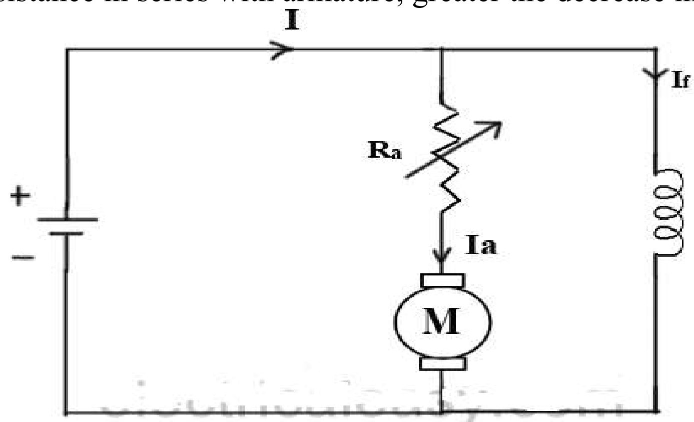
- ✓ By varying the resistance in the armature circuit
- ✓ By varying the flux (field)
- ✓ By varying the applied Voltage

4.5.1.1 Armature Resistance Control

- ✓ Speed of the motor is directly proportional to the back emf E_b

$$E_b = V - I_a R_a.$$

- ✓ That is when supply voltage V and armature resistance R_a are kept constant, speed is directly proportional to armature current I_a. Thus if we add resistance in series with armature, I_a decreases and hence speed decreases.
- ✓ Greater the resistance in series with armature, greater the decrease in speed.



Advantages:

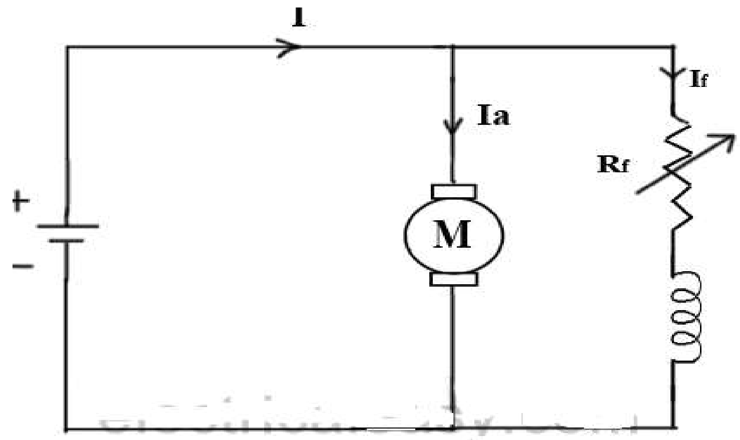
- ✓ Simple method of speed control

Disadvantages:

- ✓ The change in speed with the change in load becomes large.
- ✓ More power is wasted in this controller resistance.

4.5.1.2 Field flux control:

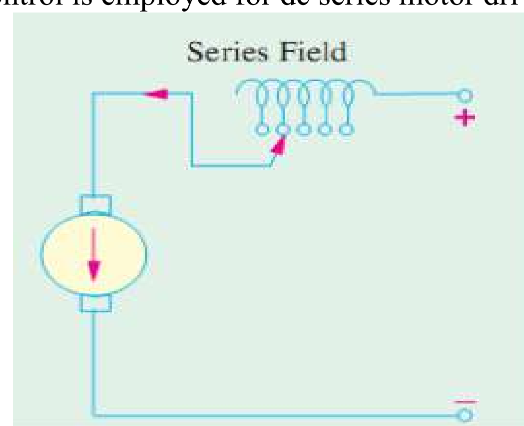
- ✓ Speed of the motor is inversely proportional to flux. Thus by decreasing flux speed can be increased and vice versa.
- ✓ To control the flux, a rheostat is added in series with the field winding, as shown in the circuit diagram.
- ✓ Adding more resistance in series with field winding will increase the speed, as it will decrease the flux.
- ✓ Field current is relatively small and hence I^2R loss is small, hence this method is quiet efficient.
- ✓ Though speed can be increased by reducing flux with this method, it puts a limit to maximum speed as weakening of flux beyond the limit will adversely affect the commutation.



4.5.2 Speed control of DC Series Motors:

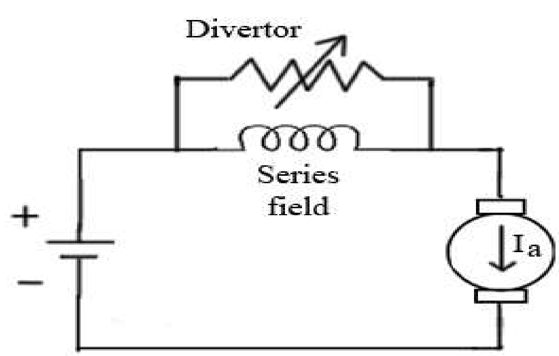
4.5.2.1 Armature Resistance Control

- ✓ The controlling resistance is connected directly in series with the supply to the motor
- ✓ The power loss in the control resistance of dc series motor can be neglected because this control method is utilized for a large portion of time for reducing the speed under light load condition.
- ✓ This method of speed control is most economical for constant torque.
- ✓ This method of speed control is employed for dc series motor driving cranes, hoists, trains etc



4.5.2.2 Field Control Method:

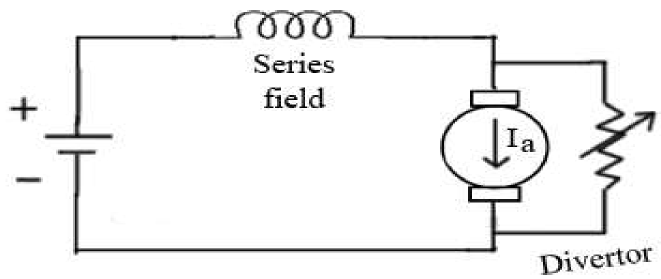
a) Field Divertor Method:



- ✓ A veritable resistance is connected parallel to the series field as shown in fig.
- ✓ This variable resistor is called as divertor, as desired amount of current can be diverted through this resistor and hence current through field coil can be decreased.

- ✓ Hence flux can be decreased to desired amount and speed can be increased.

b) Armature Divertor Method:

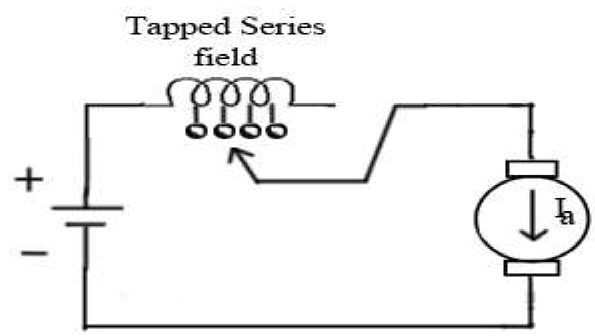


- ✓ Divertor is connected across the armature as in fig.
- ✓ For a given constant load torque, if armature current is reduced then flux must increase.

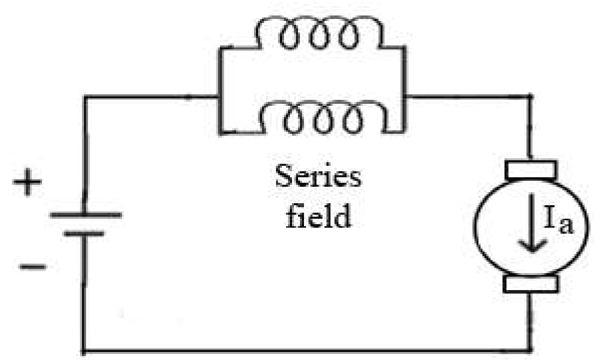
$$T_a \propto \phi I_a$$

- ✓ This will result in increase in current taken from the supply and hence flux Ø will increase and subsequently speed of the motor will decrease.

C) Tapped field Control:



D) Paralleling field Control:

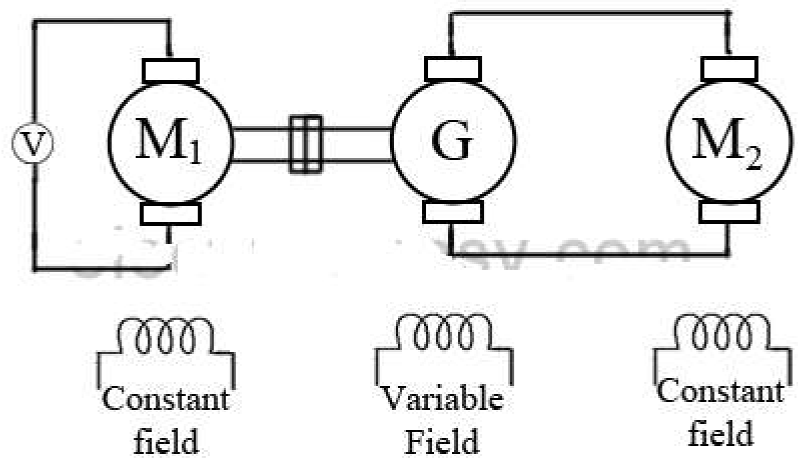


4.5.3. Ward Leonard Control System:

- ✓ This system is used where very sensitive **speed control of motor** is required (e.g electric excavators, elevators etc.) The arrangement of this system is as required in the figure beside.

- ✓ M_2 is the motor whose speed control is required. M_1 may be any AC motor or DC motor with constant speed. G is the generator directly coupled to M_1.

- ✓ In this method the output from the generator G is fed to the armature of the motor M_2 whose speed is to be controlled.
- ✓ The output voltage of the generator G can be varied from zero to its maximum value, and hence the armature voltage of the motor M_2 is varied very smoothly.
- ✓ Hence very smooth **speed control of motor** can be obtained by this method.



Advantages:

- ✓ Full forward and reverse speed can be achieved.
- ✓ A wide range of speed control is possible
- ✓ Short time overload capacity is large
- ✓ The armature current of the motor is smooth.

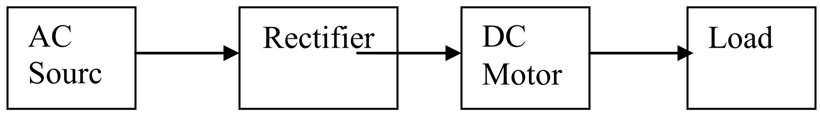
Disadvantages:

- ✓ High initial cost
- ✓ The overall efficiency is low, less than 80%
- ✓ Costly foundation and a large amount of space is required
- ✓ The drive produces noise
- ✓ It requires frequent maintenance.

4.6 Solid state Speed Control of DC Motor:

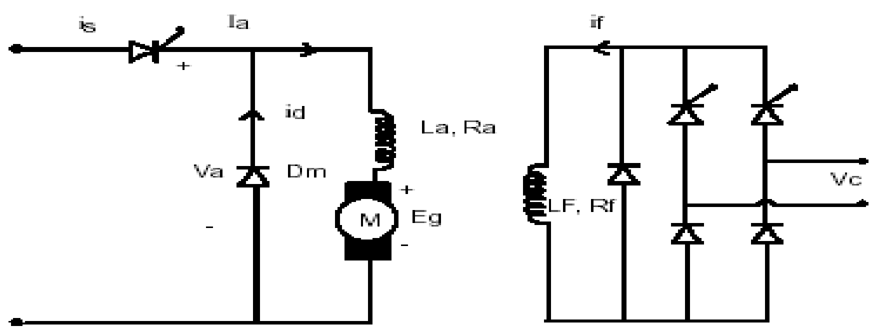
- ✓ The DC Motor speed can be controlled through power semiconductor switches. The power semiconductor switches are SCR, MOSFET, IGBT etc., this type of speed control is called static ward leonard Drive.
- ✓ Types of DC Drives:
  - ➢ Phase controlled rectifier fed DC drives
  - ➢ Single phase rectifier fed DC drives
  - ➢ Three phase rectifier fed DC drives
  - ➢ One quadrant converter
  - ➢ Two quadrant converter
  - ➢ Four quadrant converter
  - ➢ Chopper fed DC drives
  - ➢ One quadrant Chopper drives
  - ➢ Two quadrant Chopper drives
  - ➢ Four quadrant Chopper drives

4.6.1 Single phase Controlled rectifier fed DC drives:



4.6.1.1 Half wave controlled rectifiers

- ✓ In the single phase half controlled rectifier, the load resister, RL is connected in series with anode A.
- ✓ A variable resistance r is inserted in the gate circuit for controlling gate current. During the negative half cycles of the input ac voltage .
- ✓ The SCR does not conduct regardless of the gate voltage, because anode is negative with respect to cathode K.
- ✓ The SCR will conduct during the positive half cycles provided appropriate gate current is made to flow .the gate current can be varied with the help of variable resistance r inserted in the gate circuit for this purpose .the greater the gate current, the lesser will be the supply voltage at which SCR will start conducting.



- ✓ Assume that the gate current is such that SCR starts conducting at a positive voltage V, being less than peak value of input ac voltage V_{max},
- ✓ it is clear that the SCR starts conducting, as soon as input ac voltage becomes equal to V volts in the positive half cycle, and will continue conducting till ac voltage becomes zero when it will turn-off, again in next positive half cycle, SCR will start conducting when input ac voltage becomes equal to V volts.
- ✓ The angle by which the SCR starts conducting is called as firing angle or delay angle α the conduction will take place for($\Pi - \alpha$) radians.
- ✓ The thyristor circuit uses phase commutation.
- ✓ The average output voltage (V_L) from a half-wave controlled rectifier for the given input ac voltage V=V_{max}sin ωt

$$V_L = \frac{V_{max}}{\Pi} \cos^2 \frac{\alpha}{2}$$

Average output current

$$I_L = \frac{V_L}{R_L} = \frac{V_{\max}}{\Pi R_L}\cos^2\frac{\alpha}{2}$$

Thus the desired value of load current I_L can be obtained by varying firing angle α

$$I_L = \frac{V_{\max}}{\Pi R_L} when \alpha = 0$$

$$I_L = \frac{V_{\max}}{2\Pi R_L} when \alpha = \frac{\Pi}{2}$$

Hence, load current decreases with the increase in value of firing angle α. So the terminal voltage decreases the motor run slowly and vice versa.

With Freewheeling diode

- ✓ Let RL load is connected with the single-phase half controlled rectifier .Due to the inductive nature of the load, the load current lags by an angle θ with respect to the voltage.
- ✓ During voltage reversal, the voltage reaches zero but due to the inductive nature of the load, the current still flow through the thyristor.
- ✓ it takes some time for the current to reach zero. so during that instant ,a negative voltage will be appearing across the inductive load and the freewheeling diode connected in parallel with the load is turned on, as the diode is turned on, the load voltage becomes the diode forward drop.
- ✓ It is otherwise called commutating diode. This diode is connected anti parallel with load .this diode comes into picture only when the load is inductive.
- ✓ In case of inductive load even though the input voltage reaches zero and becomes negative, the current is still flowing through the thyristor, so it remains on when the voltage across the load becomes negative.
- ✓ The freewheeling diode is turned on when the load voltage is negative.
- ✓ So, the voltage across the load becomes zero and it provides a path for the load current. During this interval, the energy stored in the inductor is dissipated through this diode

- ➢ This freewheeling diode prevents the negative the negative reversal of voltage across the load.
- ➢ It improves the input power factor.
- ➢ It improves the load current wave from thereby it improves the performance parameters.

4.6.1.2 Full controlled rectifier

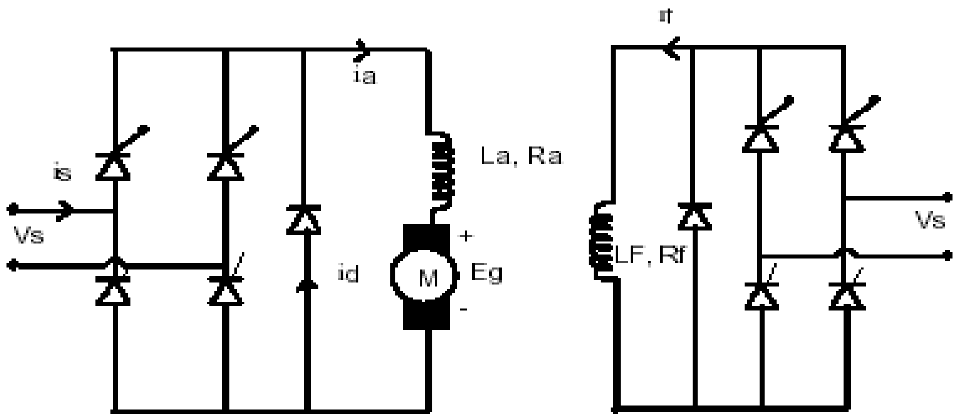
- ✓ The full wave half controlled rectifier circuit consists of two thyristors and two diodes.
- ✓ The gates of both thyristors are supplied from two gate control supply circuits.
- ✓ One thyristors (or SCR) conducts during the positive half cycles and the other during the negative half cycles and thus unidirectional current flows through the load circuit.

Now, if the supply voltage v =V_{max}sin ωt and firing angle is α ,then average output voltage is given by

$$V_L = \frac{1}{\Pi}\int_{\alpha}^{\Pi} V_{max} \sin \omega t d(\omega t)$$

$$V_L = \frac{V_{max}}{\Pi}(1+\cos\alpha)$$

$$= \frac{2V_{max}}{\Pi}\cos^2\frac{\alpha}{2}$$



Average output current,

$$I_L = \frac{V_L}{R_L} = \frac{2V_{max}}{\Pi R_L}\cos^2\frac{\alpha}{2}$$

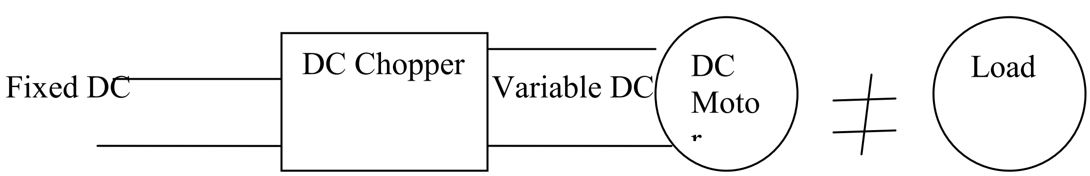
Advantages:

- ✓ Basic operation is simple and reliable
- ✓ Time response is faster
- ✓ Small size
- ✓ Less weight

Disadvantages:

- ✓ Introduce current and voltage harmonics into supply systems
- ✓ The overload capacity is lower
- ✓ Due to switching of SCR distortion of the AC supply voltage and telephone interference may be produced.

4.6.2 Chopper Fed DC Drives



- ✓ Fixed DC voltage is fed to the DC chopper circuit.

- ✓ DC chopper converts fixed DC into variable DC voltage.
- ✓ This variable DC Voltage is fed to the motor.
- ✓ By varying the DC voltage, the motor speed can be controlled.
- ✓ Self commutated devices such as MOSFET‟s, Power transistors, IGBT‟s and IGCT‟s are used for building choppers because they can be commutated by a low power control signal and do not need commutation circuit and can be operated at a higher frequency for the same rating.

Advantages:

- ✓ High efficiency
- ✓ Light weight
- ✓ Flexibility in controls
- ✓ Small size
- ✓ Quick response

Applications:

- ✓ Battery operated vehicles
- ✓ Traction motors
- ✓ Hoists
- ✓ Electric braking
- ✓ Trolley cars

UNIT-V

CONVENTIONAL AND SOLID STATE SPEED CONTROL OF A.C DRIVES

- Speed control of three phase induction motor
- Voltage control
- Voltage/frequency control
- Slip power recovery scheme
- Using inverters and AC voltage regulators
- Applications

UNIT 5

CONVENTIONAL & SOLID STATE SPEED CONTROL AC DRIVES

5.1 INTRODUCTION

- ✓ A three phase induction motor is basically a constant speed motor so it‟s somewhat difficult to control its speed. The speed control of induction motor is done at the cost of decrease in efficiency and low electrical power factor.
- ✓ To control the speed of three phase induction motor one should know the basic formulas of speed and torque of three phase induction motor as the methods of speed control depends upon these formulas.

$$N_s = \frac{120f}{P}$$

5.2 SPEED CONTROL OF DRIVES

- ✓ The electrical machine that converts electrical energy into mechanical energy and mechanical energy into electrical energy.
- ✓ Drive systems are mainly used in applications such as pumps, paper, textile mills and more…
- ✓ Industrial drive applications are generally classified into constant speed and variable speed drives.
- ✓ AC machines have been used in constant speed application, because conventional methods of their speed control have either been expensive or highly insufficient.
- ✓ But DC machines were preferred for variable speed drives. However, the main disadvantages of dc machines are,
  - Higher cost
  - Higher rotor inertia
  - Maintenance problems
  - EMI problems

5.3 Advantages of Induction motor:

- Rugged
- Cheaper
- Lighter
- Smaller
- Less maintenance

5.4 Applications of Induction motors:

- Laths
- Drilling machines
- Fans Blowers
- Water pumps
- Grinders
- Printing machines etc.,

5.5 Speed control of three phase induction motor:

5.5.1 Stator Side

- ✓ V / f control or frequency control.
- ✓ Changing the number of stator poles
- ✓ Controlling supply voltage.
- ✓ Adding rheostat in the stator circuit.

5.5.2 Rotor Side

- ✓ Adding external resistance on rotor side.
- ✓ Cascade control method.
- ✓ Injecting slip frequency emf into rotor side.

5.5.1.1 V/F control or Frequency control:

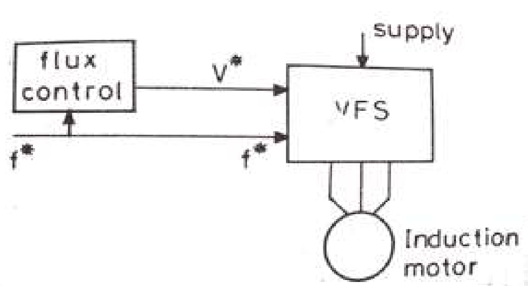
- ✓ Whenever three phase supply is given to three phase induction motor rotating magnetic field is produced which rotates at synchronous speed given by

$$N_s = \frac{120f}{P}$$

- ✓ In three phase induction motor emf is induced by induction similar to that of transformer which is given by

$$E \ or \ V = 4.44\phi K.T.f \ or \ \phi = \frac{V}{4.44KTf}$$

- ✓ Where K is the winding constant, T is the number of turns per phase and f is frequency.
- ✓ Now if we change frequency synchronous speed changes but with decrease in frequency flux will increase and this change in value of flux causes saturation of rotor and stator cores which will further cause increase in no load current of the motor .
- ✓ So, its important to maintain flux, φ constant and it is only possible if we change voltage . i.e if we decrease frequency flux increases but at the same time if we decrease voltage flux will also decease causing no change in flux and hence it remains constant.
- ✓ So, here we are keeping the ratio of V/ f as constant. Hence its name is V/ f method.
- ✓ For controlling the speed of three phase induction motor by V/ f method we have to supply variable voltage and frequency which is easily obtained by using converter and inverter set.



Variable frequency control

5.5.1.2 Pole Changing Methods:

- ✓ The speed of an induction motor depends upon the number of poes which the stator is wound.
- ✓ If two independent stator windings are used for different number of poles say for four poles and for two poles are made on the stator, definite rotor speeds can be obtained.
- ✓ The two windings are to be insulated from one another. When any of the windings is used, other winding should be kept open circuited by the switch.
- ✓ For example, a 36-slot stator may have two 3ϕ -windings, one with 4 poles and the other with 6-poles. With supply frequency of 50Hz, 4 pole winding will give $N_s = \frac{120 \times 50}{4} = 1500\ rpm$ and the 6 pole winding will give, $N_s = \frac{120 \times 50}{6} = 1000\ rpm$
- ✓ The limitation of this method is only two definite speeds can be obtained. Smooth control of speed over wide range is not possible.

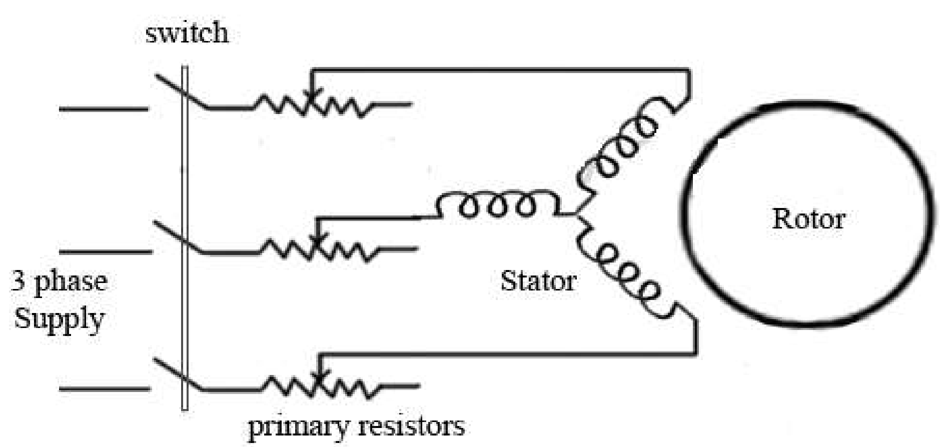
5.5.1.3 Changing Supply Voltage Method:

- ✓ Slip can be varied by changing the applied stator voltage i.e. motor speed can be varied by varying the supply voltage, because

$$Torque \propto V^2$$

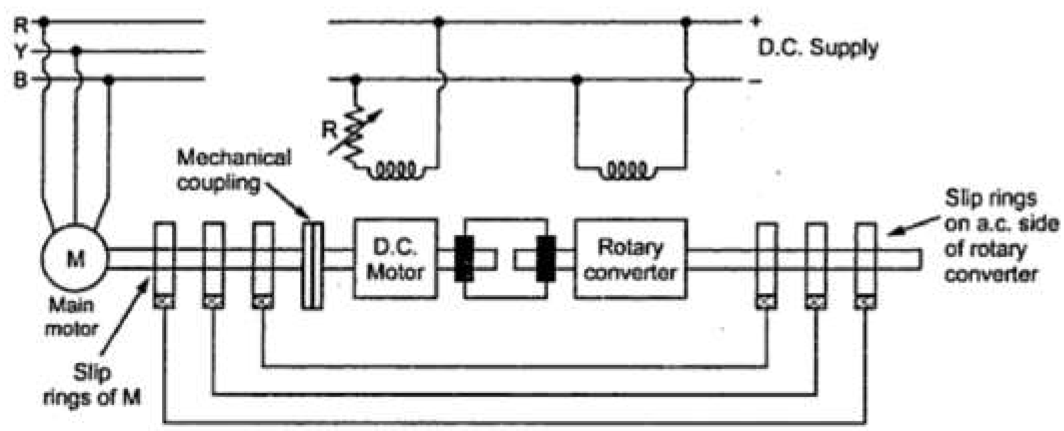
If the voltage is reduced as, torque is reduced as square of the voltage

- o For example, if the applied voltage is reduced from V to 0.9 V, the torque will be reduced from T to 0.81 T.
- ✓ Since the torque is reduced to 81 percent, the rotor cannot continue to rotate at speed N_1, it speed will be reduced. i.e. its slip will increase until the increased rotor current will make up for the reduced stator voltage and produce the required load torque at a a lower speed N_2.
- ✓ This method of speed control is rarely used for industrial three-phase motors because of the requirement of additional costly voltage changing auxiliary equipment.
- o For small induction motor used in home appliance, voltage control method of speed changing is often used.



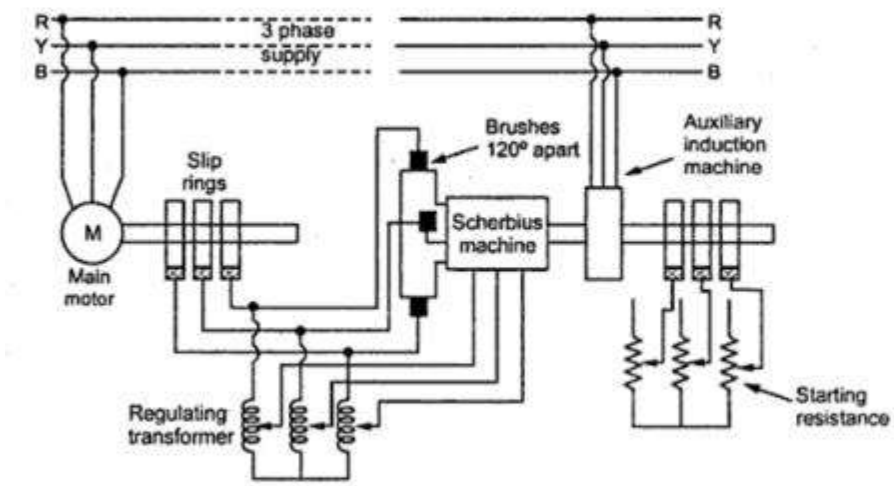
5.6 Slip Power Recovery Scheme:
5.6.1 Kramer System:

- ✓ It consists of main induction motor M, the speed of which is to be controlled.
- ✓ The two additional equipments are, d.c. motor and rotary converter.
- ✓ The d.c. side of rotary converter feeds a d.c. shunt motor commutator, which is directly connected to the shaft of the main motor.
- ✓ A separate d.c. supply is required to excite the field winding of d.c. motor and exciting winding of a rotary converter.
- ✓ The variable resistance is introduced in the field circuit of a d.c. motor which acts as s field regulator.



- ✓ The speed of the set is controlled by varying the field of the d.c. motor with the rheostat R. When the field resistance is changed, the back e.m.f. of motor changes.
- ✓ Thus the d.c. voltage at the commutator changes.
- ✓ This changes the d.c. voltage on the d.c. side of a rotary converter.
- ✓ Now rotary converter has a fixed ratio between its a.c. side and d.c. side voltages.
- ✓ Thus voltage on its a.c. side also changes. This a.c. voltage is given to the slip rings of the main motor.
- ✓ So the voltage injected in the rotor of main motor changes which produces the required speed control.
- ✓ Very large motors above 4000 kW such as steel rolling mills use such type of speed control.
- ✓ The main advantage of this method is that a smooth speed control is possible. Similarly wide range of speed control is possible.
- ✓ Another advantage of the system is that the design of a rotary converter is practically independent of the speed control required.
- ✓ Similarly if rotary converter is overexcited, it draws leading current and thus power factor improvement is also possible alongwith the necessary speed control.

5.6.2 Scherbius System:



- ✓ This method requires an auxiliary 3 phase or 6 phase a.c. commutator machine which is called Scherbius machine.
- ✓ The difference between Kramer system and this system is that the Scherbius machine is not directly connected to the main motor, whose speed is to be controlled.
- ✓ The Scherbius machine is is excited at a slip frequency from the rotor of a main motor through a regulation transformer.
- ✓ The taps on the regulating transformer can be varied, this changes the voltage developed in the rotor Scherbius machine, which is injected into the rotor of main motor.
- ✓ This control the speed of the main motor, the scherbius machine is connected directly to the induction motor supplied from main line so that its speed deviates from a fixed value only to the extent of the slip of the auxiliary induction motor.
- ✓ For any given setting of regulating transformer, the speed of the main motor remains substantially constant irrespective of the load variations.
- ✓ Similar to the Kramer system, this method is also used to control speed of large induction motors.
- ✓ The only disadvantage is that these methods can be used only for slip ring induction motors.

Unit I – Introduction
Two Marks

1. Define Drive and Electric Drive? (AU-NOV-07)

Drive: A combination of prime mover, transmission equipment and mechanical Working load is called a drive

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

2. List out some examples of prime movers?

- Hydraulic Engine,
- Steam engine,
- Turbine or electric motors.

3. List out some advantages of electric drives? (AU-NOV-08) (AUC-NOV-09) (AUC-APR-11) (AUC-JAN-09) (AUC-MAY-10)

i. Availability of electric drives over a wide range of power a few watts to mega watts.
ii. Ability to provide a wide range of torques over wide range of speeds.
iii. Electric motors are available in a variety of design in order to make them compatible to any type of load.

4. Give some examples of Electric Drives?

i. Driving fans, ventilators, compressors and pumps.
ii. Lifting goods by hoists and cranes.
iii. Imparting motion to conveyors in factories, mines and warehouses
iv. Running excavators & escalators, electric locomotives trains, cars trolley buses, lifts & drum winders etc.

5. What are the types of electric drives? (AUC-NOV-09)

- Group electric drives (Shaft drive),
- Individual Drives,
- Multi motor electric drives.

6. What is a Group Electric Drive (Shaft Drive)? (AU-MAY-05) (AUC-MAY-10)

- This drive consists of single motor, which drives one or more line Shafts supported on bearings.
- The line shaft may be fitted with either pulleys & belts or gears, by means of which a group of machines or mechanisms may be operated.

7. Classify electric drives based on the means of control?

- Manual,
- Semiautomatic,
- Automatic

8. What are the advantages and disadvantages of Group drive (Shaft drive)? (AU-MAY-05)

Advantages: (AU-APR-08)

- A single large motor can be used instead of a number of small motors.
- The rating of the single motor may be appropriately reduced taking into account the diversity factor of loads.

Disadvantages:

- There is no flexibility; Addition of an extra machine to the main Shaft is difficult.
- The efficiency of the drive is low, because of the losses occurring in several transmitting mechanisms.
- The complete drive system requires shutdown if the motor, requires Servicing or repair.

- The system is not very safe to operate
- The noise level at the work spot is very high.

9. What is an individual electric drive? Give some examples. (UQ)

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

Single spindle drilling machine, Lathe machines etc.

10. What is a multi motor electric drive? Give some examples.

In this drive, there are several drives, each of which serves to activate on of the working parts of the driven mechanisms.

Metal cutting machine tools, paper making machines, rolling mills, traction drive, Traveling cranes etc.,

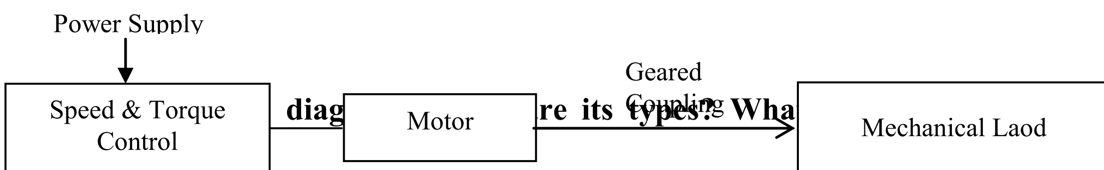
11. Write about manual control, semiautomatic control & Automatic control?

Manual control: The electric drives with manual control can be as simple as a room fan, incorporating on switch and a resistance for setting the required speed.

Semiautomatic control: This control consists of a manual device for giving a certain command (Starting, braking, reversing, change of speed etc.,) and an automatic device that in response to command operates the drive in accordance with a preset sequence or order.

Automatic control: The electric drives with automatic control have a control gear,
Without manual devices

12. What are the typical elements of an Electric Drive? (AU-MAY-05) (AUC-NOV-09) (AUC-JAN-09)



13. diag re its types? Wha v a load

A load diagram is the diagram which shows graphically the variation of torque acting on the electric drive. The motor of the electric drive has to overcome the load torque expressed as a function of time. **Types:**

- One for the static or steady state process
- Other for the dynamic process, when the dynamic components of torque are induced by the inertia of the motor & load.

  (Instantaneous speed, acceleration, Torque & power) as a function of time are required to draw…..

14. What are the types drive systems?(UQ)

- Electric Drives
- Mechanical Drives
- Electromechanical Drives
- Hydraulic drives.

15. Give an expression for the losses occurring in a machine?

The losses occurring in a machine is given by

$\mathbf{W = W_c + x^2 W_v}$

Where Wc = Constant losses

Wv = Variable losses at full load

X = load on the motor expressed as a function of rated load.

16. What are the assumptions made while performing heating & cooling calculation of an electric motor? (AU-NOV-06)

i. The machine is considered to be a homogeneous body having a uniform temperature gradient. All the points at which heat generated have the same temperature. All the points at which heat is dissipated are also at same temperature.
ii. Heat dissipation taking place is proportional to the difference of temperature of the body and surrounding medium. No heat is radiated.
iii. The rate of dissipation of heat is constant at all temperatures.

17. What are the factors that influence the choice of Electrical drives? (AU-MAY-07, 08) (AU-NOV-08, 09) (AUC-APR-11) (AUC-MAY-08,)

1. Shaft power & speed
2. Power range
3. Starting torque
4. Maintenance
5. Total purchase cost
6. Influence on power supply
7. Availability
8. Nature of electric supply
9. Types of drive
10. Service cost
11. Speed range
12. Efficiency
13. Influence on the supply network
14. Special competence
15. Cost of energy losses
16. Environment
17. Accessibility
18. Nature of load
19. Electrical Characteristics
20. Service capacity & rating

18. Indicate the importance of power rating & heating of electric drives. (AU-NOV-05)

Power rating: Correct selection of power rating of electric motor is of economic interest as it is associated with capital cost and running cost of drives.

Heating: For proper selection of power rating the most important considerations the heating effect of load. In this connection various forms of loading or duty cycles have to be considered.

19. How heating occurs in motor drives?

The heating of motor due to losses occurring inside the motor while converting the electrical power into mechanical power and these losses occur in steel core, motor winding & bearing friction.

20. What are the classes of duties? (AUC-NOV-09)

1. Continuous duty
2. Short time duty operation of motor Main classes of duties
3. Intermittent periodic duty
4. Intermittent periodic duty with starting
5. Intermittent periodic duty with starting & braking
6. Continuous duty with intermittent periodic loading
7. Continuous duty with starting & braking
8. Continuous duty with periodic load changes

21. How will you classify electric drives based on the method of speed control?

1. Reversible &non reversible in controlled constant speed
2. Reversible and non reversible step speed control
3. Reversible and non reversible smooth speed control
4. Constant predetermined position control
5. Variable position control
6. Composite control.

22. List out some applications for which continuous duty is required.

- Centrifugal pumps, fans, conveyors & compressors

23. Why the losses at starting are not a factor of consideration in a continuous duty motor?

While selecting a motor for this type of duty it is not necessary to give importance to the heating caused by losses at starting even though they are more than the losses at rated load. This is because the motor does not require frequent start nit is started only once in its duty cycle and the losses during starting do not have much influence on heating.

24. What is meant by "short time rating of motor"? (AU-NOV-06)

Any electric motor that is rated for a power rating P for continuous operation can be loaded for a short time duty (P_{sh}) that is much higher than P, if the temperature rise is the consideration.

25. What is meant by "load equalization"? (AUC-NOV-09)

In the method of "load Equalization" intentionally the motor inertia is increased By adding a flywheel on the motor shaft, if the motor is not to be reversed. For Effectiveness of the flywheel, the motor should have a prominent drooping characteristic so that on load there is a considerable speed drop.

26. How a motor rating is determined in a continuous duty and Variable load?

Method of Average losses, equivalent power, equivalent Torque

27. Define heating time constant & cooling time constant? (AU-NOV-05) (AU-MAY-08) (AU-NOV-10) (AUC-MAY-08, 10)

Heating time constant is defined as the time taken by the machine to attain 0.623 of its final steady temperature rise.

Cooling time constant is, therefore, defined as the time required cooling the machine down to 0.368 times the initial temperature rise above ambient temperature.

28. What are the various function performed by an electric drive? (AUC-NOV-09)

1. Driving fans, ventilators, compressors & pumps etc.,
2. Lifting goods by hoists & cranes
3. Imparting motion to conveyors in factories, mines & warehouses and
4. Running excavators & escalators, electric locomotives, trains, cars, Trolley buses and lifts etc.

29. Write down the heat balance equation?

Heat balance equation is given by

Ghd0 + S0 .dt = p.dt

30. What is ingress protection code? (UQ)

The protection code deals with the methods employed for safeguarding the motor against the entry of external agents like dust, water etc.

For example IP 21 deals with safeguarding motor against foreign bodies like water. IP stands for ingress protection code.

31. What are the mechanical considerations to be considered in Selection of motor (UQ)

- Types of enclosures
- Types of bearings
- Types of mounting
- Types of drive
- Noise emitted

32. Mention four types of mechanical load? (AU-MAY-05) (AUC-APR-11)

- Load torque remaining constant irrespective of the speed
- Load torque increasing with the square of the speed
- Load torque increasing with speed, Load torque decreasing

33. Define continuous duty of a motor? (AU-MAY-06)

Continuous duty: This type drive is operated continuously for a duration which is long enough to reach its steady state value of temperature. This duty is characterized by constant motor torque and constant motor loss operation. This type of duty can be accomplished by single phase/ three phase induction motors and DC shunt motors.

Examples:

Paper mill drives
Compressors
Conveyors
Centrifugal pumps and
Fans

34. Draw the block diagram of electric drive? (AU-NOV-07, 09) (AU-MAY-09)

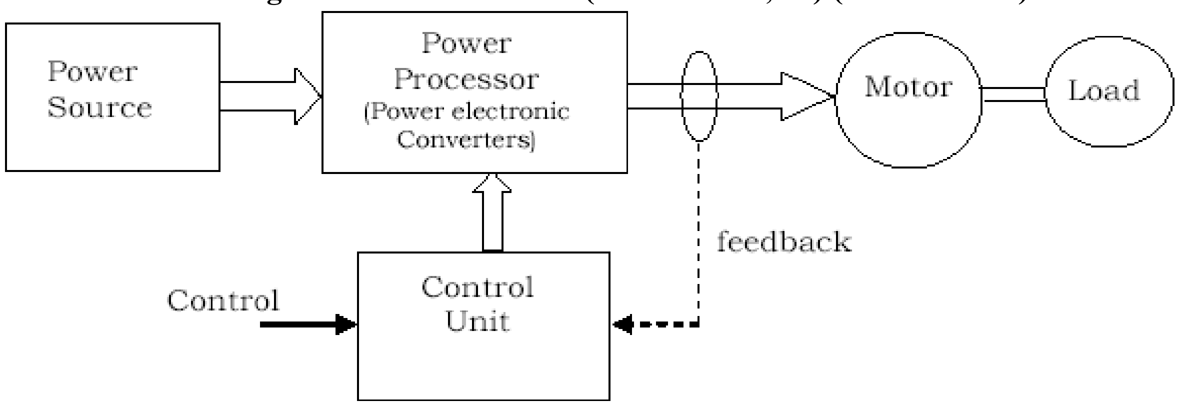
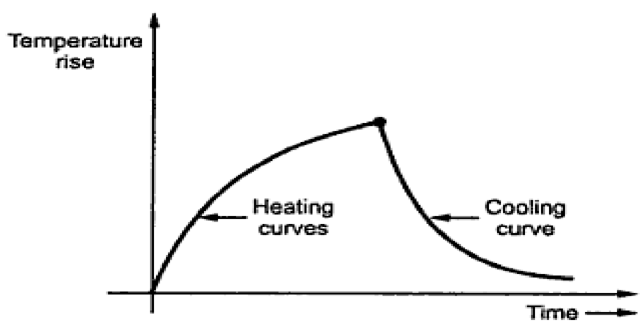


Figure 2 Modern Electric drive system employing power electronic converters

35. Draw the heating and cooling curve? (AU-APR-08)



16 Marks Questions

1. What is electric drive? Explain it briefly with neat block diagram? (AUC-MAY-08, 10)

The aggregate of the electric motor, the energy transmitting shaft and the control equipment by which the motor characteristics are adjusted and their operating conditions with respect to mechanical load varied to suit practical requirements is called as electric drive.
Drive system=Drive + load

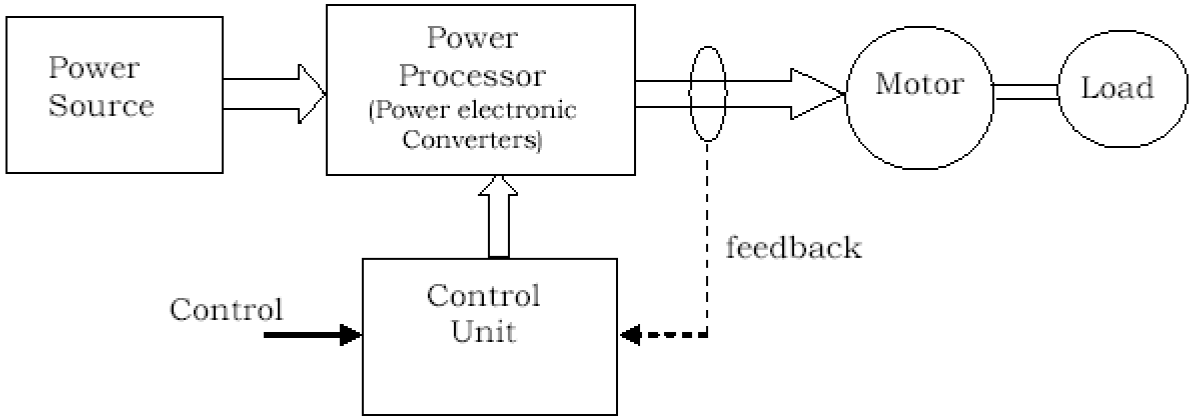


Figure 2 Modern Electric drive system employing power electronic converters

Block diagram of electric drive

Load: usually a machinery to accomplish a given task.Eg-fans, pumps, washing machine etc.

Power modulator: modulators (adjust or converter) power flow from the source to the motion

Motor: actual energy converting machine (electrical to mechanical)

Source: energy requirement for the operation the system

Control: adjust motor and load characteristics for the optimal mode.

Power moduators: power modulators regulate the power flow from source to the motor to enable the motor to develop the torque speed characteristics required by the load.

The common function of the power modulator is

- They contain and control the source and motor currents with in permissible limits during the transient operations such as starting, braking, speed reversal etc.
- They converts the input electrical energy into the form as required by the motors.
- Adjusts the mode of operation of the motor that is motoring, braking are regenerative.

Power modulators may be classified as

- Converters uses power devices to convert uncontrolled valued to controllable output.
- Switching circuits switch mode of operation
- Variable impedance

- **Converters**

They provide adjustable voltage/current/frequency to control speed, torque output power of the motor.

The various type of converters are,

- AC to DC rectifiers
- DC to DC choppers
- AC to AC choppers
- ✓ AC to AC –AC voltage controllers (voltage level is controlled)
- ✓ Cyclo converter (Frequency is controlled)
- ✓ DC to AC inverters

- **Switching circuits**

Switching circuits are needed to achieve any one of the following.

- Changing motor connection to change its quadrant of operation.

- Changing motor circuits parameters in discrete steps for automatic starting and braking control.
- For operating motors and drives according to a predetermine sequence
- To provide inter locking their by preventing maloperation
- Disconnect under up normal condition

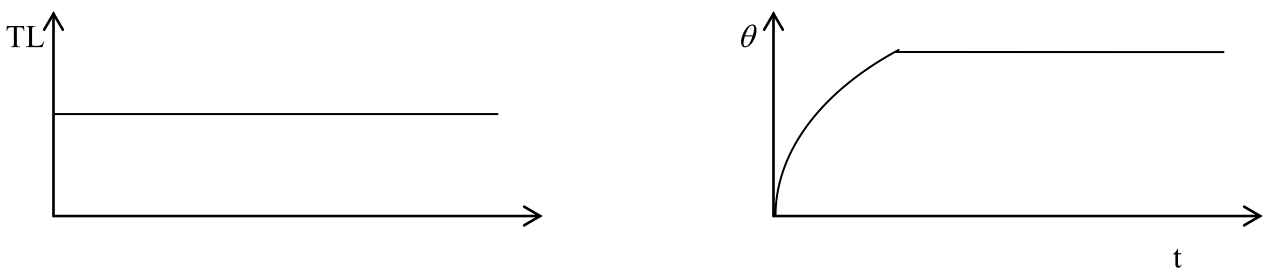
Eg: electromagnetic contacters, PLC in sequencing and inter locking operation, solid state relays etc.

- **Variable impedance**
  - Variable resisters are commonly used for AC and DC drives and also needed for dynamic braking of drives
  - Semiconductors switch in parallel with a fixed resistance is used where stepless variation is needed. inductors employed to limit starting current of ac motors

2. Explain about the Classes of Motor Duty with a neat diagram? (AU-NOV-07, 08, 09, 10) (AU-APR-08) (AUC-NOV-09, 10) (AUC-APR-11)

According to IS: 4722-1968 categories various load time variations encountered into eight classes as

(ix) **continuous duty**
(x) **short time duty**
(xi) **intermittent periodic duty**
(xii) **intermittent periodic duty with starting**
(xiii) **intermittent periodic duty with starting & braking**
(xiv) **continuous duty with intermittent periodic loading**
(xv) **continuous duty with starting & braking**
(xvi) **Continuous duty with periodic speed changes.**



(a) t (b)

Fig-1

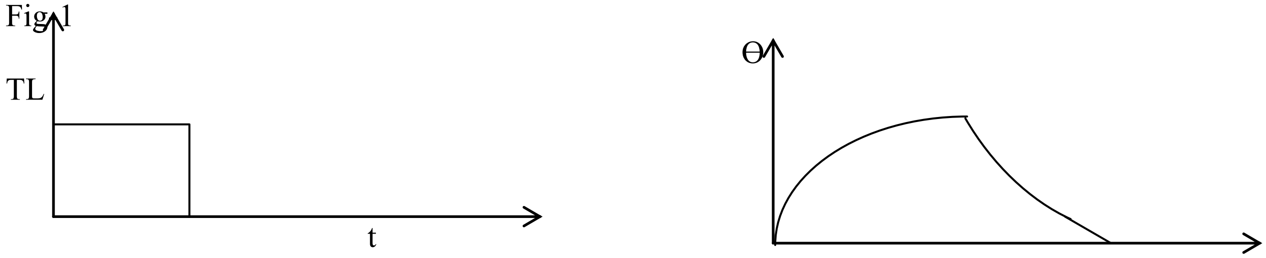
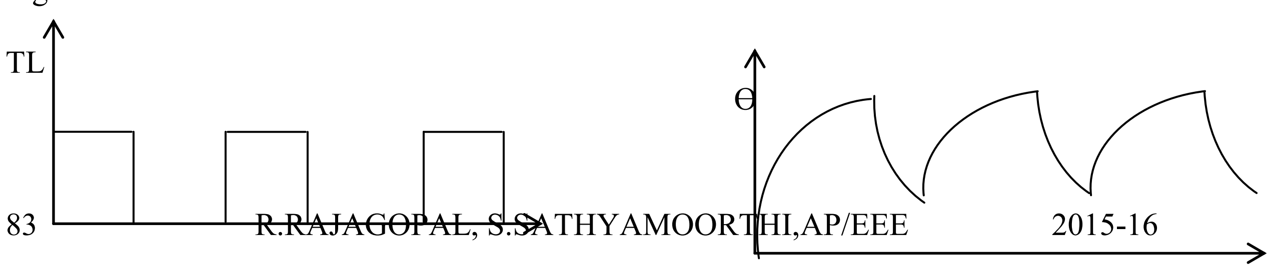
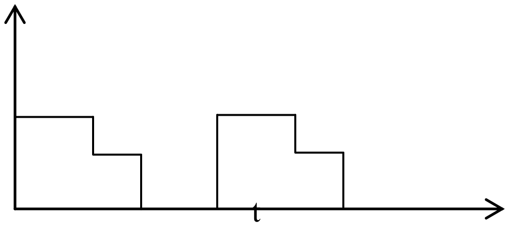


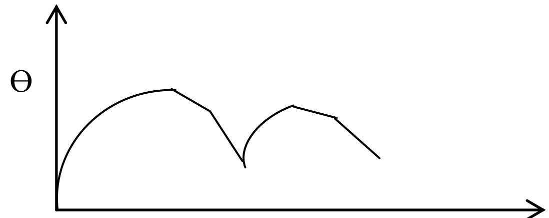
Fig-2



(a) t t
(b)

Fig-3

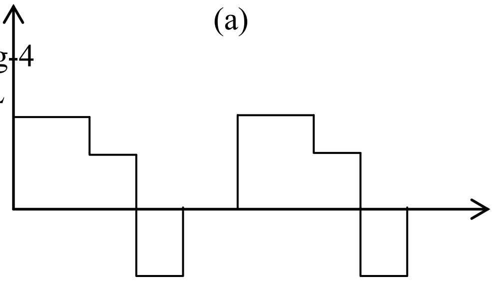


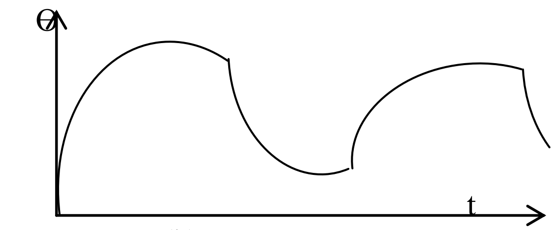


t t

(a) (b)

Fig-4
TL





(a) (b)

Fig-5

Where,
TL – Load torque in N-M,
Ө- Temperature in Deg.centigrade,
t- Time in seconds.

Continuous duty: This type drive is operated continuously for a duration which is long enough to reach its steady state value of temperature. This duty is characterized by constant motor torque and constant motor loss operation. Depicted in fig.1 (a) & (b). This type of duty can be accomplished by single phase/ three phase induction motors and DC shunt motors.

Examples:

Paper mill drives
Compressors
Conveyors
Centrifugal pumps and
Fans

Short time duty: In this type drive operation, Time of operation is less than heating time constant and motor is allowed to cool off to room temperature before it is operated again. Here the motor can be overloaded until the motor temperature reaches its permissible limit. Depicted in fig.2 (a) & (b). This type of duty can be accomplished by single phase/ three phase induction motors and DC shunt motors, DC series motors, universal motors.

Examples:

Crane drives
Drives for house hold appliances
Turning bridges
Sluice gate drives
Valve drives and

Machine tool drives.

Intermittent periodic duty: In this type drive operation, It consists of a different periods of duty cycles

I.e. a period of rest and a period of running, a period of starting, a period of braking. Both a running period is not enough to reach its steady state temperature and a rest period is not enough to cool off the machine to ambient temperature.

In this type drive operation, heating due to starting and braking is negligible. Depicted in fig.3 (a) & (b). This type of duty can be accomplished by single phase/ three phase induction motors and DC shunt motors, universal motors.

Examples:

Pressing
Cutting
Drilling machine drives.

Intermittent periodic duty with starting: This is intermittent periodic duty where heating

Due to starting can‟t be ignored. It consists of a starting period; a running period, a braking period & a rest period are being too short to reach their steady state value.

In this type of drive operation, heating due to braking is negligible. Depicted in fig.4 (a) & (b). This type of duty can be accomplished by three phase induction motors and DC series motors, DC compound motors, universal motors.

Examples:

Metal cutting,
Drilling tool drives,
Drives for forklift trucks,
Mine hoist etc.

Intermittent periodic duty with starting & braking: This is intermittent periodic duty where heating during starting & braking can‟t be ignored. It consists of a starting period, a running period; a braking period & a rest period are being too short to reach their steady state temperature value. Depicted in fig.5 (a) & (b). This type of duty can be accomplished by single phase/ three phase induction motors and DC shunt motors, DC series motors, DC compound motors, universal motors.

Examples:

Billet mill drive
Manipulator drive
Ingot buggy drive
Screw down mechanism of blooming mill
Several machine tool drives
Drives for electric suburban trains and
Mine hoist

Continuous duty with intermittent periodic loading: This type of drive operation consists a period of running at constant load and a period of running at no load with normal voltage to the excitation winding in separately excited machines. Again the load and no load periods are not enough to reach their respective temperature limits. This duty is distinguished from intermittent periodic duty by running at no load instead of rest period. This type of duty can be accomplished by single phase/ three phase induction motors and DC compound motors, universal motors.

Examples:

Pressing
Cutting
Shearing and
Drilling machine drives.

Continuous duty with starting & braking: It consists a period of starting, a period of running & a period of electrical braking. Here period of rest is negligible. This type of duty can be accomplished by single phase/ three phase induction motors.

Examples:

The main drive of a blooming mill.

Continuous duty with periodic speed changes: It consists a period of running in a load with a particular speed and a period of running at different load with different speed which are not enough to reach their respective steady state temperatures. Further here is no period of rest. This type of duty can be accomplished by single phase/ three phase induction motors and DC series motor in traction.

Examples:

All variable speed drives.

3. Derive the heating and cooling curves? (AU-MAY-06, 09) (AU-NOV-08, 09) (AUC-NOV-09, 10)

A machine can be considered as a homogeneous body developing heat internally at uniform rate and dissipating heat proportionately to its temperature rise,

<u>RELATION SHIP BETWEEN TEMPERATURE RISE AND TIME</u>

Let P=heat developed, joules/sec or watts
G=weight of active parts of machine, kg
h=specific heat per kg per deg cell
S= cooling surface, m2
λ = specific heat dissipation (or) emissivity, J per sec per m^2 of Surface per deg cell difference between surface and ambient cooling medium
θ = temperature rise, deg cell
θ_m =final steady temperature rise, deg cell
t =time, sec
τ =heating time constant, seconds
τ' =cooling time constant, seconds

Assume that a machine attains a temperature rise after the lapse of time t seconds.
In an element of time "dt" a small temperature rise "d" takes place.
Then, heat developed=p.dt
Heat developed=Gh.dθ
Heat dissipated=S $\theta\lambda$. dt

Therefore, total heat developed=heat stored + heat dissipated

Ghdθ + S $\theta\lambda$.dt= p.dt

$$\frac{d\theta}{dt} + \theta.\frac{s\lambda}{Gh} = \frac{p}{Gh}$$

This is a differential equation and solution of this equation is,

$$\theta = \frac{p}{s\lambda} + ke^{-(s\lambda/Gh)t}$$

Where k is a constant of integration determined by initial conditions.

Let the initial temperature rise to be zero at t=0.

$$\text{Then, } 0 = \frac{p}{s\lambda} + k$$

$$k = \frac{-p}{s\lambda}$$

Hence, $\theta = \frac{p}{s\lambda}(1 - e^{-(\frac{s\lambda}{Gh}t)})$ - - - - - - - - - - - - - (1)

When t= ∞ , $\theta = \frac{p}{s\lambda} = \theta m$, the final steady temperature rise.

Represent $\frac{p}{s\lambda} = \theta m and \frac{Gh}{s\lambda} = \tau$ - - - - - - - - - - - - - -(2)

Equation 1 can be written as

$\theta = \theta m(1 - e^{-1})$ - - - - - - - - - - - -- -(3)

Where is called as heating time constant and it has the dimensions of time.

Heating time constant

Heating time constant is defined as the time taken by the machine to attain 0.623 of its final steady temperature rise.

When t= τ ,

$$\theta = \theta m(1 - e^{-1})$$

$$\theta = 0.632\theta m$$

- The heating time constant of the machine is the index of time taken by the machine to attain its final steady temperature rise.
- We know that $\tau = \frac{Gh}{s\lambda}$, therefore, the time constant is inversely proportional to has a larger value for ventilated machines and thus the value of their heating time constant is small.

The value of heating time constant is larger for poorly ventilated machines. with large or totally enclosed machines, the heating time constant may reach several hours or even days.

- When a hot body is cooling due to reduction of the losses developed in it, the temperature time curve is again an exponential function

$$\theta = \theta_f + (\theta_i - \theta_f)e^{-\frac{t}{\tau}} \quad \text{-------------} (4)$$

Where,

θ_f =final temperature drop (the temperature at which whatever heat is generated is dissipated)

$\frac{p}{s\lambda'}$ = where, λ is rate of heat dissipation while cooling

θ_i = the temperature rise above ambient in the body at time t=0

τ' = cooling time constant= $\frac{Gh}{s\lambda'}$

If motor where disconnected from supply during cooling, there would be no losses taking place and hence, final temperature reached will be the ambient temperature.

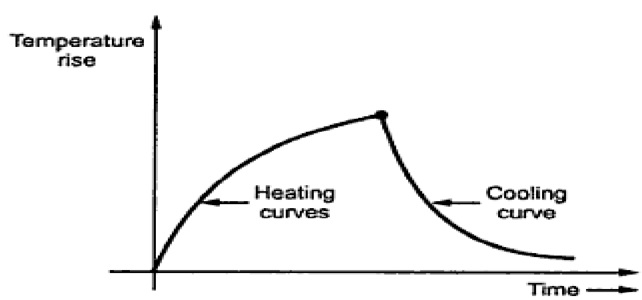
There fore, θ_f =0 and hence equation (4) becomes

$$\theta = \theta_i e^{\frac{1}{\tau'}}$$

Cooling time constant

At t= τ', $\theta = 0.368\theta_i$

Cooling time constant is, therefore, defined as the time required cooling the machine down to 0.368 times the initial temperature rise above ambient temperature.



Heating and cooling time curves

3. Explain the load conditions in motor? (AU-MAY-05)

The load requirements are in either of

- Speed control
- Torque control

Depending upon the load requirements the motor has to be chosen.

For example in traction system the load (traction network) needs high starting torque (initiali.e.,high current value is needed at t6he start. A series motor provides a high starting torque as .Hence series motor should be chosen for traction system.

Classification of loads

- Torque dependent on speed
  (Ex-hoists, pumping of water or gas against constant pressure)
- Torque linearly dependent on speed
  (Ex- motor driving a DC generator connected to a fixed resistance load [generator field value is kept constant])
- Torque proportional to square of speed
  (Ex- fans, sentrifugal pumps, propellers)
- Torque inversely proportional to speed
  (Ex-milling and boring, machines)

Different type of industrial loads

There are three types of industrial loads under which electric motors are required to work. they are

- Continuous load
- Intermittent load
- Variable or fluctuating load
  - **Continuous load**
    - Load is continuous in nature
    - Ex- Pumps or fans require a constant power input to keep them operating**.**
  - **Intermittent load**
    - This type classified in to two types
    - Motor loaded for short time and then shunt off for sufficiently longer duration temperature is brought to the room temperature eg: kitchen mixie.the electrical loss is more due to constant ON/OFF delay period
    - Motor loaded for short time and shunt off for short time .here the motor cannot be cooled down to the room temperature comparison of the two methods it can be Inferred. the temperature level of motor is not brought to the room temperature

4. Explain the classification of electric drives with factor? (AUC-APR-11) (AU-NOV-07)

The choice of the electric drives

There are three classification namely

- ✓ grope drive
- ✓ individual drive
- ✓ multimotor drive

Group drive

One motor is used as a drive for two or more than machines. The motor is connected to a long shaft. All the other machines are connected to this shaft through belt and pulleys**.**

Advantages

- Grope drive is most economical because, the rating of the motor used may be comparatively less then the aggregate of the individual motors required to drive each equipment, because all of they may not be working simultaneously.

- Grope drive reduces the initial cost of installing a particular industry.
- Cost is less because of investment in one motor which is lesser in HP rating.

Disadvantages

The use of this kind of drive is restricted due to the following reasons:

- It is not possible to install any machine as per our wish. so, flexibility of lay out is lost.
- The possibility of installation of additional machines in an existing industry is limited.
- In case of any fault to the main driving motor, all the other motors will be stopped immediately.
- so, all systems will remain idle and is not advisable for any industry.
- Level of noise produced at the site is high.
- Because of the restrictions in placing other motors, this kind of drive will result in untidy appearance, and it is also less safe to operate.
- Since all the motors has to be connected through belts and pulleys, large amount of energy is wasted in transmitting mechanisms.Therefore, power loss is high.

Individual drive

In this drive, there will be a separate driving motor for each process equipment.
One motor is used for transmitting motion to various parts or mechanisms belonging to signal equipment.

Ex-Lathe

One motor used in lathe which rotates the spindle, moves feed with the help of gears and imparts motion to the lubricating and cooling pumps).

Advantages

- Machines can be located at convenient places.
- Continuity in the production of the processing industry is ensured to a high level of reliability.
- If there is a fault in one motor, the effect on the production or output of the industry will not be appreciable.

Disadvantages

- Initial cost is very high.

Multimotor drive

In this type of drive, separate motors are provided for actuating different parts of the driven mechanism. (Ex-cranes, drives used in paper mills, rolling mills etc.,

In cranes, separate motors are used for hoisting, long travel motion and cross travel motion.

5. **Explain the Factors influencing the choice of electrical drives? (AU-NOV-05, 10) (AU-MAY-05,07, 09) (AU-APR-08) (AUC-NOV-09) (AUC-APR-11)**

- ✓ Nature of electric supply
  - Whether AC or DC supply is to be used for supply
- ✓ Nature of the drive
  - Whether the particular motor is going to drive individual machine or a group of machines
- ✓ Capital and running cost
- ✓ Maintenance requirement
- ✓ Space ad weight restrictions
- ✓ Environment and location
- ✓ Nature of load
  - Whether the load requires light or heavy starting torque
  - Whether load torque increases with speed remain constant
  - Whether the load has heavy inertia which may require longer straight time
- ✓ Electrical characteristics of motor

- Startingcharacteristics,runningcharacteristics,speed control and braking characteristics
- ✓ Size,rating and duty cycle of motors
  - Whether the motor is going to the operator for a short time or whether it has to run continuously intermittently or on a variable load cycle
- ✓ Mechanical considerations
  - Type of enclosures, type of bearings, transmission of drive and Noise level.

Due to practical difficulties, it may not possible to satisfy all the above considerations. In such circumstances, it is the experience and knowledge background which plays a vital role in the selection of the suitable drive.

The following points must be given utmost important for the selection of motor. The factors are:

- Nature of the mechanical load driven
- Matching of the speed torque characteristics of the motor with that of the load
- Starting conditions of the load

6. **Briefly explain the Selection of power rating of motors? (AU-NOV-05, 10) (AU-MAY-07) (AU-APR-08)**

From the point of view of motor rating for various duty cycles in section 1.6 can be broadly classified as:

- Continuous duty and constant load
- Continuous duty and variable load
- Short time rating

<u>Continuous duty and constant load</u>

If the motor has load torque of T N-m and it is running at ω radians/seconds, if efficiency in η, then power rating of the motor is

$$P = \frac{T\omega}{1000} KW$$

Power rating is calculated and then a motor with next higher power rating from commercially available rating is selected.

Obviously, motor speed should also match load‟s speed requirement .It is also necessary to check whether the motor can fulfill starting torque requirement also.

<u>Continuous duty and variable load</u>

- The operating temperature of a motor should never exceed the maximum permissible temperature, because it will result in deterioration and breakdown of insulation and will shorten the service life of motors. It is general practice to base the motor power ratings on a standard value of temperature, say 35° c. Accordingly, the power given on the name plate of a motor corresponds to the power which the motor is capable of delivering without overheating at an ambient temperature of 35° c. the duty cycle is closely related to temperature and is generally taken to include the environmental factors also.
- The rating of a machine can be determined from heating considerations. How ever the motor so selected should be checked for its overload capacity and starting torque. This is because, the motor selected purely on the basis of heating may not be able to meet the mechanical requirements of the basis of heating may not be able to meet the mechanical requirements of the load to be driven by it.

- The majority of electric machines used in drives operate continuously at a constant or only slightly variable load. The selection of the motor capacity for these applications is fairly simple in case the approximate constant power input is known
- In many applications, the power input required for a motor is not known before hand and therefore certain difficulties arise in such cases. For the determination of ratings of machines whose load characteristics have not been thoroughly studied, it becomes necessary to determine the load diagram i.e., diagram shown the variation of power output versus time.

The temperature of the motor changes continuously when the load is variable. On account of this, it becomes difficult to select the motor rating as per heating.

- The analytical study of heating becomes highly complicated if the load diagram is irregular in shape or when it has a large number of steps. Therefore it becomes extremely difficult to select the motor capacity through analysis of the load diagram due to select the motor capacity through analysis of the load diagram due to lack of accuracy of this method.

On the other hand it is not correct to select the motor according to the lowest or highest load because the motor would be overloaded in the first case and under loaded in the second case. Therefore it becomes necessary to adopt suitable methods for the determination of motor ratings.

Methods used

The four commonly used methods are:

- Methods of average losses
- Equivalent current method
- Equivalent torque method
- Equivalent power method

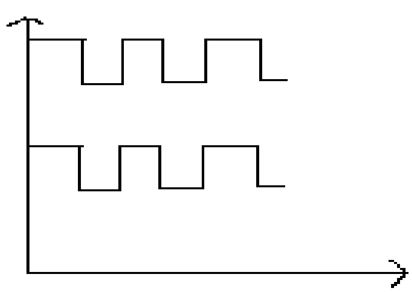
<u>Methods of average losses</u>

The method consists of finding average losses Q_{av} in the motor when it operates according to the given load diagram. These losses are then compared with the Q , the losses corresponding to the continuous duty of the machine when operated at its normal rating.

The method of average losses presupposes that when $Q_{av} = Q_{nomn}$, the motor will operate without temperature rise going above the maximum permissible for the particular class of insulation. The figure shows a simple power load diagram and loss diagram for variable load conditions.

The losses of the motor are calculated for each portion of the load diagram by referring to the efficiency curve of the motor.

Power



Time

The average losses are given by

$$Q_{av} = \frac{Q_1 t_1 + Q_2 t_2 + Q_3 t_3 + \ldots\ldots\ldots\ldots + Q_n t_n}{t_1 + t_2 + \ldots\ldots + t_n}$$

- In case ,the two losses are equal or differ by a small amount ,the motor is selected .if the losses differ considerably ,another motor is selected and the calculations repeated till a motor having almost the same losses as the average losses is found. it should be checked that the motor selected has a sufficient overload capacity and starting torque.
- The method of average losses dopes not take into account, the maximum temperature rise under variable load conditions .However, this method is accurate and reliable for determining the average temperature rise of the motor during one work cycle.

The disadvantage of this method is that it is tedious to work with and also many a times the efficiency curve is not readily available and the efficiency has to be calculated by means of empirical formula which may not be accurate.

EQUIVALENT CURRENT METHOD

The equivalent current method is based on the assumption that the actual variable current may be replaced by an equivalent current i_{eq} which produces the same losses in the motor as the actual current.

$$I_{eq} = \sqrt{\frac{I_1^2 t_1 + I_2^2 t_2 + I_3^2 t_3 + \ldots\ldots\ldots + I_n^2 t_n}{t_1 + t_2 + t_3 + \ldots\ldots\ldots\ldots + t_n}}$$

The equivalent current is compared with the rated current of the motor selected and the conditions $I_{eq} \leq I_{nom}$ should be met. I_{nom} is the rated current of the machine.

The machine selected should also be checked for its overload capacity,

For DC motors, $\frac{I_{max}}{I_{nom}} \leq 2 to 2.5 and for induction motors, \frac{I_{max}}{nom} \leq 1.65 to 2.75$

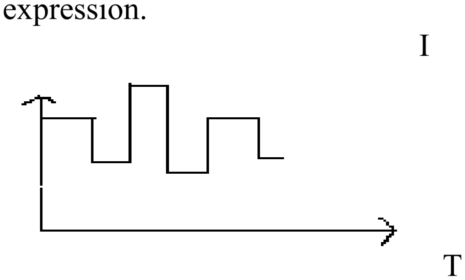
$I_{max} = \max imum current during the work cycle.$

$T_{max} = \max imum load torque$

$T_{nom} = torque of the motor at rated power and speed$

If the over load capacity of the motor selected is not sufficient, it becomes necessary to select a motor of higher power rating.

The equivalent current may not be easy to calculate especially in cases where the current load diagram is irregular .the equivalent current in such cases is calculated from the following expression.



For a triangular shape diagram,

$I_{eq} = \sqrt{\frac{I^2}{3}}$

For a trapezoidal shaped diagram,

$$I_{eq} = \sqrt{\frac{I^2 + I_1 I_2 + I_2^2}{3}}$$

The above method allows the equivalent current values to be calculated with accuracy sufficient for practical purposes.

Equivalent torque method

Assuming constant flux and power factor, torque is directly proportional to current.

$$T = \sqrt{\frac{T_1^2 t_1 + T_2^2 t_2 + ...+ T_n^2 t_n}{t_1 + t_2 + ...+ t_n}}$$

Equivalent power method

The equation for equivalent power method, power is directly proportional to torque.

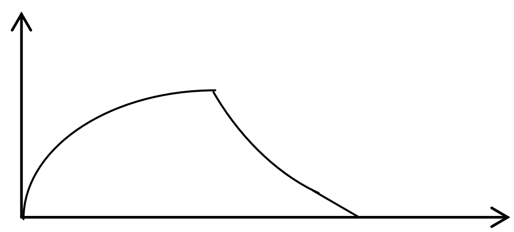
At constant speed or where the changes in speed are small, the equivalent power is given by the following relation ship,

$$P_{eq} = \sqrt{\frac{P_1^2 t_1 + P_2^2 t_2 + ...+ P_n^2 t_n}{t_1 + t_2 + ...+ t_n}}$$

Short time rating of motor

An electric motor of rated power P_r subjected to its rated load continuously reaches its permissible temperature rise after due to time. If the same motor is to be used for short time duty, it can take up more load for a short period without increasing the maximum permissible temperature of the motor during this period.

$$\theta = \theta_m (1 - e^{\frac{N}{\tau}}) \qquad \theta_m = \theta_m^{'} (1 - e^{-\frac{N}{\tau}})$$



Where=operating time under rated load

θ_m =maximum permissible temperature which the motor running on short time rating will reach if run continuously at that rating.

θ_m = Maximum permissible temperature rise of the motor run continuously at continuous rating.

If it is assumed that the temperature rise is proportional to losses corresponding to the rating of the motor.

$$\frac{\theta_m^{'}}{\theta_m} = \frac{W_x}{W_r} = \frac{1}{(1 - e^{-\frac{N}{\tau}})}$$

The ratings of the motor will be proportional to the losses .If P_x is the short time load P_r is the continuous rating of the motor, losses for continuous rating are,

$$W_r = W_{const} + W_{cu}$$

$$W_x = W_{const+}(\frac{P_x}{P_r})^2 W_{cu}$$

The ratio of $\frac{P_x}{P_r}$ can be determined.

Unit II – Drive Motor Characteristics
Two Marks

1. Why a single phase induction motor does not self start?

When a single phase supply is fed to the single phase induction motor. Its stator winding produces a flux which only alternates along one space axis. It is not a synchronously revolving field, as in the case of a 2 or 3phase stator winding, fed from 2 or 3 phase supply.

2. What is meant by plugging? (AU-APR-08) (AU-NOV-06) (AUC-NOV-09, 10) (AUC-MAY-08)

The plugging operation can be achieved by changing the polarity of the motor there by reversing the direction of rotation of the motor. This can be achieved in ac motors by changing the phase sequence and in dc motors by changing the polarity.

3. Give some applications of DC motor?

Shunt: driving constant speed, lathes, centrifugal pumps, machine tools, blowers and fans, reciprocating pumps

Series: electric locomotives, rapid transit systems, trolley cars, cranes and hoists, conveyors

Compound: elevators, air compressors, rolling mills, heavy planners.

4. What are the different types of electric braking? (AU-MAY-05, 09) (AUC-NOV-09)

- Dynamic or Rheostatic braking,
- Counter current or plugging and
- Regenerative braking

5. What is the effect of variation of armature voltage on N-T curve and how it can be achieved?

The N-T curve moves towards the right when the voltage is increased. This can be achieved by means of additional resistance in the armature circuit or by using thyristor power converter.

6. Compare electrical and mechanical braking?

Mechanical	**Electrical**
Brakes require frequent maintenance	very little maintenance
Not smooth	smooth
Can be applied to hold the system at any position	cannot produce holding torque.

7. When does an induction motor behave to run off as a generator?

When the rotor of an induction motor runs faster than the stator field, the slip becomes negative. Regenerative braking occurs and the K.E. of the rotating parts is return back to the supply as electrical energy and thus the machine generates power.

8. Define slip? (AUC-NOV-09) (AUC-MAY-08)

$$S = \frac{N_s - N_r}{N_s}$$

Where, N_s = synchronous speed in rpm.

N_r = rotor speed in rpm

S = Slip

9. Define synchronous speed? (AUC-MAY-08)

It is given by $N_s = 120f / p$ rpm.

Where N_s = synchronous speed, p = no. of stator poles, f = supply frequency in Hz

10. What is meant by regenerative braking? (AU-APR-08) (AU-NOV-08) (AUC-NOV-09) (AUC-JAN-09)

In the regenerative braking operation, the motor operates as a generator, while it is still connected to the supply here, the motor speed is grater that the synchronous speed. Mechanical energy is converter into electrical energy, part of which is returned to the supply and rest as heat in the winding and bearing.

11. What are the disadvantages of inserting resistance in the rotor circuit in slip ring induction motor?

Disadvantages:

1. Losses (I^2R) is increasing and efficiency of the motor is decreased.
2. Since speed is dependent on both resistance and load. We can change speed for short periods only.

12. under what condition, the slip in an induction motor is

a. Negative

b. Greater than one

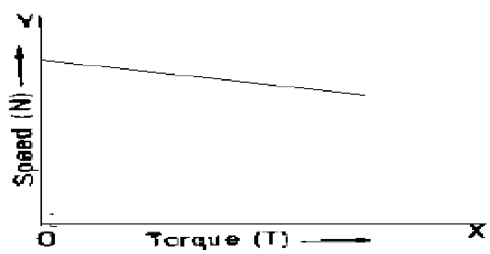
a) Slip of an induction motor is negative when the induction motor is operating in generating mode.

b) Slip of an induction motor is greater than one when the induction motor is operating in the braking mode (its direction is opposite to the direction of rotating magnetic field).

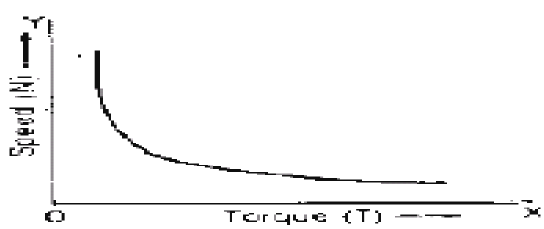
13. Differentiate cumulative and differential compound motors?

Cumulative	differential
The orientation of the series flux **aids** the shunt flux	series flux opposes shunt flux

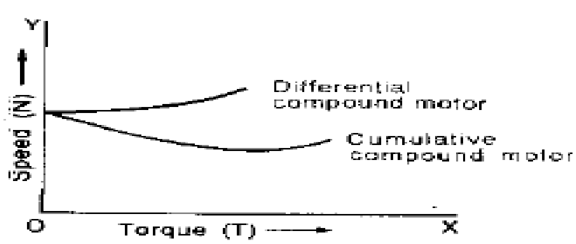
14. Draw the speed torque characteristics of DC shunt motor? (AU-NOV-08, 10) (AUC-NOV-09)



15. Draw the speed torque characteristics of DC series motor? (AU-MAY-05, 09) (AU-APR-08) (AU-NOV-06) (AUC-NOV-09)



16. Draw the speed torque characteristics of compound motor? (UQ)



17. What is meant by mechanical braking?

In mechanical braking, the stored energy of the rotating parts is dissipated in the form of heat by a brake shoe (or) a break drum. in electric braking, the stored energy of rotating parts is converted into electrical energy and dissipated in the resistance in the form of heat or returned to the supply.

18. What is back emf?

If the voltage is applied and current is passing in the armature, the motor starts rotating. At that time armature conductors also rotates and hence cuts the flux. Due to that an emf is induced in the armature and the direction is found to be opposite to that of the supply this is known as back emf.

19. What are all the types of electrical machines?

Electrical machines are classified as AC machines and DC machines.

Types of DC machines

1. DC Generator
2. DC Motor

Types of AC machines

1. Transformers
   (a) Single phase (b) three phase
2. Alternators
3. Synchronous motor
4. Induction motor
   (a) Single phase (b) three phase

20. What are the two types of 3 phase induction motor?

There are two types of 3-phase induction motor based on the type of rotor used:

(i) Squirrel cage induction motor.
(ii) Slip ring induction motor.

21. What is the principle used in induction motor?

Conversion of electrical power into mechanical power takes place in the rotating part of an Electric motor. In D.C. motor, the electrical power is conducted directly to the armature (i.e. rotating part) through the brushes and Commutator. Hence, in this sense, a D.C. motor can be called a conduction motor. However, in A.C. motors, the rotor does not receive electric power by conduction but by induction in exactly the same way as the secondary of a 2-winding transformer receives its power from primary. That is why such motors are called induction motors. In fact, induction motors can be treated as a rotating transformer i.e. in one which primary winding is stationary but the secondary is free to rotate.

22. What are the advantages of the slip-ring induction motor over squirrel cage Induction motor?

Advantages:

- It is possible to speed control by regulating rotor resistance.
- High starting torque of 200 to 250% of full load voltage.
- Low starting current of the order of 250 to 300% of the full load current.

  Hence slip ring induction motors are used where one or more of the above requirements are to be met.

23. What are the types of single phase induction motors?

The types of single phase induction motors are:

1. Split phase induction motor.
2. Capacitor start induction motor.
3. Capacitor start and capacitor run motor.
4. Shaded pole induction motor.

24. Why regenerative braking not possible in DC series motor? (AU-NOV-05)

In DC series motor, regenerative braking is not possible without necessary modifications, because reversal of Ia would result in reversal of field and hence of E_b.

25. What is meant by dynamic braking? (AU-MAY-07) (AUC-JAN-09)

In this method of breaking, the motor is disconnected from the supply, the field connections are reversed and motor is connected in series with a variable resistance R

16 MARKS

1. Explain the characteristics of dc shunt motors with a neat diagram? (AU-NOV-05, 08, 06) (AU-MAY-05, 07, 09)

1. Electrical characteristics

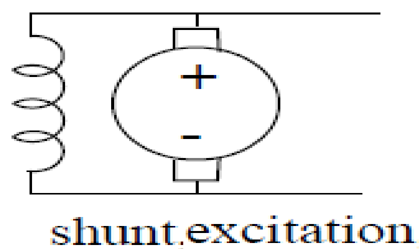
Torque / Armature current characteristics

Speed / Armature current characteristics

2. Mechanical characteristics

Speed / Torque characteristics

Characteristics of dc shunt motor

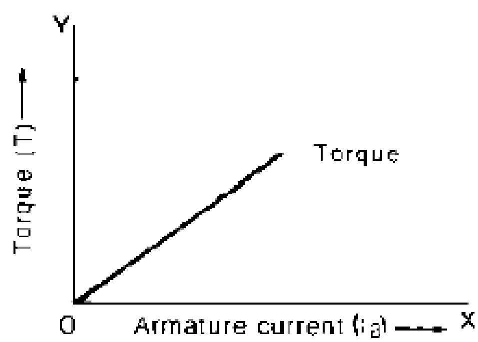


Torque vs Armature current characteristics.

The torque developed by the dc motor T □ □ □ □ □ Ia

In case of dc shunt motors the field excitation current is constant and supply voltage is kept constant. Therefore flux per pole □ □ will be constant.

□ □ T □ □ Ia



Therefore torque developed in a dc shunt motor will be directly proportional to the armature current.

The graph representing the variation of torque with armature current.

Speed/Armature current characteristics

The back emf equation for dc motor is Eb = □ PNZ /60A = V– Ia Ra

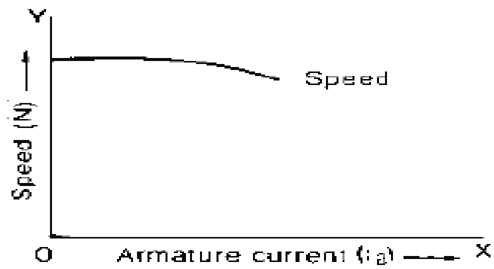
Therefore

$$N = \frac{V - IaRa}{\phi PZ} 60A = \frac{K(V - IaRa)}{\phi}$$

Where K = 60A/ ZP and it is constant.

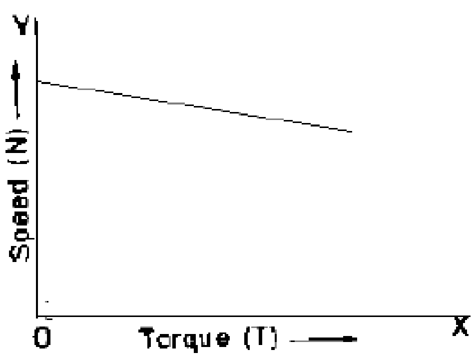
In dc shunt motor, when supply voltage V is kept constant the shunt field current and hence flux per pole will also be constant.

□ □ N □ □ V–Ia Ra



- ❖ The speeds of the dc shunt motor decreases with increase in armature current due to loading.
- ❖ The graph representing variation of speed with armature current is drooping slightly.
- ❖ The drop is speed from no load to full load will be about 3 to 6 percent.
- ❖ But the armature reaction effect weakens the field on load and tends to oppose drop in speed so that the rarely drops by more than about 5 percent from no load to full load.
- ❖ Therefore shunt motor is considered as constant speed motor.

Speed vs Torque characteristics:



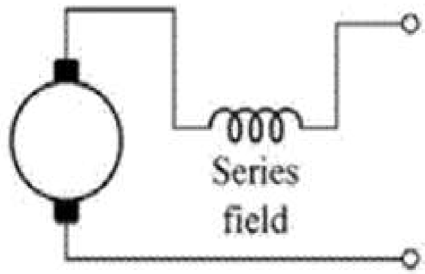
- ❖ From the above two characteristics of dc shunt motor, the torque developed and speed at various armature currents of dc shunt motor may be noted.
- ❖ If these values are plotted, the graph representing the variation of speed with torque developed is obtained.

This curve resembles the speed Vs current characteristics as the torque is directly proportional to the armature current.

2. Explain the characteristics of dc series motors with a neat diagram? (AU-MAY-05, 07) (AU-NOV-06, 10)

- ❖ In dc series motors, the load current drawn from the supply passes through both armature and field windings as they are in series.

- Therefore when the load on the motor changes, field flux also changes.
- Hence the characteristics of D.C. series motors entirely differ from the characteristics of D.C. shunt motors.



Torque Vs Armature current characteristics

Torque developed in any dc motor T □ □ □ □ Ia.

In series motors since field current is equal to armature current.

Therefore,

When Ia is small, □ □ is proportional to Ia.

Then torque developed in dc series motor T □ □ Ia^2.

Therefore

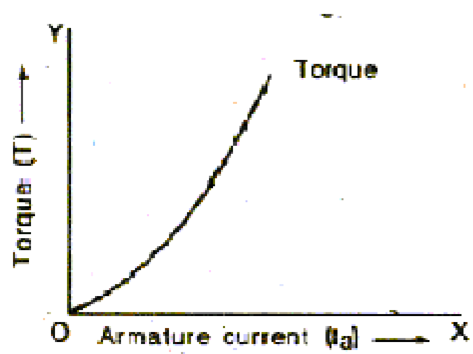
The torque is proportional to square of the armature current at low values of armature current.

When Ia is large □ □ remains constant due to saturation.

Then T α □ Ia.

Therefore torque is proportional to armature current at large values of armature current.

Thus, the torque Vs armature current characteristics begins to rise parabolic ally at low values of armature current and when saturation is reached it becomes a straight line as shown in the following figure.

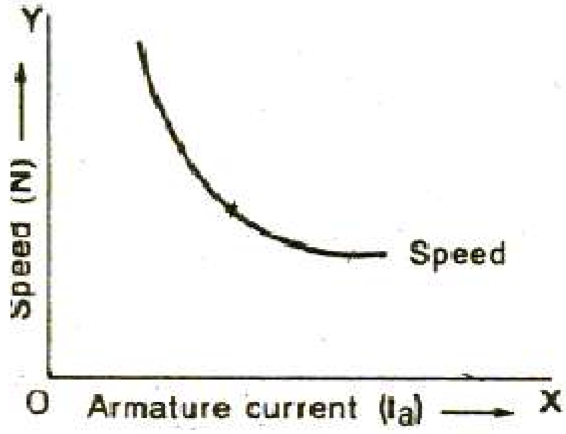


Speed Vs Armature current characteristics

Consider the speed equation

$$N = \frac{K(V - IaRa)}{\phi}$$

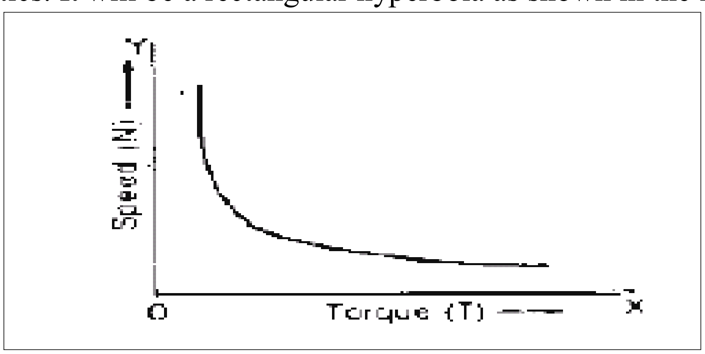
When supply voltage V is kept constant, speed of the motor will be inversely proportional to flux. In dc series motors field exciting current is equal to armature current which happened to load current. Therefore at light loads, when saturation is not attained, flux will be proportional to armature current and hence speed will be inversely proportional to the armature current. Hence speed Vs armature current characteristics of dc series motor will be rectangular hyperbola as shown in the following figure.



As the load on the motor is increased armature current increases and field gets saturated. Once field is saturated flux □ □ will be constant irrespective of increase in armature current. Therefore at heavy loads, speed will be constant. This type dc series motor has high starting torque.

Speed Vs Torque characteristics

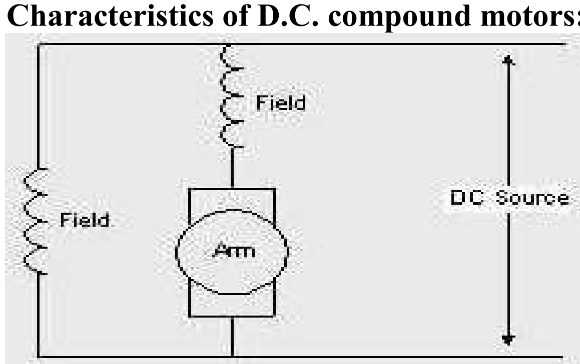
The speed Vs Torque characteristics of series motor will be similar to the speed Vs armature current characteristics. It will be a rectangular hyperbola as shown in the following figure.



In dc series motors, torque increases with decrease of speed and they are most suitable for operating cranes, lifts, trains, etc.

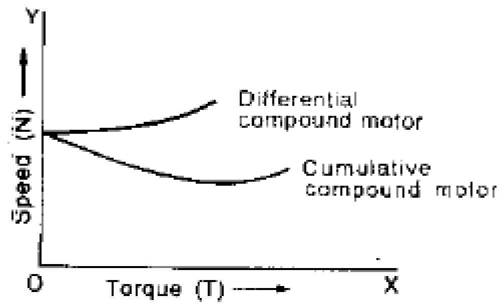
3. Explain the characteristics of dc compound motor with a neat diagram?

Characteristics of D.C. compound motors:

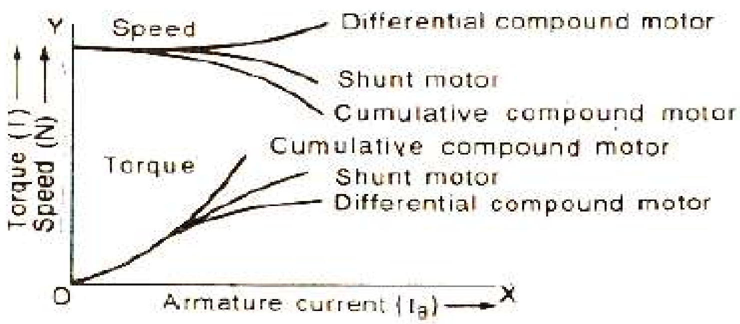


In dc compound motors both shunt field and series field will be acting simultaneously. In cumulative compound motors the series field assists the shunt field. In such motors when armature current increases the field flux increases. So for given armature current the torque developed will be greater and speed lower when compared to a shunt motor. In differentially compounded motors the series field opposes the shunt field. Therefore when armature current increases the field flux decreases. So for given armature current, the torque developed will be lower and the speed greater when compared to shunt motor.

Torque Vs armature current and speed Vs armature current characteristics of dc compound motors are shown in the following figure.



The speed Vs torque characteristics are compared with that of shunt motor as shown in the following figure.



4. Write the applications of dc motors? (AUC-APR-11)

APPLICATIONS OF DC MOTORS

Type of motor	Characteristics	Applications
shunt	Approximately constant speed. Speed can be controlled. Medium starting torque (Upto 1.5 Full load torque)	For driving constant speed line shafting lathes, centrifugal pumps, machine tools, blowers and fans, reciprocating pumps.
Series	Variable speed. Speed can be controlled. High starting torque.	For traction work i.e. electric locomotives rapid transit systems trolley cars etc. cranes and hoists, conveyors
Cumulative compound	Variable speed Speed can be controlled. High starting torque.	For intermittent high torque loads, for shears and punches, elevators, conveyors, heavy planers, rolling mills, ice machines, printing presses, air compressors

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5. Write the types and application of braking?

There are two types of braking namely mechanical braking and electrical braking.

In mechanical braking, the stored energy of the rotating parts is dissipated in the form of heat by a brake shoe (or) a break drum. in electric braking, the stored energy of rotating parts is converted into electrical energy and dissipated in the resistance in the form of heat or returned to the supply.

Advantages

- ❖ In mechanical braking, due to excessive wear on the brake blocks or brake lining, needs frequent and costly replacement but no such replacement is needed in electric braking. Hence, there is saving in cost.
- ❖ In electric braking, there no cost incurred by way of maintenance of brake shoes or lining .But in mechanical braking, frequent adjustments are necessary to compensate for the wear and tear, there by making maintenance costly.
- ❖ Mechanical braking produces metal dust due to frequent operation, which will cause over wearing of bearings .No such dust, is produced in electric braking.
- ❖ In some type of electric braking, a part of energy is returned back to the supply there by effecting a considerable saving in the operating cost. This is not possible with mechanical braking.
- ❖ Smooth stopping is not possible in mechanical braking, because it depends on the smoothness of the braking surface and skill of the operator. But in electrical braking, smooth stopping is always.
- ❖ In mechanical braking, due to frequent operation, heat is produced at brake blocks or brake lining which may lead to failure of brakes. In electrical braking also heat is produced due to operation, but in no way, this heat is harmful to the braking system.

6. Write the types of electric braking in dc shunt motor and draw its characteristics waveforms? (AU-NOV-05, 10) (AU-MAY-07) (AU-APR-08) (AUC-APR-11) (AUC-MAY-08)

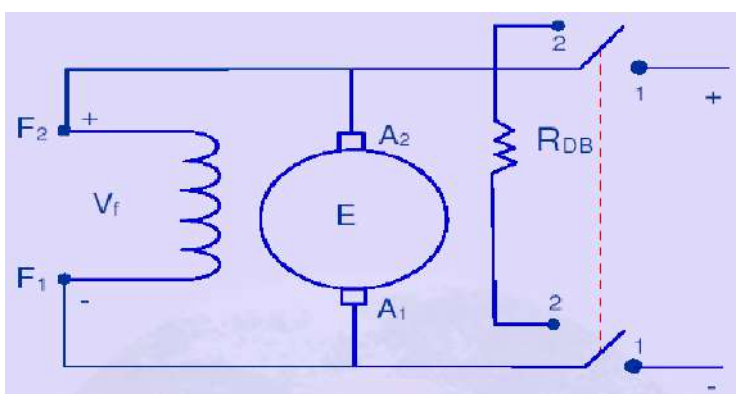
There are three types of electric braking namely,

- ❖ Rheostatic or Dynamic braking
- ❖ Plugging or counter current braking or reverse current braking
- ❖ Regenerative braking

Electric braking of DC shunt motors

Rheostatic braking

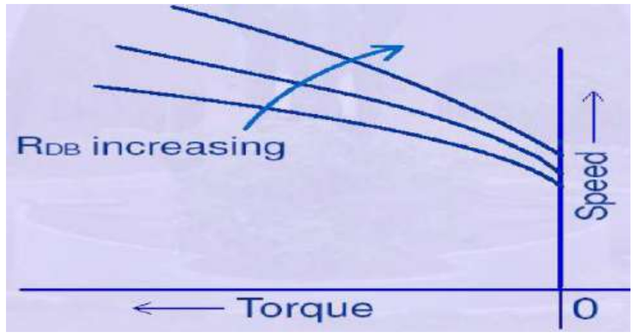
In this method of braking, the armature is disconnected from the supply and is connected across a variable resistance R.



The field winding is left connected across the supply and it is undisturbed.The braking effect is controlled by varying the series resistance R.

Speed-torque characteristics under dynamic braking

It will be a straight line through the origin in the second quadrant .In the first quadrant ,the curve shows that the motor is operating steadily for a given load torque TL at the point A on its natural characteristics. The speed no represents ideal no load speed.Due to braking the operating point shifts to point B on the characteristics in the II quadrant from point A. The motor then decelerates along B O to stand still condition. The slope of the braking characteristics in II quadrant can be controlled by varying the braking resistor R.Hence, any braking time can be obtained by proper choice of the braking resistor,R.

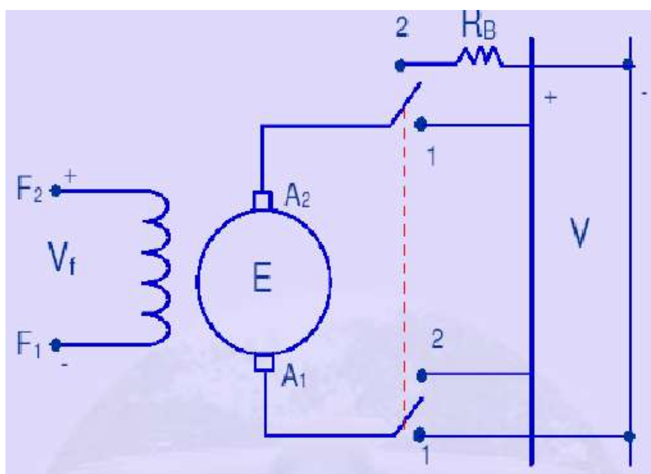


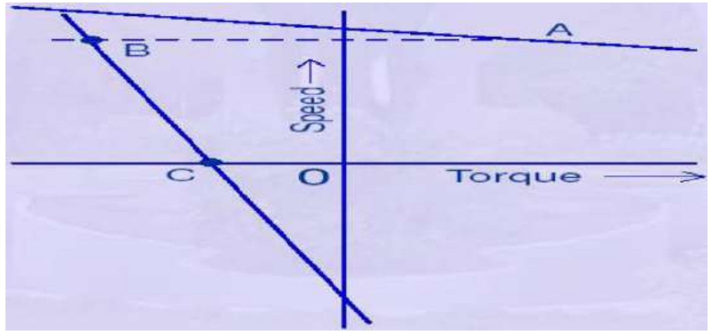
Plugging (or) counter current braking

In this method of breaking, connections to the armature terminals are reversed so that motor tends to run in the opposite direction.

Due to the reversal of armature connections, both V and E_b start acting in the same direction around the circuit. in order to limit the armature current to a safe value, it is essential to insert a resistor in the circuit while reversing the armature connections.

When compared with rheostat braking, plugging gives better braking torque. This method is commonly used for Printing presses,elevators,rolling mills and machine tools.





Speed torque characteristics under plugging condition

Plugging is executed at a time when the motor is operating at the point E characteristics A for a load torque T_L.Due to plugging, the operating point shifts to point F on characteristics B as the speed of the motor cannot change instantaneously due to inertia.

Due to braking torque developed ,the motor decelerates along the characteristics B until the motor stops at GwHEN reversal of rotation is not required, the supply must be switched off when the motor speed becomes very near to zero.

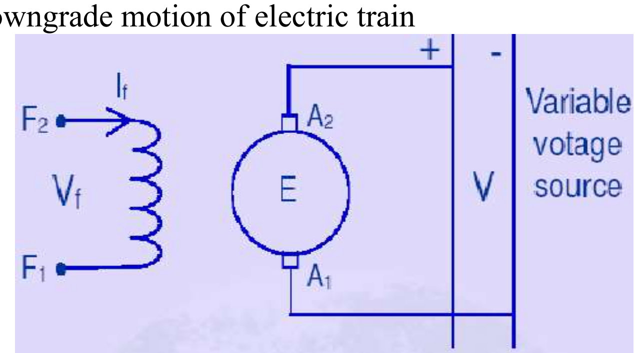
If the supply is not switched off,the motor will gain speed in the opposite direction along GH on characteristics B .as soon as the direction of the rotation is reversed ,the induced emf in the armature changes its polarity and again acts against the applied voltage so that the drive will rotate in the reverse direction under motoring condition.

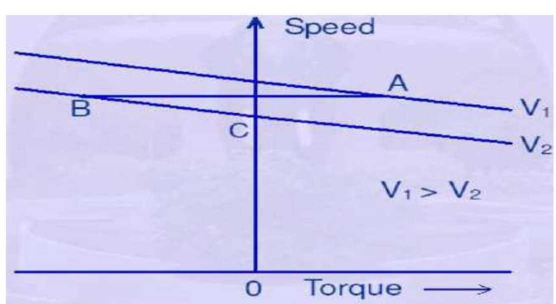
At point H,additional resistance are cut out from the armature circuit and hence the operating point shifts to point I on the natural characteristics C for a load torque,T_L

If plugging is executed again at the point J,then braking and acceleration in the forward direction will corresponded to J –K-L-M-E.

Regenerative braking

This method is used when the load on the motor has overhauling characteristics as in the lowering of the case of a hoist or downgrade motion of electric train





Regenerative takes place when Eb becomes greater than V.this happens when the overhauling load acts as a prime mover and so drives the machine asa generator.Hence ,the direction of Ia and armature torque is reversed and speed falls until eb becomes less than V.

During slowing down of the motor ,power is returned to the line which may be used for supplying another train on an upgrade motion there by ressential to have some type of mechanical braking also in order to hold the load in the event of power failure.

At zero torque characteristics passes through thepoint corresponding to ideal no load speed,no as in the case of motoring.

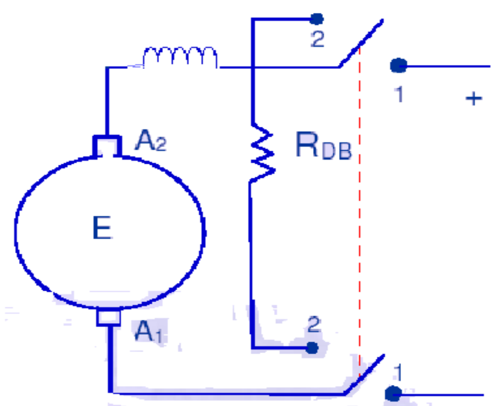
From the characteristics curves,it is clear that,higher the armature circuit resistance ,the higher is the speed at which the motor has to run for a given braking torque.

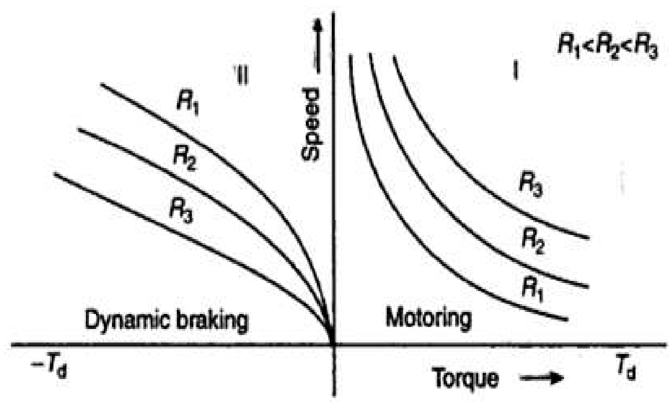
7. Write the types of electric braking in dc series motor and draw its characteristics waveforms? (AU-MAY-07) (AU-APR-08) (AUC-APR-11) (AUC-NOV-10)

Electric braking of DC series motor

Rheostatic braking

In this metod of breaking, the motor is disconnected from the supply,the field connections are reversed and motor is connected in series with a variable resistance R as shown in





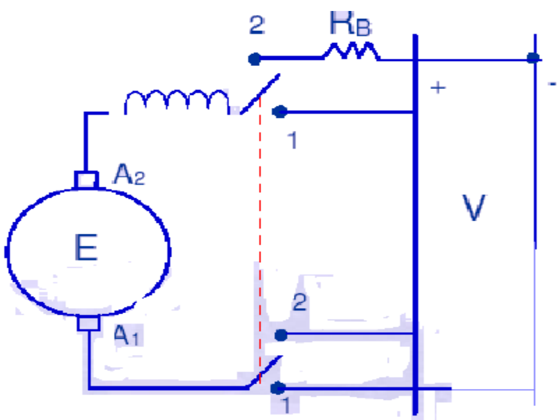
The field connections are reversed to make sure that,the current through the field winding flows in the same direction as before (i.e.,from A to B)in order to assist for residual magnetism.

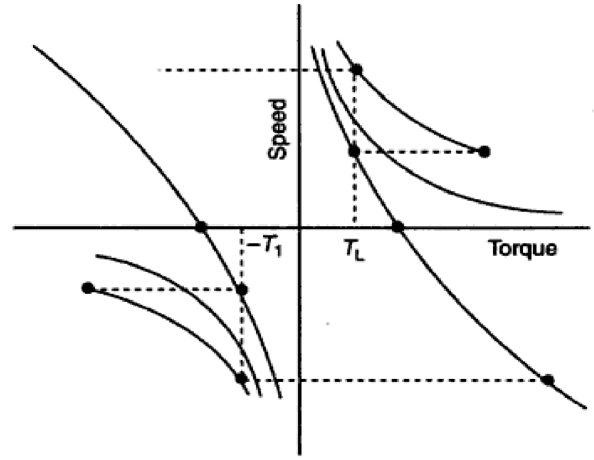
In practice,the variable resistance used for starting purpose is itself used for braking purposes.

The speed-torque characteristics of DC series motor during rheostatic braking is shown in the following figure.explanations are similar to rheostatic braking method applied to DC shunt motor.

Plugging

In this method of braking,the connections of the armature are reversed and a variable resistance R is put in series with the armature .





The above characteristics have been constructed in the same manner as that of plugging conditions applied to DC shunt motor.

Regenerative braking

In DC series motor, regenerative braking is not possible without necessary modifications, because reversal of Ia would result in reversal of field and hence of E_b.

This method is however used in traction motors with special arrangements.

8. Write the types of electric braking in dc compound motor and draw its characteristics waveforms. (AU-MAY-07) (AU-APR-08)

The Dc compound motor has the series as well as the shunt field.

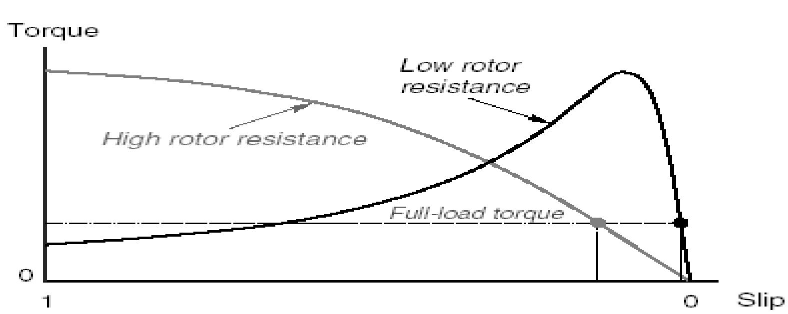
- Regenerative braking
- Dynamic braking
- Counter braking

In the regenerative braking operation of the compound motor, the direction of the armature and the series field are reversed. this may be demagnetized the motor to avoid the demagnetization, the series field winding of the motor is shunt as soon as the speed raises to Wo .therefore the speed torque characteristics of regenerative braking is the straight line.

The dynamic braking of the compound motor is similar to the dynamic braking of the shunt motor. During dynamic braking the armature of the motor is disconnected from the supply and is connected across the braking resister and only the shunt field winding is excited. Therefore the field flux is constant.

Counter current braking of the compound motor is similar to the series motor .This is because of the influence of series field winding.

9. Explain the torque-slip curve for induction motor? (AU-NOV-05, 08) (AUC-NOV-09, 10) (AUC-APR-11) (AUC-MAY-08)



Torque, T = $\dfrac{k\phi S E_2^2 R_2}{R_2^2 + (SX_2)^2}$

When S = 0, T =0. Hence curve starts from point 0.

At normal speeds, close to synchronism the terms (SX2) is small an hence negligible with respect to R_2.

$$T \propto \frac{S}{R_2}$$

(Or) T $\propto$ S. If R_2 is constant.

As slip increases, torque also increases and becomes maximum when

S = $\dfrac{R_2}{X_2}$. This torque is known as „Pull out" or „breakdown" torque. Therefore, for large values of slip,

$$T \propto \frac{S}{(SX_2)^2} \propto \frac{1}{S}$$

Hence, torque/slip curve is a rectangular hyperbola

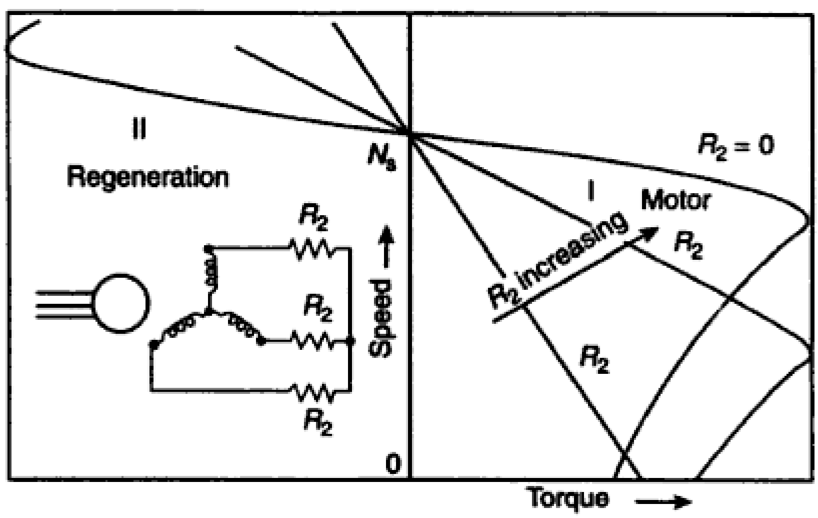
10. Write the types of electric braking in ac induction motor and draw its characteristics waveforms? (AU-MAY-07, 09) (AU-NOV-08, 06) (AUC-NOV-09, 10)

Braking on AC induction motors

- Regenerative braking
- Dynamic braking
- Plugging(op)counter current braking

Regerative braking

In the regerative braking the energy is returned to the supply, is possible if the motor runs faster that its synchronous speed.



The motor torque approach to zero as the motor begins to approach the no load speed i.e the synchronous speed .the further increase in the motor speed, the motor will acts as a generator ,connected in parallel to the supply and ill return electric energy. the regenerative braking operation ia represented by the portions of the speed torque characteristics extended into the second quadrant.

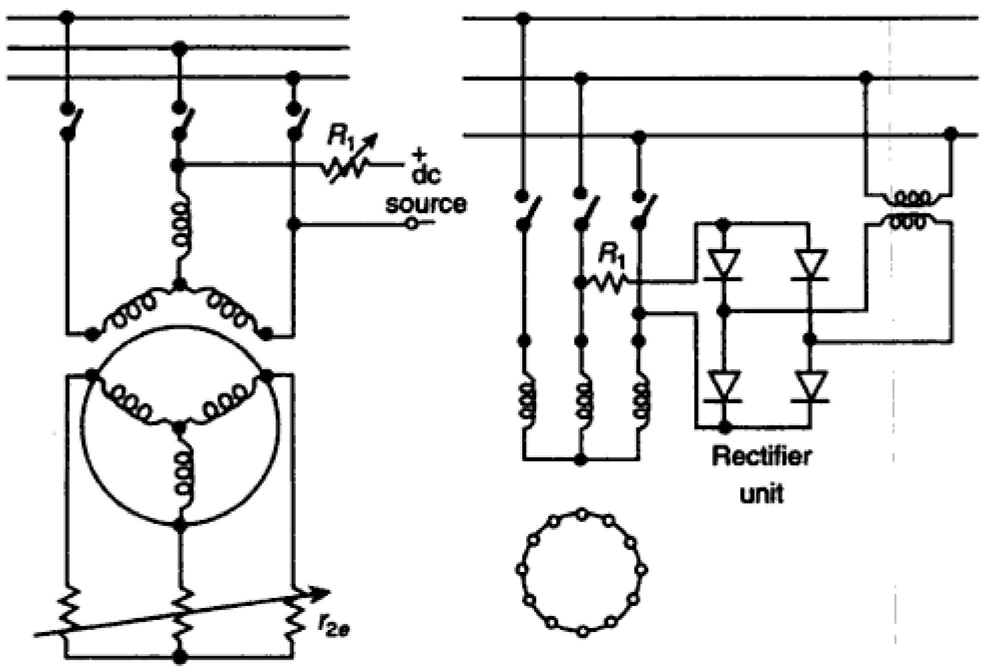
The maximum torque developed on regenerative braking operation will react a higher value than on motoring operation .this can be calculated as below,

$$T_{max} = \frac{3V^2{}_{ph}}{2\omega_0[R_1 - \sqrt{R_1^2 + (X_1 + X_2)^2}]}$$

The application of this braking are in crane hoists, excavators etc.

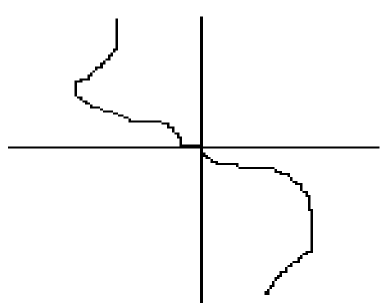
Dynamic braking

Dynamic braking of an induction motor is used achieved by switching over its starter to a DC supply and shunting the rotor external resistance.



To perform dynamic braking the switch Sw1 is opened and cut off a.c apply the DC power. for limiting the current the rotor is connected to a suitable resistor Rb .the flow of direct current sent through the starter winding sets up a stationary magnetic flux.rotation of the rotor in this field will produces a flow of induced alternating current in the rotor which also sets up a magnetic field, stationary with respect to the stater.Due to the interaction of the resultant magnetic field set up by the stator winding ,the rotor circuit resistance and the speed of the rotor.

Speed torque characteristics of the induction motor under dynamic braking



The speed torque characteristics of the induction motor under this braking conditions lies in the second quadrant of the speed torque phase.

If the effect of saturation is neglected, the magnitude of the maximum torque developed will be directly proportional to the square of the voltage applied to the starter.

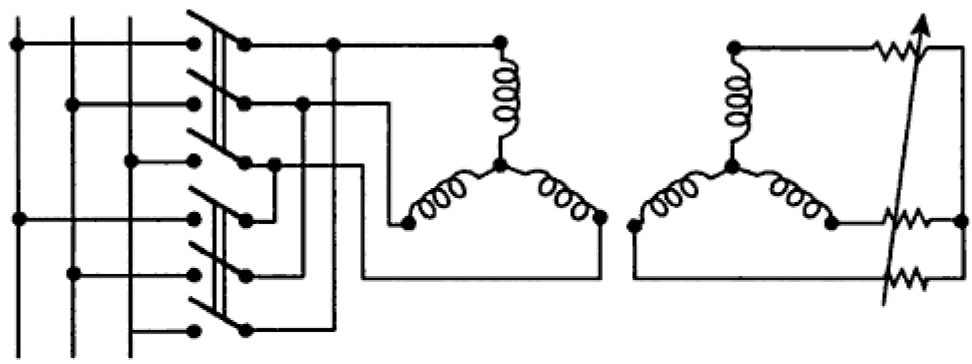
Plugging

The counter braking is widely used in drives .the counter current braking condition can be setup when the torque T_L is greater than Tst‟

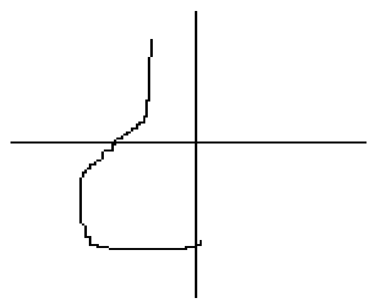
i.e TL>Tst

where,TL=load torque

Tst=starting torque



To limit the current and develop the braking torque a resistance is introduced in to the rotor circuit.under this counter-current braking the steady-state operation will correspond to the point ()on the characteristics.



Speed torque characteristics of induction motor under counter current braking

A counter –current braking condition can also be set up by interchanging the supply leads of any two phases of the starter winding to reverse the direction of rotation of the motor field with the rotor still rotation in the initial direction. since the rotor rotation is now opposed by a torque acting in the opposite direction, the rotor begins to slow down. when the speed drops to zero, the motor should be de-energized,otherwise,it will again begin motoring and cause the rotor to run in the opposite direction.

Unit III – Starting Methods
Two Marks

1. What is the need for starter in an induction motor? (AU-NOV-10) (AUC-MAY-07) (AUC-APR-08) (AUC-MAY-10)

At starting when full voltage is connected across the stator terminals of an induction motor, large current is drawn by the windings. This is because, at starting (i.e before the rotor starts rotating) the induction motor behaves as s short circuited transformer.

At starting, when the rotor is at stand still emf is induced n the rotor circuit exactly similar to the emf induced in the secondary windings of a transformer. This induced emf of the rotor will circulate a very large current through its windings, due to short. The primary will draw very large current nearly 5 – 7 times of the rated current from the supply mains to balance rotor ampere turns. This current will however be gradually decreasing as motor will pick up speed.

In order to reduced starting current starters are used. Induction motor starter will supply reduced voltage to the stator of induction motors.

2. Write the starting torque to full load torque ration in case of D.O.L starter?

In D.O.L starter starting torque to full load torque ratio is given by

$$\frac{T_{st}}{T_f} = \left(\frac{I_{SC}}{I_f}\right)^2 .S_f$$

Where

I	=	Short circuit line current at the starting condition
I_f	=	Full – load current.
S_f	=	Full load slip.

3. What is the starting torque to full load torque ratio in case of primary resistance (or) reactance starter?

$$\frac{T_{st}}{T_f} = x^2\left(\frac{I_{SC}}{I_f}\right)^2 .S_f$$

Where, x $\longrightarrow$ reduced voltage to full line voltage ratio

4. What is the starting torque to full load torque ratio in case of Auto –transformer starter?

$$\frac{T_{st}}{T_f} = K^2\left(\frac{I_{SC}}{I_f}\right)^2 .S_f$$

Where

K = tapping of transformation ratio
(or)
Reduced voltage ratio using tappings.

5. What is starting torque to full load torque ratio in case of star-delta starter?

$$\frac{T_{st}}{T_f} = 1/3\left(\frac{I_{SC}}{I_f}\right)^2 .S_f$$

Where

$I_{sc} =$ Short circuited line current at starting.

$I_f =$ Full load slip.

6. Mention the Starters used to start a DC motor? (AUC-NOV-06)

- Two point Starter
- Three point Starter
- Four point Starter

7. Mention the Starters used to start an Induction motor? (AU-MAY-05) (AUC-MAY-07) (AUC-NOV-08) (AU-NOV-08) (AUC-MAY-10)

- D.O.L Starter (Direct Online Starter)
- Star-Delta Starter
- Auto Transformer Starter
- Reactance or Resistance starter
- Stator Rotor Starter (Rotor Resistance Starter)

8. What are the protective devices in a DC/AC motor Starter? (AU-MAY-06)

- Over load Release (O.L.R) or No volt coil
- Hold on Coil
- Thermal Relays
- Fuses (Starting /Running)
- Over load relay

9. Is it possible to include/ Exclude external resistance in the rotor of a Squirrel cage induction motor? Justify

No it is not possible to include/ Exclude external resistance in the rotor of a Squirrel cage induction motor because, the rotors bars are permanently short circuited by means of circuiting rings (end rings) at both the ends. i.e. no slip rings to do so.

10. Give the prime purpose of a starter for motors? (AU-MAY-07) (AUC-MAY-08) (AUC-NOV-09) (AUC-APR-11)

When induction motor is switched on to the supply, it takes about 5 to 8 times full load current at starting. This starting current may be of such a magnitude as to cause objectionable voltage drop in the lines. So Starters are necessary

11. Why motor take heavy current at starting?

When 3 phase supply is given to the stator of an induction motor, magnetic field rotating in space at synchronous speed is produced. This magnetic field is cut by the rotor conductors, which are short, circuited. This gives to induced current in them. Since rotor of an induction motor behaves as a short circuited secondary of a transformer whose primary is stator winding, heavy rotor current will require corresponding heavy stator balancing currents. ***Thus motor draws heavy current at starting***

12. What are the methods to reduce the magnitude of rotor current (rotor induced current) at starting?

- By increasing the resistance in the rotor circuit
- By reducing the magnitude of rotating magnetic field i.e by reducing the applied voltage to the stator windings.
-

13. What is the objective of rotor resistance starter (stator rotor starter)? (AUC-JAN-09) (AUC-APR-11)

To include resistance in the rotor circuit there by reducing the induced rotor current at starting. This can be implemented only on a slip ring induction motor.

14. Why squirrel cage induction motors are not used for loads requiring high starting torque? (AUC-APR-08) (AUC-JAN-09)

Squirrel cage motors are started only by ***reduced voltage starting*** methods which lead to the development of low starting torque at starting. This is the reason why squirrel cage induction motors are not used for loads requiring high starting torque.

15. How reduced voltage starting of Induction motor is achieved? (AU-MAY-07) (AUC-NOV-09)

- D.O.L Starter (Direct Online Starter)

- Star-Delta Starter
- Auto Transformer Starter
- Reactance or Resistance starter
-

16. Give the relation between line voltage and phase voltage in a
(i) Delta connected network (ii) Star connected network

Delta connected network:

$V_{phase} = V_{line}$

Star connected network:

$V_{phase} = V_{line} / \sqrt{3}$

17. Give some advantages and disadvantages of D.O.L starter? (AU-NOV-05)

Advantages:

Highest starting torque
Low cost
Greatest simplicity

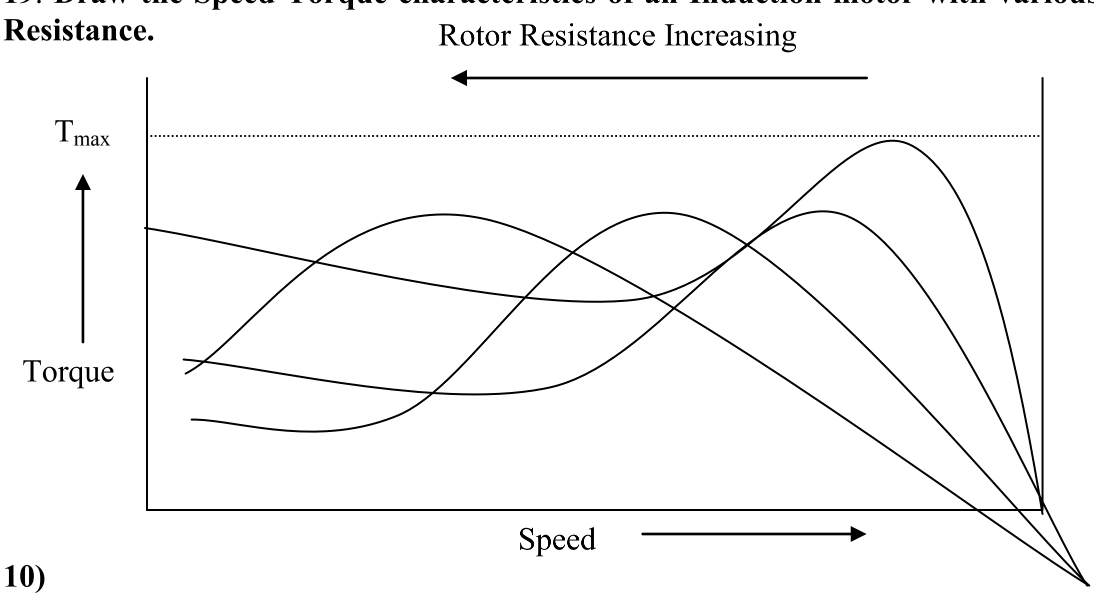
Disadvantages:

The inrush current of large motors may cause excessive voltage drop in the weak power system
The torque may be limited to protect certain types of loads.

18. Explain double stage reduction of line current in an Auto transformer starter?

First stage reduction is due to reduced applied voltage
Second stage reduction is due to reduced number of turns

19. Draw the Speed-Torque characteristics of an Induction motor with various values of Rotor Resistance. (AU-NOV-05, 10)



20. Mention any two methods of making a single phase induction motor self starting? (AU-NOV-08)

To make single phase induction motor self starting it is temporarily converted into 2 phase machine during starting period.

- By using split phase method
- Shaded pole method

16 MARKS

1. **Explain the starting methods in dc motor? (AU-NOV-05) (AUC-NOV-06)**

Types of starters used in dc motor are

1. Two point starter **(AUC-MAY-08)**
2. three point starter**(AU-MAY-07,09) (AUC-MAY-07, 08) (AUC-NOV-08) (AUC-NOV-09) (AUC-MAY-10)**
3. four point starter**(AU-MAY-06) (AU-MAY-05) (AU-NOV-10) (AUC-NOV-10)**

Three point starters

The component used and the internal wiring for a three point starter are shown. Three terminals L, Z, and A are available in the starter circuit for connecting to the motor.

The starting resistance R_s provided with tapping and each tapping is connected to a brass stud. The handle of the starter, H is fixed in such a way to move over the brass studs. Two protective devices namely over load release and no voltage coil provided to protect the motor during over and during failure of supply.

To start the motor, the starter handle, full resistance is connected in series with the armature and the armature circuit of the motor is closed through the starting resistance and over load release coil. Field circuit of motor is also closed through the no voltage coil. Then the handle is moved over the studs against the spring force offered by a spring S_p mounted on the handle. As handle movers, the staring resistance is gradually cut out from the motor circuit.

A soft iron pieces is attached to the handle. The no voltage coil, NVC consists of an electro magnet energized by the field current. When the handle reaches the ON position, the NVC attracts the soft iron piece and holds the handle firmly.

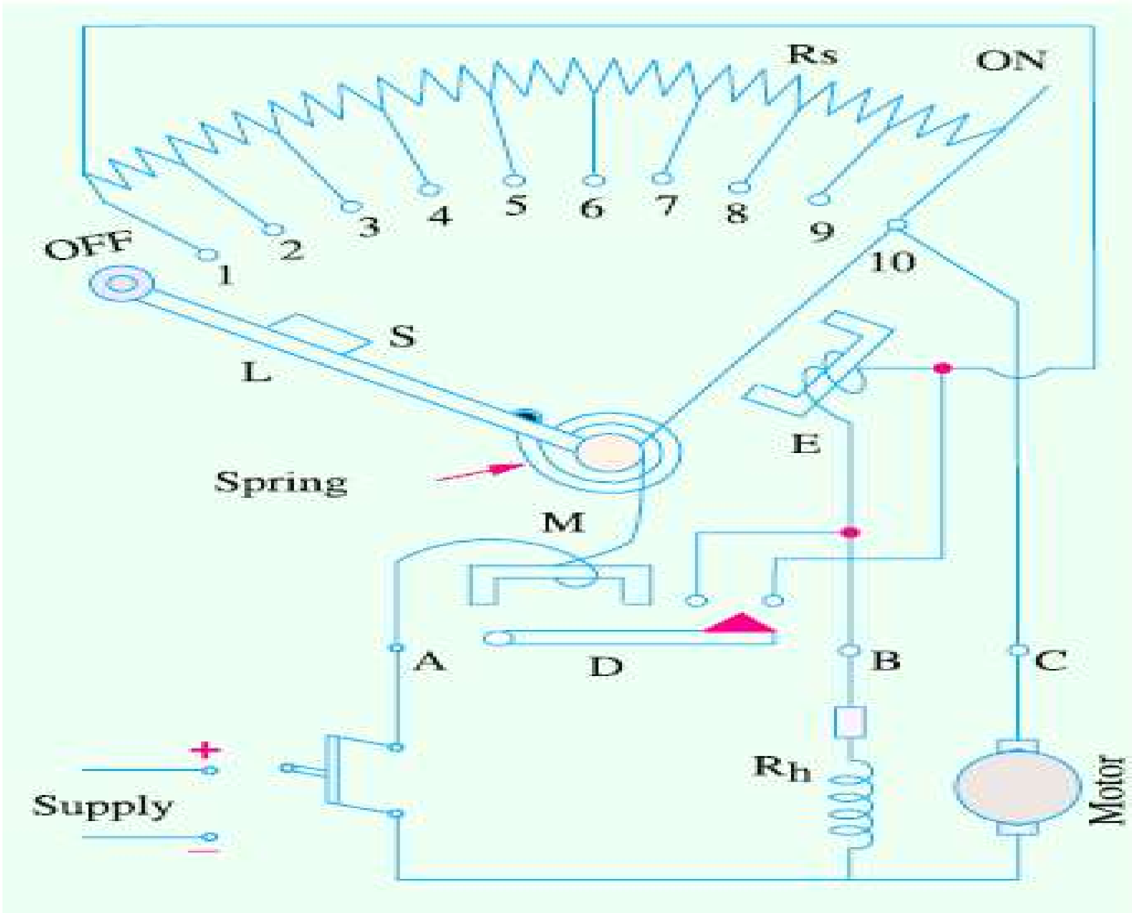
Whenever there is a failure of supply, the NVC de-energies and releases the handle. The handle position returns to off position due to the spring tension. If this arrangement is provided, then when the power supply is restored, the armature alone will be connected to the supply and the current through the armature will be high and it will damage the armature winding. Thus the armature is protected against failure of supply by NVC.

The over load release also has an electromagnet and the line current energizes it. When the motor is overloaded, the iron strip P is attracted to the contacts (c and c‟) due to the electromagnetic force produced by the overload release coil and the contacts c and c‟ are bridged. Thus in this case NVC is de-energized and the handle comes to off position thus the motor is protected against overloading.

We can see that under normal running of the motor the starting resistance when the handle touches the first stud it also touches the brass arc through which full voltage is supplied to the field coil.

Disadvantage

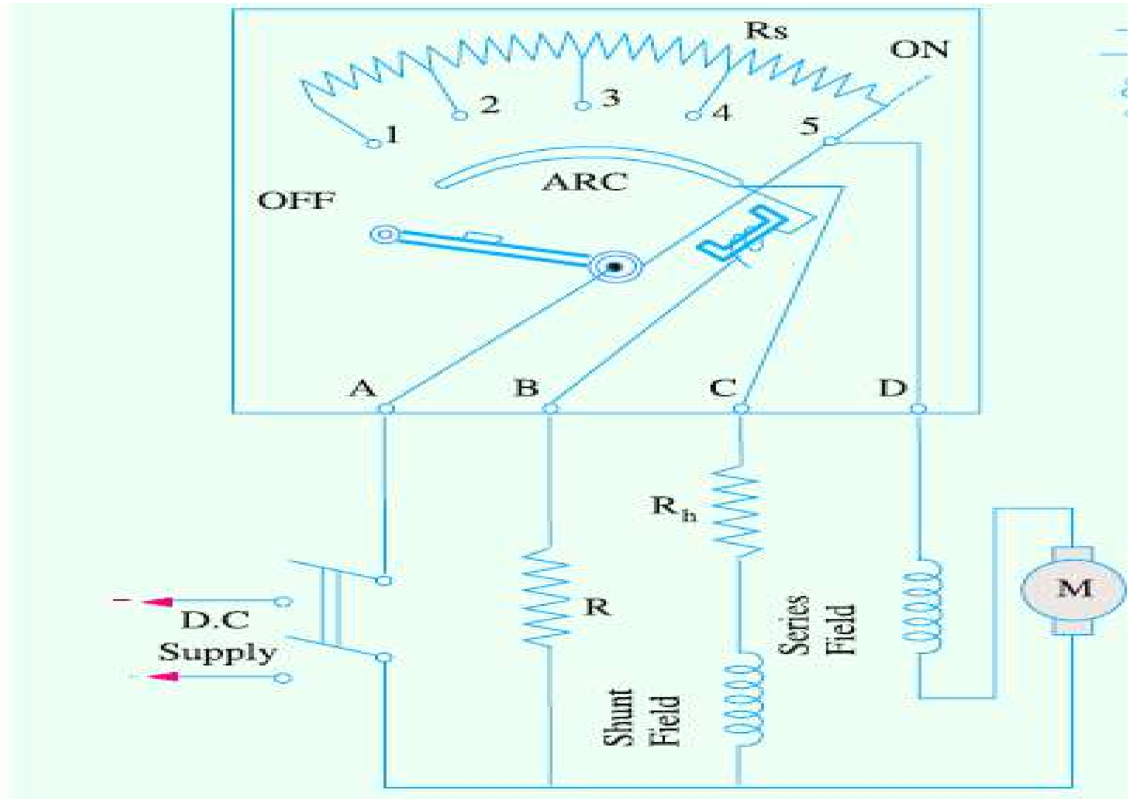
This three point starter is not suitable when we have to control the speed of the motor by connecting a variable resistance in series with the field winding. When the speed, the no voltage coil will be de-energized and handle will return the off position. Due to this disadvantage, four point starters is widely used for starting shunt and compound motors.



Four point starter

The basic difference between three point and four starters is the connection of NVC. In three point, NVC is in series with the field winding while in four point starter NVC is connected independently across the supply through the fourth terminal called „N" in addition to the „L", „F" and „A".

Hence any change in the field current does not affect the performance of the NVC. Thus it is ensured that NVC always produce a force which is enough to hold the handle in „Run" position, against forces of the spring, under all the operating conditions. Such a current is adjusted through NVC with the help of fixed resistance R connected in series with the NVc using fourth point „N" as shown



Disadvantages:

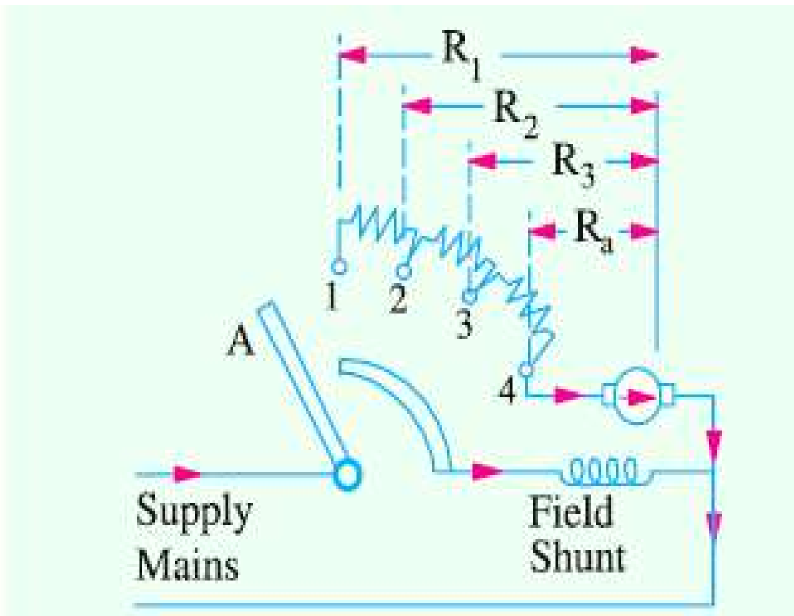
The only limitation of the four point starter is , it does not provide high speed protection to the motor. If under running condition, field gets opened, the field current reduces to zero. But there is some residual flux present and $N \alpha \frac{1}{\phi}$ the motor tries to run with dangerously high speed. This is called high speeding action of the motion. in three point starter as NVC is in series with the field, under such field failure, NVC releases handle to the OFF position. But in four point starter NVC is connected directly across the supply and its current is maintained irrespective of the current through the field winding, hence it always maintains handle in the RUN position, as long as supply is there. And thus it does not protect the motor from field failure condition which result into the high speeding of the motor.

Two Point Starter:-

Three point and four point starters are used for d.c. shunt motors. In case of series motors, field and armature are inserted and hence starting resistance is inserted in series with the field and armature. Such a starter used to limit the star4ting current in case of dc series motor is called two point starters. The basic construction of two point starter is similar to that of three point starter the fact that is has only two terminal namely line (L) and field F. The terminal is one end of the series combination of field and the armature winding.

The action of the starter is similar to that of three point starter. The handle of the starter is in OFF position. When it is moved to on, motor gets the supply and the entire starting resistance is in series with the armature and field. It limits the starting current. The current through no volt coil energizes it and when handle reaches to RUN position, the no volt coil holds the handle by attracting the soft iron piece on the handle. Hence the no volt coil is also called hold on coil.

The main problem in case of dc series motor is it over speeding action when the load is less. This can be prevented using two point starters. The no volt coil is designed in such a way that it holds the handle in RUN positions only when it carries sufficient current, for which motor can run safely. If there is loss of load then current drawn by the motor decreases, due to which no volt coil losses its required magnetism and releases the handle. Under spring force, handle comes back to OFF position, protecting the motor from over speeding. Similarly if there is any supply problem such that voltage decreases suddenly conditions.



The overload condition can be prevented using overload magnet increases. This energizes the magnet up to such an extent that it attracts the lever below it. When lever is lifted upwards, the triangular piece attached to it touches the two pints, which are the two ends of no volt coil. Thus no volt coil gets shorted, loosing its magnetism and releasing the handle back to OFF position. This protects the motor from overloading conditions.

2. What is the necessity for starter? (AU-NOV-05)

At starting when full voltage is connected across the stator terminals of an induction motor, large current is drawn by the windings. This is because, at starting (i.e before the rotor starts rotating) the induction motor behaves as a short circuited transformer. This induced emf of the rotor will circulate a very large current through its windings, due to short. The primary will draw very large current nearly 7 times of the rated current from the supply main to balance the rotor ampere turns. This current will however be gradually decreasing as the motor will pick up speed.

Hence if induction motors are started direct-online heavy current is drawn by the motor, such as heavy starting current of short duration may not cause harm to the motor since the construction of induction motors are rugged. Moreover, it takes time for intolerable temperature rise to endanger the insulation of the motor windings. But this heavy in high of current will cause a large voltage drop in the lines leading to the motor. Other motors and equipment connected to the supply lines will receive reduced voltage.

In industrial installation, however, it a number of large motors are started direct on-line, the voltage drop will be very high and may be really objectionable for the other types of loads connected to the system. The amount of voltage dro0p will no only dependent on the size of the motor but also on factors like the capacity of the power supply system, the size and length of the line leading to the motors, etc.

Types of starters available for induction motors are:

3. Full voltage direct online starting
   a. DOL starter
4. Reduced voltage starting
   a. Star-Delta starter
   b. Auto transformer starter

} Stator control

3. Rotor resistance starter ⟶ Rotor control

3. What are the types of starters available for induction motors? (AU-MAY-06)

Full voltage Direct online starting:

D.O.L Starter:

It is recommended that large three phase squirrel-case induction motors be started with reduced voltage applied across the stator terminals at starting. But small motors up to 5HP ratings may however be started Direct – ON-Line (DOL)

Direct-on-line method of starting of induction motors applicable up to a rating of 5 HP is shown in fig1. In the circuit in addition to fuses, thermal motor windings against overload.

Derivation for starting current and torque in case of DOL starters

Rotor input $2\pi N_S T = kT$ (1)

Rotor copper loss $S \times$ rotor input

$\therefore \quad 3I_2^{\,2} R_2 = S \times kT$

$\therefore \quad T \propto I_2^{\,2} / S$ 9if $R_2$0 is the same

Now $I_2 \propto I_1$

$\therefore \quad T \propto I_1^{\,2} / S$ (or) $T = K\, I_1^{\,2} / S$

At starting moment, S = 1

$\therefore \quad T_{st} = K\, I_{st}^{\,2}$ where I_{st} = Starting current

If,

I_f = normal full load current and
S_f = Full load slip

4. Explain the starters for Squirrel cage induction motor? (AU-NOV-05, 10) (AU-MAY-05, 07, 09) (AUC-MAY-08) (AUC-APR-08) (AUC-MAY-10)

Reduced voltage starting:

- ✓ **Stator resistance (or) Primary resistance starter:**

Their purpose is to drop some voltage and hence reduce the voltage applied across the motor terminals. In this way, the initial current drawn by the motor is reduced. However, it should be noted that whereas current varies directly as the voltage, the torque varies as square of applied voltage.

[Note: When applied voltage is reduced, the rotating flux ϕ is reduced which in turn decreases rotor e.m.f and hence rotor current I_2. Starting torque which depends both on ϕ and I_2 suffers on two counts when impressed voltage is reduced]

For example if voltage applied across motor terminals is reduced by 50%, starting current is reduced by 50%, but torque is reduced to 25% of the full-voltage value.

Then,

$$T_f = KI_f{}^2 / S_f$$

$$\therefore \quad \frac{T_{st}}{T_f} = \left(\frac{I_{st}}{T_f}\right)^2 .S_f$$

When motor is direct-switched on to normal voltage, then starting current is the short –circuit current I_{sc}.

$$\therefore \quad \frac{T_{st}}{T_f} = \left(\frac{I_{sc}}{T_f}\right)^2 .S_f = a^2 .S_f$$

Where $a = I_{sc} / I_f$ Suppose in a case, $I_{sc} = 7I_f$,

$S_f = 4\% = 0.04$,

Then,

$$\frac{T_{st}}{T_f} = 7^2 \times 0.04 = 1.96$$

$\therefore$ Starting torque = 1.96 x Full load torque.

Hence, even if current is greater than full load current the starting torque is only 1.96 times full-load torque.

If applied voltages/phase can be reduced by fraction „x", then

$$I_{st} = xI_{sc} \quad \text{and} \quad T_{st} = x^2 T_{sc}$$

$$\frac{T_{st}}{T_f} = \left(\frac{I_{st}}{I_f}\right)^2 .S_f = \left(\frac{xI_{sc}}{I_f}\right)^2 .S_f$$

$$= x^2 \left(\frac{xI_{sc}}{I_f} \right)^2 .S_f$$

$$\Rightarrow \qquad \frac{T_{st}}{T_f} = x^2 .a^2 .S_f$$

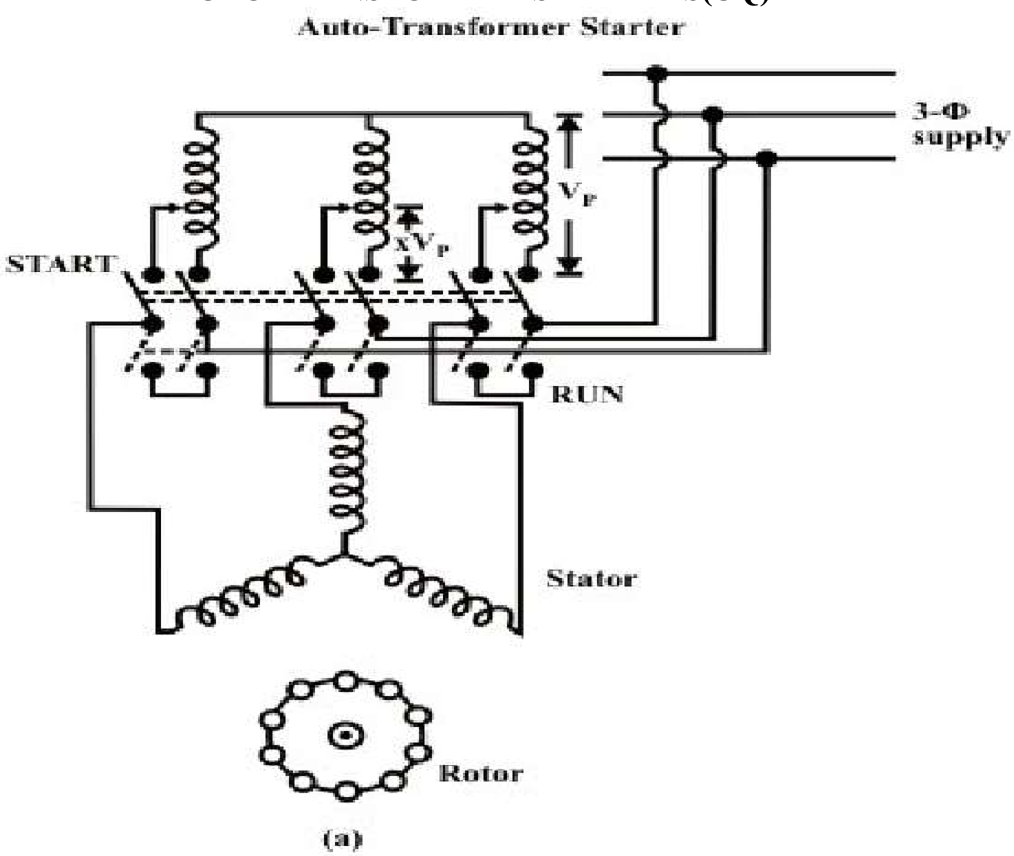
$$\boxed{\frac{T_{st}}{T_f} = x^2 .a^2 .S_f}$$

It is obvious that the ratio of starting torque of full-load torque is x^2 of that obtained with direct switching (or) across the line starting. This method is useful for the smooth starting of small machines only.

(ii). PRIMARY REACTANCE STARTER:

The working principle of the primary reactance starter is same as that of primary resistance starter except that voltage drop occurs across the reactor, so that i/p voltage applied to the stator of induction motor reduces.

- ✓ **AUTO TRANSFORMER STARTERS(UQ)**



- An auto transformer consists of a n auto transformer and a switch as shown in fig.

- When the switch S is put on start position, a reduced voltage is applied across the motor terminals. When the motor picks up speed, say to 80 percent of its normal speed, the switch is put to RUN position. Then the quato-transformer is cut out of the circuit and full rated voltage gets applied across the motor terminals.
- The switch making these changes from „start" to „run" may be air break (for small motors) or may be oil-increased (for large motors) to reduce sparking.

Derivation for autotransformer starter:

- When full voltage is applied without suing autotransformers say starter, then current taken by the motor is 5 times the full load current. If V is pre line voltage then voltage/phase across the motor is $V/\sqrt{3}$.

$\therefore$ $$I_{sc} = S\ I_f = \frac{V}{\sqrt{3Z}}$$ Where Z is starter impedance /phase

- In the case of autotransformer, if a tapping of transformation ratio k is used, then phase voltage across motor is $kV/\sqrt{3}$

$\therefore$ Motor starting current $$I_2 = \frac{kV}{\sqrt{3Z}} = \frac{kV}{\sqrt{3Z}}$$

- The current taken from supply (or) by auto transformer is $I_1 = kI_2 = k^2$ $S_{if} = k.^2 T_{sc}$ if magnetizing current of the transformer is ignored phase is reduced only k times, the direct switching current $\because k < 1$, the current taken by the line is reduced to k^2 times.

The torque is proportional to square of the voltage, we get, (i) with direct =switching,

$$T_1 \propto \left(V/\sqrt{3}\right)^2;$$

with auto – transformer,

$$T_2 \propto \left(kV/\sqrt{3}\right)^2$$

$$\therefore \frac{T_2}{T_1} = \frac{\left(kV/\sqrt{3}\right)^2}{\left(V/\sqrt{3}\right)^2}$$

(or)

$$T_2 = k^2 T_{sc}$$

$\therefore$ Torque with quto transformer starter is, = k^2 x Torque with direct – switching.

Relation between starting and full-load torque:

It is seen that voltage across the motor phase on direct –switching is $V/\sqrt{3}$ and starting current is $I_{st} = I_{sc}$. With autotransformer –starter, voltage across the motor phase is $kV/\sqrt{3}$ and $I_{st} = kI_{sc}$

Now,

$$T_{st} \propto I_{st}^{2}(S=1) \text{ and}$$

$$\therefore \frac{T_{st}}{T_f} = \left(\frac{I_{st}}{I_f}\right)^2 .S_f. \text{ (Or)}$$

$$\frac{T_{st}}{T_f} = k^2\left(\frac{I_{sc}}{I_f}\right)^2 .S_f.$$

$$\therefore \frac{T_{st}}{T_f} = k^2 9^2 .S_f. \qquad \therefore I_{st} = kI_{sc}$$

From Fig. 1(a) it is seen than for star connection of windings, phase current.

$$I_p = I_{LY} = \frac{V}{\sqrt{3}} \times \frac{1}{Z_P} \text{ Ampere}$$

when I_{LY} is the line current when windings are connected and Z_p is the windings impedance per phase.

For delta connection of windings

$$I_p = \frac{V}{Z_p} \text{ and } \qquad \boxed{I_{LD} = \sqrt{3} I_P \ Ampere}$$

The ratio of line currents drawn in star and delta –connection is therefore,

$$\frac{I_{LY}}{I_{L\Delta}} = \frac{V/\sqrt{3} \times Z_p}{\sqrt{3}V/Z_p}$$

$$\Rightarrow \quad \frac{I_{LY}}{I_{LD}} = \frac{1}{3}$$

$$\Rightarrow \quad \boxed{\frac{I_{LY}}{I_{LD}} = \frac{1}{3} IL\Delta}$$

- ✓ **STAR –DELTA STARTER: (AUC-MAY-07) (AUC-NOV-10)**

In this method, the stator phase windings are first corrected in star and full voltage is connected across its free terminals. As the motor pickup speed, the windings are disconnected through a switch and they are reconnected in delta across the supply terminals. The current drawn by the motor from the lines is reduced to 1/3 as compared to the current it would have drawn if connected in delta.

Reduced Torque due to star connection:

- In induction motor, torque developed is proportional to the square of applied voltage. As the phase voltage is reduced to $\left(1/\sqrt{3}\right)$ times that in star-connection, the starting torque will be reduced to one third. To get full torque in the motor, it must be switched over to delta connection.
- In making connections for star-delta starting, care should be taken such that sequency of supply connections to the winding terminals does not change wile changing form star-connection to delta-connection. Otherwise the motor will start rotating in opposite direction, when connections are changed from star to delta.
- Star-delta starters are available for manual operation using push-button control. An automatic star-delta starters uses time-delay relays (TDR) through which star to delta connections take place automatically with some pre-fixed time fixed keeping in view the starting time of the motor.

Derivation:

Relation between starting and full load torque:

I^{st} per phase $= \frac{1}{\sqrt{3}} I_{Sc}$ per phase.

Where I_{Sc} is the current /phase which Δ -connected motor would have taken if switched on to supply directly (however line current at start $=1/3$ of Line I_{SC}).

Now,

$$T_{st} \propto I_{st}^{\ 2} \qquad \left(s=1\right)$$

$$\therefore \frac{T_{st}}{T_{st}} = \left(\frac{I_{st}}{I_f}\right)^2 .S_f$$

$$= \left(\frac{I_{sc}}{\sqrt{3}} \cdot \frac{1}{I_f}\right)^2 .S_f$$

$$= \frac{1}{3} a^2 .S_f$$

$$\therefore \frac{T_{st}}{T_f} = \frac{1}{3} a^2 .S_f$$

Here, I_{st} and I_{SC} represent phase values.

It is clear that star-Delta switch is equivalent to a n auto-transformer of ratio $1/\sqrt{3}$ (or) 58% approximately.

5. Explain the starters for slip –ring induction motors? (AU-MAY-06, 09) (AUC-JAN-09) (AUC-NOV-06)

Rotor resistance starters:

The easiest method of starting wound rotor (slip-ring) induction motors is to connect some extra resistance in the rotor circuit as shown in fig. Connection of extra resistance in the rotor circuit decreases the starting current and at the same time increases the starting torque. As the motor starts rotating the extra resistance is gradually cut out. When the motor attains rated speed the resistance is fully cut out.

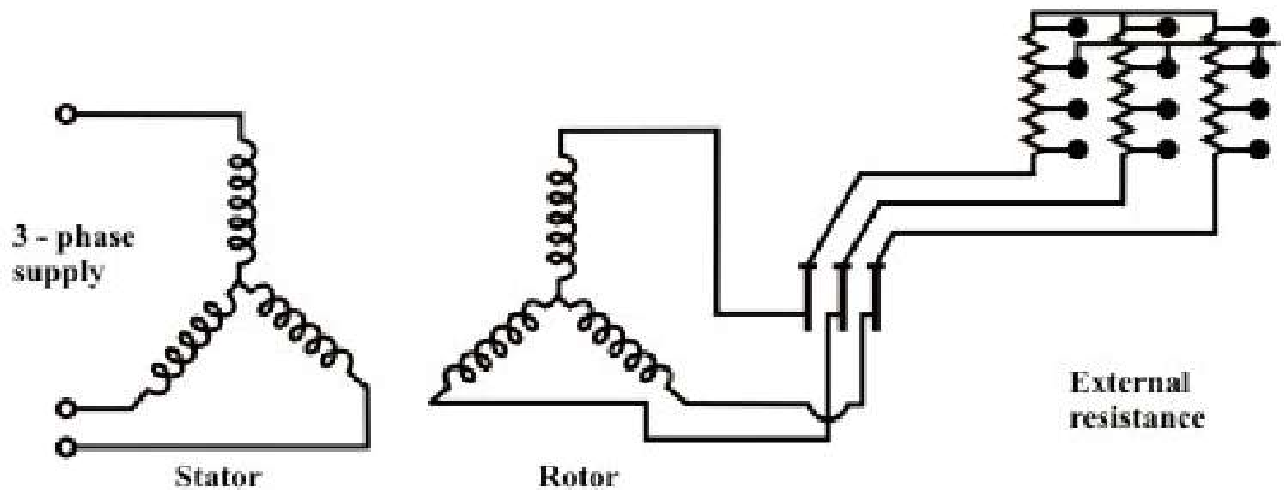


Fig. 33.4: Rotor resistance starter for IM

When the motor attains rated speed the resistance is fully cut out and the slip ring terminals are short circuited. The motor now operates on its own characteristics which give rise to maximum torque at a low slip.

6. Compare the Induction motor starters? (AU-NOV-05)

Description of Starter	**% of line voltage applied**	**Starting current (I_s)compared with**		**Starting torque (Ts)compared with**	
		D.O.L current(I_{dol})	**Full load current(I)**	**D.O.L Torque(T_{dol})**	**Full load torque(T)**
D.O.L Starter	100%	$I_s = I_{dol}$	$I_s = 6I$	$T_s = T_{dol}$	$T_s = 6T$
Star Delta starter	57.7%	$I_s = (1/\sqrt{3})^2 I_{dol}$	$I_s = 2I$	$T_s = (1/\sqrt{3})^2 T_{dol}$	$T_s = 2/3T$
Auto transformer starter	80%	$I_s =(0.8)^2 I_{dol}$	$I_s = 3.84\ I$	$T_s = =(0.8)^2 T_{dol}$	$T_s = 1.28\ T$
	60%	$I_s =(0.6)^2 I_{dol}$	$I_s = 2.16\ I$	$T_s = =(0.6)^2 T_{dol}$	$T_s = 0.72\ T$
	40%	$I_s =(0.4)^2 I_{dol}$	$I_s = 0.96\ I$	$T_s = =(0.4)^2 T_{dol}$	$T_s = 0.32\ T$
Reactance-resistance starter	64%	$I_s = (0.64)^2 I_{dol}$	$I_s = 2.5\ I$	$T_s =(0.425)^2 T_{dol}$	$T_s = 0.35T$

Unit IV – Conventional & Solid State Speed Control of DC Drives

Two Marks

1. Give the expression for speed for a DC motor?

Speed $N = \dfrac{k\,(V - I_a R_a)}{\varphi}$

Where V = Terminal Voltage in volts
Ia = Armature current in Amps
Ra = Armature resistance in ohms
φ= flux per pole.

2. What are the ways of speed control in dc motors? (AU-MAY-07) (AU-NOV-08)

Field control (i) by varying the flux per pole.-for above rated speed
(ii)In armature control method the speed below base speed is obtained.
Armature control (i) by varying the terminal voltage -for below rated speed
(ii)In field control method the speeds above base speed can be obtained.

3. Give the Limitation of field control? (AUC-JAN-09)

- ✓ Speed lower than the rated speed cannot be obtained.
- ✓ It can cope with constant kW drives only.
- ✓ This control is not suitable to application needing speed reversal.

4. What are the 3 ways of field control in DC series motor?

- ✓ Field diverter control
- ✓ Armature diverter control
- ✓ Motor diverter control
- ✓ Field coil taps control
- ✓ Series-parallel control

5. What are the main applications of Ward-Leonard system? (AU-MAY-07)

- ✓ It is used for colliery winders.
- ✓ Electric excavators
- ✓ In elevators
- ✓ Main drives in steel mills and blooming and paper mills.

6. What are the merits and demerits of rheostat control method? (AU-MAY-06)

- ✓ Impossible to keep the speed constant on rapidly changing loads.
- ✓ A large amount of power is wasted in the controller resistance.
- ✓ Loss of power is directly proportional to the reduction in speed. Hence efficiency is decreased.
- ✓ Maximum power developed is diminished in the same ratio as speed.
- ✓ It needs expensive arrangements for dissipation of heat produced in the controller resistance.
- ✓ It gives speed below normal, not above.

7. What are the advantages of field control method? (AUC-NOV-10)

- ✓ More economical, more efficient and convenient.
- ✓ It can give speeds above normal speed.

8. Compare the values of speed and torque in case of motors when in parallel and in series.

- ✓ The speed is one fourth the speed of the motor when in parallel.
- ✓ The torque is four times that produced by the motor when in parallel.

9. Mention the speed control method employed in electric traction. (UQ)

Series-parallel speed control.

10. What is the effect of inserting resistance in the field circuit of a dc shunt motor on its speed and torque? (AU-NOV-06)

For a constant supply voltage, flux will decrease, speed will increase and torque will increase.

11. While controlling the speed of a dc shunt motor what should be done to achieve a constant torque drive?

Applied voltage should be maintained constant so as to maintain field strength.

12. What are the advantages of ward –Leonard Scheme? (AU-APR-08) (AUC-MAY-10)

- ❖ Wide range of speed variation is possible
- ❖ Regenerative action is possible
- ❖ Good speed regulation
- ❖ Stepless and smooth speed control in either direction is possible.

13. What are the disadvantages of ward –Leonard Scheme? (AU-NOV-06)

- ❖ Overall efficiency of the system is low especially at light loads
- ❖ Costlier since two extra machines are required

14. Differentiate controllable and uncontrollable rectifiers (AUC-NOV-09)

Controlled rectifiers	**Uncontrolled rectifiers**
Use only diodes	Use only thyristors
Output voltage is variable	Output voltage is fixed

15. Define holding current in SCR?

Holding current of SCR is defined as the maximum forward current that must be maintained to keep the SCR in the conducting state. If the current through the SCR is reduced below the level of holding current, the device returns off.

16. Define chopper? (AU-MAY-07) (AU-APR-08) (AUC-MAY-10)

A chopper is dc to dc converter. The fixed voltage of a dc source can be converted into an adjustable average voltage across a load by inserting a high speed switch between the dc source and the load .This high speed switch is called the chopper.

17. What is time ratio control? (AU-MAY-09)

Varying output voltage by varying time period of duty cycle is called as Time ratio control.

18. Write the methods of obtaining time ratio control?

- ❖ By varying the duration of ON time with respect to off time keeping total time period T constant
- ❖ By keeping ON time constant and varying the frequency.
- ❖ By adjustment of both

19. How to classify rectifier circuits? Define phase controlled rectifier? And write the applications (AUC-APR-11)

- ❖ Uncontrolled rectifiers
- ❖ Controlled rectifiers

Controlled rectifier converts fixed ac voltage to variable dc output voltage.

- Dc traction
- Magnet power supplies
- High voltage dc transmission
- Electrochemical and electrometallurgical process
- Portable hand tool drives

20. What is meant by step -up and step -down chopper?

The average output voltage Vo is less than the input voltage Vs (Vo<Vs) - **step-up chopper or buck converter**

The average output voltage Vo is greater than the input voltage Vs (Vo>Vs) - **step-up chopper or boost converter**

21. Define duty cycle? (AUC-NOV-10)

Duty cycle is defined as the ratio of the on time of the chopper to total time of the chopper

$$\alpha = \frac{T_{on}}{T}$$

22. Write the application and advantages of chopper? (AU-APR-08) (AUC-APR-11) (AUC-MAY-10)

Applications

- ✓ Battery operated vehicles
- ✓ Traction motors control in electric traction
- ✓ Trolley cars
- ✓ Electric braking
- ✓ Marine hoists
- ✓ Mine haulers

Advantages

Chopper control provides

- High efficiency
- Smooth acceleration
- Fast dynamic response
- Regeneration

23. What are the different types of commutation in chopper? Define it. (AUC-JAN-09) (AUC-NOV-09) (AUC-APR-11)

- ✓ **Voltage commutation**

  When the charge capacitor momentarily reverses biases the conducting thyristor and it turn off.
- ✓ **Voltage commutation**

  When a current pulse is made to flow in the reverse direction through the conducting thyristor current is zero, it is turned off.
- ✓ **Load commutation**

  When the load current flowing through the thyristor either becomes zero or is transferred to another device from the conducting thyristor.

24. What are the different types of controlled rectifier?

According to input supply

- ❖ Single phase controlled rectifier
- ❖ Three phase controlled rectifier

According to the quadrant operation

- ❖ Semi converter
- ❖ Full converter
- ❖ Dual converter

According to number of pulse per cycle

a) One pulse converter

i) Single phase half controlled rectifier

b) Two pulse converter

i) Single phase half controlled rectifier

ii) Single phase full controlled converter

c) Three pulse converter

i) Three phase half wave controlled rectifier

ii) Three phase full controlled converter

d) Six pulse converter

i) Three phase full converter

e) Twelve pulse converter

25. Define half controlled rectifier, full converter? (AU-MAY-06)

A half controlled rectifier or semi converter uses a mixture of diodes and thyristors and there is a limited control over the level of dc output voltage. it is also known as one-quadrant converter.

A fully controlled converter or full converter uses thyristors only and there is a wider control over the level of dc output voltage .it is also known as quadrant converter.

26. What is the function of free-wheeling diode in controlled rectifier? And write its advantages?

The freewheeling diode is used to circulate the current within the motor armature circuit itself. The fee-wheeling diodes considerably improve the rectifier power factor and the motor performance.

Advantages

- ✓ Input factor is improved
- ✓ Load current waveform is improved and thus the load performance is better.

27. What is the control techniques used in chopper controlled drives? (AUC-JAN-09)

(i) Time ratio control (TRC).

(ii) Current limit control (CLC).

28. Explain in brief about Time ratio control? (AU-NOV-05)

The TRC, also known as pulse-width control, the ratio of „ON" time to chopper period is controlled. The TRC is again divided into two types:

- ✓ Constant frequency TRC:
  The chopping period „T" is kept constant and varying the „ON" period of the switch S, the duty ratio δ is controlled.
- ✓ Variable Frequency TRC:
  In this the duty ratio δ is varied either by keeping t_{ON} constant and varying T or by varying both t_{ON} and T. This method is rarely used because of the following drawbacks.
  (a) Low output voltage at low chopper frequencies.
  (b) Low frequency operation adversely affects the motor performance.
  (c) Design of input filter becomes difficult.

29. What are the advantages of chopper drives over rectifier drives? (AU-MAY-05)

Advantages:

(i) This however reduces the torque per ampere at zero and low speeds.

(ii) There is lot of problems with re-generative braking of a series motor.

- ✓ On the other hand, re-generative braking of a separately excited motor is fairly simple and can be implemented down to very low speeds.
- ✓ Because of the limitations of a D.C. motor, separately excited motors are preferred even for traction at present.

30. What are the advantages in using chopper for speed control of DC motors?

Advantages:

- ✓ High Efficiency
- ✓ Flexibility in control
- ✓ Light weight

- ✓ Small size
- ✓ Quick response
- ✓ Re-generation down to very low speed.

31. What are the applications of DC drives?

The applications of DC drive are:

- ✓ Steel rolling mills
- ✓ Paper mills
- ✓ Printing press
- ✓ Mine winders
- ✓ Machine tools

32. Write some special features of thyristor drive motors? (AU-MAY-07)

- ✓ The use of octoganal,rather than circular, shape for the frame accommodates more material and gives a larger rating for the same frame size
- ✓ The yoke as well as the main and commutating poles are laminated to reduce the eddy current effects. the use of a laminated yoke instead of a solid yoke improves the commutation to a greater extent
- ✓ The thyristors drive dc motors are made with larger diameter armature and larger size poles of reduced height.
- ✓ Low inertia armatures are employed for improving the response
- ✓ Compensating windings are used in large motors to reduce for reducing the effect of transformer voltage in the coils undergoing commutation.
- ✓ The use of large number of commutator bars reduces the voltage between commutator segments and improves the commutation.

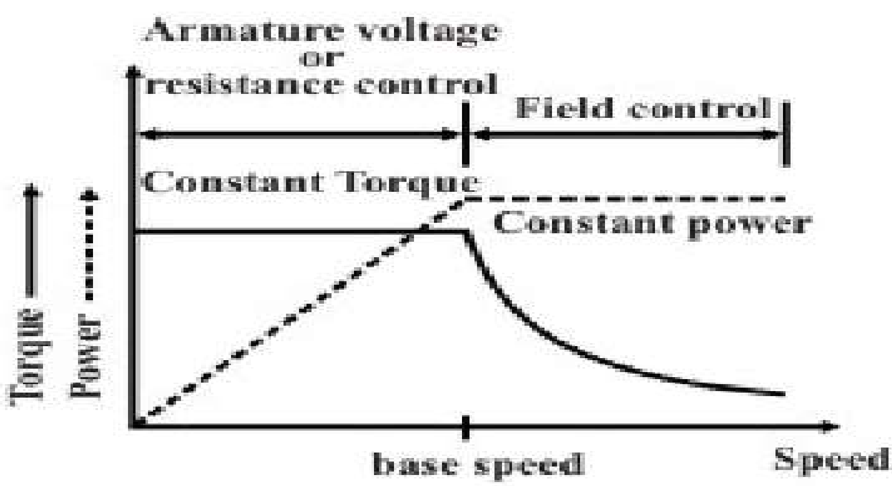
16MARKS

1. Explain about the necessity of speed control?

The speed of a given machine (DC) has to be controlled for the required speed variations of an operation.

Either armature voltage or field current can be varied or controlled. A separately excited motor is a versatile variable speed motor. The speed control using the variation of the armature voltage can be used for constant torque application in the speed range from zero to base or rated speed.

The speed control using the field weakening can be used for constant power application in the speed range from zero to above base or rated speed. The operating limits of a Dc drive are as shown below:



The speed of motion is given by the relation,

$$N = \frac{V - I_a R_a}{Z\phi}(\frac{Z}{A})$$

$$N = k\frac{V - I_a R_a}{\phi}.rps$$

$$or N \alpha \frac{V - I_a R_a}{\phi} or N \alpha \frac{E_b}{\phi}$$

Where,
N – Speed of the motor

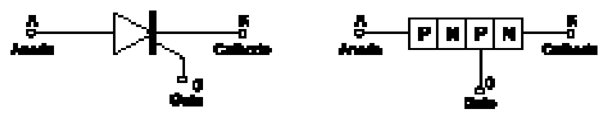
$I_a R_a$ - Armature resistive drop
V – Applied voltage
ϕ - Flux developed people
P – No of poles
Z – No of armature conductors
A – No of parallel path

Now, it is clear that speed can be controlled with either of V or $I_a R_a$ or ϕ. The speed can therefore be controlled by (1) Armature voltage or rheostat control (2) Field flux control (3) Armature resistance control.

2. (I) write short notes on controlled rectifier(AU-NOV-05)
(II) How is the speed control of the dc drive achieved using half, fully controlled rectifier (AU-NOV-05, 09) (AU-MAY-05) (AUC-NOV-09) (AUC-APR-11)

Controlled rectifier

Rectifier is a circuit which converts fixed A.C voltage into fixed D.C voltage. in various industrial applications variable D.C voltage is required. For example to vary the speed of D.C motor the applied dc voltage has to be varied. phase controlled rectifier (or) simply controlled rectifier is a circuit which converts fixed A.C voltage into variable D.C voltage .in rectifier circuit power diodes are used as a switch .in phase controlled rectifier circuit diodes are replaced by thyristors or SCR"s.
An SCR is a three terminal device used to control large currents to a load.



Symbol of SCR

An SCR acts a very much like a switch .when it is turned –on there is a low resistance current flow path from anode to cathode .then it acts like a closed switch. When it is turned off, no current can flow from anode to cathode then it acts like an open-switch .the switching action of an SCR is very fast, because SCR is a solid state device. the switching action of gate takes place only when

- SCR is forward biased i.e. anode is positive with respect to cathode
- Suitable positive voltage is applied between the gate and the cathode

Once the SCR has been switched on it has no control on the magnitude of current flowing through it. The current through the SCR is entirely controlled by the external impedance connected in the circuit an the applied voltage, the forward current through the SCR can be reduced by reducing the applied voltage or by increasing the circuit impedence.there is a minimum forward current that must be maintained to keep the SCR .if the current through the SCR is reduced below the level of holding current, the device returns to off-state or blocking state.

The SCR can be switched off by reducing the forward current below the level of holding current, which may be done either by reducing the applied voltage or by increasing the circuit impedence.the gate can only trigger or switch –on the SCR, it can not switch-off .in SCR‟s output voltage or current can be varied by controlling the point in the input ac cycle, at which thyristor is turned –on with application of a suitable low-power gate pulse. Once triggered or fired into conduction, the thyristor remains in the conducting state for the rest of the half-cycle i.e. upto 180 degrees. The firing angle can be adjusted with the help of a control circuit .firing delay angle and conduction angle always total 180 degree.

Types of phase controlled rectifier.

Based on the input supply phase controlled rectifier is broadly classified into two types they are,

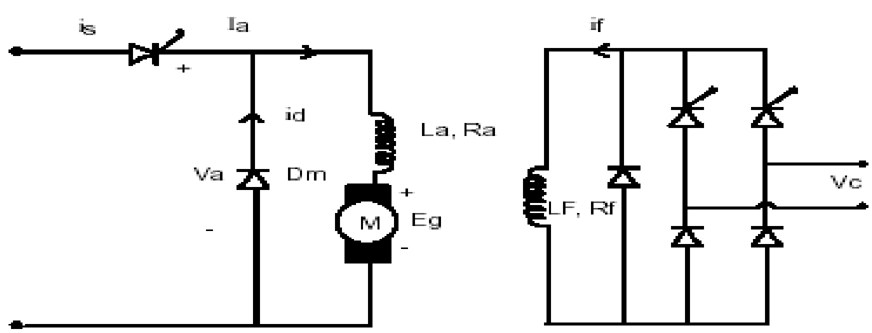
- Single phase controlled rectifier
- Three phase controlled rectifier

These converters are further classified into,

- Half wave controlled rectifier
- Fully wave controlled rectifier

Half wave controlled rectifiers

In the single phase half controlled rectifier, the load resister, RL is connected in series with anode A.A variable resistance r is inserted in the gate circuit for controlling gate current. during the negative half cycles of the input ac voltage .the SCR does not conduct regardless of the gate voltage, because anode is negative with respect to cathode K.the SCR will conduct during the positive half cycles provided appropriate gate current is made to flow .the gate current can be varied with the help of variable resistance r inserted in the gate circuit for this purpose .the greater the gate current, the lesser will be the supply voltage at which SCR will start conducting.



Assume that the gate current is such that SCR starts conducting at a positive voltage V, being less than peak value of input ac voltage $V_{max,}$ it is clear that the SCR starts conducting, as soon as input ac voltage becomes equal to V volts in the positive half cycle, and will continue conducting till ac voltage becomes zero when it will turn-off, again in next positive half cycle, SCR will start conducting when input ac voltage becomes equal to V volts.

The angle by which the SCR starts conducting is called as firing angle or delay angle α the conduction will take place for($\Pi - \alpha$) radians. The thyristor circuit uses phase commutation.

The average output voltage (V_L) from a half-wave controlled rectifier for the given input ac voltage $V=V_{max}\sin \omega t$

$$V_L=\frac{V_{max}}{\Pi}\cos^2\frac{\alpha}{2}$$

Average output current

$$I_L = \frac{V_L}{R_L} = \frac{V_{\max}}{\Pi R_L}\cos^2\frac{\alpha}{2}$$

Thus the desired value of load current I_L can be obtained by varying firing angle α

$$I_L = \frac{V_{\max}}{\Pi R_L} when \alpha = 0$$

$$I_L = \frac{V_{\max}}{2\Pi R_L} when \alpha = \frac{\Pi}{2}$$

Hence, load current decreases with the increase in value of firing angle α . So the terminal voltage decreases the motor run slowly and vice versa.

Free wheeling diode

Let RL load is connected with the single-phase half controlled rectifier .Due to the inductive nature of the load, the load current lags by an angle θ with respect to the voltage. During voltage reversal, the voltage reaches zero but due to the inductive nature of the load, the current still flow through the thyristor .it takes some time for the current to reach zero. so during that instant ,a negative voltage will be appearing across the inductive load and the free wheeling diode connected in parallel with the load is turned on, as the diode is turned on, the load voltage becomes the diode forward drop.

It is other wise called commutating diode. This diode is connected anti parallel with load .this diode comes into picture only when the load is inductive. In case of inductive load even though the input voltage reaches zero and becomes negative, the current is still flowing through the thyristor, so it remains on when the voltage across the load becomes negative. The freewheeling diode is turned on when the load voltage is negative. So, the voltage across the load becomes zero and it provides a path for the load current. During this interval, the energy stored in the inductor is dissipated through this diode

- This freewheeling diode prevents the negative the negative reversal of voltage across the load.
- It improves the input power factor.
- It improves the load current wave from thereby it improves the performance parameters.

Full controlled rectifier

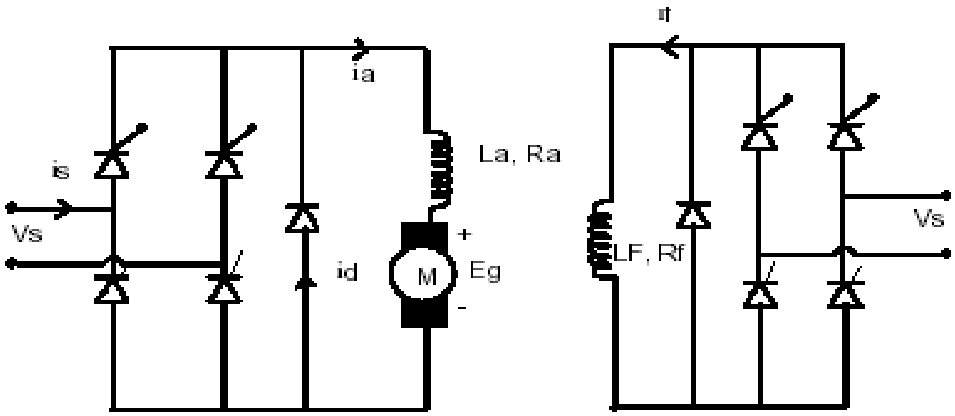
The full wave half controlled rectifier circuit consists of two thyristors and two diodes. The gates of both thyristors are supplied from two gate control supply circuits. One thyristors (or SCR) conducts during the positive half cycles and the other during the negative half cycles and thus unidirectional current flows through the load circuit.

Now, if the supply voltage v $=V_{max}\sin \omega t$ and firing angle is α ,then average output voltage is given by

$$v_L = \frac{1}{\Pi}\int_{\alpha}^{\Pi} V_{\max}\sin\omega t d(\omega t)$$

$$V_L = \frac{V_{\max}}{\Pi}(1+\cos\alpha)$$

$$= \frac{2V_{\max}}{\Pi}\cos^2\frac{\alpha}{2}$$



Average output current,

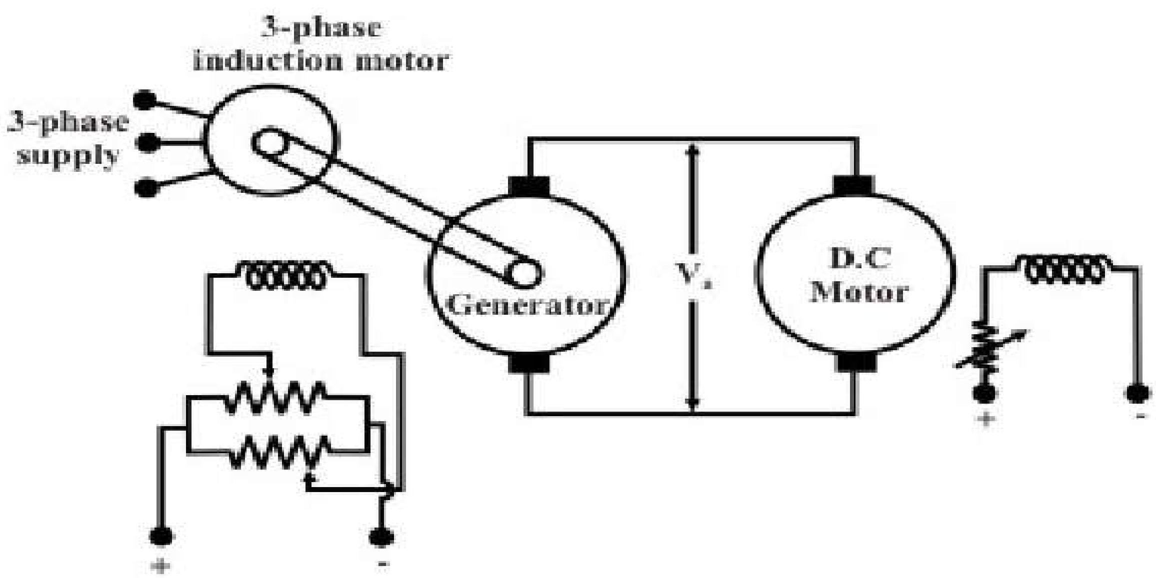
$$I_L = \frac{V_L}{R_L} = \frac{2V_{\max}}{\Pi R_L}\cos^2\frac{\alpha}{2}$$

So the terminal voltage decreases the motor run slowly and vice versa

3. Explain ward-Leonard system of speed control? (AU-NOV-05) (AU-MAY-05, 07, 09) (AUC-JAN-09) (AUC-APR-11) (AUC-NOV-10)

In this method of speed control the armature is supplied with a variable voltage with the help of a motor-generator set since the supply voltage available from the electricity authority cannot be varied. The field winding is connected across the supply terminals since otherwise the torque produced may be insufficient to start the motor.

This system of speed control without is also known as Ward Leonard system.M_2 is the motor whose speed is to be controlled. By applying a variable voltage across its armature, any desired speed can be obtained. This variable voltage is supplied by a motor M_1-Generator (G) set. The motor M_1 runs at approximately constant speed. The output voltage G is directly fed to the main motor M_2 .The voltage of the generator can be varied, by changing the polarity of armature supply terminals, speed can be controlled in the opposite direction also.



ADVANTAGES:

1. Smooth control of speed over a wide range in both directions is possible.
2. The system in more efficient at low speeds as there are no resistors connected in series with the armature circuit.

DISADVANTAGES:

1. Separate motor –generator set is required which may be costly.

Ward-Leonard –lllgner system.

A modification of ward- Leonard system is known as ward-Leonard ilgner system which uses a small motor generator set with addition of a flywheel, whose function is to reduce fluctuations in the power demand from the supply circuit.

When the main motor M2 becomes suddenly overloaded, the driving motor M1 of the motor generator set slows down, thus allowing the inertia of the fly wheel to supply a part of overload. However, when the load is suddenly thrown off from the main motor M2, then M1 speeds up there by again storing energy in the flywheel.

When the ilgner system is driven by means of an AC motor (whether induction or synchronous in place of M1) another refinement in the form of a slip regulator can be usefully employed thus giving an additional control.

4. Compare D.C. and A.C. drives? (AU-MAY-05) (AUC-MAY-10)

S.NO.	D.C. Drives	A.C. Drives
1.	The size becomes bulky, so, heavy and costly due to commutator. Sparking at the brushes makes it unsuitable in certain locations. The highest speed and rating are limited due to commutation. The commutator needs frequent maintenance.	The problems are not there. Speed and design ratings have no upper limits. Reliable and require little maintenance. Can be used in all locations.
2.	D.C. motors are costly.	Not so costly. Squirrel cage motors are less expensive and hence economical.
3.	Power converter technology is well established, simple and less cost.	The inverter technology is still to be improved. The power circuit of inverter and its control are complex.
4.	Line commutation of converter.	Forced commutation is used for induction motors. Machine commutation may be used for synchronous motors.
5.	Line conditions are poor i.e. poor power factor, harmonic distortion of the current.	Power factor is poor for re-generative drives. Power factor is better for non-regenerative drives.
6.	Fast response, wide speed range, smooth control.	Response depends on type of control. The speed range is wide with solid state control, but the speed is speed one and limited,

		with conventional method.
7.	Small power/weight ratio.	Higher power / weight ratio.
8.	Cost does not depend on the solid state converter.	Cost depends on the type of solid state control.

5. (I) write short notes on chopper
(ii) Explain the control of dc drives using chopper? (AU-MAY-06)

Chopper is a circuit which converts fixed d.c voltage into variable d.c voltage without any intermediate stage. it is classified in to two types

- Step up chopper
- Step down chopper

Step up chopper is a circuit which steps don the input d.c voltage. step up chopper is a circuit which steps up the input d.c voltage.so choppers are otherwise called as d.c equivalent of transformers.

In chopper circuits, power transistors, power MOSFETS are used as switch, because these devices can be easily turned on by providing base voltage and turned off by removing base voltage. Generally thyristors are not preferred as a switch inD.C .chopper because in chopper input is d.c supply so no chance of natural commutation .so turn off the thyristor it requires external commutating circuit.it makes the circuit complex. The following control strategies are used in D.C chopper,

- Pulse width modulation method
- Variable frequency method

In pulse width modulation method the total time period is kept constant but either duration of on period or off period is varied. So there by varying the pulse width applied to the transistor base the output load voltage can be varied.

In variable frequency method, the pulse width is kept constant but the switching frequency is varied there by the output load voltage can be varied .but this method is not preferred because it introduces unknown harmonics to filter

Types of thyristor drives

DC motors for different applications require speed control in a forward direction, reverse direction and regenerative braking. Closed loop control is invariably employed in all thyristor drives

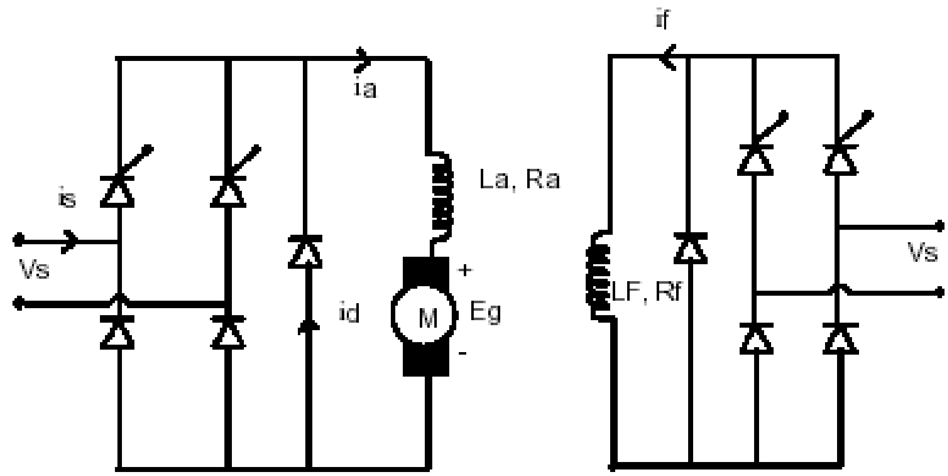
The various types of thyristors drives employed are,

- Single phase half-wave controlled rectifier circuits for dc motors up to 1 kw rating.
- Single phase half bridge circuits for dc motors up to 5 kw rating
- Three phase half bridge circuits for dc motors of 5 to 75 kw rating
- Three phase full bridge circuits for dc motors of 75 to 400kw rating
- Twelve pulse converters for dc motors of rating exceeding 400 kw rating.

Single phase half-bridge thyristor drive

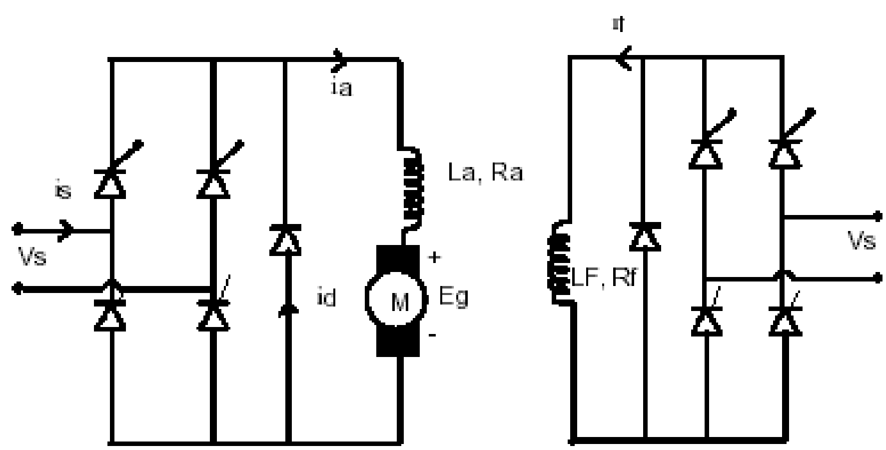
The bridge rectifier converts ac voltage into dc voltage. The dc shunt field winding is directly fed from the bridge rectifier through the SCR .the dc voltage applied to the armature is controlled by varying the triggering angle.

The free wheeling diode D is connected across the motor armature to provide a circulating current-path for the energy stored in the inductance of the armature winding at the time SCR turns-off.in absence of free wheeling diode, current will flow through SCR and bridge rectifier and thus prohibit SCR from turning –off.



Single phase full wave thyristor drive

The circuit diagram for speed control of a dc motor consist of diodes D1,D2,D3 and D4 form the bridge, which converts ac into dc to supply the field winding of the motor. During the positive half cycles of input ac supply, SCR1 conducts and supplies the armature winding. During negative half cycles, SCR2 is made to conduct and supply the armature winding. Thus voltage applied to the armature controls the speed of the motor. The angle of conduction of SCR can be changed by varying the gate current.



Dc chopper speed control

In this method of speed control of a dc motor, available ac supply is first rectified into dc supply using uncontrolled rectifiers. The supply is then filtered and smoothened dc output is supplied to the thyristor chopper. It allows dc to flow through for time Ton and then disconnect for time T_{off}.the cycles is repeated. During the supply –on period (i.e. for period Ton), the dc motor accelerates.during the supply-off period (i.e. for period T_{off}), there is no supply to the motor and, therefore, motor decelerates till the next on-cycle begins. If the cycles are repeated continuously at a definite frequency and the elements of the cycle are maintained in a fixed relationship, the motor will then operate at a constant average speed.

The average value of voltage across the motor will be,

$$V_o = V \times \frac{T_{on}}{T_{on} + T_{off}} = V \times \frac{T_{on}}{T} = fV \times T_{on}$$

and the dc voltage across the motor can be controlled by varying the time ratio control TRC which may be accomplished by,

- Varying the duration of on-time keeping the total time period T or frequency f constant,
- Keeping the on-time (Ton) constant and varying the frequency f
- Adjustment of both

The variable dc voltage below supply voltage (dc) is made available to the dc motor and, therefore, the motor speed available is below base (or normal) speed. Foe automatic control of speed both current feedback and speed feed back are used .in case supply available is dc, then the rectifier is not required and only chopper is used for speed control of a dc motor. The voltage and current waveforms appearing at the armature terminals of the motor.

Because the inductance of armature winding plays an important role in storing sufficient magnetic energy, chopper drives are frequently used with dc series motors, the series motor has large armature inductance than the shunt motor, although perfectly acceptable performance can be had when the latter machine is used with an external series inductance.

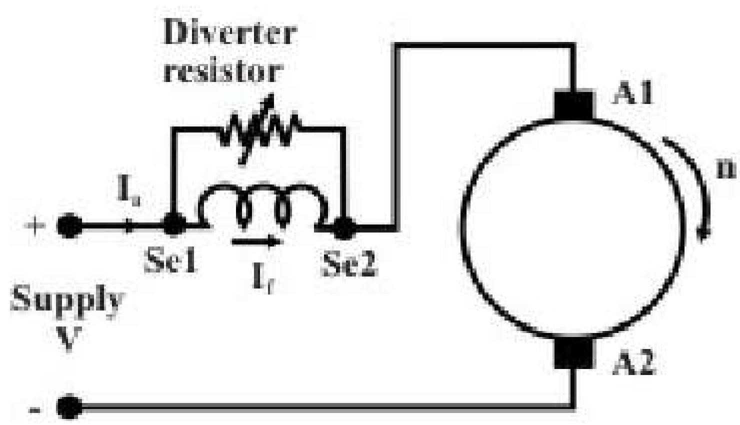
6. Explain the field control methods used for d.c series motor for speed control. (AU-MAY-06) (AU-APR-08)

1. Flux control of series motors:

Variations in the flux of a series motor can be brought about in any one of the following ways.

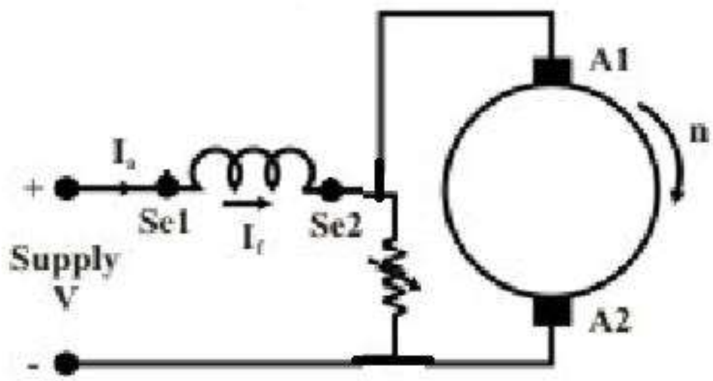
a) Field diverters

The series windings are shunted by a variable resistance known as field diverter. any desired amount of current can be passed through the diverter by adjusting its resistance. Hence the flux can be decreased and, consequently, the speed of the motor increased.



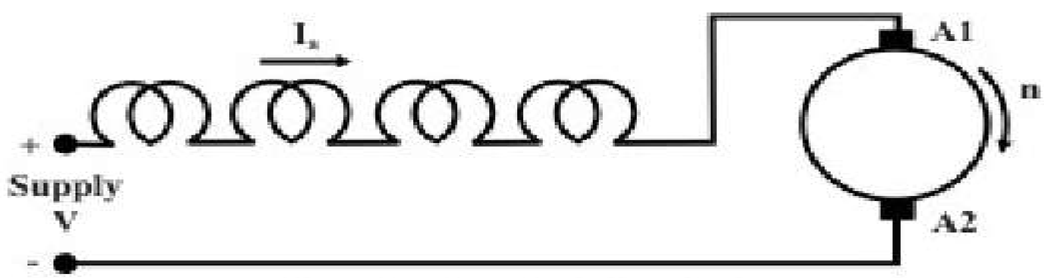
b) Armature diverter

A diverter across the armature can be used for giving speeds lower than the normal speed. For a given constant load torque, if Ia is reduced due to armature diverter, then ϕ must increase $\therefore T_a \alpha \phi I_a$) this results in an increase incurrent taken from the supply (which increases the flux and a fall in speed (N$\alpha I/\phi$)).the variation in speed can be controlled by varying the diverter resistance.



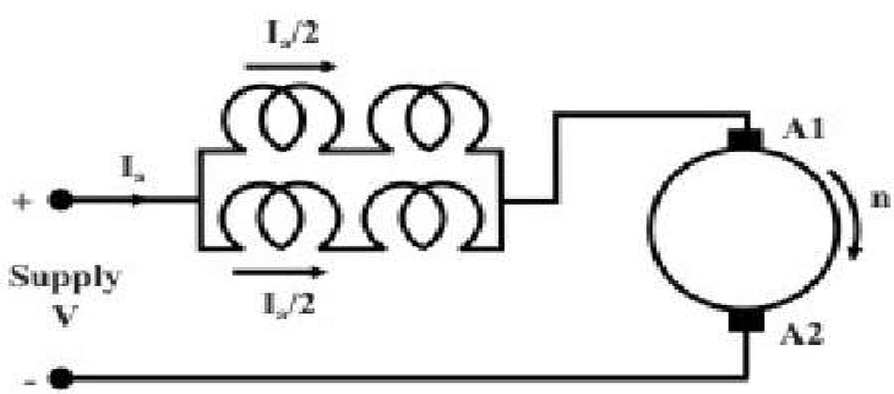
c) Tapped field control

This method is often used in electric traction .the number of series field turns in the circuit can be changed at will as shown. With full field, the motor runs at its minimum speed which can be raised in steps by cutting out some of the series turns.



d) Paralleling field coils

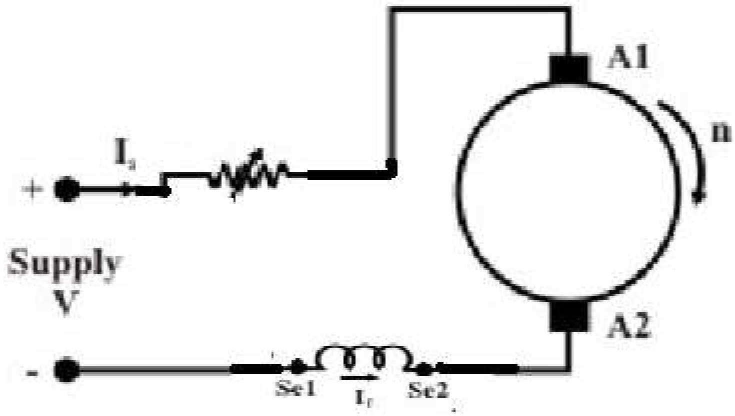
In this method, used for fan motors, several speeds can be obtained by regrouping the field coils .it is seen that for a 4- pole motor, three speeds can be obtained easily.



2. Armature resistance in series with motor.

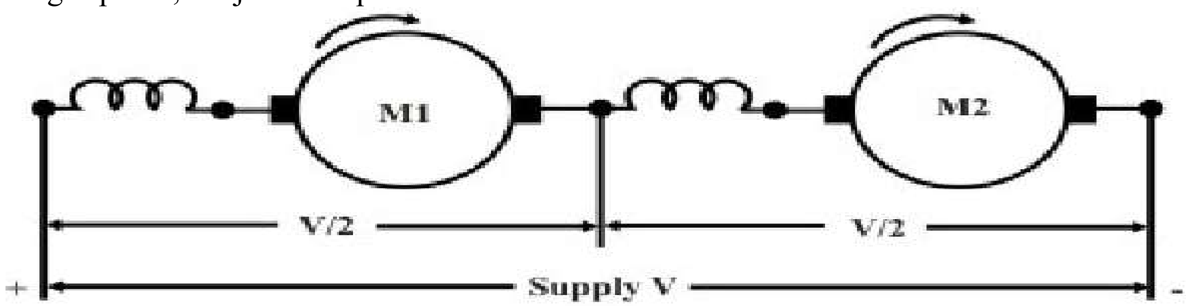
By increasing the resistance in series with the armature the voltage applied across the armature terminals can be decreased.

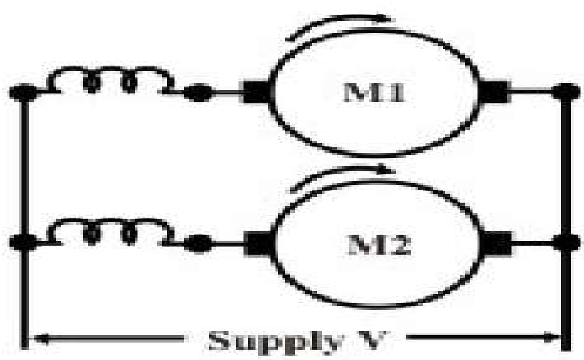
With reduced voltage across the armature, the speed is reduced .how ever, it will be noted that since full motor current passes through this resistance, there is a considerable loss of power in it.



7. Briefly explain about the Series-parallel control

In this system of speed control, which is widely used in electric traction, two or more similar mechanically –coupled series motors are employed. At low speeds, the motors are joined in series and foe high speeds, are joined in parallel





When in series ,the two motors have the same current passing through them, although the voltage across each motors is V/2 i.e. .half the supply voltage .when joined in parallel ,voltage across each machines is V,though current drawn by each motor is I/2.

When parallel

Now speed α $E_b/2$ α E_b/current (being series motors)

Since E_b is approximately equal to the applied voltage V

Therefore speed $\alpha \dfrac{V}{I/2} \alpha \dfrac{2V}{I}$

Also torque α Φ I α I^2 (therefore Φ α I)

Therefore T $\alpha \left(\dfrac{I}{2}\right)^2 \alpha \dfrac{I^2}{4}$

When in series

Here speed $\alpha \dfrac{E_b}{\Phi} \alpha \dfrac{V/2}{I} \alpha \dfrac{V}{2I}$

This speed is one-fourth of the speed of the motors when in parallel

Similarly T $\alpha \Phi I \alpha I^2$

The torque is four times that produced by motors when in parallel.

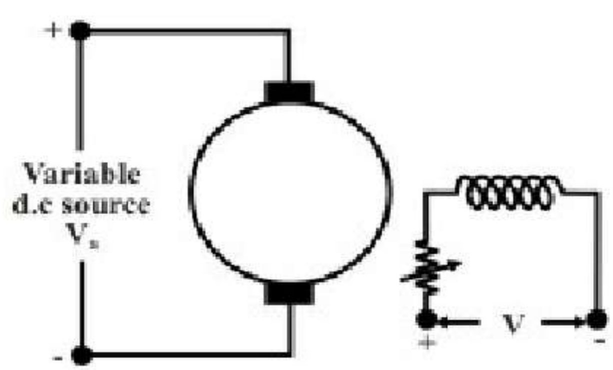
This system of speed control is usually combined with the variable resistance method of control.

The two motors are started up in series with each other and with variable resistance which is cut out in sections to increase the speed. When all the variable series resistance is cut out, the motors are connected in parallel and at the same time, the series resistance is re inserted. As the variable series controller resistance is not continuously rated, it has to be cut of the circuit fairly quickly although in the four running positions A, B, C and D, it may be left in circuit for any length of time.

8. How do you control the speed of the shunt motor by field control method? (AU-APR-08) (AU-NOV-06) (AUC-MAY-10)

A variable resistor called a field regulator is connected in series with the shunt field winding as shown in figure. The overall resistance of the field circuit can be changed by varying the field regulator resistance.

When the field circuit resistance is increased the field current and therefore flux produced by the field is decreased. Since speed is inversely proportional to flux, speed is increased with reduced flux. By introducing the field regulator the field circuit resistance can only be increased, i.e. the field flux can only decreased and there by the speed of the motor can be increased. It is not possible to decrease the speed by the use of a field regulator. This method of speed control is applicable in shunt and compound motors.



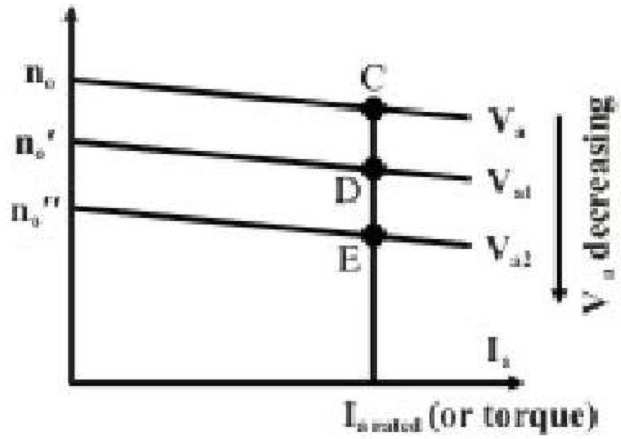


Figure shows the variation of speed with respect to variation of field current under constant applied voltage.

Advantages:

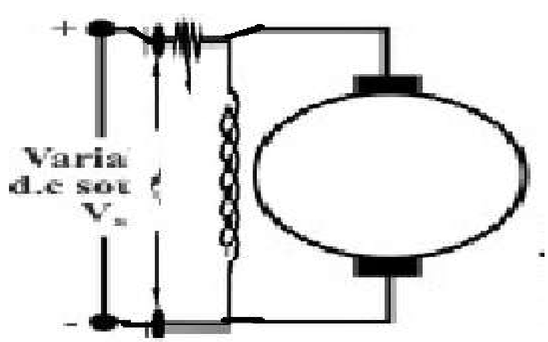
1. The regulating resistance has to carry only a small current and hence is available and power wasted in the regulating resistance is very small and hence this method is more economical.

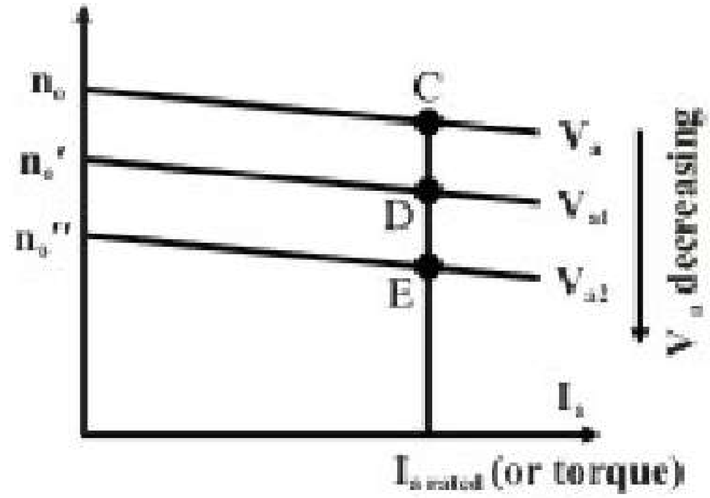
Disadvantage:

1. Speed cannot be decreased below the normal speed level.

9. How do you control the speed of the shunt motor by armature (or) rheostatic control method? (UQ)

This method is used when speeds below the no-load speed are required. As the supply voltage is normally constant, the voltage across the armature is varied by inserting a variable rheostat or resistance in series with the armature circuit .as controller resistance is increased, p.d across the armature is decreased; there by decreasing the armature speed.for a load of constant torque, speed is approximately proportional to the p.d across the armature. from the speed/armature current characteristics. It is seen that greater the resistance in the armature circuit, greater is the fall in speed.





I_{a1}=armaturecurrent in thefirstcase
$Ia2$=armturecurrent in thesecondcase
if ($I_{a1}=I_{a2}$,thentheloadis.of .constant.torque)

N_1, N2=corresponding speeds=supply voltage
Then $N_1 \alpha V-I_aR_a \alpha E_{b1}$

Let some controller resistance of value R be added to the armature circuit resistance so that its value becomes $(R+R_a) = R_1$

$$\therefore thenN_2 \alpha V - I_{a2} Rt \alpha E_{b2} \quad . \frac{N_1}{N_2} = \frac{E_{b2}}{E_{b1}}$$

(In fact, it is a simplified form of relation given by $\Phi_1 = \Phi_2$)

Considering no-load speed, we have $\dfrac{N}{N_o} = \dfrac{V - I_a R_t}{V - I_{ao} R_a}$

Neglecting $I_{ao}R_a$ with respect to V, we get

$$N = N_o = (1 - \frac{I_a R_t}{V})$$

It is seen that for a given resistance R1, the speed is a linear function of armature current I_a.
The load current for which the speed would be zero is found by putting N=0 in the above relation,

$$\therefore 0 = N_o(1 - \frac{I_a R_t}{V}) \text{ or } I_a = \frac{V}{R_t}$$

This is the maximum current and is known as stalling current.

This method is very wasteful,expensive and unsuitable for rapidly changing loads because for a given value of R_1 ,speed will change with load .A more stable operation can be obtained by using diverter across the armature in addition to armature control resistance .now ,the changes in armature current (due to changes in the load torque) will not be so effective in changing the p.d across the armature (and hence the armature speed).

10. Briefly explain about the DC chopper drives? (AU-MAY-07) (AU-APR-08) (AU-NOV-08, 09) (AUC-NOV-09)

Choppers are used to get variable dc voltage from a dc fixed voltage.self commutated devices such as MOSFETS, power transistors,IGBTs ,GTOs and IGCTs are used for building choppers because they can be commutated by a low power control signal and do not need commutation circuit and can be operated at a higher frequency for the same rating.

The choppers offer a number of advantages over a controlled rectifiers for a dc motor control in open –loop and closed –loop configurations. the operation at high frequency improves motor performance by reducing current ripples ,because a reduction in the armature current ripple, reduces a machine losses and its derating,eliminating discontinues condition .the elimination of discontinues conduction region improves speed regulation and transient response of a drive

Advantages of using chopper in speed control of dc motors are:

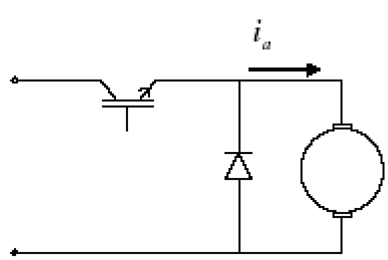
- High efficiency
- Flexibility in control
- Light weight
- Small size
- Quick response and regeneration down to very low speeds

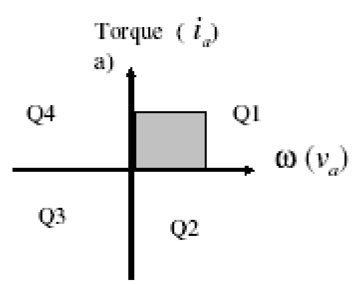
(i) First -quadrant (or) Type –A chopper

When chopper CH1 is on, output voltage is equal to supply voltage.i.e VO=Vs and current Io flows in the arrow direction i.e. positive`

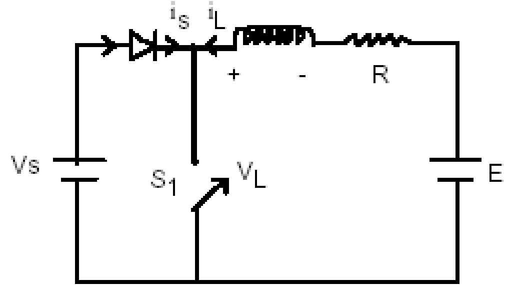
When CH1 is off, output voltage is equal to zero,i.e Vo=0 but Io in the load continues flowing in the same direction through freewheeling diode FD.here,the average output voltage and load current always positive.

The type A chopper power flows from source to load .it is also called as step-down chopper because average output voltage Vo is less than the input dc voltage Vs.





(ii) Second - quadrant (or) Type –B chopper



In this chopper, the load must contain the dc source E, like a dc motor
When CH2 is on, output voltage is equal to zero, i.e Vo=0 but load voltage E drives current through L and CH2.during on time of the chopper (Ton), the inductor L stores energy

When CH2 is off, output voltage V0= [E+L di/dt] exceeds source voltage Vs. As a result, diode D2 is forward biased and conducts, thus allowing power to flow to the source .chopper CH2 may be on or off, load current Io flows out of the load. Here load current Io is treated as negative.

The power flows from load to source because output voltage V0 is always positive and load current Io is negative. As load voltage Vo is greater than the source voltage Vs, type B chopper is also called as step-up chopper or boost converter. It is also known as regenerative chopper

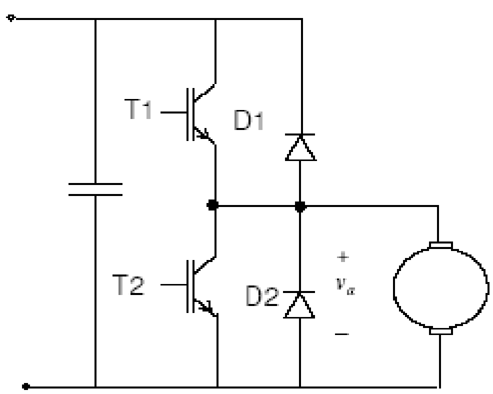
(iii) Two quadrant type-A chopper or type-C chopper

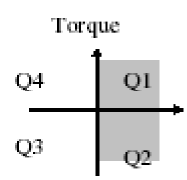
Type C chopper is obtained by connecting type –A and type –B chopper in parallel. Here the output voltage Vo is always positive but the load current Io is positive as well as negative.

When chopper CH1 or FD conduct operate together as type-A chopper in first quadrant. When chopper CH2 or diode D2 conduct, the output voltage is positive but the load current is negative. In other words CH2 and D2 operate together as type-B chopper in second quadrant.

Average load voltage is always positive but average load current may be positive or negative .therefore, the power flow may be from source to load or from load to source.

Choppers CH1And CH2 should not be on simultaneously otherwise direct short circuit will occur. This type of chopper configuration is used for motoring and regenerative braking of dc motors. The operating region of this type chopper is hatched area in first and second quadrants.



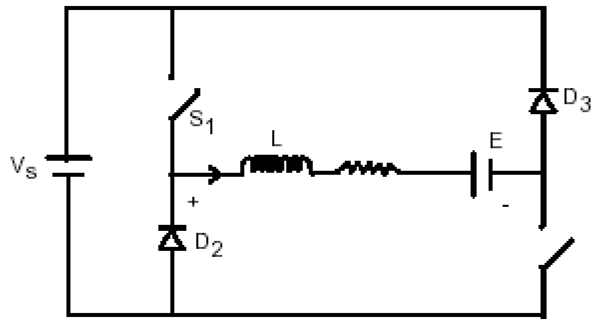


(iv) Two quadrant type-B chopper or type D chopper

The output voltage is equal to the supply voltage I.e. Vo=Vs when both CH1 and CH2 are on and output voltage is equal to negative value of supply voltage i.e. Vo=-Vs when both choppers are off but both diodes D1 and D2 are conduct.

Average output voltage Vo is positive when on time of the choppers (Ton) is greater than the turn off time (Toff) .Average output voltage Vo is negative when on time of the choppers (Ton) is lesser than the turn off time (Toff).

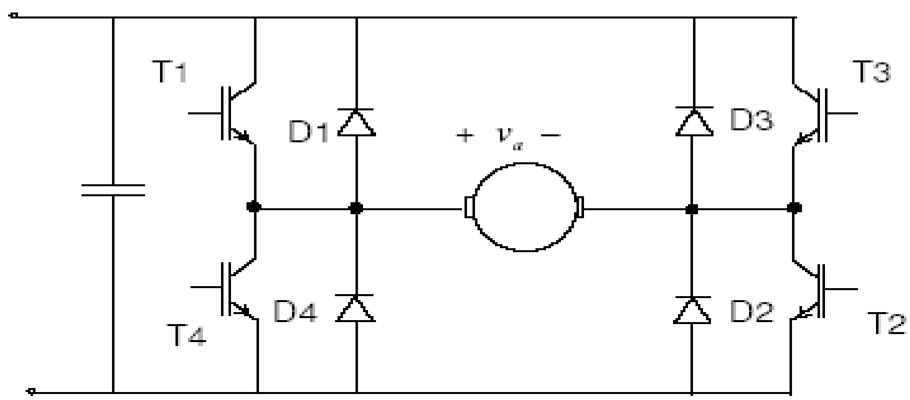
The direction of load current is always positive because choppers and diode can conduct current only in the direction of arrows**.** Here the output voltage (Vo) is negative, the power flows from load to source. The operation of this type –D chopper is shown by hatched area in first and fourth quadrants.



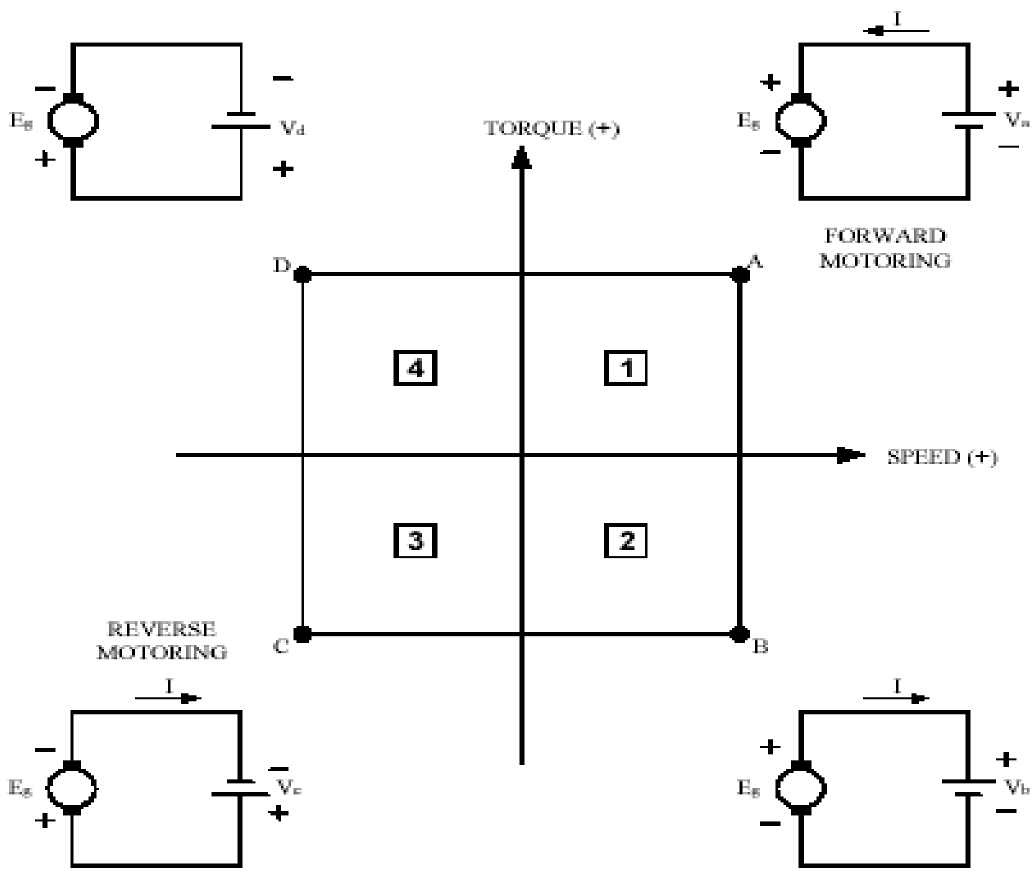
(v) Four quadrant chopper or type-E chopper

This type of chopper consist of four semiconductor switches CH1 to CH4 and four diodes D1 to D4 in antiparallel.

Working of this chopper consist off four quadrant,



FOUR QUADRAN OPERATION



Forward motoring mode

In this mode CH4 kept on, CH3 is kept off and CH1 is operated. With CH1, CH4 on, load voltage is equal to supply voltage i.e. Vo=Vs and load current Io begins to flow. Here both output voltage Vo and load current Io is positive giving first quadrant operation .when CH1 is turned off, positive current freewheels through CH4,D2 in this way, both output voltage Vo,load current Io can be controlled in the first quadrant. first quadrant operation gives forward motoring mode.

Forward braking mode

Here CH2 is operated and CH1, CH3 and CH4 are kept off. With CH2 on reverse (or negative) current flows through L, CH2, D4 and E.During the on time of CH2 the inductor L stores energy. When CH2 is turned off, current is fed back to source through diodes D1, D4 note that there [E+ Ldi/dt] is greater than the source voltage Vs. As the load voltage V0 is positive and load current Io is negative, it is second quadrant operation of chopper. Also power is flows from load to source. second quadrant gives forward braking mode.

Reverse motoring mode

CH1 is kept off, CH2 is kept on and CH3 is operated. Polarity of load emf E must be reversed for this quadrant operation. With CH3 on, load gets connected to source Vs so that both output voltage Vo, load current Io are negative. It gives third quadrant operation. it is also known as reverse motoring mode. When CH3 is turned off, negative current freewheels through CH2, D4 .in this way, output voltage Vo and load current Io can be controlled in the third quadrant.

Reverse braking mode

Here CH4 is operated and other devices are kept off. Load emf E must have its polarity reversed. For operation in the fourth quadrant .with CH4 on, positive current flows through CH4, D2, L and E. During the on time of CH4 inductor L stores energy .When Ch4 is turned off, current is feedback to source through diodes D2, D3.here load voltage is negative, but load current is positive leading to the choppers operation in the fourth quadrant. Also power is flows from load to source. the fourth quadrant operation gives reverse braking mode.

Unit V – Conventional & Solid State Speed Control of AC Drives

Two Marks

1.What are the speed control methods available for speed control of induction motor on stator side? (AU-MAY-08)

Speed control methods available for speed control from stator side are:

i. By controlling supply voltage
ii. By pole changing
iii. Changing supply frequency

2. What are the speed control methods available for speed control of induction motor on rotor side? (AU-NOV-05)

The speed control methods available for sped control of IM on rotor side are;

i. Rotor resistance control
ii. Cascade speed control
iii. By injected voltage method.

3. What are the three possible speeds that can be obtained in cascaded operation of induction motor? (AU-MAY-07) (AUC-NOV-10)

i. $$N_s = \frac{120 f}{P_a}$$

Where, Pa = No of stator poles in motor A

ii. $$N_s = \frac{120 f}{P_b}$$

Where, Pa = No of stator poles in motor B

iii. $$N_s = \frac{120 f}{P_a + P_b}$$

4. What are the disadvantages of inserting resistance in the rotor circuit in slip ring induction motor?

Disadvantages:

1. Losses (I^2R) is increasing and efficiency of the motor is decreased.
2. Since speed is dependent on both resistance and load. We can change speed for short periods only.

5. under what condition, the slip in an induction motor is

a. Negative

b. Greater than one

c) Slip of an induction motor is negative when the induction motor is operating in generating mode.
d) Slip of an induction motor is greater than one when the induction motor is operating in the braking mode (its direction is opposite to the direction of rotating magnetic field).

6. How the speed is controlled by changing the supply voltage?

Since,

Torque, $T \propto V^2$

By changing the supply voltage, torque is proportional to the square of the supply voltage. Hence, example if voltage is reduced by half (1/2), the torque will be reduce d by (1/4) quarter.

7. How the speed is changed by changing the supply frequency? (AU-MAY-06)

Since

$$N = \frac{120}{p},$$

By changing the supply frequency directly, the speed is reduced directly.

8. What is „slip" in an induction motor? (AUC-NOV-09)

The induction motor speed is always less than the speed of synchronous speed of revolving flux. The difference in speed between synchronously revolving flux and the rotor speed is called slip speed.
The ratio between the slip speed and synchronous speed of induction motor is called slip. It is denoted by„s".

Slip, $S = \frac{N_s - N}{N_s}$.

% slip, $\%S = \frac{N_s - N}{N_s} \times 100$ %.

The motor speed is given by ,

1. $N = N_s$ (1-S) Rpm.

9. How the speed is controlled by changing the supply voltage?

Since $N \propto \frac{1}{p}$

Speed is inversely proportional to number of poled, the speed decreases with increase in number of poles.

However, torque capability of motor increases with increase in number of poles.

10. How speed control can be achieved by inserting resistance in the rotor circuit of slip ring induction motor?

By inserting external resistance in the rotor circuit of slip ring induction motor, the total rotor circuit resistance is increased. For a particular motor speed, the induced emf in the rotor is constant. Hence, with increase in the rotor circuit resistance, rotor winding current wills decreases.

$I_2 = \frac{SE_2}{R_2}$ [Without adding external resistance]

$$I_2^1 = \frac{SE_2}{(R_2 t_r)} \text{ [By adding external resistance r]}$$

Hence, the new current I_2^1 is smaller than I_2. But torque,

$$T \propto \phi\, I_2 Cos\phi$$

Since I_2 is decreased torque is decreased and the motor is peed starts to fall.

When motor speed is reduced, the term SE_2 will be becomes increased since slip S is increased.

Hence with decrease in motor speed, rotor circuit current I_2 will increase and hence the torque will goes on increasing.

The motor will attains a speed at which $I_2 = I_1$ condition achieved ie the motor is able to handle the load torque.

11. What is slip power? (AUC-NOV-09)

It is the power wasted in the rotor circuit resistance. IN case of slip ring induction motor, the speeded control is achieved by adding external resistance in the rotor circuit. But, with adding external resistance in the rotor circuit, (I^2R) losses in the external resistances will be increased. Hence, slip power is wasted in rotor resistance.

Without wasting this slip power, the slip power can be usefully utilized in slip power recovery scheme.

12. What is slip power recovery scheme? (AU-MAY-06, 07) (AU-APR-08) (AUC-NOV-10)

The power wasted in the external resistance in the rotor circuit in case of slip ring induction motor, is called slip power. This wastage slip power can be usefully fed back to the source by used of slip power recovery scheme.

Two types of slip power recovery scheme available are;

i. Static scherbius drive
ii. Static Kramer‟s drive

13. What is meant by inverter? (AUC-MAY-10)

A device that converts dc power into ac power at desired output voltage and frequency is called an inverter

14. What are the applications of inverters?(UQ)

- ✓ Adjustable speed ac drives
- ✓ Induction heating
- ✓ Stand by air-craft power supplier
- ✓ UPS
- ✓ HVDC transmission

15. What is the main classification of inverters? (AUC-NOV-10)

- ✓ Voltage source inverter(VSI)
- ✓ Current source inverter(CSI)

16. What is meant by VSI?

A VSI, is one in which the dc source has small or negligible impedence. In other words a VSI has stiff dc voltage source at its input terminals.

17. What is meant by CSI?

A current fed inverter or CSI is fed with adjustable current from a dc source of high impedance is from a stiff dc current source.

18. Give two advantages & applications of CSI?

Advantages

- ❖ CSI does not require any feedback diodes.
- ❖ Communication circuit is simple as it contains only capacitors.

Applications

- Induction heating
- Lagging VAR compensation
- Speed control of AC motors
- Synchronous motor sharing

19. How the thyristor inverters are classified?

- According to the method of commutation
  - ✓ Line commutated inverter
  - ✓ Forced commutated inverter
- According to the connection
  - ✓ Series inverter
  - ✓ Parallel inverter
  - ✓ Bridge inverter

20. What is meant by series inverter write its applications?

Series inverter means commutating elements L and C connected in series with load.

The thyristorised series inverter produces an approximately sinusoidal waveform at a high output frequency, ranging from 200HZ to 100KHZ.It is commonly used for fixed output applications such as

- ✓ Ultrasonic generators
- ✓ Induction heating
- ✓ Sonar transmitter
- ✓ Fluorescent lighting

21. Compare VSI and CSI? (AU-NOV-08) (AUC-MAY-10)

S.NO	Voltagesource inverter(VSI)	Current source inverter(CSI)
1	In voltage source inverter, input voltage is maintained constant.	In current source inverter, input currents constant but adjustable
2	In VSI,the output voltages does not depend on the load	In CSI,the amplitude of output currents constant but adjustable
3	The magnitude of output current and its waveform depends upon thenature of the load impedance	The magnitude of output voltage and its waveform depends upon the nature of the load impedance
4	It requires feed back diodes	It does not require any feedback diode
5	Commutation circuit complex	Commutation circuit is simple i.e., it contains only capacitors.

16-MARKS

1. Explain the speed control of induction motor from starter side? (AU-MAY-08) (AU-NOV-08, 09) (AUC-MAY-10)

The various methods available for speed control of induction motors from stator side are:

a. By changing the applied voltage.
b. By changing the applied frequency.
c. By changing the number of stator poles

A. By changing the applied voltage (UQ)

- Slip can be varied by changing the applied stator voltage i.e. motor speed can be varied by varying the supply voltage, because

$$Torque \propto V^2$$

- If the voltage is reduced as, torque is reduced as square of the voltage.

- For example, if the applied voltage is reduced from V to 0.9 V, the torque will be reduced from T to 0.81 T. The torque –speed characteristics at reduced stator voltage say 0.9V.
- Since the torque is reduced to 81 percent, the rotor cannot continue to rotate at speed N_1, it speed will be reduced. i.e. its slip will increase until the increased rotor current will make up for the reduced stator voltage and produce the required load torque at a a lower speed N_2. This method of speed control is rarely used for industrial three-phase motors because of the requirement of additional costly voltage changing auxiliary equipment.
- For small induction motor used in home appliance, voltage control method of speed changing is often used.

B). **BY POLE CHANGING METHOD**:

- The speed of an induction motor depends upon the number of poes which the stator is wound.
- If two independent stator windings are used for different number of poles say for four poles and for two poles are made on the stator, definite rotor speeds can be obtained.
- The two windings are to be insulated from one another. When any of the windings is used, other winding should be kept open circuited by the switch.
- For example, a 36-slot stator may have two 3ϕ -windings, one with 4 poles and the other with 6-poles. With supply frequency of 50Hz, 4 pole winding will give $N_s = \dfrac{120 \times 50}{4} = 1500\ rpm$ and the 6 pole winding will give, $N_s = \dfrac{120 \times 50}{6} = 1000\ rpm$
- The limitation of this method is only two definited speeds can be obtained. Smooth control of speed over wide range is not possible.

C). **BY CHANGING SUPPLY FREQUENCY:-**

- The speed of an induction motor is directly proportional to supply frequency. By gradually changing supply frequency, speed can be increased (or) decreased smoothly.

- There are, however, several drawbacks in this system. Electricity supply authorities supply power at a fixed frequency of 50 HZ, provision for supply at variable frequency can be made by consumers by having separate arrangement.

- Frequency conversion equipment are, therefore, to be installed by the industries at additional costs. Variable frequency conversion equipment are therefore, to be installed by the industries at additional costs. Variable frequency supply can be obtained from solid-state equipment, rotary converters i.e. motor generator gets.

- If speed control is to be achieved by changing frequency, the supply voltage should also simultaneously be changed. This is because if the supply frequency is reduced keeping the applied voltage constant, the flux is increased. If flux is increased, core-losses will reduce the efficiency on the other hand if frequency is increased, flux will decrease, thereby reducing the torque developed.

✶ It is important, therefore, that frequency changing device should change frequency and voltage simultaneously as a direct ratio. i.e. if frequency is increased, the supply voltage must also increase and if frequency is decreased the supply voltage must also decrease proptionately

✶ A fundamental. Block diagram showing scheme of speed control of an induction motor using thyristor is shown in fig. Three phase supply at the input is first converted into controlled DC. This DC is applied to inverter circuit, whose frequency is controlled by pulses from voltage to frequency converter units. A large smoothing reactor, L is in the circuit to filter the controlled DC.

2. What are the speed control methods available to control speed from rotor side? (UQ)

(Or)

Explain the speed of induction motor from rotor side?

The various methods available for speed control of induction motor from rotor side are:

i. Control of speed by changing rotor circuit resistance.
ii. Injected voltage method
iii. Cascade (or) concatenation operation.

I Control of speed by changing rotor circuit resistance.

✶ In slip-ring type motor, slip at a particular load can be changed by changing the rotor circuit resistance. The effect of change of rotor circuit resistance on slip when the motor is connected to a mechanical load is shown in fig.

✶ Torque –slip characteristics corresponding to rotor resistance R_1, R_2 and R_3 are shown respectively by the curve A and B and curve L shows the load characteristics. The motor runs at speed with slip S_1 with R_1 as its rotor circuit resistance.

✶ With rotor circuit resistance R_2 which is greater than R_1, the rotor slip increases from S_1, to S_2. Thus the speed of the rotor decreases. If we further change the rotor circuit resistance, the speed of the motor will further drop to a new value as indicated by the slip, S_3.

Thus, the speed of the motor can be varied by changing the rotor circuit resistance

✶ The disadvantage of this method of speed control is as follows.

a. Decreased efficiency due to power lost in the external rotor circuit resistance.
b. Rotor speed regulation when the motor is working with higher rotor circuit resistance.

ii. **Cascade or concatenation operation.(UQ)**

✶ In this method, two motors are used and are ordinarily mounted don the same shaft, so that both run at same speed (or else they may be geared together).

✶ The starter winding of the main motor A is corrected to the mains in the usual way, while that of the auxiliary motor B is fed from the rotor circuit of motor A. For satisfactory operation, the main motor A should be phase-wound i.e. of slip-ring type with stator to rotor winding ratio of 1:1 so that, in addition to concatenation, each motor may be run from supply mains separately.

There are at least three ways in which the combination may be run.

1. Main motor A may be run separately from the supply. In that case, the synchronous speed is

$$N_{Sa} = \frac{120\ f}{P_a}$$

Where, Pa = Number of stator poles of motor A.

2 Auxiliary motor B may be run separately from the mains (with motor A being disconnected). In that case, synchronous speed,

$$N_{Sb} = \frac{120\ f}{P_b}$$

Where P_b = Number of stator poles of motor B.

3. The combination may be connected in cumulative cascade i.e in such a way that the phase rotation of the stator fields of both motors is in the same direction. The synchronous speed of the cascaded set, in this case is,

$$N_{Sc} = \frac{120\ f}{(P_a + P_b)}$$

3. Explain the slip recovery scheme in induction motor? (AU-NOV-05, 09) (AU-MAY-07) (AU-APR-08) (AUC-NOV-09) (AUC-APR-11) (AUC-JAN-09) (AUC-MAY-10)

This system is mainly used for speed control of slip ring induction motor. The speed of slip ring induction motor can be controlled either by varying the stator voltage or by controlling the power flow in the rotor circuit.

It has been discussed earlier that the power delivered to the rotor across the air gap (P_{ag}) is equal to the mechanical power (Pm) delivered to the load and the rotor copper loss (P_{cu}).thus
Rotor power=mechanical loss rotor copper loss

$$P = P_{m+}P_{cu}$$

$$P_{ag} = \omega_s T$$

$$and P = \omega T$$

$$\omega = \omega_s(1-s)$$

$$P_{cu} = s\omega_s T$$

$$sP_{ag} = slippower$$

$$P_m = (1-s)P_{ag}$$

Where T=electromagnetic torque developed by the motor

ω_s = Synchronous angular velocity

The air gap flux of the machine is established by the stator supply and it remains practically constant if the stator impedance drops and supply voltage fluctuations are neglected. The rotor copper loss is proportional to slip. The speed control of a slip ring induction motor by connecting the external resistance in the rotor side. This method of speed control has been discussed earlier. The main draw back of the system is large slip power is dissipated in the resistance and this reduces the efficiency of the motor at low speeds.

This slip power can be recovered to the supply source can be used to supply an additional motor which is mechanically coupled to the main motor.this type of drive is known as a slip power recovery system and improves the overall efficiency of the system.

The speed of the slip ring induction motor can be controlled both in the sub-synchronous and super synchronous regions.this is called cascade connection the slip power is taken from the rotor and fed back to the supply at this condition the motor operates in the sub-synchronous region. Similarly if electric power is pumped to the rotor, the motor operates in the super-synchronous region. The torque equation is

$$T = K_1 \Phi I_2 \cos\Phi_2$$

$$= K_2 I_2$$

When the motor operates at a constant input voltage, the flux remains constant and the power factor $\cos\Phi_2$ of the rotor circuit may be assumed to be unity. The motor operates under constant torque operation, rotor current I_2 is also constant.

$$I_2 = \frac{E_2}{Z_2}$$

$$Z_2 = totalrotorimpedence$$

Where $E_2 = rotoremf$

Z_2 May be assumed constant and independent of frequency .hence ,at a particular speed and torque, the rotor emf E_2 can be assumed constant

In the cascade connection,

$$E_2 = K\Phi(\omega_s - \omega) + E_{ext}$$

$$E_{2-}E_{extr} = K\Phi(\omega_s - \omega)$$

$$where\omega = rotorspeed$$

$$E_{ext} = externalemffedtorotor$$

from this equation ,the motor speed is dependent on the external emf E_{ext}.if(E_2-E_{ext}) is positive ,power flows from the rotor to source of E_{ext} and the motor operates in sub-synchronous region

Rotor (slip power) main source (E_{ext})

If (E_2-E_{ext}) is negative, the power flows from source of E_{ext} to the rotor and the motor operates in the super-synchronous region

Main source rotor side E_{ext}

TYPES OF SLIP POWER RECOVERY SCHEME

The slip power recovery system can be classified two types

- Kramer system
- Scherbius system

These two systems can further be classified two methods

- Conventional method
- Static method

Conventional method

Kramer system

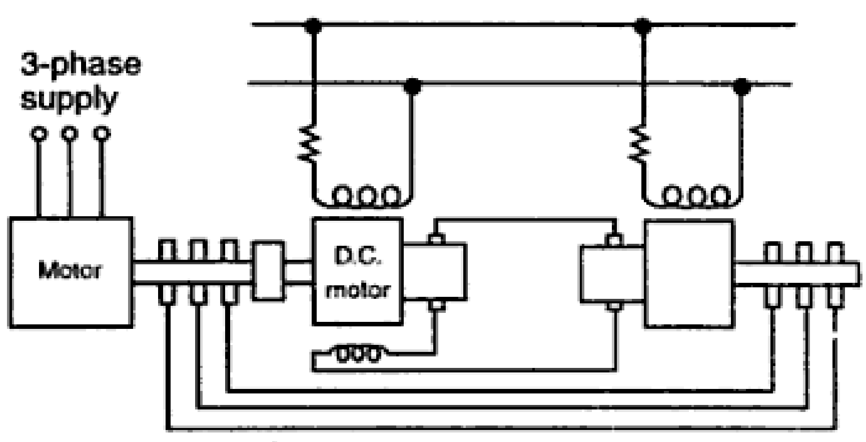
- ✶ The Kramer"s system of slip power recovery scheme, which is used, is case of large motors of 4000 KW (or) above.

Construction and working:

- ✶ It consists of a rotary converter C which converts the low-slip frequency a.c. power into D.C. power, which is used to drive a d.c shunt motor D, mechanically coupled to the main motor m.

- ✶ The main motor is coupled to the shaft of the d.c shunt motor D. The slip rings of m are connected to those of the rotary converter C. The d.c output of C is used to drive D. But C and D are excited from the D.C bus bars (or) from an exciter.

- ✶ There is a field regulator which governs the back emf E_b of D and hence the d.c potential at the commutator of C which further controls the slip ring voltage and therefore the speed of M.



✶ The main advantage is that any speed within working range can be obtained by this method. Another advantage is that if the rotary converter is over-excited, it will take a leading current which compensates for lagging current drawn by main motor m and hence improves the power factor of the system

Scherbius machine (or) Drive:

- This is another method of speed control system in which slip power is recovered.
- The polyphase winding of machine C is supplied with the low frequency output of machine M through a regulating transformer (R_T). The commutator motor C is a variable speed motor and its speed (and hence of M) is controlled by either varying the tappings on R_T or by adjusting the position of brushes on C.

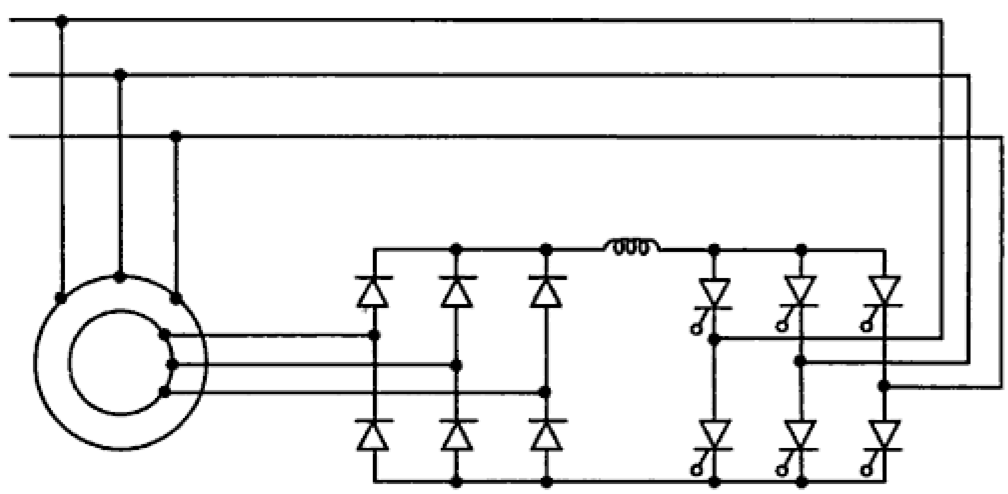
Static method

Scherbius machine (or) Drive:

- This is another method of speed control system in which slip power is recovered.
- The induction motor is started using three rheostats in the rotor circuit.
- The ac slip power is first rectified by the three-phase diode briodge,then turned back into ac power at line frequency by the thyristor inverter and finally returned to the supply network by means of a transformer ,which brings the rotor circuit voltage of the ac supply network. The speed of the induction motor is regulated by the controlling the firing angle of the inverter. the gate pulses are provided by the firing circuits ,synchronized with the supply voltage. Both the rectifier and the inverter are line-commutated by the alternating emfs appearing at the slip rings and supply network respectively. The average counter emf of the inverter may be considered as an injected emf opposing the rectified rotor voltage.
- The system is started by switching on first S1 and then S2 while switches S3 and S$ remain off. As soon as the motor attains a steady speed, the rectifier –inverter combination as well as the transformer is connected to the supply network switching S2 off and S3 and S4 on.

Krammer cascade

A slip ring induction motors rotor circuit feeds the slip power, rectified by means of a diode bridge, to the armature of a separately excited dc motor, which is mechanically coupled to the induction motor



The system is started by switching on S_1 first and then S_2, while switches S_3 and $S_4$are off. As soon as the motor attains steady speed, the dc motor is energized by switching S_2 off and S3 and S4 on. Speed control is achieved by varying the field current of the motor .an emf proportional to the back emf of the dc motor may be considered to be injected into the rotor circuit of the induction motor to cause variation in speed of the system.

4.Losses in Three Phase Induction Motor:

The various power losses in an induction motor can be classified as,

(i) Constant losses

(ii) Variable losses

(i) Constant losses:

These can be further classified as core losses and mechanical losses.

Core losses occur in stator core and rotor core. These are also called iron losses. These losses include eddy current losses and hysteresis losses.

The eddy current losses are minimized by using laminated construction while hysteresis losses are minimized by selecting high grade silicon steel as the material for stator and rotor.

The iron losses depend on frequency. The stator frequency is always supply frequency hence stator iron losses are dominant. As against this rotor circuit, the frequency is very very small which is slip times the supply frequency. Hence the rotor iron losses are very small hence generally neglected, in running condition.

The mechanical losses include frictional losses at the bearings and windage losses. The friction changes with speed but practically the drop [in speed is very small hence these losses are assumed to be the part of constant losses.

(ii) Variable losses:

This includes the copper losses in stator and rotor winding due to current flowing in the winding. As current changes as load changes, these losses are said to be variable losses.

Generally stator iron losses are combined with stator copper losses at a particular load condition.Rotor copper loss = 3 $I_{2r}^2 R_2$

ELECTRICAL DRIVES AND CONTROL

ANSWER ALL THE QUESTIONS (10*2=20)

1. What are the methods by which the power rating of the motor is determined?
2. Define heating time constant.
3. What do you understand by matching of speed torque characteristics of load and motor?
4. Why is the regenerative braking not possible in dc series motor?
5. Where three point and four point starters are recommended?
6. State the advantages and disadvantages of direct on line starting of an induction motor?
7. In what ratio will the starting line current and starting torque be reduced in autotransformer starter?
8. List the different methods of speed control applicable to 3 phase slip ring induction motor.
9. What do you mean by time ratio control in dc choppers?
10. Draw the circuit of stator controlled induction motor using AC voltage regulators.

PART B-(5*16=80 marks)

11.(i)what are the factors governing the selection of electric drives for any particular application? (8)

(ii)Show that for a short time rated machine with rated power Pr and short time rating Px of duration N.

$$\frac{P_x}{P_r} = \frac{1+\alpha}{1-e^{-\frac{N}{\tau}}} - \alpha$$

Where T-heating time constant.
α -ratio of costant losses to copper losses at full load.(8)

12. (a) (i) Explain how the speed torque characteristics of a dc shunt motor can be modified by the introduction of armature series resistance? (8)
(ii) How is the electric braking employed in dc shunt motor? (8)

(Or)

(b) (i) from the equivalent circuit ,derive the expression for torque. (8)
(ii) Draw the speed torque characteristics of an induction motor (8)

13. (a) (i) what is the necessity of starters for DC motors. (4)
(ii) Draw a neat sketch of a 3 point starter for a DC shunt motor and explain how the motor is protected against overloads and loss of supply voltage. (12)

(Or)

(b) (i)compare (1) stator resistance (2) Auto-transformer and (3) star delta methods of starting an induction motor with regard to line current, starting torque and field of applications. (10)
(ii)Is a single phase induction motor is self starting? Why? (6)

14. (a) (i) explain in detail the ward Leonard system for the speed control of DC motors (12)
(ii) State the advantages and disadvantages of the system (4)

(Or)

(b) (i) What is controlled rectifier? (4)

(ii) How is the speed control of the dc drive achieved using fully controlled rectifier? (12)

15. (a) What do you mean by slip power recovery ?Explain any method of slip power recovery scheme. (16)

(Or)

(b) Explain the methods of speed control of three phase induction motor using inverters. (16)

– ELECTRICAL DRIVES AND CONTROL

PART A – (10 X 2 = 20 marks)

1. What are types of electrical drives?
2. List the factors to be considered for the selection of electrical drives.
3. Draw speed-torque characteristics during regenerative braking of induction motor.
4. What are the types of electric braking of electric motor?
5. State the basic principles in DOL for 3-phase induction motor.
6. What is the basic principle in starting 3-phase induction motor using rotor resistance starter?
7. Draw the speed-torque characteristics of DC series motor by armature resistance method.
8. Draw the block diagram of phase controlled rectifier fed DC drives.
9. Draw the block diagram of conventional scherbius system.
10. What are the variable frequency AC drive applications?

PART B – (5 X 16 = 80 marks)

11. (a) Explain various classes of motor drives. (16)

Or

(b) Describe the selection of motor rating for continuous duty load. (16)

12. (a) Explain speed-torque characteristics of different types of load with graph. (16)

Or

(b) Explain with speed-torque characteristics of DC series motor under dynamic braking. (16)

13. (a) Describe with diagram working of 3-point starter for DC shunt motor. (16)

Or

(b) With diagram explain auto transformer starter for three phase induction motor. (16)

14. (a) With circuit describe DC motor Ward-Leonard control system. (16)

Or

(b) Explain first quadrant chopper control of separately excited motor for continuous conduction. 15. (a) Explain voltage/frequency control of 3-phase induction motor. (16)

Or

(b) Describe Kramer system slip power recovery system of 3-phase induction motor. (16)