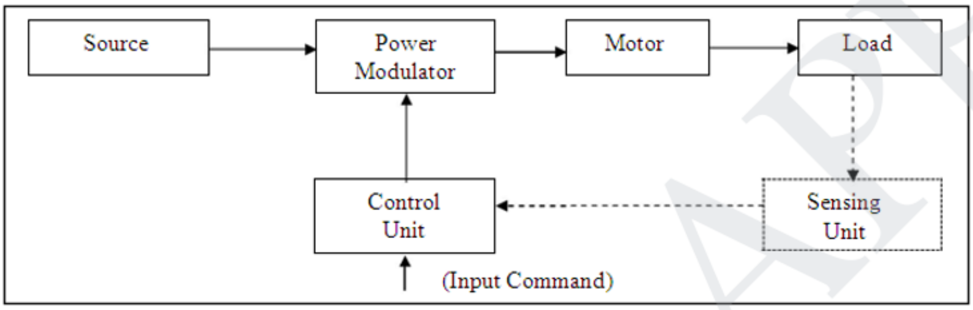
KONGUNADU COLLEGE OF ENGINEERING AND TECHNOLOGY
DEPARTMENT OF MECHANICAL ENGINEERING
EE8353-ELECTRICAL DRIVES AND CONTROLS
THIRD SEMESTER
UNITWISE NOTES

UNIT-1
INTRODUCTION

BASIC BLOCK DIAGRAM OF THE ELECTRICAL DRIVES AND ELEMENTS.

- Drives are systems employed for motion control. It Require prime movers.
- Drives that employ electric motors as prime movers are known as Electrical Drives



A modern variable speed electrical drive system has the following components

- Electrical machines and loads Power Modulator
- Sources
- Control unit
- Sensing unit

Electrical Machines:

Most commonly used electrical machines for speed control applications are the following

DC Machines

- Shunt, series, compound, separately excited DC motors and switched reluctance machines.

AC Machines

- Induction, wound rotor, synchronous, PM synchronous and synchronous reluctance machines.

Special Machines

- Brush less DC motors, stepper motors, switched reluctance motors are used.

Power Modulators:

Functions:

- Modulates flow of power from the source to the motor in such a manner that motor is imparted speed-torque characteristics required by the load
- During transient operation, such as starting, braking and speed reversal, it restricts source and motor currents with in permissible limits.
- It converts electrical energy of the source in the form of suitable to the motor Selects the mode of operation of the motor (i.e.) Motoring and Braking.

Types of Power Modulators

- In the electric drive system, the power modulators can be any one of the following
  - Controlled rectifiers (ac to dc converters) Inverters (dc to ac converters)
  - AC voltage controllers (AC to AC converters) DC choppers (DC to DC converters)
  - Cyclo converters (Frequency conversion)

Electrical Sources:

- Very low power drives are generally fed from single phase sources. Rest of the drives is powered from a 3 phase source. Low and medium power motors are fed from a 400v supply. For higher ratings, motors may be rated at 3.3KV, 6.6KV and 11 KV. Some drives are powered from battery.

Sensing Unit:

- Speed Sensing (From Motor)
- Torque Sensing Position Sensing
- Current sensing and Voltage Sensing from Lines or from motor terminals From Load
- Torque sensing
- Temperature Sensing

Control Unit

- Control unit for a power modulator are provided in the control unit. It matches the motor and power converter to meet the load requirements.

FACTORS FOR SELECTION OF DRIVE

Factors for selection of drive:

1. The limit of speed range
2. The efficiency
3. The braking
4. Starting requirements
5. Power factor
6. Load factor
7. Availability of Supply
8. Effects of supply variations
9. Economical aspects
10. Reliability of operation
11. Environmental Effects

1. **The limit of speed range:**
   The range over which the speed control is necessary, for the load. Similarly how hard it is to control the speed and the speed regulation also affects the choice of the motor.
2. **The efficiency:**
   The motor efficiency varies with the variation of load. So for the variable speed operation efficiency affects the choice of the motor.
3. **The braking:**
   Braking is depends the type of load used in motor. Easy and effective braking is used for good a drive.
4. **Starting requirements:**
   The starting necessary for the load, the corresponding starting current also affects the selection of drive.
5. **Power factor:**
   If power factor is less, that motor is not economical. The power factor varies with the load variation. So the type of load and the power factor are the important factors for selection of a drive.
6. **Load factor:**
   Load factor varies with types of load connected to the motor and types of duty like intermittent, continuous duty. So load variation and types of duty are important factors for selection of a drive.
7. **Availability of Supply:**
   The motor types are AC or DC. The availability of supply types is decides the type of motor is to be select for a drive.
8. **Effects of supply variations:**
   The supply frequency is varied with respect to load. So the motor to be select is can withstand for these frequencies.
9. **Economical aspects:**
   The size and rating of the motor decides the initial cost. Similarly losses and temperature decides the running cost. So these costs are should considered for selection of a drive.
10. **Reliability of operation:**
    It is the important factor for the motor stable operating condition. It is the important factor for selection of a drive.
11. **Environmental Effects:**
    The motor will used in different environment like moisture, heat, dust places. So the suitable motor with enclosure is to be select for a good drive.

Classify the drives by different operating duty methods with neat diagram.

According to the operating conditions of motor are classified into eight classes as

- Continuous duty
- Short time duty
- Intermittent periodic duty
- Intermittent periodic duty with starting
- Intermittent periodic duty with starting & braking
- Continuous duty with intermittent periodic loading
- Continuous duty with starting & braking
- Continuous duty with periodic speed changes.

Continuous Duty:

Motor runs at constant load for long duration without rest up to maximum temperature raise θ_f. It is called continuous duty. Examples: Paper mill drives, Compressors Conveyors, Centrifugal pumps and Fans.

Short Time Duty:

- Motor runs at constant load for some duration and then comes to rest period for sufficient duration. Examples: Crane drives, Drives for house hold appliances turning bridges Sluice gate drives, Valve drives and Machine tool drives.

Intermittent Periodic Duty:

- In this type drive operation, It consists of a different periods of duty cycles
- A period of rest and a period of running, a period of starting, a period of braking.
- Both a running period is not enough to reach its steady state temperature and a rest period is not enough to cool off the machine to ambient temperature.
- In this type drive operation, heating due to starting and braking is negligible.
- This type of duty can be accomplished by single phase/ three phase induction motors and DC shunt motors, universal motors. Examples: Pressing Cutting Drilling machine drives.

Intermittent Periodic Duty With Starting:

- This is intermittent periodic duty where heating due to starting can't be ignored.
- It consists of a starting period; a running period, a braking period & a rest period are being too short to reach their steady state value.
- In this type of drive operation, heating due to braking is negligible.
- This type of duty can be accomplished by three phase induction motors and DC series motors, DC compound motors, universal motors.Examples: Metal cutting, Drilling tool drives, Drives for fork lift trucks, Mine hoist, etc

Intermittent Periodic Duty With Starting And Braking:

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

Continuous Duty With Intermittent Periodic Loading:

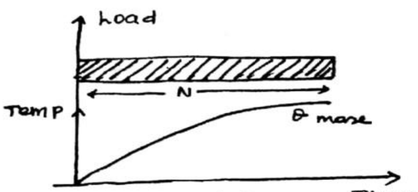
- This type of drive operation consists a period of running at constant load and a period of running at no load with normal voltage to the excitation winding in separately excited machines.
- Again the load and no load periods are not enough to reach their respective temperature limits.
- This duty is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

Continuous Duty with Starting & Braking:

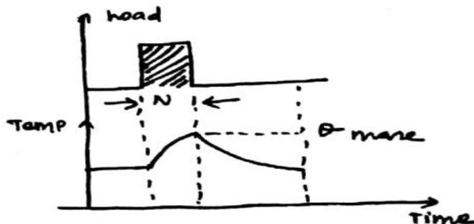
- It consists a period of starting, a period of running & a period of electrical braking.
- Here period of rest is negligible.
- This type of duty can be accomplished by single phase/ three phase induction motors.

Continuous Duty With Periodic Speed Changes:

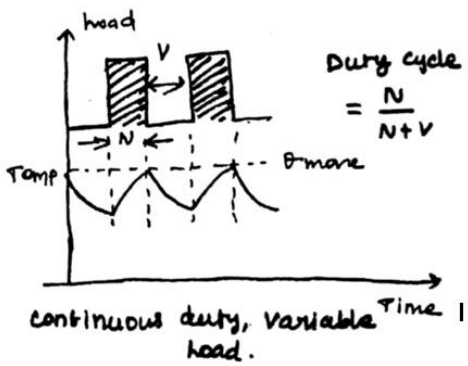
- It consists a period of running in a load with a particular speed and a period of running at different load with different speed which are not enough to reach their respective steady state temperatures.
- Here there is no period of rest.

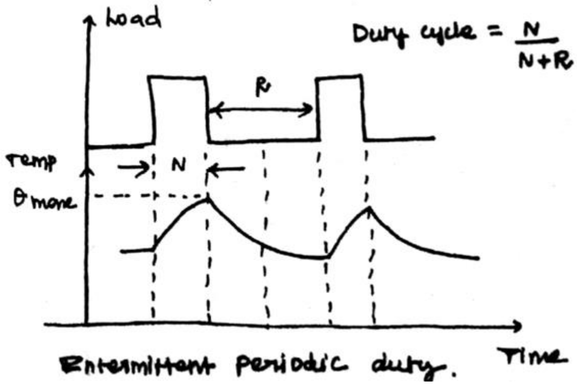


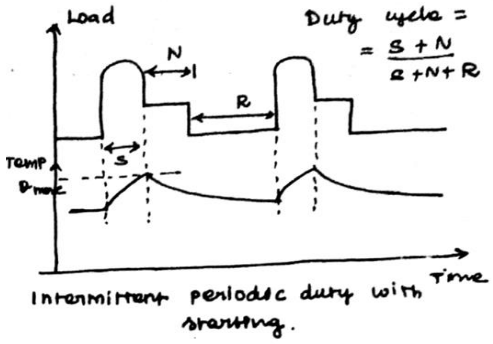
continuous duty.

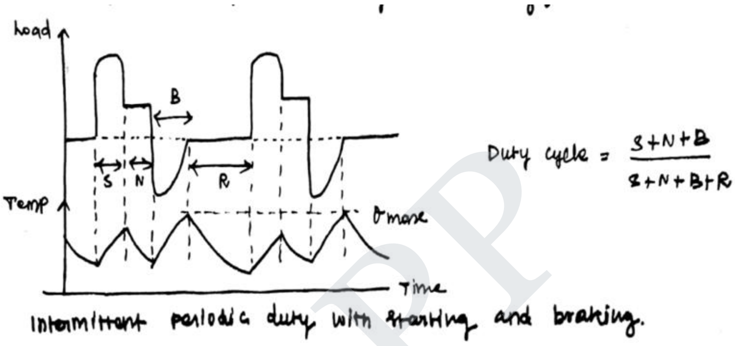


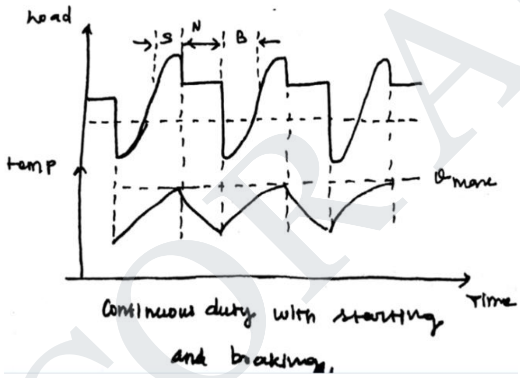
Short time duty.







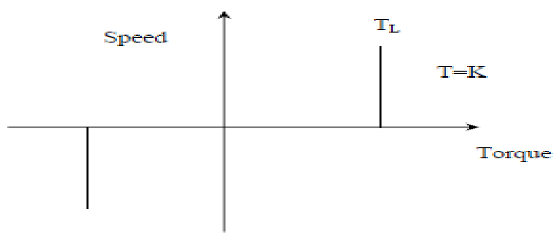




CHARACTERISTICS OF DIFFERENT TYPES OF LOADS

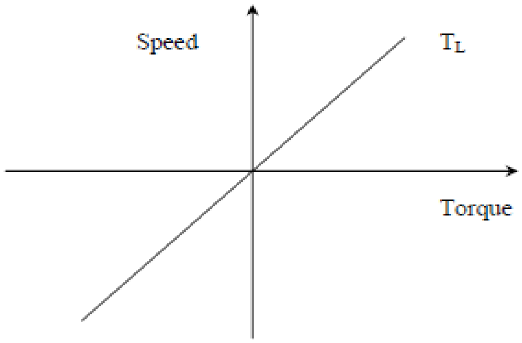
- One of the essential requirements in the section of a particular type of motor for driving a machine is the matching of speed-torque characteristics of the given drive unit and that of the motor.
- Therefore the knowledge of how the load torque varies with speed of the driven machine is necessary.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

1. Constant torque type load
2. Torque proportional to speed (Generator Type load)
3. Torque proportional to square of the speed (Fan type load)
4. Torque inversely proportional to speed (Constant power type load)
5. Most of the working machines that have mechanical nature of work like shaping, cutting,
6. Grinding or shearing, require constant torque irrespective of speed. Similarly cranes during the hoisting and conveyors handling constant weight of material per unit time also exhibit this type of characteristics.



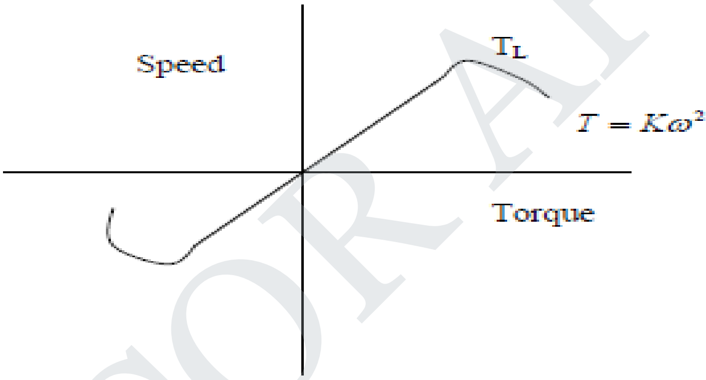
TORQUE PROPORTIONAL TO SPEED:

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



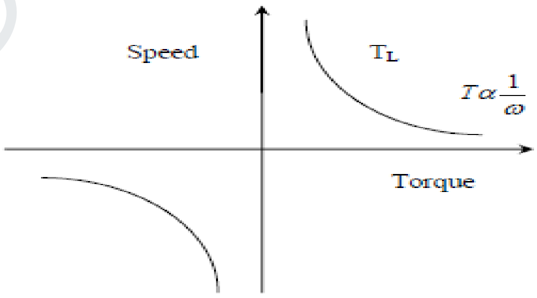
TORQUE PROPORTIONAL TO SQUARE OF THE SPEED:

Another type of load met in practice is the one in which load torque is proportional to the square of the speed. Example: Fans rotary pumps, compressors and ship propellers.



TORQUE INVERSELY PROPORTIONAL TO SPEED:

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



LOADING CONDITIONS FOR MOTOR

- Torque – A twisting movement, which plays a major role in the loading conditions of motor drives.
- The electric motor develops a electromagnetic torque of such magnitude which can counter balance the actual load torque of the connected equipment(load) and an opposing torque due to the losses(gear and transmission loss)

CLASSIFICATION OF LOADS

$T = T_L + T_{mech} + T_{dyn}$

T- Torque developed by the motor

T_L – Load torque

T_{mech} – Torque due to losses of gear and transmission mechanisms

T_{dyn} – Inertia torque

- **TORQUE DEPENDENT ON SPEED**

(Ex-hoists, pumping of water or gas against constant pressure)

- **TORQUE LINEARLY DEPENDENT ON SPEED**

(Ex- motor driving a DC generator connected to a fixed resistance load [generator field value is kept constant])

- **TORQUE PROPORTIONAL TO SQUARE OF SPEED**

(Ex- fans, centrifugal pumps, propellers)

- **TORQUE INVERSELY PROPORTIONAL TO SPEED**

(Ex-milling and boring, machines)

DIFFERENT TYPE OF INDUSTRIAL LOADS

- Continuous constant loads
- Continuous variable type loads
- Pulsating loads
- Impact loads
- Short time intermittent loads
- Short time loads

CONTINUOUS CONSTANT LOAD

These loads occur for a long time under the same conditions.

CONTINUOUS VARIABLE TYPE LOADS

This load is variable over a period of time, but occurs respectively for a longer duration.
Example- metal cutting lathes, conveyors etc.,

PULSATING LOADS

This types of loads exhibit a torque behavior which can be thought of as constant torque superimposed by pulsations.
Example- Reciprocating pumps and all loads having crank-shafts.

IMPACT LOADS

These are peak loads occur at regular intervals at time.
Example- rolling mills, forging hammers etc.

- **SHORT TIME INETERMITTENT LOAD**

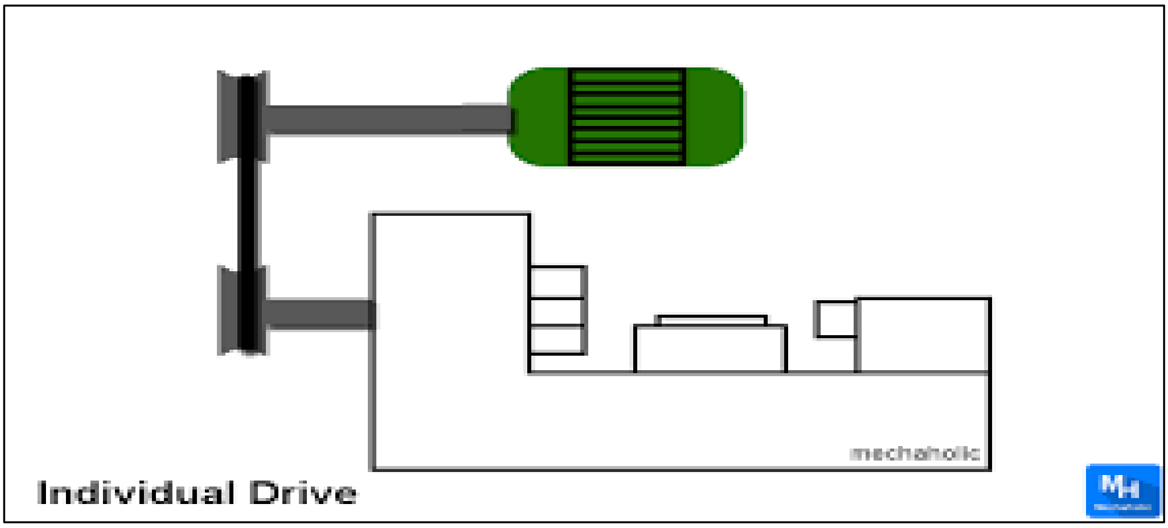
These loads appears periodically in identical duty cycles.
Example- cranes and hoisting mechanisms.

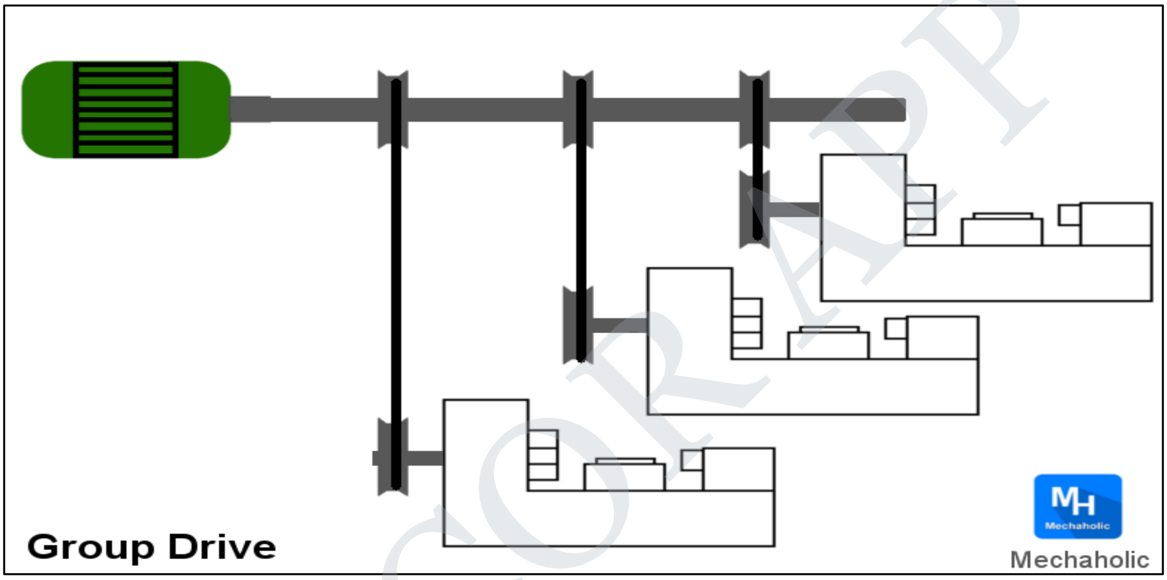
- **SHORT TIME LOADS**

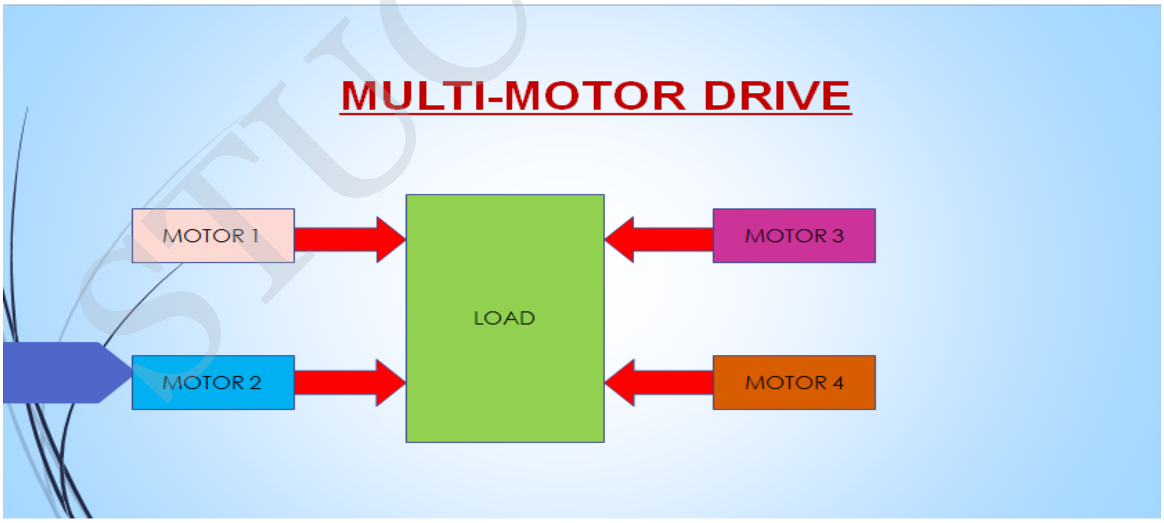
This a constant load appears on the drive for a short time and the system rests for the remainder.
Example- Battery charging, house holding equipment.

TYPES OF ELECTRICAL DRIVES

- GROUP DRIVE
- INDIVIDUAL DRIVE
- MULTIMOTOR DRIVE


mechaholic
Individual Drive


Group Drive
Mechaholic


MULTI-MOTOR DRIVE
MOTOR 1
MOTOR 2
LOAD
MOTOR 3
MOTOR 4

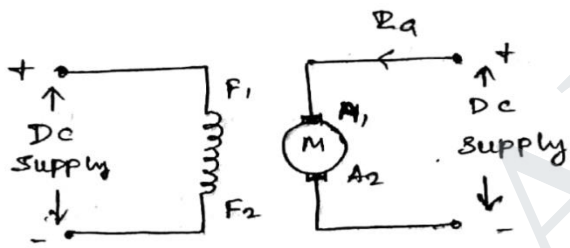
UNIT- 2
MOTOR CHARACTERISTICS

DIFFERENT DC MOTORS WITH ITS VOLTAGE AND CURRENT EQUATIONS.

- Depending on the way of connecting the armature and field windings of a DC motors are classified.
  - Separately excited DC motor.
  - Self Excited DC motor.
    - a) Series motor.
    - b) Shunt motor.
    - c) Compound motor.
      1. Long shunt.
      2. Short shunt.

Separately excited DC motor:

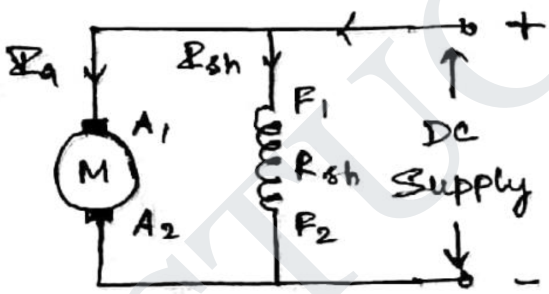
- The armature and field windings are connected to the separate supplies. Two DC sources are need.



separately excited DC Motor.

DC Shunt motor:

- Here armature and field of DC motor are connected in parallel and both are excited by single supply. So it is called self excited DC motor.



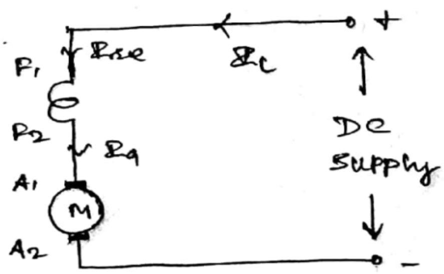
$I_L = I_a + I_{sh}$

$I_{sh} = \frac{V}{R_{sh}}$ = shunt field current

$V = E_b + I_a R_a$.

DC Series motor:

- Here armature and field of DC motor are connected in series and both are excited by single supply. So it is called self excited DC motor.



$I_L = I_{se} = I_a$

I_{se} = series field current

$V = E_b + I_a R_a + I_a R_{se}$.

DC Compound motor:

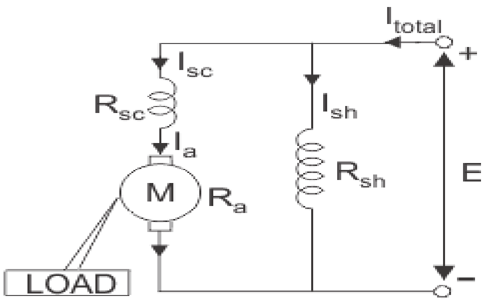
- Compound motor consists of two field winding (shunt, series) and one armature winding. All are excited by single supply. So it is called self excited DC motor.
    1. Long shunt compound motor.
    2. Short shunt compound motor.

1. Long Shunt Compound Motor:

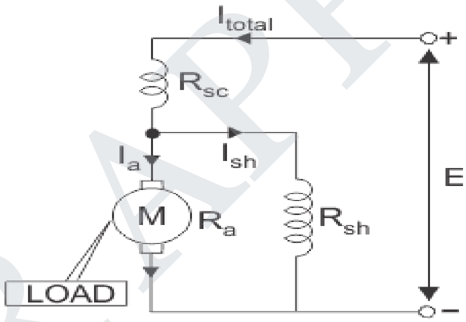
- In long shunt dc motor, one shunt field winding is connected across the series combination of the armature and series field winding.

2. Short Shunt Compound Motor:

- In short shunt compound motor, armature and field windings are connected in parallel with each other and this combination is connected in series with the one series filed winding.
- The long shunt and short shunt compound motors are further classified as **cumulative and differential compound motors.**



Long shunt compound dc motor



Short shunt compound dc motor

Equations for Long shunt compound dc motor:

$$I_L = I_{se} + I_{sh} = I_a + I_{sh} \quad \ldots\ldots \text{ as } I_{se} = I_a$$

$$I_{sh} = \frac{V}{R_{sh}}$$

$$V = E_b + I_a R_a + I_{se} R_{se}.$$

Equations for Short shunt compound dc motor:

$$I_L = I_{se}$$

$$I_L = I_a + I_{sh} = I_{se} \quad , \quad I_{sh} = \frac{V - I_L R_{se}}{R_{sh}}$$

$$V = E_b + I_L R_{se} + I_a R_a.$$

DYNAMIC BRAKING

In this braking a high resistance is inserted in the rotor circuit of induction motor, with the help of rheostat. In the below diagram braking on 3 phase induction motor is shown. Whenever we need braking one of the supply line out of R, Y or B is disconnected from the supply. Depending upon the condition of this disconnected line, we classified two types they are,

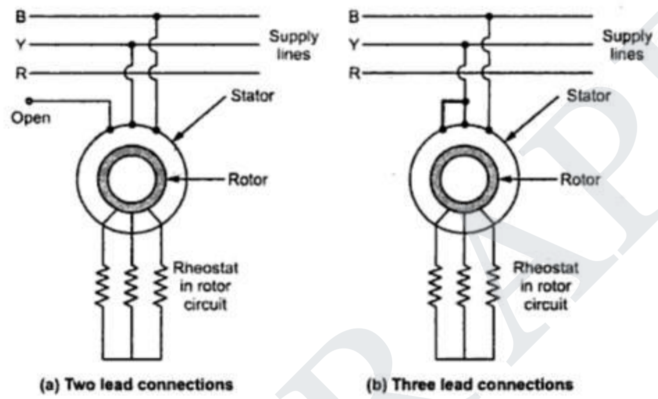
1. Two lead connections: In this method, the line disconnected, kept open. This is shown in the Fig and is called two lead connections of Rheostatic braking.

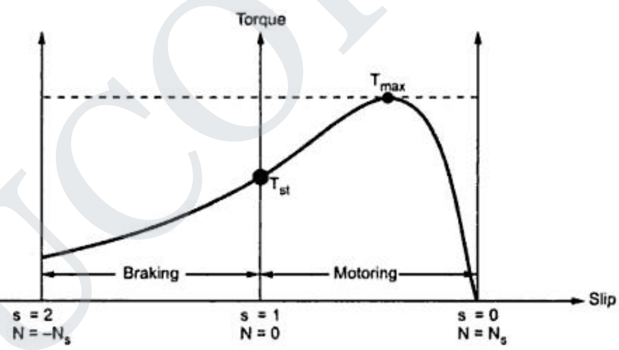
2. Three lead connections: In this method, After disconnection of the line, it is connected directly to the other line of the machine.

This method is effective only for slip ring or wound rotor induction motors.As one of the motor terminal is disconnected from the supply, the motor continues to run as single phase motor.

In this case the, breakdown torque i.e. maximum toque decreases to 40% of its original value and motor develops no starting torque at all. And due to high rotor resistance, the net torque produced becomes negative and the braking operation is obtained.

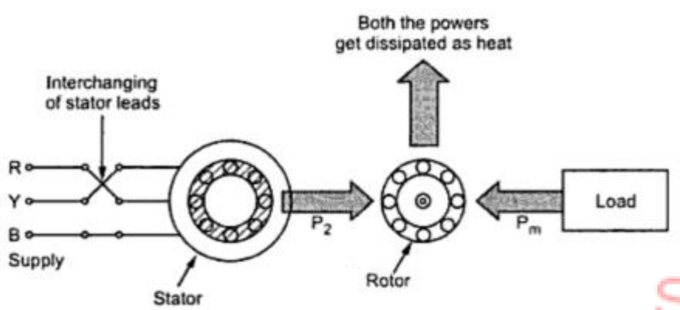
The braking torque is small in the case of two lead connections, high in the case of three lead connections. The braking torque is high at high speeds. But in three lead connections there is possibility of inequality between the contact resistances in connections of two paralleled lines. This might reduce the braking torque and even may produce the motoring torque again.So we prefer two lead connection over three lead connection. Even there is low braking torque in two lead system.





COUNTER CURRENT BRAKING

- Plugging induction motor braking is applied by just reversing the supply phase sequence.by interchanging connections of any two phases of stator we can attain plugging braking of induction motor.
- Due to the reversal of phase sequence, the direction of rotating magnetic field gets reversed. This produces a torque in the reverse direction and the motor tries to rotate in opposite direction. This opposite flux acts as brake and it slows down the motor.
- During plugging the slip is **(2 - s)**, if the original slip of the running motor is **s**.



Disadvantages of plugging induction motor braking:

1. During the plugging operation very high I²R losses occur in the form of heat. This heat is more than produced when rotor is normally locked.

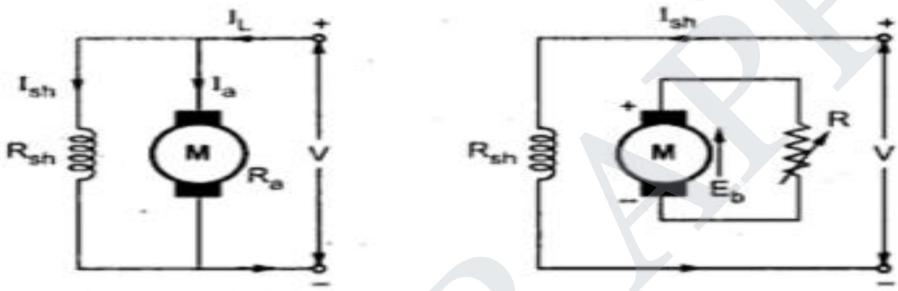
2. So we can't apply plugging frequently as due to high heat produced rotor which can damage or melt the rotor bars and even may over heat the stator as well.

Advantages of plugging induction motor braking:
1. It the quickest way.

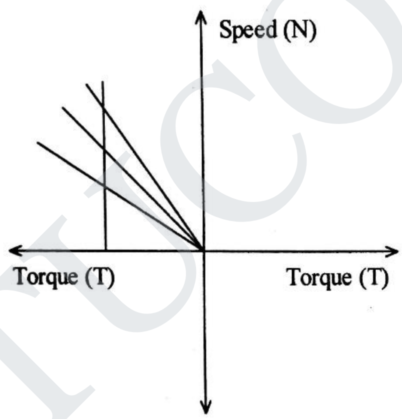
ELECTRIC BRAKING FOR D.C. SHUNT MOTOR

Rheostatic or Dynamic Braking :

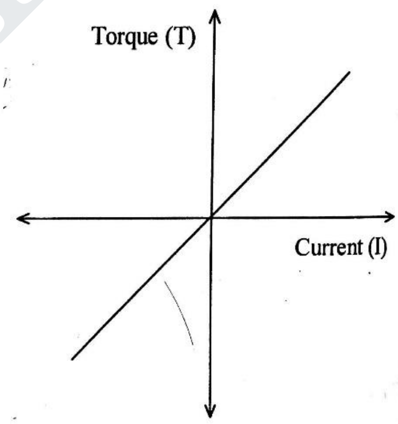
In this method, the armature is simply disconnected from the supply and connected to a resistance, while the field remains connected to the supply as shown in Fig. 1(a) and (b).



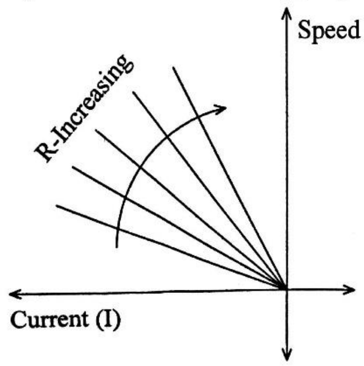
(a) Running (b) Braking



(a) - Speed versus torques



(b) - Torque versus current

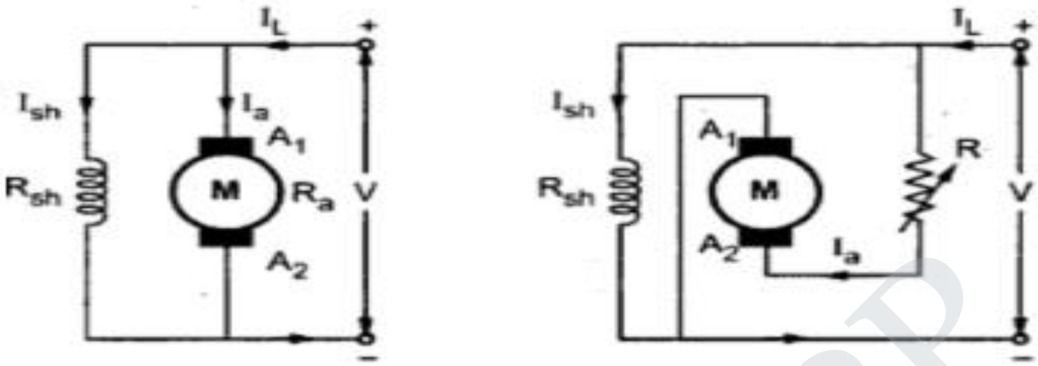


(c) - Speed versus current

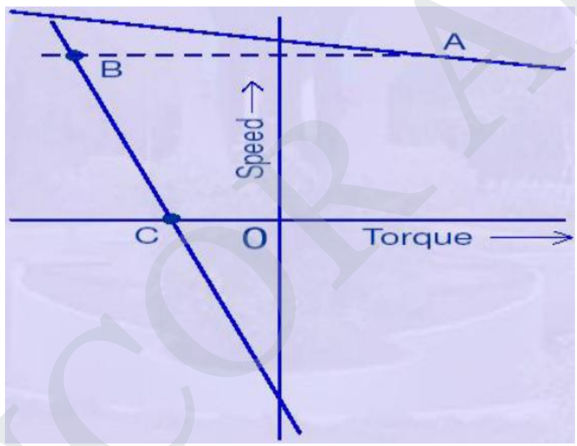
(b) Plugging :

- This involves the reversing of the armature connections of the motor. We have seen that if the direction of current through armature or field is reversed.

- In case of plugging, motor is subjected to the reversely directed torque. To limit high inrush of current an additional resistance R is connected. In this method, motor tries to accelerate in the other direction, after coming to rest.
- So some auxiliary device is required to cut-off the supply as soon as motor comes to rest. In case of failure of supply this method is ineffective. This method gives more braking torque that the rheostatic braking.

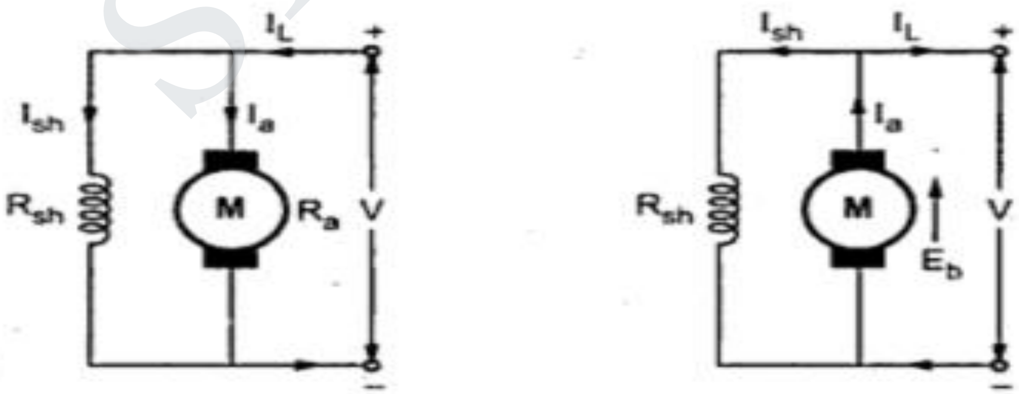


(a) Running (b) Braking

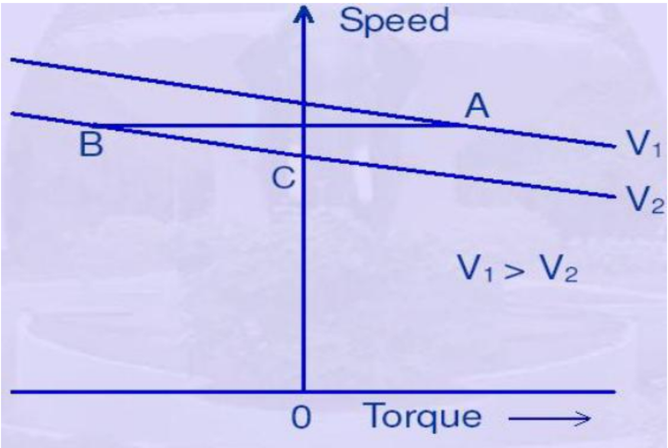


REGENERATIVE BREAKING

In this method, instead of being disconnected from the supply, it remains connected and returns the braking energy to the line.



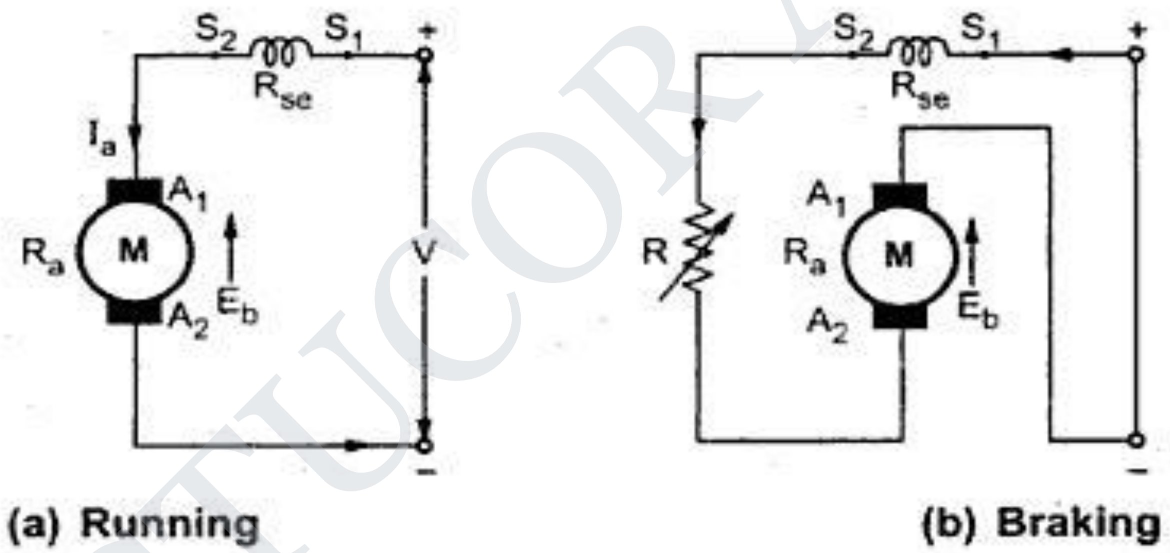
(a) Running (b) Braking

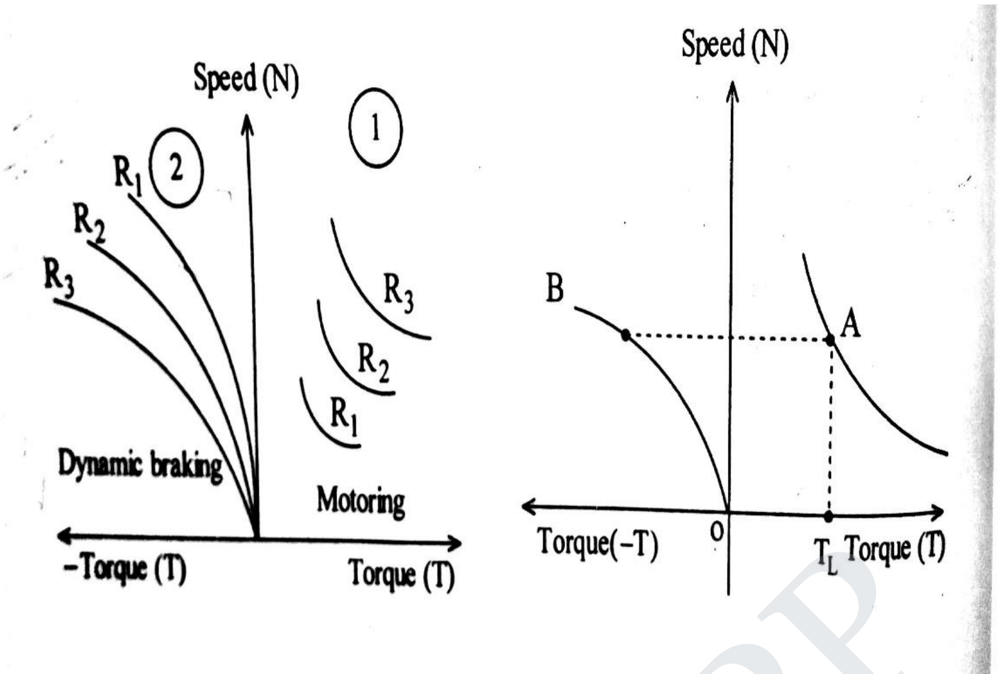


ELECTRIC BRAKING FOR SERIE DC MOTORS

Rheostatic or dynamic braking :

The basic principle of disconnecting the armature from the supply remains the same. The direction of the current through the armature reverse while braking. The motor runs as a generator. In case of series motor care should be taken to see that the direction of current through field does not change

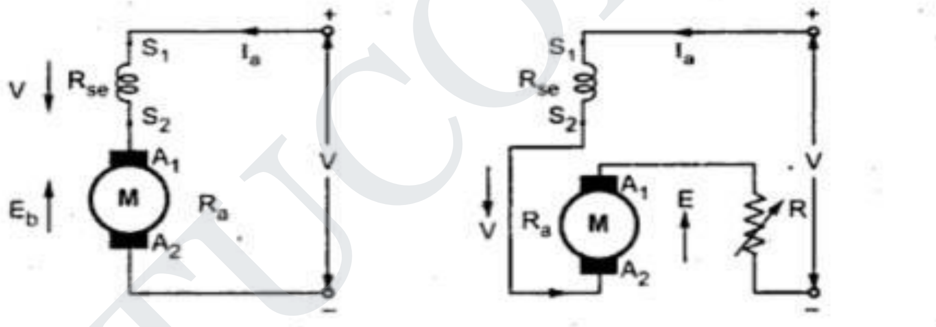




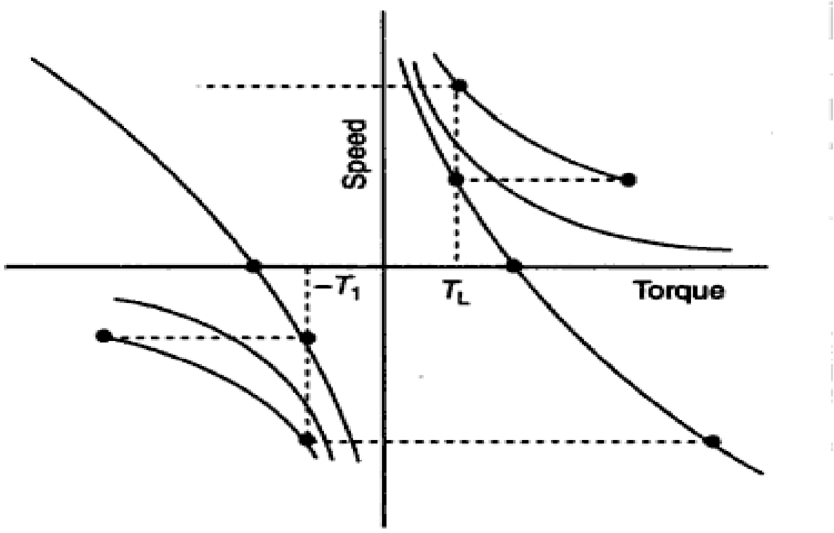
(a) (b)

Plugging :

The basic principle of reversing the armature connection remains same. Similar to the shunt motor, the resistance R added can be controlled to control the magnitude of the braking torque.



(a) Running (b) Braking

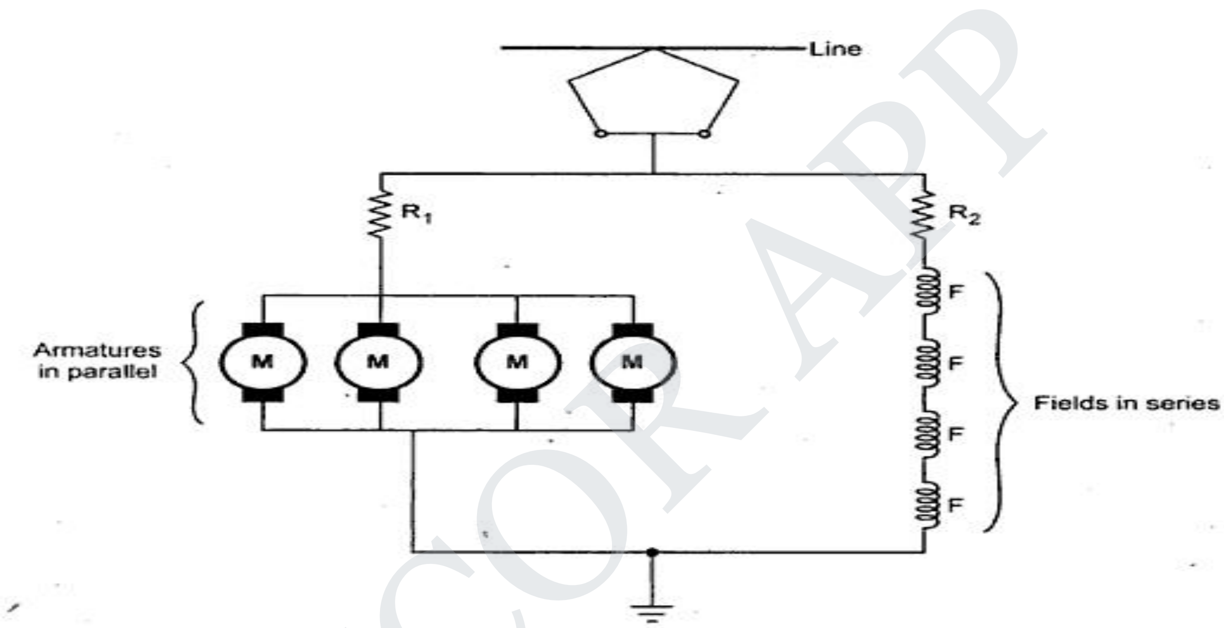


Regenerative braking

In case of a d.c. series motor, increase in excitation results decrease in speed. As such it is not possible to get e.m.f. more than voltage. It is not possible to make field current more than the armature current. Hence regeneration braking with series motor is not possible. But can be used with traction motors with some special arrangements.

Note : The flow of disturbance current through the series field causes the electrical instability for the series motors when used for regenerative braking.

Hence while using series motors for regenerative braking the fields must be excited separately and use stabilizing circuits.



UNIT-3
STARTING METHODS

THREE POINT STARTER

A 3 point starter in simple words is a device that helps in the starting and running of a shunt wound DC motor or compound wound DC motor. Now the question is why these types of DC motors require the assistance of the starter in the first case. The only explanation to that is given by the presence of back emf E_b, which plays a critical role in governing the operation of the motor. The back emf, develops as the motor armature starts to rotate in presence of the magnetic field, by generating action and counters the supply voltage. This also essentially means, that the back emf at the starting is zero, and develops gradually as the motor gathers speed.

The general motor emf equation

$$E = E_b + I_a . R_a$$

At starting is modified to $E = I_a.R_a$ as at starting $E_b = 0$.

$$\therefore \ I_a = \frac{E}{R_a}$$

Thus we can well understand from the above equation that the current will be dangerously high at starting (as armature resistance R_a is small) and hence its important that we make use of a device like the **3 point starter** to limit the starting current to an allowable lower value.

Let us now look into the construction and **working of three point starter** to understand how the starting current is restricted to the desired value. For that let's consider the diagram given below showing all essential parts of the three point starter.

Construction of 3 Point Starter

Construction wise a starter is a variable resistance, integrated into number of sections as shown in the figure beside. The contact points of these sections are called studs and are shown separately as OFF, 1, 2, 3, 4, 5, RUN. Other than that there are 3 main points, referred to as

1. 'L' Line terminal. (Connected to positive of supply.)
2. 'A' Armature terminal. (Connected to the armature winding.)
3. 'F' Field terminal. (Connected to the field winding.)

And from there it gets the name 3 point starter. Now studying the construction of 3 point starter in further details reveals that, the point 'L' is connected to an electromagnet called overload release (OLR) as shown in the figure. The other end of OLR is connected to the lower end of conducting lever of starter handle where a spring is also attached with it and the starter handle contains also a soft iron piece housed on it. This handle is free to move to the other side RUN against the force of the spring. This spring brings back the handle to its original OFF position under the influence of its own force. Another parallel path is derived from the stud '1', given to another electromagnet called No Volt Coil (NVC) which is further connected to terminal 'F'. The starting resistance at starting is entirely in series with the armature. The OLR and NVC acts as the two protecting devices of the starter.

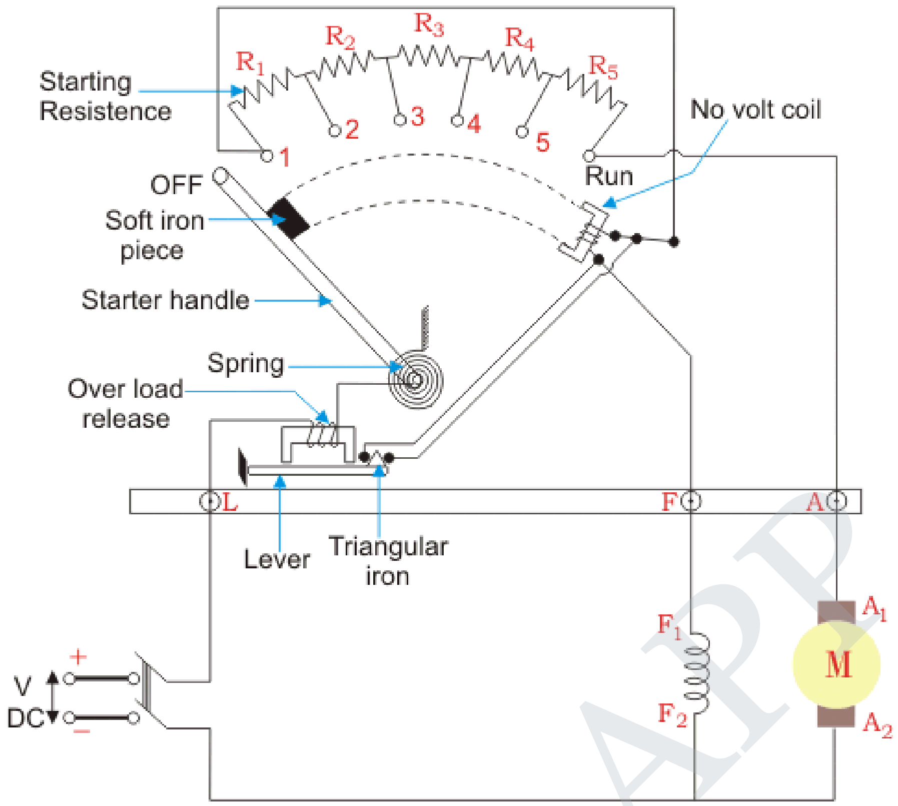


Fig. Three Point Starter

Working of Three Point Starter

Having studied its construction, let us now go into the **working of the 3 point starter**. To start with the handle is in the OFF position when the supply to the DC motor is switched on. Then handle is slowly moved against the spring force to make a contact with stud No. 1. At this point, field winding of the shunt or the compound motor gets supply through the parallel path provided to starting resistance, through No Voltage Coil. While entire starting resistance comes in series with the armature. The high starting armature current thus gets limited as the current equation at this stage becomes

$$I_a = \frac{E}{(R_a + R_{st})}$$

As the handle is moved further, it goes on making contact with studs 2, 3, 4 etc., thus gradually cutting off the series resistance from the armature circuit as the motor gathers speed. Finally when the starter handle is in 'RUN' position, the entire starting resistance is eliminated and the motor runs with normal speed.

This is because back emf is developed consequently with speed to counter the supply voltage and reduce the armature current. So the external electrical resistance is not required anymore, and is removed for optimum operation. The handle is moved manually from OFF to the RUN position with development of speed. Now the obvious question is once the handle is taken to the RUN position how is it supposed to stay there, as long as motor is running? To find the answer to this question let us look into the working of No Voltage Coil.

Working of No Voltage Coil of 3 Point Starter

The supply to the field winding is derived through no voltage coil. So when field current flows, the NVC is magnetized. Now when the handle is in the 'RUN' position, soft iron piece connected to the handle and gets attracted by the magnetic force produced by NVC, because of flow of current through it. The NVC is designed in such a way that it holds the handle in 'RUN' position against the force of the spring as long as supply is given to the motor. Thus NVC holds the handle in the 'RUN' position and hence also called **hold on coil**.

Now when there is any kind of supply failure, the current flow through NVC is affected and it immediately loses its magnetic property and is unable to keep the soft iron piece on the handle, attracted. At this point under the action of the spring force, the handle comes back to OFF position, opening the circuit and thus switching off the motor. So due to the combination of NVC and the spring, the starter handle always comes back to OFF position whenever there is any supply problems. Thus it also acts as a protective device safeguarding the motor from any kind of abnormality.

Drawbacks of a Three Point Starter

The **3 point starter** suffers from a serious drawback for motors with large variation of speed by adjustment of the field rheostat. To increase the speed of the motor field resistance can be increased. Therefore current through shunt field is reduced. Field current becomes very low which results in holding electromagnet too weak to overcome the force exerted by the spring. The holding magnet may release the arm of the starter during the normal operation of the motor and thus disconnect the motor from the line. This is not desirable. A four point starter is thus used.

Working Principle of Four Point Starter

The **4 point starter** like in the case of a 3 point starter also acts as a protective device that helps in safeguarding the armature of the shunt or compound excited DC motor against the high starting current produced in the absence of back emf at starting. The 4 point starter has a lot of constructional and functional similarity to a three point starter, but this special device has an additional point and a coil in its construction. This naturally brings about some difference in its functionality, though the basic operational characteristic remains the same. The basic difference in circuit of **4 point starter** as compared to 3 point starter is that the holding coil is removed from the shunt field current and is connected directly across the line with current limiting resistance in series. Now to go into the details of operation of 4 point starter, lets have a look at its constructional diagram, and figure out its point of difference with a 3 point starter.

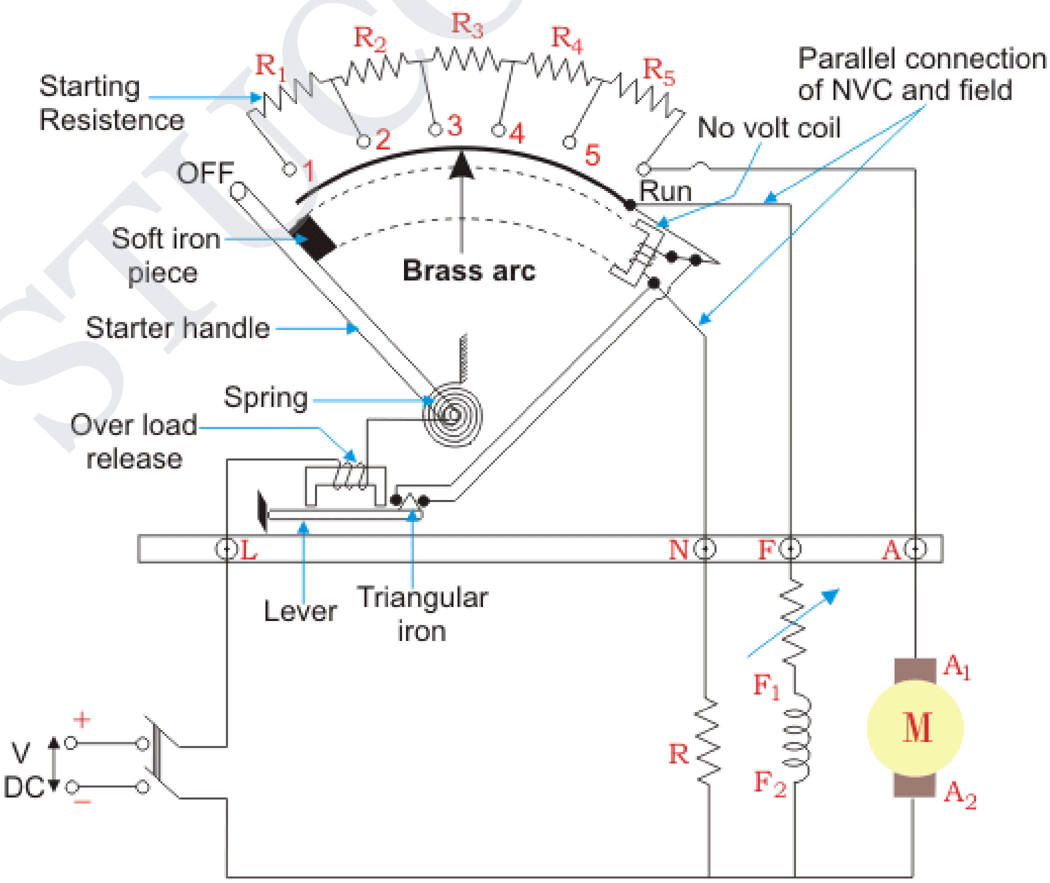


Fig. Four Point Starter

Construction and Operation of Four Point Starter

A 4 point starter as the name suggests has 4 main operational points, namely

'L' Line terminal. (Connected to positive of supply.)

'A' Armature terminal. (Connected to the armature winding.)

'F' Field terminal. (Connected to the field winding.)

Like in the case of the 3 point starter, and in addition to it there is, A 4th point N. (Connected to the No Voltage Coil NVC). The remarkable difference in case of a 4 point starter is that the No Voltage Coil is connected independently across the supply through the fourth terminal called 'N' in addition to the 'L', 'F' and 'A'. As a direct consequence of that, any change in the field supply current does not bring about any difference in the performance of the NVC. Thus it must be ensured that no voltage coil always produce a force which is strong enough to hold the handle in its 'RUN' position, against force of the spring, under all the operational conditions. Such a current is adjusted through No Voltage Coil with the help of fixed resistance R connected in series with the NVC using fourth point 'N' as shown in the figure above.

Apart from this above mentioned fact, the 4 point and 3 point starters are similar in all other ways like possessing is a variable resistance, integrated into number of sections as shown in the figure above. The contact points of these sections are called studs and are shown separately as OFF, 1, 2, 3, 4, 5, RUN, over which the handle is free to be maneuvered manually to regulate the starting current with gathering speed.

Now to understand its way of operating lets have a closer look at the diagram given above. Considering that supply is given and the handle is taken stud No.1, then the circuit is complete and line current that starts flowing through the starter. In this situation we can see that the current will be divided into 3 parts, flowing through 3 different points.

1^{st} part flows through the starting resistance (R1+ R2+ R3…..) and then to the armature.

A 2_{nd} part flowing through the field winding F.And

A 3_{rd} part flowing through the no voltage coil in series with the protective resistance R.

So the point to be noted here is that with this particular arrangement any change in theshunt field circuit does not bring about any change in the no voltage coil as the two circuits are independent of each other. This essentially means that the electromagnet pull subjected upon the soft iron bar of the handle by the no voltage coil at all points of time should be high enough to keep the handle at its RUN position, or rather prevent the spring force from restoring the handle at its original OFF position, irrespective of how the field rheostat is adjusted. This marks the operational difference between a 4 point starter and a 3 point starter. As otherwise both are almost similar and are used for limiting the starting current to a shunt wound DC motor or compound wound DC motor, and thus act as a protective device.

D.O.L STARTER

To start, the contactor is closed, applying full line voltage to the motor windings. The motor will draw a very high inrush current for a very short time, the magnetic field in the iron, and then the current will be limited to the Locked Rotor Current of the motor. The motor will develop Locked Rotor Torque and begin to accelerate towards full speed.

As the motor accelerates, the current will begin to drop, but will not drop significantly until the motor is at a high speed, typically about 85% of synchronous speed. The actual starting current curve is a function of the motor design, and the terminal voltage, and is totally independent of the motor load.

The motor load will affect the time taken for the motor to accelerate to full speed and therefore the duration of the high starting current, but not the magnitude of the starting current.

Provided the torque developed by the motor exceeds the load torque at all speeds during the start cycle, the motor will reach full speed. If the torque delivered by the motor is less than the torque of the load at any speed during the start cycle, the motor will stops accelerating. If the starting torque with a DOL starter is insufficient for the load, the motor must be replaced with a motor which can develop a higher starting torque.

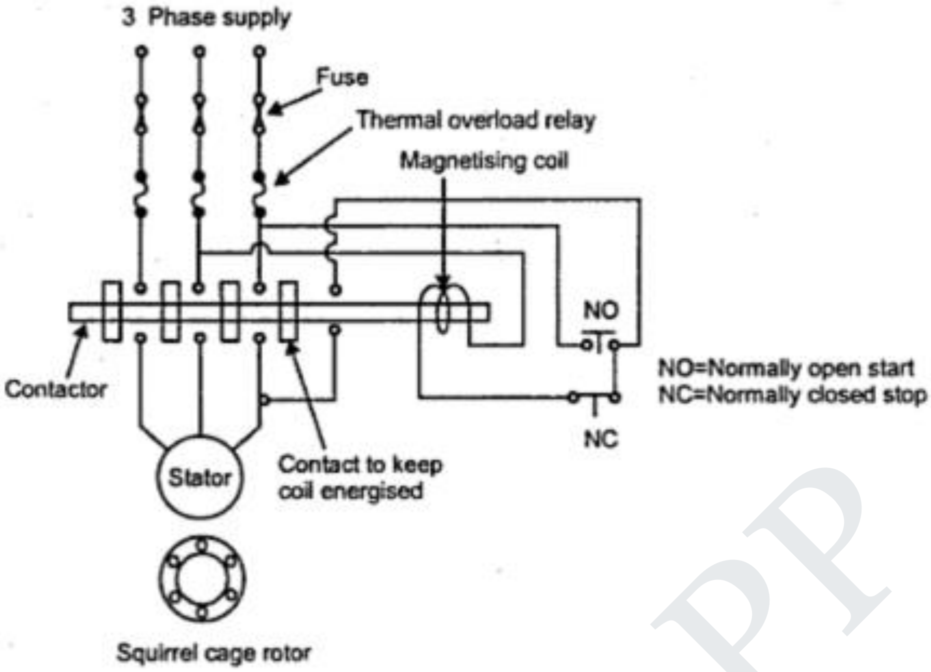


Fig. D.O.L Starter

The acceleration torque is the torque developed by the motor minus the load torque, and will change as the motor accelerates due to the motor speed torque curve and the load speed torque curve. The start time is dependent on the acceleration torque and the load inertia.This may cause an electrical problem with the supply, or it may cause a mechanical problem with the driven load. So this will be inconvenient for the users of the supply line, always experience a voltage drop when starting a motor. But if this motor is not a high power one it does not affect much.

Over Load Relay (Overload protection)

Overload protection for an electric motor is necessary to prevent burnout and to ensure maximum operating life. Under any condition of overload, a motor draws excessive current that causes overheating. Since motor winding insulation deteriorates due to overheating, there are established limits on motor operating temperatures to protect a motor from overheating. Overload relays are employed on a motor control to limit the amount of current drawn.

Working principle of DOL Starter

The main heart of DOL starter is Relay Coil. Normally it gets one phase constant from incoming supply Voltage.when Coil gets second Phase relay coil energizes and Magnet of Contactor produce electromagnetic field and due to this Plunger of Contactor will move and Main Contactor of starter will closed and Auxiliary will change its position NO become NC and NC become .

Pushing Start Button

When We Push the start Button Relay Coil will get second phase from Supply Phase-Main contactor-Auxiliary Contact-Start button-Stop button-To Relay Coil.Now Coil energizes and Magnetic field produce by Magnet and Plunger of Contactor move. Main Contactor closes and Motor gets supply at the same time Auxiliary contact become from NO to NC.

Release Start Button

Relay coil gets supply even though we release Start button. When we release Start Push Button Relay Coil gets Supply phase from Main contactor -Auxiliary contactor – Auxiliary contactor -Stop Button-Relay coil.In Overload Condition of Motor will be stopped by intermission of Control circuit.

Pushing Stop Button

When we push Stop Button Control circuit of Starter will be break at stop button and Supply of Relay coil is broken, Plunger moves and close contact of Main Contactor becomes Open, Supply of Motor is disconnected.

AUTOTRANSFORMER STARTER

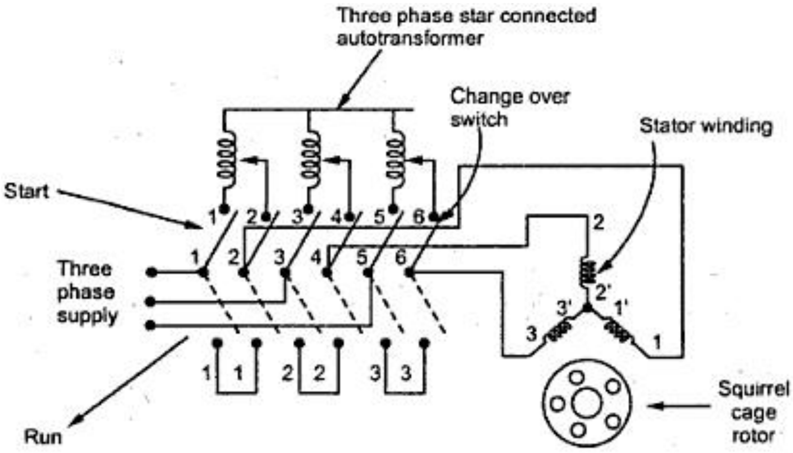


Fig. Autotransformer Starter

- A three phase star connected autotransformer can be used to reduce the voltage applied to the stator. Such a starter is called an autotransformer starter.
- It consists of a suitable change over switch.
- When the switch is in the start position, the stator winding is supplied with reduced voltage. This can be controlled by tapping's provided with autotransformer.
- The reduction in applied voltage by the fractional percentage tappings x.

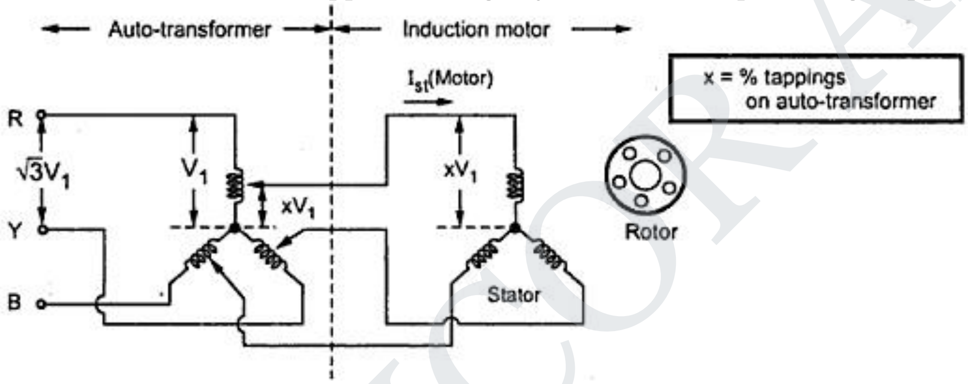


Fig. Use of Autotransformer to reduce voltage at start

- When motor gathers 80% of the normal speed, the changeover switch is thrown into run position.Due to this, rated voltage gets applied to stator winding. The motor starts rotating with normal speed. Changing of switch is done automatically by using relays. The power loss is much less in this type of starting.
- It can be used for both star and delta connected motors. But it is expensive than stator resistance starter. Let x be the fractional percentage tapping's used for an autotransformer to apply reduced voltage to the stator. So if,

  I sc = Starting motor current at rated voltage, and

  I st = Starting motor current with starter, then

  I st = x I sc .....Motor side ....(1)
- But there is exists a fixed ratio between starting current drawn from supply I st (supply) and starting motor current I st (motor) due to autotransformer, as shown in the Fig.

  Autotransformer ratio x = I st (supply)/ I st (motor)

  I st (supply) = x I st (motor) ....(2)

  Substituting I st (motor) from equation (1)

  I st (supply) = x . x I sc = x 2 I sc ....(3)

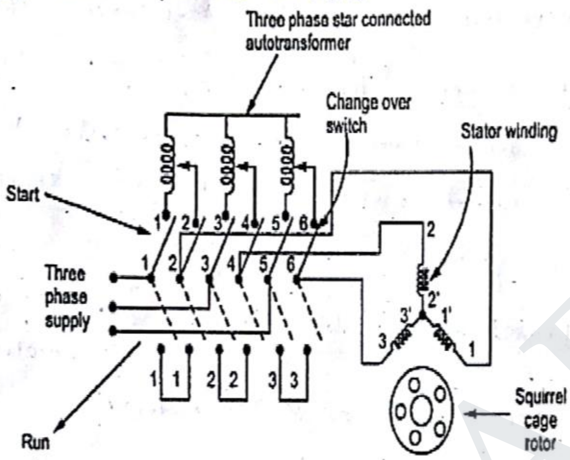
Now T st α I st 2 (motor) α x 2 I sc 2 and T F.L. α (I F.L.) 2/s f

$$\therefore \quad \boxed{\frac{T_{st}}{T_{F.L.}} = x2\left[\frac{I_{sc}}{I_{F.L.}}\right]^2 \times s_f}$$

Auto transformer starter

A three phase star connected autotransformer can be used to reduce the voltage applied to the stator.

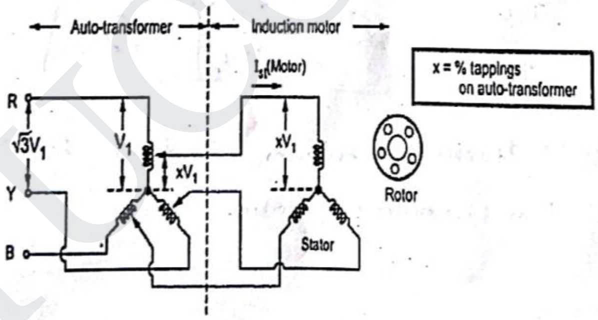
* It consists of a suitable change over switch.
* When the switch is in the start position, the stator winding is supplied with reduced voltage — (2M)



— (3M)

This can be controlled by tappings provided with auto transformer.

The reduction in applied voltage by the fractional percentage tappings x, used for an auto transformer as shown in figure. → (1M)



— (2M)

When motor gathers 80% of the normal speed, the change over switch is thrown into run position.

Due to this, rated voltage gets applied to the stator winding.

Changing of switch is done automatically by using relays.

It can be used for both star and delta connected motors.

It is expensive than stator resistance starter.

Relationship between T_{st} and $T_{F.L}$ — (5M)

I_{sc} - starting motor current at rated voltage

I_{st} - starting motor current with starter

$I_{st} = x I_{sc}$ ..... (motor side)

Auto transformer ratio $x = \frac{I_{st}(supply)}{I_{st}(motor)}$

$I_{st}(supply) = x I_{st}(motor)$

$I_{st}(supply) = x^2 I_{sc}$

$T_{st} \propto I_{st}^2 (motor) \propto x^2 I_{sc}^2$

$T_{F.L} \propto \frac{(I_{F.L})^2}{s_f}$

$$\boxed{\frac{T_{st}}{T_{F.L}} = x^2 \left[\frac{I_{sc}}{I_{F.L}}\right]^2 \times s_f}$$

Thus starting torque reduces by x^2 where x is the transformation ratio.

STAR – DELTA STARTER

- It is the most commonly used reduced voltage starting method of three phase induction motor. In this method, induction motor is connected in star during start and delta while running with rated speeds.These starters are designed to run on delta connected stator of an induction motor.

- This starter uses a TPDT (triple pole double throw) switch and it connects the stator winding in star during the starting condition. Due to this star connection, the applied voltage to the motor is reduced by the factor 1/√3. This reduced voltage results the less current through the motor.

- When the motor picks up the speed, the TPDT switch is thrown manually the winding is now connected in delta across the supply. So the normal voltage is applied to the motor and hence the motor runs at normal speed

- This method is cheap and maintenance free as compared to other methods. However, this is suitable only for delta connected motors and also the factor by which starting voltage reduced to 1/√3 and starting torque is reduced to 1/3 of starting torque obtained with direct switching.

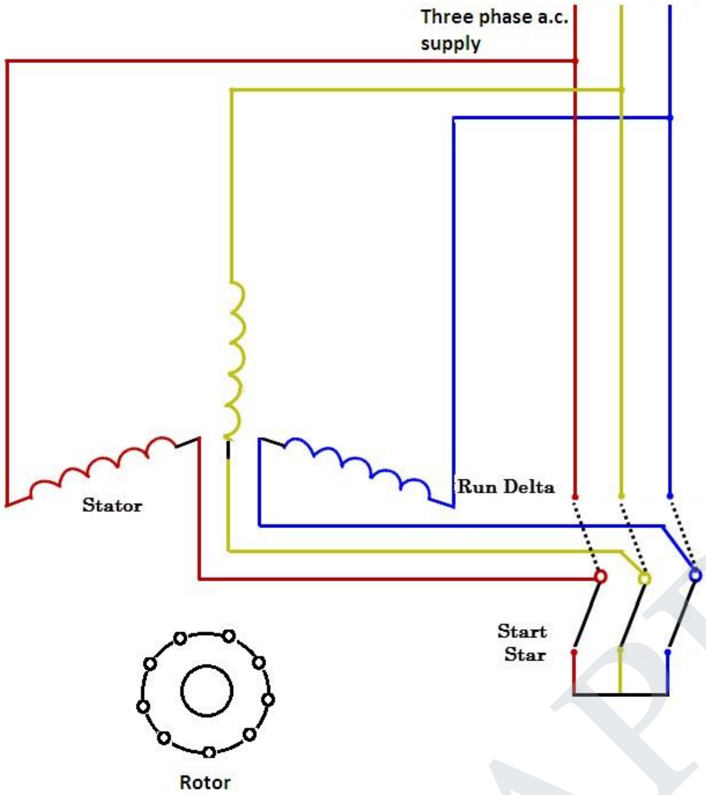


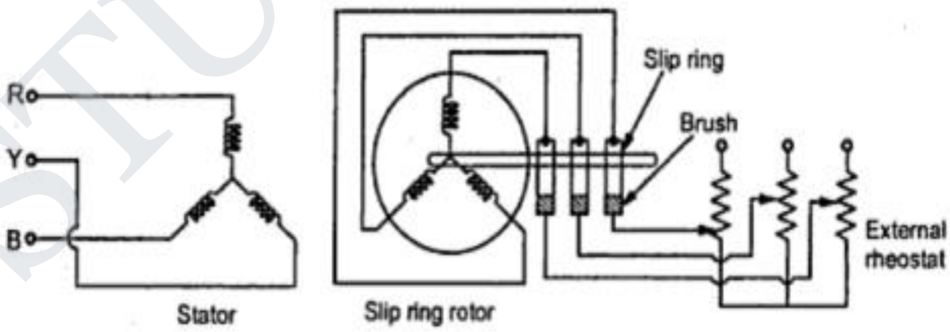
Fig. Star – Delta Starter

ROTOR RESISTANCE STARTER

To **limit the rotor current which consequently reduces the current drawn by the motor** from the supply, the resistance can be inserted in the rotor circuit at start.

This addition of the resistance in rotor in the form of 3 phase star connected rheostat. The arrangement is shown in the Fig.

The external resistance is inserted in each phase of the rotor winding through slip ring and brush assembly. Initially maximum resistance is in the circuit. As motor gather speed, the resistance is gradually cut-off. The operation may be manual or automatic.



We have seen that the starting torque is proportional to the rotor resistance. Hence **important advantage** of this method is not only the **starting current is limited** but **starting torque of the motor also gets improved.**

The only limitation of the starter that it can be used only for slip ring induction motors as in squirrel cage motors, the rotor is permanently short circuited.

TORQUE-SPEED AND TORQUE-SLIP CHARACTERISTICS OF 3 PHASE INDUCTION MOTOR WITH DIFFERENT REGIONS.

- It is a curve drawn between **Torque (T) and Slip (S)** from S=1 (at start N=0) to S=0 (at N=Ns)
- Torque equation as

$$T \ \alpha \ \frac{sE_2^2R_2}{R_2^2+(sX_2)^2}$$

- Here input voltage is **constant (E2).** So it becomes,

$$T \ \alpha \ \frac{sR_2}{R_2^2 + (sX_2)^2}$$

It consist of three regions:

- Stable operating region.
- Unstable operating region.
- Normal operating region.

Stable region: (low slip region)

- Here slip S is very small.
- So SX_2^2 is very small compare to R_2^2

$$T \ \alpha \ \frac{sR_2}{R_2^2 + (sX_2)^2}$$

$$T \ \alpha \ \frac{sR_2}{R_2^2} \ \alpha \ s \quad \text{as } R_2 \text{ is constant}$$

$$\therefore \ T \alpha s$$

- So load ↑, N ↓, S ↑,
- So straight line characteristics is obtained in this stable region (curve AB).

Unstable region: (high slip region)

- Slip is increased up to Sm. In this region slip S is high.
- So R_2^2 is very small compare to SX_2^2
- R_2^2 is neglected.

$$T \ \alpha \ \frac{s}{(sX_2)^2} \ \alpha \ \frac{1}{s} \quad \text{where } X_2 \text{ is constant}$$

$$\therefore \ T \ \alpha \ \frac{1}{s}$$

- S ↑, T ↓
- Increasing load ↑, N ↓, S ↑, finally motor comes to stop (N=0)
- Motor cannot run long time in this region. It comes to stop.

Normal operating region:

- It is also low slip region. In this region motor can run continuously for long time.

Starting torque (Tst):

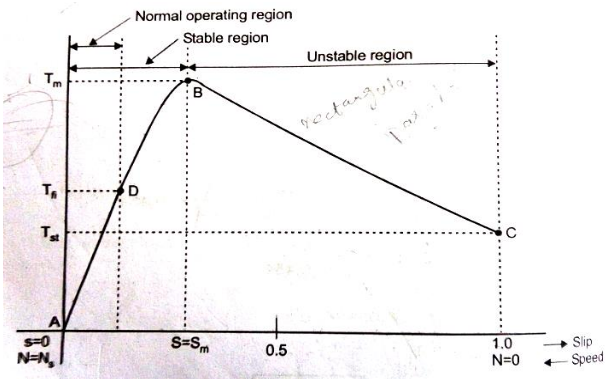
- At starting condition **N=0, S=1**. In this condition motor torque is called Starting torque.

Maximum torque (Tm):

- At **S=Sm** , the motor torque is called Maximum torque.
- Sm = Slip at maximum torque occurs.
- It is called pullout torque or breakdown torque.

Full load torque(Tfl):

- Point D is full load torque of the motor. When full load is applied to motor, at this condition the torque is called full load torque.



UNIT-4

CONVENTIONAL AND SOLID STATE SPEED CONTROL OF D.C DRIVES

WARD-LEONAD SPEED CONTROL

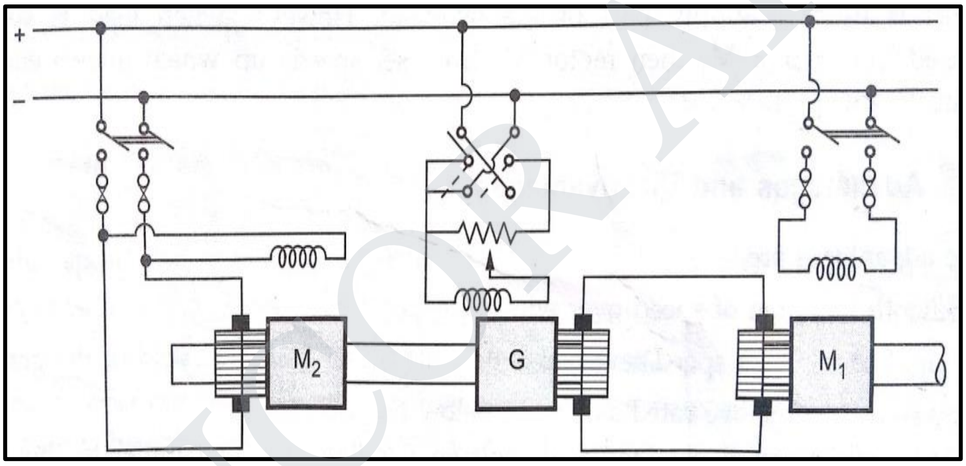
- It is used when very sensitive and wide range of speed control is needed.
- It is used to control the speed of separately excited DC motor.

Elements of ward-leonad system:

- Main motor M1- this motor speed is to be controlled by this system.
- Auxiliary motor M2- it is dc shunt motor, connected to Generator.
- DC Generator G - it gives the variable voltage to the M1 motor.
- DC supply

Construction of ward-leonad system:

- M1 is the main motor is to be controlled. This motor field is directly connected to the supply. Only armature is connected to generator setup.
- Generator setup used to give variable voltage to the M1 motor. Generator shaft connected to M2 motor shaft. Field winding of generator is connected to dc supply with variable resistor and reversing switch S.



Operation of ward-leonad system:

- The motor M2 is a shunt motor is connected to dc supply. Its shaft connected to generator shaft.
- When supply is on this generator setup gives the supply to M1 armature. M1 start rotate in one speed.
- Generator setup used to give variable voltage to the M1 motor. Field winding of generator is connected to dc supply with variable resistor and reversing switch S.
- This setup can change the field of generator. So the generator speed and output voltage is changes. This output voltage is given as an input armature voltage to the M1 motor. The speed of M1 motor also changes.
- Switch S is used to reverse the supply of generator field. So direction of generator rotation also can change. Due this armature voltage of M1 motor also changes, it leads Motor M1 rotation also reversed.
- In this system both armature voltage and field control methods are used to control the speed of motor.

Advantages of ward-leonad system:

- Smooth variation of speed for wide range.
- Rapid and instant speed reverse is possible by field reversal of generator.
- Above and below rated speed control is possible. (Armature voltage and field control)
- No need of starting requirement.
- Good speed regulation at any speed.

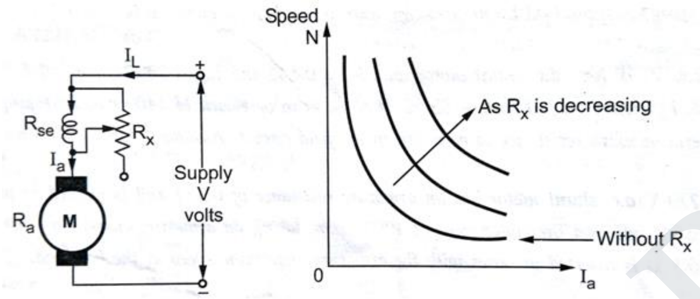
onad system:

- More number of machines used. So efficiency is low.
- Initial cost is very high.

SPEED CONTROL OF D.C SERIES MOTOR USING FLUX CONTROL

1. Field divertor method

In this method the series field winding is shunted by a variable (Rx) known as field diverter. The arrangement as shown.

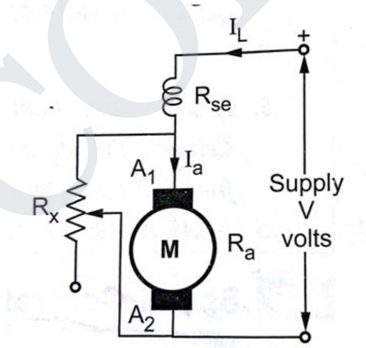


Due to the parallel path of Rx, by adjusting the value of Rx, any amount of current can be diverted through the diverter. Hence current through the field winding can be adjusted of the motor gets controlled.

By this method the speed of the moyot can be controlled above rated value. The speed armature current characteristics with change in Rx as shown.

2. Armature Diverter method

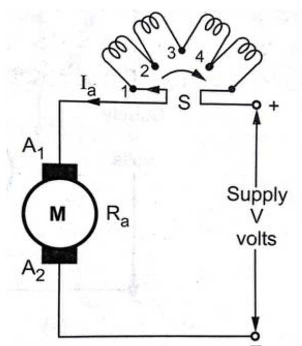
This method is used for the motor which require constant load torque. An armature of the motor is shunted with an external variable as shown, this resistance Rx is called armature diverter.



Any amount of armature current can be diverted through the divertor. Due to this, armature current reduces. But as T α Ia and load torque is constant, the flux is to be increases. So motor reacts by drawing more current from the supply. So current through field winding increases, so flux increases and speed of the motor redueces. The method is used to control the speed below the normal value.

3. Taped field method

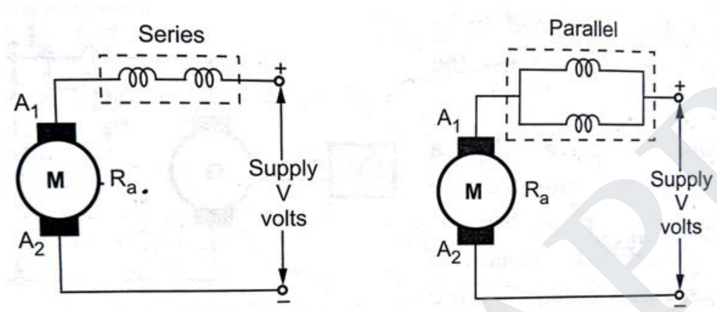
In this method, flux change is achieved by changing the number of thrns of the field winding. The field winding is provided with the taps as shown.



The selector switch "S" is provided to select the number of turns as per the requirement. When the switch is in position 1 the entire field winding is in the circuit and motor runs with normal speed. As the switch is moved from position 1 to 2 and onwards, the number of turns of the field winding in the circuit decreases. Due to this m.m.f require to produce the flux, decreased. Due to this flux produced decreases, increases the speed of the motor above rated value. The method is often used in electric motor.

4. Series-Parallel combination of field

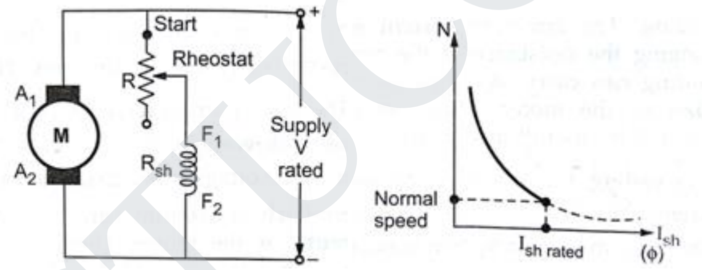
In this method, the field coil is diverted into various parts. These parts can be connected in series or parallel as per two per the requirement. The fig shows the two parts of the field coil connected in series and parallel.



For the same torque, if the field coil is arranged in series or parallel, mmf produced by the coil changes, hence the flux produced also changes. Hence speed can be controlled. Some fixed speeds only can be obtained by thid method. In parallel grouping, the mmf produced decreases, hence higher speed can be obtained by parallel grouping. The method is generally used in case of fan motors.

SPEED CONTROL OF D.C SHUNT MOTOR USING FLUX CONTROL

The speed is inversely proportional to the flux. The flux is dependent on the current through the shunt field winding. Thus flux can be controlled by adding with the shunt field winding as shown



At the beginning the rheostat R is kept at minimum indicated as start as shown. The supply voltage is at its rated value. So current through shunt filed winding is also at its rated value. Hence the speed is also called normal speed. Then the resistance R is increased due to which shunt field current Ish decreases, decreasing the flux produced. As N α (1/φ), the speed of the motor increases beyond its rated value.
Thus the this method, speed control above rated value is possible. This is shown in the fig, by speed against field current curve. The curve shows the inverse relation between N and φ as its nature is rectangular hyperbola.
It is mentioned that the rated values of electrical parameter should not be exceeded but the speed which is mechanical parameter can be increases upto twice its rated value.

Advantages of Flux control method

- It provides relatively smooth and easy control
- Speed control above rated speed is possible
- As the field winding resistance high, the field current is small. Hence power loss in the external resistance is very small. Which makes the method more economical
- As the current is small, the size of the rheostat required is small.

Disadvantages of Flux control method

- The speed control below normal rated speed is not possible as flux can be increased only upto its rated value.
- As flux reduces, speed increases. But high speed affect the commutation making motor operation unstable. So there is limit to the maximum speed normal, possible by this method.

The factors affecting the speed of DC motor:

According to the speed equation of d.c motor can write

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

The factors Z, P, A are constant for d.c motor.

But as the value of armature resistance Ra and series field resistance Rse is very small, the drop IaRa and Ia(Ra+Rse) is very small compared to the applied voltage V. hence neglecting these voltage drops the speed equation can be modified as,

$$N \propto \frac{V}{\phi} \qquad \text{as } E_b \approx V$$

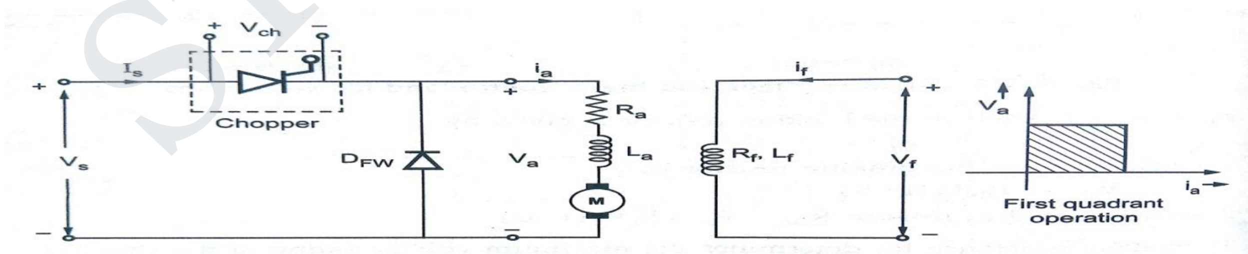
Thus the factors affecting the speed of a d.c motor are,

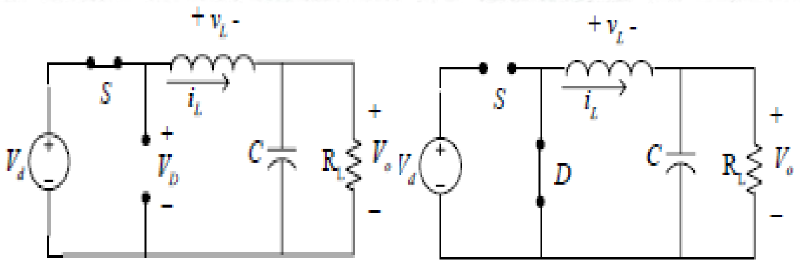
- The flux
- The voltage across the armature
- The applied voltage V

Depending upon these factors the various methods of speed control are,

- Changing the flux by controlling the current through the field winding called flux control methods.
- Changing the armature path resistance which inturn changes the voltage applied across the armature called rhoestatic control.
- Changing the applied voltage called voltage control method.

STEP-DOWN CHOPPER OPERATION TO CONTROL THE SPEED OF THE DC MOTOR WITH OUTPUT WAVEFORMS.





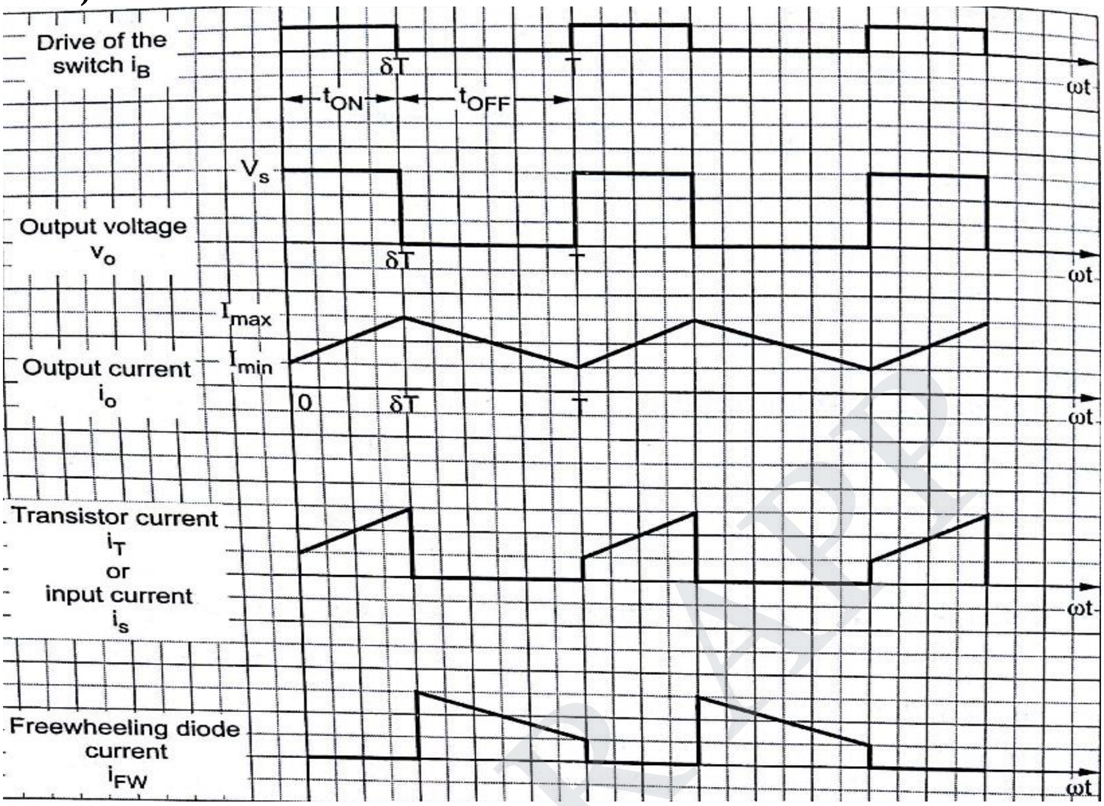
Circuit operation when switch is turned on (closed)

- Diode is reversed biased. Switch conducts inductor current
- This results in positive inductor voltage, i.e.: $V_L = V_d - V_O$
- It causes linear increase in the inductor current.

Operation when switch turned off (opened)

- Because of inductive energy storage, i_L continues to flow.
- Diode is forward biased.
- Current now flows through the diode.

(Vs>Vo)



From the waveform of output voltage we can write, the average output

$$V_o = V_s\left[\frac{t_{ON}}{t_{ON}+t_{OFF}}\right]$$

$$= V_s\left[\frac{t_{ON}}{T}\right] \quad \text{where } T = t_{ON} + t_{OFF}$$

Let $\frac{t_{ON}}{T} = \alpha$ where α is duty cycle.

Hence the average output voltage is given by,

$$\therefore \quad V_o = \alpha \cdot V_S$$

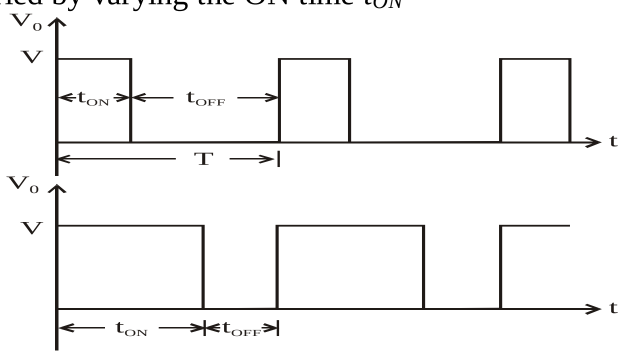
VOLTAGE CONTROL METHODS IN DC CHOPPER.

The output dc voltage can be varied by the following methods.

1. **Time ratio control**
   - Pulse width modulation control or constant frequency operation.
   - Variable frequency control.
2. **Current limit control.**

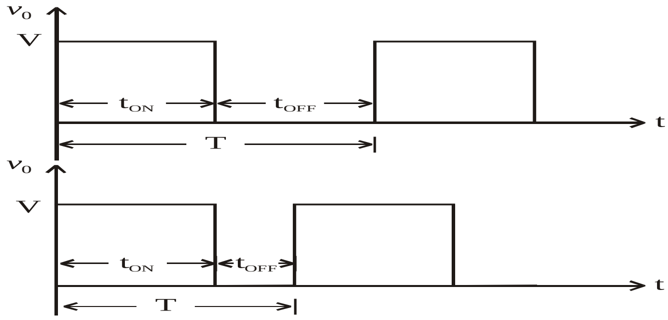
Constant Frequency Operation.

- t_{ON} is varied keeping chopping frequency 'f'& chopping period 'T' constant.
- Output voltage is varied by varying the ON time t_{ON}



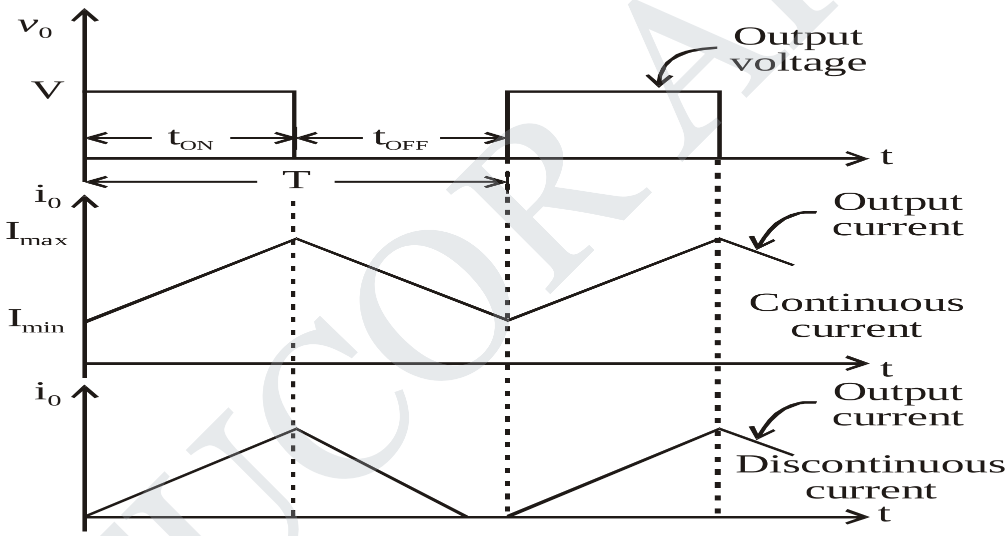
Variable frequency control

- Chopping frequency *'f'* is varied keeping either t_{ON} or t_{OFF} constant.
- To obtain full output voltage range, frequency has to be varied over a wide range.
- This method produces harmonics in the output and for large t_{OFF} load current may become discontinuous.

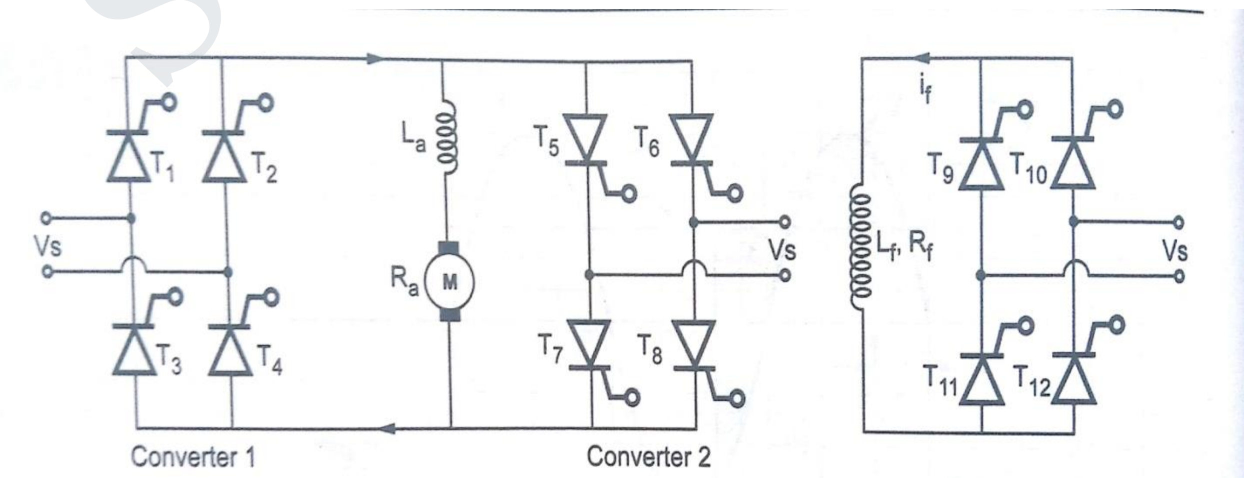


Current limit control.

- Chopper on and off operation and output voltage is controlled by current limits (Imax and Imin)
- Imax Reached chopper gets off the Vo is zero.
- Imin reached chopper gets ON ,Vo is obtained.



DUAL CONVERTER CONTROL SPEED CONTROL OF DC MOTOR.



- ➢ It consists of two single phase fully controlled converters. (conv 1, conv 2).
- ➢ In one mode of operation converter 1 supplies the voltage to motor.

- In another one mode of operation converter 2 supplies the voltage to motor in opposite polarity.
- It can operate in four quadrant operations.
    - ✓ Forward motoring (quadrant 1)
    - ✓ Forward braking (quadrant 2)
    - ✓ Reverse motoring (quadrant 3)
    - ✓ Reverse braking (quadrant 4)
- It operates above and below rated speed controls.
- It can use up to 15KW applications.

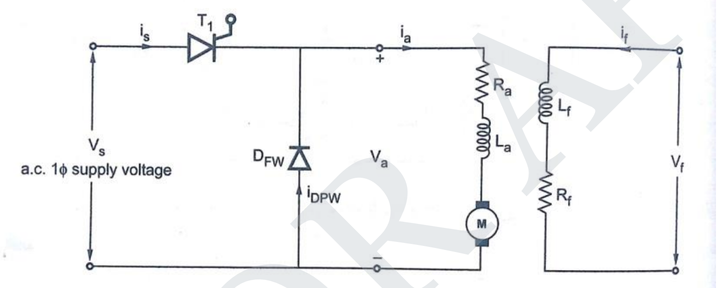
Converter 1 voltage:

Va = 2Vm/π cos α1

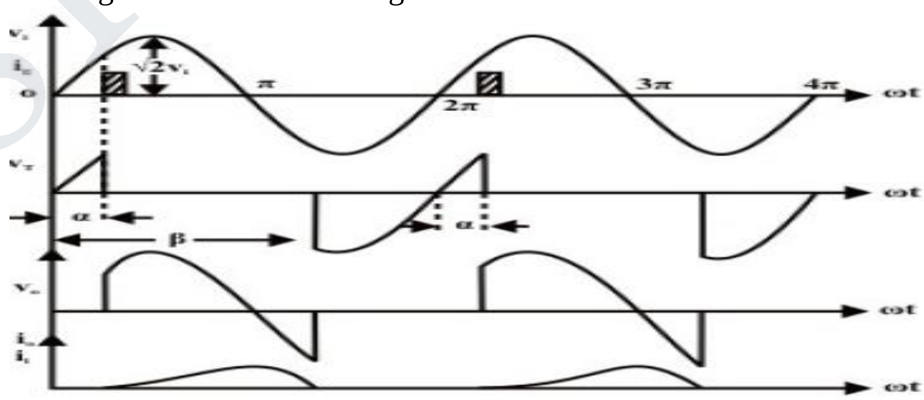
Converter 2 voltage:

Va = 2Vm/π cos α2

SINGLE PHASE FULLY CONTROLLED HALF WAVE RECTIFIER FED DC SEPARATELY EXCITED MOTOR.



- Can be turned on by applying gate signal when SCR is forward biased.
- Operation is almost same as that of diode circuit
- Thyristor turns ON at ωt= α& voltage appears across Load & current starts building up.
- Inductor does not changes current instantaneously, so load current does not become zero at ωt = π
- It continues to flow but the negative supply voltage decreases its magnitude. At ωt= β current becomes zero and thyristor starts blocking until again turned ON.
- By changing the firing angle up to 90°we can change the speed of the motor.
- FD used to neglect the reversal voltage.



Average output voltage,

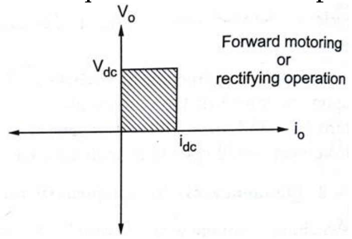
$$v_{av} = \frac{1}{2\pi}\int_{\alpha}^{\beta}\sqrt{2}v_i \sin \omega t d\omega t$$

$$v_{av} = \frac{v_i}{\sqrt{2}\pi}(\cos\alpha - \cos\beta)$$

CLASSIFICATION OF CHOPPERS AND QUADRANT OPERATION.

Class A chopper

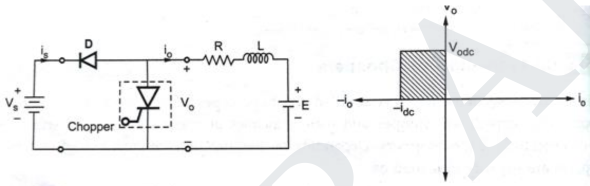
In this chopper, both output voltage and output current is positive. This values never negative in this class A chopper. Thus it operates in the first quadrant of Vo-Io plane as shown in fig.



This chopper operates as rectifier. Also energy flows from the source to load, it is also called forward motoring. The step down chopper is a class A chopper.

Class B chopper

In this chopper, output voltage is positive but output current is negative. Thus it operate in the second quadrant of Vo-Io plane as shown in fig. here output current is negative means it flows out of load towards source. Hence energy flow is from load to source. This is called inverting operation. During the braking of dc motor, the energy associated with back e.m.f is fed back to the source. Hence become negative but motor rotate in same direction. The energy fed back to the source is called forward regeneration.

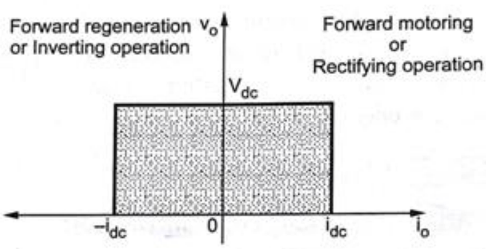


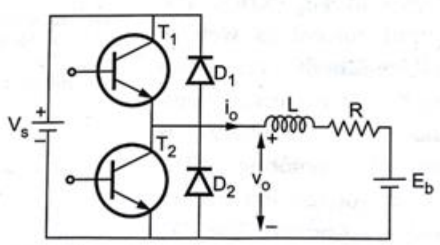
(a) Circuit diagram (b) Quadrant operation

The diode used in above circuit allows current to flow only from load to source. At the load side R and L represents resistance and inductance respectively. While voltage E represents back e.m.f of motor. When the chopper is turned ON, the output voltage Vo=0. But the load voltage E drives current through R, L and chopper. This current increases gradually during ton and the inductor L stores energy during ON period. When chopper is turned OFF, output voltage becomes increases due to inductive action. Hence this exceed supply voltage and forward biases the diode D. thus current flows out of load to source. Thus energy flows from load to source during OFF period only. This type of energy transfer possible only load is active. The regenerative braking of dc motor is common example. For the short duration, dc motor act as a generator and the kinetic energy stored in the system is returned back to the input supply. As the output voltage exceeds the input supply voltage, class B chopper is step up chopper.

Class C chopper

The class C chopper operates in two quadrant. It is the combination of class A and class B choppers. The fig shows the quadrants of operation of chopper.





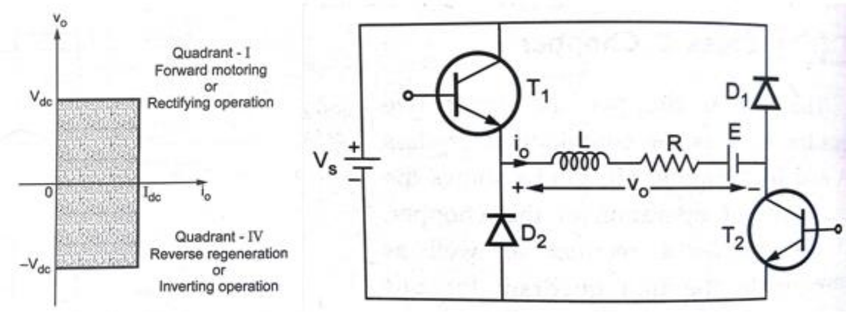
It operates as rectifier as well as inverter. In the first quadrant forward motoring takes place and in the second quadrant regenerative braking takes place.

Fig shows he circuit diagram of class C chopper having transistor switches. It is basically obtained by combination class A and B choppers. T1 and D2 conducts for the operation in the first quadrant. Here

nt alwa ys positive.

Class D chopper

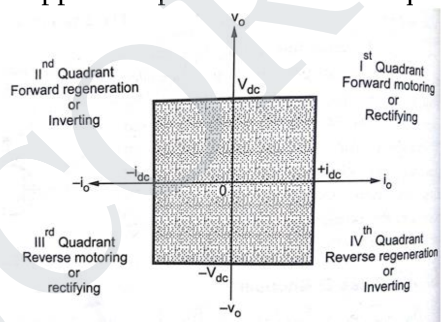
The class D chopper also operates in two quadrants as shown.



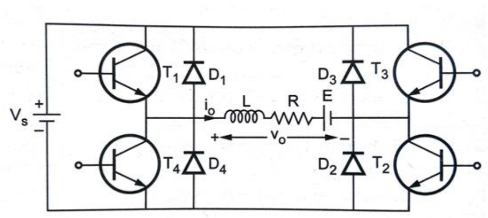
The output current is always positive. The output voltage can be positive or negative. When Vo and Io both positive, rectifying operation takes place. It is also called forward motoring. When the voltage is reversed, inverting operation takes place. The energy fed from load to source. The 4th quadrant operation is also called reverse regeneration. Fig shows the circuit diagram of class D chopper having transistor switches. When T1 and T2 are conducting, output voltage and current are positive. Power taken from the source and given to the load. This is operation in the first quadrant. When T1 and T2 are switched OFF, the load inductance generates the large voltage to maintain the current in the same direction. The inductance voltage forward biases diode D1 and D2. The diode conduct and supply energy from load to the source. The output voltage is negative. Hence chopper operates in the 4th quadrant.

Class E chopper

Class E chopper is a four quadrant chopper. It operates in the four quadrant as shown.



The output current as well as voltage both can takes positive or negative values. The first quadrant is forward motoring. The output voltage and current both positive. The 3rd quadrant is reverse motoring. This means the motor rotates in the opposite direction compared to the first quadrant. Since the power flows source to the load in 3rd quadrant, it is called rectifying operation. In 2nd and 4th quadrant, the power flows from load to the source hence it is called inverting operation. Fig shows the circuit diagram of the four quadrant chopper having transistor switches. Whenever T1 and T2 conducts the chopper operates in 1st quadrant. When T3 and T4 conducts Vo and Io both are negative. The chopper operates in third quadrant.

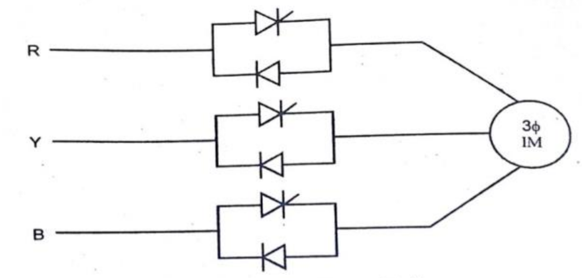


Four quadrant chopper has the capability to operates in the all the four quadrants. Hence it is used in reversible dc drives. The braking is regenerative. Hence four quadrant chopper drive are highly efficient. Their dynamic response is also fast.

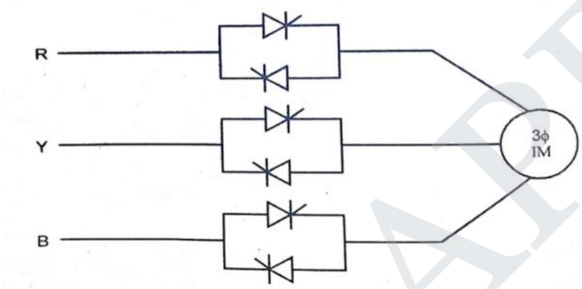
UNIT-5
CONVENTIONAL AND SOLID STATE SPEED CONTROL OF A.C DRIVES

SALIENT ASPECTS OF SPEED CONTROL SCHEME FOR AC VOLTAGE CONTROLLER FED THREE PHASE INDUCTION MOTOR.

- The stator voltage is controlled in these speed control system by means of a power electronics controller.Three are two methods of control as follows (a) on-off control (b) phase controll.

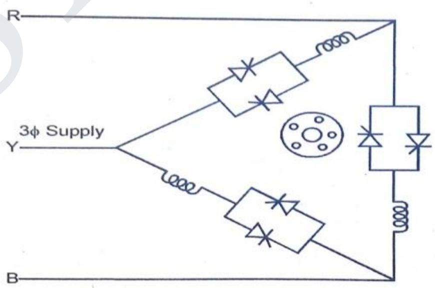


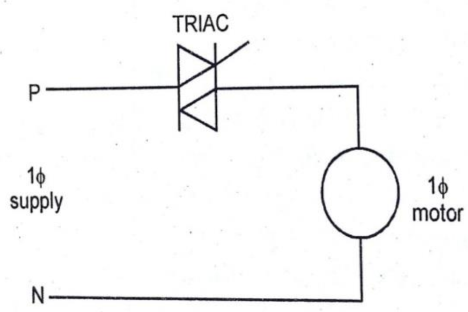
(a) Half wave ac voltage controller



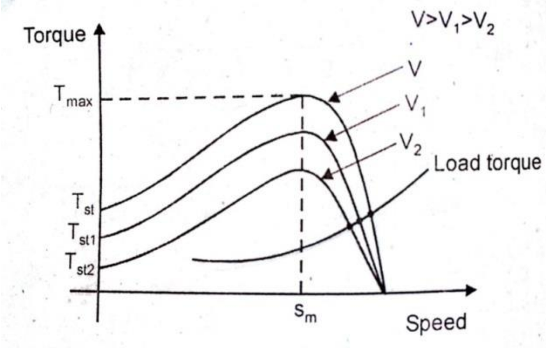
(b) Full wave ac voltage controller

- In on-off control,the thyristors are employed as switches to connect the load circit to the source for a few cycles of source voltage and then disconnect it for another few cycle.This method is known as integral cycle control.
- In phase control ,the thyristors are employes s switches connect the load to the AC source for a portion of each cycle of input voltage .
- Normally thyristors in phase controll modes are used .the various schemes are (i) single phase or 3-phase halfwave ac volatge controller (ii) single phase or three phase fullwave ac voltage controller.
- In half wave ac voltage controller consists of 3SCRs and 3 Diodes.
- The full wave ac voltage controller consists of SCRs. Here 2 SCRs in antiparallel are connected between the line motor in phase.
- The main advantages of half wave controller is a saving the cost of semiconductor devices and does not give rise to dc components in any parts of the system.
- The disadvantage is that, it introduces more harmonics into the line current.
- Load voltage is varied by varying the thyristors firing angles.
- Delta connected load has more advantage which is used to reduce the current of the devices.





- This control has more power loss and harmonic contents, so this type of control is inefficient.
- Input power factor also very low.
- The load torque is directly proportional to speed squared and input current is maximum when slip S=1/3.(1)



Advantages of Stator voltage control

- The control circuit is very simple.
- More compact and less weight.
- In response time is quick.

Disadvantages

- The input power factor is very low.
- Voltage and current waveforms are highly distorted due to harmonics, which affects the efficiency of the machine.
- Performance is very poor running condition at low speed.
- Operating efficiency is low as resistance are high.
- Maximum torque available from the motor decreases with decreases in stator voltage.
- At low speeds, motor currents are excessive currents.

Application

- They are mainly used in low power applications such as fans, blowers and centrifugal pumps, where the starting torque is low.
- They are also used for starting high power induction motors to limit the in-rush current.

CONVENTIONAL SLIP POWER RECOVERY SCHEME FOR THREE PHASE INDUCTION MOTOR

- In three phase slip ring induction motor slip power is wasted at the time of running condition. This slip power is recovered by slip power recovery methods and used as a source of auxiliary dc motor or return back to SRIM.
- **Conventional slip power recovery methods:**
    - In this method rotary converter is used to recover the slip power.
    - Conventional Kramer system.
    - Conventional scherbius system.

Conventional Kramer system:

- This system used to recover the slip power and return back to SRIM as a mechanical power. The rotary converter is used for this slip power recovery system.

Elements:

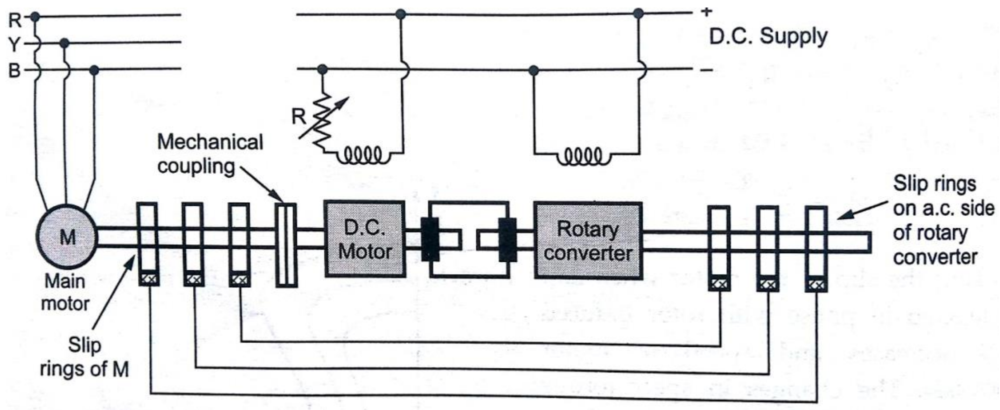
- 3 phase supply. (R,Y,B)
- Slip ring induction motor.
- Rotary converter.
- DC motor.
- Common Shaft

Construction:

- The three phase supply connected to the SRIM.
- The slip power from slip ring is given to the rotary converter.
- Rotary converter connected to the DC motor.
- Dc motor shaft is connected to the SRIM shaft.

Operation:

- The wasted slip power is given the rotary converter.
- It converts the AC slip power into DC like a rectifier. This converted DC power is given to the DC motor
  armature.
- Wasted slip power is used to give supply to the DC motor. DC motor shaft is connected to the SRIM shaft then wasted slip power return back to SRIM in the form of mechanical rotation.



Conventional scherbius system:

- In three phase slip ring induction motor slip power is wasted at the time of running condition. This slip power is recovered by slip power recovery methods and used as a source of auxiliary dc motor and that motor is connected to induction generator to convert that mechanical power into electrical power. This generated electrical power is return to SRIM in the form of electrical power.

Elements:

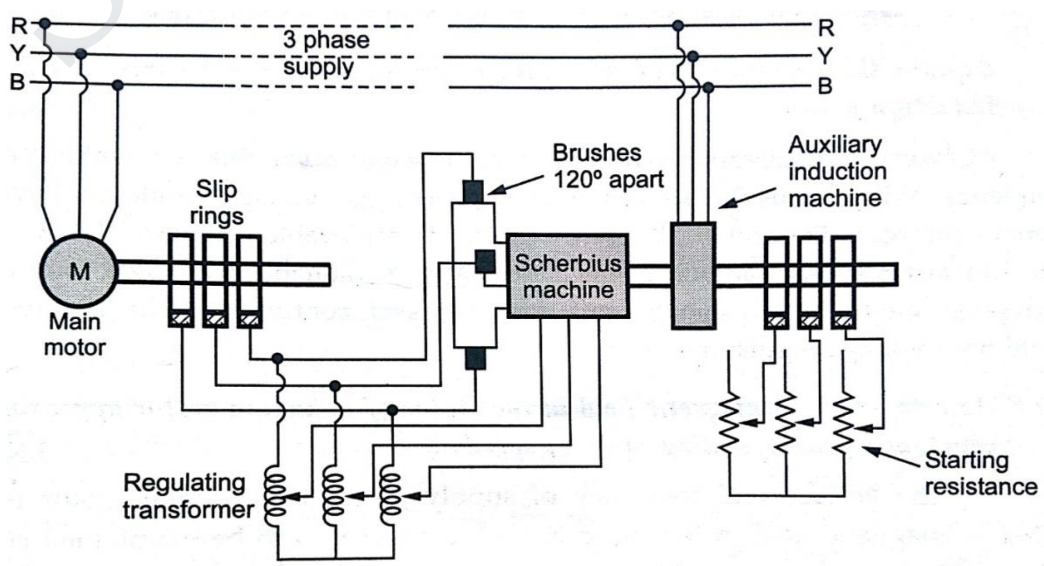
- 3 phase supply. (R,Y,B)
- Slip ring induction motor.
- Rotary converter.
- DC motor.
- Induction Generator.

Construction:

- The three phase supply connected to the SRIM.
- The slip power from slip ring is given to the rotary converter.
- Rotary converter connected to the DC motor.
- This motor is connected to induction generator and three phase supply of SRIM.

Operation:

- The wasted slip power is given the rotary converter.
- It converts the AC slip power into DC like a rectifier. This converted DC power is given to the DC motor armature.
- Wasted slip power is used to give supply to the DC motor. This DC motor connected to induction generator and it converts the mechanical power into electrical power.
- This generated electrical power is return to SRIM in the form of electrical power, then wasted slip power return back to SRIM in the form of mechanical rotation.



TWO CONVENTIONAL SPEED CONTROL METHODS USED TO CONTROL THE SPEED OF THREE PHASE INDUCTION MOTOR FROM STATOR SIDE.

- Stator side control.
- Rotor side control.

Stator side control:

- It is used for squirrel cage and slip ring induction motors.
- Changing the motor speed by changing the stator parameters like stator voltage, stator frequency, stator number of poles.

Rotor side control:

- It is used only for slip ring induction motors.
- Changing motor speed by changing the rotor resistance.
- Types of speed control:

Stator side control:

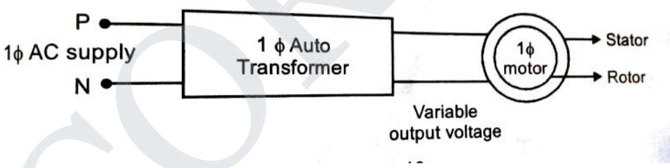
- Stator voltage control.
- Stator frequency control.
- V/F control.
- Pole changing method.

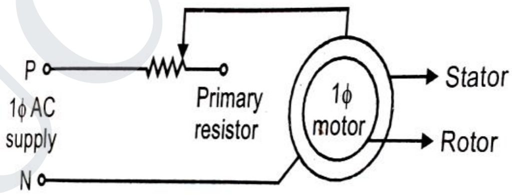
Stator voltage control:

- By changing stator voltage, we can change speed of induction motor.
- Stator voltage changing methods:
  - Using auto transformer.
  - Primary resistors connected series with stator.

Using auto transformer:

- Input is fixed AC voltage➔ output is variable AC voltage with constant
  - Frequency. So stator voltage varied then, speed of motor also varied.



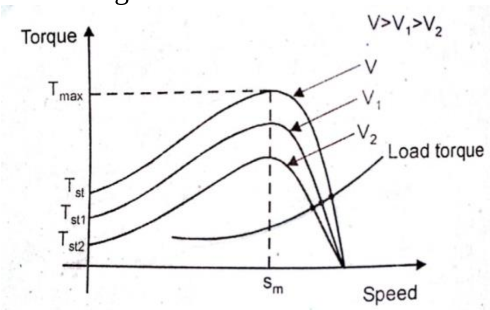


<u>Primary resistors connected series with stator:</u>

- By increasing primary resistance values, the voltage is reduced.
- This reduced voltage applied to the motor. So speed also reduced.
- Stator voltage changes, then torque also changes.

TαV2

- Tmax and speed changes with stator voltage.



Frequency control:

- By Changing supply voltage frequency, we can changing the motor speed.
- In low slip region, N is nearly equal to Ns. **Ns = 120f/P**
- F- changing , motor speed also changing.
- Changing stator frequency done at prime movers of generators.

- The emf V induced in the stator winding is,

$$V = 2\pi f T \Phi K_w$$
$$\Phi = (V / 2\pi f T K_w)$$

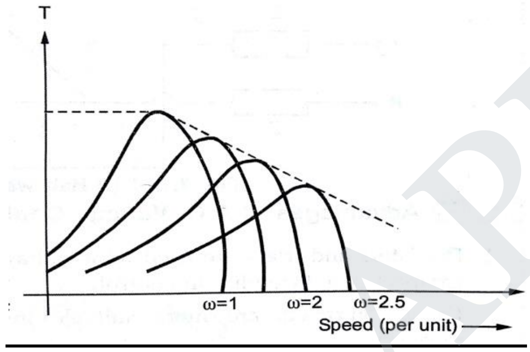
- So Φ is inversely propositional to the f.

Low frequency operation at constant voltage:

V- Constant.
F-Decreases.
Φ- increases.
N- Decreases.

High frequency operation at constant voltage:

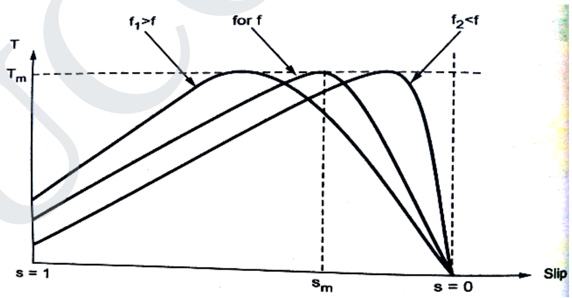
V- Constant.
F-Increases.
Φ- Decreases.
N- Increases.



V/F control:

$$\Phi = (V / 2\pi f T K_w) = (1/2\pi T K_w)(V/f) \quad (1)$$
$$T_{max} \ \alpha \ (V/f)^2$$

- Φ and Tmax maintained constant.
- So V/f maintained constant.
- V increases, f decreases or V decreases, f increases. But V/f ratio should maintained constant for variable speeds.

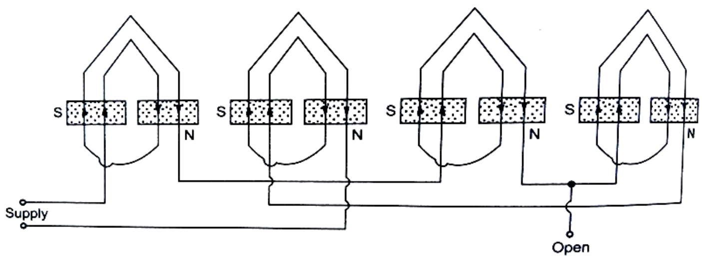


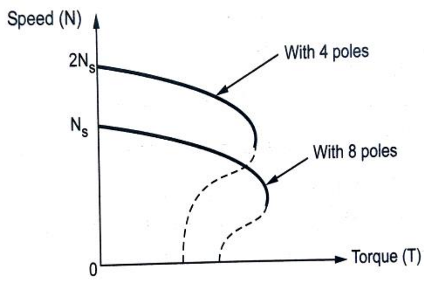
Changing number of poles:

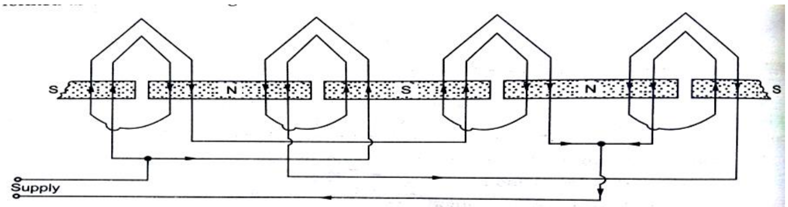
- At constant frequency, the speed of the motor is inversely proportional to the number of poles.

$$N_s \ \alpha \ 120f/P$$
$$N_s \ \alpha \ 1/P$$

- P increases speed of the motor is decreases.
- For squirrel cage induction motor➔ stator poles only change for speed change.
- For slip ring induction motor ➔ stator and rotor poles are must change for speed change. Because rotor winging is similar to stator for SRIM.
- So it is complex process. So this pole changing speed control only used for SCIM.







CONVENTIONAL ROTOR SIDE SPEED CONTROL METHODS TO CONTROL THE SPEED OF THREE PHASE INDUCTION MOTOR.

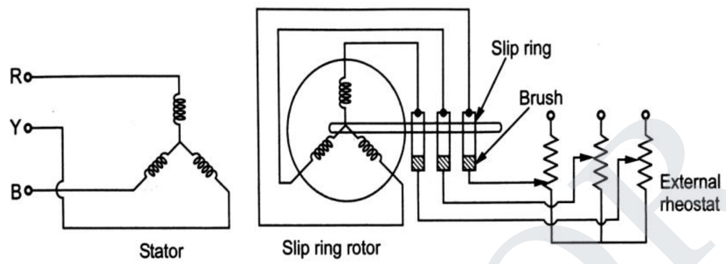
- Rotor resistance control.(Adding External Resistance in Stator Circuit)
- Cascade connection.

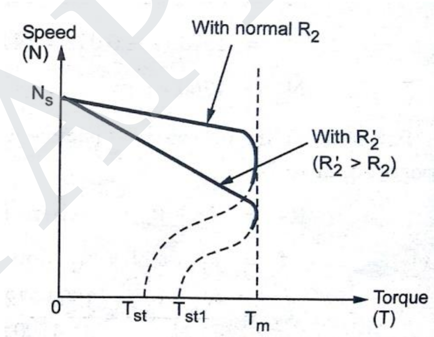
Rotor resistance control:

- In this speed control variable resistors are connected in the rotor of induction motor. Rotator resistance can change by this setup.

$$T \propto \frac{s E_2^2 R_2}{R_2^2 + (s X_2)^2} \qquad T \propto \frac{s R_2}{(R_2)^2} \propto \frac{s}{R_2}$$

- Rotor resistance increases rotor current getting reduced and the motor speed also getting reduced.
- Rotor resistance is decreases the rotor current is increased and speed of the motor also increased.
- This speed control method only used for slip ring induction motor not for squirrel cage induction motor. (3)





Cascade connection:

- In this speed control two slip ring induction motors are used and both are coupled in same shaft.
- First motor speed is controlled by second motor. It is cascade connection.

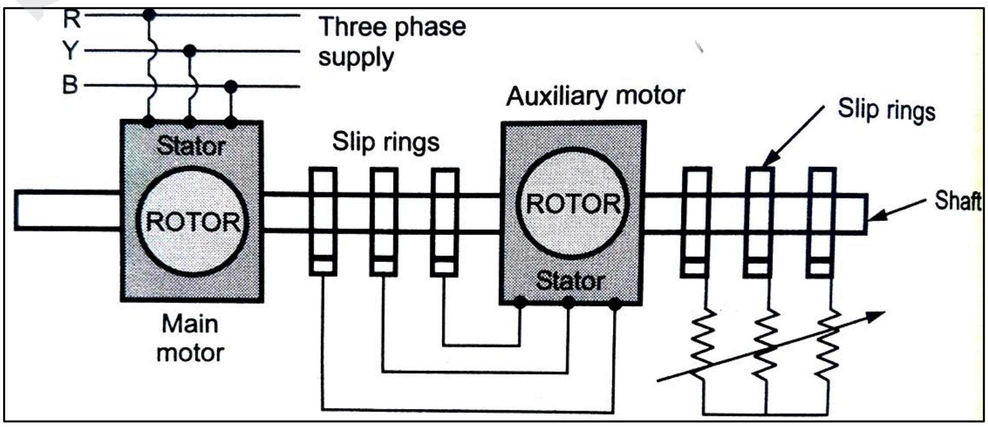
Elements:

- Slip ring induction motor.
- Variable rotor resistors.
- Three phase supply (R,Y,B)

Working:

When the first motor rotates, the slip power of first motor is given to the second motor stator as a input supply.

- In second motor rotor a variable resistor is connected to change the rotor resistance.
- If rotor resistance increases rotor current getting reduced and the motor speed also getting reduced.
- If rotor resistance is decreases the rotor current is increased and speed of the motor also increased.
- The speed of second motor is changed by resistance then the first motor speed also changes because both are connected in same shaft.



DIFFERENT STATIC SLIP POWER RECOVERY SCHEMES IN THREE PHASE SLIP RING INDUCTION MOTOR.

- In three phase slip ring induction motor slip power is wasted at the time of running condition. This slip power is recovered by slip power recovery methods and used as a source then return back to SRIM through transformer.

Static slip power recovery methods:

- In this method rotary converter is not used to recover the slip power.

1) Static Kramer system.
2) Static scherbius system.

Static Kramer system:

- In this system semiconductor switches are used instead of rotary converter to convert AC to DC conversion.
- Here no rotational parts like motor, generator only static devices present like transformer and switches.

Elements:

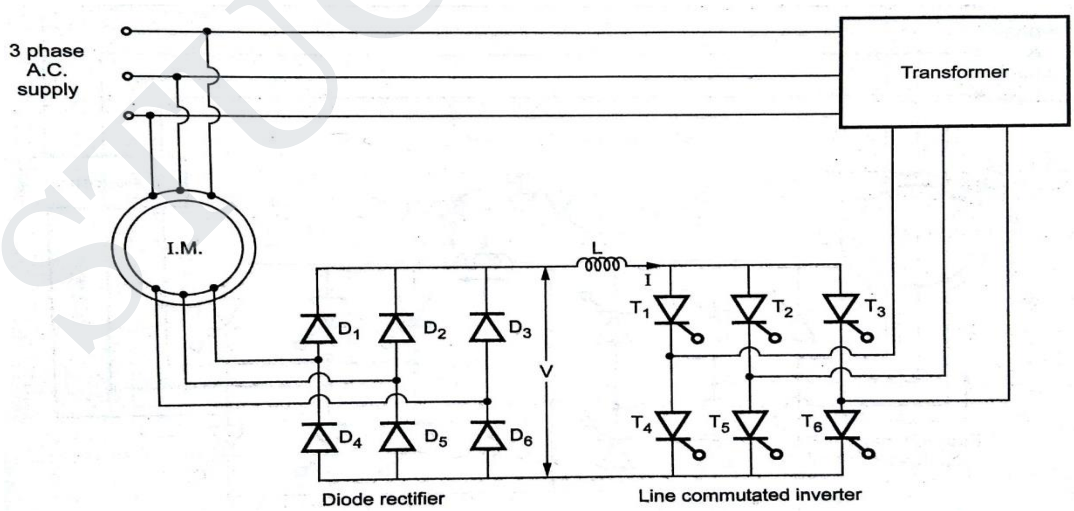
- Diode Bridge rectifier.
- Thyristor bridge inverter.
- DC link.
- Slip ring induction motor.
- Transformer.
- Three phase supply.

Construction:

- Slip power is given to the Diode rectifier.
- Rectifier is connected to DC link and inverter.
- Inverter output is connected to the supply of SRIM through transformer.

Operation:

- The slip power from slip ring is given to the input of Diode rectifier. This converts the AC into Fixed Dc voltage.
- This DC voltage is given to the DC link for filtering and given to the inverter input side.
- Inverter is converting Fixed DC into Variable voltage variable frequency supply. This converted voltage is given back to SRIM supply. Slip power is recovered. (3)



Static scherbius system:

- In this system semiconductor switches are used instead of rotary converter to convert AC to DC conversion.
- Here no rotational parts like motor, generator only static devices present like transformer and switches.

Elements:

- Thyristor Bridge rectifier.
- Thyristor bridge inverter.
- DC link.
- Slip ring induction motor.

- Transformer.
- Three phase supply.

Construction:

- Slip power is given to the control rectifier.
- Rectifier is connected to DC link and inverter.
- Inverter output is connected to the supply of SRIM through transformer.

Operation:

The slip power from slip ring is given to the input of control rectifier. This converts the AC into variable DC voltage.

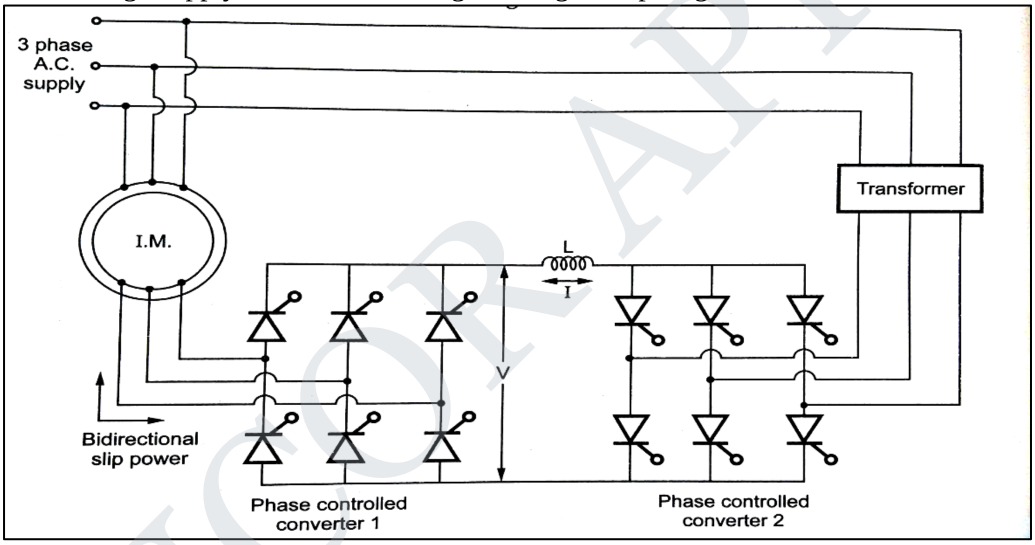
- This DC voltage is given to the DC link for filtering and given to the inverter input side.
- Inverter is converting DC into Variable voltage variable frequency supply. This converted voltage is given back to SRIM supply. Slip power is recovered.

Sub synchronous mode:

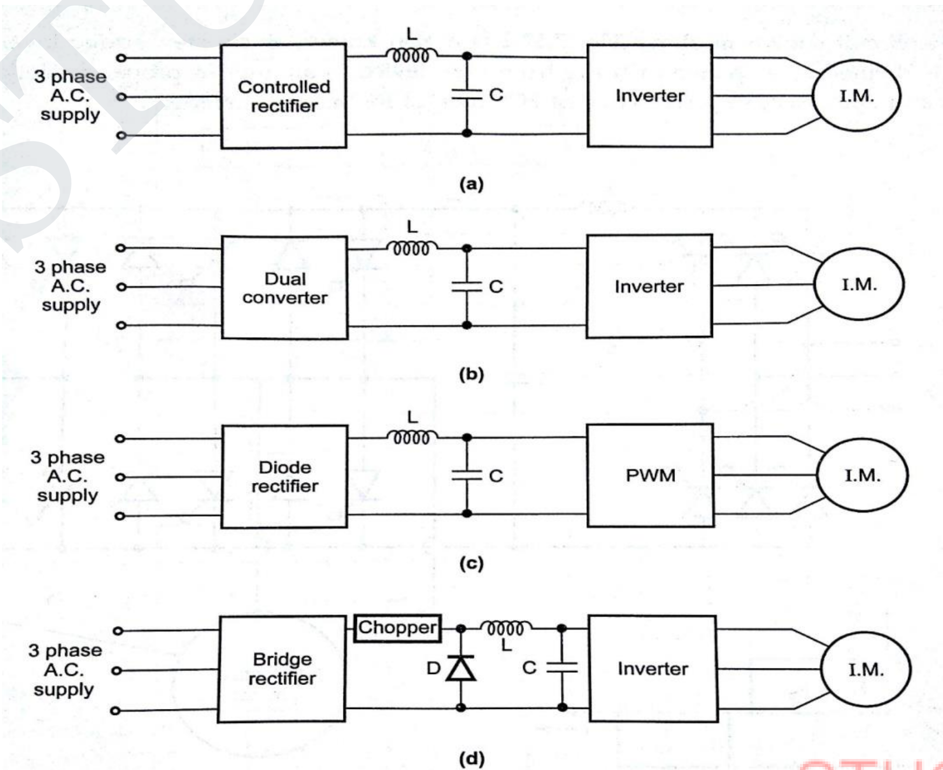
- It is used only below rated speed control.
- Power flow through slip ring, bridge1, bridge2, transformer, supply.

Super synchronous mode:

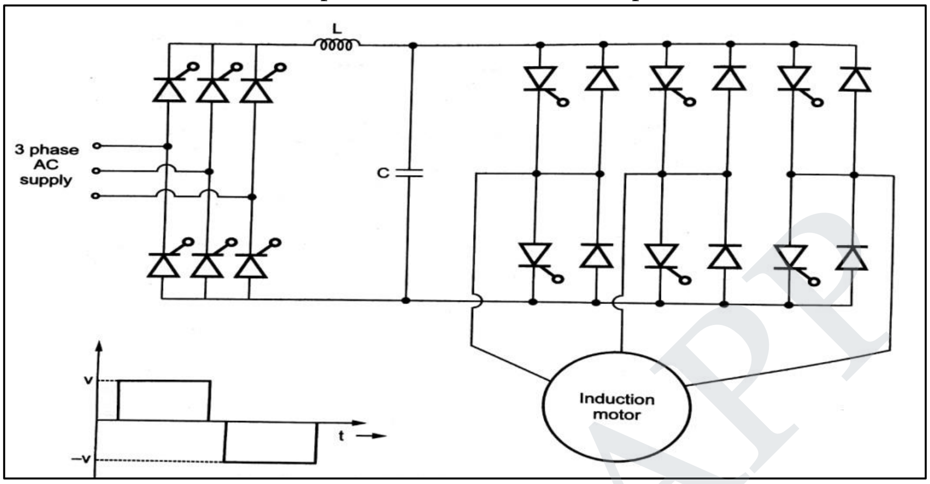
- It is used only above rated speed control.
- Power flow through supply, transformer, bridge2, bridge1, slip ring.



VVVF SPEED CONTROL METHODS FOR THREE PHASE INDUCTION MOTOR WITH NEAT DIAGRAM.



- VVVF provides variable voltage and variable frequency supply to the load from fixed supply. It is highly reliable and efficient.
- PWM inverter used to change both voltage and frequency of fixed supply.
- It provides smooth control without torque pulsations.
- Forced commutation is not need.
- Harmonic and commutation losses are less.
- If source is fixed AC means controlled rectifier convert that into variable DC voltage.
- This DC voltage given to DC link for filtering and given to inverter. It gives variable voltage and variable frequency output to the motor. The motor speed can control by firing angle of rectifier and inverter.
- VSI and CSI fed drives are the examples of VVVF control. It operates in 120 and 180 degree modes. (4)



- Three phase voltages for 180 degree mode operation of VSI fed drives.
- Each phase voltages are differ 120 degree each other.