ENERGY EFFICIENT PRACTICE

18EEO304T

UNIT -1

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Course Outcomes

Analyze efficiency of electrical supply system and energy saving methodologies

Electrical Supply System

An electrical supply system is a network of components that generates, transmits, and distributes electricity to consumers.

Components

•**Power station**

Generates electricity in a favorable location

•**Transmission lines**

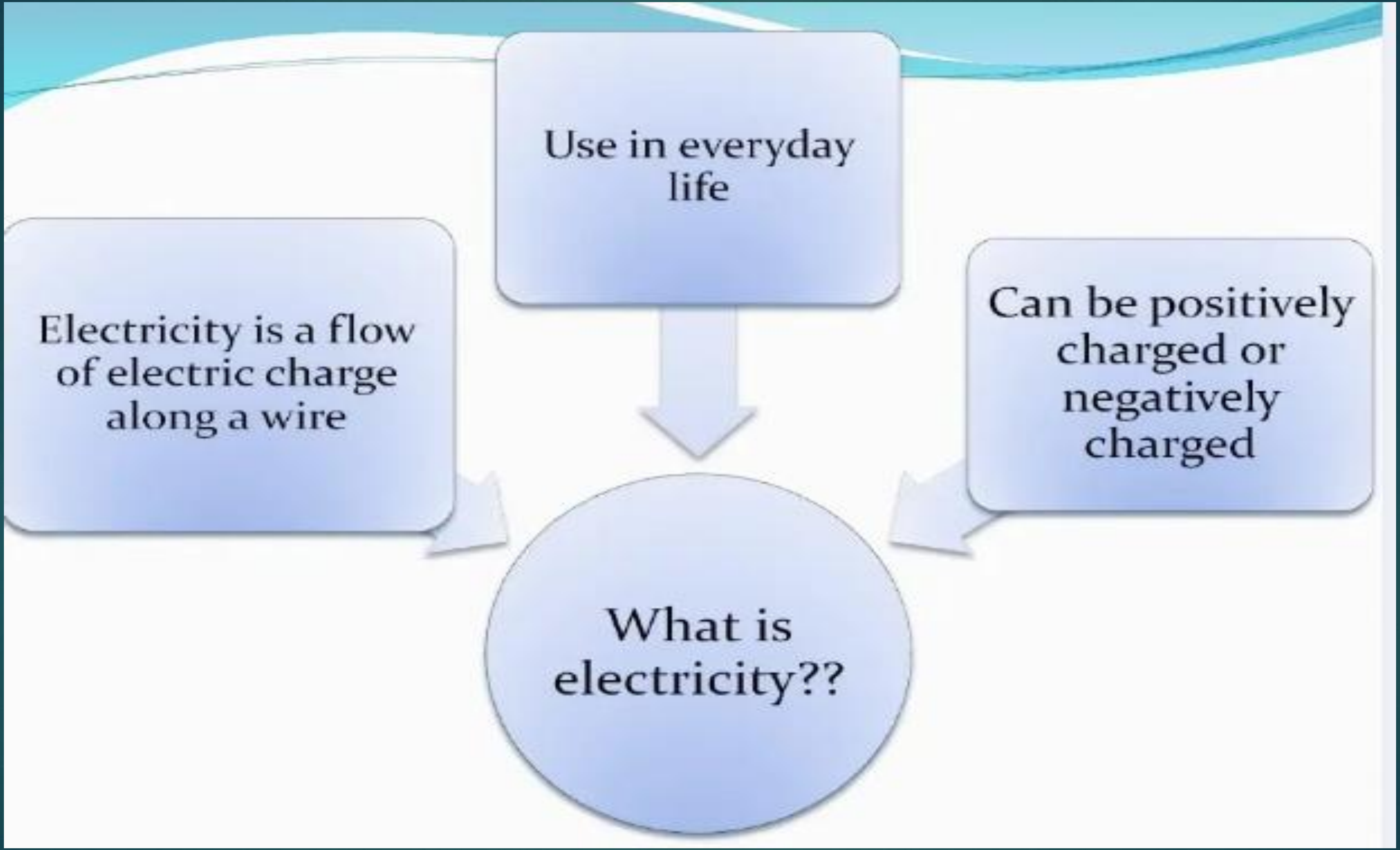
Conduct electricity over long distances from the power station to load centers

•**Distribution system**

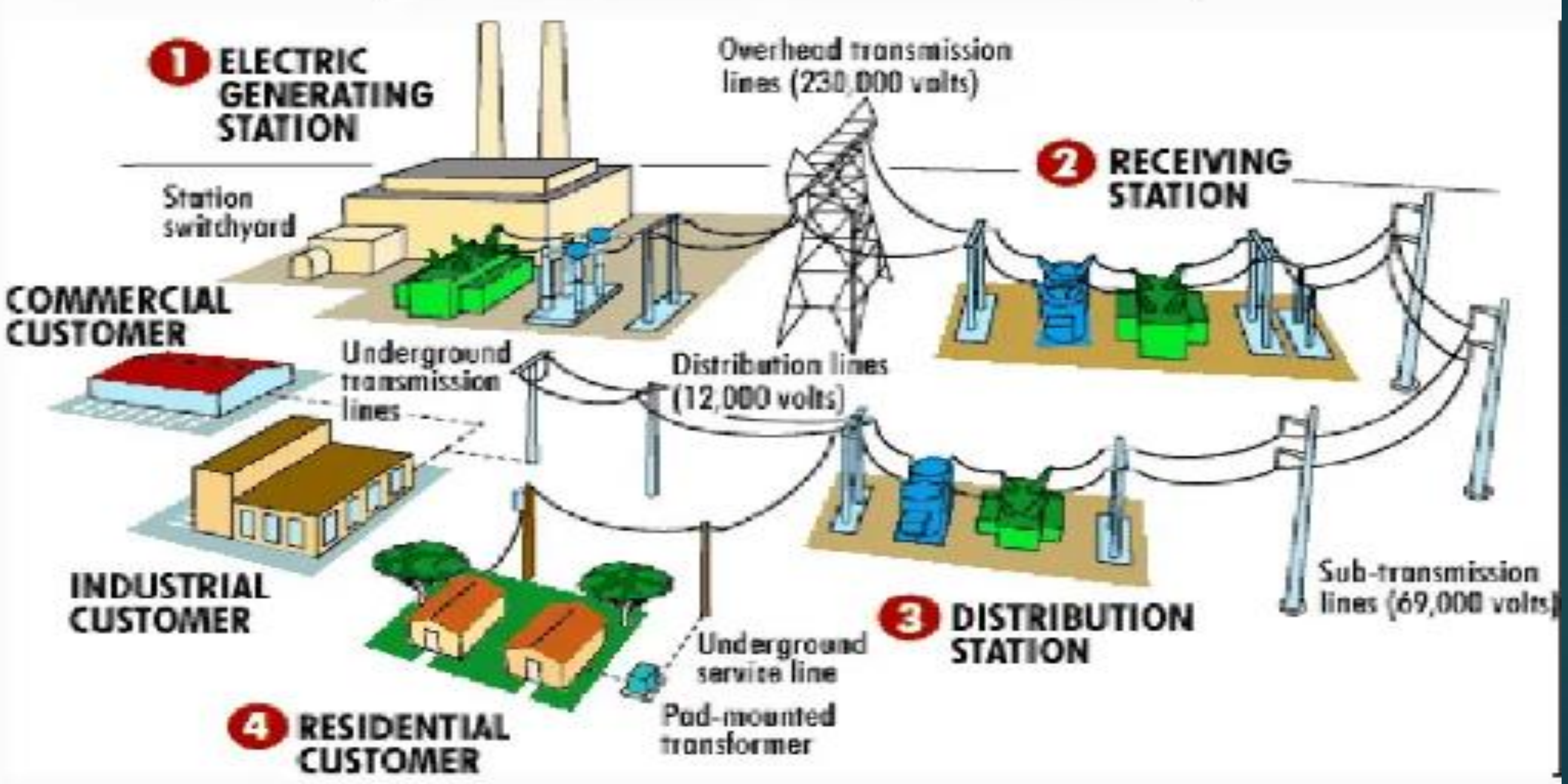
Distributes electricity to consumers through distribution substations, primary distribution lines, and secondary distribution circuits

•**Substations**

Transform voltage levels to produce, convert, regulate, and distribute electricity


Use in everyday life
Electricity is a flow of electric charge along a wire
Can be positively charged or negatively charged
What is electricity??

GENERATION



Process of electrical supply system

GENERATION

In the electrical supply system there are involve 4 main processes including :

Generation

↓

Transmission

↓

Distribution

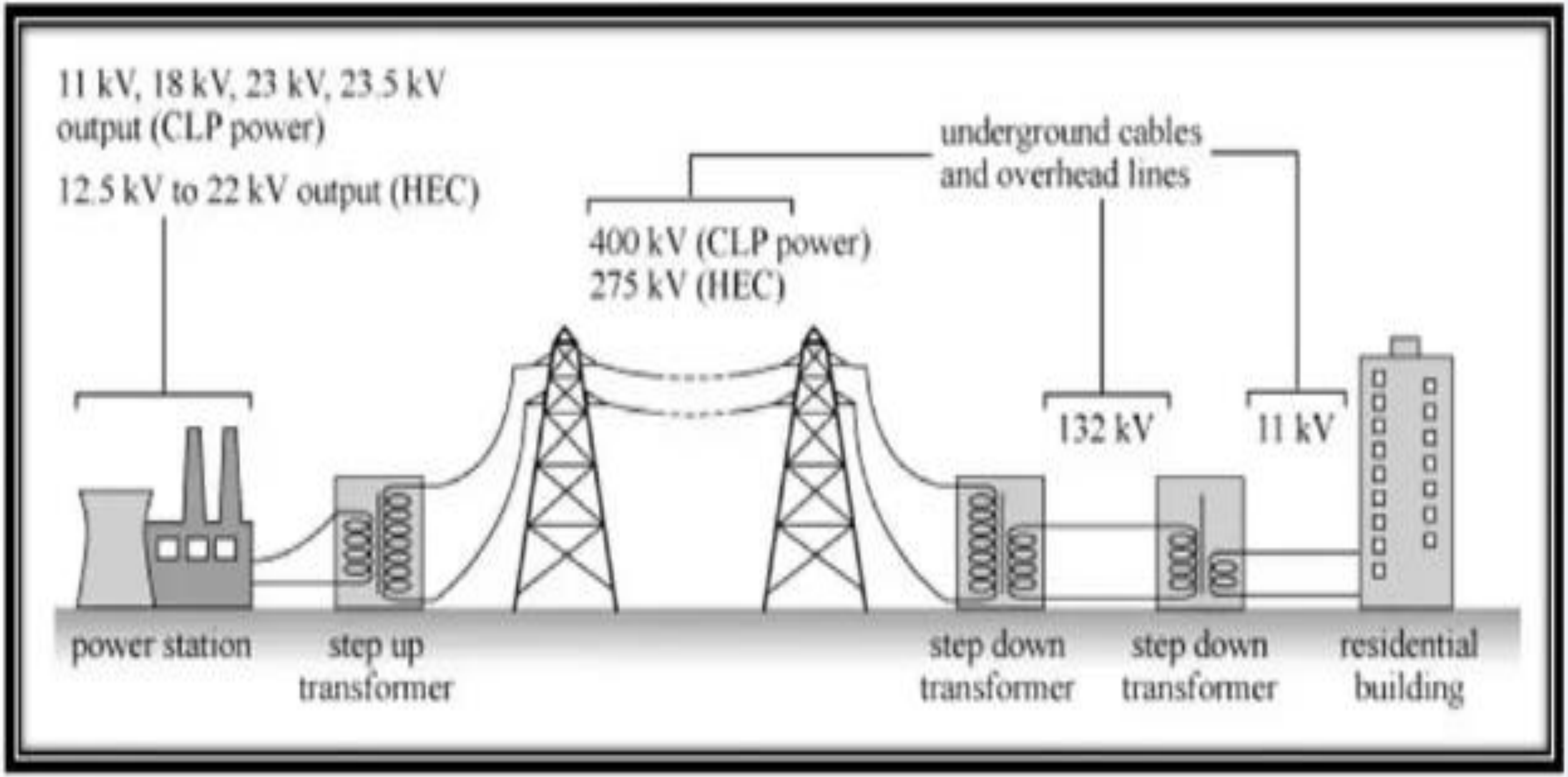
↓

Supply to the consumers

TRANSFORMER

SUBSTATION

PYLONS


11 kV, 18 kV, 23 kV, 23.5 kV
output (CLP power)
12.5 kV to 22 kV output (HEC)
underground cables
and overhead lines
400 kV (CLP power)
275 kV (HEC)
132 kV
11 kV
power station
step up
transformer
step down
transformer
step down
transformer
residential
building

Distribution of Electricity

- Generally supply categorized into:
  1. Supplies to **heavy industries** are given at a voltage of **33kV**
  2. **Light industries – 11kV**
  3. Supplies to **small industries, schools, offices**, etc are given at three phases 4 – wire of **415V**
  4. Supplies to **domestic premises** are given at single phase 2 – wire of **240V**

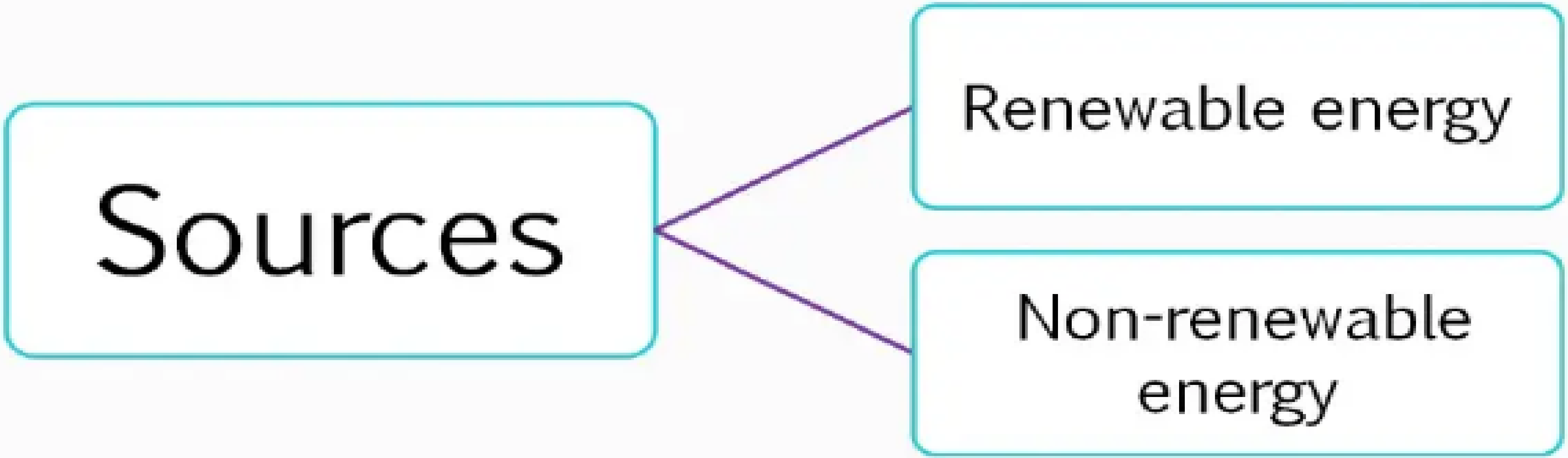
GENERATION

What is electricity generation?

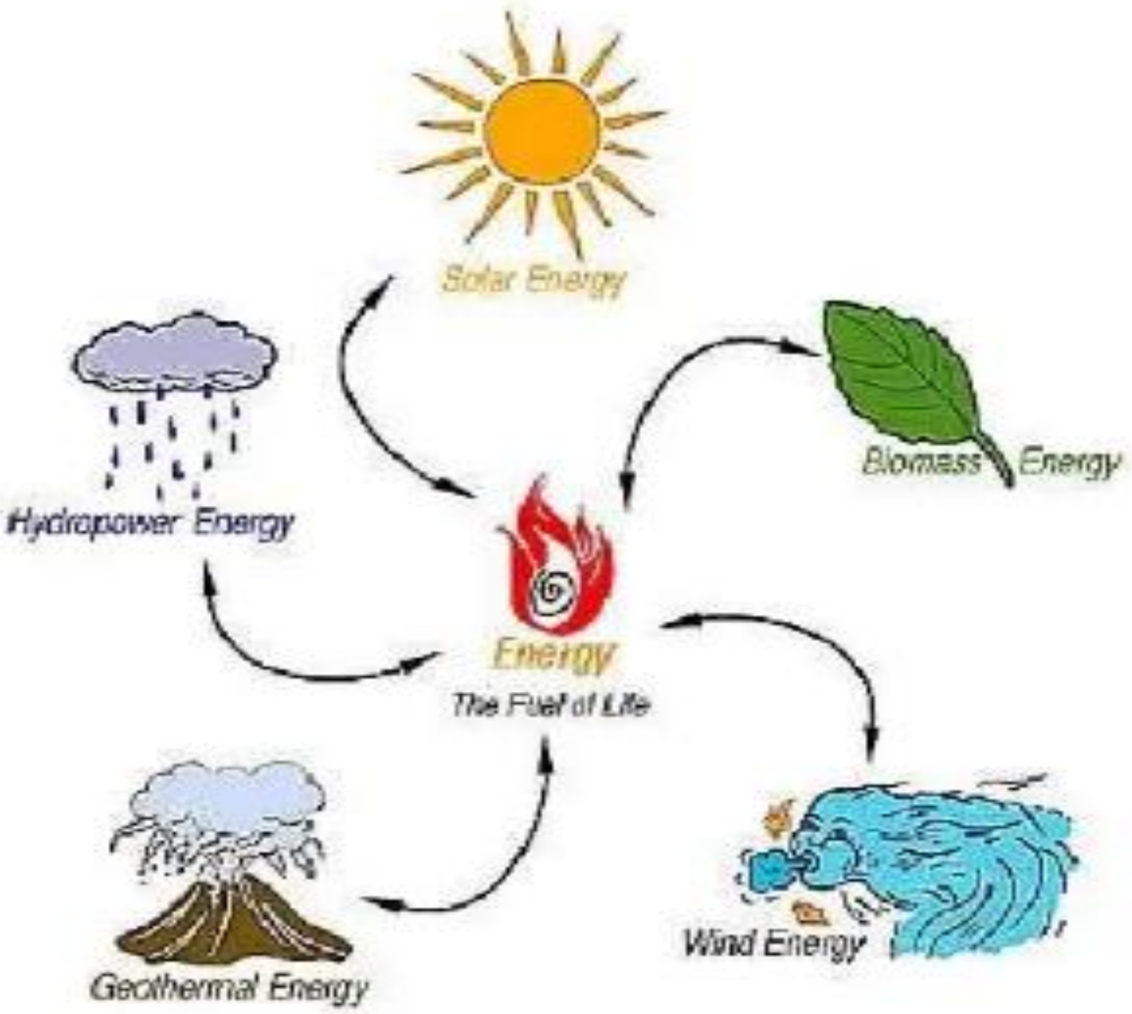
- process of creating electricity from other forms of energy.
- first process in the delivery of electricity to consumers
- is generated at a power station by the generators

GENERATION

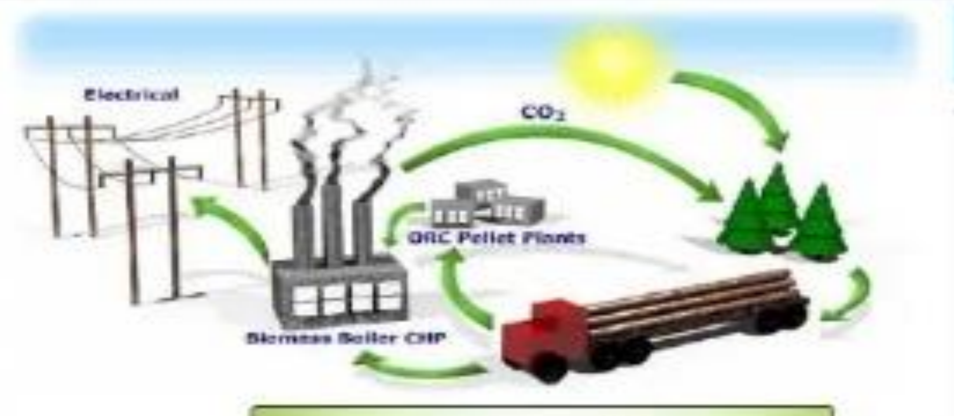
In the producing of electricity, it can be divided into two types of sources :



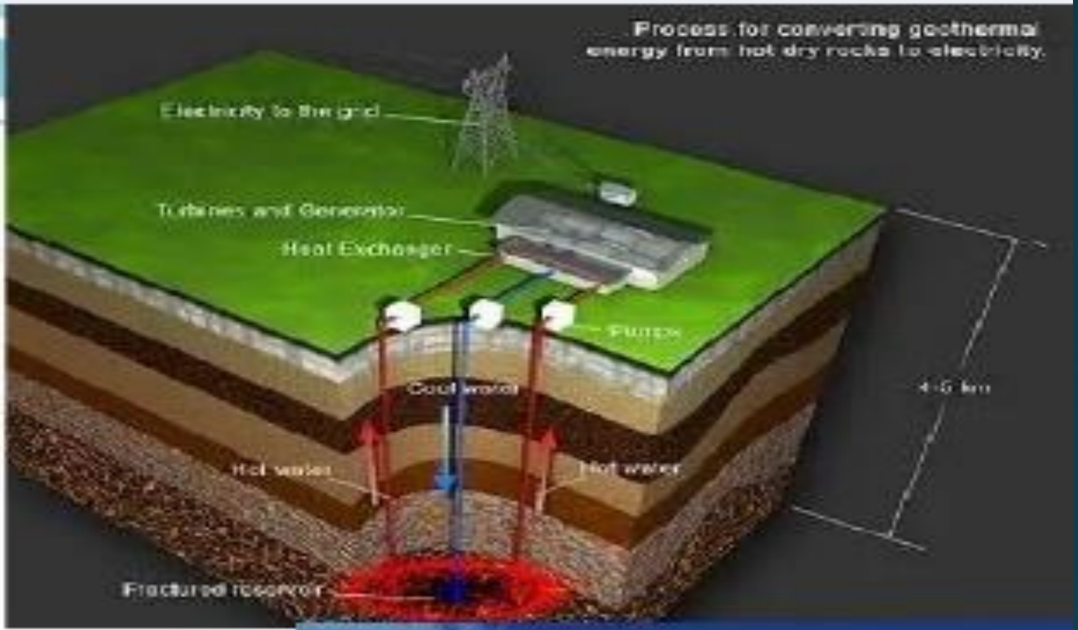
GENERATION



- energy which comes from the natural sources such as hydro, wind, solar, wave, biomass and geothermal
- generating electricity can contribute better air quality, reduce of used fossil fuels, global warming, protect environmental values such as habitat and water quality.
- renewable energy always available and can be replace in a reasonable of time
- It is because this source is a natural process that enables us to use it over and over again.

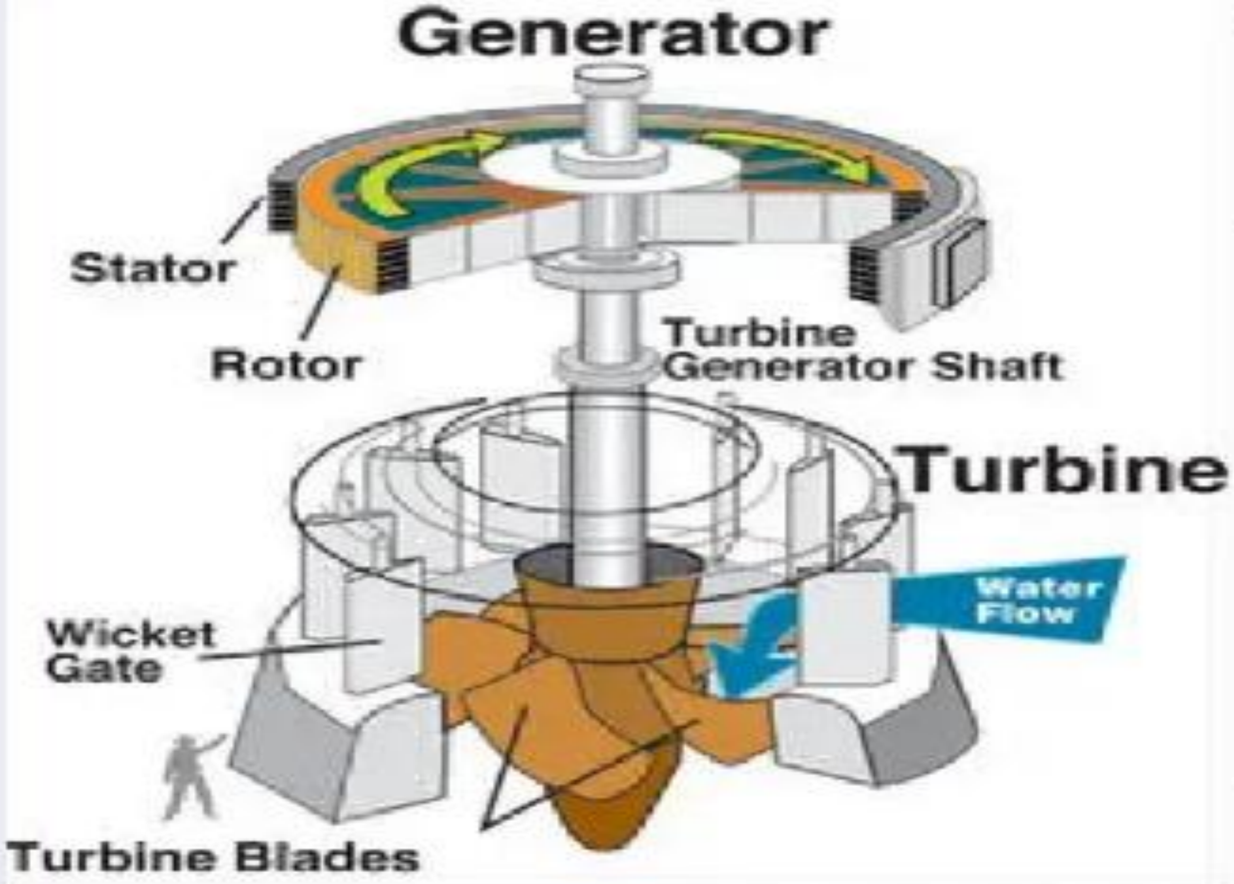

Electrical
CO_2
ORC Pellet Plants
Biomass Boiler CHP


BIOMASS SOURCES


Process for converting geothermal energy from hot dry rocks to electricity.
Electricity to the grid
Turbines and Generator
Heat Exchanger
Pumps
Cool water
Hot water
Hot water
Fractured reservoir

GENERATION

Hydraulic Turbine and Electrical Generator



- Giant wheels called turbines are used to spin the magnets inside the generator.
- It takes a lot of energy to spin the turbine and different kinds of power plants get that energy from different sources.
- In a hydroelectric station, falling water is used to spin the turbine. In nuclear stations and in thermal generating stations powered by fossil fuels, steam is used.
- A wind turbine uses the force of moving air.

GENERATION

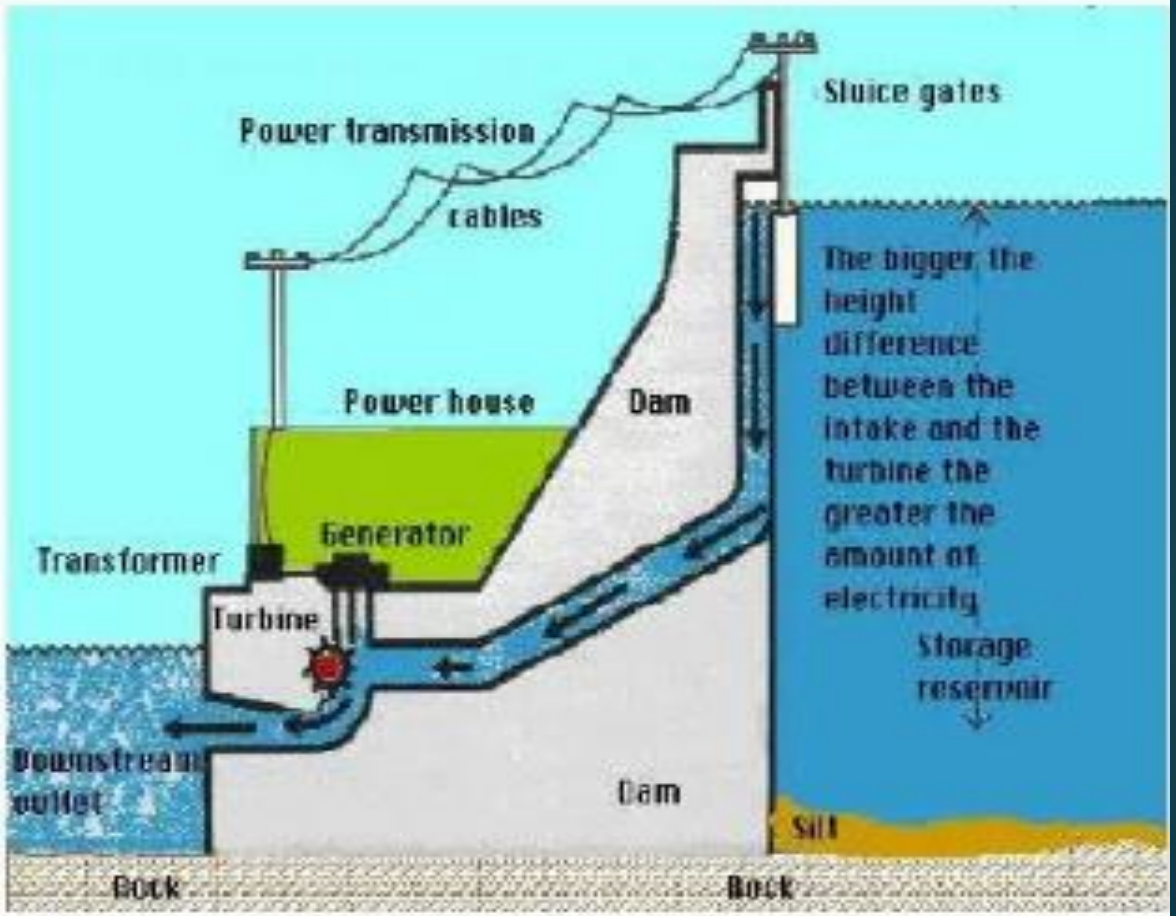
Hydraulic Turbine and Electrical Generator

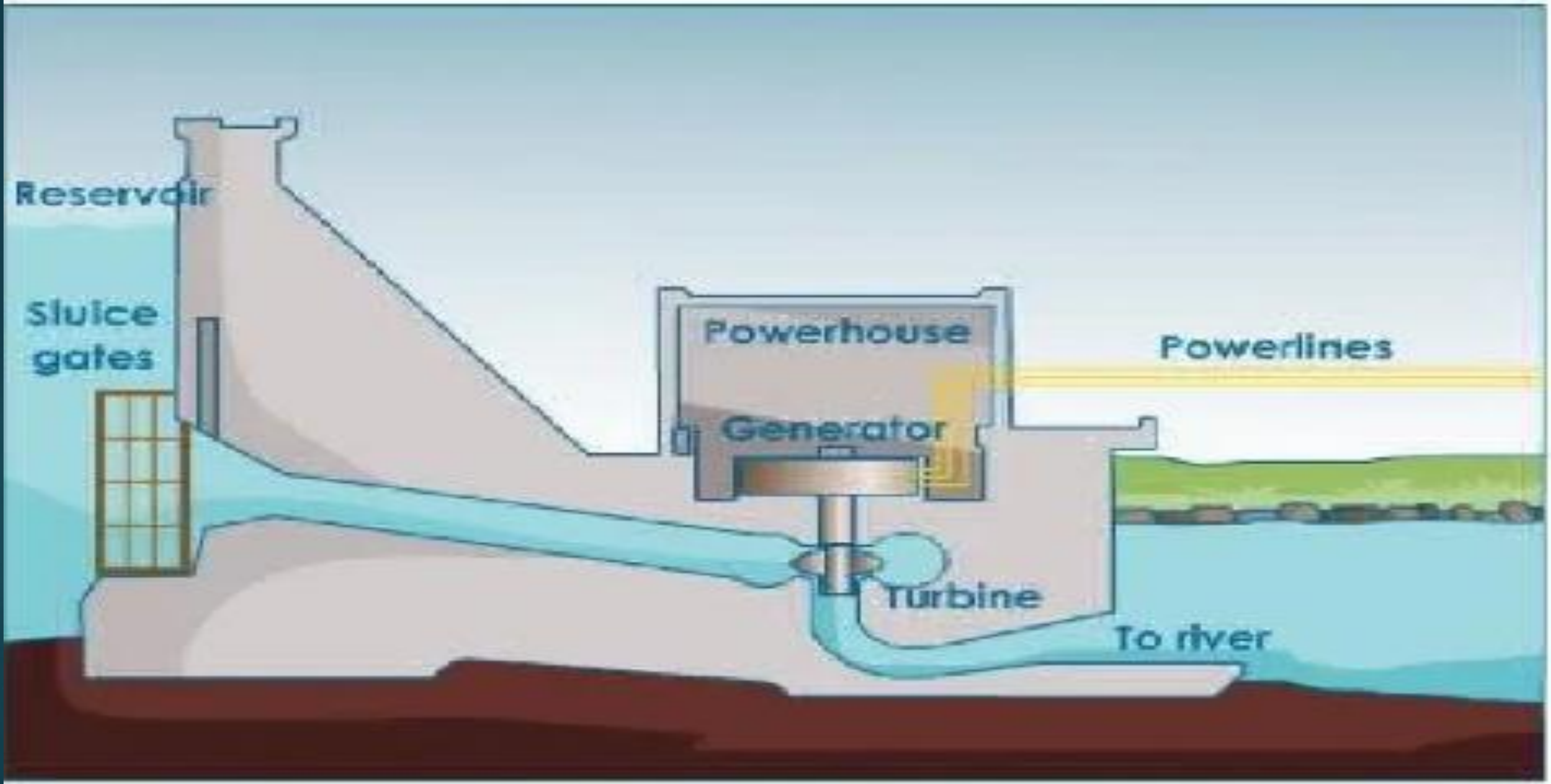
- At a power plant, a **generator** is used to make electricity.
- Inside of the generator, a magnet called a **rotor** spins inside coils of copper wire called a **stator**.
- This pulls the electrons away from their atoms, and a flow of electrons is created in the copper wires.
- Those electrons can be then be sent along power lines to wherever electricity is needed.

GENERATION

Hydroelectric Power Plant

A dam creates a "head" or height from water flows known as sluice gate → A pipe (penstock) carries the water from reservoir to the turbine → The fast-moving water pushes the turbine blades like a pinwheel in the wind → The waters forces on the turbines blades turns → when the tubines moving, it will touch the coil wires in the generator → The stator in the generator moved, and electricity is produced

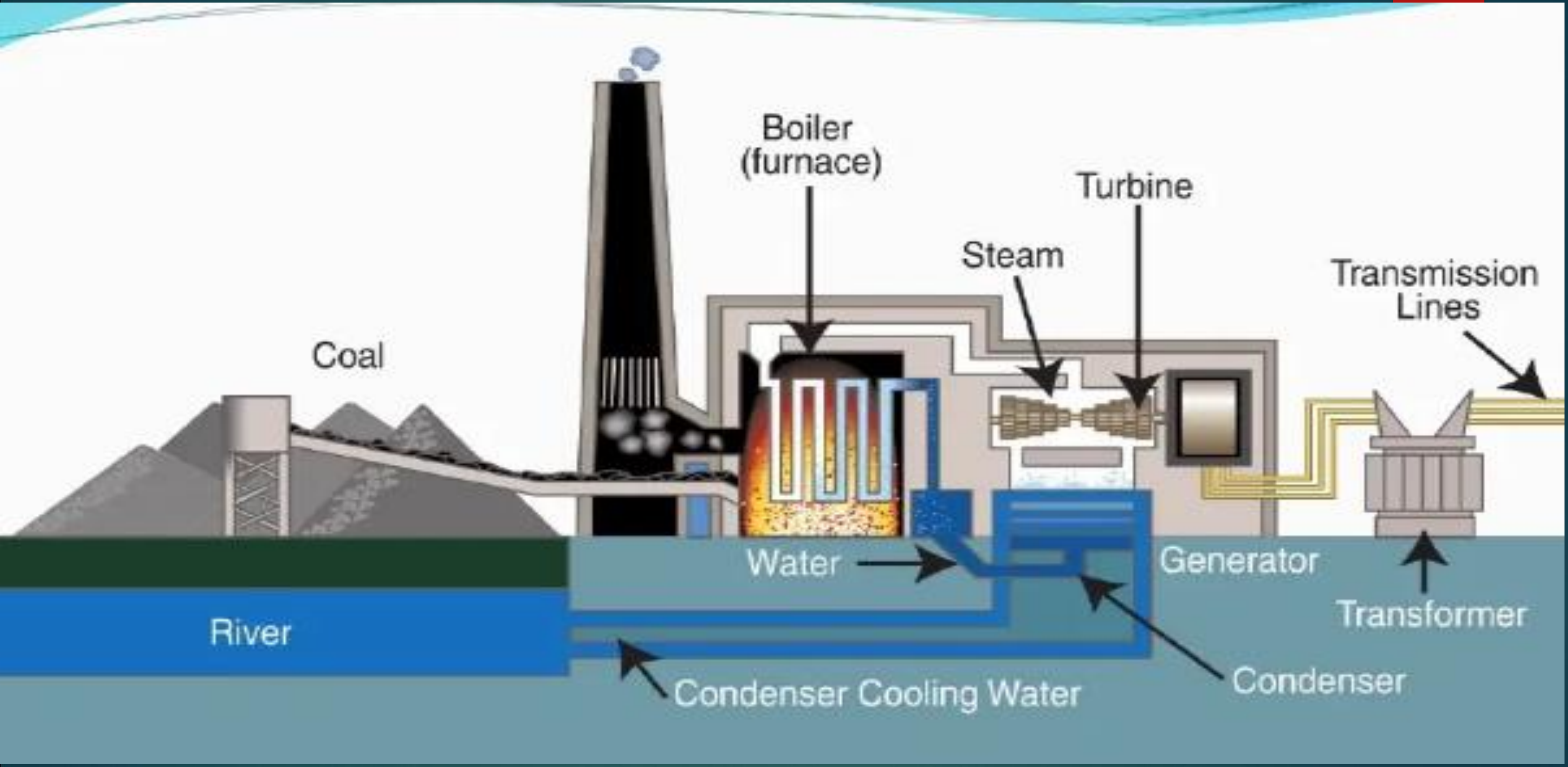




A schematic view of a hydro power plant

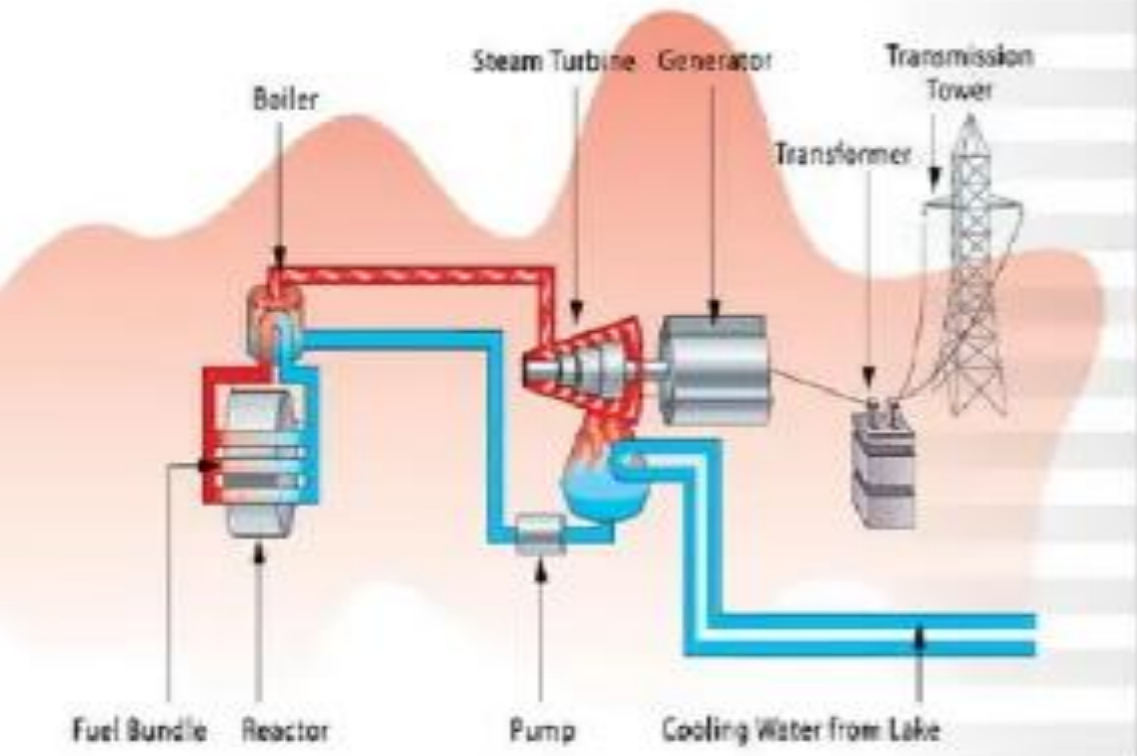
GENERATION

ADVANTAGES	DISADVANTAGES
• No fuel cost	• Wildlife and fishes get affected
• Low operating cost and less maintenance	• Earthquake vulnerability
• Low electricity cost	• Siltation
• No air pollution	• Tail risk, dam failure
• Energy storage	• Cannot be built anywhere


Boiler
(furnace)
Turbine
Steam
Transmission
Lines
Coal
Water
Generator
River
Transformer
Condenser
Condenser Cooling Water

GENERATION

Nuclear Generating Station



Nuclear fission makee heat → Heat water to make steam → Steam turns turbines → Turbines turns generator → Electrical will transmit and distribute to the consumer

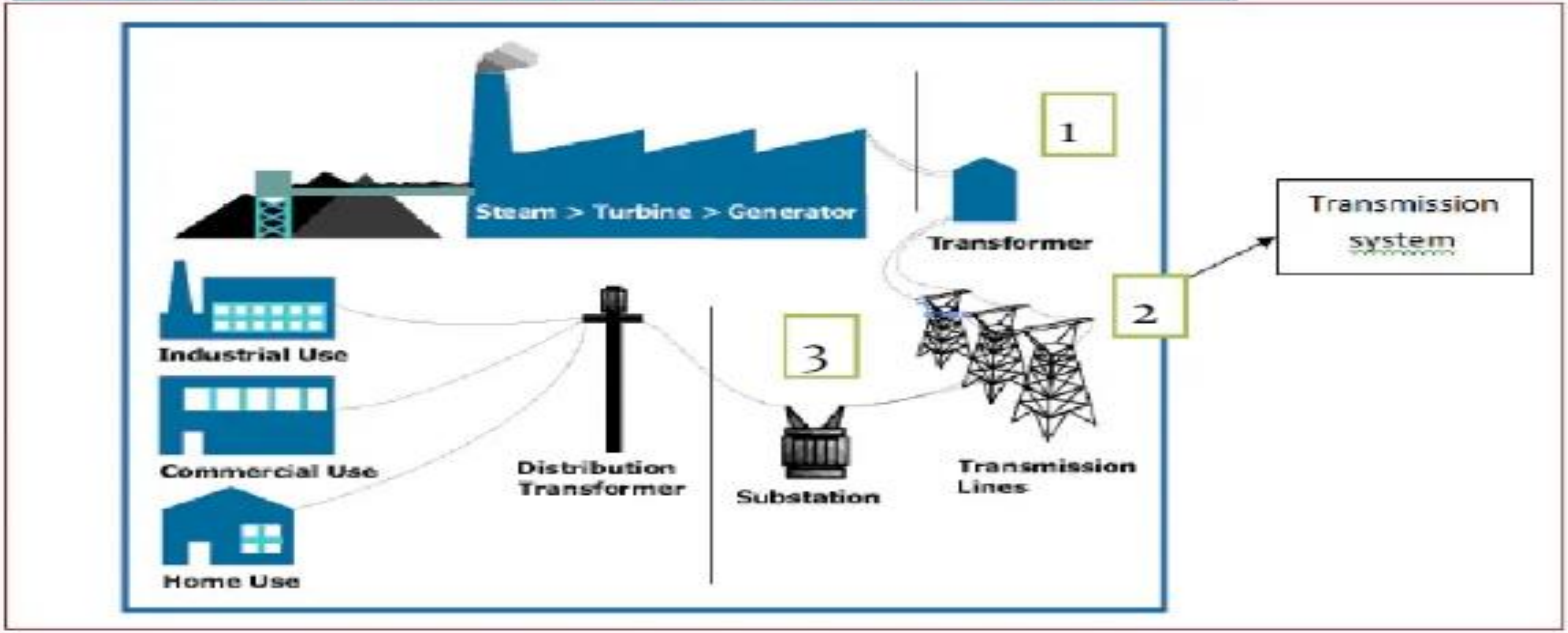
GENERATION

ADVANTAGES	DISADVANTAGES
• Low fuel cost • Low electricity cost • No air pollution • Reliability	• Nuclear and radiation accidents • Nuclear waste disposal • Nuclear proliferation • High capital of investment, cost overruns • Fuel danger

ELECTRIC TRANSMISSION

- Electric transmission is a system of **high voltage network** which **interconnect main generating station** with major load centre or substation. The system also enables bulk transfer of power between these transmission points. In penisular (Malaysia), this transmission system is known as the National Grid system

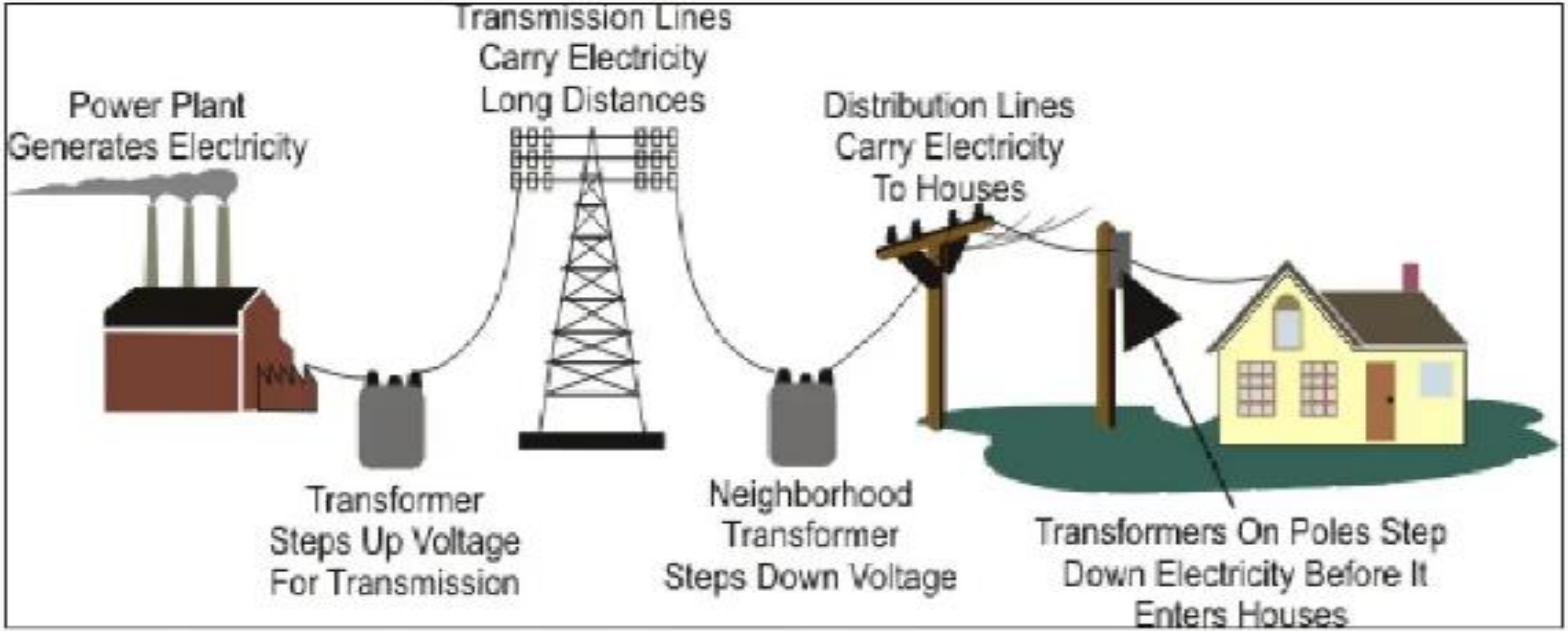
ELECTRIC TRANSMISSION



1. TRANSFORMER

A transformer is an **electrical device that transfer energy from one circuit** to another purely by magnetic coupling. Relative motion of the parts of the transformer is not required for transfer of energy. Transformer are **often used to convert between high an low voltages**, to change impedance, and to **provide electrical isolation between circuits**.

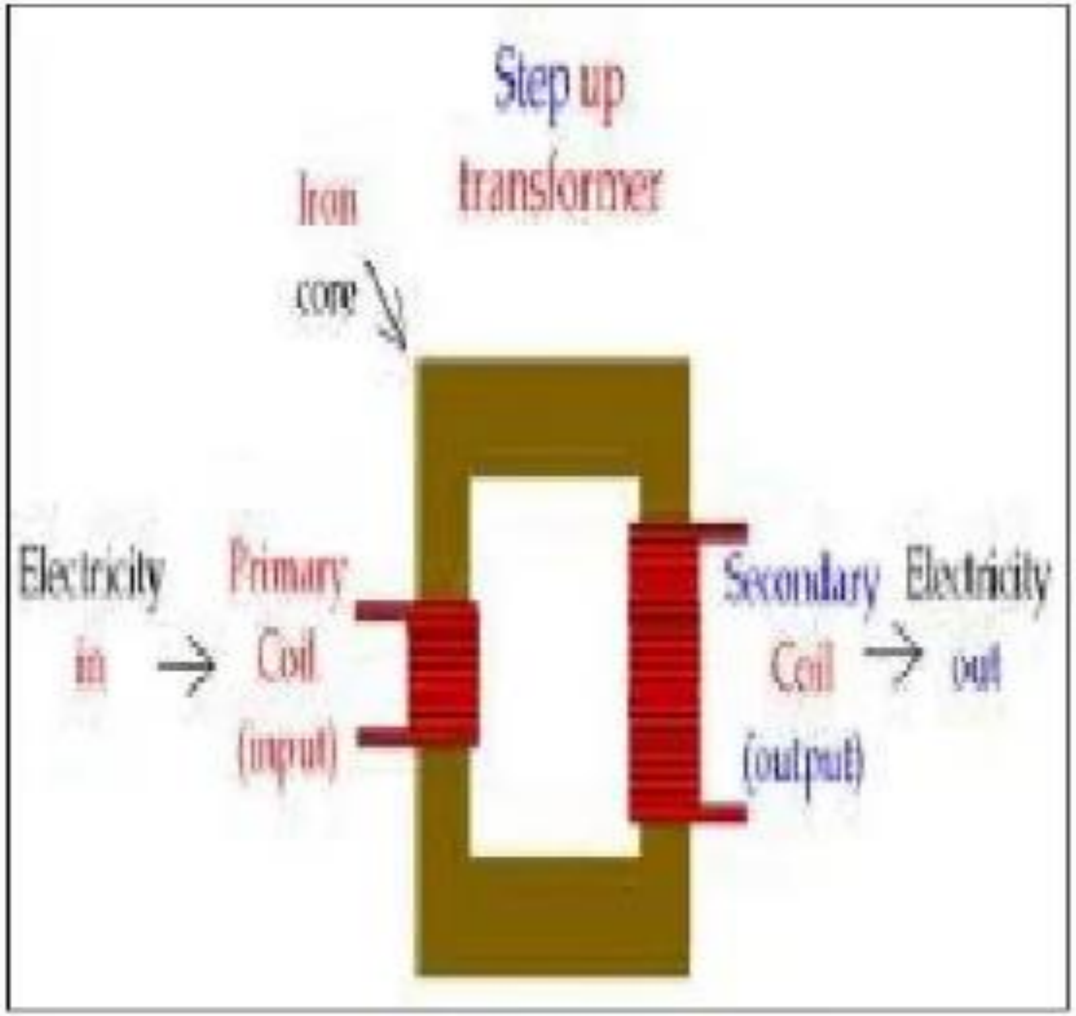
TRANSFORMER



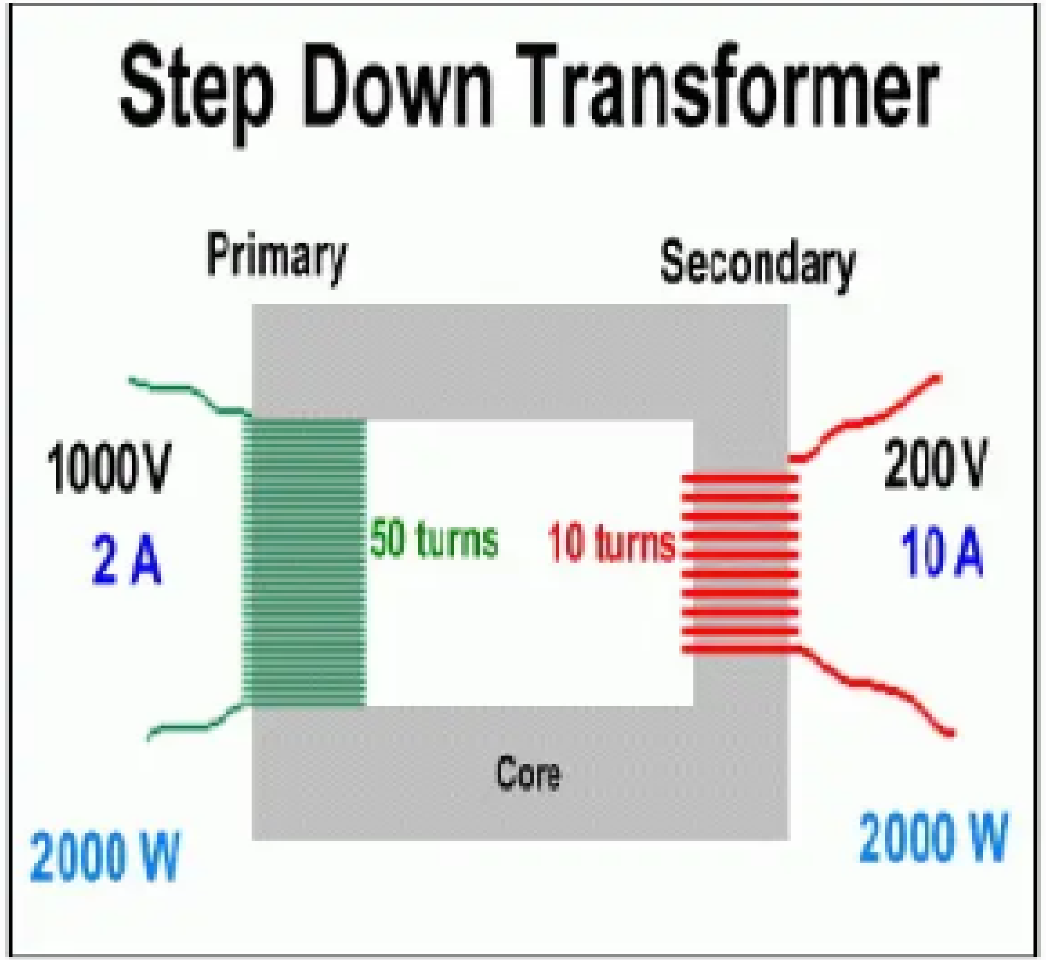
STEP UP TRANSFORMER

Allows a devices that requires a high voltage power supply operate from a lower voltage source.

A step up transformer is one whose secondary voltage is greater than its primary voltage.

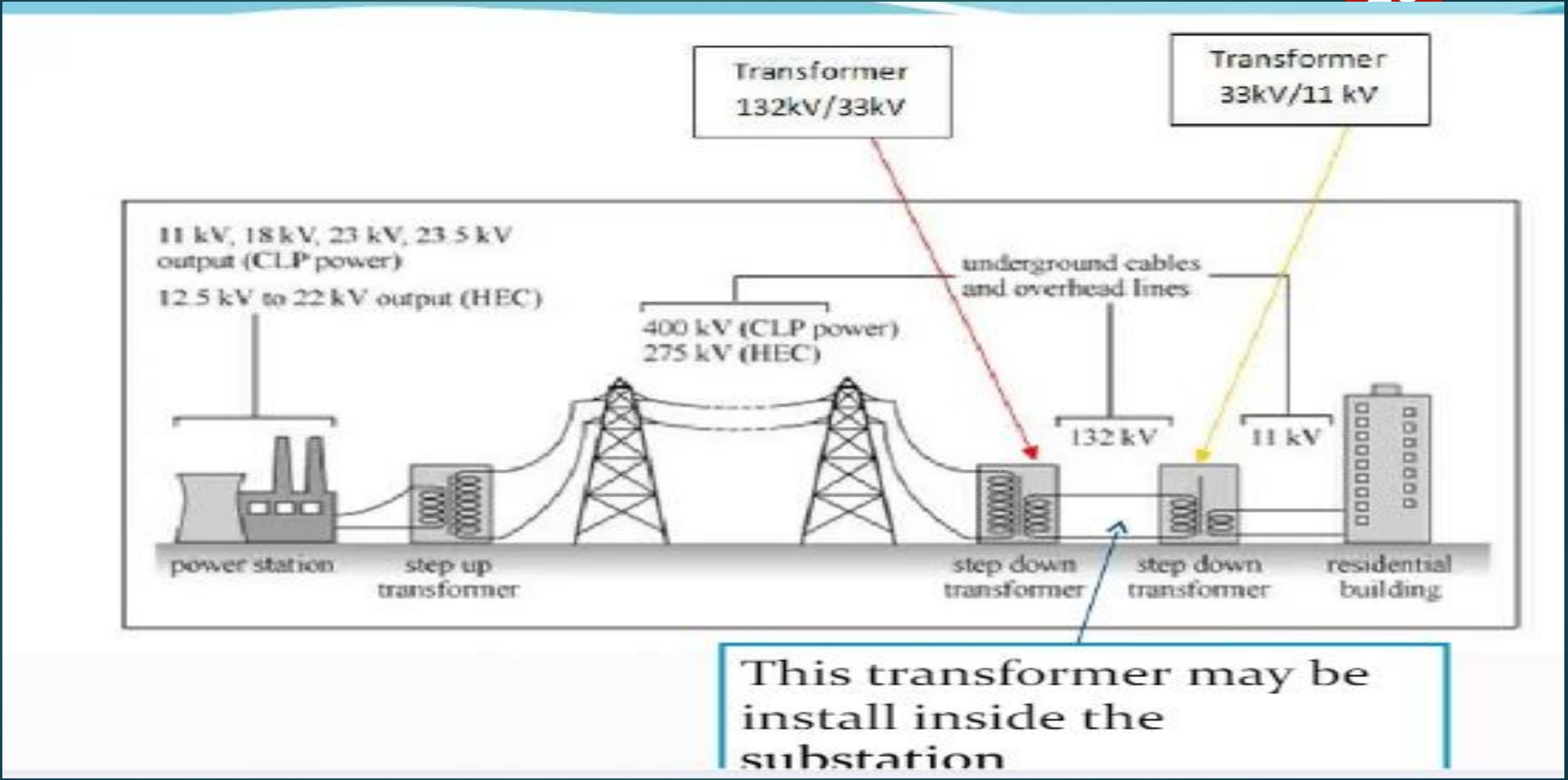


STEP DOWN TRANSFORMER



Allows a device that requires a low voltage power supply to operate from a high voltage.

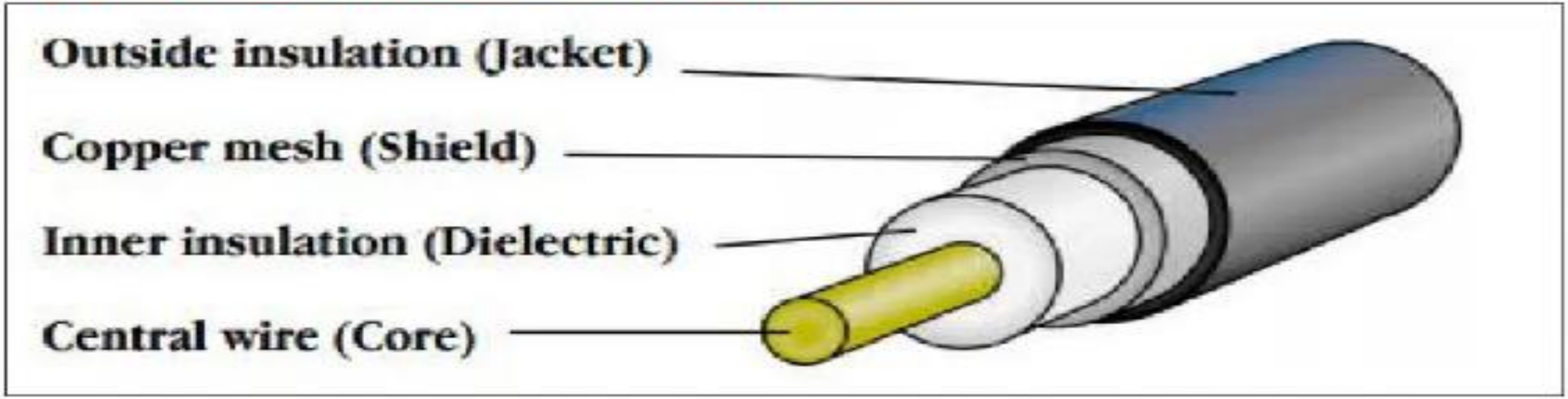
A step down transformer is one whose secondary voltage is less that its primary voltage.


Transformer
132kV/33kV
Transformer
33kV/11 kV
11 kV, 18 kV, 23 kV, 23.5 kV
output (CLP power)
12.5 kV to 22 kV output (HEC)
400 kV (CLP power)
275 kV (HEC)
underground cables
and overhead lines
132 kV
11 kV
power station
step up
transformer
step down
transformer
step down
transformer
residential
building
This transformer may be
install inside the
substation

2. PYLONS (TRANSMISSION TOUR AND TRANSMISSION LINES)

Pylons is to carry the high voltage cable. It transfer the voltage to the transformer. By using transformer, the voltage will step down to distribute. Transformer will reduce the voltage to the suitable amount to distribute to the user. For commercial building, the voltage is about 415 V in a three phases. For residential area, the voltage is 240 V in one phases and for industrial area, the voltage is 11 kV and above.

Transmission Line



It is : Material medium or structure that forms all or part of a path from one place to another for directing the transmission of energy, such as electric currents, magnetic fields, acoustic waves, or electromagnetic waves.

Examples : wires, optical fibers and coaxial cables.

DISTRIBUTION

- Electricity distribution networks carry electricity from the transmission systems and some generators that are connected to the distribution networks to industrial, commercial and domestic users

DISTRIBUTION

- Distribution system is the process of transmission of electricity from major load consists to the end of consumers.
- After electricity is generated and transmitted,step-down transformers located in distribution substations reduce the voltage so it can be carried on smaller cables or distribution lines.

NATIONAL GRID SYSTEM

ADVANTAGES

- Permitted transfer of electricity throughout the country
- Standardize electrical frequency and voltage to customers
- Enable bulk transfer over long distances

DISADVANTAGES

- Requires a long time to complete the whole grid (& connection to other countries)
- Requires high degree of management & maintenance
- Requires high capital cost for infrastructure, generating stations, substations, equipment, etc.

3. SUBSTATION

A substation is a place which electric power is received from generating station via incoming transmission lines and delivered to the distribution system via outgoing transmission line. Substation are integral parts of a power stations system and form important links between generating station, transmission system, distribution system and load points.

There are 2 types of substation in Malaysia that is outdoor and indoor. An outdoor or outside station is a substation located under an open sky and an indoor substation is a substation located inside the building. Indoor substation is used when the switchgear are of the GIS (Gas Insulated Switchgear) type and which land area is limited for example city area.

Outdoor Substation

Indoor Substation

Classification of Substation

(a) Indoor substations.

- For voltages up to 11 kV, the equipment of the substation is installed indoor because of economic consideration.
- However, when the atmosphere is polluted with impurities, these sub-stations can be erected (setup) for voltages up to 66 kV.

(b) Outdoor substations.

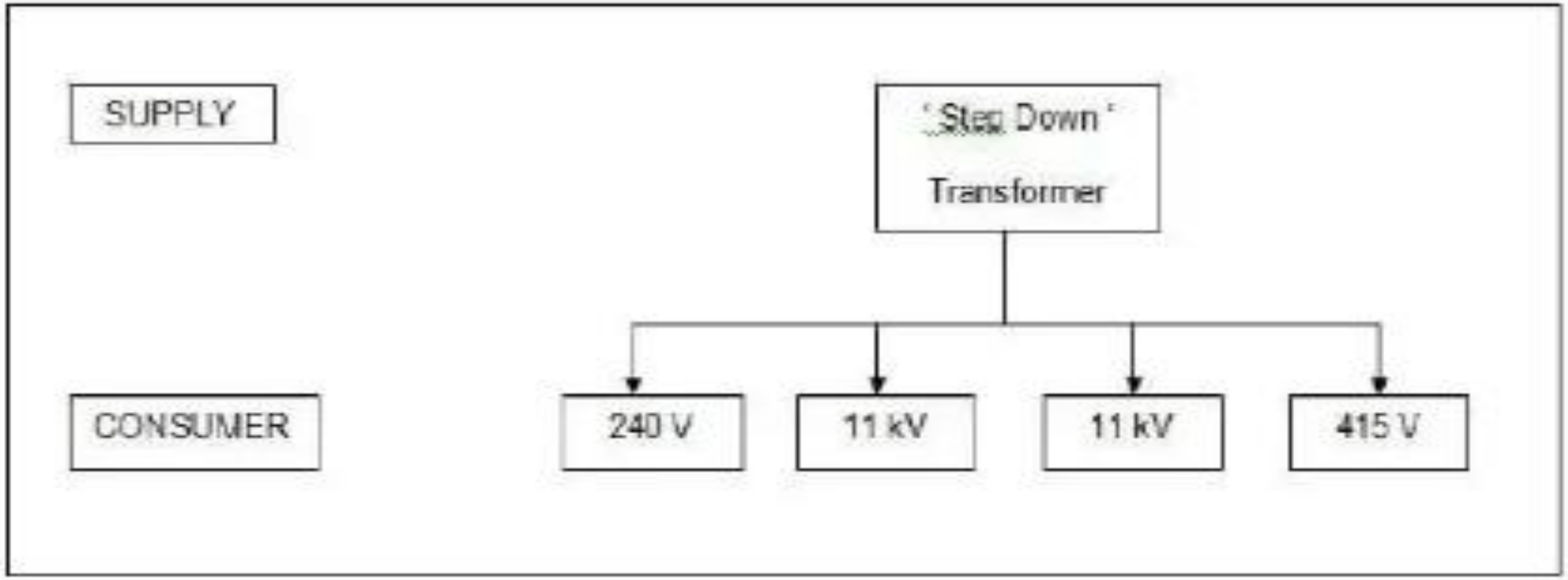
- For voltages beyond 66 kV, equipment is invariably (constant) installed outdoor. It is because of such voltages, the clearances between conductors and the space required for switches, circuit breakers and other equipment becomes so great that it is not economical to install the equipment indoor.

(c) Underground substations.

- In thickly populated areas, the space available for equipment and building is limited and the cost of land is high.
- Under such situations, the sub-station is created underground.

SUPPLY SYSTEM

- the last process of the electrical supply system.
- involving process : distributor will 'step down' the voltage → consumer .



Supply to a building

1) Consumer supply system

400 kV 240 k V 132 kV	Generation and distribution	
33 kV	Large/heavy industries, cities, towns and railways	→ AC, 3-phase supply with 4-wire cable
11 kV	Light industries, hospitals, towns and villages	AC, 3-phase supply with 3-wire cable
400 V	Small industries, offices, farms	
240 V	Housing, schools, small commercial premises	→ DC or AC, single-phase supply with 2-wire cable

3 phase wiring.:

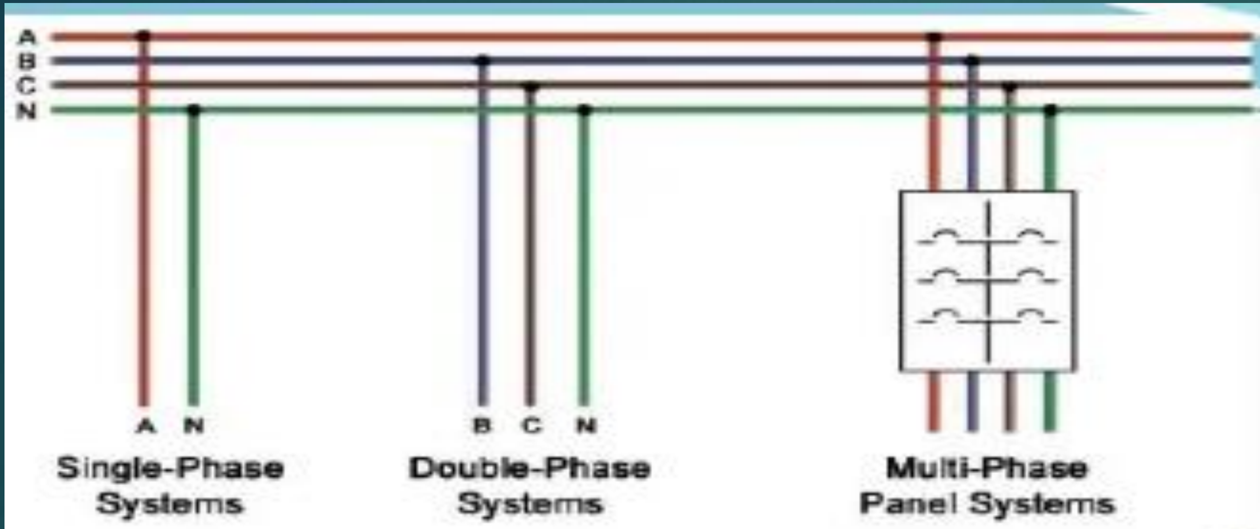
Note the 3 wires (red, yellow and blue) and the 3 fuses.

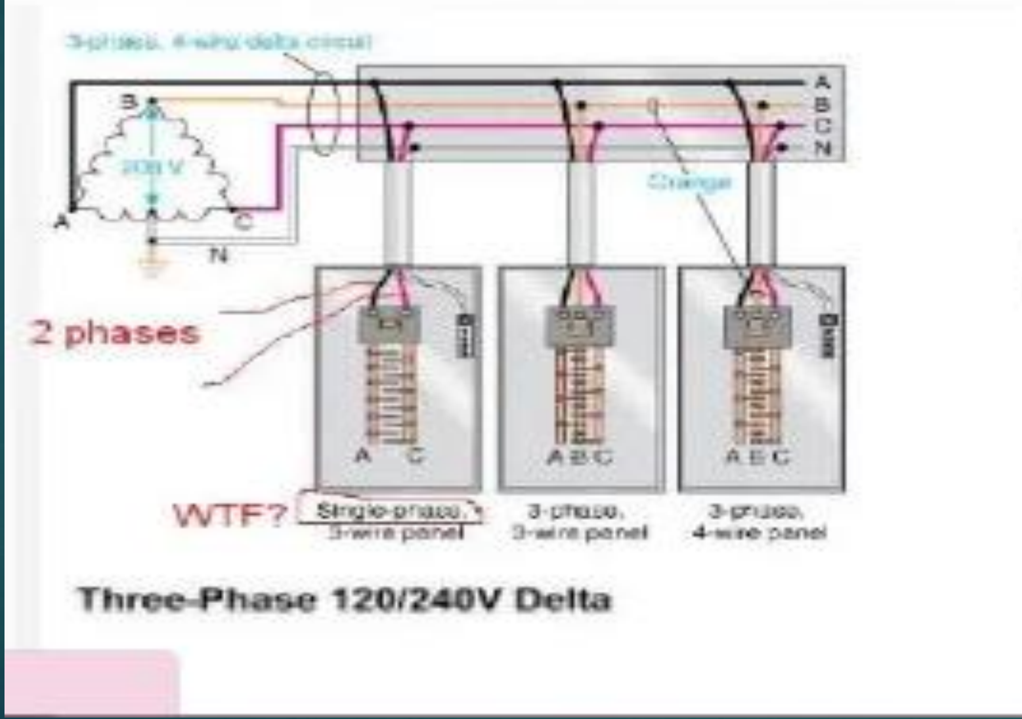
Metering.:

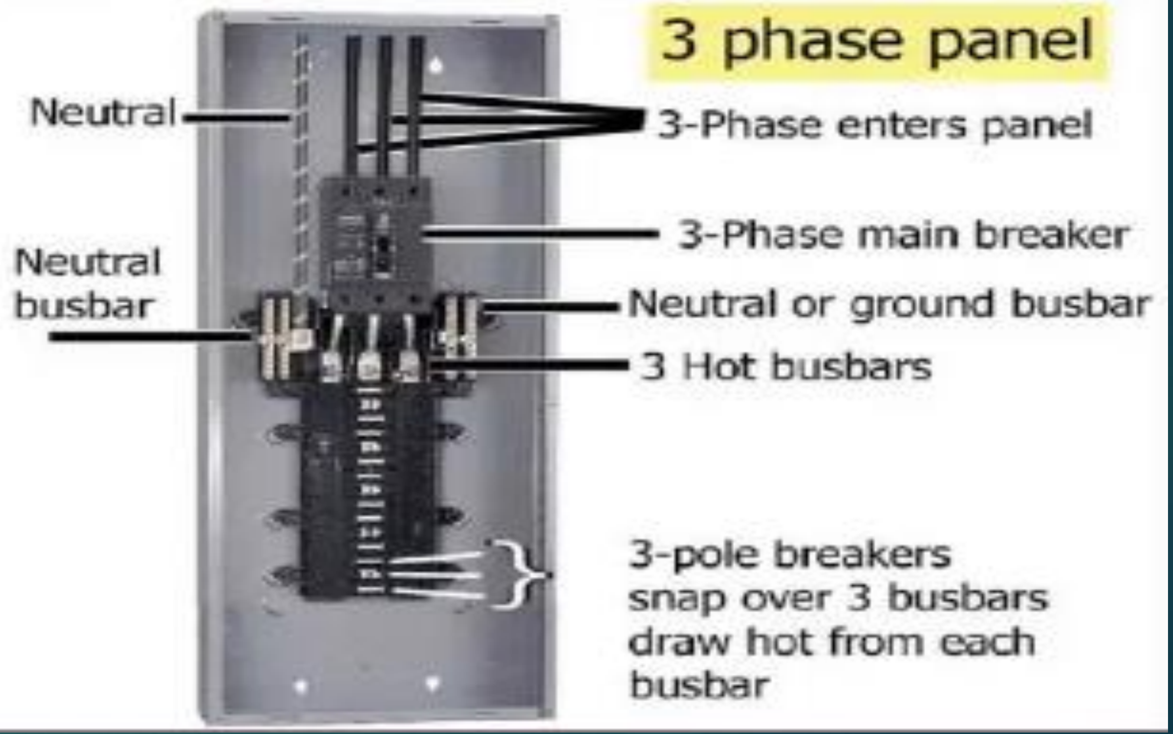
It is known as watt hour meter which use to measuring the recording the quantity of electrical power consumed with respect to time.

This meter consist 2 coils.:

- The current coil connected across the phase
- The voltage coil across the phase and neutral


A
B
C
N
A N
Single-Phase Systems
B C N
Double-Phase Systems
Multi-Phase Panel Systems


A
B
C
N
2 phases
A C
A B C
A B C
WTF?
Single-phase, 3-wire panel
3-phase, 3-wire panel
3-phase, 4-wire panel
Three-Phase 120/240V Delta

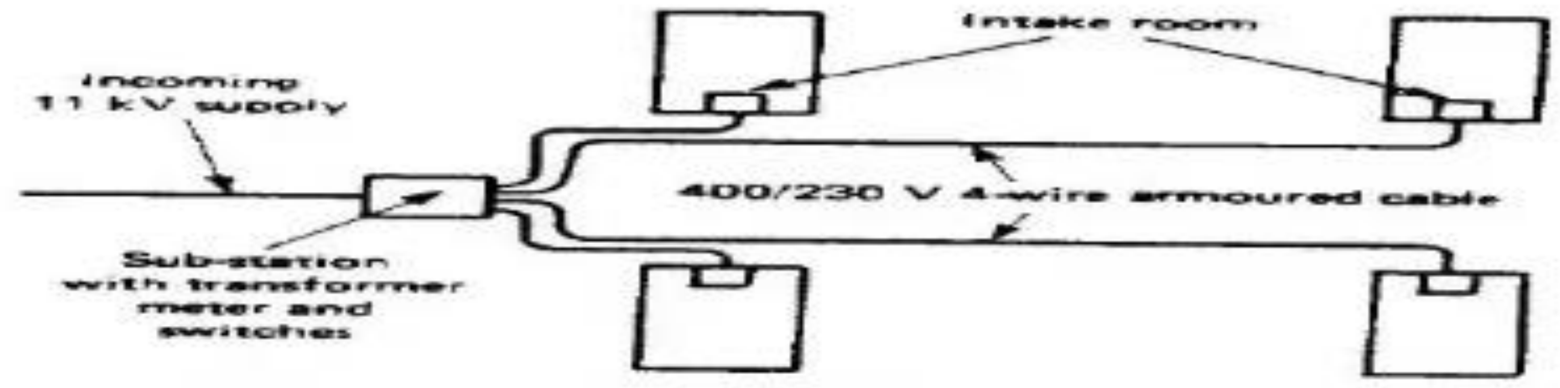

3 phase panel
Neutral
3-Phase enters panel
3-Phase main breaker
Neutral busbar
Neutral or ground busbar
3 Hot busbars
3-pole breakers snap over 3 busbars draw hot from each busbar

2) Large and high rise building

There are three (3) types of distribution :

a) Radial system

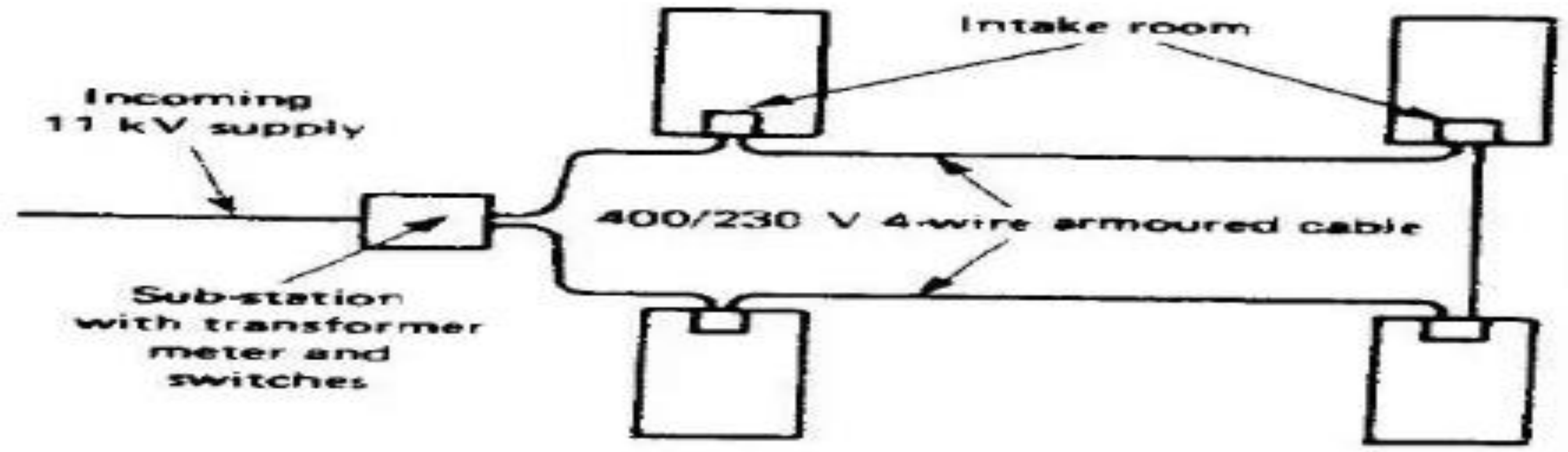
- The electrical is supply radiates from the main intake panel.
- The main panel consists of a main switch connected to fused switches through a bus-bar chamber.
- For example : factories and resort complexes.



Radial distribution (block plan)

b) Ring main distribution

- for a large development buildings around the perimeter of site.
- The ring main circuit would be taken around the site into each building
- For example : Holiday resorts, small factory and residential complexes

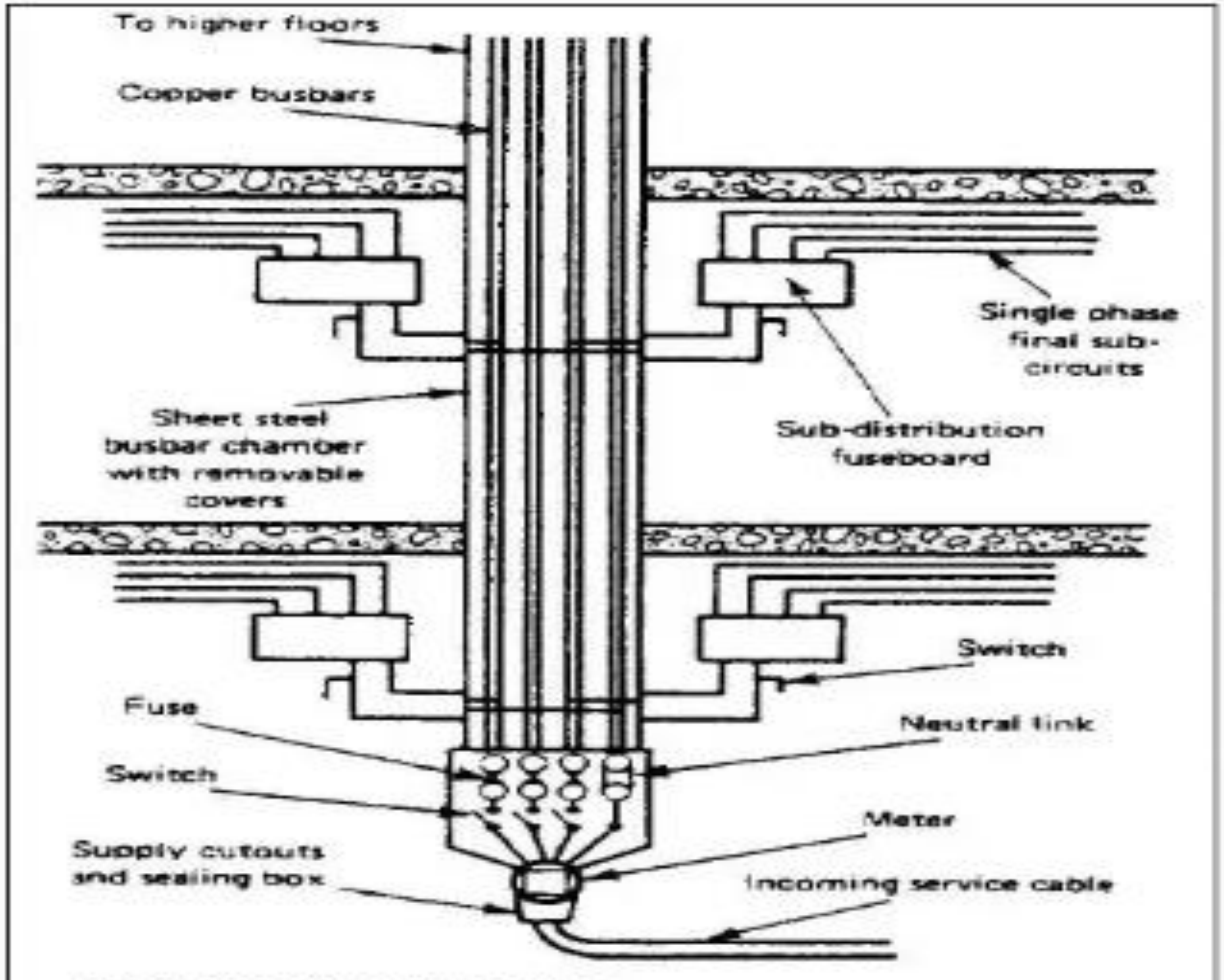


Ring distribution (block plan)

c) Rising main distribution

- for buildings five storey and above, preferable to conductors vertically
  through the building.

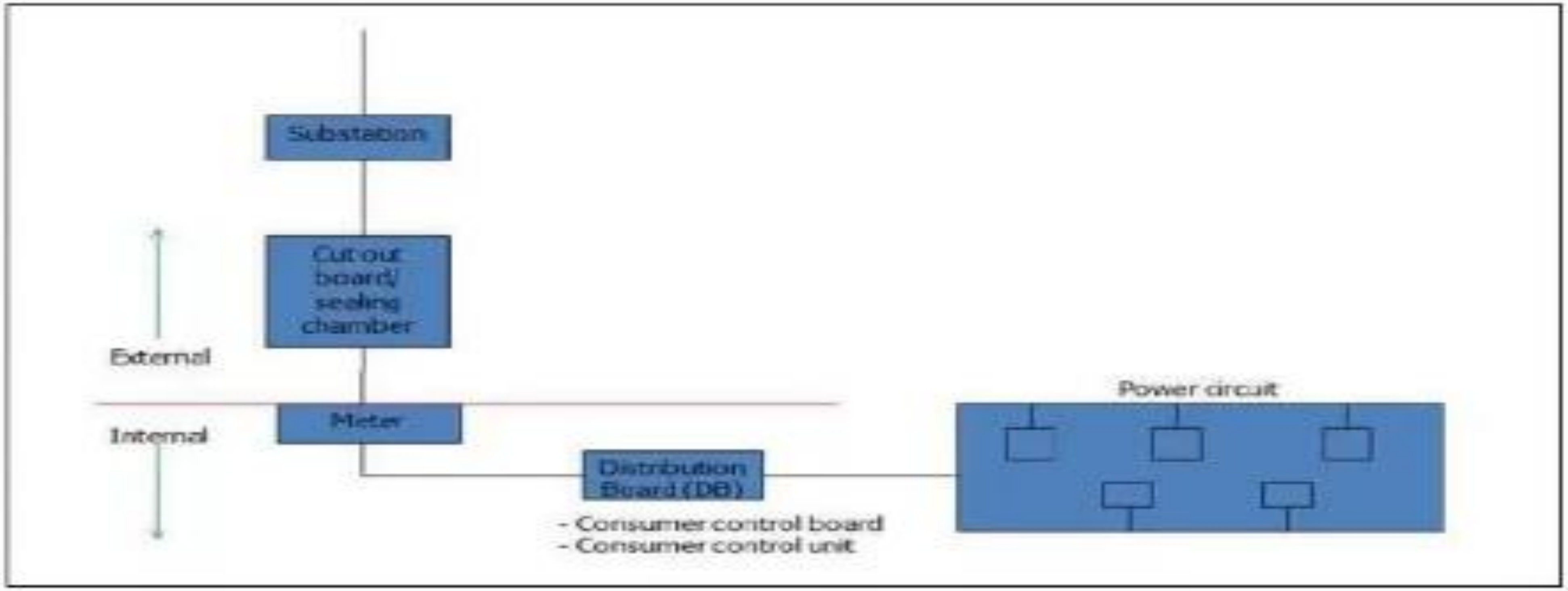
- The supply to each
  floor is connected.



Detail of rising main system

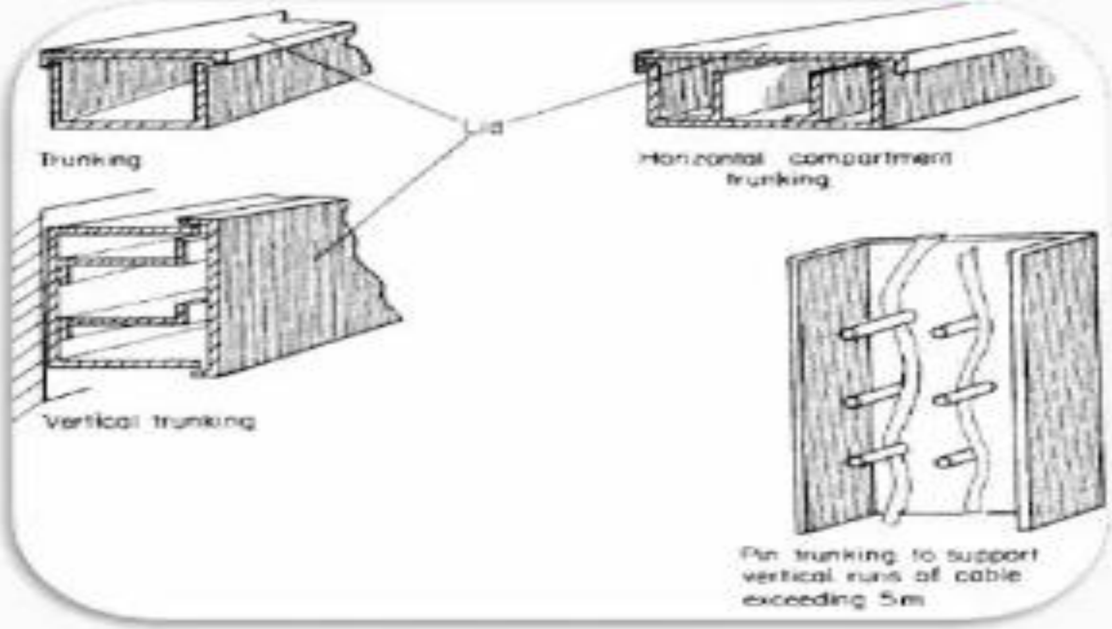
Domestic building

- the electric are supplied with the single phase.
- contains a live phase and a neutral in one cable and terminating at the meter board.
- can be of two (2) forms which are overhead cables and underground about 0.5m below.
- used consumer board to serve individual circuits.



ELECTRIC TRUNKING & CONDUIT

- Metal
- Non Metal
- Flexible
- Underground



- Horizontal
- Vertical

The main components of AC power are resistors, capacitors, and inductors. These are passive components that limit the flow of electric current in a circuit.

Explanation

Resistors, capacitors, and inductors

These passive components limit the flow of electric current in a circuit. They can be combined in many ways to create circuits with different functions.

Transformers

These components step down AC voltage to meet the required voltage of the power supply load.

Rectifiers

These components transform the sinusoidal AC waveform into a set of positive troughs and crests.

Filters

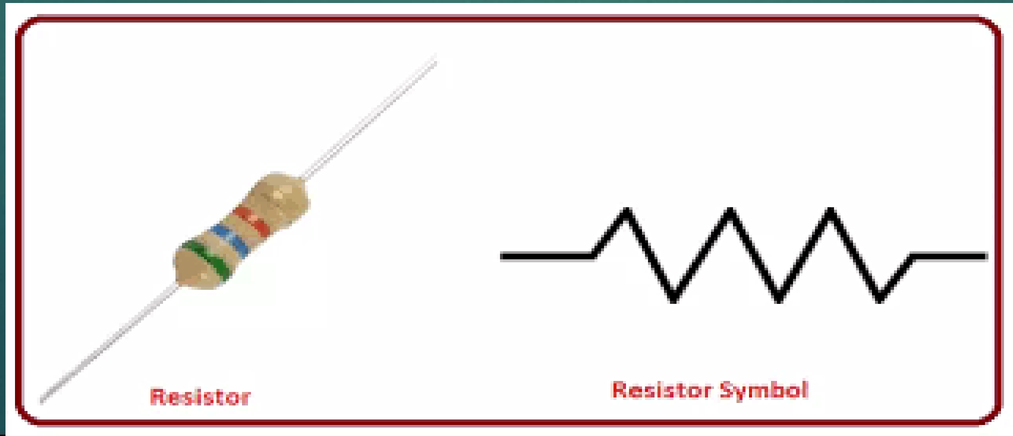
These components smooth out the AC voltage into a usable DC supply.

AC power is a common electricity format that comes out of outlets. It's used in household appliances and for transmitting electrical power.

Resistor

A **resistor** is a passive two-terminal electrical component that implements electrical resistance as a circuit element.

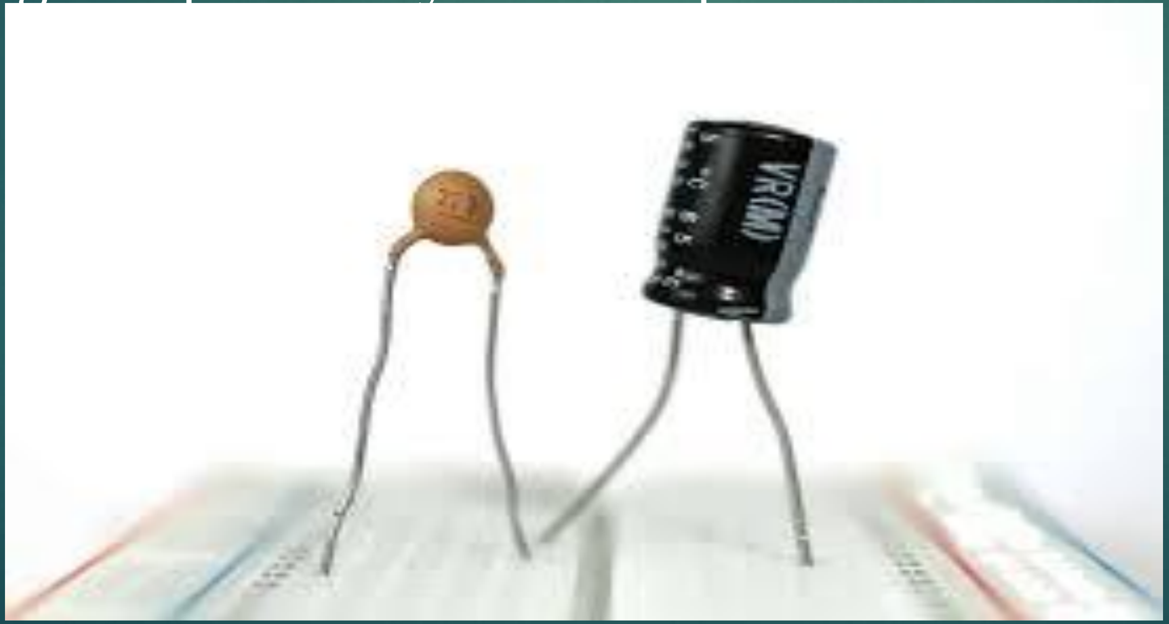
- In electronic circuits, resistors are used to reduce current flow, adjust signal levels, to divide voltages, bias active elements, and terminate transmission lines, among other uses.
- High-power resistors that can dissipate many watts of electrical power as heat may be used as part of motor controls, in power distribution systems, or as test loads for generators.
- Fixed resistors have resistances that only change slightly with temperature, time or operating voltage.
- Variable resistors can be used to adjust circuit elements (such as a volume control or a lamp dimmer), or as sensing devices for heat, light, humidity, force, or chemical activity.



Capacitor

A **capacitor** is a device that stores electrical energy by accumulating electric charges on two closely spaced surfaces that are insulated from each other.

- The capacitor was originally known as the **condenser**,a term still encountered in a few compound names, such as the condenser microphone. It is a passive electronic component with two terminals.
- The utility of a capacitor depends on its capacitance. While some capacitance exists between any two electrical conductors in proximity in a circuit, a capacitor is a component designed specifically to add capacitance to some part of the circuit.



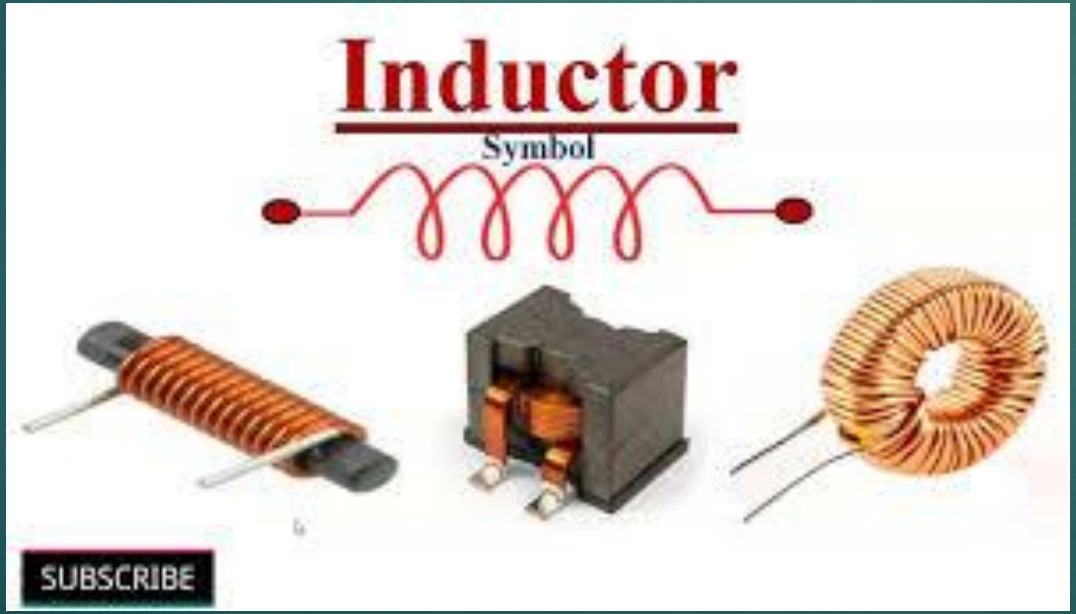
Inductor

An inductor is a passive component that is used in most power electronic circuits to store energy in the form of magnetic energy when electricity is applied to it.

• One of the key properties of an inductor is that it impedes or opposes any change in the amount of current flowing through it.

• Whenever the current across the inductor changes, it either acquires charge or loses the charge in order to equalise the current passing through it.

•The inductor is also called a choke, a reactor or just a coil.



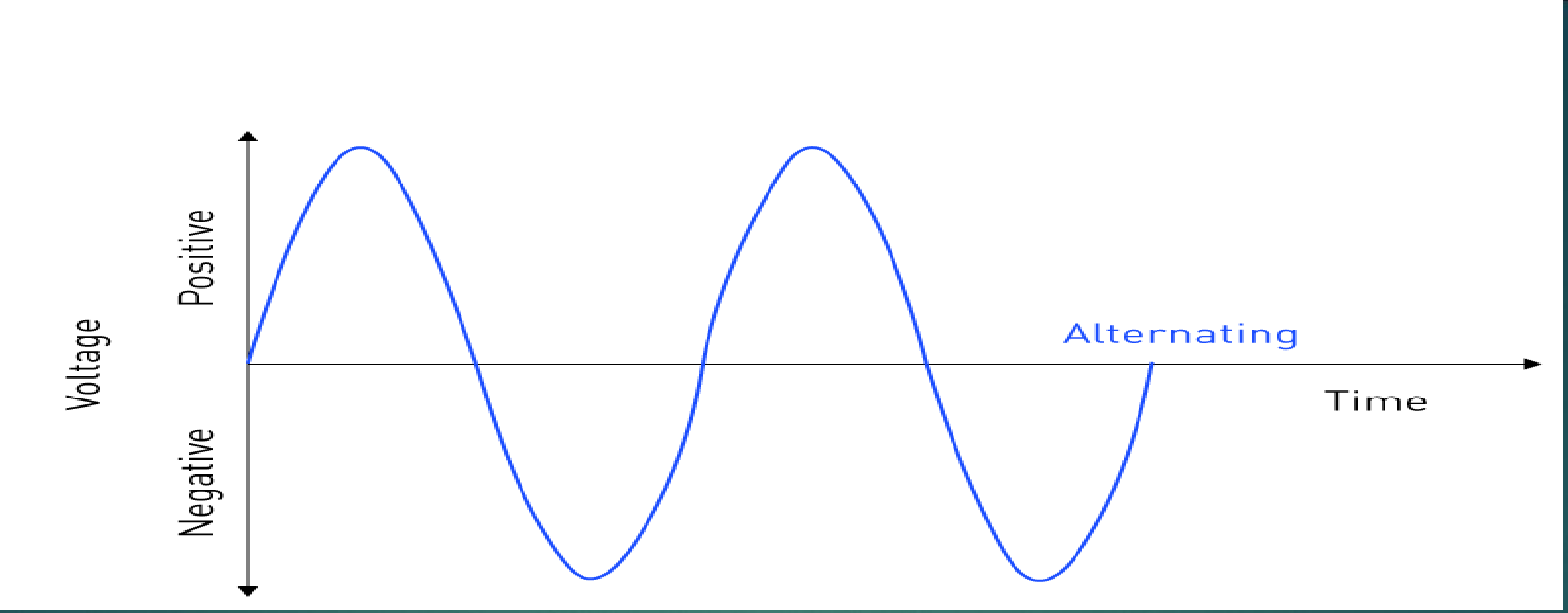


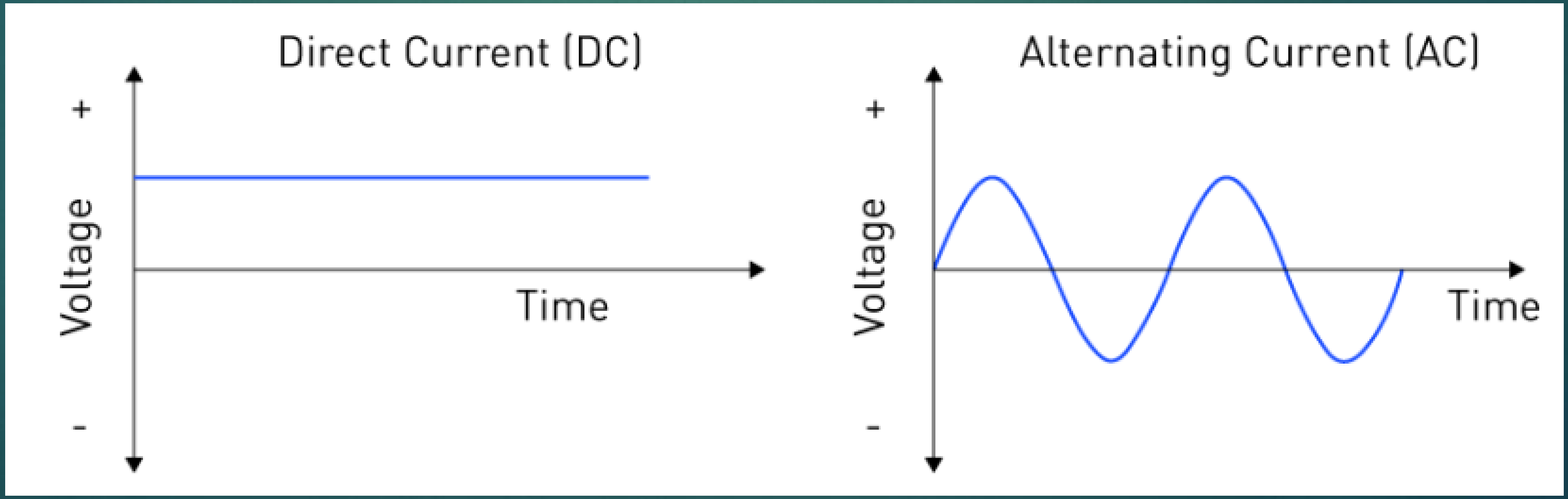
Figure 1: AC power waveform

The "War of Currents" in the late 19th century, which resulted in a triumph for AC mainly because of AC's advantage in long-distance electrical transmission, was the reason why AC power was adopted over DC rather than DC.

These days, the use of AC electricity goes beyond simple heating and lighting to include sophisticated technological equipment, transportation networks, and industrial machines. Modern electrical engineering and energy distribution networks continue to rely heavily on AC power due to its versatility, efficiency, and safety in both residential and commercial settings.

AC vs. DC Power

The direction of the electron flow is the main technical distinction between AC and DC power. Electrons in DC systems only move in one direction, which maintains a steady voltage. Because of its constancy, DC is perfect for applications like electronic gadgets that need steady, dependable power. On the other hand, the direction of electron flow periodically changes in AC systems. Because of its alternating nature, power distribution is optimized and losses are minimized through the easy use of transformers to step up or step down voltage levels.



AC Power Applications	DC Power Applications
Residential lighting	LED lighting
Industrial motors	Mobile phones
HVAC systems	Battery backup systems
Household appliances	Electric vehicles (EVs)
Power grid distribution	Drones

Concept of sanctioned load

Sanctioned load means the load in Kilo Watt, which is agreed to be supplied to the customer. The Sanctioned Load may be calculated by the simultaneous use of load (machines, appliances, fans, lights etc.) at any duration.

A "sanctioned load" refers to the maximum amount of electricity a consumer is authorized to draw from the power grid, as determined by their local electricity distribution company (DISCOM), based on factors like the size of their premises and anticipated energy consumption; essentially, it's the limit on how much power they can use at any given time, measured in kilowatts (kW).

Key points about sanctioned load:

Defined by the DISCOM:

The electricity provider sets the sanctioned load for each consumer based on their needs and the capacity of the power lines serving their area.

Impact on electricity usage:

A consumer cannot exceed their sanctioned load without potential penalties or service disruptions.

Factors considered:

When determining sanctioned load, the DISCOM takes into account the size of the property, type of appliances used, and anticipated peak power usage.

Importance for solar installations:

For rooftop solar systems, the sanctioned load is crucial as it dictates the maximum capacity of the solar panel system that can be installed.

Example: If a house has a sanctioned load of 5kW, it means the owner is authorized to use a maximum of 5 kilowatts of electricity at any given time or maximum of 4 kilowatts in some state.

PROVISIONS REGARDING REVISION OF SANCTIONED LOAD

1. The Electricity Act 2003 envisages that, consumers would keep a **reasonable security** with the distribution licensee based on electricity consumption. Currently, the Security Deposit is linked to sanctioned load.
2. The Commission has permitted the distribution licensees of Delhi to take up annual revision of sanctioned load of the **domestic consumers based on the average of the three highest maximum demand readings recorded during the last financial year** (rounded off to the next higher whole number) by the meter installed at the consumer's premises.
3. The load revision can be **upward or downward**.
4. **A prior notice** for above said revision shall be given in **April every year**.
5. In case **of increase, the consumer shall be given 30 days period to make payment**. If payment is not made in 30 days, the **additional Security Deposit** will be recovered in the next bill generated by the DISCOM.
6. Security Deposit will be charged **@ 600/- per kW** of additional load for domestic consumers
7. In case of decrease, the consent of the consumer shall be taken by the Discom and the **reduction in Security Deposit will be refunded in the next bill**. Security deposit will be refunded on pro-rata basis.

8. Consumers will be entitled to interest – presently at **6% per annum** – on the Security Deposit from the date of deposit.
9. Charges as applicable for replacement of the service line, if required, shall be payable by the consumer.
10. The fixed charges will be payable as applicable for different slabs and categories in the forthcoming bills.
11. To avoid increase of sanctioned load, additional temporary supply can be taken from Discoms for short-term requirements such as marriages, religious functions, construction activities, exhibitions, cultural functions etc.
12. All consumers other than domestic shall continue to be governed by the relevant provisions in the Supply Code and Performance Standard Regulations

Components of an electricity bill

Meter: Our electricity meter known as Energy Meter is identified by a specific nomenclature called the "RR No." (Revenue Registration Number)' found at the top/first line of the bill (like a vehicle registration number). It is an alpha-numeric code assigned to consumer installation.

Tariff category: This is the category of "rate for connected load and consumption", which determines charges applied to your meter.

Sanctioned load (in yellow): This is the maximum power/load you can draw, hence it is called sanctioned load

Recorded MD: Maximum demand or MD is the actual power drawn by a consumer

Power factor (PF): This is a measure of how effectively incoming power is used in your electrical system (energy efficiency)

Tariff structure

Fixed charges: This is the charge on the sanctioned load (3 KW, 5 KW as per the bill). This has to be paid every month, whether you consume any electricity or not, and they are based on your sanctioned load or capacity. The charges are usually in Rs/KW.

Energy charges: This is the per unit rate (consumed as per meter reading)

Tax: 9% (GST)

FPPCA charges: Fuel and Power Purchase Cost Adjustment (variable-month on month)
Apart from these, there may be arrears or adjustments from previous months. If your consumption increases, you may be asked to pay an additional security deposit (ASD).

Additional charges

PF Penalty

MD Penalty

Sanction load

Sanction load refers to the maximum amount of electricity a consumer is authorised to draw from the grid. BESCOM determines the sanction load based on factors such as the size of the premises and anticipated energy consumption.

Generally, builders apply for 3 KW / 5 KW sanction load for a 2 and 3 BHK flat. However, newer high-rises, especially the premium condominiums, have sanction loads of up to 10 KW.
When we say 3 KW – we can draw a max of 13.05 Amps at any given time (1 KW is 4.35 Amps at 230 volts supply).

AC single phase

Given power (kW) = 3 kW
Voltage (V) = 230 volts (rms)
Current (I)= 13.05 Amps

KW and Ampere ratings for major equipments

Item	BTU/KW rating	Amper draws at full load
1 Ton AC	12,000 BTU	5.0 Amps
1.5 Ton AC	18,000 BTU	7.5 Amps
15 to 35 Litre geyser	2 KW	8.2 Amps
6.5 Kg Top Loading W/m	350 – 650 watts	2.5-3.5 AMps
6.5 Kg Front loading W/M	650 – 800 watts	3 – 3.5 Amps
20 Litre Microwave	0.8 KW (800 watts)	3.25 Amps
365 Litre fridge (3*)	0.215 Kw (215 watts)	0.93 Amps

What can you run on a 3 KW sanction load?

Air conditioner: Typically, a 1.5 ton AC unit consumes around 1.5 kW to 2 kW of power.

Geyser: A 2000W geyser consumes 2 kW of power.

Fridge: A typical fridge consumes around 100-400 watts of power, assuming your fridge consumes 200 watts or 0.2 kW.

LED panel lights: LED panel lights typically consume around 10-50 watts each, depending on their brightness.

Fans: Ceiling fans generally consume around 50-80 watts each.
At any given point, you can simultaneously run one AC of 1.5 ton, one fridge and 2-3 lights.
If you run an AC of 1.5 ton and a geyser of 20 litres, you will cross the allowable amperage (15.7 amps against 13.5 amps), leading to penalty.
In 2022, BESCOM began replacing mechanical electricity meters with digital/electronic meter, which can record MD, this has led to consumers blaming the new meters for higher bills.
Penalty for overshooting MD is 1.5 times the per unit rate.

Maximum Demand

The greatest Power demanded by load on The Power station during a given Time Period is called maximum demand.

- Maximum demand is the maximum current (Amps) which can be drawn by an electrical installation.
- Maximum Demand = Consumption
- The maximum demand is the sum of all ‘downstream’ equipment
- The electrical installation is *sized* for the expected maximum demand including:

Transformers

Main Switchboard

Distribution Boards

Protective Devices

Cables

AS/NZS 3000 Section 2.2.2

Most

2.2.2 Maximum demand

The maximum demand in consumer mains, submains and final subcircuits, taking account of the physical distribution and intended usage of electrical equipment in the electrical installation and the manner in which the present requirements might vary, shall be determined using one of the methods set out in Items (a) to (d).

If the actual measured maximum demand is found to exceed that obtained by calculation or assessment, the measured value shall be deemed to be the maximum demand.

(a) *Calculation* The maximum demand may be calculated in accordance with the guidance given in this Standard for the appropriate type of electrical installation and electrical equipment supplied.

NOTE: Guidance on the determination of maximum demand is provided for basic electrical installations in Appendix C.

It is recognized that there may be considerable differences in loading from one electrical installation to another. Alternative methods of calculating the maximum demand may be used taking account of all the relevant information available for any particular electrical installation.

(b) *Assessment* The maximum demand may be assessed where—

A1 (i) the electrical equipment operates under conditions of fluctuating or intermittent loading, or a definite duty cycle; or

(ii) the electrical installation is large and complex; or

(iii) special types of occupancy exist.

(c) *Measurement* The maximum demand may be determined by the highest rate of consumption of electricity recorded or sustained over a period of 30 minutes when demand is at its highest by a maximum demand indicator or recorder.

(d) *Limitation* The maximum demand may be determined by the current rating of a fixed setting circuit-breaker, or by the load setting of an adjustable circuit-breaker.

The maximum demand of consumer mains and submains may be determined by the sum of the current settings of the circuit-breakers protecting the associated final subcircuit/s and any further submain/s.

Connected Load

The connected load is defined as the sum of continuous ratings of all the equipment connected to the Home, office or Some whare.

Contract Load

The contract load in an electricity bill refers to the maximum amount of power that a customer has agreed to be able to draw from the grid at any given time. It is usually measured in kilowatts (kW) and is determined based on the customer's electricity usage patterns and the capacity of their electrical infrastructure.

Demand Factor

The demand factor of an electric power station is defined as the ratio of maximum demand on the power station to its connected load, i.e.,

$$\text{Demand Factor} = \frac{\text{Maximum Demand}}{\text{Connected Load}}$$

Load Factor

The load factor of a power station is defined as the ratio of average load to the maximum demand on the power station during a given period, i.e.,

$$\text{Load Factor} = \frac{\text{Average Load}}{\text{Maximum Demand}}$$

calculating maximum demand in an electrical supply system is:
Maximum Demand = Total Connected Load x Demand Factor;
where "Total Connected Load" is the sum of all connected appliances' power ratings and "Demand Factor" is a factor that accounts for the unlikely scenario of all appliances being turned on simultaneously, usually expressed as a decimal value less than 1.

Calculating your maximum demand

How To Calculate Maximum Demand (MD)?

Formula for Maximum demand is as follows.

Max demand = The units of kWh used over a period of time, divided by the time period.

So the Maximum Demand from 8am to 830am, is 300kWh divide by 0.5 or 600kW.

So say at 8am, your kWh meter reads 18200kWh and say at 830am, your meter reads 18500kWh, it means that in this half an hour period, you have used (18500 minus 18200) kWh units of power, or 300kWh. This amount of electrical power was used in 30 mins

So the Maximum Demand from 8am to 830am, is 300kWh divide by 0.5 or 600kW

AC Machine

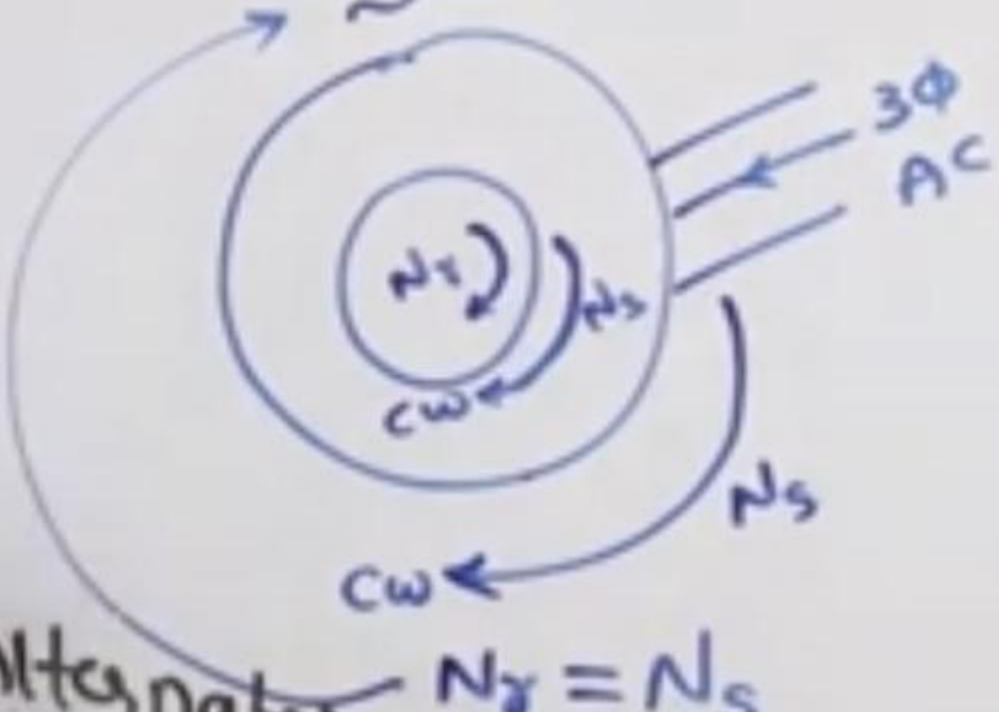
The principle of operation is govern by *(i) the law of electro-magnetic induction and (ii) law of interaction.*

(i) *Law of electromagnetic induction (Faraday's 1st law): An emf is induced in* a conductor whenever it cuts across the magnetic field

(ii) *(ii) Law of interaction:* whenever a current carrying conductor is placed in the magnetic field, by the interaction of the magnetic fields produced by the current carrying conductor and the main field, force is exerted on the conductor and torque is developed

AC Machines

Syn m/c

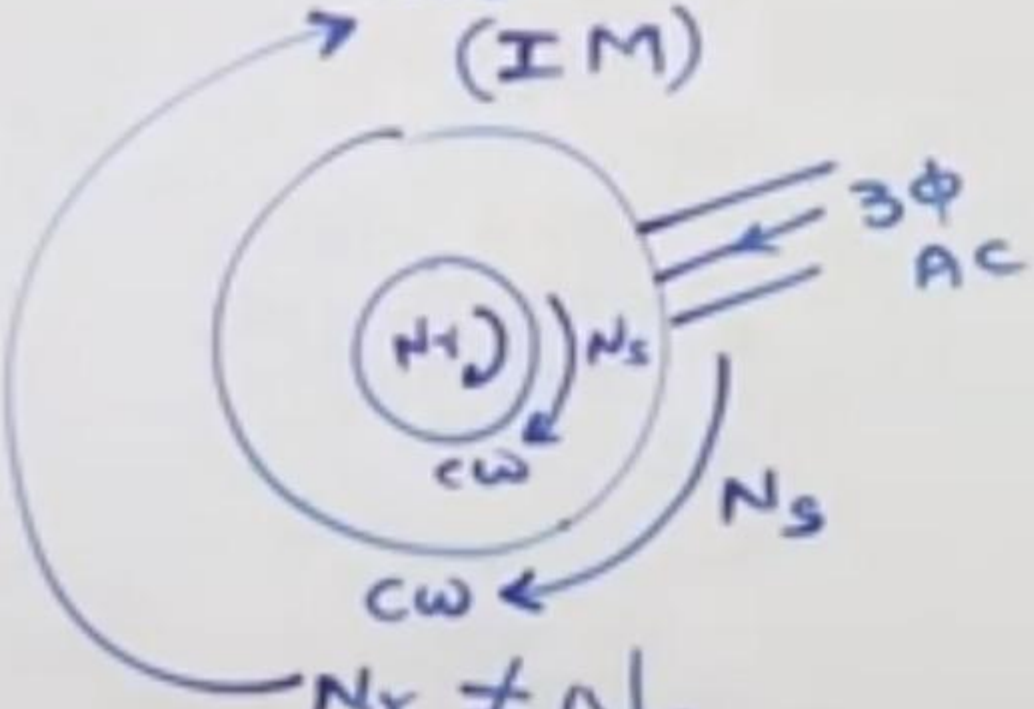


Alternator
Syn. Gen

$N_r = N_s$

Syn. motor

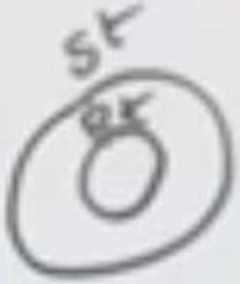
Asyn m/c
(IM)



$N_r \neq N_s$

I. Gen

I. Motor

Syn → 

Altenator

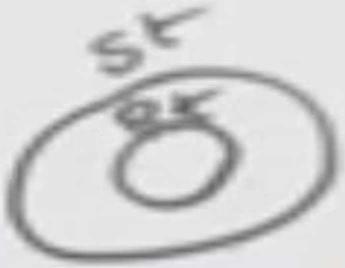
Syn. motor

↓

Syn m/c

st → Arm wndg

Rt → field wndg

Syn → 

Alternator

Syn. motor

DC m/c

Arm → Rt

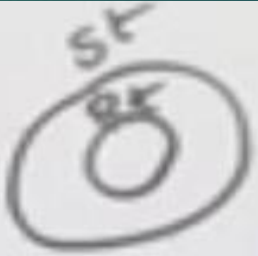
o/w

No - comm

DC $\cancel{\leftrightarrow}$ AC

Syn m/c

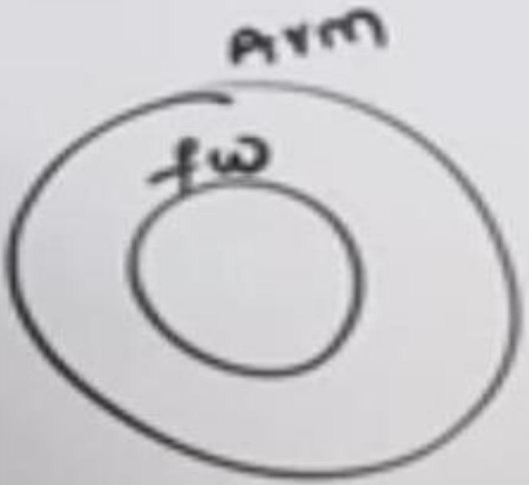
Syn →



Alternator

Syn. motor

Syn m/c

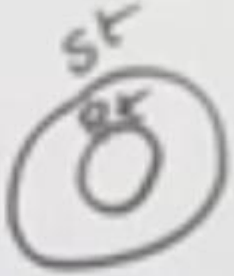


Arm < St
Rt

Rt
fw
St

Arm → St

Syn →

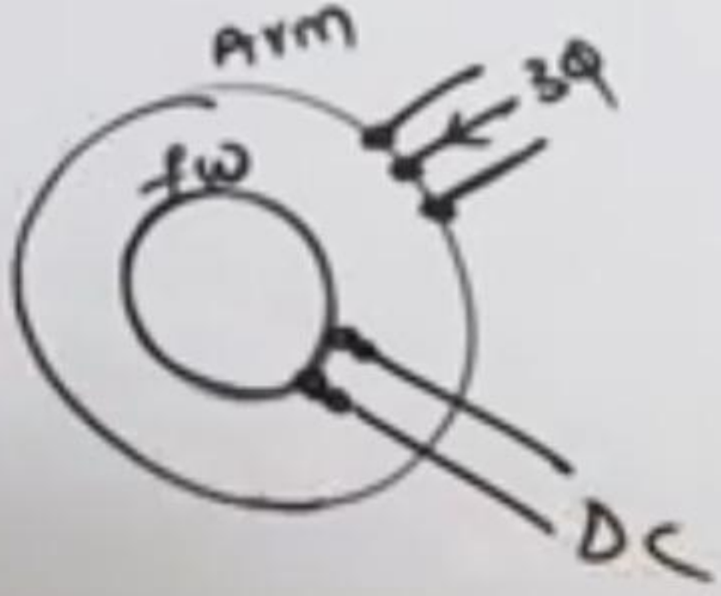


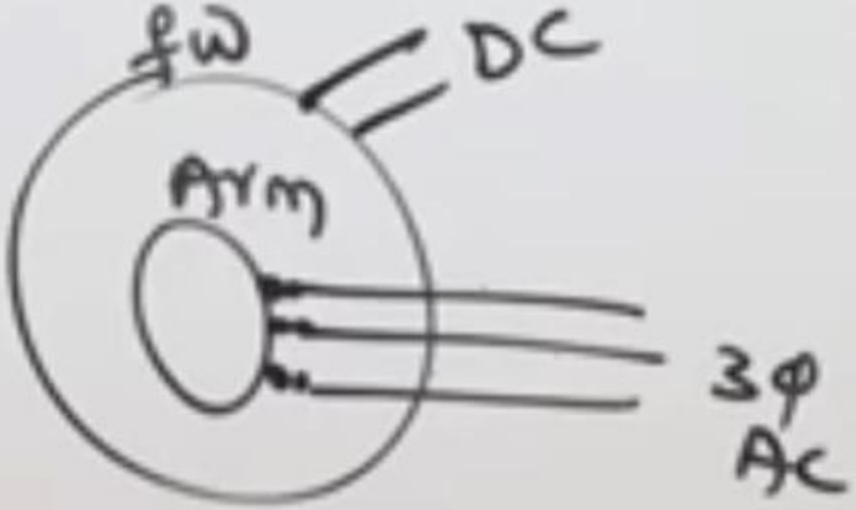
Altenator

Syn. motor

AC/DC

Arm — AC
fw — DC





Syn →

Alternator

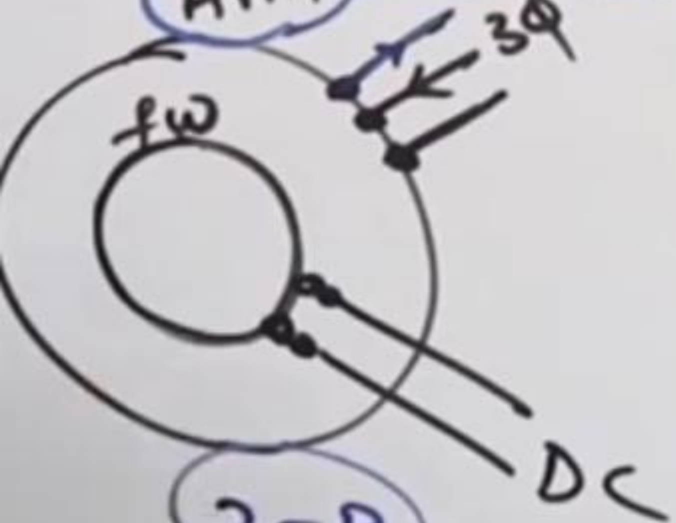
Syn. motor

Easy cooling

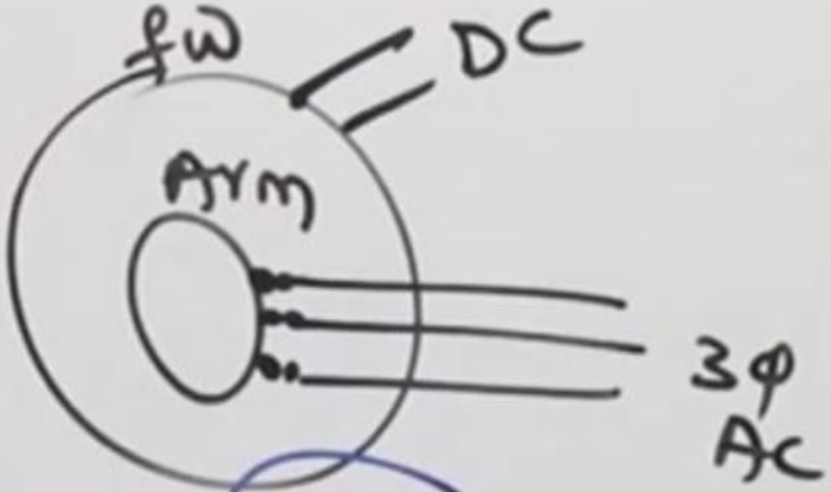
Easy collect cur

AC / DC

Arm — AC
fw — DC



2-B



3-SR

maint ↑

losses ↑

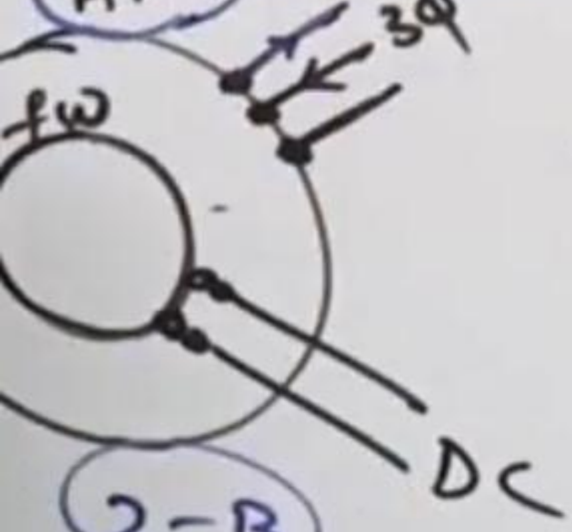
Alternator — syn. motor

Arm cooling

Arm — Easy collection

AC/DC

Arm — AC
fw — DC



→ Easy collection of current

→ Easy Insulation

→ less No of B/S.R

→ less cost, weight, size. Main, losses

→ more η

2-B
2-S.R

AC Machines

Synchronous Machines

Synchronous Generator

A primary source of **electrical energy**

Synchronous Motor

Used as motors as well as **power factor compensators** (synchronous condensers)

Asynchronous Machines (Induction Machine)

Induction Generator

Due to lack of a separate field excitation, these machines are rarely used as generators.

Induction Motor

Most **widely used electrical motors** in both domestic and industrial applications

SYNCHRONOUS GENERATOR

Types of Synchronous Machine

According to the ***arrangement of the field and armature windings***, synchronous machines may be classified as

(a) Stationary Armature - Rotating Field (Above 5 kVA)

(b) Stationary Field – Rotating Armature (Below 5 kVA)

Advantages of stationary armature - rotating field:

i) The High Voltage ac winding and its insulation not subjected to centrifugal forces.(11kV - 33 kV) (BETTER INSULATION)

ii) Easier to collect large currents from a stationary member.

iii) Rotating field makes overall construction simple.

iv) Problem of sparking at the slip ring can be avoided.

v) Ventilation arrangement for HV can be Improved.

vi) The LV(110 V – 220V) dc excitation easily supplied through slip rings and brushes to the rotor field winding.

vii) Noiseless running is possible.

viii) Air gap length is uniform

CONSTRUCTION OF ALTERNATOR

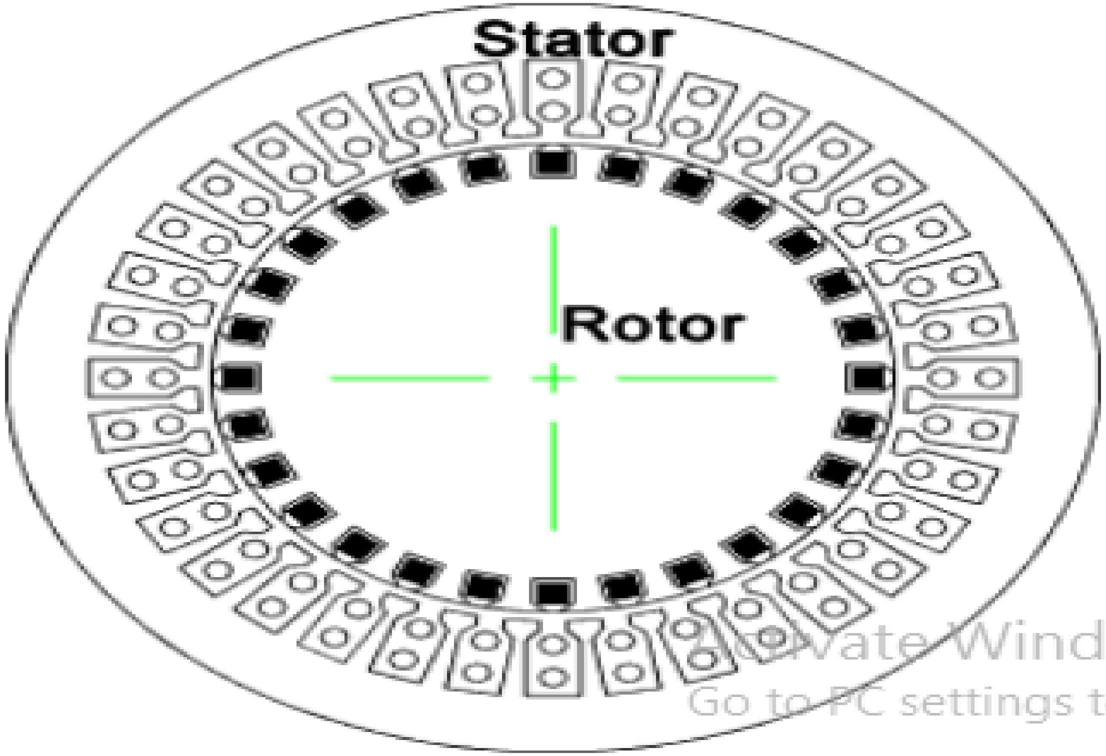
Stationary Armature - Rotating Field

An alternator has 3 phase winding on the stator and DC field winding on the rotor.

STATOR

Stationary part of the machine.
It is built up of Sheet-Steel Lamination Core (Stampings) with slots to hold the armature Conductor

Armature winding is connected in STAR

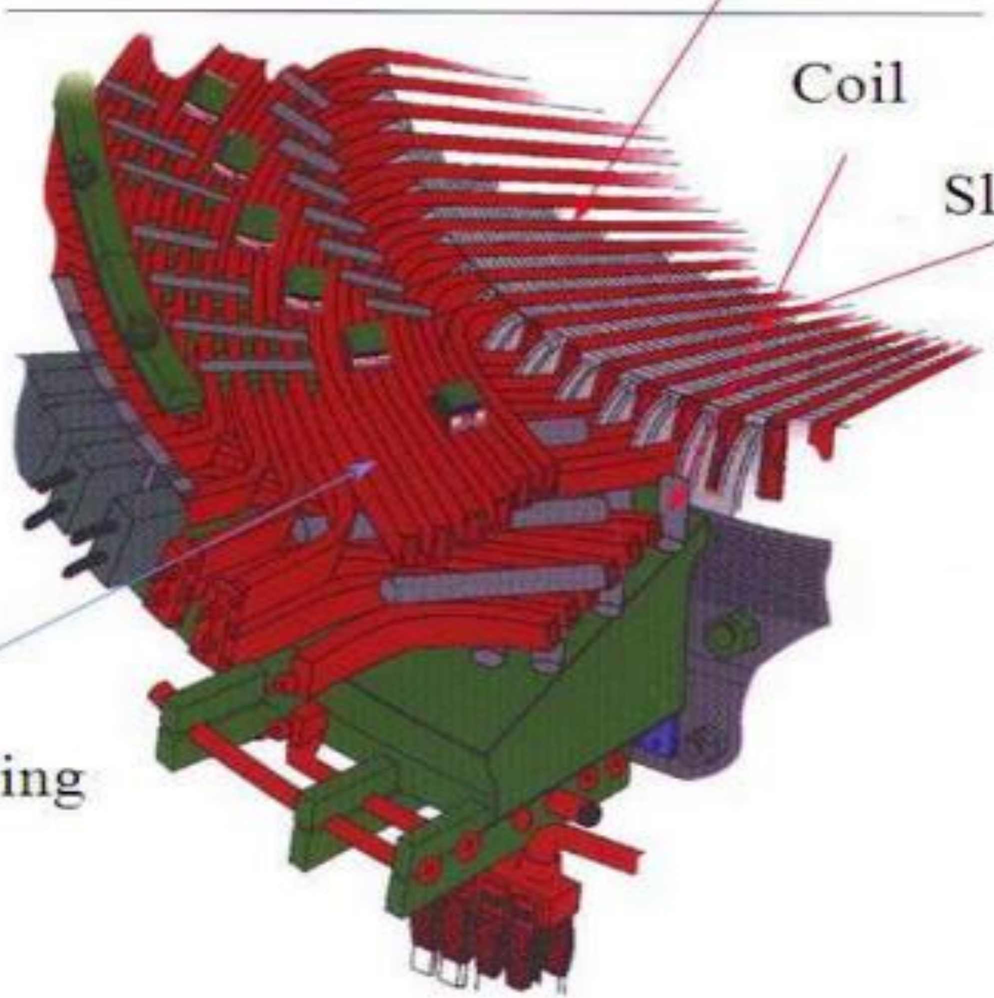


Stator

- Laminated iron core with slots
- Steel Housing

Stator details

- Coils are placed in slots
- Coil end windings are bent to form the armature winding.



ROTOR:

There are two types of rotor

i) Salient Pole type {Projected Poles}

ii) Non - Salient Pole type {Non – Projected Poles}
Smooth Cylindrical Type

Salient Pole type {Projected Poles}

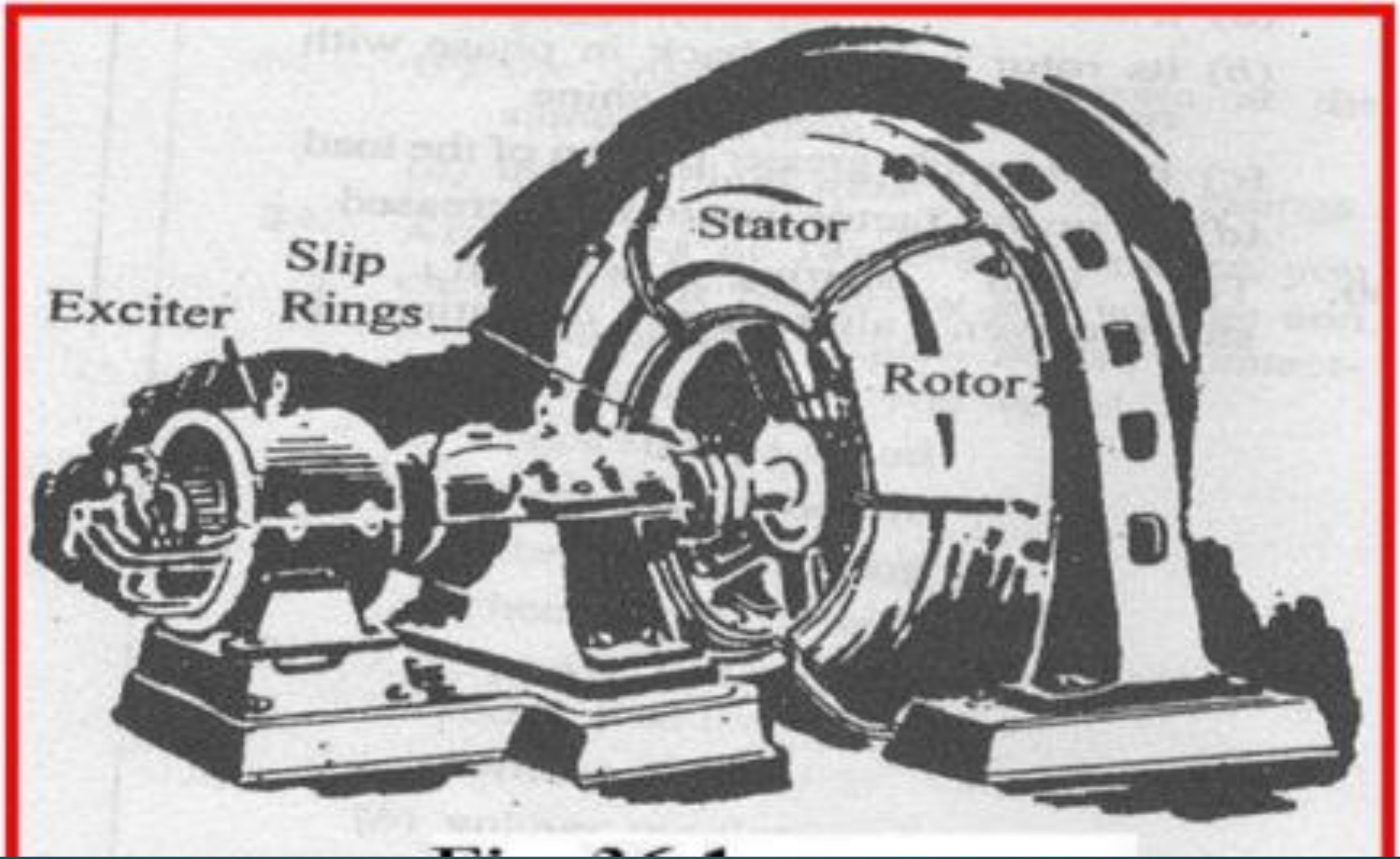
It is also called Projected Poles.
Poles are mounted on the larger circular frame.
Made up of Thick Steel Laminations.
Field Winding are connected in series.
Ends of the field winding are connected to the DC Supply through Slip Rings

Features
Large Diameter and short Axial Length.
Poles are Laminated to reduced Eddy Current Losses

Employed for Low and Medium Speed
120 RMP to 500 RPM
(Diesel & Hydraulic Turbines)

This cannot be used for Large speed

Synchronous Motor



Synchronous Motor-General

A synchronous motor is electrically identical with an alternator or AC generator.

A given alternator (or synchronous machine) can be used as a motor, when driven electrically.

Some characteristic features of a synchronous motor are as follows:

1. It runs either at synchronous speed or not at all *i.e.* while running it maintains a constant speed. The only way to change its speed is to vary the supply frequency (because $N_S=120f/P$).

2. It is not inherently self-starting. It has to be run up to synchronous (or near synchronous) speed by some means, before it can be synchronized to the supply.

3. It is capable of being operated under a wide range of power factors, both lagging and leading. Hence, it can be used for power correction purposes, in addition to supplying torque to drive loads.

Principle of Operation

When a 3-phase winding is fed by a 3-phase supply, then a magnetic flux of constant magnitude but *rotating* at synchronous speed, is produced.

Consider a two-pole stator of **Fig. 36.2**, in which are shown two stator poles (marked N_S and S_S) rotating at synchronous speed say, in clockwise direction.

Since the two similar poles, N (of rotor) and N_S (of stator) as well as S and S_S will repel each other, the rotor tends to rotate in the anti-clockwise direction.

But half a period latter, stator poles, having rotated around, interchange their position *i.e.* N_S is at position B and S_S at point A. under these conditions, N_S attracts S and S_S attracts N and rotor tends to rotate clockwise.

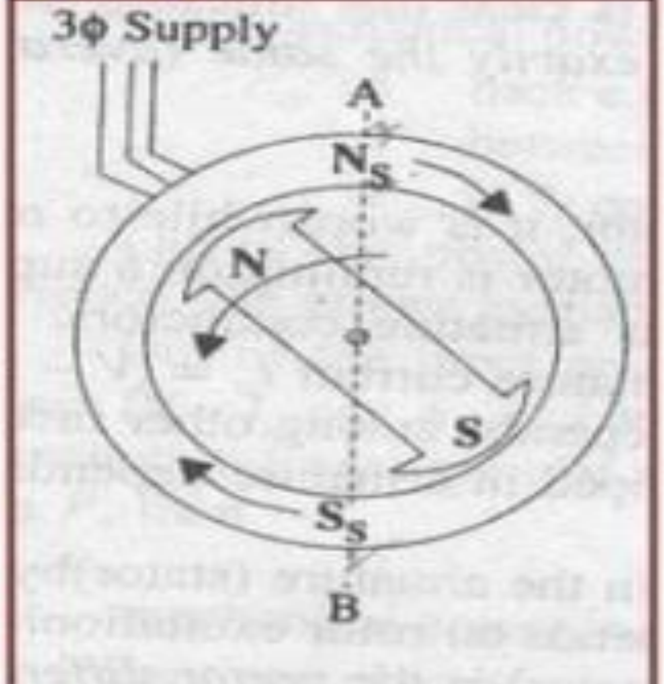


Fig. 36.2

Hence, we find that due to continuous and rapid rotation of stator poles, the rotor is subjected to torque which tends to move it first in one direction and then in the opposite direction.

Owing to its large inertia, the rotor cannot instantaneously respond to such quickly reversing torque, with the result that it remains stationary.

Now, consider the condition shown in **Fig. 36.3**(a) where the stator and rotor poles are attracting each other.

Suppose that **the rotor is not stationary, but it is rotating clockwise**, with such a speed that turns through one pole-pitch by the time the stator poles interchange their positions, as shown in Fig. 36.3(b).

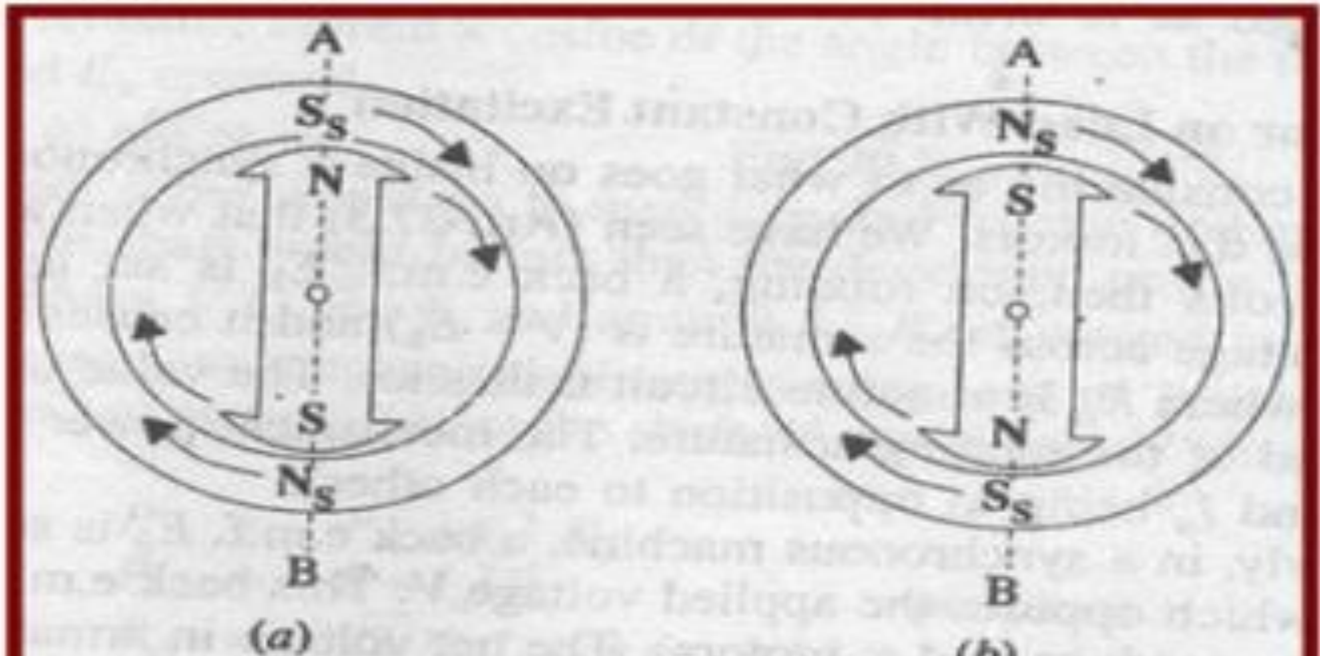


Fig. 36.3

Here, again the stator and rotor poles attract each other.

It means that if the rotor poles also shift their positions along with the stator poles, then they will continuously experience a **unidirectional torque** *i.e.* clockwise torque, as shown in Fig. 36.3.

Method of Starting

There are several methods to start the synchronous motor such as:

(a) Auxiliary drive (induction motor or dc motor),

(b) Induction start (using damper winding), etc

General Starting Procedure: The rotor (which is as yet unexcited) is **speeded up to synchronous or near synchronous speed** by some arrangement and then excited by the DC source.

The moment this (near) synchronously rotating rotor is excited, it is **magnetically locked into position with the stator** *i.e.* the rotor poles are engaged with the stator poles and both run synchronously in the same direction.

It is because of this inter-locking of stator and rotor poles that the motor has either to run synchronously or not at all.

However, it is important to understand that the arrangement between the stator and rotor poles is *not an absolutely rigid one*.

As the **load on the motor is increase, the rotor progressively tends to fall back *in phase*** (but *not* in speed as in DC motors) by some angle (**Fig. 36.4**) *but it still continuous to run synchronously*.

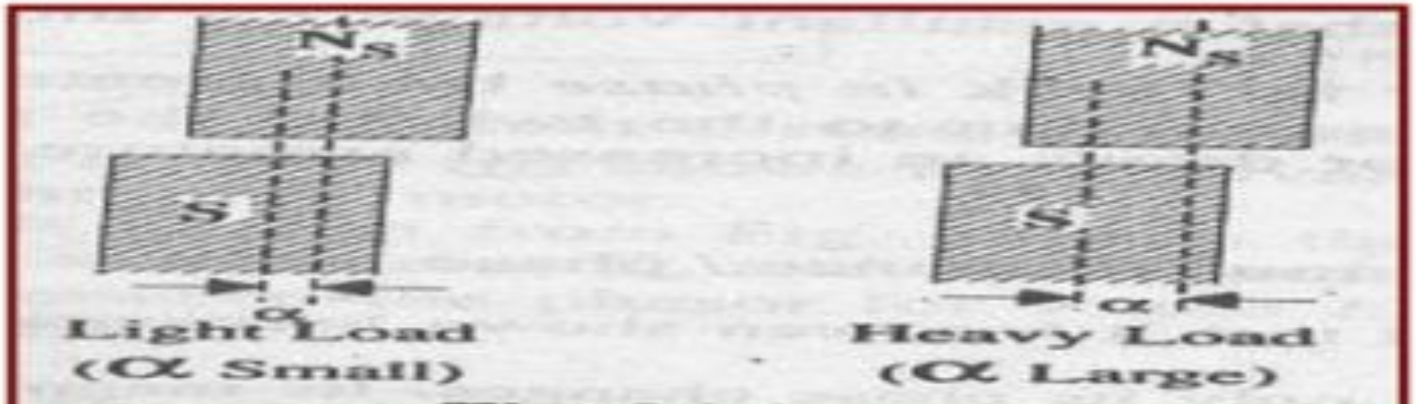


Fig. 36.4

The value of this load angle or coupling angle (as it is called) depends on the amount of load to be met by the motor.

In other words, the torque developed by the motor depends on this angle, say, α.

This angle is referred as ***load angle* or *coupling angle*.**

This is also the **angle between rotor and stator fields.**

Advantages of SM over IM

Synchronous motors have the following advantages over induction motor:

1. SM can be used for power factor correction in addition to supplying torque to drive loads
2. SMs are more efficient (at unity power factor) than IM of corresponding horsepower and voltage rating.
3. The field pole rotor of SM can permit the use of wider airgap than the squirrel cage IM.

4. SM can operate lagging, leading and unity power factor but IM can operate only lagging power factor.
5. SM may less costly for the same horsepower, speed and voltage ratings.
6. They give constant speed from no-load to full-load.

Disadvantages of SM over IM

1. They require dc excitation which must be supplied from external source.
2. They have tendency to hunt.
3. They cannot be used for variable speed jobs as speed adjustment cannot be done.
4. They cannot be started under load. Their staring torque is zero.
5. They may fall out of synchronism and stop when overloaded.

Compare a Synchronous Motor with an Induction Motor

1. For a given frequency, the synchronous motor **runs at constant average speed** whatever the load, while the speed of an **induction motor falls** somewhat with increase in load.
2. The synchronous motor can be operated over a wide range of power factors, both lagging and leading, but induction motor always runs with a lagging power factor which may become very low at light loads.
3. A synchronous motors is inherently not self-starting but induction motor is self-starting.
4. The changes in applied voltage do not affect synchronous motor torque as much as they affect the induction motor torque.

5. The breakdown torque of a synchronous motor varies approximately as the first power of applied voltage whereas that of an induction motor depends on the square of this voltage.

6. A DC excitation is required be synchronous motor but not by induction motor.

7. Synchronous motor are usually more costly and complicated than induction motors, but they are particularly attractive for low speed drives (below 300 rpm) because their power factor can always be adjusted to 1.0 and their efficiency is high. However, induction motors are excellent for speeds over 600 rpm.

8. Synchronous motor can be run at ultra-low speeds by using high power electronics converters which generated very low frequencies. Such motors of 10 MW range are used for driving crusher, rotary kilns and variable speed ball mills etc.

Synchronous Motor Applications

Synchronous motors find extensive application for the following classes of service:

1. Power factor correction;
2. Constant speed, constant load drives; and
3. Voltage regulation.

The synchronous motors have the following fields of applications:

Power houses and sub-station: Used in power houses and sub-station in parallel to the bus-bar to improve the power factor.

Factories: Used in factories having large of induction motors or other power apparatus, operating at lagging power factor, to improve the power factor.

Mills-industries etc.: Used in textile mills, rubber mills, and other big industries, cement factories for power applications.

Constant speed equipments: Used to drive continuously operated and constant speed equipment such as: Fans, blowers, centrifugal pumps, motor-generator sets, and air compressors etc.