Department of Electrical and Electronics Engineering

Course Name: Basic Electrical Engineering – EE233P

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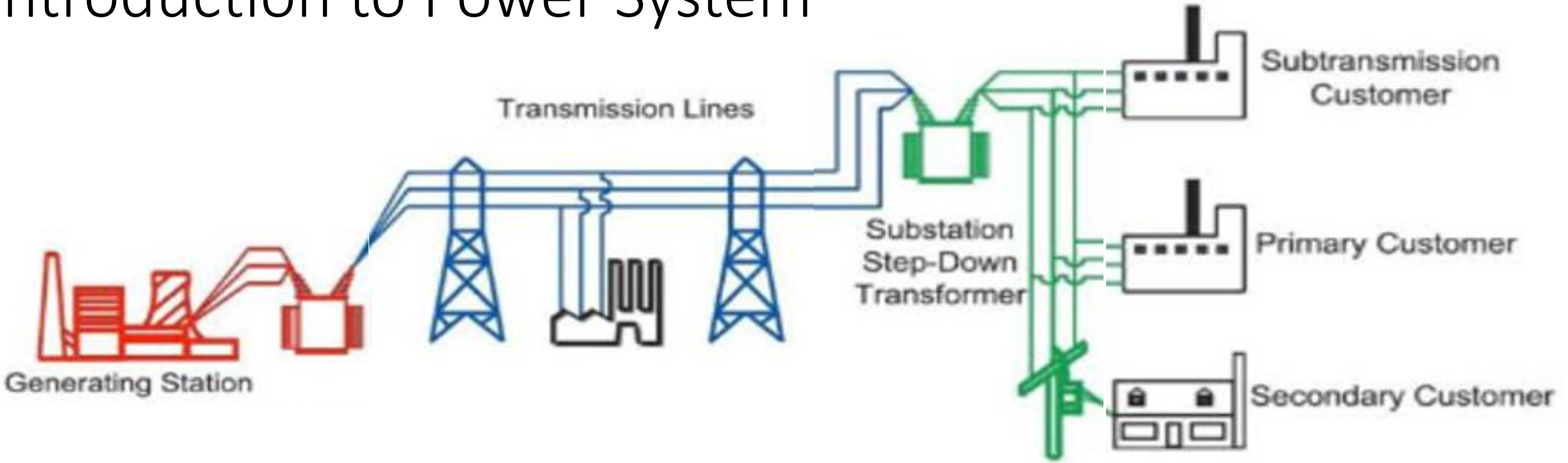
Unit 3

- **Power System Components:** Power system components-overview, Alternator-construction, working and generated voltage equation, Transformer – types, construction, working, emf equation, voltage regulation and efficiency, Switchgears (Fuse, MCB, relay), earthing, electric safety, standards and best practices.
- DC Motor- construction and working, torque and speed equations of shunt motors, Single phase induction motors - construction and working

Introduction to Power System



Generation

Hydel

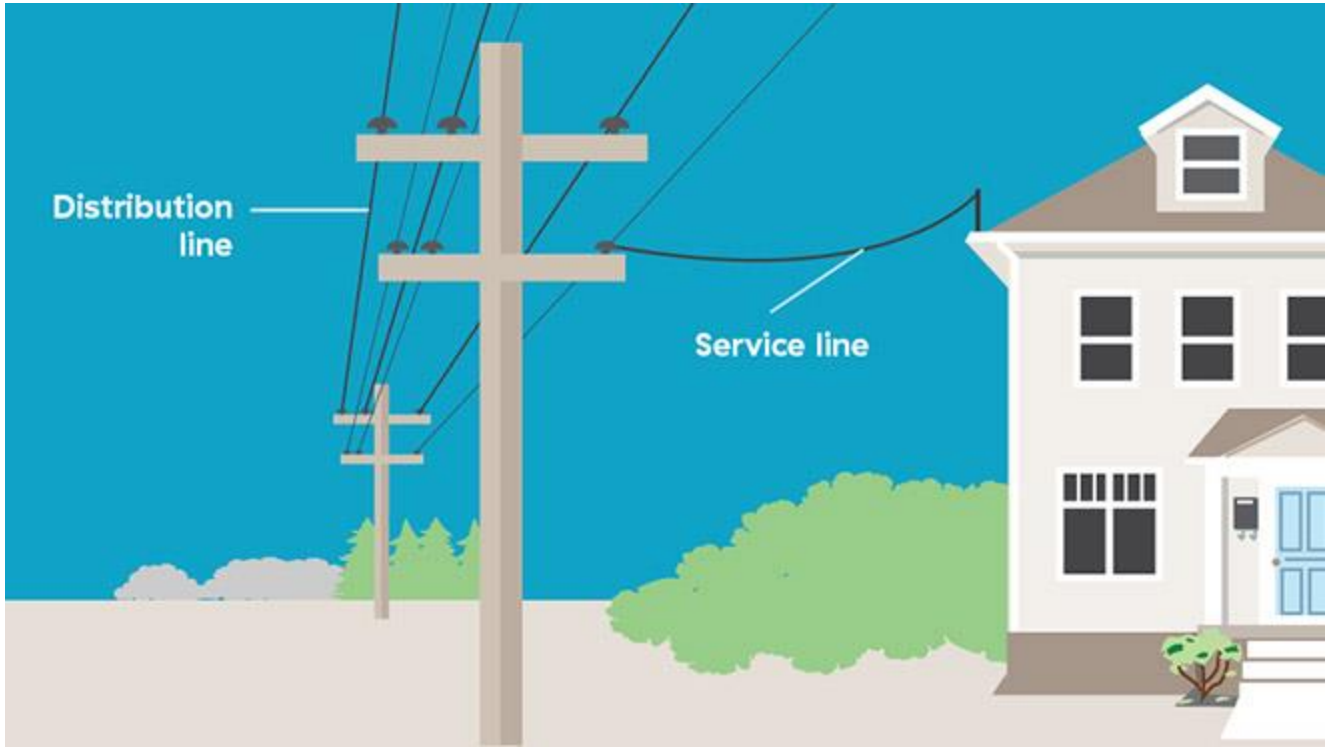
Thermal (coal-fired)

Nuclear

Transmission System

- Is made up of transmission lines that transport the power from the generation system to the distribution
- Typical Voltage Levels
    - usually considered to be 110 kV and above.
    - Lower voltages, such as 66 kV and 33 kV, are usually considered subtransmission voltages, but are occasionally used on long lines with light loads.
    - Voltages less than 33 kV are usually used for distribution.
    - Voltages above 765 kV are considered extra high voltage and require different designs compared to equipment used at lower voltages.

Distribution System



Courtesy: https://www.bchydro.com/news/conservation/2018/9-things-about-power-lines.html

Electrical Load

- Nature of Load
- Power System Load

Nature of Load

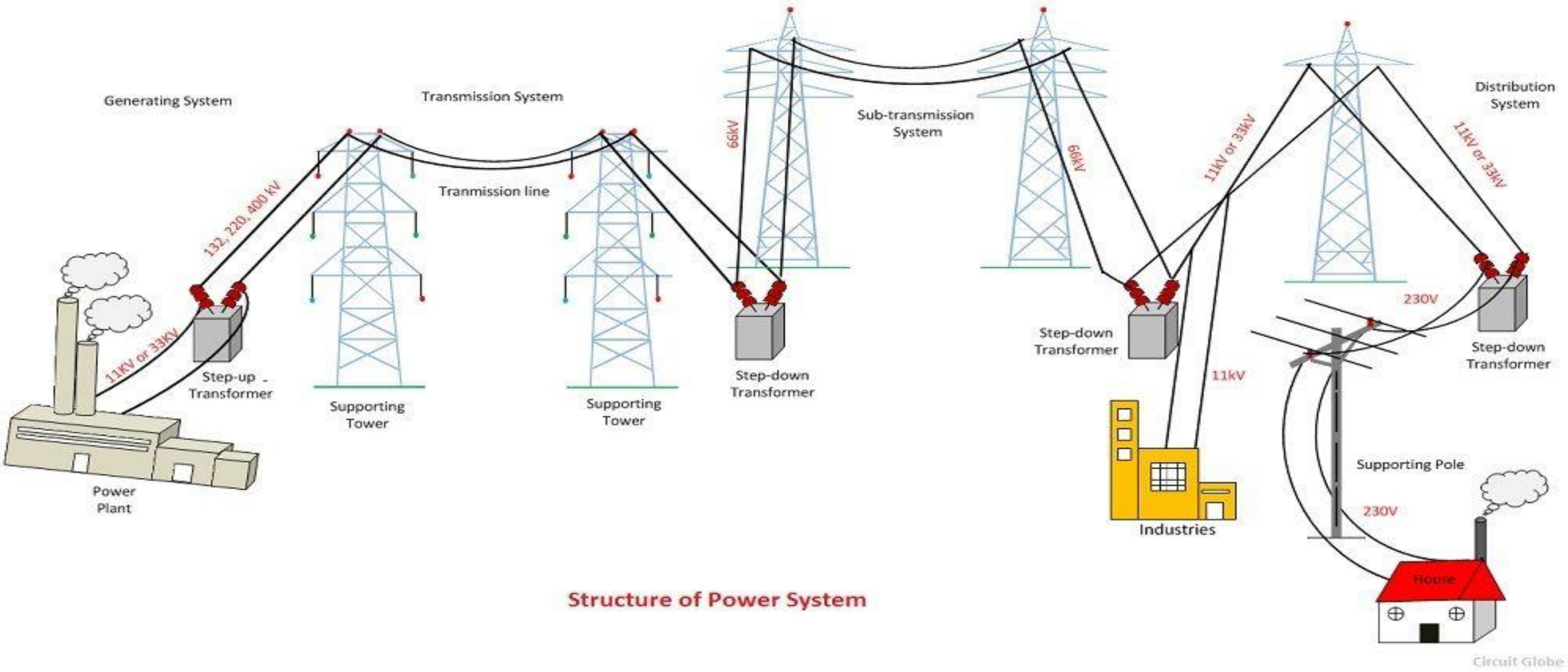
Resistive Load

Inductive Load

Capacitive Load

Power System Load

- Domestic Load
- Industrial Load
- Commercial Load
- Agricultural Load



Structure of Power System

Single Line Diagram

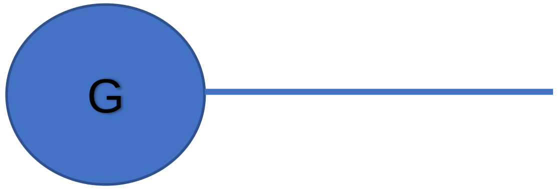
- Single line diagram is the representation of a power system using the simple symbol for each component.
- It is the network which shows the main connections and arrangement of the system components along with their data (such as output rating, voltage, resistance and reactance, etc.).

Points to note

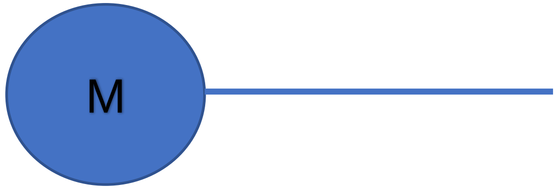
- Single line diagram is a representation of balanced power system on per phase basis with neutral eliminated.
- Neutral wire is not shown in single line diagram.
- Winding connections (star or neutral) is represented beside the symbol of transformer with its Impedance and rating.
- Only balanced power system can be represented by a single line diagram.
- Single line diagram is drawn on per phase basis.
- A power system with LLG, LG and LL faults becomes unbalanced and can not be represented in per phase basis.

Circuit Symbols for drawing Single Line Diagrams

- **Generator**

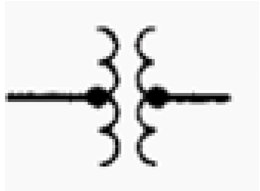


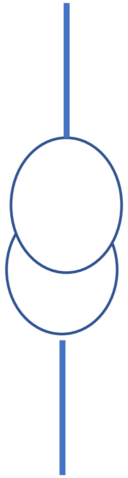
- **Motor**

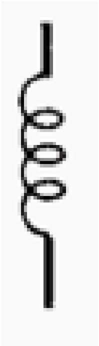


- **Bus**

- **Circuit Breaker** 

- **Transformer** 

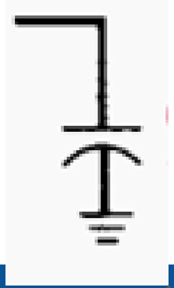


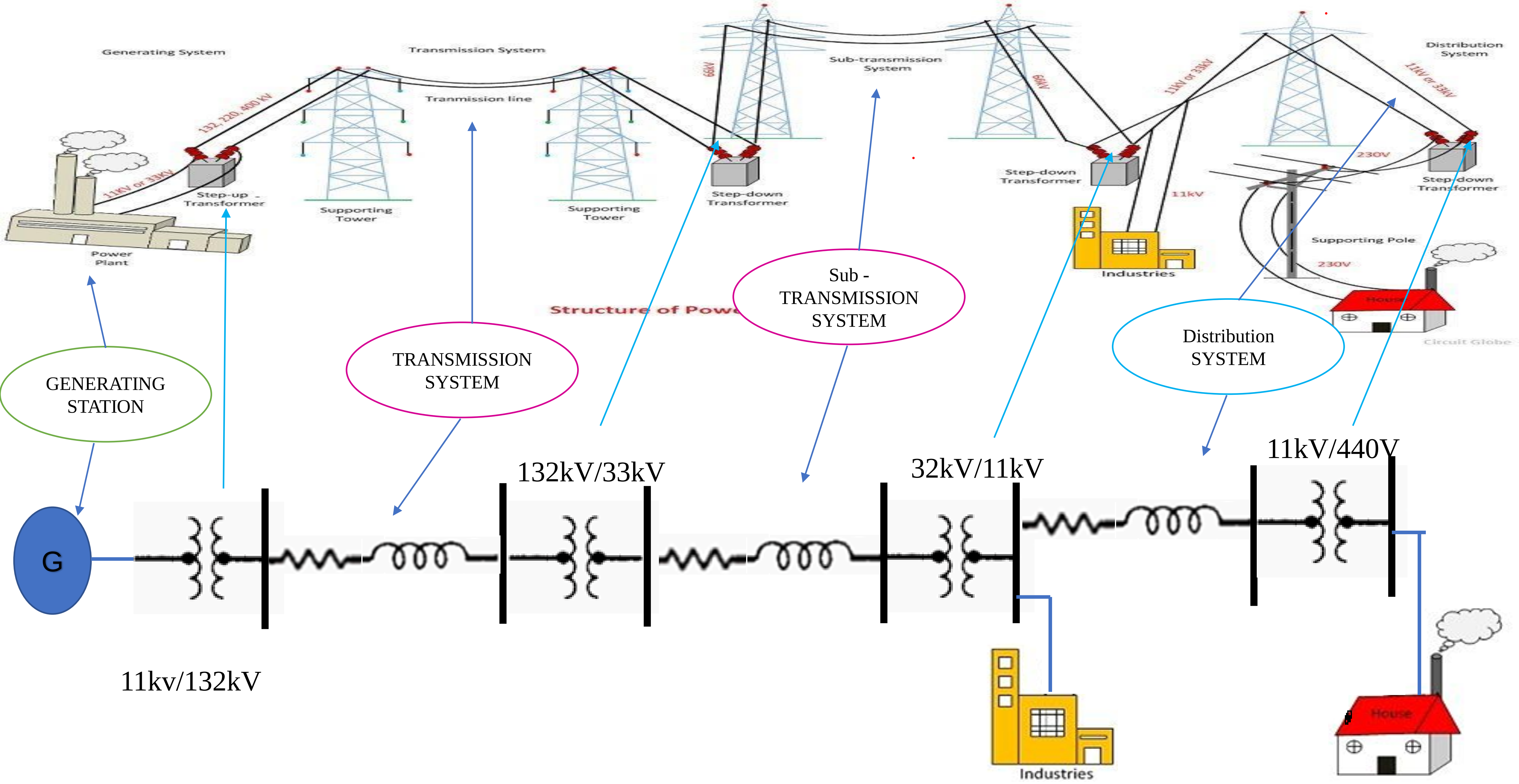
- **Inductance** 

- **Resistance**

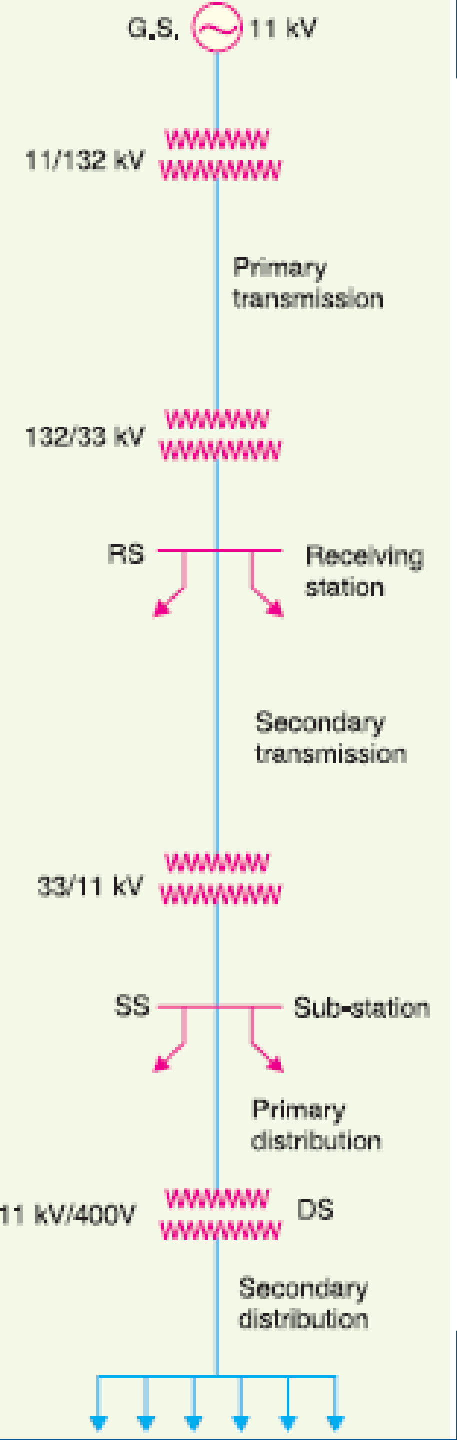
- **Load** 

- **Capacitor to Ground**





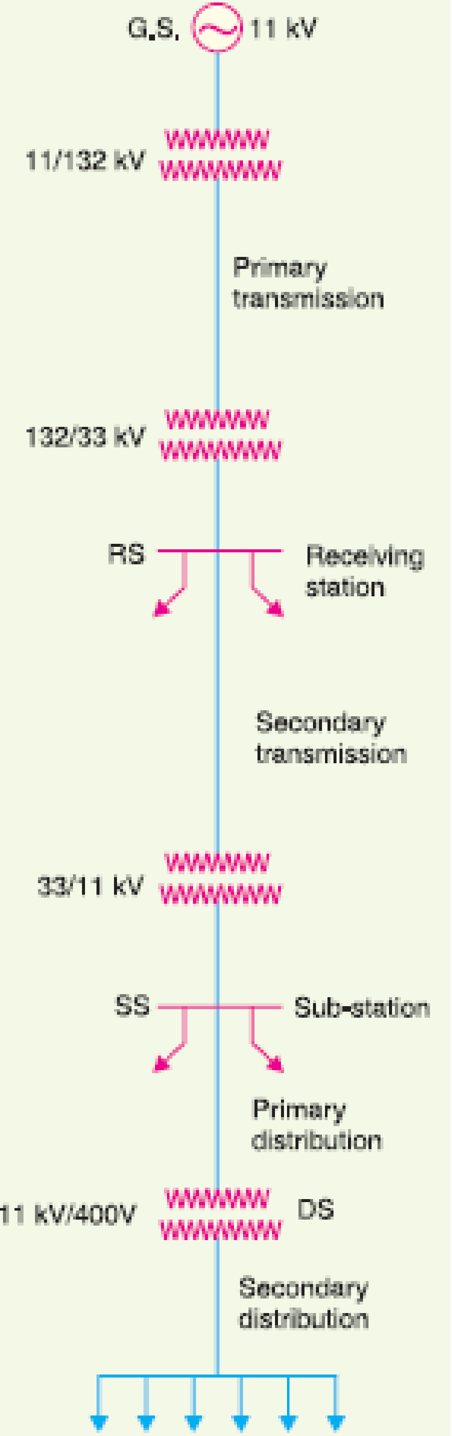
Generating System
Transmission System
Sub-transmission System
Distribution System
Tranmission line
132, 220, 400 KV
11KV or 33KV
66kV
11kV or 33kV
11kV
230V
Step-up Transformer
Supporting Tower
Step-down Transformer
Supporting Pole
Power Plant
Industries
House
Structure of Powe
Circuit Globe
GENERATING STATION
TRANSMISSION SYSTEM
Sub - TRANSMISSION SYSTEM
Distribution SYSTEM
G
11kv/132kV
132kV/33kV
32kV/11kV
11kV/440V



High Voltage Transmission System

- The electric power can be transmitted either by means of d.c. or a.c.
- Each system has its own merits and demerits.

- HVDC & HVAC



High Voltage Transmission System

- HVAC - Advantages of High Transmission Voltage

The transmission of electric power is carried at high voltages due to the following reasons :

(*i*) Reduces volume of conductor material.

(*ii*) Increases transmission efficiency

(iii) Decreases percentage line drop

High Voltage Transmission System

Reduces volume of conductor material.

Consider the transmission of electric power by a three-phase line.

Let P = power transmitted in watts
V = line voltage in volts
cos φ = power factor of the load
l = length of the line in metres
R = resistance per conductor in ohms
ρ = resistivity of conductor material
a = area of X-section of conductor

$$\text{Load current, } I = \frac{P}{\sqrt{3}\, V \cos\phi}$$

$$\text{Resistance/conductor, } R = \rho l / a$$

$$\text{Total power loss, } W = 3 I^2 R = 3\left(\frac{P}{\sqrt{3}\, V \cos\phi}\right)^2 \times \frac{\rho l}{a}$$

$$= \frac{P^2 \rho l}{V^2 \cos^2\phi\, a}$$

$$\therefore \quad \text{Area of X-section, } a = \frac{P^2 \rho l}{W V^2 \cos^2\phi}$$

Total volume of conductor material required

$$= 3\, a\, l = 3\left(\frac{P^2 \rho\, l}{W V^2 \cos^2\phi}\right) l$$

High Voltage Transmission System

Reduces volume of conductor material.

$$= \frac{3P^2 \rho l^2}{W V^2 \cos^2 \phi} \qquad \ldots(i)$$

It is clear from exp. (*i*) that for given values of *P*, *l*, ρ and *W*, the volume of conductor material required is inversely proportional to the square of transmission voltage and power factor. In other words, the greater the transmission voltage, the lesser is the conductor material required.

(*ii*) Increases transmission efficiency

$$\text{Input power} = P + \text{Total losses}$$

$$= P + \frac{P^2 \rho\, l}{V^2 \cos^2 \phi\, a}$$

Assuming J to be the current density of the conductor, then,

$$a = I/J$$

$$\therefore \quad \text{Input power} = P + \frac{P^2 \rho\, l\, J}{V^2 \cos^2 \phi\, I} = P + \frac{P^2 \rho\, l\, J}{V^2 \cos^2 \phi} \times \frac{1}{I}$$

$$= P + \frac{P^2 \rho\, l\, J}{V^2 \cos^2 \phi} \times \frac{{}^{*}\sqrt{3}\, V \cos \phi}{P}$$

$$= P + \frac{\sqrt{3}\, P\, J\, \rho\, l}{V \cos \phi} = P\left[1 + \frac{\sqrt{3}\; J\, \rho\, l}{V \cos \phi}\right]$$

$$\text{Transmission efficiency} = \frac{\text{Output power}}{\text{Input power}} = \frac{P}{P\left[1 + \frac{\sqrt{3}\; J\, \rho\, l}{V \cos \phi}\right]} = \frac{1}{\left[1 + \frac{\sqrt{3}\; J\, \rho\, l}{V \cos \phi}\right]}$$

$$= {}^{**}\left[1 - \frac{\sqrt{3}\; J\, \rho\, l}{V \cos \phi}\right] \text{ approx.} \qquad \ldots(ii)$$

As J, ρ and l are constants, therefore, transmission efficiency increases when the line voltage is increased.

(iii) Decreases percentage line drop

$$\text{Line drop} = I\,R = I \times \frac{\rho\, l}{a}$$

$$= I \times \rho\, l \times J/I = \rho\, l\, J \qquad [\because\ a = I/J]$$

$$\text{\%age line drop} = \frac{J\,\rho\, l}{V} \times 100 \qquad \ldots(iii)$$

As J, ρ and l are constants, therefore, percentage line drop decreases when the transmission voltage increases.

Major components of a power system

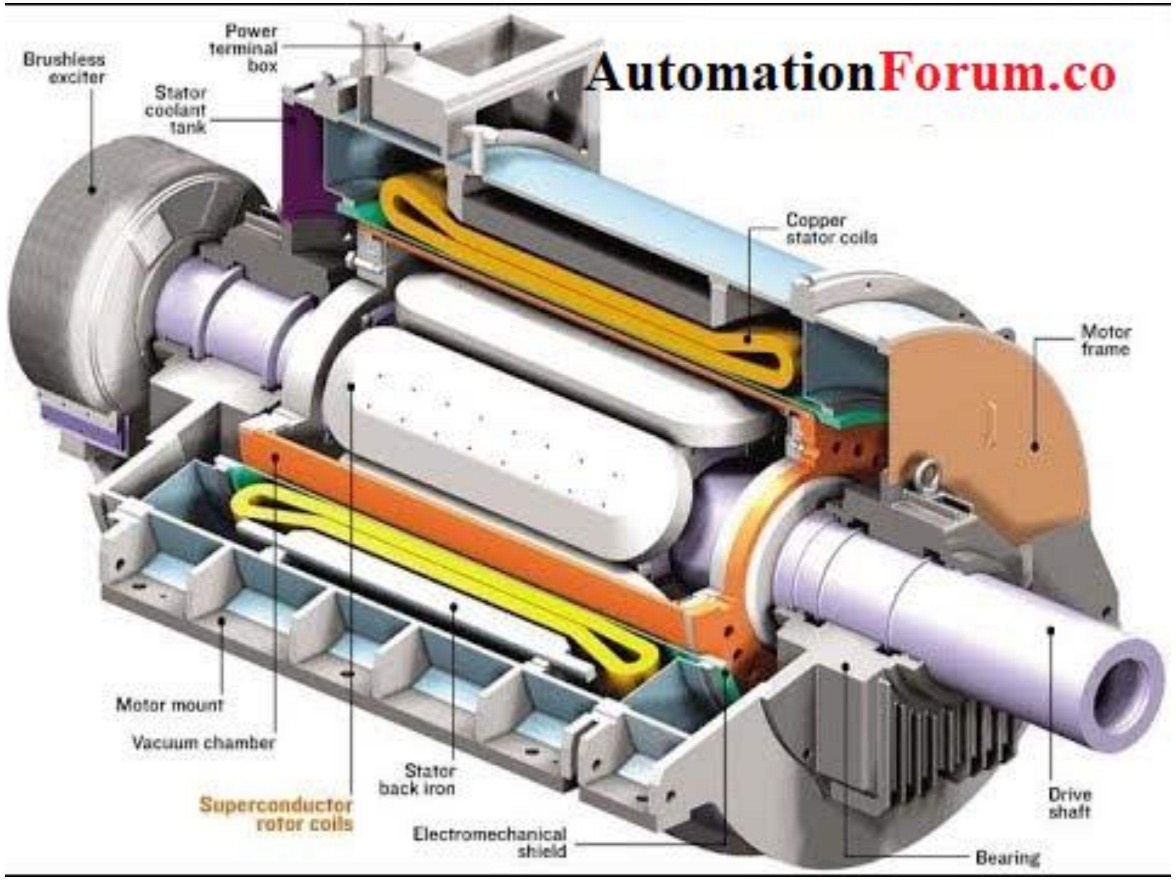
- Synchronous machines,
- transformers,
- transmission lines,
- static and dynamic loads

Synchronous machine

- Generally two types
  - Synchronous Generator
  - Synchronous Motor

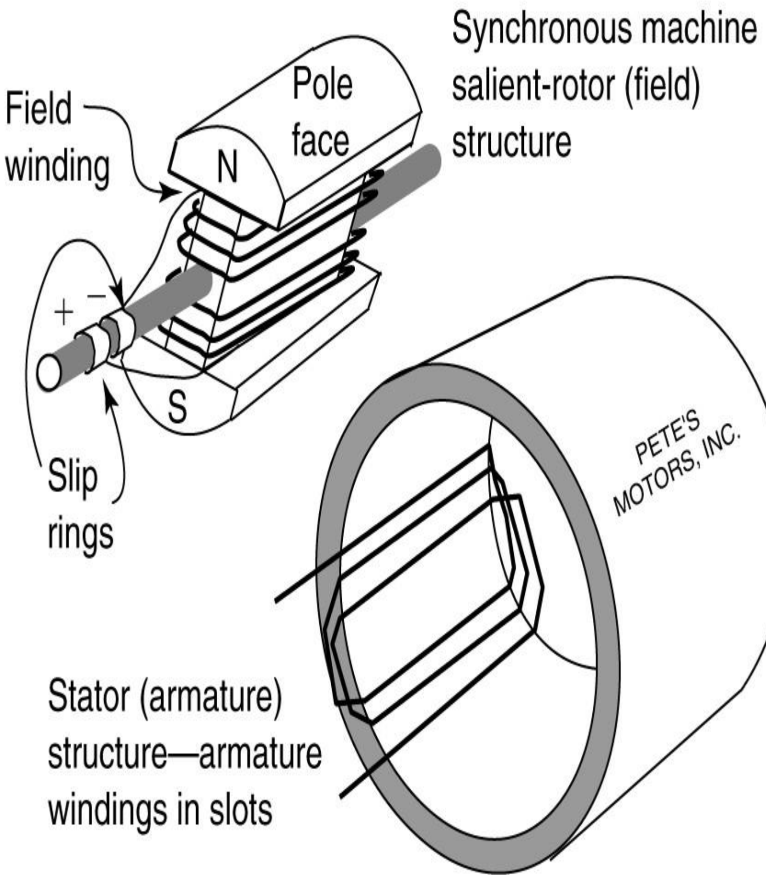
- Based on the Rotor Construction
  - Salient Pole
  - Non-Salient Pole

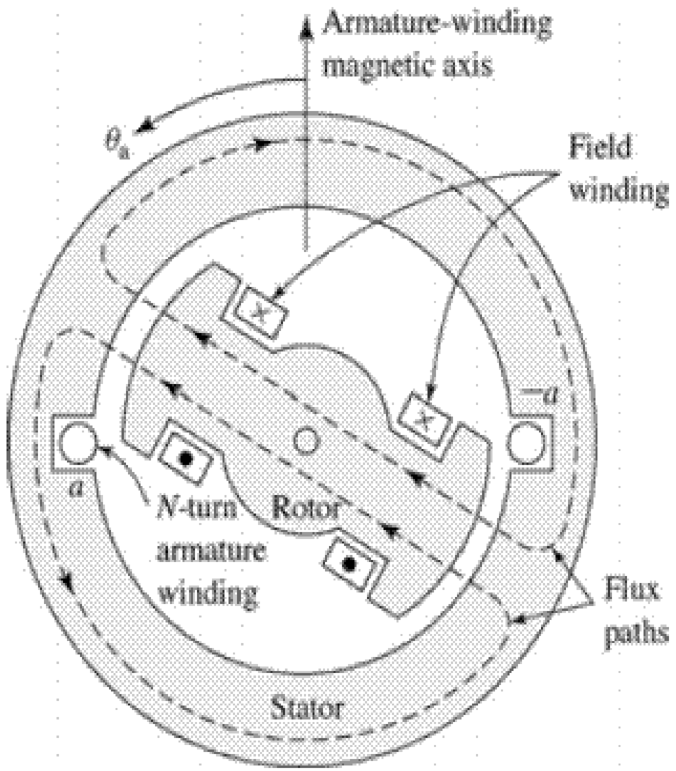
Synchronous Generator



Constructional Diagram

Synchronous Machine





Synchronous Machine

- **Synchronous Machine** constitutes of both synchronous motors as well as synchronous generators.

- The machine which converts mechanical power into AC electrical power is called as **Synchronous Generator** or Alternator. However, if the same machine can be operated as a motor is known as **Synchronous Motor.**

- A synchronous machine is just an electromechanical transducer which converts mechanical energy into electrical energy or vice versa.

- The fundamental phenomenon or law which makes these conversions possible are known as the **Law of Electromagnetic Induction**

Synchronous Machines

Synchronous generators form the principle source of electric energy in power systems. Many large loads are driven by synchronous motors.

Synchronous condensers are sometimes used as a means of providing reactive power compensation and controlling voltage.

The schematic diagram of a three-phase synchronous machine is given in fig 1.

The schematic of the cross section of a three-phase synchronous machine with one pair of field poles. The machine consists of two essential elements: the field and the armature.

The field winding carries direct current and produces a magnetic field which induces alternating voltages in the armature windings.

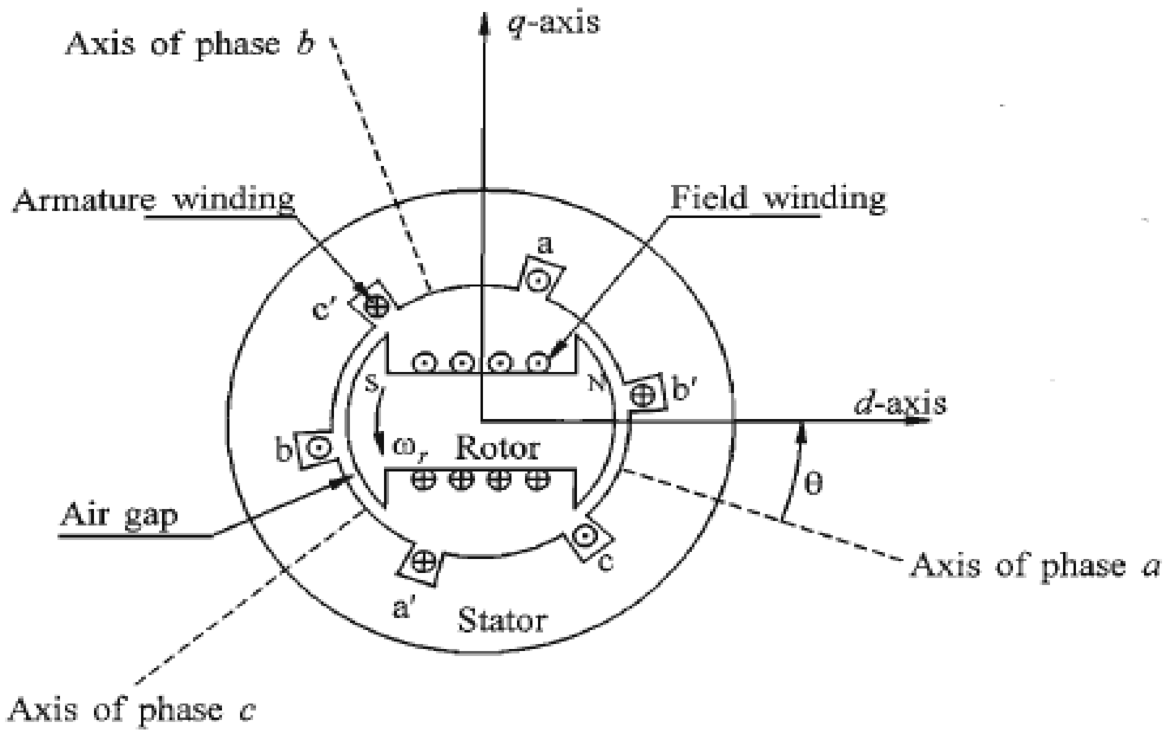
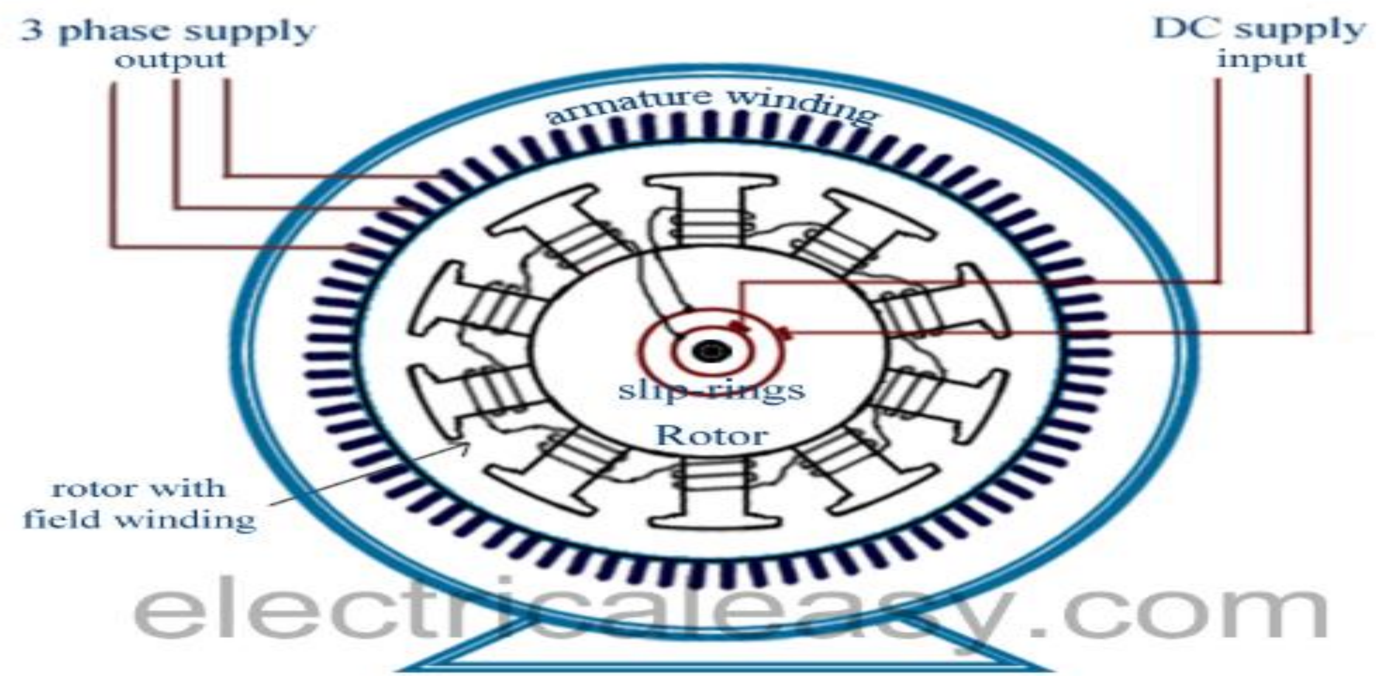


Fig 1 schematic fig of three phase synchronous machine

ALTERNATORS

Construction of AC Synchronous Generator (Alternator



Salient pole type alternator

The main parts of an alternator, obviously, consists of a stator and a rotor. But, unlike other machines, in most of the alternators, field exciters are rotating and the armature coil is stationary.

Construction:

- An alternator or AC generator (dynamo) is a device which convert mechanical energy to electrical energy. When we supply the magnetizing current by DC shunt generator through two slip rings (in recent alternators, they use electronic starting system instead of slip rings and commutators) because the field magnets are rotating. keep in mind that most alternators use a rotating magnetic field with a stationary armature.

- Stator: Unlike in a DC machine, the stator of an alternator is not meant to serve a path for magnetic flux. Instead, *the stator is used for holding armature winding*. The stator core is made up of lamination of steel alloys or magnetic iron, to minimize the eddy current losses.

- When the rotor rotates, the stator conductors which are static in case of alternator cut by magnetic flux , they have induced EMF produced in them (according to **Faraday's law of electromagnetic induction** which states that if a conductor or coil links with any changing flux, there must be an induced emf in it.

Construction of Stator & Rotor

- Stator- The armature is an iron ring , formed of laminations of special magnetic iron or steel alloy (silicon steel), having slots on its inner periphery to accommodate armature conductors and is called stator. The entire structure is held in a frame which is of caste steel .

- Rotor-it is similar to that of DC generator which is excited from a separate source of 125V or 250 V supply. The excitation is provided from a small DC shunt or compound generator known as exciter. The field system of alternator is rotated with armature ring and is known as rotor.

Working principle of an Alternator.

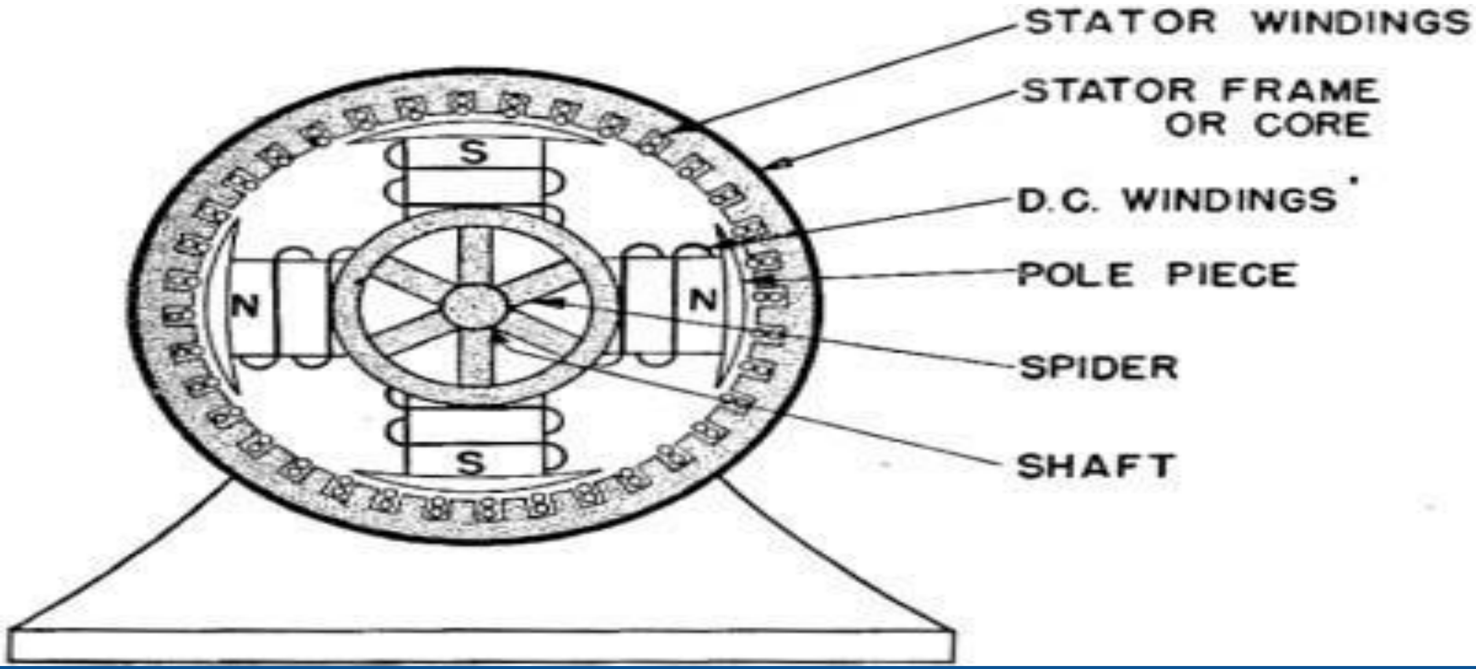
- Every rotating electrical machine works based on Faraday's law.
- Every electrical machine requires a magnetic field and a coil (Known as armature) with a relative motion between them.
- In case of an alternator, we supply electricity to pole to produce magnetic field and output power is taken from the armature.
- Due to relative motion between field and armature, the conductor of armatures cut the flux of magnetic field and hence there would be changing flux linkage with these armature conductors.

Working principle of an Alternator.

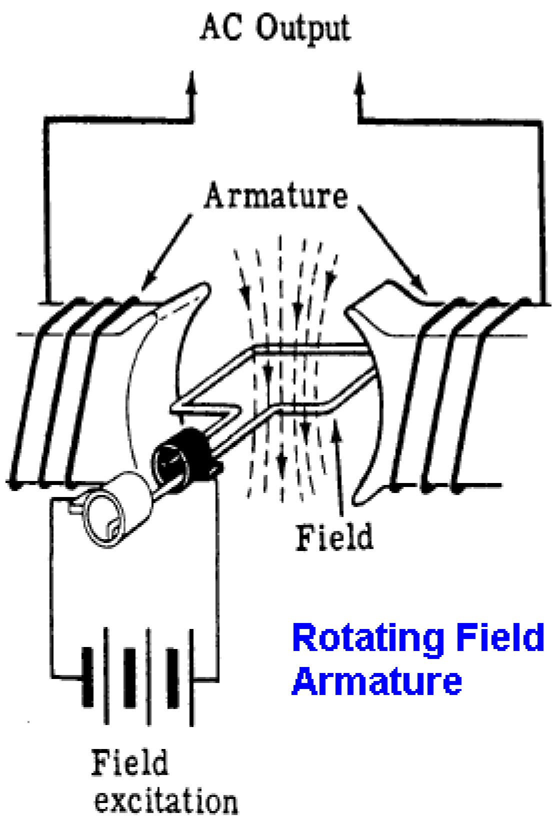
- According to Faraday's law of electromagnetic induction there would be an emf induced in the armature.
- Thus, as soon as the load is connected with armature terminals, there is a current flowing in the armature coil.
- As soon as current starts flowing through the armature conductor there is one reverse effect of this current on the main field flux of the alternator (or synchronous generator).
- This reverse effect is referred as **armature reaction in alternator or synchronous generator**.
- In other words the effect of armature (stator) flux on the flux produced by the rotor field poles is called armature reaction.

Working principle of Alternator

- Rotor coils are excited with a DC power source. Magnetic field produced around it would be as shown.
- The rotor is made to rotate by a prime mover. This makes the rotor flux also rotate along with it, at the same speed.
- Revolving magnetic flux now intersects the armature coils.
- This will generate an alternating E.M.F across the winding

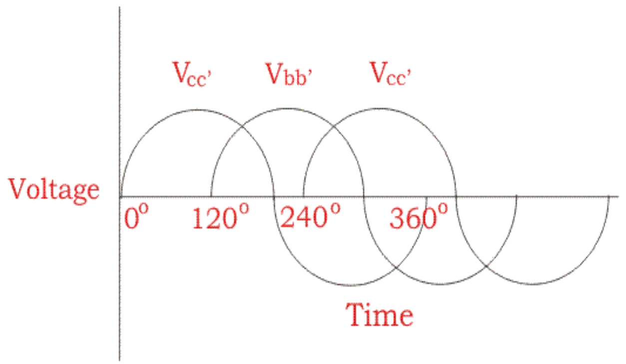


Working Principle:



Rotating Field Armature

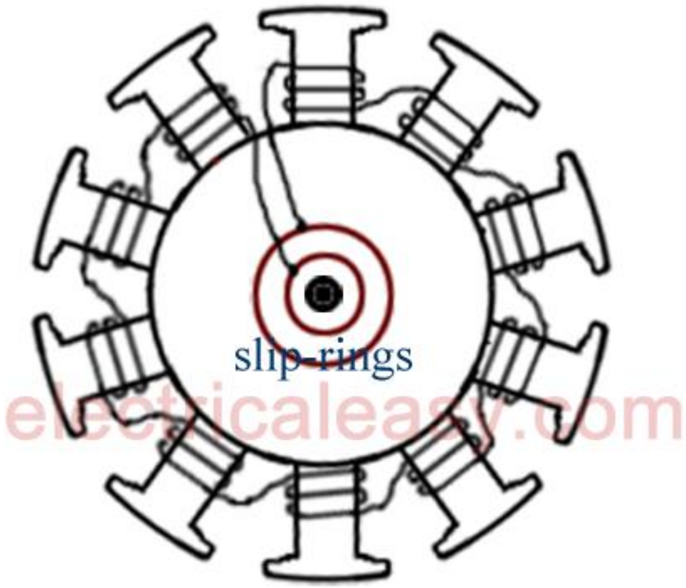
- The revolving-field type alternator has a stationary armature and a rotating magnetic field.
- The generated voltage can be connected directly to the load without having to pass across the slip rings and brushes.
- The voltage applied to generate the rotating field is a small DC voltage (called a “field excitation” voltage)



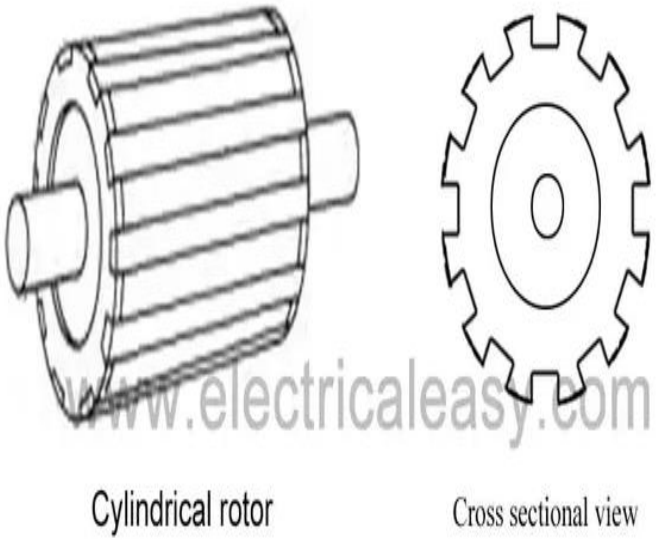
3 phase generated voltage

Types of alternators

- Salient pole type



- Non salient pole or smooth cylindrical type



Features of Salient pole type

- In **salient pole** type of rotor consist of large number of **projected poles** (salient poles) mounted on a magnetic wheel. **Construction of a salient pole rotor** is as shown in previous figure. The projected poles are made up from laminations of steel. The rotor winding is provided on these poles and it is supported by pole shoes. **Salient pole rotors** have large diameter and shorter axial length.
- They are generally used in lower speed electrical machines, say 100 RPM to 1500 RPM.
- As the rotor speed is lower, more number of poles are required to attain the required frequency. ($N_s = 120f / P$ therefore, $f = N_s*p/120$ i.e. frequency is proportional to number of poles). Typically number of salient poles is between 4 to 60.
- Flux distribution is relatively poor than non-salient pole rotor, hence the generated emf waveform is not as good as cylindrical rotor.
- Salient pole rotors generally need damper windings to prevent rotor oscillations during operation.
- **Salient pole synchronous generators** are mostly used in hydro power plants.

Features of Non salient pole type or smooth cylindrical type

- **Non-salient pole rotors** are cylindrical in shape having parallel slots on it to place rotor windings. It is made up of solid steel. The **construction of non-salient pole rotor** (**cylindrical rotor**) is as shown in figure above. Sometimes, they are also called as drum rotor. They are smaller in diameter but having longer axial length.
- **Cylindrical rotors** are used in high speed electrical machines, usually 1500 RPM to 3000 RPM.
- Windage loss as well as noise is less as compared to salient pole rotors.
- Their construction is robust as compared to salient pole rotors.
- Number of poles is usually 2 or 4.
- Damper windings are not needed in **non-salient pole rotors**.
- Flux distribution is sinusoidal and hence gives better emf waveform.
- **Non-salient pole rotors** are used in nuclear, gas and thermal power plants.

Advantages of Stationary Armature

- The field winding of an alternator is placed on the rotor and is connected to d.c. supply through two slip rings. The 3-phase armature winding is placed on the stator. This arrangement has the following advantages:
- It is easier to insulate stationary winding for high voltages for which the alternators are usually designed. Ii is because they are not subjected to centrifugal forces and also extra space is available due to the stationary arrangement of the armature.
- The stationary 3-phase armature can be directly connected to load without going through large, unreliable slip rings and brushes.
- Only two slip rings are required for d.c. supply to the field winding on the rotor. Since the exciting current is small, the slip rings and brush gear required are of light construction.
- Due to simple and robust construction of the rotor, higher speed of rotating d.c. field is possible. This increases the output obtainable from a machine of given dimensions.

Frequency of the Generated EMF:

In one complete revolution of the rotor, each of the 'N' and 'S' poles move past all the stator conductors. When one pair of 'N' and 'S' poles moves past on armature conductor, the e.m.f. induced in the conductor undergoes one full cycle. Therefore, in one full revolution of the field system, since $(P/2)$ pairs of poles sweep past every armature conductor, the e.m.f induced undergoes $P/2$ cycles.

In one second, there are $N/60$ full revolutions of the rotor,

Therefore, the number of cycles of the induced e.m.f./second

= No. of cycles/revolution × No. of revolutions/sec.

$$= \frac{P}{2} \times \frac{N}{60} = \frac{NP}{120} \text{ cycles per sec}$$

i.e., Frequency of Generated e.m.f, $\boxed{f = \frac{NP}{120} \text{ Hz}}$

$n = \frac{N}{60}$

If n = Revolutions per second, then the above expression may be written as

$$\boxed{f = \frac{nP}{2}}$$

n = rps, N = rpm

Emf Equation of an Alternator

The induced EMF can be found by the **EMF equation of the alternator** which as follow:
Let

- **P** = No. of poles
- **Z** = No. of Conductors or Coil sides in series/phase i.e. **Z = 2T**…Where T is the number of coils or turns per phase (Note that one turn or coil has two ends or sides)
- ***f*** = frequency of induced EMF in Hz
- **Φ** = Flux per pole (Weber)
- **N** = rotor speed (RPM)

f = Frequency of induced E.M.F. (in Hz)

N = Rotational speed of rotor (r.p.m.)

In one revolution of the rotor, each stator conductor is cut by $P\phi$ webers.

The time taken to complete one revolution is = 60/N second

$$\therefore \quad d\phi = P\phi \quad \text{and} \quad dt = \frac{60}{N} \text{ second}$$

So, average e.m.f. induced per conductor

$$= \frac{d\phi}{dt} = \frac{P\phi}{\frac{60}{N}} = \frac{\phi NP}{60} \text{ volt} \qquad \text{—(i)}$$

$$\text{Frequency, } f = \frac{NP}{120} \quad \text{or} \quad N = \frac{120f}{P}$$

Substituting this value of N in (i), we get

$$\text{Average e.m.f. induced per conductor} = \frac{\phi \cancel{P}}{60} \times \frac{120f}{\cancel{P}} = 2f\phi \text{ volts}$$

For Z conductors in series/phase, we have

Average e.m.f induced/phase = $2 f \phi Z$ volts ---(ii)

If T = No. of coils or turns per phase, then the no. of conductors, $Z = 2T$, which, when substituted in eqn (ii) gives

Average e.m.f. induced /phase = $4 f \phi T$ volts

One factor that should be considered is the *Form Factor* (k_f) of the space distribution of flux, assumed to be sinusoidal, in which case its value is 1.11, *i.e.*, $\boldsymbol{k_f = 1.11}$.

$\therefore$ R.M.S. value of e.m.f induced/phase

= Form Factor (k_f) $\times$ Average e.m.f. induced/phase

= $1.11 \times 4 f \phi T$ volts —(iii)

Had all the coils been full-pitched (instead of being short-pitched) and concentrated in one slot (instead of being distributed in several slots under poles), the expression (iii) above would have been the actual value of the induced voltage in a phase. However as this is not so, the induced e.m.f. is reduced in the ratio of the following two factors :

a) *Pitch Factor* $k_c = \cos\frac{\alpha}{2}$ β

$E_{ph} = 2.22 K_c K_d f \phi Z$ volts

b) *Distribution Factor*, $k_d = \dfrac{\sin\left(\frac{m\beta}{2}\right)}{m \sin\left(\frac{\beta}{2}\right)}$ n α

$Z \rightarrow 2.22$

$T \rightarrow 4.44$

$\therefore$ R.M.S. value of e.m.f induced/phase, actually available

$= 4.44 \; k_c \; k_d \; f \; \phi \; T$ volts

$E_{ph} = 4 \; k_f \; k_c \; k_d \; f \; \phi \; T$ volts $\quad (\because \; k_f = 1.11)$

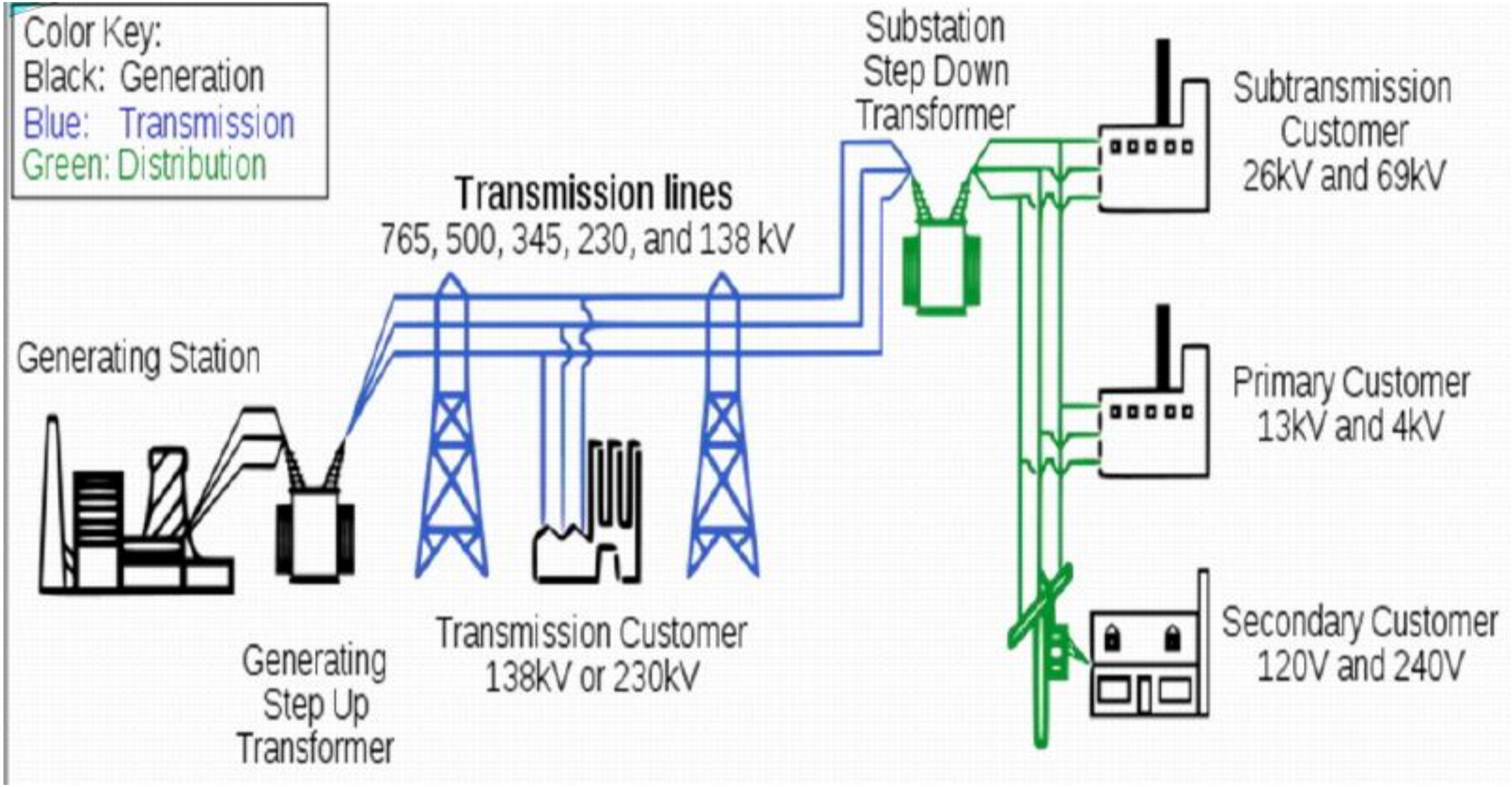
In the case of star-connected alternator, the line voltage is $\sqrt{3}$ times the phase voltage derived above.

$E_{trans} = 4.44 . f \phi_m N_1$

Transformers

- A transformer is a static device.
- The word ‘transformer’ comes form the word ‘transform’.
- **Transformer** is not an energy conversion device, but it is device that changes electrical power at one voltage level into electrical power at another voltage level through the action of magnetic field but with a proportional increase or decrease in the current ratings., without a change in frequency.
- It can be either to step-up or step down.


www.EdisonTechCenter.org
First transformer by
Ottó Bláthy, Miksa Déri, & Károly Zipernowsky
Budapest 1885
Displayed at the Deutsches Museum, Munich, Germany

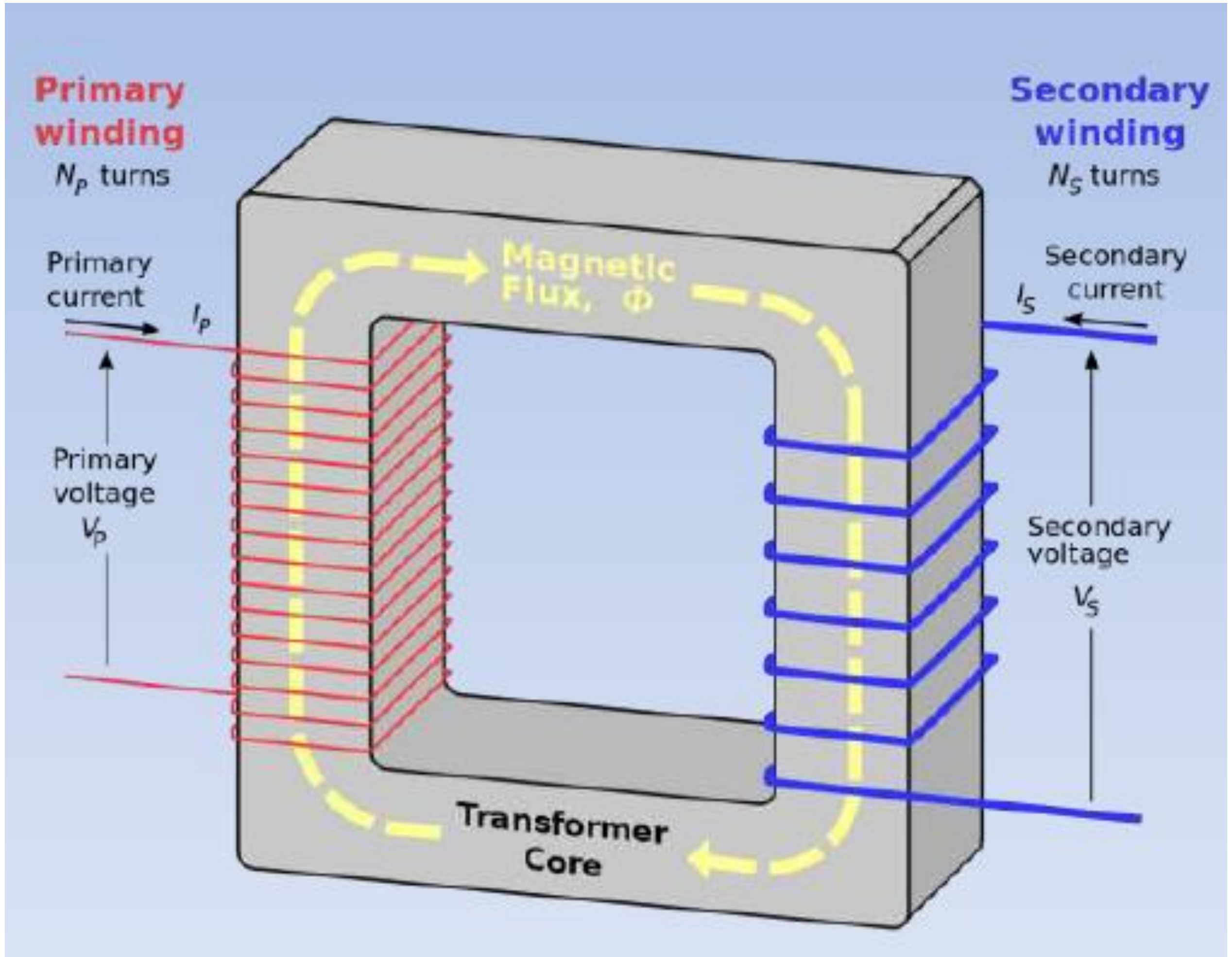

Color Key:
Black: Generation
Blue: Transmission
Green: Distribution
Transmission lines
765, 500, 345, 230, and 138 kV
Substation
Step Down
Transformer
Subtransmission
Customer
26kV and 69kV
Primary Customer
13kV and 4kV
Secondary Customer
120V and 240V
Generating Station
Generating
Step Up
Transformer
Transmission Customer
138kV or 230kV

Working Principle

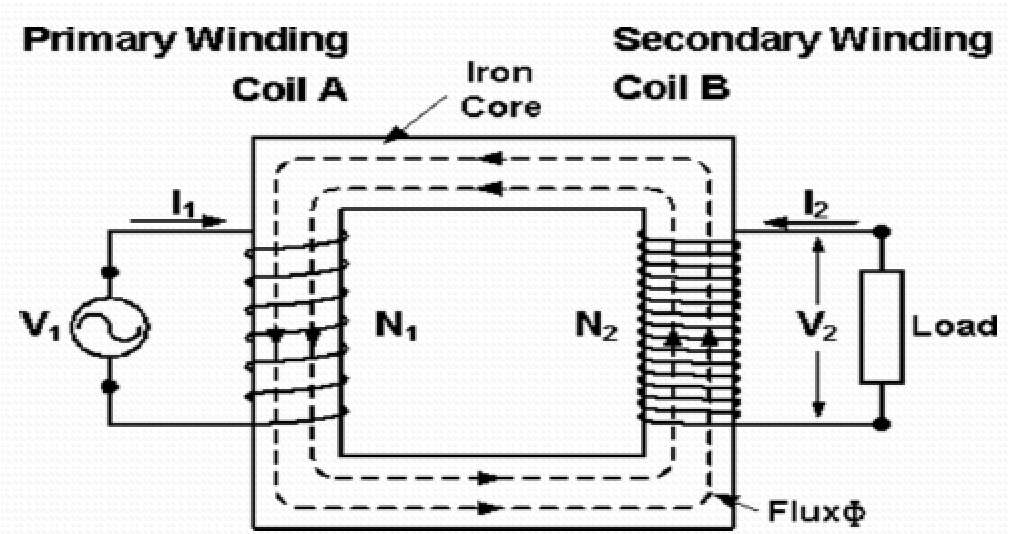
The transformer works in the principle of mutual induction

“The principle of mutual induction states that when the two coils are inductively coupled and if the current in coil change uniformly then the e.m.f. induced in the other coils. This e.m.f can drive a current when a closed path is provide to it.”

When the alternating current flows in the primary coils, a changing magnetic flux is generated around the primary coil. The changing magnetic flux is transferred to the secondary coil through the iron core
The changing magnetic flux is cut by the secondary coil, hence induces an e.m.f in the secondary coil


Primary winding
N_P turns
Primary current
I_P
Primary voltage
V_P
Magnetic Flux, Φ
Transformer Core
Secondary winding
N_S turns
Secondary current
I_S
Secondary voltage
V_S

- Now if load is connected to a secondary winding, this e.m.f drives a current through it.
- The magnitude of the output voltage can be controlled by the ratio of the no. of primary coil and secondary coil.
- **The frequency of mutually induced e.m.f as same that of the alternating source which supplying to the primary winding**



According to Faraday's laws, "The Rate of change of flux linkage with respect to time is directly proportional to the EMF induced in a conductor or coil".

$E = N\, d\phi / dt$

Where,

E = Induced EMF

N = the number of turns

$d\phi$ = Change in flux

dt = Change in time

Transformer Construction

- For the simple construction of a transformer, you must need two coils having mutual inductance and a laminated steel core. The two coils are insulated from each other and from the steel core. The device will also need some suitable container for the assembled core and windings, a medium with which the core and its windings from its container can be insulated.
- In order to insulate and to bring out the terminals of the winding from the tank, apt bushings that are made from either porcelain or capacitor type must be used.
- In all transformers that are used commercially, the core is made out of transformer sheet steel laminations assembled to provide a continuous magnetic path with minimum of air-gap included.

Transformer construction

- The steel should have high permeability and low hysteresis loss. For this to happen, the steel should be made of high silicon content and must also be heat treated.
- By effectively laminating the core, the eddy-current losses can be reduced. The lamination can be done with the help of a light coat of core plate varnish or lay an oxide layer on the surface. For a frequency of 50 Hertz, the thickness of the lamination varies from 0.35mm to 0.5mm for a frequency of 25 Hertz.

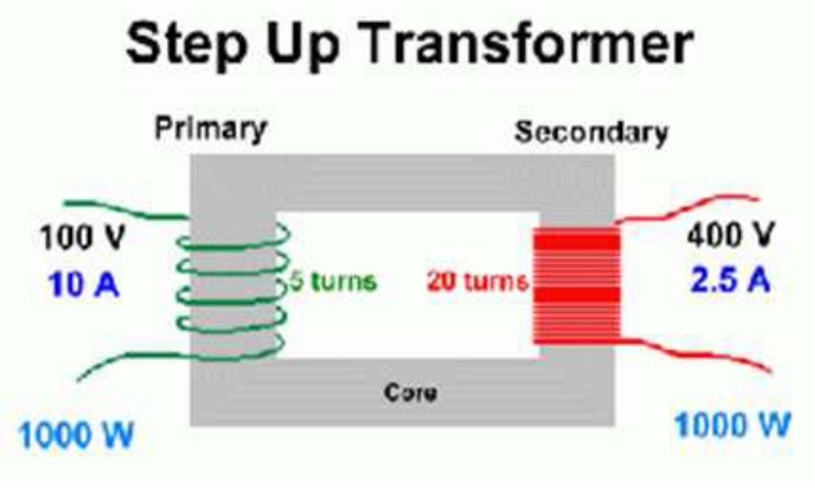
Classification of Transformers

- Based on Number of Phases
  - Single-Phase Transformers
  - Three-Phase Transformers
- Based on core Construction
  - Core Type
  - Shell Type
- Based on Cooling System
  - Self-Cooled
  - Air –Cooled
  - Oil-Cooled

- Based on Voltage Levels
  - Step-up Transformers
  - Step-down Transformers
- Based on **Core Medium Used**
  - Air Core
  - Iron Core
- Based on Winding Arrangement
  - Auto Transformer
  - Air –Cooled
  - Oil-Cooled

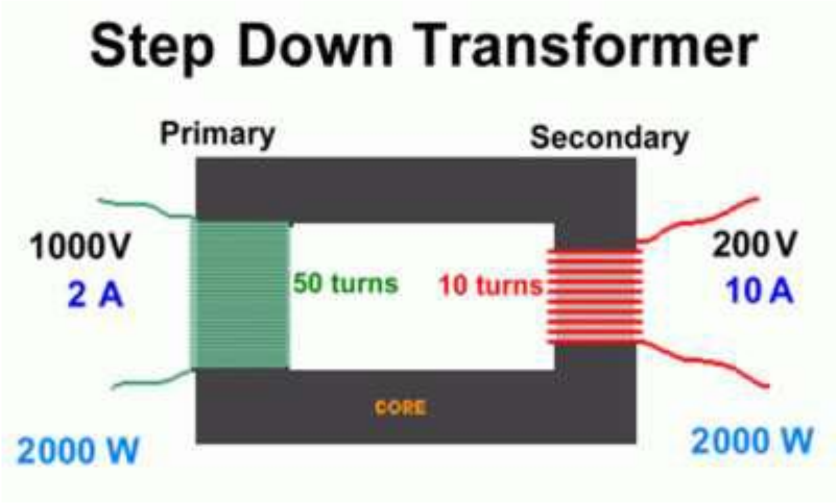
TYPES OF TRANSFORMER

- **STEP UP TRANSFORMER:**
- A transformer in which voltage across secondary is greater than primary voltage is called a step-up transformer (shown in figure)
- In this type of transformer, Number of turns in secondary coil is greater than that in Primary coil, so this creates greater voltage across secondary coil to get more output voltage than given through primary coil.



TYPES OF TRANSFORMER

- **STEPDOWN TRANSFORMER:**
- •A transformer in which voltage across secondary is lesser than primary voltage is called a step-down transformer (shown in figure)
- In this type of transformer, Number of turns in secondary coil is lesser than that in Primary coil, so this creates lesser voltage across secondary coil, so we get low output voltage than given through primary coil.

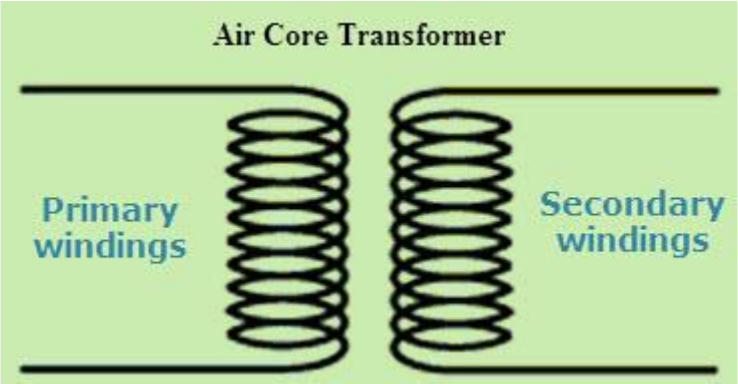


Transformers based on Core medium used

- Based on the medium placed between the primary and secondary winding the transformers are classified as Air core and Iron core

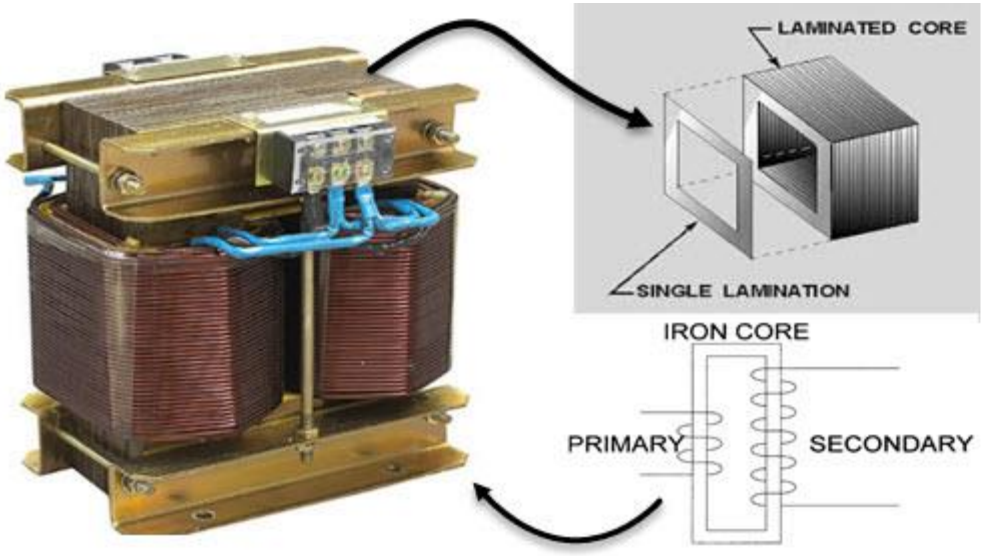
Air Core Transformers

- Both the primary and secondary windings are wound on a non-magnetic strip where the flux linkage between primary and secondary windings is through the air.
- Compared to iron core the mutual inductance is less in air core, i.e. the reluctance offered to the generated flux is high in the air medium. But the hysteresis and eddy current losses are completely eliminated in air-core type transformer



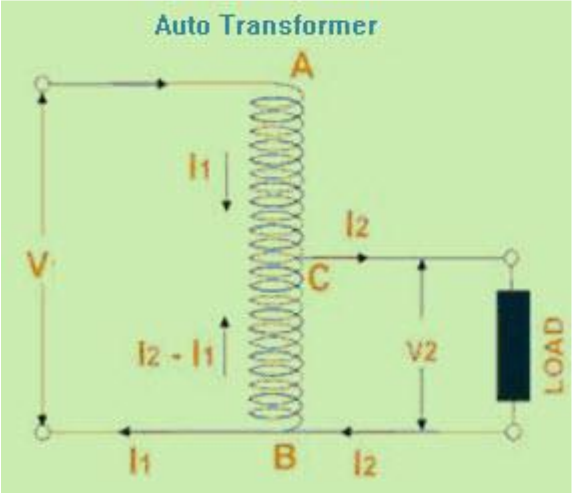
Iron Core Transformer

- Both the primary and secondary windings are wound on multiple iron plate bunch which provide a perfect linkage path to the generated flux. It offers less reluctance to the linkage flux due to the conductive and magnetic property of the iron. These are widely used transformers in which the efficiency is high compared to the air core type transformer.



Transformers Based on Winding Arrangement
Auto-Transformer

- Standard transformers have primary and secondary windings placed in two different directions, but in autotransformer windings, the primary and the secondary windings are connected to each other in series both physically and magnetically as shown in the figure below.
- On a single common coil which forms both primary and secondary winding in which voltage is varied according to the position of secondary tapping on the body of the coil windings.



Transformers Based on Usage

- According to the necessity, these are classified as
  - the power transformer,
  - distribution transformer
  - measuring transformer, and
  - protection transformer.

Power Transformer

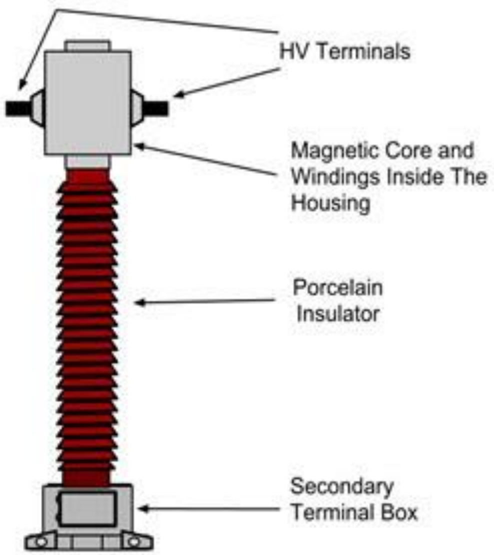
- The power transformers are big in size. They are suitable for high voltage (greater than 33KV) power transfer applications. It used in power generation stations and Transmission substation. It has high insulation level.

Distribution Transformer

- In order to distribute the power generated from the power generation plant to remote locations, these transformers are used. Basically, it is used for the distribution of electrical energy at low voltage is less than 33KV in industrial purpose and 440v-220v in domestic purpose.
- It works at low efficiency at 50-70%
- Small size
- Easy installation
- Low magnetic losses
- It is not always fully loaded

Measurement Transformer

- Used to measure the electrical quantity like voltage, current, power, etc. These are classified as potential transformers, current transformers etc.



Protection Transformers

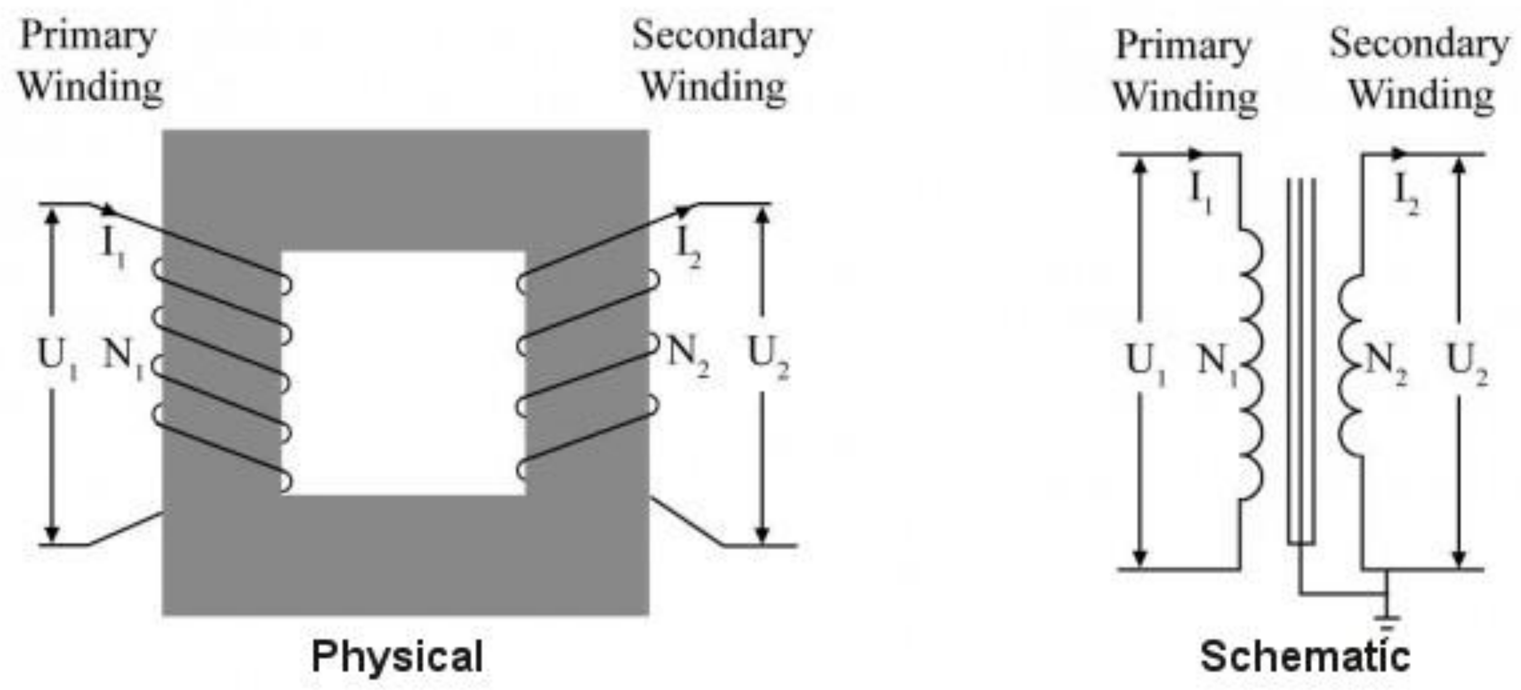
- This type of transformers is used in component protection purpose. The major difference between measuring transformers and protection transformers is the accuracy that means that the protection transformers should be accurate as compared to measuring transformers.

Transformers Based on the Place of Use

- These are classified as indoor and outdoor transformers. Indoor transformers are covered with a proper roof like as in the process industry. The outdoor transformers are nothing but distribution type transformers.

Transformers

- **Single Phase Transformer**



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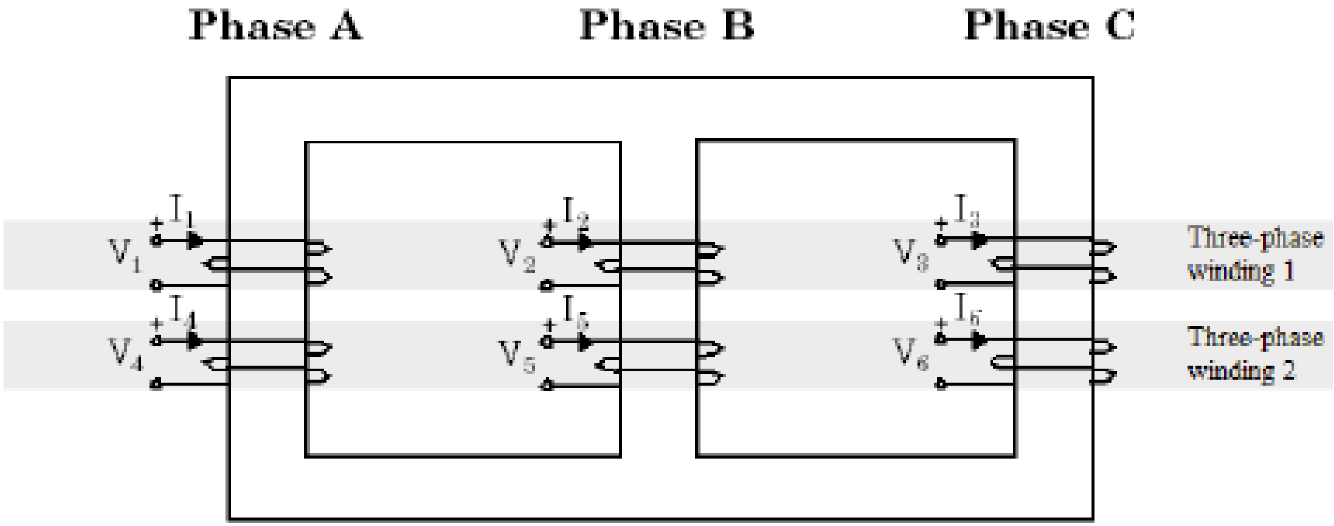
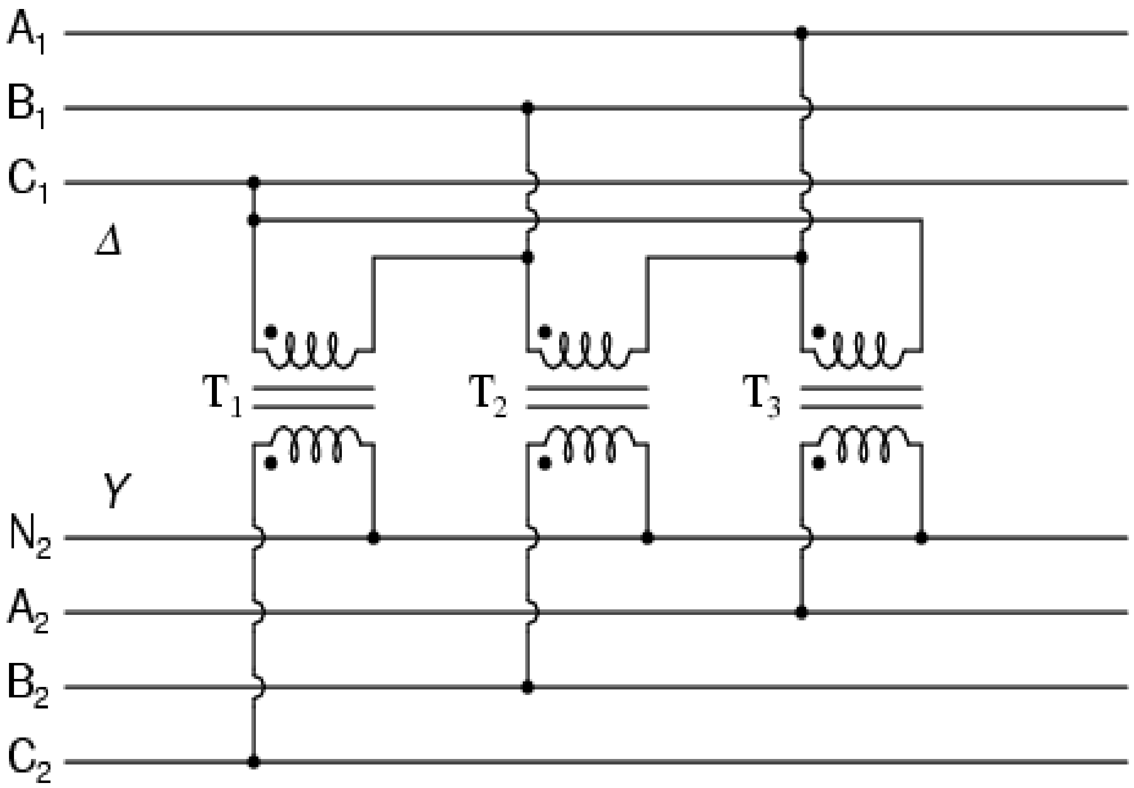
Transformers

- **Three Phase Transformer**





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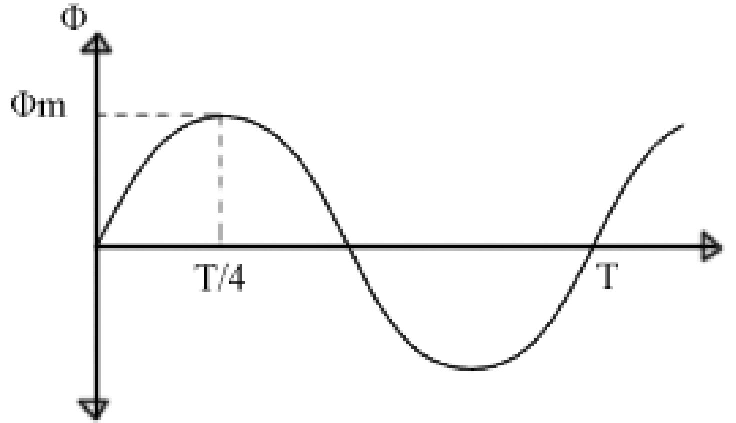
EMF equation of a transformer and Voltage Transformation Ratio

- In a transformer, source of alternating current is applied to the primary winding.
- Due to this, the current in the primary winding (called as magnetizing current) produces alternating flux in the core of transformer.
- This alternating flux gets linked with the secondary winding, and because of the phenomenon of mutual induction an emf gets induced in the secondary winding.
- Magnitude of this induced emf can be found by using the following **EMF equation of the transformer**.

EMF equation of the Transformer



- Let,
  N_1 = Number of turns in primary winding
  N_2 = Number of turns in secondary winding
  Φ_m = Maximum flux in the core (in Wb) = (B_m x A)
  f = frequency of the AC supply (in Hz)
- As, shown in the fig., the flux rises sinusoidally to its maximum value Φ_m from 0.
- It reaches to the maximum value in one quarter of the cycle i.e in T/4 sec
  - (where, T is time period of the sin wave of the supply = 1/f).

Therefore, average rate of change of flux = $\Phi_m / _{(T/4)}$ = $\Phi_m / _{(1/4f)}$

Therefore, average rate of change of flux = 4f Φ_m .... (Wb/s).

Now,

Induced emf per turn = rate of change of flux per turn

Therefore, average emf per turn = 4f Φ_m ....(Volts).

Now, we know, Form factor = RMS value / average value

Therefore, RMS value of emf per turn = Form factor X average emf per turn.

As, the flux Φ varies sinusoidally, form factor of a sine wave is 1.11

Therefore, RMS value of emf per turn = 1.11 x 4f Φ_m = 4.44f Φ_m.

- RMS value of induced emf in whole primary winding (E_1) = RMS value of emf per turn X Number of turns in primary winding

$E_1 = 4.44f\ N_1\ \Phi_m$ .... eq 1

Similarly, RMS induced emf in secondary winding (E_2) can be given as

$E_2 = 4.44f\ N_2\ \Phi_m$. .... eq 2

from the above equations 1 $\frac{E_1}{N_1} = \frac{E_2}{N_2} = 4.44f\ \Phi m$

from the above equations 1 and 2,

$$\frac{E_1}{N_1} = \frac{E_2}{N_2} = 4.44f\,\Phi m$$

This is called the **emf equation of transformer**, which shows, emf / number of turns is same for both primary and secondary winding.

For an ideal transformer on no load, $E_1 = V_1$ and $E_2 = V_2$.
where, V_1 = supply voltage of primary winding
V_2 = terminal voltage of secondary winding

Voltage Transformation Ratio (K)

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

- Where, K = constant

This constant K is known as **voltage transformation ratio**.

If $N_2 > N_1$, i.e. $K > 1$, then the transformer is called step-up transformer.

- If $N_2 < N_1$, i.e. $K < 1$, then the transformer is called step-down transformer.

Single phase Induction Motor

The single phase motors are simple in construction, cheap in cost, reliable and easy to repair and maintain.

Due to all these advantages, the single phase motor finds its application in vacuum cleaners, fans, washing machines, centrifugal pumps, blowers, washing machines, etc.

Single phase Induction Motor

Like any other electrical motor asynchronous motor also have two main parts namely rotor and stator.

Stator:

As its name indicates stator is a stationary part of induction motor. A single phase AC supply is given to the stator of single phase induction motor.

Rotor:

The rotor is a rotating part of an induction motor. The rotor connects the mechanical load through the shaft. The rotor in the single-phase induction motor is of squirrel cage rotor type.

Single phase Induction Motor

The **construction of single phase induction motor** is almost similar to the squirrel cage three-phase induction motor.

But in case of a single phase induction motor, the stator has two windings instead of one three-phase winding in three phase induction motor.

Working principle of IM:

- NOTE: We know that for the working of any electrical motor whether its AC or DC motor, we require two fluxes as the interaction of these two fluxes produced the required torque.
- When we apply a single phase AC supply to the stator winding of single phase induction motor, the alternating current starts flowing through the stator or main winding. This alternating current produces an alternating flux called main flux. This main flux also links with the rotor conductors and hence cut the rotor conductors.
- According to the Faraday's law of electromagnetic induction, emf gets induced in the rotor. As the rotor circuit is closed one so, the current starts flowing in the rotor. This current is called the rotor current. This rotor current produces its flux called rotor flux. Since this flux is produced due to the induction principle so, the motor working on this principle got its name as an induction motor. Now there are two fluxes one is main flux, and another is called rotor flux. These two fluxes produce the desired torque which is required by the motor to rotate.

Types of Induction Motor:

- Depending upon the methods for making asynchronous motor as Self Starting Motor, there are mainly four types of single phase induction motor namely,

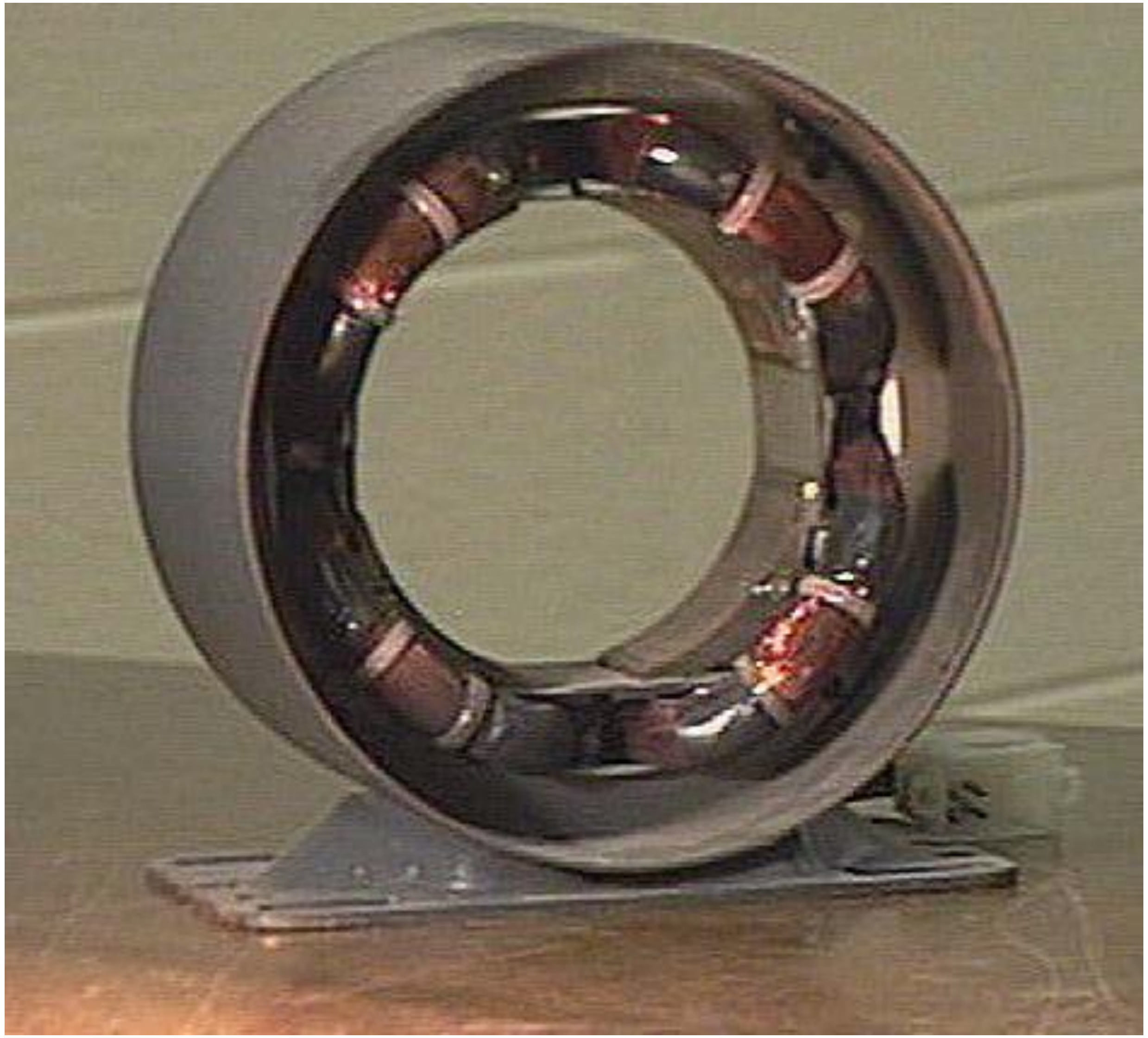
- 1. Split phase induction motor,
- 2. Capacitor start inductor motor,
- 3. Capacitor start capacitor run induction motor,
- 4. Shaded pole induction motor.
- 5. Permanent split capacitor motor or single value capacitor motor.

DC Motor Construction

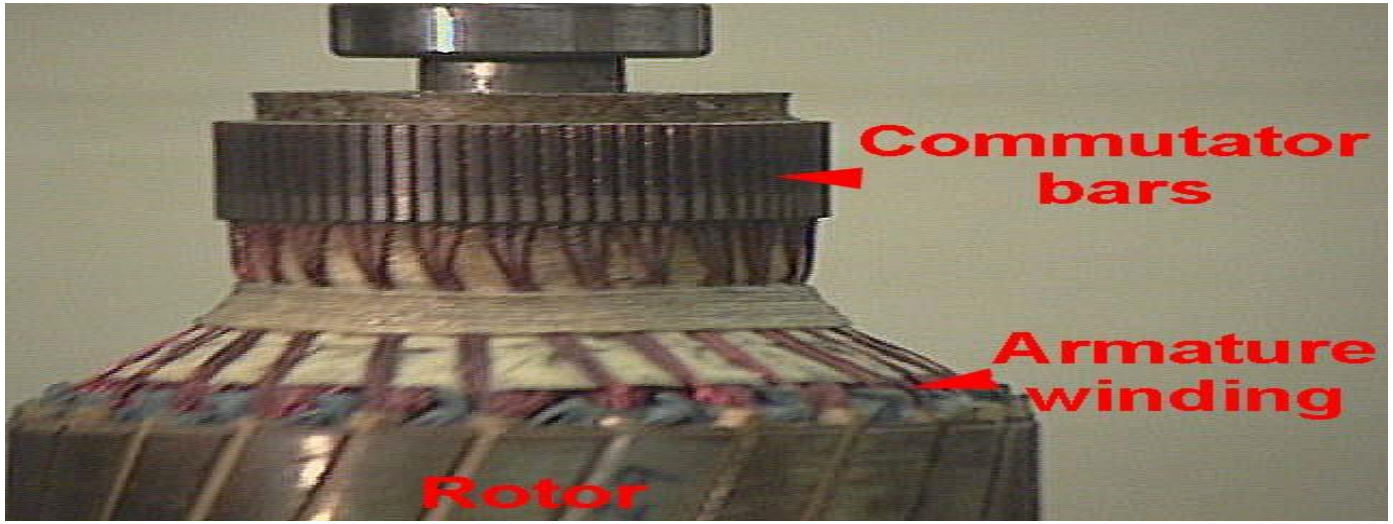
Main Parts:

- **Yoke**
- **Poles & Pole shoes**
- **Field Windings**
- **Armature Core**
- **Armature Winding**
- **Commutator**
- **Brushes**

Field winding

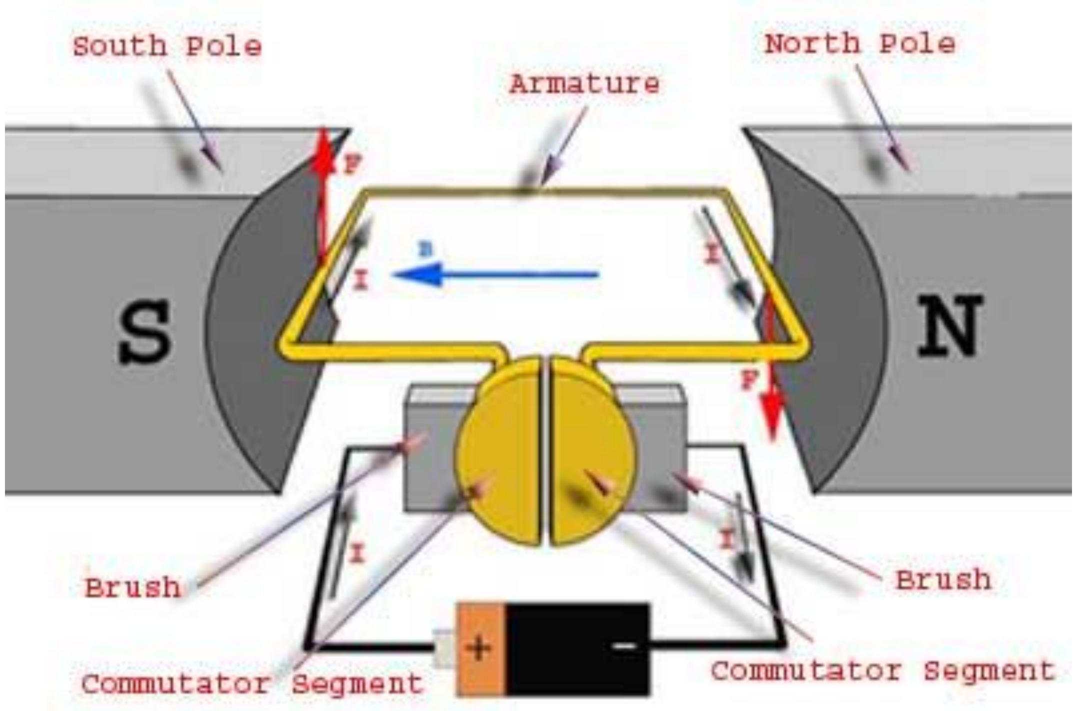


Rotor and rotor winding



DC Motor

Working:

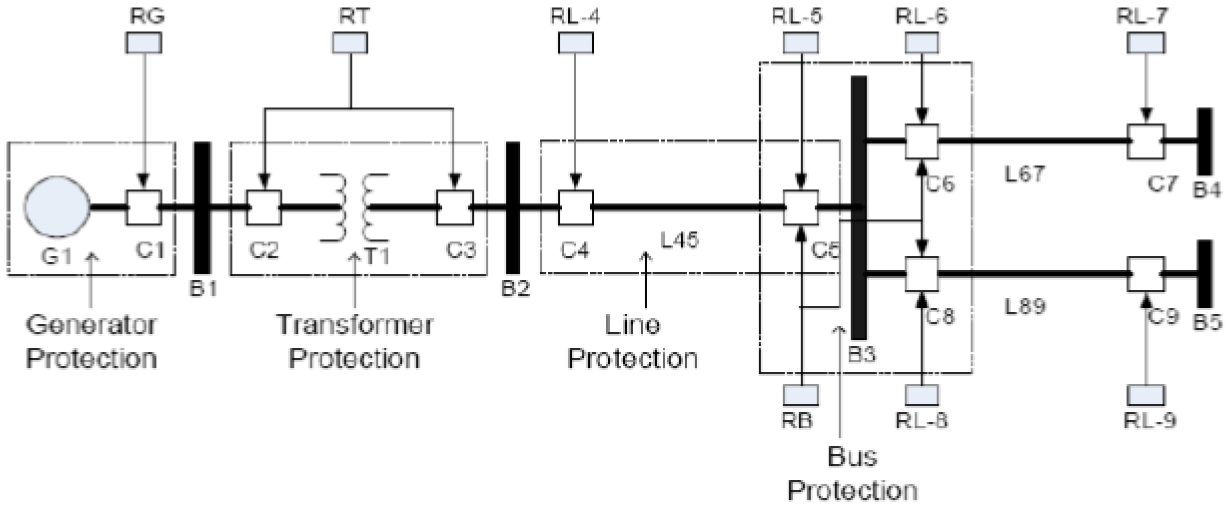


OBJECTIVE OF POWER SYSTEM PROTECTION

- To isolate a faulty section of electrical power system from rest of the live system so that the rest portion can function satisfactorily without any severer damage due to fault current.

COMPONENTS OF POWER SYSTEM NEEDS TO BE PROTECTED.

- GENERATORS
- TRANSFORMERS
- BUS-BARS
- TRANSMISSION LINES



Switch Gear

The apparatus used for switching, controlling and protecting the electrical circuits and equipment is known as switchgear.

They contain :-

- Switches
- Fuse
- Circuit breaker
- Relays etc.

FUSES

- A **fuse** is a type of low resistance resistor that acts as a sacrificial device to provide overcurrent protection.
- A fuse interrupts an excessive current so that further damage by overheating or fire is prevented.

Fuse Wire Rating

The melting point and specific resistance of different metals used for fuse wire

Metal	Melting point	Specific Resistance
Aluminium	240^{0}F	2.86 μ Ω - cm
Copper	2000^{0}F	1.72 μ Ω - cm
Lead	624^{0}F	21.0 μ Ω - cm
Silver	1830^{0}F	1.64 μ Ω - cm
Tin	463^{0}F	11.3 μ Ω - cm
Zinc	787^{0}F	6.1 μ Ω - cm

Electrical Fuse

- **“An electrical fuse is a weakest part of an electrical circuit which breaks when more than predetermined current flows through it. “**
- If fault occurs in the network, the network current crosses the rated limits.
- This high current may have very high thermal effect which will cause a **permanent damage** to the valuable equipment connected in the electrical network.
- So this high fault current should be interrupted as fast as possible.

Fuse Wire

The function of **fuse wire** is to carry the normal current without excessive heating but more than normal current when pass through **fuse wire**, it **rapidly heats up and melts**.

Circuit Breaker

- A **switching device** which can be operated **manually as well as automatically** for controlling and protection of electrical power system respectively
- During short circuit fault or any other types of electrical fault these equipment as well as the power **network suffer a high stress of fault current** in them which may damage the equipment and networks permanently.
- For saving these equipment and the power networks the **fault current should be cleared from the system as quickly** as possible.
- So for timely disconnecting and reconnecting different parts of power system network for protection and control, there must be some special type of switching devices which can be operated safely under huge current carrying condition.
- During interruption of huge current, there would be large arcing in between switching contacts, so care should be taken to quench these arcs in circuit breaker in safe manner.

CIRCUIT BREAKER

A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by Overcurrent/overload or short circuit. Its basic function is to interrupt current flow after Protective relays detect faults condition.

- The commonly-available preferred values for the rated current are 6 A, 10 A, 13 A, 16 A, 20 A, 25 A, 32 A, 40 A, 50 A, 63 A, 80 A, 100 A and 125 A.
- The circuit breaker is labelled with the rated current in amperes, but without the unit symbol "A". Instead, the ampere figure is preceded by a letter "B", "C" or "D", which indicates the instantaneous tripping current

Type	Tripping Current	Operating Time
Type B	3 To 5 time full load current	0.04 To 13 Sec
Type C	5 To 10 times full load current	0.04 To 5 Sec
Type D	10 To 20 times full load current	0.04 To 3 Sec

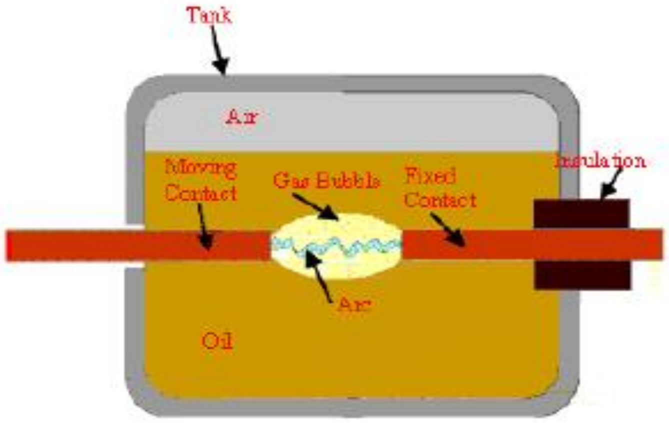
Types of Circuit Breakers

According to their arc quenching media the circuit breaker can be divided as-

- Oil circuit breaker.
- Air circuit breaker.
- SF_6 circuit breaker.
- Vacuum circuit breaker.

According to the voltage level of installation types of circuit breaker are referred as-

- High voltage circuit breaker.
- Medium voltage circuit breaker.
- Low voltage circuit breaker.



Conceptual view of Bulk Oil Circuit Breaker

Low-Voltage Circuit Breaker

- Low-voltage (less than 1,000 V_{AC}) types are common in domestic, commercial and industrial application, and include:
- MCB (Miniature Circuit Breaker)—rated current not more than 100 A. Trip characteristics normally not adjustable. Thermal or thermal-magnetic operation.

Working Principle

- The circuit breaker mainly consists of **fixed contacts and moving contacts**.
- In normal "on" condition of circuit breaker, these two contacts are physically connected to each other due to applied mechanical pressure on the moving contacts.
- There is an arrangement **stored potential energy** in the **operating mechanism of circuit breaker** which is realized if switching signal given to the breaker. The potential energy can be stored in the circuit breaker by different ways like by deforming metal spring, by compressed air, or by hydraulic pressure.
- The circuit breaker has to **carry large rated or fault power**.
- Due to this large power there is always **dangerously high arcing** between moving contacts and fixed contact during operation of circuit breaker.

Fuse or Circuit Breaker

Fuses

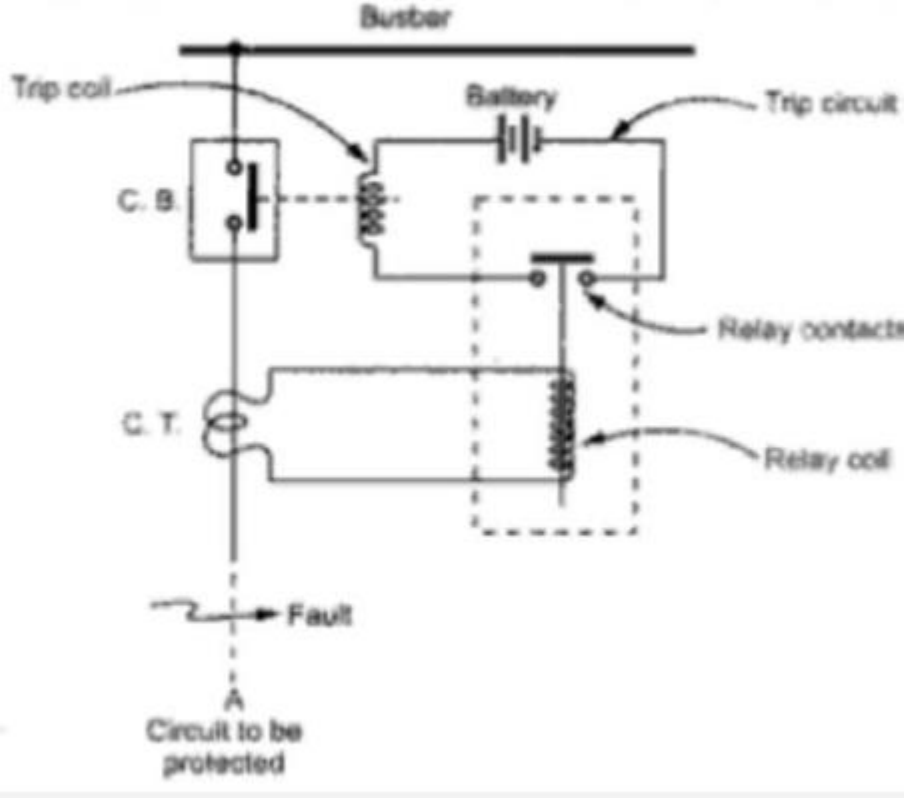
–Component Protection often Possible
–Replacement required
–Not suitable for high ratings

Circuit Breakers

–Arc Flash Mitigation
–Selective Coordination
–Maintenance Requirements
–High reliability
–Suitable for all ratings
–Costly

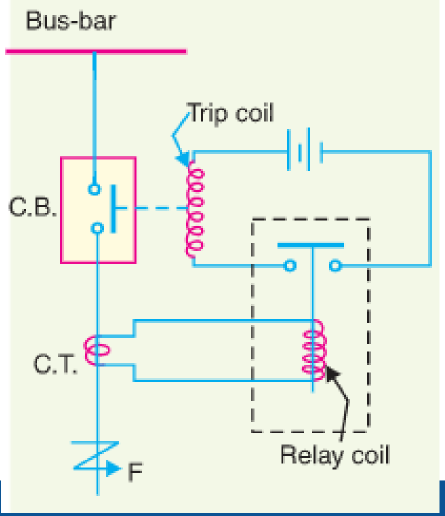
RELAYS

- A **protective relay** is a compact device designed to sense the abnormal condition and trip a circuit breaker when a fault is detected



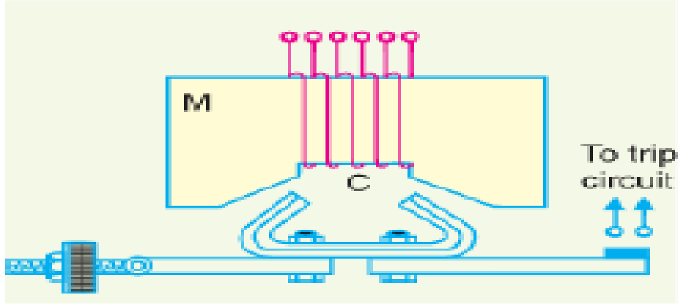
Protective Relays

- A protective relay is a device that detects the fault and initiates the operation of the circuit breaker to isolate the defective element from the rest of the system.
- The relays detect the abnormal conditions in the electrical circuits by constantly measuring the electrical quantities which are different under normal and fault conditions.

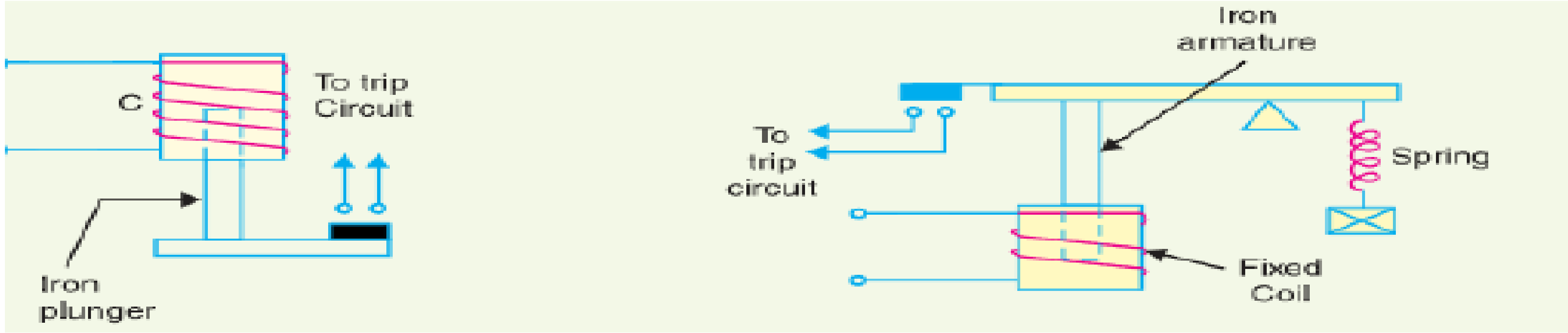


Basic Relays

- Electromagnetic attraction
  - Attracted armature type relay



  - Solenoid type relay.

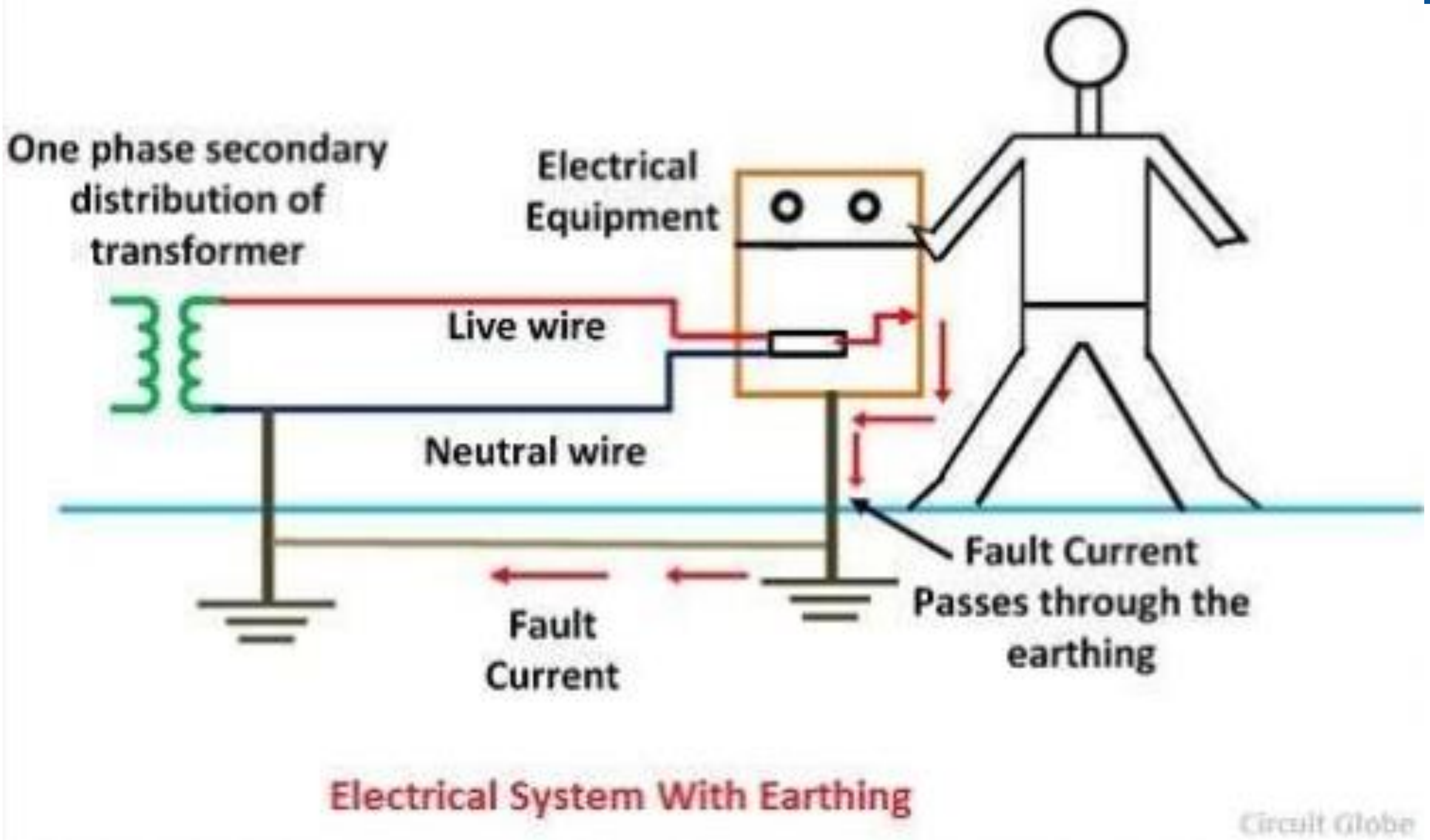


- The armature is balanced by a counterweight and carries a pair of spring contact fingers at its free end.
- Under normal operating conditions, the current through the relay coil C is such that counter-weight holds the armature in the position shown.
- when a short-circuit occurs, the current through the relay coil increases sufficiently and the relay armature is attracted upwards.

Earthing and Grounding

WHAT IS GROUNDING OR EARTHING?

" To connect the metallic (conductive) Parts of an Electric appliance or installations to the earth (ground) is called Earthing or Grounding " To connect the metallic parts of electric machinery and devices to the earth plate or earth electrode (which is buried in the moisture earth) through a thick conductor wire (which has very low resistance) for safety purpose is known as ***Earthing or grounding.***


One phase secondary distribution of transformer
Electrical Equipment
Live wire
Neutral wire
Fault Current
Fault Current Passes through the earthing
Electrical System With Earthing
Circuit Globe

EARTHING	GROUNDING
Earthing means connecting the dead part(the one which does not carry current under normal condition) to the earth(ground).	Grounding means connecting the live part(the one which carry current under normal condition) to the earth (ground) .
Earthing is to ensure safety or protection of electrical equipment and living being by discharging electrical energy to earth (ground).	Grounding provides a safe return path around the electrical system of your house thus minimizing damage from occurrences like lightning...
For example electrical equipment frames etc.	For example grounding of neutral point of a star connected transformer.

Finally There is **no major difference** between earthing and Grounding, both means "***Connecting an electrical circuit or device to the Earth***"

WHY EARTHING IS IMPORTANT?

- •The primary purpose of earthing is to avoid or minimize the danger of electrocution, fire due to earth leakage of current through undesired path and to ensure that the potential of a current carrying conductor does not rise with respect to the earth than its designed insulation.
- •When the metallic part of electrical appliances comes in contact with a live wire, maybe due to failure of installations or failure in cable insulation, the metal become charged and static charge accumulates on it**. *If a person touches such a charged metal, the result is a severe shock.***

BASIC NEEDS OF EARTHING

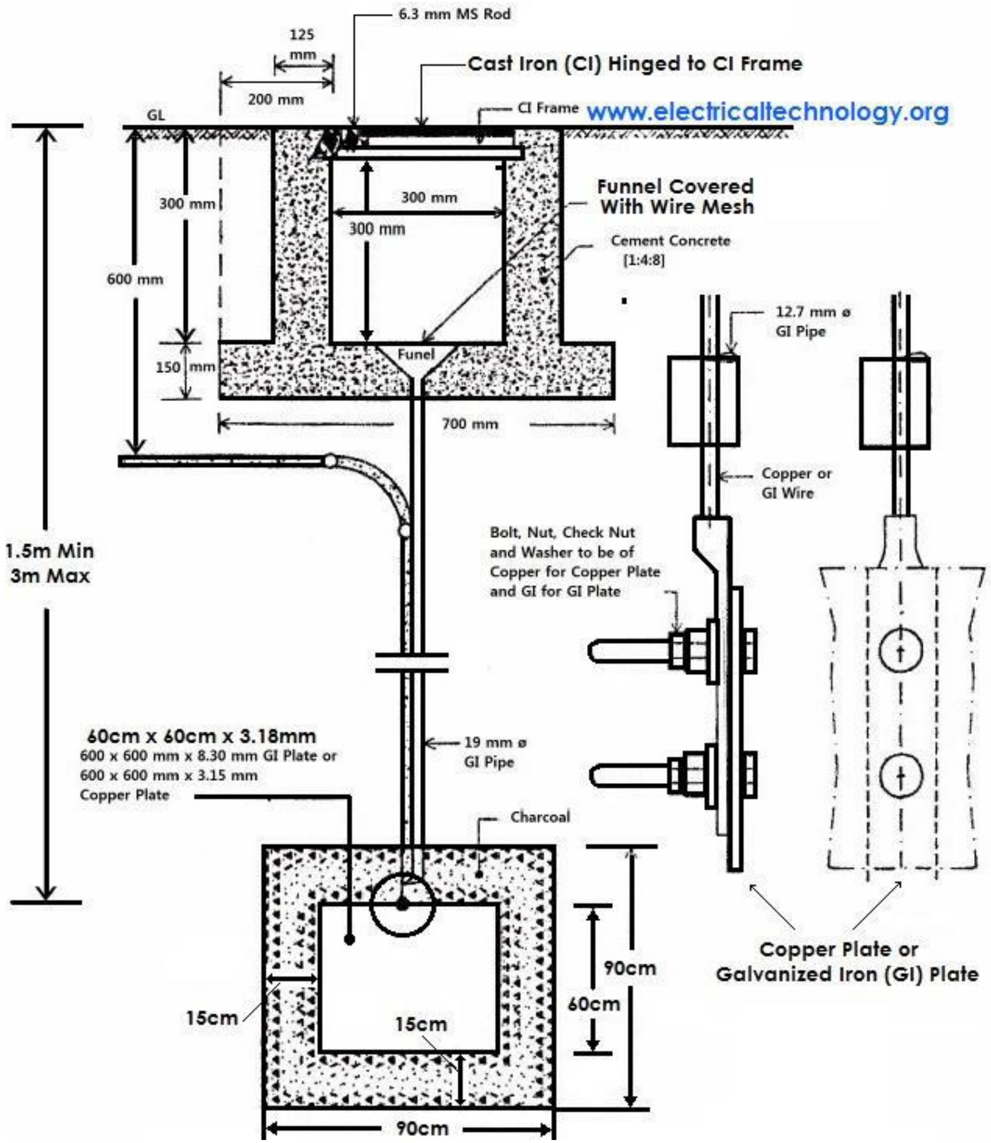
- •To ***protect human lives*** as well as provide ***safety to electrical devices and appliances*** from leakage current.
- •To keep voltage as constant in the healthy phase (If fault occurs on any one phase).
- •To protect Electric system and buildings ***from lighting***.
- •To serve as a return conductor in electric traction system and communication.
- •To avoid the ***risk of fire*** in electrical installation systems.

POINTS TO BE EARTHED

- •***Earth pin of 3-pin lighting plug sockets*** and 4-pin power plug should be efficiently and permanently earthed.
- •***All metal casing or metallic coverings containing or protecting any electric supply line or apparatus such as GI pipes*** and conduits enclosing VIR or PVC cables, iron clad switches, iron clad distribution fuse boards etc. should be earthed (connected to earth).
- •The ***frame of every generator, stationary motors and metallic parts of all transformers*** used for controlling energy should be earthed by two separate and yet distinct connections with the earth.
- •In a dc 3-wire system, the ***middle conductors should be earthed*** at the generating station.
- •Stay wires that are for overhead lines should be connected to earth by connecting at least one strand to the earth wires.

METHODS OF EARTHING

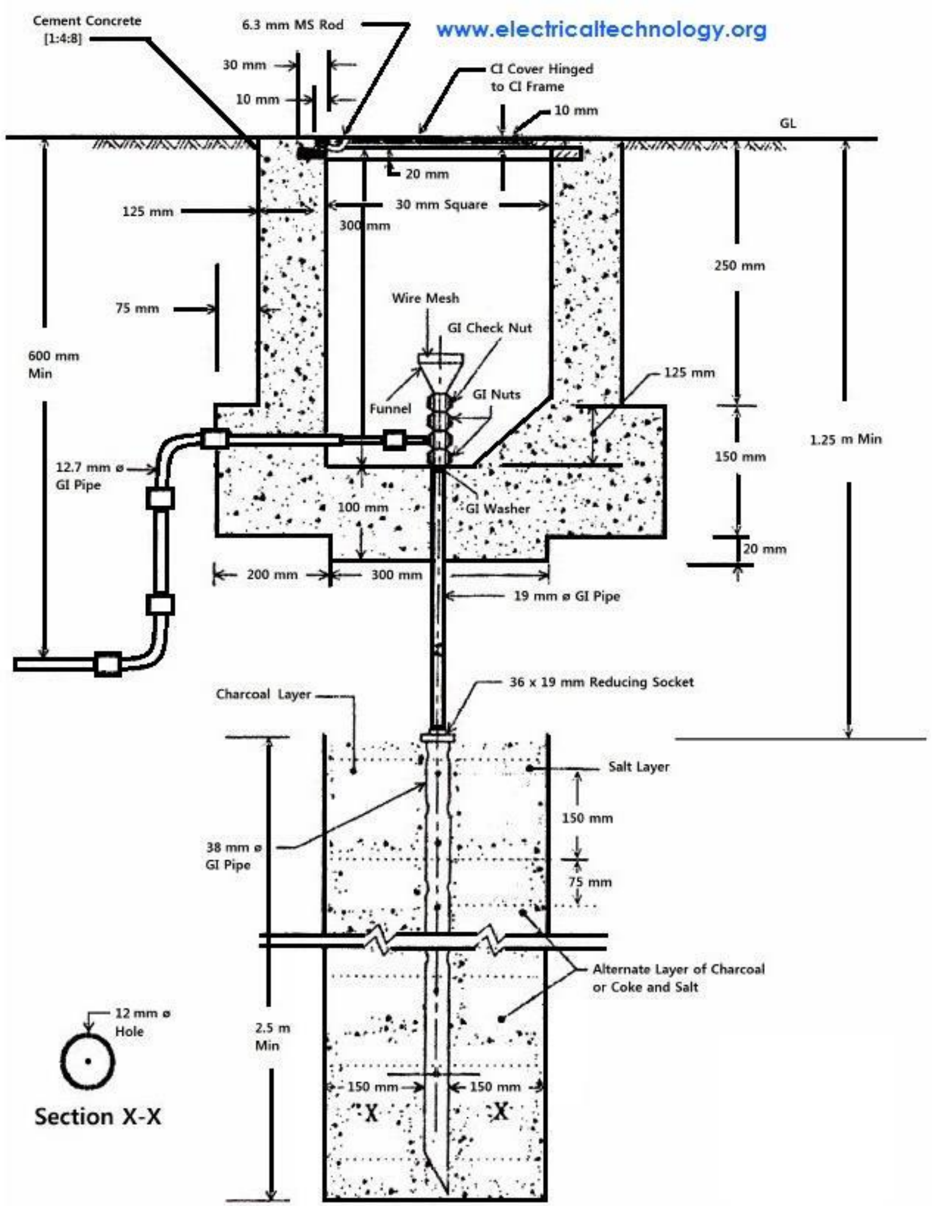
- ***Plate Earthing***
- In plate earthing system, a plate made up of either copper with ***dimensions 60cm x 60cm x 3.18mm (i.e. 2ft x 2ft x 1/8 in) or galvanized iron (GI) of dimensions 60cm x 60cm x 6.35 mm (2ft x 2ft x ¼ in)*** is buried vertical in the earth (earth pit) which should not be less than 3m (10ft) from the ground level.



METHODS OF EARTHING

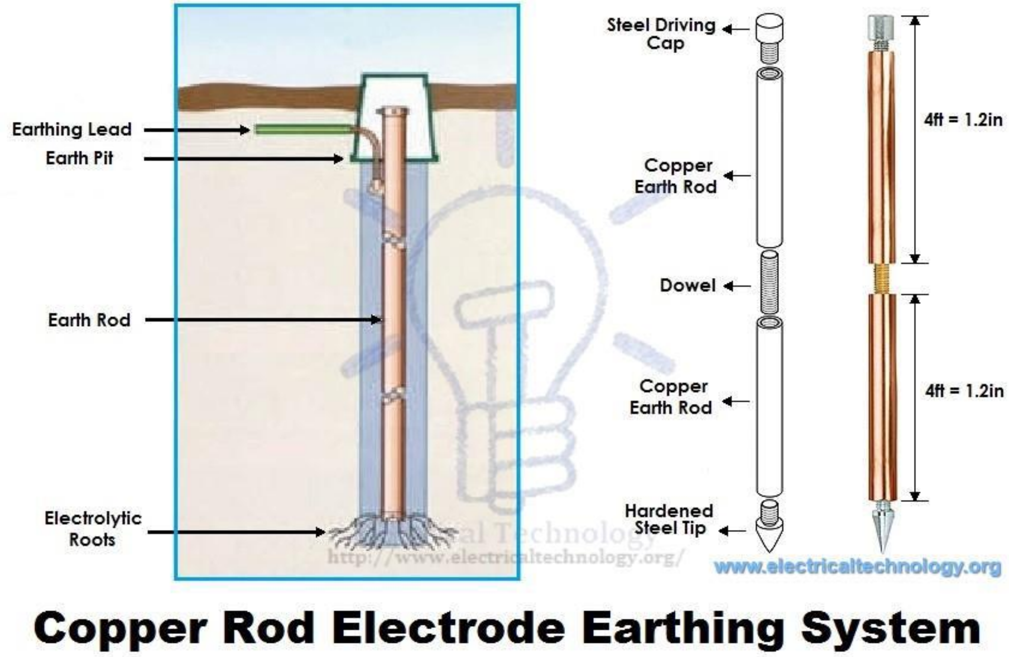
Pipe Earthing

- A ***Galvanized steel and a perforated pipe of approved length and diameter is placed vertically in a wet soil*** in this kind of system of earthing. It is the most common system of earthing. The size of pipe to use depends on the magnitude of current and the type of soil. The dimension of the pipe is usually ***40mm (1.5in) in diameter and 2.75m (9ft)*** in length for ordinary soil or greater for dry and rocky soil. The moisture of the soil will determine the ***length of the pipe to be buried*** but usually it should be ***4.75m (15.5ft).***



Rod Earthing

- A copper rod of ***12.5mm (1/2 inch)*** diameter or ***16mm (0.6in)*** diameter of galvanized steel or hollow section 25mm (1inch) of GI pipe of ***length above 2.5m (8.2 ft)*** are buried upright in the earth manually or with the help of a pneumatic hammer.



GROUND & NEUTRAL

- •***Ground or earth*** in a mains (AC power) electrical wiring system is a conductor that provides a low-impedance path back to the source to prevent hazardous voltages from appearing on equipment. Under normal conditions, a grounding conductor ***does not carry current***.

- •***Neutral*** is a circuit conductor that normally ***carries current***, and is connected to ground (earth) at the main electrical panel. All neutral wires of the same earthed electrical system should have the same electrical potential, because they are all connected through the system ground.