UNIT 3

SPEED CONTROL OF ELECTRICAL MACHINES

SPEED CONTROL OF DC MOTOR:

STARTING OF DC MOTORS:

<u>Introduction</u>

DC motors are self-starting motors, whenever the armature and field winding of a DC motor receives supply, motoring action takes place. So, DC motors do not require any additional device to start it.

<u>Necessity of Starter</u>

When a de motor is started with full voltage applied across its armature terminals during the starting period, it will draw more current than its rated current. This excessive current will overheat the armature winding and may even damage the winding. During starting period, a variable resistance called a starter is connected in series with the armature circuit to limit the starting current.

<u>Starting of DC Motors</u>

Voltage equation $E_b = V - I_a R_a$

Armature current $I_a = \dfrac{V - E_b}{R_a}$

During starting, the back emf is zero

$$E_b = \frac{\phi Z N}{60} \times \frac{P}{A}$$

It speed is zero, back emf is also zero. For example, we assume that R_a value is 0.5 Ω. The supply voltage is 220 V. Power rating of the motor is 7500 W.

Then, the armature current

$I_a = V / R_a = 220 / 0.5 = 440$ A.

But the full-load current:

$I_L = 7500 / 220 = 34$ A.

Without using starter, if the motor is started directly, the starting current is around 13 times of the full-load current.

Thus the absence of back emf causes the armature current as the time of starting to shoot up to about (13 to 15) times the normal armature current.

Sudden drawing of this large current from the supply system is unwarranted. It causes sudden drop in voltage of the supply system.

This voltage drop affects the other loads connected in the system. However, this large current exists only for a brief period.

Just at the time of closing the supply to the armature, as and when the armature pick its speed, the back emf starts increasing and the armature current will come down.

The difficulty is that the circuit breaker may not be able to withstand this large current and it may open the supply connection.

In order to start and accelerate the motor within a reasonable time, it may be enough to have 2 to 3 times the rated current as the starting current.

Therefore, to limit the starting current, an additional resistance R_{st} should be added in series with the armature circuit.

Two-point Starter

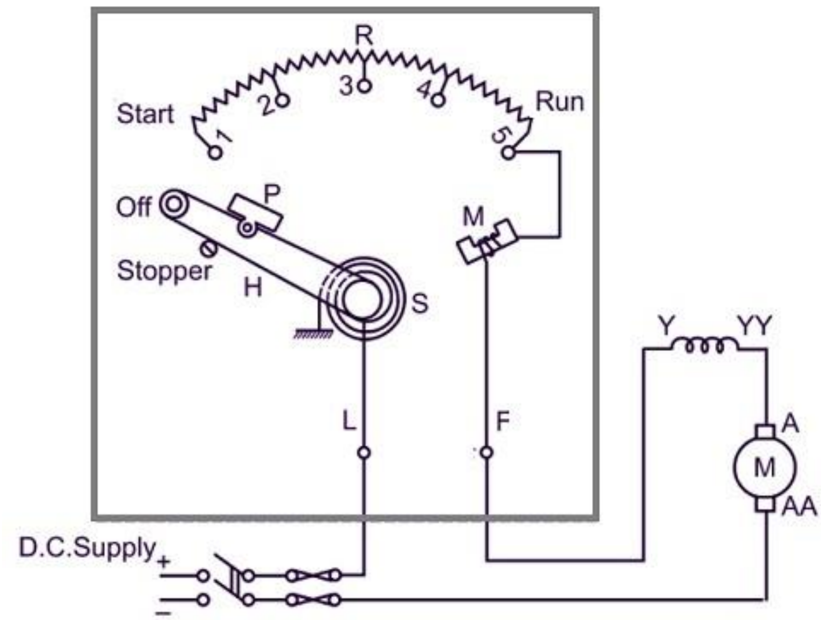
a starter that is used to restrict the starting current of a DC series motor by starting and controlling its speed is known as a two-point starter. The main function of this starter is to defend the DC series motor from overvoltage and high starting current by restricting the high starting armature current to a secure value, by simply connecting a resistance within the series by the armature only at the starting time. This resistance can be decreased gradually whenever the motor gets speed.

Working:

A 2-point starter includes two main parts; a rheostat & a set of contacts. In this starter, the rheostat is mainly used for controlling the flow of current throughout the motor whereas the set of contacts is used for firstly start & after that control the speed of the motor. Whenever the contacts are closed, the motor is directly connected to the power supply to start. Once this motor gets speed, the set of contacts will be opened gradually by increasing the resistance within the circuit & decreasing the flow of current to the motor to control its speed. So, this kind of starter is used commonly in applications wherever exact speed control is required like in industrial equipment & machinery.

Circuit Diagram:

The circuit diagram of the 2-point starter is shown below. This circuit is similar to a three-point and four-point starter because it includes a starting resistance ‘R’ which is subdivided in between the contact studs from 1 to 5. In this circuit, the ‘H’ is a starting handle and is turned on a single side where the other side is easily moved from a strong ‘S’ spring. So that it makes contact with every stud during the starting operation. The starter in the circuit is provided simply with a protective device with no load release.



2 Point Starter Circuit Diagram

Working

A two-point starter works by starting the dc motor which has the over-speeding trouble because of load loss from its shaft. To start the DC motor, the control arm will be turned in a clockwise direction from its OFF to ON position against the spring tension. The L & F are two starter points that are simply connected through the motor terminals & supply.

The control arm will be held within the turn-ON position through an electromagnet. Here, the hold-on electromagnet is simply connected with the armature circuit in series. If the DC motor loses its load, then the flow of current reduces, thus the electromagnet strength also reduces. The control arm comes back to its OFF position because of its spring pressure and prevents the DC motor from overspending. Whenever the voltage supply reduces considerably, the starter arm can also return to its OFF position.

Difference between 2-Point Starter and 3-Point Starter

The difference between 2-point starters and 3-point starters includes the following.

2 Point Starter	3 Point Starter
A two-point starter is a device used to limit the starting current of a DC series motor.	A three-point starter is a device used to start & maintain the DC shunt motor's speed.
The main function of this starter is to guard the DC series motor from maximum starting current.	The main function of this starter is to decrease the starting current, thus defending the motors from damage.
This starter uses two terminals to start the motor; the line terminal and the field terminal.	This starter uses three terminals to start the motor; line terminal, field terminal, and armature terminal.
The main components used in this starter mainly include; the overload trip coil, a resistor, a holds-on coil	The main components of the three-point starter are; Overload release (OLR), no volt coil (NVC) & series

& a spring-controlled arm.	resistance.

Advantages & Disadvantages

The **advantages of a 2-point starter** include the following.

- This starter helps protect the motor from drawing maximum starting current.
- These starters protect from short circuits and overload faults.
- When the power supply is not there then it automatically turns OFF.

The **disadvantages of a 2-point starter** include the following.

- It offers no adjustable starting characteristics and a soft stop is not possible at all
- These are mechanically tough
- This starter may decrease the lifespan of the motor.
- This is not used for all types of motors.
- This starter can cause a major dip in voltage.

Applications

The **applications of the 2-point starter** include the following.

- 2 point starters are used with DC series motors.
- These types of starters are used in cranes.
- These are used in railways for starting and stopping the rail.
- These starters help in starting the dc motor which has an over-speeding problem because of load loss from its shaft.
- These are used normally in applications wherever the motor is anticipated to work above standard speed

3 Point Starter

A 3 point starter is a device that helps in the starting and running of a DC shunt motor or compound wound DC motor (similar to a 4 point starter). Now the question is why these types of DC motors require the assistance of the starter in the first place? Well, it's due to 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. Hence the back emf at the starting of the motor is zero, but it develops gradually as the motor gathers speed.

The general motor emf equation is:

$E = E_b + I_a R_a$

Where E - Supply Voltage; E_b - Back EMF; I_a - Armature Current; and R_a = Armature Resistance. Since at starting $E_b = 0$, then $E = I_a R_a$. Hence we can rearrange for the armature current I_a:

$I_a = E / R_a$

We can see from the above equation that the current will be dangerously high at ort or we can starting (as the armature resistance R_a is small). This is why it's important that we make use of a device like the *3 point starter* to limit the starting current to acceptably low value.

To understand how the starting current is restricted to the desired value, we need to look at the construction and *working of three-point starter*. The electrical symbols in the diagram below show all the essential parts of a three-point starter.

Construction of 3 Point Starter

Construction wise a starter is a variable resistance, integrated into the 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 three 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)

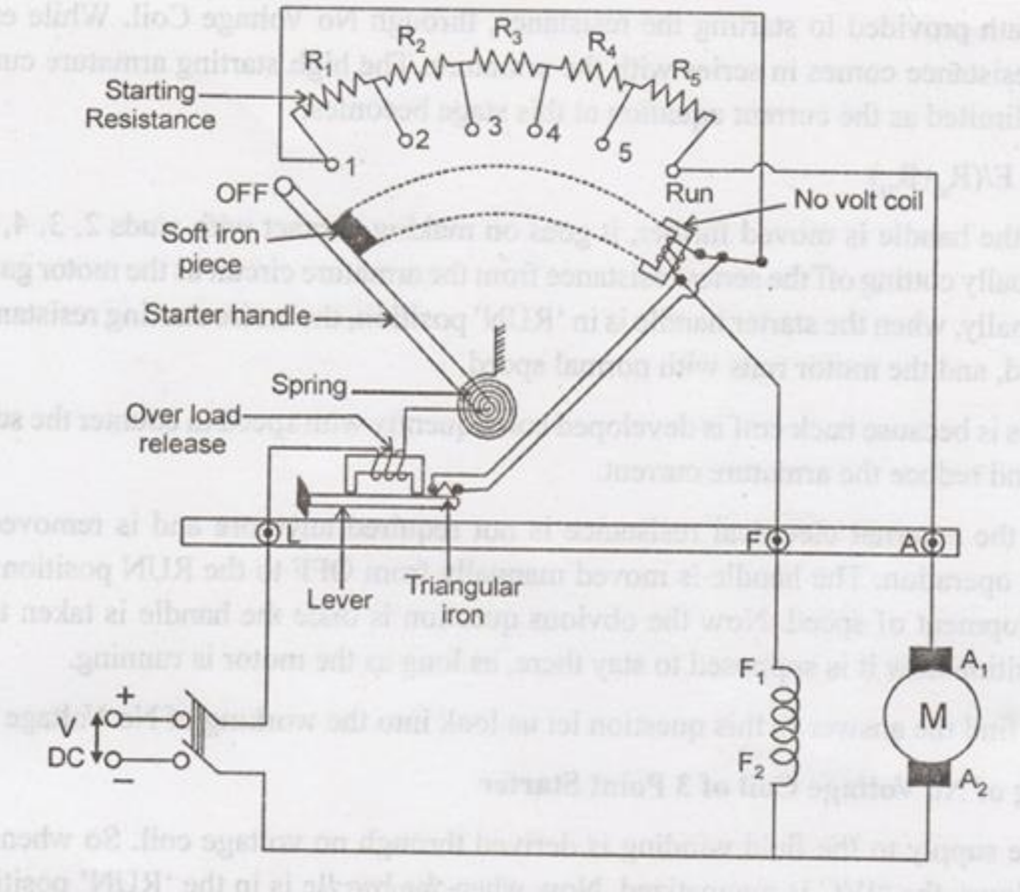


Fig. Three Point Starter

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 spring is also attached with it, and the starter handle also contains a soft iron piece housed on it. This handle is free to 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 act as the two protecting devices of the 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 contact with stud No. 1. At this point, field compound motor gets supply through the parallel path provided to starting the 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:

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

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 the development of speed. Now the obvious question is once the handle is taken to the RUN position how it is supposed to stay there, as long as the 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, a soft iron piece is 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 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 problem. 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 a 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 the 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 4 point starter is thus used instead, which does not have this drawback.

4 Point Starter

A *4 point starter* protects the armature of a DC shunt motor or compound wound DC motor against the initially high starting current of the DC motor. The 4 point starter has a lot of constructional and functional similarity to a 3 point starter, but this special device has an additional point and coil in its construction (as the name suggests). This brings about some difference in its functionality, though the basic operational characteristic remains the same. The basic difference in the circuit of a *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 *the operation of 4 point starter*, let's have a look at its construction diagram. This will help demonstrate the difference between a 4 vs 3 point starter.

Construction and Operation of Four Point Starter

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

i. '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.)

4. 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 the 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.

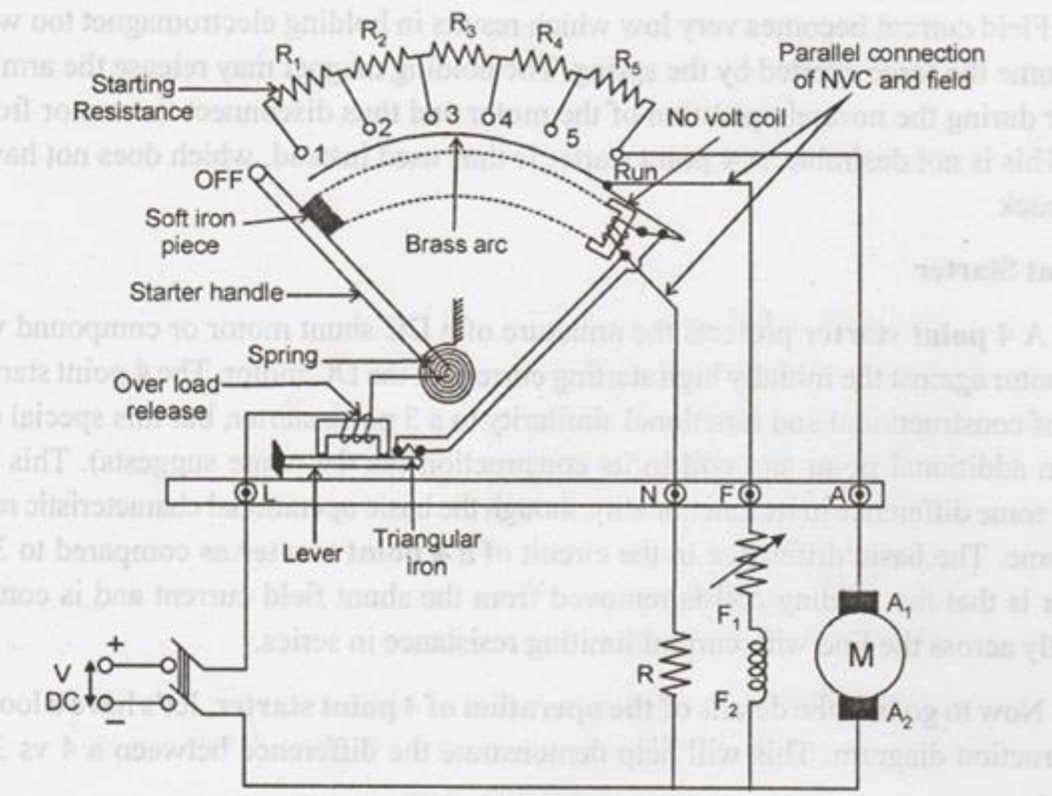


Fig.: Four Point Starter

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 let's 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 the 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.

i. 1 part flows through the starting resistance ($R_1 + R_2 + R_3$.....) and then to the armature.

2. A 2nd part flowing through the field winding F.

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

4. So the point to be noted here is that with this particular arrangement any change in the shunt field circuit does not bring about any change in the no voltage coil as the two circuits are independent of each other.

5. 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.

Starting Methods for Induction Motors

A 3 phase induction motor is theoretically self starting. The stator of an induction motor

consists of 3-phase windings, which when connected to a 3-phase supply creates a rotating magnetic field. This will link and cut the rotor conductors which in turn will induce a current in the rotor conductors and create a rotor magnetic field. The magnetic field created by the rotor will interact with the rotating magnetic field in the stator and produce rotation.
Therefore, 3-phase induction motors employ a starting method not to provide a starting torque at the rotor, but because of the following reasons;
1) Reduce heavy starting currents and prevent motor from overheating.
2) Provide overload and no-voltage protection.
There are many methods in use to start 3-phase induction motors. Some of the common methods are;

1- Direct On-Line Starter (DOL)
2- Star-Delta Starter
3- Auto Transformer Starter
4- Rotor Impedance Starter
5- Power Electronics Starter

Direct On-Line Starter (DOL)

The Direct On-Line (DOL) starter is the simplest and the most inexpensive of all starting methods and is usually used for squirrel cage induction motors. It directly connects the Contacts of the motor to the full supply voltage. The starting current is very large, normally 6 to 8 times the rated current. The starting torque is likely to be 0.75 to 2 times the full load Torque. In order to avoid excessive voltage drops in the supply line due to high starting currents, the DOL starter is used only for motors with a rating of less than 5KW
There are safety mechanisms inside the DOL starter which provides protection to the motor as well as the operator of the motor. The power and control circuits of induction motor with DOL starter are shown in figure(1).
* K1M Main contactor

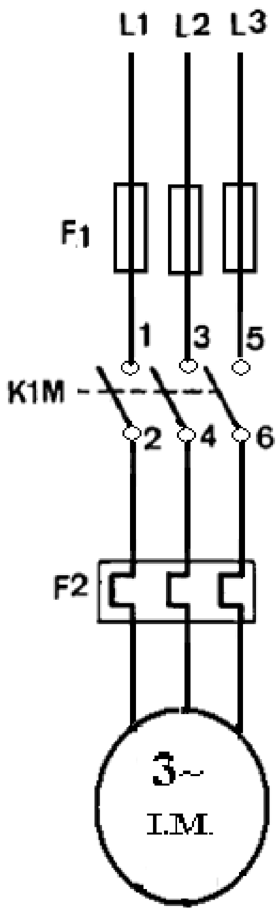


Fig.(1): power and control circuits of I.M. with DOL starter

Star-Delta Starter

The star delta starting is a very common type of starter and extensively used, compared to the other types of the starters.
This method used reduced supply voltage in starting. Figure(2) shows the connection of a 3phase induction motor with a star – delta starter.
The method achieved low starting current by first connecting the stator winding in star configuration, and then after the motor reaches a certain speed, throw switch changes
the winding arrangements from star to delta configuration. By connecting the stator windings, first in star and then in delta, the line current drawn by the motor at starting is reduced to one-third as compared to starting current with the windings connected in delta. At the time of starting when the stator windings are start connected, each stator phase gets voltage $\frac{Vl}{\sqrt{3}}$ where

Vl is the line voltage. Since the torque developed by an induction motor is proportional to the square of the applied voltage, star- delta starting reduced the starting torque to one – third that obtainable by direct delta starting.

- K2M Main Contactor
- K3M Delta Contactor
- K1M Star Contactor

- F1 Thermal Overload Relay

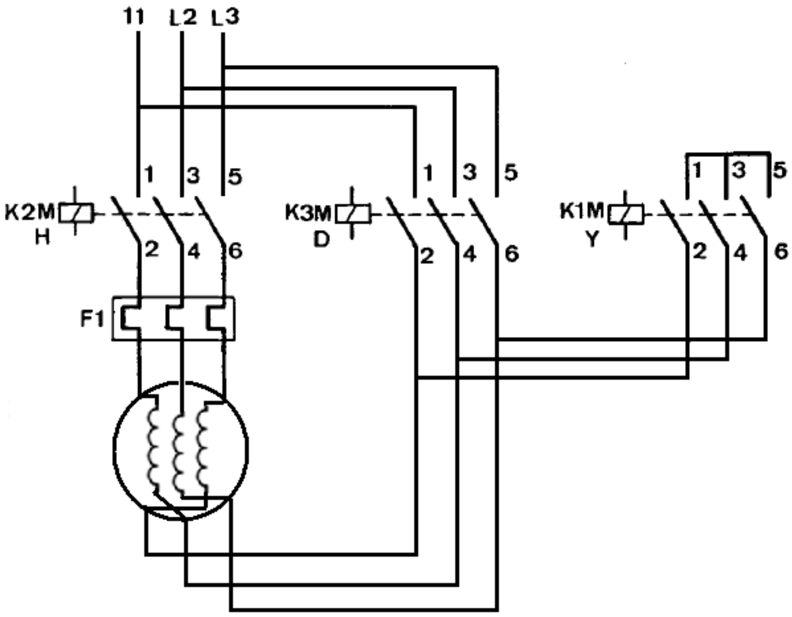


Fig.(2) Induction Motor with Star Delta Starter

Auto Transformer Starter

The operation principle of auto transformer method is similar to the star delta starter method. The starting current is limited by (using a three phase auto transformer) reduce the initial stator applied voltage. The auto transformer starter is more expensive, more complicated in operation and bulkier in construction when compared with the star – delta starter method. But an auto transformer starter is suitable for both star and delta connected motors, and the starting current and torque can be adjusted to a desired value by taking the correct tapping from the auto transformer. When the star delta method is considered, voltage can be adjusted only by factor of .$^{1}/_{\sqrt{3}}$ Figure (3) shows the connection of a 3phase induction motor with auto transformer starter.

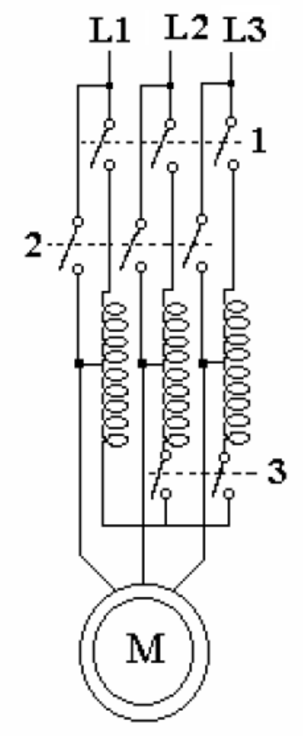


Fig.(3) shows I.M with auto transformer starter.

Rotor Impedance Starter

This method allows external resistance to be connected to the rotor through slip rings and brushes. Initially, the rotor resistance is set to maximum and is then gradually decreased as the motor speed increases, until it becomes zero.

The rotor impedance starting mechanism is usually very bulky and expensive when compared with other methods. It also has very high maintenance costs. Also, a considerable amount of heat is generated through the resistors when current runs through them. The starting frequency is also limited in this method. However, the rotor impedance method allows the motor to be started while on load. Figure (4) shows the connection of a 3phase induction motor with rotor resistance starter.

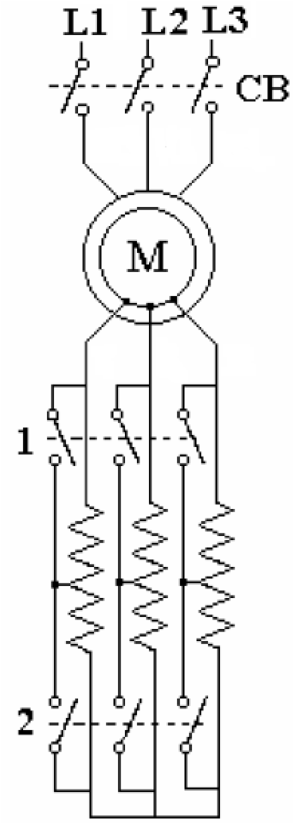


Fig. (4) Shows the I.M. with rotor resistance starter.

SPEED CONTROL OF DC MOTOR:

Back emf E_b of a DC motor is nothing but the induced emf in armature conductors due to rotation of the armature in magnetic field. Thus, the magnitude of E_b can be given by EMF equation of a DC generator.

$E_b = {}^{PØNZ}/_{60A}$

(where, P = no. of poles, Ø = flux/pole, N = speed in rpm, Z = no. of armature conductors, A = parallel paths)

E_b can also be given as,
$E_b = V - I_aR_a$

thus, from the above equations

$N = {}^{E_b\,60A}/_{PØZ}$

but, for a DC motor A, P and Z are constants

Therefore, $N \propto K\,{}^{E_b}/_{Ø}$ (where, K=constant)

This shows the **speed of a dc motor** is directly proportional to the back emf and inversely proportional to the flux per pole.

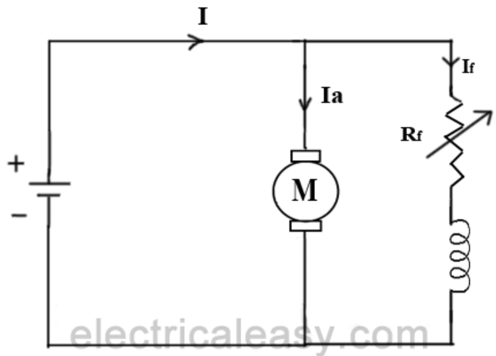
Speed Control Methods Of DC Motor

Speed Control Of Shunt Motor

1. Flux Control Method

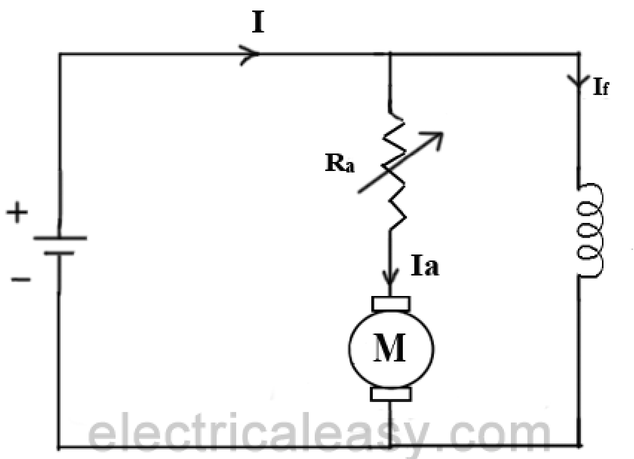
It is already explained above that the **speed of a dc motor** is inversely proportional to the flux per pole. Thus by decreasing the flux, speed can be increased and vice versa.

To control the flux, a rheostat is added in series with the field winding, as shown in the circuit diagram. Adding more resistance in series with the field winding will increase the speed as it decreases the flux. In shunt motors, as field current is relatively very small, I_{sh}^2R loss is small. Therefore, this method is quite efficient. Though speed can be increased above the rated value by reducing flux with this method, it puts a limit to maximum speed as weakening of field flux beyond a limit will adversely affect the commutation.



2. Armature Control Method

Speed of a dc motor is directly proportional to the back emf E_b and $E_b = V - I_aR_a$. That means, when supply voltage V and the armature resistance R_a are kept constant, then the speed is directly proportional to armature current I_a. Thus, if we add resistance in series with the armature, I_a decreases and, hence, the speed also decreases. Greater the resistance in series with the armature, greater the decrease in speed.



3. Voltage Control Method

a) **Ward-Leonard System**:

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

A smooth variation of speed from zero to above normal with inherent stability of speed at all loads is achieved through an adjustable voltage system of speed control called Ward-Leonard Method of speed control.

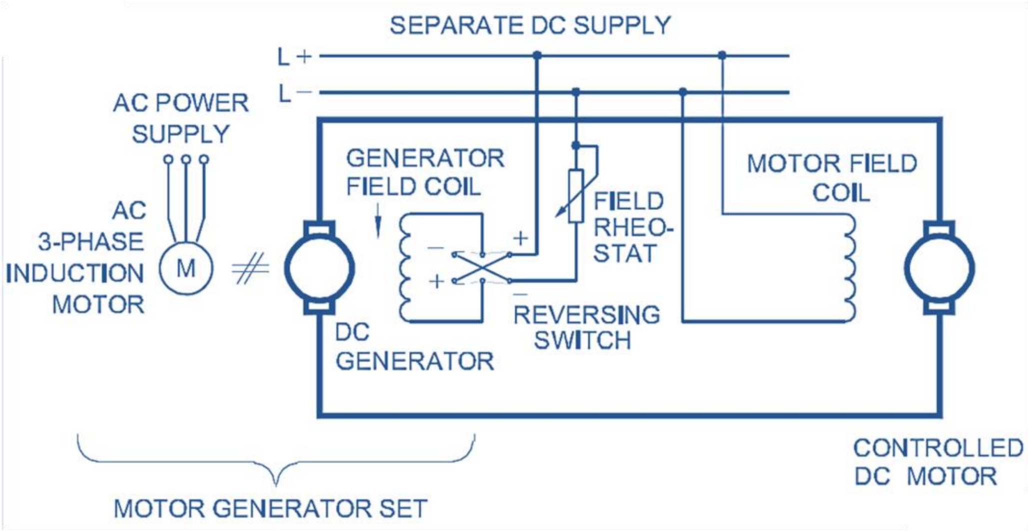


Fig. 1: Ward Leonard Method of Speed Control.

In all the Speed Control methods, it is clear that the speed cannot be varied from zero to above normal by any one method and atleast two methods are required to be combined to do so. Further, the efficiency of the above mentioned controls is much less, due to power loss and instability due to load variation.

Working of Ward Leonard Method of Speed Control

In this method, a DC generator is mechanically coupled to a constant speed DC motor or an AC 3-phase induction motor as shown in Fig 1. The generated supply from the DC generator is fed directly to the armature of the controlled DC motor. The fields of both the DC generator and the controlled DC motor are separately excited from a suitable DC supply. The field of the DC generator is controlled through a field rheostat and a change-over switch to vary the generated voltage and to change the polarity respectively. This enables the supply to the controlled DC motor to vary at a wide range and also makes it possible to reverse the supply voltage polarity. This, in turn, changes the speed of the controlled DC motor to vary from zero to above normal speed as well as change the direction of rotation, if necessary. The controlled DC motor speed can be brought down to zero by reducing the supply voltage of the generator to a suitable level.

Advantages of Ward Leonard Method of Speed Control

1. By this system, a speed as low as zero and as high as two times the normal speed could be achieved.
2. The direction of rotation of the controlled DC motor can be changed simply by reversing the controller in the field circuit of the generator.

3. As there is not much power loss in the field rheostat, the speed variations are achieved at higher efficiency.
4. The speed of the controlled DC motor is independent of the load.

Disadvantages of Ward Leonard Method of Speed Control

This method requires high initial cost and low overall efficiency due to three machines in operation.

Applications of Ward Leonard Method of Speed Control

This system is used in steel rolling mills and paper mill drives, hoists, elevators etc, where precise control of speed over a wide range is required.

ELECTRICAL BRAKING & ITS TYPES:

Electric Braking

Electric braking is a method used to slow down or stop electric motors and machinery quickly and efficiently. It involves the use of electrical systems and components to create a braking force that opposes the motor's motion, converting its kinetic energy into heat or other forms of energy dissipation. Electric braking is crucial in various applications, including machine tools, cranes, and elevators, where rapid stopping is essential for safety and precision.

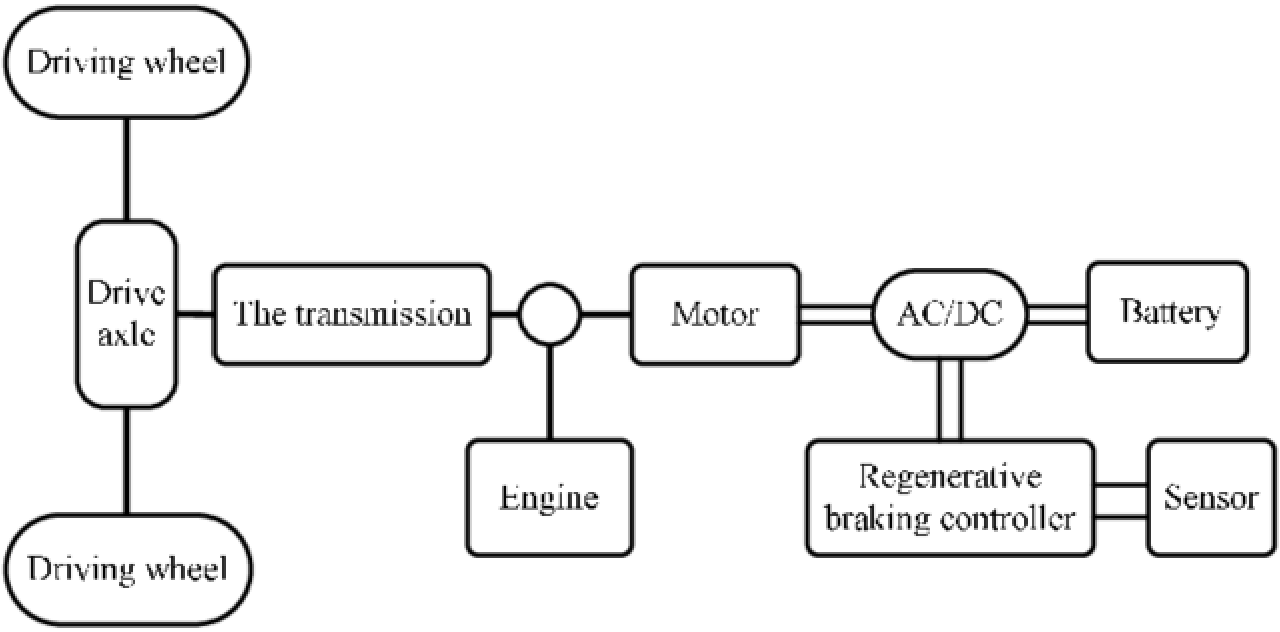
Types of Electric Braking

Brakes are used to slow down or stop motors. There are different types of motors like DC, induction, synchronous, and single-phase motors, each with unique characteristics. Consequently, braking methods vary, but we can categorize them into three main types that work with most motors:

1. Regenerative Braking
2. Plugging type braking.
3. Dynamic braking

1. Regenerative Braking

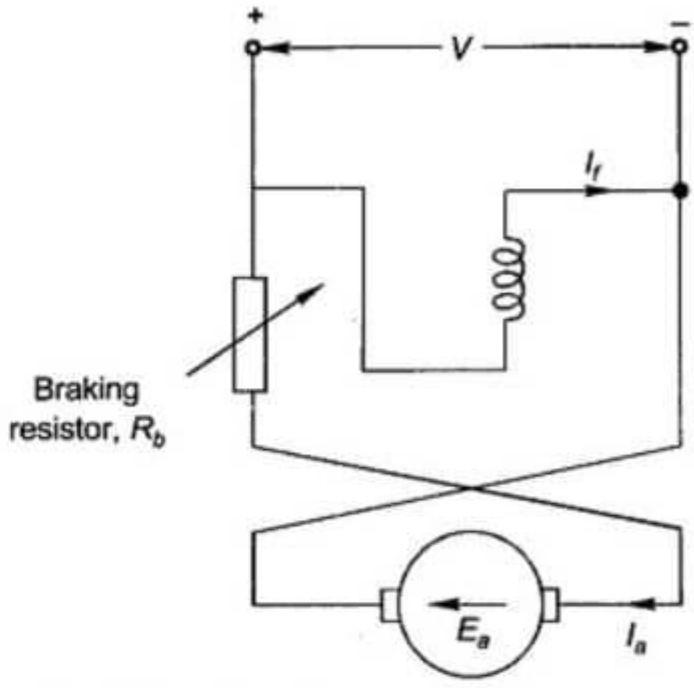
Regenerative braking happens when a motor goes faster than its normal speed. In this method, the motor becomes a generator and uses the power it generates to slow itself down. To make regenerative braking work, the motor's rotor (the part that spins) must go faster than its regular speed. When this happens, the direction of the electric current changes, and the motor starts slowing down.



The drawback of this braking method is that it can harm the motor because it needs to run faster than usual. However, if you have a variable frequency source, you can use regenerative braking even when the motor is slower than its normal speed, which is safer for the motor.

2. Plugging Type Braking

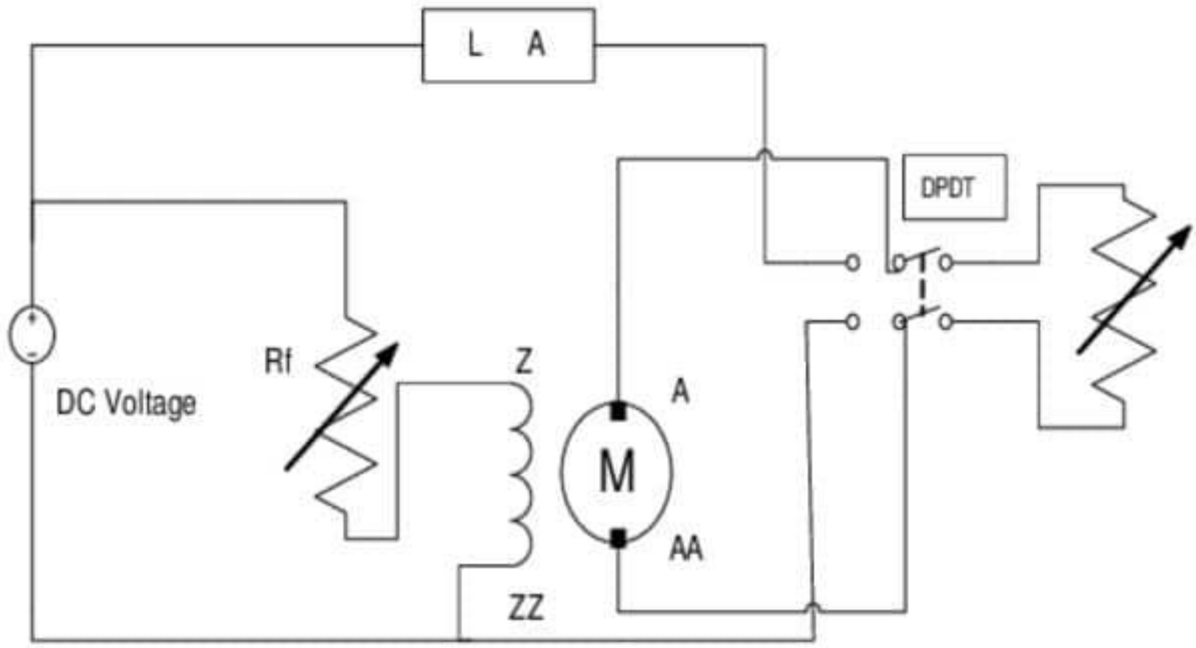
Plugging-type braking involves switching the power supply terminals to reverse the direction of the motor. This causes the motor to produce a torque that opposes its usual rotation, leading to a decrease in speed. During plugging, an external resistance is added to control the current flow. However, a significant downside of this method is that it results in energy being lost or wasted.



3. Dynamic braking

Dynamic braking, also known as rheostatic braking, is a less efficient way to slow down a motor because it converts kinetic energy into heat.

It works like this: First, the motor is disconnected from the power source. Then, a braking resistor is quickly connected to the motor. The motor's kinetic energy is turned into electrical energy, which is mostly wasted as heat.



Regenerative braking, on the other hand, is more commonly used to control the speed of motors that drive things like elevators, trains, cranes, and hoists. It’s a more efficient way to slow down because it actually recovers some of the energy and puts it back into the system instead of wasting it as heat.

Advantages of Electric Braking

Here are the main points about mechanical and electric braking:

Mechanical Braking:

1. Uses brake blocks and lining.
2. Functions on friction, requiring frequent replacement and adjustments.
3. Brake components wear out and need readjustment.
4. Not suitable for heavy loads or high speeds.
5. All braking energy is lost as heat.
6. Can be rough and cause shocks if not adjusted correctly.
7. Generates metal dust that can damage bearings.
8. The heat produced can harm brake components and lead to failure.

Electric Braking:

1. Maintenance-free.
2. Ideal for higher speeds and heavy loads.
3. Regenerative electric braking returns some energy, saving costs.
4. Provides smooth and jerk-free braking.
5. No generation of metal dust or bearing damage.
6. The heat produced does not harm motor components.
7. Faster compared to mechanical friction braking.

Disadvantages of Electric Braking

1. Electric braking makes the motor act as a generator to slow down the machine.
2. Electric braking can stop the motor but can’t hold it stationary, so a mechanical friction brake is needed for that purpose.
3. Different motors have unique speed-torque characteristics, and motor selection should match the specific application.
4. A motor suitable for one type of load may not work well for other loads.
5. Specially designed motors for electrical braking can be costly due to their unique features and capabilities.

Applications of Electric Braking

1. **Gym Equipment:** Many gym machines employ electric braking systems for precise control.
2. **Industrial Equipment:** Numerous industrial machines and tools also rely on electric braking for efficient operation.
3. **Recreation Equipment:** Various recreational devices, including those used for entertainment and leisure, incorporate electric braking mechanisms.
4. **Tesla Model S:** Tesla’s Model S utilizes electric brakes since it operates solely on electricity or electrical energy.