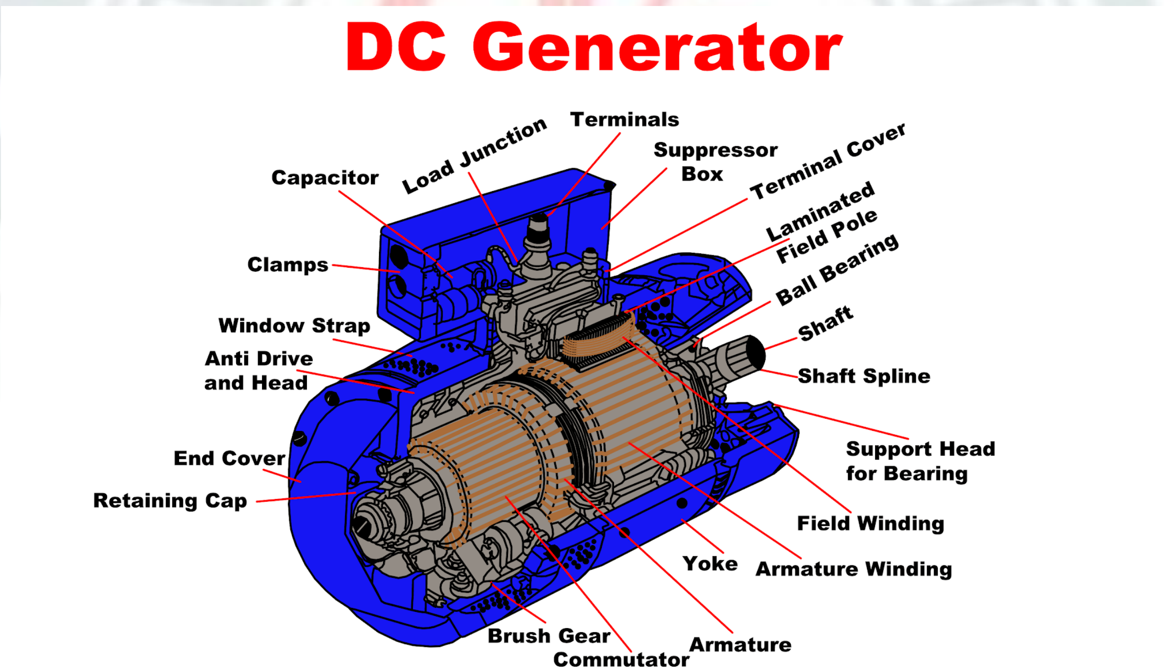
DC GENERATOR

A DC generator is an electrical device used for generating electrical energy. The main function of this device is to change mechanical energy into electrical energy. There are several types of mechanical energy sources available such as hand cranks, internal combustion engines, water turbines, gas and steam turbines. Generator provides power to all the electrical power grids. The reverse function of the generator can be done by an electric motor. The main function of the motor is to convert electrical energy to mechanical. Motors, as well as generators, have similar features.

What is a DC Generator?

A DC generator or direct current generator is one kind of electrical machine, and the main function of this machine is to convert mechanical energy into DC (direct current) electricity. The energy alteration process uses the principle of energetically induced electromotive force. The dc generator diagram is shown below.



When a conductor slashes magnetic flux, then energetically induced electromotive force will be generated in it based on the Electromagnetic Induction principle of Faraday's Laws. This electromotive force can cause a flow of current when the conductor circuit is not opened.

Construction of a DC Generator

A DC generator is also used as a DC motor by without changing its construction. Therefore, a DC motor otherwise a DC generator can be generally called as a DC machine. The construction of a 4-pole DC generator is shown below. This generator comprises of several parts like yoke, poles & pole shoes, field winding, an armature core, armature winding, commutator & brushes. But the two essential parts of this device are stator as well as the rotor.

Stator

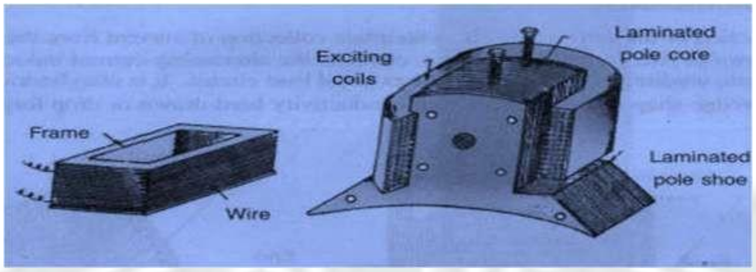
The stator is an essential part of the DC generator, and the main function of this is to provide the magnetic fields where the coils spin. This includes stable magnets, where two of them are with reverse poles facing. These magnets are located to fit in the region of the rotor.

Rotor or Armature Core

Rotor or armature core is the second essential part of the DC generator, and it includes slotted iron laminations with slots that are stacked to shape a cylindrical armature core. Generally, these laminations are offered to decrease the loss because of the eddy current.

Armature Windings

The armature core slots are mainly used for holding the armature windings. These are in a closed circuit winding form, and it is connected in series to parallel for enhancing the sum of produced current.



Yoke

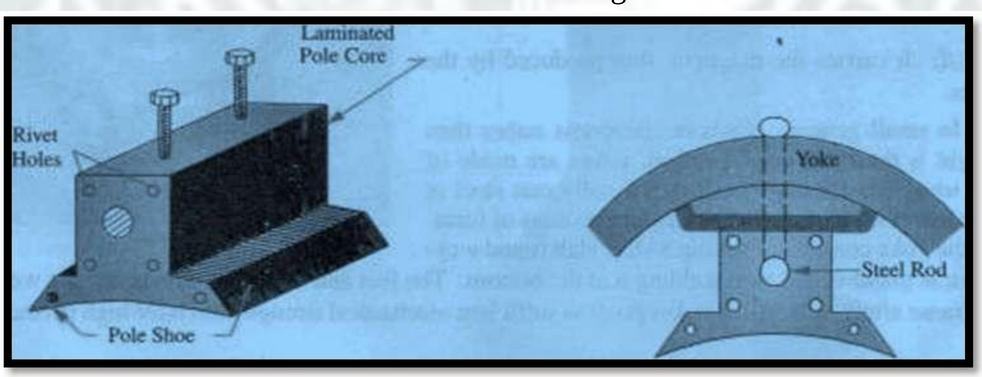
The external structure of the DC generator is Yoke, and it is made with cast iron otherwise steel. It gives the necessary mechanical power for carrying the magnetic-flux given through the poles.

Poles

These are mainly used to hold the field windings. Usually, these windings are wound on the poles, & they are connected in series otherwise parallel by the armature windings. In addition, the poles will give joint toward the yoke with the welding method otherwise by using screws.

Pole Shoe

The pole shoe is mainly utilized for spreading the magnetic flux as well as to avoid the field coil from falling.



Commutator

The working of the commutator is like a rectifier for changing AC voltage to the DC voltage within the armature winding to across the brushes. It is designed with a copper segment, and each copper segment is protected from each other with the help of mica sheets. It is located on the shaft of the machine.

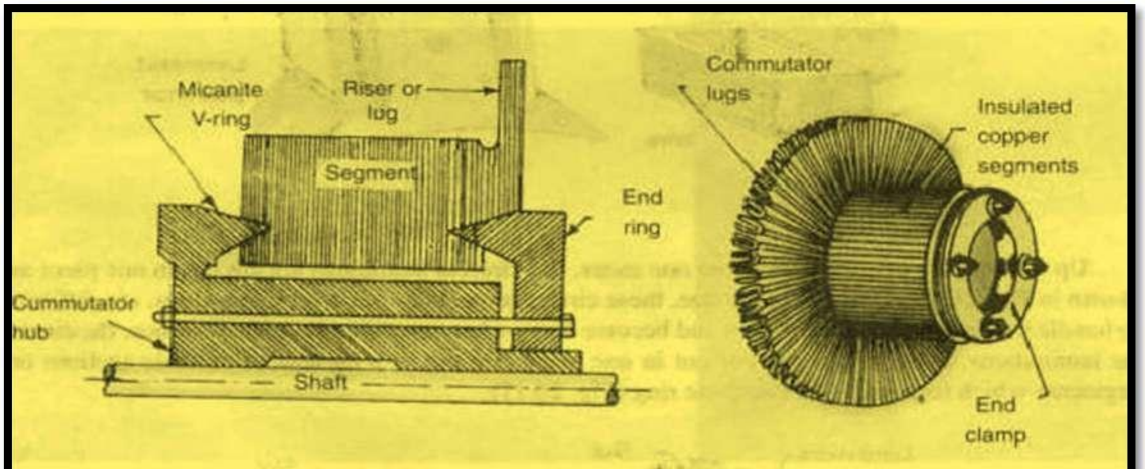


Fig. 26.18 Fig. 26.19

Brushes

The electrical connections can be ensured between the commutator as well as the exterior load circuit with the help of brushes.

Working Principle of DC Generator

The DC generator working principle is based on Faraday's laws of electromagnetic induction. When a conductor is located in an unstable magnetic field, an electromotive force gets induced within the conductor. The induced e.m.f magnitude can be measured from the equation of the electromotive force of a generator.

If the conductor is present with a closed lane, the current which is induced will flow in the lane. In this generator, field coils will generate an electromagnetic field as well as the armature conductors are turned into the field. Therefore, an electromagnetically induced electromotive force (e.m.f) will be generated within the armature conductors. The path of induced current will be provided by Fleming's right-hand rule.

DC Generator E.M.F Equation

The emf equation of dc generator according to Faraday's Laws of Electromagnetic Induction is Eg= PØZN/60 A

Where Φ is a flux or pole within Webber

Z is a total no.of armature conductor

P is a number of poles in a generator

A is a number of parallel lanes within the armature

N is the rotation of armature in r.p.m (revolutions per minute)

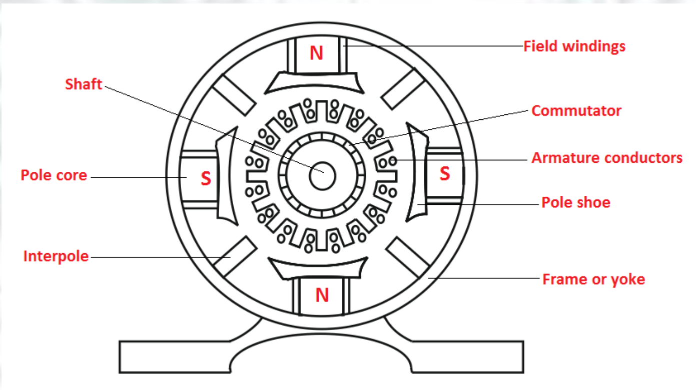
E is the induced e.m.f in any parallel lane within the armature

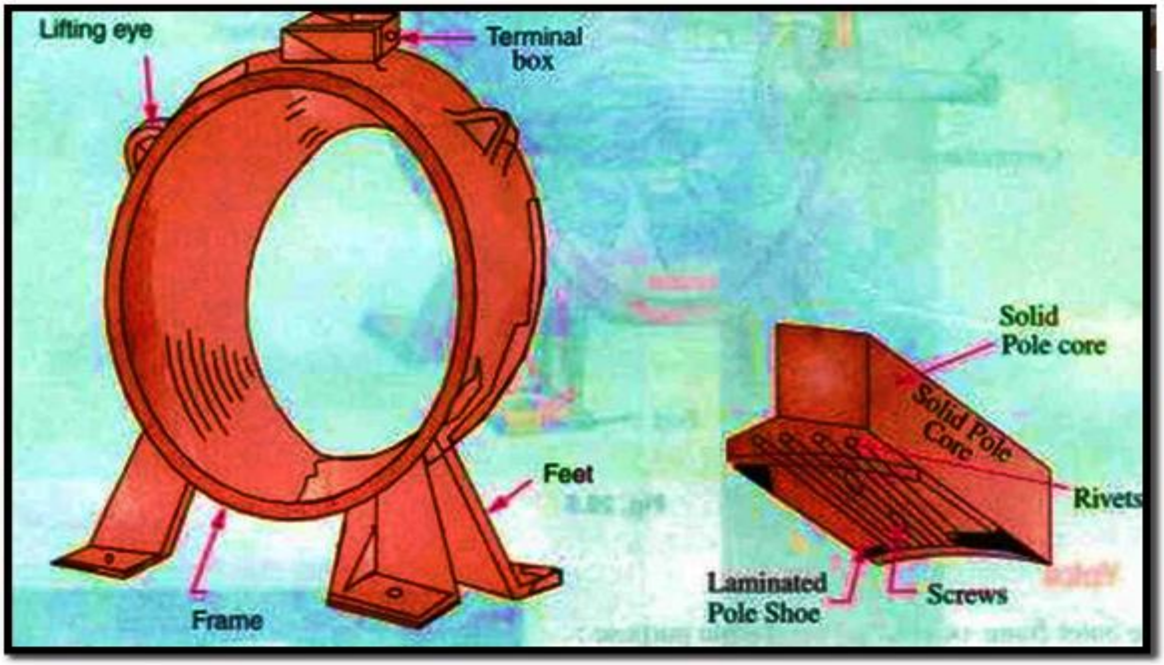
Eg is the generated e.m.f in any one of the parallel lanes

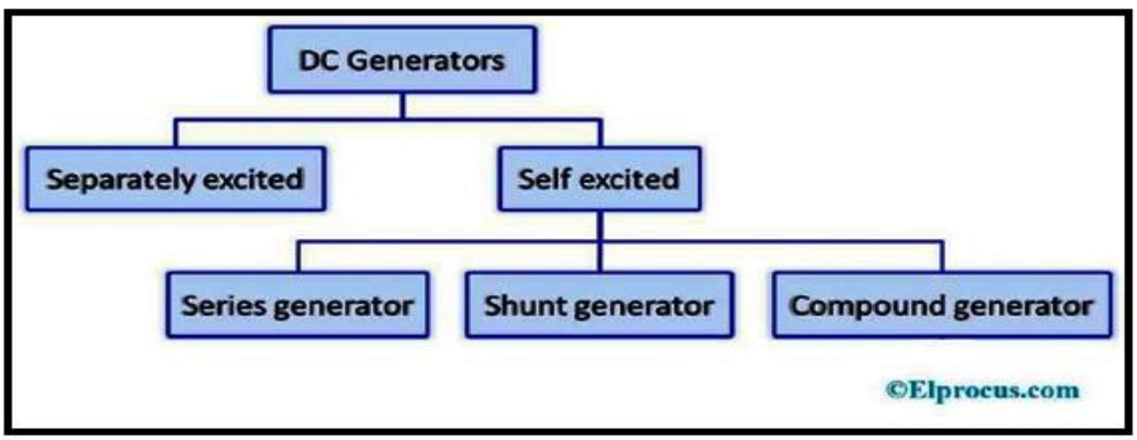
N/60 is the number of turns per second

Time for one turn will be dt = 60/N sec

$$E_g = P\text{Ø}ZN/60A$$




Lifting eye
Terminal box
Solid Pole core
Solid Pole Core
Rivets
Feet
Laminated Pole Shoe
Screws
Frame


DC Generators
Separately excited
Self excited
Series generator
Shunt generator
Compound generator
©Elprocus.com

Separately Excited

In separately excited type, the field coils are strengthened from an autonomous exterior DC source.

Self-Excited

In self-excited type, the field coils are strengthened from the generated current with the generator. The generation of first electromotive force will occur because of its outstanding magnetism within field poles.

The produced electromotive force will cause a fraction of current to supply in the field coils, therefore which will increase the field flux as well as electromotive force generation. Further, these types of dc generators can be classified into three types namely series wound, shunt wound, and compound wound.

*In a series wound, both the field winding & armature winding are connected in series with each other.

*In shunt wound, both the field winding & armature winding are connected in parallel with each other.

*The compound winding is the blend of series winding & shunt winding.

Applications of DC Generators

The applications of different types of DC generator include the following.

*The separately excited type DC generator is used for boosting as well as electroplating. It is used in power and lighting purpose using field regulator

*The self-excited DC generator or shunt DC generator is used for power as well as ordinary lighting using the regulator. It can be used for battery lighting.

*The series DC generator is used in arc lamps for lighting, stable current generator and booster.

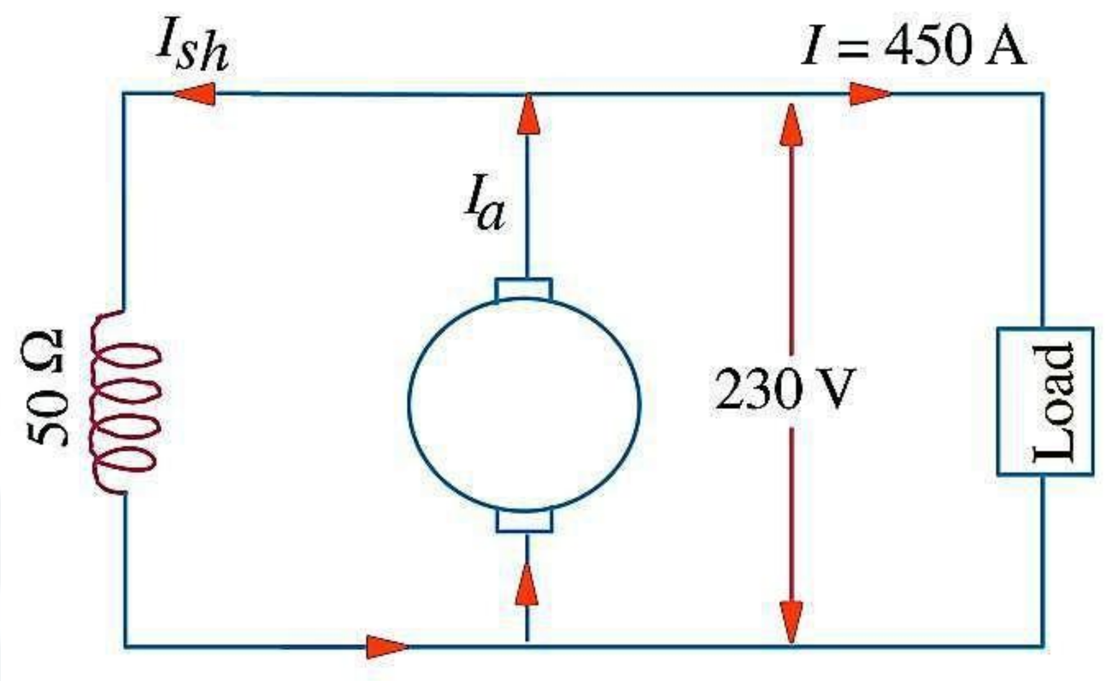
*Compound DC generator is used to provide the power supply for DC welding machines.

*Level compound DC generator is used to provide a power supply for hostels, lodges, offices, etc.

Numerical

1.A shunt generator delivers 450 A at 230 V and the resistance of the shunt field and armature are 50 Ω and 0.03 Ω respectively. Calculate the generated e.m.f?

Solution:



$$\text{Current through shunt field winding is,}$$
$$I_{sh} = 230/50 = 4.6\ A$$
$$\text{Load current, } I = 450\ A$$
$$\therefore \text{Armature Current } I_a = I + I_{sh}$$
$$= 450 + 4.6 = 454.6\ A$$
$$\text{Armature Voltage Drop, } I_a R_a = 454.6 \times 0.03$$
$$= 13.6\ V$$
$$\text{Now, Generated Emf, } E_g = \text{terminal voltage} + \text{armature drop}$$
$$= V + I_a R_a$$
$$\therefore \text{Emf generated in armature}$$
$$E_g = 230 + 13.6$$
$$= 243.6\ V$$

2. A four pole generator having wave-wound armature winding has 51 slots, each slot containing 20 conductors. What will be the voltage generated in the machine when driven at 1500 rpm assuming the flux per pole to be 7.0 mWb ?

Solution:

For a simplex wave wound generator,

$$Emf\ Generated / Path = \frac{\phi ZN}{60}\left(\frac{P}{A}\right)$$

$$E_g = \frac{P\phi ZN}{60A}$$

Here,

$$\phi = 7 \times 10^{-3} Wb$$

$$Z = 51 \times 20 = 1020$$

$$A = P = 4$$

$$N = 1500\ rpm$$

$\therefore$

$$E_g = \frac{7 \times 10^{-3} \times 1020 \times 1500}{60}\left(\frac{4}{2}\right)$$

$$= 178.5\ V$$

DC MOTOR

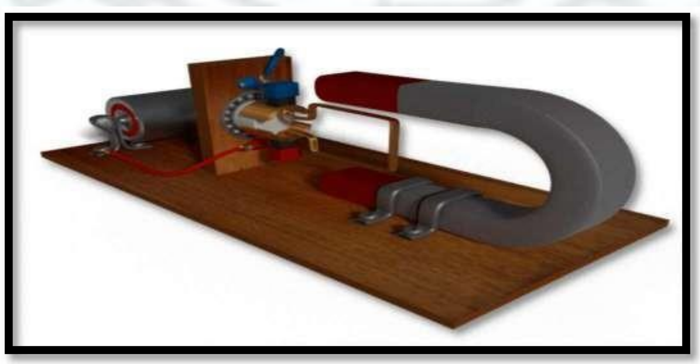
The electric motor operated by dc is called dc motor. This is a device that converts DC electrical energy into a mechanical energy.

Principle of DC Motor

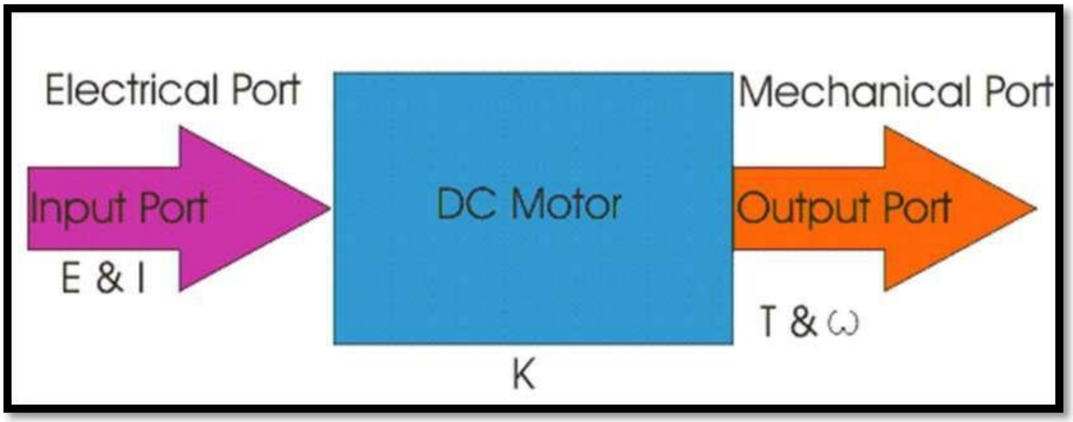
When a current carrying conductor is placed in a magnetic field, it experiences a torque and has a tendency to move. In other words, when a magnetic field and an electric field interact, a mechanical force is produced. The DC motor or direct current motor works on that principal. This is known as motoring action.

Fleming left hand rule

The direction of rotation of this motor is given by Fleming's left hand rule, which states that if the index finger, middle finger, and thumb of your left hand are extended mutually perpendicular to each other and if the index finger represents the direction of magnetic field, middle finger indicates the direction of current, then the thumb represents the direction in which force is experienced by the shaft of the DC motor.



Structurally and construction wise a direct current motor is exactly similar to a DC generator, but electrically it is just the opposite. Here we unlike a generator we supply electrical energy to the input port and derive mechanical energy from the output port. We can represent it by the block diagram shown below.



Here in a DC motor, the supply voltage E and current I is given to the electrical port or the input port and we derive the mechanical output i.e. torque T and speed ω from the mechanical port or output port.

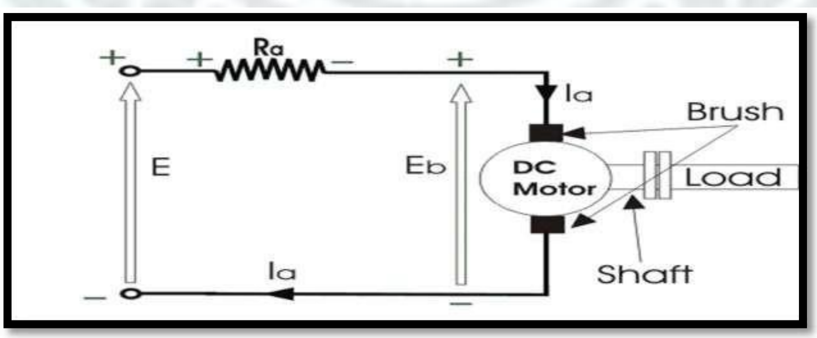
the parameter K relates the input and output port variables of the direct current motor.

$$T = KI \text{ and } E = K\omega$$

So from the picture above, we can well understand that motor is just the opposite phenomena of a DC generator, and we can derive both motoring and generating operation from the same machine by simply reversing the ports.

Detailed Description of a DC Motor

To understand the DC motor in details let's consider the diagram below,



The circle in the center represents the direct current motor. On the circle, we draw the brushes. On the brushes, we connect the external terminals, through which we give the supply voltage. On the mechanical terminal, we have a shaft coming out from the center of the armature, and the shaft couples to the mechanical load. On the supply terminals, we represent the armature resistance Ra in series.

Now, let the input voltage E, is applied across the brushes. Electric current which flows through the rotor armature via brushes, in presence of the magnetic field, produces a torque Tg. Due to this torque Tg the dc motor armature rotates. As the armature conductors are carrying currents and the armature rotates inside the stator magnetic field, it also produces an emf Eb in the manner very similar to that of a generator. The generated Emf Eb is directed opposite to the supplied voltage and is known as the back Emf, as it counters the forward voltage.

The back emf like in case of a generator is represented by

$$E_b = \frac{P.\varphi.Z.N}{60.A} \text{..........................} (1)$$

Where, P = no of poles

φ = flux per pole

Z= No. of conductors

A = No. of parallel paths

and N is the speed of the DC Motor.

So, from the above equation, we can see Eb is proportional to speed 'N.' That is whenever a direct current motor rotates; it results in the generation of back Emf. Now let's represent the rotor speed by ω in rad/sec. So Eb is proportional to ω.

So, when the application of load reduces the speed of the motor, Eb decreases. Thus the voltage difference between supply voltage and back emf increases that means E − Eb increases. Due to this increased voltage difference, the armature current will increase and therefore torque and hence speed increases. Thus a DC Motor is capable of maintaining the same speed under variable load.

Now armature current Ia is represented by

$$I_a = \frac{E - E_b}{R_a}$$

Now at starting, speed ω = 0 so at starting Eb = 0.

$$\therefore \ I_a = \frac{E}{R_a} \text{..............................} (2)$$

Now since the armature winding electrical resistance Ra is small, this motor has a very high starting current in the absence of back Emf. As a result, we need to use a starter for starting a DC Motor.

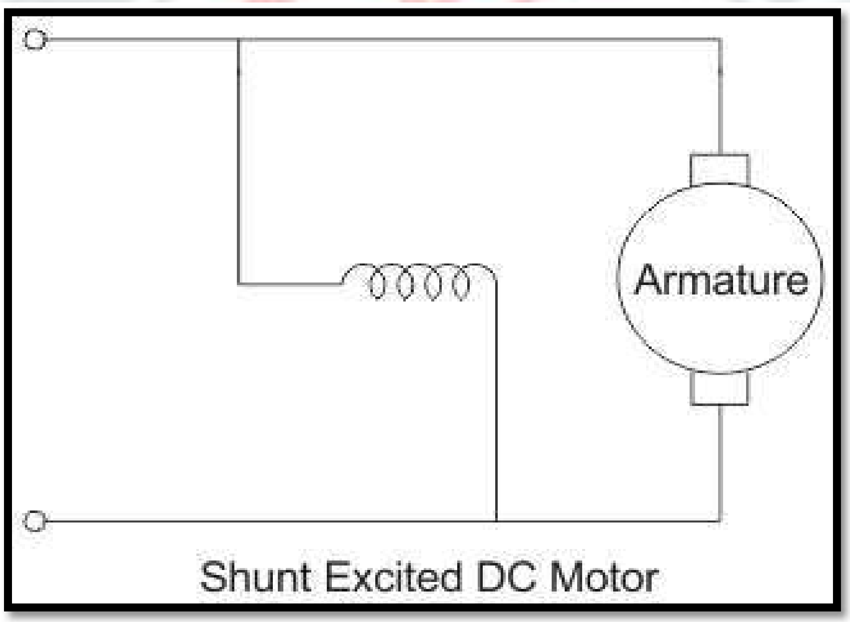
Now as the motor continues to rotate, the back emf starts being generated and gradually the current decreases as the motor picks up speed.

Types of DC Motors

Direct motors are named according to the connection o the field winding with the armature. There are 3 types:

1. **DC Shunt Motor:**

A DC shunt motor (also known as a shunt wound DC motor) is a type of self-excited DC motor where the field windings are shunted to or are connected in parallel to the armature winding of the motor. Since they are connected in parallel, the armature and field windings are exposed to the same supply voltage. Though there are separate branches for the flow of armature current and field current – as shown in the figure of below.



DC Shunt Motor Equations

Let us now consider the voltage and current being supplied from the electrical terminal to the motor be given by E and I total respectively.

This supply current in case of the shunt wound DC motor is split up into 2 parts. Ia, flowing through the armature winding of resistance Ra and Ish flowing through the field winding of resistance Rsh. The voltage across both windings remains the same.

From there we can write

$$Where\ I_{sh} = \frac{E}{R_{sh}}$$

$$or,\ I_a = I_{total} - I_{sh} = \frac{E}{R_a}$$

Thus we put this value of armature current Ia to get general voltage equation of a DC shunt motor.

$$E = E_b + I_a R_a$$

$$Or\ E = E_b + (I_{total} - I_{sh}) R_a$$

Now in general practice, when the motor is in its running condition, and the supply voltage is constant and the shunt field current given by,

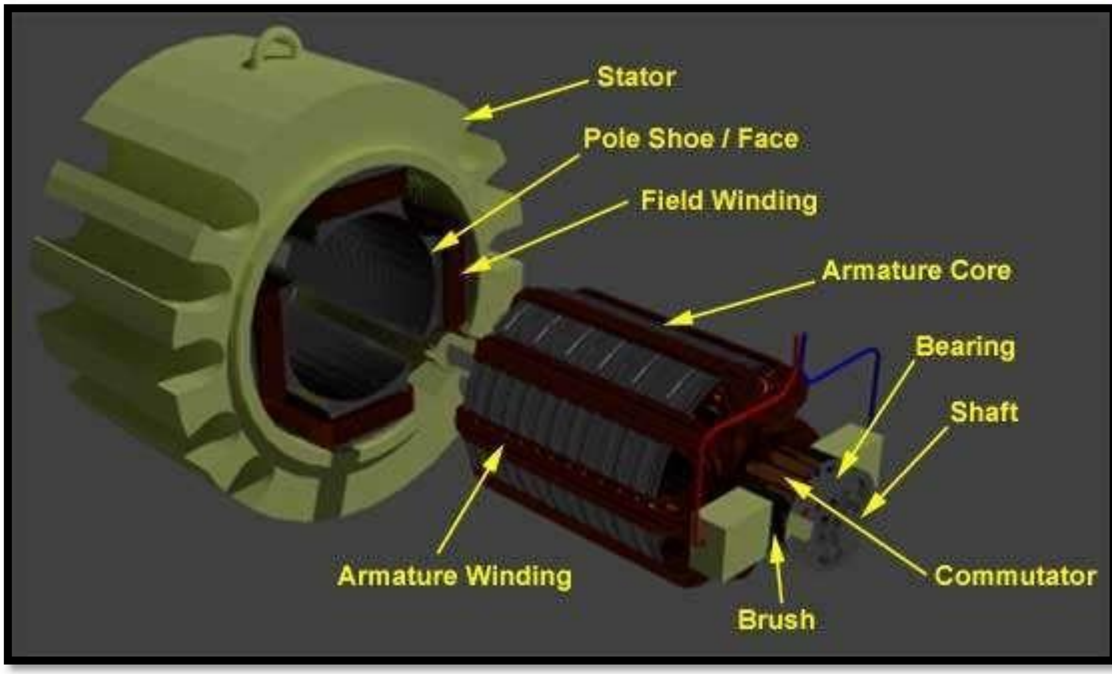
$$I_{sh} = \frac{E}{R_{sh}},\ remains\ constant$$

But we know Ish ∝ Φ

i.e. field flux Φ is proportional to filed current Ish

Thus the field flux remains more or less constant, and for this reason, a shunt wound DC motor is called a constant flux moto

Construction of a Shunt Wound DC Motor



Just that there is one distinguishable feature in its designing which can be explained by taking into consideration, the torque generated by the motor. To produce high torque,

The armature winding must be exposed to an amount of current that's much higher than the field windings current, as the torque is proportional to the armature current.

The field winding must be wound with many turns to increase the flux linkage, as flux linkage between the field and armature winding is also proportional to the torque.

Keeping these two above mentioned criterion in mind a DC shunt motor has been designed in a way, that the field winding possess much higher number of turns to increase net flux linkage and are lesser in diameter of conductor to increase resistance (reduce current flow) compared to the armature winding of the DC motor. And this is how a shunt wound DC motor is visibly distinguishable in static condition from the DC series motor (having thicker field coils) of the self-excited type motor's category.

Self-Speed Regulation of a Shunt Wound DC Motor

A very important and interesting fact about the DC shunt motor, is in its ability to self-regulate its speed on the application of the load to the shaft of the rotor terminals. This essentially means that on switching the motor running condition from no load to loaded, surprisingly there is no considerable change in speed of running, as would be expected in the absence of any speed regulating modifications from outside. Let us see how?

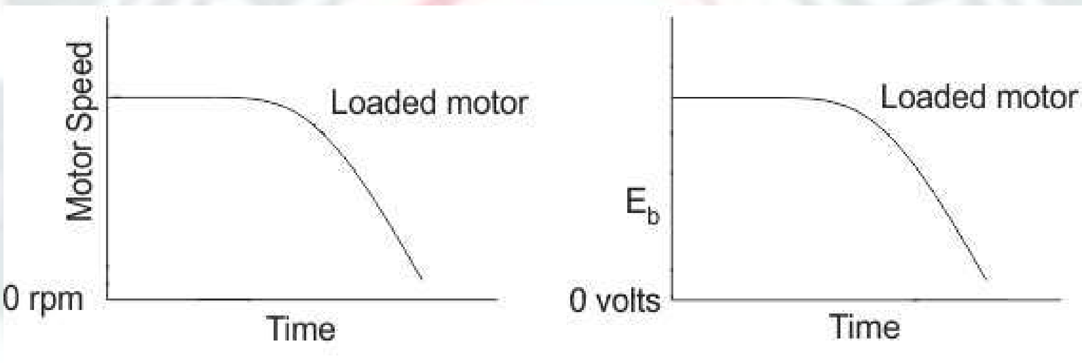
Let us do a step-wise analysis to understand it better.

*Initially considering the motor to be running under no load or lightly loaded condition at a speed of N rpm.

*On adding a load to the shaft, the motor does slow down initially, but this is where the concept of self-regulation comes into the picture.

*At the very onset of load introduction to a shunt wound DC motor, the speed definitely reduces, and along with speed also reduces the back emf, Eb. Since Eb ∝ N, given by,

$$E_b = \frac{P.\varphi.Z.N}{60}$$



No load to loaded condition

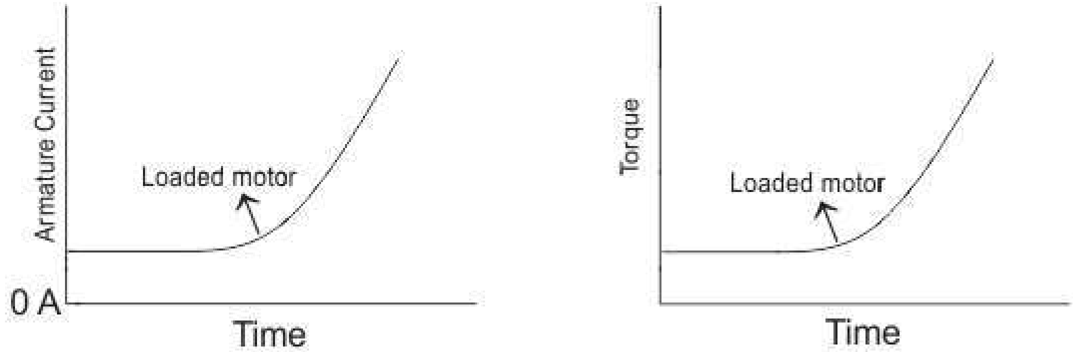
*This reduction in the counter emf or the back emf Eb results in the increase of the net voltage. As net voltage Enet = E − Eb. Since supply voltage E remains constant.

*As a result of this increased amount of net voltage, the armature current increases and consequently the torque increases.

Since, Ia ∝ T given by

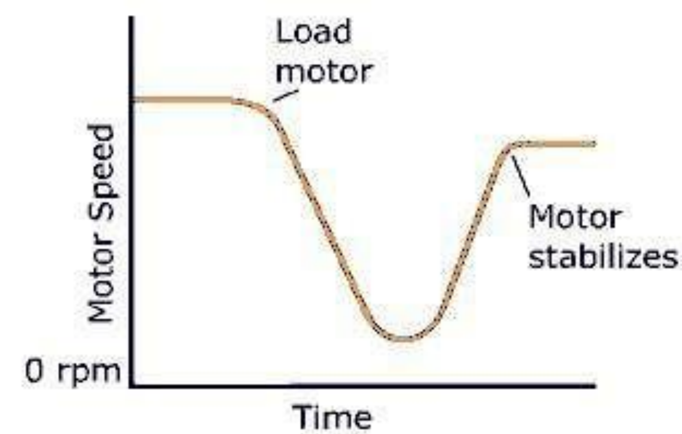
$$T = \frac{P.Z.\varphi.I_a}{2.\pi.A}$$

The change in armature current and torque on supplying load is graphically shown below.



No load to loaded condition

This increase in the amount of torque increases the speed and thus compensating for the speed loss on loading. Thus the final speed characteristic of a DC shunt motor, looks like.



No load to loaded condition

From there we can well understand this special ability of the shunt wound DC motor to regulate its speed by itself on loading and thus its rightly called the constant flux or constant speed motor. Because of which it finds wide spread industrial application where ever constant speed operation is required.

2. **Series Wound DC Motor or DC Series Motor**

A series wound DC motor like in the case of shunt wound DC motor or compound wound DC motor falls under the category of self-excited DC motors, and it gets its name from the fact that the field winding in this case is connected internally in series to the armature winding. Thus the field winding is exposed to the entire armature current unlike in the case of a shunt motor.

Construction of Series DC Motor

Construction wise this motor is similar to any other types of DC motors in almost all aspects. It consists of all the fundamental components like the stator housing the field winding or the rotor carrying the armature conductors, and the other vital parts like the commutator or the brush segments all attached in the proper sequence as in the case of a generic DC motor.

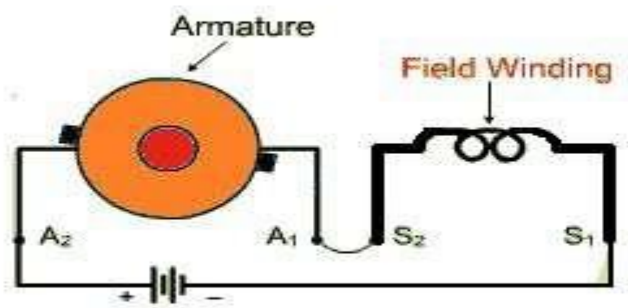
Yet if we are to take a close look into the wiring of the field and armature coils of this DC motor, its clearly distinguishable from the other members of this type.

To understand that let us revert back into the above mentioned basic fact, that this motor has field coil connected in series to the armature winding. For this reason, relatively higher current flows through the field coils, and its designed accordingly as mentioned below.

*The field coils of DC series motor are wound with relatively fewer turns as the current through the field is its armature current and hence for required mmf less numbers of turns are required.

*The wire is heavier, as the diameter is considerable increased to provide minimum electrical resistance to the flow of full armature current.

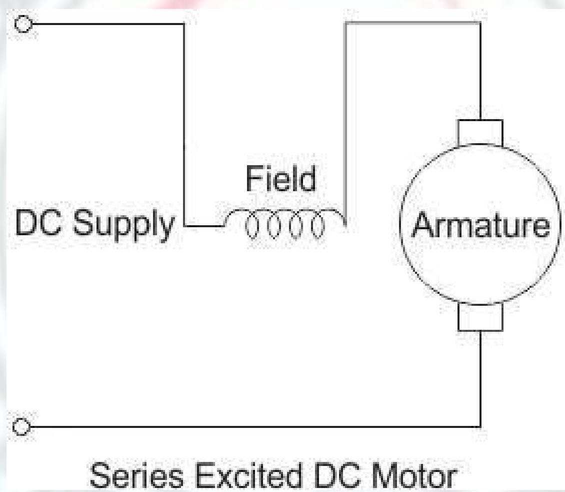
*In spite of the above mentioned differences, about having fewer coil turns the running of this DC motor remains unaffected, as the current through the field is reasonably high to produce a field strong enough for generating the required amount of torque. To understand that better let’s look into the voltage and current equation of DC series motor.



Field winding with thicker diameter & fewer turns.

Voltage and Current Equation of Series DC Motor

The electrical layout of a typical series wound DC motor is shown in the diagram below.



Let the supply voltage and current given to the electrical port of the motor be given by E and I total respectively.

Since the entire supply current flows through both the armature and field conductor.

$$Therefore,\ I_{total} = I_{se} = I_a$$

Where, Ise is the series current in the field coil and Ia is the armature current.

Now form the basic voltage equation of the DC motor.

$$E = E_b + I_{se}R_{se} + I_aR_{se}$$

Where, Eb is the back emf.

Rse is the series coil resistance and Ra is the armature resistance.

Since Ise = Ia, we can write,

$$E = E_b + I_a(R_a + R_{se})$$

This is the basic voltage equation of a series wound DC motor.

Another interesting fact about the DC series motor worth noting is that, the field flux like in the case of any other DC motor is proportional to field current.

$$I_{se} \propto \phi$$

$$I_{se} = I_a = I_{total}$$

$$\phi \propto I_{se} \propto I_a$$

i.e. the field flux is proportional to the entire armature current or the total supply current. And for this reason, the flux produced in this motor is strong enough to produce sufficient torque, even with the bare minimum number of turns it has in the field coil.

Speed and Torque of Series DC Motor

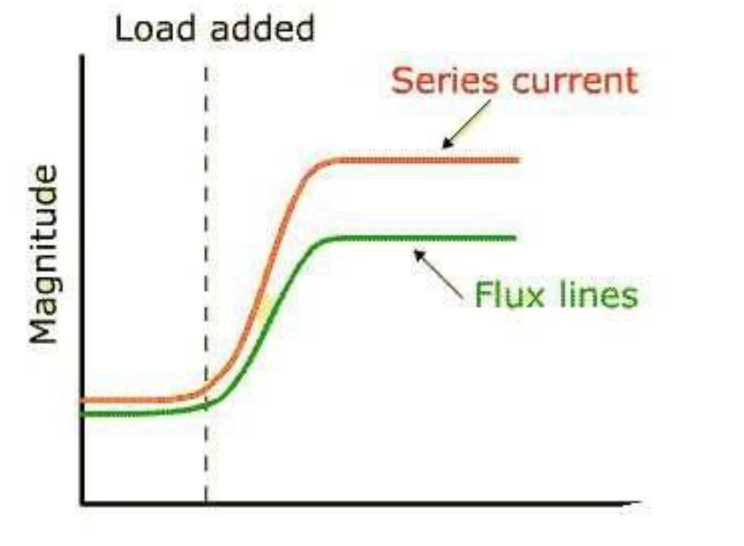
A series wound motors has linear relationship existing between the field current and the amount of torque produced. i.e. torque is directly proportional to current over the entire range of the graph. As in this case relatively higher current flows through the heavy series field winding with thicker diameter, the electromagnetic torque produced here is much higher than normal. This high electromagnetic torque produces motor speed, strong enough to lift heavy load overcoming its initial inertial of rest. And for this particular reason the motor becomes extremely essential as starter motors for most industrial applications dealing in heavy mechanical load like huge cranes or large metal chunks etc. Series motors are generally operated for a very small duration, about only a few seconds, just for the purpose of starting. Because if its run for too long, the high series current might burn out the series field coils thus leaving the motor useless.

Speed Regulation of Series Wound DC Motor

Unlike in the case of a DC shunt motor, the DC series motor has very poor speed regulation. i.e. the series motor is unable to maintain its speed on addition of external load to the shaft. Let us see why?

When mechanical load is added to the shaft at any instance, the speed automatically reduces whatever be the type of motor. But the term speed regulation refers to the ability of the motor to bring back the reduced speed to its original previous value within reasonable amount of time. But this motor is highly incapable of doing that as with reduction in speed N on addition of load, the back emf given by,

$$E_b = \frac{P\varphi ZN}{60A}$$



Effect of load addition on dc series motor.

This decrease in back Emf Eb, increases the net voltage E – Eb, and consequently the series field current increases,

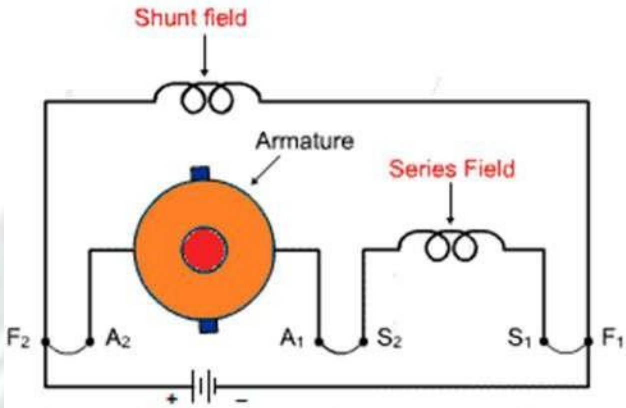
$$I_{se} = E - \frac{E_b}{R_a + R_{se}}$$

The value of series current through the field coil becomes so high that it tends to saturate of the magnetic core of the field. As a result, the magnetic flux linking the coils increases at a much slower rate compared to the increase in current beyond the saturation region as shown in the figure below.

The weak magnetic field produced as a consequence is unable to provide for the necessary amount of force to bring back the speed at its previous value before application of load.

3. **Compound Wound DC Motor or DC Compound Motor:**

A compound wound DC motor (also known as a DC compound motor) is a type of self-excited motor, and is made up of both series the field coils S1 S2 and shunt field coils F1 F2 connected to the armature winding as shown in the figure below.



Schematic diagram of dc compound motor

Both the field coils provide for the required amount of magnetic flux, that links with the armature coil and brings about the torque necessary to facilitate rotation at the desired speed. As we can understand, a compound wound DC motor is basically formed by the amalgamation of a shunt wound DC motor and series wound DC motor to achieve the better off properties of both these types. Like a shunt wound DC motor is bestowed with an extremely efficient speed regulation characteristic, whereas the DC series motor has high starting torque.

So the compound wound DC motor reaches a compromise in terms of both these features and has a good combination of proper speed regulation and high starting torque.

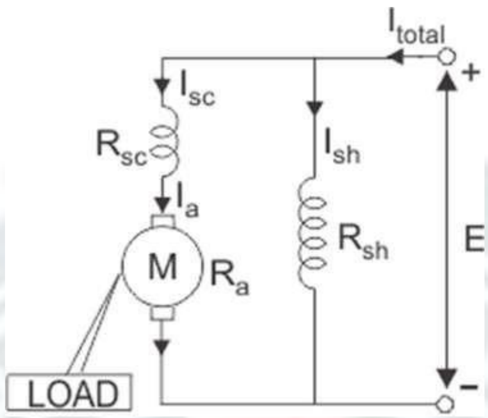
Though its starting torque is not as high as in case of DC motor, nor is its speed regulation as good as a shunt DC motor. Overall characteristics of DC shunt motor falls somewhere in between these 2 extreme limits. You can learn more about motors by studying our electrical MCQs.

Types of Compound Wound DC Motor

The compound wound DC motor can further be subdivided into 2 major types on the basis of its field winding connection with respect to the armature winding, and they are:

Long Shunt Compound Wound DC Motor

In case of long shunt compound wound DC motor, the shunt field winding is connected in parallel across the series combination of both the armature and series field coil, as shown in the diagram below



Voltage and Current Equation of Long Shunt Compound Wound DC Motor

Let E and I total be the total supply voltage and current supplied to the input terminals of the motor. And Ia, Ise , Ish be the values of current flowing through armature resistance Ra, series winding resistance Rse and shunt winding resistance Rsh respectively.

Now we know in shunt motor,

$$I_{total} = I_a + I_{sh}$$

And in series motor

$$I_a = I_{se}$$

Therefore, the current equation of a compound wound DC motor is given by

$$I_{total} = I_{se} + I_{sh} \cdots\cdots\cdots\cdots\cdots\cdots\cdots (1)$$

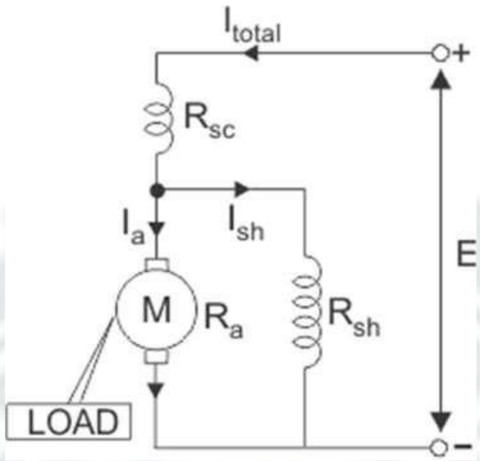
And its voltage equation is,

And its voltage equation is,

$$E = E_b + I_a(R_a + R_{se})$$

Short Shunt Compound Wound DC Motor

In case of short shunt compound wound DC motor, the shunt field winding is connected in parallel across the armature winding only. And series field coil is exposed to the entire supply current, before being split up into armature and shunt field current as shown in the diagram below.



Voltage and Current Equation of Short Shunt Compound Wound DC Motor

Here also let, E and I total be the total supply voltage and current supplied to the input terminals of the motor. And Ia, Ise, Ish be the values of current flowing through armature resistance Ra, series winding resistance Rse and shunt winding resistance Rsh respectively.

But from the diagram above we can see,

$$I_{total} = I_{se} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots (2)$$

Since the entire supply current flows through the series field winding.

And like in the case of a DC shunt motor,

$$I_{total} = I_a + I_{sh} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots (3)$$

Equation (2) and (3) gives the current equation of a short shunt compound wound DC motor.

Now for equating the voltage equation, we apply Kirchhoff's law to the circuit and get,

$$E = E_b + I_a R_a + I_{se} R_{se}$$

But since

$$I_{se} = I_{total}$$

Thus the final voltage equation can be written as,

$$E = E_b + I_a R_a + I_{total} R_{se}$$

Apart from the above mentioned classification, a compound wound DC motor can further be sub divided into 2 types depending upon excitation or the nature of compounding. i.e.

Cumulative Compounding of DC Motor

A compound wound DC motor is said to be cumulatively compounded when the shunt field flux produced by the shunt winding assists or enhances the effect of main field flux, produced by the series winding.

$$\phi_{total} = \phi_{series} + \phi_{shunt}$$

Differential Compounding of DC Motor

Similarly, a compound wound DC motor is said to be deferentially compounded when the flux due to the shunt field winding diminishes the effect of the main series winding. This particular trait is not really desirable, and hence does not find much of a practical application.

$$\phi_{total} = \phi_{series} - \phi_{shunt}$$

The net flux produced in this case is lesser than the original flux and hence does not find much of a practical application.

The compounding characteristic of the self-excited DC motor is shown in the figure below.

<u>Numerical</u>

A 220-V d.c. machine has an armature resistance of 0.5 Ω. If the full-load armature current is 20 A. find the induced e.m.f. when the machine acts as (i) generator (ii) motor.

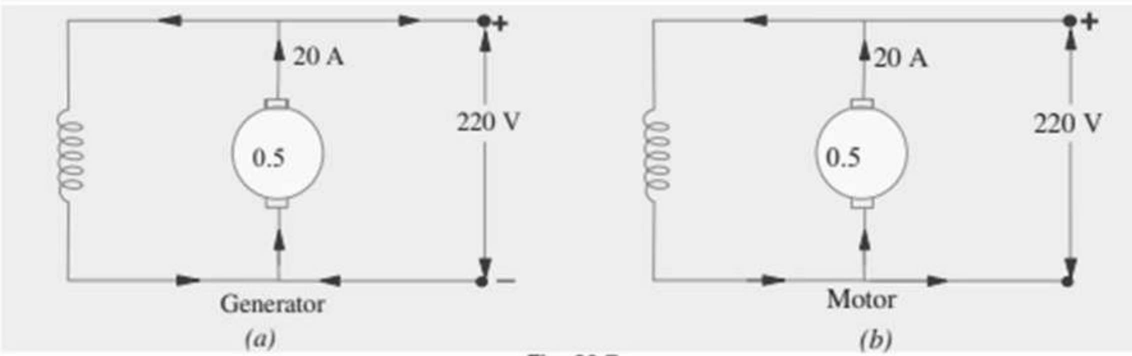


Fig. 29.7

Solution. As shown in Fig. 29.7, the d.c. machine is assumed to be shunt-connected. In each case, shunt current is considered negligible because its value is not given.

(*a*) As Generator [Fig. 29.7(*a*)] $E_g = V + I_a R_a = 220 + 0.5 \times 20 = \mathbf{230\ V}$

(*b*) As Motor [Fig 29.7 (*b*)] $E_b = V - I_a R_a = 220 - 0.5 \times 20 = \mathbf{210\ V}$

A d.c. shunt machine while running as generator develops a voltage of 250 V at 1000 r.p.m. on no-load. It has armature resistance of 0.5 Ω and field resistance of 250 Ω. When the machine runs as motor, input to it at no-load is 4 A at 250 V. Calculate the speed and efficiency of the machine when it runs as a motor taking 40 A at 250 V. Armature reaction weakens the field by 4 %.

Solution. $$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\Phi_1}{\Phi_2}$$

Now, when running as a generator, the machine gives 250 V at 1000 r.p.m. If this machine was running as motor at 1000 r.p.m., it will, obviously, have a back e.m.f. of 250 V produced in its armature. Hence $N_1 = 1000$ r.p.m. and $E_{b1} = 250$ V.

When it runs as a motor, drawing 40 A, the back e.m.f. induced in its armature is

$$E_{b2} = 250 - (40 - 1) \times 0.5 = 230.5 \text{ V; Also } \Phi_2 = 0.96\ \Phi_1,\ N_2 = ?$$

Using the above equation we have

$$\frac{N_2}{1000} = \frac{230.5}{250} \times \frac{\Phi_1}{0.96\ \Phi_1};\ N_2 = \mathbf{960\ r.p.m.}$$

Efficiency

No-load input represents motor losses which consists of

(*a*) armature Cu loss = $I_a^2 R_a$ which is variable.

(*b*) constant losses W_c which consists of (*i*) shunt Cu loss (*ii*) magnetic losses and (*iii*) mechanical losses.

No-load input or total losses = 250 × 4 = 1000 W

Arm. Cu loss = $I_a^2 R_a = 3^2 \times 0.5 = 4.5$ W, ∴ $W_c = 1000 - 4.5 = 995.5$ W

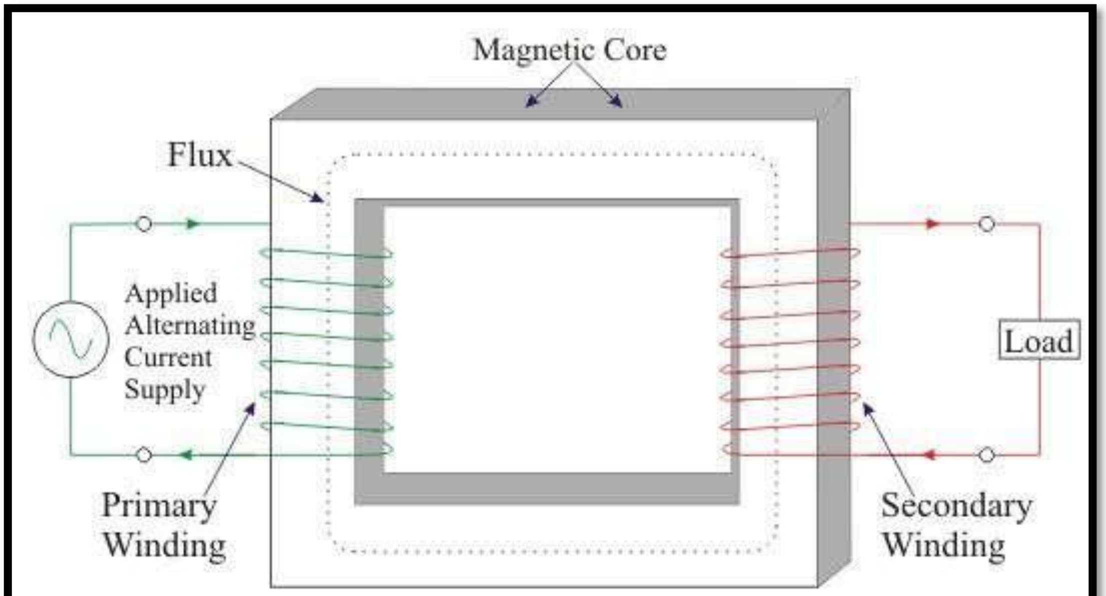
When motor draws a line current of 40 A, its armature current is (40 – 1) = 39 A

$$\text{Arm. Cu loss} = 39^2 \times 0.5 = 760.5 \text{ W; Total losses} = 760.5 + 955.5 = 1756 \text{ W}$$

$$\text{Input} = 250 \times 40 = 10{,}000 \text{ W; output} = 10{,}000 - 1756 = 8{,}244 \text{ W}$$

$$\therefore \quad \eta = 8{,}244 \times 100/10{,}000 = \mathbf{82.44\%}$$

SINGLE PHASE TRANSFORMER



Single Phase Transformer

Transformer is electromagnetic static electrical equipment (with no moving parts) which transforms magnetic energy to electrical energy. It consists of a magnetic iron core serving as a magnetic transformer part and transformer cooper winding serving as electrical part. The transformer is high-efficiency equipment, and its losses are very low because there isn't any mechanical friction inside. Transformers are used in almost all electrical systems from low voltage up to the highest voltage level. It operates only with alternating current (AC), because the direct current (DC) does not create any electromagnetic induction. Depending on the electrical network where the transformer is installed, there are two transformer types, three-phase transformers and single phase transformers. The operation principle of the single-phase transformer is: the AC voltage source injects the AC current through the transformer primary winding

The AC current generates the alternating electromagnetic field. The magnetic field lines are moving through iron transformer core and comprise the transformer secondary circuit. Thus the voltage is induced in the secondary winding with the same frequency as the voltage of the primary side. The induced voltage value is determine by Faraday's Law.

Where,

f → frequency Hz

N → number of winding turns

Φ → flux density Wb

If the load is connected on the secondary transformer side the current will flow through secondary winding. Basically, the single phase transformers can operate as step up transformer or step down transformers.

The main parts of a transformer are windings, core, and isolation. The windings should have small resistance value and usually they are made of copper (rarely of aluminium). They are wound around the core and must be isolated from it. Also, the windings turns have to be isolated from each other. The transformer core is made from very thin steel laminations which have high permeability. The laminations have to be thin (between 0.25 mm and 0.5 mm) because of decreasing power losses (known as eddy current losses). They have to be isolated from each other, and usually, the insulating varnish is used for that purpose. The transformer insulation can be provided as dry or as liquid-filled type. The dry-type insulation is provided by synthetic resins, air, gas or vacuum. It is used only for small size transformers (below 500 kVA). The liquid insulation type usually means using mineral oils. The oil has a long life cycle, good isolation characteristics, overload capability and also provides transformer cooling. Oil insulation is always used for big transformers.

The single phase transformer contains two windings, one on primary and the other on the secondary side. They are mostly used in the single-phase electrical power system. The three-phase system application means using three single phase units connected in the three-phase system. This is a more expensive solution, and it is used in the high voltage power system.

A Transformers Turns Ratio

$$\frac{N_P}{N_S} = \frac{V_P}{V_S} = n = \text{Turns Ratio}$$

Assuming an ideal transformer and the phase angles: $\Phi P \equiv \Phi S$

Note that the order of the numbers when expressing a transformer turns ratio value is very important as the turns ratio 3:1 expresses a very different transformer relationship and output voltage than one in which the turns ratio is given as: 1:3.

Transformer Basics Example No1

A voltage transformer has 1500 turns of wire on its primary coil and 500 turns of wire for its secondary coil. What will be the turns ratio (TR) of the transformer

$$T.R. = \frac{N_P}{N_S} = \frac{\#Pri.\,Coils}{\#Sec.\,Coils} = \frac{1500}{500} = \frac{3}{1} = 3:1$$

This ratio of 3:1 (3-to-1) simply means that there are three primary windings for every one secondary winding. As the ratio moves from a larger number on the left to a smaller number on the right, the primary voltage is therefore stepped down in value as shown.

Transformer Basics Example No2

If 240 volts rms is applied to the primary winding of the same transformer above, what will be the resulting secondary no load voltage.

$$T.R. = 3:1 \text{ or } \frac{3}{1} = \frac{V_P}{V_S} = \frac{\#Pri.\,Volts}{\#Sec.\,Volts} = \frac{240}{V_S}$$

$$\therefore \text{Sec. Volts, } V_S = \frac{V_P}{3} = \frac{240}{3} = 80 \text{ volts}$$

Again confirming that the transformer is a “step-down” transformer as the primary voltage is 240 volts and the corresponding secondary voltage is lower at 80 volts.

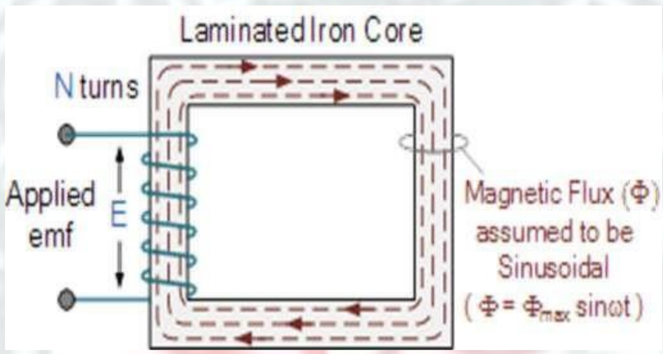
Then the main purpose of a transformer is to transform voltages at present ratios and we can see that the primary winding has a set amount or number of windings (coils of wire) on it to suit the input voltage. If the secondary output voltage is to be the same value as the input voltage on the primary winding, then the same number of coil turns must be wound onto the secondary core as there are on the primary core giving an even turns ratio of 1:1 (1-to-1). In other words, one coil turns on the secondary to one coil turn on the primary.

If the output secondary voltage is to be greater or higher than the input voltage, (step-up transformer) then there must be more turns on the secondary giving a turns ratio of 1: N (1-to-N), where N represents the turns ratio number. Likewise, if it is required that the secondary voltage is to be lower or less than the primary, (step-down transformer) then the number of secondary windings must be less giving a turns ratio of N:1 (N-to-1).

Transformer Action

We have seen that the number of coil turns on the secondary winding compared to the primary winding, the turns ratio, affects the amount of voltage available from the secondary coil. But if the two windings are electrically isolated from each other, how is this secondary voltage produced?

We have said previously that a transformer basically consists of two coils wound around a common soft iron core. When an alternating voltage (VP) is applied to the primary coil, current flows through the coil which in turn sets up a magnetic field around itself, called mutual inductance, by this current flow according to Faraday's Law of electromagnetic induction. The strength of the magnetic field builds up as the current flow rises from zero to its maximum value which is given as dΦ/dt.



As the magnetic lines of force setup by this electromagnet expand outward from the coil the soft iron core forms a path for and concentrates the magnetic flux. This magnetic flux links the turns of both windings as it increases and decreases in opposite directions under the influence of the AC supply.

However, the strength of the magnetic field induced into the soft iron core depends upon the amount of current and the number of turns in the winding. When current is reduced, the magnetic field strength reduces. When the magnetic lines of flux flow around the core, they pass through the turns of the secondary winding, causing a voltage to be induced into the secondary coil. The amount of voltage induced will be determined by: N*dΦ/dt (Faraday's Law), where N is the number of coil turns. Also this induced voltage has the same frequency as the primary winding voltage.

Then we can see that the same voltage is induced in each coil turn of both windings because the same magnetic flux links the turns of both the windings together. As a result, the total induced voltage in each winding is directly proportional to the number of turns in that winding. However, the peak amplitude of the output voltage available on the secondary winding will be reduced if the magnetic losses of the core are high.

If we want the primary coil to produce a stronger magnetic field to overcome the cores magnetic losses, we can either send a larger current through the coil, or keep the same current flowing, and instead increase the number of coil turns (NP) of the winding. The product of amperes times turns is called the “ampere-turns”, which determines the magnetising force of the coil.

So assuming we have a transformer with a single turn in the primary, and only one turn in the secondary. If one volt is applied to the one turn of the primary coil, assuming no losses, enough current must flow and enough magnetic flux generated to induce one volt in the single turn of the secondary. That is, each winding supports the same number of volts per turn.

As the magnetic flux varies sinusoid ally, $\Phi = \Phi max \sin\omega t$, then the basic relationship between induced emf, (E) in a coil winding of N turns is given by:

emf = turns x rate of change

$$E = N\frac{d\Phi}{dt}$$

$$E = N \times \omega \times \Phi_{max} \times \cos(\omega t)$$

$$E_{max} = N\omega\Phi_{max}$$

$$E_{rms} = \frac{N\omega}{\sqrt{2}} \times \Phi_{max} = \frac{2\pi}{\sqrt{2}} \times f \times N \times \Phi_{max}$$

$$\therefore\ E_{rms} = 4.44 f N \Phi_{max}$$

Where:

f – is the flux frequency in Hertz, = $\omega/2\pi$

N – is the number of coil windings.

Φ – is the amount of flux in Weber’s

This is known as the Transformer EMF Equation. For the primary winding emf, N will be the number of primary turns, (NP) and for the secondary winding emf, N will be the number of secondary turns, (NS).

Also please note that as transformers require an alternating magnetic flux to operate correctly, transformers cannot therefore be used to transform or supply DC voltages or currents, since the magnetic field must be changing to induce a voltage in the secondary winding. In other words, transformers DO NOT operate on steady state DC voltages, only alternating or pulsating voltages.

If a transformers primary winding was connected to a DC supply, the inductive reactance of the winding would be zero as DC has no frequency, so the effective impedance of the winding will therefore be very low and equal only to the resistance of the copper used. Thus the winding will draw a very high current from the DC supply causing it to overheat and eventually burn out, because as we know I = V/R.

Electrical Power in a Transformer

Another one of the transformer basics parameters is its power rating. The power rating of a transformer is obtained by simply multiplying the current by the voltage to obtain a rating in Volt-amperes, (VA). Small single phase transformers may be rated in volt-amperes only, but much larger power transformers are rated in units of Kilo volt-amperes, (kVA) where 1 kilo volt-ampere is equal to 1,000 volt-amperes, and units of Mega volt-amperes, (MVA) where 1 mega volt-ampere is equal to 1 million volt-amperes.

In an ideal transformer (ignoring any losses), the power available in the secondary winding will be the same as the power in the primary winding, they are constant wattage devices and do not change the power only the voltage to current ratio. Thus, in an ideal transformer the Power Ratio is equal to one (unity) as the voltage, V multiplied by the current, I will remain constant. That is the electric power at one voltage/current level on the primary is “transformed” into electric power, at the same frequency, to the same voltage/current level on the secondary side. Although the transformer can step-up (or step-down) voltage, it cannot step-up power. Thus, when a transformer steps-up a voltage, it steps-down the current and vice-versa, so that the output power is always at the same value as the input power. Then we can say that primary power equals secondary power, (PP = PS).

$$Power_{Primary} = Power_{Secondary}$$

$$P_{(PRIM)} = P_{(SEC)} = V_P I_P \cos\theta_P = V_S I_S \cos\theta_S$$

Where: ΦP is the primary phase angle and ΦS is the secondary phase angle.

Note that since power loss is proportional to the square of the current being transmitted, that is: I2R, increasing the voltage, let’s say doubling (×2) the voltage would decrease the current by the same amount, (÷2) while delivering the same amount of power to the load and therefore reducing losses by factor of 4. If the voltage was increased by a factor of 10, the current would decrease by the same factor reducing overall losses by factor of 100.

Transformer Basics – Efficiency

A transformer does not require any moving parts to transfer energy. This means that there is no friction or windage losses associated with other electrical machines. However, transformers do suffer from other types of losses called "copper losses" and "iron losses" but generally these are quite small. Copper losses, also known as I2R loss is the electrical power which is lost in heat as a result of circulating the currents around the transformers copper windings, hence the name. Copper losses represents the greatest loss in the operation of a transformer. The actual watts of power lost can be determined (in each winding) by squaring the amperes and multiplying by the resistance in ohms of the winding (I2R). Iron losses, also known as hysteresis is the lagging of the magnetic molecules within the core, in response to the alternating magnetic flux. This lagging (or out-of-phase) condition is due to the fact that it requires power to reverse magnetic molecules; they do not reverse until the flux has attained sufficient force to reverse them. Their reversal results in friction, and friction produces heat in the core which is a form of power loss. Hysteresis within the transformer can be reduced by making the core from special steel alloys. The intensity of power loss in a transformer determines its efficiency. The efficiency of a transformer is reflected in power (wattage) loss between the primary (input) and secondary (output) windings. Then the resulting efficiency of a transformer is equal to the ratio of the power output of the secondary winding, PS to the power input of the primary winding, PP and is therefore high.

An ideal transformer is 100% efficient because it delivers all the energy it receives. Real transformers on the other hand are not 100% efficient and at full load, the efficiency of a transformer is between 94% to 96% which is quite good. For a transformer operating with a constant voltage and frequency with a very high capacity, the efficiency may be as high as 98%. The efficiency, η of a transformer is given as:

Transformer Efficiency

$$\text{efficiency}, \eta = \frac{\text{Output Power}}{\text{Input Power}} \times 100\%$$

$$= \frac{\text{Input Power} - \text{Losses}}{\text{Input Power}} \times 100\%$$

$$= 1 - \frac{\text{Losses}}{\text{Input Power}} \times 100\%$$

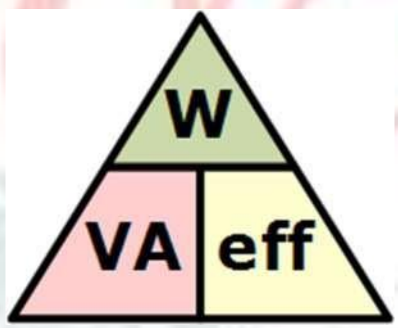
Where: Input, Output and Losses are all expressed in units of power.

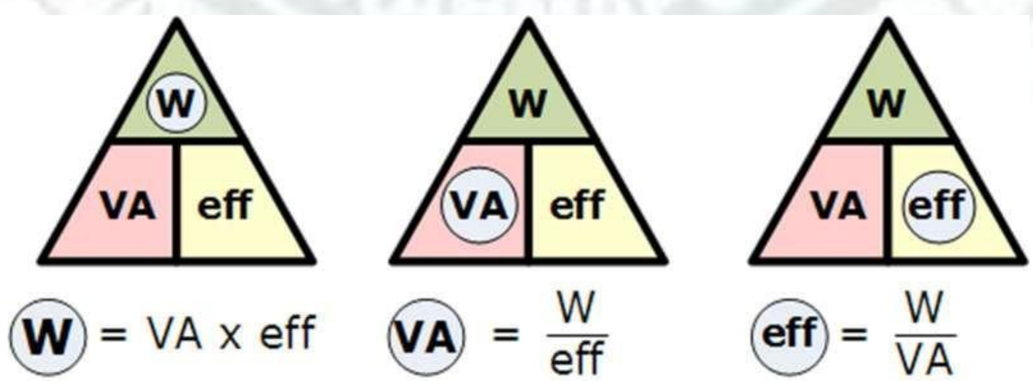
Generally, when dealing with transformers, the primary watts are called “volt-amps”, VA to differentiate them from the secondary watts. Then the efficiency equation above can be modified to:

$$\text{Efficiency}, \eta = \frac{\text{Secondary Watts (Output)}}{\text{Primary VA (Input)}}$$

It is sometimes easier to remember the relationship between the transformers input, output and efficiency by using pictures. Here the three quantities of VA, W and η have been superimposed into a triangle giving power in watts at the top with volt-amps and efficiency at the bottom. This arrangement represents the actual position of each quantity in the efficiency formulas.

Transformer Efficiency Triangle





Applications of Single Phase Transformer

The advantages of three single-phase units are transportation, maintenance, and spare unit availability. The single-phase transformers are widely used in commercial low voltage application as electronic devices. They operate as a step-down voltage transformer and decrease the home voltage value to the value suitable for electronics supplying. On the secondary side, rectifier is usually connected to convert a AC voltage to the DC voltage which is used in electronics application.

Numerical

The parameters of a 2300/230 V, 50Hz transformer are given below:

$R_1 = 0.286\,\Omega$ $R_2' = 0.319\,\Omega$ $X_1 = 0.73\,\Omega$

$X_2' = 0.73\,\Omega$ $R_c = 250\,\Omega$ $X_m = 1250\,\Omega$

The secondary is connected to two parallel loads, the first is 40 kVA at 0.85 p.f lagging and the second is 70 kW at 0.9 p.f lagging. Draw the exact equivalent circuit refereed to the H. V side assuming rated voltage across the secondary (L.V side) and then use it to find:

1. Primary voltage
2. Input power factor
3. Power input.
4. Total power output
5. Primary copper loss
6. Secondary copper loss
7. Core loss

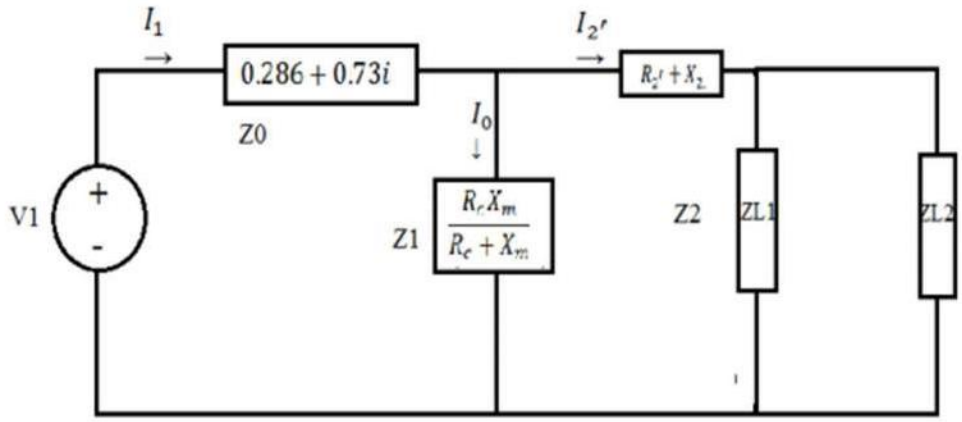
Solution

Since V_2 is rated Voltage, then;

$$V_2 = 230V$$

$$V_{2'} = aV_2 = 2300V$$

2parallel Loads $Z_{L1} \& Z_{L2}$



$$\cos^{-1}(0.85)lag = -31.78$$

$$\cos^{-1}(0.9)lag = -25.84$$

$$|I_{L1'}| = \frac{S_{L1}}{V_2'} = \frac{40k\llcorner -31.78}{2300} = 17.3\llcorner -31.78\,A = 14.7 - 9.11i\,A$$

$$|I_{L2'}| = \frac{P_{L2}}{V_2' p.f} = \frac{70k\llcorner -25.84}{2300\;0.9} = 33.84\llcorner -25.84\,A = 30.45 - 14.75i\,A$$

$$I_{2'} = I_{L1'} + I_{L2'} = 51\llcorner -27.95\,A = 45.05 - 23.9i\,A$$

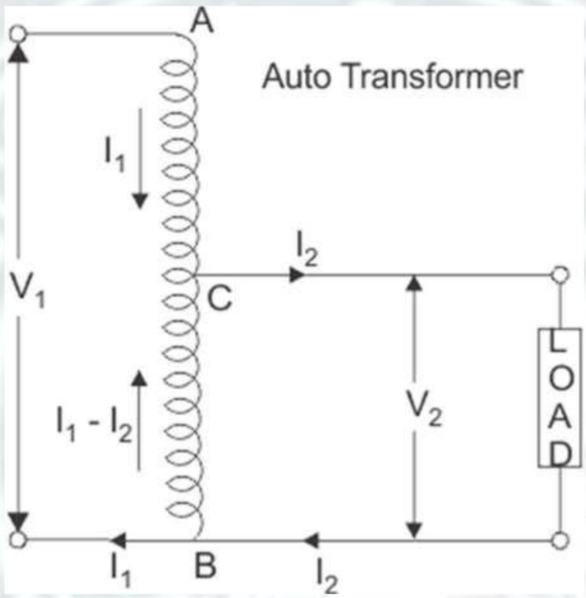
$$E = V_{2'} + I_{2'}(R_{2'} + X_{2'}) = 2332\llcorner -0.62^{\circ} = 2331.86 - 25.23i\,V$$

AUTO TRANSFORMER

An **autotransformer** is a kind of electrical transformer where primary and secondary shares same common single winding. So basically it's a one winding transformer.

Autotransformer Theory

In an auto transformer, one single winding is used as primary winding as well as secondary winding. But in two windings transformer two different windings are used for primary and secondary purpose. A circuit diagram of auto transformer is shown below.



The winding AB of total turns N_1 is considered as primary winding. This winding is tapped from point ′C′ and the portion BC is considered as secondary. Let's assume the number of turns in between points ′B′ and ′C′ is N_2.

If V_1 voltage is applied across the winding i.e. in between ′A′ and ′C′.

$$\textit{So voltage per turn in this winding is } \frac{V_1}{N_1}$$

Hence, the voltage across the portion BC of the winding, will be,

$$\frac{V_1}{N_1} X N_2 \textit{ and from the figure above, this voltage is } V_2$$

$$Hence,\ \frac{V_1}{N_1} X N_2 = V_2$$

$$\Rightarrow \frac{V_2}{V_1} = \frac{N_2}{N_1} = Constant = K$$

As BC portion of the winding is considered as secondary, it can easily be understood that value of constant 'k' is nothing but turns ratio or voltage ratio of that **auto transformer**. When load is connected between secondary terminals i.e.between 'B' and 'C', load current I_2 starts flowing. The current in the secondary winding or common winding is the difference of I_2 and I_1.

Copper Savings in Auto Transformer

Now we will discuss the savings of copper in auto transformer compared to conventional two winding transformer.
We know that weight of copper of any winding depends upon its length and cross-sectional area. Again length of conductor in winding is proportional to its number of turns and cross-sectional area varies with rated current.
So weight of copper in winding is directly proportional to product of number of turns and rated current of the winding.

Therefore, weight of copper in the section AC proportional to,

$$(N_1 - N_2)I_1$$

and similarly, weight of copper in the section BC proportional to,

$$N_2(I_2 - I_1)$$

Hence, total weight of copper in the winding of auto transformer proportional to,

$$(N_1 - N_2)I_1 + N_2(I_2 - I_1)$$

$$\Rightarrow N_1I_1 - N_2I_1 + N_2I_2 - N_2I_1$$

$$\Rightarrow N_1I_1 + N_2I_2 - 2N_2I_1$$

$$\Rightarrow 2N_1I_1 - 2N_2I_1 (Since,\ N_1I_1 = N_2I_2)$$

$$\Rightarrow 2(N_1I_1 - N_2I_1)$$

In similar way it can be proved, the weight of copper in two winding transformer is proportional to,

$$N_1I_1 - N_2I_2$$

$$\Rightarrow 2N_1I_1 \qquad (Since,\ in\ a\ transformer\ N_1I_1 = N_2I_2)$$

$N_1I_1 + N_2I_2$

$\Rightarrow 2N_1I_1$ (Since, in a transformer $N_1I_1 = N_2I_2$)

Let's assume, W_a and W_{tw} are weight of copper in auto transformer and two winding transformer respectively,

$$Hence, \frac{W_a}{W_{tw}} = \frac{2(N_1I_1 - N_2I_1)}{2(N_1I_1)}$$

$$= \frac{N_1I_1 - N_2I_1}{N_1I_1} = 1 - \frac{N_2I_1}{N_1I_1}$$

$$= 1 - \frac{N_2}{N_1} = 1 - k$$

$$\therefore W_a = W_{tw}(1-k)$$

$$\Rightarrow W_a = W_{tw} - kW_{tw}$$

∴ Saving of copper in auto transformer compared to two winding transformer,

$$\Rightarrow W_{tw} - W_a = kW_{tw}$$

Auto transformer employs only single winding per phase as against two distinctly separate windings in a conventional transformer.

Advantages of using Auto Transformers

1. For transformation ratio = 2, the size of the **auto transformer** would be approximately 50% of the corresponding size of two winding transformer. For transformation ratio say 20 however the size would be 95 %. The saving in cost of the material is of course not in the same proportion. The saving of cost is appreciable when the ratio of transformer is low, that is lower than 2. Thus auto transformer is smaller in size and cheaper.

2. An auto transformer has higher efficiency than two winding transformer. This is because of less ohmic loss and core loss due to reduction of transformer material.
3. Auto transformer has better voltage regulation as voltage drop in resistance and reactance of the single winding is less.

Disadvantages of Using Auto Transformer

1. Because of electrical conductivity of the primary and secondary windings the lower voltage circuit is liable to be impressed upon by higher voltage. To avoid breakdown in the lower voltage circuit, it becomes necessary to design the low voltage circuit to withstand higher voltage.
2. The leakage flux between the primary and secondary windings is small and hence the impedance is low. This results into severer short circuit currents under fault conditions.
3. The connections on primary and secondary sides have necessarily needs to be same, except when using interconnected starring connections. This introduces complications due to changing primary and secondary phase angle particularly in the case of delta/delta connection.
4. Because of common neutral in a star/star connected auto transformer it is not possible to earth neutral of one side only. Both their sides should have their neutrality either earth or isolated.
5. It is more difficult to maintain the electromagnetic balance of the winding when voltage adjustment tappings are provided. It should be known that the provision of tapping on an auto transformer increases considerably the frame size of the transformer. If the range of tapping is very large, the advantages gained in initial cost is lost to a great event.

Applications of Auto Transformers

1. Compensating voltage drops by boosting supply voltage in distribution systems.
2. Auto transformers with a number of tapping are used for starting induction and synchronous motors.
3. **Auto transformer** is used as variac in laboratory or where continuous variable over broad ranges are required.

INSTRUMENT TRANSFORMER

Instrument Transformers are used in AC system for measurement of electrical quantities i.e. voltage, current, power, energy, power factor, frequency. **Instrument transformers** are also used with protective relays for protection of power system.

Basic function of **Instrument transformers** is to step down the AC System voltage and current. The voltage and current level of power system is very high. It is very difficult and costly to design the measuring instruments for measurement of such high level voltage and current. Generally measuring instruments are designed for 5 A and 110 V.

The measurement of such very large electrical quantities, can be made possible by using the Instrument transformers with these small rating measuring instruments. Therefore these instrument transformers are very popular in modern power system.

Advantages of Instrument Transformers

1. The large voltage and current of AC Power system can be measured by using small rating measuring instrument i.e. 5 A, 110 – 120 V.
2. By using the instrument transformers, measuring instruments can be standardized. Which results in reduction of cost of measuring instruments. More ever the damaged measuring instruments can be replaced easy with healthy standardized measuring instruments.
3. Instrument transformers provide electrical isolation between high voltage power circuit and measuring instruments. Which reduces the electrical

Insulation requirement for measuring instruments and protective circuits and also assures the safety of operators.

4. Several measuring instruments can be connected through a single transformer to power system.

5. Due to low voltage and current level in measuring and protective circuit, there is low power consumption in measuring and protective circuits.

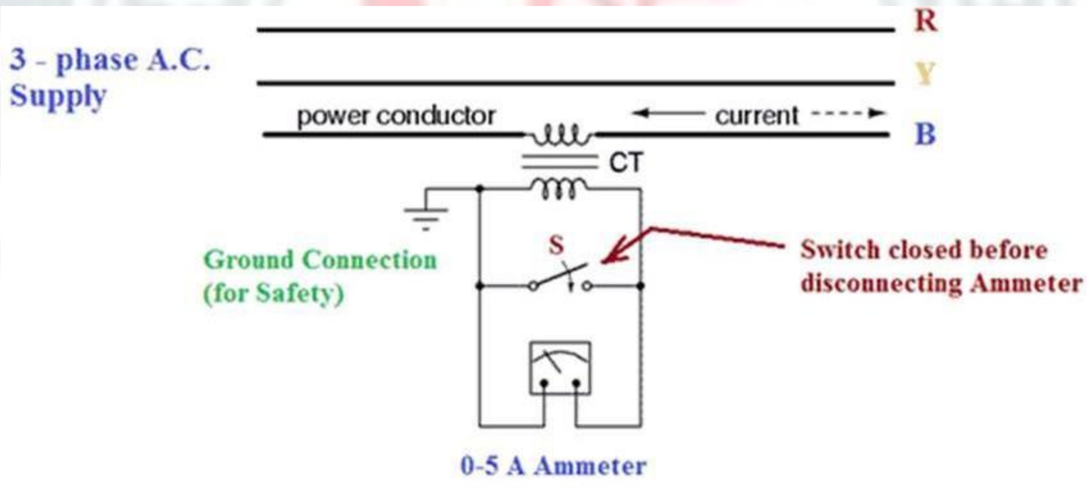
Types of Instrument Transformers

Instrument transformers are of two types –

1. Current Transformer (C.T.)
2. Potential Transformer (P.T.)

Current Transformer (C.T.)

Current transformer is used to step down the current of power system to a lower level to make it feasible to be measured by small rating Ammeter (i.e. 5A ammeter). A typical connection diagram of a current transformer is shown in figure below.

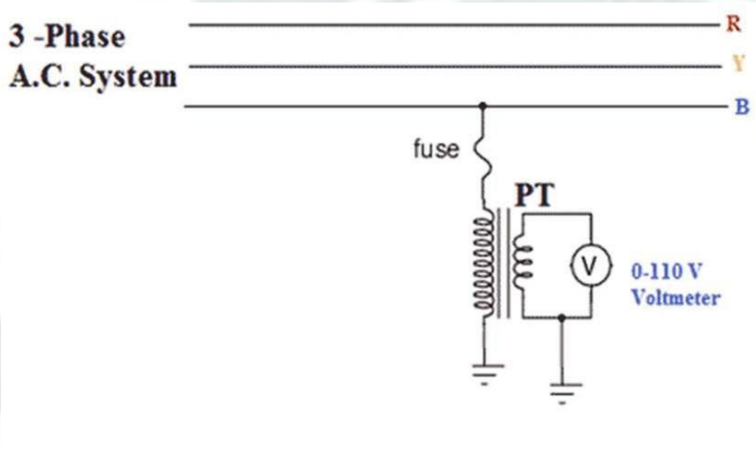


Current Transformer (C.T.)

Primary of C.T. is having very few turns. Sometimes bar primary is also used. Primary is connected in series with the power circuit. Therefore, sometimes it also called **series transformer**. The secondary is having large no. of turns. Secondary is connected directly to an ammeter. As the ammeter is having very small resistance. Hence, the secondary of current transformer operates almost in short circuited condition. One terminal of secondary is earthed to avoid the large voltage on secondary with respect to earth. Which in turns reduce the chances of insulation breakdown and also protect the operator against high voltage. More ever before disconnecting the ammeter, secondary is short circuited through a switch 'S' as shown in figure above to avoid the high voltage build up across the secondary.

Potential Transformer (P.T.)

Potential transformer is used to step down the voltage of power system to a lower level to make is feasible to be measured by small rating voltmeter i.e. 110 – 120 V voltmeter. A typical connection diagram of a potential transformer is showing figure below.



Potential Transformer (P.T.)

Primary of P.T. is having large no. of turns. Primary is connected across the line (generally between on line and earth). Hence, sometimes it is also called the **parallel transformer**. Secondary of P.T. is having few turns and connected directly to a voltmeter. As the voltmeter is having large resistance. Hence the secondary of a P.T. operates almost in open circuited condition. One terminal of secondary of P.T. is earthed to maintain the secondary voltage with respect to earth. Which assures the safety of operators.