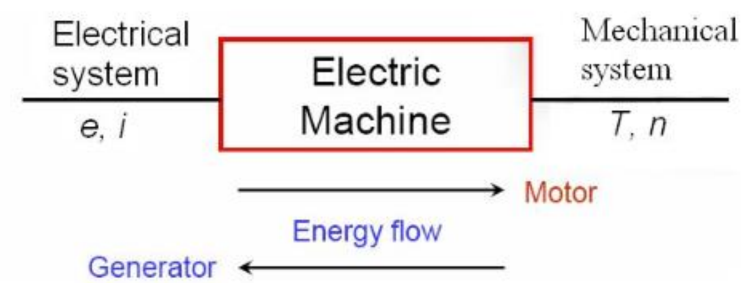
Introduction to electrical machines, classification of electrical machines, construction of rotating machine

An electrical machine is a device that converts electrical energy into mechanical energy and vice versa, as shown in the figure below:



That means:

1. The electrical machine is a link between an electrical system and a mechanical system.
2. Conversion from mechanical to electrical (generator).
3. Conversion from electrical to mechanical (motor).

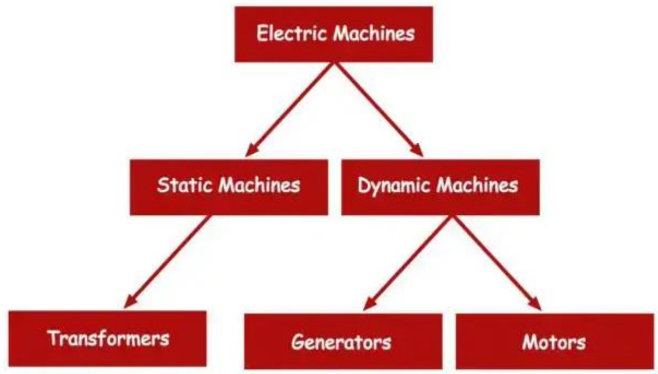
Types of Electrical Machines

Electric machines are of three main types: transformers, generators, and motors.

Electrical Transformer: In the transformer, both input and output are electrical power.

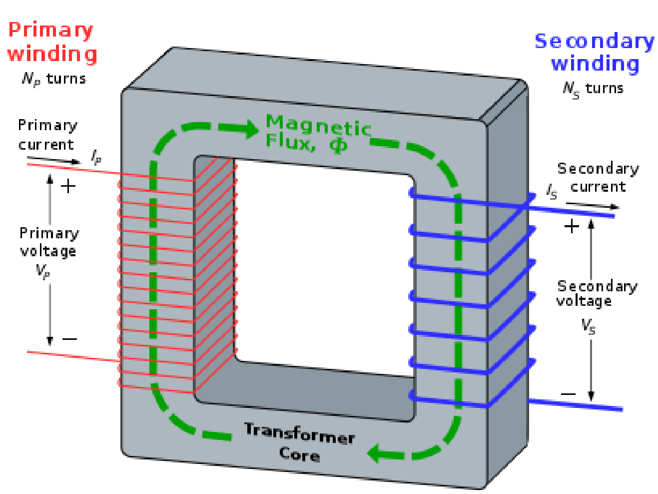
Electrical Generator: In a generator, the input is mechanical power and the output is electrical power.

Electrical Motor: In a motor, the input is electrical power and the output is mechanical power.

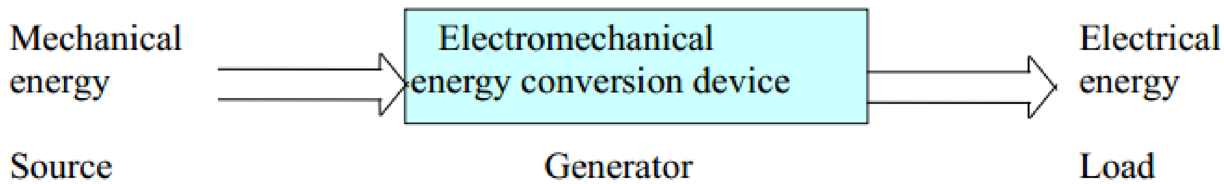


Transformer: Transformer works on the principle of mutual induction. There is an iron core that links the windings of the transformer. The flux in the core links both primary and secondary windings, due to which voltage is induced in the windings. The working principle of a transformer can be described as follows: The alternating voltage is applied to the primary winding, due to which magnetizing current flows through the primary winding, and as a result, magnetizing flux is produced and concentrated in the closed low-reluctance magnetic core path. This flux links with both primary and secondary winding. Voltage is self-induced in the primary winding and mutually induced in the secondary winding. The induced voltage per turn in both primary and secondary windings is the same. The voltage across the windings depends on the number of turns in the winding.

Depending on the voltage level, there are two types of transformers: step-up transformers and step-down transformers. Step-up transformers are for increasing the voltage level of electricity. Step-down transformers are for decreasing the voltage level of electricity.



Generator: The input is mechanical energy (from the prime mover), and the output is electrical energy. An electrical generator is a device that converts mechanical energy into electrical energy. The working principle of a generator is that when a conductor rotates in a magnetic field, an emf (electromotive force) is induced in the conductor. A generator forces electrons to flow through an external circuit. There are two main parts of a generator: the rotor and the stator. In a generator, mechanical energy is applied to the rotor. The rotor is connected to a prime mover, which is coupled to a turbine. The other sources of mechanical energy are internal combustion engines, wind turbines, compressed air, and hand cranks.



Electrical machine can be divided into: DC machines and AC machines according to the

1. Type of supply
2. According to their operation any type can be either motor or generator
3. In DC machines according to the connection of the field coils and armature coils can be subdivided into: separate excited, shunt, series, compound (cumulative or differential)

AC Generator: An AC generator is a device that converts mechanical energy into AC electricity. The AC generator is further divided into

A. Induction Generator B. Synchronous Generator

DC generator: A DC generator is a device that converts mechanical energy into DC.

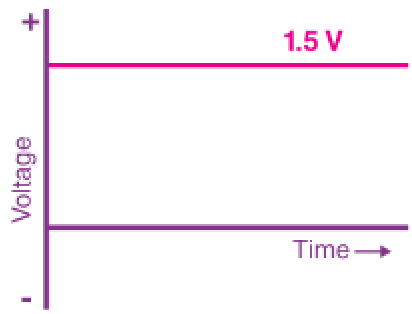
Motor: The input is electrical energy (from the supply source), and the output is mechanical energy (from the load). A motor is an apparatus that converts electrical energy into mechanical energy. The working principle of a motor is that when a current-carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force. There are two basic or main parts of a motor: the rotor and stator, which are the same as the generator. When an electrical voltage supply is given to the stator, the conductor experiences a force. Due to this force, the object starts to rotate.

There are two types of motor
1. DC Motor: An DC motor is a device that converts the direct current into mechanical energy.

2. AC Motor: An AC motor is a device that converts the alternating current into mechanical energy.

There are two types of electrical current: DC (direct current) and AC (alternating current).

The DC supply has a constant voltage with zero frequency independent of time, as shown by a straight line, and the value of the current is I=V/R (ampere), where R is the resistance of the circuit in ohms.



The AC source has a voltage that changes with time at a certain frequency, for example, $V=V_m$. Sin wt, where V represents the instantaneous value of the voltage, V_m represents the maximum or peak voltage, and the shape of the voltage is represented as shown in the figure below, wt angular frequency (w=2 πf rad / sec) , f= w/2π) , T=1/f (second: the time for one cycle).

When dealing with ac voltage (sinusoidal) in circuit analysis, we deal with the effective voltage value (V_{eff} = Vrms), which is also called the root mean square value (Vrms).

Vrms= Vm/√2 volt

The RMS value can be found according to the equation:

$\text{RMS}=\sqrt{1}/\text{T} \int_0^T f(t)dt$

The average value=$1/\text{T}\int_0^T f(t)dt$

The average value for one complete cycle =0

The average value for half a sinusoidal wave=2Vm/ π

The period (T) in second =1/f = 2 π/w, and it's equivalent to (360^o) or 2 π radiant. The wave can be written as V=Vm sinθ, and θ changes from 0 to 360^o or from 0 to 2 π radiant. For any value of θ, the V has a magnitude-changing value of Vm ≥V≥ -Vm, and this value is called the instantaneous value of the voltage. In general, for ac circuit V, I have a phase shift between them, for example.

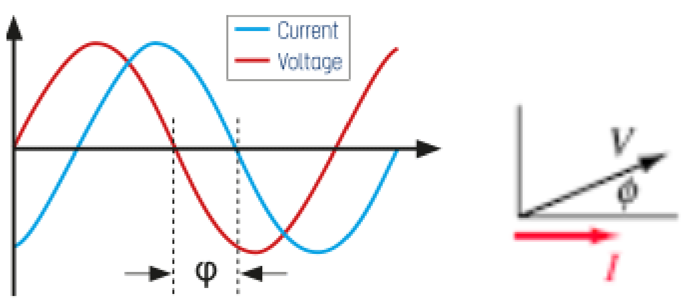
V=Vm sin wt   I=Im sin(wt+30)   in this circuit the I leads V by 30^o

V=Vm sin wt   I=Im sin(wt-40)   in this circuit the I lags V by 40^o

For dc circuits the power P=I*V with unit watt(W) and in ac circuits power value will give the volt-ampere value of the circuit (VA) (KVA or MVA)

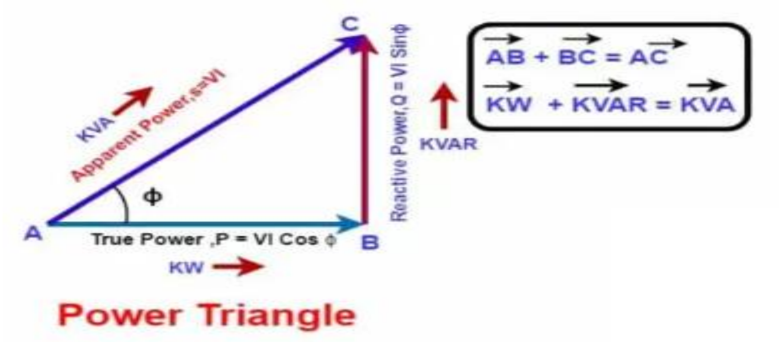
KVA=V*I/1000 =VA*10^{-3} MVA=V*I/1000000 = VA*10^{-6}

The power in ac=VA*cosθ where θ represent the angle between V and I cosθ is called power factor(pf) where, 1 ≥p.f ≥-1   and 90 ≥θ ≥-90

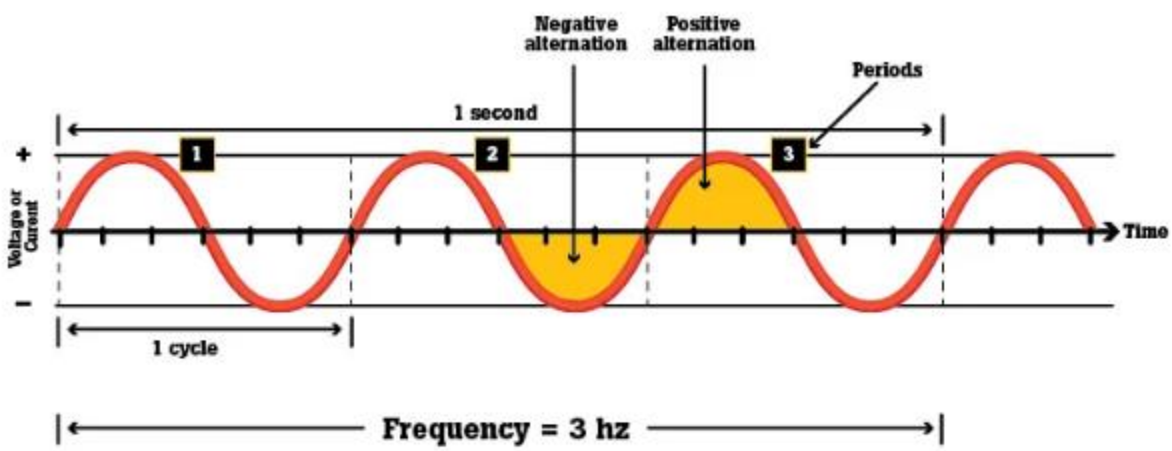


Power factor (PF) is the ratio of working power (active power), measured in kilowatts (kW), to apparent power, measured in kilovolt amperes (kVA).

(Real or working power is the one which converts the electrical energy into other forms of energy. Apparent power provides the total power i.e. active power as well as reactive power in the circuit)



The time of one cycle (T) is called the period (Sec). Alternating current (ac) frequency is the number of cycles per second in an ac sine wave. Frequency is the rate at which current changes direction per second. It is measured in hertz (Hz), an international unit of measure where 1 hertz is equal to 1 cycle per second. **Example:** If an alternating current is said to have a frequency of 3 Hz (see diagram below), that indicates its waveform repeats 3 times in 1 second.



Sometimes within a country; most electric power is generated at either 50 or 60 Hertz. Some countries have a mixture of 50 Hz and 60 Hz supplies, notably electricity power transmission in Japan.

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The RMS value can be found according to the equation:

RMS=$\sqrt{1}/T \int_0^T f(t)dt$ The average value=1/T$\int_0^T f(t)dt$

The average value for one complete cycle =0

The average value for half a sinusoidal wave=2Vm/ π

Different between AC&DC supply

DC Circuit	**AC Circuit**
Current flows in one direction in a DC circuit	Current flows in alternating directions in an AC circuit.
DC voltage and power supply cannot travel very far as it loses the energy frequently	It is considered safer for transfer of electricity over longer distances to provide more power
Electrons move in one direction, steadily	Electrons continuously switches the direction flow between backward and forward movement
Batteries or cells are used in DC circuit as a power supply	AC generators are used as a power source in AC circuit
Frequency of current in a DC circuit remains zero	Frequency of current varies from 50-60 Hz according to the country

construction of rotating machine:

All rotating AC electrical machines consist of two windings, one placed on the stator part and another on the rotor part. The winding of the machine in which voltage is induced is known as the armature winding. The winding that is used to produce the main working magnetic flux in the machine is known as the field winding. There is an air gap separating the stator and rotor. The stator is the stationary (non-movable) part of the electrical machine. In general, the stator is the outer frame of the machine. The rotor is the rotating (movable) part of the machine. Both the stator and rotor are constructed by using laminated ferromagnetic materials to reduce the reluctance in the path of magnetic flux.

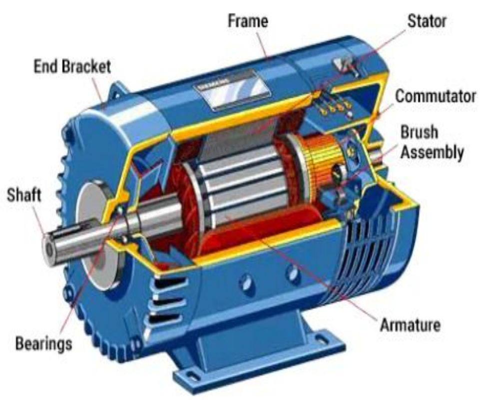
DC machine construction

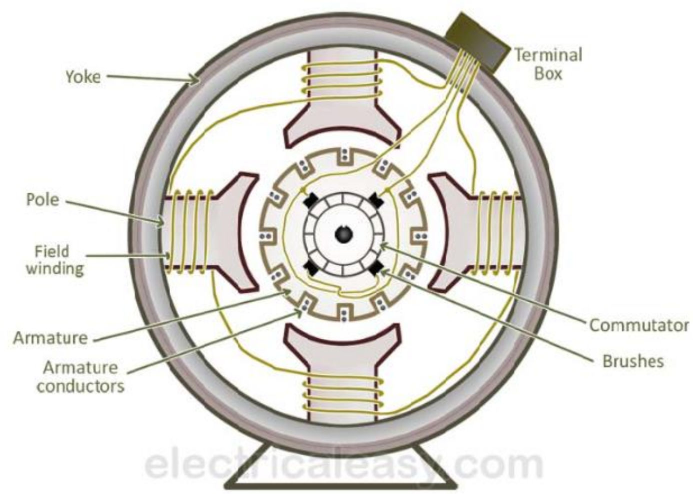
Theoretically, a DC generator can be used as a DC motor without any constructional changes, and vice versa is also possible. Therefore, a DC generator or a DC motor can be broadly termed a DC machine. These basic construction details are also valid for both the DC generator and the DC motor. The DC machine has the main two parts the stationary part which is called stator and mainly use for producing the required flux per pole and the rotary part which is called the armature and hold the winding. In additional to that a commutator with brushes are used to take the induced emf in the rotating part to the outside (generator) or to feed dc current to that winding in the case of motor. The commutator is necessary to make a dc voltage with fixed polarity positive and negative when the winding rotate round the magnetic field.

Basic constructional parts of a DC machine are described below:

1. **Yoke:** The outer frame of a dc machine is called as yoke. It is made up of cast iron or steel. It not only provides mechanical strength to the whole assembly but also carries the magnetic flux produced by the field winding.
2. **Poles and pole shoes:** Poles are joined to the yoke with the help of bolts or welding. They carry field winding and pole shoes are fastened to them. Pole shoes serve two purposes; (i) they support field coils and (ii) spread out the flux in air gap uniformly.
3. **Field winding:** They are usually made of copper. Field coils are former wound and placed on each pole and are connected in series. They are wound in such a way that, when energized, they form alternate North and South poles
4. **Armature core:** Armature core is the rotor of a dc machine. It is cylindrical in shape with slots to carry armature winding. The armature is built up of thin laminated circular steel disks for reducing eddy current losses. It may be provided with air ducts for the axial air flow for cooling purposes. Armature is keyed (fixed) to the shaft.
5. **Armature winding:** It is usually a former wound copper coil which rests in armature slots. The armature conductors are insulated from each other and also from the armature core. Armature winding can be wound by one of the two methods; lap winding or wave winding. Double layer lap or wave windings are generally used. A double layer winding means that each armature slot will carry two different coils.

6. **Commutator and brushes:** Physical connection to the armature winding is made through a commutator-brush arrangement. The function of a commutator, in a dc generator, is to collect the current generated in armature conductors. Whereas, in case of a dc motor, commutator helps in providing current to the armature conductors. A commutator consists of a set of copper segments which are insulated from each other. The number of segments is equal to the number of armature coils. Each segment is connected to an armature coil and the commutator is keyed (or fixed) to the shaft. Brushes are usually made from carbon or graphite. They rest on commutator segments and slide on the segments when the commutator rotates keeping the physical contact to collect or supply the current.





EMF (electromotive force) equation, torque equation and speed equation of DC machine

The main relationship for the induced emf in a number of turns cutting a magnetic flux is given by faraday's law: $e = -N\frac{d\emptyset}{dt}$ where Φ is the magnetic flux, N is the number of turns, and $\frac{d\emptyset}{dt}$ is the rate at which the flux cutting the conductors of the turns.

The voltage induced in each active conductor is : $e_c = K_f B_g LV \quad volt$

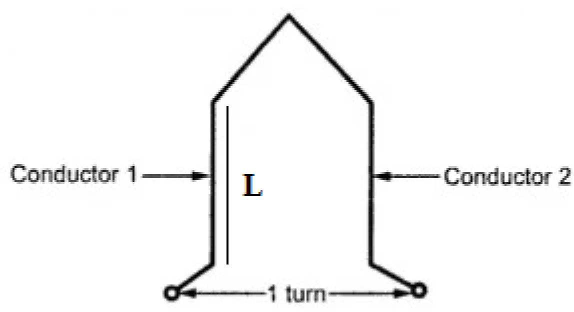
Where: K_f field form factor = $\frac{B\ ave}{B\ g}$ B $_{ave}$: average flux density over a pole pitch

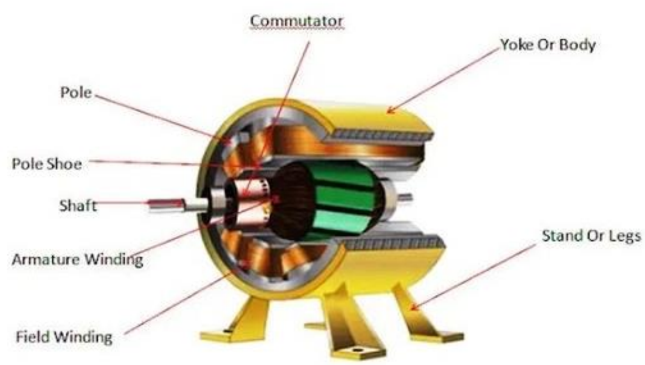
B_g the air gap flux density = $\frac{\emptyset}{A}$ (weber/m^2) = Tesla (used to measure the strength of magnetic fields)

L= effective length of the conductor (meter)

V= surface speed of the conductor (m/s) and $V = wr$ where w is angular speed(rad/sec) and r is radius of armature (m)

$W = \frac{n}{60} 2\pi$ where n= rotational speed in (rev/min)





$e_c = B_{ave} \times L \times V$ volt in one conductor or e_c can be given as total flux cut per second

$e_c = flux\ per\ pole \times number\ of\ poles \times rev/\sec = 2P \times \emptyset \times n$

P= No. of pole pairs θ= flux per pole weber n= speed RPM/60

For Zc connected in series

Total voltage induced= $Z_c\ e_c = Z_c \times 2P\emptyset n\ volt = K_f\, Z_c\, B_g\, LV$

$Z_c = No\ of\ conductor\ per\ path$ $Z_c = \frac{Z_t}{a}$ where Z_t = total number of conductors per armature a= number of parallel paths

For wave wound armature, a=2

For lap wound armature, a= number of poles

For example 6 poles dc machine, when the winding is wave wound it will be equivalent to the given circuit each path has N/2 turns= total armature conductors/2 per path

For lap wound armature the circuit will be equivalent to each path has N/6 turns or total armature conductors/6

Types of DC generators:

Dc generators can be also subdivided into:

1. **Separate excited DC generator**

A *separately excited DC generator* is one whose field winding is supplied by an independent external DC source (like a battery). The magnitude of the generated voltage depends upon the speed of rotation of the armature and the field current, i.e., the greater the speed and the field current, the higher the generated voltage. In practice, the separately excited DC generators are rarely used. The field winding is connected to external supply V_f volt and it's has an internal resistance r_f, a field regulator R_f is connected in series with field winding. By changing the value of Rf, the field current can be changed hence θ can be change. The generator is driven by prime mover at angular speed W(rad/sec).

$I_f = \frac{V f}{rf+Rf}$ Ampere

Due to saturation effect the relationship between I_f and θ is not linear.

The induced emf = $V_{o.c}$

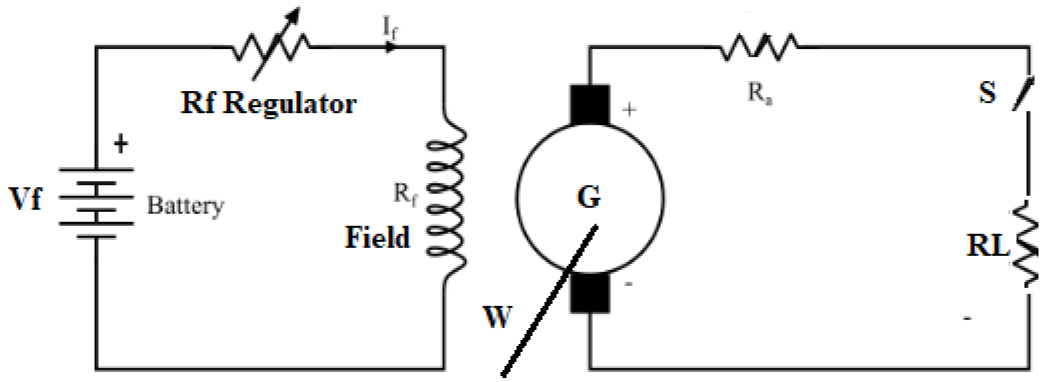
$V_{o.c=}\ Zc\times 2P\emptyset n$ where Zc= $\frac{Z\ t}{a}$ = number of conductor per path

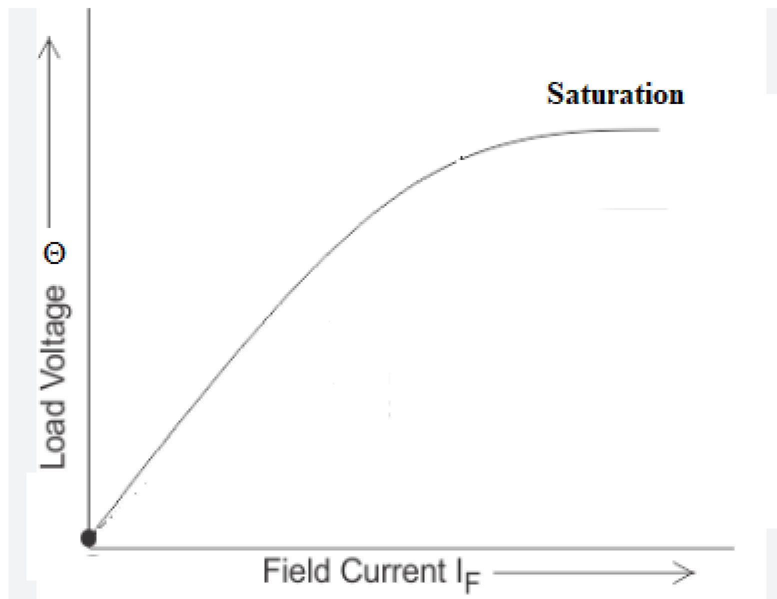
P= number of pole pairs, Θ= average flux per pole, n= rotational speed RPM

This voltage appears at the armature terminal when switch S is opened.

When S closed, armature current will pass: $I_a = \frac{V\ o.c}{RL+ra}$

R_L will be VL= $V\ o.c$ - $I_a\ ra$ ra is the internal resistance of the armature.





2. **Self-excited DC generators**

A d.c. generator whose field magnet winding supplies current from the output of the generator itself is called a self-excited generator. There are three types of self-excited generators depending upon the manner in which the field winding is connected to the armature, namely:

(i) Shunt generator;

(ii) Series generator;

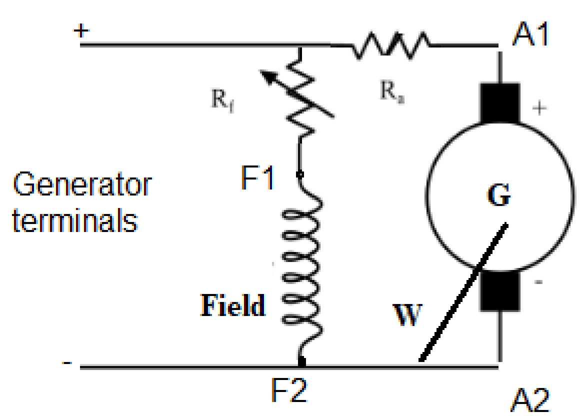
(iii) Compound generator

(i) Shunt DC generator

In this type of generator, no need to external voltage to supply the field winding. The field winding is connected in parallel with the armature, as show in figure.

When the armature is rotated by a prime mover at speed(n) the generator will built up its voltage if:

a. Present of residual magnetize.
b. The correct polarity of connection between the field and armature.
c. The total resistance of the field windings is less than the critical value at the given speed (n).
d. The speed of rotation is higher than the critical speed at given field resistance value.



Shunt field current, $I_{sh} = V/R_{sh}$

Armature current, Ia = IL + I_{sh} where I_L is load current

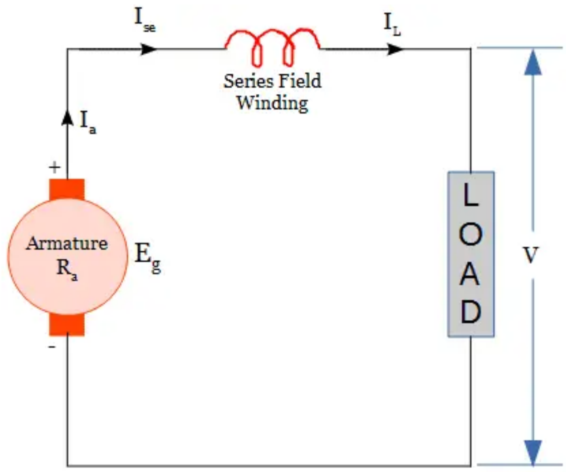
e.m.f generated, $E_g = V + I_aR_a$ where V= terminal voltage

Power developed in armature = E_gI_a

Power delivered to load = VI_L

(ii) Series DC generator

In a series-wound generator, the field winding is connected in series with the armature winding, so the whole armature current flows through the field winding as well as the load. The figure below shows the connections of a series wound generator. Since the field winding carries the whole load current, it has a few turns of thick wire with low resistance. Series generators are rarely used except for special purposes, e.g., as boosters.



Armature current, $I_a = I_{se} = I_L = I$

e.m.f generated, $E_g = V+I\ (R_a + R_{se})$

Power developed in armature = E_gI_a

Power delivered to load = VI or VI_L

(iii) Compound generator

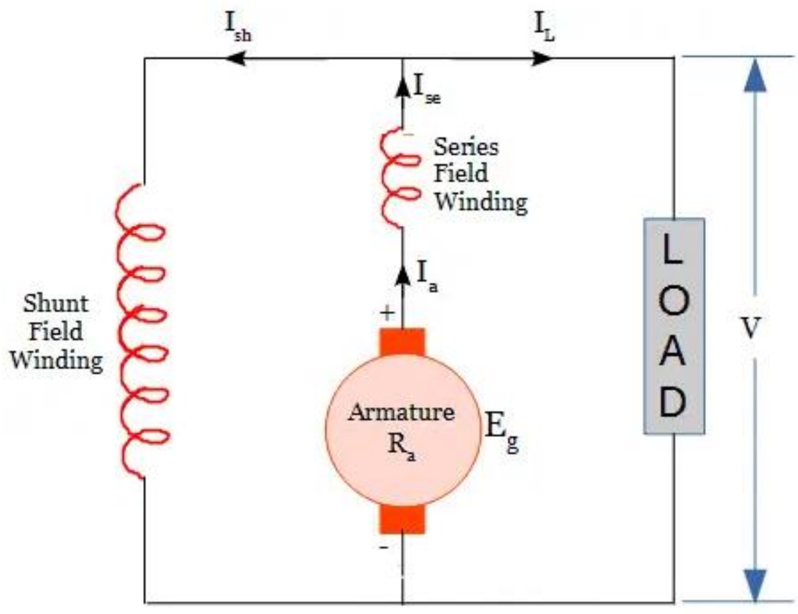
In a compound-wound generator, there are two sets of field windings on each pole-one in series and the other in parallel with the armature. A compound wound generator may be:

(a) Short Shunt, in which only the shunt field winding is in parallel with the armature winding

(b) Long Shunt, in which the shunt field winding is in parallel with both series field and armature winding.

Long shunt Compound wound generator

The below figure shows the circuit diagram of a long shunt compound wound generator. In this, the shunt field winding is connected in parallel with a combination of series winding and armature conductors.



In the above circuit diagram,

I_{sh} – Shunt field current, I_{se} – Shunt field current, I_a – Armature current, I_L – Load current, R_a – Armature resistance, V – terminal voltage, V_{br} – Brush contact drop

Armature current is given by, $I_a = I_{se} = I_L + I_{sh}$

Shunt field current $I_{sh} = V/R_{sh}$, Where R_{sh} – shunt field resistance

Terminal voltage equation is given by, $V = E_g – I_a R_a – I_a R_{se} – V_{br}$

Series field current, $I_{se} = I_a = IL + I_{sh}$

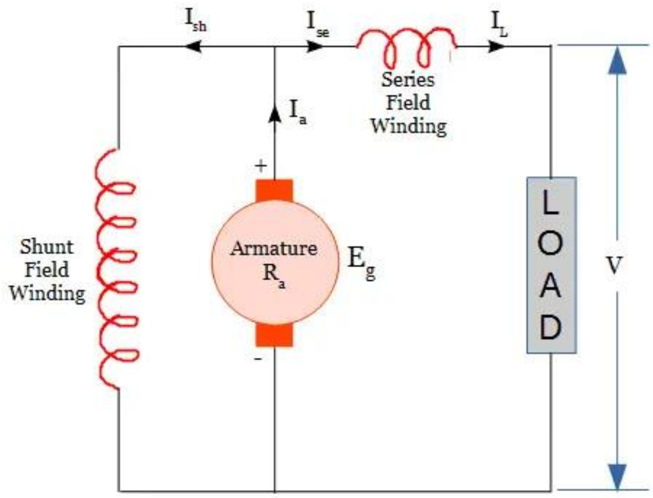
e.m.f generated, $E_g = V + I_a(R_a + R_{se})$

Power developed in armature = $E_g I_a$

Power delivered to load = $V I_L$

Short shunt Compound wound generator

In short shunt DC compound generator, the shunt field winding is connected across the armature conductors and this combination is connected in series with a series field winding. The following figure shows the circuit diagram of short shunt compound generator.



In the above circuit diagram,

I_{sh} – Shunt field current, I_{se} – Series field current, I_a – Armature current, I_L – Load current,

R_a – Armature resistance, V – terminal voltage, V_{br} – Brush contact drop

Series field current, Ise = IL

e.m.f generated, Eg = V+ IaRa + IseRse

Armature current is given by, $I_a = I_L + I_{sh}$ where $I_L = I_{se}$

Terminal voltage equation is given by, $V = E_g – I_a R_a – I_{se} R_{se} – V_{br}$

Voltage drop across shunt field winding = $I_{sh} R_{sh}$

Shunt field current $I_{sh} = (E_g – I_a R_a – V_{br})/R_{sh}$, Where R_{sh} – shunt field resistance

By substituting the value of E_g in the above equation, we get shunt field current $I_{sh} = (V + I_{se} R_{se})/R_{sh}$

Power developed in the DC generator = $E_g I_a$

Power delivered to load = VI_L

Ex1: 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: Shunt current Ish = 230 50 = 4.6

Armature current Ia = I + Ish = 450 + 4.6 = 454.6

Armature voltage drop IaRa = 454.6 × 0.03 = 13.6 V

Eg = terminal voltage + armature drop = V + IaRa = 230 + 13.6 = 243.6 V

Ex2/long-shunt compound generator delivers a load current of 50 A at 500 V and has armature, series field and shunt field resistances of 0.05 Ω, 0.03 Ω and 250 Ω respectively. Calculate the generated voltage and the armature current. Allow 1 V per brush for contact drop.

Solution:

Ish = 500/ 250 = 2 A

Current through armature and series winding is = 50 + 2 = 52 A

Voltage drop on series field winding = 52 × 0.03 = 1.56 V

Armature voltage drop $IaRa$ = 52 × 0.05 = 2.6 V

Drop at brushes = 2 × 1 = 2 V

Now, Eg = V + IaRa + series drop + brush drop = 500 + 2.6 + 1.56 + 2 = 506.16 V

Ex3: A short-shunt compound generator delivers a load current of 30 A at 220 V, and has armature, series-field and shunt-field resistances of0.05 Ω, 0.30 Ω and 200 Ω respectively. Calculate the induced e.m.f. and the armature current. Allow 1.0 V per brush for contact drop.

Solution: drop in series winding = 30 × 0.3 = 9 V

Voltage across shunt winding = 220 + 9 = 229 V

Ish = 229/200 = 1.145 A

Ia = 30 + 1.145 = 31.145 A

IaRa = 31.145× 0.05 = 1.56 V

Brush drop = 2×1 = 2 V

Eg = V + series drop + brush drop + IaRa = 220 + 9 + 2 + 1.56 = 232.56 V

Ex4: In a long-shunt compound generator, the terminal voltage is 230 V when generator delivers 150 A. Determine (i) induced e.m.f. (ii) total power generated and, given that shunt field, series field, divertor and armature resistance are 92 Ω, 0.015 Ω, 0.03 Ω and 0.032 Ω respectively. Solution:

I_{sh} = 230/92 = 2.5 A

I_a = 150 + 2.5 = 152.5 A

Since series field resistance and diverter resistances are in parallel (their combined resistance is = 0.03 × 0.015/0.045 = 0.01 Ω

Total armature circuit resistance is = 0.032 + 0.01 = 0.042 Ω

Voltage drop = 152.5 × 0.042 = 6.4 V

(**i**) Voltage generated by armature Eg = 230 + 6.4 = 236.4 V

(**ii**) Total power generated in armature EgIa = 236.4 × 152.5 = 36,051 W

Generated E.M.F. or E.M.F. Equation of a Generator

Let Φ = flux/pole in weber

Z = total number of armature conductors = No. of slots. No. of conductors/slot

P = No. of generator poles

A = No. of parallel paths in armature

N = armature rotation in revolutions per minute (r.p.m.)

E = e.m.f. induced in any parallel path in armature

Generated e.m.f. Eg = e.m.f. generated in any one of the parallel paths i.e. E.

Average e.m.f. generated/conductor = $d\Phi/dt$ v (∵n = 1)

Now, flux cut/conductor in one revolution dΦ = ΦP Wb No. of revolutions/second = N/60

∴ Time for one revolution, dt = 60/N second Hence, according to Faraday's Laws of Electromagnetic Induction, E.M.F. generated/conductor = $d\Phi\ dt = \Phi\ P\ N$ 60 volt

$$Eg = \frac{\Phi \times P \times N}{60} \times \frac{Z}{A}$$

Where, A=2 for a simplex wave-wound generator

A=P for a simplex lap-wound generator

Ex5: An 8-pole d.c. generator has 500 armature conductors, and a useful flux of 0.05 Wb per pole. What will be the e.m.f. generated if it is lap-connected and runs at 1200 rpm ? What must be the speed at which it is to be driven produce the same e.m.f. if it is wave-wound?

Solution:

$$Eg = \frac{\Phi \times P \times N}{60} \times \frac{Z}{A}$$

Φ = 0.05 Wb , Z = 500, A = p,N = 1200 rpm

Thus, Eg= 500 V

Φ = 0.05 Wb , Z = 500, A = 2, p = 8 ,N = 1200 rpm

Thus, N= 300 rpm

Ex6: An 8-pole d.c. shunt generator with 778 wave-connected armature conductors and running at 500 r.p.m. supplies a load of 12.5 Ω resistance at terminal voltage of 250 V. The armature resistance is 0.24 Ω and the field resistance is 250 Ω. Find the armature current, the induced e.m.f. and the flux per pole.

Solution:

Load current = V/R = 250/12.5 = 20 A

Shunt current = 250/250 = 1 A

Armature current = 20 + 1 = 21 A

Induced e. m. f. = 250 + (21 × 0.24) = 255.04 V

$$Eg = \frac{\Phi \times P \times N}{60} \times \frac{Z}{A}$$

$$255.04 = \frac{\Phi \times 8 \times 500}{60} \times \frac{778}{2}$$

Φ = 9.83 mWb

Ex7: A 4-pole lap-connected armature of a d.c. shunt generator is required to supply the loads connected in parallel: (1) 5 kW Geyser at 250 V, and (2) 2.5 kW Lighting load also at 250 V. The Generator has an armature resistance of 0.2 ohm and a field resistance of 250 ohms. The armature has 120 conductors in the slots and runs at 1000 rpm. Allowing 1 V per brush for contact drops and neglecting friction, find Flux per pole.

Solution:

Geyser current = 5000/250 = 20 A

Current for Lighting = 2500/250 = 10 A

Total current = 30 A

Field Current for Generator = 1 A (250v\250ohm) Hence, Armature Current = 31 A

Armature resistance drop = 31 × 0.2 = 6.2 volts

Generated e. m. f. = 250 + 6.2 + 2(2 brushes) = 258.2 V,

$$Eg = \frac{\Phi \times P \times N}{60} \times \frac{Z}{A}$$

$$258.2 = \frac{\Phi \times 1000 \times 120}{60}$$

Φ = 129.1 mWb

Ex8: A 4-pole, d.c. shunt generator with a shunt field resistance of 100 Ω and an armature resistance of 1 Ω has 378 wave-connected conductors in its armature. The flux per pole is 0.02 Wb. If a load resistance of 10 Ω is connected across the armature terminals and the generator is driven at 1000 r.p.m., calculate the power absorbed by the load.

Solution: Induced e.m.f. in the generator is

$$Eg = \frac{\Phi \times P \times N}{60} \times \frac{Z}{A}$$

$Eg = \frac{0.02 \times 4 \times 1000}{60} \times \frac{378}{2} = 252\ V$

Load current =V/10

Shunt current= V/100

Armature current = V /10 + V/ 100 = 11V /100

V = Eg − armature drop

V = 252 − 1 × 11V 100 V = 227 V Load current = 227/10 = 22.7 A

Power absorbed = 227 × 22.7 = 5135 W

Losses in a D.C. Machine

The losses in a dc machine (generator or motor) may be divided into three classes

(i) copper losses
(ii) iron or core losses and
(iii) mechanical losses.

All these losses appear as heat and thus raise the temperature of the machine. They also lower the efficiency of the machine.

Copper Losses

In dc machines, the losses that occur due to resistance of the various windings of the machine are called **copper losses**. The copper losses are also known as ***I^2R* losses** because these losses occur due to current flowing through the resistance of the windings.

The major copper losses that occur in dc machines are as,

Armature copper loss $= Ia^2 Ra$

Shunt field copper loss$= Ish^2 Rsh$

Series field copper loss$= Ise^2 Rse$

In dc machines, there is also a **brush contact loss** due to brush contact resistance. In practical calculation, this loss is generally included in armature copper loss.

Iron or core losses

These losses occur in the armature of a dc machine and are due to the rotation of the armature in the magnetic field of the poles. They are of two types:

(i) hysteresis loss and (ii) eddy current loss.

Hysteresis loss

The core loss that occurs in core of the armature of a dc machine due to magnetic field reversal in the armature core when it passes under the successive magnetic poles of different polarity is called **hysteresis loss**. The hysteresis loss is given by the following empirical formula:

Hysteresis loss: $P_h = \eta\, B^{1.6}max\, f\, V$ watts

Where *Bmax* = Maximum flux density in armature

f = Frequency of magnetic reversals = *NP*/120 where N is in r.p.m.

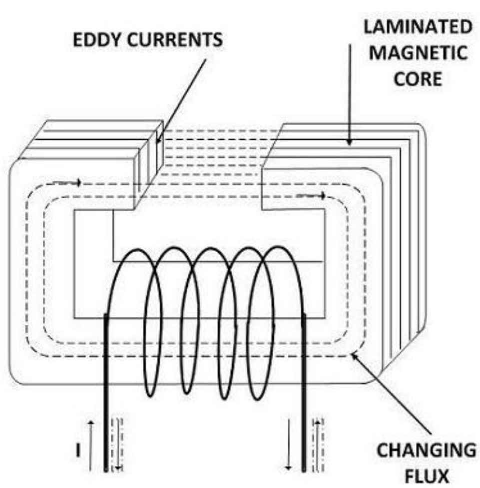
V = Volume of armature in m^3

η = Steinmetz hysteresis co-efficient

In order to reduce this loss in a DC machine, the armature core is made of materials that have a low hysteresis coefficient, e.g., silicon steel.

Eddy current loss

In addition to the voltages induced in the armature conductors, there are also voltages induced in the armature core. These voltages produce circulating currents in the armature core as shown in Figure below These are called eddy currents and power loss due to their flow is called eddy current loss. The eddy current loss appears as heat which raises the temperature of the machine and lowers its efficiency.



Mechanical losses

These losses are due to friction and windage. (i) friction loss, e.g., bearing friction, brush friction, etc. (ii) windage loss, i.e., the air friction of the rotating armature. These losses depend on the speed of the machine. But for a given speed, they are practically constant. Note. Iron losses and mechanical losses together are called stray losses.

Constant losses

Those losses in a DC generator that remain constant at all loads are known as constant losses. The constant losses in a DC generator are:

(a) iron losses (b) mechanical losses (c) shunt field losses.

Variable losses

Those losses in a DC generator that vary with load are called variable losses. The variable losses in a DC generator are:

(a) Copper loss in armature winding, $Ia^2 Ra$

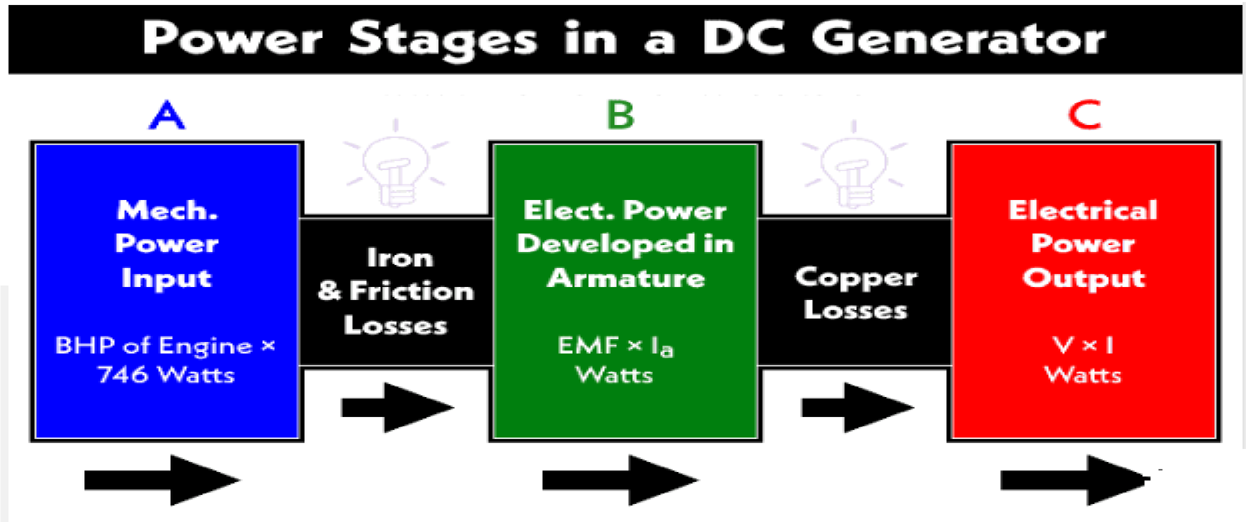
(b) Copper loss in series field winding, $Ise^2 Rse$

Total losses = constant losses + variable losses

Note: field Cu loss is constant for shunt and compound generators.

Power Stages

The various power stages in a DC generator are represented diagrammatically in the following figure.



Mechanical efficiency

$$\eta_m = \frac{B}{A} = \frac{E_g\, I_a}{Mechanical\ power\ input}$$

Electrical efficiency

$$\eta_e = \frac{C}{B} = \frac{V\, I_L}{E_g\, I_a}$$

Commercial or overall efficiency

$$\eta_c = \frac{C}{A} = \frac{V\ I_L}{Mechanical\ power\ input}$$

$$\eta_c = \eta_e \cdot \eta_m$$