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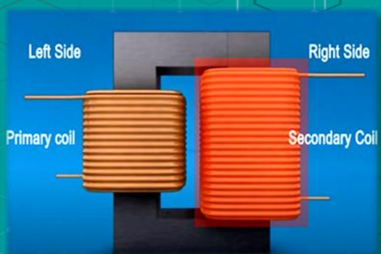

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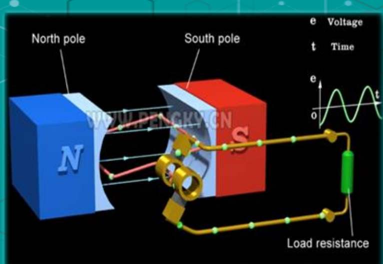

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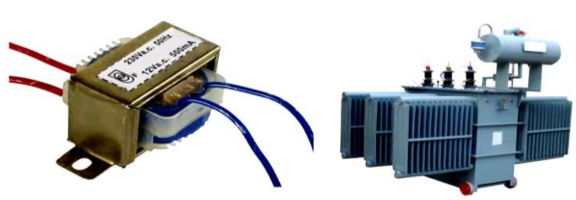
The Success Destination...

TRANSFORMER



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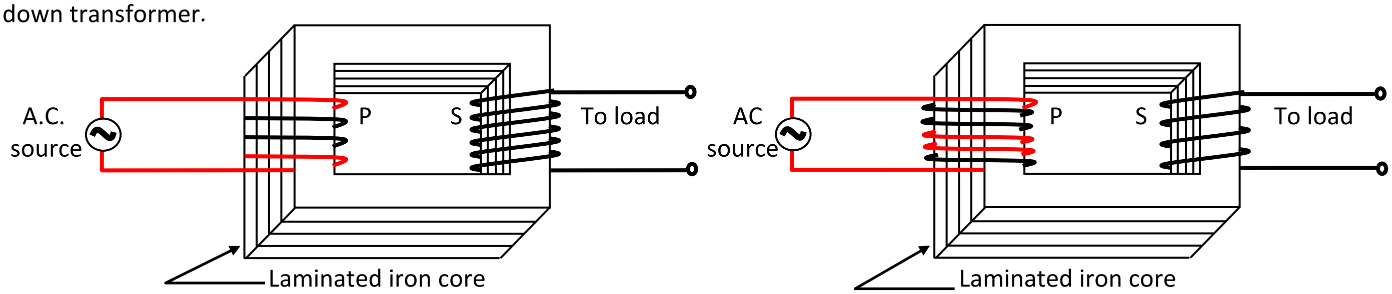
TRANSFORMER

"Transformer is a device by virtue of which we can transform AC supply from one voltage to another".

or,

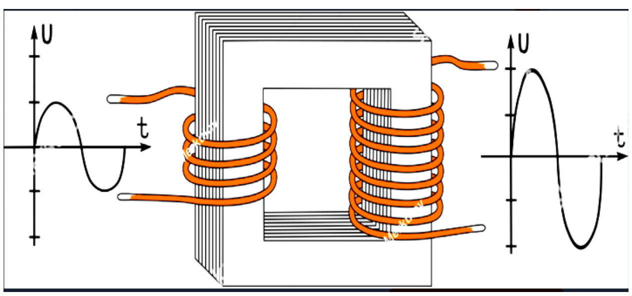
"Transformer is a device used to convert low alternating voltage at higher current into high alternating voltage at lower current and Vice-versa."

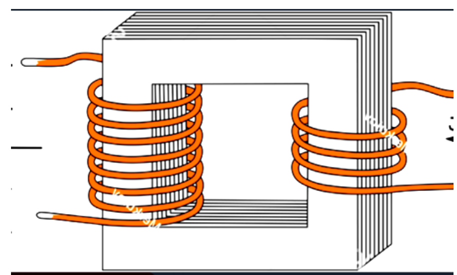
✸ A transformer is an electrical device for converting an alternating current at low voltage into that at high voltage or vice versa. If it increases the input voltage, it is called step up transformer and if it decreases the input voltage, it is called step down transformer.

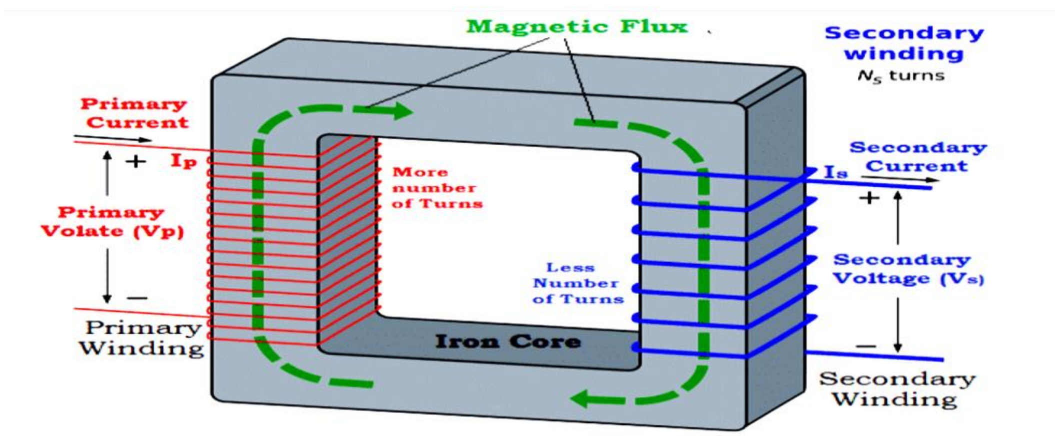


(a) (b)

(a) Step-up **(b) step-down, transformer**



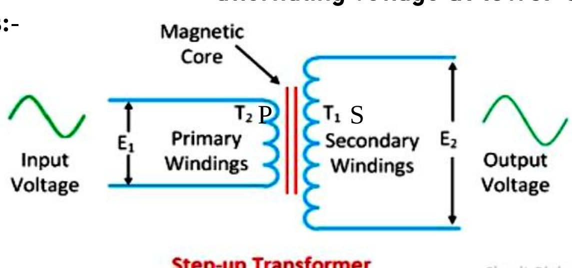




0 0 Type of Transformer:-

0 (i) Step up Transformer:- **"The transformer which converts low alternating voltage at higher current into a high alternating voltage at lower current in called step – up transformer."**

Symbols:-

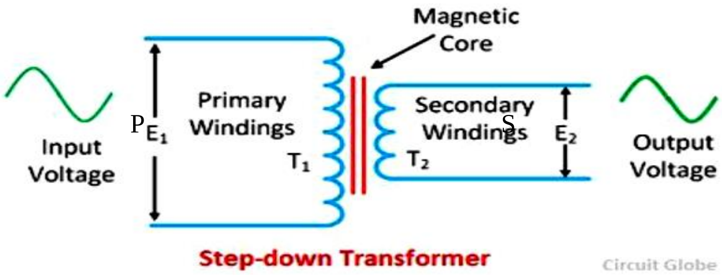


No. of turns of secondary coil is more than no. of turns in primary coil i.e., $N_S > N_P$

(Increased alternating voltage output)

(ii) Step down Transformer:- "**The transformer which converts high alternating voltage at lower current into a low alternating voltage at higher current is called step – down transformer".**

Symbol:-



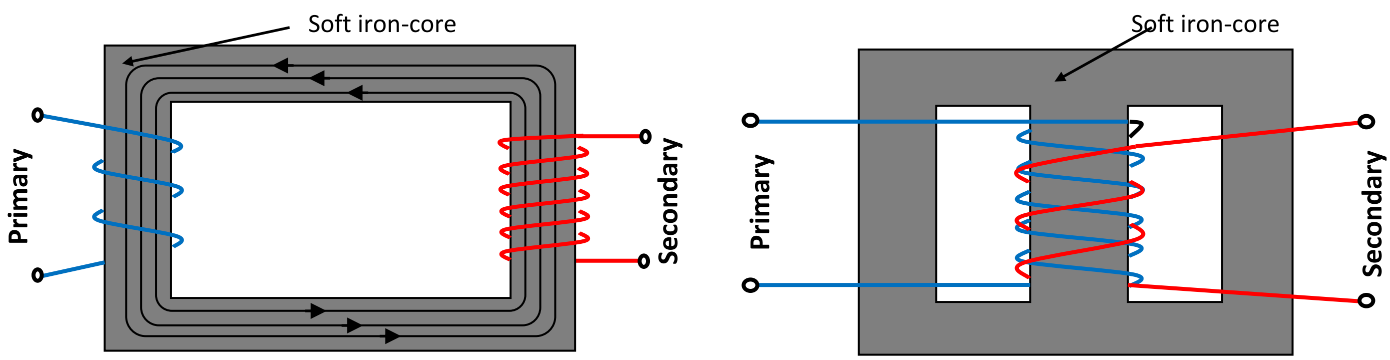
$N_P > N_S$

PRINCIPLE: It works on the principle of mutual induction, i.e., when a changing current is passed through one of the two inductively coupled coils, an induced emf is set up in the other coil.
i.e. whenever the amount of magnetic flux linked with a coil changes an emf induced in the neighbouring coil.

CONSTRUCTION: A transformer essentially consists of two coils of insulated copper wire having different number of turns and wound on the same soft iron core. The coil P to which electric energy is supplied is called the primary and the coil from which energy is drawn or output is obtained is called secondary. To prevent energy losses due to eddy currents, a laminated core is used. Because of high permeability of soft iron, the entire magnetic flux due to the current in the primary coil practically remains in the iron core and hence passes fully through the secondary. This also prevents the stray currents being generated in the conductors lying around and the consequent power loss.

- Two types of arrangements are generally used for winding of primary and secondary coils in a transformer:

1. Core type: In the core type transformers, the primary and secondary coils are wound on separate limbs of the core so that the core is largely surrounded by the coils. Many of the modern transformers are of closed core type Fig. (a)



(a) (b)

[(a) Core type and (b) shell type transformer]

2. Shell type: In the shell type transformers, the primary and secondary coils are wound one over another on the same limb of the iron core. The coils are very largely surrounded by the iron core. **Transformers used in radio and TV transmitted and receivers are of shell type Fig. (b).**

Working: As the alternating current flows through the primary, it generates an alternating magnetic flux in the core which also passes through the secondary, also a self-induced emf in the primary. If there is no leakage of magnetic flux, then flux linked with each turn of the primary will be equal to that linked with each turn of the secondary.

Theory: Consider the situation when no load is connected t the secondary, i.e., its terminals are open Let N_1 and N_2 be the number of turns in the primary and secondary respectively. Then

Induced emf in the primary coil, $$E_1 = -N_1 \frac{d\phi}{dt}$$

where ϕ is the magnetic flux linked with each turn of the primary or secondary at any instant. Thus

$$\frac{E_2}{E_1} = \frac{N_2}{N_1}$$

Let E be the emf applied to the primary. By Lenz's law, self-induced emf $\mathcal{E}_1$ opposes $\mathcal{E}$ in the primary coil.

∴ Resultant emf in the primary = $E - E_1$

This emf sends currents I_1, through the primary coil of resistance R.

∴ $E - E_1 = RI_1$

But R is very small, so the term RI_1 can be neglected.

Then $E = E_1$

Thus E_1 may be regarded as input emf and $\mathcal{E}_2$ as the output emf.

$$\frac{E_2}{E_1} = \frac{\text{Output emf}}{\text{Input emf}} = \frac{N_2}{N_1} \quad \dots (1)$$

The ratio N_2 / N_1, of the number of turns in the secondary to that in the primary, is called the turns ratio of the transformer. It is also called transformation ratio.

- **In a step up transformer, $N_2 > N_1$, i.e., the turns ratio is greater than 1 and therefore $E_2 > E_1$. The output voltage is greater than the input voltage.**

- Equation (1) has been derived by using the following **three assumptions:**

---1. The primary resistance and current are small.

---2. The same flux links both with the primary and secondary windings as the flux leakage from the core is negligibly small.

---3. The terminals of the secondary are open or the current taken from it is small.

✱ **Currents in primary and secondary**: Assuming the transformer to be ideal one so that there are no energy losses,

then Input power = Output power or $E_1I_1 = E_2 I_2$ where I_1 and I_2 are the currents in the primary and secondary, respectively.

Hence, $$\frac{I_1}{I_2} = \frac{E_2}{E_1} = \frac{N_2}{N_1} \quad \dots (2)$$

Thus ***a step up transformer steps up the voltage, but steps down the current exactly in the same ratio. Similarly, a step down transformer steps down the voltage but steps up the current exactly in the same ratio.***

The efficiency of a transformer is defined as

$$\eta = \frac{\text{Power output}}{\text{Power input}} \times 100\ \% \quad \dots (3)$$

- The efficiency of real transformers is fairly high (90 – 99%) through not 100 %.

✱ **Energy losses in transformers:** The main causes for energy loss in transformers are as:

1. **Copper loss:** Some energy is lost due to heating of copper wires used in the primary and secondary windings. This power loss (= $I^2 R$) can be minimised by using thick copper wire of low resistance.
2. **Eddy current loss**: The alternating magnetic flux induces eddy currents in the iron core which leads to some energy loss in the form of heat. This loss can be reduced by using laminated iron core.
3. **Hysteresis loss**: The alternating current carries the iron core through cycles of magnetisation and demagnetisation. Work is done in each of these cycles and is lost as heat. This is called hysteresis loss and can be minimised by using core material having narrow hysteresis loop.
4. **Flux leakage**: The magnetic flux produced by the primary may not fully pass through the secondary. Some of the flux may leak into air. This loss can be minimised by winding the primary and secondary coils over one another.
5. **Humming loss:** As the transformer works, its core lengthens and shortens during each cycle of the alternating voltage due to a phenomenon called magnetostriction. This gives rise to a humming sound. So, some of the electrical energy is lost in the form of humming sound.

✱ **For an ideal transformer – We assume that the resistance of the primary and secondary coil are negligible.**

✱ **For an ideal transformer – The energy loss due to magnetic hysteresis in the core is also negligible.**

✱ **Well-designed high-capacity transformer have energy losses as low as 1% large outdoor transformer are immersed in oil.**
Oil provides a good electric insulation (It also acts cooling medium).

Conceptual tips..

☑ A step up transformer changes a low-voltage into a high-voltage. This does not violate the law of conservation of energy. The current decreases by the same proportion. When voltage increases n times, the current reduces to 1/n times.

☑ A transformer is essentially an a.c. device. It cannot work on d.c. It cannot work on d.c. It changes alternating voltages/currents. It does not affect the frequency of a.c.

☑ The small transformers are self-cooled, which transfer heat directly to the surroundings. Large transformers are cooled by placing them in oil tanks to prevent overheating.

USES OF TRANSFORMERS

1. Small transformers are used in radio receivers, telephones, loud speakers, etc.
2. In voltage regulator for TV, refrigerators, air conditioners, computers, etc.
3. In stabilised power supplies.
4. A step-down transformer is used for obtaining large current for electric welding.
5. A step-down transformer is used in induction furnace for melting metals.
6. A step-up transformer is used for the production of X-rays.
7. In the transmission of electric energy from the generating stations to the consumers.

LONG DISTANCE TRANSMISSION OF ELECTRICAL POWER

Use of transformers in long distance transmission of electric power: The most important application of transformers is in the transmission of electrical power from a power station to far away areas where it is actually used.

Following are the disadvantage of transmitting the electrical power at low voltage:

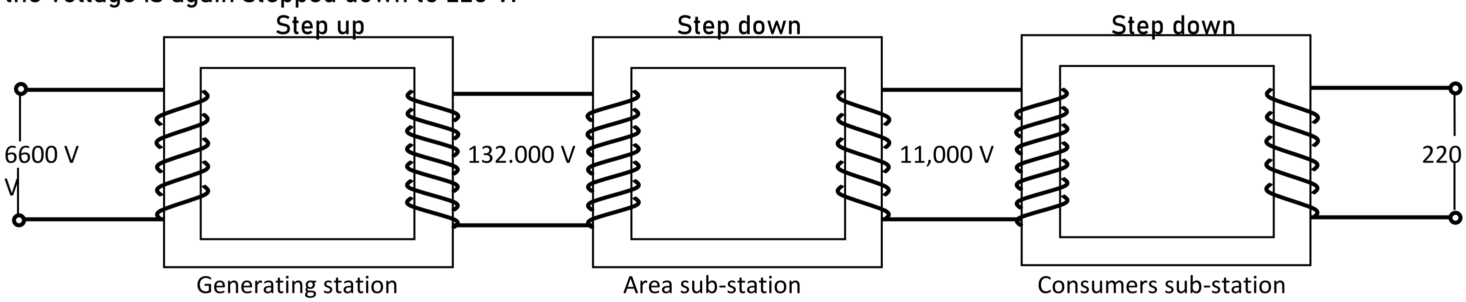
- 1. Large length of transmission cables have appreciable resistance. Hence a large amount of energy ($I^2 Rt$) will be lost as heat during transmission.

- 2. Large voltage drop (IR) occurs along the line wire. Hence the voltage at the receiving station will be much smaller than that at the generating station.

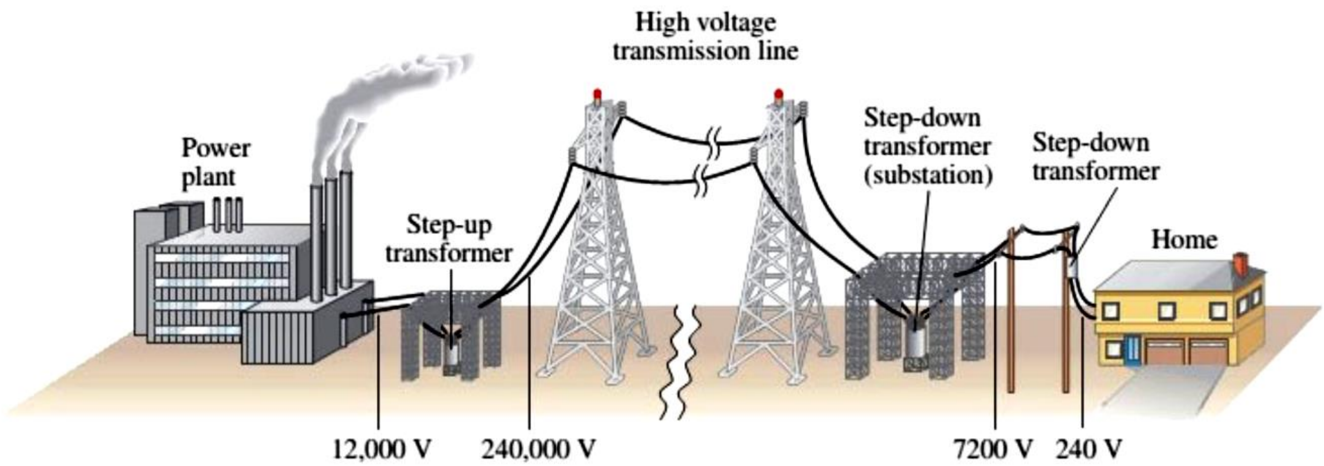
- 3. To carry large currents and to keep the resistance of transmission wires low, thick wires have to be used. The cost of installing thick wires will be extremely high.

Thus the long distance power transmission at low voltage and high current is neither efficient nor economical. If I is the current in the cable, and R its resistance, the power wasted in the cable is $I^2 R$. the **power loss can be reduced by reducing I or R**. The power supplied by the generator is given by P = VI, where V is the voltage across its terminals. Since I = P/V, for a given amount of power P, the power loss is less if I is less or V is high.

In actual practice, as shown in Fig. a typical power station generates 1000 kW at 6600 volts. this voltage is first stepped up to 132000 volts before transmission. Transmission lines from different power stations in a region deliver power to a common regional pool, called the grid. From the grid, the power is fed to the cities at 33000 V, the stepping down is done outside the city. Then again at a sub-station, the supply is stepped down to 6600 V. for domestic purposes, the voltage is again stepped down to 220 V.



Transformers In Transmission System



Examples based on Transformers and Long Distance Power Transmission

◆ Formula Used

1. The voltage and currents in a transformer are related as $\frac{\mathcal{E}_2}{\mathcal{E}_1} = \frac{I_1}{I_2} = \frac{N_2}{N_1} = k$

where suffix 1 refers to primary coil, 2 to secondary coil and k is the transformation of turns ratio.

2. $\mathcal{E}_1 I_1$ (Power in primary coil) = $\mathcal{E}_2 I_2$ (Power in secondary coil)

3. Efficiency of a transformer, $\eta = \frac{\text{Output power}}{\text{Input power}} \times 100\ \%$

4. Power is transmitted from power stations to sub-stations at very high voltages to reduce cost and reduce losses.

◆ Units Used

Voltages $\mathcal{E}_1$, $\mathcal{E}_2$ are in volts, currents I_1, I_2 in ampere; and k and η have no units.

Q. 1. The primary coil of an ideal step-up transformer has 100 turns and the transformation ratio is also 100. The input voltage and the power are 220 V and 1100 W respectively. Calculate:
(i) number of turns in the secondary (ii) the current in the primary (iii) voltage across the secondary
(iv) the current in the secondary (v) power in the secondary.

Sol. Here $N_1 = 100$, $\mathcal{E}_1 = 220$ V, $P_1 = 1100$ W

(i) Transformation ratio, $k = \frac{N_2}{N_1} = 100$

$\therefore N_2 = 100\ N_1 = 100 \times 100 = 10,000$

(ii) $I_1 = \frac{P_1}{\mathcal{E}_1} = \frac{1100}{220} = 5$ A

(iii) $\mathcal{E}_2 = k\mathcal{E}_1 = 100 \times 220 = 22,000$ V

(iv) $I_2 = \frac{I_1}{k} = \frac{5}{100} = 0.05$ A

(v) For an ideal transformer

Output power = Input power = 1100 W.m

Q. 2. How much current is drawn by the primary of a transformer which steps down 220 V to 22 V to operate a device with an impedance of 220 Ω?

Sol. Here $\mathcal{E}_1 = 220$ V, $\mathcal{E}_2 = 22$ V, $Z_2 = 220\ \Omega$

Current drawn by the secondary or by the device of impedance 220 Ω is

$I_2 = \frac{\mathcal{E}_2}{Z_2} = \frac{22}{220} = 0.1$ A

If there are no energy losses, then

Input power = Output power i.e., $\mathcal{E}_1 I_1 = \mathcal{E}_2 I_2$

or $I_1 = \frac{\mathcal{E}_2 I_2}{\mathcal{E}_1} = \frac{22 \times 0.1}{220} = 0.01$ A

Q. 3. A transformer has 500 turns in the primary and 1000 turns in its secondary winding. The primary voltage is 200 V and the load in the secondary is 100 Ω. Calculate the current in the primary, assuming it to be an ideal transformer.

Sol. Here $N_1 = 500$, $N_2 = 1000$, $\mathcal{E}_1 = 220$ V, $R_2 = 100\ \Omega$

$\mathcal{E}_2 = \frac{N_2}{N_1}\mathcal{E}_1 = \frac{1000}{500} \times 200 = 400$ V

Current in the secondary,

$I_2 = \frac{\mathcal{E}_2}{R_2} = \frac{400}{100} = 4$ A

For an ideal transformer, $\mathcal{E}_1 I_1 = \mathcal{E}_2 I_2$

$\therefore$ Current in the primary,

$I_1 = \frac{\mathcal{E}_2 I_2}{\mathcal{E}_1} = \frac{400 \times 4}{200} = 8$ A

Q. 4. ***In an ideal transformer, number of turns in the primary and secondary are 200 and 1000 respectively. If the power input to the primary to 10 kW at 200 V, calculate (i) output voltage and (ii) current in primary.***

Sol. Here $N_1 = 200$, $N_2 = 1000$, $\mathcal{E}_1 = 200$ V, $P_1 = 10$ kW $= 10{,}000$ W

(i) As $\frac{N_2}{N_1} = \frac{\mathcal{E}_2}{\mathcal{E}_1}$

∴ Output voltage,

$\mathcal{E}_2 = \frac{N_2}{N_1} \times \mathcal{E}_1 = \frac{1000}{200} \times 200 = 1000$ V

(ii) Input power, $P_1 = I_1 \mathcal{E}_1$.

∴ Current in primary, $I_1 = \frac{P_1}{\mathcal{E}_1} = \frac{10{,}000}{200} = 50$ A

Q. 5. ***The output voltage of an ideal transformer, connected to a 240 V a.c. mains is 24 V. When this transformer is used to light a bulb with rating 24 V, 24 W, calculate the current in the primary coil of the circuit.***

Sol. Here $\mathcal{E}_1 = 240$ V, $\mathcal{E}_2 = 24$ V, $P_2 = 24$ W

Current in the secondary, $I_2 = \frac{P_2}{\mathcal{E}_2} = \frac{24}{24} = 1$ A

For ideal transformer, $\mathcal{E}_1 I_1 = \mathcal{E}_2 I_2$

∴ Current in the primary, $I_1 = \frac{\mathcal{E}_2 I_2}{\mathcal{E}_1} = \frac{24 \times 1}{240} = 0.1$ A

Q. 6. ***A transformer of 100 % efficiency has 200 turns in the primary and 40,000 turns in the secondary. It is connected to a 220 V a.c. mains and the secondary feeds to a 100 k Ω resistance. Calculate the output potential difference per turn and the power delivered to the load***

Sol. Here $N_1 = 200$, $N_2 = 40{,}000$, $\mathcal{E}_1 = 220$ V, $R_2 = 100\ \text{k}\Omega = 10^5\ \Omega$

As $\frac{\mathcal{E}_2}{\mathcal{E}_1} = \frac{N_2}{N_1}$

∴ $\mathcal{E}_2 = \frac{N_2}{N_1} \cdot \mathcal{E}_1 = \frac{40000}{200} \times 220 = 44{,}000$ V

Output p.d. per turn $= \frac{\mathcal{E}_2}{N_2} = \frac{44000}{40000} = 1.1$ V

Power delivered to the load $= \mathcal{E}_2 I_2 = \frac{\mathcal{E}_2^2}{R_2} = \frac{(44000)^2}{10^5} = 19360$ W $= 19.36$ kW.

Q. 7. ***A step down transformer is used to reduce the main supply of 220 V to 11 V. If the primary draws a current of 5 A and the secondary 90 A, what is the efficiency of the transformer?***

Sol. Here $\mathcal{E}_1 = 220$ V, $\mathcal{E}_2 = 11$ V, $I_1 = 5$ A, $I_2 = 90$ A

Power input $= \mathcal{E}_1 I_1 = 220 \times 5 = 1100$ W

Power output $= \mathcal{E}_2 I_2 = 11 \times 90 = 990$ W

Efficiency, $\eta = \frac{\text{Power output}}{\text{Power input}} = \frac{990}{1100} = 0.90 = 90\ \%$

Q. 8. ***Calculate the current drawn by the primary of a transformer, which steps down 200 V to 20 V to operate a device of resistance 20 Ω. Assume the efficiency of the transformer to be 80%.***

Sol. Here $\mathcal{E}_1 = 20$ V, $\mathcal{E}_2 = 200$ V, $R_2 = 20\ \Omega$ $\eta = 80\ \%$

Current flowing through secondary, $I_2 = \frac{\mathcal{E}_2}{R_2} = \frac{20}{20} = 1$ A

Efficiency, $\eta = \frac{\text{Power output}}{\text{Power input}} = \frac{\mathcal{E}_2 I_2}{\mathcal{E}_1 I_1}$

∴ $\frac{80}{100} = \frac{20 \times 1}{200 \times I_1}$ or $I_1 = 0.125$ A

Q. 9. ***A 10 kW transformer has 20 turns in the primary and 100 turns in the secondary circuit. An a.c. voltage $\mathcal{E}_1 = 600 \sin 314\, t$ is applied to the primary. Find (i) the maximum value of flux and (ii) the maximum value of the secondary voltage.***

Sol. (i) Flux lined with each turn of primary, $\phi = BA \cos \omega t = \phi_0 \cos \omega t$

Here $\phi_0 = BA$ = maximum value of flux linked with each turn

∴ $\mathcal{E}_1 = -N_1 \frac{d\phi}{dt} = -N_1 \frac{d}{dt}(\phi_0 \cos \omega t) = \omega N_1 \phi_0 \sin \omega t$

Peak value of $\mathcal{E}_1 = \mathcal{E}_0 = \omega N_1 \phi_0$ or $\phi_0 = \frac{\mathcal{E}_0}{\omega N_1}$

Given, $\mathcal{E}_1 = 600 \sin 314\, t = \mathcal{E}_0 \sin \omega t$ ∴ $\mathcal{E}_0 = 600$ V, $\omega = 314$ rad s^{-1}

Hence, $\phi_0 = \frac{600}{314 \times 20} = 0.0955$ Wb.

(ii) $\frac{\mathcal{E}_0^2}{\mathcal{E}_1^0} = \frac{N_2}{N_1}$ ∴ Maximum value of secondary voltage is $\mathcal{E}_2^0 = \frac{N_2}{N_1} . \mathcal{E}_1^0 = \frac{100}{20} \times 600 = 3000$ V.

Q. 10. ***(i) The primary of a transformer has 400 turns while the secondary has 2000 turns. If the power output from the secondary at 1100 V is 12.1 kW, calculate the primary voltage. (ii) if the resistance of the primary is 0.2 Ω and that of the secondary is 2.0 Ω and the efficiency of the transformer is 90 %, calculate the heat losses in the primary and the secondary coils.***

Sol. (i) $N_1 = 400$, $N_2 = 2000$, $\mathcal{E}_2 = 1100$ V

$$\mathcal{E}_1 = \mathcal{E}_2 . \frac{N_1}{N_2} = 1100 \times \frac{400}{2000} = 220 \text{ V}$$

(ii) Resistance of primary, $R_1 = 0.2\ \Omega$; Resistance of secondary, $R_2 = 2.0\ \Omega$

Output power = $\mathcal{E}_2 I_2$ = 12.1 kW = 12100 W

∴ Current in the secondary, $I_2 = \frac{\mathcal{E}_2 I_2}{\mathcal{E}_2} = \frac{12100}{1100} = 11$ A

As Efficiency = $\frac{\text{Output power}}{\text{Input power}} = \frac{90}{100} = \frac{12100 \text{ W}}{\text{Input power}}$

or Input power, $\mathcal{E}_1 I_1 = \frac{12100 \times 100}{90} = 13.44 \times 10^3$ W

Current in the primary, $I_1 = \frac{\mathcal{E}_1 I_1}{\mathcal{E}_1} = \frac{13.44 \times 10^{-3}}{220} = 61.1$ A

Power loss in the primary = $I_1^2 R_1 = (61.1)^2 \times 0.2 = 746.61$ W

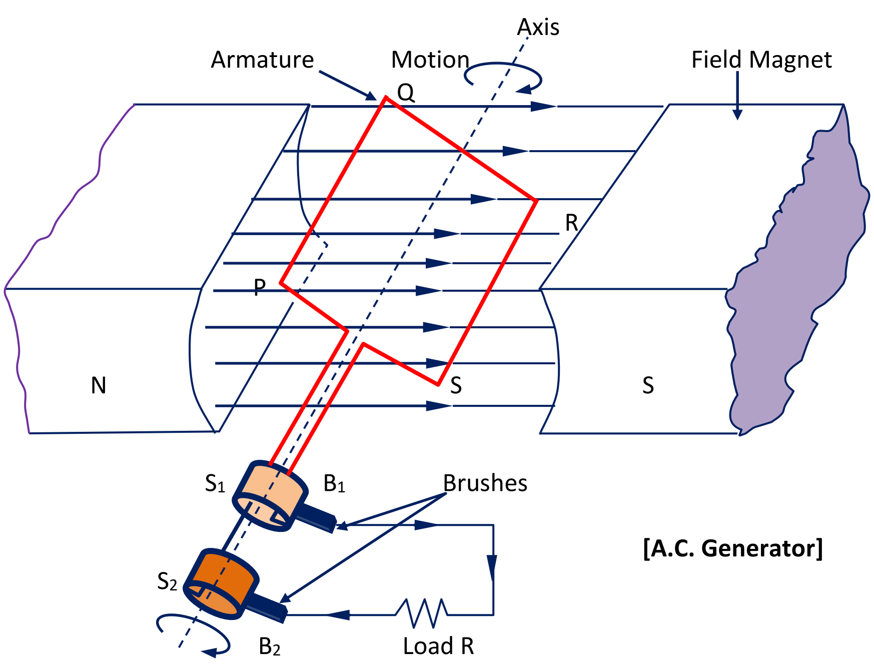
Power loss in the secondary = $I_2^2 R_2 = (11)^2 \times 2.0 = 242$ W

0 0 A.C. GENERATOR

[Nikola Tesla, the great Yugoslav scientist who built it in the year 1888]

A generator or dynamo is a device which converts mechanical energy into electrical energy. Actually, the name generator is a misnomer because it does not generator any energy. It just converts mechanical energy into electrical energy.

An a.c. generator is the one which produces a current that alternates or changes it direction regularly after a fixed interval of time, i.e., it is a device which converts mechanical energy into alternating from of electrical energy.



[A.C. Generator]

Principle: The working of an a.c. generator is based on the principle of electromagnetic induction. When a closed coil is rotated in a uniform magnetic field with its axis perpendicular to the magnetic field, the magnetic flux linked with the coil changes and an induced emf and hence a current a current is set up in it.

Construction: It essentially consists of the following main parts:

1. **Field magnet:** It is a permanent magnet of the horse shoe shape in a small dynamo (magneto) or it is a powerful electromagnet in a large dynamo. it produces a strong magnetic field in the region between its pole-pieces.

2. Armature: It consists of a rectangular coil PQRS having a large number of turns of insulated copper wire wound on a soft iron cylindrical core. the core is laminated one to avoid losses due to eddy current. The soft iron core concentrates the lines of force of increase the flux density B. The armature can be rotated in the magnetic field of the field magnet about an axis perpendicular to field B.

3. Slip rings: The two ends of the armature coil are connected to two coaxial brass rings S_1 and S_2 called slip rings. The rings are rigidly fixed to same shaft which is used to rotate the coil. The slips are insulated from each other as well as from the shaft. As the armature coil rotates, the slip rings also rotate about the same axis of rotation.

4. Brushes: Two graphite or flexible metallic rods called brushes are lightly pressed against the two slip rings. The brushes B_1 and B_2 remain fixed in their positions and maintain sliding contacts with the rotatable slip rings S_1 and S_2 respectively. It is through these brushes that the current induced in the armature coil is fed to the external circuit by means of line wires.

5. Source of energy: The armature coil is rotates about its axis with the help of turbine or any other device connected to it. It is the rotational kinetic energy of the turbine which is ultimately converted into electrical energy by the a.c. generator.

Working: As the armature coil rotates, the magnetic flux linked with it changes and so an induced current flows through it. Suppose initially the coil PQRS be in the vertical Position and it is rotated in the clockwise direction. The side PQ moves downward and SR moves upward. According to Fleming's right hand rule, the induced current flows from Q to P and from S to R. So during the first half rotation of the coil, the induced current flows in the direction SRQP, with brush B_1 acting as positive terminal and brush B_2 as negative terminal. During the second half-rotation, the side PQ moves upward and SR moves downward. The direction of induced current is reversed, i.e., it flows along PQRS, so that the brush B_2 now functions as the positive terminal and brush B_1 as the negative terminal. Thus the direction of current in the external circuit is reversed after every half cycle. Hence alternating current is produced by the generator. Such a generator which generator alternating current is called an a.c. **generator** or an **alternator**.

Expression for induced emf: Let N = number of turns in the coil
A = face area of each turn
B = magnitude of the magnetic field
θ = angle which normal to the coil makes with field B at any instant t
ω = the angular velocity with which coil rotates.

Then the magnetic flux linked with the coil at any instant t will be

$$\phi = NBA\cos\theta = NBA\cos\omega t$$

By Faraday's flux rule, the induced emf is given by

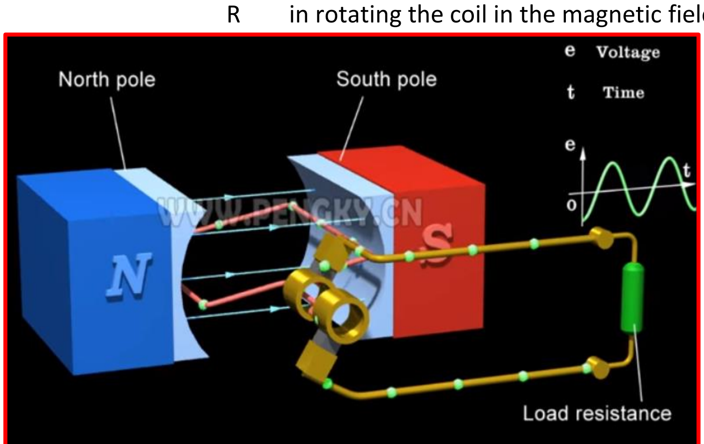
$$E = -\frac{d\phi}{dt} = -d\,(NBA\cos\omega t) = NBA\,\omega\sin\omega t.$$

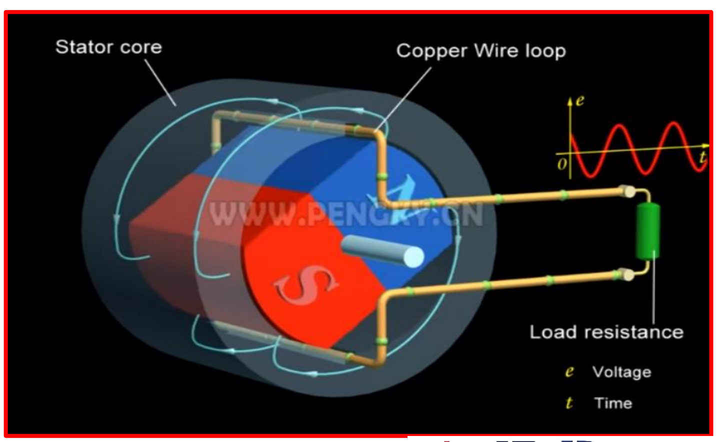
or $$E = E_0\sin\omega t$$

where $E_0 = NBA\,\omega$. When a load of resistance R is connected across the terminals, a current I flows in the external circuit.

$$I = \frac{E}{R} = \frac{E_0\sin\omega t}{R} = I_0\sin\omega t$$

where $I_0 = \frac{E_0}{R}$. Both current and voltage vary sinusoidally with time. The power dissipated in the load is supplied by the agent in rotating the coil in the magnetic field.





Variation of induced emf with different position of the coil w. r. t. The magnetic field

- (I) When $\theta = \theta^o$ — [Plane of the coil is $\perp^{ar}$ to the magnetic field]
  $E = E_0 \sin 0 = 0$
- (II) When $\theta = 90^0$ — [Plane of the coil is along the direction of the mag. field.]
  then **$E = E_0 \sin 90^0 = E_0$ (Max)**
- (III) When $\theta = 180^0$ — [Plane of the coil is $\perp^{ar}$ to the mag. field]
  then **$E = E_0 \sin 180^0 = 0$**
- (IV) When $\theta = 270^0$ — [Plane of the coil is $\perp^{ar}$ to the direction of magnetic **$E = E_0 \sin 270^0 = - E_0$**
- (V) When $\theta = 360^0$ — [Plane of the coil is $\perp^{ar}$ to the direction of the magnetic field]
  $E = E_0 \sin 360^0 = 0$

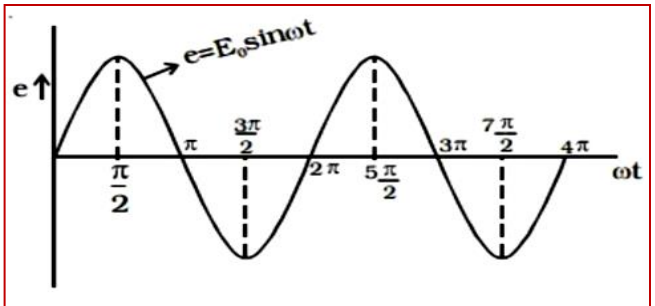
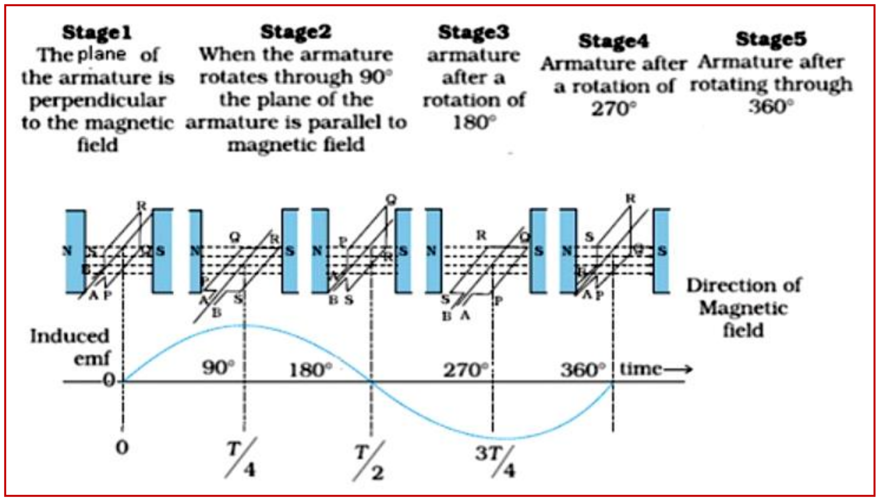
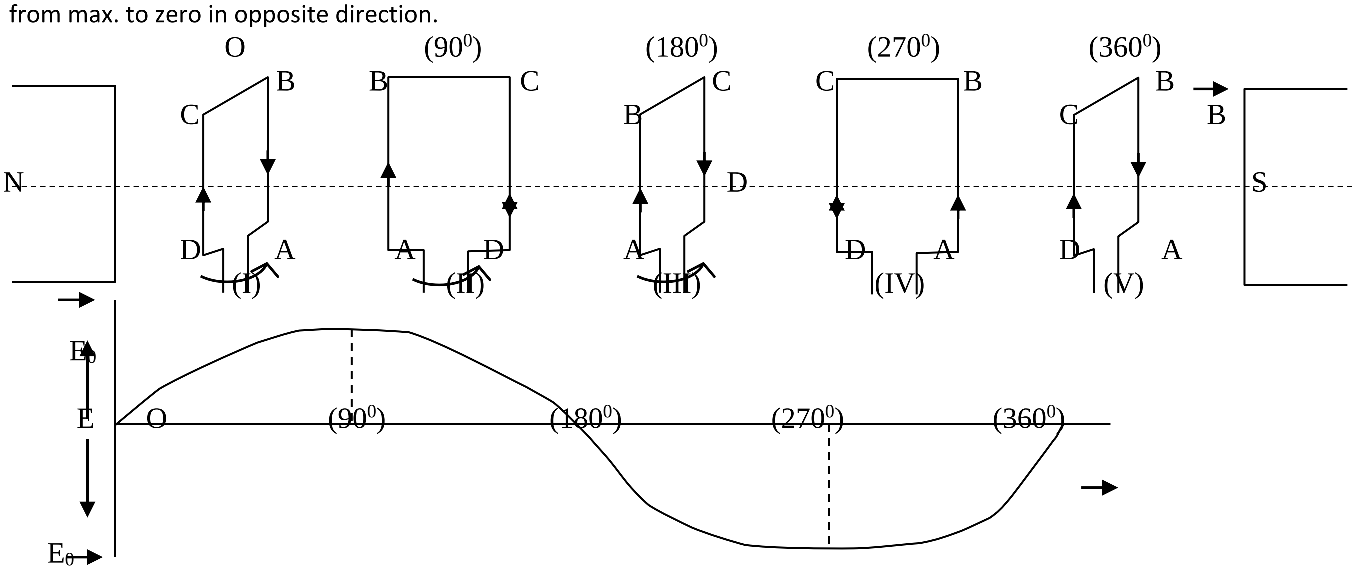


Fig emf varies sinusoidally



Explanation: When the coil is rotated from its position at right angle to the magnetic field through 108^0, the induced emf and coil is further rotated through the next 180^0, the emf and current rises from zero to max and then decreases from max. to zero in opposite direction.



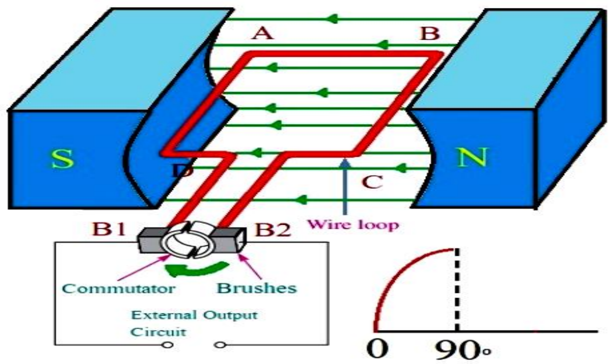
Hydroelectric power station: In a hydroelectric power station, water is stored in a dam at a height, from where it falls into giant water wheels or turbines. These turbines are connected to the loops of wires in a.c. generators. The kinetic energy of the falling water thus gets converted into rotational energy of the turbines and ultimately into electrical energy supplied by the generator.

Thermal power station: In a thermal power station, steam is produced by boiling water using coil or oil as fuel. The turbines coupled to the loops of a.c. generators are rotated by steam rushing past them and thus electrical energy is generated.

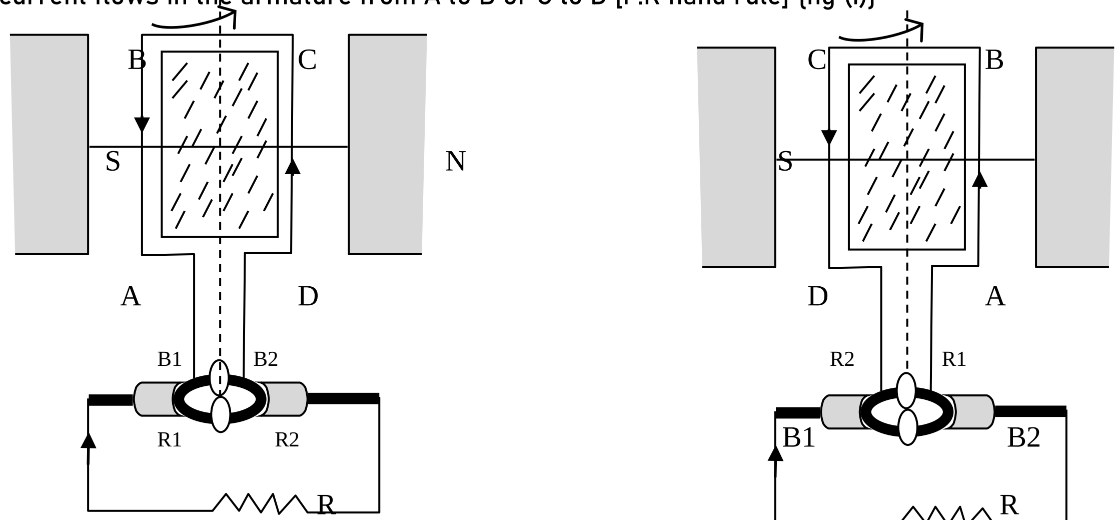
Nuclear power plant: In a nuclear power plant, a nuclear fuel is used instead of coal to generate electrical energy.

DC generator: *(A DC generator is the converse of DC motor.)*

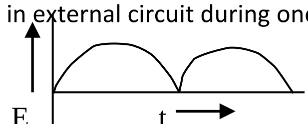
Construction: The slip rings R_1 & R_2 of the AC generator are replaced by split ring commutator. It consists of a metal ring split up into two halve (insulated from one another), R_1 and R_2 which remains fixed to the two ends of the coil.
As R_1 & R_2 rotate with the coil they rub past stationary brushes B_1 & B_2.

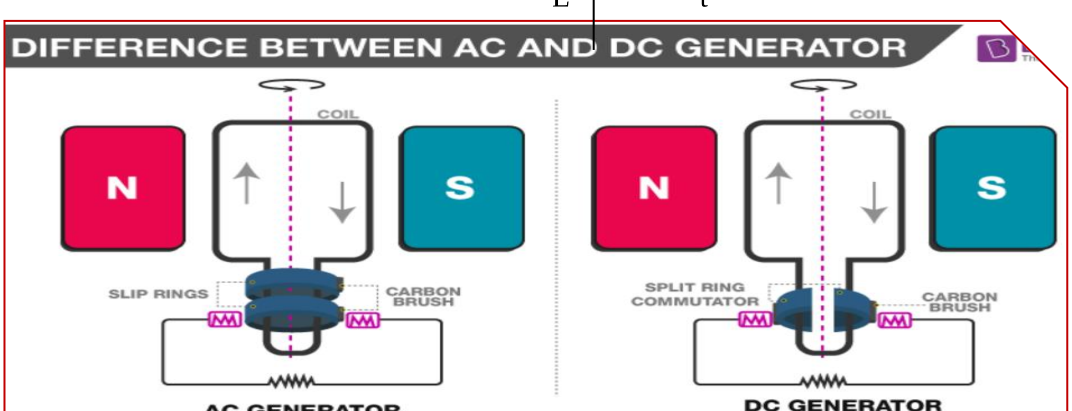


Working: Let us assume that to start with, plane of the coil is $\perp^{ar}$ to the plane of paper in which magnetic field is applied. Let the armature coil ABCD is moving in such a way that arm AB moves inward and CD moves outward.
Therefore, current flows in the armature from A to B or C to D [F.R hand rule] {fig (i)}



After the armature coil rotated through 180^0, it occupies position (ii) CD – inward, AB – outward.
Therefore, **Current flow in the armature from D to C or from B to A.**
i.e., the direction of induced emf and induced I does not change in external circuit during one complete rotation of the coil.
Mag. of emf induced $\mathbf{E = E_0 \sin \omega t}$



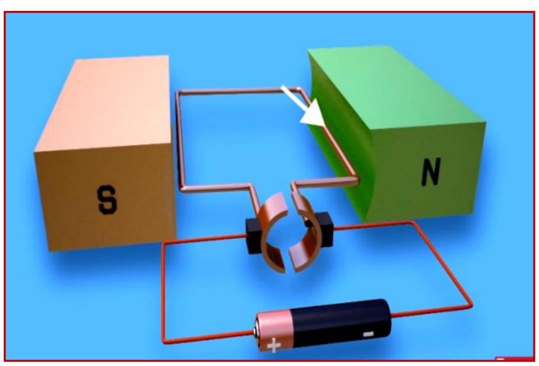


Sl. No.	Differentiating Property	AC Generator	DC Generator
1	**Definition**	AC generator is a mechanical device that converts mechanical energy into AC electrical power.	DC generator is a mechanical device that converts mechanical energy into DC electrical power.
2	**Direction of Current**	In an AC generator, the electrical current reverses direction periodically.	In a DC generator, the electrical current flows only in one direction.
3	**Basic Design**	In an AC generator, the coil through which the current flows is fixed while the magnet moves. The construction is simple and costs are less.	In a DC generator, the coil through which the current flows rotate in a fixed field. The overall design is very simple but construction is complex due to commutators and slip rings.
4	**Commutators**	AC generator does not have commutators.	DC generators have commutators to make the current flow in one direction only.
5	**Rings**	AC generators have slip-rings.	DC generators have commutators.
6	**Efficiency of Brushes**	Since slip-rings have a smooth and uninterrupted surface, they do not wear quickly and are highly efficient.	Both brushes and commutators of a DC generator wear out quickly and thus are less efficient.
7	**Short Circuit Possibility**	As the brushes have high efficiency, a short circuit is very unlikely.	Since the brushes and commutators wear out quickly, sparking and short circuit possibility is high.
8	**Rotating Parts**	The rotating part in an AC Generator is a low current high resistivity rotor.	The rotating part in a DC generator is generally heavy.
9	**Current Induction**	In an AC generator, the output current can be either induced in the stator or in the rotor.	In a DC generator, the output current can only be induced in the rotor.
10	**Output Voltage**	AC generators produce a high voltage which varies in amplitude and time. The output frequency varies (mostly 50Hz to 60Hz).	DC generators produce a low voltage when compared to AC generator which is constant in amplitude and time i.e. output frequency is zero.
11	**Maintenance**	AC generators require very little maintenance and are highly reliable.	DC generators require frequent maintenance and are less reliable.
12	**Types**	AC generators can of varying types like 3 Phase generators, single-phase generators, synchronous generator, induction generator, etc.	DC generators are mainly two types which are Separately excited DC generator and Self-excited DC generator. According to field and armature connection, they can be further classified as DC series, shunt, or compound generators respectively.
13	**Cost**	The initial cost of an AC generator is high.	The initial cost of a DC generator is less when compared to AC generators.
14	**Distribution and Transmission**	The output from AC generators is easy to distribute using a transformer.	The output from DC generators is difficult to distribute as transformers cannot be used.
15	**Efficiency**	AC generators are very efficient as the energy losses are less.	DC generators are less efficient due to sparking and other losses like copper, eddy current, mechanical, and hysteresis losses.
16	**Applications**	It is used to power for smaller motors and electrical appliances at homes (mixers, vacuum cleaners, etc.)	DC generators power very large electric motors like those needed for subway systems.

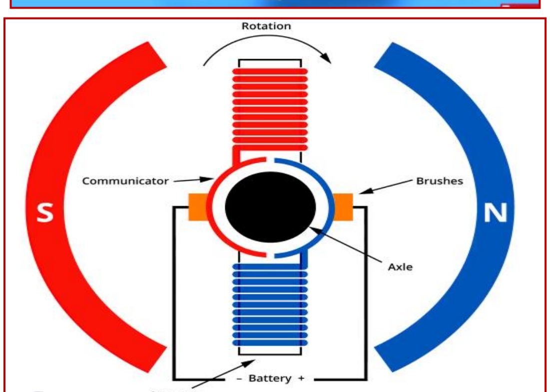
0 0 **DC Motor**: *A DC motor is the converse of generator (DC)*

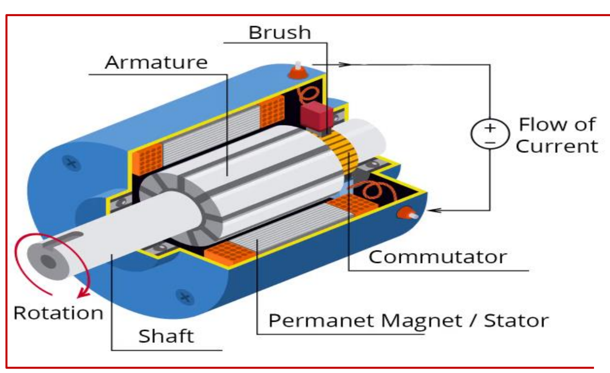
"A dC motor is a device which converts dC energy into mechanical energy of rotation."

Principle: It is based on the fact that when a current carrying coil placed in a magnetic field, it experiences a torque due to which the coil rotates.

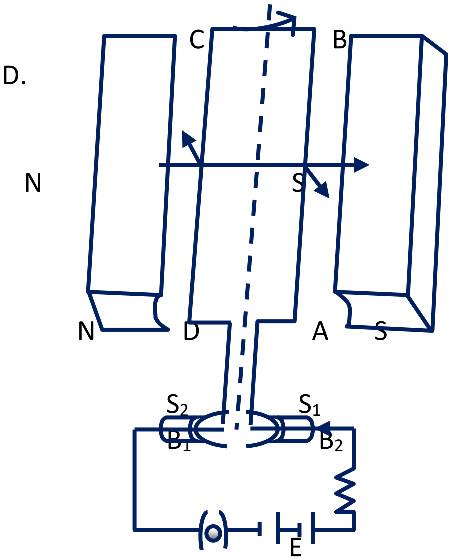


A Typical Small DC Motor





Construction: Armature field magnet, split rings, brushes and battery. In a magnetic field B a coil of area A having N turns is placed with its axis at right to the lines of magnetic flux. The ends of the coil terminate in two split cylinders S_1 & S_2 of a split ring. The brushes B_1 & B_2 just touch S_1 & S_2 at diametrically opposite point. E is a battery and R the adjustable starting Resistance.



Working: When we put the key, the current flows from A to B and C to D. A current carrying conductor placed in a magnetic field experience a mechanical force whose direction is given by F (left hand rule.) The side CD of the coil (Near N – Pole) gets upward force while the side AB of the coil (Near South Pole) experience an equal and opposite downward force, these two equal and opposite forces constitute a coupled and create a torque.

τ = NBAI (I = current flowing in the coil)

After the coil has rotated through 180^0 the AB & CD is reversed. Now CD experience an outward force. So the torque continues to operate in the same sense and the coil continues to rotate. A suitable pulley can be forced on the axis of the coil. And through it, the rotation could be transmitted to any device by mean of a belt.

Back emf and the need of a starter Resistance: The coil starts rotating in the magnetic field, itself becomes a sort of a DC generator. As the armature rotates in the magnetic field, the amount of magnetic flux linked with the coil changes. Therefore, an emf (e) is induced in the coil. The direction of the induced emf is such that it opposes a battery current in the circuit. This emf is called the back emf and its magnitude goes on increases with the speed of the Armature.

Therefore, net current flowing in the coil at any instant.

$I = \frac{E - e}{r}$ (as e and E acts in opp. Direction), (r= Resistance of the armature of coil quite small)

Therefore, Ir = E – e

$e = E - I r$ .... (I)

Because of this back emf, the current in the circuit is always quite small. However, a complication arise just when we switch on the current. At that time the motor is not operating and e = 0 thus, the current at the start.

$I_{start} = E/r$ becomes quite large and may actually burn out the motor, to prevent this, we have a starting Resistance (starter) R in series with the circuit. In the beginning 'R' is very high so as we switch on the motor, the current is

$I_{start} = E/r + R$ and is reasonably small value because of the increased resistance as the motor starts picking up speed, we go on reducing the value of R till at full speed R may be zero.

Efficiency of the dC motor: Ratio of the output mechanical power to the input mechanical power.

We have, E = Applied emf; e = back emf; I = current in the armature; R = Resistance of armature coil.

$I = \frac{E - e}{R}$

Input electric power = EI

Power lost (or wasted) as heat = $I^2 R$

Output mechanical power (power connected into external work) = $E I - I^2 R$

Therefore, **Efficiency**, η = output power/input power = $\frac{IE - I^2 R}{EI}$

$= \cancel{I}(E - I R)/ E\cancel{I} = E - I R/E = e/E$ [from (i)]

η = back emf / applied emf

=> i.e., efficiency increases with increase in back emf if the emf is equal to the applied emf, then the efficiency is maximum i.e., 100%

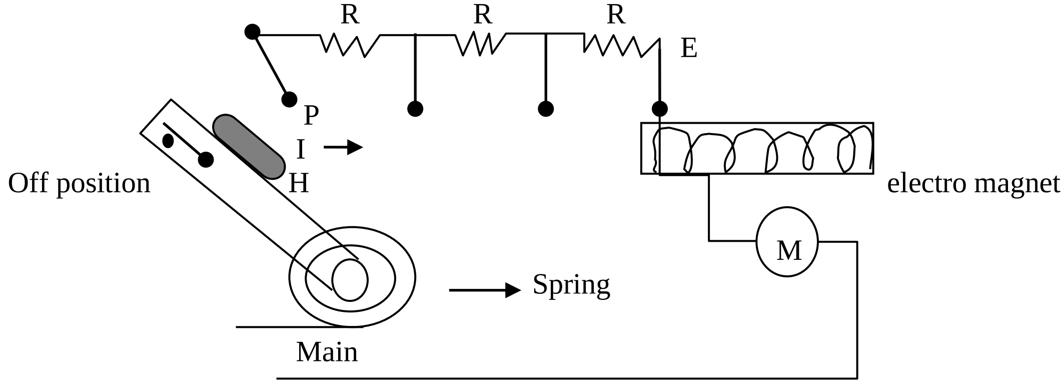
But in that case, I flowing through the armature coil become ZERO as

I = E – e/R and the motor in this case will case to week.

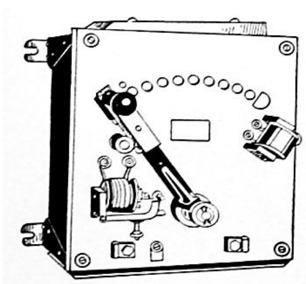
Motor starter: It is a adjustable resistance used in series with the armature of the motor and is used for stating a dc motor safely. The function of motor starter is to introduce a suitable resistance in the circuit at the time of starting the motor. This resistance decreases gradually and reduce to zero when the motor runs at full speed.

In consists of a soft Iron which is capable of rotating about an axis passing through O, while one end of this rod is connected to a spring system the other end can slide over different resistance.

To start: Handle 'H' is brought in contact with point P so that its entire resistance R is in series with motor M. Therefore, initial current becomes small. The electromagnet E gets magnetized due to the passage of current. It attracts the iron piece attached to the handle H. As the H moves towards E, the series resistance decreases gradually. When H just touches E resistance R of the starter is out of the circuit. The current becomes maximum and the armature rotates at full speed.



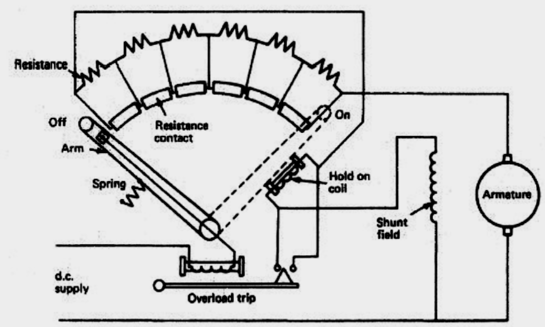
While starting a DC motor huge amount of current can be driven to the windings due to the absence of the back emf. The current may rise about 4-6 times higher than the rated load current of the winding wire. So, it can damage the winding of the motor at the starting itself. To prevent such high current rush, starters are used in DC motors.



Two-point Starter

A two-point starter is used for starting dc motor which has the problem of over-speeding due to loss of lod from its shaft. Such a starter is shown in figger.

Here for starting the motor, the control arm is moved clockwise from its OFF position to the ON position against the spring tension. The control arm is held in the ON position by an electromagnet. The hold-on electromagnet is connected in series with the armature



circuit. If the motor losses its load, current decreases and hence the strength of the electromagnet also decreases. The control arm returns to the OFF position due to spring tension, this preventing the motor from overspending. The starter arm also returns to the OFF-position when the supply voltage decreases appreciably. L and F are two points of the starter which are connected with the supply and motor terminals.

ADVANTAGE AND DISADVANTAGE OF A.C. GENERATOR

Advantage of a.c. over d.c.

1. The generation of a.c. is more economical than d.c.
2. The alternating voltage can be easily stepped up or stepped down by using a transformer.
3. The alternating currents can be reduced by using a choke coil without any significant wastage or energy.
4. The alternating currents can be transmitted to distant places without any significant line loss.
5. Also a.c. can be easily converted into d.c. by using rectifiers.
6. A.C. machines are simple and robust and do not require much attention during their use.

Disadvantage of a.c. over d.c.

1. Peak value of a.c. is high ($I_0 = \sqrt{2}\, I_{rms}$). It is dangerous to work with a.c.
2. The shock of a.c. is attractive, whereas that of d.c. is repulsive.
3. In phenomena like electroplating, electrorefining, electrotyping, etc; a.c. cannot be used.
4. A.C. is transmitted more from the surface of conductor than from inside. This is called skin effect. Therefore, several fine insulated wires (and not a single thick wire) are required for the transmission of a.c.

Examples based on Generators

- **FORMULA USED**

I. For an a.c. generator,

1. Flux linked, $\phi = NBA \cos \omega t$
2. Instantaneous induced emf, $\mathcal{E} = \mathcal{E}_0 \sin \omega t$
3. Maximum induced emf, $\mathcal{E}_0 = NBA\,\omega$
4. Instantaneous current, $I = I_0 \sin \omega t$
5. Maximum current, $I_0 = \dfrac{\mathcal{E}_0}{R} = \dfrac{NBA\,\omega}{R}$

◆ **UNITS USED**

Flux ϕ is in weber, field B in tesla, area A in m^2, emf's $\mathcal{E}$ and $\mathcal{E}_0$ in volt, currents I and I_0 in ampere, resistance R in ohm.

Q. 1. Kamla peddles a stationary bicycle the pedals of which are attached to a 100 turn coil of area 0.10 m². The coil rotates at half a revolution per second and it is placed in a uniform magnetic field of 0.01 T perpendicular to the axis of rotation of the coil. What is the maximum voltage generated in the coil?

Sol. Here N = 100, A = 0.10 m^2, f = 0.5 Hz, B = 0.01 T

The maximum voltage generated in the coil, $\mathcal{E}_0 = NBA\,\omega = NBA \times 2\pi f$

$= 100 \times 0.01 \times 0.10 \times 2 \times 3.14 \times 0.5 = 0.314$ V.

Q. 2. An a.c. generator consists of a coil of 50 turns and area 2.5 m² rotating at an angular speed of 60 rad s⁻¹ in a uniform magnetic field B = 0.30 T between two fixed pole pieces. The resistance of the circuit including that of the coil is 500 Ω.
(a) What is the maximum current drawn from the generator?
(b) What is the flux through the coil when the current is zero? What is the flux when the current is maximum?
(c) Would the generator work if the coil were stationary and instead the pole pieces rotated together with the same speed as above?

Sol. Here N = 50, A = 2.5 m^2, $\omega = 60$ rad s^{-1} B = 0.30 T, R = 500 Ω

Maximum current,

$$I_0 = \frac{\mathcal{E}_0}{R} = \frac{NBA\,\omega}{R} = \frac{50 \times 0.30 \times 2.5 \times 60}{500} = 4.5 \text{ A}$$

(b) Current, $I = I_0 \sin \omega t = \dfrac{NBA\,\omega}{R} \sin \omega t$

Flux, $\phi_B = NBA \cos \omega t$

Current is zero if $\sin \omega t = 0$, or $\omega t = 0°$. Then flux is maximum and its value is

$\phi_B = NBA \cos 0° = NBA = 50 \times 0.30 \times 2.5$ Wb $= 37.5$ Wb

Current is maximum when $\sin \omega t = 1$ or $\omega t = 90°$. Then flux is zero because, $\phi_B = NBA \cos 90° = 0$

(c) Yes, the generator would work if the coil were stationary and the pole pieces are rotated together with the same speed because this will also bring about the necessary flux change.

Q. 3. An a.c. generator consists of a coil of 100 turns and cross-sectional area of 3 m², rotating at a constant angular speed of 60 radians/sec in a uniform magnetic field of 0.04 T. The resistance of the coil is 500 ohm. Calculate (i) maximum current drawn from the generator and (ii) maximum power dissipation in the coil.

Sol. Here N = 100, A = 3 m^2, $\omega = 60$ rad s^{-1}, B = 0.04 T, R = 500 Ω

(i) Maximum current drawn,

$$I_0 = \frac{\mathcal{E}_0}{R} = \frac{NB\,A\omega}{R} = \frac{100 \times 0.04 \times 3 \times 60}{500} = 1.44 \text{ A}$$

(ii) Max. power dissipation $= \mathcal{E}_{eff}.\, I_{eff} = \dfrac{\mathcal{E}_0}{\sqrt{2}} . \dfrac{I_0}{\sqrt{2}} = \dfrac{I_0^2 R}{2} = \dfrac{(1.44)^2 \times 500}{2} = 218.4$ W

Q. 4. A generator develops an emf of 120 V and has a terminal potential difference of 115 V, when the armature current is 25 A. What is the resistance of the armature?

Sol. Here $\mathcal{E} = 120$ V, V = 115 V, I = 25 A

As $I = \dfrac{\mathcal{E} - V}{R}$

$\therefore \quad R = \dfrac{\mathcal{E} - V}{I} = \dfrac{120 - 115}{25} = 0.2\,\Omega$