UNIT 1

Introduction to Drive System

Drive System
Basic Elements of Drive System

A Drive System is a one, which consists of various elements combined together to move or rotate the mechanical load. The mechanical load is kept in motion with the help of a equipment known as Prime mover. The Prime mover is mechanically coupled with Mechanical load through Shaft and Coupling devices. Since the mechanical load is driven by prime mover it is also known as Driven load. Since the Prime mover is driving (rotating) the mechanical load it is also known as driving device.

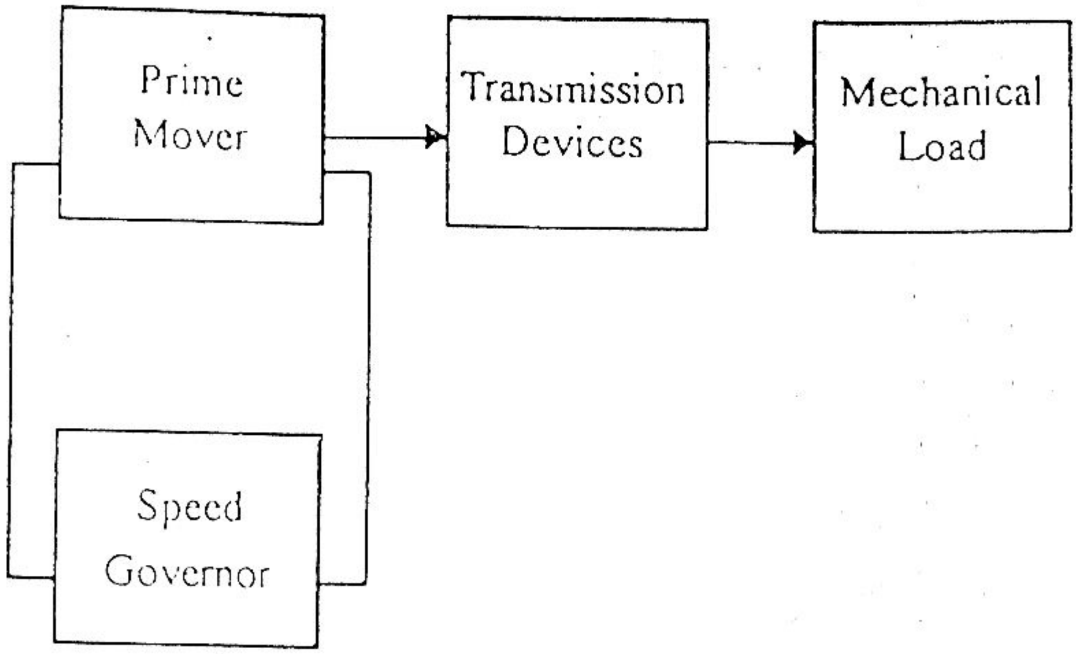

Fig :1 General Block Diagram Of The Drive System

Generally the prime mover may be an IC engine, a Steam Turbine or an electric motor. The prime mover and the mechanical load is connected by means of an Energy Transmission Device. The Energy Transmission Devices transfer energy from Prime mover to the Mechanical load. The example for Transmission equipment is Gear or Multistepped pulley and belt arrangement fitted in the shaft.

The mechanical load can also be directly and permanently connected to the prime mover by fixed coupling. The speed of the Prime mover is controlled using Speed Governors i.e., Throttle in case of IC Engines and Jet valve in case of Turbines. A combination of Prime mover, Speed Governor, Transmission device and Mechanical load is known as a Drive System.

Basic Elements of Electrical Drive System

An electric drive system consists of an Electric Motor, which is used to drive (rotate) the Mechanical load. Here the electric motor acts as a Prime mover and it is known as electric Drive motor. The Electric drive motor can be a DC motor or an AC motor. The drive system with Electric motor as Prime mover is known as Electric Drive System. If DC motor is used as a drive motor then the drive system is known as DC drives. If AC motor is used as a drive motor then drive system is known as AC drives.

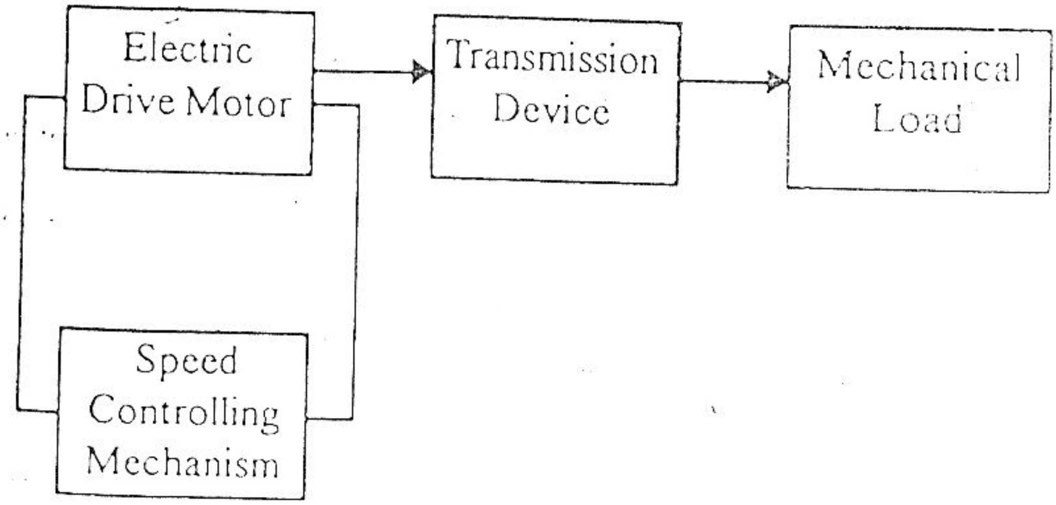

Fig : 2 General Block Diagram Of The Electric Drive System

The mechanical equipment (load) the is set into motion is also known as driven load. The devices that are used to interconnect Electric motor and Mechanical load is collectively known as Energy Transmission Devices. The mechanical load can be permanently or temporarily connected with the electric Drive Motor. For permanent connection Staft with fixed coupling is used. For temporary connection Gears and Multistepped Pulleys and Belt arrangement are used.

Transmission equipment is used to transmit the rotary motion of the electric drive motor to the Mechanical load. In some cases the transmission device is also used to convert the rotary motion of the drive motor into linear motion of mechanical load. If gears are used as transmission device then speed of the mechanical load can also be varied.

The speed of the electric drive motor is controlled by speed control mechanism. Based on the type of speed control mechanism used, the speed control of electric drive motor is classified into conventional speed control and solid – State speed control. In conventional speed control, manually electrical equipments such as Rheostat (variable resistor) is used to control the speed of the Electric drive motor. In solid State speed control, electronics or Semiconductor devices (solid State devices) are used to control the speed of the electric drive motor.

Advantages of Electric Drives

The drive system that uses electric motor as prime mover is known as Electric Drive. The electric drives are classified into DC drive and AC drive. A DC drive uses DC motor as drive motor. An AC drive uses AC motor as drive motor. The Electric drive has many advantages over the other types of drives. Nowadays, the electric drive replaced completely the other typers of drives such as Mechanical drive (IC Engine). The Electric drive is turned into the backbone of the modern era industrial applications. The main advantages of Electric drive over the other drives are as follows:

1. The electric drive provides almost noiseless operation.
2. The troubles involved in staring procedure of other drives are eliminated incase of electric drive
3. The electric drive never pollutes the working environment i.e no smoke and no leak.
4. The wear and tear associated with the other drives is completely eliminated. So the life of electrical drives is more.
5. The braking of electric drive is dome electro-dynamically i.e brake drum and belt is not needed which is noisy. So less maintenance is needed. Here the drive motor acts as a braking device.
6. The working characteristics of electric drive are smooth and can be easily modified.
7. The speed of the electric drive is controlled over wide range is possible i.e., from almost zero speed to speed above the rated speed. The electric drive is efficient during speed control.
8. The electric drive provides neat and flexible layout. It is compact and occupies less space
9. The electric drive can make use of wonderful advancements in the semiconductor industry and hence its speed control is accurate. Here The speed control circuitry is made of semiconductor (solid state) devices.
10. The electric drive is easily automated i.e., it can be controlled by microprocessor or by computer. So its efficiency and accuracy is further increased.

Types of electrical Drives

The drive system with Electric as prime mover is known as Electric drive. Depending on type of the motor used Electric drive system is classified into AC drives and DC drives. Generally the electric drive system consists of

Electric drive motor. Energy Transmitting device, Mechanical load and Speed control devices and circuitry.

Depending upon the mode of connection between Electric drive motor and Mechanical load, the number of drive motor used and the layout of drive, the electrical drive motor is classified as,

1. Group drive or Line shaft drive,
2. Individual drive, and
3. Multi-motor drive.

Group Drive or Line Shaft Drive

The Group drive consists of a single motor which drives or actuates several mechanical load by means of one or more line shafts supported on bearings. It is also called as ‘Line Shaft Drive’.

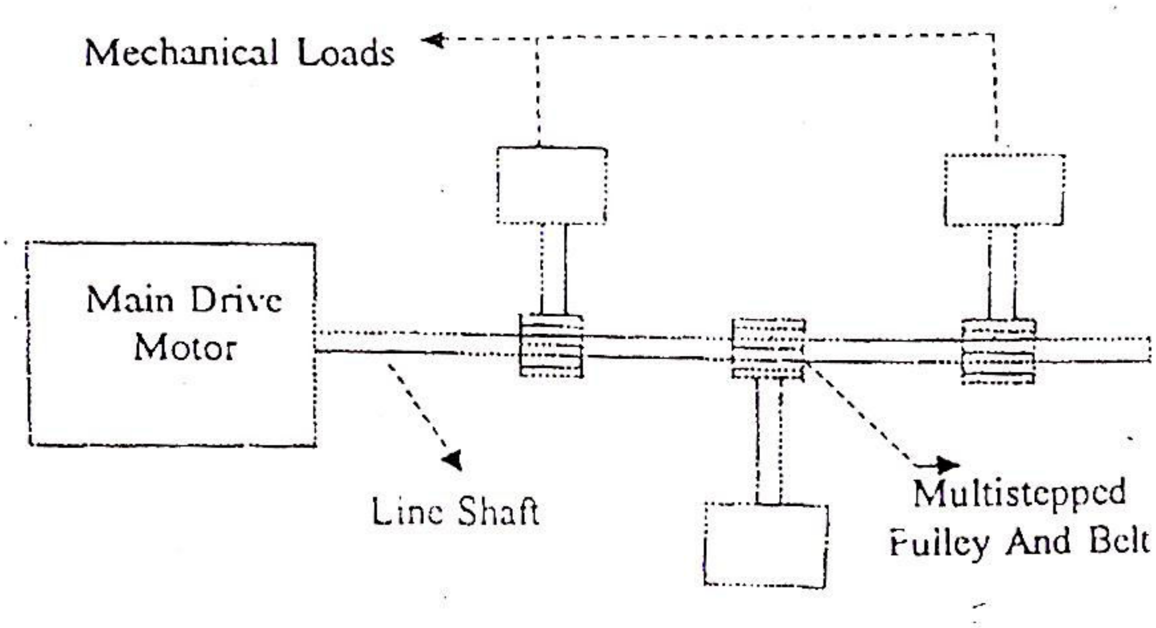

Fig 3. Block Diagram showing Layout of Group Drive

The line shaft of the group drive is connected with mechanical load through multi-stepped pulleys and belts. The size of the line shaft pulley and load shaft pulley determines the speed of the drives machines or loads.

Advantage of Group Drive

1. The group drive is the most economic even after taking into account the cost of line shaft, pulleys, belts and other installations. This is because the rating of the main motor is less than sum of the rating of the individual motors required to drive each load separately.

2. All the loads may not be working at the same time. So the HP of the group drive motor is less than the sum of HP of individual motor working separately. So the cost is reduced.

Disadvantages of Group Drive

Nowadays group drive is rarely used because of following factors.

1. If the fault occur in driving motor, then all the driven loads becomes idle.
2. Since line shaft is long and large and numbers of pulleys are connected, considerable power loss takes place in energy transmitting device. [Line shaft]
3. The level of noise produced at the work site is high
4. The driven loads have to be installed to suit the layout of line shaft.
5. Due to the line shaft arrangement and belts the drive do not have clean appearance.
6. Due to the belt and multistepped pulley arrangement, this drive is not safe.
7. An Individual load speed control is very difficult because of the usage of stepped pulleys and belt arrangement.

Applications of Group Drive

Group drive is used in processes where the stoppage of one operation needs the stoppage of sequence of operation, as in the case of 'Textile mills'

Individual Drive

The individual drive system consist of only one electric drive motor. This system activates various parts of single Mechanical equipment. Here each part of Mechanical equipment is considered as a separate load. The single electric drive motor is connected to all the individual mechanical load through suitable energy transmission devises

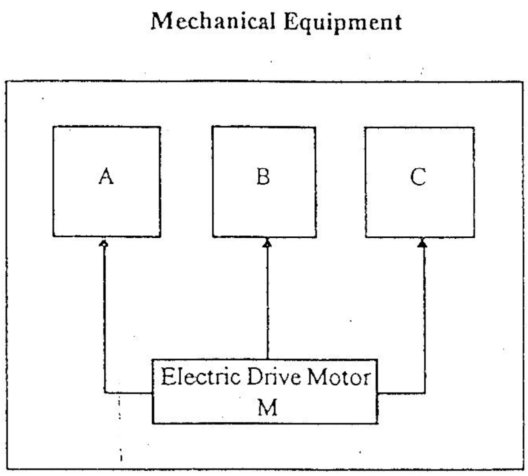

Fig 4. Block Diagram of Layout of Individual Drive

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In the above block diagram the mechanical equipment has single electric drive motor M and three individual load parts namely A, B and C. The individual load parts A,B and C are connected to the electric motor M. The individual load parts are kept at different position inside the mechanical equipment. Each load part is connected to the electric motor through different energy transmission devices.

The best example for individual drive is Lathe. Here the individual motor drive is used for activating various parts i.e., rotating the spindle with the tools, moving the feed (job) and drives cooling and lubricating pumps. Here all the operation mentioned is carried out by single electric motor. The energy transmission devices used here are gears and pulley etc.

Advantages of individual Drive

1. Individual drive has affective layout flexibility i.e. all the drive parts are placed inside single equipment.
2. Individual drive provides safe working condition, because no moving parts are visible.
3. The appearance of the Individual drive is clean and neat.

Disadvantages of Individual Drive

1. The Individual drives is less efficient because the single electric motor is connected with number of load parts through number of gears. So the energy loss is high.

2. The failure of electric motor stops the entire operations of the mechanical equipment.

Multi-Motor Drive

The Multi-motor drive has separate electric motor to drive the different load parts of single mechanical equipment. In some cases all the motors are used to drive only one load part of the equipment to fulfill different operation.

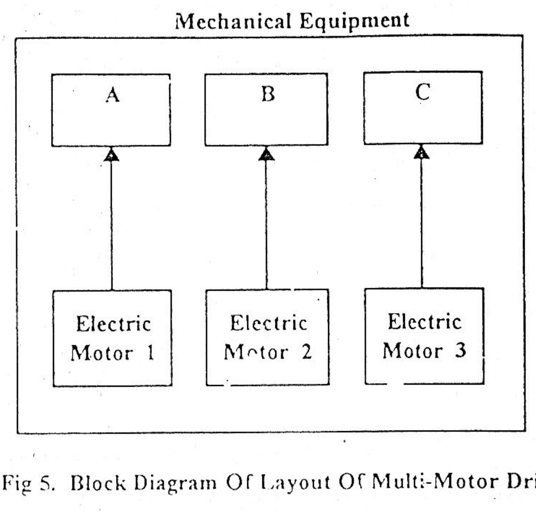


Fig 5. Block Diagram Of Layout Of Multi-Motor Drive

The block diagram shows Multi-motor drive system with three separate electric motors (1,2,3). Each motor drives separate load parts (A, B, C). In some cases there is only one load, each motor drives this load at different instant of time.

The best example of multi-motor drive is traveling cranes .The Traveling crane has only one load i.e., the movies arm with hook . There are three basic operations in Traveling crane, namely Hoisting (lowering and raising), Long-travel motion (stretching forward and backward of the arm) and Cross-travel motion (moving to the Right and Lift) These three operations are carried out by three separate electric motor i.e. one for Hoisting, one for cross-travel motion and one for long –travel motion.

Applications of Multi – Motor Drive

Multi –motor is mostly used in

1. Paper mills,
2. Rolling mills,
3. Rotary printing machines and
4. Metal working machines.

Advantages of Multi-Motor Drive

1. Multi-motor driver offers flexibility of layout of loads.
2. Stoppage of one motor do not affects the operation of other motors and loads.
3. The speed control is very easy.

Disadvantage of Multi-Motor Drive

1. Its only disadvantage is that it is costly in the initial stages
2. The usage of number of motors leads to confusion during control operation.

Factors Influencing choice Of Electrical Drives

There are certain factor that governs or influences, the selection choice electrical drives. They are:

1. Availability of Electrical Supply

The electric drive is a drive system with electrical motor as a prime mover. The selection of electrical drive is based on the availability of electrical supply. There are three-types electrical supplies, namely AC supply, DC supply, and Rectified DC supply. If AC supply is available. Then AC drive is selected motor. An AC drive consists of AC motor as a drive motor .If DC supply is available, then DC drive is selected .DC drive consist of DC motor as a drive motor . Hence nature of electrical supply available governs selection of electric drive.

2. **Nature of Operation characteristics of Electric drive motors**

The electric drive motor has different types of operating characteristics such as

1) Starting characteristics
2) Running characteristics
3) Speed control characteristics
4) Braking characteristics

For example the running characteristic of electric drive motor shows how the motor behaves where it is loaded .In some cases if the load is increased , the speed of the motor is drastically reduced .so such motors are not selected for constant speed applications.

3. **Economic Consideration**

The electrical motor is selected based on two economic considerations, namely

1. **Initial cost:**
   The initial cost is nothing out capital cost. This is the cost occurred during purchase and erection.
2. **Running cost :**
   This is the cost running the electric drive E.G. maintenance cost, fuel cost etc.

4. Type of the Drive system

Type of the Drive system available also governs the choice of electric motor. There are three types of drive system namely Group drive, Individual diver and Multi motor drive. Assume that at any particular location, different small loads are available. Since the loads are separate unit, it can be driven by single large motor (group drive) So here a DC motor or an AC motor is selected with huge HP rating.

5. Types of Load

The type of load available , also governs the selection of electric drive . Generally the loads are classified based on the Torque characteristics .Torque is the twisting force required to drive (rotate) the load ,based on the Torque characteristics loads are classified as follows.

1. Load requiring constant Torque with speed
2. Load requiring increasing Torque with speed
3. Load requiring high starting Torque (high inertia load)

Assume that load cannot with high inertia available .This high inertia loads cannot be accelerated or deaccelerated quickly .They require high starting Torque . Therefore motor with high starting torque such as DC series or 3 (There Phase) Slip ring induction motor is selected .Thus type of load influence the choice of electric motor.

6. Mechanical considerations

i) Type of enclosure
ii) Type of bearings
iii) Type of Transmission devices

7. Environmental Considerations

I. Noise pollution
II. Environmental Pollution

8. Load – With standing Capability of motors

The size and rating required for the drive motor influence the selection of the electric drive motor. The size of the motor describes load-withstanding capability .when the motor is loaded , the line current drawn by the motor increases. As a result losses increases and more heat is developed .If the heat is hot dissipated then insulation in the motor fails leading to complete breakdown of the motor. Here duty cycle of the load and the Torque requirement are important factors in deciding size and rating of the motor.

Heating and Cooling Curves of a drive motor

(i) Heating curve or Heating time curve

The heating curve of electric motor is otherwise known temperature rise curve. The electric motor when loaded, draws current. As a result the power losses increases .All the power looser are converted into heating of the motor. The part of the temperature is dissipated to the surrounding. The heat dissipation takes place only when the ambient temperature is less than the temperature of the motor. The heat curve of the motor is drawn with help of equation showing the relationship between initial temperature and the temperature. The temperature rise equation can be derived as following

Let us make the following assumptions,

W = losses taking place in motor in watt,
S = Specific that heat in watt-seconds/kg/ ^{o}C,
G = Mass of active parts of the motor in kg
A = Area of cooling surface in m^2,
θ = Temperature rises above ambient temperature in ^{o}C
θ_f = Final temperature rise in ^{o}C
λ = Rate of heat dissipation in Watts / m2 / °C,
dt = Small rise in time,
dθ = Small rise in temperature

It clear from the above discussion

$\boxed{\textbf{Heat generated =Heat stored + Heat dissipated}}$ $\longrightarrow$ (1)

The heat generated in the motor is directly proportional to total (W) taking place in motor during time interval dt.

Total losses during time dt = W dt

The part of generated heat is stored . The heat storage depends upon mass of the active elements in motor (G) and specific heat (s) and the temperature rise ($d\theta$)

Heat stored in motoò = G.S. $d\theta$

The part of hear generated is dissipated to the surrounding. The heat dissipation depends on Area of cooling surface (A), Rate of heat dissipation (λ), temperature rise above ambient temperature and time during temperature θ rises dt.

Heat dissipated in motor = $A..\lambda.\theta.dt$

Equation (1) becomes,

$$Wdt = G.S.d\theta + A.\lambda.\theta.\ dt \qquad (2)$$

(or) $(W - A.\lambda\ \theta)\ dt = G.S.d\theta$

$$\frac{dt}{GS} = \frac{d\theta}{W-A.\lambda.\theta}$$

(or) Dividing denominators of both sides by $A\lambda$.

$$\frac{dt}{\frac{GS}{A\lambda}} = \frac{d\theta}{\frac{W}{A\lambda} - \theta} \longrightarrow \qquad (3)$$

When the motor reaches its final temperature. (f), the heat cannot be stored further. So all the heat generated is dissipated.

$$Wdt = A.\lambda.\theta.\ dt$$

(or) $\theta_f = \dfrac{W}{A\lambda}$

Substituting θ_f for $\dfrac{W}{A\lambda}$ In equation (3),

$$\frac{dt}{\frac{GS}{A\lambda}} = \frac{\frac{W}{A\lambda}}{\theta_f - \theta}$$

Integrating the above equation, we get,

$$\int \frac{dt}{\frac{GS}{A\lambda}} = \int \frac{d\theta}{\theta_f - \theta}$$

(or) $\dfrac{A\lambda}{GS} \displaystyle\int dt = \int \dfrac{d\theta}{\theta_f - \theta}$

$$\frac{A\lambda}{GS}\ t = -\log_e(\theta\ -\ \theta) + C \longrightarrow \quad (4)$$

Where C is the integration constant and its value is obtained as below
At time, t = 0; $\theta = \theta_1$
Substituting the above values in equation (4), we get

$$0 = -\log_e (\theta_f - \theta_1) + C$$
$$\therefore C = -\log c\ (\theta_f - \theta_1)$$

Substituting the value of C in equation (4), we get

$$\frac{A\lambda}{GS}\ t = -\log_e(\theta_f\ -\ \theta_1) + \log_e(\theta_f\ -\ \theta_1)$$
$$= \log_e(\theta_f\ -\ \theta_1) + \log_e(\theta_f\ -\ \theta_1)$$
$$= \log_e \left[\frac{(\theta_f\ -\ \theta_1)}{(\theta_f\ -\ \theta_1)}\right]$$

$$\therefore e^{\frac{A\lambda}{GS}} = \log \frac{(\theta_f\ -\ \theta_1)}{(\theta_f\ -\ \theta_1)}$$

$$\theta_f\ -\ \theta = \frac{\theta_f\ -\ \theta_1}{e^{\frac{A\lambda}{GS}}}$$

$$\theta_f\ -\ \theta = (\theta_f\ -\ \theta_1)\ .\ e^{\frac{-A\lambda\, t}{GS}}$$

$$\theta\ -\ \theta_f = (\theta_f\ -\ \theta_1)\ .\ e^{\frac{-A\lambda\, t}{GS}}$$

The constant $\frac{A\lambda}{GS}$ is known as heating time constant and is denoted by T.

$$\theta\ -\ \theta_f = (\theta_f\ -\ \theta_1)\ .\ e^{\overline{\quad}}$$

If the motor is started from ambient temperature then

$\theta_1 = 0$, we get
$$\theta = \theta_f\ -\ \theta_f\ .\ e^{\frac{-t}{T}}$$

$$\boxed{\theta = \theta_f\ (1 - e^{\frac{-t}{T}}}$$

The above equation is known as heating equation, which shows the relationship between the temperature rise () and time (t) time with respect to final temperature rise (1).

Heating time constant (T)

The definition for heating time constant is obtained from heating or temperature rise equation by putting t =T.

i.e, $\theta = \theta_f (1 - e^{-T/\zeta})$

$\theta = \theta_f (1 - 0.367)$

$$\boxed{\theta = 0.633\ \theta f} \longrightarrow \quad (6)$$

From the above equation, Heating time constant is defined as time required to heat the motor to 63.3% of final temperature rise.

To draw the Heating curve

The heating or temperature rise equation is used to get heating curve. By putting different value of t such as T, 2T, 3T etc., in equation (5) we get different values of in terms of f. The typical heating curve is shown below.

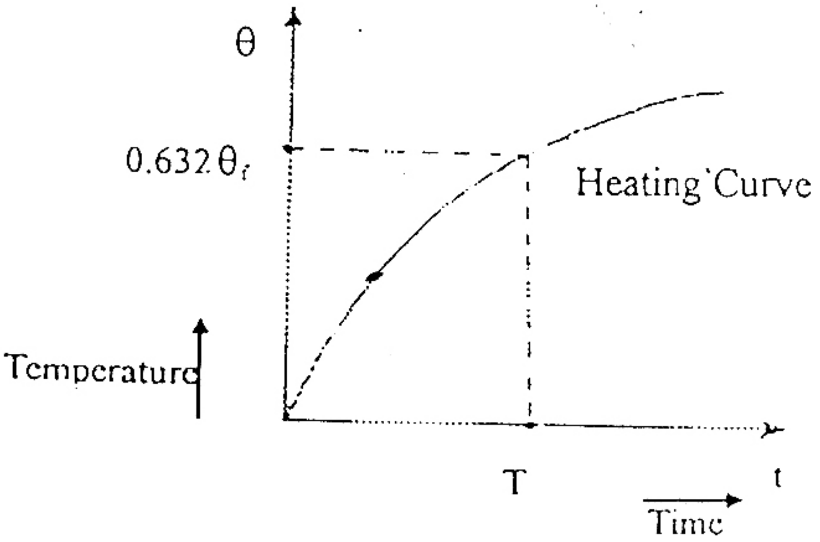


Fig : 6 Typical Heating Curve of a Drive Motor

(ii) Cooling Curve or Cooling time curve

The motor cools down when rate of heat dissipation is more than the rate of heat generation. This condition prevails when effective cooling system is available or load is removed from the motor.

During given time interval total heat generated and heat stored is equal to heat dissipated

$Wdt + GSd\theta = A\lambda\ \theta dt$

Here denotes rate of heat dissipation during cooling.

$$GSd\theta = A\lambda\, \theta dt - Wdt$$

(or) $$GSd\theta = (A\lambda\, \theta - W)\, dt$$

(or) $$GSd\theta = A\lambda\, (\theta - \frac{W}{A\lambda})\, dt \longrightarrow (1)$$

In the above equation the left hand side is negative because it has d. The negative sign denotes temperature fall (cooling)

$$GSd\theta = A\lambda\, (\theta - \frac{W}{A\lambda})\, dt$$

(or) $$\frac{d\theta}{(\theta - \frac{W}{A\lambda})} = - \frac{A\lambda}{GS}\, dt$$

Integrating the above equation on both sides we get.

$$\int \frac{d\theta}{(\theta - \frac{W}{A\lambda})} = - \frac{A\lambda}{GS} \int dt$$

If θ_f is the final temperature fall, then at this temperature whatever heat generated is dissipated.

i.e Heat generated = Heat dissipated

$$Wdt = A' f' dt$$

$$\theta'_f = -\frac{W}{A\lambda'}$$

Substituting $\frac{W}{A\lambda'} = \theta'_f$ in equation (2) we get

$$\int \frac{d\theta}{\theta - \theta f} = \frac{A\lambda}{GS} \int dt$$

$$\log_e (\theta - \theta f) = \frac{A\lambda}{GS} t + C \longrightarrow \quad (3)$$

Where C is the integration constant and its value is obtained as below.

At $t = 0$, $\theta = \theta_o$

The equation (3) after substituting above values becomes

$C = \log_e (\theta - \theta_f)$

Substituting the value of C in equation (3); we get,

$$\log_e(\theta - \theta_f) = \frac{A\lambda}{GS} t + \log_e(\theta_o - \theta_1)$$

$$\log_e(\theta - \theta_f) - \log_e(\theta_o - \theta_1) = \frac{A\lambda}{GS} t$$

$$= \frac{(\theta - \theta f)}{(\theta_o - \theta f)} = e^{\frac{-A\lambda t}{GS}}$$

$\frac{GS}{A\lambda}$ is known as cooling time constant and it is denoted by T'

Putting $\frac{GS}{A\lambda}$ = T' in above equation we get,

$$= \frac{(\theta - \theta f)}{(\theta_o - \theta f)} = e^{\frac{-A\lambda t}{GS}}$$

$$(\theta - \theta f) = (\theta_o - \theta f)\, e^{\frac{-t}{T}} \longrightarrow \quad (4)$$

Aλ During cooling the final temperature 1 = . Therefore equation (4) becomes,

(4)

$$\boxed{(\theta = \theta_o \,.\, e^{\frac{-t}{T}}} \longrightarrow$$

The above equation is known as Cooling equation or temperature drop/fall equation of the motor

Cooling Time constant T

The cooling time constant can be defined putting t = T in Cooling equation (5)

i.e., $\theta = \theta_o .e$

$\theta = \theta_o .e$

$$\boxed{\theta = 0.368\ \theta_o}$$

From the above equation, The cooling time constant is defined as time required to cool the machine to 36.8% of initial temperature rise above the ambient temperature.

The cooling curve can be obtained by putting various values for t, i.e., T, 2T etc., in equation (5) and we get the following curve.

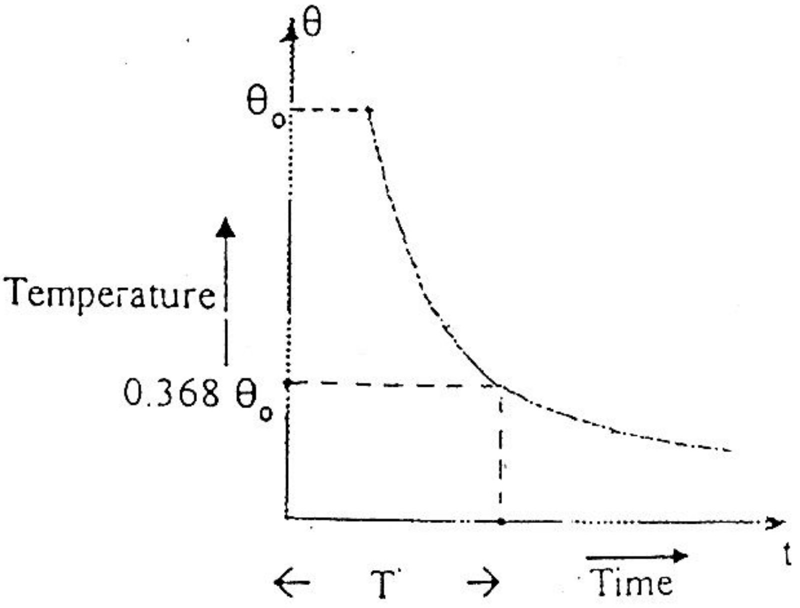


Fig : 7 Typical Cooling Curve of a Drive Motor

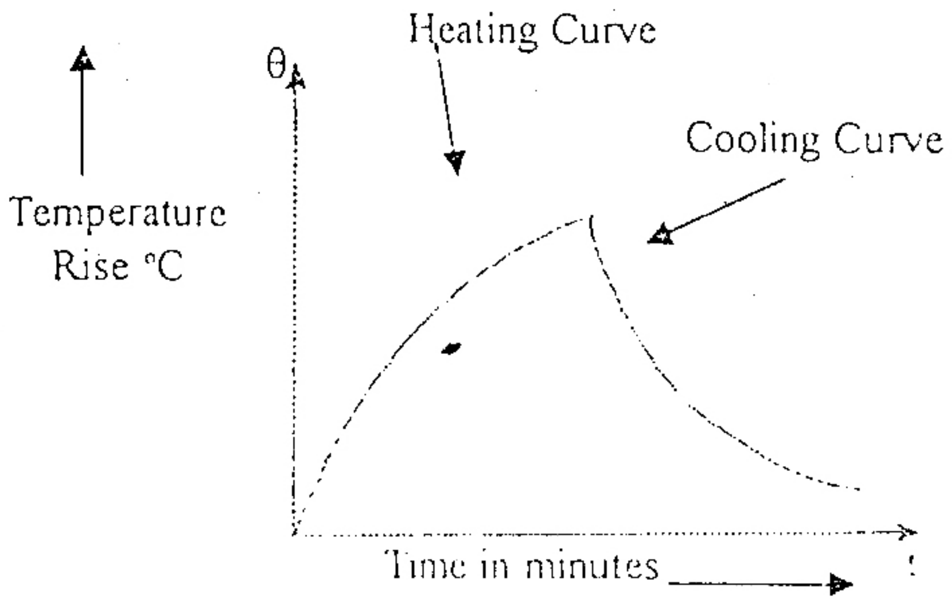


Fig 8 : Heating and Cooling Curve of a Drive Motor

From the above curve it is observed that both heating and cooling

curves shows 'Exponential rise and fall' in temperature.

1. A motor has heating time constant of 45minutes. When motor runs continuously on full load, its final temperature rise is 80 °C
   a) What the temperature rise after 1 hour, if the motor runs continuously on full load?
   b) If the temperature rise on 1 hr rating is 80 °C find the maximum steady stare temperature at this rating

Solution

Given data

T = 45minuts

θf = 80 °C

t =1 hr = 60 minutes

a) To find temperature rise after 1hr i.e.o

w.k.t temperature = $\theta = \theta f\,(1 - e^{-t/T})$

$= 80\,(1 - e^{-60/45})$

$\theta = 80\,(1 - e^{-1.333})$

$\theta = 58.9\,^{o}C$

b) To find maximum steady state teperature

It is given that Temperature rise on 1 hr rating, θ□= 80 °

$= \theta = \theta f\,(1 - e^{-t/T})$

$80 = \theta f\,(1 - e^{-60/45})$

$$\theta_f = \frac{80}{(1 - e^{-1.333})}$$

$$\boxed{\theta_f = 108.64\ C}$$

Loading Conditions and Class of Duty

Loading Conditions

The loading condition is nothing but Torque requirement that is to be supplied by electric motor under load. When motor is loaded two types of operation is possible

i)Steady – state operation

ii)Transient – state operation

i) Steady – State Operation

When the motor is started, it produces a torque in one direction which is known as Motor Torque (T Motor). Steady state operation of the motor refers to, motor running with constant load. The load.

Produce Torque known as Load Torque (T1), Which acts in the direction opposite to that of Motor Torque (Tmotor). So motor has to produces torque that should be greater than Load Torque. The energy transmission device produces a torque due to friction and is known as Frictional Torque (TF). This Frictional Torque is also acts in the direction opposite to that of Motor Torque. So Motor Torque has supply both the Load Torque and Frictional Torque.

$$\boxed{T_{motor} = T_L + T_F}$$

ii. Transient conditions

The Transient condition refers to the state, when the motor is running at constant load and suddenly additional load is applied. Here the motor is running in Steady state condition and the load is applied suddenly. The suddenly applied load produces the torque in direction opposite to that of Motor torque and is known as Inertia torque. This Inertia torque is also known as Dynamic torque (TD). Now the motor has to over come inertia Torque of suddenly applied load. But the motor is already supplying two torque, namely Load torque (TL) and Frictional torque (TF). Therefore motor torque should now supply three torques. I.e.

$$\boxed{T_{motor} = T_L + T_F + T_D}$$

Pull-out torque

Pull-out torque is the maximum torque that can be supplied by the motor. If the torque exceeds pull-out torque, the motor comes to standstill.

The knowledge about the load torque is essential because it determines size and rating of the drive motor

1.5.2. Classes of Duty

The Size and rating of a motor is selected from the viewpoint of heat development, when the motor is loaded. The temperature inside the motor rises due to the losses taking place in it. The losses are mainly due to high current taken by the motor, when it is loaded. Temperature rise varies directly with the square of current (Losses I2 and T I2). If the heat is not dissipated properly, then temperature rises to the extreme limit. As a result, motor get damaged.

The heating of the motor depends upon load conditions or duty to which it is subjected. Here the Duty means the application of load with respect to time. If the load is applied continuously without any gap, then it is known as Continuous Duty. In this case, motor heats up and never cools down. From the above discussion it is clear that load applied to motor with respect to time is known as Duty. The duty can be classified under three broad categories, namely

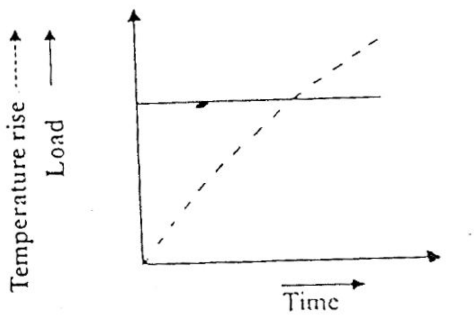
a. **Continuous duty**
   (i) Continuous Duty With Constant Load
   (ii) Continuous Duty With Short Time Load
   (iii) Continuous Duty With Intermittent Load
b. Short time duty
c. Intermittent duty

(a) Continuous duty

The load, which is applied continuously without any break is known as Continuous duty. I.e the drive motor always run with some load. It is classified into three types as follows

(i) Continuous Duty With Constant Load
(ii) Continuous Duty With Short Time Load
(iii) Continuous Duty With Intermittent Load

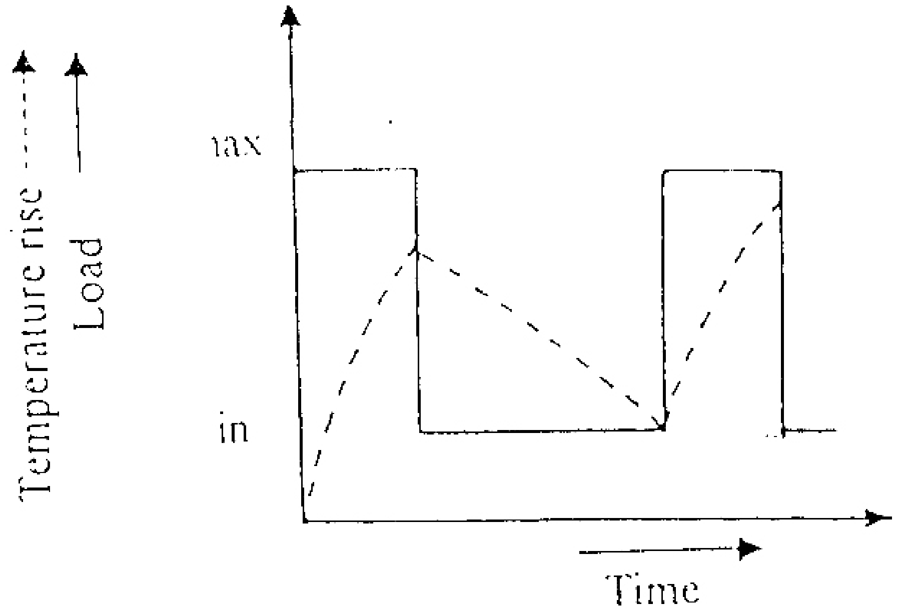
(i) Continuous Duty With Constant Load



The load that is continuous without any break and of constant magnitude is known as Continuous Duty With Constant Load. Here the motor is always loaded with constant load. Due to continuous duty temperature rises exponentially in the drive motor as the time progresses. The duty (Load) is shown as straight line and the temperature rise is shown as broken line in the fig 9.

Since temperature rises continuously, selection of rating of the motor is very important. The rating of the motor selected for Continuous duty load is known as Continuous rating. The continuous rating here means, the temperature rise is inside the maximum limit, when the motor is continuously loaded. Since temperature rises exponentially, small load is normally selected for continuous rating. The example of this kind of load is fan type loads.

(ii) Continuous Duty With Short Time Load



The load that is continuous and fluctuates between two levels (maximum and minimum) with the maximum level existing only for short duration is known as Continuous Duty With Short time Load. Here the time interval between the occurrence of two maximum levels is large. Even thought the load fluctuates, the motor is constantly loaded with the minimum level load. The temperature rises when the load is at maximum level and falls when at minimum level. The temperature never falls to zero level (ambient temperature) because the motor is always loaded with minimum level of load. The best examples of this kind of load is Metal cutting lathes and conveyors.

(iii) Continuous Duty With Intermittent Load

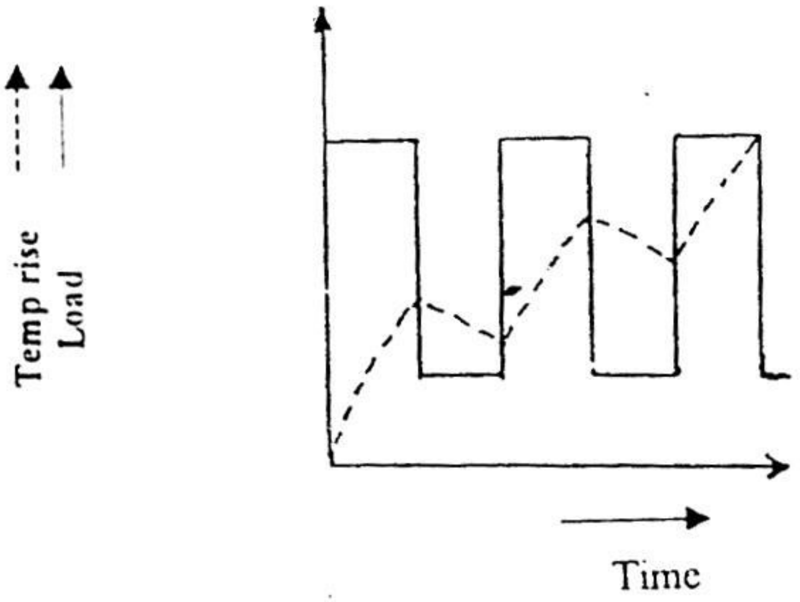


Fig.11.

The load that is continuous and fluctuates between two levels (maximum and minimum) with the maximum level occurring intermittently is known as Continuous Duty With Intermittent Load. Her time interval between the occurrence two maximum levels is small. Even though the load fluctuates intermittently, the motor is continuously loaded with the minimum level load.. the temperature rises when the load is at maximum level and falls when at minimum level. The temperature never falls to zero level (ambient temperature) because the motor is always loaded with minimum level of load. The temperature rises steadily because of intermittent nature of the load. The bet examples of kind o load are Metal cutting lathes and Conveyors.

(b) Short time duty

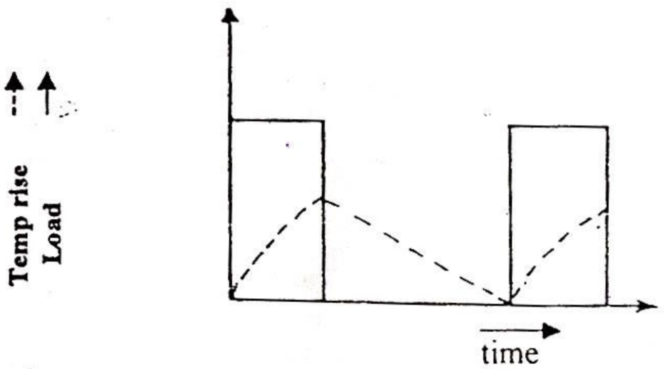


Fig.12

The load that exists only for the short duration of time is known as short Time Load. Between two short time loads the motor is not loaded and it is switched off. The time interval between two short time load is known as Off-

Load Period. When the motor is subjected to short time load, the temperature rises and during the off load period the motor cool completely and the temperature falls to the ambient temperature (room or initial temperature). The best examples of this kind of load are Weirs, Household appliances, Automatic lock gates and bridges.

(c) Intermittent duty

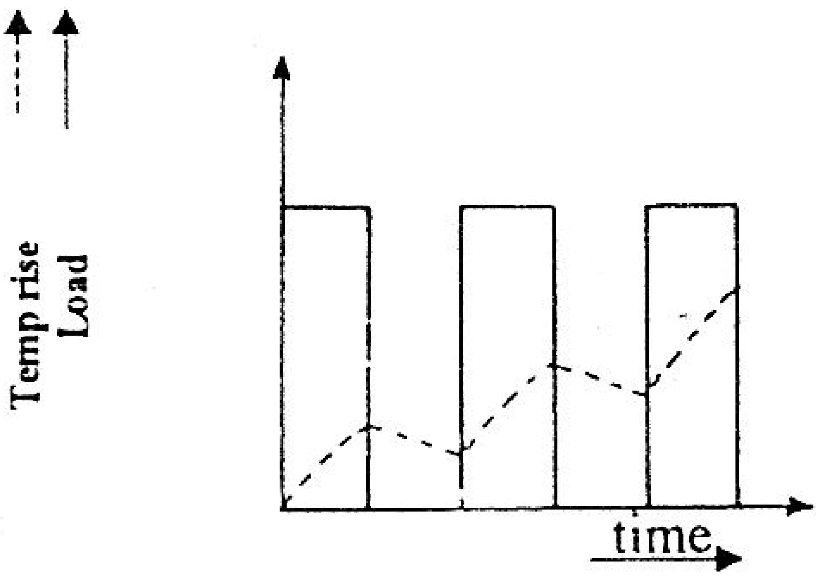


Fig.13.

The load that occurs intermittently with very small off-load period is known as Intermittent Duty. The time interval between two load is known as Off-Load Period. Between two load occurrences the motor can be switched off. When the motor is subjected to intermittent load, the temperature rises during the on-load period and the temperature falls during off-load period. But the motor is not completely cooled to ambient temperature. This is because the off-load period is very small and not sufficient to cool to ambient temperature. The best examples of this kind of load are Weirs, Household appliances, Automatic lock gates and bridges.

Selection of power Rating for Drive Motor

Determination of power Rating for Continuous and Constant Torque Load

In order to find the size of the electric motor, the determination of power rating is necessary. For constant torque loads size of motor required can be calculated out by formulae given below.

(i) In case of rotary motion,

$$\text{Size or power rating} = P = \frac{TN}{716\eta} \text{ HP}$$

KW (For most of the application)

Where, T – Load torque in Kg – m.

N – Speed in rpm

-Product of the efficiency of driven equipment and transmitting device.

(ii) In case of linear motion, size of the motor required.

$$\text{Size or power rating} = P = \frac{F\upsilon}{75\eta} \text{ HP (for lifts or elevators)}$$

Where, F = force caused by the load in Kg
N = Velocity of the load in m/sec
η= Efficiency

For power rating for various devices

i) For hoists, lift or elevators

$$\text{Size or rating} = P = \frac{F\upsilon}{102\eta} \text{ KW}$$

ii) **When counter weight, which balance weight of cage is used** then one half of the useful load will be always present then,

$$\text{Size or rating} = P = \frac{F\upsilon}{2 \times 102\eta} \text{ KW}$$

iii) In case of pump (centrifugal & reciprocating pump)

$$\text{Size or rating} = P = \frac{\rho\, HQ}{102\eta} \text{ KW}$$

Where, ρ - Density of the liquid pumped, kg/m3
H – Gross head (static head & Friction head) m
Q – Delivery/discharge of pump, m3
- Efficiency.

iv) In case of fan motor

$$\text{Size or rating} = P = \frac{Qh}{102\eta} \text{ KW}$$

Where, Q – Volume of air or any other gas in m3/sec
H – Pressure in kg/m2 or mm of water
η - Efficiency

v) Motor used in metal shearing lathe

$$\text{Size or rating} = P = \frac{F\upsilon}{2\, ø\, 102\eta} \text{ KW}$$

Where, Æ – Shearing force, kg
υ - Velocity of shearing , m/min
η - Mechanical efficiency of lathe

1.6.2 Determination of Power Rating For Intermittent and Short Time Loads

For Short time and intermittent load, the size of the motor can be found out by two methods

i) Root mean Torque Method
ii) Root mean Power Method

1.6.2 (a) Root Torque Method

The motor current is proportional to the torque and heating is proportional to square of current. Therefore heating is proportional to the square of torque. In case of torque does not remain constant as shown in diagram below.

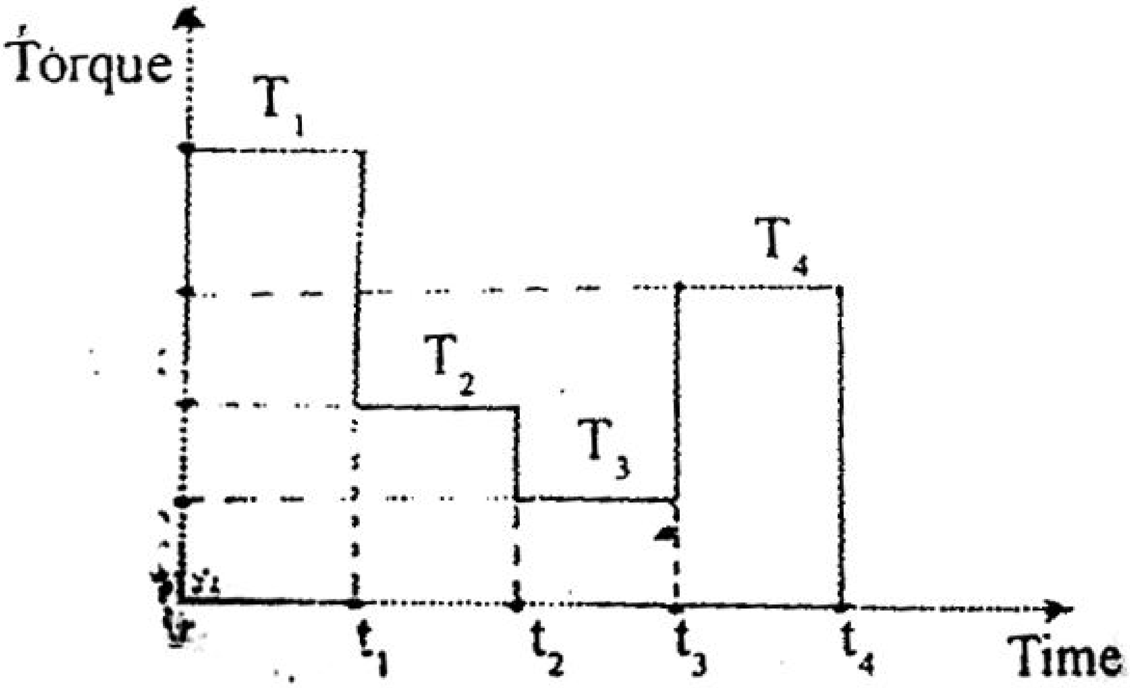


Fig.14

Heating effect is equal to that of equivalent torque (Teq) whose magnitude is equal to root mean square value of load torque at different times i.e.

$$\text{Equivalent Torque, } T_{eq} = \sqrt{\frac{T_1^2 \times t_1 + T_2^2 \times t_2 + T_3^2 \times t_3 + T_4^2 \times t_4}{t_1 + t_2 + t_3 + t_4}}$$

If we substitute this torque T_{eq} in the rating or size equation, we can determine power required by short time and intermittent load.

i.e $$P = \frac{TN}{716\eta} \text{ HP} \quad \text{becomes}$$

$$P = \frac{T_{eq}N}{716\eta} \text{ HP} \quad \text{(or)}$$

$$P = \frac{T_{eq}N}{716\eta} \text{ KW}$$

1.6.2. (b) Root Mean power

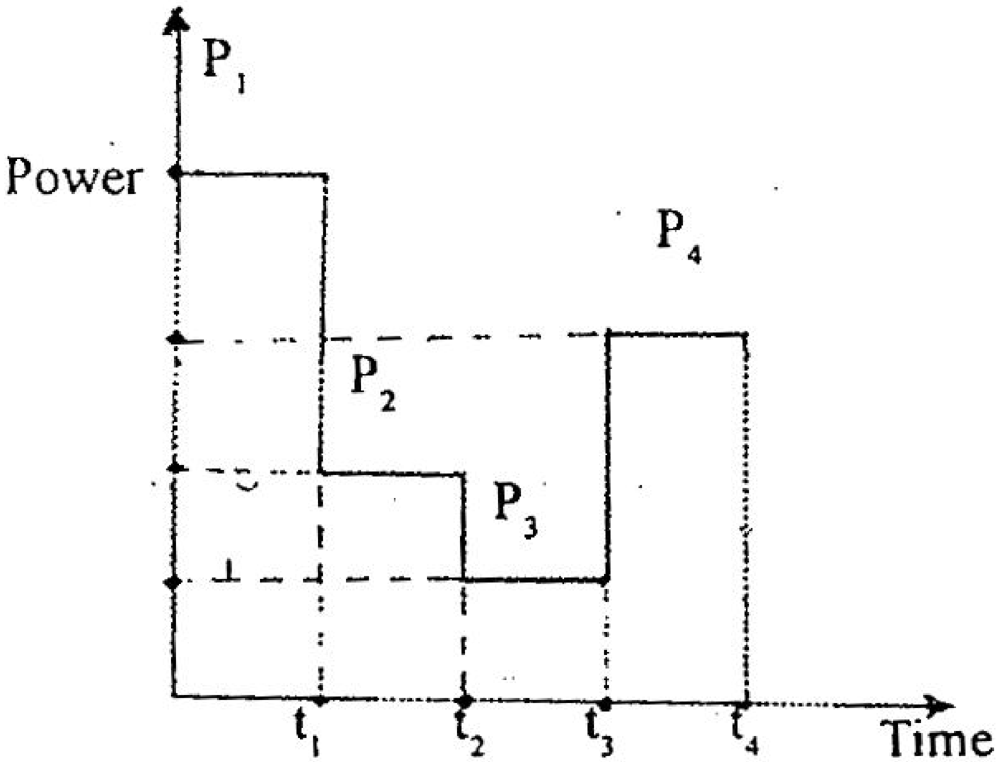


Fig.15

This method of determining the rating is applicable to motor running at constant or (intermittent load) slightly variable speed Eg.synchronous, induction motors. For constant power load equivalent power is obtained by squaring and taking mean. For variable power load, equivalent, power is obtained from taking mean of integrate squared power. I.e.

$$P_{eq} = \sqrt{\frac{P_1^2 \times t_1 + P_2^2 \times t_2 + P_3^2 \times t_3 + P_4^2 \times t_4}{t_1 + t_2 + t_3 + t_4}}$$

2. A motor driving colliery-winding equipment has to deliver a load, having the following characteristic:

a) Rising uniformly from zero to maximum of 2000KW in 20 sec, driving accelerating period.
b) 1000KW for 40 sec, during the full speed period.
c) During deceleration period of 10sec, when regenerative braking is taking place, the power returned to the supply falls from an intial value of 330KW to zero.

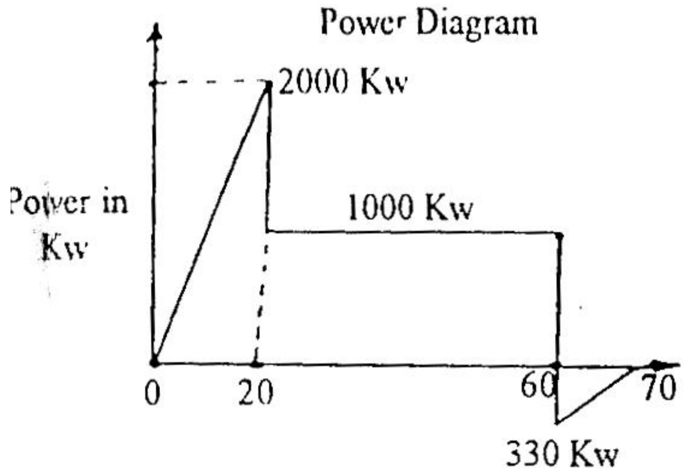
The internal of decking the next load cycle is 20 sec. What 'size' of continuously rated motor would be suitable? State assumption made.

Solution:

Given P_1 = 0 –2000KW (variable in 20 secs)
P_2 = 1000KW (constant for 40 secs)
P_3 = 330KW-0 (reverse variable in 10 secs)

Decking intenal (20 secs)

$$P_{eq} = \sqrt{\frac{\frac{(2000)^2 \times 20}{3} + (1000) \times 40 + \frac{(330)^2 \times 10}{3}}{20 + 40 + 10 + 20}}$$



P_{eq} = 863KW

3. Select the motor for driving the equipment, which has following torque at various load.

a) For the first 10 secs the torque is constant and equal to 41 Kg-m.
b) For the next 30 secs the torque drops linearly with time from 38kg-m to 17kg-m
c) For the last 46secs the torque is constant and is equal to 8kg-m.

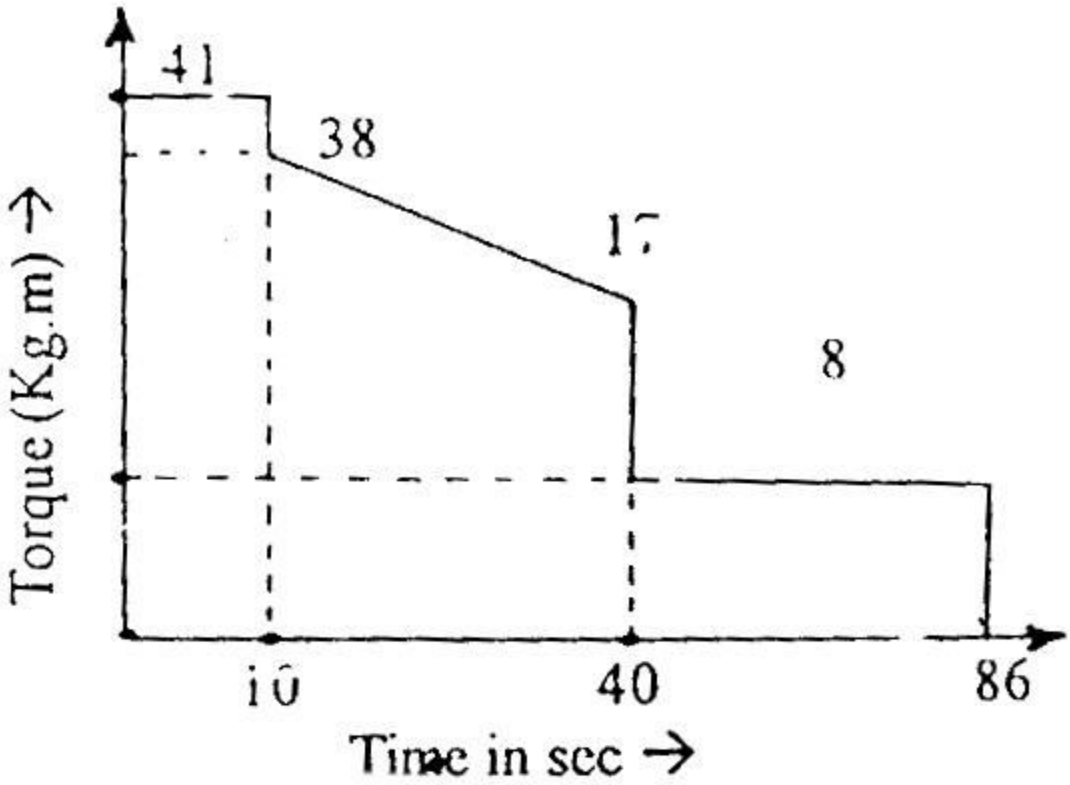
Solution:

Given :

T_1 = 40 Kg-m (for 10 sec)
T_2 = 38 to 17 Kg-m (for 30 sec)
T_3 = 8 Kg-m (for 46 sec)

$$P_{eq} = \sqrt{\frac{(41^2 \times 10) + \frac{38^2 + (38 \times 17) + 17^2}{3} + 8^2 \times 46}{10 + 30 + 46}}$$

Teq = 22.5 kg-m



From the above torque, if speed is given then power can be calculated.

4.A motor has following duty cysle,

i) Load rising from 200 to 400 h.p - 4 minutes
ii) Uniform load 300 h.p - 2 minutes
iii) Regenerative braking – h.p returned to supply from 50 – zero h.p - 1 minute
iv) Remains idle for - 1 minute

Estimate suitable h.p rating for motor i.e. find out power rating.

Solution:

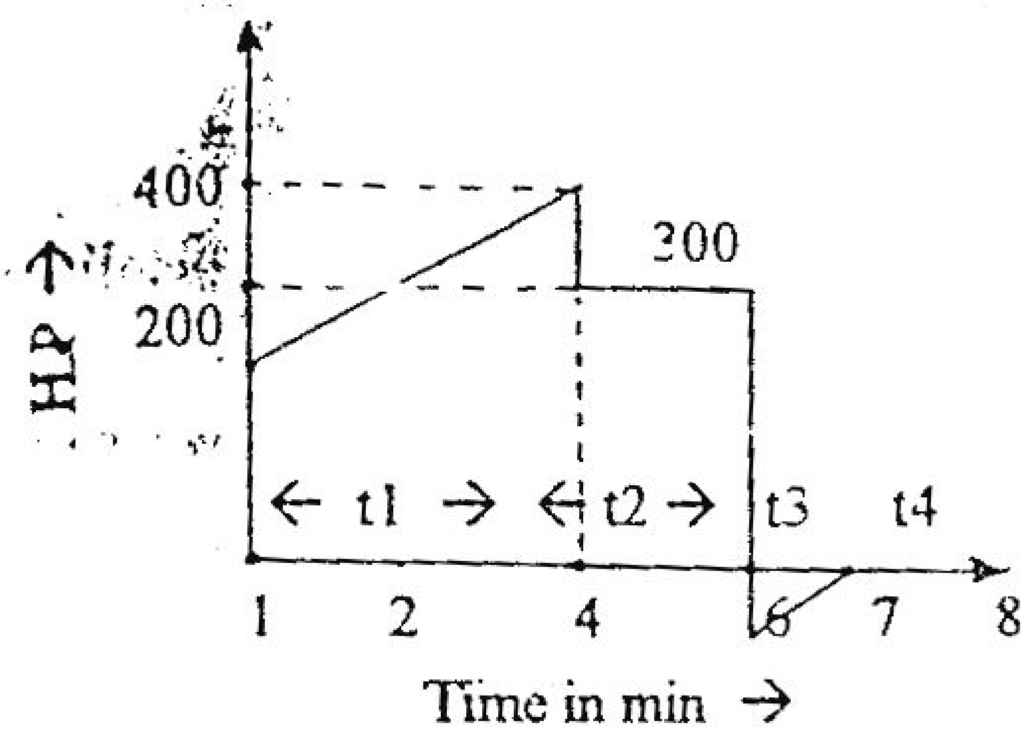
Given data

H1 = 200 – 400 h.p (4 minutes)
H2 = 300 h.p (2 minutes)
H3 = 50 h.p = 0h.p (1 minute)
Idle time (1 minute)

During rising load – H_1 (200) to (400), $(H.P)^2$ dt has to be taken for the that period.

$$P_{eq} \text{ (or) } HP_{eq} = \sqrt{\frac{\frac{(200^2 + 200 \times 400) + 400^2}{3} + 300 \times 2 + \frac{1}{3}\, 50 \times 1}{4 + 2 + 1 + 1}}$$

$$= \sqrt{\frac{1662500}{24}}$$



UNIT 2

Drive Motor Characteristics

Mechanical Or Speed / Torque Characteristics of Various Types of Loads

The Mechanical characteristic is also known as Speed / Torque characteristics. It is very important to study about Speed – Torque characteristics of various types of loads. To select motor with the proper speed / torque characteristics, it is necessary to know the motor and the load should be matched before the selection of the motor. Generally speed / torque characteristic of the load falls under following four categories. They are

1. Constant Load Torque with speed
2. Increasing Load Torque With Speed.
    a. Linear Increase of Torque with Speed
    b. Increase of Load Torque with square of speed
3. Decreasing Load Torque with speed

Constant load torque with speed

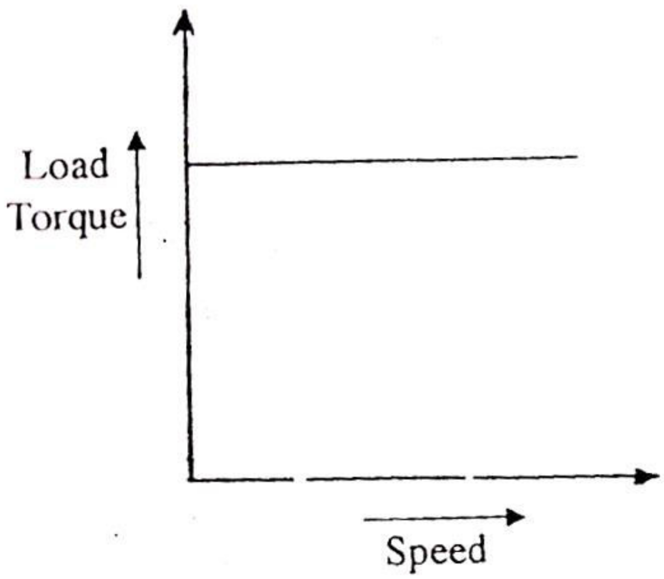


FIG.16

In certain loads, the load torque remains constant with speed i.e. at all speed the value of the load torque remains the same. The best examples of this kind of load are crane, hoist and in moving system where lubricant is not used (Dry Friction)

Increasing Load Torque with Speed

The load torque in some cases increases when the speed increases. The increase in load torque may be liner or varies as the square of the speed. These two types of load toque is explained as below.

(a) Linearly increasing load torque with speed.

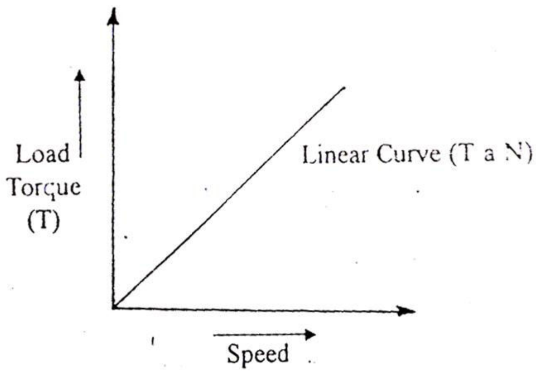


Fig .17

In this type of load, the torque increases linearly with the speed. The load torque is directly proportional to the speed ($T \alpha N$). the main example of this type of load is in cases where fluid friction is used, i.e. the type of lubricant used is fluid in nature.

(b) Load Torque increasing with square of the speed

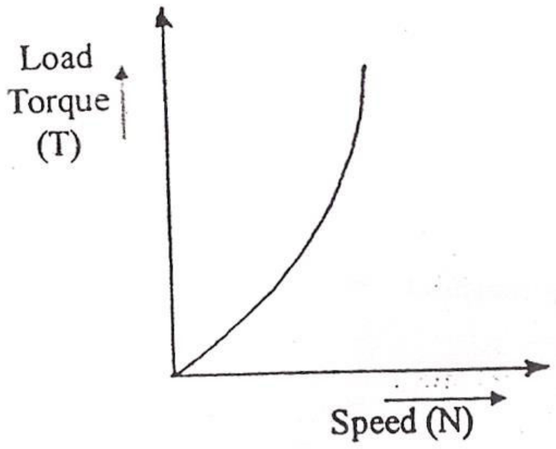


Fig .18

In this type of load the torque increase with the square of the speed, i.e. the load torque is directly proportional to the square of the speed ($T \alpha N^2$). The main example of this type load is in cse where fluid friction is used, i.e. the type of lubricant used is fluid in nature.

Decreasing load torque with speed

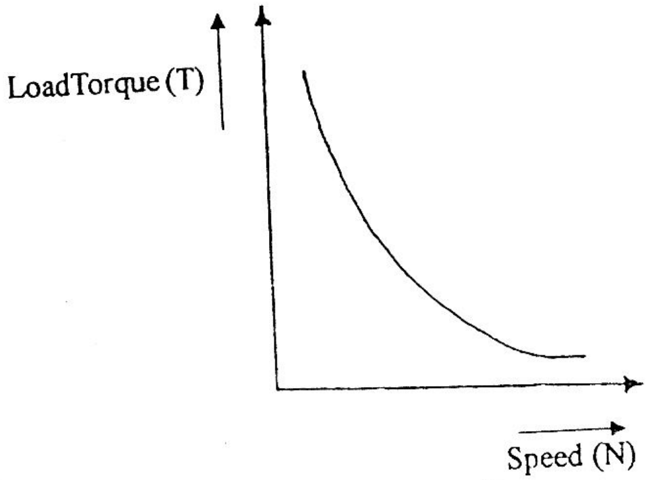


Fig .19

In this type of load the torque decreases with the speed. The load torque is inversely proportional to the speed ($T \alpha 1 / N$). If the speed increases the torque decease. The main example of this type load is in cases where deformation of materials takes place such as Grinding, Metal Drawing and Crushing.

Mechanical or Speed / Torque Characteristics or Various types of Electric Drive motor

The Speed / Torque characteristic of any motor is very important during the selection of the motor for electric drive system. The behaviour of the motor during load condition can be clearly studied from the speed / torque characteristics. By carefully studying the speed / torque characteristics of any motor its applications can be clearly stated. The following three diagram explains the classification of electric drive motor.

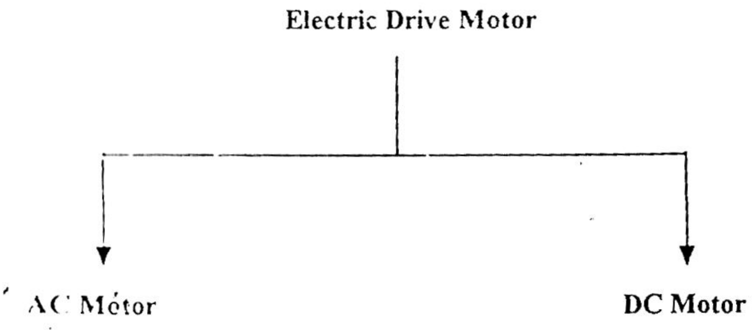


Fig.20. Classification Tree Of Electric Drive Motor

The electric drive motor is classified into two types namely AC motor and DC motor/ any one of the these two motors is selected depending upon the availability of the supply. If AC supply is available then AC motor is selected and if DC supply is available then DC motor is selected. The following sections deals with Speed /Torque characteristics of DC and AC motor.

Speed / Torque characteristics of DC motor

The DC motor is an Electro – Mechanical Energy conversion device, which converts given DC electric supply input into mechanical output. The DC motor is particularly selected where the available electric supply is of DC in nature. The DC drive is also selected due to quick response and wide range of control. The selection of DC motor for particular application depends on its speed / torque characteristics. The main parts of any DC motor is armature winding and field winding. The armature winding is used to carry the motor current and field winding used to produce flux. Depending upon the type of excitation of field system the DC motor is classified into types as shown by following diagram.

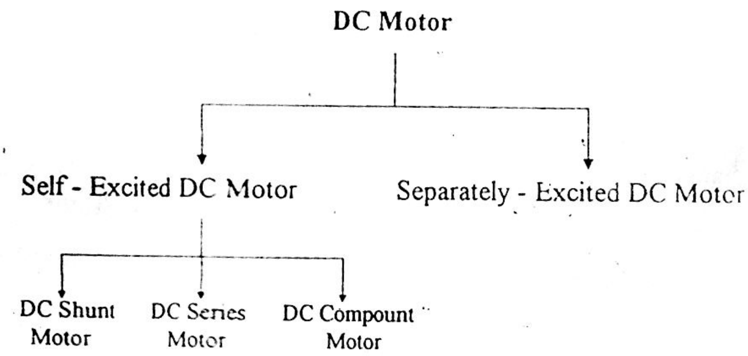


Fig.21. Classification Tree Of DC Motor

If there is connection between the armature and field winding then the DC motor is know as self – excited motor. If there is no connection between armature and field winding and separate supply is given for field system, the DC motor is known as Separately-Excited DC moor. Depending upon the connection between the armature system and field system the DC motor classified into the three types namely DC shunt motor, DC series motor and DC compound motor.

Before seeing the speed / torque characteristics of these three motor, the relationship between speed and torque must be determined. The following section deals with deriving speed and torque equations of DC motors. From the speed and torque equation the speed / torque characteristic can be drawn.

Speed equation & Torque Equation of DC motor

The speed and torque equation of DC motor is obtained from voltage and power equations. So before deriving speed and torque equation, voltage and power equation must be derived.

Voltage and power equation of DC motor

The DC shunt motor has armature and field winding connected in parallel, i.e. the field is connected across the armature or shunts the armature. The connection diagram of the DC shunt – motor is shown below.

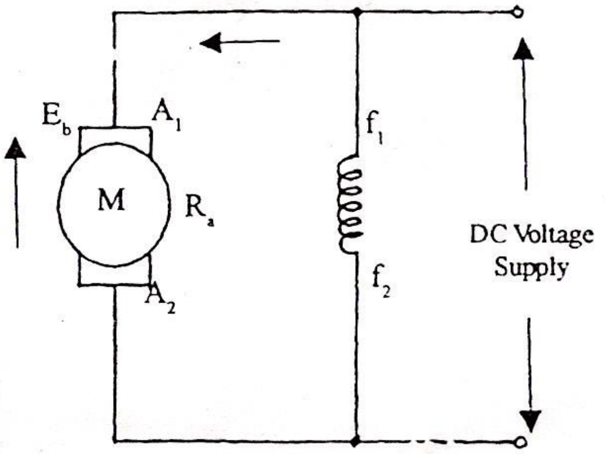


Fig.22.Connection diagram for D.C Shunt motor

The field winding (f_1 f_2) is connected across the motor armature (A_1, A_2). The field winding is placed in the poles of the motor. The DC voltage supply is applied to motor as a result current pass through armature conductors. This current is armature current

(I) At the same time small current flows through the field winding also, which produce flux (ϕ) or magnetic field. According to faraday's low of electromagnetic induction, whenever a current carrying conductor rotates in the magnetic flux, an emf (voltage) is induced in the armature conductor. This induced emf, opposes the supply voltage (V). hence this emf is known as Back emf (E_b) because of the fact that is opposes the supply voltage.

The back emf exists across the armature. The armature conductors has small amount of resistance known as armature resistance (R_a). This resistance gives armature voltage drop (I_a R_a) from the connection diagram supply voltage is equal to sum of back emf and armature voltage drop.

i.e. $V = E_b + I_a R_a$

where, V = DC Supply voltage

E_b = Back emf

$I_a R_a$ = Armature voltage drop

The above equation is known as voltage equation of DC shunt motor. Power is equals to the product of voltage and current. So to obtain the power equation, the voltage equation has to be multiplied with current.

Multiplying the voltage equation I_a, we get

$VI_a = E_b I_a + I_a^2 R_a$

Where VI_a = Input Power

$I_a^2 R_a$ = Armature power loss

The above equation is called power equation of DC shunt motor. Here VI_a is the Electrical input power, $I_a^2 R_a$ is the armature power loss and therefore E_bI_a is the output power, which is nothing but mechanical output.

Torque equation

The power equation describes the mechanical power output is equal to E_b I_a. This is actually electrical power equivalent of the mechanical power.

$E_b I_a$ = Mechanical power output (1)

But we known the mechanical power developed in terms of torque is given by

$$\text{Mechanical Power Output} = \frac{2\pi NT}{60} \qquad (2)$$

Where N - Speed in r.p.m

T - Torque in N-m

From the equation (1) and (2)

$$E_b\, I_a = \frac{2\pi NT}{60} \qquad (3)$$

The back emf E_b is nothing but the induced emf, which is given by

$$E_b = \frac{\phi ZNP}{60A}$$

Where ϕ - Flux per pole in Weber
Z – Number of Armature conductors
N – Speed in r.p.m.
A – Number of parallel paths
P – Number of Poles

Substituting the above value of E_b in equation (3) we get

$$\left(\frac{\phi\, ZNP}{60A}\right) I_a = \frac{2\pi NT}{60}$$

$$\left(\frac{ZNP}{60A}\right) \phi\, I_a = \frac{2\pi N}{60}\, T$$

In the above equation Z, N, P and A are constant and therefore

$$T \;\alpha\; \phi I_a$$

The above relation is generally known as Torque Equation. This equation shows the relationship between torque and Armature current.

Speed equation

From the voltage equation of DC motor the expression for Back emf is obtained.

i.e. $E_b = V - I_a R_a \qquad (5)$

substituting the value E_b from Equation (4) in (5) we get

$$\left(\frac{\phi\, ZNP}{60A}\right) = V - I_a R_a$$

$$N = \left(\frac{A\, 60}{ZP}\right) \frac{V - I_a R_a}{\phi}$$

In the above Equation Z, A and P are constant and therefore

$$N \;\alpha\; \frac{V - I_a R_a}{\phi}$$

Substituting E_b for $V - I_a R_a$ in the above equation we get

$$N \;\alpha\; \frac{E_b}{\phi}$$

The above Equation (6) and (7) is generally known as Speed Equation. Speed Equation shows the relationship between Speed and Armature current. It also shows the relationship between Speed and Flux and also Speed and Back emf.

(b) Speed / Torque Characteristics of DC shunt Motor
DC Shunt Motor

The DC Motor is which in Field Winding is connected in Parallel with Armature conductors is known as DC Shunt motor since Field winding is connected in parallel with both supply and the armature, the voltage across the field winding is always constant. So the current flowing through the field winding and hence the flux produced in the DC shunt Motor is Constant.

To draw the Speed / Torque Characteristic or Curve of the DC shunt motor, the relationship between speed and torque must known. But there is no direct relationship exist between speed and torque. So speed / torque curve be drawn directly. But we known the relationship between torque (T) and Armature Current (I_a) and Speed (N) and Armature Current (I_a). Therefore first Speed / Current Characteristics (N $V_s I_a$) and Torque / Current characteristics (T V_s I_a) are drawn. From these two curves Speed / Torque curves is obtained.

(i) Speed / Current Characteristics (N V_s I_a)

The Speed / Current Characteristics of DC shunt motor is obtained with the help of Speed Equation, which shows the relationship between Speed and Armature Current. When the motor is loaded it takes more current to supply the increased load demand. The flux ϕ and Back emf E_b in the shunt motor is practically constant. So from the speed equation given below it is clear that speed of shunt motor is constant. And this is shown as ideal curve in N / I_a Characteristics.

$$N \quad \alpha \quad \frac{E_b}{\phi} \quad \frac{V - I_a R_a}{\phi}$$

Case (i)

When the load is not applied armature current very les and as the result. Armature voltage drop is less. So the value of $V - I_a R_a$ (which is $E_{b,}$ the Back emf) is not reduced and hence the speed is also not reduced. Now the motor runs with maximum rated no load speed N_0.

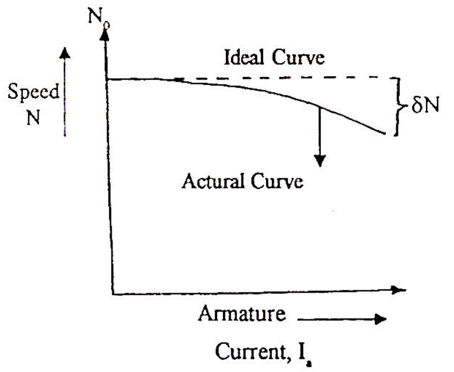


Fig.23. N/I_a Characteristics of DC Shunt Motor

Case (ii)

As load on motor increase, armature current I_a increases. Therefore armature resistance drop I_a R_a is also increases. Therefore in speed equation the values $V - I_a R_a$ is also increases. Therefore in speed equation the values $V - I_a R_a$ (i.e. E_b the Back emf) is reduced. Since speed is directly proportional to Back emf, the speed is also reduced. Hence there is drop in speed, 'δN'. The actual curve deviate from the ideal curve by 'δN'. This change in speed is very small and hence DC shunt motor is known as constant speed motor.

(ii) Torque / Current Characteistics (T Vs I_a)

The Torque / Current Characteristics of DC Shunt motor is obtained with the help of Torque equation, which shows the relationship between Torque and Armature Current. The Torque equation is given by

$$T \,\alpha\, \phi\, I_a$$

Ideal Curve

From the Torque equation it is clear that Torque is directly proportional to the Armature current. In shunt motor the Flux ϕ is constant, so the Flux can be removed from the Torque equation. Now the torque equation becomes,

$$T \alpha I_a$$

The above equation is the equation of straight line passing through the origin. From above equation, it is clearly observed that Torque varies linearly with current. Hence the characteristics 'Linear Characteristic'

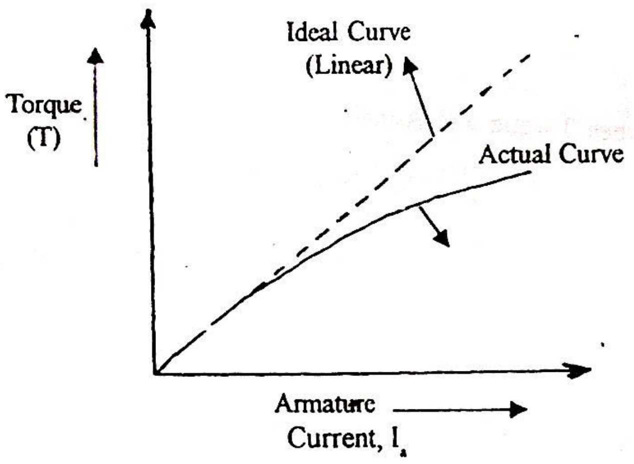


Fig.24. T / I_a Characteristics of DC Shunt Motor

Actual Curve

The actual curve deviates from the ideal curve. Because, the torque vary slowly. When compared to the armature current. The reason for this is flux is assumed current. The reason of this is flux is assumed to be constant but it is reduced due to armature reaction. That is why actual characteristics depart from ideal characteristic.

(iii) Speed / Torque Characteristics (N Vs T)

The Speed / Torque Characteristics of DC motor is other wise known as Mechanical Characteristics. Because it is drawn between two mechanical quantities namely, speed and torque. There is no equation available, which shows relationship between speed and torque. Therefore speed / torque characteristics must be drawn indirectly from Speed / Current and Torque / Current characteristics. For different values of Armature current the value of torque and speed are noted form above two curves. A graph is drawn with this values Speed and Torque. The curve obtained is known as Speed / Torque Characteristics.

The curve obtained is Drooping characterizes the speed slightly falls as the load torque (Load) increases.

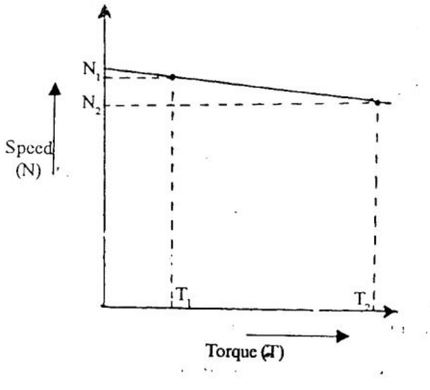


Fig.25. N / T Characteristics of DC Shunt Motor

(iv) Applications of DC Shunt Motor :

a) The main feature of DC Shunt motor is its constant speed than the other, it develops huge torque and loaded heavily.

b) It is also used in situations where possibility of load being thrown off suddenly i.e. in Lathe, Drilling machine, Grinder

1.A 200Vshunt motor having R_a =0.4 Ω takes I_a = 20 amps on full load and runs at 600 rpm. If 0.5 ohm resistor isplaced in the armature circuit. Find the speed at full load torque,hal the at full load torque.What is the ratio of stalling torque to full load torque

(c) Speed / Torque Characteristics of DC series Motor

DC Series Motor

The DC motor in which the field winding is connected in series with Armature Conductors is known as DC series Motor. In series circuit the current flowing through the armature is same as the current flowing through series field winding. Since the full load armature current flow through series field, the magnetic saturation takes place (Flux don't increase with current after certain point).

In DC series Motor Before saturation, an increase in field flux is directly proportional to increase in armature current i.e. $\phi \alpha I_a$ After saturation field flux remains constant even though armature current increase ϕ = constant

To draw the speed / Torque characteristic or Curve of the DC series motor, the relationship between speed and torque must known. But there in no direct relationship exist between speed and torque. So speed / torque curve cannot be drawn directly. But we know the relationship between torque (T) and Armature current (I) from torque equation and speed (N)And Armature Current (I) form Speed equation. Therefore first speed / current characteristics (N V_a I_a) and torque / current characteristics (T V_a I_a) are drawn. From these two curves Speed / Torque curve is obtained.

(i) Speed / current characteristics

case (i) : Before Saturation of field circuit

The field circuit of DC series motor is saturated due the flow of heavy armature current before the saturation of field circuit ϕ α i.e. the flux is directly proportional to the flux. It is shown as linear part of dotted line.

Now to draw speed / current characteristics of DC series motor consider speed equation, which is given by

$$N \quad \alpha \quad \frac{V - I_a R_a}{\phi} \quad \alpha \quad \frac{E_b}{\phi}$$

before saturation $\phi \alpha I_a$, so replacing ϕ in the speed equation by I_a. we get

$$N \quad \alpha \quad \frac{V - I_a R_a}{I_a}$$

As the load on motor increase, the armature current increase, numerator of the above equation decreases very title. So the drop $I_a R_a$ is neglected

$$N \;\; \alpha \; \frac{V}{I_a}$$

Here V is constant therefore

$$N \;\; \alpha \; \frac{1}{I_a}$$

With the above equation speed / current characteristics in drawn before saturation. The equation states that the speed is inversed proportional to the current. So we get linearly decreasing curve before saturation.

Case (ii) : After saturation

If the armature current goes on increasing after some point, the field circuit is saturated. After saturation the flux remains constant irrespective of current ϕ = constant

The speed equation is

$$N \quad \alpha \quad \frac{V - I_a R_a}{} \quad \alpha \quad \frac{E_b}{}$$

ϕ ϕ

Here E_b is constant and after saturation flux ϕ is constant, therefore the above equation become

$$N = \text{Constant}$$

From the above equation the speed is constant after saturation

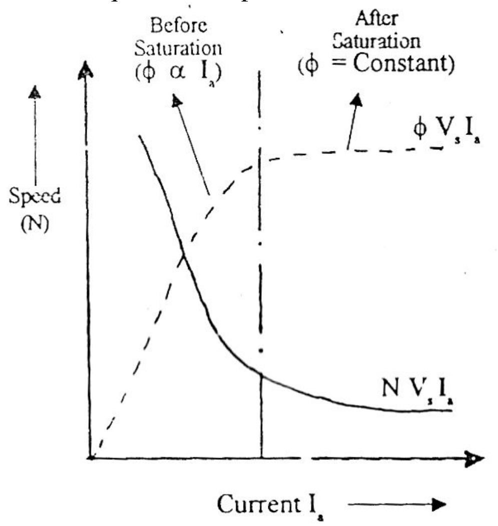


Fig.26. N/I_a Characteristics of DC Series Motor

(ii) Torque / Current Characteristics

Case (i) : Before saturation

To draw the torque / Current characteristics, consider Torque Equation which is given by

$$T \alpha \phi I_a$$

But before saturation, $\phi \alpha I_a$ therefore the above equation replace ϕ with I_a, we get

$$T \alpha I_a I_a$$

$$T \alpha I_a^2$$

The above equation represents Parabola. Therefore before saturation the torque/current curve is drawn as parabola. Here Torque increases with the square of the Current.

Case (ii) : After Saturation

After Saturation flux becomes constant i.e. ϕ = Constant, now the Torque equation becomes,

$$T \alpha I_a$$

The above equation represents straight line. After saturation torque / current characteristics becomes a straight line i.e. torque increase linearly.

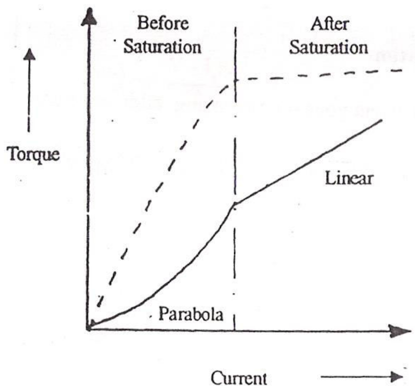


FIG 27. T/I_a Characteristics of DC Series Motor

(iii) Speed / Torque Characteristics

The Speed / Torque characteristic is obtained from speed / current and torque / current characteristics. For different values of armature current, the values of Torque and speed are noted from above two curves.

A graph is drawn with this values of speed and torque. The curve obtained is known as Speed / Torque Characteristics or Mechanical Characteristics.

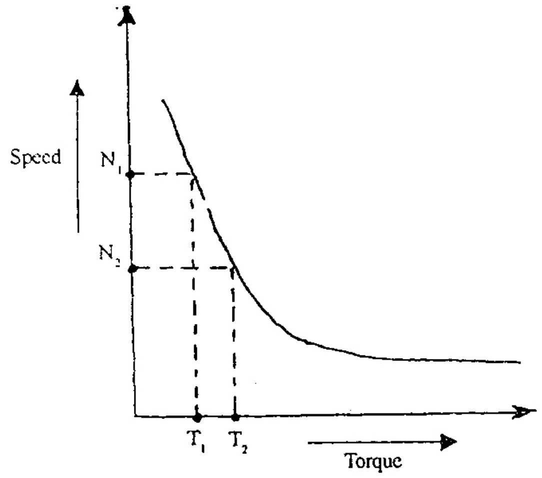


Fig.28. N / T Characteristics of DC Series Motor

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(iv) Applications of DC series motor

i) Used for drives requiring very high starting torque E.g. Electric Locomotive

ii) Used where permanent load is solidly connected to motor. E.g. hoist and Cranes.

iii) Used applications where speed varies E.g Trolley and conveyors.

1.A 460V series motor runs at 500 rpm taking a current of 40A. Calculate speed and percentage change in torque if the load is reduced so that motor is taking 30A. Total resistance of armature and field is 0.8 ohm.

Solution

Given : $V = 460$ v

$I_{a1} = I_{se1} = 40A$

$N_1 = 500$ rpm

To find : N_2, T_2, & % change in torque where $I_{a2} = I_{sc2} = 30A$

Solution : Since the machine is series motor,

$T_1 \alpha I_{a1}^2 \Rightarrow T_1 \alpha 40^2$

$T_2 \alpha I_a^2 \Rightarrow T_2 \alpha 30^2$

$$\frac{T_2}{T_1} = \frac{30^2}{40^2} = \frac{900}{1600} = \frac{9}{16}$$

i) Therefore, percentage change in torque is

$$= \frac{T_1 - T_2}{T_1} \times 100 = \frac{16-9}{16} \times 100$$

$$= \frac{7}{16} \times 100 = 43.75\%$$

ii) To find N_2

$E_{b1} = V - I_{a1}(R_a + R_{sc})$

$= 460 - 40\,(0.8)$

$E_{b1} = 428$ V

$E_{b2} = V - I_{a2}(R_a + R_{sc})$

$= 460 - 30\,(0.8)$

$E_{b2} = 436$ V

We know that for series motor,

E_b E_b

$$N \quad \alpha \quad \frac{}{\phi} \quad \alpha \quad \frac{}{I_a}$$

$$N_1 = \frac{E_{b1}}{I_{a1}} \quad \alpha \quad N_2 = \frac{E_b}{I_{a2}}$$

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{I_{a1}}{I_{a2}}$$

$$\frac{N_2}{N_1} = \frac{436}{428} \times \frac{40}{30}$$

$$N_2 = 679 \text{ rpm}$$

(d) Speed / Torque Characteristics of DC compound Motor
DC Compound Motor

The DC motor that has both shunt as well as series field winding is known as DC compound Motor. If the flux produced by series field winding helps (aids) the flux produced by shunt field, then the total flux increases and DC compound motor is known as Cumulative Compound Moor. On the other hand, if the series field flux opposes the Shunt field flux, total flux decreases and the motor is known as Differential compound Motor.

(i) Speed – Current Characteristics

In cumulative compound motor shunt flux aids or helps (acts in same direction) the series flux. So the total flux increases, when current increases since the speed is inversely proportional to flux, speed is reduced. This decreasing speed curve is shown below. In differential compounded motor shunt field flux opposes the series field flux (acts in opposite direction). So the total flux is decreases, when current increases. Now the speed increase, which is inversely proportional to the flux. This increasing speed curve is shown below.

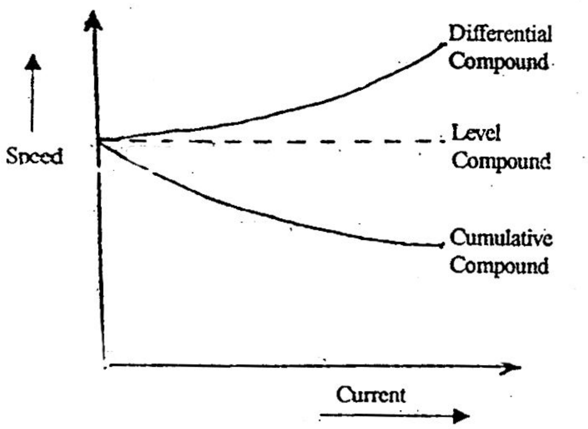


Fig.29. N / Ia Characteristics of DC Compound Motor

If speed drop due to Armature voltage drop is neutralized by speed rise due to reduced flux of differential series field winding, then motor will have same speed at all loads it is known as Level compound motor.

(ii) Torque / Current Characteristics

From the torque equation we know that torque is directly proportional to product of flux and current. In case of cumulative compound motor, total flux increases when the current increases. The torque, here increase very rapidly as shown in below curves. In case of differential compound motor the total flux is decreases, which the current increases. So the torque here increases very slowly as shown below.

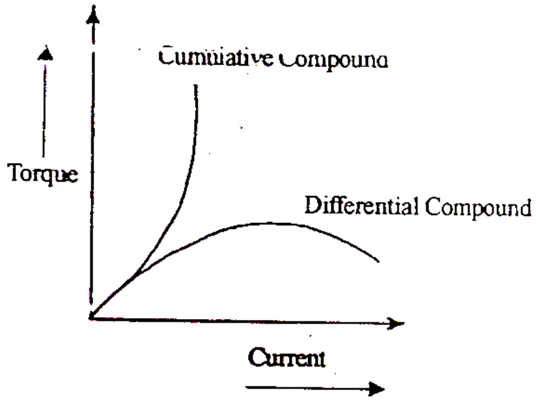


Fig.30. T / I_a Characteristics of DC Compound Motor

(iii) Speed / Torque Characteristics

From Speed / Current and Torque / Current Characteristics the speed / torque is obtain, which almost resembles the speed / current characteristics.

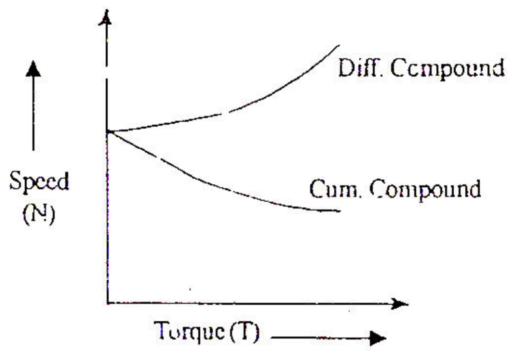


Fig. 31. N / T Characteristics of D.C. Compound Motor

It is observed that, speed of differential compound motor increases with the torque requirement which is very dangerous condition. So differential compound is generally not used in practices. The speed of cumulative compound motor decreases slight with the increases in the load. It is almost similar to that of shunt motor (constant Speed)

(iv) Application of DC compound Motor

(a) Differential compound motor is not suitable for any practical applications

(b) Cumulative compound motor has almost constant speed as that of shunt motor. So it is used in constant speed application, such as Blowers and fans.

(c) Cumulative compound motor has very high starting torque as that of series motor. So it is used for applications requiring high starting torque such as Rolling Mills, Elevator and heavy planners.

Speed / Torque Characteristics of AC motor

If the AC motor is used as the drive motor, then the drive system is known as AC drives. The classification AC motor can be known from the following tree diagram.

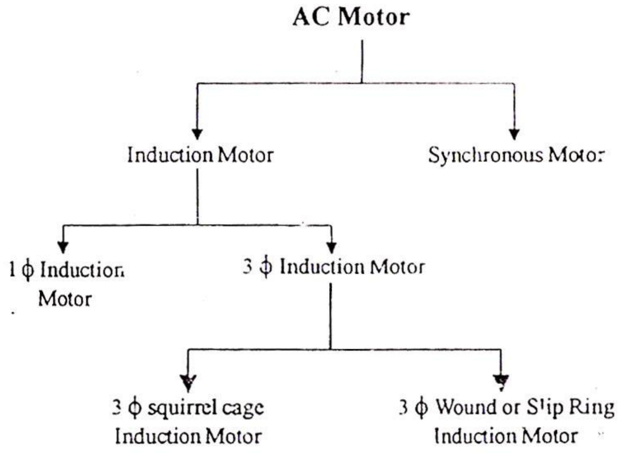


Fig.32. Classification Tree Of AC Motor

In this section, we are going to concentrate mainly on AC induction motor, which is known as work horse of the modern industries.

(a) Introduction to 3 ϕ Induction Motor

Induction motor has two parts namely stator and rotor. The stator is stationary part which holds 3 ϕ winding. Rotor is the rotating part which may be of squirrel cage type (has short circuited conductors) or of wound or slip ring rotor type (has 3ϕ windings with slip rings). In induction motors, the rotor does not receive electric power by conduction, but by induction in exactly the same way as the secondary of transformer receives its power from primary winding. That is why these motors are called as induction motor.

Principle of 3ϕ induction motor

When the 3ϕ (3 phase) stator winding, are fed by a 3ϕ supply (R, Y, B) then, magnetic flux of constant magnitude, but rotating at synchronous speed, is set up. The flux passes through air gap and sweeps the rotor surface and cuts the rotor conductor. Due to the relative speed different between rotating flux an dthe stationary conductors, and emf is induced in rotor conductors by Faraday's law of electromagnetic induction. The direction of the induced emf is given by Fleming's Right hand rate. Closed circuit, current flows in the rotor, the direction of the current is given by Lenz's law. The Lenz's law states that the direction of current is such as to oppose the cause, which produces it . Here the cause is 'relative speed' in order to oppose relative speed, the rotor starts rotating in the direction of flux and tries to catch with rotating flux.

Slip of the induction motor

The rotor never catches the stator field. If it catches, then there will be no relative speed between these two, hence no rotor emf, no rotor current and no torque to maintain rotation, as a result the motor stops.

The difference between the synchronous speed Ns and actual speed N of the rotor is known as Slip.

$$\% \text{ Slip } S = \frac{N_s - N}{N_2} \times 100$$

Where, $N_2 - N$ is slip speed

$$\text{Synchronous Speed } N_s = \frac{120f}{P}$$

Rotor speed $N = N_s\,(I - S)$

When the rotor is stationary, the frequency of rotor current is same as supply frequency (f). When rotor starts revolving, then frequency (f) depends on relative speed or slip speed.

i.e. $$N_s = \frac{120f}{P}$$

$$N_s - N = \frac{120f'}{P}$$

$$\frac{N_2 - N}{N_2} = \frac{f'}{f}$$

$$S = \frac{f'}{f}$$

$$f' = sf$$

(b) Relationship between Torque, Speed & Slip of 3 ϕ Induction Motor

(i) Torque Equation At standstill : (Starting Torque)

Let = E_2 = Rotor emf per phase

X_2 = Rotor reactance per phase

R_2 = rotor resistance per phase

Z_2 = rotor impedance per phase = $\sqrt{R_2^2 + X_2^2}$

Then rotor current $$I_2 = \frac{E_2}{Z_2} = \frac{E_2}{\sqrt{R_2^2 + X_2^2}}$$

Power factor $$\cos\phi_2 = \frac{R_2}{Z_2} = \frac{R_2}{\sqrt{R_2^2 + X_2^2}}$$

In case of an induction motor, torque (starting) is proportional to the product of flux per pole and the rotor current and power factor of rotor.

Starting Torque $T_{st} \alpha \phi \text{ x } I_2 \text{ x } \cos\phi_2$

The factor emf is proportional to flux, $E_2 \alpha \phi$

$T_{st} \alpha E_2 I_2 \cos\phi_2$

$T_{st} = KE_2 I_2 \cos\phi_2$

$$T_{st} = K_1 E_2 \frac{E_2}{\sqrt{R_2^2 + X_2^2}} \frac{R_2}{\sqrt{R_2^2 + X_2^2}}$$

$$T_{st} = \frac{K_1 E_2^2 R_2}{R_2^2 + X_2^2} \qquad (1)$$

(ii) Torque Equation at running Condition (with Slip)

Rotor emf per phase = $S. E_2$

Rotor resistance per phase = R_2

Rotor reactance per phase $=X_2$ = 2 f'L

= 2 (sf) L

= S (2fL)

= SX_2

Rotor impedance per phase Z_2 = $\sqrt{R_2^2 + X_2^2}$

Rotor current $$I_2 = \frac{E_2}{Z_2} = \frac{E_2}{\sqrt{R_2^2 + (SX_2)^2}}$$

Rotor power factor $\cos\phi_2 = \dfrac{R_2}{Z_2} = \dfrac{R_2}{\sqrt{R_2^2 + (SX_2)^2}}$

$T \alpha \phi I_2 \cos\phi_2$

$T \alpha E_2 I_2 \cos\phi_2$

$T = K_1 E_2 I_2 \cos\phi_2$

$$= K_1 E_2 \frac{SE_2}{\sqrt{R_2^2 + (SX_2)^2}} \frac{R_2}{\sqrt{R_2^2 + (SX_2)^2}}$$

$$T = \frac{K_1 SE_2^2 R_2}{\sqrt{R_2^2 + (SX_2)^2}}$$

(c) Torque / Slip & Torque / Speed Characteristics 3ϕ Induction Motor.

The torque equation of induction motor is given by

$$T = \frac{K_1 SE_2^2 R_2}{\sqrt{R_2^2 + (SX_2)^2}}$$

From the above equation, relationship between torque and slip is understand. When Slip, S = 0, the torque, T = 0, hence the curve starts from point O. At normal speeds, close to synchronism (no load s = 1%, S = 01) the term SX_2 is small and hence neglible with respect to R_2.

Therefore, $T \alpha \dfrac{S}{R_2}$

$T \alpha S$ (R_2 is constant)

Therefore the curve is approximately straight line for lower value on slip. As slip increase, torque also increase and becomes maximum when $S = R_2 / X_2$. This torque is known as 'Pull out torque'. As the slip further increases R_2 becomes negligible torque as compared to SX_2.

$$T \alpha \frac{S}{(SX_2)^2} \alpha \frac{S}{S^2X_2^2}$$

$$T \alpha \frac{1}{SX_2^2}$$

$$T \alpha \frac{1}{S}$$

Hence torque slip curve is rectangular hyperbola

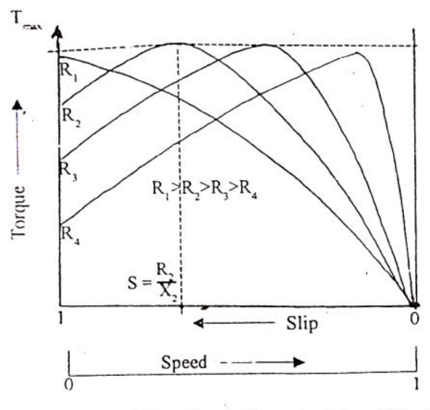


Fig.33.Torque - Slip - Speed Characteristics of 3 Inducti Motor

(d) Speed / Torque Characteristic of 1ϕ Induction Motor

1 ϕ Induction Motor

1 ϕ Induction motor has two parts namely stator and rotor. Here the stator has 1ϕ. Winding fed with 1ϕ supply. The rotor has short circuited conductor. A 1ϕ induction motor never develops a starting torque, so it does not self – start. The reason for this is 1ϕ supply produce alternating flux which produce tow torque in opposite direction in cycle. Since rotor is subjected to two torques acting in opposite direction 1 ϕ induction does not self-start.

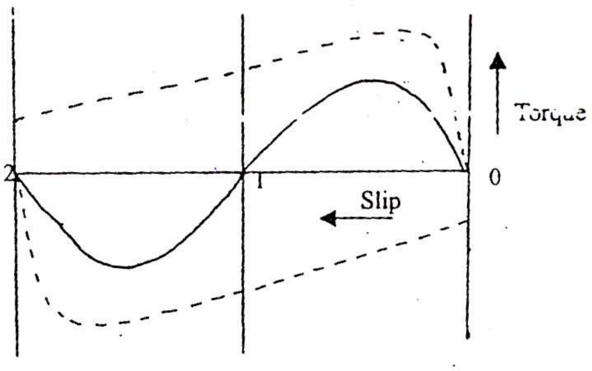


Fig.34.Torque / Slip – Speed Characteristics of 1ϕ Induction Motor

The torque in the opposite direction is shown in the above curves. Slip – 1 corresponds to stand still condition. Slip – 1 to 0 corresponds to motoring in forward direction slip = 2 corresponds to reverse torque and motoring in the reverse direction. If the starting methods are employed then speed torque curve is obtained only in the forward motoring direction. In the characteristic shown in Fig. curve in dotted lines are forward torque and reverse torque and the curve shown in solid lien in resultant torque.

From the characteristics it is noted that, when slip = 1 the resultant torque is zero. Slip = 1 corresponds to standstill (i.e rotor is stationary). It is clear from the above discussion that 1ϕ induction motor has no starting torque.

The various methods of self – starting is the base for classification of 1ϕ induction motor. There are 3 types of 1ϕ induction motor, they are split phase induction motor, capacitor start induction motor and shaded pole induction motor.

Braking of Electrical motor

The electric drive uses to electric motor as the prime mover. The braking is required in electric drive to stop the load and to reverse the direction of the rotation of the load. The braking is applied to Electric drive motor by two methods as given below

1. Electrical braking
2. Mechanical braking

Electrical Braking V_3 Mechanical Braking

To stop the rotating object, torque is reverse direction is required. This torque is known as braking torque. The direction of braking torque is opposite to that of forward motor torque. The braking torque is required to stop the rotating load quickly. When the electrical supply is removed the motor do not stop, because of the inertia of the heavy load. So the braking torque is need to be generated to stop the high inertia load and load connected to Hoist and cranes.

The Braking torque can obtained by both electrical mean and by mechanical means. If braking torque is obtained by electrical means, then the process is known as electrical braking. If braking torque is obtained by mechanical means, then the process is known as mechanical braking.

The electrical braking is applied by producing the braking torque by means of changing the electrical connections of the electric drive motor. This method of generation the braking torque is also known as Electro-dynamic braking.

The mechanical braking is applied by producing the braking torque or frictional torque by means of Brake drum / Brake lining and brake shoe/brake rope arrangements. The entire kinetic energy of moving mass is wasted in case of mechanical braking. The mechanical brake requires frequent maintenance, in the form of replacement of brake shoe and brake linings due to wear and tear.

Advantage of electrical braking

The electrical braking has number of advantages over the mechanical braking, they are

1. The maintenance required is low when compared to mechanical braking, because of the absence of moving parts.
2. The electrical braking provide pollution free atmosphere because of absence of dust, which is produced during mechanical braking.
3. The kinetic energy of the moving mass wasted during braking is converted into electrical energy and supplied to the supply mains. This is the main advantage of electric braking.
4. Since the energy of moving mass is returned to the supply mains, the efficiency of electrical braking is high when compared to Mechanical braking.

Electrical Braking methods for DC motor.

The Electrical braking is applied to DC motor by generating the electrical braking torque. The braking torque is obtained by just changing some of the electrical connection of the electric motor. In electric braking the drive motor itself methods available, they are

1. Plugging or reverse current or counter current
2. Rheostatic or Dynamic braking
3. Regenerative braking

(a) Plugging or Reverse current or Counter Current braking

This method involves, reconnection of motor to supply in a such a way that motor develops torque in opposite direction. This torque is known as braking torque. Plugging is done by reversing the connection of armature of the DC motor, while the connection of field winding remains unchanged.

Plugging in DC Shunt Motor

Reverse current Braking is applied to the shunt motor by reversing the armature connection (A_1, A_2 are reversed). But the field terminals (f_1 f_2) are not reversed. Due to the reversal of armature connection, the direction of the current is also reversed. This reversed current creates torque in the direction opposite to that of forward motor torque. This torque is known as braking torque.

Now the direction of the back emf is also reversed i.e it is no longer oppose the supply voltage, but acts in the same direction that of supply voltage. This condition is dangerous because the sum of supply voltage and back emf acts across the armature circuit and cause large current. To avoid this over current, resistance R is included in the armature circuit during reverse current braking.

Due to braking torque in reverse current braking method, the speed is reduced to zero. After this instant of time, the motor accelerates in the opposite direction, because of reversed armature connection. So it is necessary to stop the motor by disconnect supply as soon as system reaches the Zero speed.

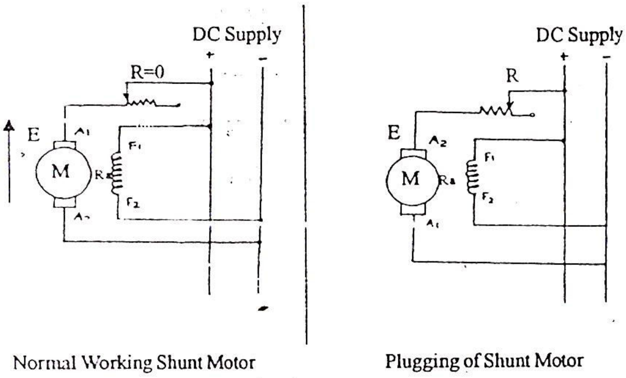


Fig.35. The Connection Diagram Of Plugging Of DC Shunt Motor (Separately Exited).

Plugging in DC Series Motor

The reverse current braking of series motor is obtained by reversing the armature terminals. Due to reversal of armature terminals, the direction of the armature current is reversed. Enough care should be taken to ensure that the field current is not reversed.

This is because in series motor armature and series field are in the same circuit. The braking torque is produced due to reversal of armature current. To limit the over current during braking an external resistance R is included in the armature current. The Plugging is also done in series motor by separately existing the series field winding.

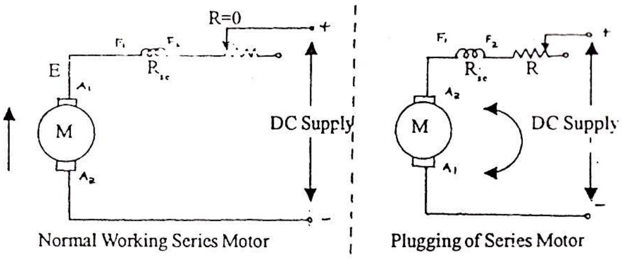


Fig.36. Connection Diagram of Plugging of DC Series Motor

Expression for Reverse Current Braking torque

Braking torque of motor varies with speed as shown below. During plugging supply voltage (V) and Back emf (E_b) acts in the same direction.

Armature current, $I_a = \dfrac{V + E_b}{R_{sc} + R}$

$$= \frac{V + \dfrac{\phi ZNP}{60A}}{R_{sc} + R}$$

$$I_a = \frac{V + K_1 N\phi}{R_{sc} + R} \qquad \text{[Z,P,A are constant]}$$

Braking Torque,

$T_B \propto \phi I_a$

$T_B = K_a \phi (I_a)$

Subst Value of I_a from equation

$$T_B = K_a \phi \left(\frac{V + K_1 N\phi}{R_{sc} + R} \right)$$

$$= \frac{K_2 V \phi}{R_{sc} + R} + \frac{K_1 K_2 \phi^2 N}{R_{sc} + R}$$

$$T_B = K_3 \phi + K_4 \phi^2 N$$

For Shunt motor the above equation becomes

$$T_B = K_5 + K_6 N \qquad - \qquad (2)$$

Because ϕ is constant in shunt motor.

Form the above equation (2) it is clear that when speed is zero i.e. (N = 0) there is some torque given by $T_B = K_5$. This is known as Holding torque. The holding torque is the torque develop by the braking method, when speed S = 0. So this method of braking used where torque is required at zero speed, such as lifts, hoist and elevators even it is not efficient.

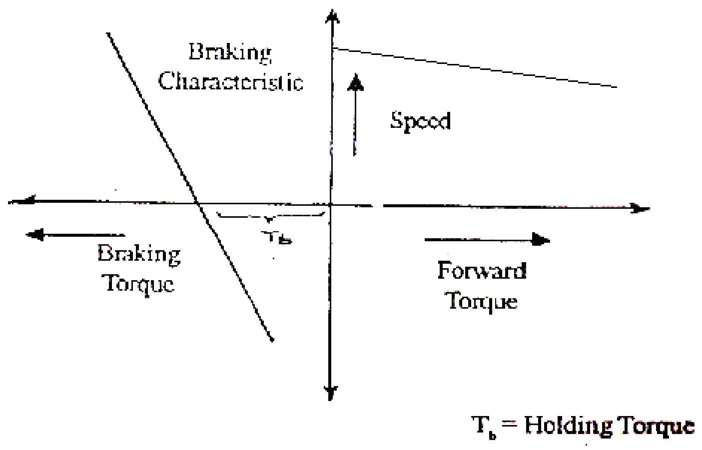


Fig.37. Reverse Current Braking Characteristics of DC Shunt Motor

Advantages of Plugging

1. Provides quick stoppage of the motor. It is the fastest of all electrical braking methods.
2. The Plugging may be employed to lower the load at constant speed.

Disadvantage of Plugging

1. This method is most inefficient because the kinetic energy of moving masses is wasted.
2. It requires additional energy, that is absorbed from supply for the development of Braking torque.
3. In case of failure of supply, this method becomes ineffective.
4. Supply has to be disconnected as soon as motor comes to zero speed, otherwise the motor accelerate in the opposite direction.

(b) Rheostatic or Dynamic Braking

Rheostatic braking of DC motor is obtained by disconnecting the armature terminals from the supply and connecting it to the external resistance R. The field winding is not disturbed.

Rheostatic Braking of DC shunt Motor

The armature terminals are disconnected from the supply and connected to external resistance R. now the armature current direction is reversed. Due to this reversed current direction the torque is produced in the opposite direction. Which is known as braking torque. Now the armature generates voltage and hence acts as a separately exited generator. The kinetic energy of the moving system is converted into electrical energy, which is dissipated in the external resistance R. Here the motor is braked by generated action. The connection diagram for Rheostatic braking of DC shunt motor shown below.

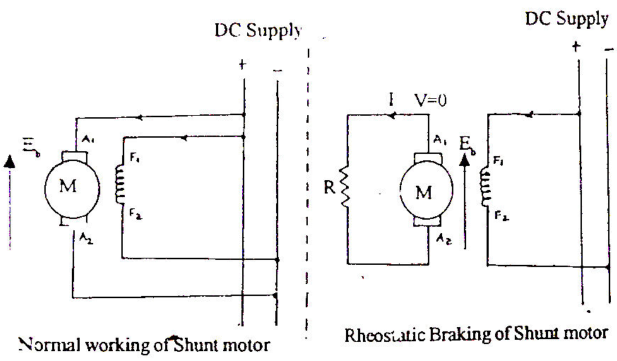


Fig. 38.Connection Diagram of Rheostatic Braking of DC Shunt Motor
(Separately Exited).

Rheostatic braking of DC series Motor

The Rheostatic braking of DC series motor is shown. Here armature and field winding present in the same circuit. Rheostatic Braking is obtained by disconnecting the armature circuit form the supply and connected to external resistance R. Now armature current is reversed. Since this is series motor, the field current is also reversed (armature current is also the field current). This leads to demagnetization of field circuit, as a result generator action do not takes place. To avoid this, field terminals (f_1, f_2) are reversed when armature circuit is connected to the external resistance R.

Now motor acts as a generator and as the a result, kinetic energy of the moving system is converted to the electrical energy and wasted in the resistance R. Since the kinetic energy of the moving system is wasted, Braking torque is produced.

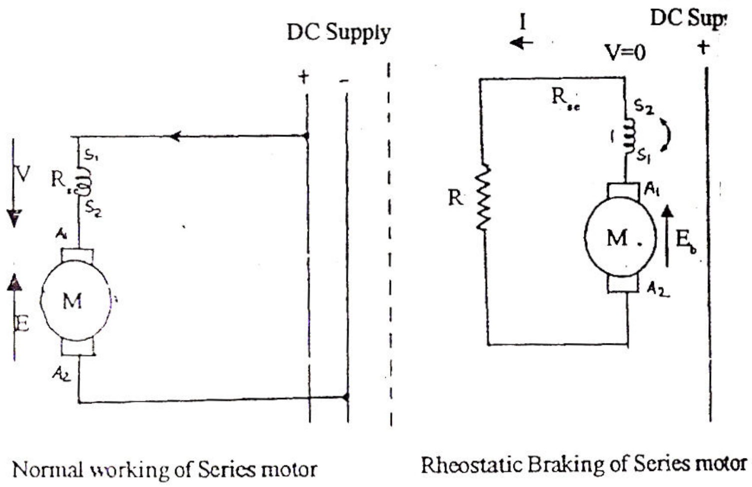


Fig.39. Connection Diagram of Rheostatic Braking of DC Series Motor

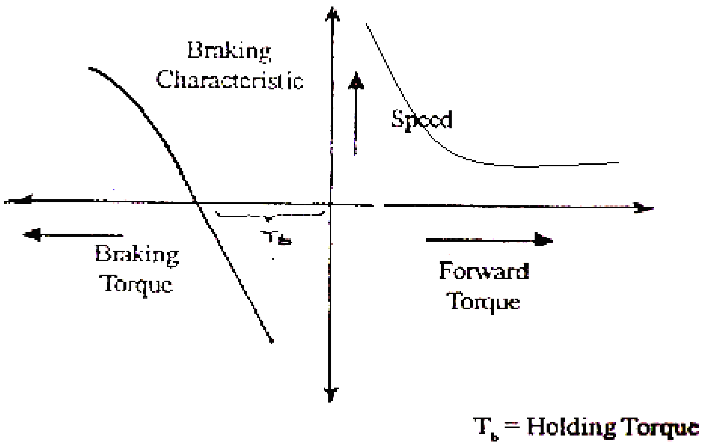


Fig.37. Reverse Current Braking Characteristics of DC series Motor

Expression For Rheostatic Braking Torque

Braking Torque (T_B) of motor varies with speed as shown below

$$\text{Armature Current, } I_a = \frac{E_b}{R_{sc} + Rh} \quad \text{(Because V = O)}$$

$$= \frac{V + \dfrac{\phi ZNP}{60A}}{R_{sc} + R}$$

$$I_a = K_1 \phi N$$

Braking Torque $T_B \alpha \phi I_a$

$$T_B = K_2 \phi I_a$$

$$T_B = K_2 \phi (K_1 \phi N)$$

$$T_B = K_3 \phi^2 N \quad - \quad (1)$$

In case of shunt motor, flux is constant : ϕ Cosnt.

$\therefore$ Equation (1) => $T_B = K_4 N$ (Linear char) - (2)

The equation (2) is the Rheostatic Braking torque equation of the DC shunt motor. With the help of the above equation, Rheostaic braking characteristics is drawn. Its clear form the equation, when speed N = 0, the torque T = 0. this is equation straight line, passing though the origin.

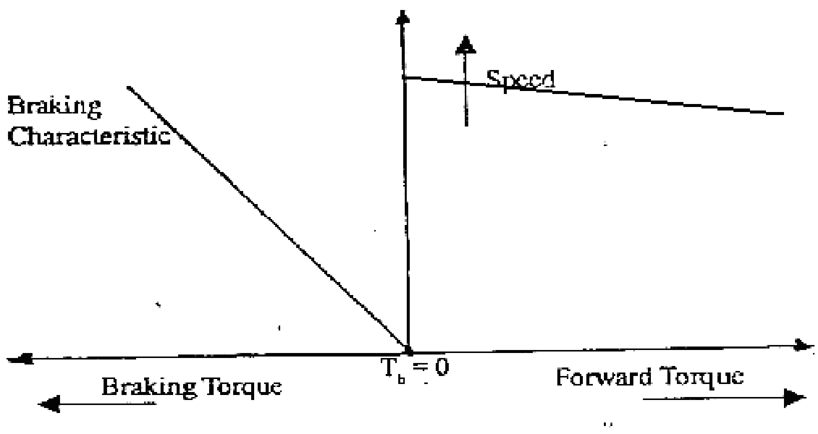


Fig.40. Rheostatic Braking Characteristics of DC Shunt Motor (Separately Exited)

In case of DC series motor, flux varies with the I_a because the armature current passes through field winding. Hence braking characteristics is non – linear. From shunt motor equation it is clear that at zero speed the torque is also zero.

Advantage of Rheostatic braking

1. When Rheostatic braking is applied the motor is stopped and never accelerates in the opposite direction.
2. The magnitude of braking torque is varied by altering the value of external resistance R.

Disadvantages of Rheostatic braking

1. Kinetic energy of moving system is wasted in the external resistance R. so the efficiency of the system is reduced .
2. in case of failure of electric supply, this method of braking of DC motor becomes ineffective.

(c) Regenerative Braking

Motoring

In a DC machine, when supply voltage is more than the generated back emf, then supply voltage drives current into the armature against the back emf, then supply voltage drives current into the armature against the back emf, Now the DC machine is said to the motoring. During motoring, the machine converts electrical energy into mechanical energy.

Generating

In a DC machine when generated back emf is more than the supply voltage, now the back emf drives the current to supply main. Now the DC machine is said to be generating. During generating, the machine converts mechanical energy into electrical energy. If the machine rotates with speed greater than rated no load speed, then the back emf is more than supply voltage.

Principle of Regenerative Braking

The braking torque produced in regenerative braking depends on the principle of generating action of the DC machine. The motoring machine can be converted into generating machine, only when speed exceeds the rated no load speed. So the braking torque obtained in regenerative braking, only when the speed exceeds the rated no load speed. The speed exceeding rated no load speed only possible in case of lowering loads and overhauling load.

Regenerative braking of DC shunt motor

The regenerative braking takes place in case of overhauling loads. The regenerative braking of shunt motor is shown in fig. when the motor works normally the supply voltage (V) is greater than the back emf (E_b). When the overhauling load acts on the shunt motor, then the speed of the shunt motor exceeds the rated no load speed. Now the back emf (E_b) exceeds the supply voltage (V). The machine now enters generating mode.

The current direction is reversed now (towards the supply mains), as a result regenerative braking torque is produced, due to magnetic drag associated with generating mode. The speed of the machine is reduced till it reaches the rated no load speed. When the speed of the machine reaches rated no load speed, back emf is no longer greater than supply voltage and the machine re-enters into the motoring mode. Therefore the regenerative braking toque is automatically generated when the over hauling load increases the speed of the motor above rated no load speed.

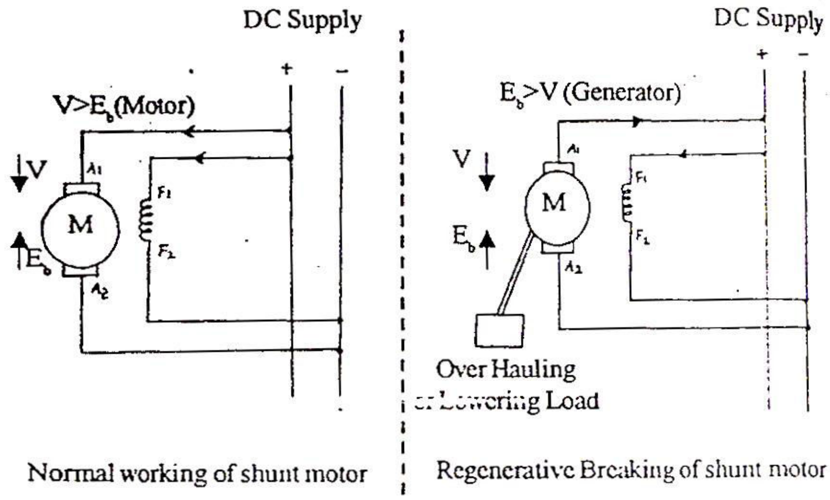


Fig. 41.Connection Diagram of Regenerative Braking of DC Shunt Motor

Regenerative braking of DC series Motor

In series motor the armature and the field, both present in the san circuit. Here the armature current is equal to the field current. When the over hauling load increase the speed of the DC motor, the back emf also increase. So the current also flow through the field windings the flux is also decreases. Due to decrease in flux, it is clear that the back emf never exceeds the supply voltage. So there is no possibility of motor entering into the generating mode. So there is no chance of regenerative braking torque. It is clear from the above discussion that Regenerative braking is not possible in case of DC series motor.

The DC series motor in practice is subjected to over hauling loads, as in the case of hoist (lowering load) and traction (when descending the mountain). So the regenerative braking can be obtained in the DC series motor by separately exciting the series field winding. This method of separately exciting DC series motor to obtain Regenerative braking. Now the Back emf (E_b) exceeds the supply voltage (V), as a result the machine enters into generating mode. The current direction is reversed now (towards the supply mains), as a result regenerative braking torque is produced, due to magnetic drag associated with generating mode. The speed of the machine is reduced till it reaches the rated no load speed. When the speed of the machine reaches rated no load speed, back emf is no longer greater than supply voltage and the machine reenters the motoring mode.

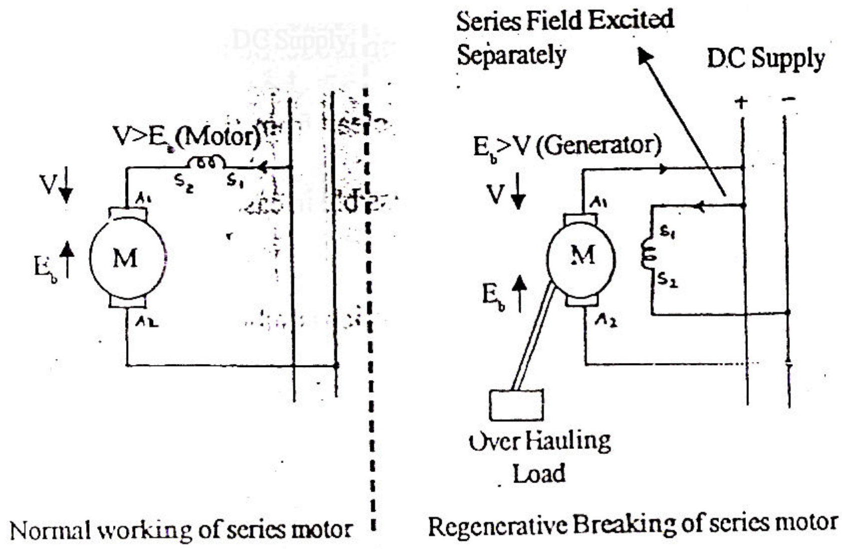


Fig.42. Regenerative Braking Characteristics of DC Shunt motor.

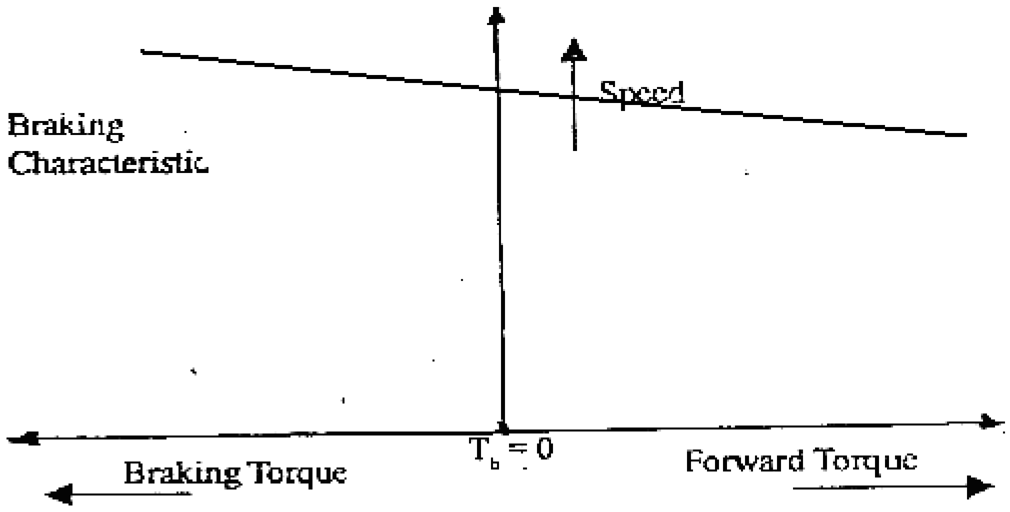


Fig.40. Regenerative Braking Characteristics of DC Shunt Motor
(Separately Exited)

Advantages of Regenerative Braking

1. This method of braking is the most efficient when compared to other methods, because kinetic energy of rotating mass is not wasted and it is returned back to the supply due to regeneration.
2. during braking, no energy is consumed from the supply, but energy is send back to supply.
3. this method does not required power dissipating Rheostat, as in the cse of dynamic braking. So the efficiency is increased.

2.A 220V , 500 RPM , DC shunt motor with an armature resistance of 0.08 ohm and full load armature current of 150A is to be braked by plugging . 1)Estimate the value of resistance to be placed in series with armature to limit the initial braking current of 200A.2)What would be the speed at which electric braking torque is 75% of its initial value.

Solution

$V = 22V$, $N = 500$ rpm, $R_a = 0.08\Omega$, $I_a = 150A$

I) During plugging braking current, $I_{ab} = \dfrac{V + E_b}{R_a + R}$

Where R is the additional resistance.

Back emf $E_b = V - I_a R_a$

$= 220 - 150 \times 0.08$

$= 208$ V

Voltage across armature during brakign $= V + E_b$

$= 220 + 208$

$= 428$ V

To restrict initial braking current to $I_{ab} = 200$ A the resistance required is

We know that $I_{ab} = \dfrac{V + E_b}{R_a + R}$

Therefore, $R + R_a = \dfrac{V + E_b}{I_{ab}}$

$= \dfrac{428}{200}$

$R + R_a = 2.14\ \Omega$

$R = 2.14\Omega - R_a$

$= 2.14 - 0.08$

$R = 2.06\ \Omega$

2) Let Speed at braking torque be N_2 = 75% of initial value

In shunt motor $T \alpha \phi I_{ab}$ (ϕ is constant)

Therefore $T \alpha I_{ab}$

i.e If the torque is 75% of initial value, current is also 75% of initial value of 200A, i.e. I_{ab} = 75% of 200A, I_{ab} = 150 A

we know that

$$\frac{E_{b2}}{E_{b1}} = \frac{N_2}{N_1}$$

$$E_{b2} = \frac{N_2}{N_1} \times E_{b1}$$

$$E_{b2} = \frac{N_2 \times 208}{500}$$

therefore, Total voltage across armature circuit

$$= V + E_{b2}$$

$$= 220 + \frac{N_2 \times 208}{500}$$

We know that

$$I_{ab} = \frac{V + E_b}{R_a + R}$$

$$150 = \frac{220 + \frac{N_2 \times 208}{500}}{2.14}$$

$$220 + 0.416\, N_2 = 150 \times 2.14$$

$$N_2 = 242.8 \text{ RPM}$$

3.A 220V Shunt motor drives 700N-M torque load when running at 1200 rpm . R_a is 0.08 ohm,$R_f$is 55 ohm. The motor efficiency is 90%. Calculate the value of dynamic braking resistance that will be capable of braking 375 Nm at 1050rpm.

Solution

Given data :

V = 220 V, T_1 = 700N-M, N_1 = 1200 rpm, T_2 = 375 N – M, N_2 = 1050 rpm, n = 90%, R_a = 0.8, R_{sh} = 55 Ω

$$\text{Motor output power} = \frac{2\pi NT}{60}$$

$$= \frac{2\pi \times 1200 \times 700}{60} = 87965 \text{ W}$$

$$\text{Efficiency} = \frac{\text{Motor output power}}{\text{Motor input power}}$$

$$\text{Motor input power} = \frac{\text{Motor output power}}{\text{Efficiency}} = \frac{87965}{0.9}$$

$$= 97740 \text{ W}$$

$$\text{Current drawn by motor} = \frac{\text{Input power}}{\text{Voltage}}$$

$$= \frac{97,740}{220}$$

$$I_L = 444\text{ A}$$

$$\text{Shunt field current } I_{sh} = \frac{\text{Supply voltage (V)}}{\text{Shunt field resistance } (R_{sh})}$$

$$= \frac{220}{55}$$

$$I_{sh} = 4\text{A}$$

We known that, $I_L = I_a + I_{sh}$

$$I_a = I_L - I_{sh}$$

$$I_a = 444 - 4 = 440\text{ A}$$

i.e. $I_{sl} = 440$ A

Therefore $E_{b1} = V - I_a R_a$

$$= 220 - 440 \times 0.08$$

$$= 216.5\text{ V}$$

$T_1 \alpha I_{al}$, $T_2 \alpha I_{a2}$, (because ϕ is constant)

Therefore

$$\frac{T_2}{T_1} = \frac{I_{a2}}{I_{a1}}$$

$$I_{a2} = \frac{T_2}{T_1} \times I_{a1}$$

$$I_{a2} = \frac{375 \times 440}{700}$$

$$I_{a2} = 236\text{ A}$$

We know that

$$\frac{E_{b2}}{E_{b1}} = \frac{N_2}{N_1}$$

$$E_{b2} = \frac{N_2}{N_1} \times E_{b1}$$

$$E_{b2} = \frac{1050}{1200} \times 216.5$$

$$E_{b2} = 189.4\text{ V}$$

$$E_{b2} = V - I_{a2} (R_a + R)$$

Where R_h is rheostatic braking resistance since armature is disconnected from the supply V = 0 during braking

Therefore $E_{b2} = I_{a2} (R_a + R_h)$

$$189 = 236 (0.08 + R_h)$$

$$R_h = 0.794\ \Omega$$

Electrical braking Methods of AC motor (Induction motor)

The braking methods that are applied to DC motors are also applied to AC motors, particularly 3ϕ induction motor. The braking methods are

1. Plugging or Reverse Current Braking
2. Dynamic or Rheostatic Braking and
3. Regenerative Braking

(a) Plugging or Reverse Current Braking of 3ϕ Induction Motor

Plugging incase of 3ϕ induction motor is obtained by interchanging any of the two phases, out of the three phases. There are three phase terminals in 3ϕ induction motor and it is represented by R, Y and B. The order in which, these phases progresses is known as Phase sequence. The phase sequence determines the direction of rotation and torque. The normal working induction motor is shown in Fig. The phase sequence applied is RYB and the motor rotates in Clockwise direction. The Plugging or Reverse Current Braking is obtained by interchanging supply phase terminals Y and B. Now the phase sequence is changed to RBY. The change is phase sequence from RYB to RYB changes the direction of current and hence the direction of rotating magnetic field. Due to this, direction of torque is reversed and this torque is known as Braking torque. The Braking torque reduced the speed of the motor to standstill. If the supply terminal is not disconnected at this stage, then the braking torque accelerates the motor in the anit clockwise direction. So plugging is accomplished by changing the supply terminals.

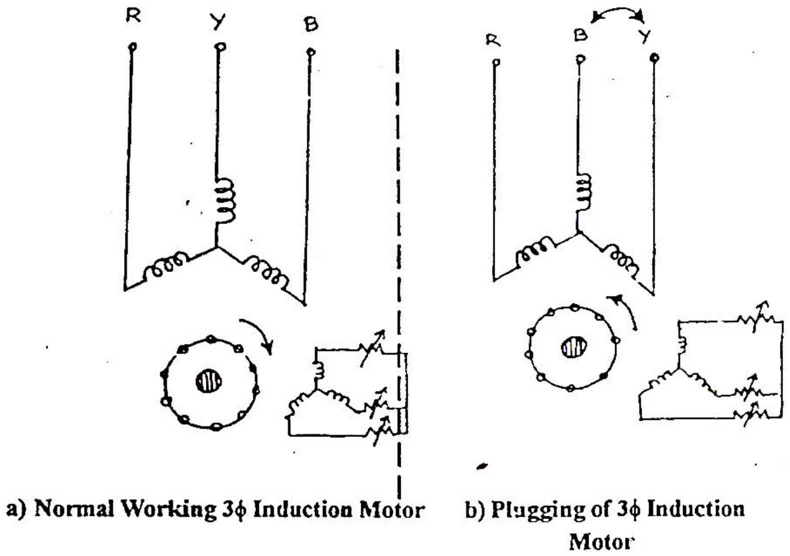
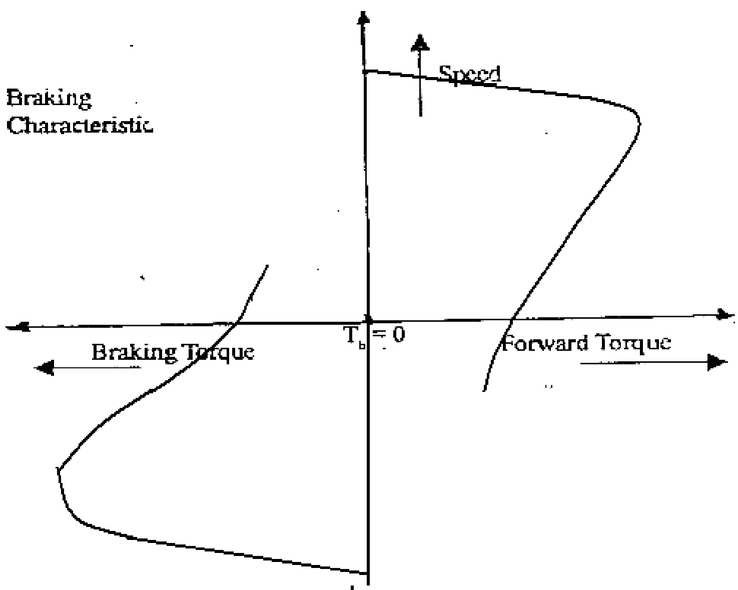


Fig.43. Plugging of 3ϕ induction motor

The reverse current braking characteristic is shown in Fig.. It has two part namely normaly motoring zone before the application of plugging. The Slip = 0 corresponds to Synchronous speed N_s. The induction motor always runs at speed less than synchronous speed. When reverse current braking is applied the braking torque is generated and is shown as braking zone in Fig. The Speed reduced to zero i.e., n = 0 and the corresponding Slip, S = 1



plugging Characteristics of
3 phase induction Motor

b.Dynamic or Rheostatic braking (3ϕ Slip Ring Induction Motor)

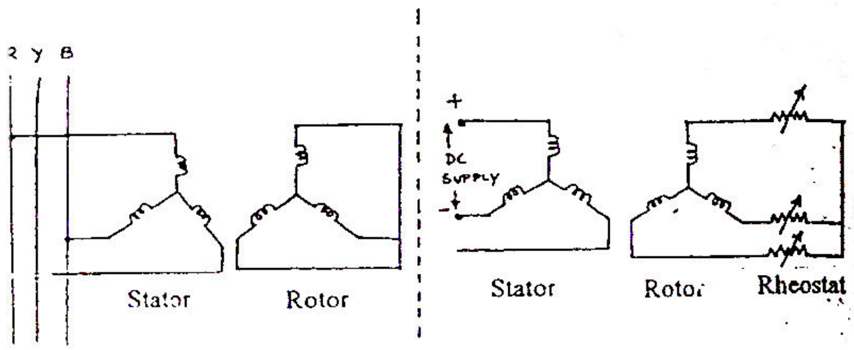
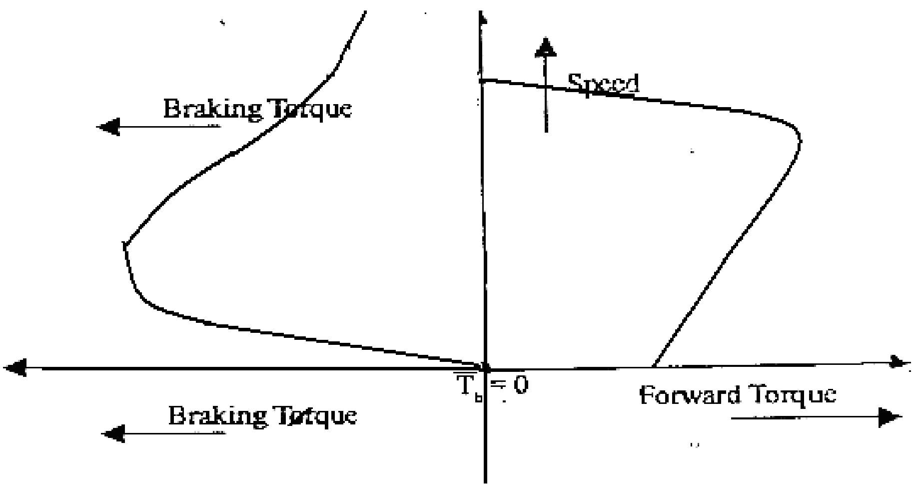


Fig. Normal working Slip ring induction motor Rheostatic braking of Slip ring induction motor

Rheostatic braking is not possible in case of squirrel cage induction motor and is only possible in the case of slip ring induction motor. Here braking is obtained by exciting any of the two stator phase with DC supply and rotor circuit is connected to star connected external rheostat. The braking is accomplished by disconnecting the stator form 3ϕ supply and connecting any of the two phases with DC supply. Simultaneously external star connected rheostat is connected to the rotor circuit through slip rings. Now the start produced constant flux due to DC supply and the rotor is still rotating due to inertia. So emf is induced in the rotor and current flows in such a direction to oppose the cause (speed). So braking torque is produced that results in, stoppage of the motor. The principle of rheostatic braking can also arrived by the fact that the kinetic energy of rotating mass is converted into electrical energy in rotor and it is wasted in star connected rheostat and the motor stops, because the kinetic energy is consumed.



Rheostatic braking Characteristics of 3 phase induction Motor

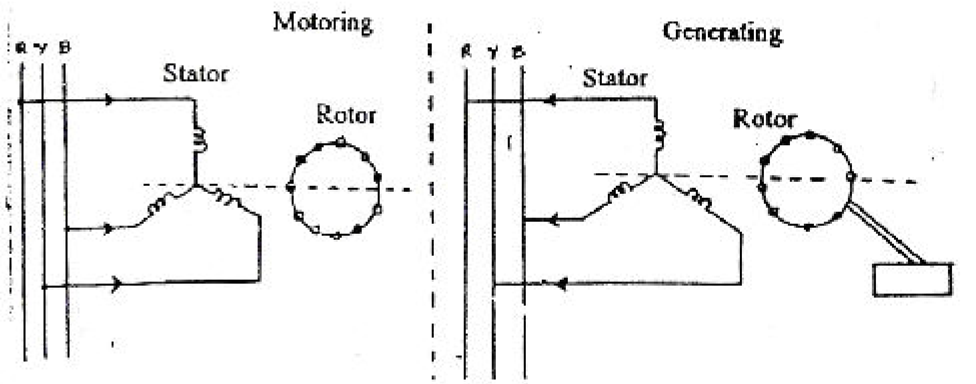
From the braking characteristics it is clear that braking torque become zero, when the motor is stopped i.e there is no holding torque. The magnitude of braking torque is varied by changing the resistance of the star connected rheostat.

(c) Regenerative Braking

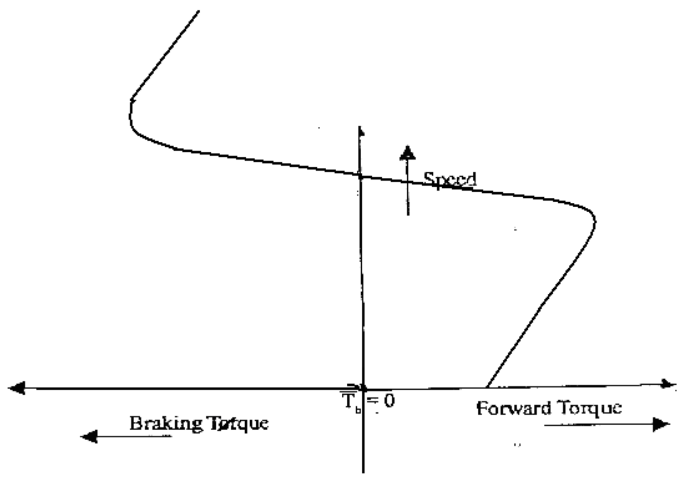
when the induction motor is driving the overhauling load, the speed of the rotor exceeds synchronous speed. Now the induction machine is no larger acts as a induction motor but act as an induction generator. The machine enters generating mode because it is accelerated above synchronous speed by overhauling load. Now the kinetic energy of the rotor is converted into electrical energy in the stator and is given back to the supply mains.

Since the induction machine is in generating mode the torque acts in the rverse direction as that of motoring mode. This is the regenerative braking torque, as when compared to result the speed of the motor is reduced. When the speed is reduced below the synchronous speed the machine re-enters into the motoring mode.

The fig. given below shows normal working induction motor and regenerative braking of induction motor when driven by overhauling load.



Normal Working 3ϕ Induction Motor Regenerative Braking of 3ϕ Induction Motor



Regenerative braking Characteristics of 3 phase induction Motor

The regenerative braking characteristics is shown in fig.. The braking torque characteristics of 3ϕ induction motor is nothing but the generating torque characteristics of 3ϕ induction generator. During braking operation, the slip is negative because the speed exceeds the synchronous speed (slip corresponding to synchronous sped is zero, i.e., S = 0

UNIT 3
STARTING METHODS

Need for starter In case of DC Motor

When the DC motor is directly switched on to the supply it takes huge current. This current will damage the motor, if it is not reduced. The reason for huge current is explained below.

The voltage equation of DC motor is given by,

$$V = E_b + I_a R_a$$

From the voltage equation, the current drawn by a DC motor is given by

$$I_a = \frac{V - E_b}{R_a} \longrightarrow (1)$$

Where, V – supply Voltage

E_b - Back emf

R_a - Armature resistance

From the above equation it is clear that total voltage across armature is reduced because of back emf. The back emf is generated when the motor rotates. During starting the motor is at stand still and no back emf is developed in the armature (E_b = 0). If fully supply voltage is applied across stationary armature, it draws, it draws a very large current. Now the current taken by the motor is given by,

Equation (1) becomes $$I_a = \frac{V}{R_a} \longrightarrow (2)$$

This is the starting current which is of very large value and capable of damaging the motor. This huge starting current is due to the absence of back emf (E_b). The value of starting current can be estimated from the following rough calculation. For a supply voltage of 440 V and armature resistance of 0.25 Ω the starting current according to equation 92) is I_a = 1760A which is nearly "35 times" of its full load current. This excessive current will below out the fuses and prior to that, it will damage the commentator and brushes in the motor. This initial high current should be restricted. The deice that is used to restrict initial high current (starting current) to a safe value is known as starters. Very small motors are started be connecting them directly to the supply lines, without starter because,

1. Small motor (upto 2 KW) have relatively higher armature resistance than the large motor hence their starting current is not so high.

2. Being small, they have low moment of inertia and hence they speeds up quickly. Here the back emf builds up quickly to restrict the initial inrush of current.

Disadvantages of high starting current

1. Due to high starting current, the supply lines are heavily loaded and huge voltage drop takes place. This affects other consumers connected to that supply lines.

2. Due to very high starting current, the motor generates huge torque and hence damages the load connected to it.

The principle of starter in DC motor

The principle of starter is based on inserting a variable resistor in the armature circuit during starting. This resistor is inserted during starting and removed during running and is known as starting resistor. The starting resistor restricts the initial high current i.e. starting current. The starting resistor causes voltage drop and as a result only part of the supply voltage is applied across the armature. Since the voltage across the armature is reduced the high current taken by the motor during starting is considerable reduced. If starting resistor is connected before the armature and field windings, it reduces both armature current and field current (Flux), as a result the starting torque is also reduced.

So the starting resistor should connected only in the armature circuit. If the motor develops speed, the back emf is increased. So the current taken from the supply main is reduced. Therefore the starting resistor is not required when the motor is running. Usually the starting resistor is gradually removed from the armature circuit, when the motor picks up speed. When the motor reaches rated no load speed, the starting resistor is completely removed from the armature circuit.

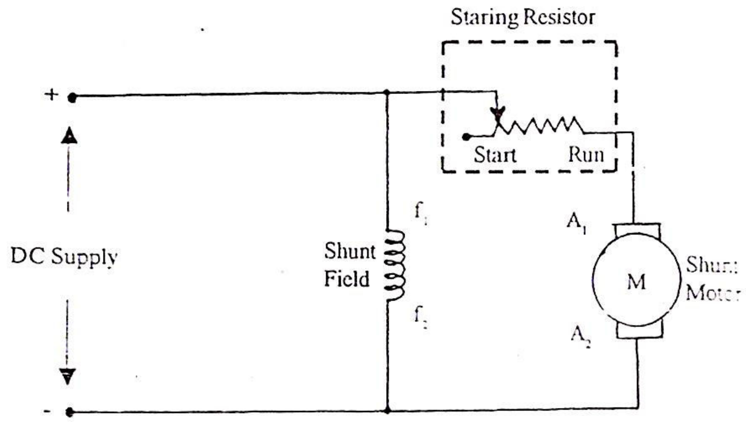


Fig.48. Connection diagram DC motor with Starter

The connection diagram shows the method of connecting starting resistor in the armature circuit during starting. During starting, the movable arm of starting resistor is in the position . When the motor attains rated speed the movable arm is placed in the other end (Resistance, R = 0)

Types of DC motor starters

The starter for DC motor is classified into three types based on number of connection points available in it. They are,

1. Three – point Starter
2. Four – Point Starter
3. Two – Point Starter

The three – point starter is used for starting DC shunt and compound motor. The two-point starter is used for starting DC series motor.

Starter for DC shunt motor and Compound Motor

DC stunt motor and compound motor can be started with three-point starter as well as with four-point starter. The following section deals with Three-point starter and four point starter in detail.

(a) Three-point Starter

The three – point starter consist of the variable resistance, available with number of partitions. It has three connection points namely L,F and A. Hence it is known as three-point starter.

L - Line terminal - Connected with supply mains.
F - Field terminal - Connected with field circuit of DC motor
A - Armature terminal - Connected with armature circuit of DC motor

The supply main is connected to the connection point L. The connection point L is connected to Over Current magnet(OC). The OC is connected with conducting movable arm which makes contact with variable starting resistor. The other end of the starting resistor is connected to the connection point A. The connection point F is connected with the No volt magnet (NV)

Operation

The motor is connected with the starter as shown in the connection. Here the DC shunt motor is connected with the Three-point starter. The supply main is connected with point L. The shunt field (f_1 and f_2) of the motor is connected with point. The armature (A_1 and A_2) is connected with the control spring.

The start the motor, the handle is slowly moved against the control spring force, to make contact with first division (on position) of the variable starting resistance. At this point field winding gets supply through the metal rod and the No-Volt coil is energized. The metal rod forms parallel path with the starting resistance. The this point entire starting resistance is available in the armature circuit. As the handle moved further, it goes on making contact with divisions 2, 3, 4 etc. When starter handle is at division 3, the division to 1 and 2 are removed from the circuit.

If the starter handle reaches Run position, the entire starting resistance is removed from the armature circuit. Now the motor runs at rated speed. The starter is placed in the Run position with the help of No – Volt magnet.

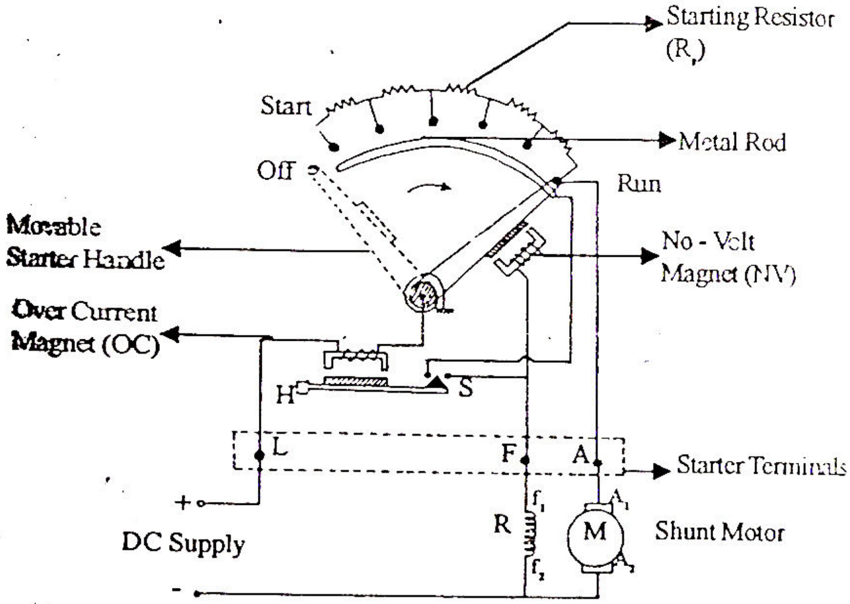


Fig. 49.Typical Control Circuit For starting Shunt Motor Using Three Point Starter

Function of No-Volt magnet (NV)

1. The No-Volt magnet keeps starter handle at run position against the control spring. The No-Volt magnet attracts the soft iron bar place din the handle. The No-Volt magnet is energized by the current flowing through the field circuit. If there is no No-Volt magnet, the starter handle is pulled back to the Off position by the control spring and the motor is switched Off.

2. During the failure of DC supply the No-Volt magnet is de-energized so the magnetic power is lost. The handle comes backs to the Off position by the action of control spring, if the No-Volt magnet is not there.

Due to the presence of No-Volt magnet and control spring the starter handle comes backs back to the Off position whenever the supply fails. If there is no control spring then handle remains in the run position when the supply fails. When the supply returns the motor is directly connected to the supply main, developing high starting current.

3. During low voltage condition the No-Volt magnet releases the handle to the Off position and hence protect the motor form low voltage

Function of Over Current magnet (OC)

When the load on motor increases above the rated limit then the armature takes high current. When the motor is left unprotected from this high current, then it is damaged. The over current magnet is used for this protection. When there is high current due to over load or due to short circuit the over current magnet is energized and attracts soft iron rod H. As a result, the soft iron rod H closes the switch S. When the switch S is closed, it short circuits the No-Volt magnet. As a result No-Volt magnet is de-energized and release the starter handle to the Off position. So the motor is switched off and protected from the over current or high current.

Disadvantage of Three point starter

During the speed control of DC shunt motor, using flux control method, the field current is reduced to get speed above the rated speed. Now the No-Volt magnet is de-energized due to reduced field current. This is because No-Volt magnet is connected in the field circuit. Since the No-Volt magnet is de-energized, the handle reaches Off position and the motor is switches Off. This problem can be rectified if No-Volt coil and field circuit are separated. This is done four – point starter, which is described in the following section.

1 . A 10 b h p, 200 V shunt motor has full load efficiency of 8.5%. The armature has a resistance of 0.25Ω Calculator the value of starting current to 1.5 times the full load current. The shunt field current may be neglected.

Solution :

Given :

10 bhp = 10 hp = 10 x 746 W

10 bhp = 7460 W

$V = 200$ V ; $R_a = 0.25\Omega$, $\eta = 85\%$

$I_{st} = 1.5 \times I_a$; let $R_t = R_{st} + R_a$

During Starting the current is given by

$$I_{st} = \frac{V - E_b}{R_a}$$

$$I_{st} = \frac{V}{R_a} \quad (1)\ (\text{Because } E_b = 0 \text{ during starting})$$

Output = Input x Efficiency

= 7460n x 0.85

$$I_a = \frac{\text{output}}{\text{Voltage}} = \frac{7460 \times 0.85}{200} = 43.88\text{A}$$

I_a = Full load current

I_{st} = Starting current

I_{st} = 1.5 x I_a (given)

= 1.5 x 43.88

= 65.33 A

$$\text{From (I)}R_t = \frac{V}{I_{st}} = \frac{200}{65.83}$$

R_t = 3.038Ω

Starting resistance R_{st} = $R_l - R_a$

= 3.038 – 0.25

R_{st} = 2.788 Ω

(b) Four Point Starter

The Three-point starter control circuit cannot be used for speed control of DC shunt motor and compound motor. This is because in Three-Point starter, the No-Volt magnet and field windings are in the same circuit and connected to point F. The four – point starter is the modification of three point starter so that it is used for speed control of DC motor. Hence No-volt magnet and field winding is placed in the separate circuits. The four-point starter has four connection terminals namely L_1, L_2 F and A

L_1 - Terminal that is connected to the supply main

L_2 - Terminal that is connected to the No Volt magnet

F - Terminal that is connected to the field winding of the motor

A - Terminal that is connected to the armature of the motor

Operation

Initially the handle is at Off position. When the handle is placed is division 1 of the starting resistor, the three circuits are connected to the supply mains i.e. No-Volt magnet circuit, field circuit and armature circuit. Now full starting, resistance is in the armature circuit, so the starting current is reduced.

When the handle is placed in the Run position, the No-Volt Magnet attracts the handle and the handle is placed in the Run Position against the action of spring control.

Here the No-Volt magnet which is connected to the L_2 to terminal is directly connected across the DC supply. So this circuit forms the shot circuit. To overcome this problem a resistor is included in the field circuit (F). The field current is reduced to get the speed above the rated speed. Here the No-Volt magnet circuit is not affected because it forms the separate circuit. So the problem of speed control that exist in three point starter is eliminated in the four – point starter. The Typical Control Circuit For starting Shunt Motor Using Four Point Starter.

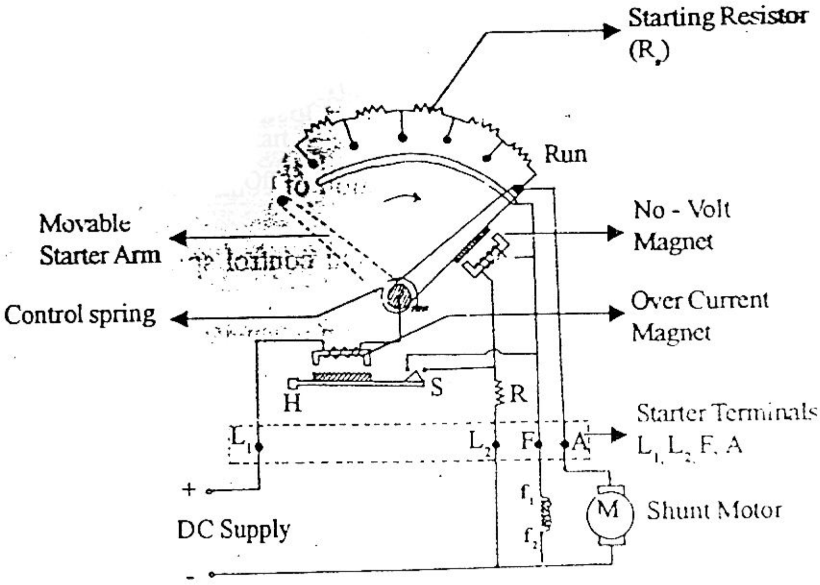


Fig.50. Typical Control Circuit For starting shunt motor using four point starter

Function of No-Volt magnet (NV)

1. The No-Volt magnet keeps starter handle at run position against the control spring. The No-Volt magnet attracts the soft iron bar placed in the handle. The No-Volt magnet is energized by the current flowing through the field circuit. If there is no No-Volt magnet the starter handle is pulled back to the Off position by the control spring and the motor is switched Off.

2. During the failure of DC supply, the No-Volt magnet is de-energized and the magnetic power is lost. So the handle comes back to the Off position by the action of control spring. Due to the presence of No-Volt magnet and control spring, the starter handle comes back to the Off position whenever the supply fails. If there is no control spring, the handle remains in the run position when the supply fails. When the supply returns the motor is directly connected to the supply main, developing high starting current.

3. During low voltage condition the No-Volt magnet releases the handle to the Off position and hence protect the motor from low voltage.

Function of Over Current magnet (OC)

When the load on motor increases above the rated limit, then armature takes high current. When the motor is left unprotected from the high current, then it is damaged The Over Current magnet is used for this protection. When there is high current due to over load or due to short circuit, the over current magnet is energized and attracts soft iron rod H. Now the soft iron rod H closes the switch S. When the switch S is closed, it short circuit the No-Volt magnet is de-energized and release the starter handle to the Off position. So the motor is switched off and protected from the over current or high current.

Disadvantage of Four point Starter

The Four - point starter has only one disadvantage i.e. it does not provide high-speed protection. If the field circuit of the motor suddenly opens, the flux is zero. The speed is inversely proportional to Flux. Since the flux is zero speed becomes infinity theoretically, but practically speed rises to the dangerous limit. This problem is because of the fact that when the field circuit opens the No-Volt magnet is still energized and the motor is not switched Off. But this problem never takes place incase of three-point starter. If field circuit is opened the No-volt magnet present in the same circuit releases the starter handle, so the motor is switched off.

Starters for D.C. Series motor

The DC series motor has armature and field winding connected in series and hence forms the single circuit. So no extra terminal is required for the field circuit. Therefore DC series motor used special kind of starter known as Two-point starter.

Two-Point starter

All the series motor starters are based on same principle of inserting high resistance at starting in series with armature of motor and then gradually removing it when the speed increases.

The DC Series motor should be started with load. When DC series motor is started without load, the armature current is very low. In series motor, armature current is same as field current, so the flux is also very low. The speed of the motor is inversely proportional to the flux. If the flux is very low the speed becomes dangerously high. Hence the series motor should be started with load on it. The DC series motor hence needs the No Load protection besides No-Volt protection. So the two-point state for DC series motor is classified into two types. Namely

1. Two-point Starter with No-Load Protection
2. Starter with No-Volt Protection

(a) Two Point Starter (with No-Load Protection)

The Two-point starter has two terminals namely L and A. The DC series motor has only one circuit that contains armature connected in series with the field winding.

L - Line terminal - Connected with the supply main
A - Armature terminal - Connected with armature of the DC series motor

This starter provides No Load protection for DC series motor.

Operation

Initially the starter handle is in off position. To switch on the DC series motor, the handle is placed at division 1 (On) of starting resistance. Now the entire resistance is included in the series circuit containing armature and field winding. So the initial high starting current is reduced. Now the handle is gradually moved over the various divisions of starting resistance and finally reach the run position, where the entire starting resistance is removed from the series circuit. The handle is kept at Run position, due to the presence of No-Load magnet which is connected in series with the armature and field windings.

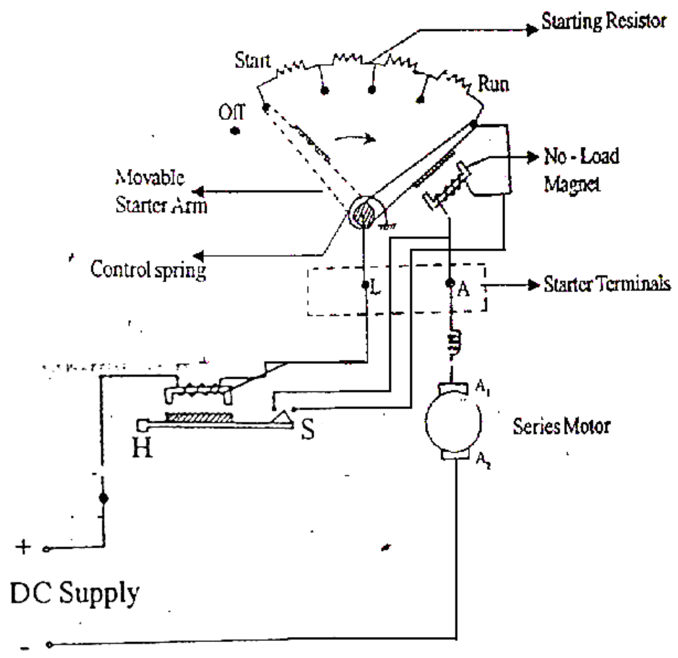


Fig.51.Typical Control Circuit For Starting DC Series Motor
Using Two Point Starter with No - Load Protection

No-Load Protection

When the DC series motor is started without any load, the armature current is very low because of starter resistance. Since the starting current is very low due to the absence of load, the No-Load magnet is not sufficiently energized to attract the starting handle. So if the starter handle is placed at run position it returns back to the off position due to spring action. The DC series motor is now switched off and No Load protection is thus accomplished.

No-Volt Protection

When supply fails, the No-Volt magnet that is connected in parallel across the supply gets de-energized. As a result it releases the starter handle. So the starter handle reaches the off position, protecting the DC series motor from No-Volt. If No-Volt protection is not there, the starter handle remains at Run position. When supply returns the DC series motor is directly connected across the supply producing high starting current.

Disadvantage of Two point starter with No-Load Protection

The two-point starter seen above never provides the No-Volt protection. When the power fails and suddenly returns, the starter handle is at un position. This condition is equivalent to direct switch on of DC series motor. So there will be high starting current.

Need for starter in case of 3ϕ Inducting Motors

The 3ϕ inducting motor has two windings namely stator winding and rotor winding. Stator winding is supplied with 3ϕ supply. The rotor winding ahs conductors whose ends are short circuited. Now a 3ϕ induction motor is considered as transformer whose secondary (rotor) is short circuited. The stator winding is considered as primary or the transformer and the Rotor winding is considered as secondary of the transformer and the Rotor winding is considered as secondary of the transformer. The rotor conductors are short circuited, hence there is heavy rotor current which require corresponding heavy stator balancing current. Thus the stator of the 3ϕ induction motor draws heavy current during starting.

The heavy starting current has value equal to 5 to 7 times of full load current. The small induction motors upto 5 HP capacity may be directly switched on to the supply lines, using the starter called Direct –

on-lines starter. But those of higher capacity must use some type of starting device or starters to restrict high starting current.

The principle behind all starting device is to reduce some amount of voltage applied to the starter winding during starting. The 3ϕ induction motor is of two types, namely squirrel cage induction motor and slip ring induction motor. In squirrel cage induction motor starter can be connected only in the stator side. But in the slip ring induction motor the starters can be connected both in stator side and rotor side.

Starters for 3ϕ squirrel Cage Induction Motor

The 3ϕ induction motor has high starting current due to short circuited rotor conductors. The starters in case of squirrel cage induction motor can be connected only in the stator side, because rotor is short circuited. The small motors up to 5 HP can be directly switched on to the supply using Direct-on-line starter.

1. **Starter Up to 5 h.p**
   a) Direct-on-line starter
2. **Starter above 5 h.p**
   a) Stator rheostat starter
   b) Auto transformer Starter
   c) Star-delt Starter

(a) Direct-On-Line Starter (DOL Starter)

The 3ϕ induction motor below 5 HP can be directly switched on to the supply mains by means of DOL Starter. The motor below 5 HP has high armature resistance and hence has low starting current. Hence the motors up to 5 HP can be directly switched on using DOL Starter. The DOL starter provides protection against No-Voltage and Overload current.

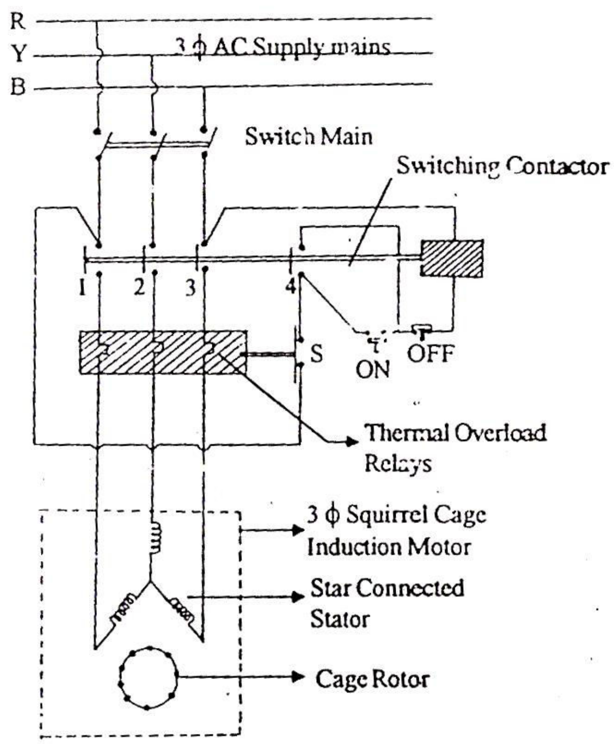


Fig.53. Typical Control circuit For Starting 3ϕ Induction Motor Using DOL Starter

Operation

The 3ϕ induction motor (upto 5HP) is started by means of DOL starter. Typical control circuit for starting 3ϕ induction motor by DOL starter. The induction motor is connected to supply mains through switching main and four normally open contacts. Initially the switching main is closed. The DOL starter consists of a Switching contacts are activated by plunger and No-volt coil arrangement. No-Volt coil is connected through two push buttons (ON and OFF) across any of the two phases of 3ϕ supply. The ON and

OFF button are used to start and stop the motor. These are the manually operated control buttons available in DOL starter. There is a set of thermal relays which is connected in series with stator of induction motor provide overload protection.

To start the motor, the "ON" push button (normally open) is pressed which energize the 'No-Volt Coil' by connecting across two phase. The No-Volt, Coil pulls the plunger is such a direction that all the normally open (N.O) contacts are closed and now the motor is connected across the supply through three contacts. The fourth contact (4) serves as a 'hold on contact', which keeps the no volt coil circuit complete even after the ON Push button is released.

When the supply goes off or when 'OFF' switch (normally closed) is pressed, the No-Volt coil circuit is opened and hence is de-energized, as a result plunger is released. And all the contacts returns to open position thereby, disconnecting the motor from the supply mains. When the motor is overloaded, the thermal over load coil opens the switch S, hence the No-Volt coil circuit is open and plunger is sent back the contacts to normally open position. Thus disconnecting motor from the supply.

Expression for Starting Torque

We know that,

Rotor input = $2\pi N_s T = KT$

Also rotor cu loss = $31_2^2 R_2$ = S x rotor input

Therefore $3I_2^2 R_2 = RKT$

$$T \ \alpha \ \frac{I_2^2}{S} \text{ (if } R_2 \text{ is constant)}$$

Now $I_2 \ \alpha \ I_1$ [If $R_1 = R_2$]

$$T \ \alpha \ \frac{I_1^2}{S}$$

There fore $T = \frac{I_1^2}{S}$

At stating S = 1 ; $T = T_{st}$; $I_1 = I_{st}$

Therefore, $T_s = KI_{st}^2$

Let I_1 = normal full load current and S_f = full load slip

$$\text{Then } T_f = \frac{KI_f^{\ 2}}{S_f}$$

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

When the motor is directly switched on to voltage lines, then starting current is the short circuit current Isc

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

(b) Stator Rheostat (Resistance) Starter

Principle

The basic principle behind the AC induction motor starters is reduction of applied voltage, thereby reducing high starting current. In stator Rheostat starter the voltage is reduced by, inserting the variable resistance in series with each of stator phase during starting

Operation

The variable resistance is connected in series with each stator phases, hence this kind starter is known as stator Rheostat Starter. The 3ϕ induction motor is connected with 3ϕ supply through the Stator Rheostat Starter. Typical control circuit for starting 3ϕ induction motor with stator Rheostat starter. During starting, the slide contact of stator rheostat is in maximum (Max) position. Now entire resistance is included in the stator circuit. So the voltage drop is more at this position of slide contact. The voltage applied to stator phases is reduced due to voltage drop in stator Rheostat. The reduction of stator voltage causes the starting current to decrease.

When the motor picks up speed, the sliding contact is moved from maximum (Max) position to the minimum (Min) position. When the sliding contact of stator rheostat is at the minimum (Min) position, the entire resistance is moved from the stator. Now 3ϕ induction motor is directly connected with 3ϕ AC supply mains. The stator rheostat starter is suitable only for small motors voltage is reduced during starting. This starter can be used for induction motor with both star connected stator and Delta-connected stator. In this starter huge power loss takes place in the stator Rheostat.

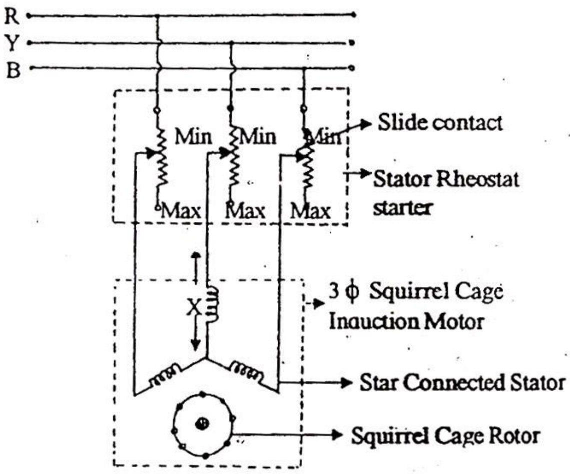


Fig.54. Typical Control Circuit For Starting 3 ϕ Induction Motor Using Stator Rheostat Starter

Disadvantage

1. Since the starting torque is proportional to square of the supply voltage, any reduction in the applied voltage will reduce the starting torque considerably.
2. Though this method of starting is cheapest, yet it is not commonly used because of more power wastage in the rheostat.

Expression for Starting Torque

If X = Fraction of voltage (v) reduced by stator resistors

Then $I_{st} = X I_{sc}$ [$I \alpha V$]

$T_{st} = x^2 T_{sc}$ [$T \alpha V^2$]

$$\frac{T_{st}}{T_f} = \left(\frac{I_{st}}{I_f}\right)^2 x \; S_f = \left(\frac{XI_{sc}}{I_f}\right)^2 x \; S_f$$

$$\frac{T_{st}}{T_f} = X^2 \left(\frac{I_{sc}}{I_f}\right)^2 x \; S_f$$

This method is suitable for starting only small motor. The torque is also reduced based on value of fraction X.

2 . A small induction motor has hsort circuit current of 5 times of full load current and full load slip is 5% . Calculate starting torque and stator current, if stator resistance starter' is used to reduce the voltage across stator winding to 60% of normal voltage.

Solution :

Give, X = 0.6, $I_{sc} = 51 = 51_p$ $S_f = 0.05$

i) Starting current ,

$I_{st} = 0.6 \; I_{sc}$

$= 0.6(51_f)$

$I_{st} = 3I_f$

ii) **Starting Torque**

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

$$= (0.6)^2 \times (5)^2 \times (0.05)$$

$$\frac{T_{st}}{T_f} = 0.45$$

$$T_{st} = 0.45\ T_f$$

(c) Auto Transformer Starter

Principle

A 3ϕ Star-connected Autotransformer is used to reduce the voltage applied to the stator of the 3ϕ induction motr. Such starter is known as Autotransformer starter. The primary winding of Autotransformer is supplied with 3ϕ voltage from the supply mains. The secondary of Autotransformer produce reduced variable voltage.

Circuit connections

An Auto-transformer is connected between 3ϕ supply mains and 3ϕ squirrel cage induction motor. The primary (P) of the autotransformer is connected with the 3ϕ supply mains through a change over switch. The secondary (S) of the autotransformer is connected with the 3ϕ induction motor through change over switch.

The change over switch has two positions namely, Start and Run. When the change over switch is in Start position, the 3ϕ induction motor is connected to 3ϕ supply mains through autotransformer. When the change over switch is in Run position, the 3ϕ induction motor is directly connected to the 3ϕ supply mains. i.e., Auto transformer is removed.

Operation

To start the 3ϕinduction motor the change over switch is kept is Start position. Now the 3ϕ induction motor is connected to 3ϕ supply mains through Autotransformer. The voltage is reduced in the Auto-transformer and it depends upon on position of slide contact available in the transformer and this position decides transformation ratio (K). If the transformation ratio is 0.5, then half of the voltage applied to the primary appears across the secondary. This reduced voltage is now applied to the stator of 3 ϕ induction motor, through change over switch. Sincere reduced voltage is applied across the stator, the starting current is reduced to the safe limit.

Once the motor picks up 80% of rated speed, the change over switch can be switched to the Run position. Now the transformer is eliminated from the stator circuit. So 3ϕ induction motor is directly connected to supply mains. Due to this, rated voltage is applied to the stator winding. The motor starts rotating with rated speed. The changing of switch position can also be done automatically by the usage of relays. The power loss is very low in this type of starter. If can be used for both Star and Delta connected motors. This method is used for starting large motors.

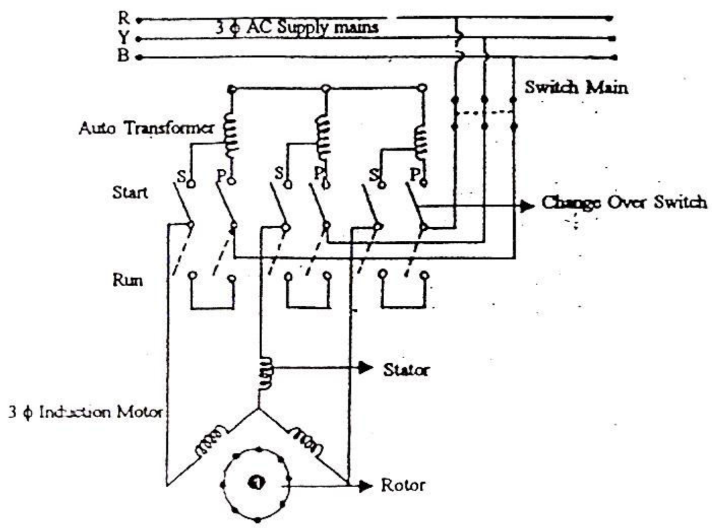


Fig.55. Typical Control Circuit For Starting 3 ϕ Induction Motor Using Auto Transformer Starter

Expression for Staring Torque

Let the motor be started by an Auto-transformer having transformation ratio (K). If I_{sc} is the starting current when normal voltage is applied and applied voltage during starting is KV, then motor input current $I_{st} = KI_{sc}$ (Secondary current)

Supply current = Current of auto transformer

$$KI_{st} = K(KI_{sc}) = K^2 I_{sc}$$

$$T_{st} \propto K^2 I_{sc}^2$$

$$T_f \propto \frac{I_f^2}{S_f}$$

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

If may be noted is similar o the expression obtained for stator rheostat starter except that x has been replaced by transformer ratio K.

3 Find the percentage tapping required on an autotransformer required for a squirrel cage motor to start the motor against ¼ of full load torque. The short circuit current on normal voltage is 4 times the full load current and the full load slip is 3%

Solution

Given : $\frac{T_{st}}{T_f} = \frac{I}{4}$; $\frac{I_{sc}}{I_f} = 4$; $S_f = 0.03$

In auto transformer starter

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

Therefore $$K^2 = \frac{T_{st}}{T_f}\left(\frac{I_f}{I_{sc}}\right)^2 \frac{I}{S}$$

$$K^2 = \frac{1}{4}\left(\frac{1}{4}\right)^2 \times \frac{I}{0.03}$$

$$K^2 = 0.521$$

$$K = 0.722$$

Therefore % Tapping = 72.2%

(d) Star-Delta Starter

The 3ϕ stator winding of 3ϕ induction motor can be connected either in Star of Delta. If it is connected in Star the voltage per phase is reduced by the factor √3. If connected in Delta the voltage per phase is not reduced. During staring the stator windings can be connected in Star to get reduced voltage, hence the starting current is also reduced.

Operation

The Star-Delta starter uses triple pole double throw (TPDT) switch hat connects stator windings of 3ϕ induction motor either in Start or Delta. During starting the switch is in Start position. Now the switch connects stator windings in Star. The phase voltages of Star connected stator windings is reduced by the factor 1 /√3 when compared to the lien voltage. Since the voltage applied to the stator is reduced, the starting current is also reduced.

Once the motor picks up 80% of rated speed the changed over switch can be thrown over to the Run position. Now the switch connects stator windings in Delta. In Delta connection the phase voltage are not reduced and it is equal to the line voltage. So entire supply voltage is applied across the motor. The motor starts rotating with rated speed. The switch can also be operated automatically with the help of relays. This starter is the cheapest of all starters because no special device like rheostat or transformer is included in the circuit. The starter works by simply connecting the stator windings in Star and Delta.

This starter is normally used for 3ϕ induction motor with delta connected stator windings. This starter is used in places where the motor is not started with heavy load.

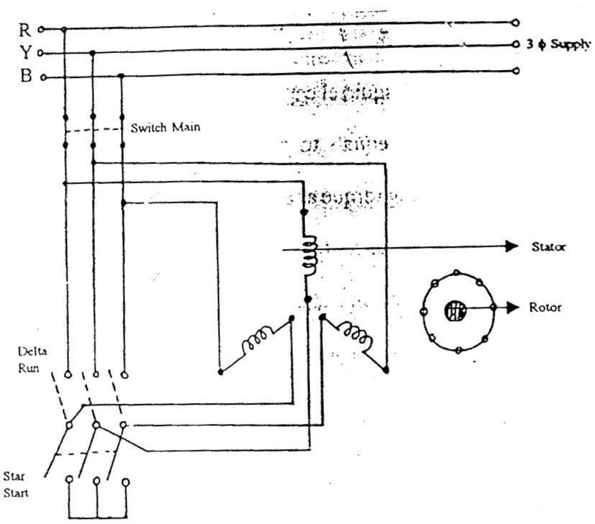


Fig.56. Typical Control Circuit For Starting 3 ϕ Induction Motor Using Star – Delta Starter

Expression for Starting Torque

$$I_{st} \text{ per phase} = \frac{1}{\sqrt{3}} I_{sc} \text{ per phase}$$

Now starting torque $T_{st} \alpha I_{st}^2$

Full load torque

$$\frac{T_{st}}{T_f} = \left(\frac{I_{st}}{I_f}\right)^2 \times S_f = \left(\frac{I_{sc}}{\sqrt{3} I_f}\right)^2 \times S_f$$

Therefore $$\frac{T_{st}}{T_f} = \frac{1}{3} \times \left(\frac{I_{sc}}{I_f}\right)^2 \times S_f$$

5. A 3ϕ squirrel cage induction motor has a short circuit current equals to 4 times the full load current. Find the starting torque as a percentage of full load torque if the motor is starter by

i) Direct-on-line starter
ii) A Star – delta starter
iii) An auto transformer starter, and
iv) Stator rheostat

The stator current in (iii) & (iv) is limited to 2 times the full load current and full load slip is 3%

Solution

Given : $I_{sc} = 4I_p$ $S_f = 3\%$ or 0.03

(i) Starting torque with DOL starter

$$T^{st} = T_f \times \left(\frac{I_{sc}}{I_f}\right)^2 \times S_f$$

$$= T_f \times (4)^2 \times 0.03$$

$$T_{st} = 48\% \text{ of } T_f$$

(ii) Starting with star – delta starter

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

$$T_{st} = T_f \times \frac{1}{3} \times (4)^2 \times 0.03$$

$$T_{st} = 16\% \text{ of } T_f$$

(iii) Starting with Auto-transformer starter

Stator current = supply current = $K^2 I_{sc} = 2I_f$

$$\text{Transformer ration } K = \frac{2I_f}{I_{sc}} = \frac{2I_f}{4I_f} = \frac{I}{\sqrt{2}}$$

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

$$T_{st} = T_f \times \left(\frac{1}{2}\right)^2 \times 4^2 \times 0.03$$

$$T_{st} = 24\% \text{ of } T_f$$

(iv) Starting torque with stator rheostat starter

$$T_{st} = T_f \times \left(\frac{I_{sc}}{I_f}\right)^2 \times S_f \quad (I_{sc} = 2I_r)$$

$$T_{st} = T_f \times \left(\frac{2I_f}{I_f}\right)^2 \times 0.03$$

$$T_{st} = 12\% \text{ of } T_f$$

6 . A 15 BHP metric, 3ϕ, 6 pole, 50 HZ, 400V induction motor runs at 960 rpm on full load. If it takes 80 amps on direct-on-line switching, find the ration starting torque to full load torque in following cases, take efficiency 95.6% and cosϕ (p.f) = 834

a) When started D.O.L
b) When started by star – delta starter
c) When started by auto transformer with 60% tapping
d) When started by stator resistance starter, limiting the starting current to 50 amps.

Solution :

Given : HP – 15 HP = {735.5 (metric) x 15} ; P = 6

3ϕ ; V = 400 V; f = 50 Hz ; N_r = 960 rpm, η = 95.6%

cosϕ = 0.834

Output = 15 Hp

= 15 x 735.5 watts

$$\text{Input} = \frac{\text{output}}{\eta} = \frac{15 \times 735.5}{0.956} = 11540.2 \text{ watts}$$

Let full load current = I_r

Input = $\sqrt{3}\, V_2 I_2 \cos\phi$ = 11540.2

11540.2 = $\sqrt{3} \times 400 \times I_L \times 0.834$

$$I_L = \frac{11540.2}{\sqrt{3} \times 400 \times 0.834}$$

I_L = 20 A

$$\text{Synchronous speed} = N_a = \frac{120f}{P}$$

$$= \frac{120 \times 50}{6} = 1000 \text{ rpm}$$

$$\text{Slip S} = \frac{N_s - N_r}{Ns} = \frac{1000 - 960}{10000} = 0.04$$

a) When started with D.O.L starter

$$\frac{T_{st}}{T_f} = x^2 \left(\frac{I_{sc}}{I_f}\right)^2 \times S_r$$

$$\frac{T_{st}}{T_f} = 1 \left(\frac{80}{20}\right)^2 \times 0.04$$

$$\frac{T_{st}}{T_f} = 0.64$$

b) when started by star – delta starter

$$\frac{T_{st}}{T_f} = \frac{1}{3} \left(\frac{I_{sc}}{I_f}\right)^2 \times S_r$$

$$\frac{T_{st}}{T_f} = \frac{1}{3} \left(\frac{80}{20}\right)^2 \times 0.04$$

$$\frac{T_{st}}{T_f} = 0.21$$

c) When started by auto transformer tarter

$$\frac{T_{st}}{T_f} = K^2 \left(\frac{I_{sc}}{I_f}\right)^2 \times S_r$$

$$\frac{T_{st}}{T_f} = (0.6)^2 \left(\frac{80}{20}\right)^2 \times 0.4$$

$$\frac{T_{st}}{T_f} = 0.23$$

d) When started with stator – rheostat starter

$I_{st} = x\, I_{sc}$

$$x = \frac{I_{st}}{I_{sc}} = \frac{50}{80} = \frac{5}{8}$$

$$\frac{T_{st}}{T_f} = x^2 \left(\frac{I_{sc}}{I_f} \right)^2 \times S_r$$

$$\frac{T_{st}}{T_f} = \left(\frac{5}{8} \right)^2 \left(\frac{80}{20} \right)^2 \times 0.04$$

$$\frac{T_{st}}{T_f} = 0.25$$

Starter For 3ϕ Slip Ring Induction Motor

The 3ϕ slip ring induction motor can be started by all the stator starters used for 3ϕ squirrel cage induction motor. In 3ϕ slip ring induction motor the rotor circuit can be accessed through the slip rings. In 3ϕ slip ring induction motor the rotor circuit has star connected windings. The ends of the three star connected windings are connected to three slip rings. The slip rings can be either short circuited or connected to external resistance. So starter for 3ϕ slip ring induction motor is connected in the rotor circuit. The best example for this type of starter is Rotor Rheostat starter. This is explained in the article given below

(a) Rotor Rheostat (resistances) starters

Principle

The 3ϕ induction motors has short circuited Rotor windings. So the rotor current during starting is very high. If this rotor current is reduced then stator current is also reduced. i.e, the starting current is reduced. The rotor current of squirrel cage induction motor cannot be directly reduced, because rotor current of the slip ring induction motor can be reduced by inserting rheostats through slip ring. As a result stator current, which is nothing but the staring current, is reduced.

Operation

The star connected rheostat is connected to the slip rings in the rotor circuit of 3ϕ slip ring induction motor during starting. As a result the rotor current is reduced. The stator current which depends on rotor current is also reduced i.e., starting current is reduced. The rotor resistance is gradually reduced as the motor picks up speed. When the motor picks up 80% of the rated speed, the slip rings are short circuited i.e, Star connected rotor rheostat is removed. So the motor runs at rated speed. He main advantage of this kind of starter is not only restricting the high starting current, but also increasing high starting torque. This is because starting torque is directly proportional to rotor resistance.

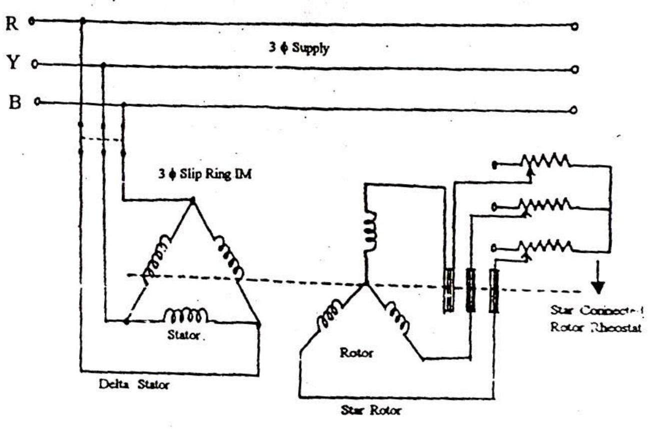


Fig.57. Typical Control Circuit For Starting 3ϕ Slip ring Induction Motor Using Rotor Rheostat Starter

The addition of rotor resistance enables slip ring Induction motor to develop a high starting torque. Hence such motors can be started under heavy load.

1.

UNIT 4

Conventional and Solid – State Sped Control of DC Drives

Conventional Speed Control of DC Drives

The Speed control of DC motor is nothing but maintaining the speed of the DC motor at the required value. The conventional speed control of DC drive deals with, changing the speed of the electric drive motor to the required value, by altering certain factors that governs the speed. The conventional here means manual control of the speed the conventional here also means speed control is achieved without the usage of solid – state devices. The speed of the DC motor can be changed by altering certain factors that governs the speed. These factors can be studied in the article given below.

Base Speed or Rated Speed

The speed in which the motor runs, when applied with the rated voltage and rated field current is known as based or rated speed. The base or rated speed is the reference speed, below and above which the speed of DC motor is required to maintain.

Factors that governs the speed of DC motor

There are certain factors that affect the speed of the DC motor. When the values of these factors are changed by some means, then the speed of the DC motor is also changed. To known the factors governing the speed of the DC moor, the speed equation of the DC motor should be derived.

Speed Equation of DC motor

Consider the voltage equation of the DC motor, which is given by,

$$\mathbf{V = E_b + I_a R_a}$$

Where V – DV supply voltage

E_b – Back emf

$I_a R_a$ – Armature voltage drop

From the above equation the Back emf,

$$\mathbf{E_b = V - I_a R_a}$$

Substituting $E_b = \frac{\phi ZNP}{60A}$ in the above equation we get,

$$= \frac{\phi ZNP}{60A} = V - I_a R_a$$

$$N = \frac{V - I_a R_a}{Z\phi P} = 60A$$

$$N \; \alpha \; \frac{V - I_a R_a}{\phi}$$

The above equation is known as speed equation of DC motor from the above equation it is clear that the speed is directly proportional to voltage across armature (v – $I_a R_a$) inversely proportional to Flux (ϕ) and inversely proportional to Armature Resistance (R_a)

Therefore the factors that affects the speed of the DC motor are

i) Flux (ϕ)

ii) Armature Resistance (R_a)

iii) Voltage across Armature ($V – I_a R_a$ or E_b)

Speed control of DC Shunt Motor

The above article described that the speed of the DC motor can be controlled by varying, Armature Resistance (R_a), Flux (ϕ) and voltage applied to armature. Accordingly the speed control methods are classified into three types namely.

1. Armature or Rheostatic Control (R_a)
2. Flux Control (ϕ)
3. Voltage Control (V)

(a) Armature or Rheostatic Control
Principle

The speed equation shows that the speed of the Dc motor is inversely proportional to Armature Resistance (R_a). If Armature Resistance (R_a) is increased, then the speed (N) is decreased. The method of speed control that is obtained by varying armature circuit resistance by including a rheostat in armature circuit is known as Armature or Rheostatic Control.

Operation

The Speed of the DC Motor is directly proportional to armature voltage (V). If the Resistance of Rheostat is increased, the voltage applied across Armature is reduced. So speed is controlled by adding variable resistance (armature rheostat in series with the armature. This method is used when speeds below the base speed (no-load rated speed) are required.

The field winding is excited by rated voltage, hence the current flowing in field winding I_{sh} is constant. Initially sliding arm of rheostat is kept in minimum (min) position. Now rheostat is not included in the armature circuit. So the full rated voltage is applied to the armature. Now the DC shunt motor is applied with the rated field current and the rated voltage and hence it runs with rated speed (Base speed). When the slider arm of rheostat is moved towards the maximum position, the voltage applied to the armature decreases.

So the speed is reduced from base speed. When the rheostat is in maximum (Max) position, the speed drops to the minimum value as shown in the characteristics curve. The speed is decreased from base speed to the low speed for the movement of slider arm from min to max position. This shows that this method is used to get speed below the base speed i.e., by increasing resistance the speed can only be reduced, because the speed is inversely proportional to armature resistance.

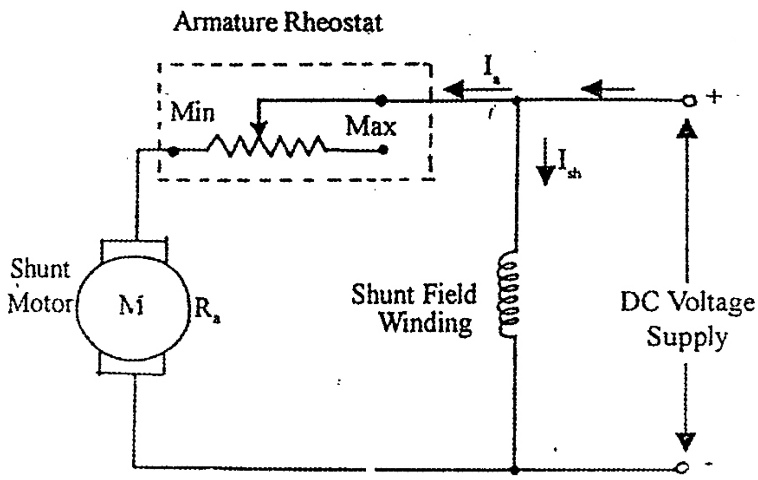


Fig .58..Rheostatic or Armature Speed Control of DC Shunt Motor

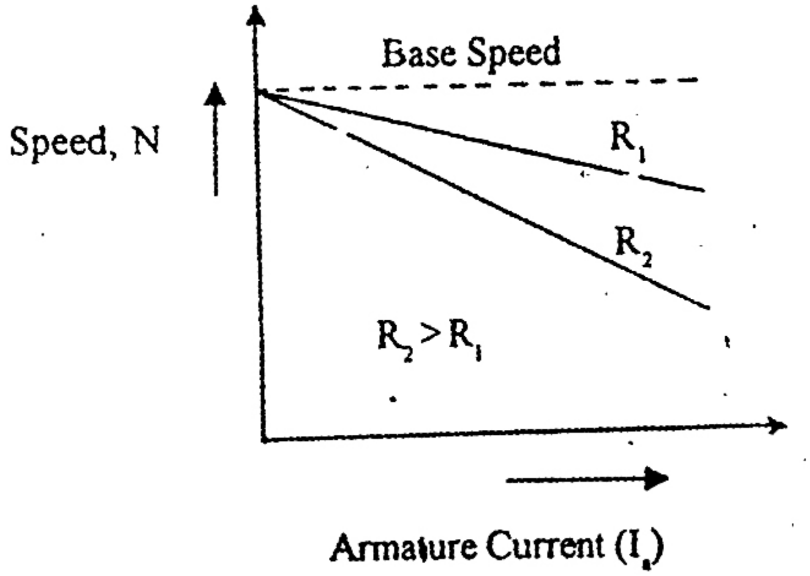


Fig.59. Characteristics of Speed Control of DC Shunt Motor by Armature Control

From speed / armature current characteristics it is seen that greater the resistance in the armature circuit, greater is fall in thr speed.

Advantages

1. Easy and smooth speed control below the base speed is possible.
2. The rheostat in the armature act as a starter during he starting. So the high current during starting can be avoided.

Disadvantage

1. The large amount of power is wasted in the armature rheostat. So the efficiency of this method is poor.
2. The Speeds above the base speed is not possible
3. This method results in poor speed regulation, i.e., the range of speed control is very small.

1.A 200V DC shunt motor running at 1000rpm takes a current of 7.5A.. Its is required to reduce the speed to 60 rpm.what must be the value of resistance to be inserted in the armature circuit if the original armature resistance is 0.4 ohm .

Given :

(Here the variables with suffix 1 denotes the condition before insertion of resistance and suffix 2 after insertion)

$V = 200$ v ; $N_1 = 1000$ rpm ; $I_{a1} = 17.5$ A $= I_{a2}$

$R_a = 0.4$; $N_2 = 600$ rpm ; $R_t = ?$ $R = ?$

Total Resistance of Armature $= R_t =$ Armature Resistance (R_a) + inserted Resistance (R)

We know that

$N_1 \alpha E_{b1}$

$N_2 \alpha E_{b2}$

$E_{bI} = V - I_a R_a$

$= 200 - 17.5 \times 0.4$

$= 193$ V

$E_{b2} = V - I_{a2} R_t$

$= 200 - 17.5 \times R_t$

We know that

$$\frac{N_2}{N_1} = \frac{Eb_2}{Eb_1}$$

$$\frac{600}{100} = \frac{200 - 17.5 R_t}{193}$$

$R_t = 4.8\ \Omega$

We know that,

$R_t = R + R_a$

➔ $R = R_t - R_a$

$= 4.8 - 0.4$

$= 4.4\ \Omega$

additional Resistance inserted = R = 4.4 Ω

(b) Flux Control method

Principle

The speed equation of DC motor shows that the speed (N) is inversely proportional to the Flux (ϕ). So by altering the flux, speed control of required range can be obtained. To change the flux the rheostat is included in the field circuit and hence it is knows as field rheostat. In the field circuit if the resistance is increased, then field current decrease, as a result the flux is also deceases. The decreasing flux gives increases in speed and vice versa.

$$N = K_1 \frac{V - I_a R_a}{\phi}$$

$$N = K_2 \frac{I}{\phi}$$

Operation

The speed control of DC shunt motor by flux control method. At the beginning, the field rheostat is kept at the minimum (min0 position. Now field rheostat is not present in the field circuit. So rated field current I_{sh}, flows in the field circuits. The rated supply voltage is applied to the armature. Now the DC Shunt motor runs at base speed because field is provided with rated field current and armature is provided with rated supply voltage.

Now the field resistance is increased by moving slider arms towards maximum (Max) position, due to which shunt field current decrease. The decreases in shunt field current causes flux to decrease. Since the flux decrease, the speed increases. Already the motor is running with base speed. By deceasing the flux speeds above the base speed is possible. So this method used to cases where speed above the rated speed is required.

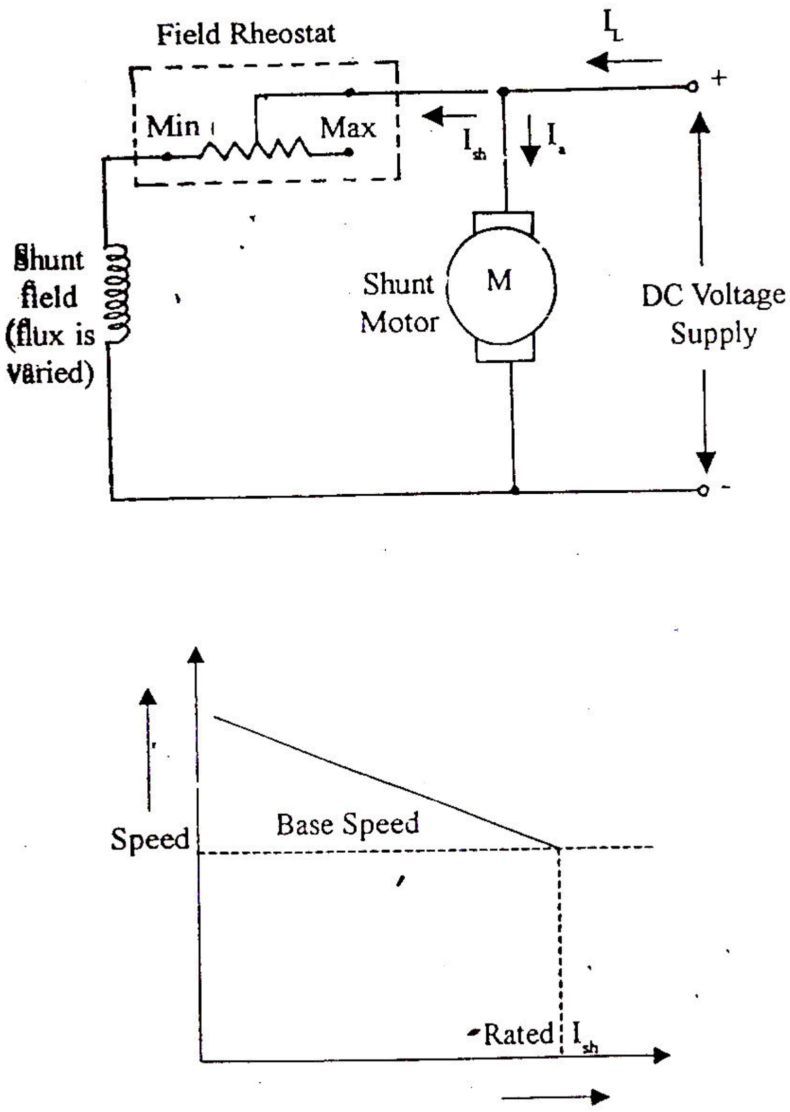


Fig.61. Characteristics of Speed Control By Flux Control

Advantage

1. This is an easy and convenient method
2. speed control above the base (rated) speed is possible
3. since the field current is very low, the size of the field rheostat and power loss is less

Disadvantage

1. The speed control below the normal speed is not possible. Because flux can be only reduced by inserting Rheostat
2. Since the speed obtained is above the rated speed, the motor operation is unstable.

2.A 500V DC shunt motor runs at its normal speed of 250rpm when armature current is 20A. The resistance of armature is 0.12 ohm . Calculate the speed when a resistance is inserted in the field circuit, thereby reducing the shunt field to 80% of normal value and armature current is 100A.

Solution :

Given :

(Here) variables with suffix 2 denotes the condition after the insertion of resistance in the field circuit)

$V = 500$ V ; $N_1 = 250$ rpm ; $I_{a1} = 200$ A ;

$I_{a2} = 100$ A ; $R_a = 0.12\Omega$; $N_2 = ?$

$\phi_2 = 0.8\ \phi_1$

$$E_{b1} = V - I_{a2}\ R_a$$
$$= 500 - 200 \times 0.12$$
$$= 476 \text{ V}$$
$$E_{b2} = V - I_{a2}\ R_t$$
$$= 500 - 100 \times 0.12$$
$$= 488 \text{ V}$$

we known that for shunt motor

$$N_1 \ \alpha \ \frac{E_{b1}}{\phi_1} \text{ (from speed equation)}$$

$$N_2 \ \alpha \ \frac{E_{b2}}{\phi_2} \text{ (from speed equation)}$$

$$\frac{N_2}{N_1} = \frac{Eb_2}{Eb_1} \times \frac{\phi_2}{\phi_1}$$

$$N_2 = 320 \text{ rpm}$$

3.A 250V DC shunt motor has armature resistance of 0.25 ohm.On load , it takes an armature current of 50 A and runs at 750 rpm.If the flux is reduced by 10% without changing the load torque. Find the new speed of the motor

Given :

(Here variables with suffix 1 denotes condition before flux reduction and variable with suffix 2 denotes condition after flux is reduced by 10%)

$V = 250$ V ; $R_a = 0.25\ \Omega$; $I_{a1} = 50$ A ;

$N_1 = 750$ rpm ; $\phi_2 = 0.9\phi\ 1$, $Tt = T2$; $N_2 = ?$

Here flux is reduced by 10%

Therefore $\phi_2 = 0.9\ \phi_1$

We know that

$T_1\ \alpha\ \phi_1\ \ I_{a1}$ and $T_2\ \alpha\ \phi_2\ \ I_{a2}$ (from Torque equation)

Given $T_1 = T_2$

$\therefore \quad \phi_1\ I_{a1} = \phi_2\ I_{a2}$

$\phi_1\ (50) = (0.9\phi_1)\ I_{a2}$

$$I_{a2} = \frac{\phi_1}{0.9\ \phi_1} \times 50$$

$$I_{a2} = 55.6 \text{ A}$$

We know that,

$$\frac{N_2}{N_1} = \frac{Eb_2}{Eb_1} \times \frac{\phi_2}{\phi_1}$$

$$E_{b1} = V - I_{a2}\ R_a$$

$= 250 - 50 \times 0.25$
$= 237$ V

$E_{b2} = V - I_{a2}\ R_t$
$= 250 - 55.6 \times 0.25$
$= 231.1$ V

$$N_2 = \frac{Eb_2}{Eb_1} \times \frac{\phi_1}{\phi_2} \times N_1$$

$$N_2 \times \frac{231.1}{237.5} \times \frac{\phi_1}{0.9\ \phi_1} \times 750$$

$N_2 = 811$ rpm

(c) "Ward – Leonard Method" Or voltage Control Method :

Principle

The speed equation of DC motor shows that by varying the supply voltage, the speed can be controlled. The speed of DC motor is directly proportional to the voltage applied to it. The speed equation is given by,

$$N = K_1 \frac{V - I_a\ R_a}{\phi}$$

$N = K_2 V$ (because R_a and ϕ are constant)

The Ward-Leonard method of speed control of DC motor uses voltage control, i.e., the speed is controlled by varying the supply voltage (V). In this method the variable voltage is obtained from 'Motor-Generator set'

Operation

The shunt field of the Main motor (DC shunt motor) is connected with fixed the DC supply line. Here DC motor (M) and DC Generator (G) forms the Motor # Generator St (i.e MG set). The armature of motor M is connected with the fixed DC supply lined Shunt field of it is also connected with fixed DC supply. So motor M rotate with constant speed. This motor is mechanically coupled with Generator (G). this forms MG set. The armature of the Generator now rotates with the constant speed. The armature of generator (G) is electrically connected with Main motor. The MG set supplies variable voltage to the main motor.

The speed control is obtained by the inserting a field regulator (Rheostat) in the field circuit of the generator (G). by adjusting the field regulator, the flux is varied. Since the generator is rotating at constant speed, the voltage produced by it depends on flux. When the flux is varied by adjusting the field regulator, the variable voltage is produced by generator (G). This variable voltage is applied to armature of main motor. So the speed of the main motor (DC shunt motor) is varied due to variable voltage. Thus the speed is controlled by voltage control in Ward – Leonard Method.

The reversing switch RS is used to reverse the connection of field terminals. As a result voltage generated is also reversed. This reversed voltage when applied to the main motor gives rotation in the opposite direction. Therefore in this method, the speed control is possible in the both the direction.

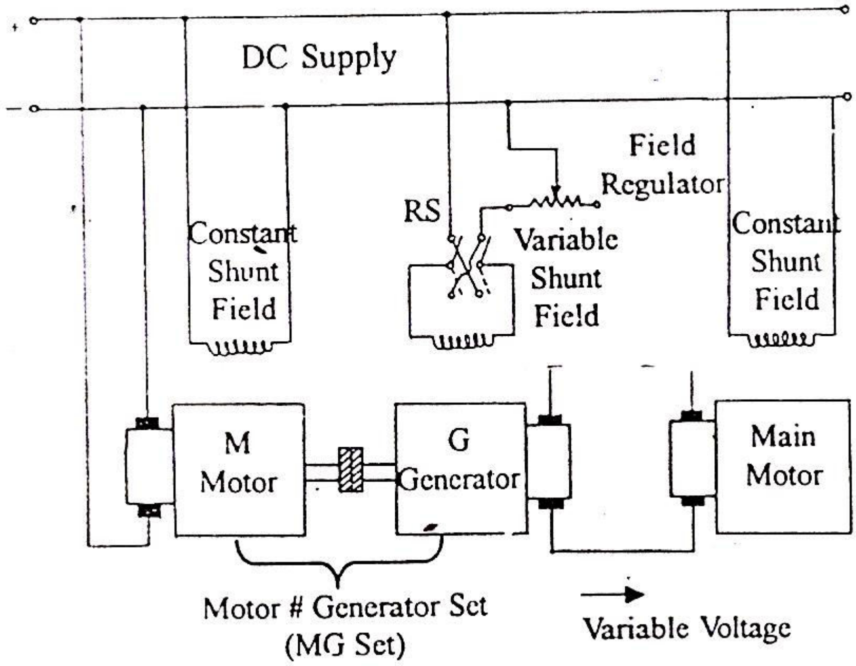


Fig.62. Speed Control By Ward Leonard Method or Voltage Control Method

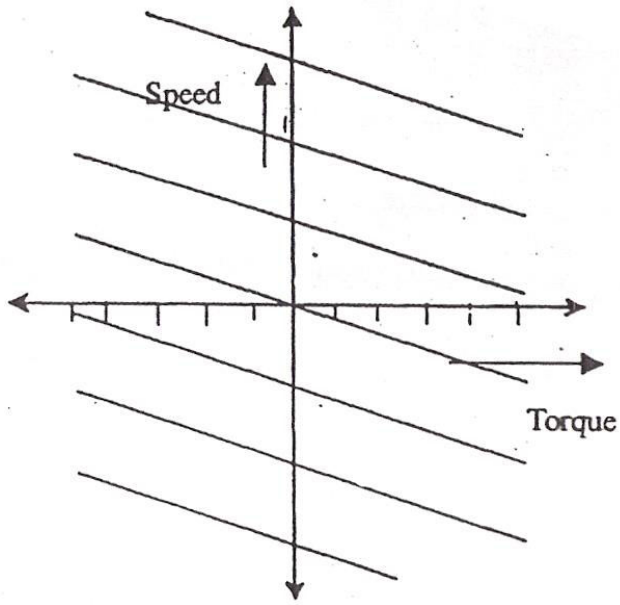


Fig.63. Speed / Torque Characteristic of Ward - Leonard

The characteristics is obtained by choosing various value of field regulator resistance.

Advantages

1. It is possible to achieve lowest limit of speed variation of 5 to 7% of its base speed.
2. Smooth speed control over very wide range is possible.

3. Rapid starting and reversing of the motor without losses in the rheostats are possible.
4. By using RS switch, speed control in both direction is possible.
5. the rheostat is in the field circuit of the generator, so very small current flows through it. As a result power loss is loss.
6. regenerative braking is also possible with this method. This is achieved by suddenly decreasing the generated voltage of the generator, to a value less than the back emf of the main motor. Hence the main motor works as generator. As a result power will be supplied back to the network.
7. In this method speed of the motor is independent of the load on the motor.

Disadvantages

1. The initial cot is high because three machines are required.
2. the efficiency of the speed control is low because there is two stages of power conversion namely, mechanical to electrical (MG set) and electrical to mechanical (Main motor)

speed control of D.C. Series Motor

in DC series motor the armature and field windings are connected in series. In series circuit, the current flowing through each element is same. Soothe same current flows through armature and field. The speed control methods of DC series motor are classifieds into two types namely.

1. Flux Control method
2. Armature Resistance Control

(a) Flux Control Method

In flux control methods the flux can be varied by number of methods. They are,

i) Field Diverter method
ii) Armature Diverter method
iii) Tapped field method
iv) Series / Parallel arrangement of field coils

These methods are explained in the below section.

i) Field Diverter Method

In this method variable resistance is connected in parallel with series field winding, which is known as Field diverter. The speed control method by which the speed of the DC series motor is controlled by varying flux with the help of field diverter is known as field diverter method. The diverter and the series field forms the parallel circuit. This parallel circuit acts as a current divider. So current flowing through the series field is reduced. As a result flux produced by the seires field is also reduced., which makes the speed to increase. If the field diverter resistance is increased then current flowing through series field increases and as a result flux increases. This makes speed to decrease, because speed is inversely proportion to flux increases. The control circuit for field diverter method is shown below. Using this method speed above be speed is possible.

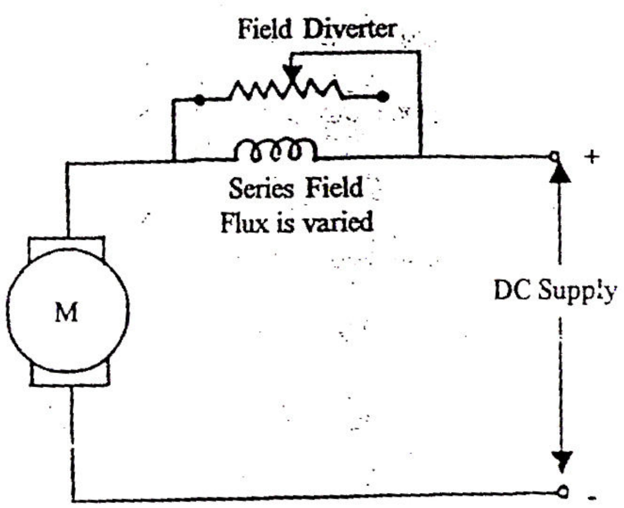


Fig.64. Speed Control Of DC Series Motor By Field Diverter Method

ii) Armature Diverter Method

This method is used for the motors that requires constant load torque. In this method, a variable resistance is connected in parallel with armature, which is known as armature diverter. The speed control of DC series motor using armature diverter is known as armature diverter method. The armature diverter and the armature forms the parallel circuit. So the current flowing thoruhg the armature is reduced. But as T α ϕ I_a, but load torque is constant, so the flux is to be increased. So the motor takes more current from the supply. As a result current through the field winding increases. This cause the flux to increases and speed of the motor to decrease. So this method is used to control the speed below the base speed.

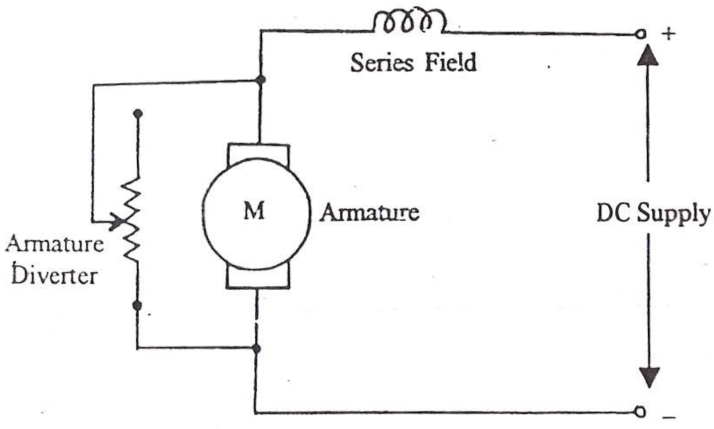


Fig.65. Speed Control Of DC Series Motor By Armature Diverter Method

iii) Tapped Field method

In this method, flux change is obtained by changing the number of turns of the series field winding. Here the series field finding is provided with number of taps. The selector switch S is provided with rotor sliding contact to select the numbers of turns through the taps, as per the requirement. When the switch is placed in position as indicated, the entire field winding is inserted in the circuit an the motor runs with base (Normal) speed.

As the switch is moved towards clockwise direction, the number of turns, that is included in the circuit, is reduced. As a result, the flux is reduced which increases the sped of the motor above the base speed. So this method is used to obtain speed above the base speed. This method often used in electric traction.

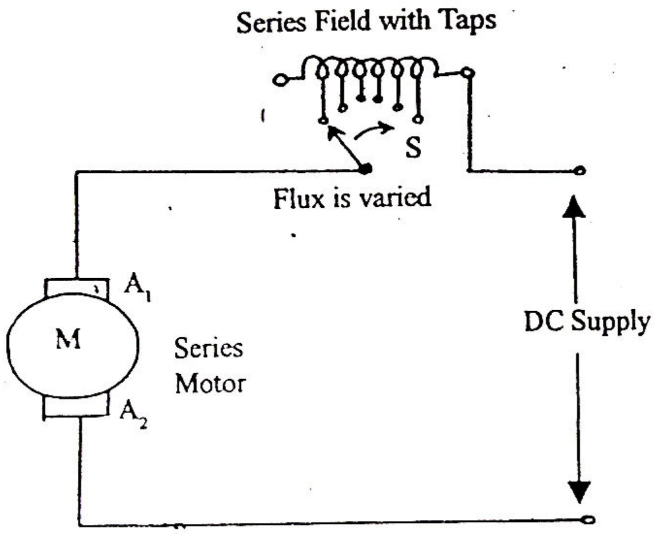


Fig.66. Speed Control Of DC Series Motor By Tapped Field Method

iv) Series / Parallel Arrangement of Field Coils

In this method the field coils is divided into various parts. These divided parts can be then connected in series and parallel as per the requirement. the field coils connected in series. The series connection of the field coil gives lower speeds. In the series circuit is not divided as a result the flux is more and the speed is less.

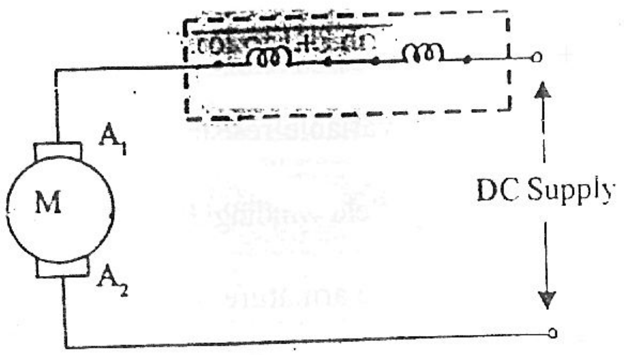


Fig.67. Speed Control Of DC Series Motor By Series Connection Of Field Coils

Below has field coils connected in parallel. The parallel connection of field coils is used to obtain higher speed. The parallel circuit acts as a current divider. So the current flowing through the field coils is reduced. So the flux is reduced. This causes increases in speed because speed is inversely proportional to the flux.

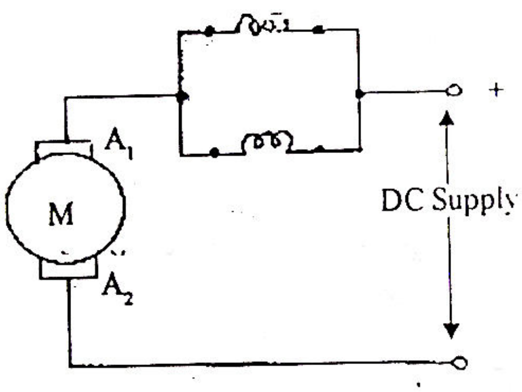


Fig.68. Speed Control Of DC Series Motor By Parallel Connection Of Field Coils

(b) Armature Resistance Control

In this method the variable resistance is connected in series with the armature and series field winding. By increasing the resistance the voltage applied across the armature, the speed is reduced. However, it is noted that entire full load current passes through the variable resistance, so the power loss is high.

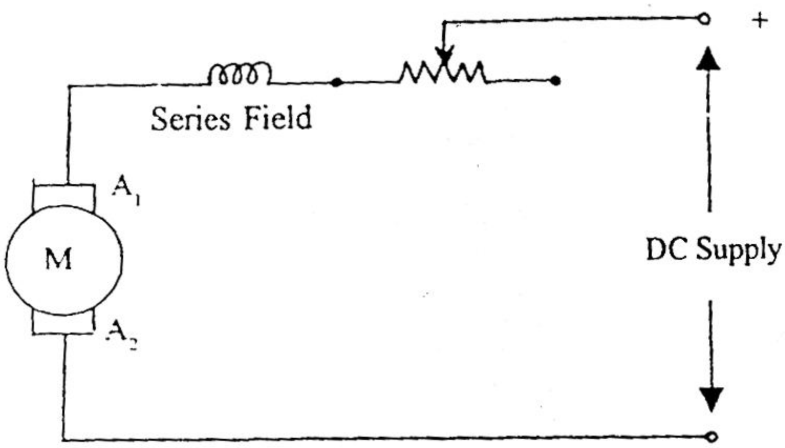


Fig.69. Speed Control Of DC Series Motor By Armature Resistance Control

The speed control of DC drive using solid – state device such as SCR and solid state circuit such as rectifier and chopper is known as Solid-state speed control of DC drives.

Introduction to solid – state devices and circuits for DC Drives

The two important circuits that are used for speed control of DC drives are rectifier and Chopper. The basic speed control method used by DC solid – state drives is voltage control method. Here variable DC voltage is applied to DC motor, to get variable speed. This is known as voltage control. The basic solid-state circuits that are used to get variable DC voltage, are Rectifier and Chopper.

A controlled rectifier is solid – state circuit which is used to convert fixed AC voltage into variable DC voltage. This circuit is normally used when available voltage supply is AC in nature and speed control is to be done on the DC motor.

A DC Chopper is solid – state circuit which is used to convert fixed DC voltage into variable DC voltage. This circuit is namely used when available voltage supply is DC in nature and control is to be done on the DC motor.

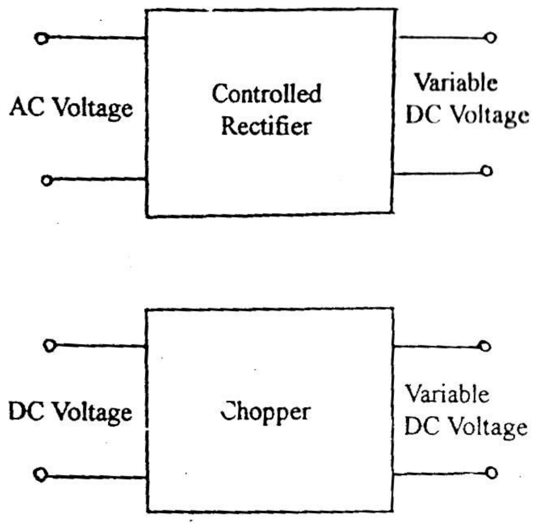


Fig.70. Functional Block diagram of Rectifier and Chopper Circuit

Uncontrolled Rectifiers Vs Controlled Rectifier

A rectifier is solid state circuit that is used to convert AC voltage into DC voltage. Depending upon the nature of the output, rectifier can be classified into two types, namely.

1. Uncontrolled Rectifiers
2. Controlled Rectifiers

The Uncontrolled Rectifiers is used to convert fixed AC voltage into fixed DC voltage. The semiconductor device used here is diode. In order to perform the speed control on DC moors, we need variable DC voltage. By giving this variable DC voltage, we uncontrolled rectifiers (Diode) we cannot control the sped of the DC motor, because it provides only fixed DC voltage.

On the other hand controlled rectifiers is made of Thyristor (SCR), hence output voltage can be varied. Here the output voltage can be varied by varying firing angle of SCR. Firing angle is nothing but the angle from which the SCR starts conducting upto 180^0. This method of varying the output voltage by varying the firing angle is known as **Phase Control**.

The uncontrolled rectifier cannot be used for speed control, because it provide fixed DC voltage at the output. But the controlled rectifier can be used for the speed control, because it provides variable DC voltage at the output.

Speed control of DC Drive Using Controlled Rectifiers (Phase Control)

The Rectifier circuits that uses Silicon Controlled Rectifier (SCR) to convert fixed AC voltage into variable DC voltage is known as Controlled rectifier. The method of obtaining variable DC voltage at the output of controlled rectifier by varying firing angle (α) is known as **Phase Control**.

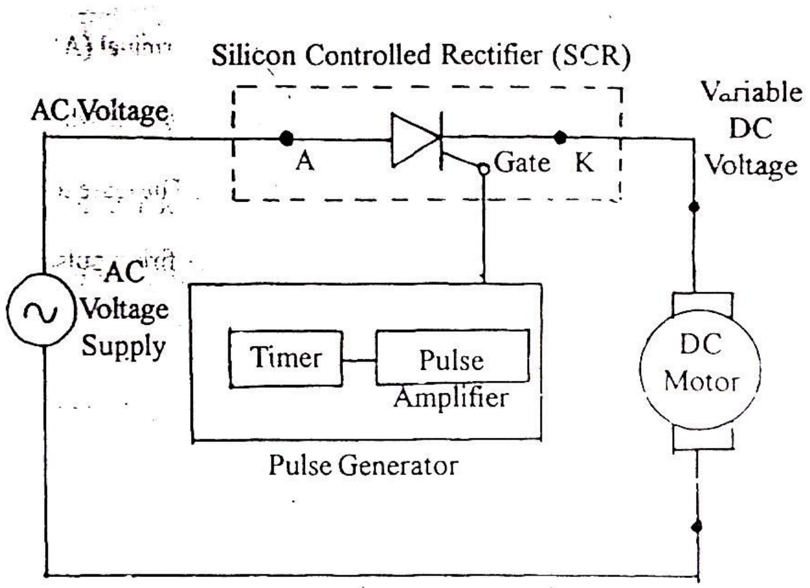


Fig.72. Circuit Connection for Speed Control of DC Motor using Controlled Rectifier (Phase Control)

In phase control techniques SCR conducts after the application of firing pulse upto remaining half cycle. The duration for which SCR conducts after the application of firing pulse upto 180^0 is known as conduction angle (β).

Operation

The connection diagram for speed control of DC motor using phase control technique. The supply is 1ϕ AC voltage . This voltage is connected to the anode terminal (A) of SCR. The cathode terminal (K) is connected to the DC moor whose sped has to be controlled by Phase control technique. The Gate terminals connected with the special circuit that produces firing pulses that is applied at required firing angle (α)

The SCR do not conduct even after the supply of forward voltage applied across the anode terminal and cathode terminal of SCR, but conducts only after the application of Firing or Triggering pulse to the gate terminal of SCR. The firing pulse is applied after certain point (angle) in reference with phase of AC wave and this angle is known as Firing angle (α).

In the waveforms of the input voltage, firing pulse, rectified voltage across the motor and voltage across the SCR of controlled rectifier are shown. During positive half cycle of input AC wave, the SCR is forward biased and it is ready for condition. After the application of firing pulse, SCR conducts in forward direction and current flows through load. The part of voltage after the firing angle appears across the motor load.

During negative half cycle of the input AC wave, the SCR is reverse biased and do not conduct. So the output appears across the motor load is DC voltage because SCR do not conduct in the reverse direction.

It is clear from the above discussion that the voltage applied to the motor load can be varied by varying the firing angle. When the value of firing angle is zero (α = 0) the entire positive half cycle appears across the motor load. When the value of firing angle is 90^0 ($\alpha = 90^0$), the entire positive voltage is blocked and the output voltage is zero.

It is clear from the above discussion that the output voltage applied to the motor load is varied by varying the firing angle in the range of 0^0 to 90^0. by varying the firing angle, the output voltage is varied.

Since the DC voltage applied to the motor load is varied, the speed of the Dc motor is varied. The method of speed control of DC motor obtained by varying the firing angle of the SCR is known as **Phase Control**.

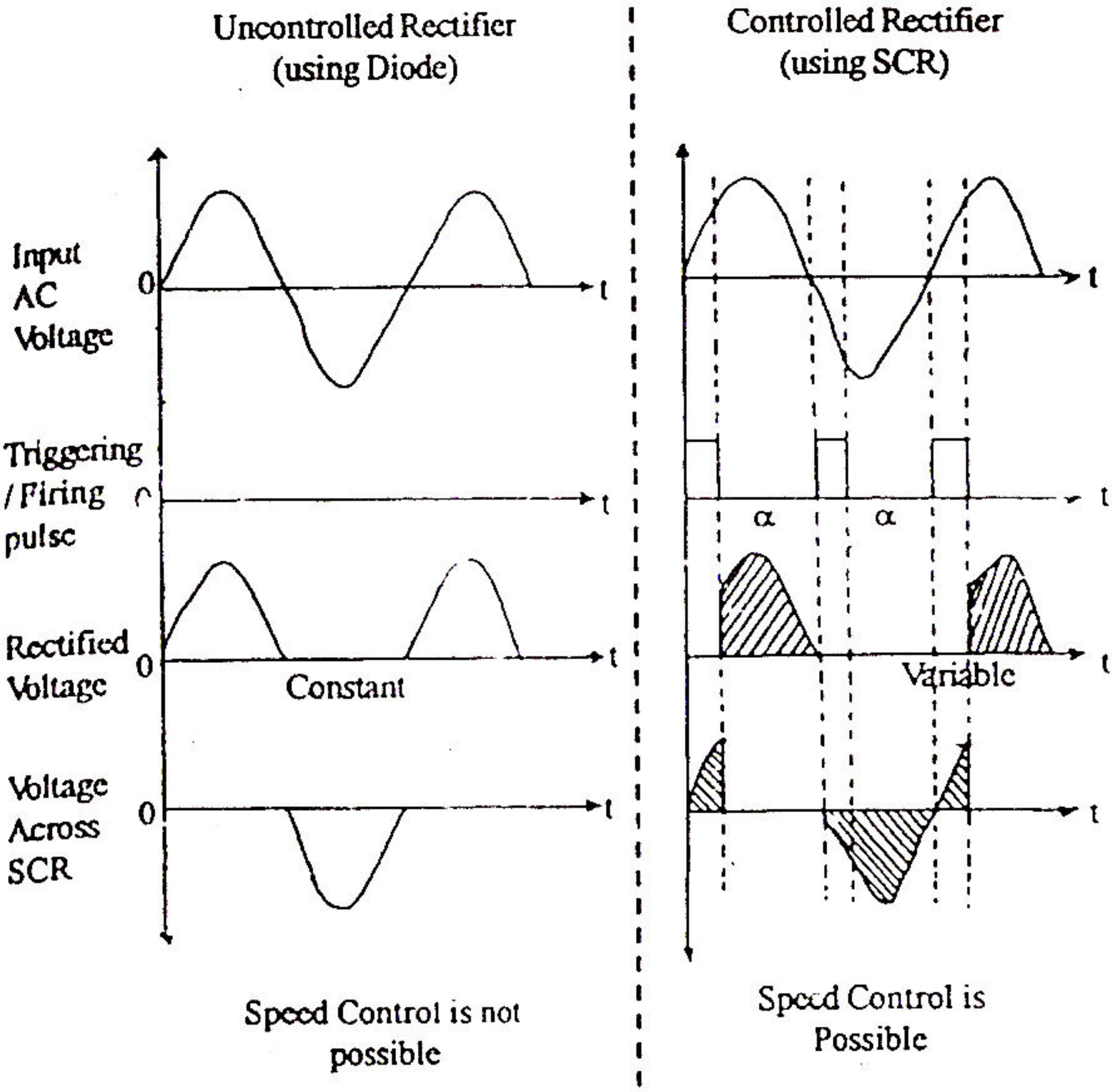


Fig. 73. Waveform Showing Output of Controlled & Uncontrolled Rectifier

The waveforms of the input voltage, firing pulse, rectified voltage across the motor and voltage across both uncontrolled and controlled rectifier is given. The uncontrolled rectifier uses diode and controlled rectifier user SCR.

Types of 1ϕ Controlled Rectifier

The 1ϕ controlled rectifier is classified in two types namely,

1. 1ϕ Half-wave controlled Rectifier
2. 1ϕ Full – wave controlled rectifier
   i. 1ϕ Full – Wave Mid-Point Controlled Rectifier
   ii. 1ϕ Full – Wave Bridge Controlled Rectifier

(a) 1ϕ Half – Wave Controlled Rectifier (Speed control of DC Motor)

A 1ϕ Half-wave Controlled Rectifier is one that converts 1ϕ AC voltage into variable DC Voltage by using only one SCR. This circuit conduct and converts only one half cycle of AC input voltage and do not conduct the other half cycle, hence it is known as Half – wave controlled rectifier. Since this circuit products variable DC voltage, it can be used for voltage control method of speed control of DC motor.

Circuit Connection

The control circuit used for speed control of DC motor using 1ϕ controlled rectifier. The AC voltage supply is connected to SCR through 1ϕ transformer, wich is used to increase or decreases the AC voltage according to the rating of SCR and the motor, whose speed is to be controlled. The AC supply voltage is connected to the primary winding (P) of transformer. The secondary winding (S) of transformer is connected to anode terminal of SCR. The cathode terminal of SCR is connected with the armature of the motor whose speed is to be controlled.

Working

During the positive half cycle of input AC supply the anode terminal A of SCR is positive with respect to cathode K. the AC voltage $e = E_m \sin\omega t$ is now applied to anode of the SCR. Since positive voltage is applied to anode and negative is applied to the cathode, the SCR is forward biased. Now the resistance across SCR is reduced and is very low. So it can conduct in forward direction (from Anode to Cathode). But SCR conducts only when triggering pulse or firing pulse is applied to the Gate (G) terminal. If firing pulse is not applied to the SCR, then it never conducts, even though AC supply is applied across anode and cathode.

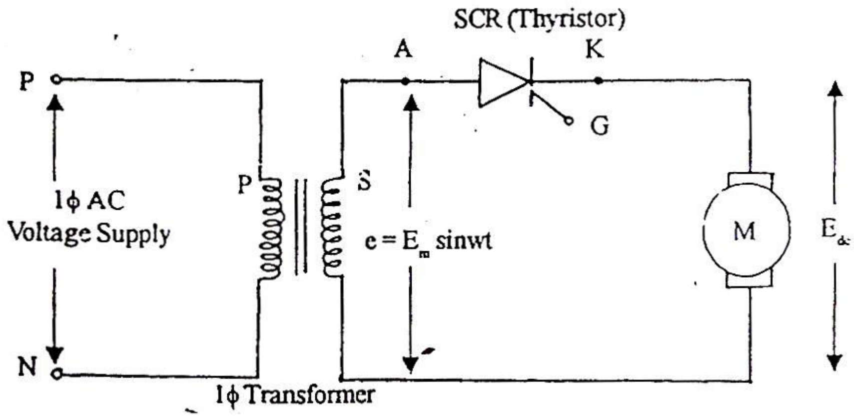


Fig.7 ‹. Control Circuit of 1ϕ Half - Wave controlled rectifier used for speed control of DC Motor.

The angle at which the firing pulse applied is known as firing angle. Now the SCR conducts as long as anode is given positive supply. The value of AC voltage becomes zero, when it reaches 180^0 or π radians. After this point the value of AC voltage becomes negative and SCR never conducts. The SCR therefore conducts from α to β. This angle is known as conduction angle β. During negative half cycle of input AC supply, the SCR never conducts (i.e. from π to 2π) so the current flowing through the load never changes its direction. Rectified DC voltage is applied across the load.

For larger conduction angle the average value of DC voltage across the motor is more. By changing the firing angle, the conduction angle is changed, thereby average value of DC voltage across the motor loaded is changed. So by changing the firing angle the speed of the DC motor can be controlled. It is clear that only one pulse applied to the SCR during one complete cycle so this circuit is also known as Single Pulse converter.

converter.

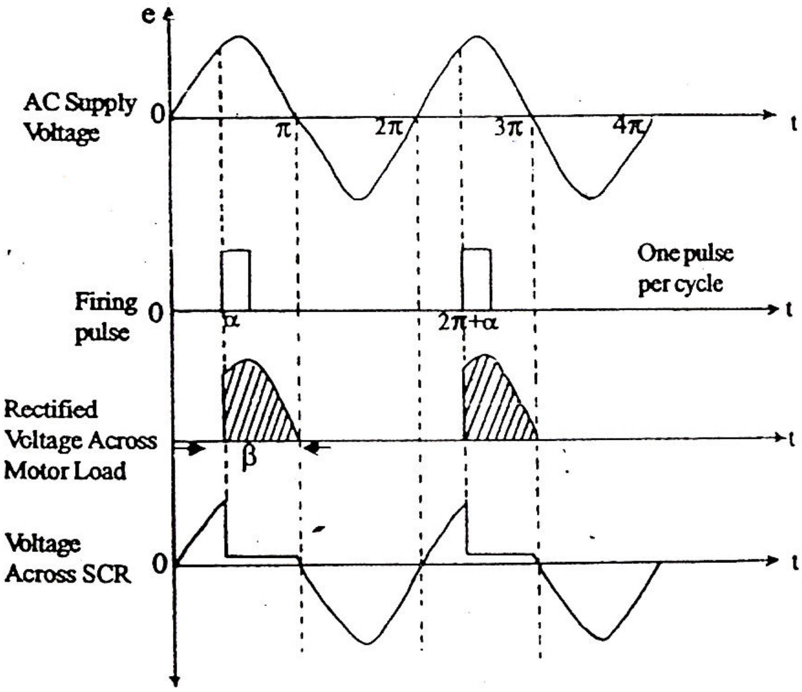


Fig.75. Waveform of a 1ϕ Half - Wave Controlled Rectifier

(b) 1ϕ Full – Wave controlled Rectifier

The rectifier that converts fixed AC voltage into variable DC voltage by utilizing full cycle (both the half cycle) of input 1ϕ AC supply is known as 1ϕ Full – Wave rectifier. Since this circuit uses SCR the output DC voltage can be controlled. Hence it is known as controlled rectifier. There are two basic configurations of full – wave controlled rectifiers. Their classification is based on method of connection the SCRs. They are

1. Mid-Point Converter
2. Bridge Converter

i) 1ϕ Full – Wave Mid-Point Controlled Rectifier

Circuit Connections

This rectifier circuit has two SCR, one SCR is triggered during positive half cycle of input AC wave and the other SCR is triggered during negative half cycle of the input AC wave. The two SCRs are connected across the motor. The AC input voltage is applied to the circuit through special transformer with mid point terminal (N) in the secondary. The mid point terminal (N) is tapped from the center of he secondary of the 1ϕ transformer. This is known as Center – Tapped Secondary. The anode of the two SCRs are connected with two ends of the secondary and one end of the motor load is connected with mid point of the transformer and the other end with cathode of the SCRs. This connection is known as mid point connection or M-2 Connection.

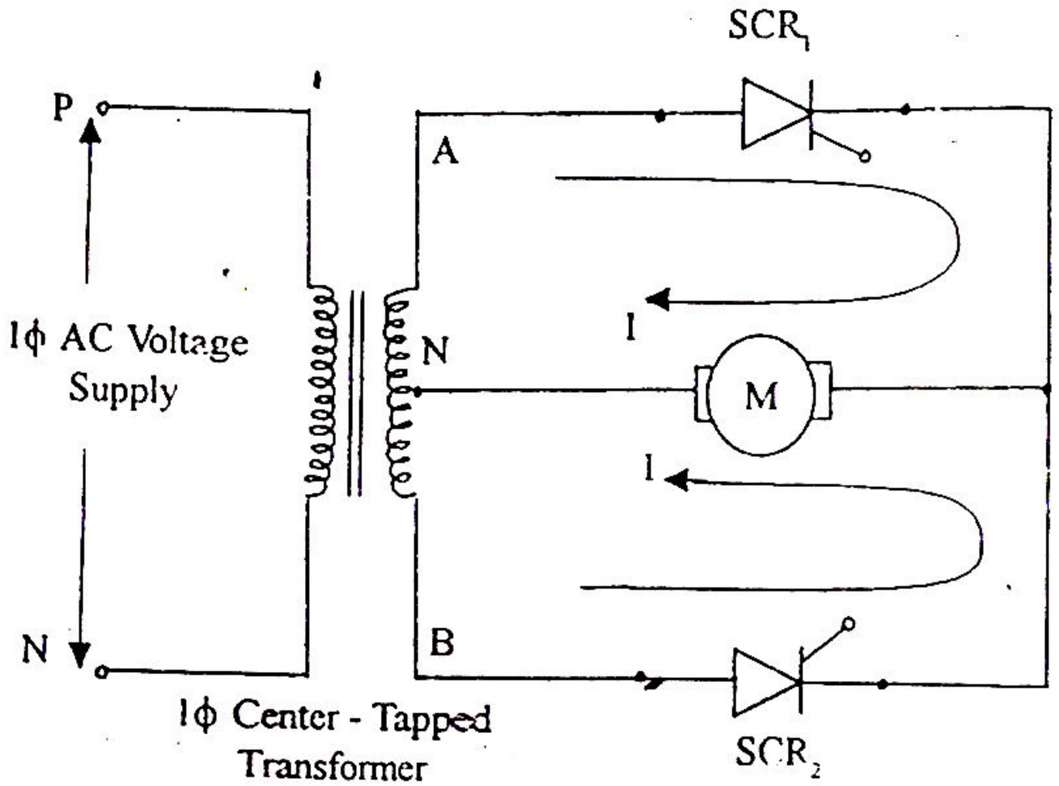


Fig.76. Controi Circuit of 1φ Full - Wave controlled mid point rectifier used for speed control of DC Motor.

Working

During positive half cycle of input AC supply, the terminal A of center – tapped transformer is positive with respect to terminal B. The positive terminal A is connected with SCR_1 and negative terminal with SCR_2. So SCR_1 is forward biased and SCR_2 is reverse biased. The SCR_1 can conduct when triggered by firing pulse and SCR_2 never conducts because it is reverse biased. The current now flows in the path A- SCR_1 – Motor – N. So positive half cycle of input AC supply appears across the motor load, when firing pulse is applied.

During negative half cycle of input AC supply, the terminal B of center – tapped transformer is positive with respect to terminal A. The positive terminal B is connected with SCR and negative terminal with SCR_1. So SCR_2 is forward biased and SCR_1 is reverse biaded. The SCR_2 can conduct when triggered by firing pulse and SCR_1 never conducts becauses it is reverse biased. The current now flows in the path B – SCR_2 – Motor – N. so negative half cycle of input AC supply appears across the motor load.

The above two cases shown that both the half cycle produces the current in same direction through the motor. Os the output voltage is rectified DC voltage. B varying the firing angle, the conduction angles of SCRs are varied. By varying the conduction angle ($\beta = \alpha$ to π) of the SCR, the average value of output DC voltage applied to the motor can be varied. By the firing angle, the conducting angle can be varied. By varying the average value of the DC voltage, the speed of the DC motor can be varied. Thus varying the firing angle can vary the speed of DC motor.

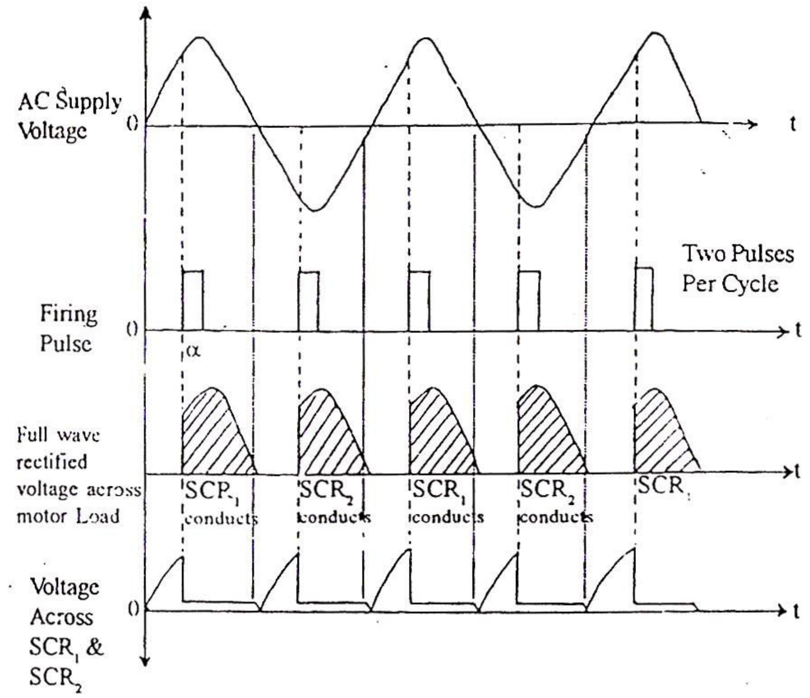


Fig.77. Waveforms of 1ϕ full – Wave Mid-point Controlled Rectifier

It is observed from the above waveform that two triggering or firing pulses are applied during each cycle of the AC voltage, so this circuit is also known as Two pulse converter.

ii) 1ϕ Full – Wave Bridge controlled Rectifier
Circuit connections

The arrangement of four SCR in a manner as Bridge connection. This connection is also known as B-2 connection. The SCR is so connected that, tow of it is forward biased during one half cycle and other tow is reverse biased. This shown that two SCRs are used to rectify each half cycle. In this circuit both the half cycle is rectified by applying triggering pulse and hence it is known as Full – wave rectifier.

Operation

During positive half cycle of input AC voltage the terminal L is positive and terminal A is negative. As a result SCR_1 and SCR_2 are forward biased an dSCR_3 and SCR_4 are reverse biased. So SCR_1 and SCR_2 conducts when triggered by firing pulse and SCR_3 and SCR_4 never conducts because it is reverse biased. Now during certain angle α of the positive half cycle SCR_1 and SCR_2 were given triggering pulses so current flows through the path L-SCR_1 – Motor – SCR_2 – N. So the part of the positive half cycle, after the application of firing pulse at firing angle (α), appears across the motor load.

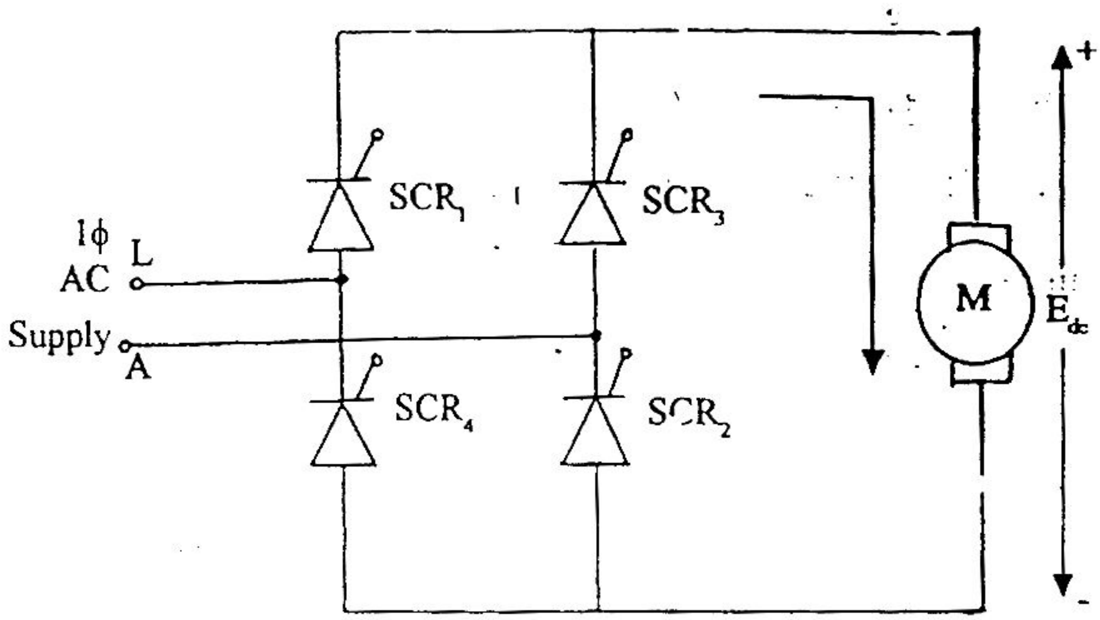


Fig.78. Control Circuit For 1ϕ Full Wave Bridge Controlled Rectifier Used For Speed Control of DC Motor

During negative half cycle of input AC voltage the terminal A is positive and terminal L is negative. As a result SCR_3 and SCR_4 are forward biased and SCR_1 and SCR_2 are reverse biased. So SCR_3 and SCR_4 conducts when triggered by firing pulse and SCR_1 and SCR_2 never conducts, because it is reverse biased. Now during certain angle α of the negative half cycle after the application of firing pulse at firing angle (α), appears across the motor load in the positive direction.

The above two cases shows that both the half cycle produces the current in same direction through the motor. So the output voltage is rectifier DC voltage. By varying the firing angle, the conduction angles of SCRs are varied. By varying the conduction angle $\beta(\alpha$ to $\pi)$ of the SCR, the average value of output DC voltage applied to the motor can be varied. By varying the average value of the DC voltage, the speed of the DC motor can be controlled. Thus the speed of DC motor can be varied by varying the firing angle.

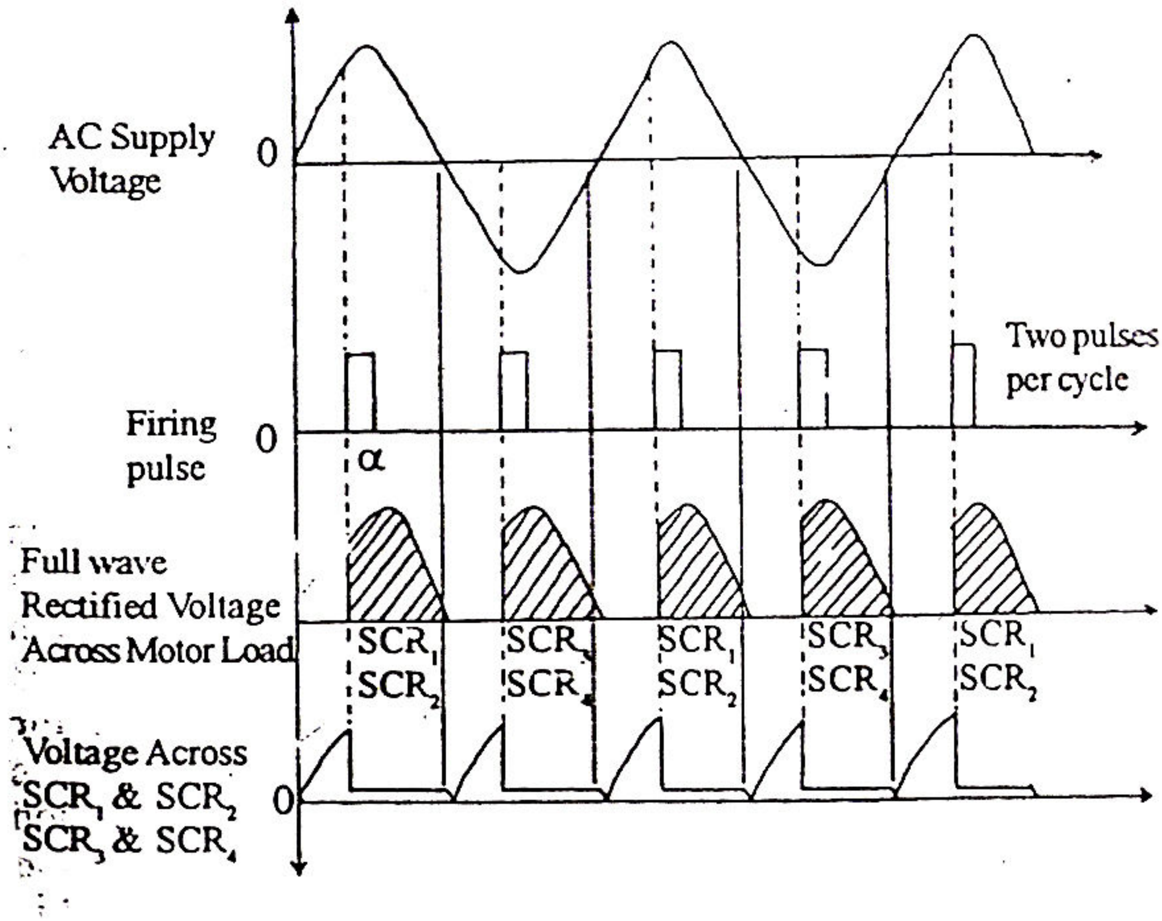


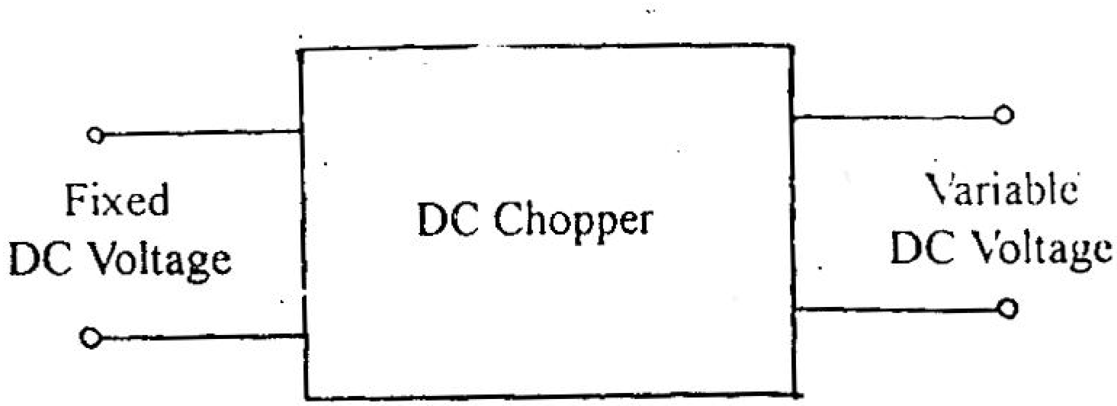
Fig.79. Waveforms of 1ϕ Full – Wave Bridge Controlled Rectifier Used For Speed Control of DC Motor

It is observed from the above waveform that tow triggering or firing pulses are applied during each cycle of the AC voltage, so this circuit is also known as Two pulse converter.

Speed control of DC drive using DC chopper

DC Chopper

A DC Chopper is solid – state circuit that converts fixed DC voltage into variable DC voltage. It is used for the speed control of DC motor because it provides variable DC voltage. This circuit is used when available voltage is DC in nature.



i) Speed control of DC shunt motor using DC chopper
Principle of operation of Chopper

A chopper is a on/off switch with SCr that produces chopped load DC voltage, from constant input voltage. The output DC chopper can eb varied and hence it can be considered as DC equivalent of AC transformer, the chopper is represented by an SCR inside a dotted square. The DC chopper circuit that is used for speed control of separate excited DC motor.

Circuit connections

The DC chopper has a SCR and the communication circuit to control the SCR. The Communication circuit is not shown in the Fig shown below. The SCR with the Fig shown below. The SCR with the communication circuit is collectively shown as dotted square box. The DC supply is applied to the anode of the SCR. When the communication circuit trigger the SCR, the SCR is switched on and conducts. The SCR remains in conduction mode for the duration of time represented by T_{on}. Now the gate of the SCR is controlled by communication circuit and as a result SCR is switched off. This method of switching off is known as forced communication.

Working

During the period T_{on} the chopper is switched on by communication circuit. Now the DC supply is connected to the motor terminal through inductor 'L'. Now the voltage $e_0 = E_{dc}$ is applied across the DC motor load. Now the current flows through the motor.

During the period 'T'_{off} the chopper is switched off by communication circuit. Now the motor is disconnected from the supply by the – Chopper. The load current flows through the 'free wheeling diode' D_F and maintain the direction of current flow as in the conduction period. The free wheeling diode prevents the reversal of current flow back into supply mains. The current through load should not fall to zero hen SCR is not conducting.

As a result, load terminals are short circuited by D_f and load voltage is zero i.e. $e_0 = 0$ during T_{off}. In this manner a chopped DC voltage is produced at motor terminals.

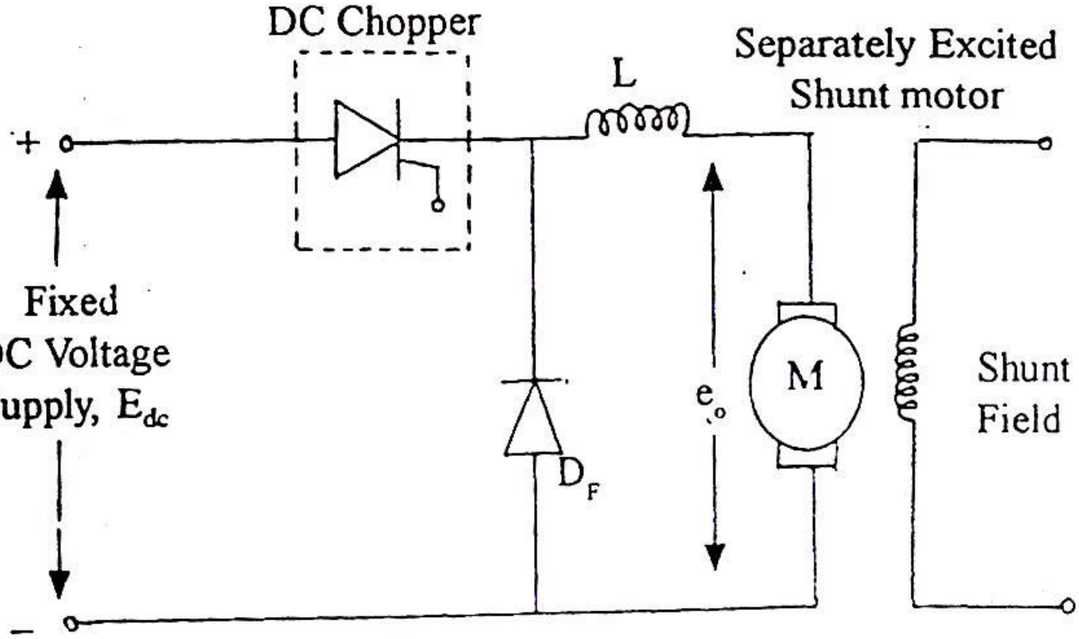


Fig.80. Control Circuit For Speed Control of Separately Excited DC Shunt Motor Using DC Chopper

The inductor allows the current to vary slowly. This property of the inductor never allows the current to fall zero even when load voltage is zero and SCR is off. If the motor current becomes zero then torque produce by it is also zero. This produce vibration and damages the load connected to the motor.

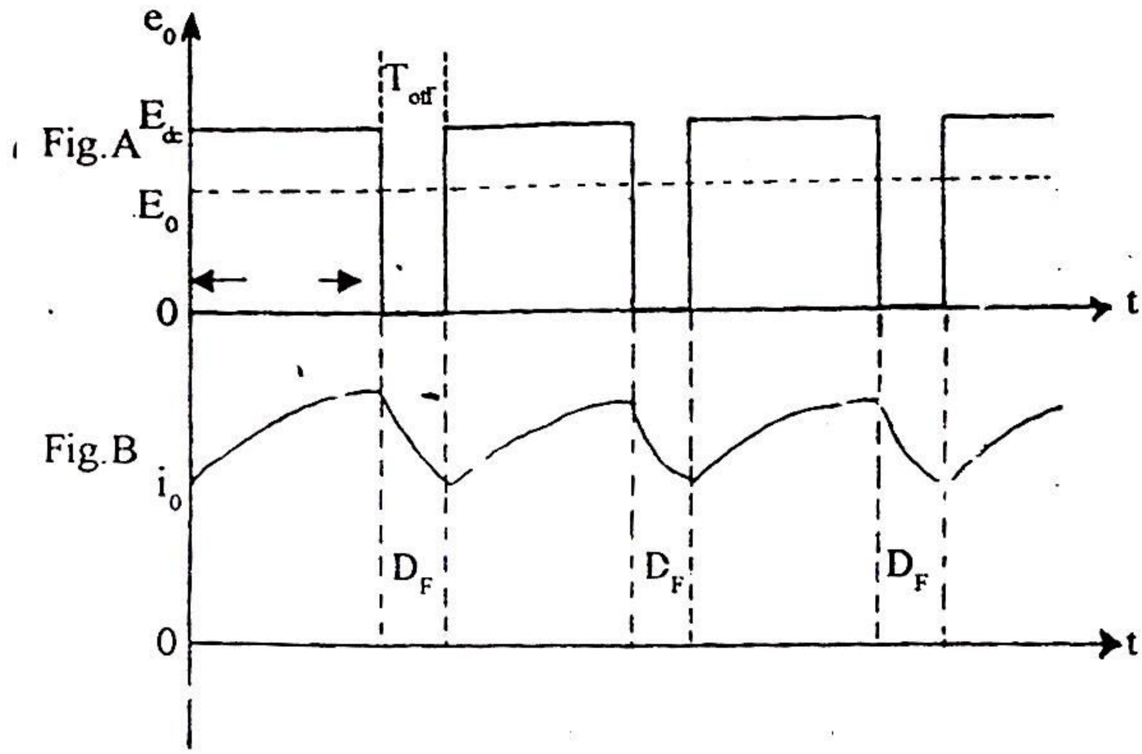


Fig.81. Waveform of DC Chopper Circuit Used For Speed Control of DC Motor

Fig. (A) Chopped DC Voltage Across Motor Load

Fig. (B) Load Current

Expression for output voltage

From above wave form,

$$\text{Average load voltage } E_0 = E_{dc} \times \frac{T_{on}}{T_{on} + T_{off}}$$

Where, T_{on} - On – time of chopper
T_{off} - off-time of chopper
$T = T_{on} + T_{off}$ - Chopping period

In the above equation the ratio between ON period (T_{on}) and the total period ($T_{on} + T_{off}$) is known ad Duty cycle α.

$$E_0 = E_{dc} \frac{T_{on}}{T}$$

$$E_0 = E_{dc} \cdot \alpha$$

Thus load voltage can be controlled by varying the duty cycle (α) of chopper, by varying α the speed of DC shunt motor if varied and thus controlled. The duty cycle can be varied with the help of communication circuit.

ii) Speed control of DC series motor using DC chopper

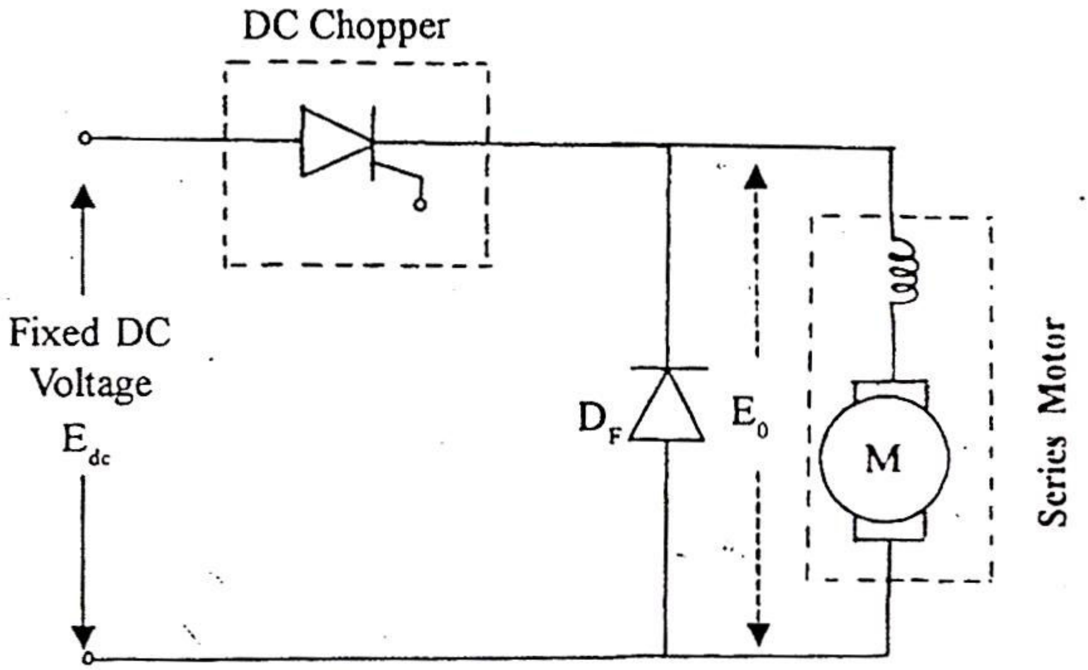


Fig.82. Control Circuit of DC Chopper Used For Speed Control of DC Series Motor

The series motor has high starting torque and hence can be used for traction. But there is the small problem exist in chopper controlled series motor drives. During the on-time of the chopper, the supply voltage E_{dc} is connected to the motor. During the off-period of the chopper, supply voltage is disconnected from the motor.

The current waveform is not of rectangular ype because of presence of series field winding. During the off – period of chopper, the free wheeling diode D_f provides the conducting path for the diode. The short circuit of motor, reduces the voltage peak generated due to inductive energy of series field.

In series circuit the current flowing though series field also flows through the armature. Sicne high load current flows through the field winding the field winding is satufrated. The main problem with chopper – controlled series motor arises due to the non liner relation ship between the armature induced voltage and armature current because of the saturation in the magnetization characteristics.

Even though the field circuit is saturated, it do not affect the average voltage produced across the motor load. So the speed of the series motor can be controlled by varying duty cycle of the chopper circuit using the communication circuit connected with the Gate terminal of the SCR used in the chopper circuit.

Average load voltage $E_0 = E_{dc} \times \dfrac{T_{on}}{T_{on} + T_{off}}$

$E_0 = E_{dc} \times \alpha$

Where E_{dc} – supply DC voltage

$\alpha = \dfrac{T_{on}}{T_{on} + T_{off}}$ - Duty cycle

From the above equation it is clear that speed of DC series motor can be altered by changing duty cycle.

UNIT 5

Conventional and solid – State Sped Control of AC Drives

Conventional Speed Control AC Drive

The speed control of AC motor is nothing but maintaining the speed of the AC motor at the desired value. The drive system with AC motor as a prime mover is known as AC drive. The conventional speed control of AC drive deals with, changing the speed of the electric drive motor to the required value, by altering certain factors that governs the speed. The conventional here means manual control of the speed of the AC motor. The conventional here also means speed controls achieved without the usage of solid state devices. The speed of the AC motor can be changed by altering certain factors that governs the speed. These factors can be studied in the article given below.

Factors governing the Speed of Induction Motor

The factors governing speed of the AC motor can be known from the speed equation of an induction motor. The derivation of speed equation is given below.

The slip shows difference in speed between rotating magnetic field and the rotor. The magnetic field is rotating with synchronous speed. The rotor rotates with speed, that is less than synchronous speed. The slip (S) of an induction motor is given by the formula,

$$S = \frac{N_s - N}{N_s} \longrightarrow \quad (1)$$

Where, S – Slip

N_s - Synchronous speed of rotating magnetic field

N - Speed of the rotor (Motor)

From equation (1), we get

$$S\,N_s = N_s - N$$

$$\therefore \quad N = N_s - S\,N_s$$

$$N = N_s (1 - S) \longrightarrow (2)$$

The above equation shows the speed of the induction motor in terms of synchronous speed and slip. The synchronous speed is given by,

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

Substituting the value of Ns in equation (2), we get

$$S = \frac{120 f}{P} (1 - S) \longrightarrow (3)$$

Where N = rotor speed in rpm
F = frequency of the supply
P = Number of poles
S = Fractional Slip

The above equation is known as Speed Equation of 3ϕ induction motor. From the speed equation, it is clear that the speed of the 3ϕ induction motor is governed by factor, such as

1. Frequency of the supply voltage (f)
2. Number of poles (P)
3. Slip of the motor (S)

Speed Control of 3ϕ Induction Motor

The speed of the induction motor is varied by changing the frequency of the supply voltage, Number of poles and Slip power of the induction motor. The speed of the induction motor can be varied from the rotor side and stator side.

Speed control method applied from the Stator side

a) Voltage control
b) Voltage control by stator resistance
c) Voltage / Frequency control
d) Pole changing method

Speed control method applied from the Rotor side

a) Rotor resistance Control – Slip power is wasted
b) Slip Power Recovery Scheme

(a) Conventional Speed Control of 3ϕ Induction Motor by "Voltage Control"

A 3ϕ induction motor is practically a constant speed motor like a DC shunt motor. But the speed of DC shunt motor can be varied smoothly just by using simple rheostats. This is main reason for good speed regulation and efficiency of DC shunt motor. But in case of 3ϕ induction motor it is very difficult to achieve smooth speed control.

The speed control of 3ϕ induction motor by voltage control can be obtained by either applying variable voltage or by using rheostats in the stator, thereby reducing the applied voltage. Here we can see how speed of the induction motor is varied by the usage for Stator rheostats.

Working

The rheostat is actually a variable resistance with the moving arm or sliding arm. By moving the position of the sliding arm various values of the resistance are obtained. The rheostats are connected in each phases. Initially, the sliding arm of the rheostats is placed in Minimum position. Now the resistance of the rheostat is zero and hence no voltage drop occurs in it. The entire supply voltage is applied across the stator and the motor runs with rated speed.

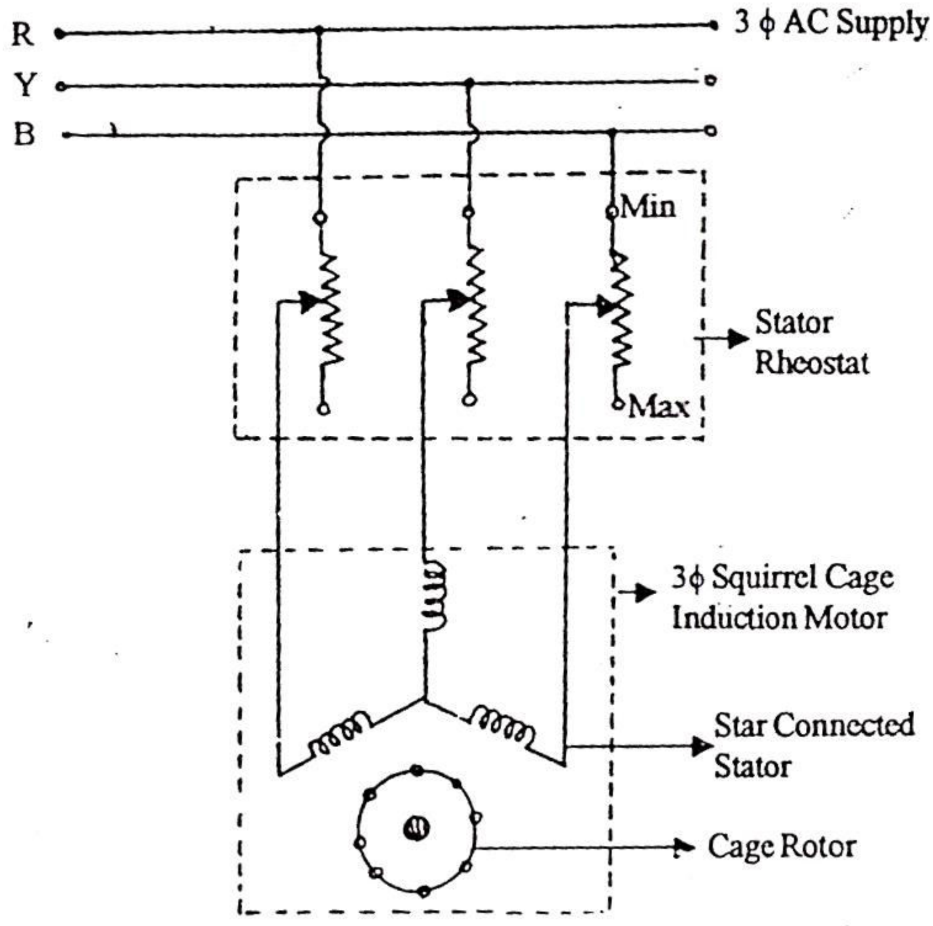


Fig.83. Conventional Voltage Control of 3ϕ Induction Motor

To perform speed control the slider arm of the rheostat is moved from Min position towards the Max position and the resistance of the rheostat is increased and hence the voltage drop across it also increase. The voltage applied to the stator of the motor is now reduced, as a result the speed of the motor is also reduced, which is explained with following Speed / Torque characteristics.

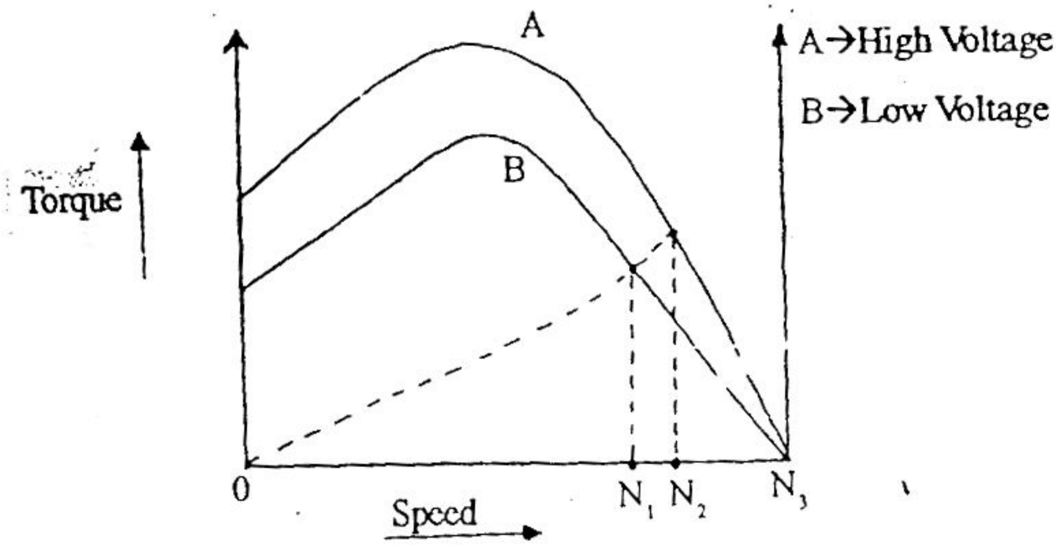


Fig.84. Characteristics Of Voltage Control Method

The curve is Torque/Speed characteristics of 3ϕ induction motor applied with two different voltages. From the Torque equation of 3ϕ induction motor it is clear that Torque developed is proportional to square of applied voltage. Here curve 'A' represents higher voltage. Since the voltage is high, the torque of the curve A is also high when compared to curve B. The intersection of load torque line with the torque curves gives corresponding speed N_2 and N_1 speed. Here speed N_1 is less than speed N_2. Hence by varying the voltage the speed of the motor can be changed.

Disadvantage

1. To obtain the small change in speed, a large change in applied voltage is required.
2. The large changed is voltage will affect the flux density thereby alters the magnetic condition of motor.
3. This method is not often used because, when voltage alone is reduced without reducing frequency, the motor takes heavy current on the account of magnetic saturation.

(b) Conventional Speed control of 3ϕ Induction Motor By "Voltage/Frequency Control"

From the Speed Equation of the induction motor, it is clear that speed of the motor is directly proportional to the frequency (f) of the supply voltage. When the frequency of the supply voltage is reduced, then the speed the induction motor is also reduced. When voltage alone is reduced then the motor draws heavy current from the supply mains. When frequency alone is reduced then also the motor draws heavy current from the supply mains. So voltage and frequency are simultaneously reduced. The method of speed control in which the supply voltage and the frequency of supply voltage is varied simultaneously to achieve the speed control is known as voltage / Frequency control.

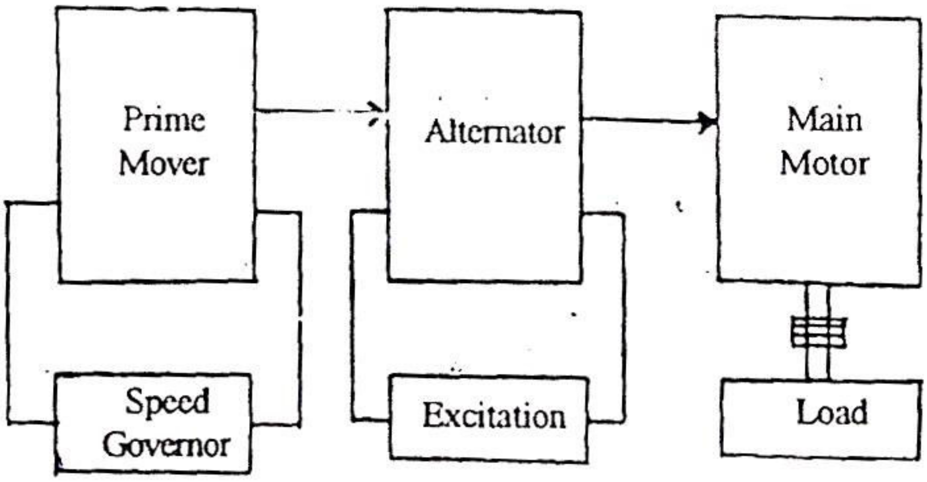


Fig.85. Voltage / Freuency control of Induction motor.

This kind of speed control is mainly used for propulsion of slip. The variable voltage and variable frequency supply is obtained by the usage of Alternator coupled with the Prime mover. The alternator converts mechanical energy of the prime mover into electrila energy. He prime mover used may be steam turbine or internal combustion engine. The electrical energy generated by the alternator is applied to the motor whose speed is to be controlled.

The voltage applied to the induction motor is varied with the help of Excitation circuit available in the Alternator. By varying the excitation given to the alternator, the voltage generated by the alternator is changed. The frequency applied to the motor is varied by changing the speed of the prime mover. The speed of the prime mover is changed with the help of Speed Governor Mechanism. The frequency of generated supply voltage is varied by varying the speed of the alternator. So by adjusting the speed governor of the prime mover and excitation of the alternator the speed of the 3ϕ induction motor is controlled by Voltage/ Frequency control method.

(c) Speed Control of 3ϕ Slip Ring Induction Motor by "Slip Power Recovery Schemes"

From the speed equation of induction motor it is clear that speed of induction motor also depends on the slip of the induction motor. The magnetic field inside the motor rotates with synchronous speed. There is speed difference between rotor and the synchronous speed of the magnetic field. This difference in speed between rotor and synchronous seed is known as Slip. The Slip represents copper loss taking place in the rotor resistance. The part of the rotor input is wanted as rotor copper loss. The Rotor copper loss is given by

$$\text{Rotor Copper Loss} = S \times \text{Rotor input}$$

$$S = \frac{\text{Rotor Copper Loss}}{\text{Rotor Input}}$$

If the rotor resistance is increased, the rotor copper loss is also increased. Due to the increases in rotor copper loss, the Slip increase. From the Speed equation it is clear that if the slip increases, the speed decreases. This method of speed control is applicable only to the 3ϕ Sli Ring or Wound rotor induction motors. This is because the rotor of slip ring induction motor can be accessed through the Slip rings. This method cannot be applied to Squirrel cage induction motor because rotor conductors are short circuited through end rings and cannot be accessed.

From the above discussion it is clear that the speed of the induction motor can be controlled by varying the slip power. The slip power can be either wasted or recovered and used. The speed control of Slip ring of induction motor is classified into following methods.

1. Rotor Resistance control (Slip power is wasted)
2. Slip Power Recovery Schemes or Cascade Control
    a. Slip Power Recovery Scheme using cascading of induction motor
    b. Slip Power Recover Scheme using Krmer's Control

1. Speed control of 3ϕ induction motor by Rotor Resistance (Rheostat) control.

In this method the star connected rheostat is connected to the slip rings of the rotor of the slip ring induction motor. As a result, the resistance of the rotor circuit is increased. The increase in rotor resistance gives the increase in the rotor copper loss. If the rotor copper loss is increased then the slip is also increased. The increase in slip means there is decrease in the speed of the motor. In this method of speed control, power is wasted in the rotor circuit in the form of rotor copper loss. The wasted power is converted into heat which is also need to be dissipated. Because of the above mentioned disadvantages, this method is not normally used. He efficiency of this method of sped control is also very low, because the power is wasted in the rotor circuit.

2. Speed Control of 3ϕ Induction Motor by "Slip Power Recovery Scheme or Cascade Control"

The Speed of the induction motor depends on the Slip. The slip is denoted by the rotor copper loss. So by varying the rotor copper loss, the speed can also be varied. In the above method, the power is wasted in the form of rotor copper loss, to vary the speed. This power can by recovered, instead of wasted in the rotor and used to drive other motor, which is coupled to main moor. Here the power is fruitfully utilized and hence the efficiency of this method of speed control is increased, where compared with other conventional seed control methods. So this method of speed control is effective and hence very important.

a) Slip Power Recovery Scheme using cascading of induction motors.

In this method of speed control, power, that is wasted in the rotor circuit is recovered and used to supply other auxiliary motors which is mechanically connected to the motor, whose speed is to be controlled. The method of speed control of induction motor by connecting it with other auxiliary moor is known as **Cascade Control.** Here the slip power is recovered from the rotor circuit of the main motor and applied to the stator of the auxiliary motor. The main motor is used must be 3ϕ slip Ring induction motor and the auxiliary motor may be either slip ring or squirrel cage induction motor.

The Motor A is the main motor, whose speed is to be controlled. The motor B is the auxiliary moor, which utilizes the slip power of the main motor. The stator of the main motor A is connected to the 3ϕ AC supply bus bar. The rotor of the main motor A is connected electrically to the stator of the auxiliary machine B. The auxiliary motor B is mechanically coupled with main motor A.

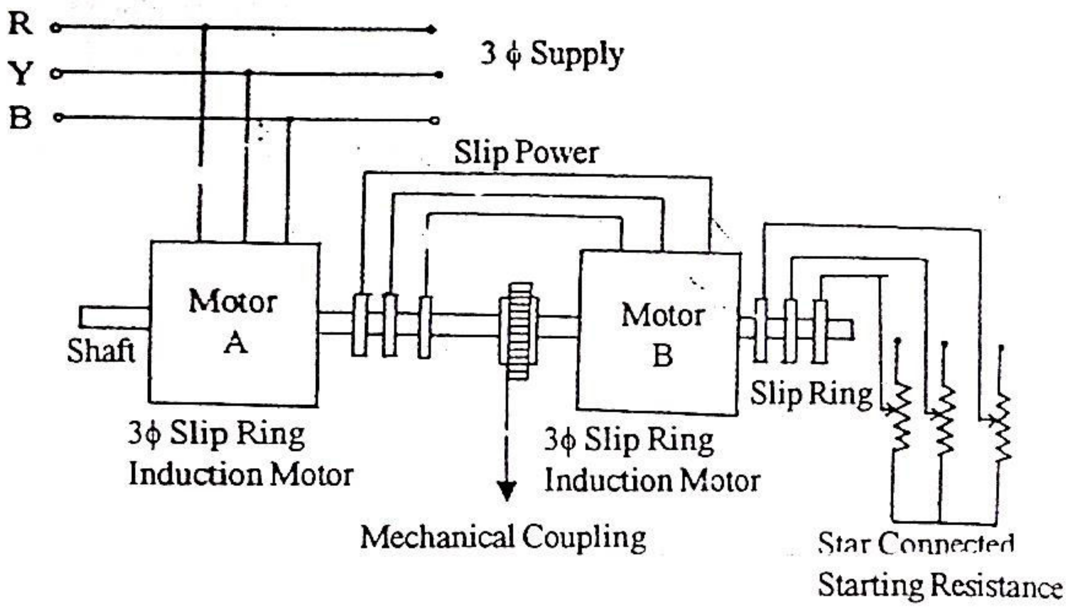


Fig.86. Speed Control 3ϕ Induction Motor By " Cascade Control"

Working

The stator of main motor A receives power form 3ϕ supply mains of frequency f. this creates a rotating flux, which rotates with synchronous speed. An emf of same frequency is set up in the rotor of main machine A. This induced emf is supplied to the stator of the auxiliary machine B through slip ring. The rotor of the auxiliary machine is connected with resistance through slip rings.

When the main motor rotates, it produces torque. The slip power is now applied to the auxiliary machine, as a result it also rotates and procedures the torque in the direction production by the main motor. If the auxiliary motor produces torque in the direction of the main motor then auxiliary motor acts as motor and draws power from the main motor. If the torque produced by the auxiliary motor opposes that of the main motor, then it acts as generator and supplies power.

When the auxiliary machine B acts as motor, then torque of it acts in same direction of main motor and total toque adds together. The set now acts as 'High Torque and Low Speed' cascade control. When the auxiliary machine B acts as Generator, then torque of it acts in opposite direction of main motor and total torque is reduced. The se now acts as "Low Torque and High Speed" cascade control.

The direction of torque of both the rotor is kept same. As the speed of the shaft rises, the rotor frequency of machine A falls and as a result synchronous speed of machine B decreases. The cascaded sets settles down to a stable sped, when the speed of the shaft becomes equal to sped of revolving field of machine B. Thus speed of main motor A is controlled by recovering the slip power from the rotor of the main motor and supplying it to the stator of the auxiliary motor B.

b) Slip Power Recover Scheme using kramer's Control

Here the speed control of induction motor is achieved with the help of rotary converter and DC machine. Here the main motor whose speed to be controlled is 3ϕ induction motor. Here he rotary converter and DC mahcien are collectively called the auxiliary machines. The function of rotary converter is to convert AC Voltage to DC voltage and to feed DC machine that works as DC motor. The rotary converter also converts DC voltage from the DC machine that works as DC generator to AC voltage. The speed control method in which speed control is achieved by injecting an emf in rotor circuit is known as Kramer's control.

Working

The main motor M is Slip ring induction moor and is started with starting resistance in its rotor circuit. Once the motor picks up speed, the speed control is achieved y throwing change over switch such that slip ring of main motor is connected with the slip ring of rotary converter. The main motor is connected mechanically with DC machine. The DC machines connected electrically with rotary converter. Now the emf is induced in the rotor circuit of main motor is applied to the frequency converter through slip ring.

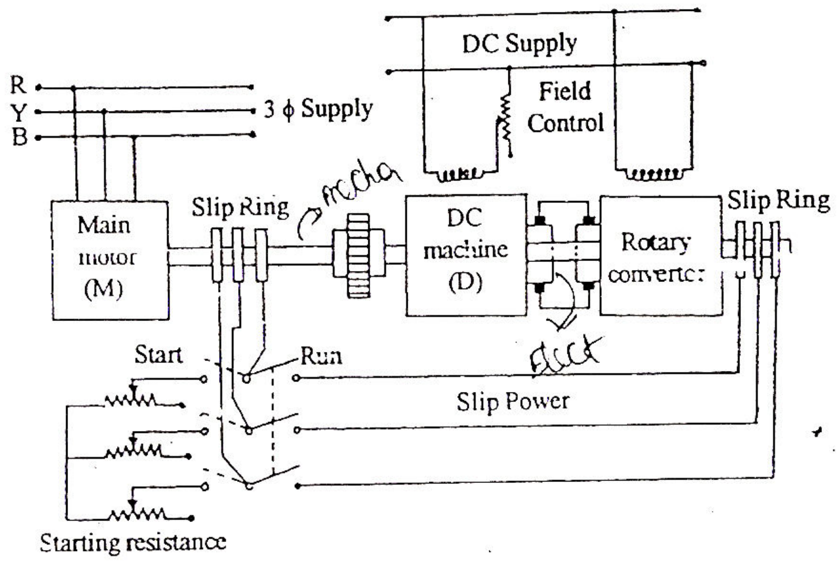


Fig.87. Speed Control of 3ϕ Induction Motor By " KRAMER'S CONTROL "

The rotary converter converts the AC voltage from the rotor circuit of main motor into DC voltage. This DC voltage is applied to the DC machine. The DC machine now works as DC motor. Since the power is given to the DC motor, it also produces torque in addition with the torque produced by the main motor. So this set now act as a ‘low speed and high torque’ drive.

When the field excitation of the DC machine now act as a DC generator. Now the generator uses some amount of torque generated by the main motor. So the torque is reduced. The DC generator gives DC voltage. This to the rotary converter, which converts it into AC voltage. This AC voltage is now applied to rotor circuit of the main motor through slip rings. Since an emf is injected in the rotor circuit of the main motor the speed of the main motor increases. So this set now act as a ‘high speed and low torque’ drive.

Thus the speed of slip ring induction motor is controlled by recovering the slip power from the rotor circuit to obtain ‘low speed and high torque’ drive and injecting an emf in the rotor circuit to obtain ‘high speed and low torque’ drive. This method of speed control is known as Kramer’s control

Solid – State Sped Control of AC Drive

The speed control of AC drive using solid – state device such as SCR and solid – state circuit as inverter and regulator is known as solid-state speed control of AC drives. The drive system which uses AC induction motor as a prime mover is known as AC drives. The speed control methods that are used for solid – state control of AC drives are

1. Voltage control using AC voltage Regulator.
2. Voltage / Frequency control using Inverter and
3. Slip power recovery scheme using Rectifier – Inverter bridge.

Introduction to solid-state device and circuits for speed control of AC drive

The two important circuits that are used for sped control of AC drive are Inverter and AC voltage Regulators. The speed control methods used by AC solid-state drives are Voltage control, voltage/frequency control and slip power recovery scheme.

An inverter is a solid – state circuit that is used to convert fixed DC voltage into variable AC voltage with variable frequency. That is inverter is used to obtained the variable voltage and frequency. This circuit can be used for sped of control induction motor by Voltage/ Frequency control. The block diagram representation of an inverter circuit.

The AC voltage regulator is a solid – state circuit that is used to convert fixed AC voltage into variable AC voltage using the phase control method, by the application of triggering pulse to the gate G of SCR since this circuit produces variable AC voltage, it can be used for speed control of induction motor by voltage control method. The block diagram representation of AC voltage regulator is shown in fig88.

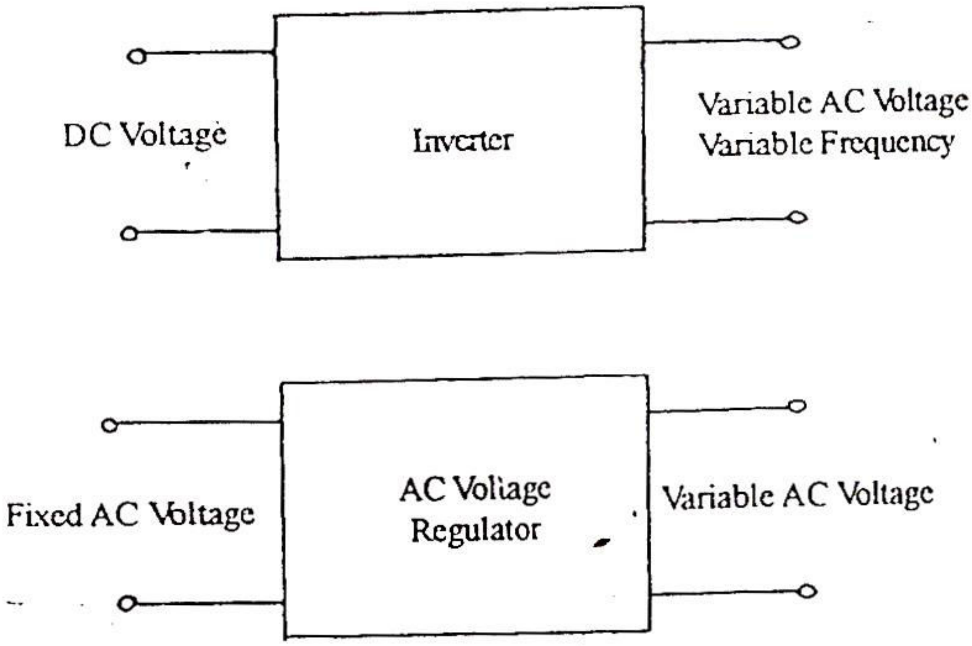


Fig.88. Block Diagram of Solid State Circuit Used for Speed Control of AC Drives

Speed control of 3ϕ induction motor using inverters (voltage/frequency control)

Voltage / frequency control V_s Inverter

The Inverter circuit acts as a DC to AC power converter. It uses SCR (thyristor) to convert DC into AC voltage. An inverter is a solid-state circuit that is used to convert fixed DC voltage into variable AC voltage with variable frequency. That is inverter is used to obtain variable voltage and frequency. That is inverter is used to obtain variable voltage and frequency. This circuit can be used for speed of control induction motor by voltage / Frequency control. The voltage / frequency control is superior when compared to the voltage control. The speed equation of induction motor is given by

$$S = \frac{120\,f}{P}(1 - S)$$

From the above equation it is clear that the speed of induction motor depends on the supply frequency. The speed of the motor is increased by increasing the supply frequency. Motor input voltage can be considered proportional to the product of frequency and flux. If frequency of the supply voltage is decreased, then the flux is increased and hence magnetizing current increased. In order to overcome the problem of increase in magnetizing current, when the frequency of supply voltage is reduced, the supply voltage is also reduced. Hence this method of speed control is also known as Voltage/frequency control i.e., V/F Control

(a) Voltage / Frequency Control using series inverter

The Inverter circuit converts DC power into AC of power of required voltage and frequency. It is used mainly for sped control of AC drive motors. Using inverter circuit the speed control of induction motor is done on AC induction motor

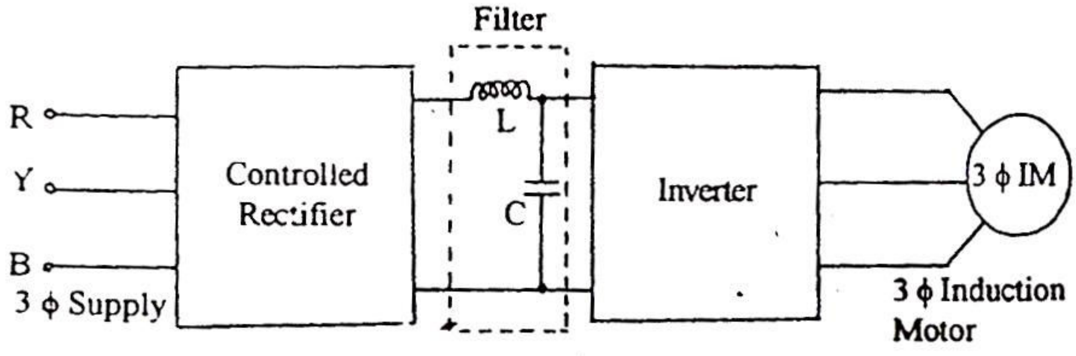


Fig.89. Block diagram of 3 ϕ Induction Motor Using Inverter When 3 ϕ Supply is Available

When the available voltage supply is AC in nature, the inverter cannot be used directly. The AC voltage is first converted into DC voltage by Rectifier. Here controlled rectifier is used so voltage can be reduced to match the motor ratings.

The rectified voltage is pulsating in nature. It is converted into fixed DC using filter circuit with inductor L and capacitor C. The fixed voltage is applied to inverter. The inverter converts fixed DC power into AC power of variable voltage and frequency. The speed of the 3ϕ induction motor is controlled by applying variable voltage and variable frequency supply available from the inverter.

Classifications of inverter

The SCR Inverter can be classified based on

1. Method of Communication
2. Method of Connection

Based on the method of connections SCR and the Commutating components, the inverters can be classified into three types namely.

a) Series inverter
b) Parallel inverter
c) Bridge inverter

Principle of Operation of Basic Series Inverter

The basic series inverter circuit has two SCR namely SCR_1 and SCR_2. Each SCR is used to get one of the half cycles of output AC supply. This inverter circuit is known as Series inverter because the commutating components inductor L and capacitor C are connected in series with the motor load and SCR. The commutating components are used because the SCRs cannot switched off by the supply voltage, because it is DC in nature.

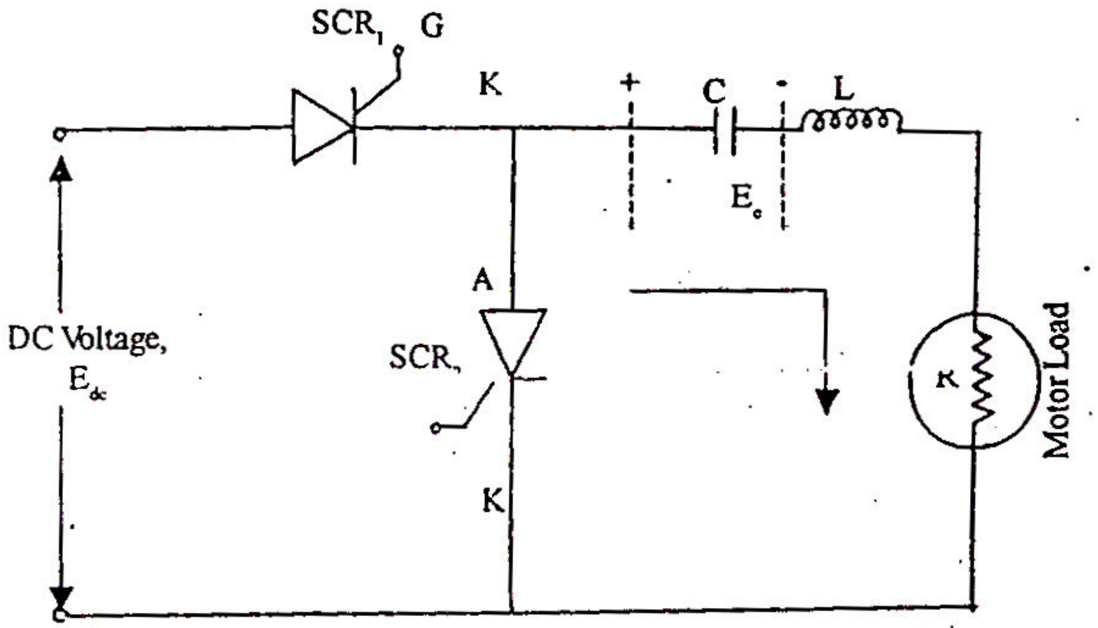


Fig.90. Control Circuit For Speed Control of Induction Motor Using Inverter

The elements L and C are connected in series with motor load R whose speed is to be controlled. These three elements form RLC series resonant circuit. The value of L and C is selected to produce under damped circuit. The output AC voltage is not exactly sinusoidal and it contains certain harmonics.

Working

The operation of basic series inverter circuit can be divided into following three modes.

MODE 1:

This mode begins when DC voltage E_{dc} is applied to circuit. Now SCR_1 is forward biased and conducts when triggered by giving pulse to gate G. Since SCR_1 conducts the current flow through R-L-C series Circuit. Now capacitor charges to E_c, with positive polarity on left plate and negative polarity on right plate. The load current is alternating in nature because of under damped RLC series circuit. When current reaches peak value the voltage across the capacitor becomes E_{dc}.

After the peak point, the current stats deceasing but capacitor voltage increases further. Finally the current becomes zero, but capacitor remains at $E_{dc} + E_c$. The current from point 0 to point P is the Positive half cycle of the output AC wave. This period is denoted by T/2 in he waveform. Now the SCR_1 is automatically turned off because the current through series circuit is Zero. This point is shown as P in waveform.

MODE 2

During this mode, the load current is Zero. It is denoted by point P in the waveform. During his mode of operation SCR_1 and SCR_2 are purposely switched off. The current is zero from point P to Q. But the voltage across the capacitor $E_{dc} + E_c$ is kept constant. During this period, both SCR_1 and SCR_2 are switched off. The time period during this mode is denoted by T_{off} in the waveform.

MODE :3

Now the positive polarity of capacitor C appears on the anode of SCR_2 hence it is forward biased and it is triggered immediately at point Q as shown in the waveform. When SCR_2 starts conducting, capacitor C is discharged through it. Now the current flows through the load in opposite direction. This is the negative half cycle of the output AC wave.

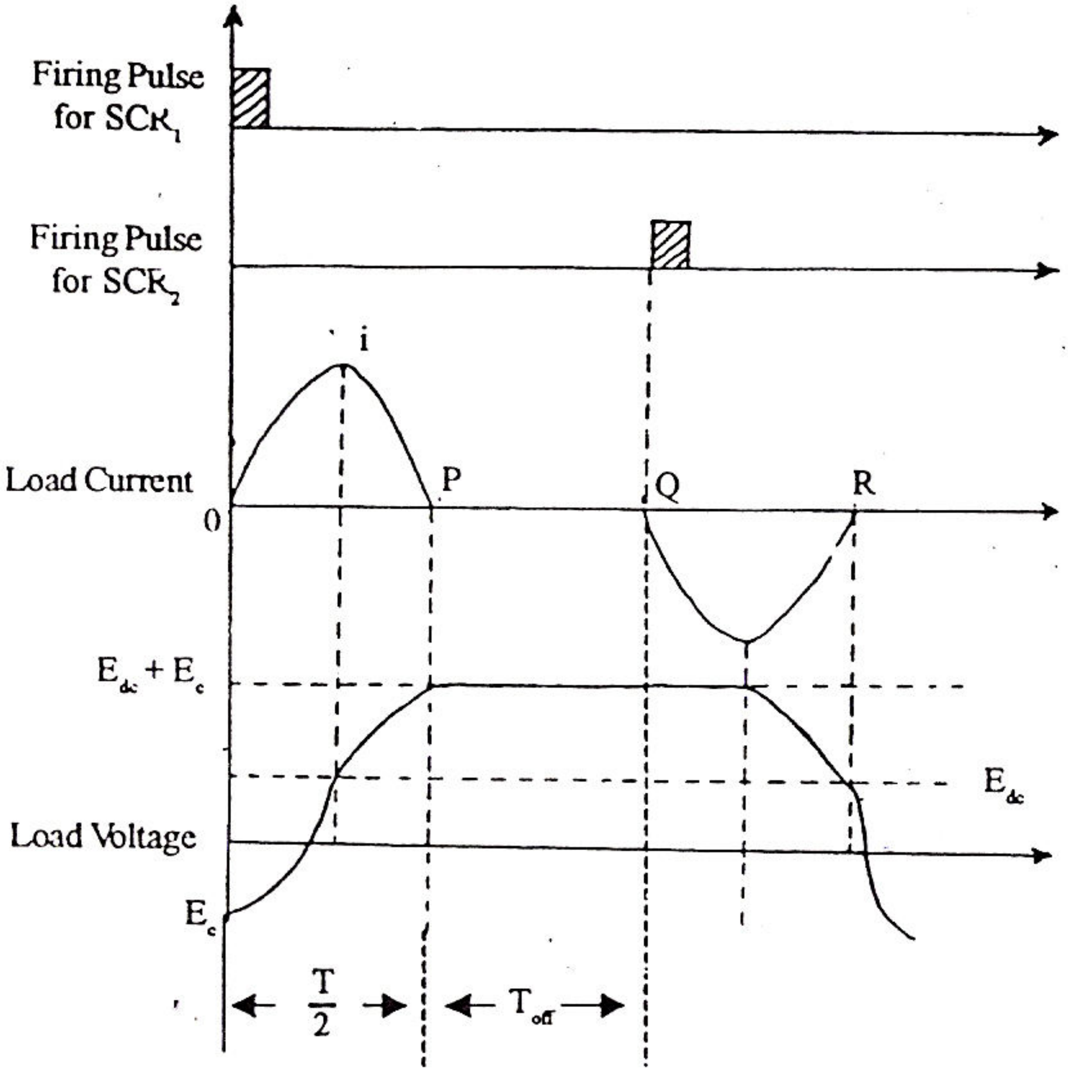


Fig.91. Waveforms of 1ϕ Series Inverter used for the speed control of Induction motor

Thus Positive half cycle (0 to P) is produced during Mode 1 and Negative half cycle (Q to R) is obtained during Mode 2. The positive half cycle of output AC wave is obtained from the power drawn from the input DC supply. The Negative half cycle of output AC wave is obtained from power drawn from the capacitor. Now the Voltage and frequency of output wave is altered by changing conducting period of SCR_1 (T/2) and off period of both the SCRs (T_{off}). The frequency of output AC wave is given by

$$F = \frac{i}{\{(T/2) + T_{off}\}}$$

Thus by varying T/2 & T_{off} both Voltage and frequency is varied and hence the sped of induction motor can be varied.

(b) Speed Control of 3ϕ Induction Motor Using AC Voltage Regulator (Voltage Control)

The AC voltage regulator is a solid – state circuit that is used to convert fixed AC voltage into variable AC voltage, using the phase control method by the application of triggering pulse to gate G of the SCR. Since this circuit produces variable AC voltage, it can be used for speed control of induction motor by Voltage control.

The AC voltage regulator is classified into two types namely,

a) 1ϕ Half – Wave AC Voltage Regulator

b) 1 ϕ Full – Wave AC Voltage Regulator

(i) Speed control using 1 ϕ Half – Wave AC Voltage Regulator (Voltage Control)

The AC voltage regulator converts fixed AC voltage into variable AC voltage that is used for he speed control of induction motor. The AC voltage regulator consists of two solid – state devices connected in Anti-Parallel with each other, i.e., the Anode and cathode of the devices are connected with each other. The AC voltage regulator which can control only one of the output half cycle is known as Half-Wave AC voltage regulator.

Working

The Half-wave AC voltage regulator has a SCR connected in anti-parallel with a Diode D. The anode of SCR is connected with the cathode of the diode. This junction point is connected with AC supply voltage. The cathode of SCR is connected with anode of the diode D. this junction point connected with the motor load whose speed is to be controlled by voltage control method.

During positive half of the input AC voltage, SCR is forward biased and diode D is reverse biased. The SCR conducts when triggering pulse is applied at certain angle. So the part of positive half cycle is applied to motor load. Now the motor load is connected with the supply. As a result, current flows through the motor load. During negative half cycle of the input AC voltage supply, diode is forward biased and SCR is reverse biased. Now the diode conducts immediately because it will not accept any firing pulse. So the entire negative half cycle, appears across the motor load is reversed. So it is clear that output is AC voltage. The output voltage can be varied by changing the firing angle of the triggering pulse applied to the SCR from 0 to π. The diode conducts during negative half-cycle, as a result voltage cannot be controlled in the negative half cycle..

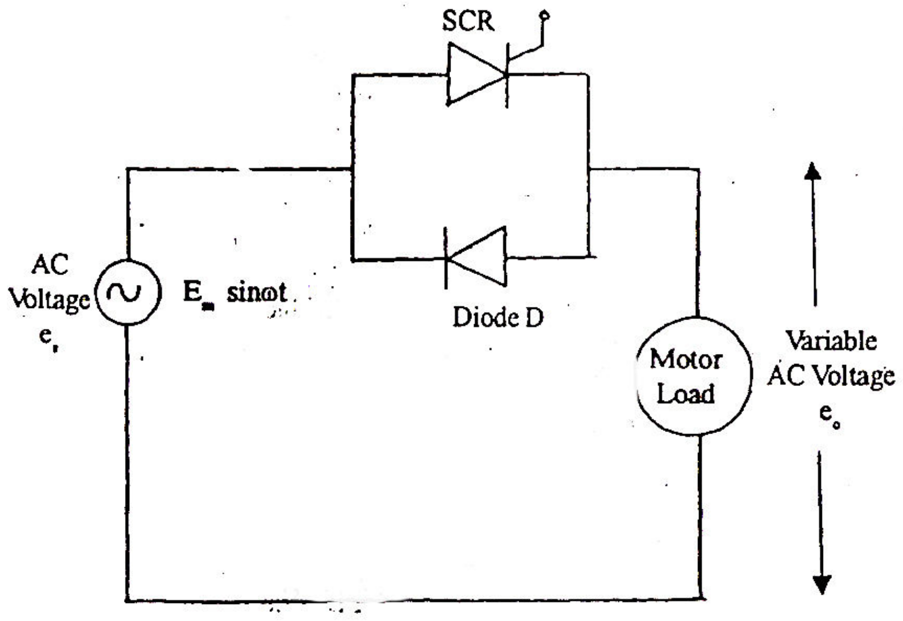


Fig.92. Control Circuit for Speed control of Induction Motor Using 1 ϕ Half – Wave AC Voltage Regulator

It is clear that voltage can be only controlled in the positive half cycle. So the name half-wave voltage regulator is justified. The output AC voltage is controlled by varying the firing angle of the SCR. So the speed of the induction motor is controlled by varying the firing angle of SCR available in voltage regulator.

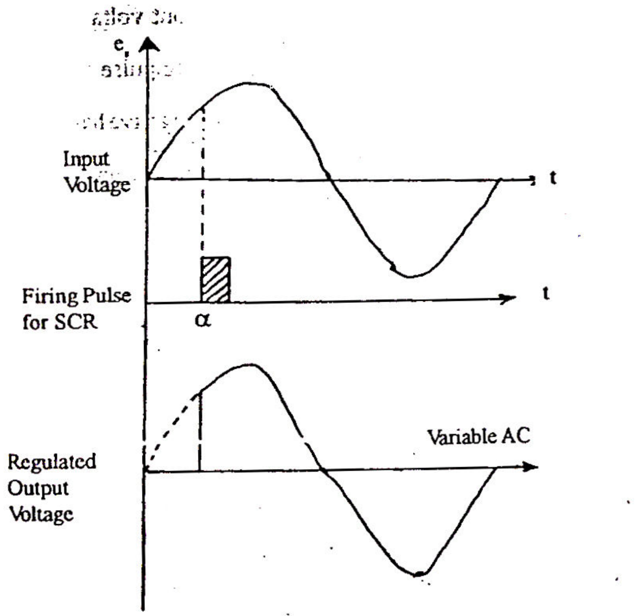


Fig.93. Waveforms of 1 ϕ Half-Wave AC Voltage Regulator

(ii) Speed Control Using 1 ϕ Full – Wave AC Voltage Regulator (Voltage Control)

The Full-Wave AC voltage regulator has two SCRs connected in anti-parallel with each other. The anode of SCR_1 is connected with the cathode of the SCR_2. This junction point is connected with AC supply voltage. The cathode of SCR_1 is connected with anode of the SCR_2. This junction point is connected with the motor whose speed is to be controlled by voltage control method.

Working

During positive half of the input AC voltage, SCR_1 is forward biased and SCR_2 is reveres biased. The SCR_1 conducts when triggering pulse is applied. So the part of positive half cycle is a applied to motor load. Now the motor load is connected with the supply. As a result, current flows through the motor load, during negative half cycle of the input AC voltage, SCR_2 is forward biased and SCR_1 is reverse biased. Now the SCR_2 conducts when triggering pulse is applied. So the part of negative half cycle is applied to the motor load. Due to negative half cycle the direction of current through motor load is reversed. So it is clear that output is AC voltage.

The output voltage can be varied by changing the firing angle of the triggering pulse applied to both the SCRs i.e. from 0 to π for SCR_1 and from π to 2π for SCR_2

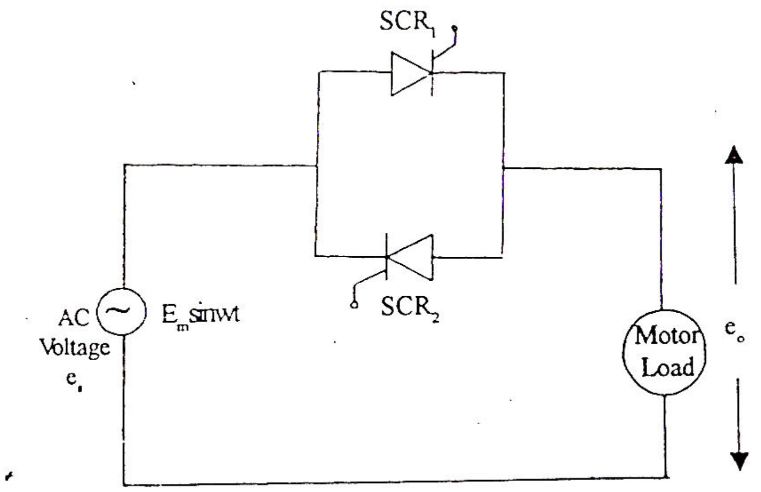


Fig.94. Control circuit for Speed Control of Induction Motor Using 1 ϕ Full – Wave AC Voltage Regulator

From the wave form, it is clear that output voltage in the both half cycle can be controlled by varying the firing angle of both the SCR.

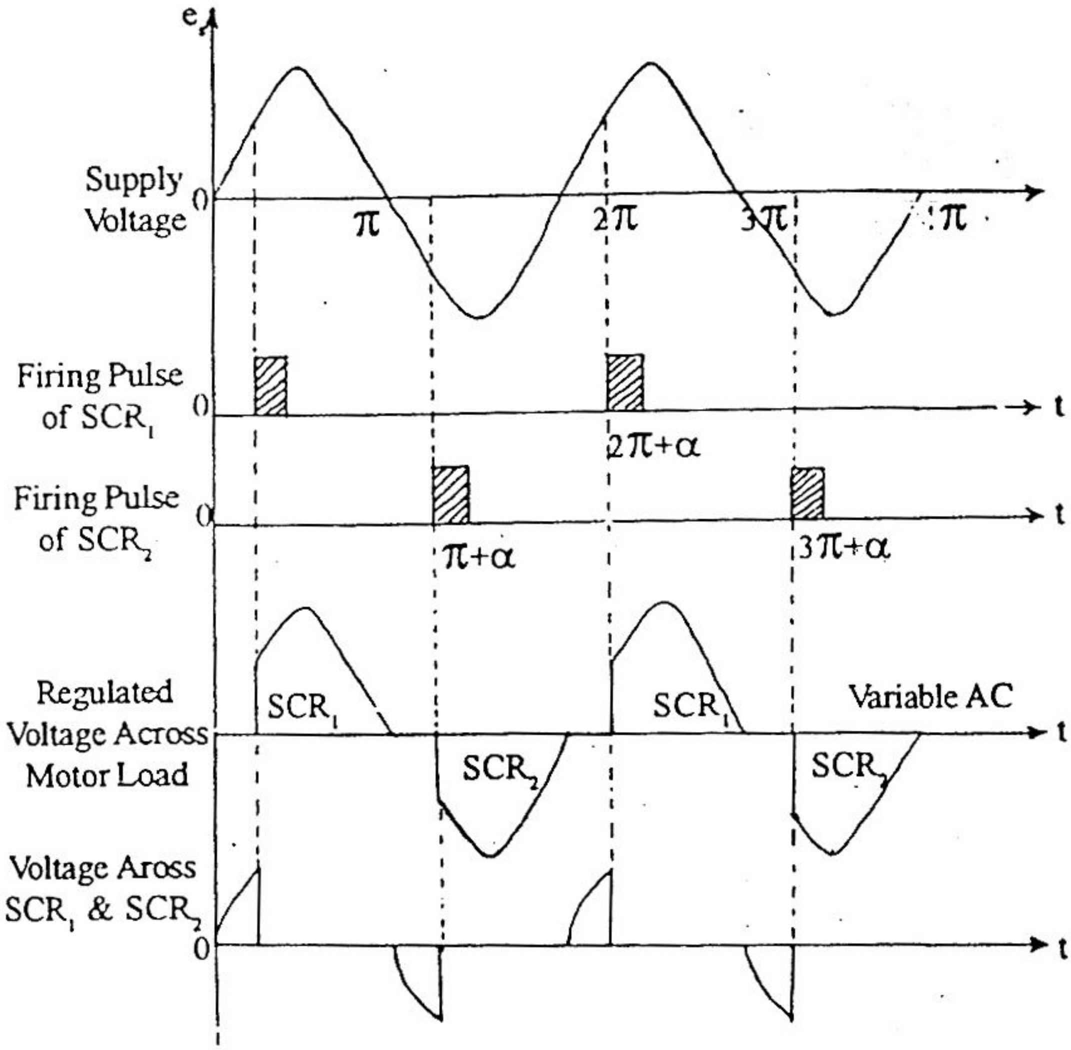


Fig.95. Waveform of 1 ϕ Full – Wave AC Voltage Regulator Used For Speed Control Induction Motor

The voltage regulator that is applied to the 3ϕ induction motor. The anti-parallel connection of SCRs are employed in each phases of the stator circuit of 3ϕ induction motor. Here three firing pulse for three (A, B, C) unit is applied during both positive and negative half cycle.

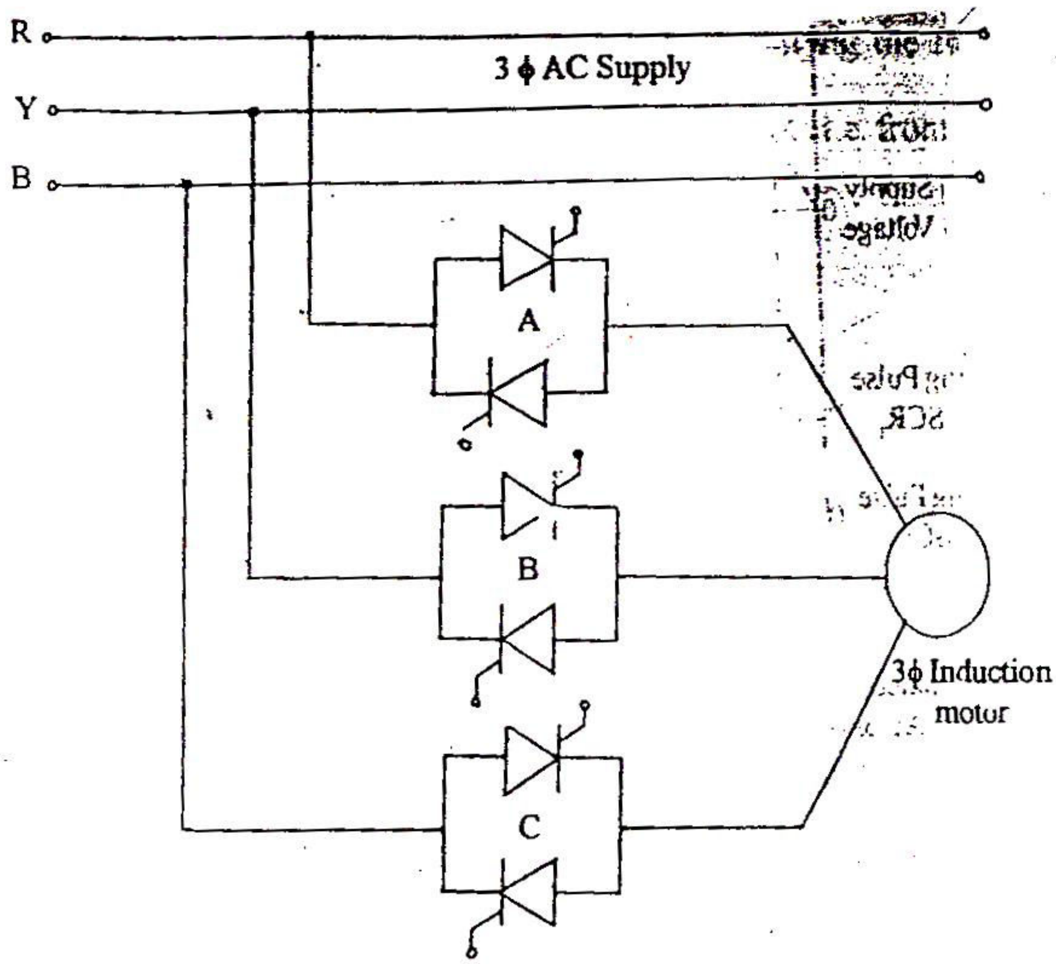


Fig.96. Speed Control of 3ϕ Induction motor by 1ϕ Full-Wave AC Voltage Regulator (Voltage Control)

(c) Slip Control Recovery Scheme Using Rectified and Inverter Bride

From the speed equation of induction motor it is clear that speed of the motor depends on the slip. The slip is difference in speed between the synchronous speed of rotating magnetic field and the motor. The slip represents copper loss in the rotor circuit of the induction motor. So by varying the copper loss the slip can be varied. By varying the slip, the speed of the induction motor can be varied. Therefore the speed of the induction motor is varied by changing the copper loss.

The copper loss can be varied by connecting resistance in the rotor circuit. Here the power is wasted in the rotor rheostat in the form of heat. So this method is not preferred. In spite of wasting the power in the rotor circuit it can be used to run other induction motor which is connected with the main moor or this slip power is converted into power of required voltage and frequency and connected to the supply mains.

The solid – state slip power recovery scheme denotes the conversion of slip power using solid state devices and this converted power of required frequency and voltage is fe back to the supply mains. This method of speed control is known as Scherbius Drive. The Scherbius Drive using Solid-state circuit is known as Static scherbius drive.

Working

The solid-state slip power recovery scheme or scherbius drive. The stator of induction motor is connected to 3ϕ supply. When the induction motor is started by switching on the main, an emf is induced in the rotor circuit. Once the motor picks up speed, the frequency of induced emf or voltage and current it reduced.

The slip rings of the rotor circuit of the induction motor are connected to rectifier – Inverter bridge circuit. The principle behind this method is to control the speed, by giving the slip power to the supply mains. The slip power is cannot supplied to the supply mains directly, because the voltage and frequency of this induced emf is less than that of supply mains. So before feeding slip power to the supply mains, the slip power matches with that of supply mains. Hence the bridge circuit is known as Slip converter.

The AC slip voltage is converted into DC voltage by the diode rectified and this DC voltage is applied to the inverter through inductor L., The inverter circuit converts this DC voltage into AC voltage of required voltage and frequency. Here the AC slip power has voltage and frequency that matches with the supply main.

Since the power is absorbed from the rotor circuit of the induction motor, the speed of the induction motor is decreased. So the speed of the induction motor is altered by supplying the slip power into the supply mains. This method is most efficient, when compared to all the speed control methods because the power is supplied to the supply mains through feed back.

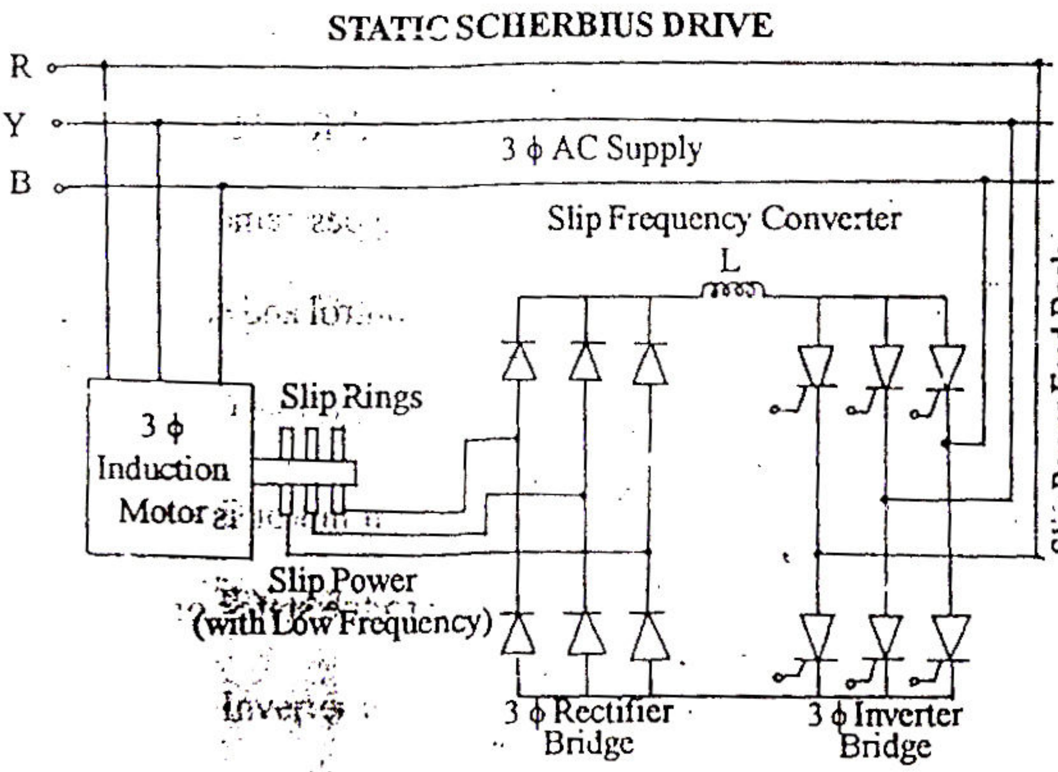


Fig.97. Control Circuit for Speed Control of 3 ϕ Slip Ring Induction Motor Using Slip Power Recovery Scheme.

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ELECTRICAL DRIVES AND CONTROL / EE6351

Two Mark Question and Answers

Chapter 1

1. What are the types of Electrical Drives
   - (i) Group Drive
   - (ii) Individual Drive
   - (iii) Multimotor Drive

2. What are the classes of Duty
   - (i) Continuous duty (S1)
   - (ii) Short duty (S2)
   - (iii) Intermittent periodic duty (S3)
   - (iv) Intermittent periodic duty with starting (S4)

3. DefineCoolingtimeconstant

   Cooling time constant is defined is the time required to cool the machine down to 0.368 times the initial temperature rise above the ambient temperature.

4. What is meant by protection code

   This 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.

5. Define Heating time constant

   Heating time constant is defined as the time taken by the machine to attain 0.632 of its final steady temperature rise. The heating time constant of the machine is the index of thee time taken by the machine to attain its final steady temperature rise.

$$T = \frac{Gh}{s\lambda}$$

6. What are the Mechanical considerations to be considered
    (i) Type of enclosures
    (ii) Type of bearings Noise level
    (iii) Transmission of drive

7. What are the types of Mechanical load
    (i) Load torque remaining constant irrespective of the speed.
    (ii) Load torque increasing with the square of the speed.
    (iii) Load torque increasing with speed.
    (iv) Load torque decreasing with speed.

8. What is Group drive

   When one motor is used as a drive for two or more then two machines, it is called as Group drive. All the other machines are connected to the main motor shaft by belt and pulleys.

9. What is Electric Drive

   Drive employing electric motors are know as Electric Drive.

   More clearly, the aggregate of electric motor, the energy transmitting shaft and the control circuit used to change the prime mover characteristics is called Electric Drive.

10. What are the Advantages of electric Drives
    (i) It is more flexible
    (ii) It is more economical
    (iii) It is more clean
    (iv) It occupies less space
    (v) It requires less maintenance
    (vi) It has long life
    (vii) It has easy starting

11. What are the Merits of Group drive:
    (i) It reduces the initial cost of investment
    (ii) It is more economical because, the rating of the motor used may be comparatively less then the aggregate of ratings of the individual motors required to drive each equipment.

12. What are the Drawbacks of Group Drive:

    (i) Flexibacks of layout it lost

    (ii) Any fault to the main motor makes the complete process to remain idle.

    (iii) Level of noise produced at the site is high.

    (iv) Large amount of enegy is wasted in the transmitting mechanisms.

13. What are the Drawbacks of: Individual drive

    Drawbacks of Individual drive is that, the initial cost of investment is very very high.

14. What are the The factors governing the selection of motors:

    (i) Nature of electric supply

    (ii) Nature of the drive

    (iii) Cost

    (iv) Maintenance requirement

    (v) Environment and location Nature of load

    (vi) Nature of load

    (vii) Electrical characteristics of motors

    (viii) Duty cycle

    (ix) Mechanical considerations

15. Define Short time duty

    Short time duty is defined that the period of operation is so short that the temperature rise of the motor does not reach its final steady value and the period of rest is so long that the motor returns to cold conditions.

16. Define Continuous duty

    Continuous duty is defined as the load that may be carried by the machine for an indefinite time without the temperature rise of any part exceeding the maximum permissible value.

17. Explain equivalent power method

    The equivalent power method cannot be used for motors whose speed varies considerably under load, especially when dealing with starting and braking conditions.

18. Explain Equivalent current method

    Equivalent current method is the accurate method. This method may be used to determine the motor capacity for all uses except where it. Is necessary to take into account the chages in “constant losses”.

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ELECTRICAL DRIVES AND CONTROL / EE6351

Two Mark Question and Answers

Chapter 2

1. What is Eletrical characteristics & Mechanical characteristics

   Torque Vs Armature current (Ta/Ia) is called as Eletrical characteristics. Speed Vs Torque (N / Ta) is called as Mechanical characteristics.

2. What are the Drawbacks of mechanical Braking:
   (i) Smooth stopping is not possible
   (ii) Excessive wear and tear
   (iii) Due to wear and tear, brake shoes needs frequent replacement
   (iv) Maintenance required is high
   (v) Heat produced is high
   (vi) Cost of replacement of parts is high

3. What are the Advantages electrical Braking
   (i) Smooth stopping at the instant required
   (ii) Maintenance is not necessary
   (iii) No wear and tear
   (iv) No cost invested by way of maintenance of brake shoes and linings
   (v) In regenerative braking, energy is returned back. This will result in saving of cost.

4. What are the types of electrical Braking.
   (i) Rheostatic Breaking (or) Plugging
   (ii) Counter current Breaking (or) Plugging
   (iii) Regenerative Breaking

5. Explain Regenerative Breaking

   Regenerative Breaking is possible when the load on the motor has over-hauling characteristics. In DC motors, regeneration takes place when Eb is greater than V.

In this Breaking, by its principle, some part of energy is returned back to the supply.

6. When does maximum torque occur
   Greater the rotor resistance, greater will be the value of slip at which the maximum torque occurs.

7. Why 1phase IM is not self starting
   Its stator winding is able to produce only alternating flux i.e., one which alternates along one space axis only. But for rotation, synchrously revolving flux is needed.

8. What is the diference detween capacitor start Induction Run & capacitor Run IM
   In the capacitor start Induction Run motor, capacitor is used for starting purpose only. But in capacitor start capacitor Run motor, capacitor is permanently connected. It will remain in the circuit all the times.

9. What are the Advantages of connecting capacitor permanently in the motor circuit
   (i) Improvement of over load capacity of the motor
   (ii) Higher power factor
   (iii) Higher efficiency
   (iv) Noiseless operation

10. Mention some of the features of two value capacitor run motor
    This motor starts with a high value of capacitor in series with the starting winding so the starting torque is high. For running lower value of capacitor is used.
    This type of motors has the following performance characteristics.
    (i) Ability to start heavy loads
    (ii) Extremely quiet operation
    (iii) Higher efficiency and power factor
    (iv) Ability to develop 25 percent over load capacity.

11. Mention some specific points regarding shaded pole IM
    They are simple in construction. Usually they are built for very small ratings, and they are very cheap.
    Disadvantages:
    (i) Low starting torque
    (ii) Low efficiency’

(iii) Very little overload capacity and

(iv) Not easy to reverse the direction of rotating.

12. Mention some applications of 1phase IM

Split phase motors

Blowers,centrifugalpumps,separators, washing, small machine tools, refrigerators.

Capacitor type

Fans,refrigerator units, Airconditioning machines, offices,laboratories, oil burners, blowers, compressors etc.,

Shaded pole type

Smallfans,toys,instruments,hairdriers,ventilators,electricclocks,adverising displays etc.,

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ELECTRICAL DRIVES AND CONTROL / EE6351

Two Mark Question and Answers

Chapter 3

1. What are the methods of starting electric motors

   At the instant of starting, heavy current flows through the motor which is not advisable. To control and safeguard the motor against this heavy inrush of current, starters are employed.

   For DC motors, this heavy current is controlled by connecting starting resistances inseries with armature.

   In the case of AC motors, reduced voltage is first applied and after the motor picks up speed, full voltage is applied.

   In the case of slip ring induction motors; large amount of resistance in the rotor circuit is included.

2. What are the methods used to reduce the energy loss during starting

   The methods used to reduce energy loss during starting are:\

   (i) By having methods and devices to here satisfactory transient operation.

   (ii) By providing means to develop good starting torque with reduced value of starting current.

   (iii) By reducing the acceleration time of the rotor.

3. How reduced voltage starting of IM is achieved

   Reduced voltage starting of induction motor is achieved by employing:

   (i) Primary resistors

   (ii) Auto transformer with tap settings adjustment

   (iii) Star-delta starter

   (iv) AC regulators (or) power Electronic regulators.

4. What are the factors to be considered while studying the starting of Electric drive systems

   (i) Type of Drive

   (ii) Type of supply

   (iii) Capacity and rating of the drive

   (iv) Purpose of application of the Drive employed

(v) Transient operation process during starting

(vi) Accelerating time

5. What are the starters can be used for starting 3 squirrel cage Induction motors:

    (i) Direct on line starter for smaller machines

    (ii) Primary resistor starter

    (iii) Auto transformer starter

    (iv) Star-Delta starter

6. Why starters are used

    At the instant of starting, there will be heavy inrush of current flowing through the windings. In order to protect the motor, there must be some provision for controlling the initial higher current. Starters are provided for this purpose.

7. What are the Type of starters used for starting DC motors

    (i) 3 point starter

    (ii) 2 point starter

    (iii) 4 point starter

8. Very small motors can be started without using staters Justify

    Very small motors can be started without using staters because of the following reasons:

    (i) Small motors have large armature resistance

    (ii) They have low moment of inertia, hence they speed up quickly

9. What are the common protective devices used in starters

    (i) No load release

    (ii) No volt release

    (iii) Over load release

10. What is the use of OLR

    If there is any overload condition, then the motor will drew larger current. This larger current will flow through the over load release coil. Due to this, the electromagnet gets energized and pulls the iron piece upward which short circuits the coils of the hold-on electromagnet. The hold on magnet gets de energized and therefore the starter arm returns to off position, thus protecting the motor against overload.

11. What is the function of NLR

    The DC series motor should not be started without load. If there is no load or low load, the speed of DC series will be dangerously high. This is not advisable. So, during this condition, no load release makes the control arm to return to OFF position, and prevents the motor from over speeding.

12. What are the Advantages of primary resister starters

(i) Very simple construction

(ii) Low cost

(iii) Useful for smooth starting of small machines.

13. What are the Drawbacks of autotransformer starters

(i) Suitable for larger rating motors only

(ii) Expensive method of starting

(iii) Maintenance necessary

14. What are the Advantages of star-delta starters

(i) cheaper tan auto-transformer starter

(ii) simple arrangement

(iii) commonly employed for both small and medium size motors.

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ELECTRICAL DRIVES AND CONTROL / EE6351

Two Mark Question and Answers

Chapter 4

1. What are the various methods of controlling speed

   Speed can be controlled by varying

   (iv) flux/pole

   (v) armature resistance

   (vi) applied voltage

2. What are the Advantages of flux control method

   (i) Good working effiency

   (ii) Accurate speed control

   (iii) Inexpensive

   (iv) Speeds above rated speeds can be obtained

3. What are the Drawbacks of rheostatic control method

   (i) Instability at high speeds due to armature reaction

   (ii) Inability to obtain speeds below the basic speed.

   (iii) Large amount of power is wasted in the controller resistance

   (iv) It needs expensive arrangement for dissipation of heat

   (v) Poor speed regulation

   (vi) Low efficiency

   (vii) Not possible to keep speed constant for fastly changing loads.

4. Why IM & dcshunt motor are called constant speed motor

   Because, in these two motors, speed is almost constant even for varying loads. The difference of speed between no load and full load condition is approximately 2% only. Hence they are called as constant speed motors.

5. What are the Advantages of Ward-Leonard scheme

   (i) Wide range of speed variation is possible

   (ii) Regenerative action possible

   (iii) Good speed regulation

(iv) Stepless and smooth speed control in either direction is possible,.

6. What are the Drawbacks of Ward-Leonard scheme
   (i) Over efficiency of the system is low especially at light loads
   (ii) Costlier since two extra machines are required
7. Where Tapped field control method is used
   Tapped field control method is used in electric traction.
8. What are the Different ways of obtaining variable flux
   (i) Using field diverters
   (ii) Using armature diverters
   (iii) Tapped field control method
   (iv) Paralleling field coils
9. Where Series parallel control method is employed
   Series parallel control method is employed in electric traction.
10. What are the Speed control methods used in DC series motors
    (i) Flux control method
        Field dicerter
        Armature diverter
        Tapped field control
        Paralleling field coils
    (ii) Connecting variable resistance in series with the motors.
11. List the advantages of thyristor controllers
    (i) Low installation cost
    (ii) Ease of maintenace
    (iii) High accuracy
    (iv) Greater reliability
    (v) Quick response
    (vi) Higher effiency
    (vii) Lower space requirement
    (viii) Operation at wide range of temperatures.
12. Mention the diffence between Uncontrolled & controlled rectifiers
    Uncontrolled rectifiers uses only diodes and not thyristors. Controlled rectifiers uses thyristors.
    In the uncontrolled rectifiers, output voltage is fixed. But in controlled rectifiers, the output voltage is variable

13. Define Holding current

Holding current of SCR is defined as the minimum 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 state.

.

14. What is a chopper

A chopper is a 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.

15. What is time ratio control

In a chopper average value of load voltage is given by, Vo = f.V.TON. It is clear that, output voltage depends on duty cycle and it is independent of load current.

Varying output voltage by varying time period of duty cycle is called as Time ratio control.

The methods of obtaining time ratio control are:

(i) By varying the duration of ON time with respect to OFF time keeping total timje period T constant.

(ii) By leeping ON time constant and varying the frequency.

(iii) By adjustment of both.

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ELECTRICAL DRIVES AND CONTROL / EE6351

Two Mark Question and Answers

Chapter – 5

1. What are the Methods applied from stator side for IM
   Methods applied from stator side
   a. Changing applied voltage
   b. Changing the applied frequency
   c. Changing the number of stator poles

2. What are the methods applied from rotor side for IM
   a. Rotor rheostat control
   b. By operating two motors in cascade
   c. By injecting emf into the rotor circuit

3. Why are the variable voltage method is very rarely used
   this method is very rarely used, because
   a. a large change in voltage is needed for a relatively small change in speed.
   b. A large in voltage will disturb the magnetic conditions of the motor.

4. Mention one application of variable frequency control
   This method of speed control has been used to some extent on electrically driven ships. Also, this method is employed in testing of scale model air planes.

5. Mention the types of schemes under slip power recovery control
   There are two types of schemes. They are
   a. krammer system main scherbus system

6. What are the limitations of the speed control by changing number of poles
   a. this method can be applicable only to squirrel cage motor since the squirrel cage rotor adopts itself to any number of stator poles.
   b. Continuous smooth speed control is not possible.

7. What is slip power recovery control
   A slip ring induction motor can be operated at reduced speds by inserting external resistance in the rotor circuit through slip rings. In this method, certain amount of slip power i.e., rotor power at slip frequency is lost as heat in the external resistance