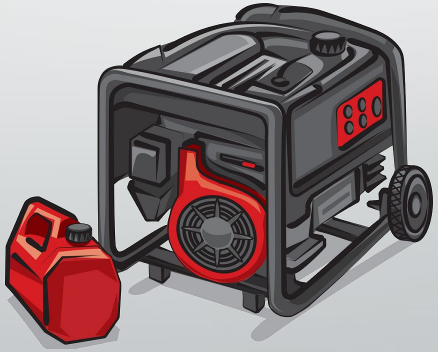
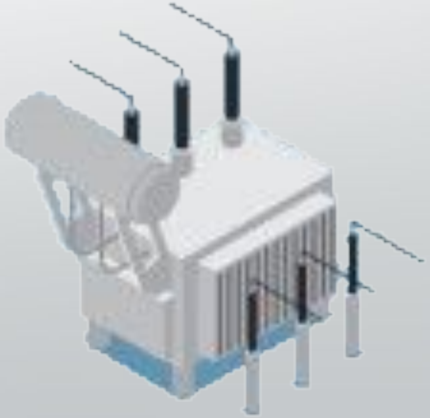
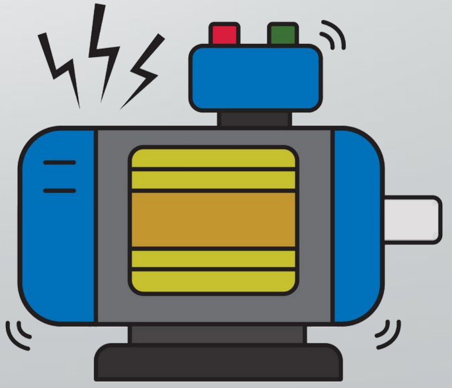
BASIC ELECTRICAL AND ELECTRONICS ENGINEERING







UNIT III: ELECTRICAL SAFETY AND ELECTRICAL MACHINES

Layout of electrical power system and its functions, Safety devices and systems, Types of domestic wiring, Wiring Accessories, Necessity of earthing, insulators, cables, fuse and circuit breakers - Sensors and its types.

Law of Electromagnetic induction, Auto transformer, Single phase transformer-load test – Open Circuit and Short Circuit test, Fleming’s Right and Left hand rule – construction, principle, load test and performance characteristics of rotating machines – DC Motor and DC Generator - single phase/three phase induction motor, Alternator and synchronous motor .

What is Electrical Power?

- Electric power is the *rate per unit time*, at which **electrical energy is transferred by an electric circuit**.

- Power = Energy transferred per Unit time

$$P = (VQ) / t$$

w.k.t. $I = Q/t$

Power, P = VI

where,

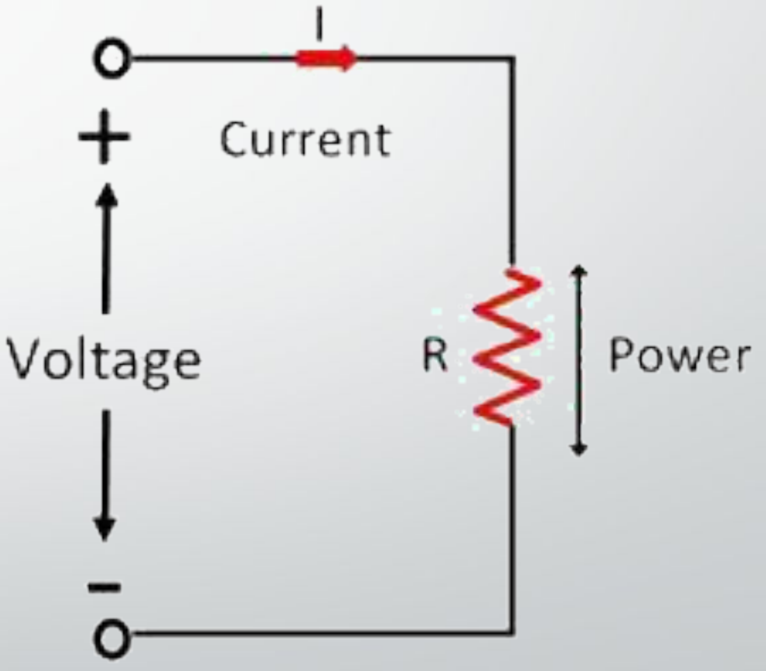
Q is the electric charge in coulombs

t is time in seconds

I is electric current in amperes

V is electric potential or voltage in volts

- SI unit of Electrical Power is **Watt**.



Electric Power

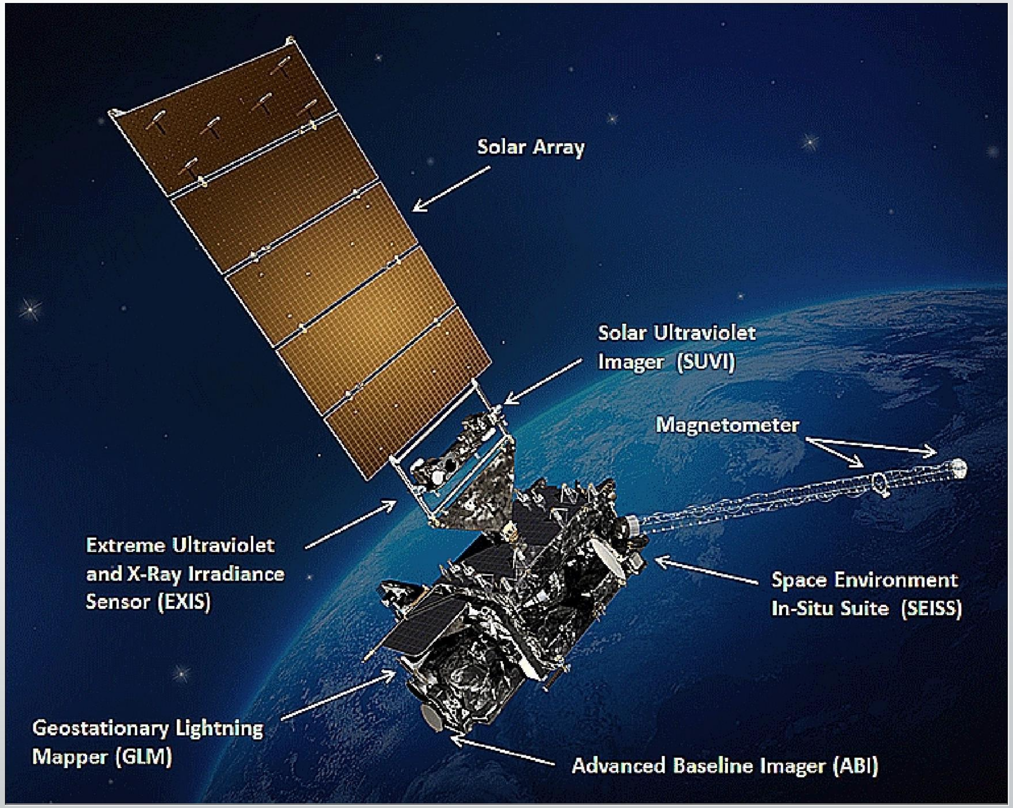
Electrical Power System

- Definition: It is a network of electrical components deployed to *supply, transfer, and use* Electric Power.
- Eg: **Electrical Grid** that provides power to homes and industry within an extended area.
- The electrical grid can be broadly divided into the *generators* that supply the power, the *transmission system* that carries the power from the generating centers to the load centers, and the *distribution system* that feeds the power to nearby homes and industries.
- Specialized power systems that do **not** always rely upon three-phase AC power are found in aircraft, electric rail systems, ocean liners, submarines and automobiles.

Electrical Power System

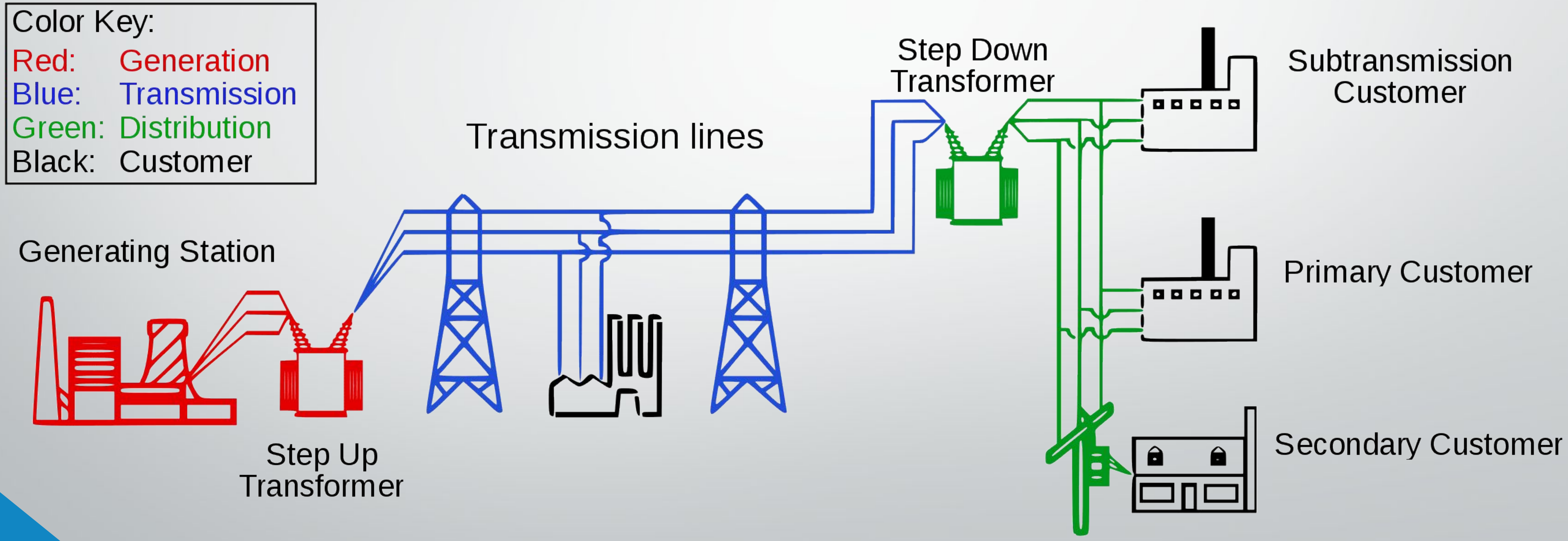
Electrical Grid

Specialized Power System



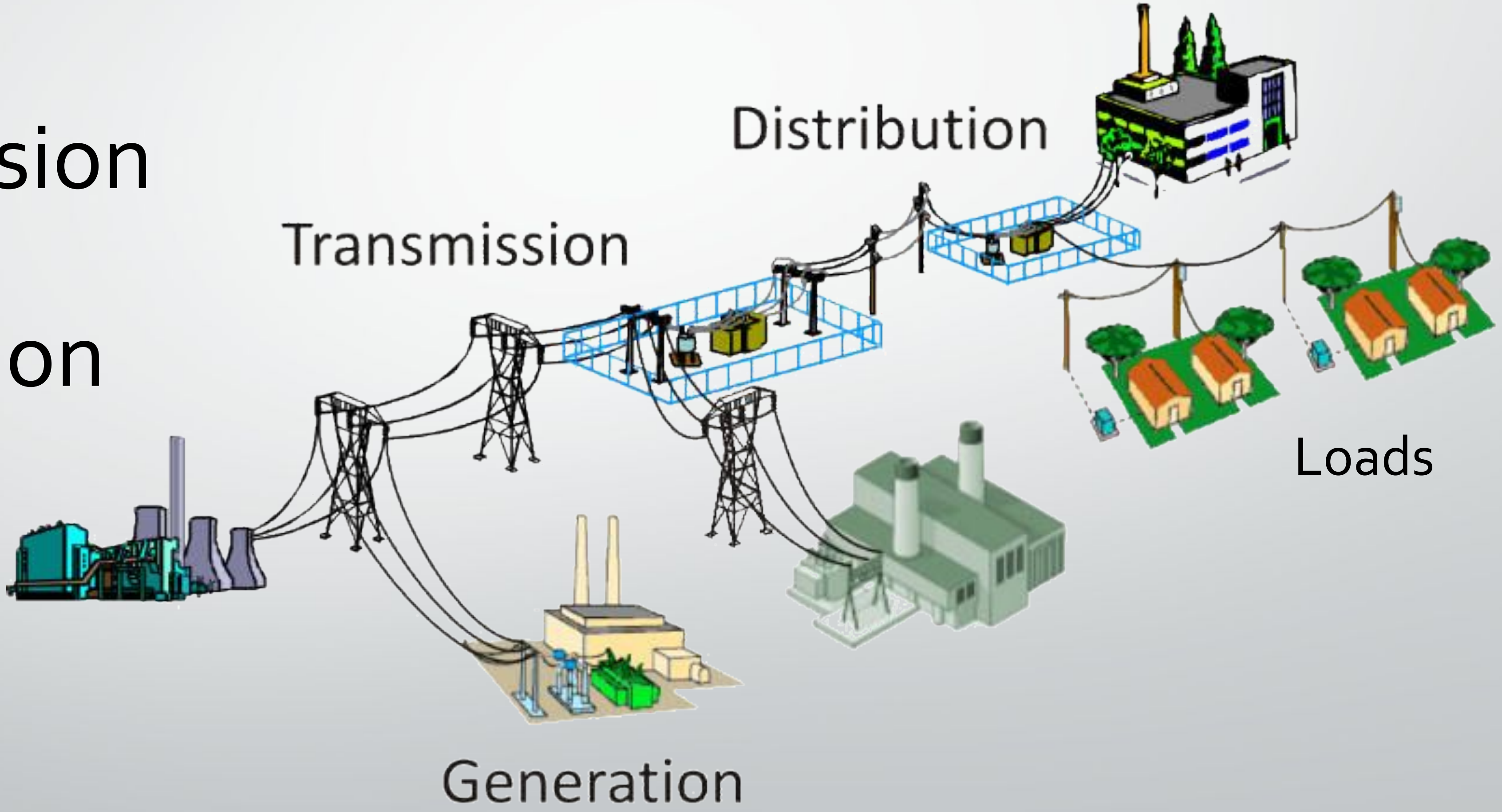
SpaceCraft

Layout of Electrical Power System



Main Parts in Electrical Power System

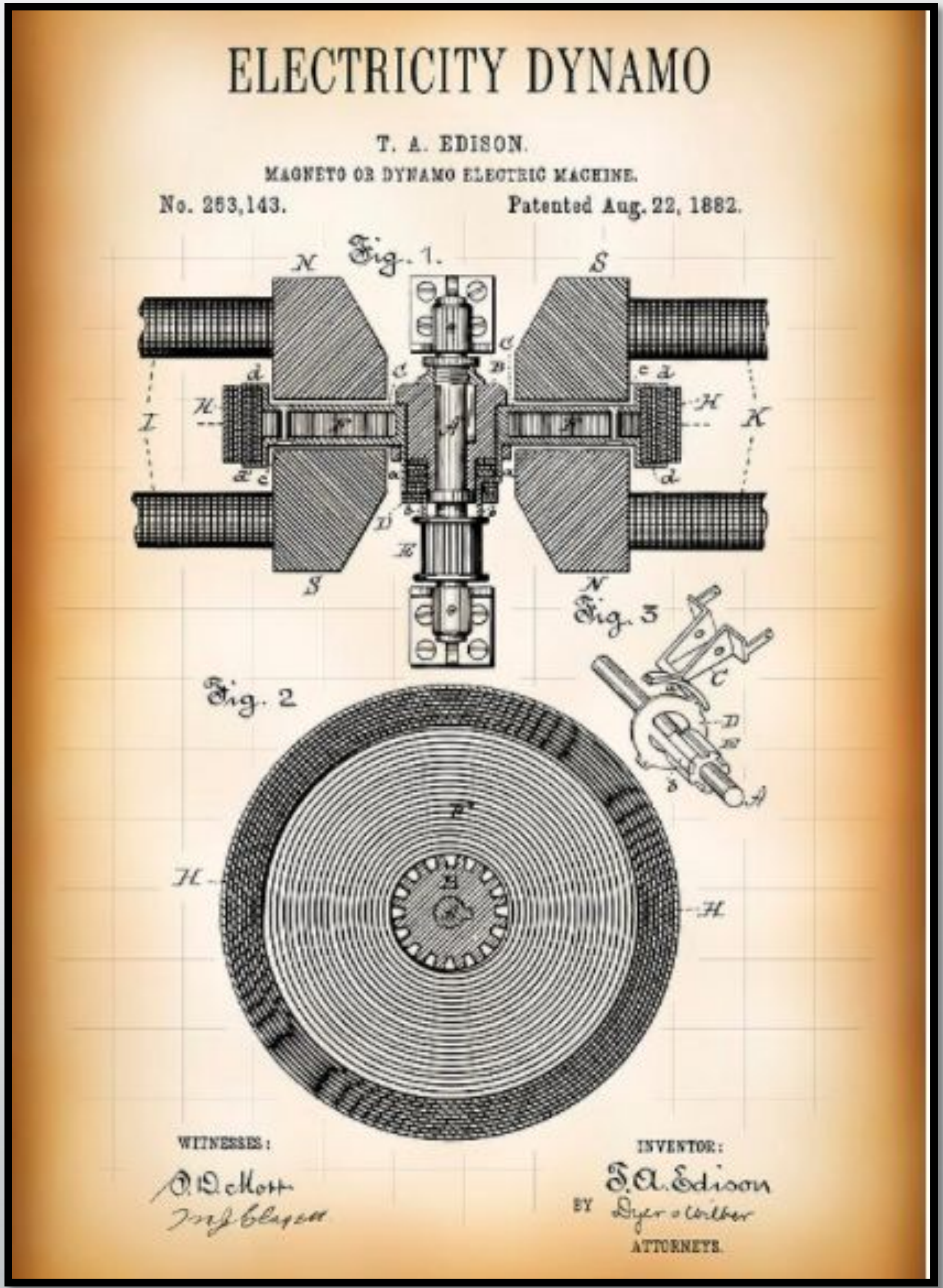
- Generation
- Transmission
- Distribution
- Loads



Generation

- History: Electricity generation at central power stations started in **1882**, when a **steam engine** driving a ***dynamo*** at Pearl Street Station produced a **DC current** that powered public lighting on Pearl Street, New York.
- Generation is the production of electricity at power stations or generating units where a form of **primary energy is converted into electricity**.
- Electric generators transform **kinetic energy into electricity** which plays a major role in generating electricity and is based on **Faraday's law**.

Pearl Street in 1882



Types of Energy System for Generation

Solar Energy System

Hydro Energy System

Types of Energy System for Generation

Coal Power Energy System

Wind Energy System

Transmission

- Transmission is the network that moves power from ***one part to another***.
- *High-voltage direct-current* (HVDC) technology is used for greater efficiency over very long distances.
- Electricity is transmitted at **high voltages** (66 kV or above) to reduce the energy loss which occurs in long-distance transmission.
- Transmission system is majorly classified into two. They are

1. ***Overhead transmission lines*** are the bare conductors that are supported on pylons. Transmission lines poles are installed at a certain distance to hang these conductors above in the air.
2. ***Underground lines*** are the insulated cables that are buried under the earth. Underground vaults, cables, and trenches are installed.

Overhead Transmission System

Underground Lines

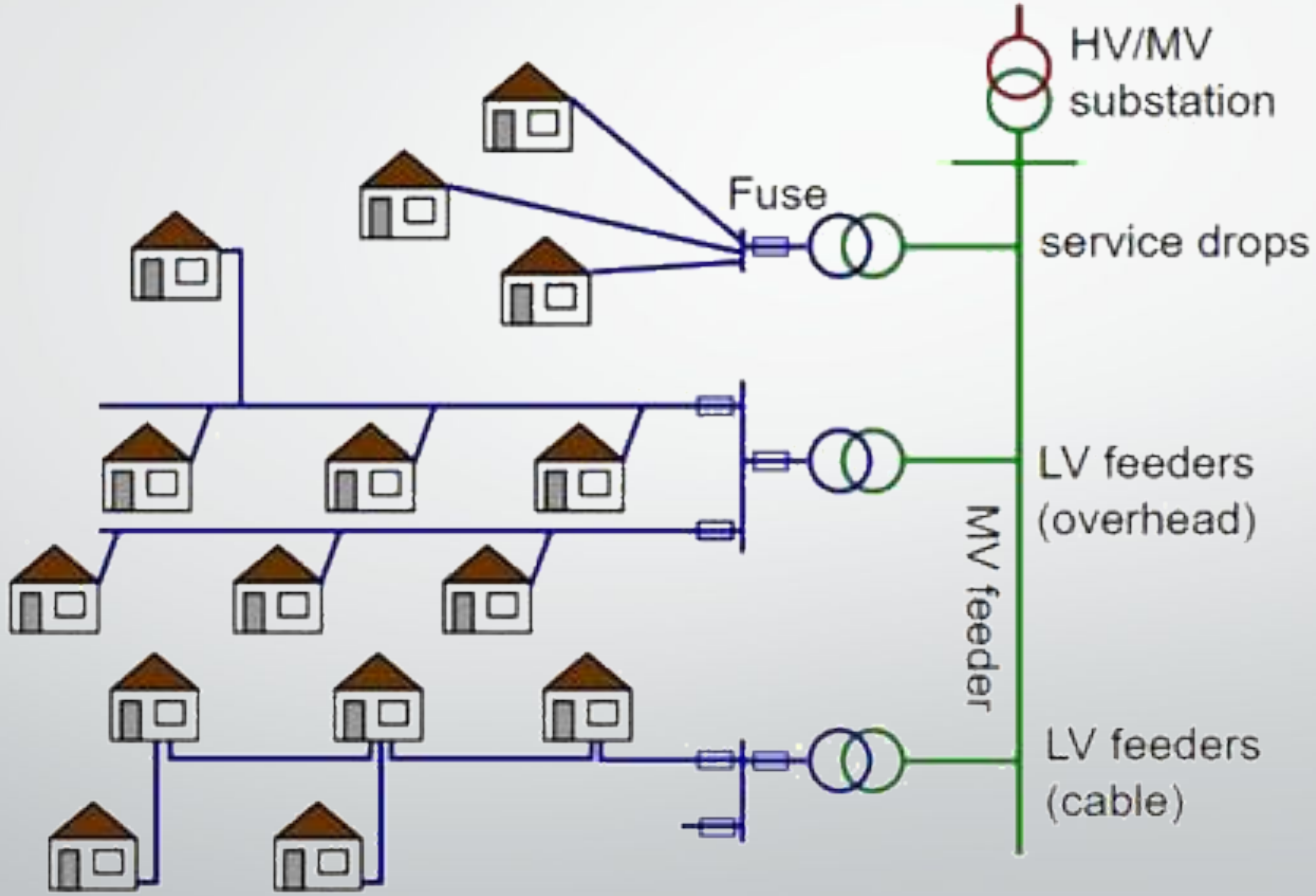
Distribution

- Distribution carries electricity from the transmission system to individual consumers.
- Distribution substations lower the transmission voltage to medium voltage ranging between 2kV and 35 kV with the use of **step-down** transformers.
- Primary distribution handles large consumers such as factories and industries. **(3-phase, 3-wire system)**
- Secondary distribution handles big properties, commercial buildings, small factories etc. **(3-phase, 4-wire system)**
- There are four basic **types** of distribution system according to its feeder connection:

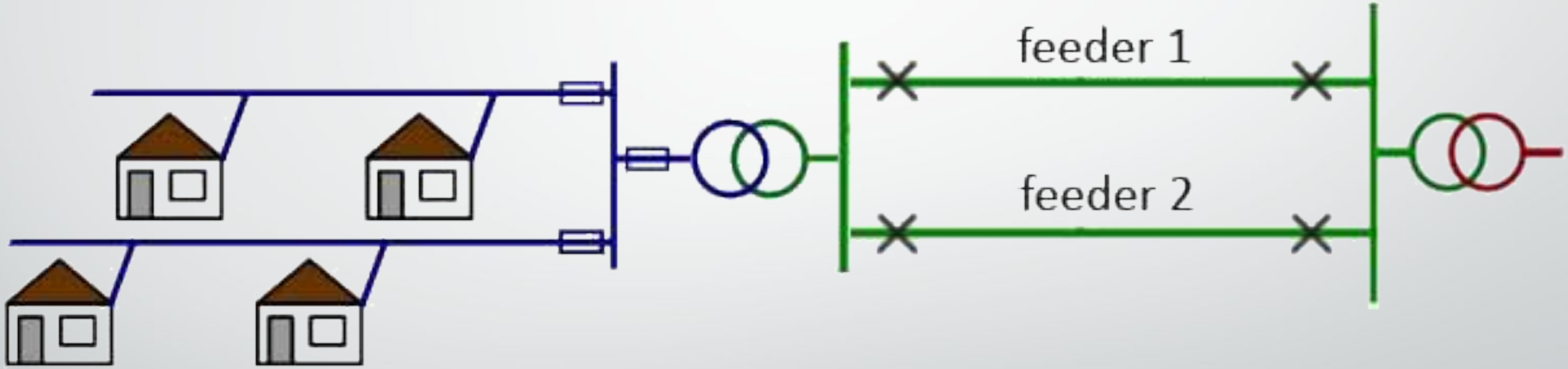
1. Radial distribution system
2. Parallel feeders distribution
3. Ring main distribution system

Interconnected distribution

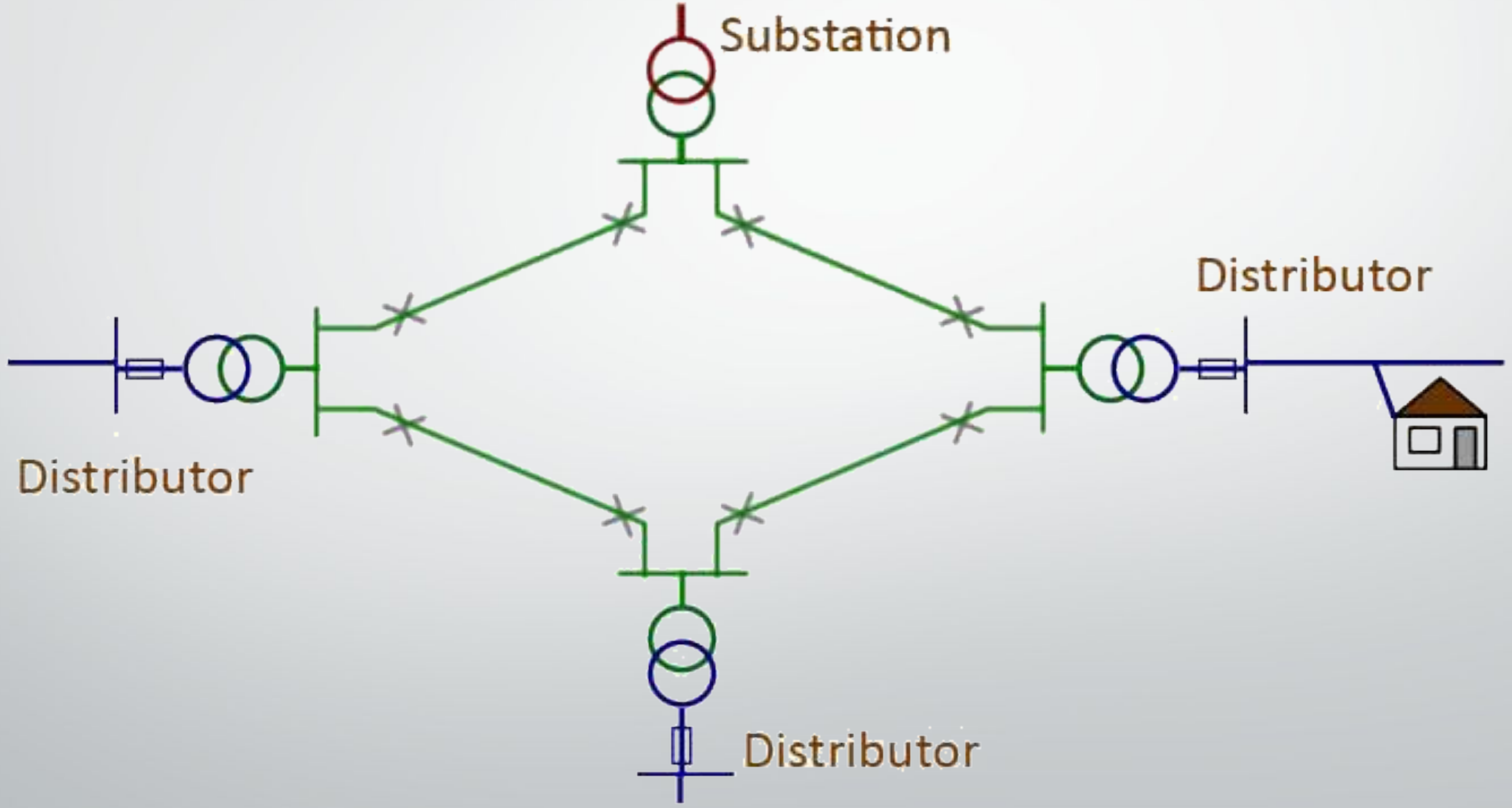
Radial Distribution System



Parallel Feeders Distribution



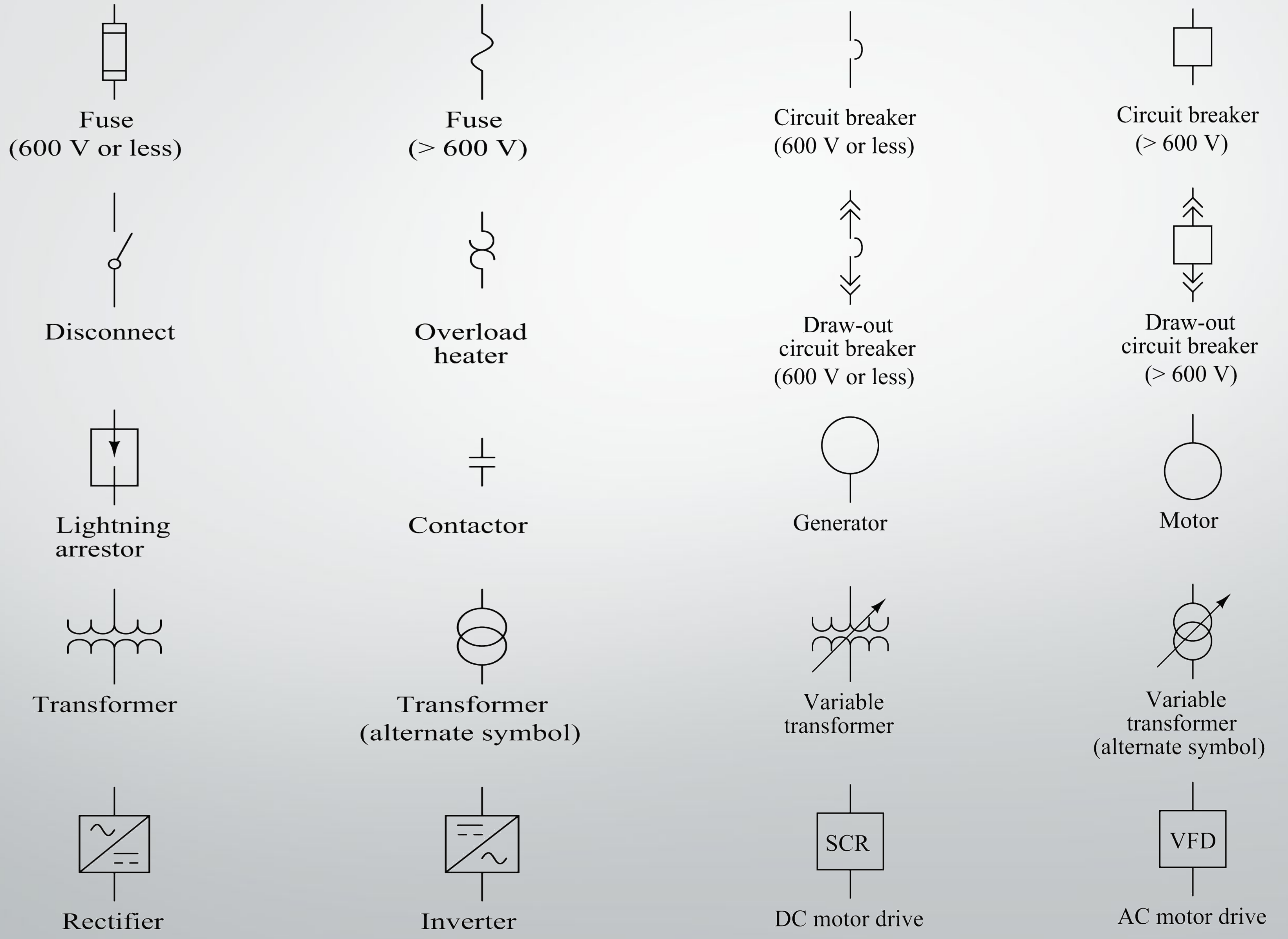
Ring-main Distribution System

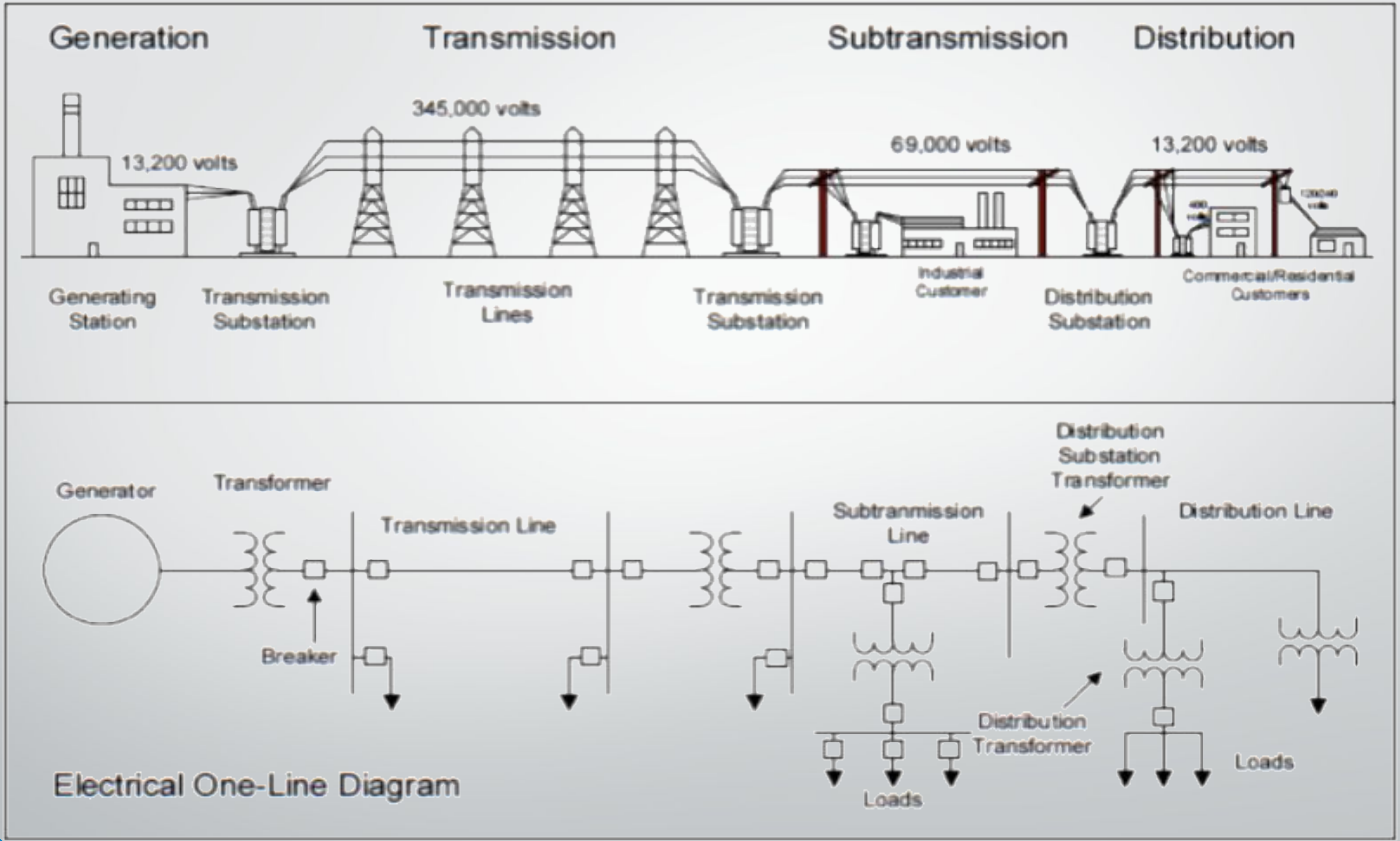


Single Line Diagram (SLD)

- Single line diagram is the representation of a power system using the *simple symbol for each component*.
- It is a form of **block diagram** graphically depicting the paths for power flow between entities of the system.
- In power system, SLD 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.).

Important SLD symbols need to know..




Generation
Transmission
Subtransmission
Distribution
345,000 volts
13,200 volts
69,000 volts
13,200 volts
Generating Station
Transmission Substation
Transmission Lines
Transmission Substation
Industrial Customer
Distribution Substation
Commercial/Residential Customers
Generator
Transformer
Transmission Line
Breaker
Subtranmission Line
Distribution Substation Transformer
Distribution Line
Distribution Transformer
Loads
Loads
Electrical One-Line Diagram

Electrical Power System(Single line diagram)

L a y o u t o f

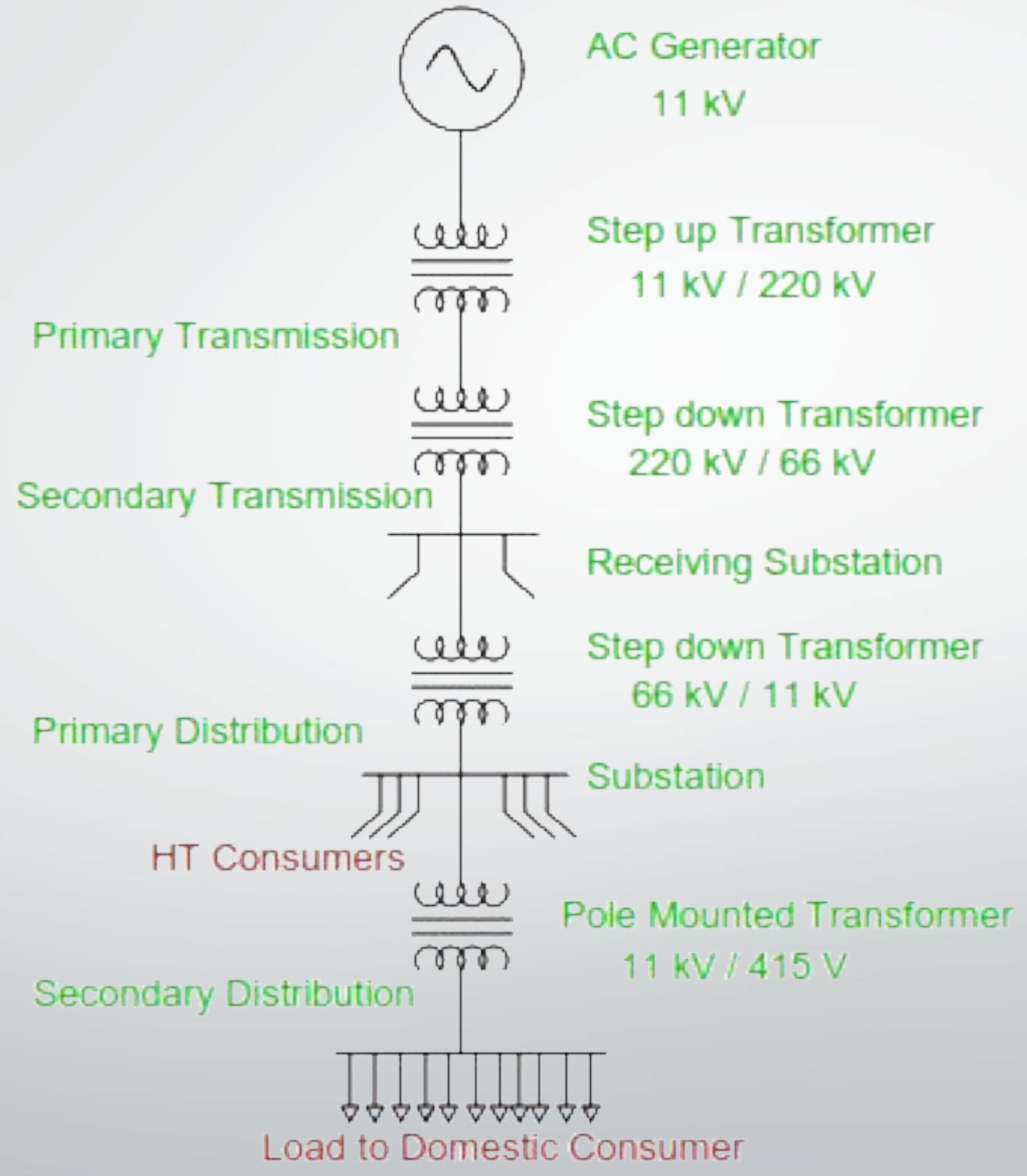


FIG : Single Line Diagram of Power Supply System

I n d i a

Safety devices and systems

- **Electrical Safety devices** include a range standard electric components that are mandatory to ensure patient and staff safety.
- Various Safety Devices & systems are listed below:

✔ Fuse

✔ Circuit Breaker

✔ Earthing

Fuse

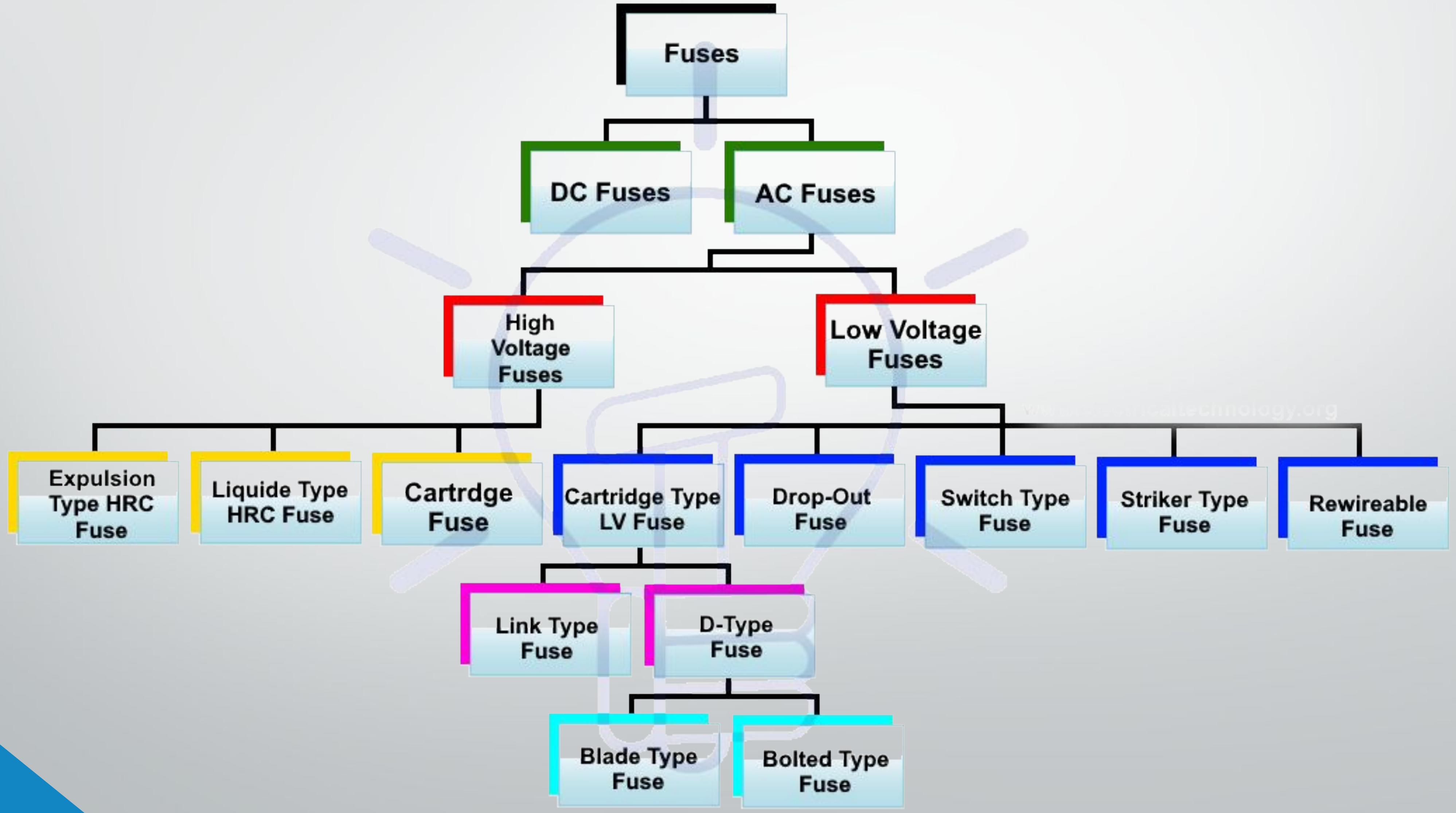
- Fuses are the safety devices which are used to protect the home appliances like televisions, refrigerators, computers with damage by high voltage.
- The fuse is made up of thin strip or strand of metal.
- The **working principle** of a fuse is based on the "**Heating effect of Current**"
- Whenever the heavy amount of current or an excessive current flow is there in an electrical circuit, the fuse melts & protect the appliances.
- **Fuse Rating = (Power / Voltage) x 1.25**
- For **example**, 1-HP (746W) motor operating at 115V would draw

  746/115 = 6.5A at full load, so theoretically a 10A **fuse** would be sufficient.

Fuse Wire Rating

Metal	Melting point	Specific Resistance
Aluminium	240oF	2.86 μ Ω – cm
Copper	2000oF	1.72 μ Ω – cm
Lead	624oF	21.0 μ Ω – cm
Silver	1830oF	1.64 μ Ω – cm
Tin	463oF	11.3 μ Ω – cm
Zinc	787oF	6.1 μ Ω – cm

Classification of Fuses



Types of Fuses

DC Fuses

In a DC system, when the **metallic wire melts** because of the heat generated by the over current, then Arc is produced and it is very difficult to extinguish this arc because of ***DC constant value***. So in order to minimize the fuse arcing, DC fuse are little bigger than an AC fuse which ***increases the distance*** between the electrodes to ***reduce the arc*** in the Fuse.

AC Fuses

On the other hand, i.e. in the AC system, voltage with 60Hz or 50Hz ***frequency changes its amplitude*** from zero to 60 times every second, so arc can be extinct easily as compared to DC. Therefore, AC fuses are a little bit small in sizes as compared to DC fuses.

Cartridge Fuses

Cartridge fuses are used to protect electrical appliances such as motors, air-conditions, refrigerator, pumps etc, where high voltage rating and currents are required. They are available up to 600A and 600V AC and widely used in industries, commercial as well as home distribution panels.

There are two types of Cartridge fuses.

1. **General purpose fuse** with *no time delay* and
2. **Heavy-duty cartridge fuses** with *time delay*.

Both are available in **250V AC to 600V AC** and its rating can be found on the end cap or knife blade.

High Voltage Fuses

High Voltage (HV) fuses are used in power systems to protect the power transformer, distribution transformers and instrument transformer etc.

.High Voltage fuses are rated for **more than 1500V and up to 13kV**.The element of High Voltage fuse is generally made of copper, silver or tin. The fuse link chamber may filled with **boric acid** in case of expulsion type HV (High Voltage) Fuses

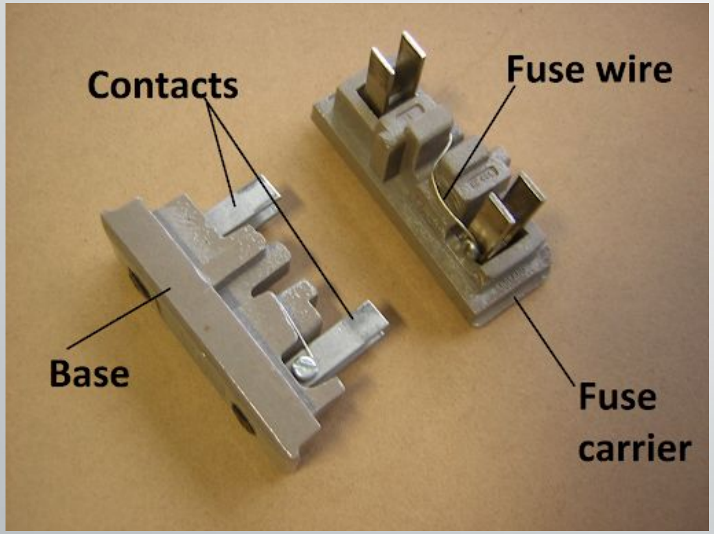
Automotive Blade Type Fuse

These types of fuses (also known as **spade** or **plug-in fuses**) come in **plastic body and two metal caps** to fit in the socket. Mostly, they are used in **automobiles** for wiring and short circuit protection. **Fuse Limiters, Glass Tube (also known as Bosch Fuse)** are widely used in automotive industries. The rating of automobile fuses are low as **12V to 42V.**

In bolted types of fuses, the base of the fuse contacted directly to the base of the fuse, same like HRC Fuses.

SMD Fuses

SMD Fuses (*Surface Mount Device* and the name derived from ***Surface Mount Technology***) are chip types of fuses (also known as **electronic fuse**) are used in **DC power applications** like Hard Drive, DVD players, Camera, cell phones etc where **space** playing an important role because SMD fuses are *very tiny* in size and hard to replace as well.



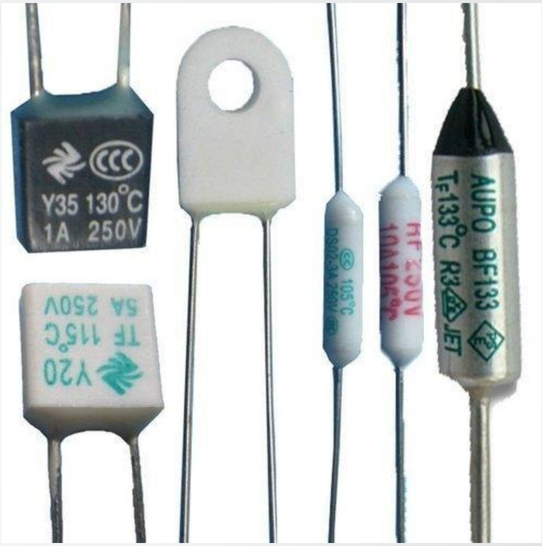
Rewirable Fuses

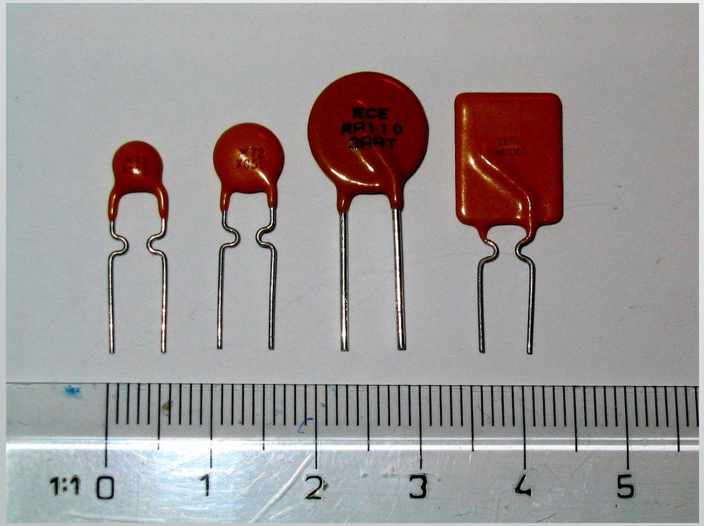
The most famous **kit-kat fuse** mostly used in industries and **home electrical wiring** for small current applications in **Low Voltage (LV) systems**. Rewireable fuse contains 2 basic parts. The inner fuse element as **fuse carrier** made of tinned copper, Aluminum, Lead etc and the base made of **porcelain** having the IN and OUT terminals which is used to be in series with the circuit to protect. The main advantage of a rewireable fuse is that It can be rewired easily in case it is blown due to *short circuit or over current* which melts the fuse elements.

Thermal Fuses

Thermal fuse is a one time used only fuse. They are temperature sensitive fuse and the fuse element is made of temperature sensitive alloy.

In a thermal fuse, the fuse element holds a mechanical spring contact which is normally closed. When high currents due to over current and short circuit flow through the elements of the fuse, the fuse elements melts down which lead to release the **spring mechanism** and prevent the arc and fire and protect the connected circuit.





Resettable Fuses

Resettable fuse is a device, which can be used multiple times without replacing it.

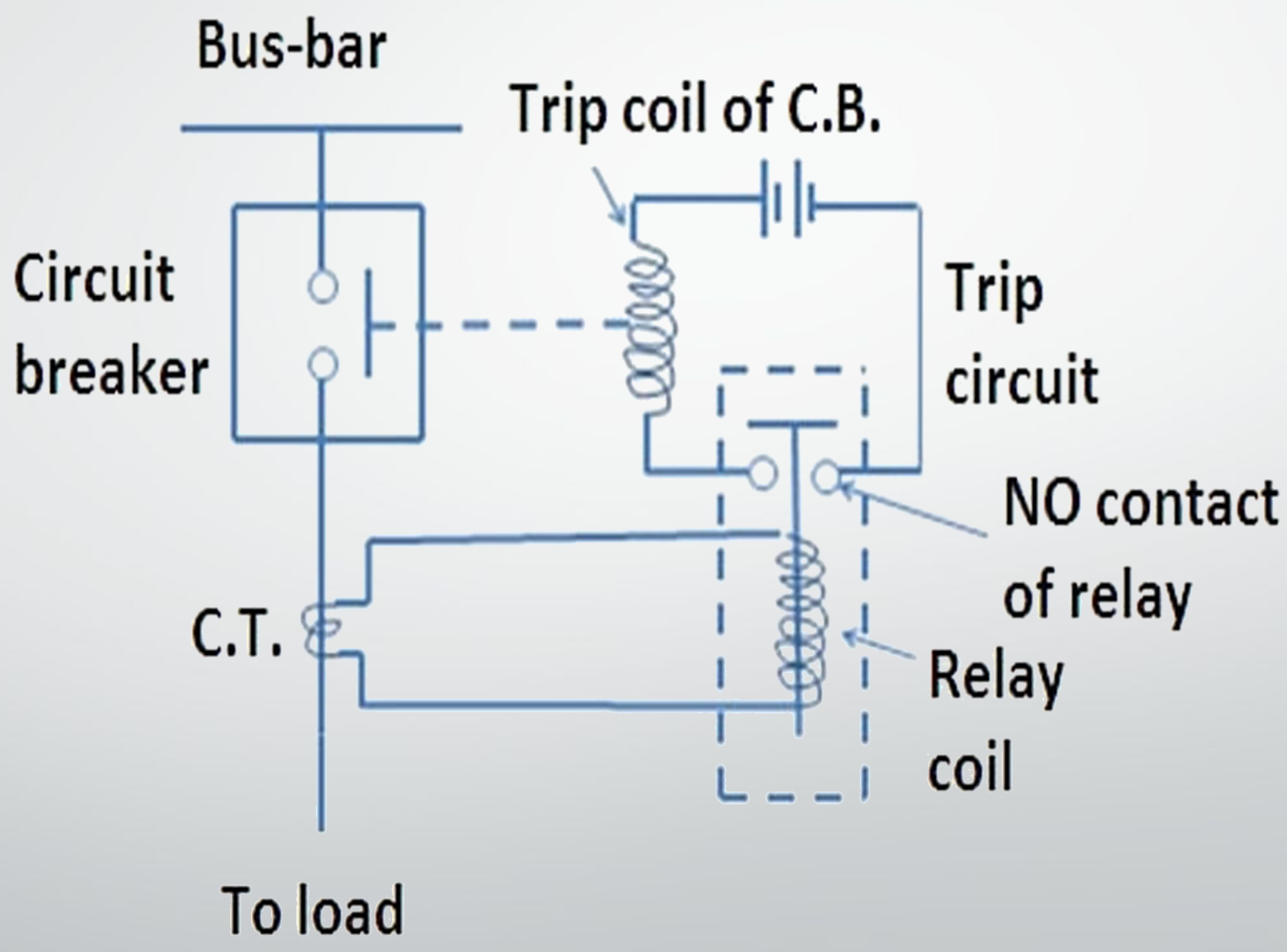
They open the circuit, when an over current event occurs and after some specific time they connect the circuit again.

Application of resettable fuses is overcome where manually replacing fuses is difficult or almost impossible, e.g. fuse in the **nuclear system** or in an **aerospace system**.

Circuit Breaker

- A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by excess current from an overload or short circuit.
- Its basic function is to interrupt current flow after a fault is detected.
- Unlike a fuse, which operates once and then must be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation.

Working Principle of Circuit Breaker



Working Principle of Circuit Breaker

- The circuit breaker is installed between the load from the Bus-bar.
- And this circuit breaker's system contains a C.T (current transformer) that gives the relay an excessive electrical signal.
- When this excessive flow occurs in the electrical circuit, then the relay receives a signal from the C.T (current transformer) and becomes active.
- After the relay is activated it closes the trip circuit. In the trip Circuit, a battery is installed and for the circuit being closed the electrical current is starting to flow.
- As a result, the trip coil gets magnetized and the moving contact in the circuit breaker gets detached from the power line and that the entire circuit is disconnected from the power system. In this way, the circuit breaker protects the entire power system.

Classification of Circuit Breaker

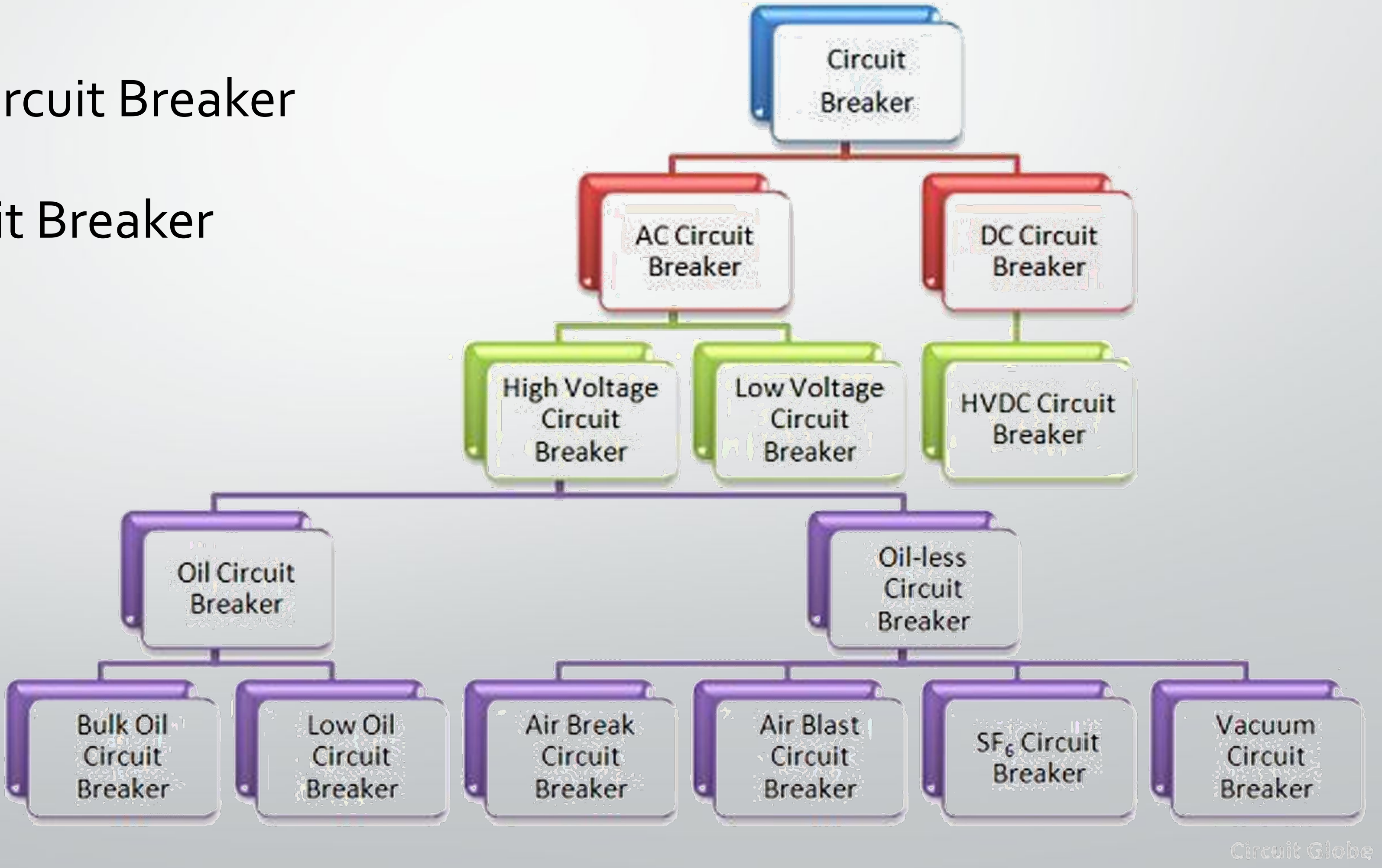
- According to **Voltage Level**,

i. Low Voltage Circuit Breaker

ii. Medium Voltage Circuit Breaker

iii. High Voltage Circuit Breaker

- According to **Arc Extinction Medium**



Low Voltage Circuit Breaker

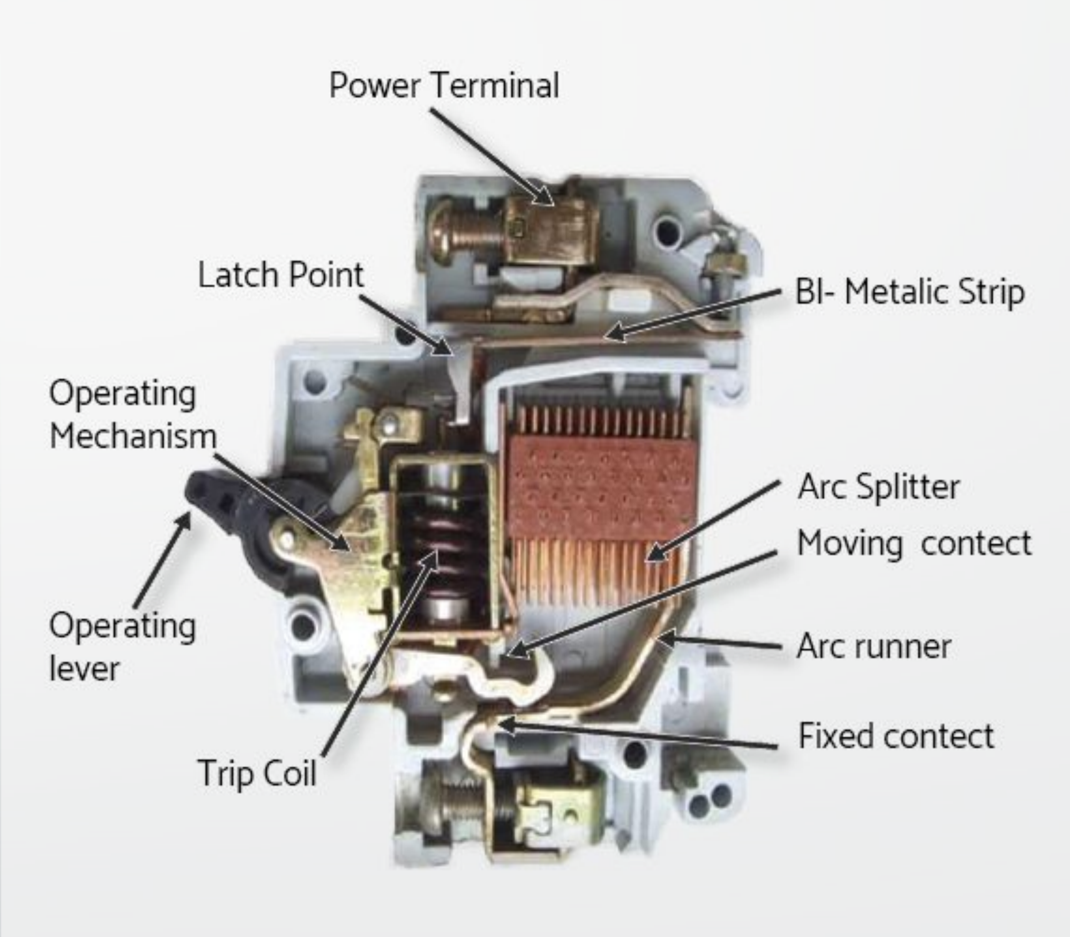
Low Voltage breaker types are common in domestic, commercial and industrial applications which includes :

1) MCB
2) MCCB

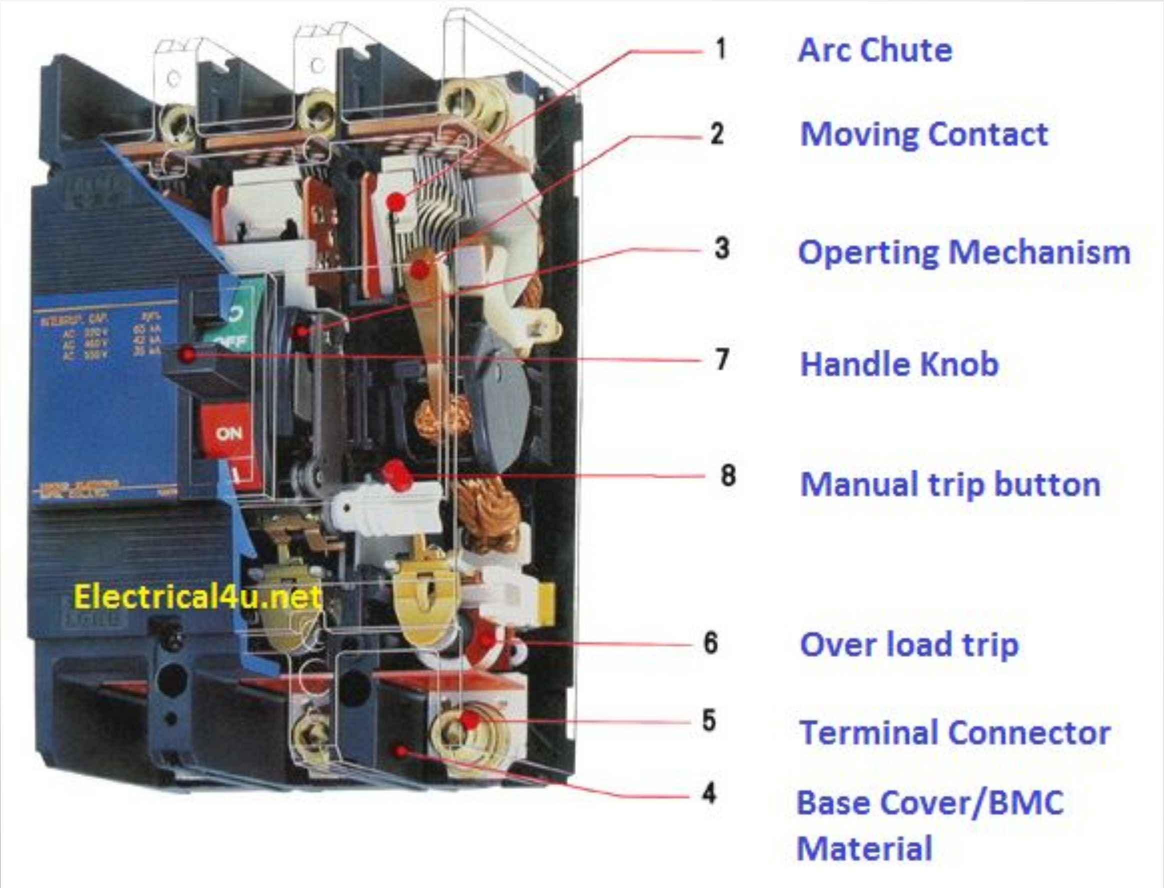
- A **Miniature Circuit Breaker** (**MCB**) is an automatically operated electrical switch used to protect low voltage electrical circuits from damage caused by excess current from an overload or short circuit. MCBs are typically rated up to a current up to **125 A**, do not have adjustable trip characteristics, and can be thermal or thermal-magnetic in operation.

- A **Moulded Case Circuit Breaker (MCCB)** is a type of electrical protection device that is used to protect the electrical circuit from excessive current, which can cause overload or short circuit. With a current rating of up to **2500A**, MCCBs can be used for a wide range of voltages and frequencies with adjustable trip settings. These breakers are used instead of miniature circuit breakers (MCBs) in large scale PV systems for system isolation and protection purposes.

Miniature Circuit Breaker (MCB)



Moulded Case Circuit Breaker (MCCB)



Medium Voltage Circuit Breaker

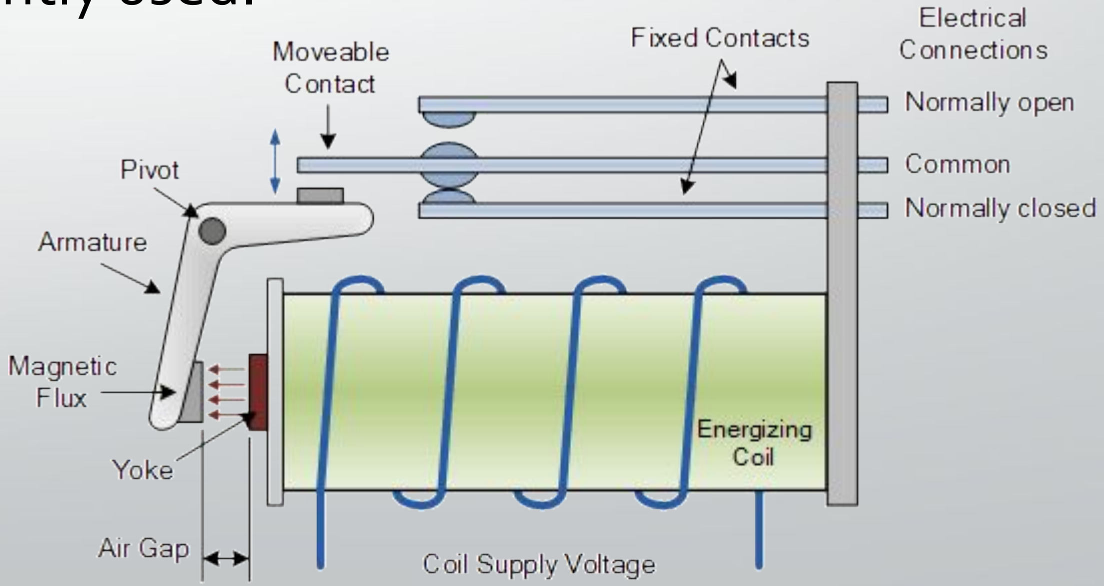
- Medium-voltage circuit breakers rated between **1 and 72 kV** may be assembled into metal-enclosed switchgear line ups for indoor use.
- Extremely low voltage conditions are not suitable for them to operate properly, neither a very high voltage helps them perform their operation accurately.
- It can be operated manually as well compared to other circuit breakers.
- The reason behind this manual operation is that since they can also operate on voltage levels **below 600 volts**, and this thing gives them the incentive to be **manually** operated.

High Voltage Circuit Breaker

- Electrical power transmission networks are protected and controlled by high-voltage breakers.
- The definition of *high voltage* varies but in power transmission work is usually thought to be **72.5 kV or higher**, according to a recent definition by the **International Electrotechnical Commission (IEC).**
- High-voltage breakers are nearly always solenoid-operated, with current sensing protective relays operated through current transformers.
- In substations the protective relay scheme can be complex, protecting equipment and buses from various types of overload or ground/earth fault.

Relay

- **Relay** is also a switch that connects or disconnects two circuits.
- But instead of manual operation a **relay** is applied with electrical signal, which in turn connects or disconnects another circuit.
- **Relays** can be of different types like electromechanical, solid state. Electromechanical **relays** are frequently used.

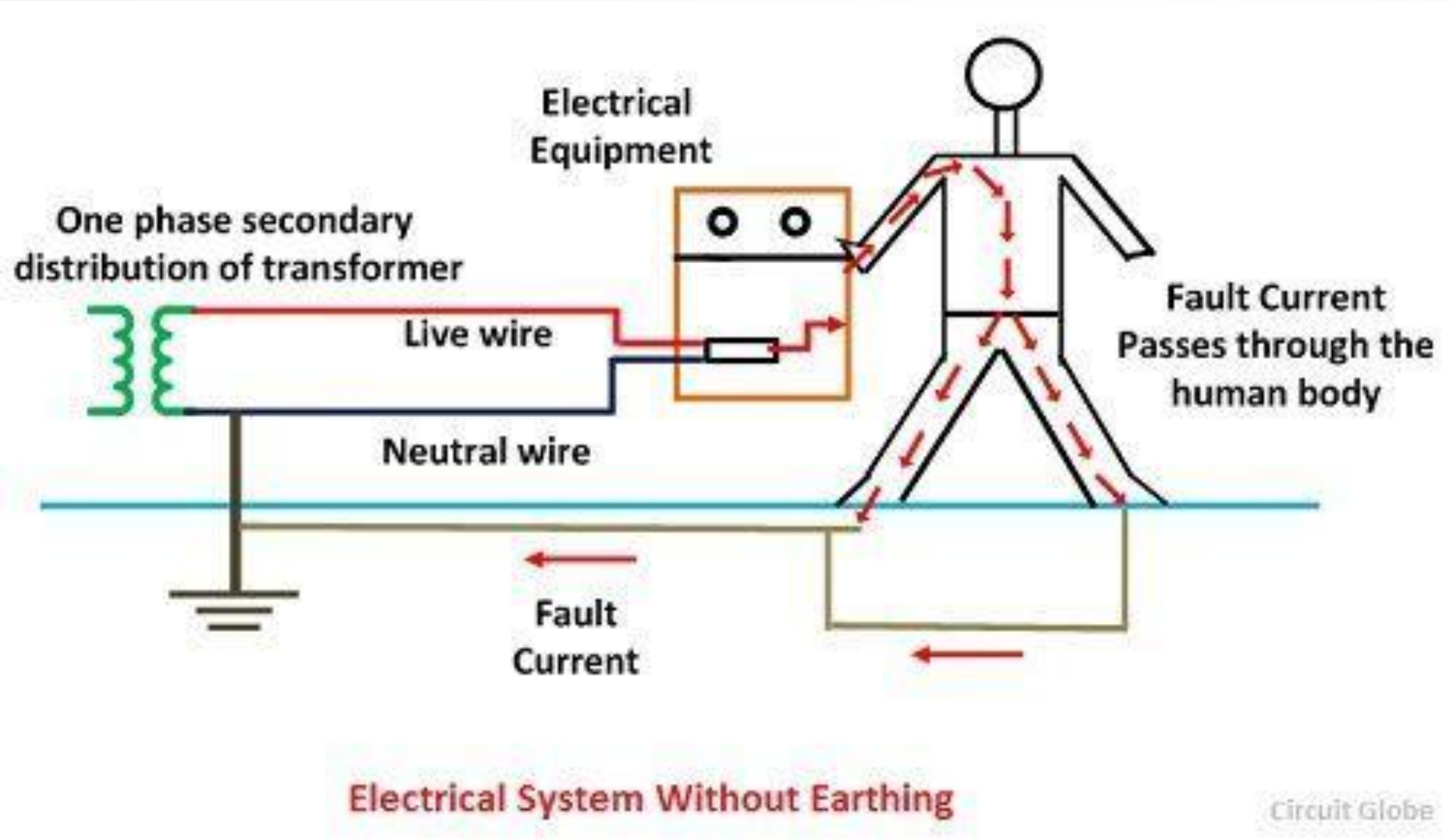


Electrical Earthing

- The process of transferring the immediate discharge of the electrical energy directly to the earth by the help of the **low resistance wire** is known as the electrical earthing.
- The electrical earthing is done by connecting the non-current carrying part of the equipment or neutral of supply system to the ground.
- Mostly, the **galvanized iron** is used for the earthing.
- The earthing provides the simple path to the **leakage current**.
- The short circuit current of the equipment passes to the earth which has **zero potential**.

Thus, it protects the system and equipment from damage.

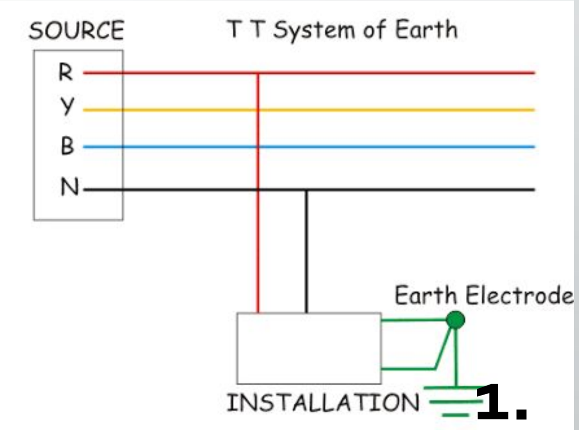
Electrical Earthing

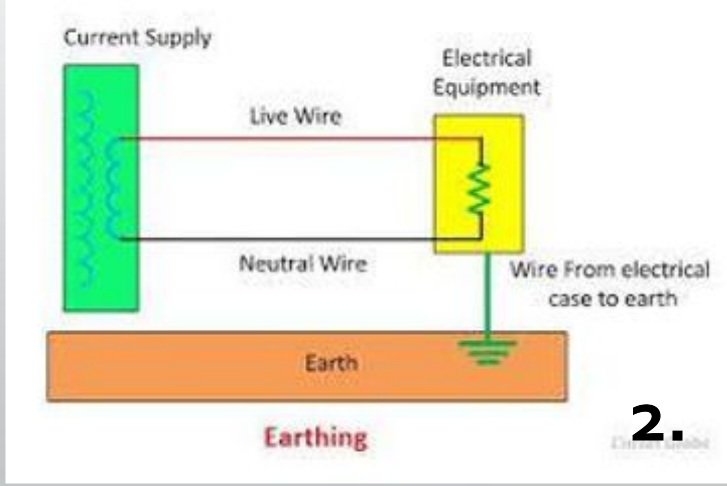


Types of Electrical Earthing

- The electrical equipment mainly consists of two non-current carrying parts.
- These parts are neutral of the system or frame of the electrical equipment.
- From the earthing of these two non-currents carrying parts of the electrical system
- Earthing can be classified into two types

1. **System(Neutral) Earthing**
2. **Equipment Earthing**





1)System(Neutral) Earthing:

- In neutral earthing, the neutral of the system is directly connected to earth by the help of the GI wire.
- The neutral earthing is also called the system earthing.
- Such type of earthing is mostly provided to the system which has star winding.
- For example, the neutral earthing is provided in the generator, transformer, motor etc.

2)Equipment Earthing:

- Such type of earthing is provided to the electrical equipment.
- The non-current carrying part of the equipment like their metallic frame is connected to the earth by the help of the conducting wire.
- If any fault occurs in the apparatus, the short-circuit current to pass the earth by the help of wire. Thus, it protect the system from damage.

Types of domestic wiring

1)Cleat Wiring

- This wiring comprises of PVC insulated wires or ordinary VIR that are braided and compounded. They are held on walls and ceilings using porcelain cleats with groves, wood or plastic. It is a temporary wiring system, therefore making it unsuitable for domestic premises. Moreover, cleat wiring system is rarely being used these days.

2)Casing and Capping Wiring

- It was quite popular in the past but it is considered obsolete these days due to the popularity of the conduit and sheathed wiring system. The cables used in this electric wiring were PVC, VIR or any other approved insulated cables. The cables were carried through the wooden casing enclosures, where the casing was made of a strip of wood with parallel grooves cut lengthwise for accommodating the cables.

3)Batten Wiring

- This is when a single electrical wire or a group of wires are laid over a wooden batten. The wires are held to the batten using a brass clip and spaced at an interval of 10 cm for horizontal runs and 15 cm for vertical runs.

4)Lead Sheathed Wiring

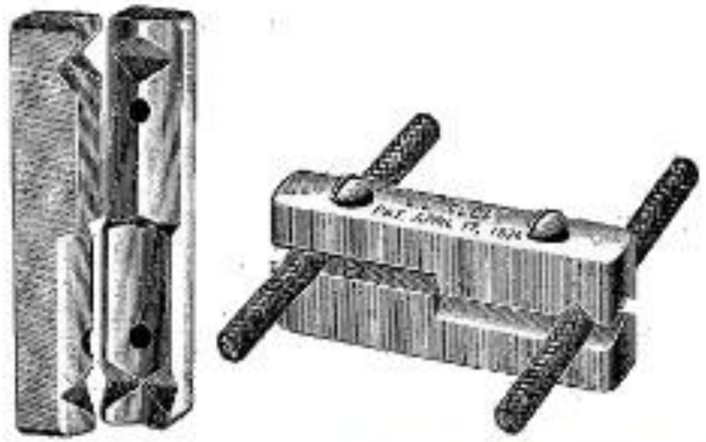
- Lead sheathed wiring uses conductors which are insulated with VIR and are covered with an outer sheath of lead aluminum alloy which contains about 95% lead. The metal sheath gives protection to cables from mechanical damage, moisture and atmospheric corrosion.

5)Conduit Wiring

There are two types of conduit wiring according to pipe installation:

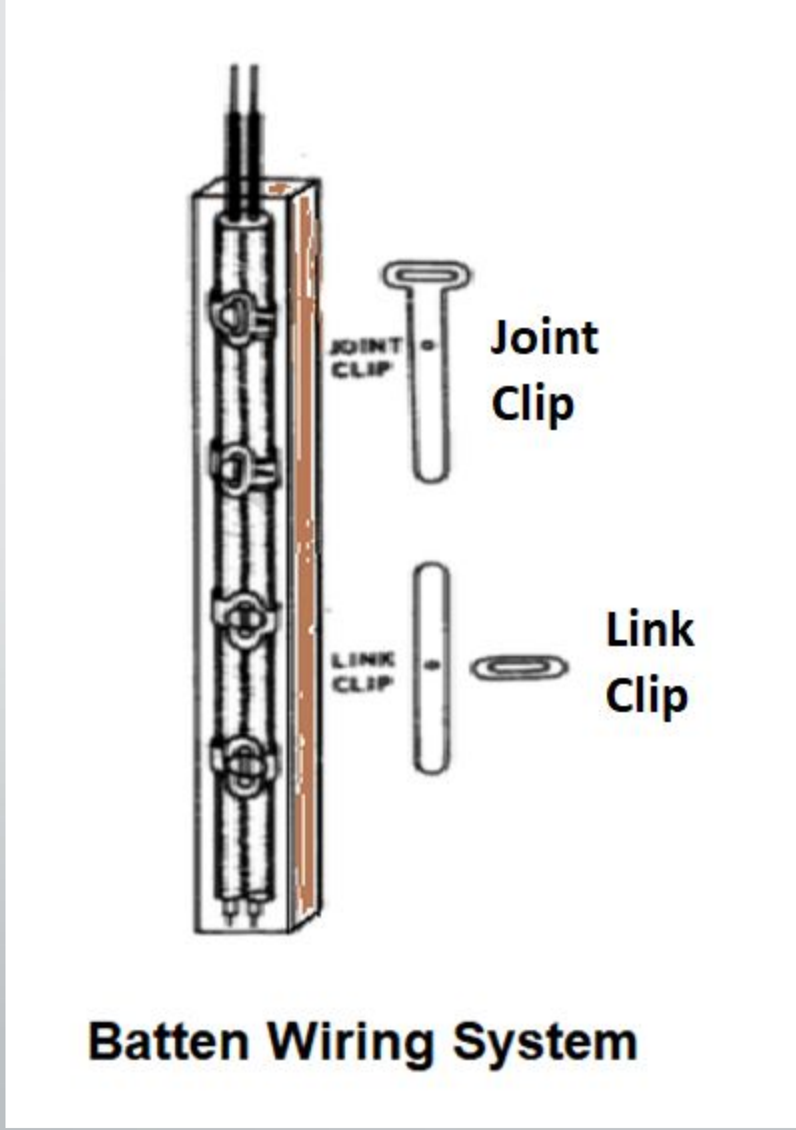
- **Surface Conduit Wiring:** When GI or PVC conduits are installed on walls or roof, it is known as surface conduit wiring. The conduits are attached to the walls with a 2-hole strap and base clip at regular distances. Electrical wires are laid inside the conduits.
- **Concealed Conduit Wiring:** When the conduits are hidden inside the wall slots or chiseled brick wall, it is called concealed conduit wiring. Electrical wires are laid inside the conduits. This is popular since it is stronger and more aesthetically appealing.

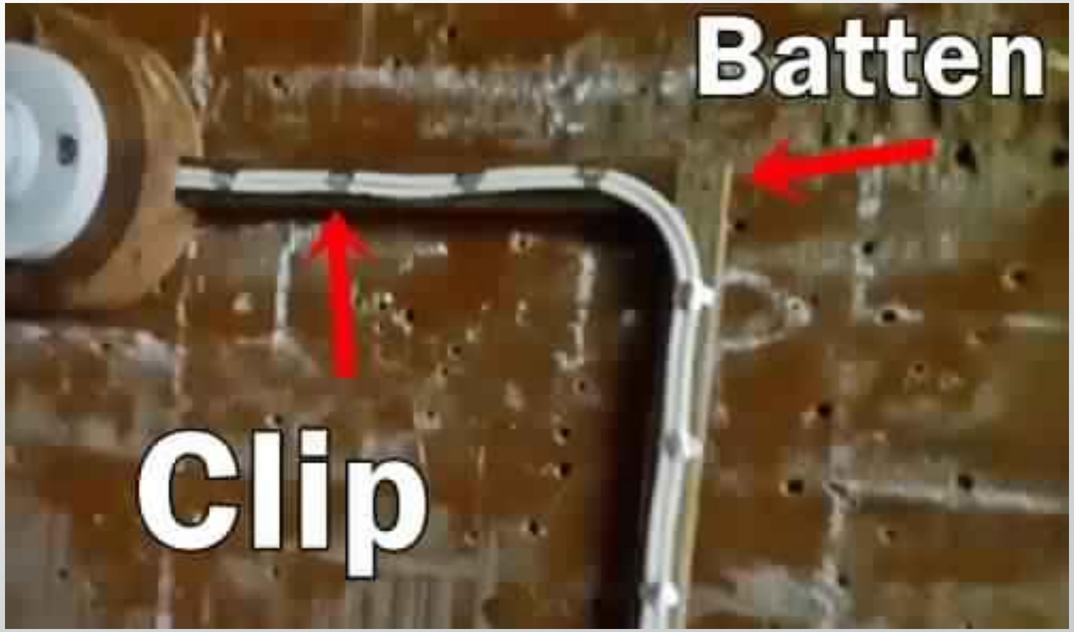
1)Cleat Wiring



2)Casing and Capping Wiring

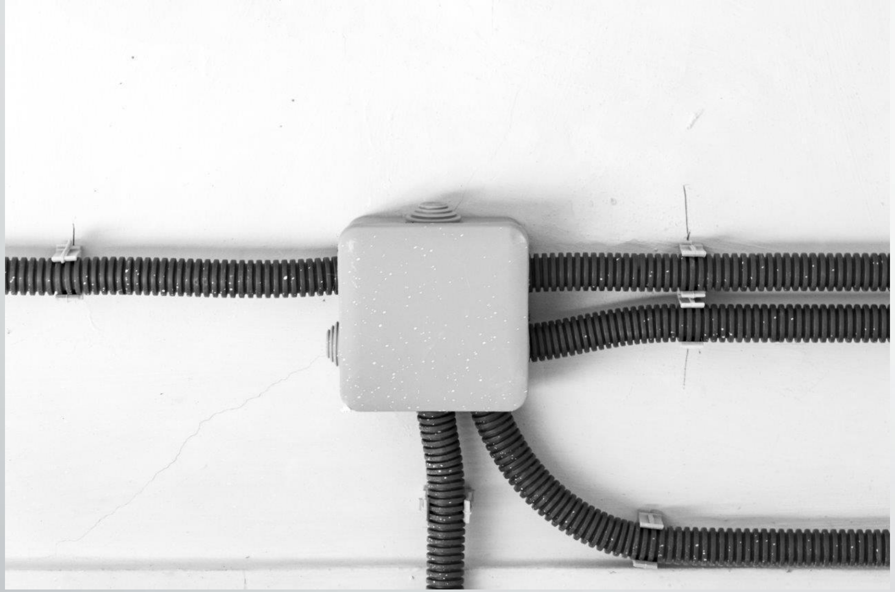
3)Batten Wiring

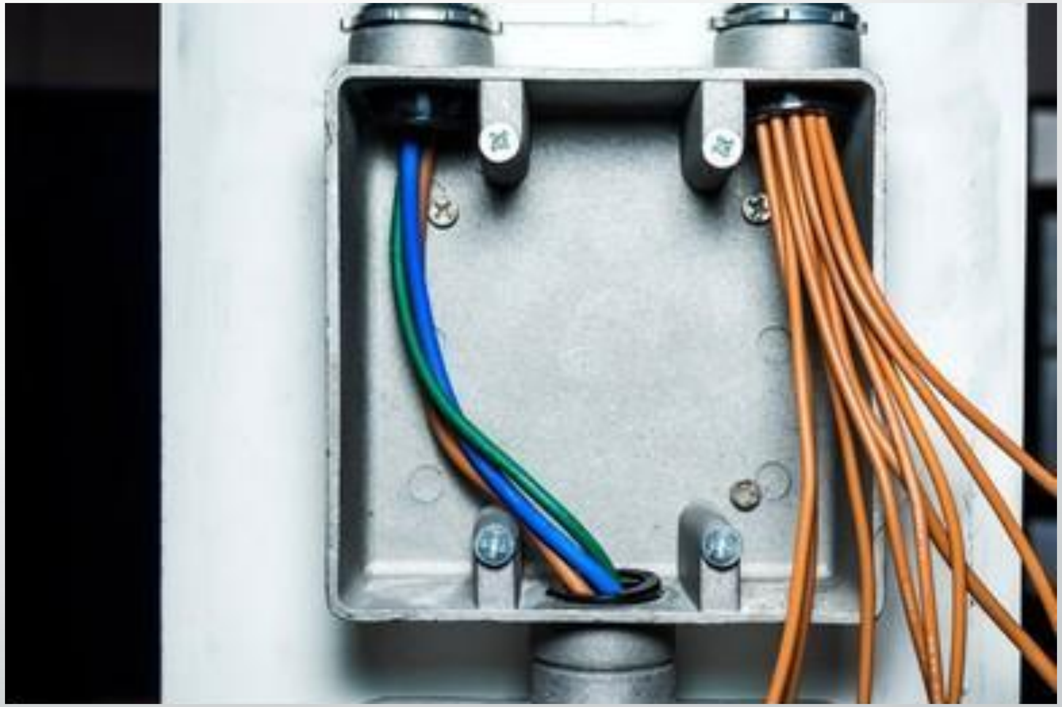




4)Lead Sheathed Wiring

5)Conduit Wiring





Wiring Accessories

- Switch
- Main switch
- Sockets and plugs
- Lamp holder
- Fuse
- Circuit breaker

Necessity of earthing

- If a fault is developed, causing unearthed metalwork of a piece of electrical equipment; it is charged to a level of dangerous potential.
- Any person touching the metal & at the same time comes in contact with earth will receive a severe electric shock.
- Had the metal been effectively earthed, the very low resistance of the circuit would result in a flow of current sufficient to blow the Fuse or to operate the protective device.
- In an earth metalwork of a piece of electrical equipment becomes a zero potential due to this; a person does not get a shock.

Necessity of fuse

- A fuse(s) is needed in any electrical system (AC or DC).
- These protection devices react to the amount of heat being produced by electricity passing through wires or components.
- They are used so as to protect wires and components from the extreme heat produced should there be an electrical overload or short circuit.

Necessity of circuit breakers

- A circuit breaker automatically disrupts the flow of a current if there’s a short circuit or overload.
- In doing so, it can prevent damage to an electrical circuit and possibly appliances, electronics, and your home.
- When a circuit breaker trips, it may mean electrical repairs are needed.
- Some reasons a breaker can trip include:

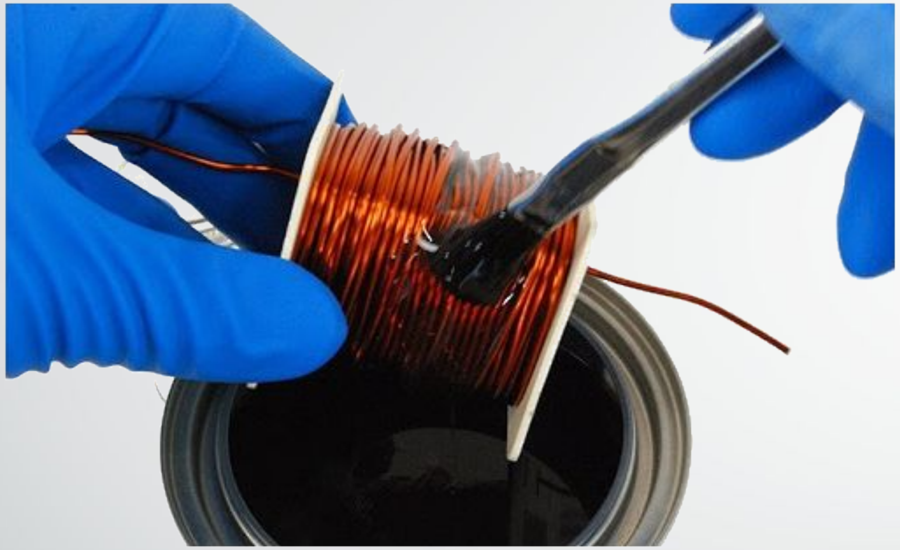
a. Too much current is flowing through the circuit

b. The hot and neutral wires have fused together (due to an overheated/melted component)

A power line has ruptured, perhaps by driving a nail in the wall

Insulators

- An **insulator** is a material that ***does not allow*** flow of electricity in it.
- Materials typically used to insulate include **rubber, plastic and glass**.
- In transformers and electric motors, **varnish** is used.
- Insulating gases such as **Sulfur hexafluoride** are used in some switches.
- Insulators have ***high electrical resistivity*** *and* ***low conductivity***.
- The insulators ***prevent the loss of current*** and make the current more efficient by concentrating the flow.



Varnish is coated in the coil

Electrical Insulator

Necessity of insulators

- An insulator opposes the flow of electricity.
- Insulators are important to keep us safe from electricity.
- The wire that carries electricity to your computer or television is covered with a rubber-like insulator that protects you from getting electrocuted.
- Thermal insulators, sound insulators and electrical insulators are used for various reasons, from keeping houses warm to protecting electrical wires and soundproofing rooms.

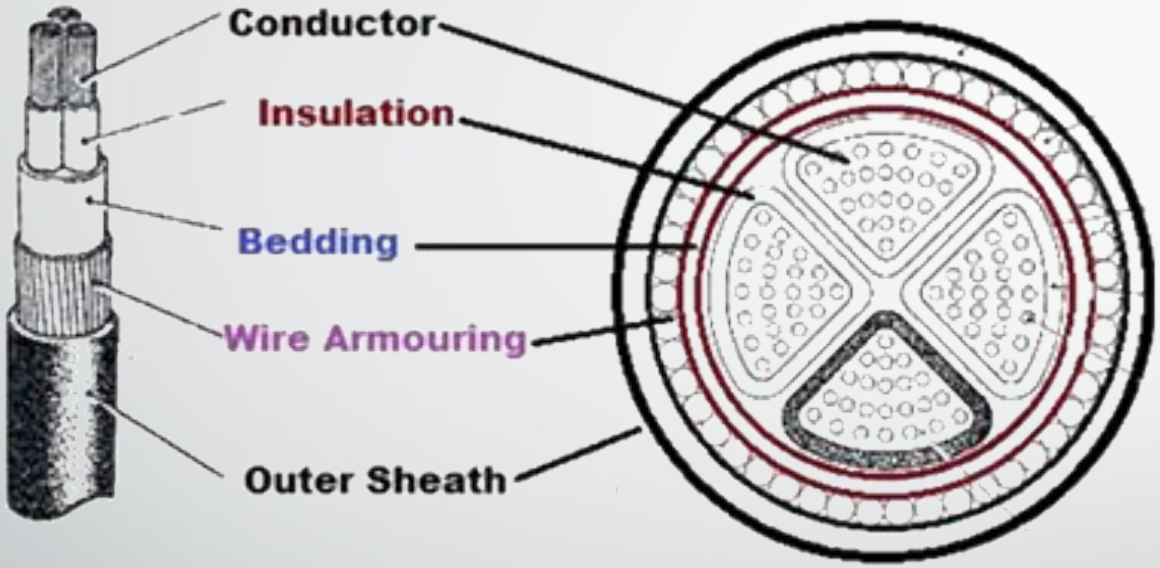
Cables

- An **electrical cable** is an assembly of one or more wires running side by side or bundled, which is used to **carry** electric current.

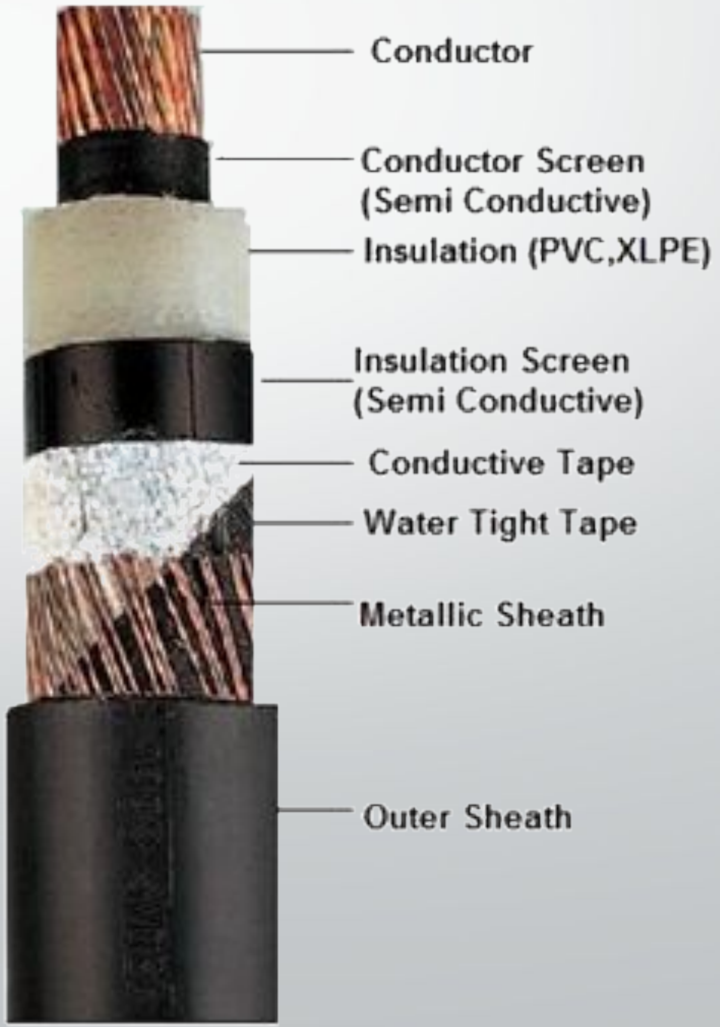
- An electric cable is measured in **volts** and, depending on these, they are categorized as follows:

1. **Low-tension cables** – maximum capacity of **1000 V (1KV)**.
2. **High-tension cables** – maximum of ***11KV.***
3. **Super-tension cables** – rating of between ***22 KV and 33 KV***.
4. **Extra high-tension cables** – rating of between ***33 KV and 66 KV***.
5. **Extra super voltage cables** – maximum voltage ratings ***beyond 132 KV***.

Cable Construction



MV / HT Cable



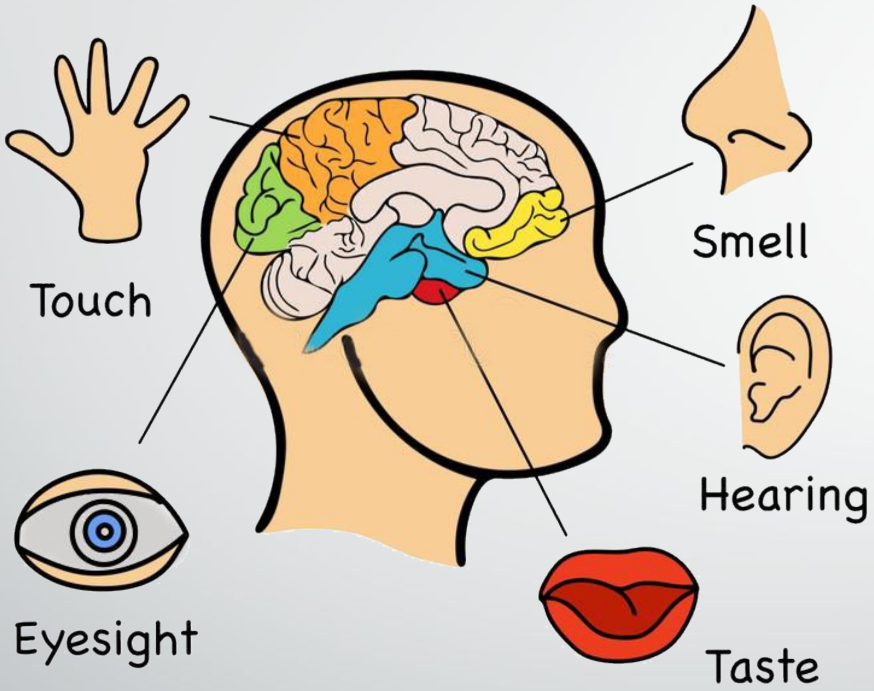
Necessity of cables

- Electrical cables are used to connect two or more devices, enabling the transfer of electrical signals or power from one device to the other.
- Cables are used extensively in electronic devices for power and signal circuits.
- Long-distance communication takes place over undersea cables.
- Power cables are used for bulk transmission of alternating and direct current power, especially using high-voltage cable.
- Electrical cables are extensively used in building wiring for lighting, power and control circuits permanently installed in buildings.

Sensors

- A **sensor** is a device that measures ***physical input*** from its environment and converts it into ***data*** that can be interpreted by either a human or a machine.
- People use sensors to measure temperature, gauge distance, detect smoke, regulate pressure and so on.

Perfect Example



Sensors:

- Pressure (switch & door closed)
- Water level/pressure
- Temperature

In Humans

In Machines

Types of Sensors

- Vision and Imaging Sensors
- Temperature Sensors
- Radiation Sensors
- Proximity Sensors
- Pressure Sensors
- Position Sensors
- Photoelectric Sensors
- Particle Sensors
- Motion Sensors

In Our Day-to-Day Life

- Level Sensors
- Leak Sensors
- Humidity Sensors
- Gas and Chemical Sensors
- Force Sensors
- Flow Sensors
- Flaw Sensors
- Flame Sensors
- Electrical Sensors
- Contact Sensors

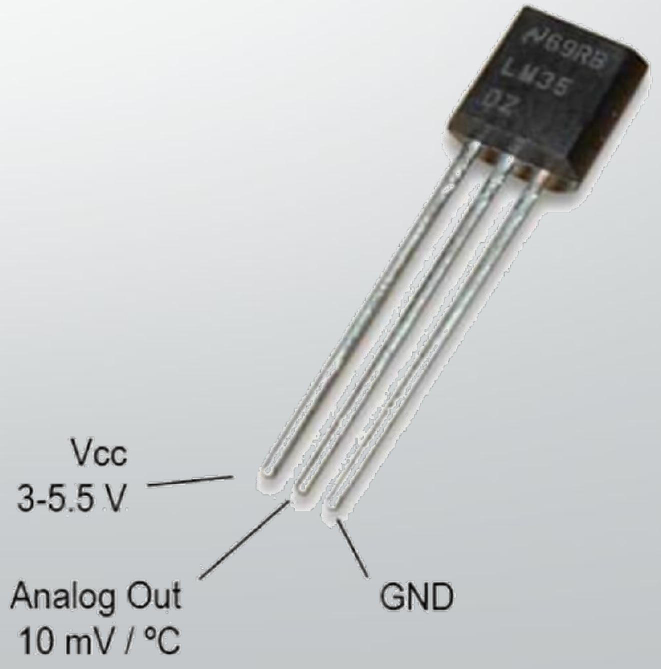
Temperature Sensor

- **Temperature Sensors** measure the amount of heat energy or even coldness that is generated by an object or system
- This sensor is made up of two metals, which generate electrical voltage once it notices a change in temperature.
- **Types of Temperature Sensors**

✔ Thermocouples

✔ RTD (Resistance Temperature Detector)

✔ Thermistors



Proximity Sensor

- A **proximity sensor** is a sensor able to detect the presence of nearby objects without any physical contact.
- A proximity sensor often emits an electromagnetic field or a beam of electromagnetic radiation (infrared, for instance), and looks for changes in the field or return signal.

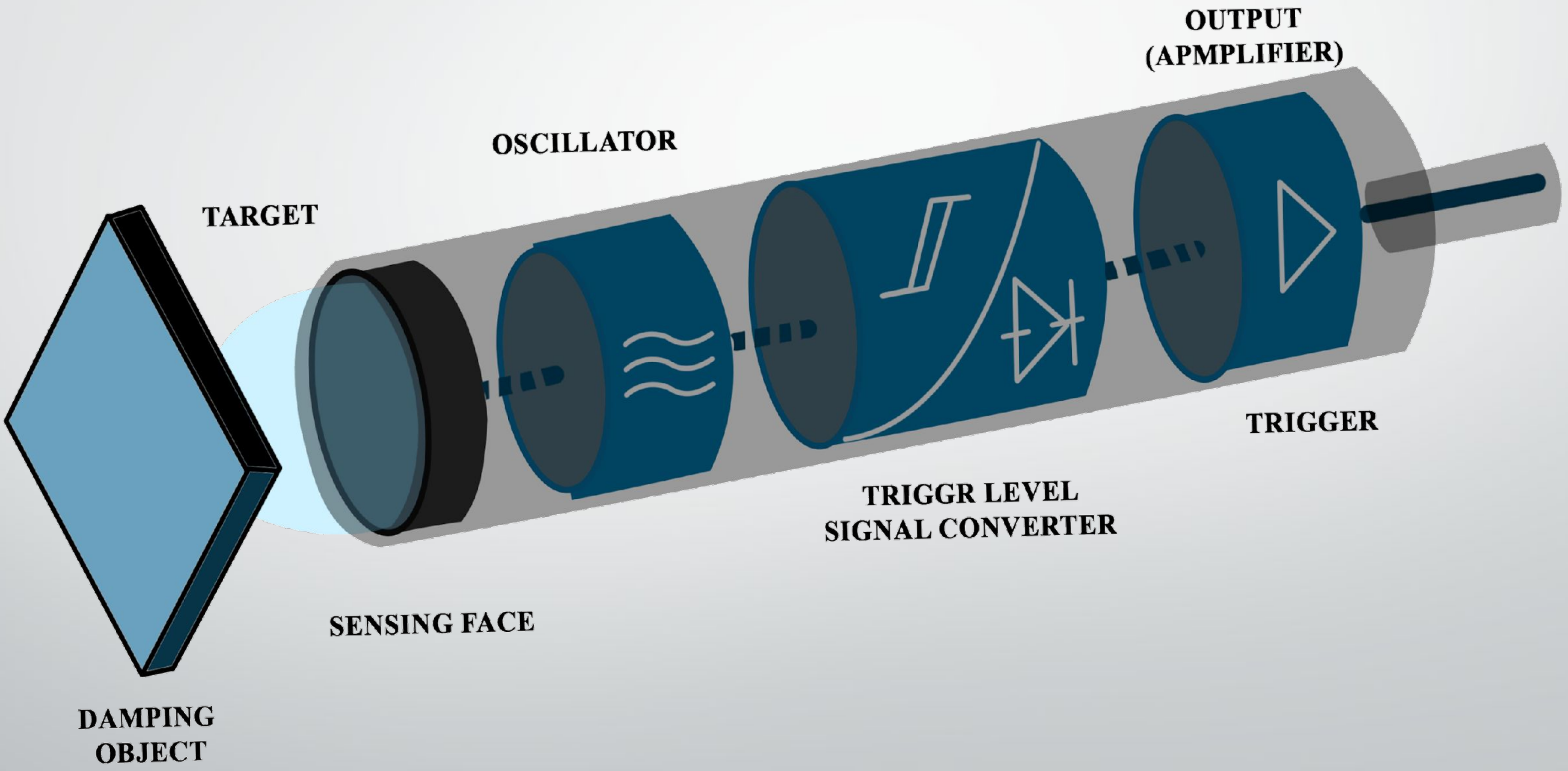
Types:

- Inductive Proximity Sensor
- Capacitive Proximity Sensor

Applications:

- It used to sense when a **phone** is held up to the users ear to turn off the display.

Working Principle of Proximity Sensor



Pressure Sensor

- A **pressure sensor** is a device for pressure measurement of **gases or liquids**.
- It can also be used to indirectly measure other variables such as **fluid/gas flow, speed, water level, and altitude**.
- These sensors are commonly manufactured out of **piezoelectric** materials such as **quartz**.

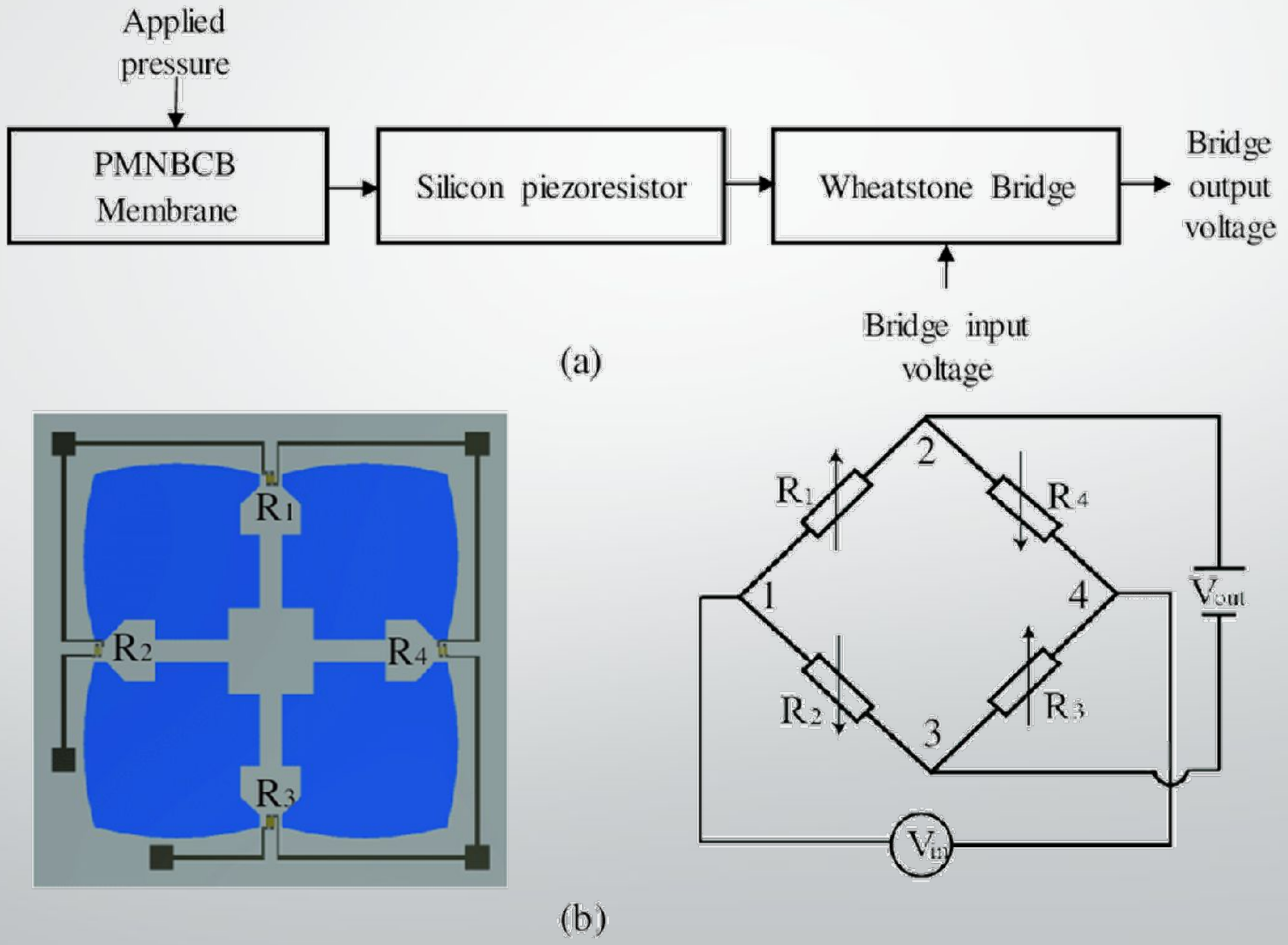
Types:

- Absolute pressure sensor
- Gauge pressure sensor
- Vacuum pressure sensor
- Differential pressure sensor
- Sealed pressure sensor

Applications:

is useful in weather instrumentation, aircraft, automobiles, and any other machinery

Working Principle
(Piezo-resistive material)

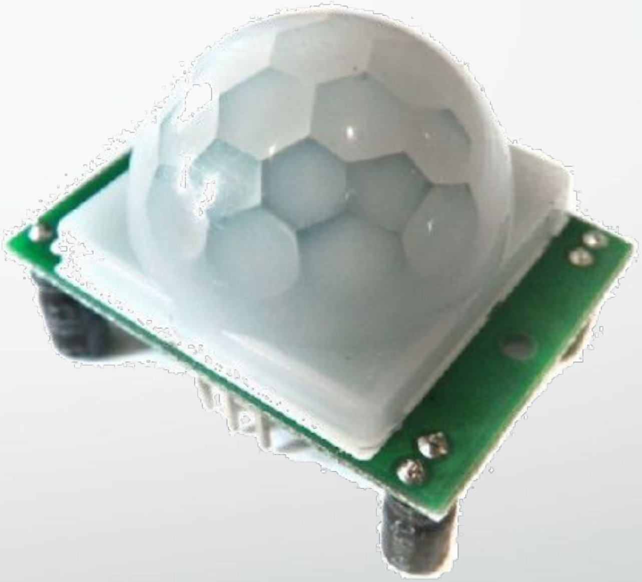


Motion Sensor

- A **motion sensor** is an electrical device that is used to detect nearby motion.

Types

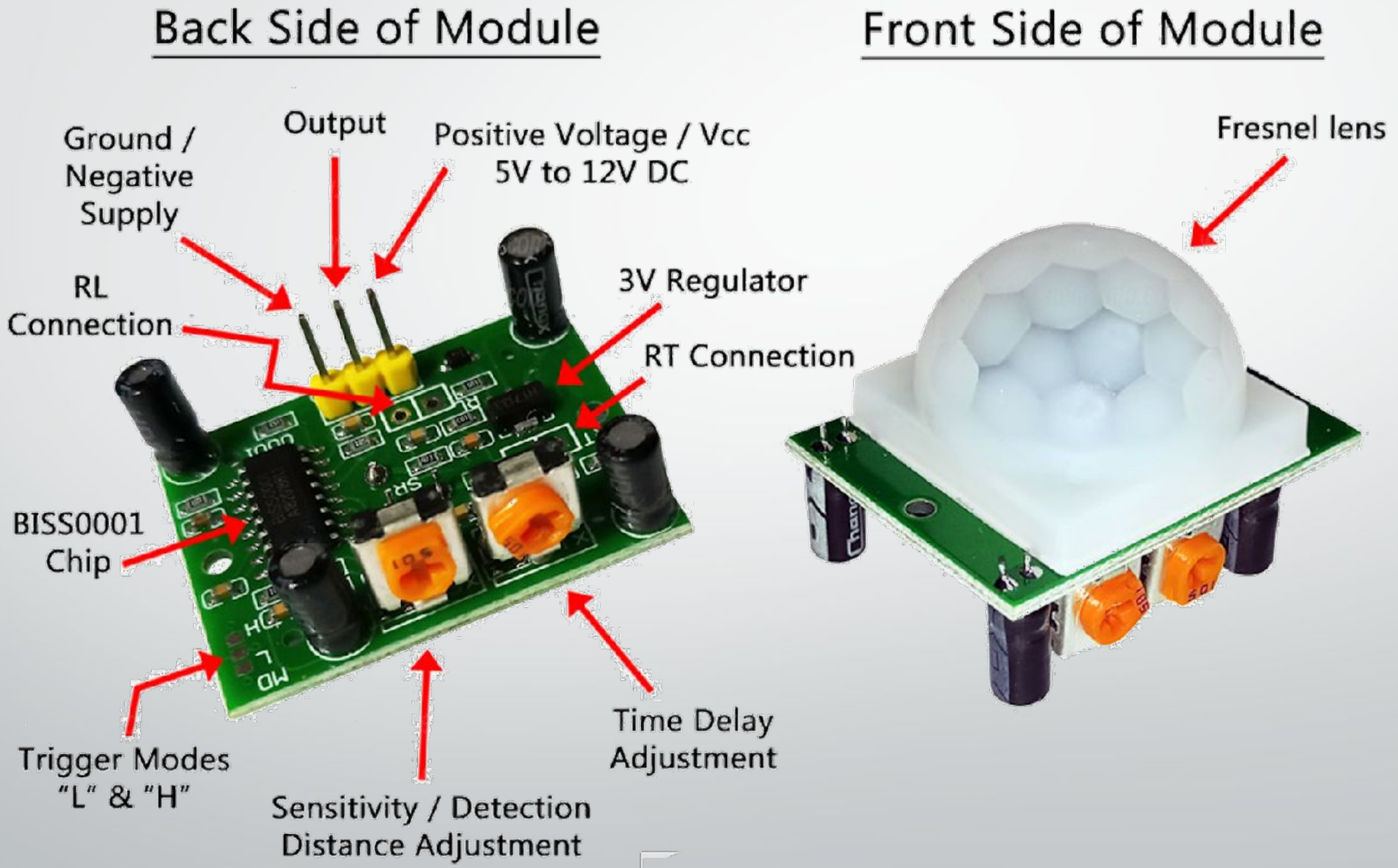
- PIR (Passive Infra Red) Sensor
- Ultrasonic Sensor
- Microwave Sensor
- Tomographic Sensor



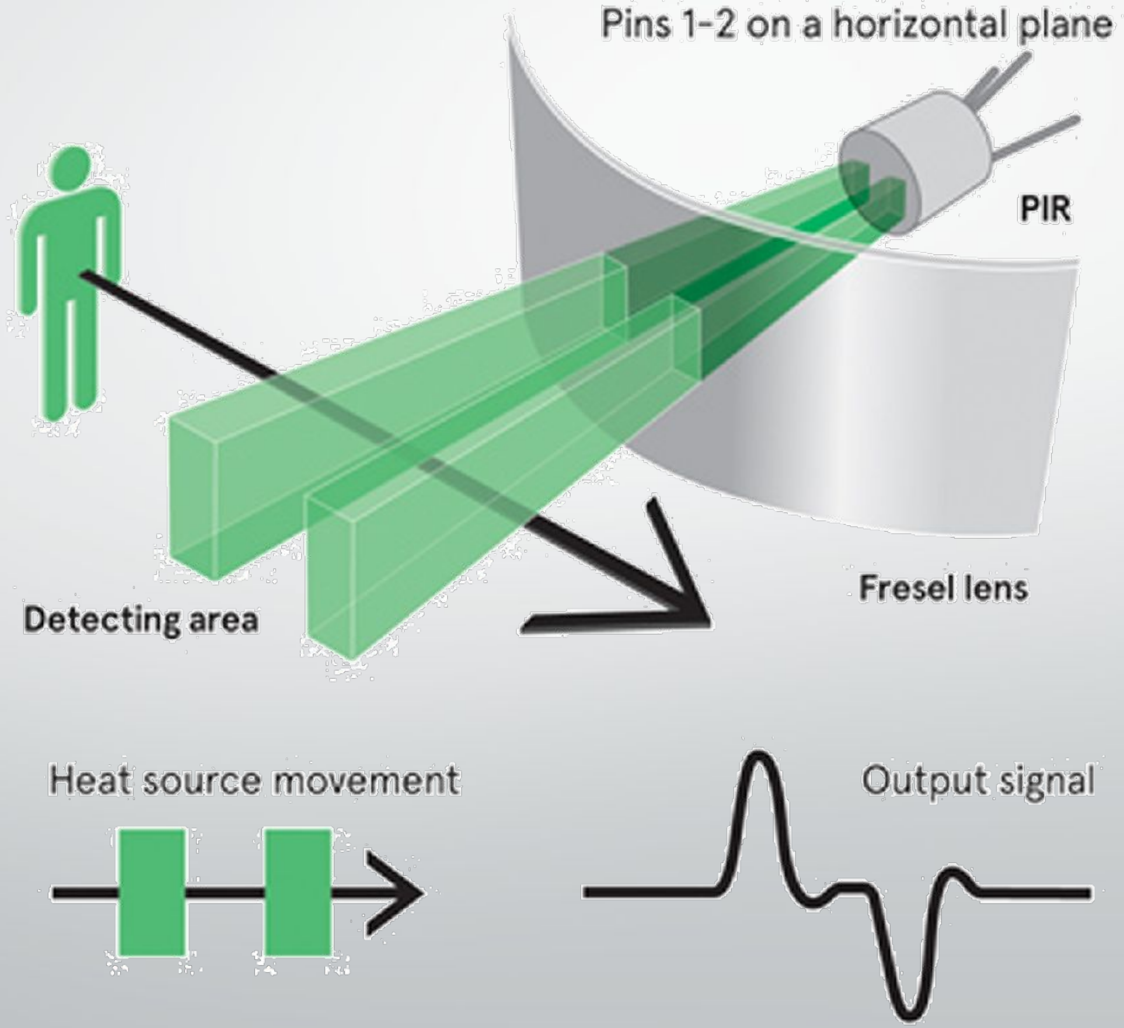
Applications

- It is used in security system, automated lighting control, home control, energy efficiency, and other useful systems.

PIR Motion Sensor



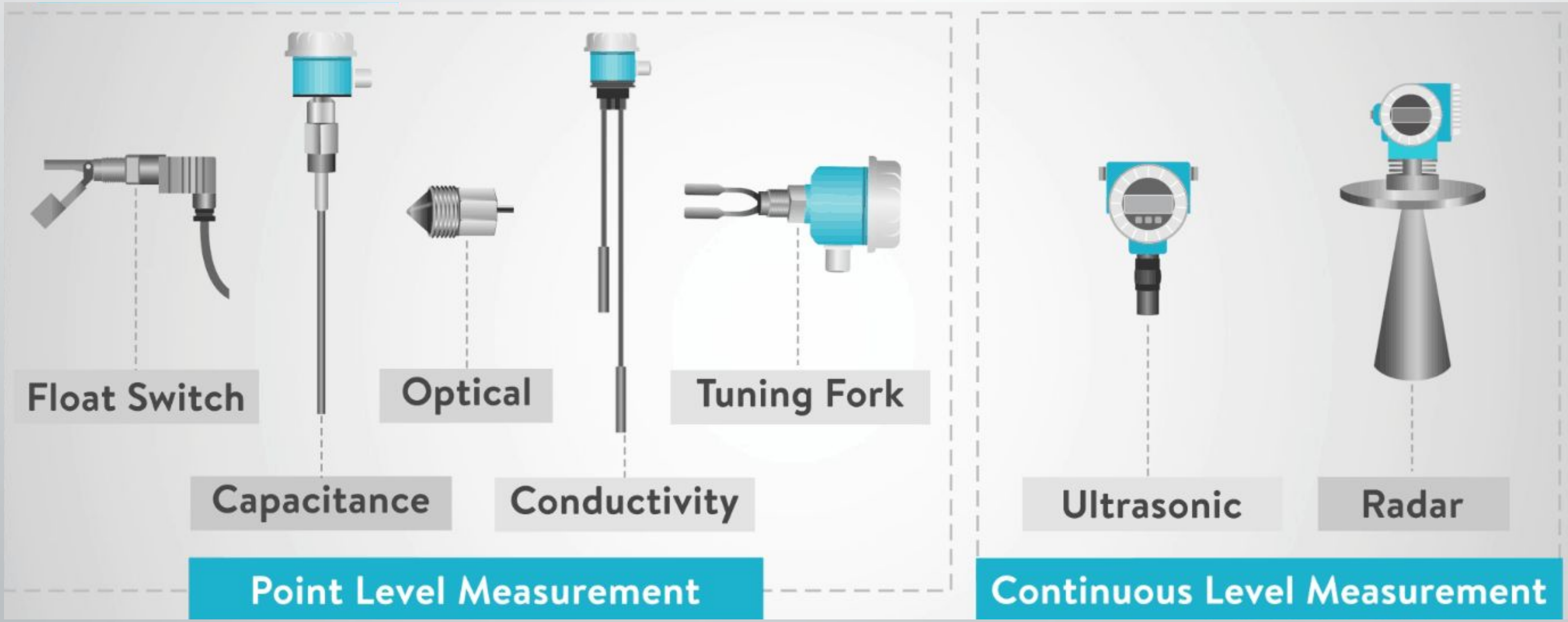
Working principle of PIR motion sensor



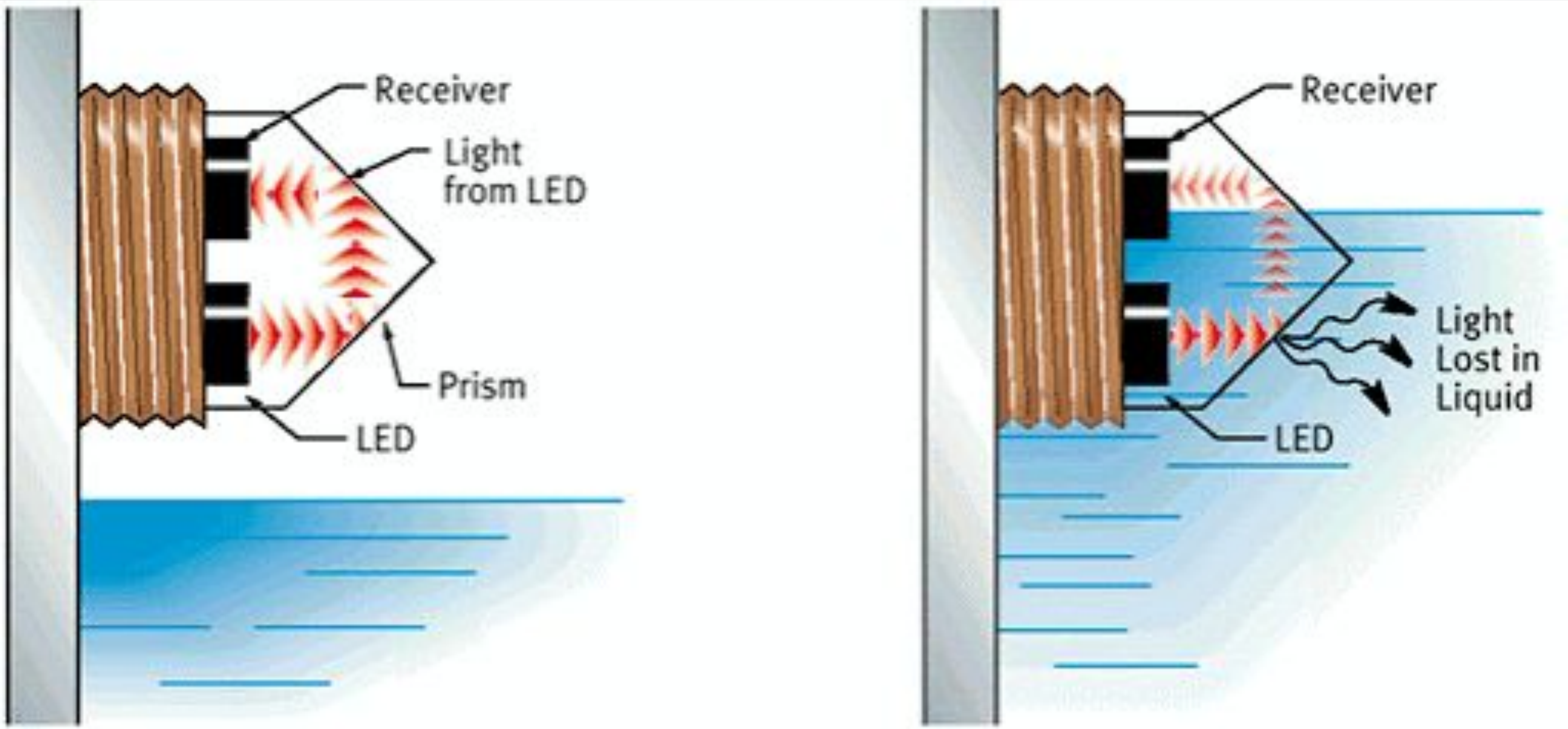
Level Sensor

- A **level sensor** is a device that is designed to monitor, maintain, and measure liquid (and sometimes solid) levels.
- There are two main classifications for level sensors: **point level sensors** and **continuous level sensors**.
- Point level sensors are designed to indicate whether a liquid has reached a specific point in a container.
- Continuous level sensors, on the other hand, are used to render precise liquid level measurements.

Types of level Sensors



Working Principle of Optical Level Sensor



Flow Sensor

- A flow sensor is an electronic device that measures or regulates the flow rate of liquids and gasses within pipes and tubes.
- Flow sensors can be divided into two groups: **contact and non-contact** flow sensors.

Types

- Electromagnetic Flow Meters.
- Vortex Time Flow Meter.
- Ultrasonic Flow Meter
- Differential Pressure Flow Meter
- Coriolis Mass Flow Meter.

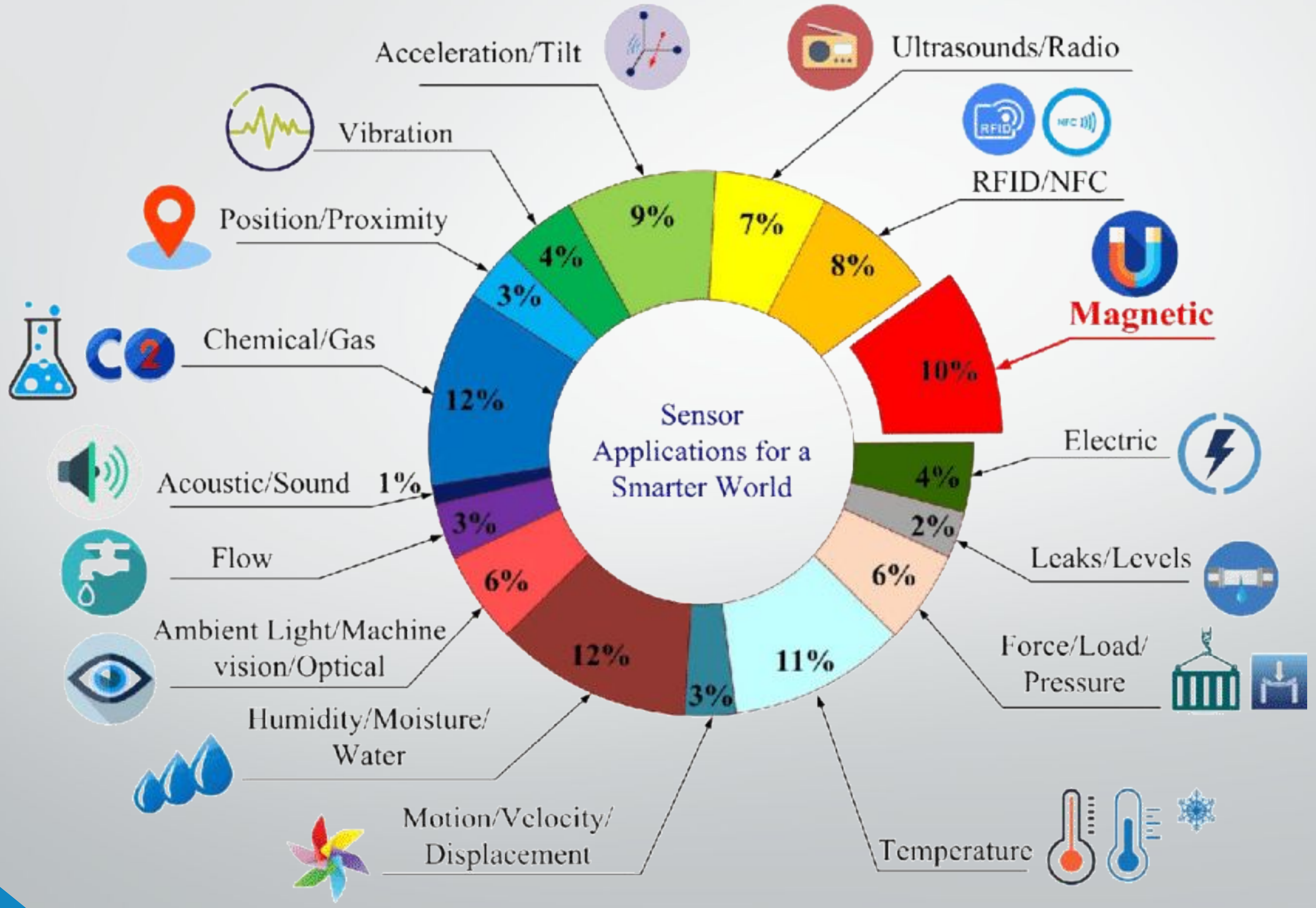
Applications

They are able to detect leaks, blockages, pipe bursts, and changes in liquid

Electrical Sensor

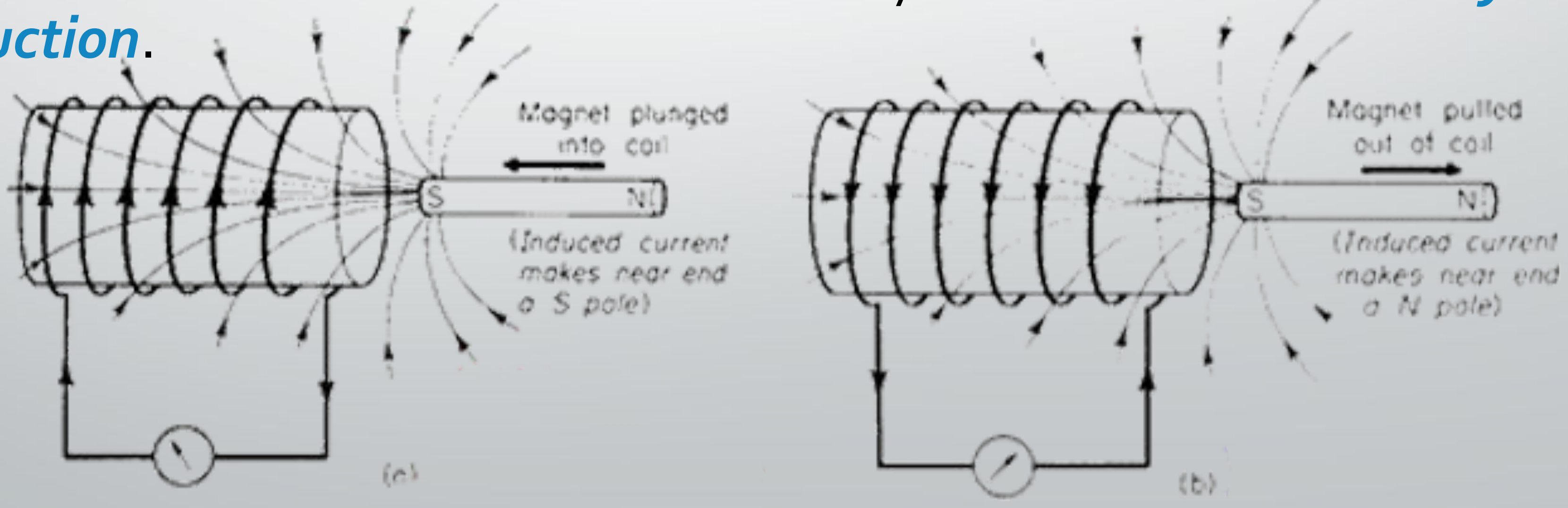
- An electrical sensor is a device or integrated circuit that detects a specific physical parameter and converts it to an **electrical signal**.
- The output signal of the electrical sensor is processed and used to provide a measurement or to trigger an action.
- These electric sensor ICs provide **high-accuracy, low-power performance** with real-time protection, robust interfaces, and **compact packaging** for use in industrial, automotive, consumer, data center and communications applications.

Applications of Sensor



Electromagnetic Induction

- **Electromagnetic Induction** is a process in which a conductor is put in a particular position and magnetic field keeps varying or magnetic field is stationary and a conductor is moving.
- This produces a **Voltage** or **EMF (Electromotive Force)** across the electrical conductor.
- **Michael Faraday** is generally credited with the **discovery** of induction in 1831, and **James Clerk Maxwell** mathematically described it as ***Faraday's law of induction***.



Electromagnetic induction

Faraday’s Experiment

Michael Faraday

James Clerk Maxwell

- Faraday's experiment showing induction between coils of wire: The liquid battery *(right)* provides a current which flows through the small coil (*A*), creating a magnetic field.
- When the coils are stationary, no current is induced.
- But when the small coil is moved in or out of the large coil (*B*), the magnetic flux through the large coil changes, inducing a current which is detected by the galvanometer (*G*)

Law of Electromagnetic induction

- **Laws of Electromagnetic induction** includes three laws:

  1) Faraday's First Law

  2) Faraday's Second Law

  3) Lenz Law

- **Faraday's law of induction** is a basic law of electromagnetism predicting *how a magnetic field will interact with an electric circuit to produce an electromotive force (EMF)*

  emf = –N (ΔΦ/Δt)

  Where , *emf* =induced voltage

  N =number of loops

  ΔΦ =change in magnetic flux

  Δt =change in time

- **Faraday's First law:** *Whenever a conductor is placed in a varying magnetic field, EMF induces* and this emf is called an induced emf and if the conductor is a closed circuit than the induced current flows through it.

- **Faraday's Second law:** The *magnitude of the induced EMF is equal to the rate of change of flux linkages*.

- **Lenz's law:** states that the direction of the current induced in a conductor by a changing magnetic field is such that the magnetic field created by the *induced current opposes the initial changing magnetic field which produced it*.

Using these laws, let us see how we get the electromagnetic induction equation in the following,

Consider a magnet approaching towards a coil. Consider two-time instances T_1 and T_2.

- Flux linkage with the coil at the time T_1 is given by

  $T_1 = N\Phi_1$

- Flux linkage with the coil at the time T_2 is given by

  $T_1 = N\Phi_2$

- Change in the flux linkage is given by

  $N(\Phi_2 - \Phi_1)$

- Let us consider this change in flux linkage as

  $\Phi = \Phi_2 - \Phi_1$

- Hence, the change in flux linkage is given by

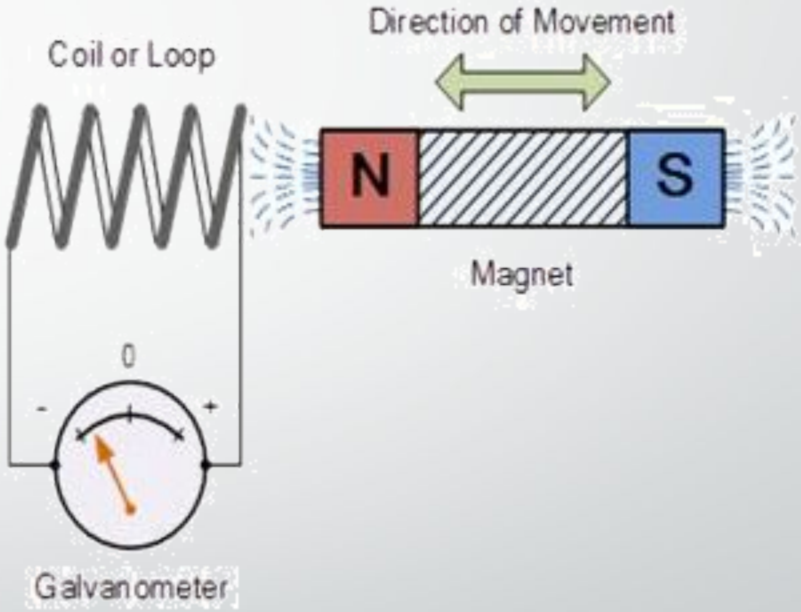
  $N*\Phi$

- The rate of change of flux linkage is given by

  $(N*\Phi)/t$

- Taking the derivative of the above equation, we get

  $N\,(d\Phi/dt)$



- Considering Faraday's Second Law, the induced emf in a coil is equal to the rate of change of flux linkage

$E = N\ (d\phi/dt)$

- Considering Lenz's law,

$E = -N\ (d\phi/dt)$

From the above equation, we can conclude the following

- *Increase* in the **number of turns** in the coil *increases* the **induced emf**
- *Increasing* the **magnetic field strength** *increases* the **induced emf**
- *Increasing* the **speed** of the relative motion between the coil and the magnet, results in the *increased* **emf**

Auto transformer

- An autotransformer is a type of electrical transformer with **only one winding**.
- The "auto" (Greek for "**self**") prefix refers to the single coil acting alone, **not** to any kind of **automatic mechanism**.
- In an auto transformer, one single winding is used as *primary winding as well as secondary winding*.
- The autotransformer winding has **at least three taps** where electrical connections are made.
- It have the advantages of often being **smaller, lighter, and cheaper** than typical dual-winding transformers, but the disadvantage of **not providing electrical isolation** between primary and secondary circuits.

Autotransformer

Working Principle:

Faraday's Law of Electromagnetic Induction

AutoTransformer Theory

- The winding AB of total turns N_1 is considered as **primary winding**. This winding is tapped from point 'C' and the portion BC is considered as **secondary**. Let's assume the number of turns in between points 'B' and 'C' is N_2.
- If V_1 voltage is applied across the winding i.e. in between 'A' and 'C'.

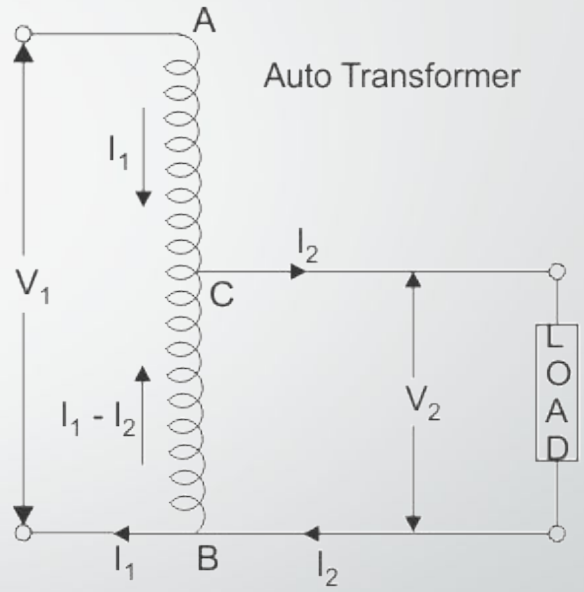
$$So\ voltage\ per\ turn\ in\ this\ winding\ is\ \frac{V_1}{N_1}$$

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

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

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

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



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

The current in the secondary winding or common winding is the difference of I_2 and I_1.

Single phase transformer

- A **single-phase transformer** is a type of ***power transformer*** that utilizes **single-phase** alternating current, meaning the **transformer** relies on a voltage cycle that operates in a ***unified time phase***.

- Types:

  1)**Power transformer**: convert voltages from one level or **phase** to another for widespread power distribution.

  2)**Rectifier transformer**: converts AC to DC.

  3)**Resonant transformer**: a capacitor is placed across one or both windings to function so the circuit can be tuned.

- Application: These are used in **power supplies** and other equipment to convert AC voltages and currents from one value to another.

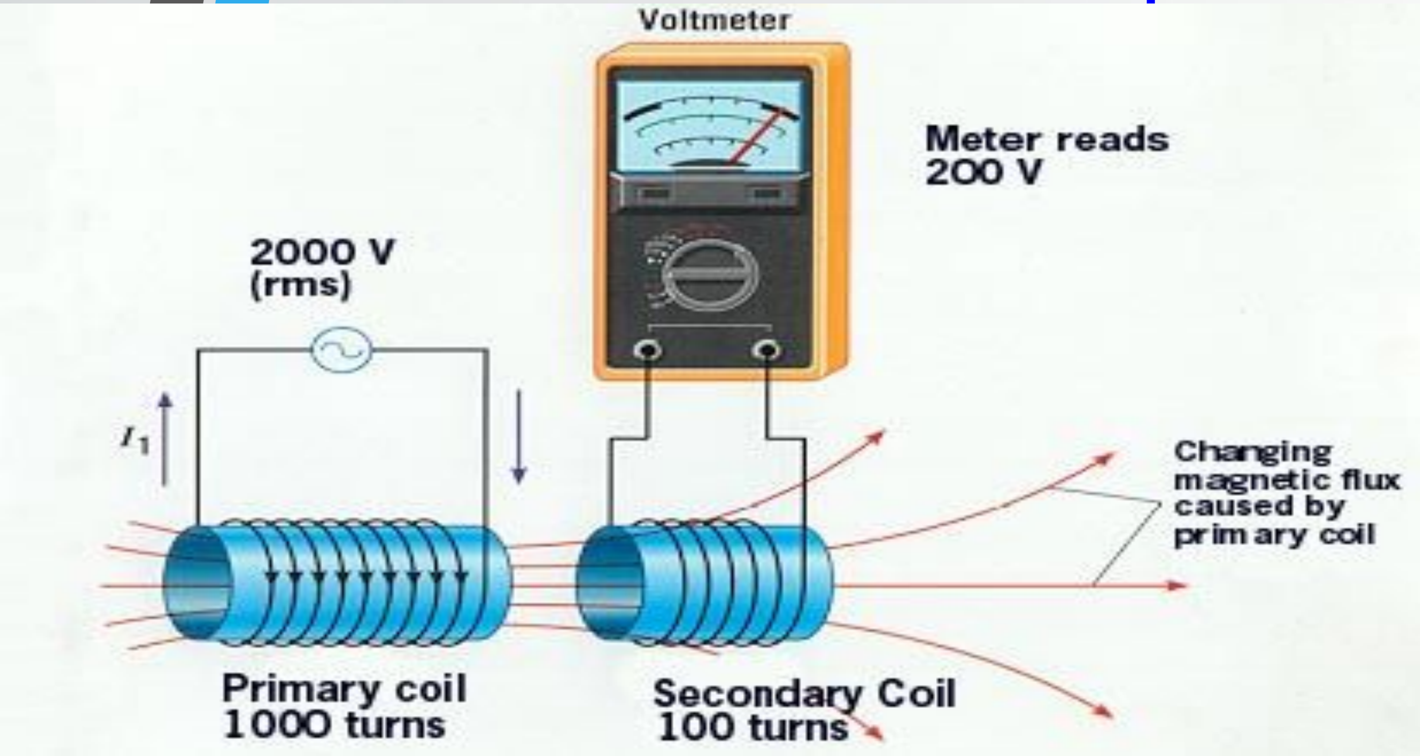
Transformer

An A.C. device used to change high voltage low current A.C. into low voltage high current A.C. and vice-versa without changing the frequency

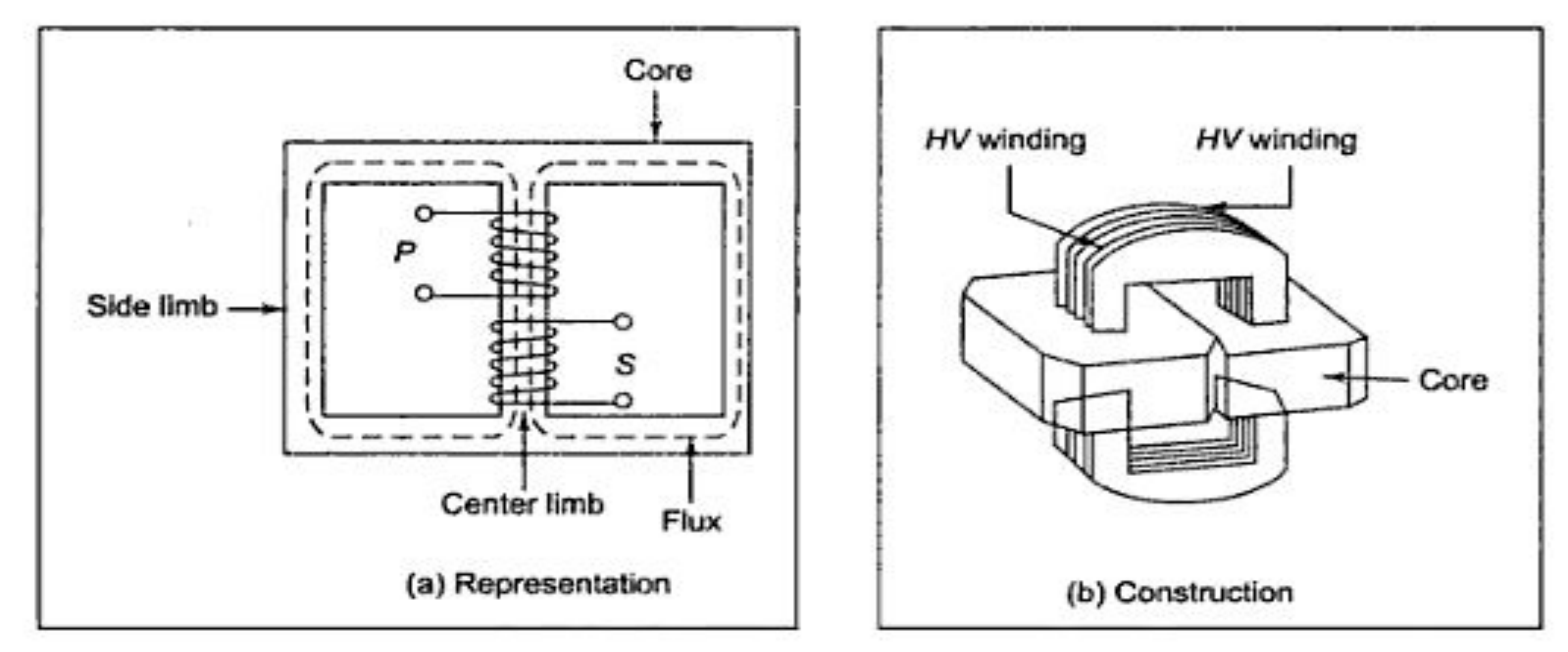
In brief,

1. Transfers electric power from one circuit to another
2. It does so without a change of frequency
3. It accomplishes this by electromagnetic induction
4. Where the two electric circuits are in mutual inductive influence of each other.

Principle of operation

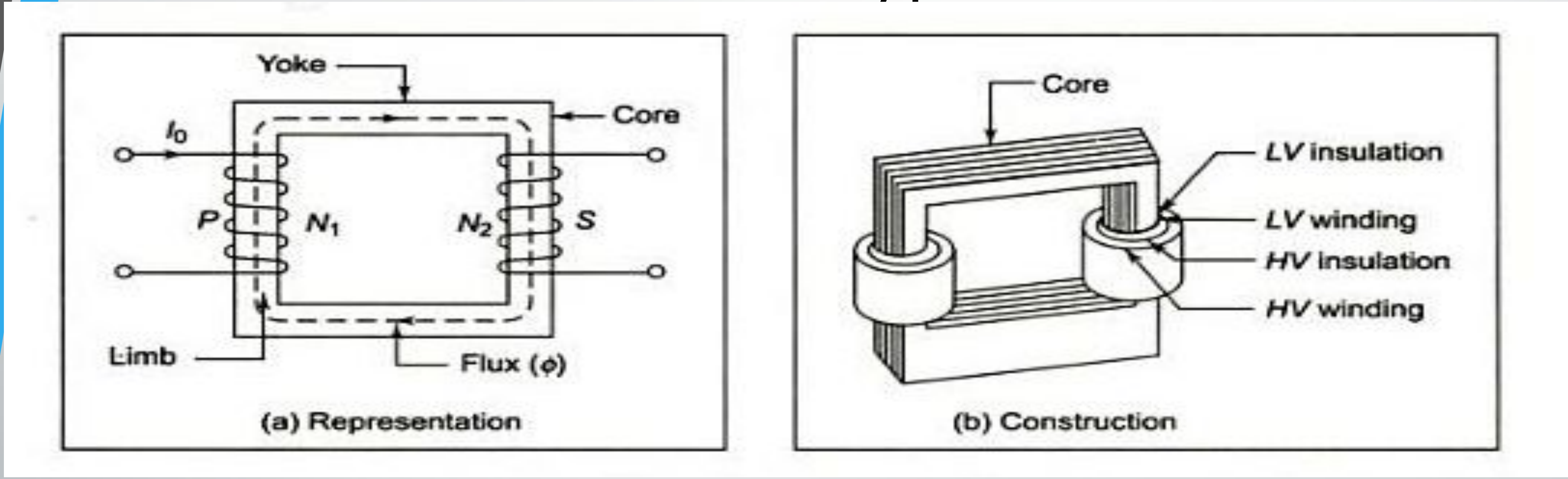


It is based on principle of MUTUAL INDUCTION. According to which an e.m.f. is induced in a coil when current in the neighbouring coil changes.



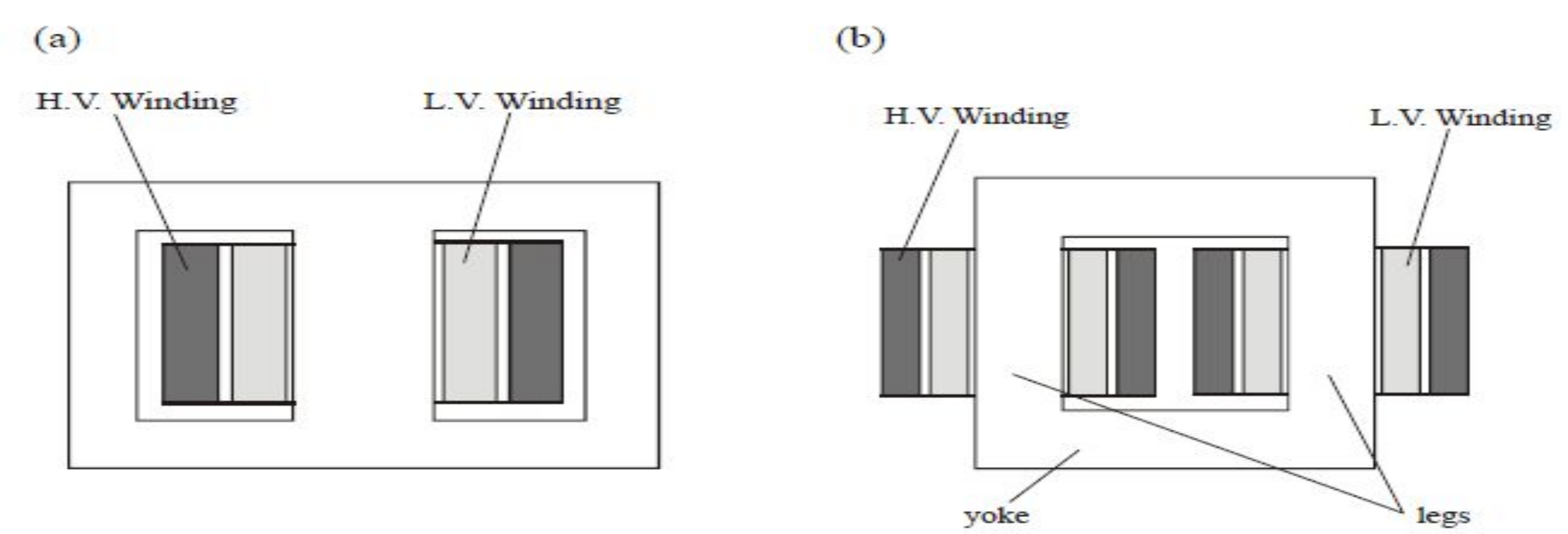
- Windings are wrapped around the center leg of a laminated core.

Core type



- Windings are wrapped around two sides of a laminated square core.

Sectional view of transformers

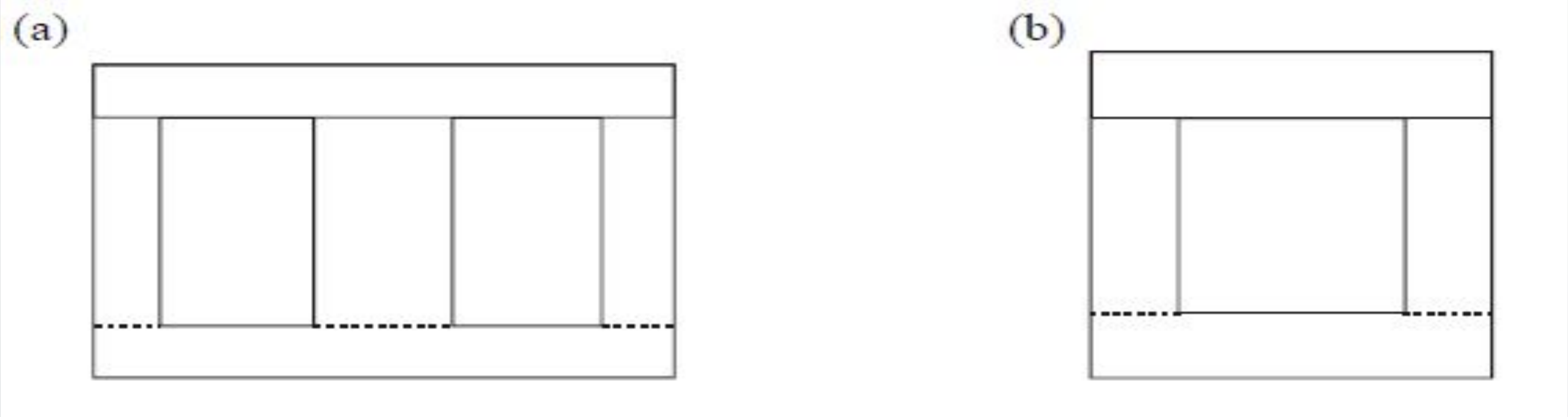


(a) Shell-type transformer, (b) core-type transformer

Note:

High voltage conductors are smaller cross section conductors than the low voltage coils

Construction of transformer from stampings



(a) Shell-type transformer, (b) core-type transformer

Core type

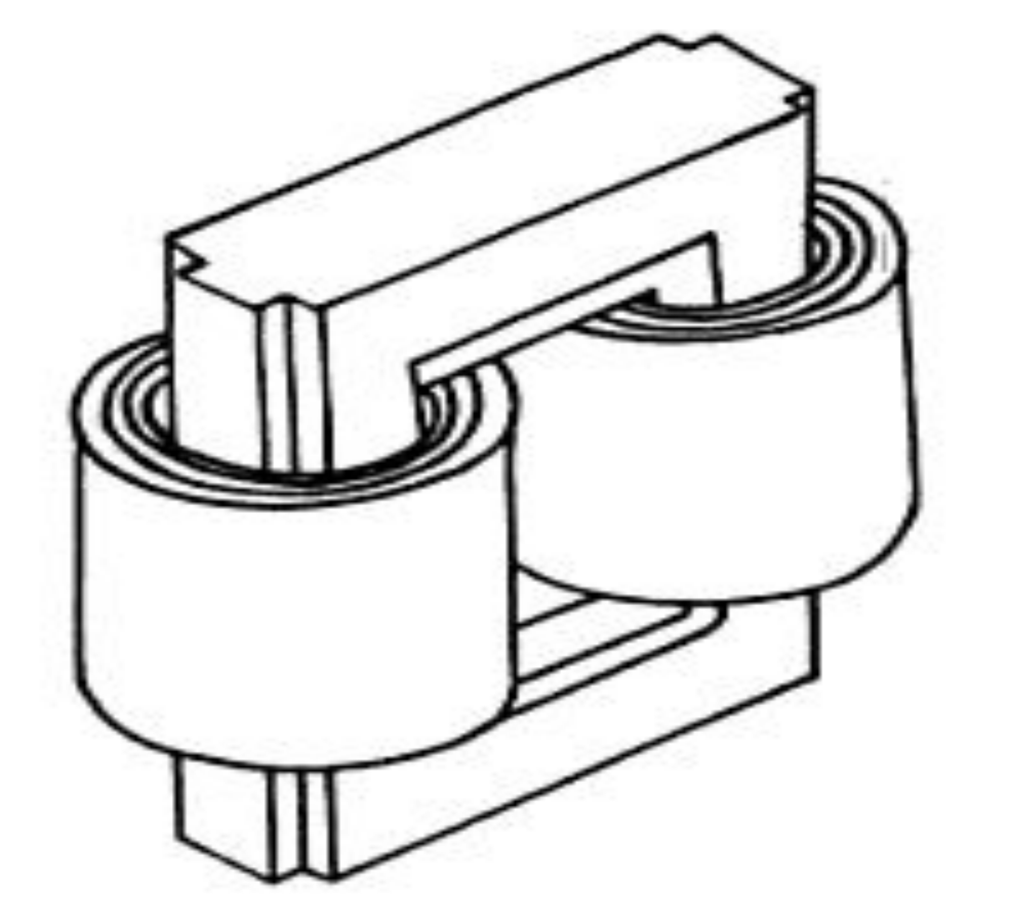


Fig1: Coil and laminations of core type transformer

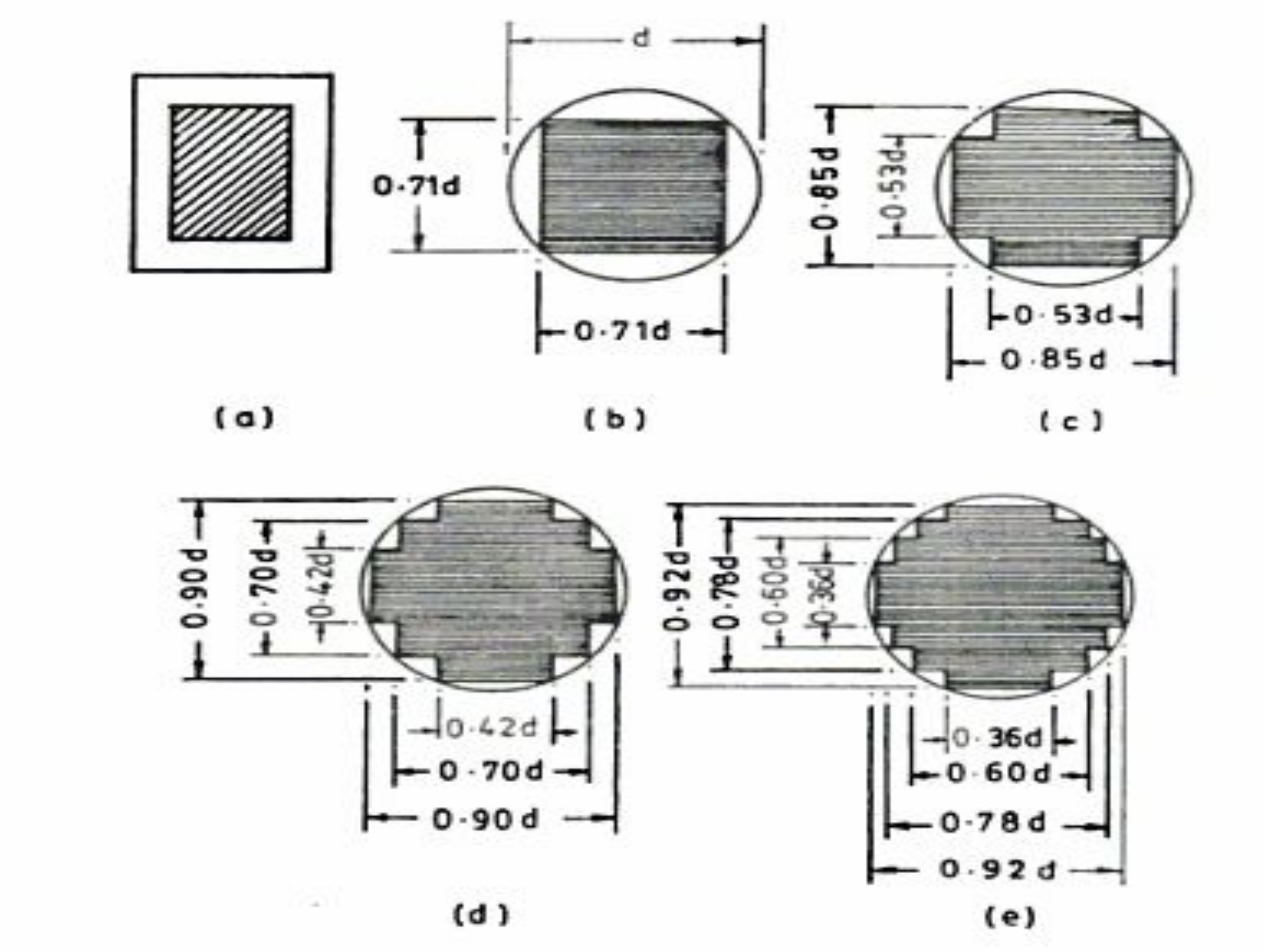


Fig2: Various types of cores

Shell type

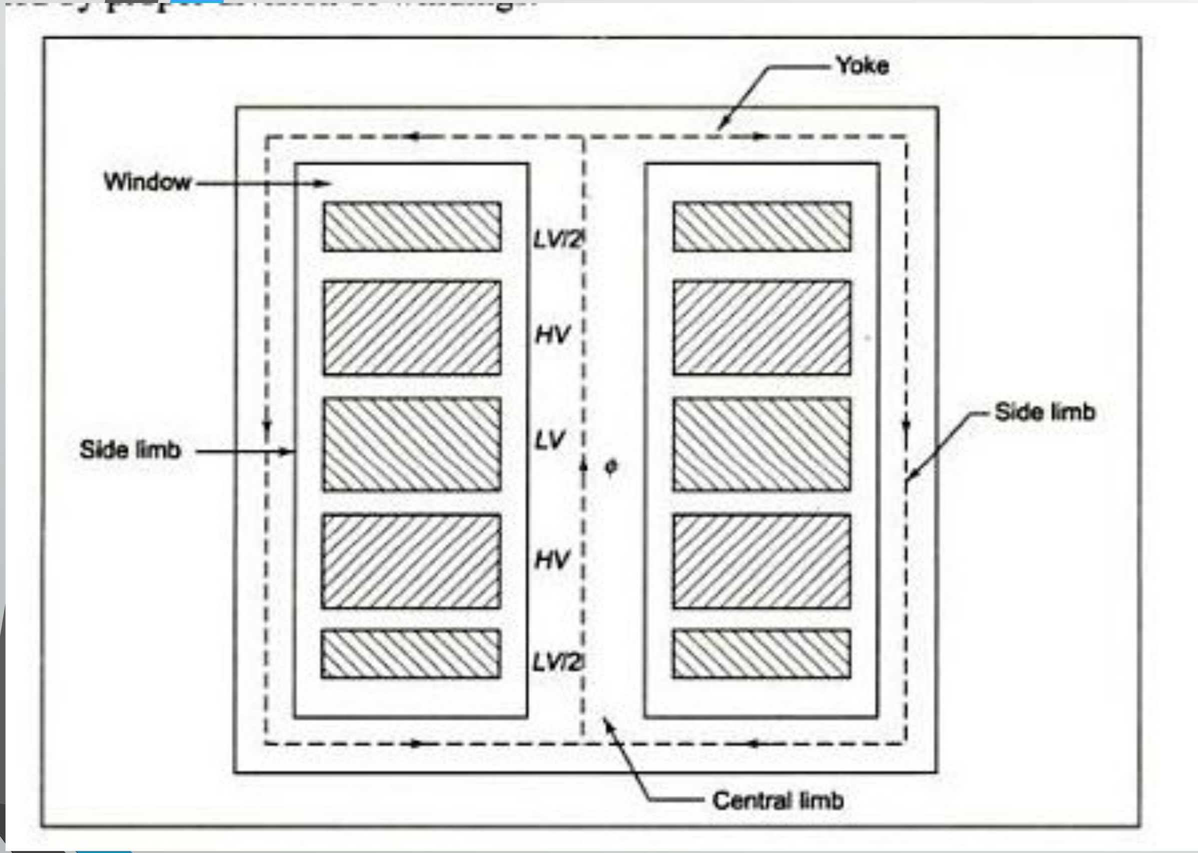
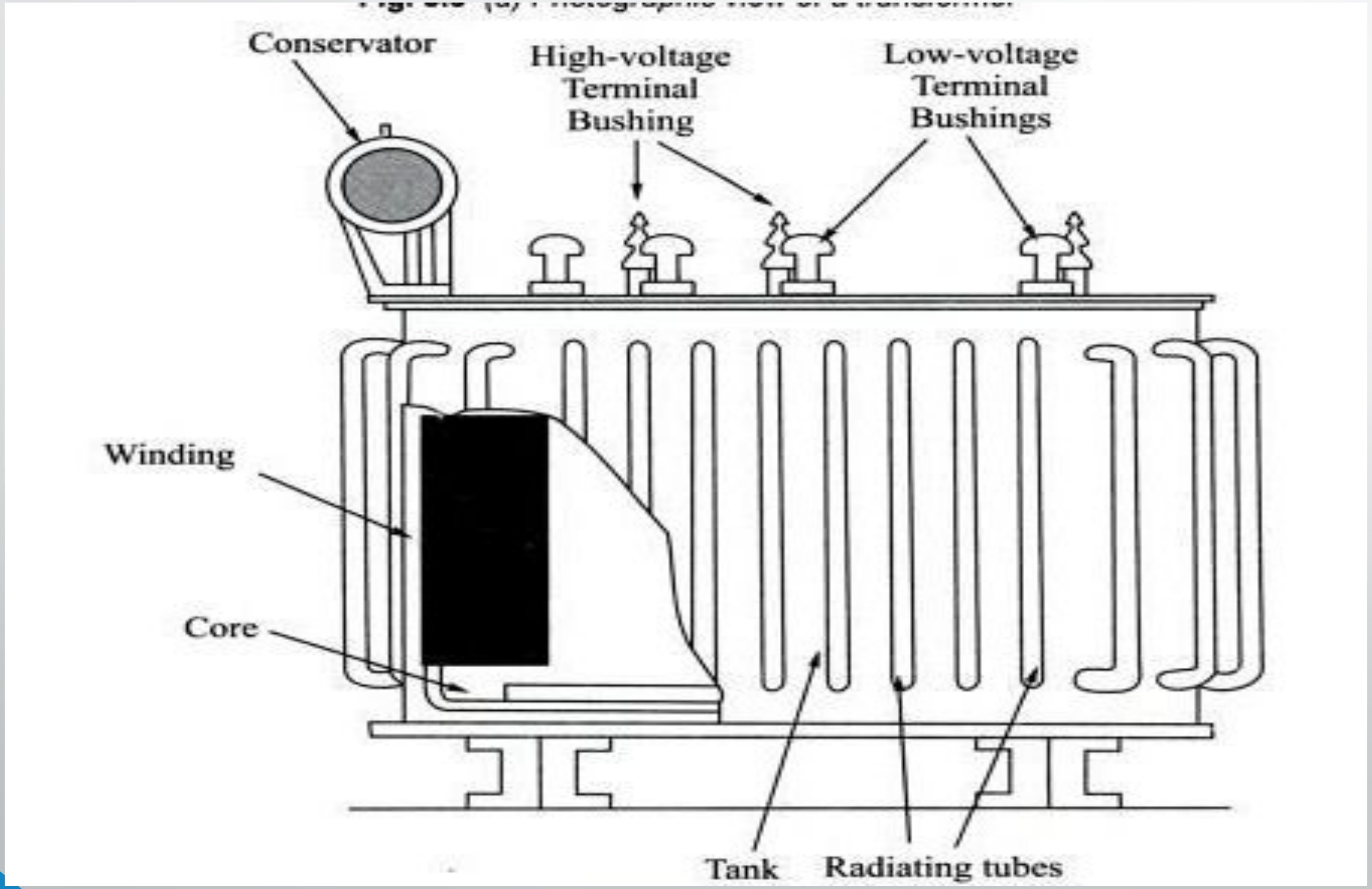


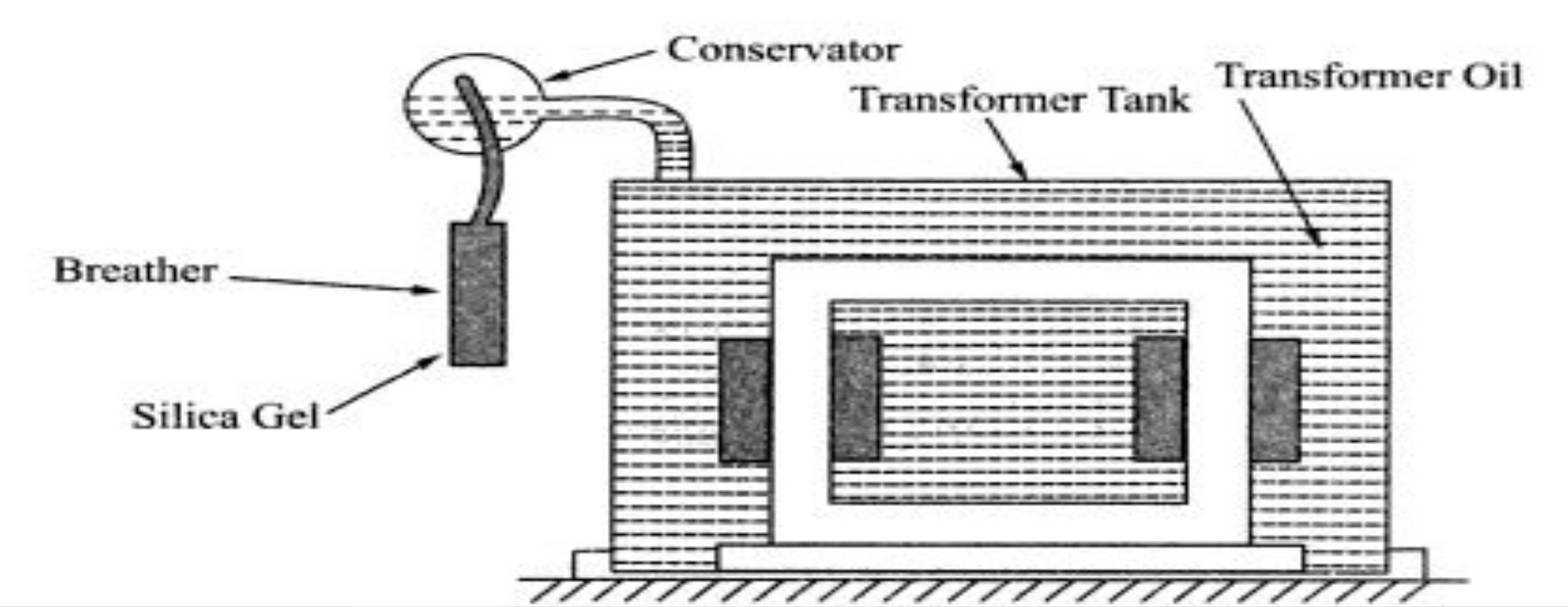
Fig: Sandwich windings

- The HV and LV windings are split into no. of sections
- Where HV winding lies between two LV windings
- In sandwich coils leakage can be controlled

Cut view of transformer

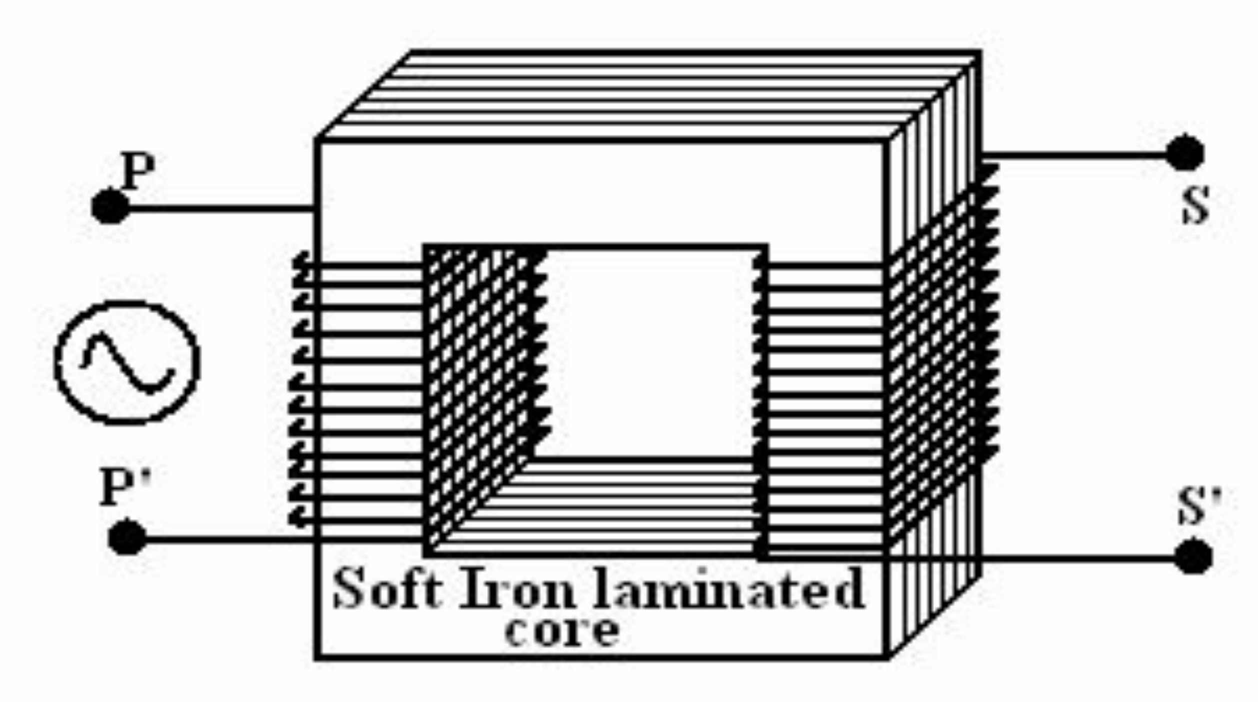


Transformer with conservator and breather



Working of a transformer

1. When current in the primary coil changes being alternating in nature, a changing magnetic field is produced
2. This changing magnetic field gets associated with the secondary through the soft iron core
3. Hence magnetic flux linked with the secondary coil changes.
4. Which induces e.m.f. in the secondary.



Single Phase Transformer

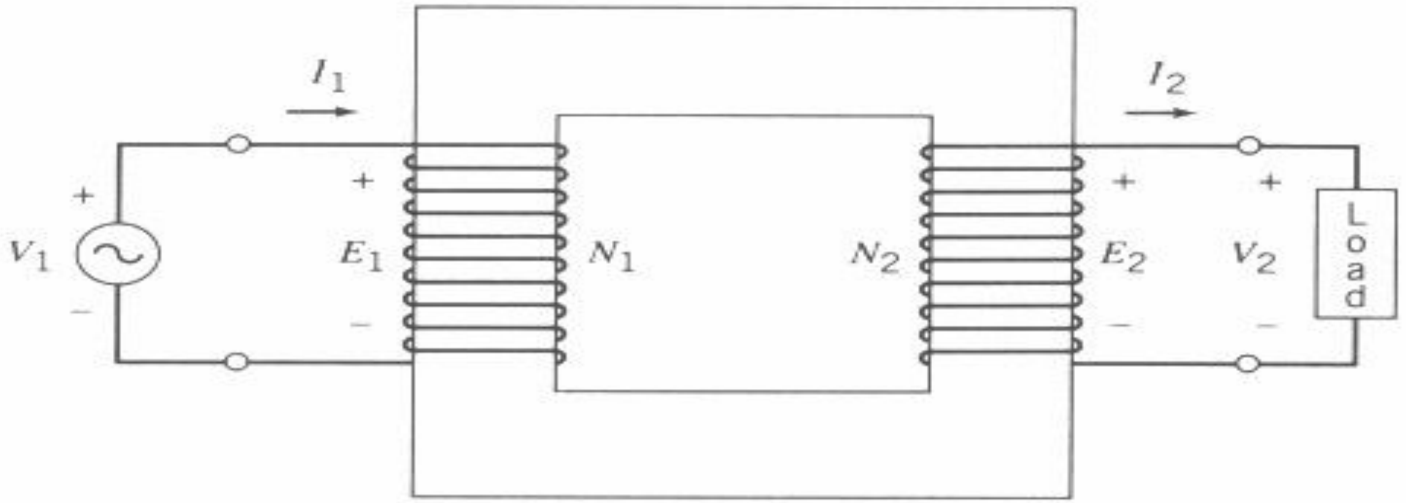


FIGURE 4.8 A transformer circuit.

- A single phase transformer
  - Two or more winding, coupled by a common magnetic core

Ideal Transformers

- **Zero leakage flux:**

  -Fluxes produced by the primary and secondary currents are confined within the core

- **The windings have no resistance:**

  - Induced voltages equal applied voltages

- **The core has infinite permeability**

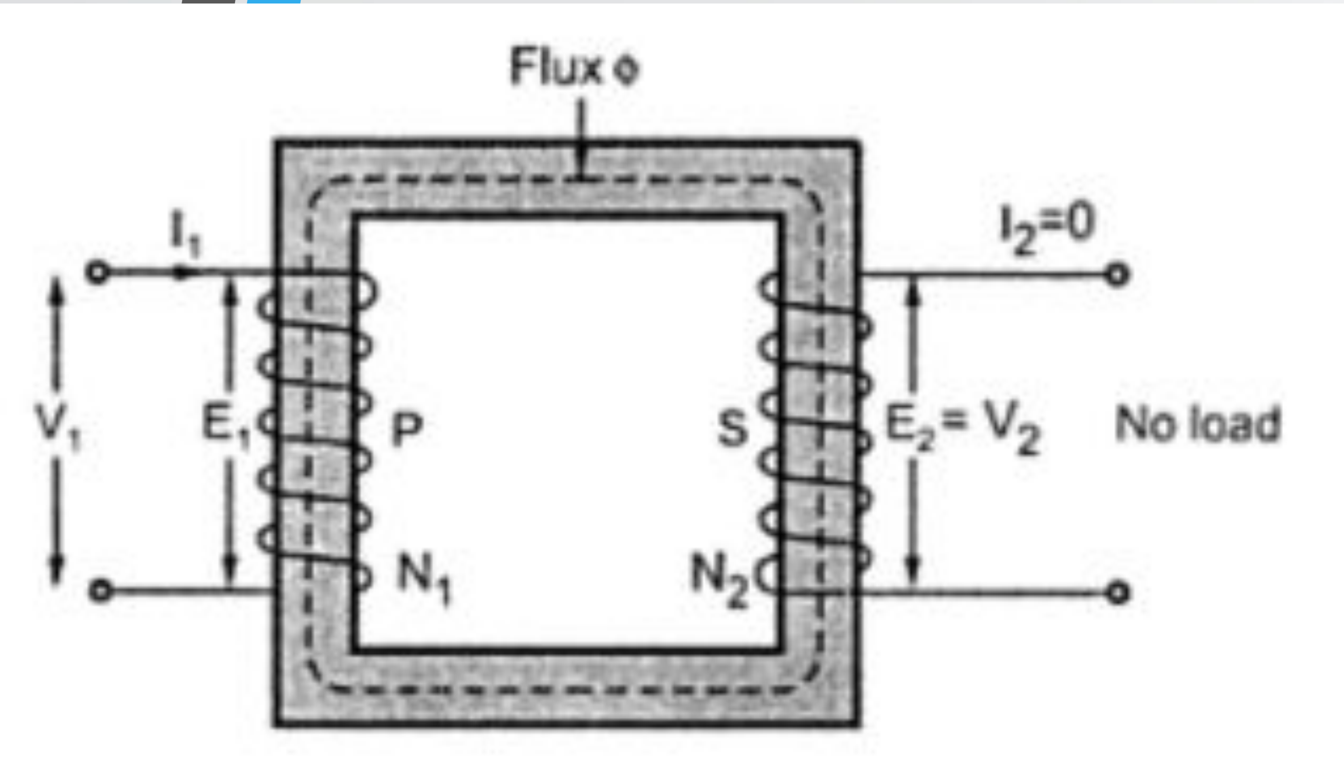
  - Reluctance of the core is zero

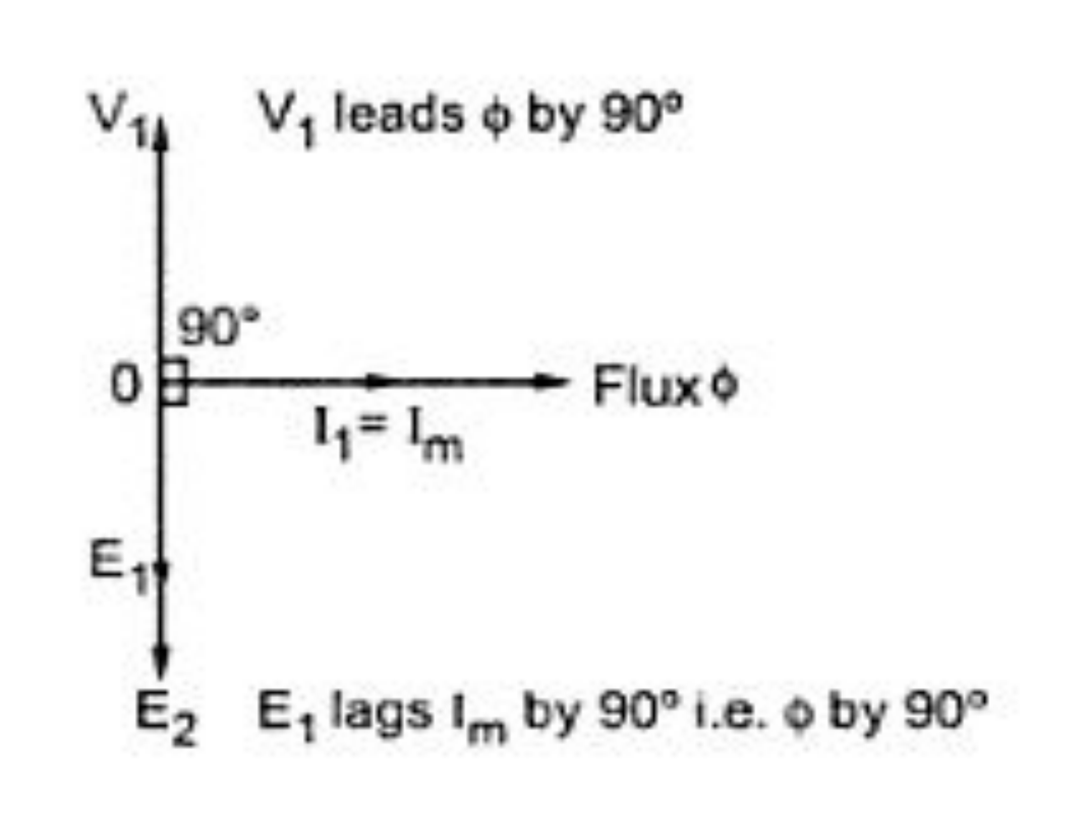
  - Negligible current is required to establish magnetic flux

- **Loss-less magnetic core**

  - No hysteresis or eddy currents

Ideal transformer





V_1 – supply voltage ; I_1- noload input current ;
V_{2-} output voltgae; I_2- output current
I_m- magnetising current;
E_1-self induced emf ; E_2- mutually induced emf

Load test

- The load test is performed to find out its efficiency and regulation.
- In this method, a resistive load is connected to the transformer and it's loaded up to the rated current.
- This is direct loading method and can be applied to transformers with a rating less than 5kVA.
- The first step is to note down the nameplate details of the transformer.
- From that, we can decide the apparatus required and range of the apparatus to conduct the load test.

Formulae for finding efficiency and regulation

- The following formulas can be used to find the efficiency and regulation of a single phase transformer.

$$\text{Efficiency} = \frac{\text{Output Power}}{\text{Input Power}} \times 100$$

$$\text{Regulation} = \frac{V_{SO} - V_S}{V_{SO}} \times 100$$

Where

V_{SO} – Secondary terminal voltage at no-load

V_S – Secondary terminal voltage on load

Open Circuit and Short Circuit test

- Open and short circuit tests are performed on a transformer to determine the:

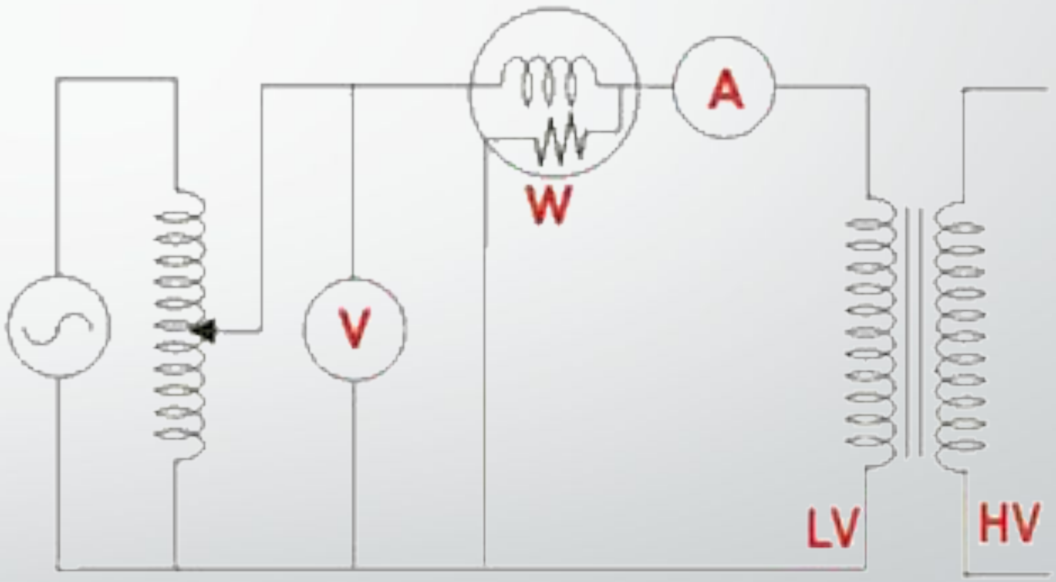
  1)Equivalent circuit of transformer

  2)Voltage regulation of transformer

  3)Efficiency of transformer

- The power required for **open circuit tests and short circuit tests on a transformer** is equal to the power loss occurring in the transformer.

Open Circuit test



Open Circuit Test on Transformer

Open Circuit test

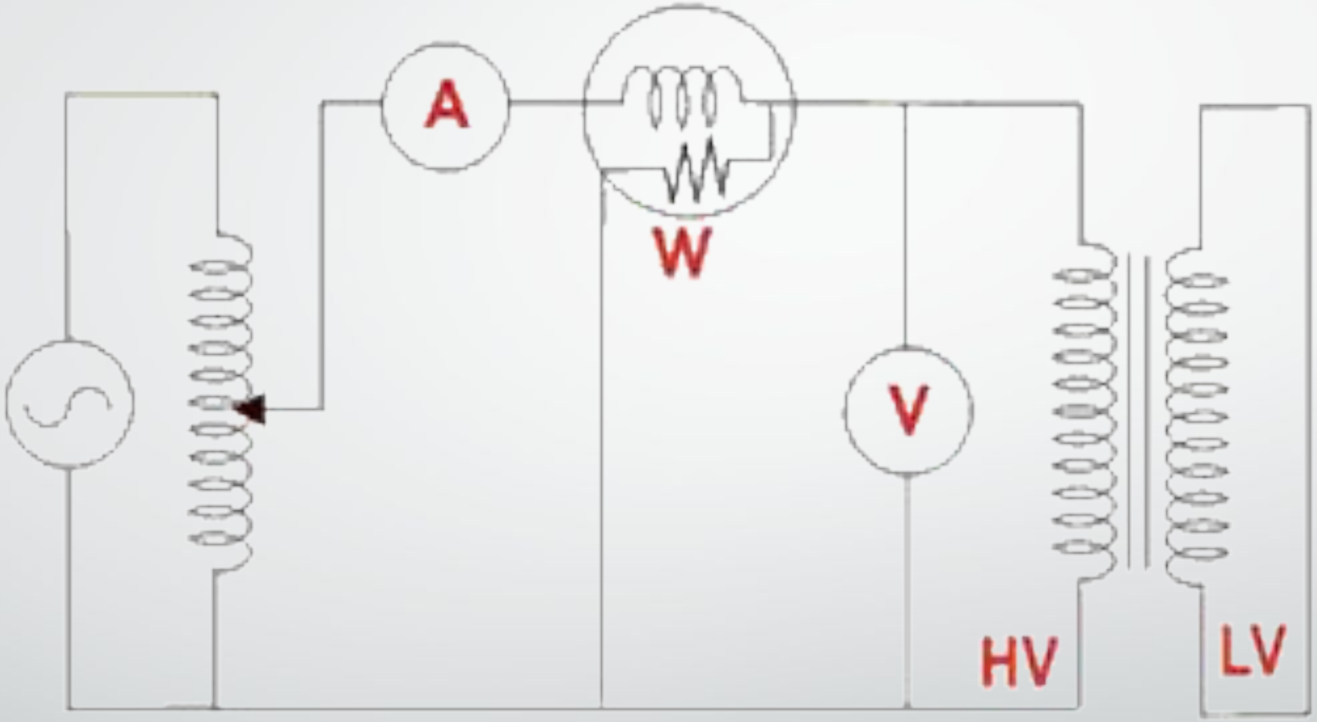
- A voltmeter, wattmeter, and an ammeter are connected in LV side of the transformer as shown. The voltage at rated frequency is applied to that LV side with the help of a variac of variable ratio auto transformer.
- The HV side of the transformer is **kept open**. Now with the help of variac, applied voltage gets slowly increased until the voltmeter gives reading equal to the rated voltage of the LV side.
- After reaching rated LV side voltage, all the three instruments reading are recorded(Voltmeter, Ammeter and Wattmeter readings).
- The ammeter reading gives the no load current I_e. As no load current I_e is quite small compared to rated current of the transformer, the voltage drops due to this current that can be taken as negligible.

- Since voltmeter reading V_1 can be considered equal to the secondary induced voltage of the transformer, wattmeter reading indicates the input power during the test.
- As the transformer is open circuited, there is no output, hence the input power here consists of core losses in transformer and copper loss in transformer during no load condition.
- But as said earlier, the no-load current in the transformer is quite small compared to the full load current so, we can neglect the copper loss due to the no-load current.
- Hence, can take the wattmeter reading as equal to the core losses in the transformer.
- Let us consider wattmeter reading is P_o.

$$P_o = \frac{V_1^2}{R_m}$$

- Therefore it is seen that the **open circuit test on transformer** is used to determine core losses in transformer and parameters of the shunt branch of the equivalent circuit of the transformer.

Short Circuit test



Short Circuit Test on Transformer

Short Circuit test

- A voltmeter, wattmeter, and an ammeter are connected in HV side of the transformer as shown. A low voltage of around 5-10% is applied to that HV side with the help of a variac (i.e. a variable ratio auto transformer).
- Short-circuit the LV side of the transformer.
- Now with the help of variac applied voltage is slowly increased until the wattmeter, and an ammeter gives reading equal to the rated current of the HV side.
- After reaching the rated current of the HV side, Record all the three instrument readings (Voltmeter, Ammeter and Watt-meter readings).
- The ammeter reading gives the primary equivalent of full load current IL.
- As the voltage applied for full load current in a short circuit test on the transformer is quite small compared to the rated primary voltage of the transformer, the core losses in the transformer can be taken as negligible here.
- Let's say, voltmeter reading is V_{sc}. The watt-meter reading indicates the input power during the test. As short-circuited the transformer is present, there is no output; hence the input power here consists of copper losses in the transformer.
- Since the applied voltage V_{sc} is short circuit voltage in the transformer and hence it is quite small compared to the rated voltage, so, neglect the core loss due to the small applied voltage.
- Hence the wattmeter reading can be taken as equal to copper losses in the transformer.

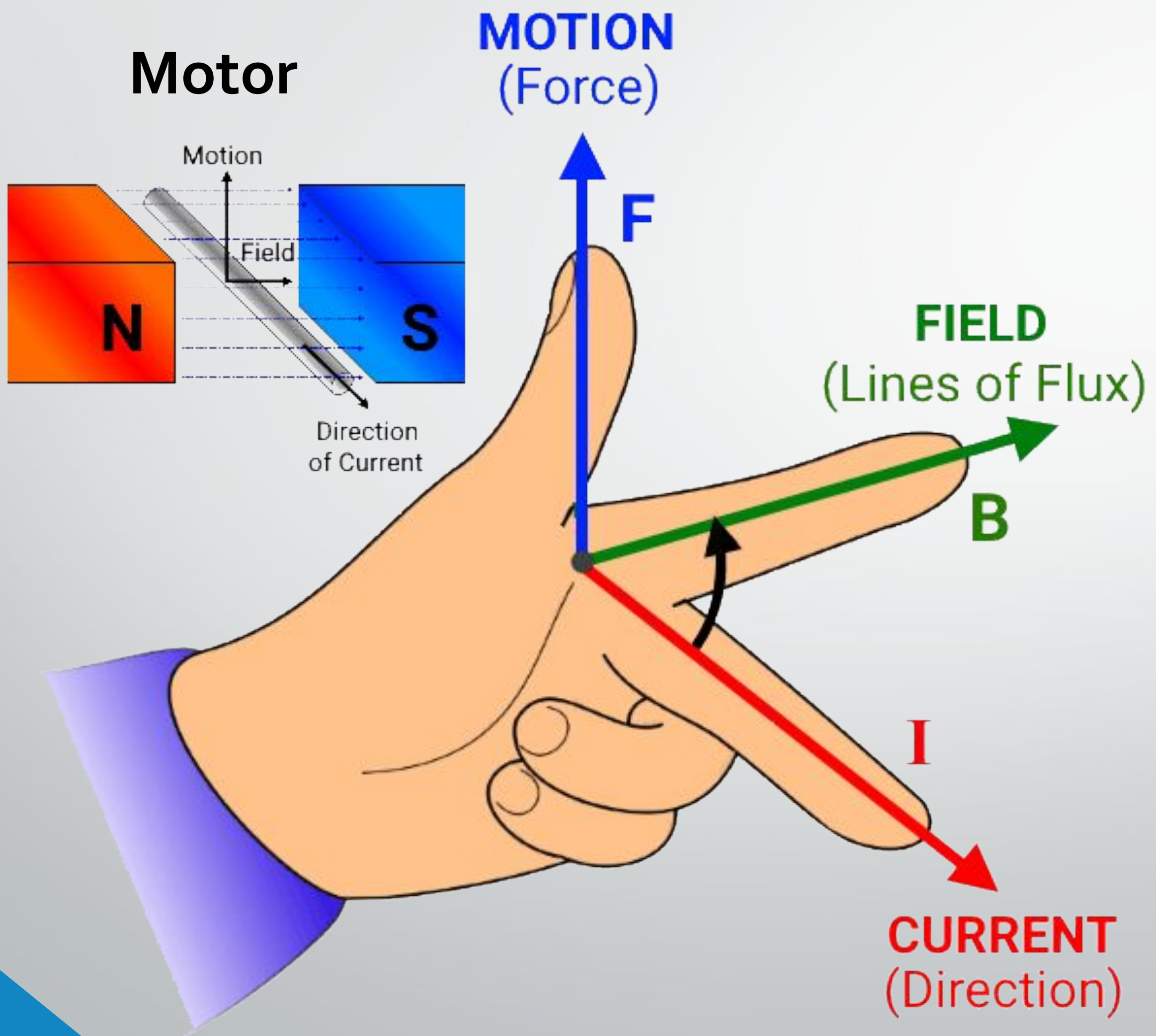
- Hence the **short-circuit test of a transformer** is used to determine copper losses in the transformer at full load. It is also used to obtain the parameters to approximate the equivalent circuit of a transformer.

EMF EQUATION OF TRANSFORMER

- Wkt, $T=1/f$ Average emf (e)= $d\Phi/dt$
- $d\Phi = \Phi m$
- $dt = 1/4f$

  Average rate of change of flux= Φm / (1/4f) = 4f Φm volts Average emf induced per turn = Average rate of change of flux= 4f Φm volts Form factor = RMS value/ Average value = 1.11 RMS value= Form factor x Average value =1.11 x Average value
- RMS value of emf induced/turn = 1.11 x 4f Φm = 4.44 f Φm volts Primary and Secondary winding having N1 and N2 turns. RMS value of emf induced Primary winding, E1 = 4.44 f Φm N1 volts RMS value of emf induced Secondary winding, E1 = 4.44 f Φm N2 volts

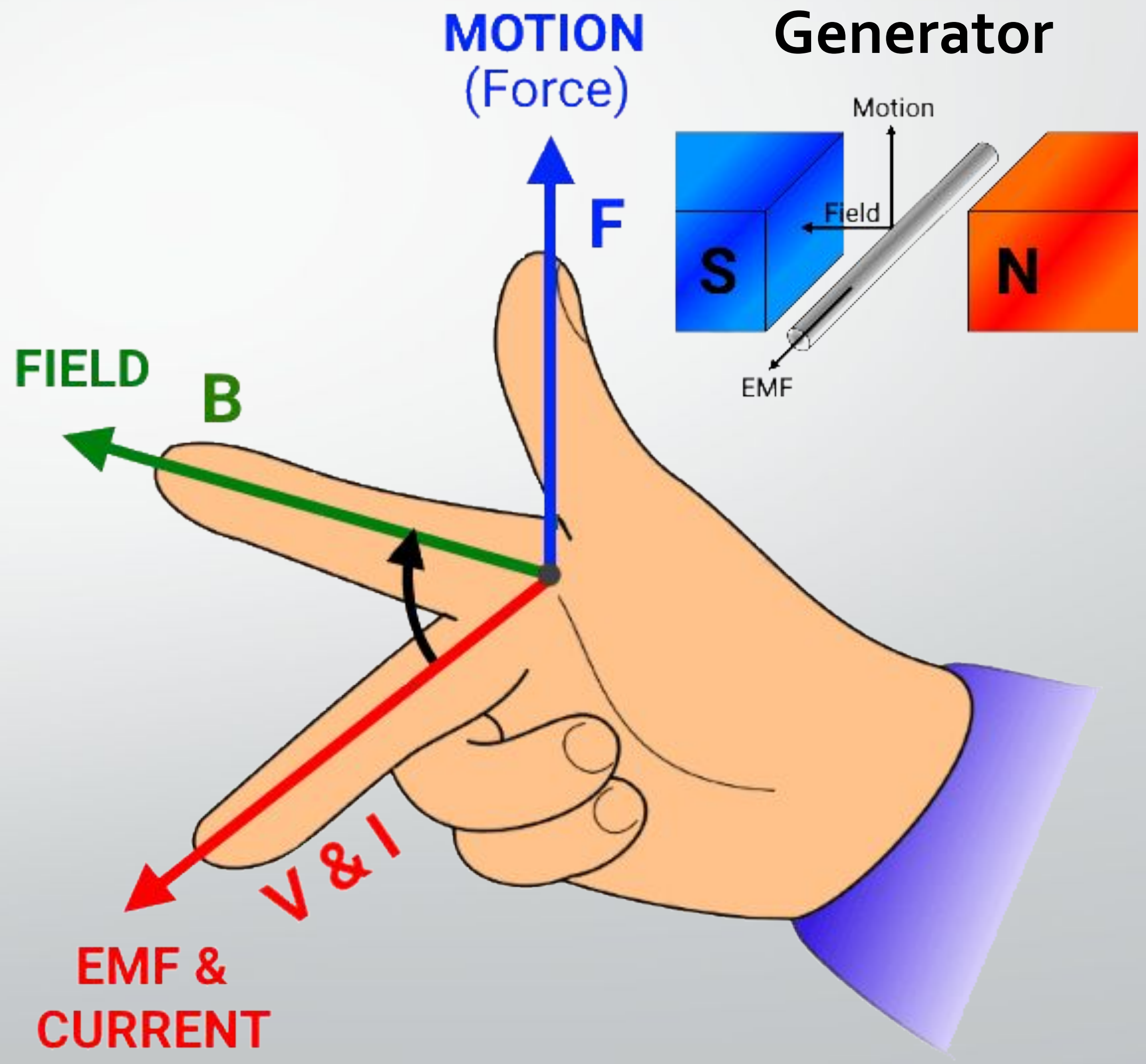
Fleming's Left hand rule



- ***Fleming's left hand states that*** "When you keep the thumb, index finger and middle finger of the left hand at ***right angles (90°)*** to each other. If the **thumb** shows the applied **force or motion**, the **index or forefinger** shows the **lines of flux (field)**, *then* the **middle finger** shows the direction of **current**".

Fleming's Right hand rule

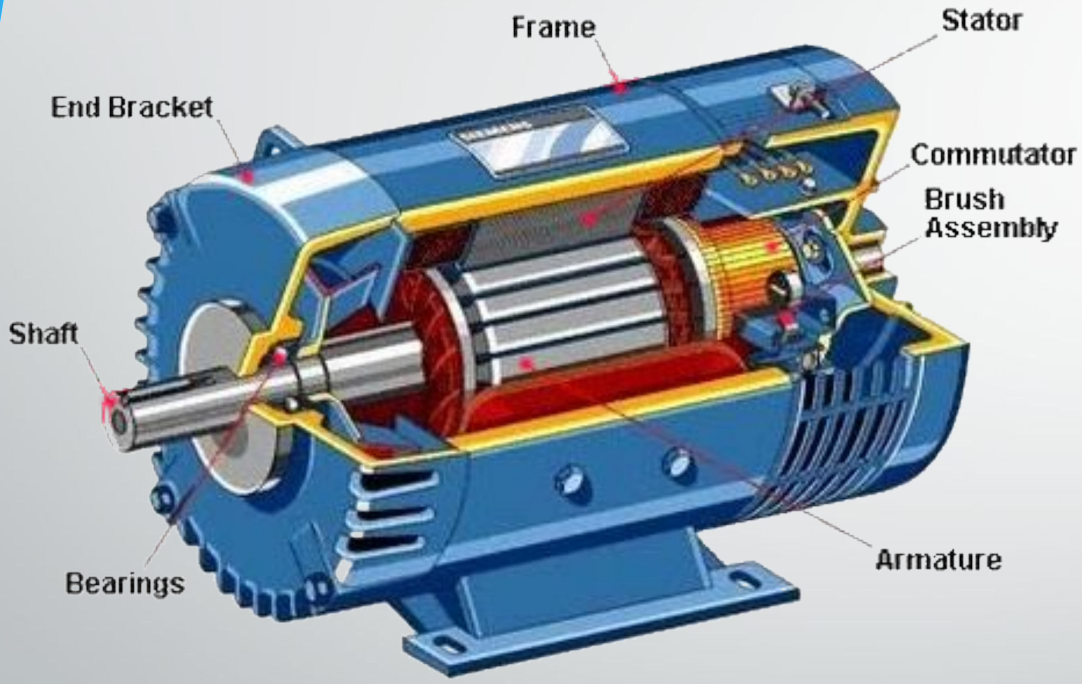
- ***Fleming's right hand rule states that*** "When the thumb, the forefinger and the middle finger of right hand are held in such a way that they are mutually perpendicular to each other ***(90° angle)***. If the **forefinger** points the direction of the **field**, the **thumb** points the direction of **motion of the conductor,** *then* the **middle finger** points the direction of the **induced current (from EMF)**"

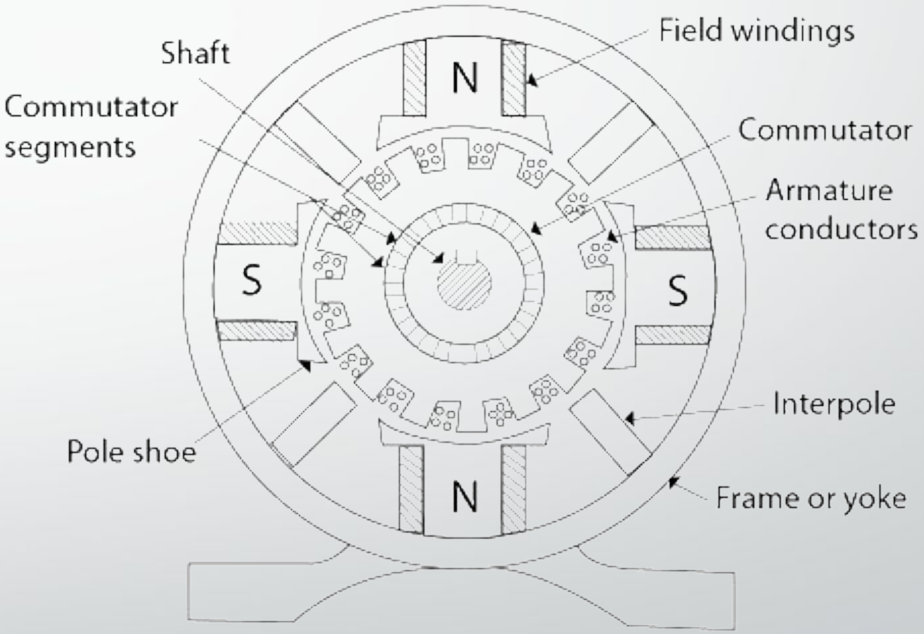


Rotating Machines

- An rotating machines is *an* ***electromechanical energy convertor*** and consists of a device having a magnetic circuit in two parts which are separated from one another by an **air gap**.
- It is commonly known as Electrical machines
- One part of the machine is stationary and is known as the *stator* or ***frame***; the moving or rotating part is known as the *rotor.*
- The rotor is installed into the stem, and the stem connects to the motor and any other loads.
- The windings are there to carry the electrical current that gener[illegible]tes ma[illegible]elds for the electrical load.

Construction of Rotating Machines





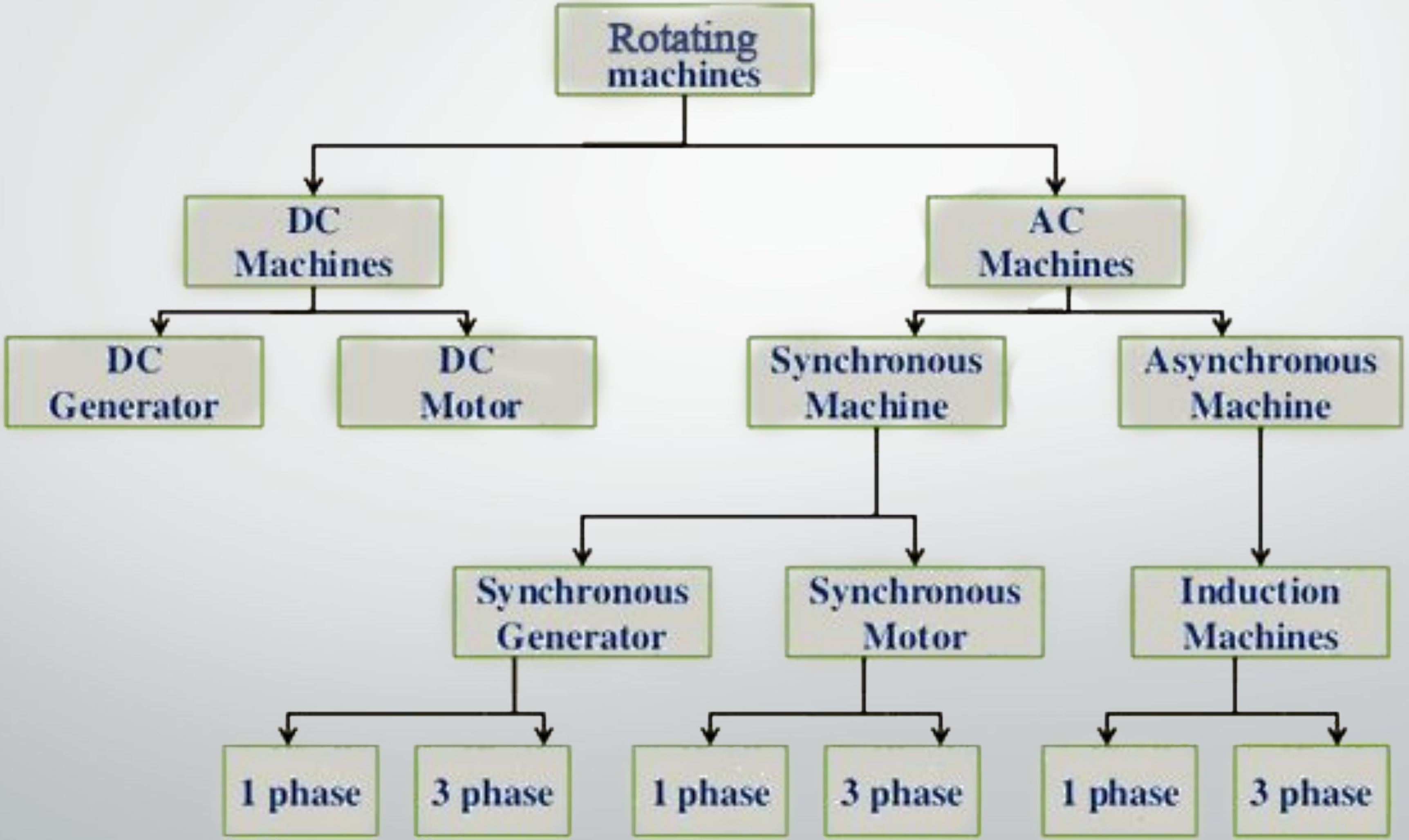
Construction of Rotating Machines

- It consists of **stator**(stationary part) & **rotor**(rotating part).
- The current can operate in the rotating machine for magnetic field generation – this current is called ***magnetising***.
- This type of winding is called ***field winding***.
- The current is low power DC, and the windings can also carry the load current, and will be called ***Armature****.*
- In DC and AC machines, windings that carry **magnetising current** and **load current** are different.
- This winding is called the **primary winding**. The output winding is the **secondary winding.**

Principle of Rotating Machines

- Rotating machines works under the principle of **Electro-mechanical Energy Conversion.**
- Its state that the **energy** cannot be created or destroyed. it can only be **converted** from one form to the another form of **energy**
- This principle is also known as **Law of Energy Conservation**

Rotating Machines Classification

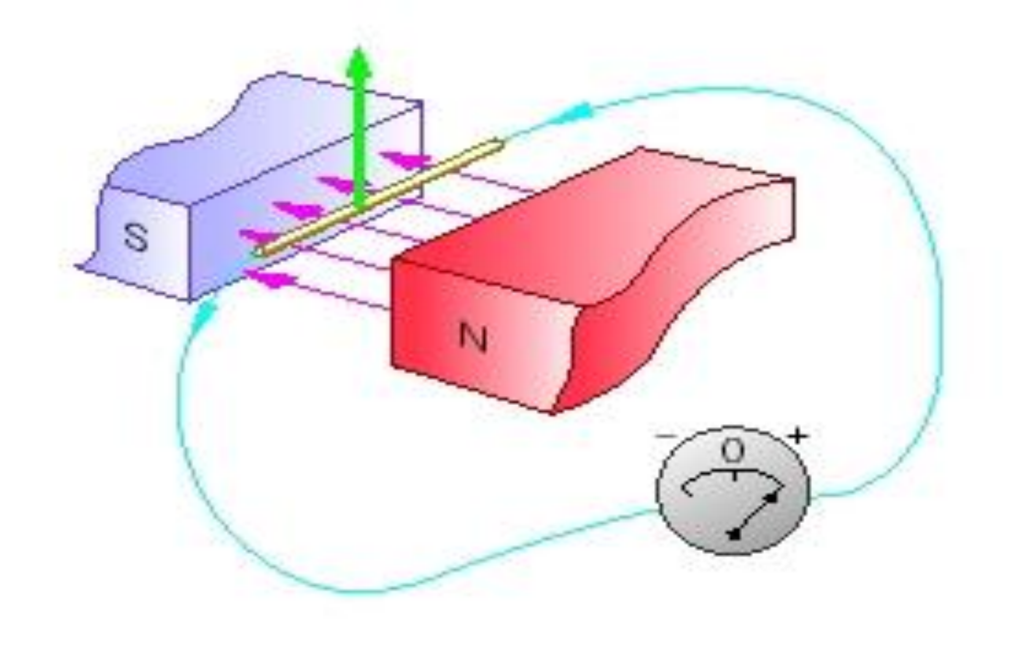


DC Generator

Mechanical energy is converted to electrical energy

Three requirements are essential

1. Conductors
2. Magnetic field
3. Mechanical energy



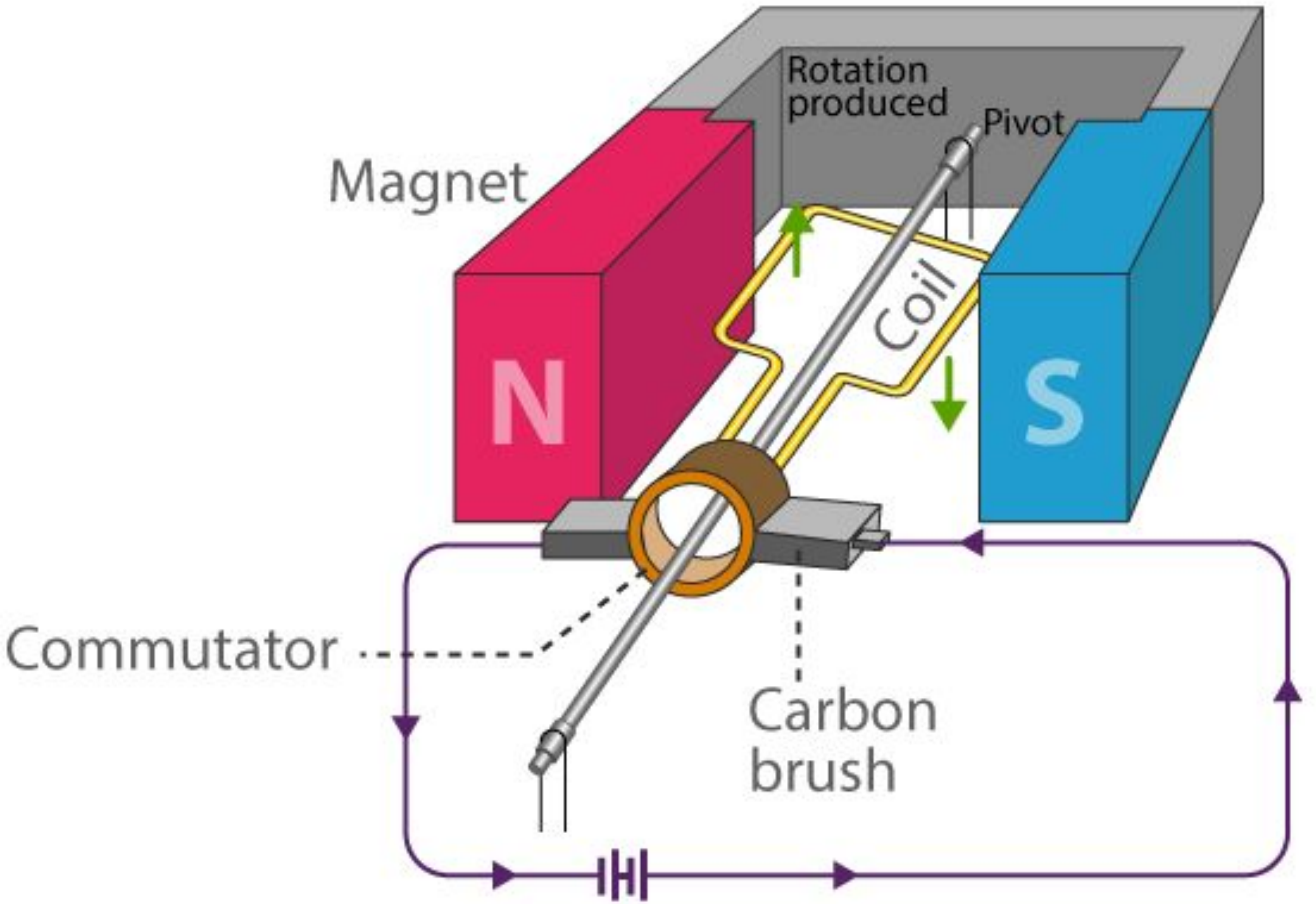
Working principle

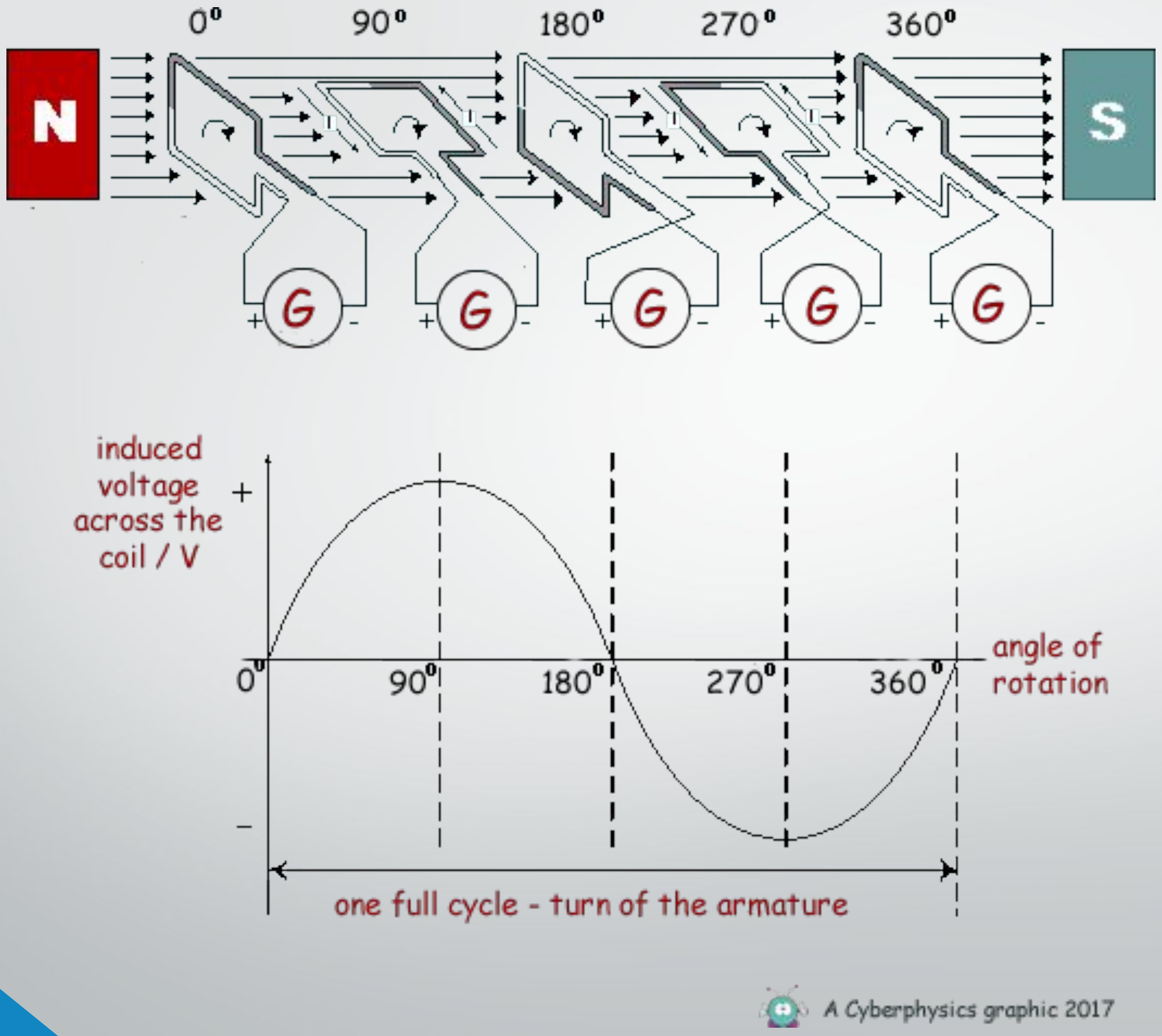
- A generator works on the principles of Faraday's law of electromagnetic induction

- Whenever a conductor is moved in the magnetic field , an emf is induced and the magnitude of the induced emf is directly proportional to the rate of change of flux linkage.

- This emf causes a current flow if the conductor circuit is closed .

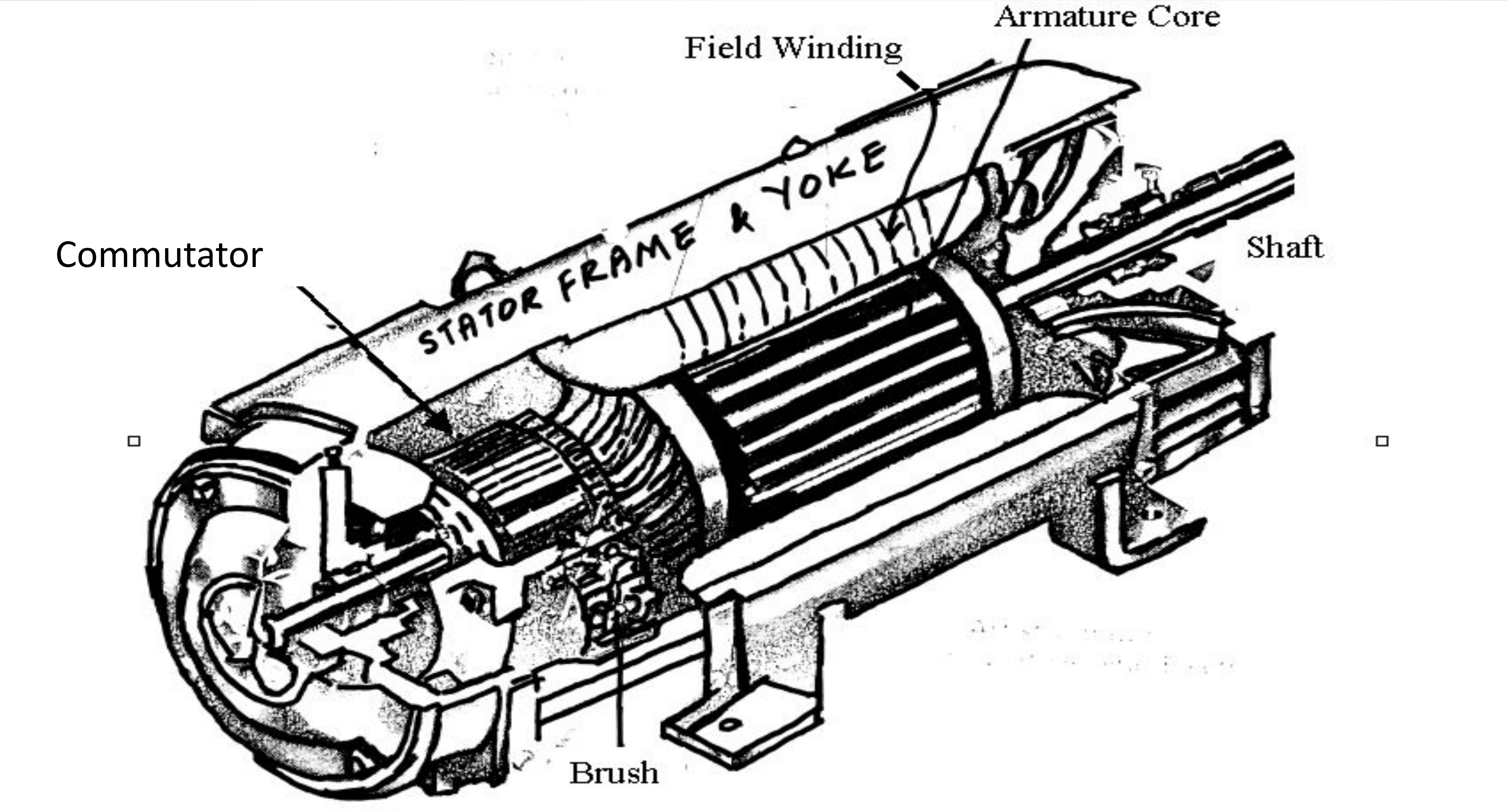
WORKING PRINCIPLE OF GENERATOR





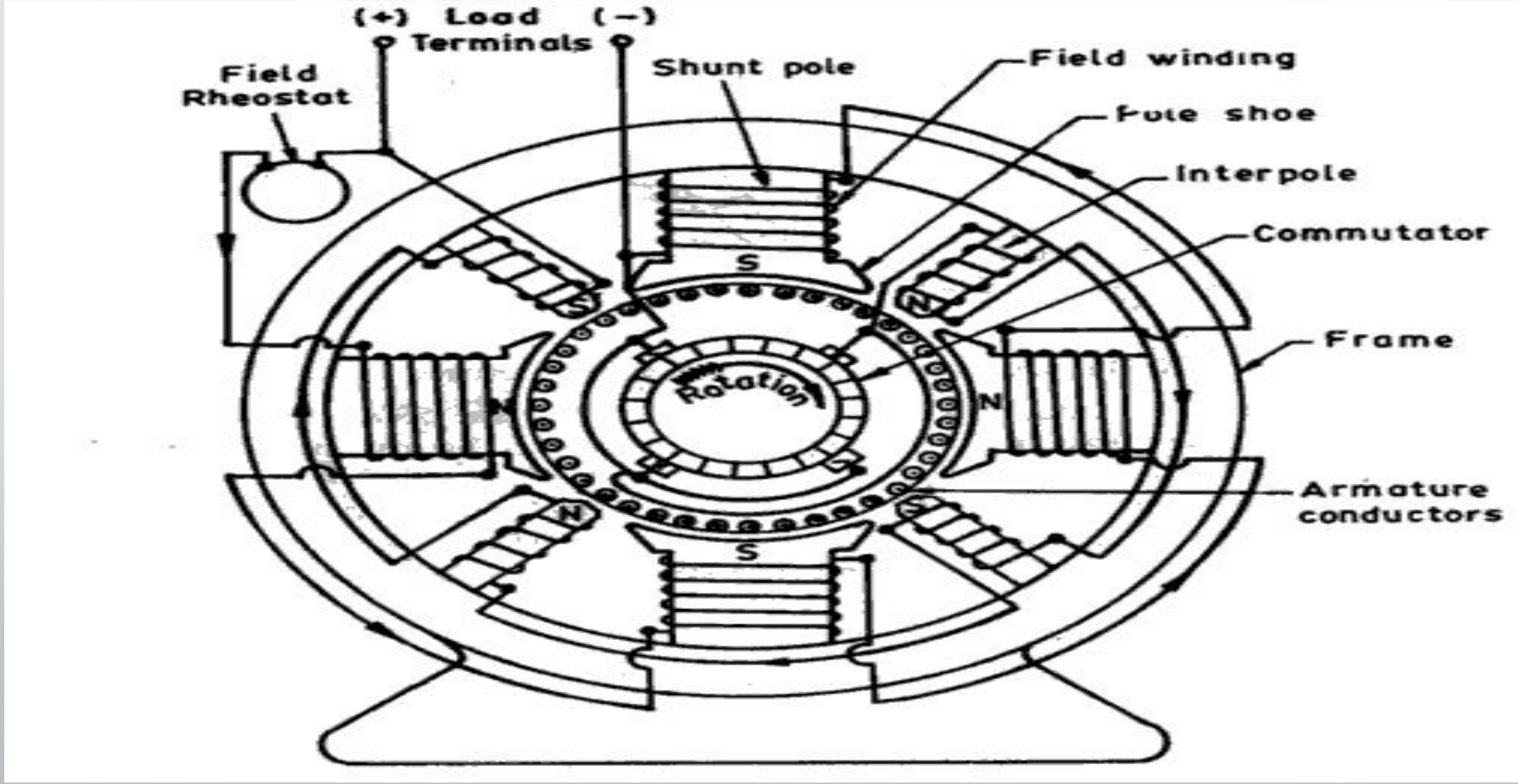
0°
90°
180°
270°
360°
N
S
G
induced voltage across the coil / V
+
–
angle of rotation
one full cycle - turn of the armature
A Cyberphysics graphic 2017

DC Machine



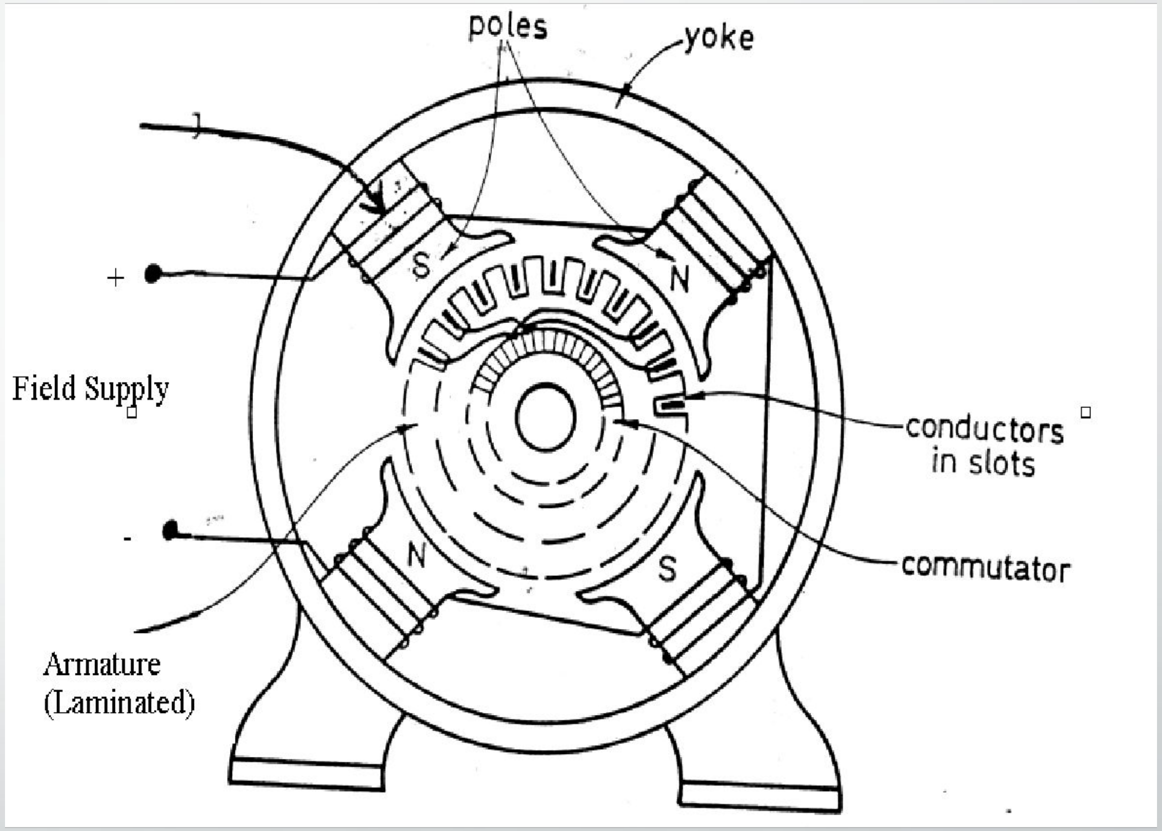
Armature Core
Field Winding
STATOR FRAME & YOKE
Commutator
Shaft
Brush

Sectional view of a DC machine

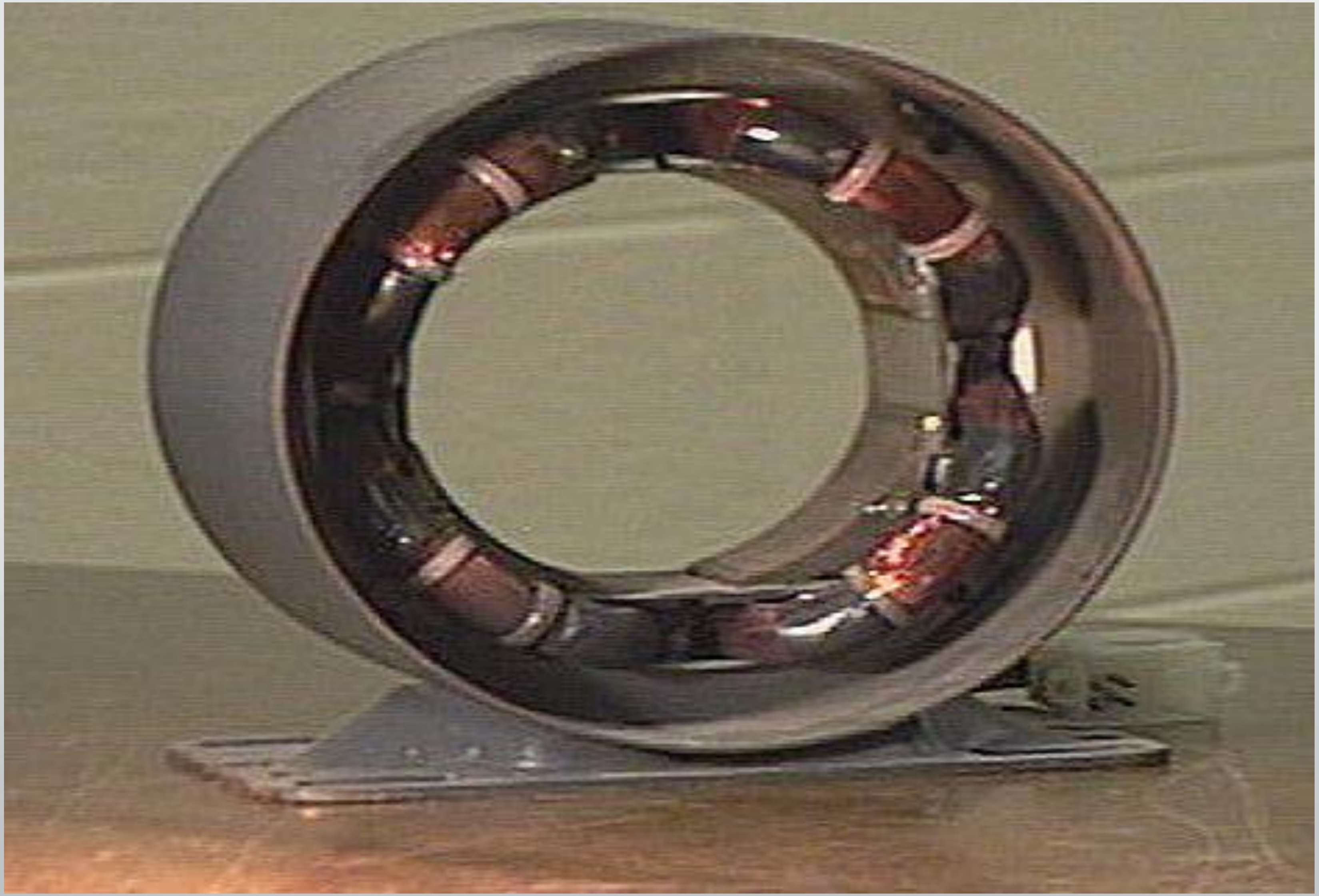


Construction of DC Generator

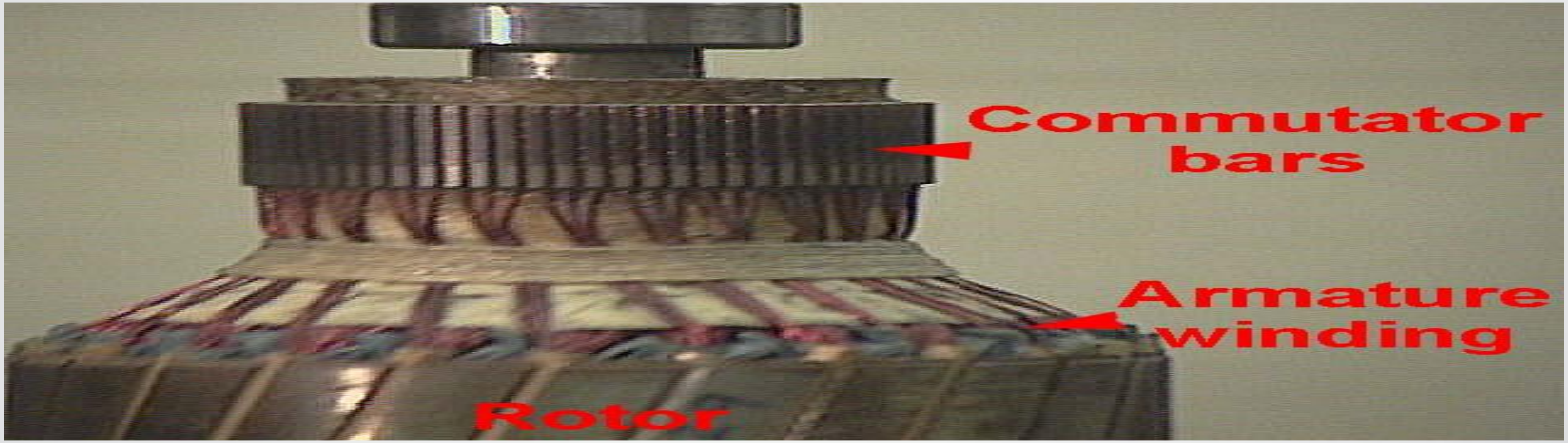
- Field system
- Armature core
- Armature winding
- Commutator
- Brushes



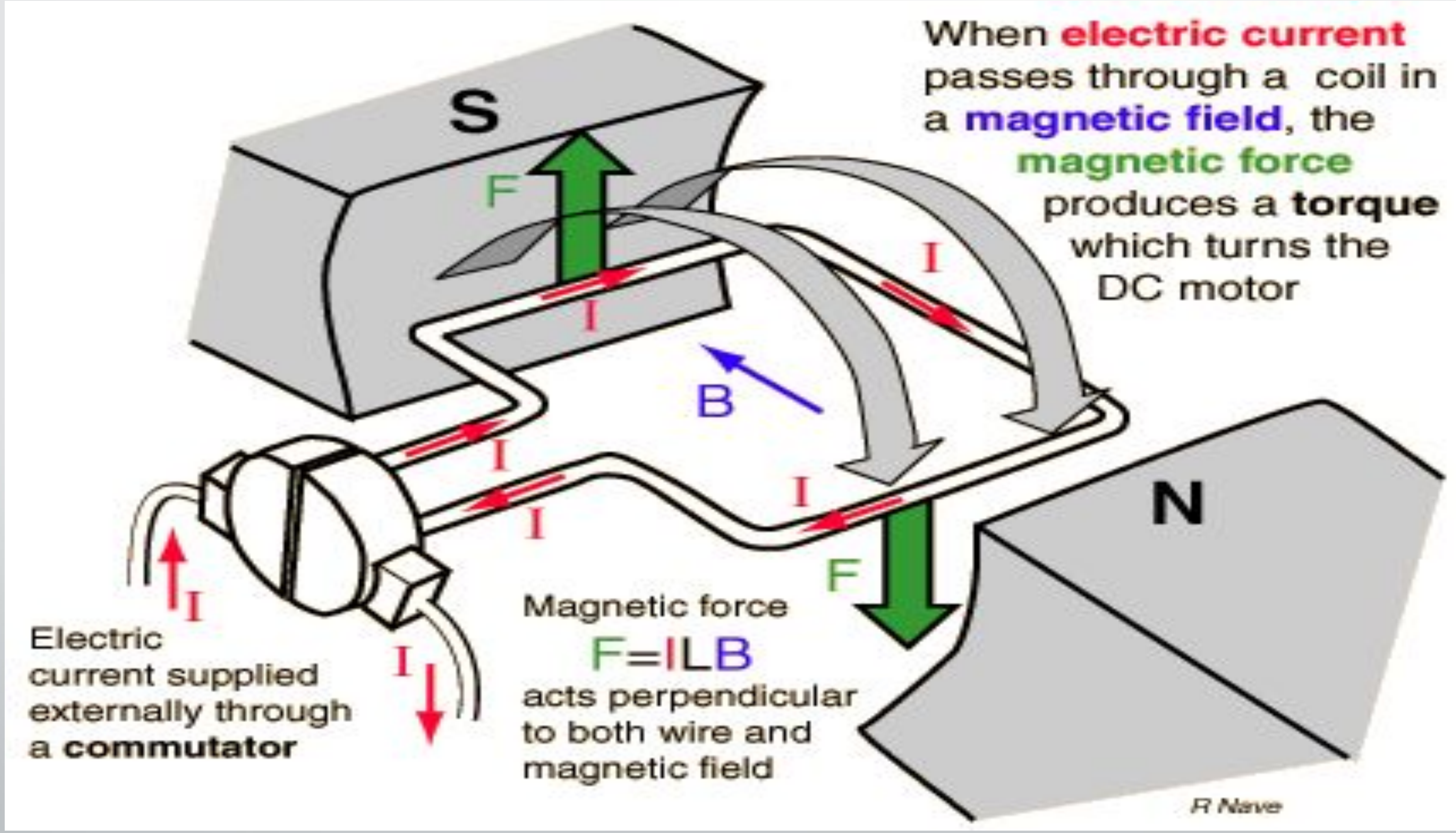
Field winding



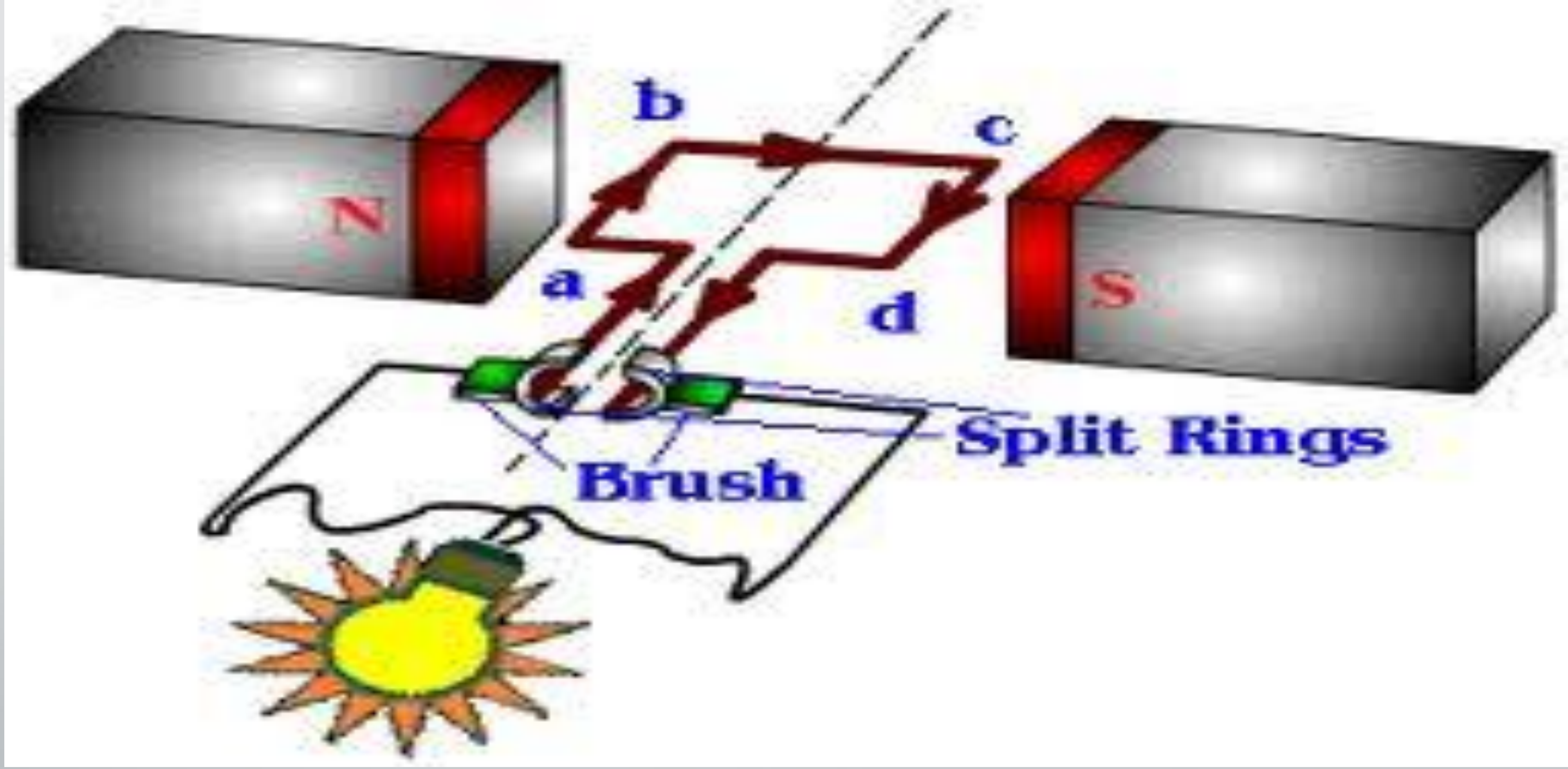
Rotor and rotor winding



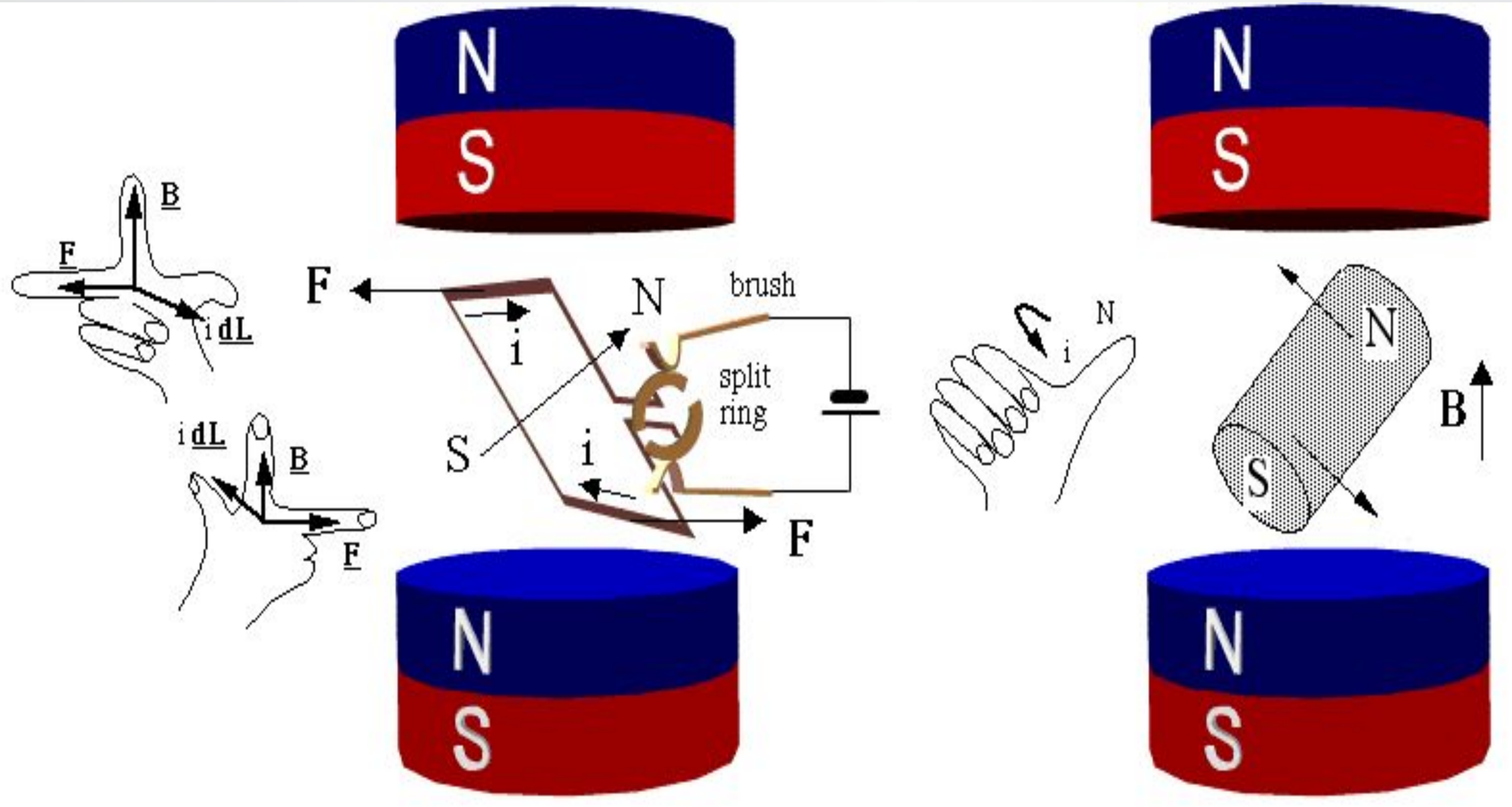
Working principle of DC motor



Working principle of DC motor



Force in DC motor



Armature winding

There are 2 types of winding

Lap and Wave winding

<u>Lap winding</u>

- **A = P**

- The armature windings are divided into no. of sections equal to the no of poles

<u>Wave winding</u>

- **A = 2**

- It is used in low current output and high voltage.

- 2 brushes

Field system

- It is for uniform magnetic field within which the armature rotates.
- Electromagnets are preferred in comparison with permanent magnets
- They are cheap , smaller in size , produce greater magnetic effect and
- Field strength can be varied

Field system consists of the following parts

- Yoke
- Pole cores
- Pole shoes
- Field coils

Armature core

- The armature core is cylindrical
- High permeability silicon steel stampings
- Impregnated
- Lamination is to reduce the eddy current loss

Commutator

- Connect with external circuit
- Converts ac into unidirectional current
- Cylindrical in shape
- Made of wedge shaped copper segments
- Segments are insulated from each other
- Each commutator segment is connected to armature conductors by means of a cu strip called riser.
- No of segments equal to no of coils

Carbon brush

- Carbon brushes are used in DC machines because they are soft materials
- It does not generate spikes when they contact commutator
- To deliver the current thro armature
- Carbon is used for brushes because it has negative temperature coefficient of resistance
- Self lubricating , takes its shape , improving area of contact

Brush rock and holder

Carbon brush

- Brush leads (pig tails)
- Brush rocker (brush gear)
- Front end cover
- Rear end cover
- Cooling fan
- Bearing
- Terminal box

Types DC Generator

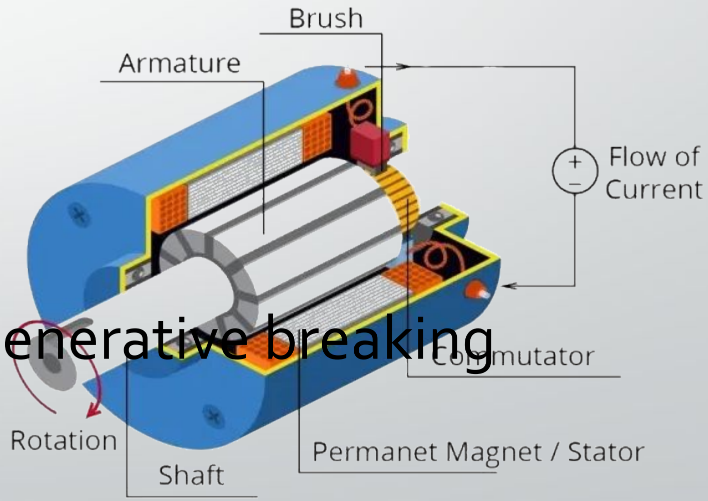
- **Types:** Permanent Magnet, Separately Excited, Self Excited

In Self Excited

1)Series Wound Generators

2)Shunt Wound Generators

3)Compound Wound Generators



- **Applications:** general lighting, charging battery & regenerative breaking

BASIS	MOTOR	GENERATOR
Function	The Motor converts Electrical energy into Mechanical Energy	Generator converts Mechanical energy to Electrical energy.
Electricity	It uses electricity.	It generates electricity
Driven element	The Shaft of the motor is driven by the magnetic force developed between armature and field.	The Shaft is attached to the rotor and is driven by mechanical force.
Current	In a motor the current is to be supplied to the armature windings.	In the generator current is produced in the armature windings.
Rule Followed	Motor follows Fleming's Left hand rule.	Generator follows Fleming's Right hand rule.
Example	An electric car or bike is an example of electric motor.	Energy in the form of electricity is generated at the power stations.

Load Test of Rotating Machines

- Load test is used to compute **Torque, Output power, Input power, Efficiency, Input power factor and Slip**
- Load Test is done by connecting load across rotating machines.
- Load test is used to measure the **in-rush current** & to obtain the **load performance characteristics**
- It is also termed as direct test & brake test(measured using brakes)
- It helps to identify the **maximum operating capacity** of an application

Performance Characteristics of Rotating Machines

- **Performance characteristics** are characteristics which describes the natue or behaviour of rotating machines & it is classified into two.

- **Static Characteristics:** The characteristics of quantities or parameters measuring instruments that **do not vary** with respect to time are called static characteristics.

Accuracy, Precision, Sensitivity, Resolution & Static Error

- **Dynamic Characteristics**: The characteristics of the instruments, which are used to measure the quantities or parameters that vary very quickly with respect to time are called dynamic characteristics.

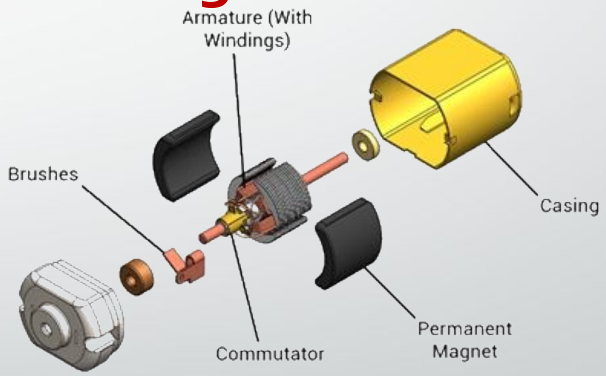
Speed of Response, Fidelity, Lag & Dynamic Error

- Using these performance curves, we can able to know machine characteristics:

  (i) Efficiency Vs Output power, (ii) Torque Vs Output power, (iii) Line current Vs Output power, (iv) Power factor Vs Output, (v) Slip Vs Output power, (vi) Torque Vs Speed

DC Motor

- A DC motor converts **DC(Direct Current) electrical energy into mechanical energy**.
- **Principle(Motoring Action):** When a current-carrying conductor is placed in a magnetic field, it experiences a torque and has a tendency to move
- The direction of rotation of this motor is given by **Fleming's left hand rule**
- There are 3 main **types** of DC Motors:



1)Shunt wound DC motor

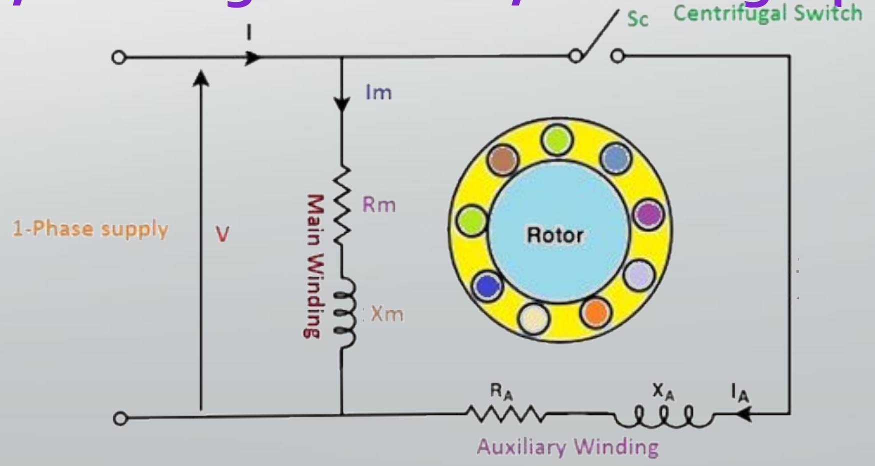
2)Series wound DC motor

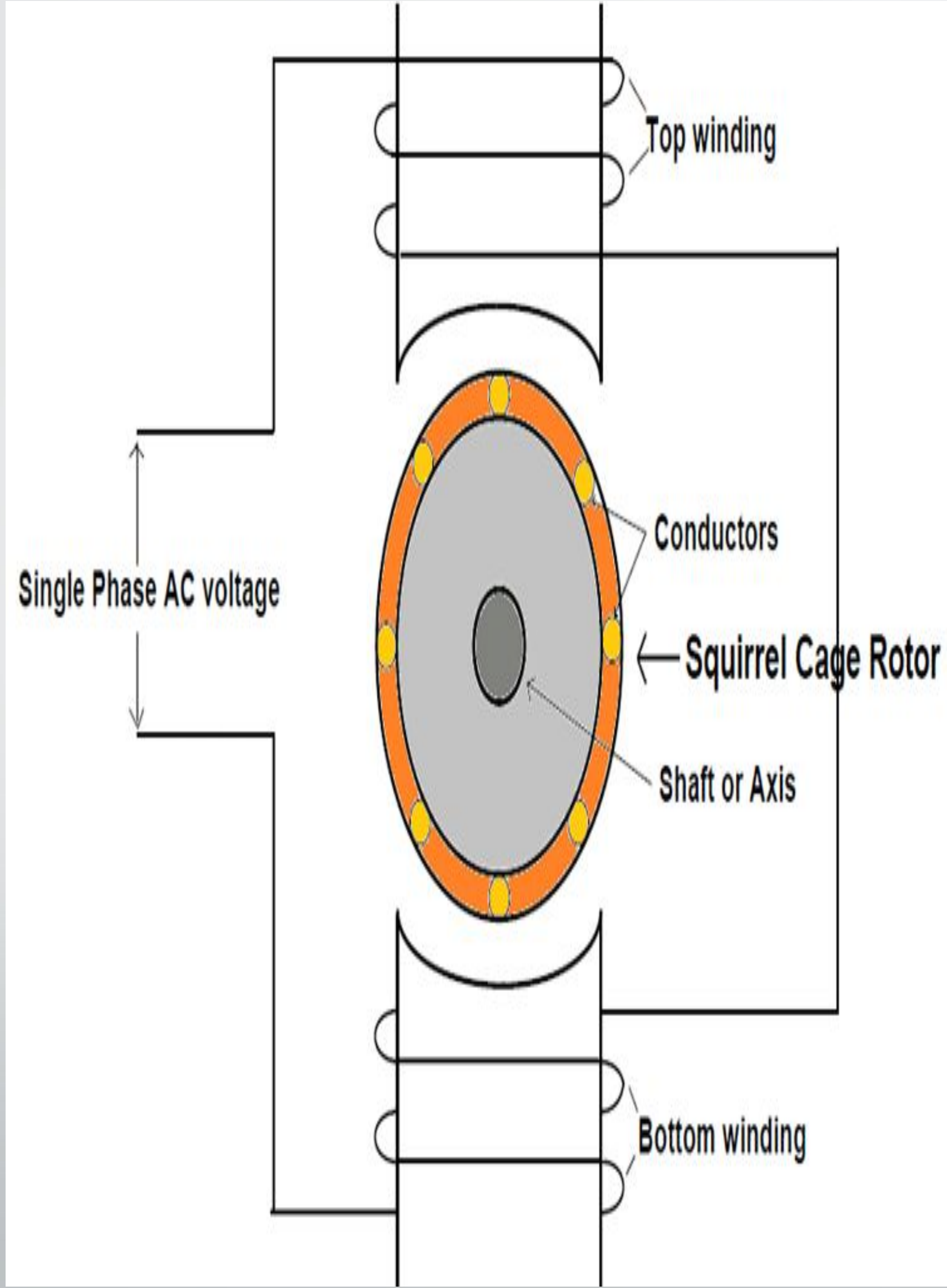
3)Compound wound DC motor

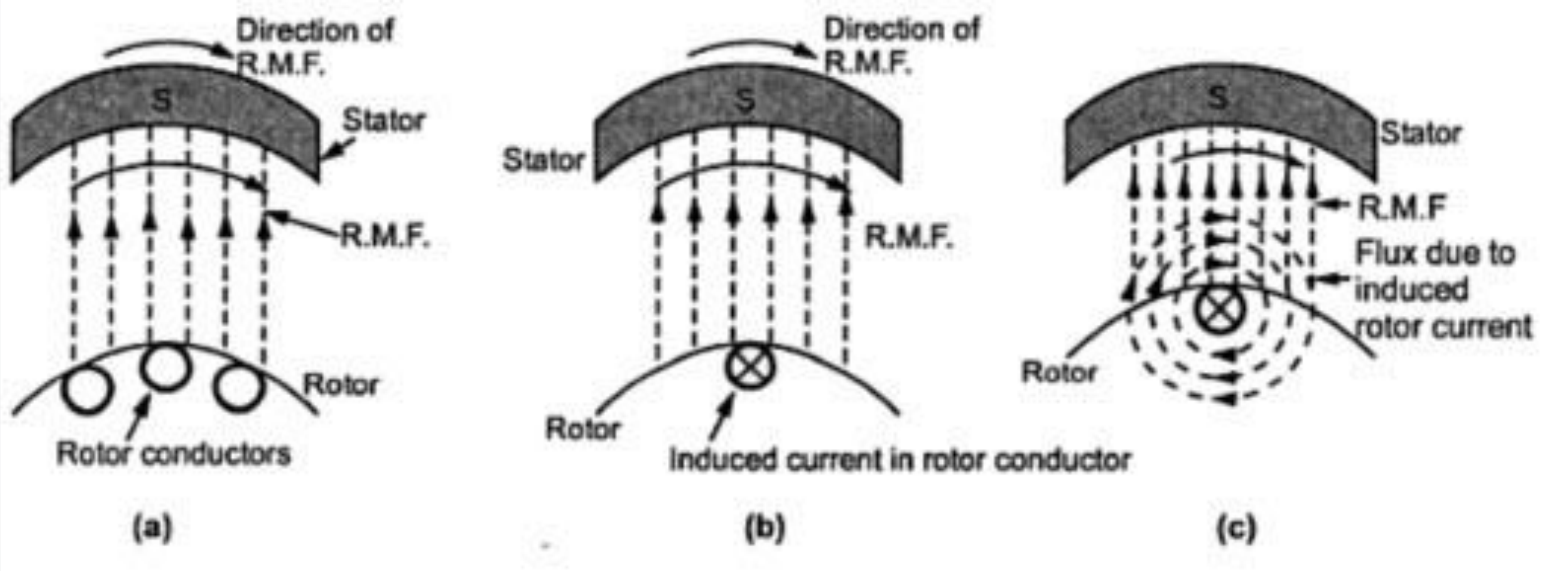
- **Applications:** Blowers and fans, Lathe machines, Cranes, Trolleys, Rolling mills & Conveyors

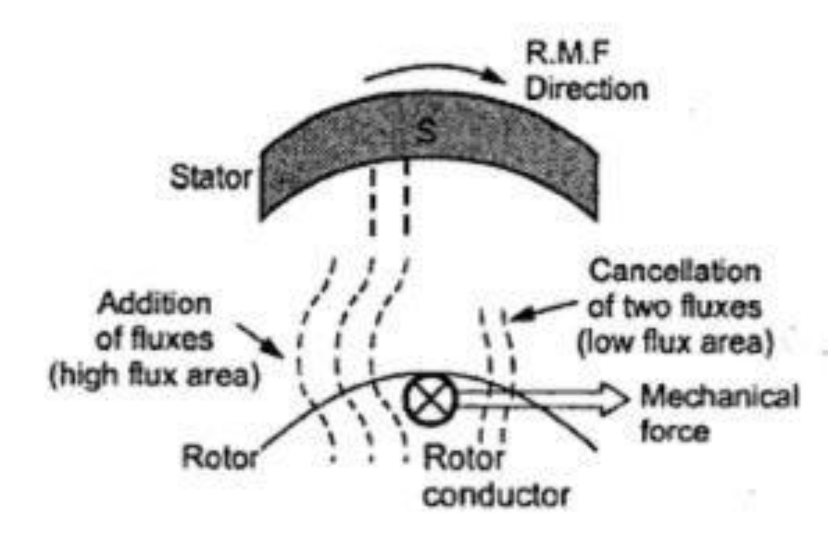
Single Phase Induction Motor

- **Induction motor** is a motor which runs at a speed **lower** than the synchronous speed.
- **Principle:** Faraday's Law of Electromagnetic Induction
- A **single phase induction motor** consists of a **single phase winding** on the stator and a **cage winding** on the rotor
- It is ***not a Self-Starting*** device
- **Applications:** **vacuum cleaners, fans, washing machines, centrifugal pumps, blowers, washing machines**.




Top winding
Conductors
Single Phase AC voltage
Squirrel Cage Rotor
Shaft or Axis
Bottom winding


Direction of R.M.F.
S
Stator
R.M.F.
Rotor
Rotor conductors
(a)
Direction of R.M.F.
S
Stator
R.M.F.
Rotor
Induced current in rotor conductor
(b)
S
Stator
R.M.F
Flux due to induced rotor current
Rotor
(c)


R.M.F Direction
S
Stator
Addition of fluxes (high flux area)
Cancellation of two fluxes (low flux area)
Mechanical force
Rotor
Rotor conductor

Three Phase Induction Motor

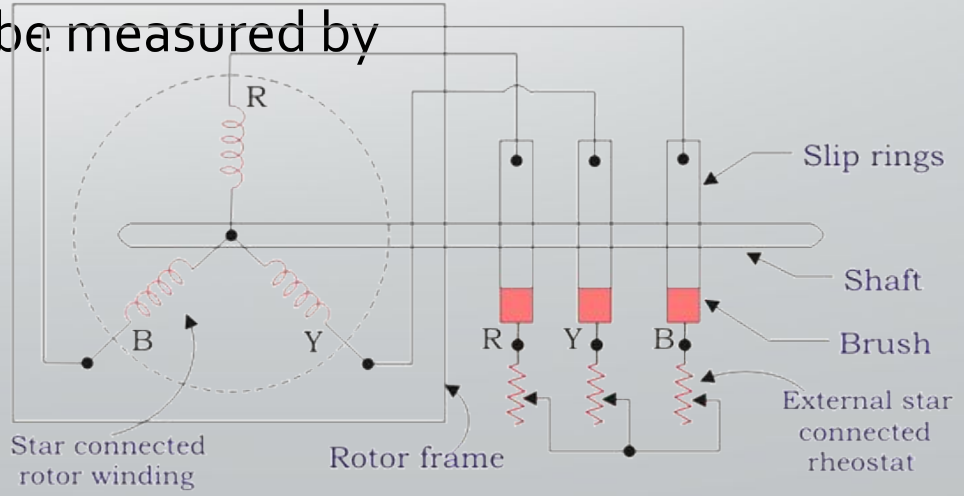
- A **3-phase induction motor** is a machine which is constructed to work on the 3-phase supply
- The windings of the stator are equally displaced from each other by an angle of **120°**
- Its working depends on the principle of the **revolving magnetic field**.
- Three phase induction motor is: **Self-starting, Less armature reaction, Robust in construction, Economical & Easier to maintain.**
- The speed of this rotating magnetic field can be measured by

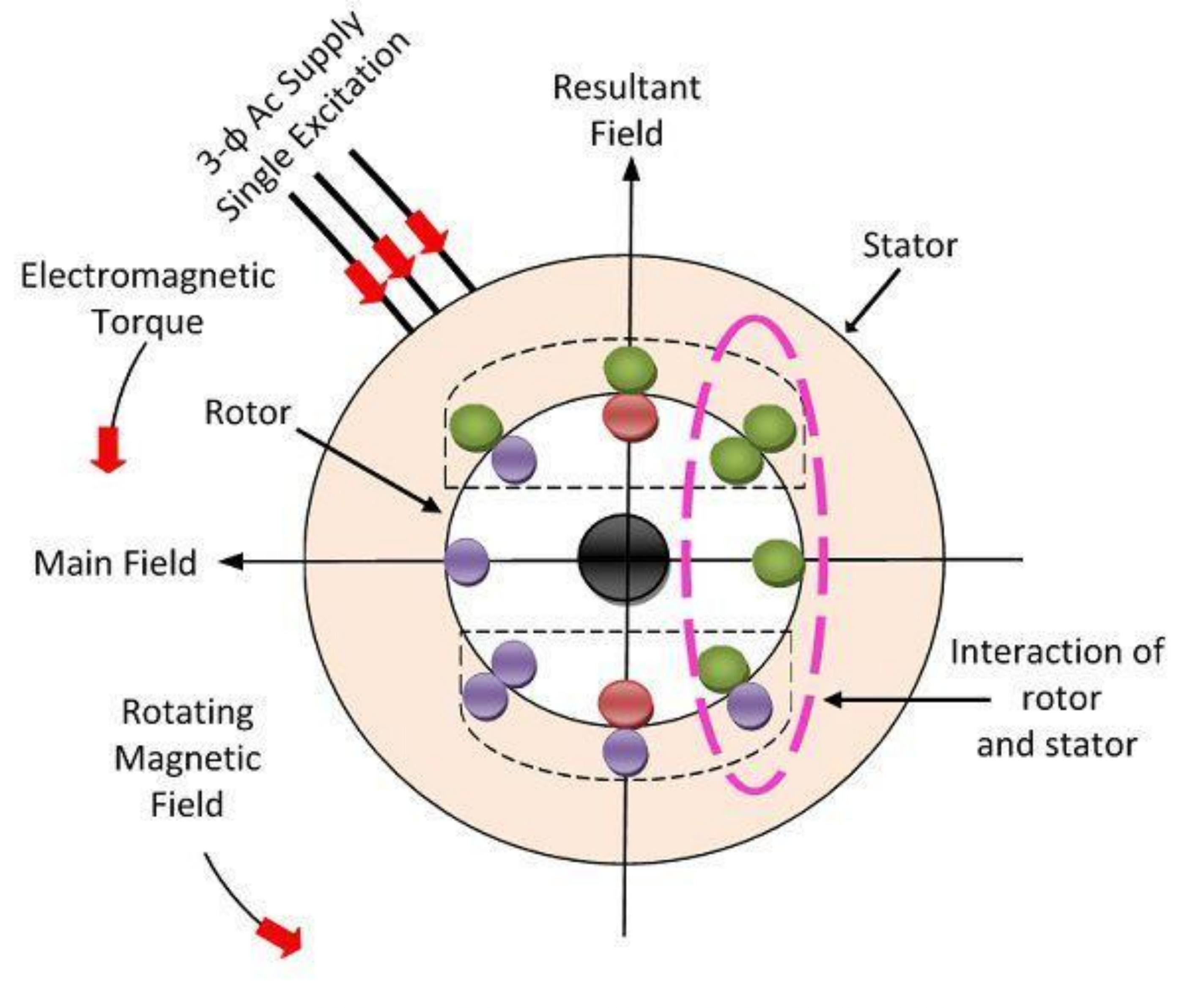
$n_{sync} = 120f/p$

Where n_{sync} -> synchronous speed.

f ->frequency.

p -> no of the poles.





Three Phase Induction Motor

Slip of an Induction Motor

- Induction motor rotor always rotate at a speed less than synchronous speed.
- The difference between the flux (N_s) and the rotor speed (N) is called slip.
- $$\% \text{ Slip (s)} = \frac{N_s - N}{N_s} * 100$$

  Where Ns=Synchronous Speed

  N= Actual Speed of rotor
- Slip speed = $N_s - N$

$$Slip = \frac{N_s - N}{N_s}$$

Where :

$N_s = Synchronous - speed$

$N = Rotor - speed$

Alternator

- An **alternator** is an electrical generator that converts ***mechanical energy to electrical energy in the form of alternating current.***
- All the alternators work on the principle of electromagnetic induction.
- **Types: Automotive, Diesel-electric locomotive, Marine, Brushless & Radio**
- **Characteristics**

1)The output of the **current decreased** when the alternator **speed reduced**.

2)**Efficiency** of an alternator is **reduced** when the alternator runs with **low speed**.

3)When the **temperature** of an alternator **increased** the output **current** will be **decreased**.

- **Applications**

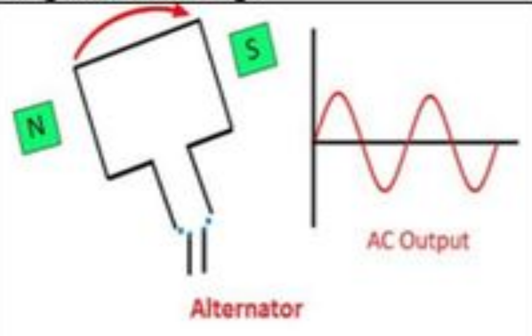
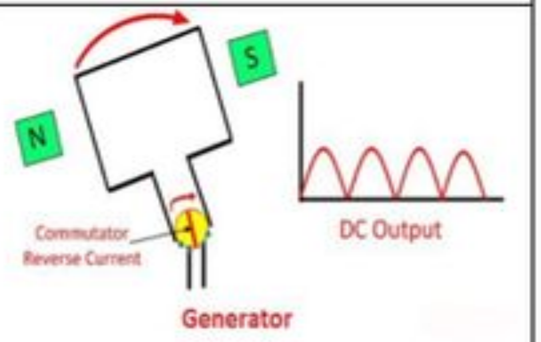
1)Automobiles

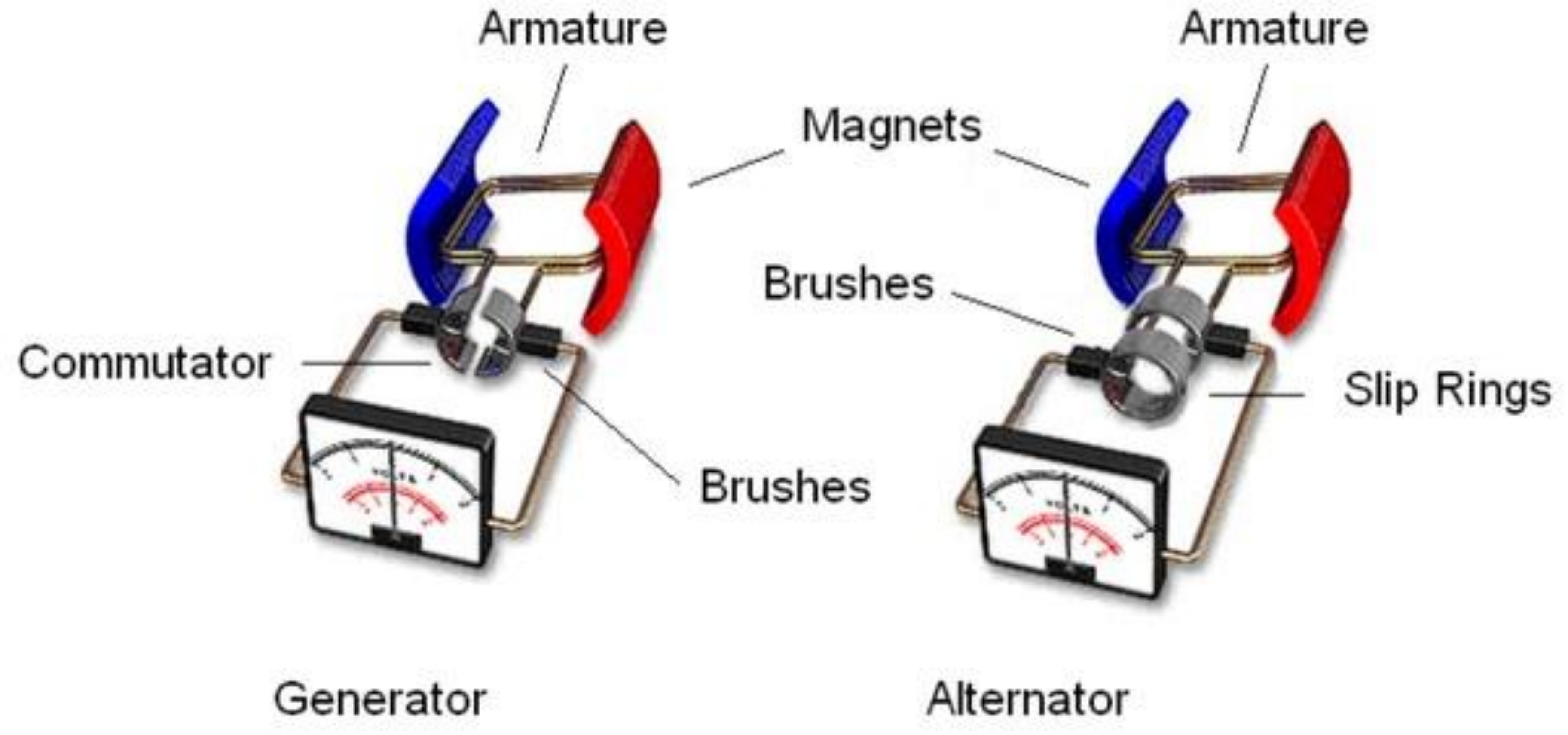
2)Electrical power generator plants

3)Marine applications

4)Diesel electrical multiple units

5)Radio frequency transmission

Sr. No.	Differentiating Property	Alternator	Generator
1	Definition	Converts mechanical energy to AC electrical energy.	Converts mechanical energy to AC or DC electrical energy.
2	Input Supply	Takes input supply from stator.	Takes input supply from rotor.
3	Magnetic field and Armature Movement	Magnetic field (inside the stator) is rotating whereas armature is stationary.	Armature is rotating whereas field is rotating.
4	Output Capacity	Has higher output ratings.	Has comparatively lower output ratings.
5	Energy Efficiency	High energy efficiency.	Comparatively less energy efficient.
6	Range of RPM (Rotations Per Minute)	Supports wider range of RPM.	Supports lesser range of RPM.
7	Size	Generally, alternators are of smaller size.	Generally, generators are of larger size.
8	Brush Durability	Higher brush durability.	Lower brush durability.
9	Commutation	No commutation mechanism present.	Consists of commutation mechanism (in case of DC generators).
10	Polarization after installation	No post-installation polarization required.	Polarization is required after installation.
11	Charging of a dead battery	Cannot be used to charge a dead battery	Can be used to charge a dead battery.
12	Uses	Mainly used in the automobiles to charge the battery while the engine is running.	Used to produce large-scale electricity like gensets etc.
13	Diagrammatic Representation		



Armature
Magnets
Armature
Brushes
Commutator
Slip Rings
Brushes
Generator
Alternator

Synchronous Motor

- Synchronous motors are a **doubly excited machine**, i.e., two electrical inputs are provided to it.
- In this rotating magnetic field rotates at a certain speed known as the **synchronous speed**.
- It is not self starting & require some external means to bring their speed close to synchronous speed to before they are synchronized
- **Damper winding** & Motor starting with **an external prime Mover** are the starting methods of synchronous motor
- **Applications:**

1)power factor improvement

2)Reciprocating pump,

3) compressor,

4) rolling mills