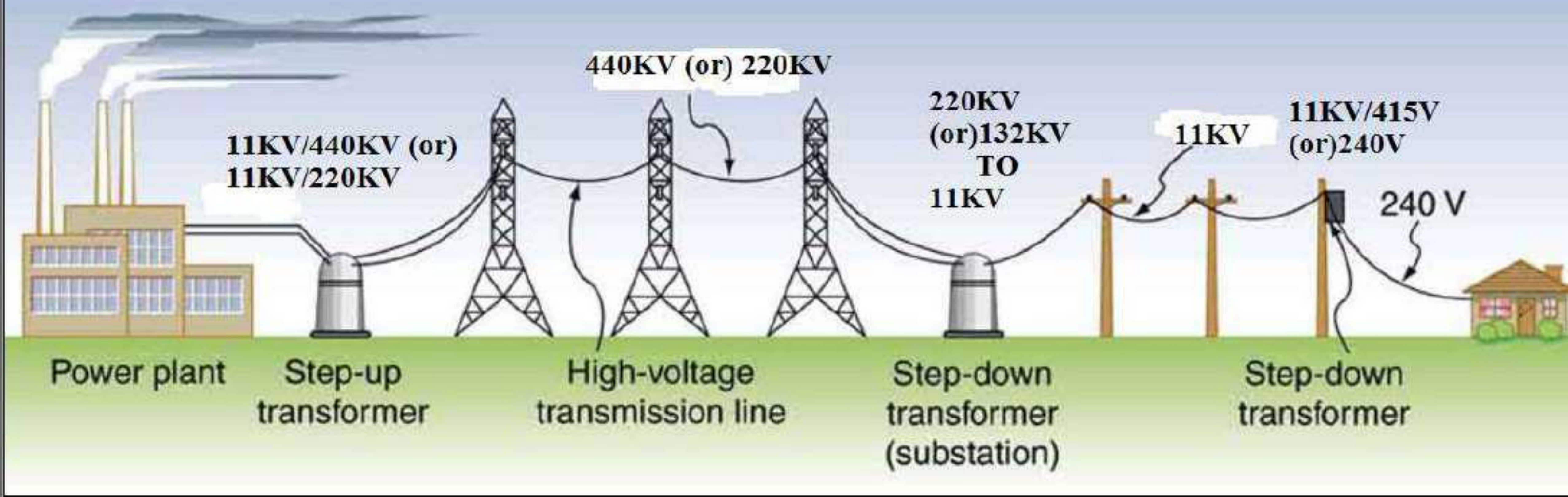



# POWER SYSTEMS

# POWER SYSTEMS-1

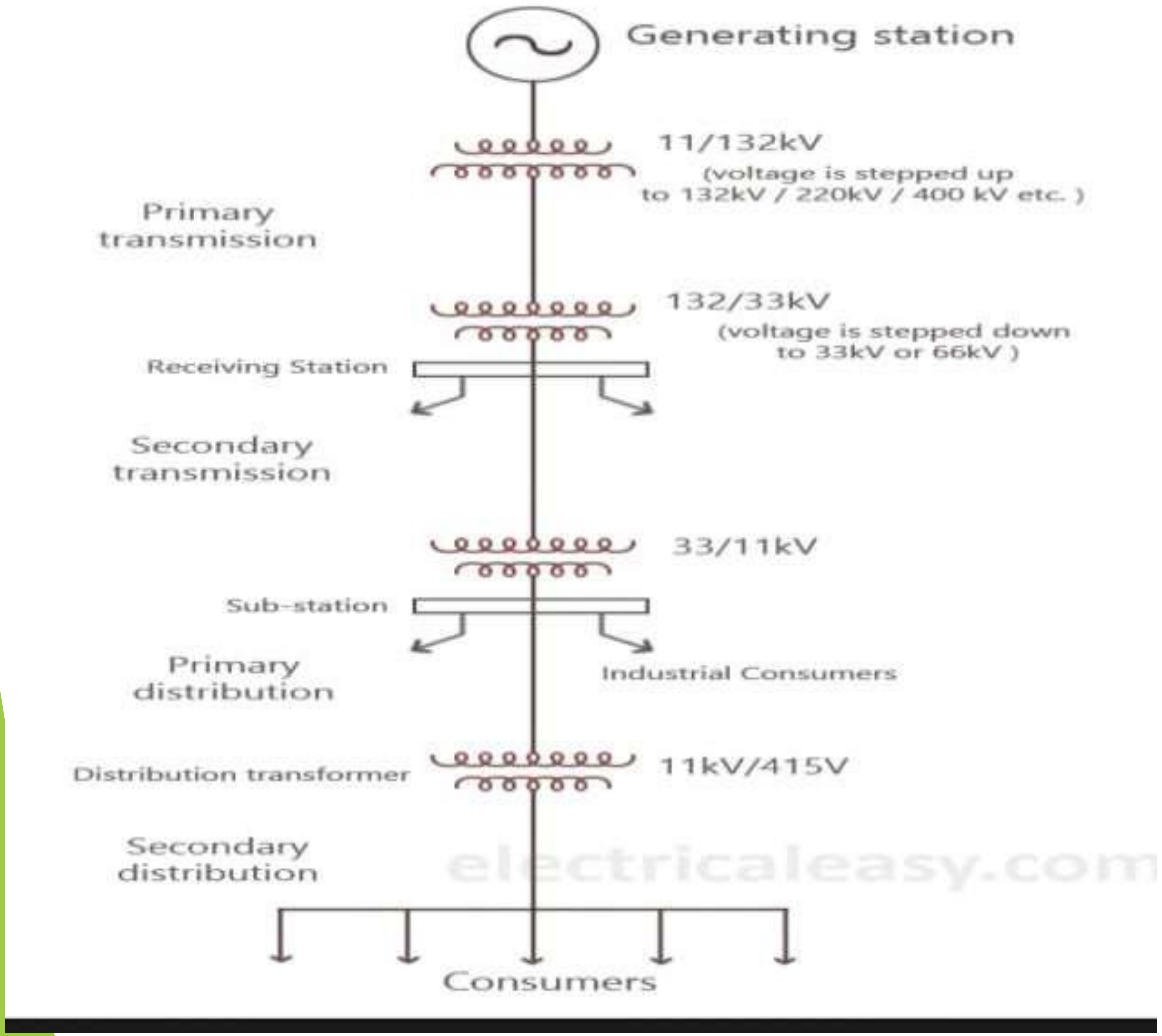
## UNIT I

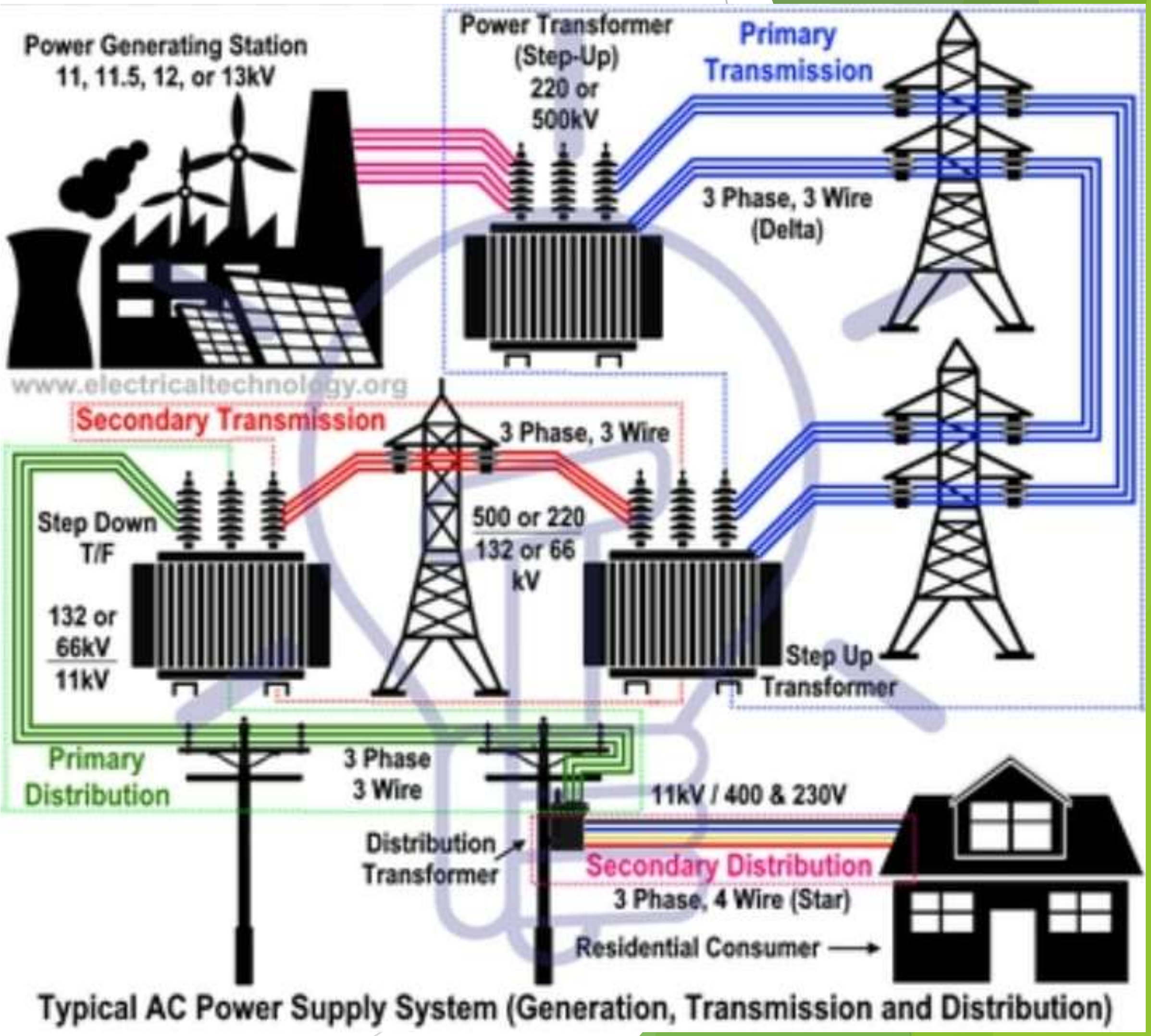
## POWER STATIONS

# CONTENTS

# 1) GENERAL INTRODUCTION OF POWER SYSTEMS

An electric power system is defined as a network of electrical components used to supply ,transfer and consume electrical power.




LINE GIAGRAM OF POWER SYSTEM

# 2)POWER STATIONS

A power station also referred to as a power plant and some times generating station (or) generating plant.

Power Stations generally connected to an electric grid generating power will be used for consumers.

HISTORY:-

In early ‘1871’ Bulgarian inventor zenobe gramme invented a generator power full enough to produce power on commercial scale for industry.

In ‘1878’ a hydro electric power station was designed and built by William lord Armstrong at crag side England.

In ‘1890’ worlds first coal fired public power station , the Edison electric light station was built in London, a project of Thomas Edison organazide by Edward Johnson.

# 3) THERMAL POWER STATION

THERMAL :-

These are created by the uneven heating of earths surface from solar radiation.

Thermal power station is a power station in which heat energy is converted to electricity.

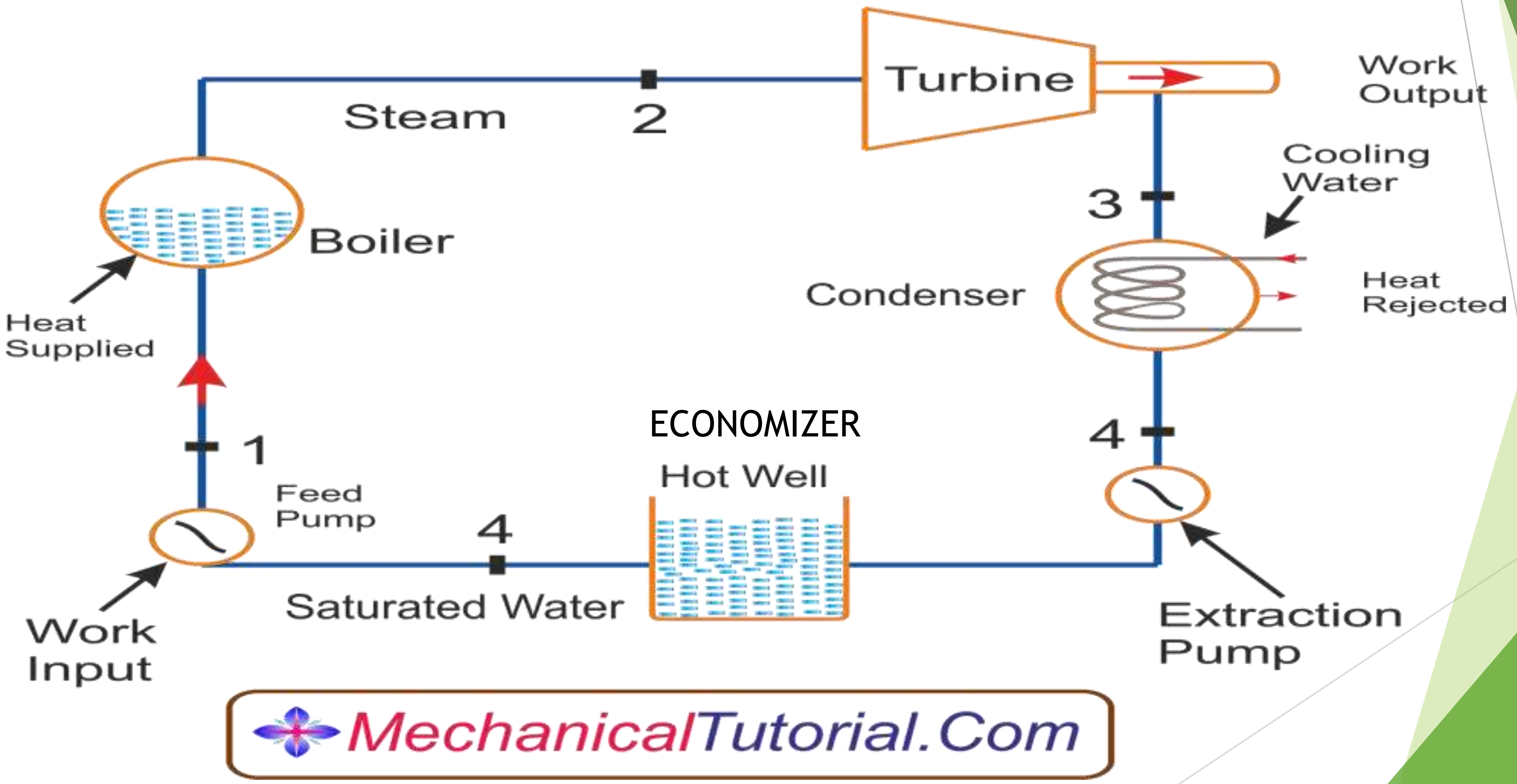
COAL :-

Coal power plant is a thermal power station which burns coal to generate electricity. The coal is usually pulverizes and then burned in pulverized coal and send to boiler.

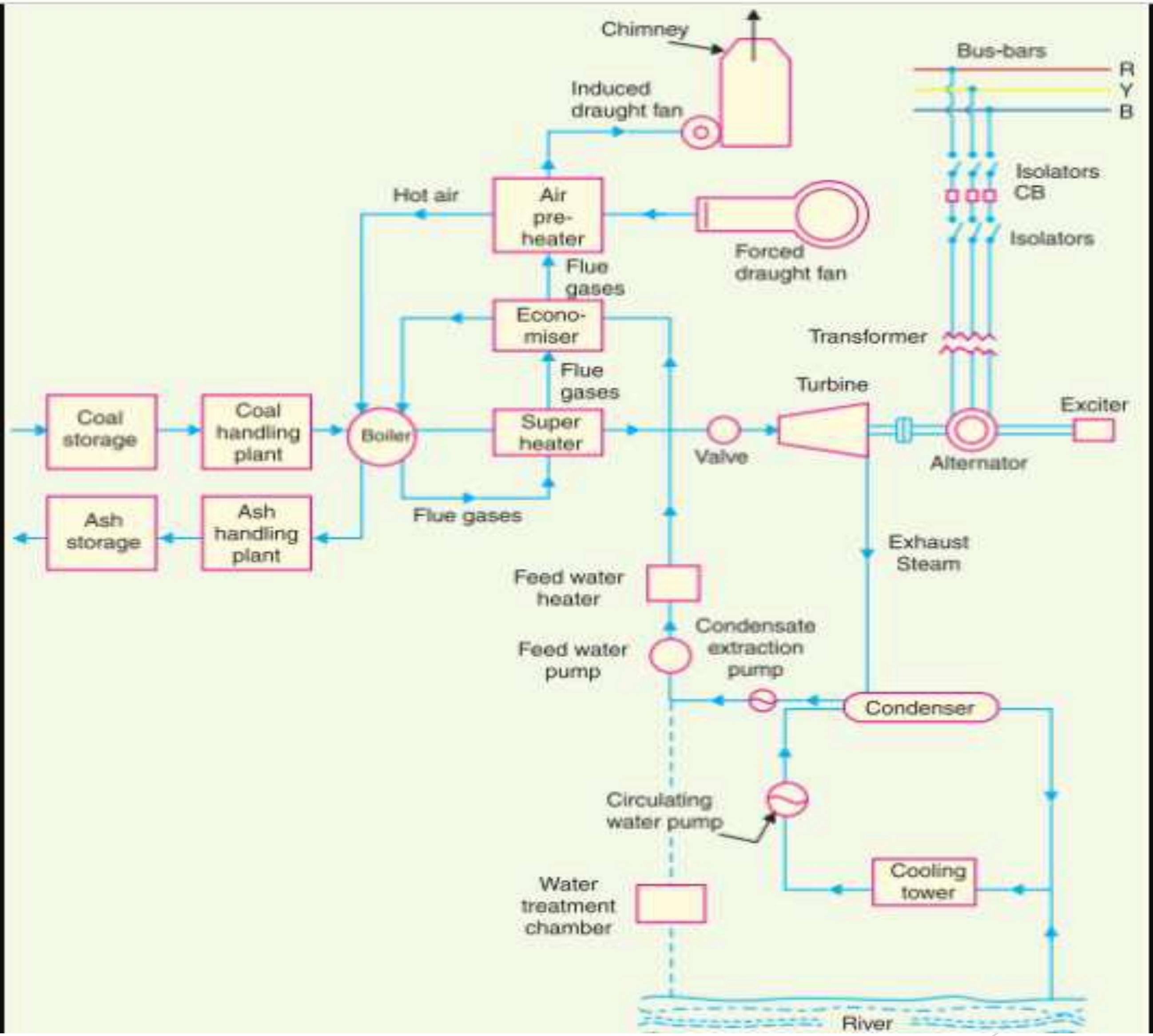
STEAM :-

Steam power plants consists of one (or) a group of steam boilers and one (or) more steam power sources with auxiliary machines , apparatus and instruments.

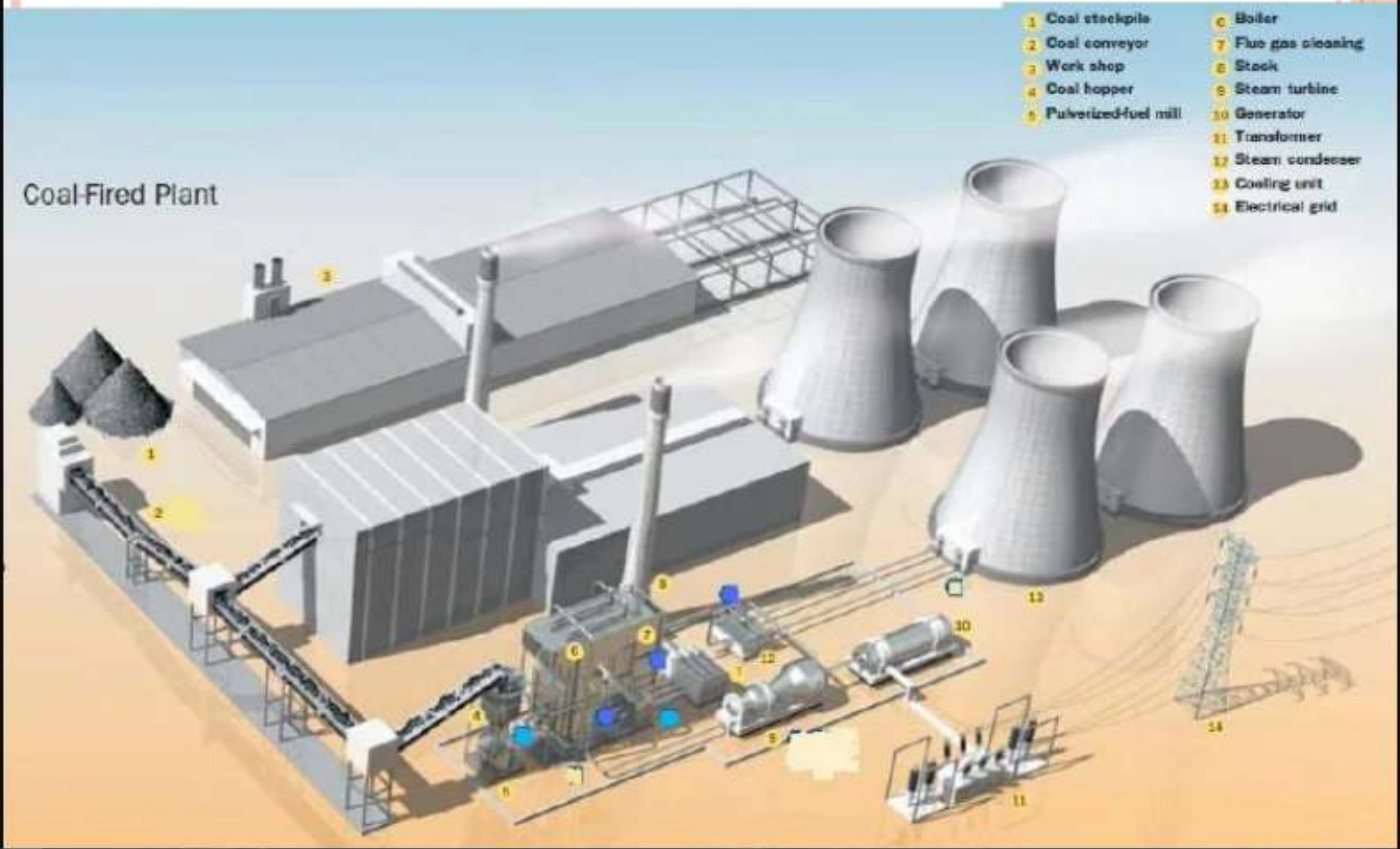
# RANKINE CYCLE



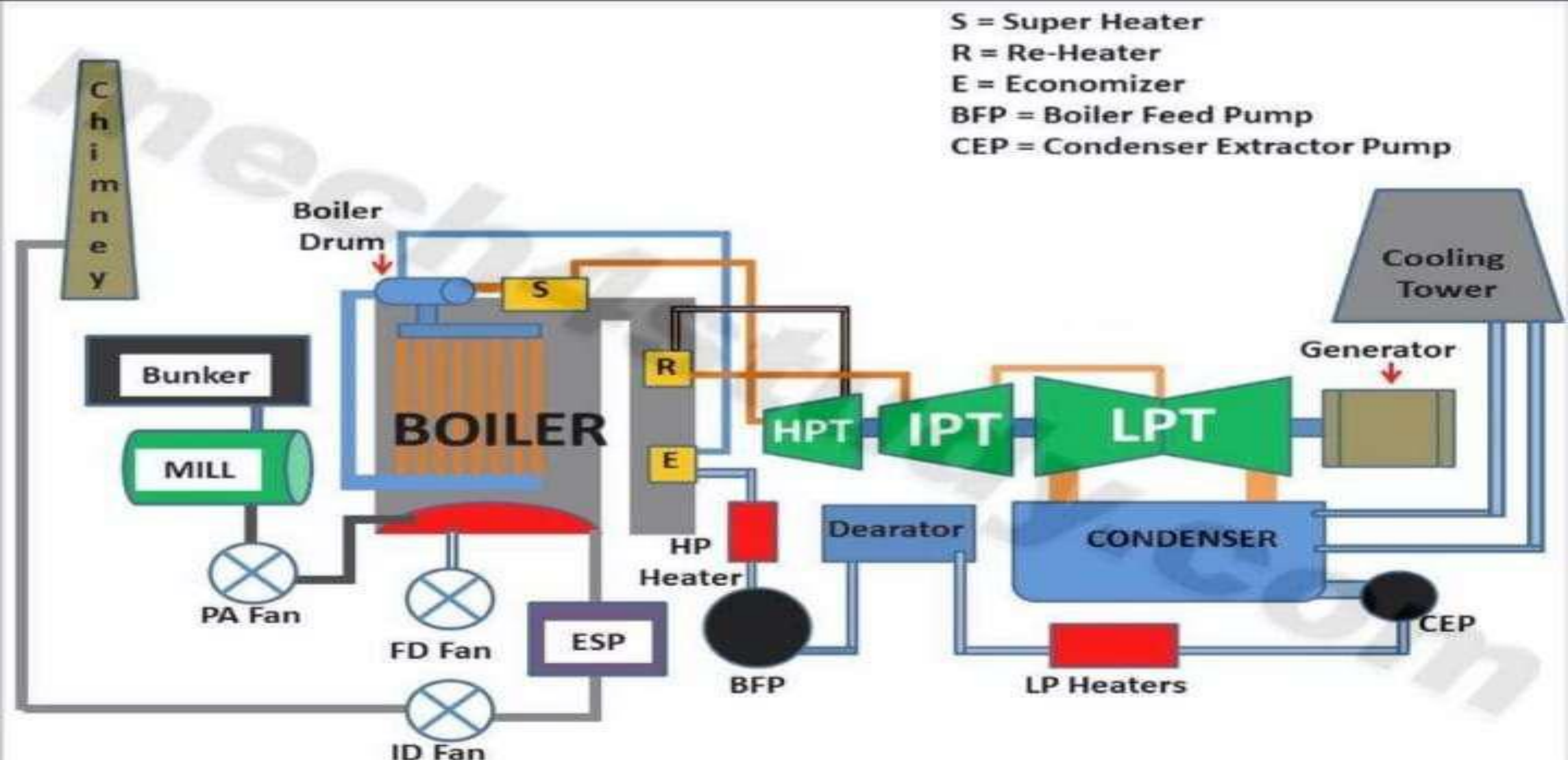
# (3)(1) LINE DIAGRAM AND COMPONENTS OF TPS



# DIAGRAM OF A TYPICAL COAL-FIRED THERMAL POWER STATION



# PRACTICAL THERMAL POWER STATION DIAGRAM



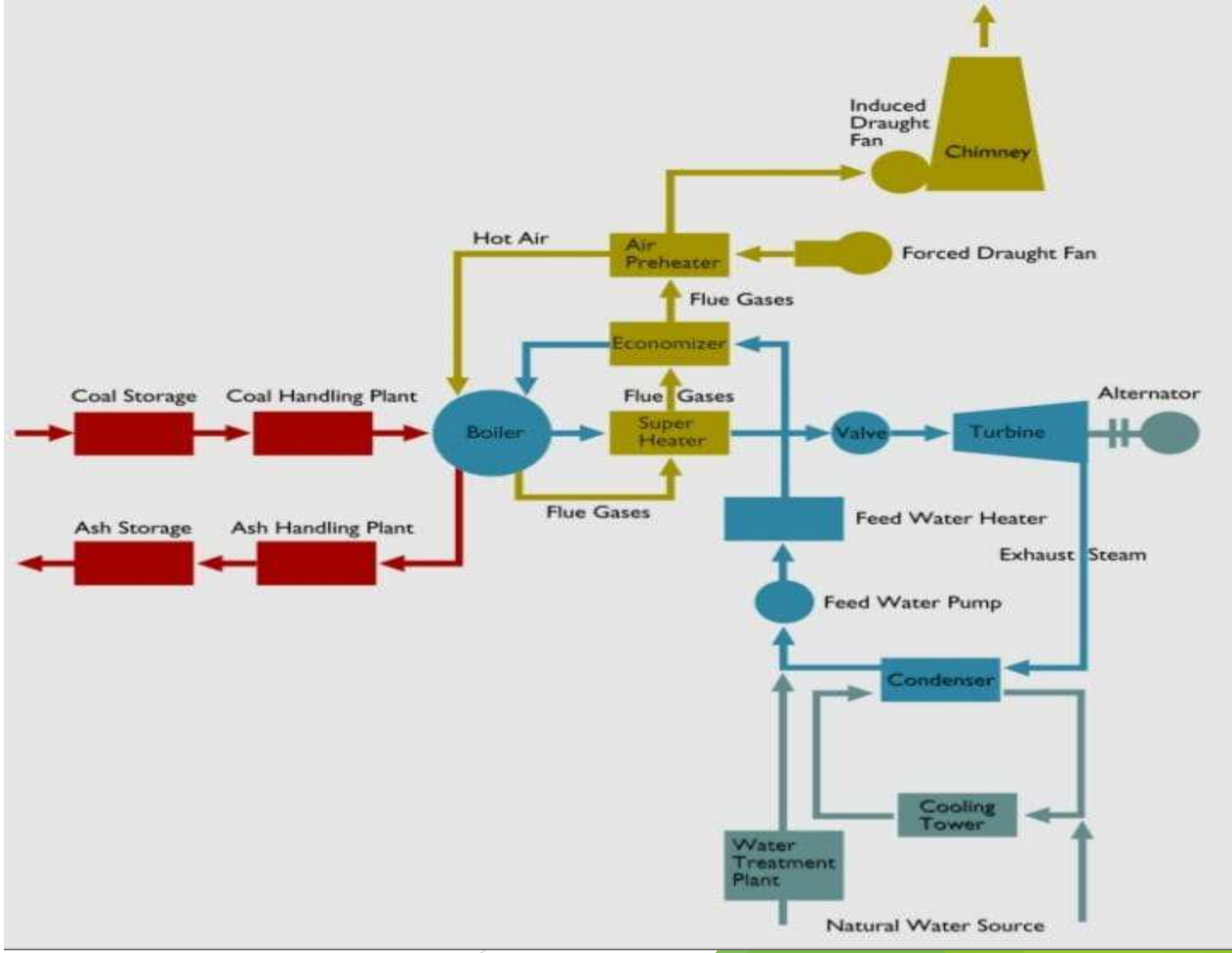
# CIRCUTES OF THERMAL POWER PLANT

1)FUEL AND ASH CIRCUIT

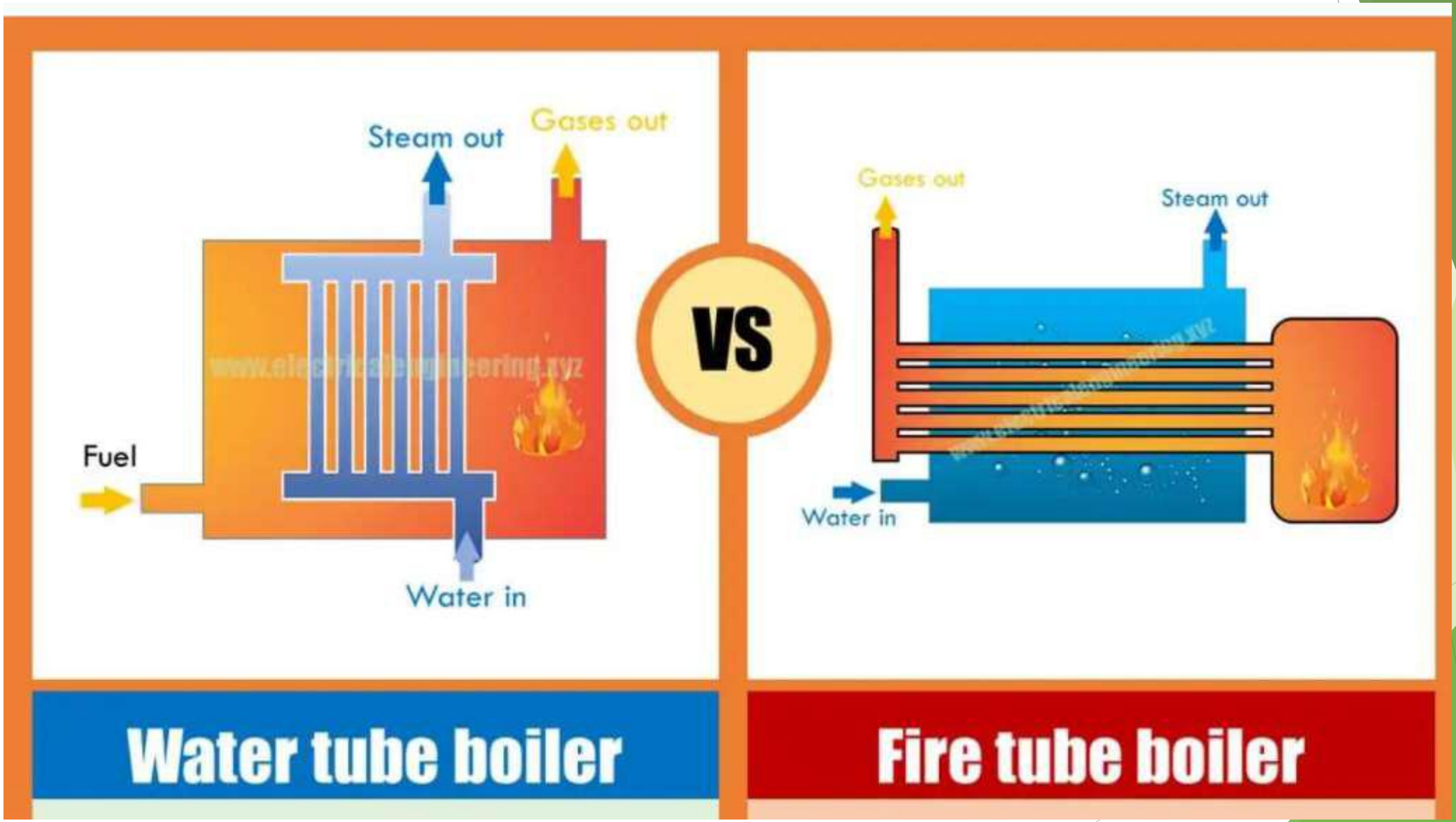
2)AIR AND FLUE GAS CIRCUIT

3)FEED WATER AND STEAM CIRCUIT (this is also called Rankine cycle)

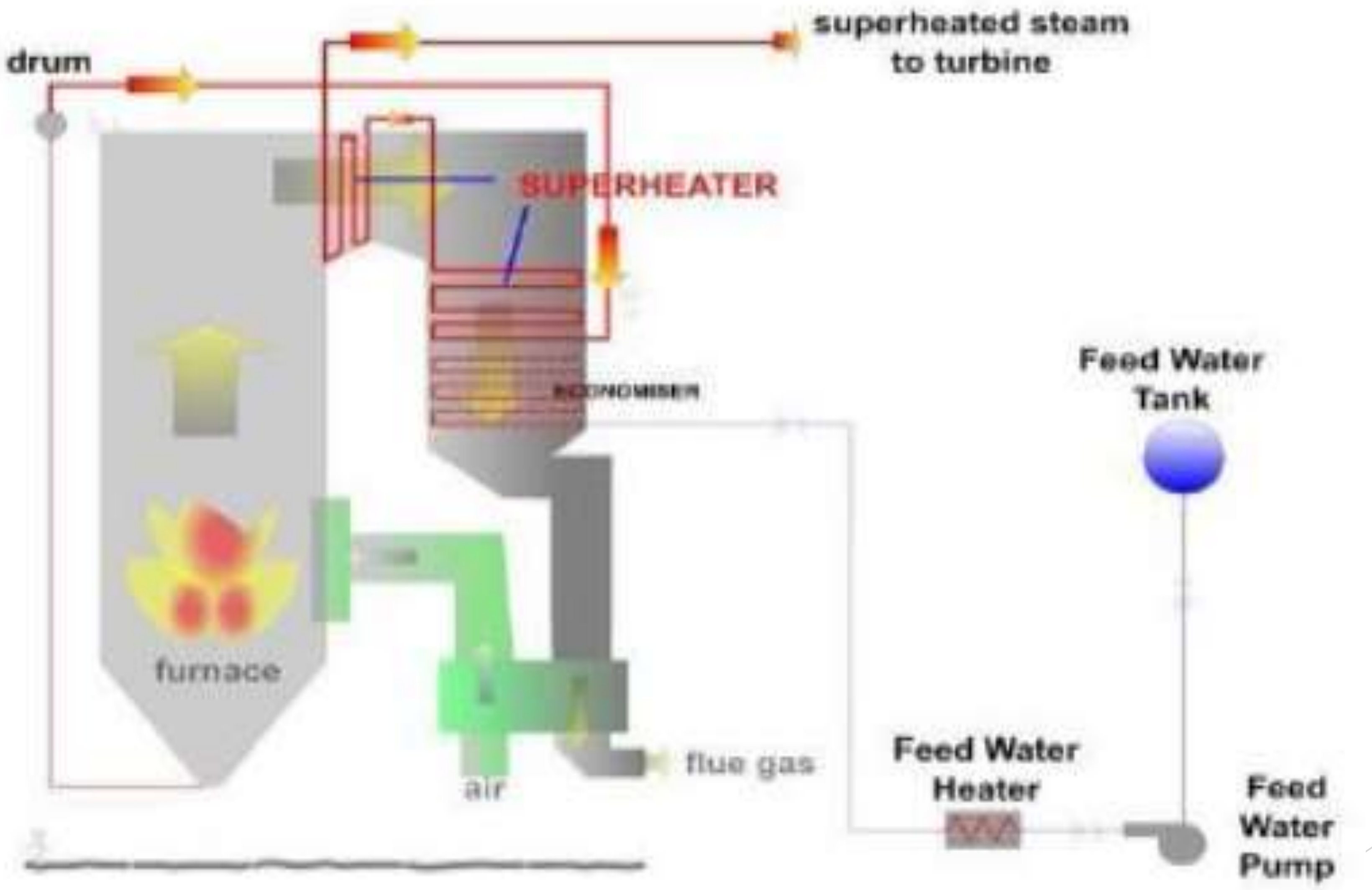
4)COOLING WATER CIRCUIT



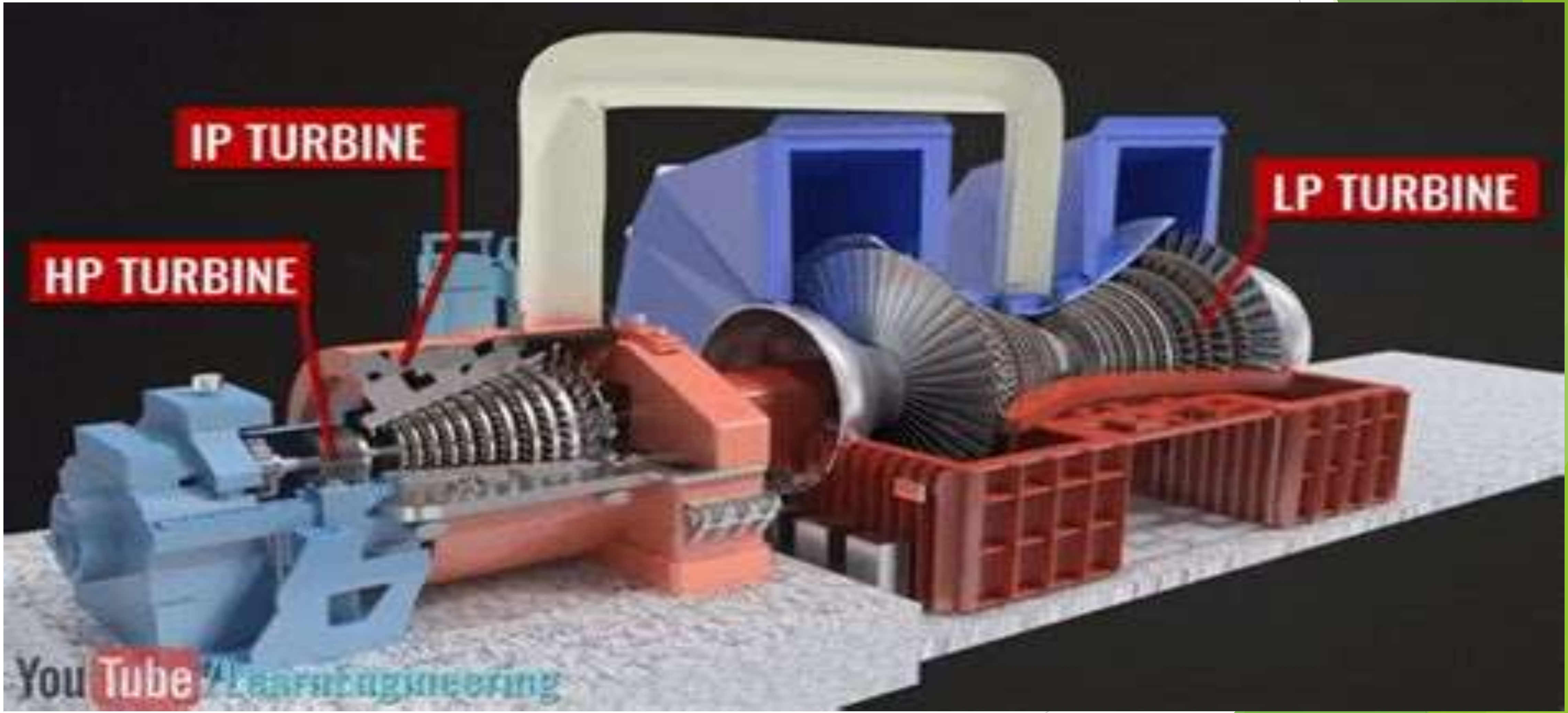
BOILERS:- boiler converts coal energy to steam energy



# SUPERHEATER:- super heat the steam coming from boiler send to turbine

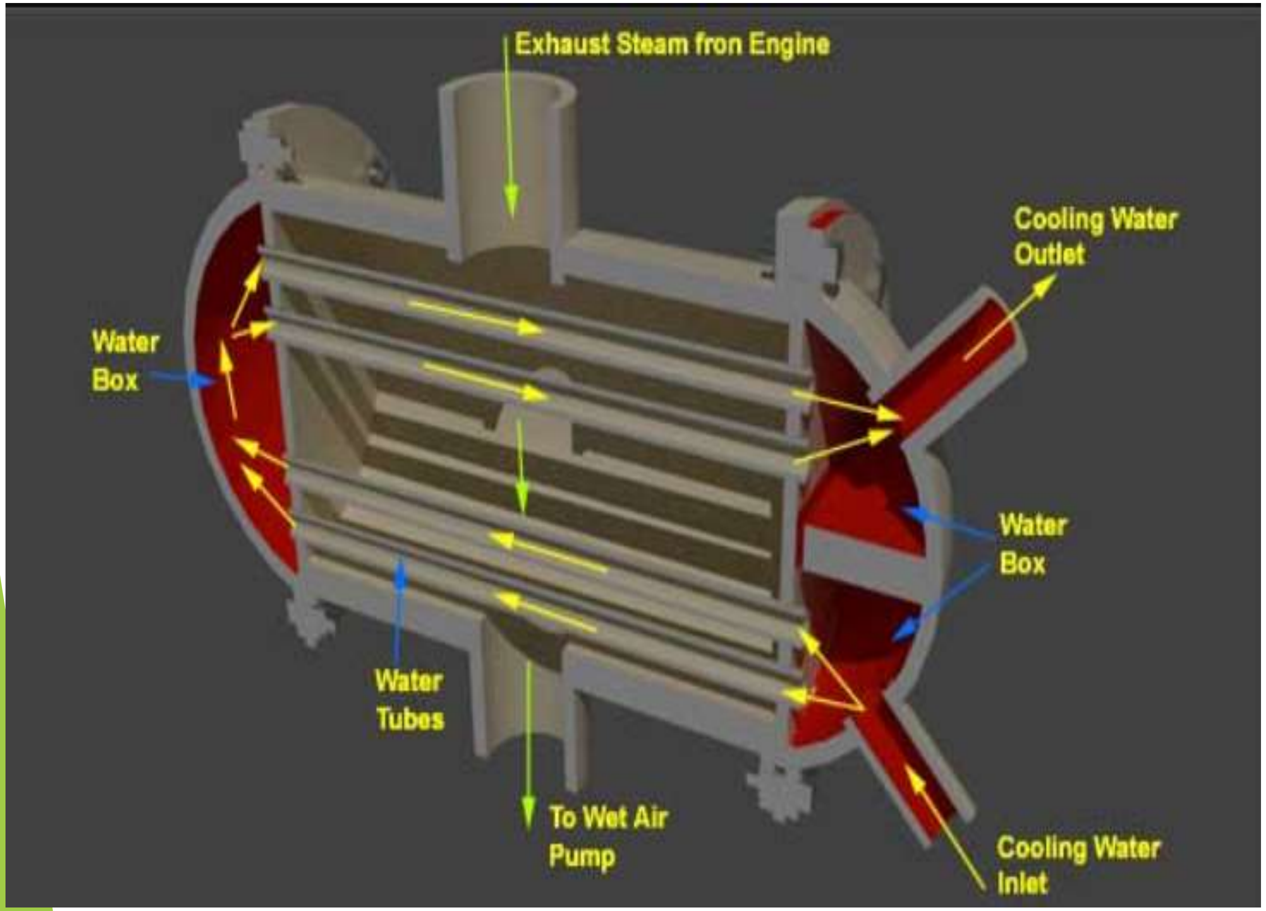


# TURBINE:- converts kinetic energy to mechanical energy exhausted steam will send to condenser

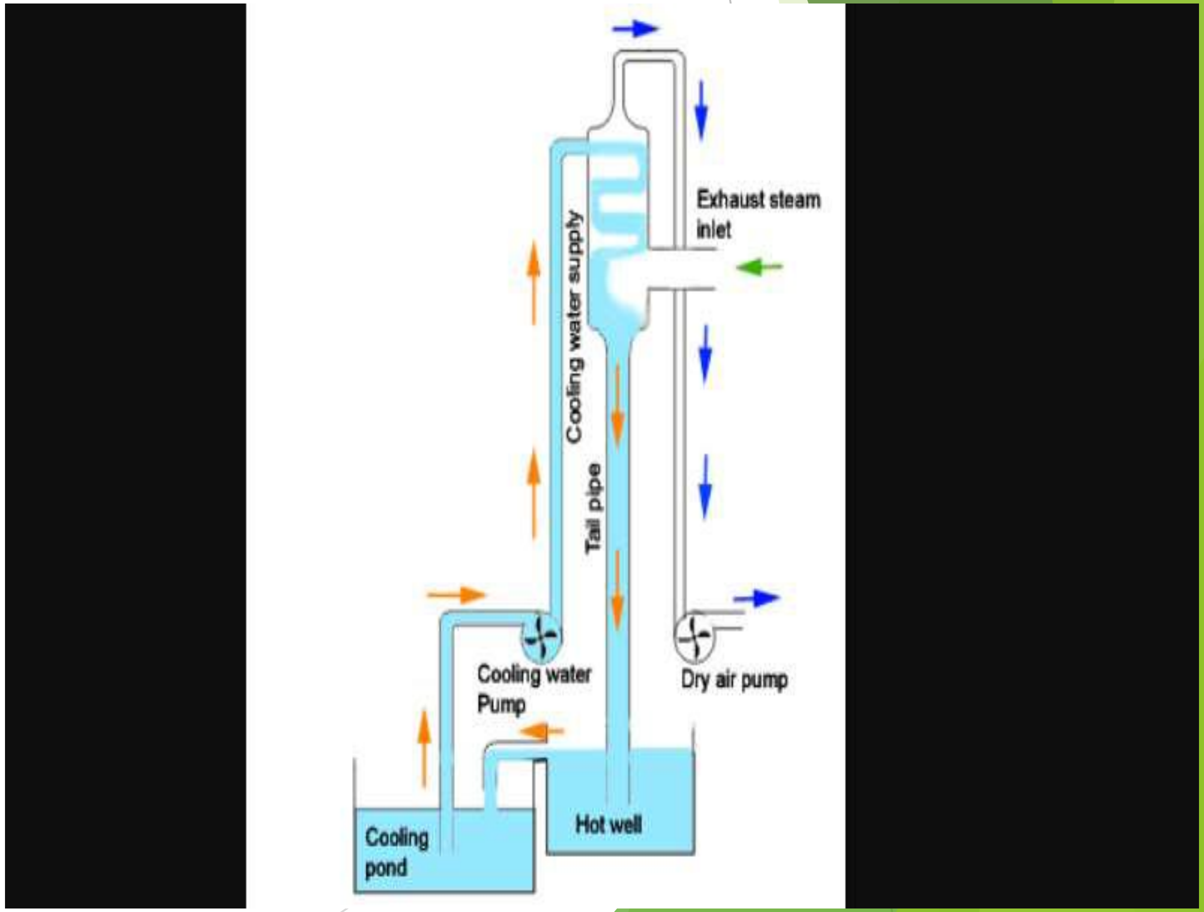


# CONDENSER:- condensate the steam and convert steam to water and send to economizer

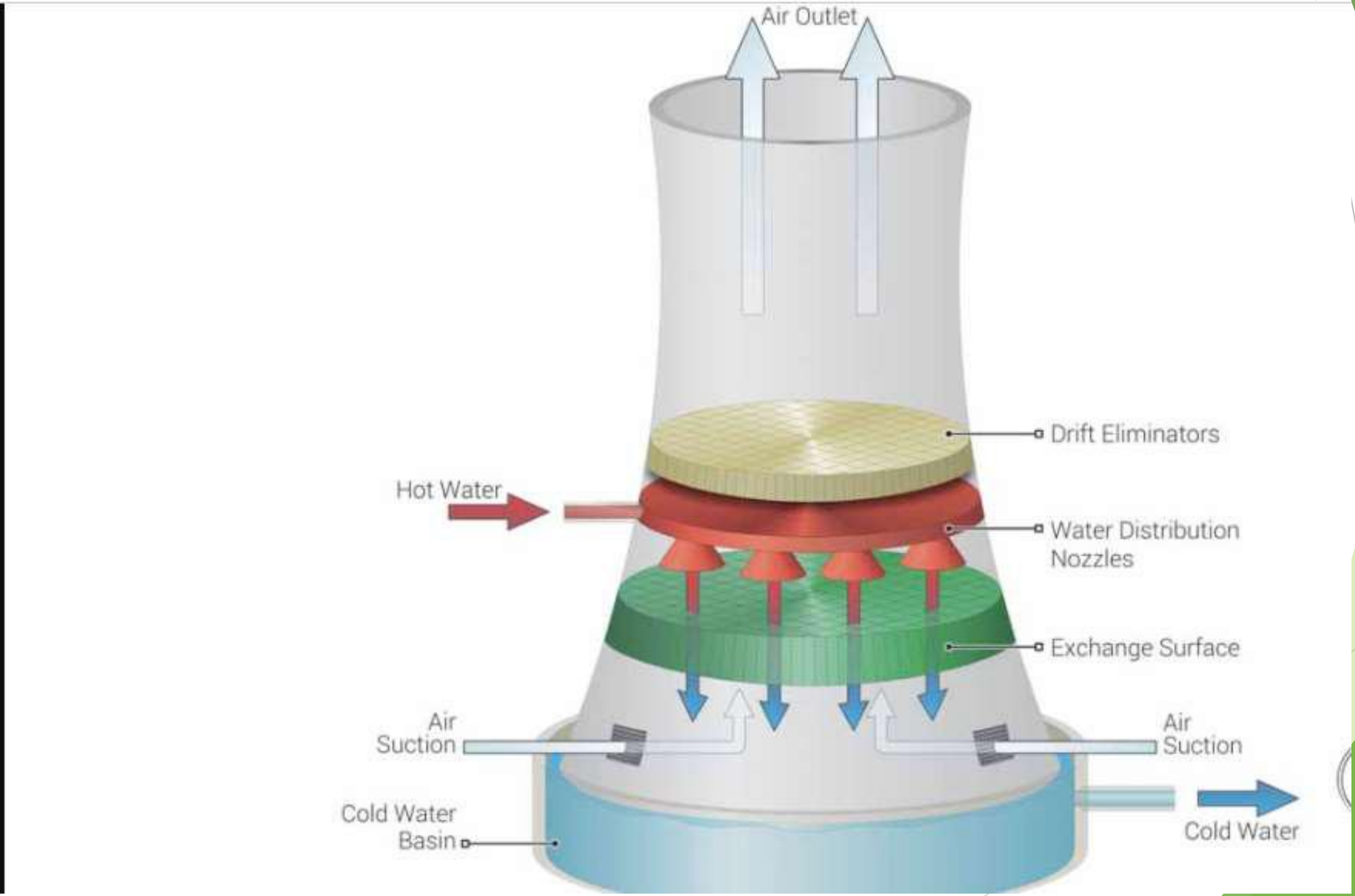
SURFACE CONDENSER




JET CONDENSER

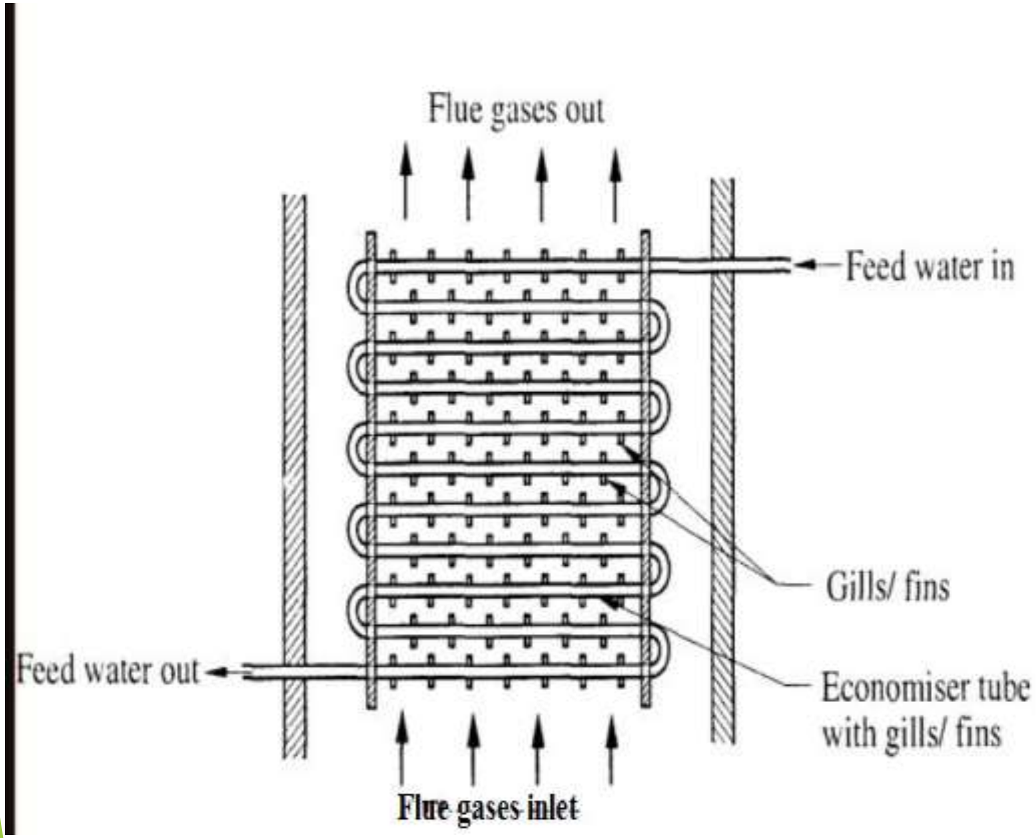


# COOLING TOWER

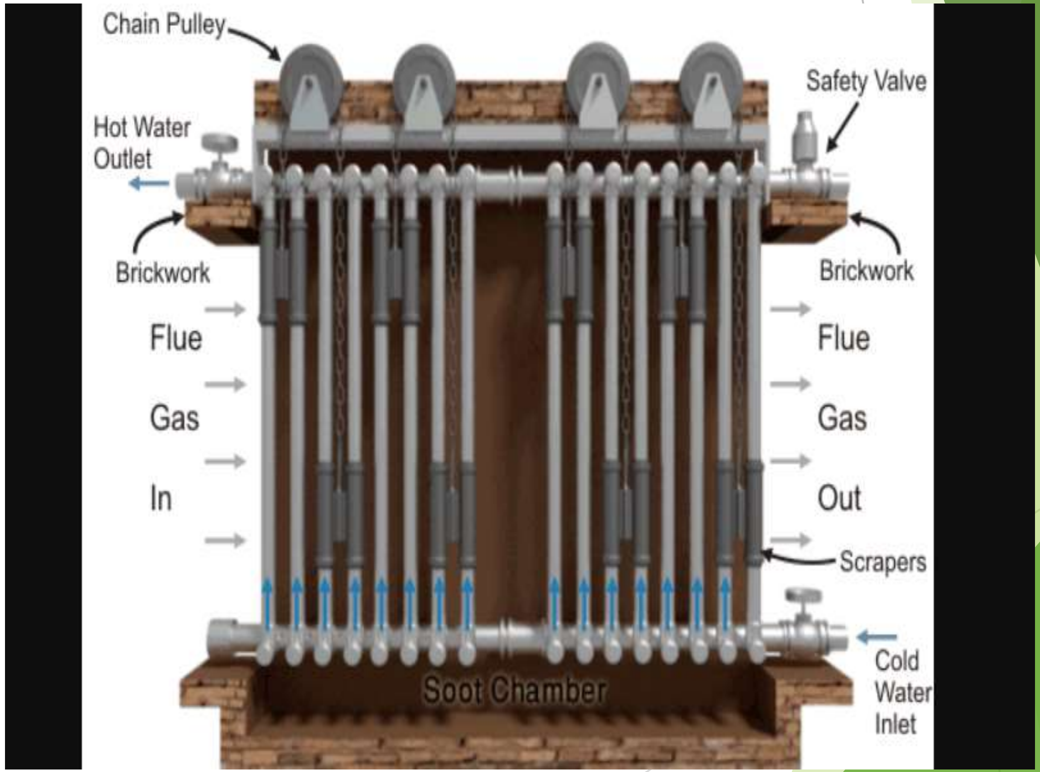


# ECONOMIZER:- heat water upto saturation temperature by using flue gases

## Line diagram

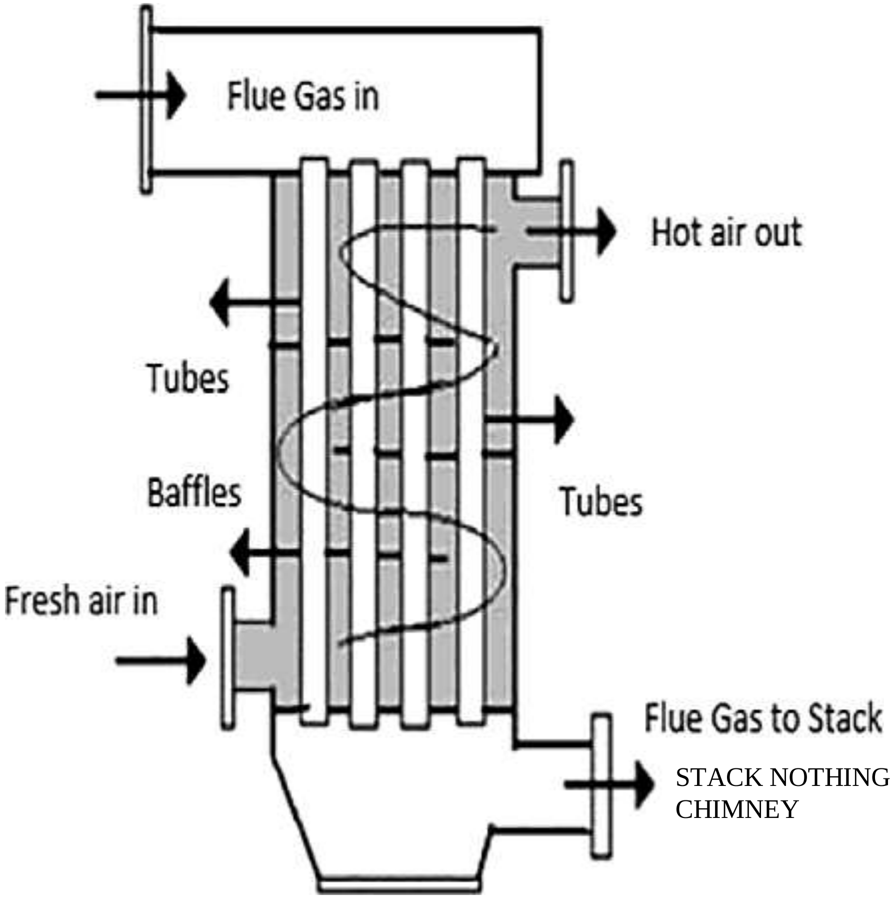



## Practical diagram



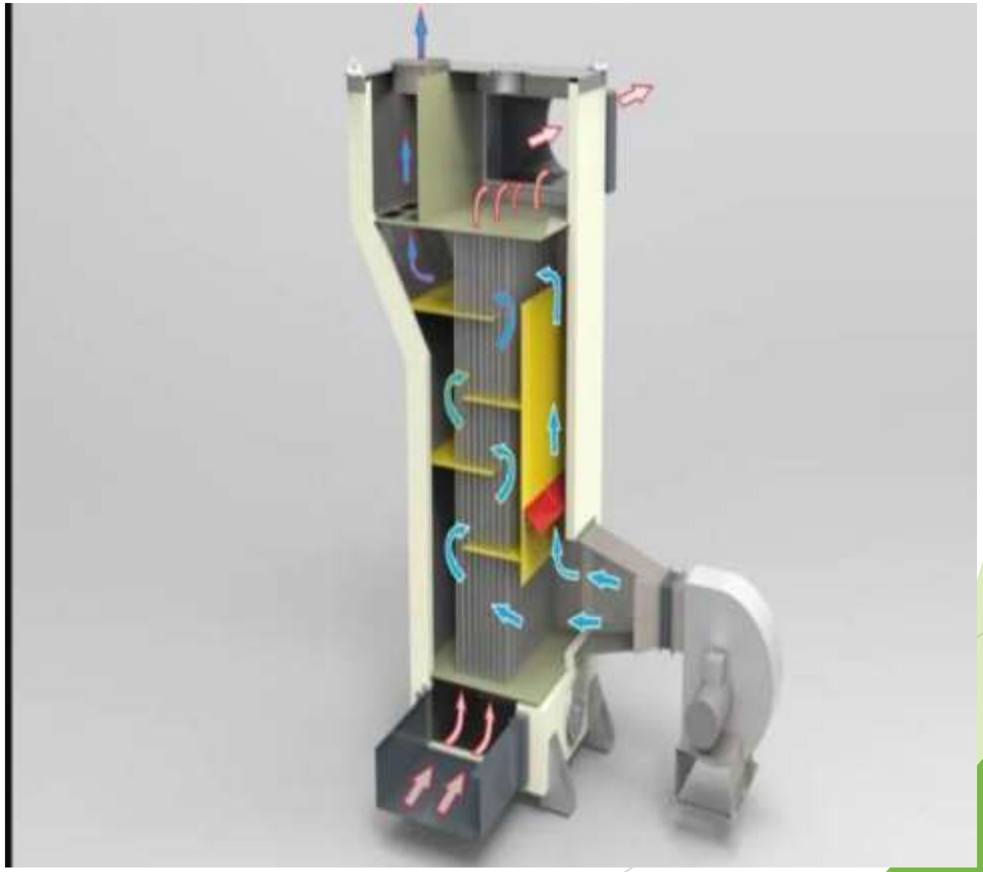
# AIR PRE HEATER

## LINE DIAGRAM




STACK NOTHING BUT CHIMNEY

## PRACTICAL DIAGRAM



# CHIMNEY

# 4)NUCLEAR POWER STATION

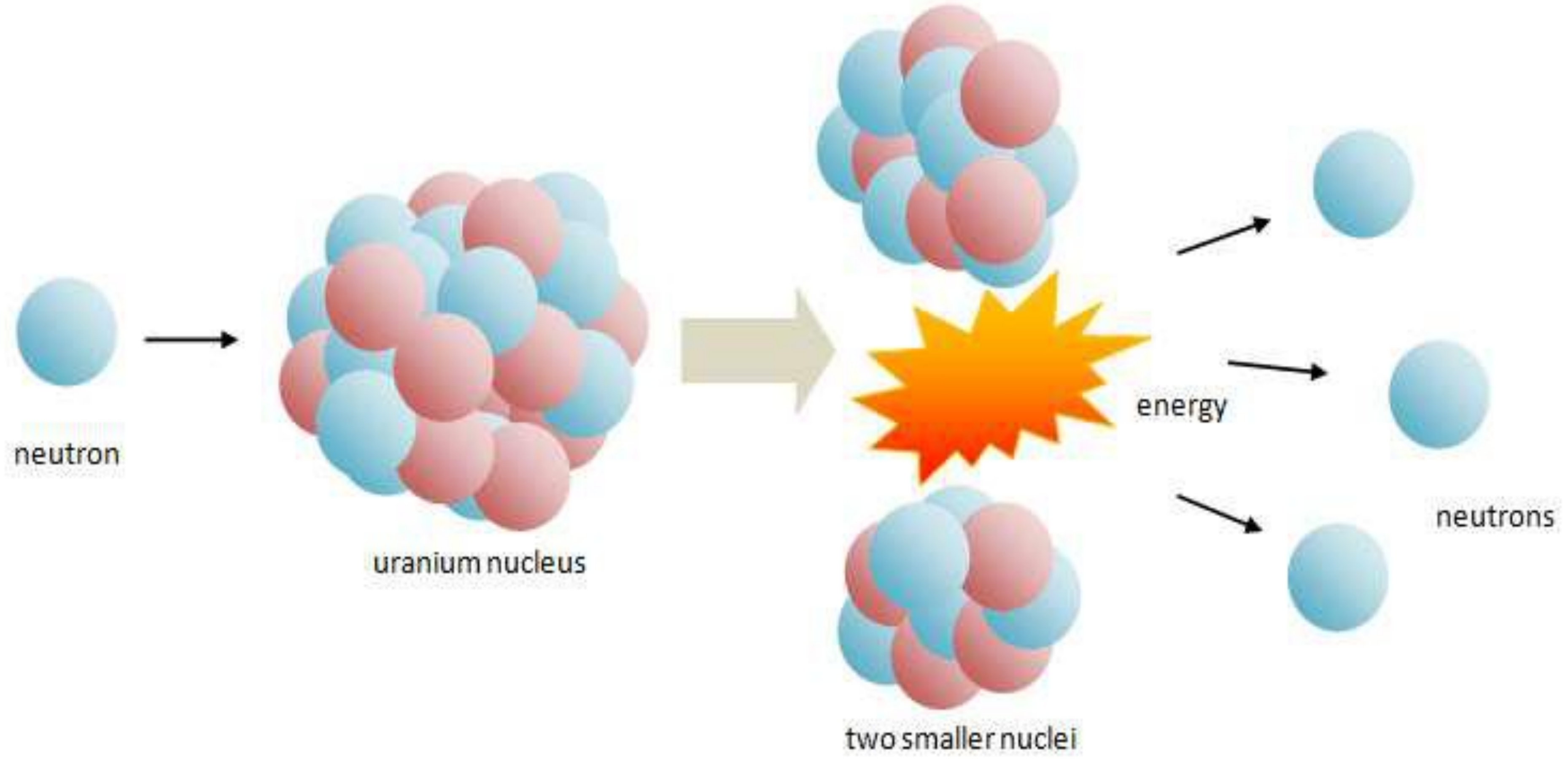
Introduction:-

The energy needed by a country cannot be not met for a single source. Hydro electric power stations produce cheap power but needs a thermal backing to increase the firm capacity . But the reserved of fossil fuels like coal, oil and gas are fast depleting.

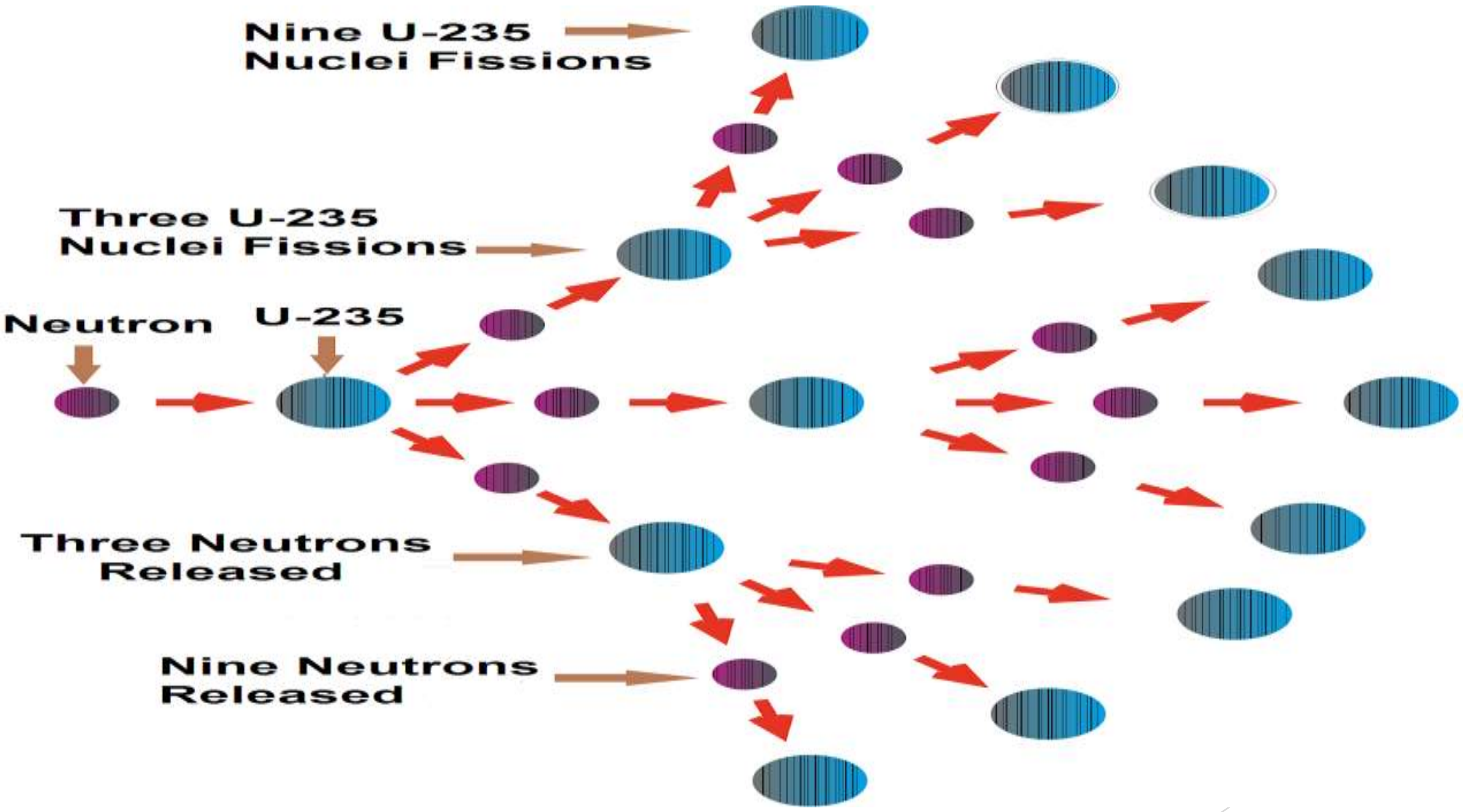
Thus these is a need to seek alternate source of energy. The nuclear power is the only source which can supply the future energy demand of the world.

One of the main attractions is that huge amount of energy can be released from small quantity of active material i.e by completely burning of 1kg of uranium would give energy equivalent to 3000tonnes of high grade coal.

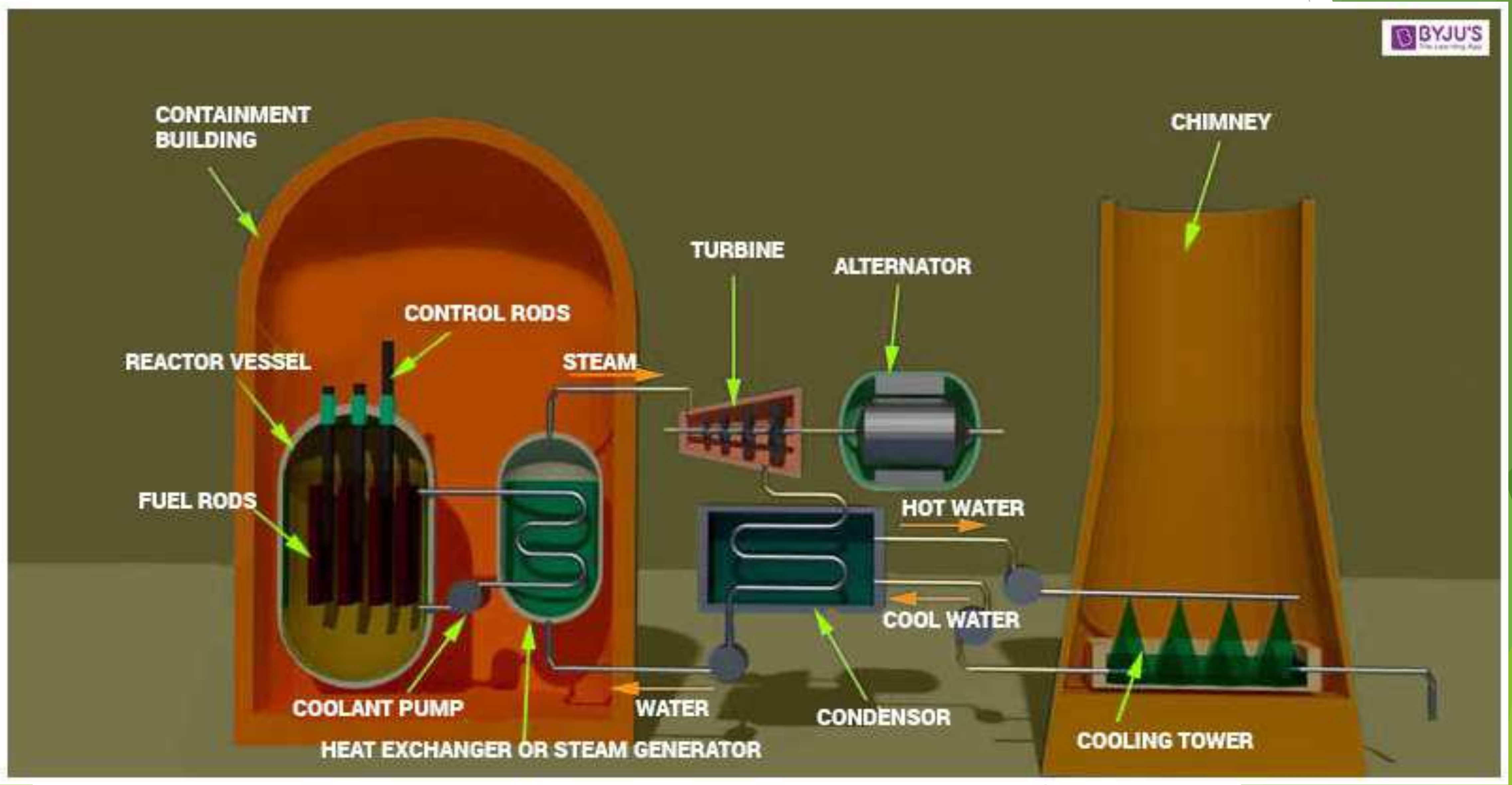
# NUCLEAR FISSION:- The splitting of heavy nucleus into two )or) more smaller nuclei



## CHAIN REACTION:- It may be defined as a fission reaction in which the neutrons from previous step continues to propagate and repeat the reaction.



# (4)(1) LINE DIAGRAM AND COMPONENTS OF NPS



# (4)(2) TYPES OF REACTORS

WHAT IS REACTOR :-

A nuclear reactor, formerly known as an atomic pile, is a device used to initiate and control a fission nuclear chain reaction

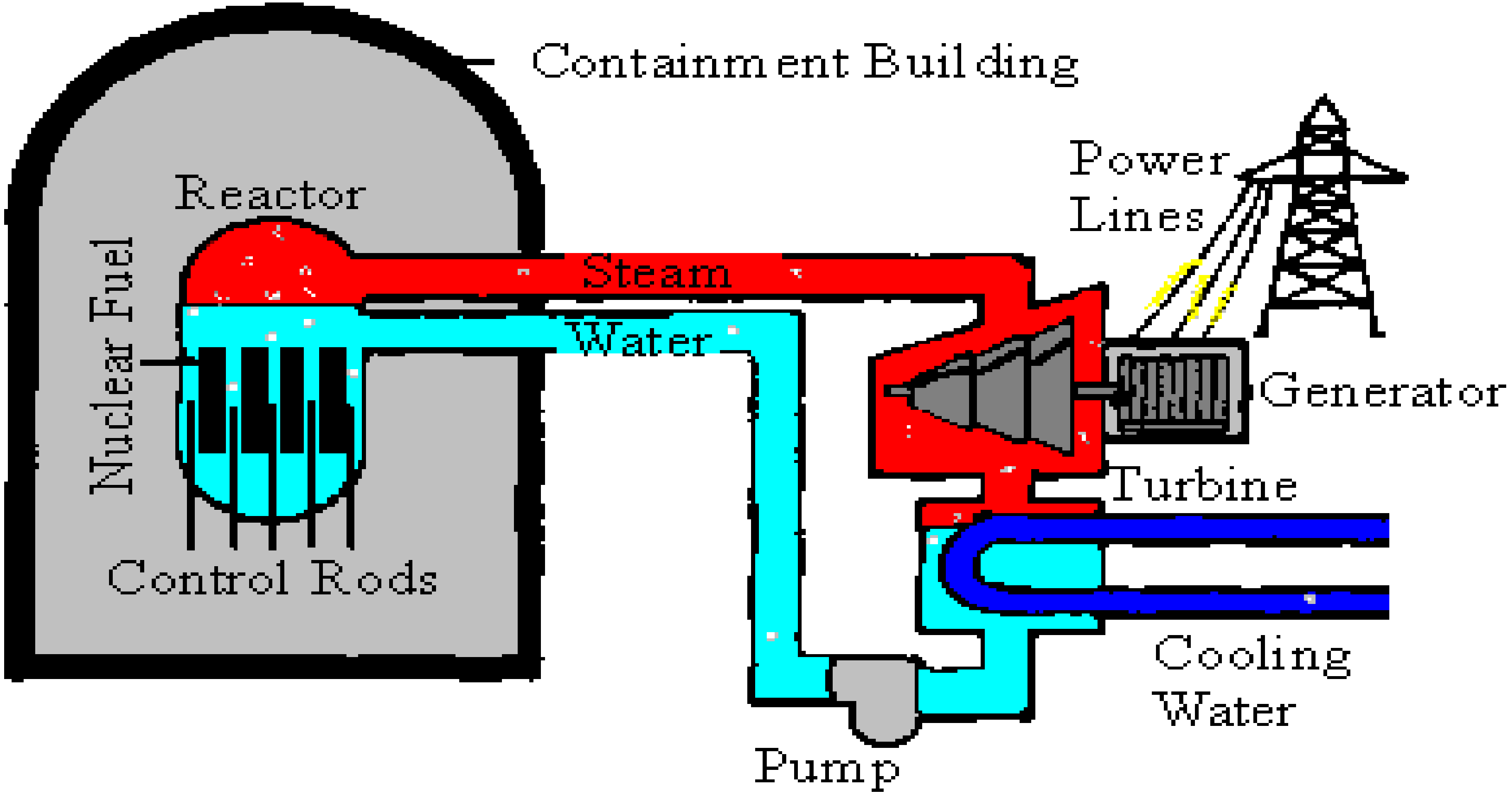
1)THERMAL REACTORS

a)BOILING WATER REACTOR

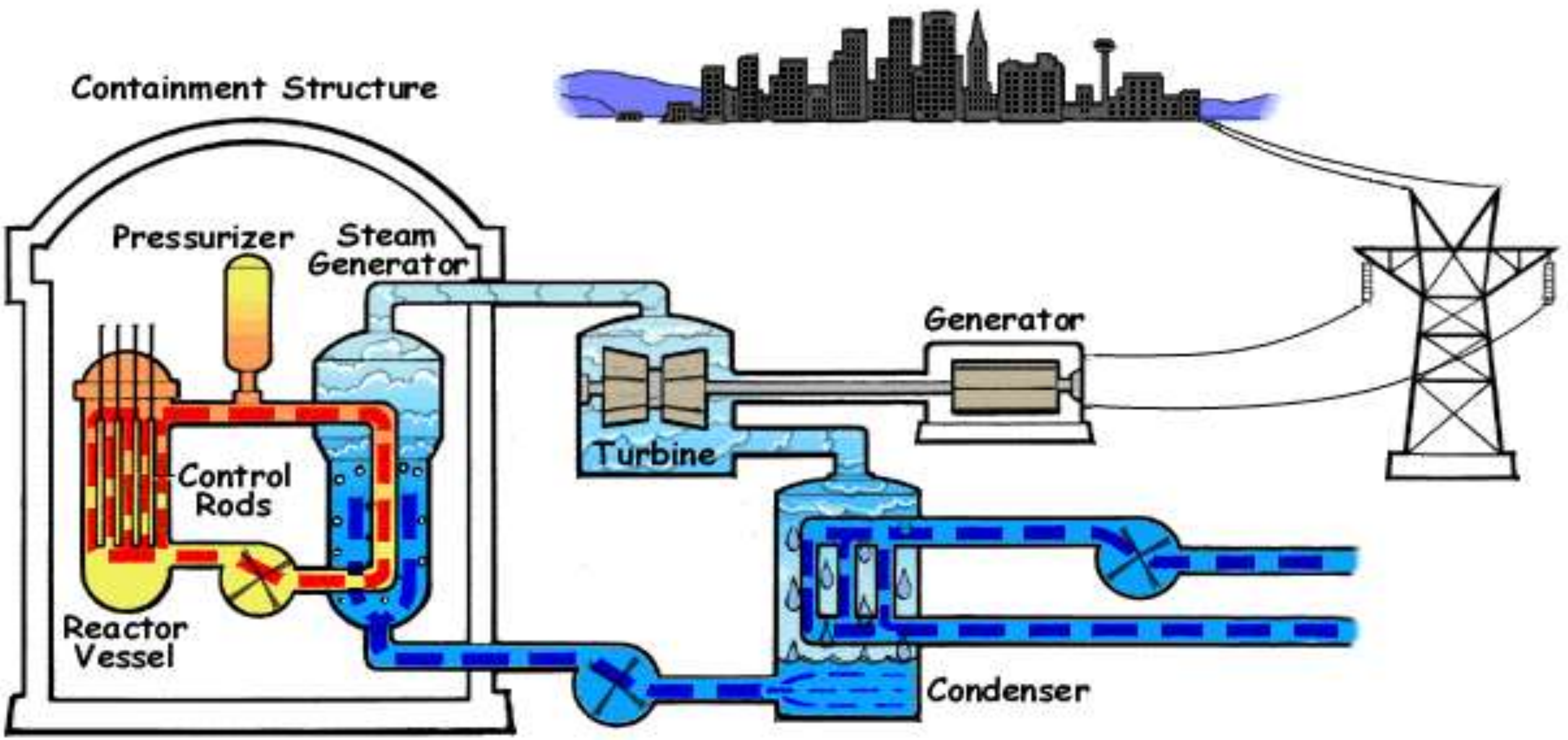
b)PRESSURIZED WATER REACTOR

2)FAST BREED REACTOR

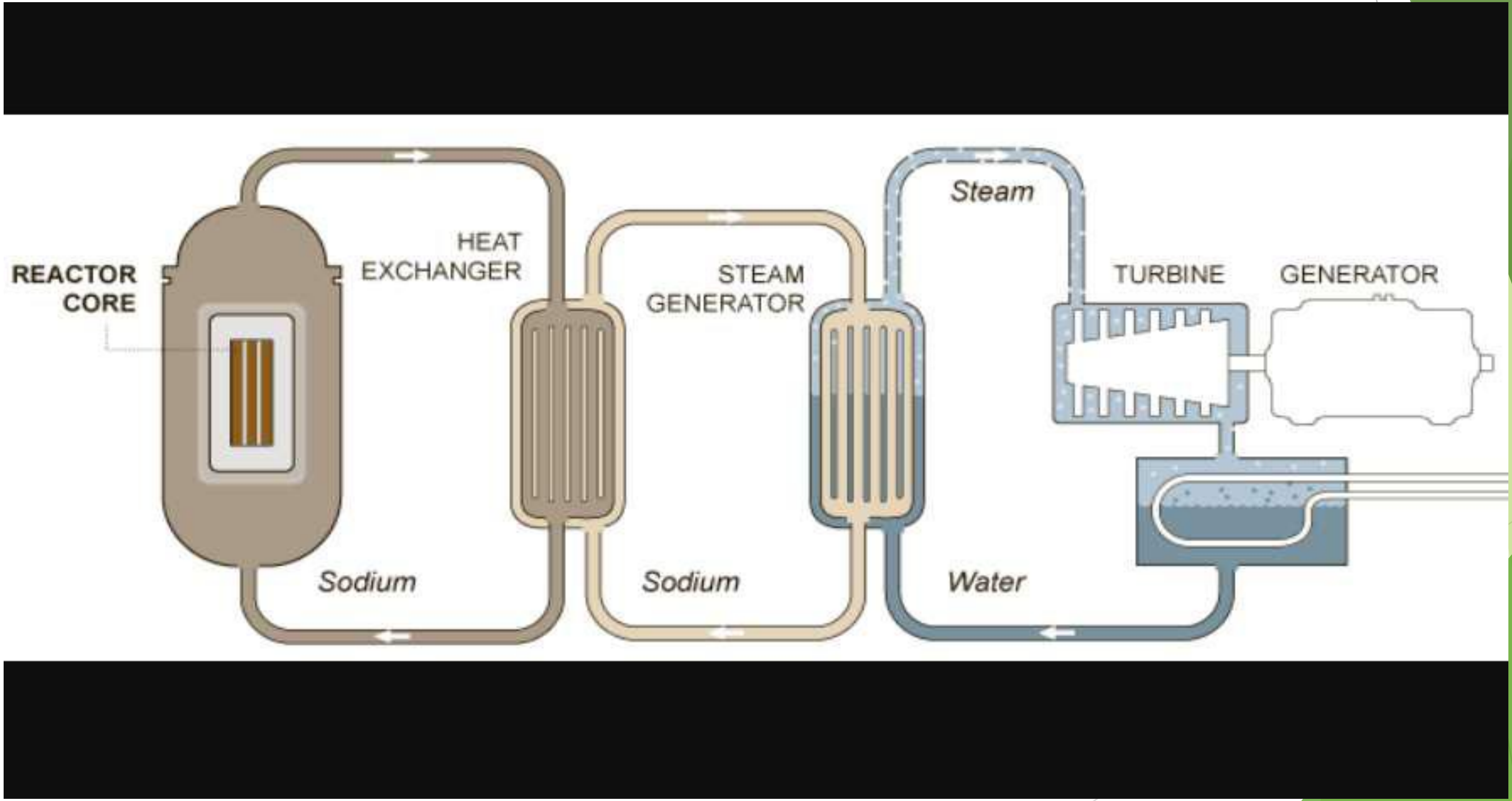
# BOILING WATER REACTOR



# PRESSURIZED WATER REACTOR



# FAST BREED REACTOR



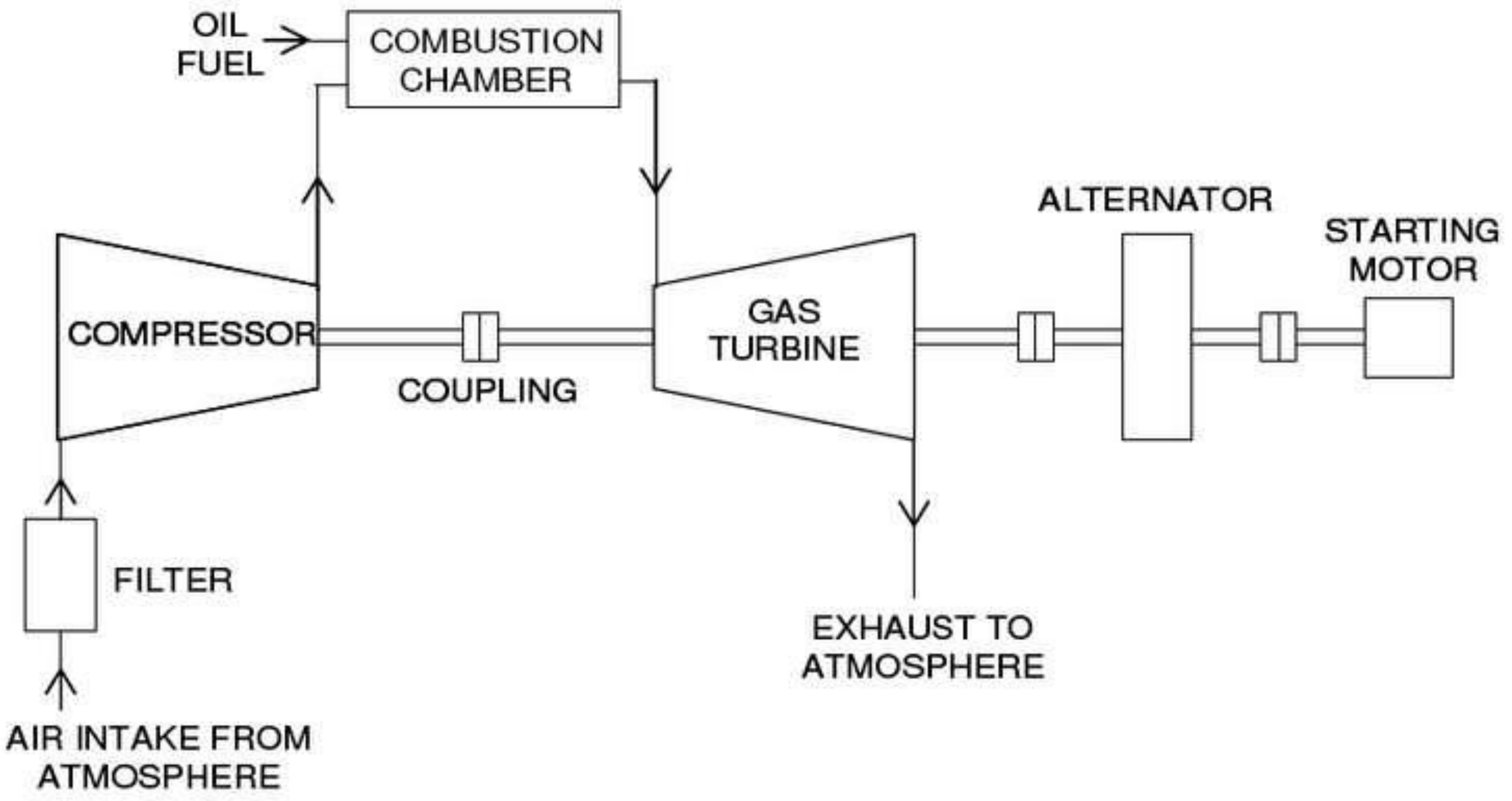
# 5) GAS POWER STATION

INTRODUCTION:-

A generating station which employs gas turbine as a prime mover for the generation of electrical energy is known as gas turbine power plant.

Works on the principle of Brayton cycle

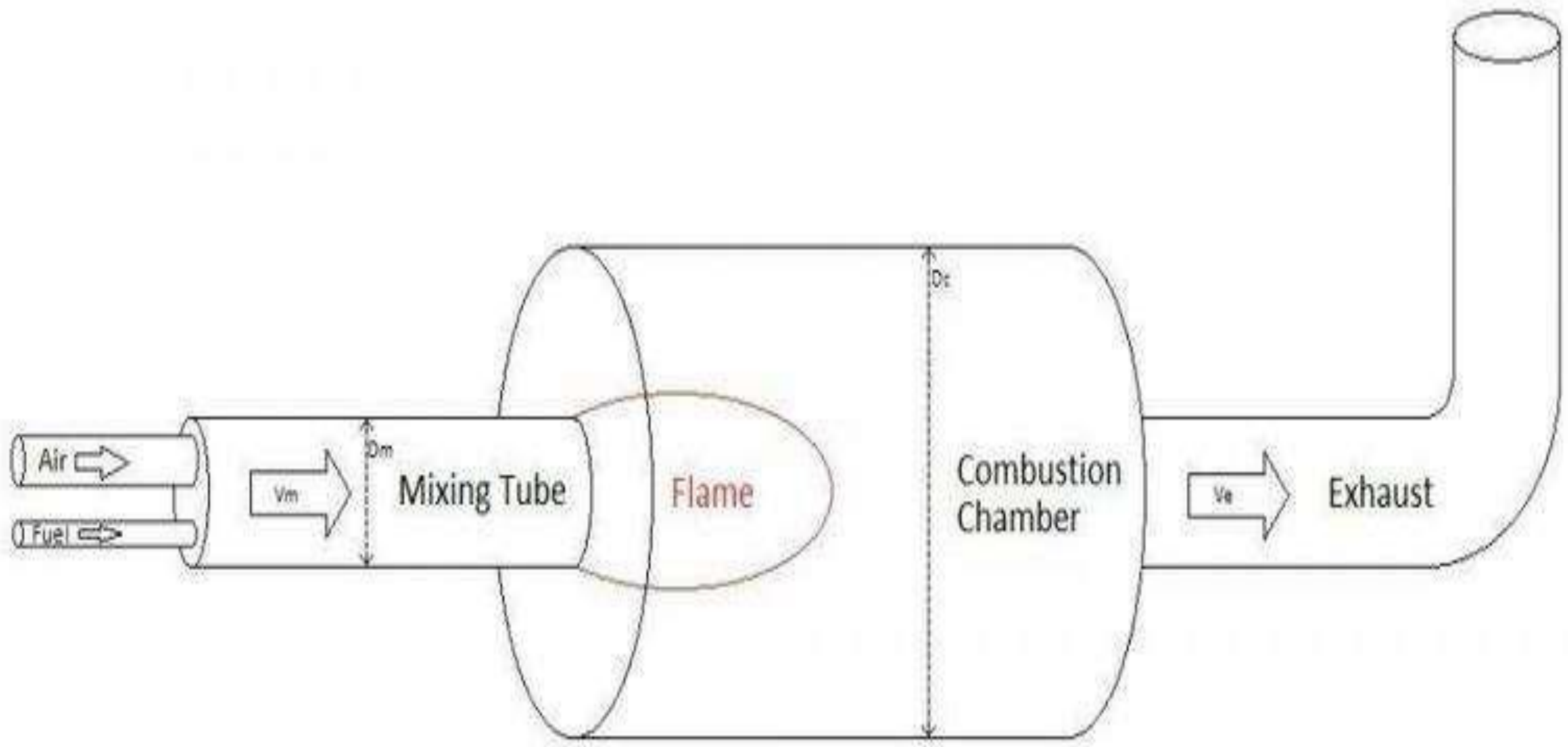
# (5)(1)LINE DIAGRAM OF GPP



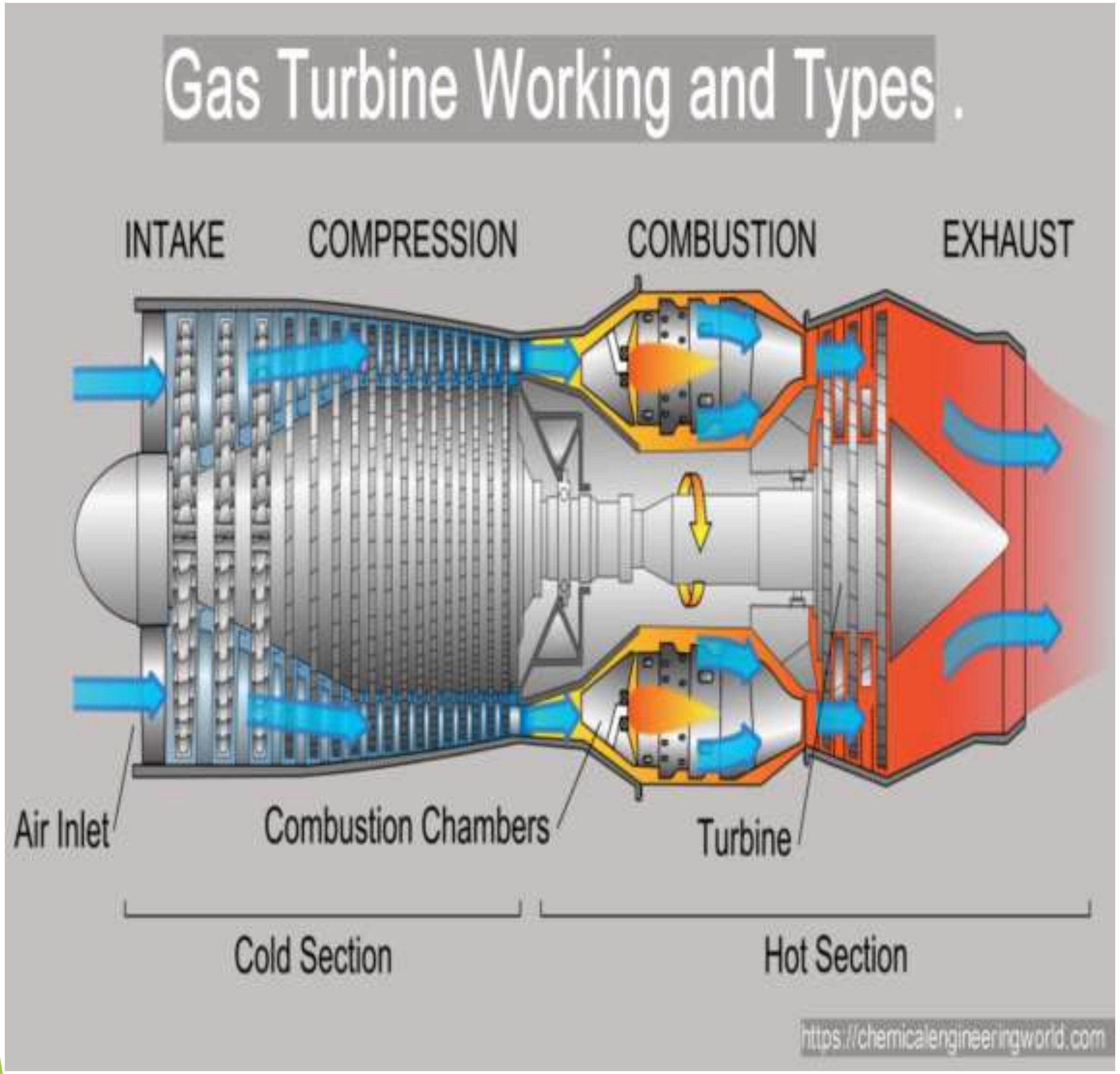
# PRACTICAL GPP

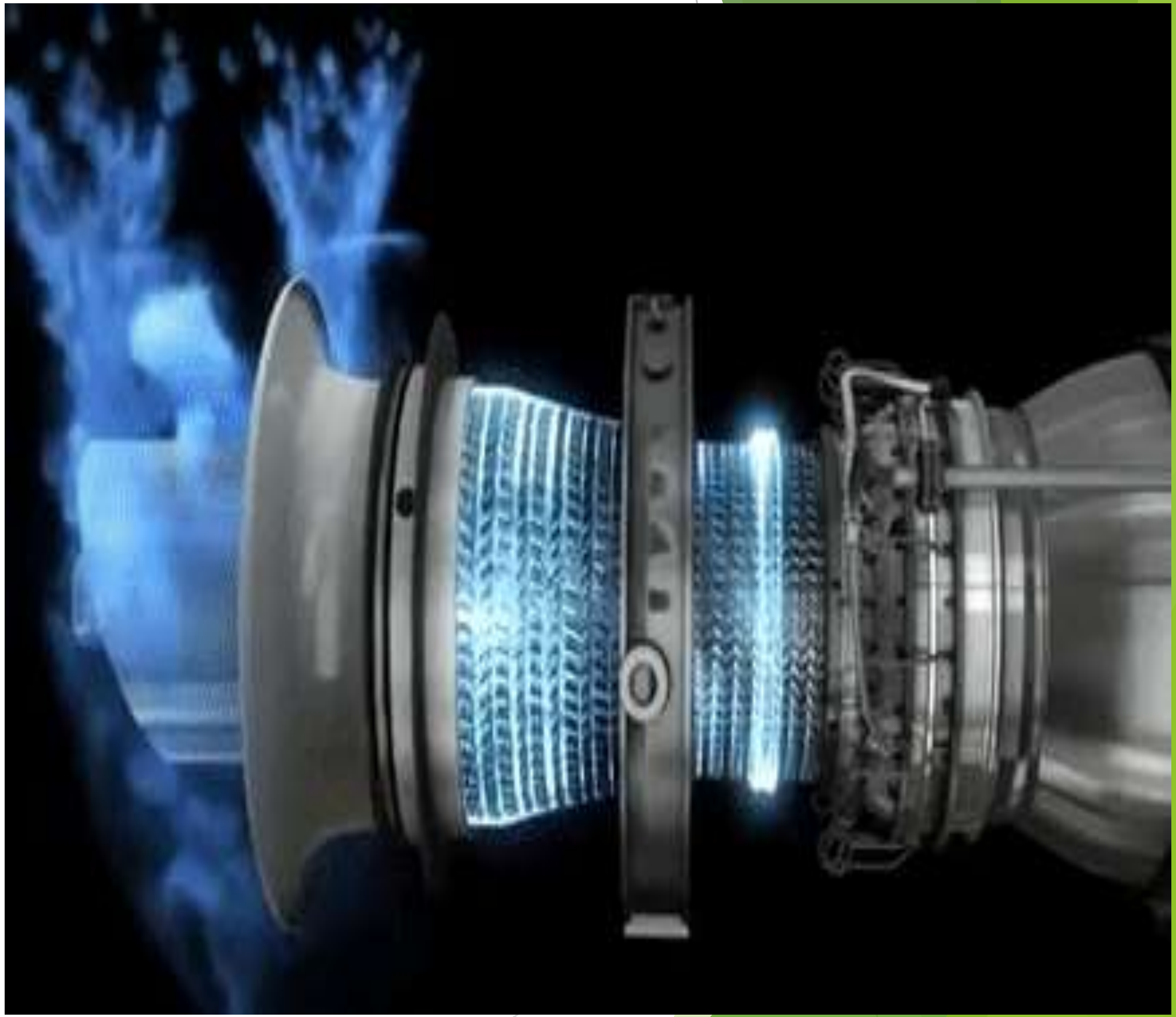
# COMPRESSOR

# COMBUSTION CHAMBER

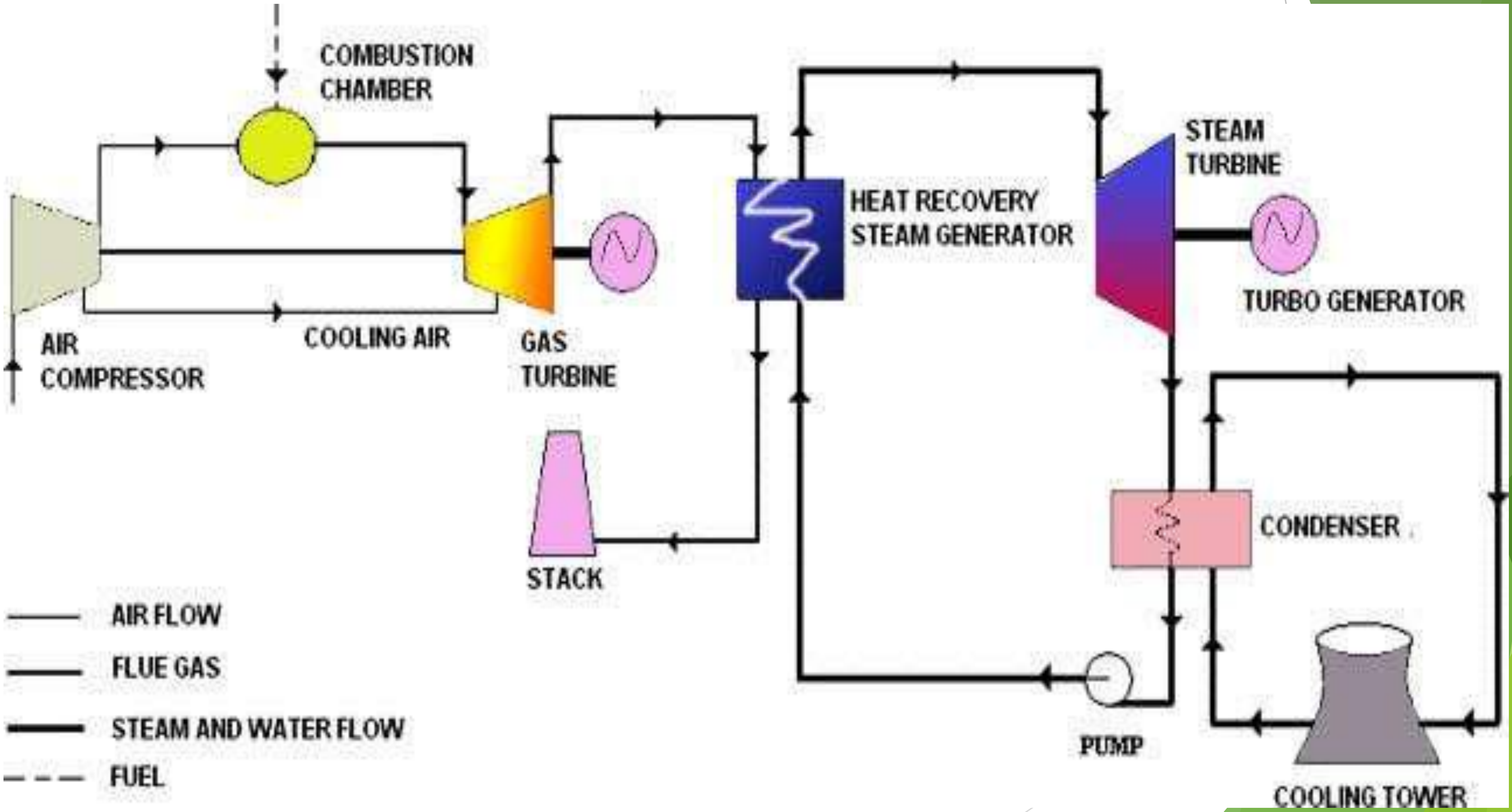


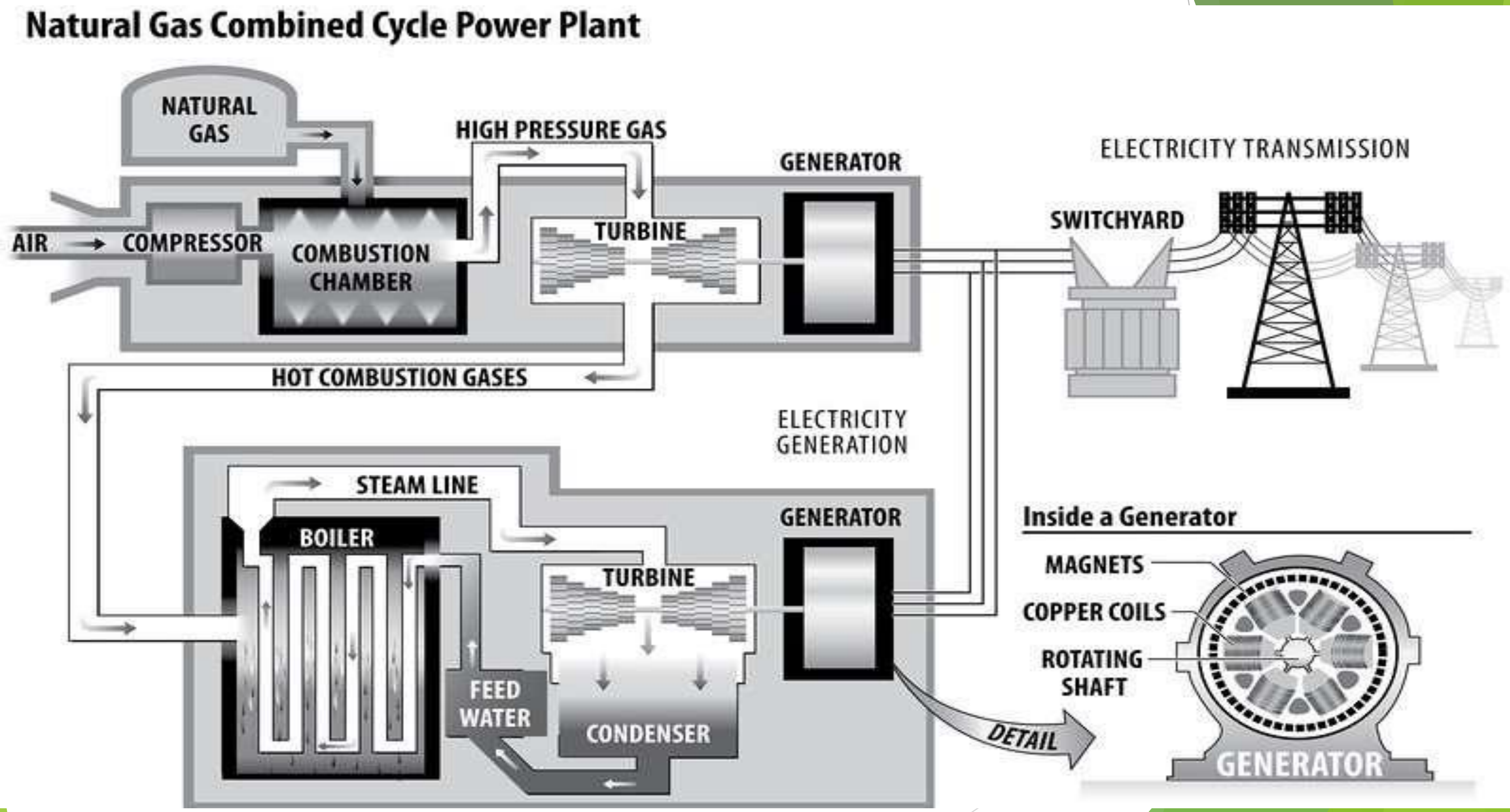
# GAS TURBINE


Gas Turbine Working and Types .
INTAKE
COMPRESSION
COMBUSTION
EXHAUST
Air Inlet
Combustion Chambers
Turbine
Cold Section
Hot Section
https://chemicalengineeringworld.com



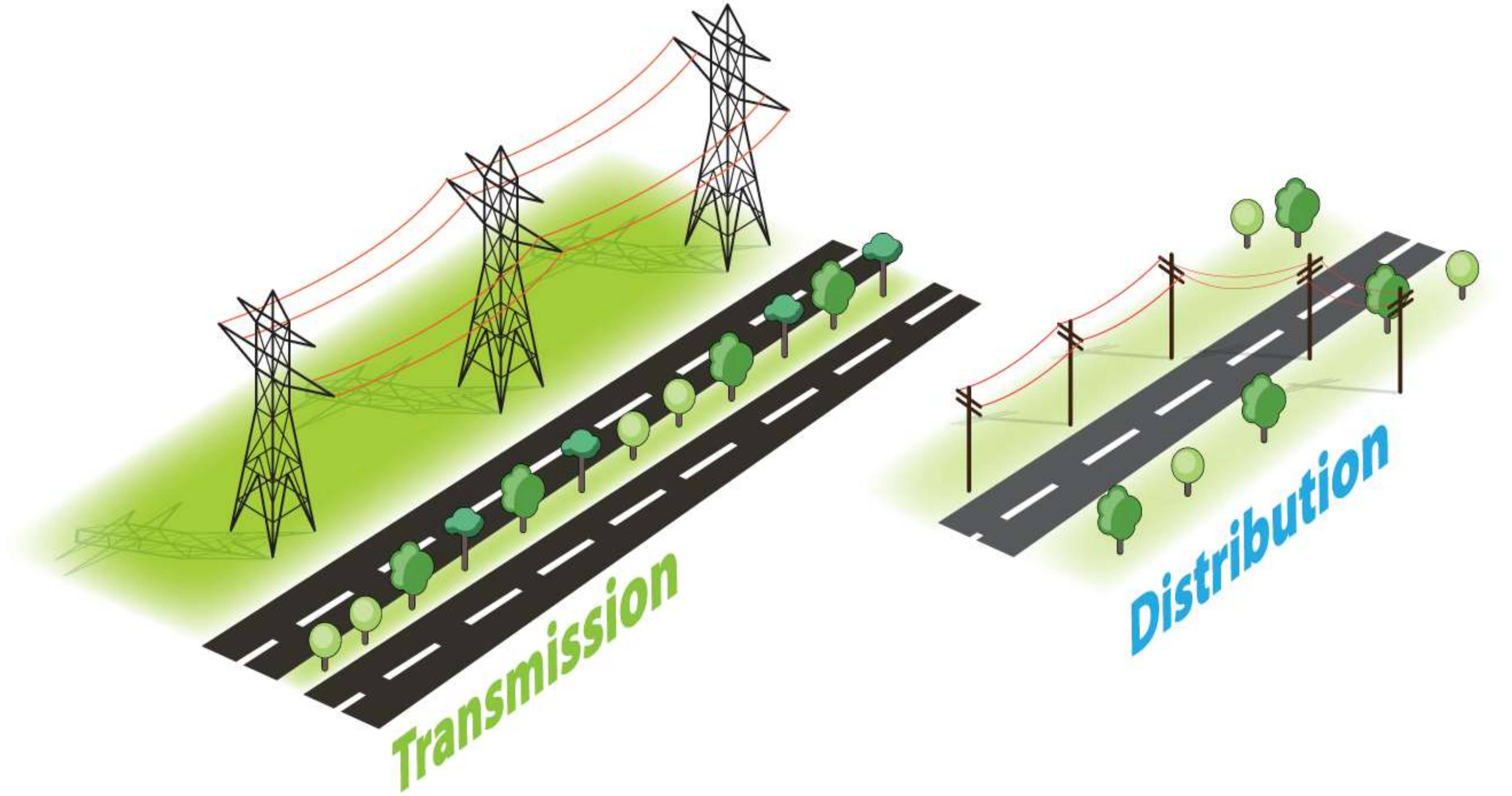
# COMBINED CYCLE POWER PLANT





Natural Gas Combined Cycle Power Plant
NATURAL GAS
HIGH PRESSURE GAS
GENERATOR
ELECTRICITY TRANSMISSION
AIR
COMPRESSOR
COMBUSTION CHAMBER
TURBINE
SWITCHYARD
HOT COMBUSTION GASES
ELECTRICITY GENERATION
STEAM LINE
BOILER
GENERATOR
TURBINE
FEED WATER
CONDENSER
DETAIL
Inside a Generator
MAGNETS
COPPER COILS
ROTATING SHAFT
GENERATOR


Combined-Cycle Power Plant
Steam Turbine
HRSG
Gas Turbine
50%
MORE
POWER


Transmission
Distribution

# UNIT -2

## GENERAL ASPECTS OF DC AND AC DISTRIBUTION SYSTEMS

# BULK POWER GRIDS

An electric power grid is generally composed of three parts

(1) Generation system (2) Transmission system (3) Distribution system

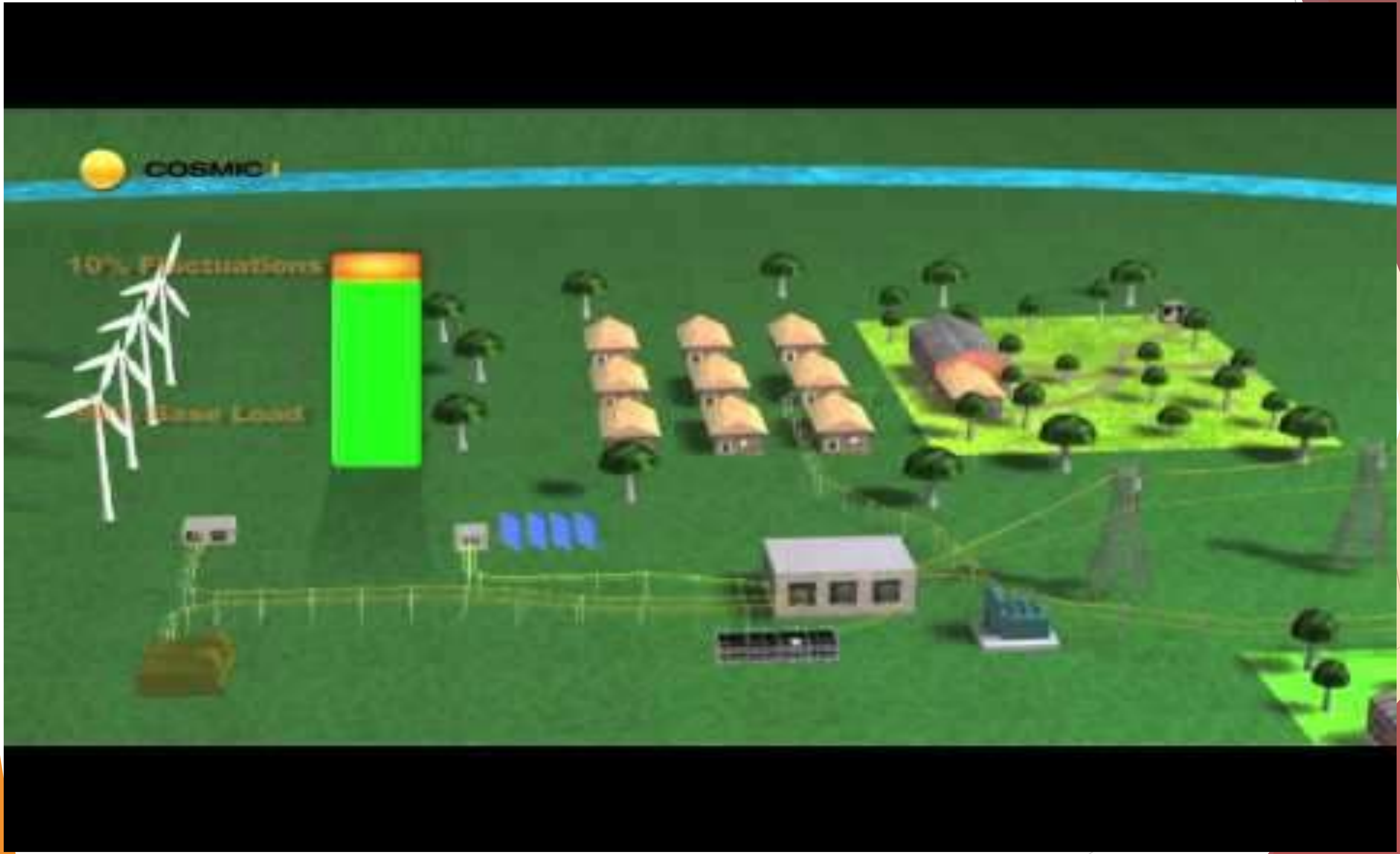
All of which contribute to the production and transportation of electric energy to consumers.

when the demand of electric energy increase day by day we need to upgrade the level of power handling capacity of the system.

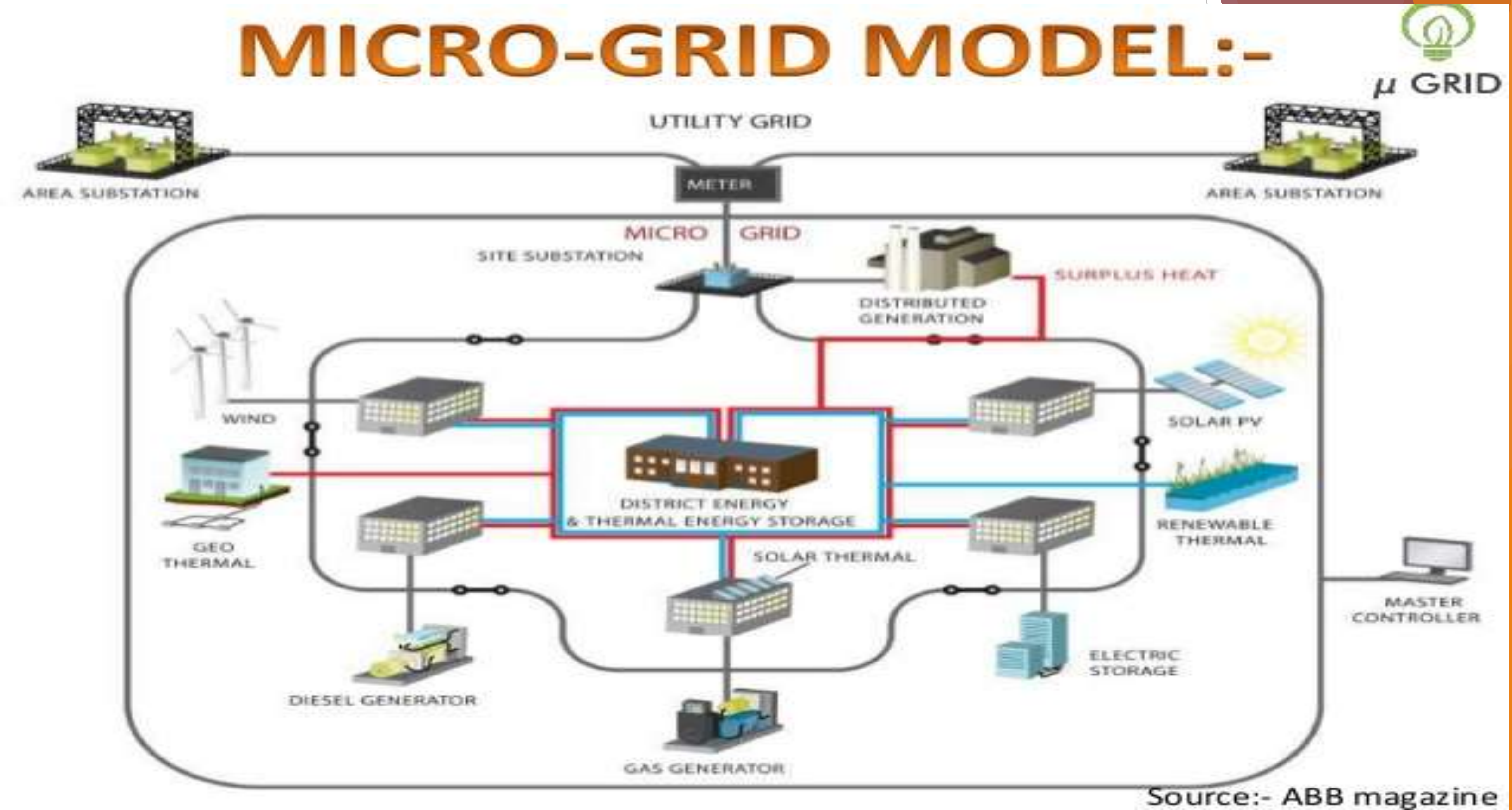
Bulk power grids reliability assessment is an important procedure at both power grid planning and operating stage to assure reliable and acceptable electricity service to consumers.

Different grids interconnect through tie lines to form a regional grids

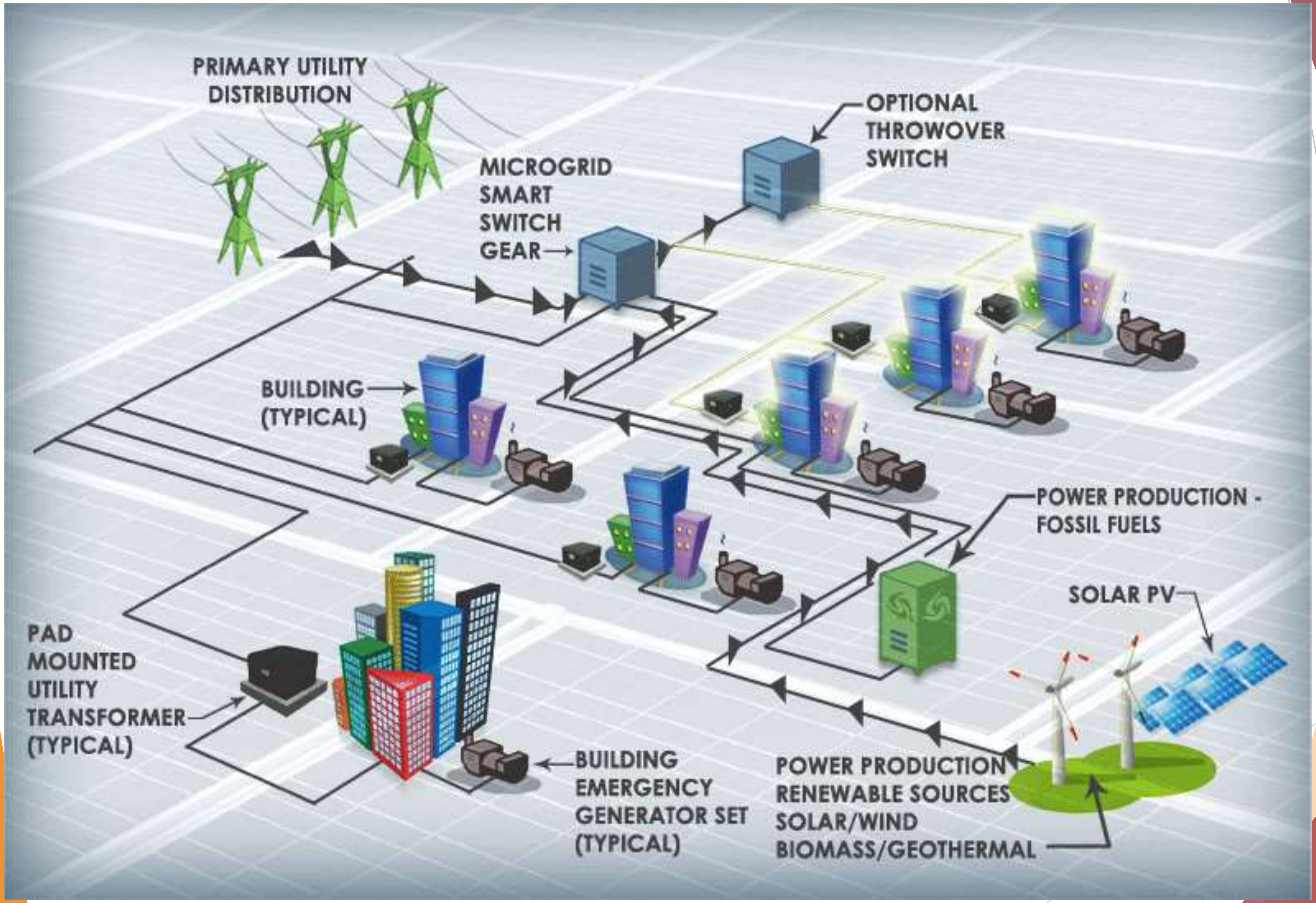
Different regional grids are further connected to form a national or bulk power grids.


COSMIC
Base Load

# MICRO GRIDS



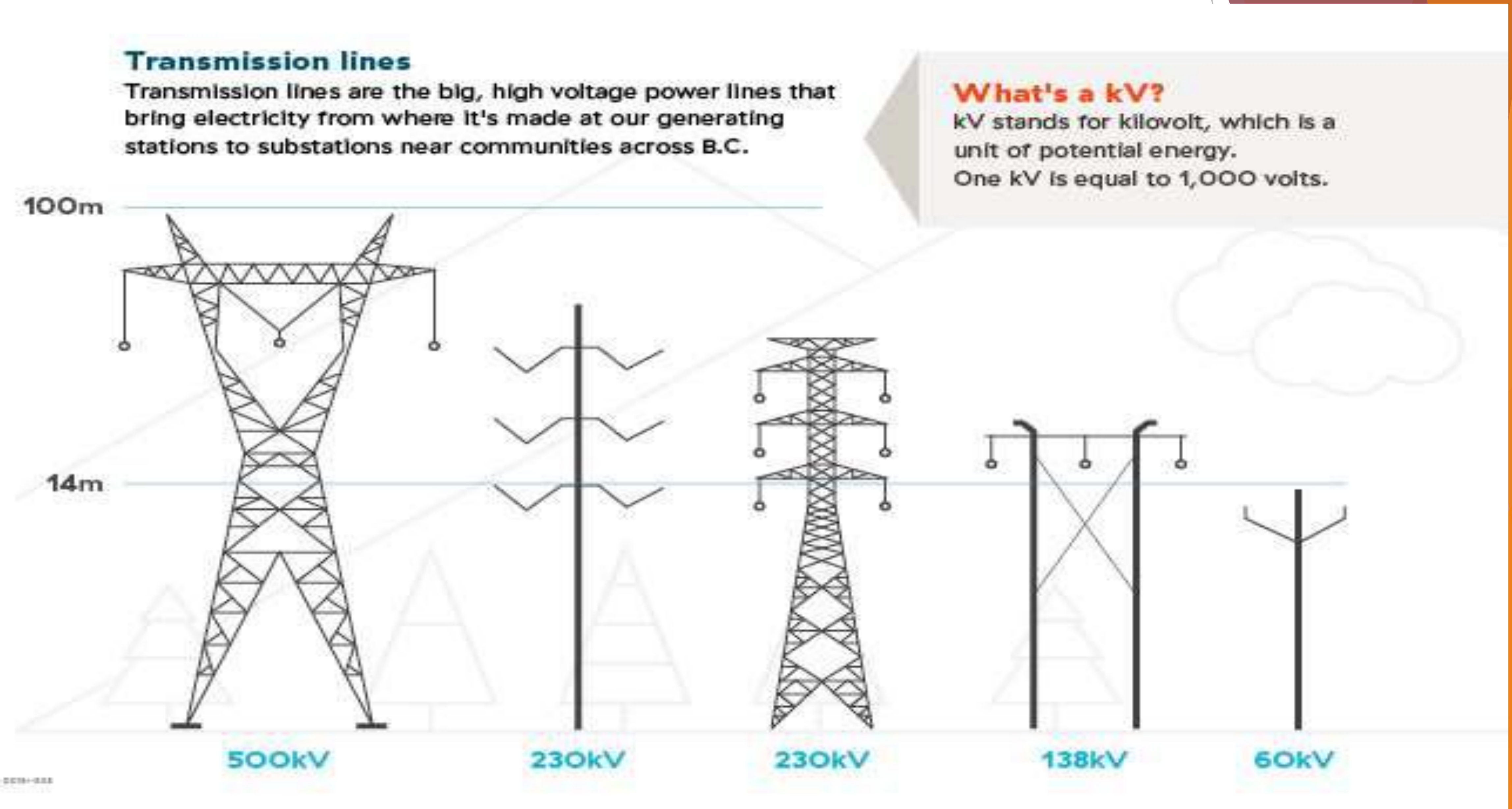
MICRO-GRID MODEL:-
μ GRID
UTILITY GRID
AREA SUBSTATION
AREA SUBSTATION
METER
MICRO GRID
SITE SUBSTATION
DISTRIBUTED GENERATION
SURPLUS HEAT
WIND
SOLAR PV
GEO THERMAL
DISTRICT ENERGY & THERMAL ENERGY STORAGE
RENEWABLE THERMAL
SOLAR THERMAL
MASTER CONTROLLER
DIESEL GENERATOR
ELECTRIC STORAGE
GAS GENERATOR
Source:- ABB magazine

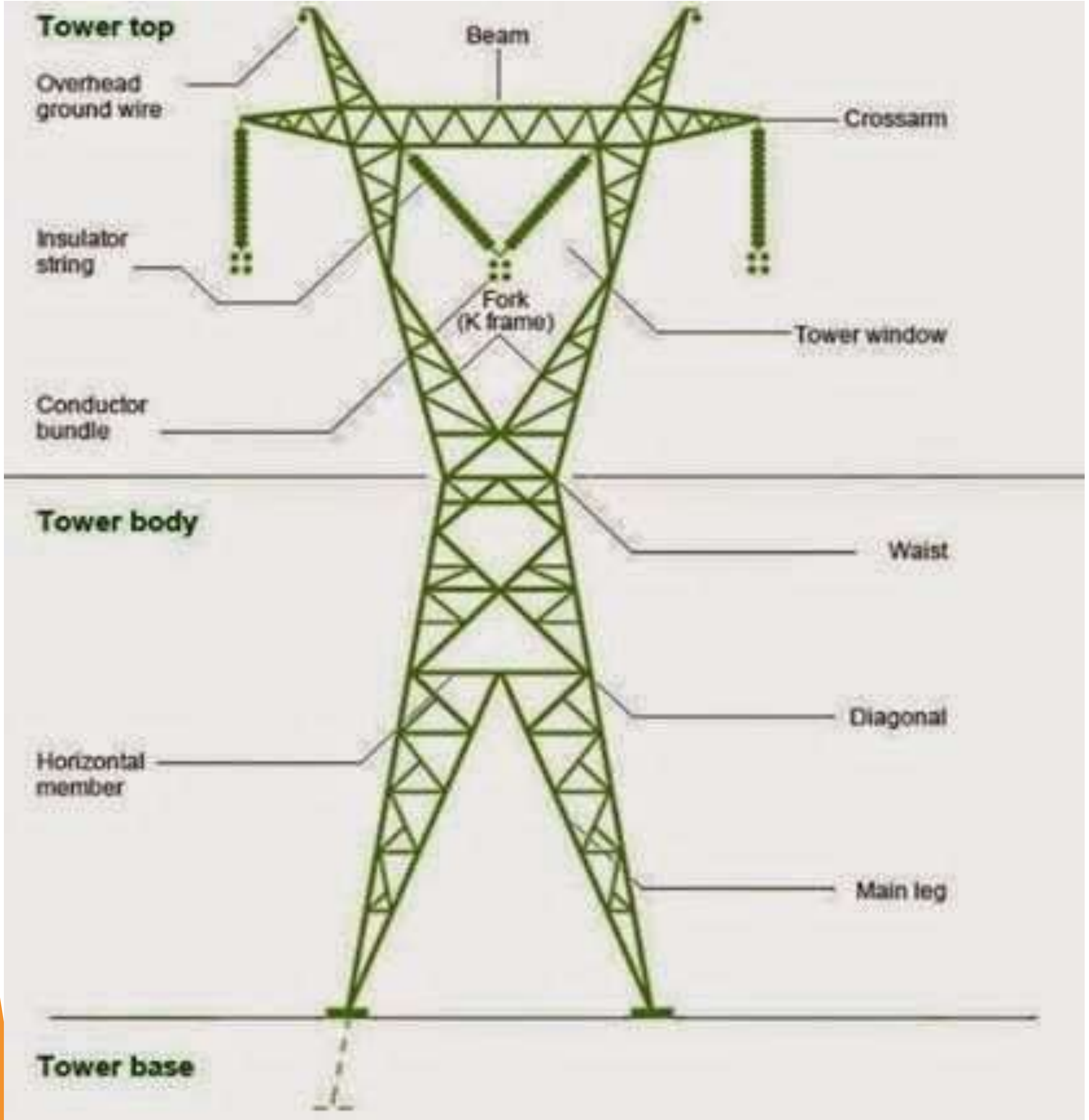

PRIMARY UTILITY DISTRIBUTION
OPTIONAL THROWOVER SWITCH
MICROGRID SMART SWITCH GEAR
BUILDING (TYPICAL)
POWER PRODUCTION - FOSSIL FUELS
SOLAR PV
PAD MOUNTED UTILITY TRANSFORMER (TYPICAL)
BUILDING EMERGENCY GENERATOR SET (TYPICAL)
POWER PRODUCTION RENEWABLE SOURCES SOLAR/WIND BIOMASS/GEOTHERMAL

# Transmission Interconnection

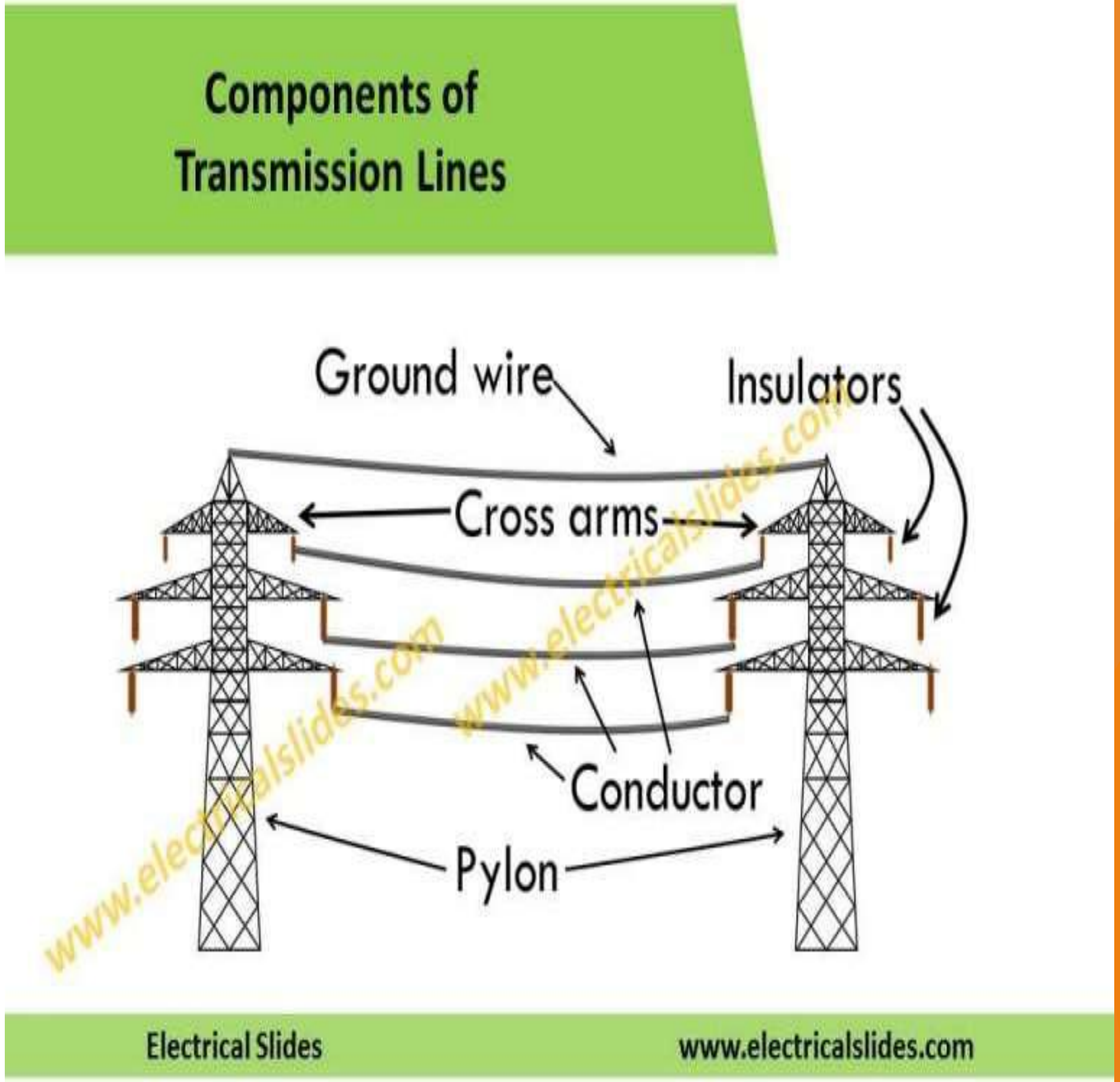
We need these interconnections because, apart from delivery, the purpose of the transmission network is to pool power plants and load centres in order to minimize the total power generation capacity and fuel cost. Transmission interconnections enable taking advantage of diversity of loads, availability of sources, and fuel price in order to supply electricity to the loads at minimum cost with a required reliability. In general, if a power delivery system was made up of radial lines from individual local generators without being part of a grid system, many more generation resources would be needed to serve the load with the same reliability, and the cost of electricity would be much higher. With that perspective, transmission is often an alternative to a new generation resource. Less transmission capability means that more generation resources would be required regardless of whether the system is made up of large or small power plants. In fact small distributed generation becomes more economically viable if there is a backbone of a transmission grid.

# TRANSMISSION OF ELECTRIC POWER

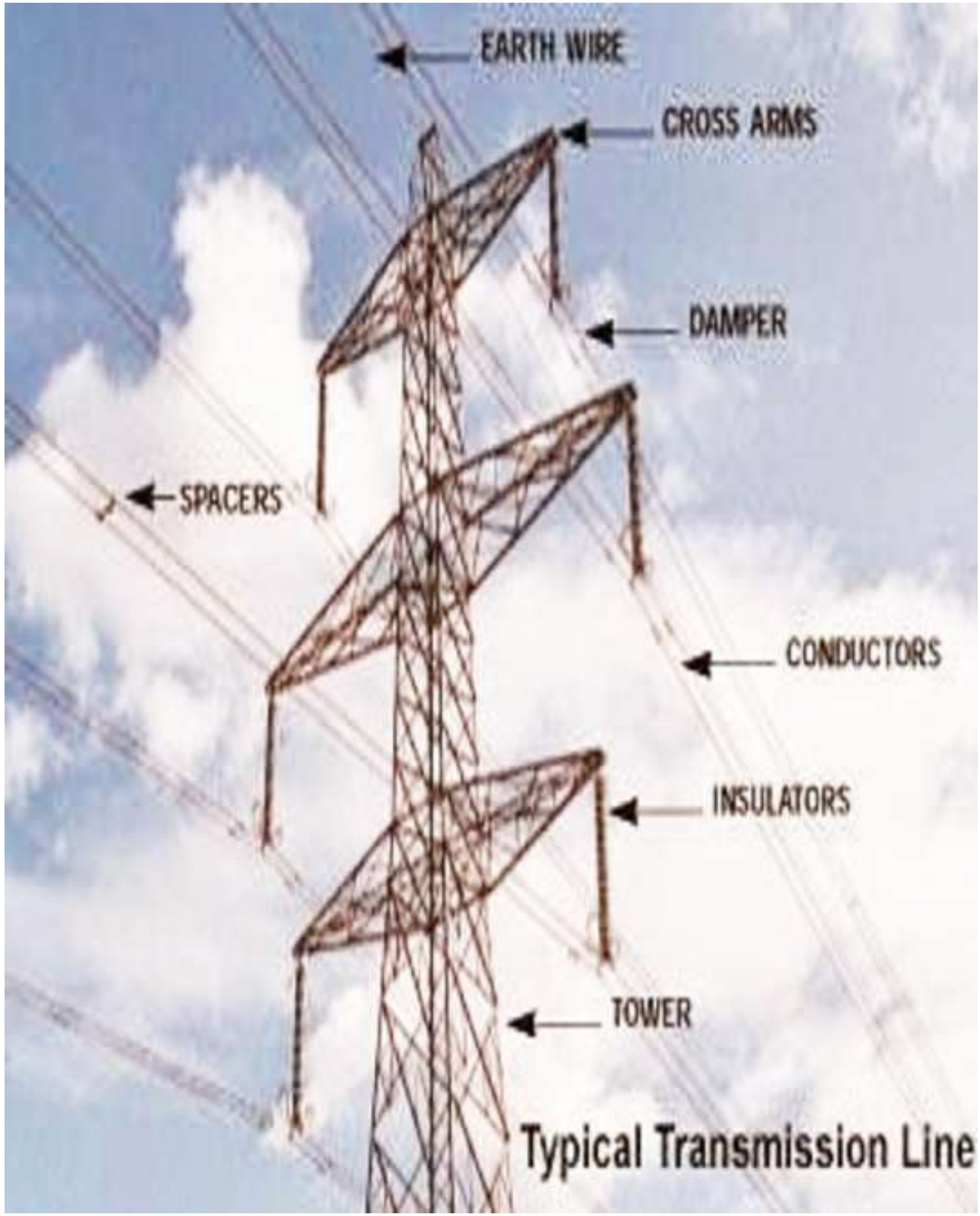




Tower top
Beam
Overhead ground wire
Crossarm
Insulator string
Fork (K frame)
Tower window
Conductor bundle
Tower body
Waist
Diagonal
Horizontal member
Main leg
Tower base

Components of Transmission Lines
Ground wire
Insulators
Cross arms
Conductor
Pylon
Electrical Slides
www.electricalslides.com





Vibration damper



**All Aluminium Conductors**

All Aluminium Alloy Conductors

Aluminium Alloy Conductor Steel Reinforced

Aluminium Conductor Alloy Reinforced

Aluminium Conductor Steel Reinforced

# CLASSIFICATION OF TRANSMISSION SYSTEM

(1) Single phase AC system

- (a) Single phase two wires
- (b) Single phase two wires with mid point earthed
- (c) Singe phase three wires

(2) Two phase AC system

- (a) Two phase three wires
- (b) Two phase four wires

(3) Three phase AC system

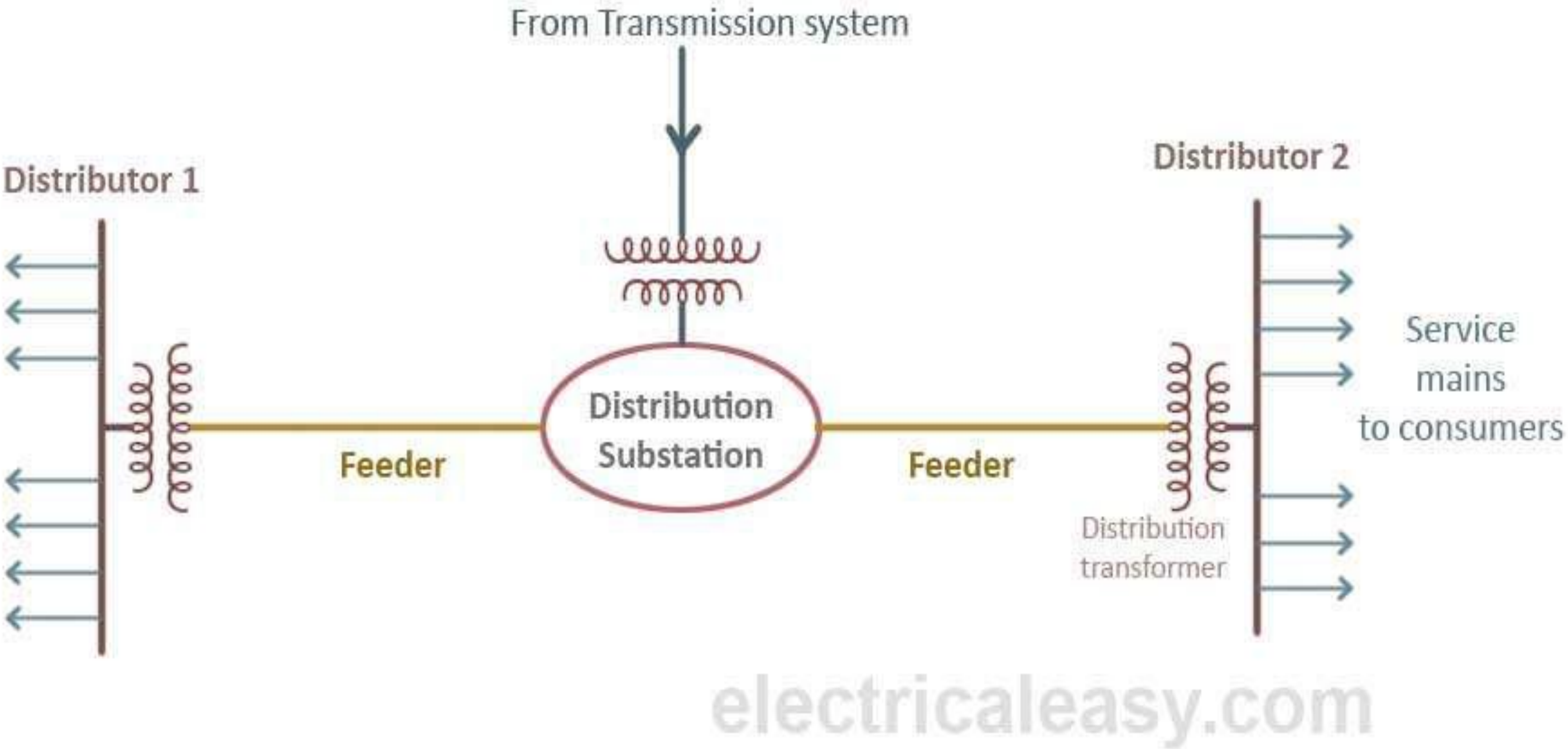
- (a) Three phase three wires
- (b) Three phase four wires

(4) DC system

- (a) DC two wires
- (b) DC two wires with midpoint earthed
- (c) DC three wires

(5) Underground Cables

# DISTRIBUTION OF ELECTRC POWER



# CLASSIFICATION OF DISTRIBUTION SYSTEM

(1) According to nature of current

(a) DC distribution system

(b) AC distribution system

(2) According to type of construction

(a) Over head distribution system

(b) Under ground distribution system

(3) According to scheme of connection

(a) Radial distribution system

(b) Ring main distribution system

(c) Interconnected distribution system

(d) Parallel feeder distribution system

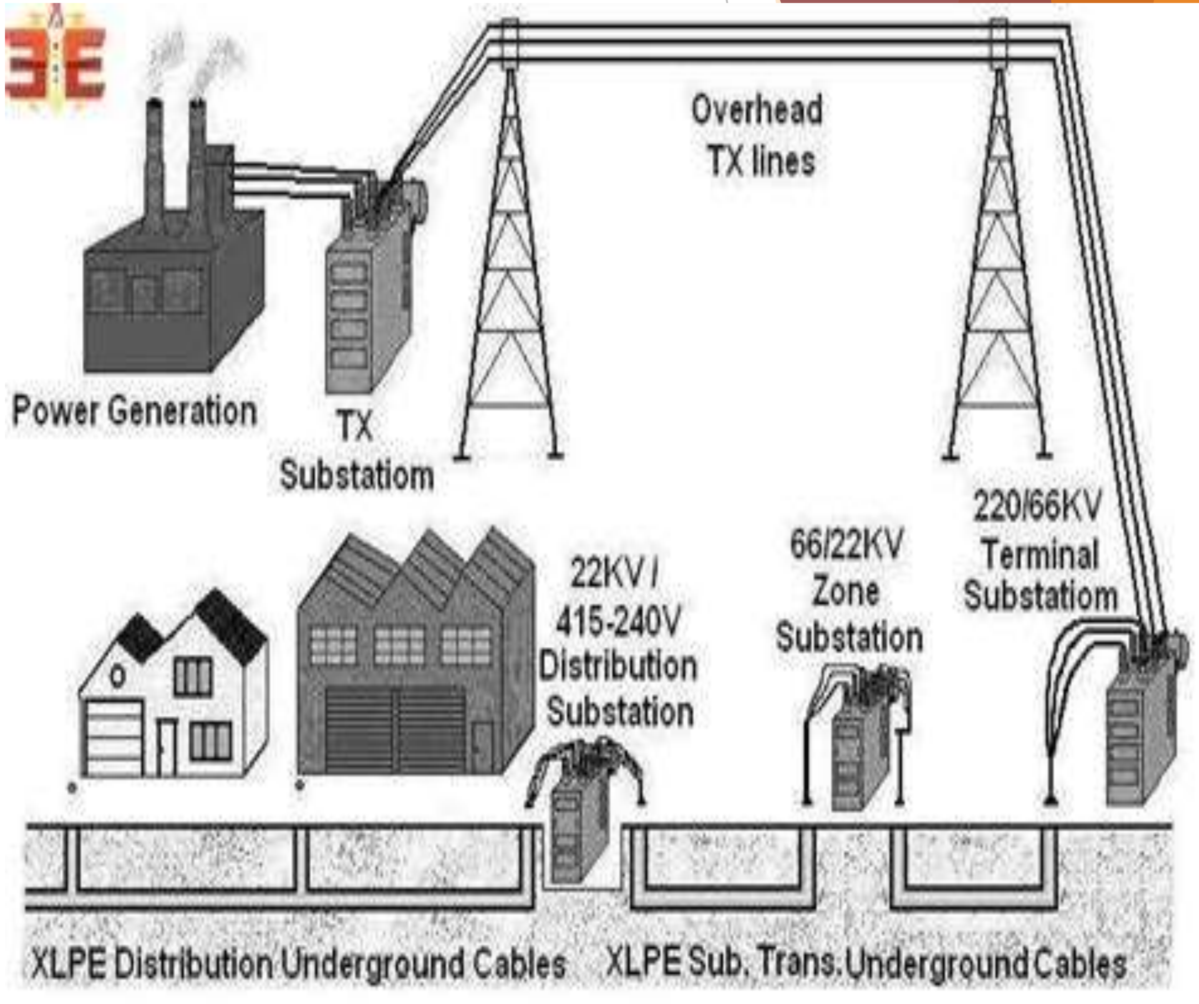
# NATURE OF CURRENT

| Influence parameters | AC distribution line | DC distribution line |
|---|---|---|
| Power transmitted | Less efficiency due to high line loss, hence less power transmission | More efficiency and more power transmission |
| | Require more conductors | Require few conductors |
| System stability | Less stable due to easily affected by external disturbances | More stable and can also increase the stability of the AC microgrid systems |
| Reluctance | Have reactance in the line | No reactance in the line and hence more power transmitted |
| Frequency (50 Hz or 60 Hz) | Frequency monitoring is mandatory | Frequency is zero, so no need of |
| | Transient stability due line clearance and | frequency monitoring |
| | Switching are problems | No transient stability problems |
| | Electromagnetic interference must be taken into consideration | No electromagnetic interference |
| Resistance | High line resistance and hence high losses | Have low line resistance and hence low line losses |
| Susceptance | Charging current and over-voltage problem lead to high cost and low power transmission | Do not exist, and hence effect of overvoltage and over-charging leading low cost and high power transmission |
| Analysis | Involve complex numbers and hence difficult to analyze | Involve only real numbers i.e. more simple |

# TYPE OF CONSTRUCTION

## OVER HEAD

## UNDER GROUND

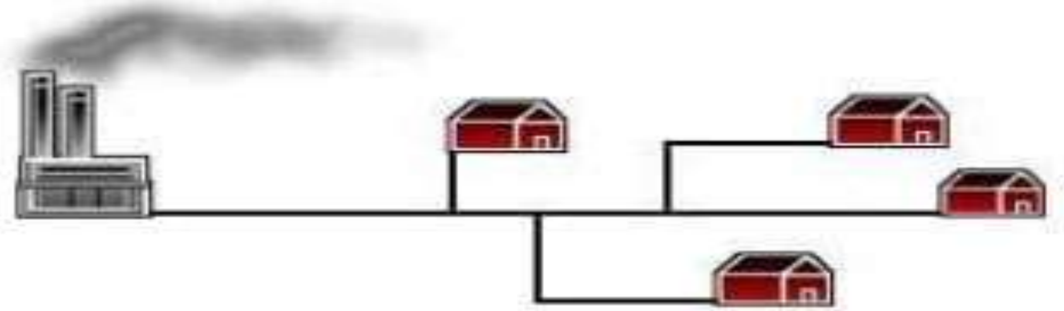


# ACCORDING TO SCHEME OF CONNECTION



## Radial Distribution System:

- separate feeders radiate from a single substation and feed the distributors at one end only.
- Only one path is connected between each customer and substation.
- Electrical power flows along a single path.
- If interrupted, results in complete loss of power to the customer.

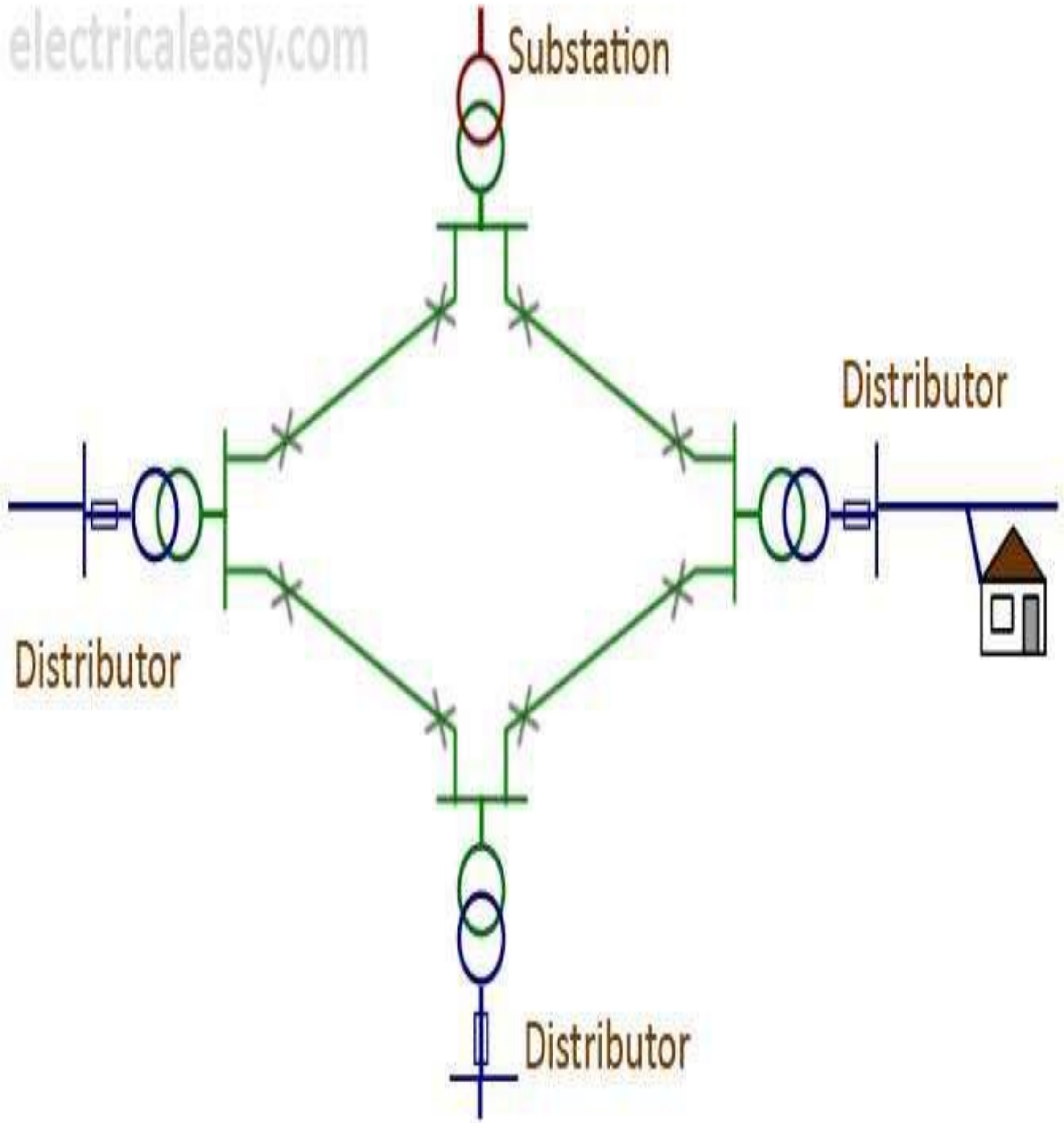


**Advantages:**

- Low cost .
- Simple planning.

**Disadvantages :**

- The radial system is employed only when power is generated at low voltage and the substation is located at the centre of the load.
- Distributor nearer to feeding end is heavily loaded.
- Consumers at far end of feeder would be subjected to serious voltage fluctuations.



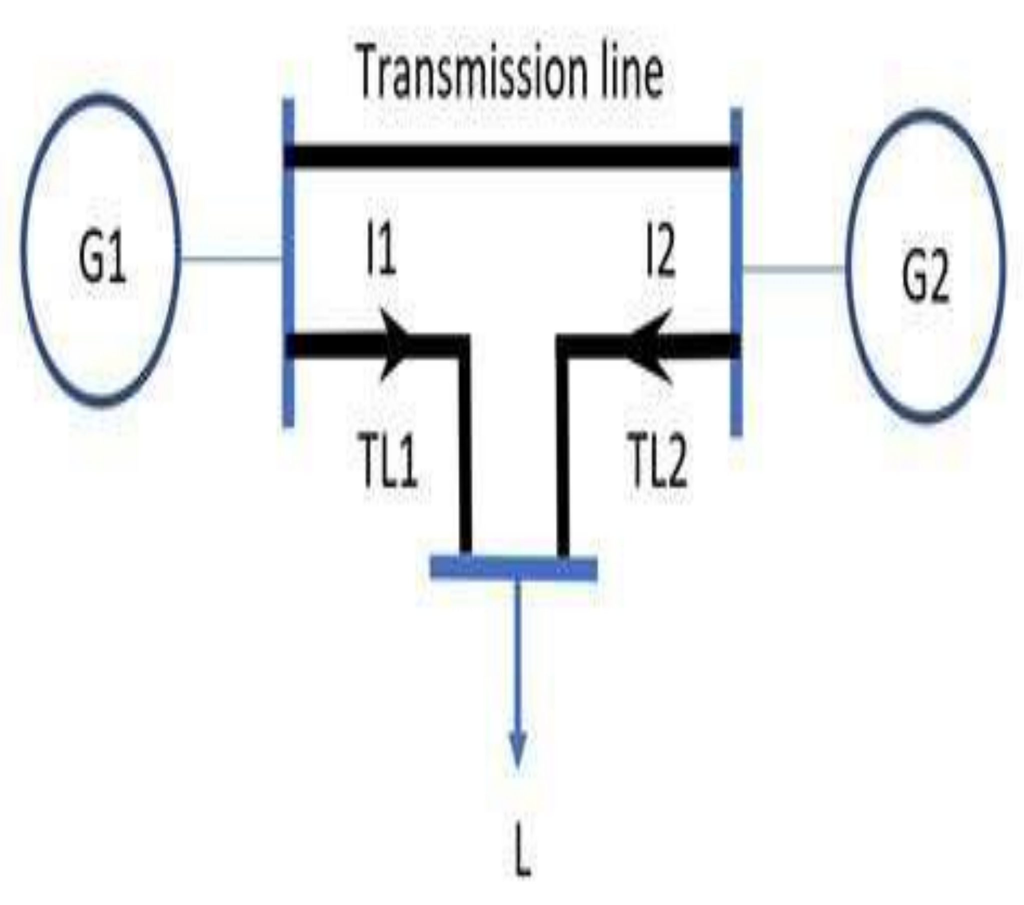

# Ring System...

- The supply main is laid all along the peripheral roads and sub mains branch out from the mains.
- This system also follows the grid iron system with the flow pattern similar in character to that of dead end system.
- So, determination of the size of pipes is easy.

# INTERCONNECTED DISTRIBUTION SYSTEM

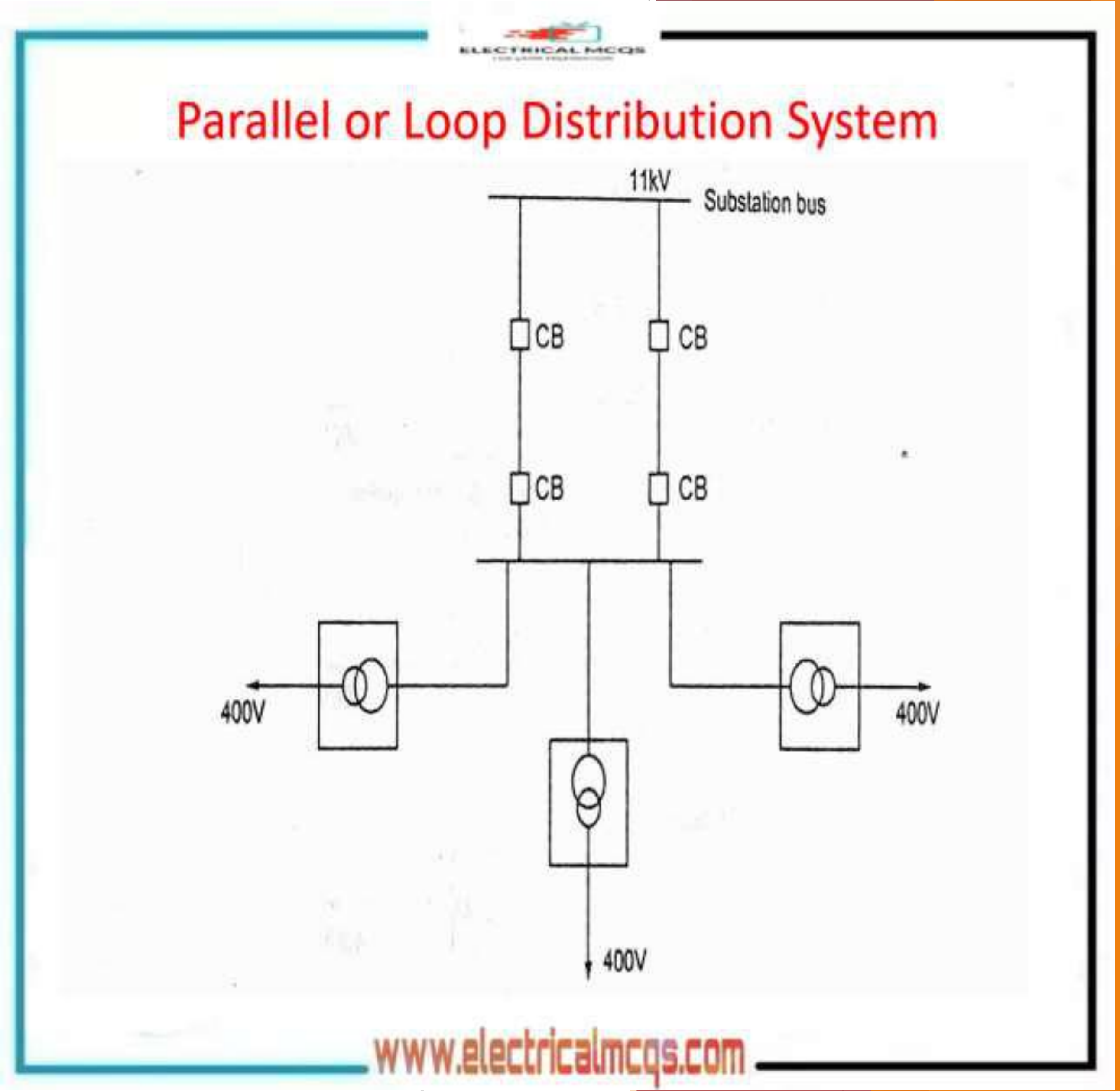
When a ring main feeder is energized by two (or) more substations (or) generating stations it is called as an interconnected distribution system.

This system ensures reliability in an event of transmission failure. Also any area fed from one generating stations during peak load hours can be fed from the other generating station (or) substation for meeting power requirements from increased load.

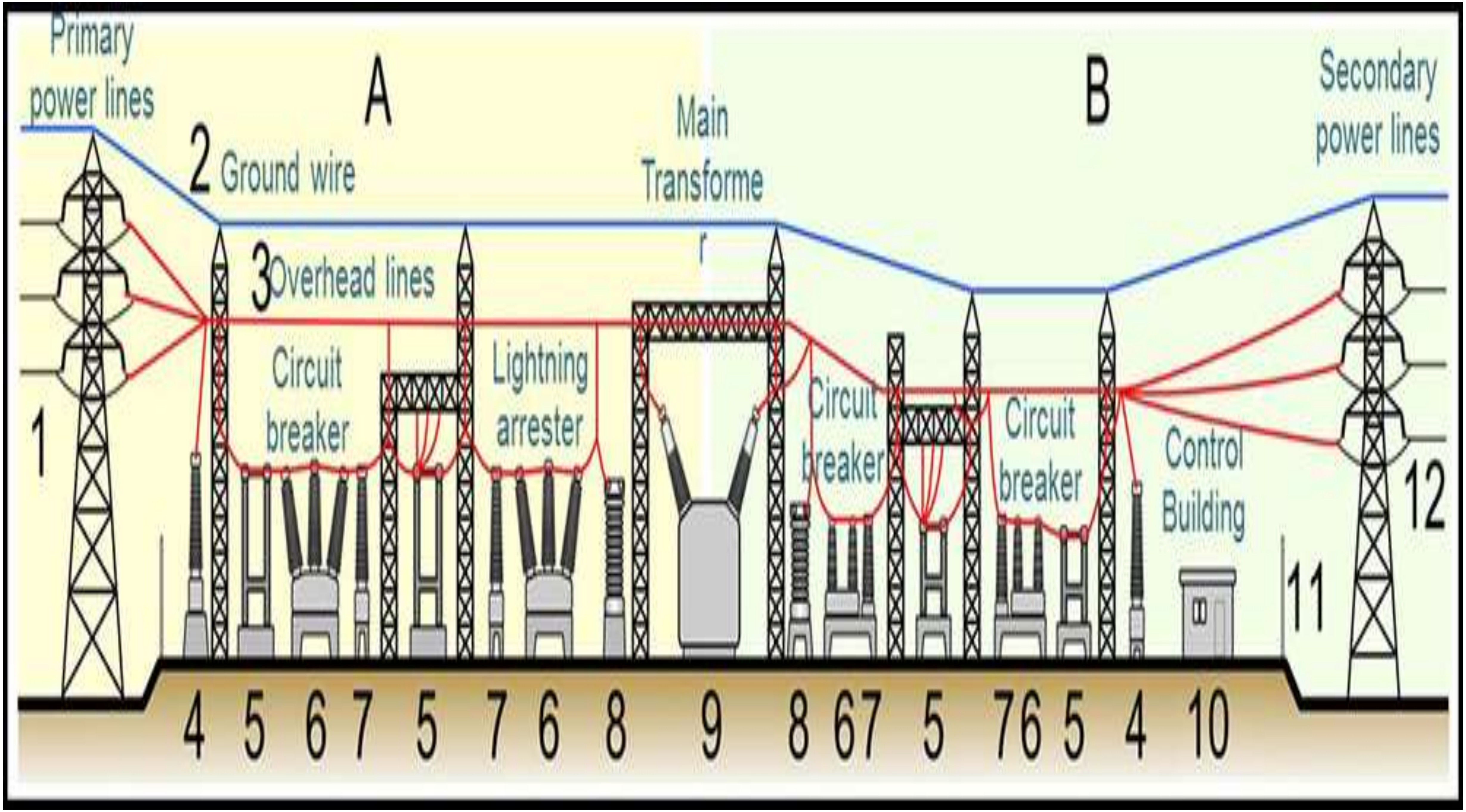


The initial cost of this system is much more as the number of feeders is doubled.

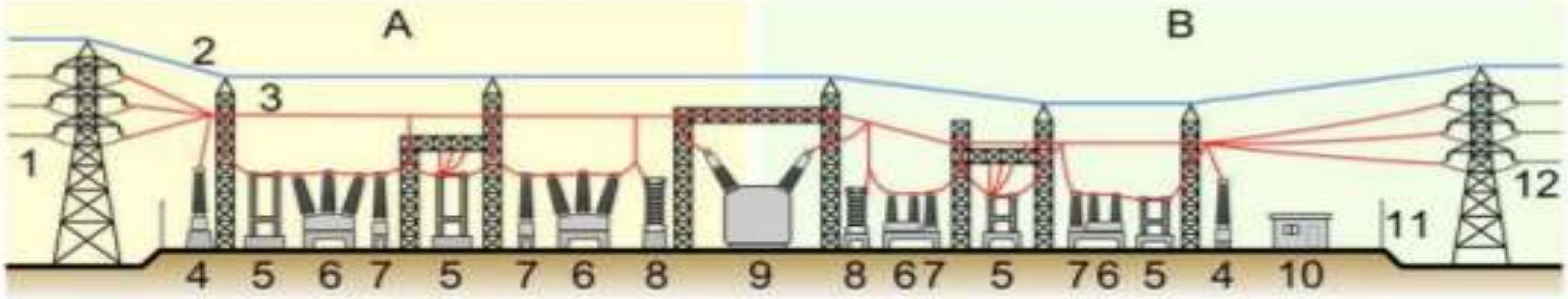
Such system may be used where reliability of the supply is important (or) for long sharing where the loads is high.



# AIR AND GAS INSULATED SUBSTSTIONS


Primary power lines
A
B
Secondary power lines
2 Ground wire
Main Transforme r
3 Overhead lines
Circuit breaker
Lightning arrester
Circuit breaker
Circuit breaker
Control Building
1
12
11
4 5 6 7 5 7 6 8 9 8 6 7 5 7 6 5 4 10

# Sub-station Layout




A:Primary power lines' side

1. Primary power lines
2. Ground wire
3. Overhead lines
4. Transformer for measurement of electric voltage
5. Disconnect switch
6. Circuit breaker
7. Current transformer
8. Lightning arrester

B: Secondary power lines' side

7. Current transformer
8. Lightning arrester
9. Main transformer
10. Control building
11. Security fence
12. Secondary power lines

# DEFINITION OF SUBSTATION

A substation may be defined ad an assembly of apparatus installed to perform any one (or) more (or) all of the following operation

- To switch 'ON' and 'OFF' the power lines known as switching operation.
- To transform voltage from higher to lower (or) lower to higher known as voltage transformation operation.
- To convert 'AC' to 'DC' (or) vice-versa known as power conversion operation.
- To convert frequencies from higher to lower (or0 lower to higher frequency converting operation.
- To improve the power factor by installing synchronous condensers at the end of the line, known as power factor correction operation.

# CLASSIFICATION OF SUBSTATIONS

1. Based on service
    a) Static (alternating )
    b) Converting
2. Based on function
    a) extra high voltage transmission
    b) distribution
    c) industrial
    d) power factor correction
    e) frequency changer

3. Type of apparatus

a) Transformer

i) Step Up (or) primary substations

ii) step up and step down (or) secondary substations

iii) step down (or) distribution substation.

b) Rotary converter

c) Rectifier

d) Motor generator

4. based on control

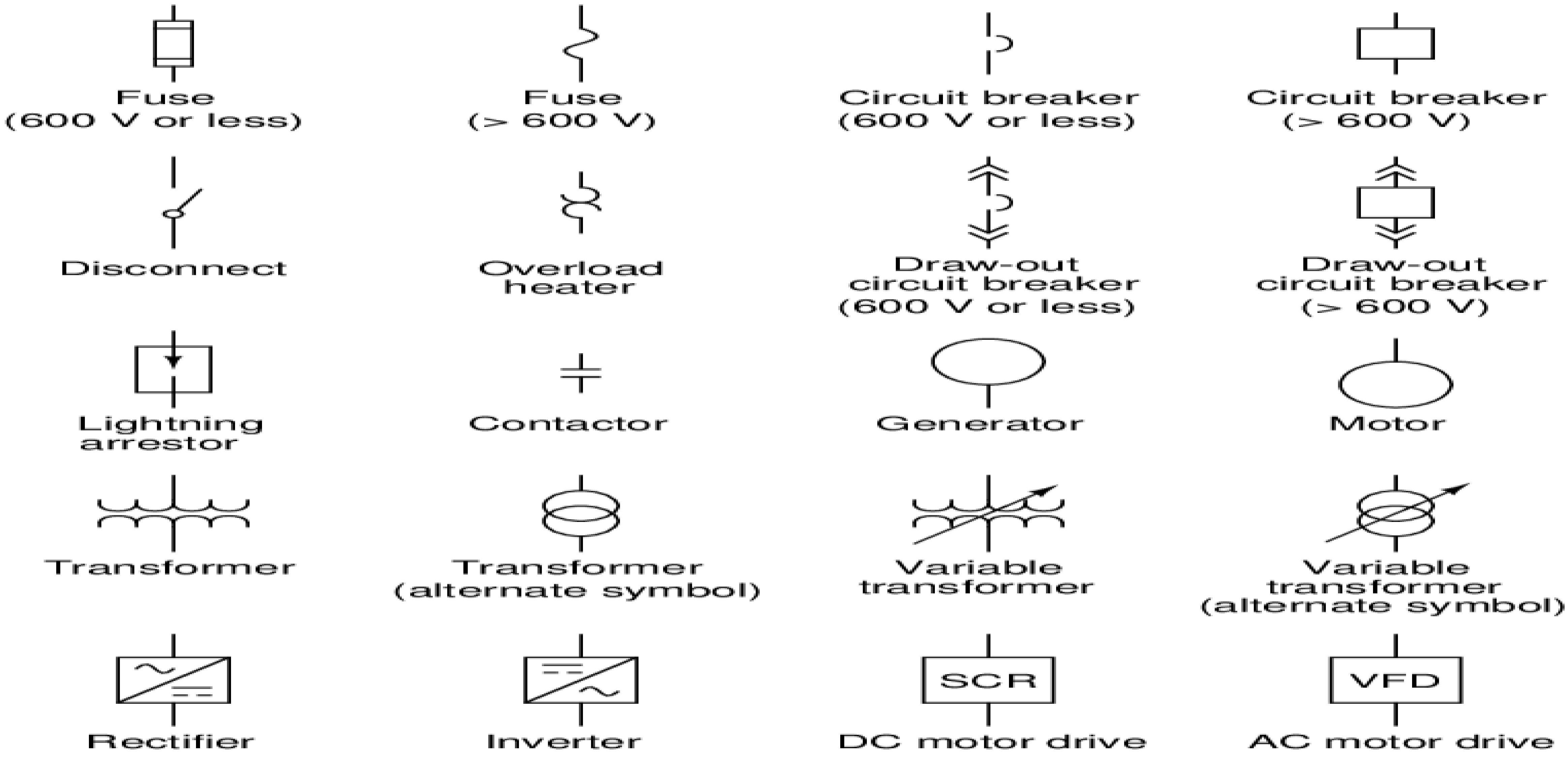
a) manual

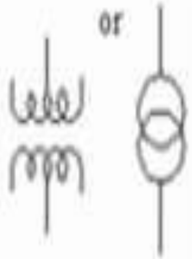
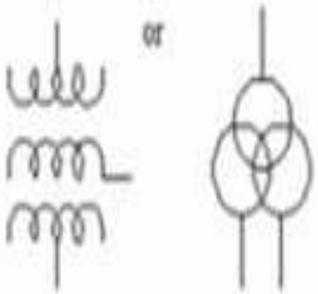
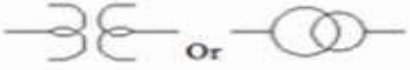
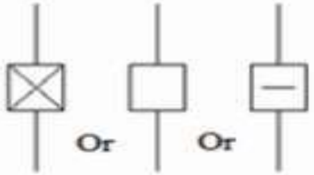
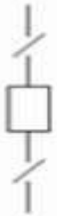
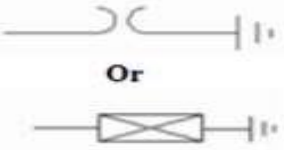
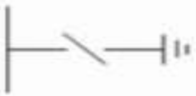
b) Automatic

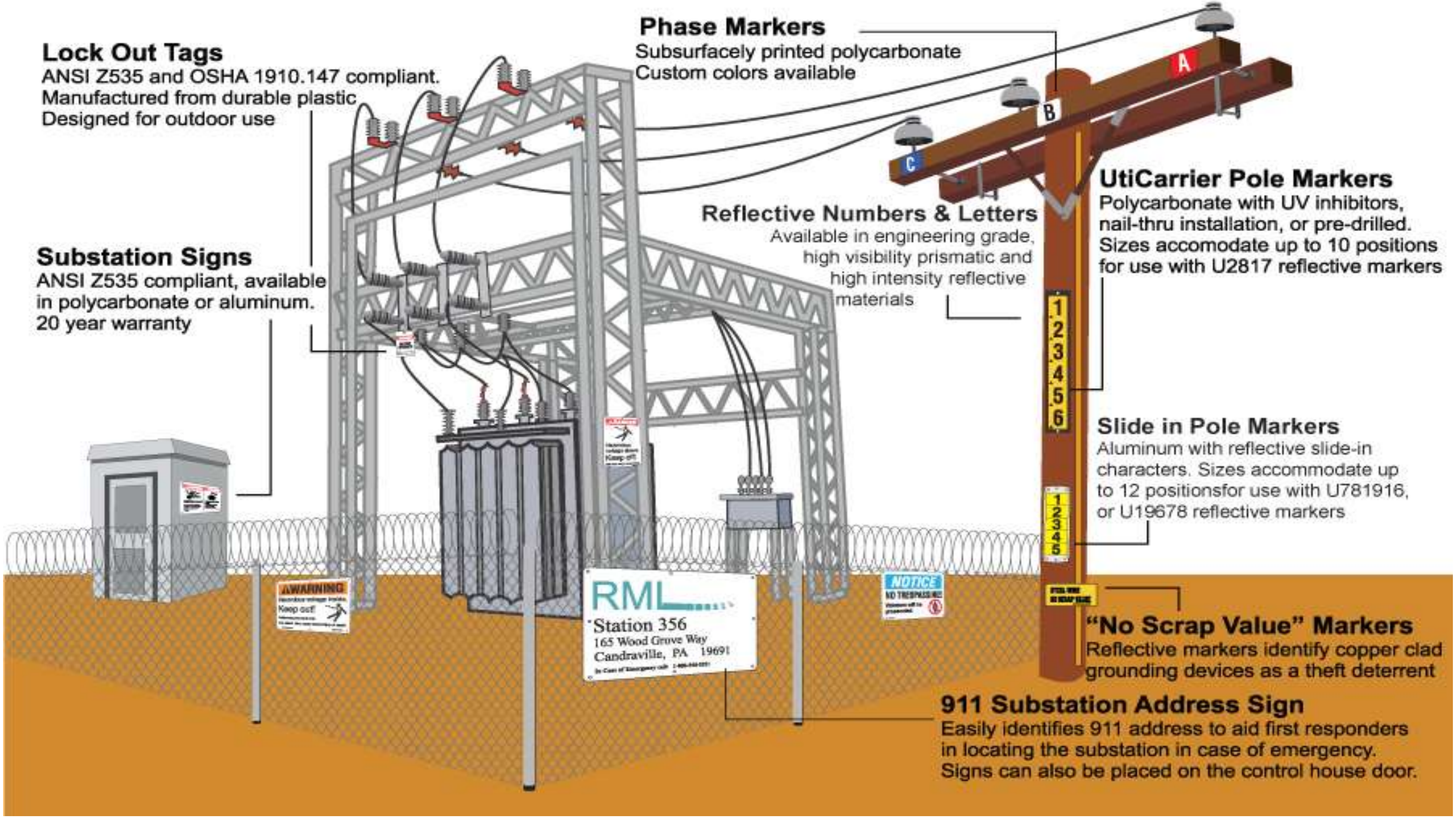
c) Supervisory

5. Constructional
    a) Under ground
    b) Indoor
    c) Outdoor
    d) pole mounted
    e) plinth mounted
6. Insulation
    a) AIS (Air Insulated Substation)
    b) GIS (Gas Insulated Substation)

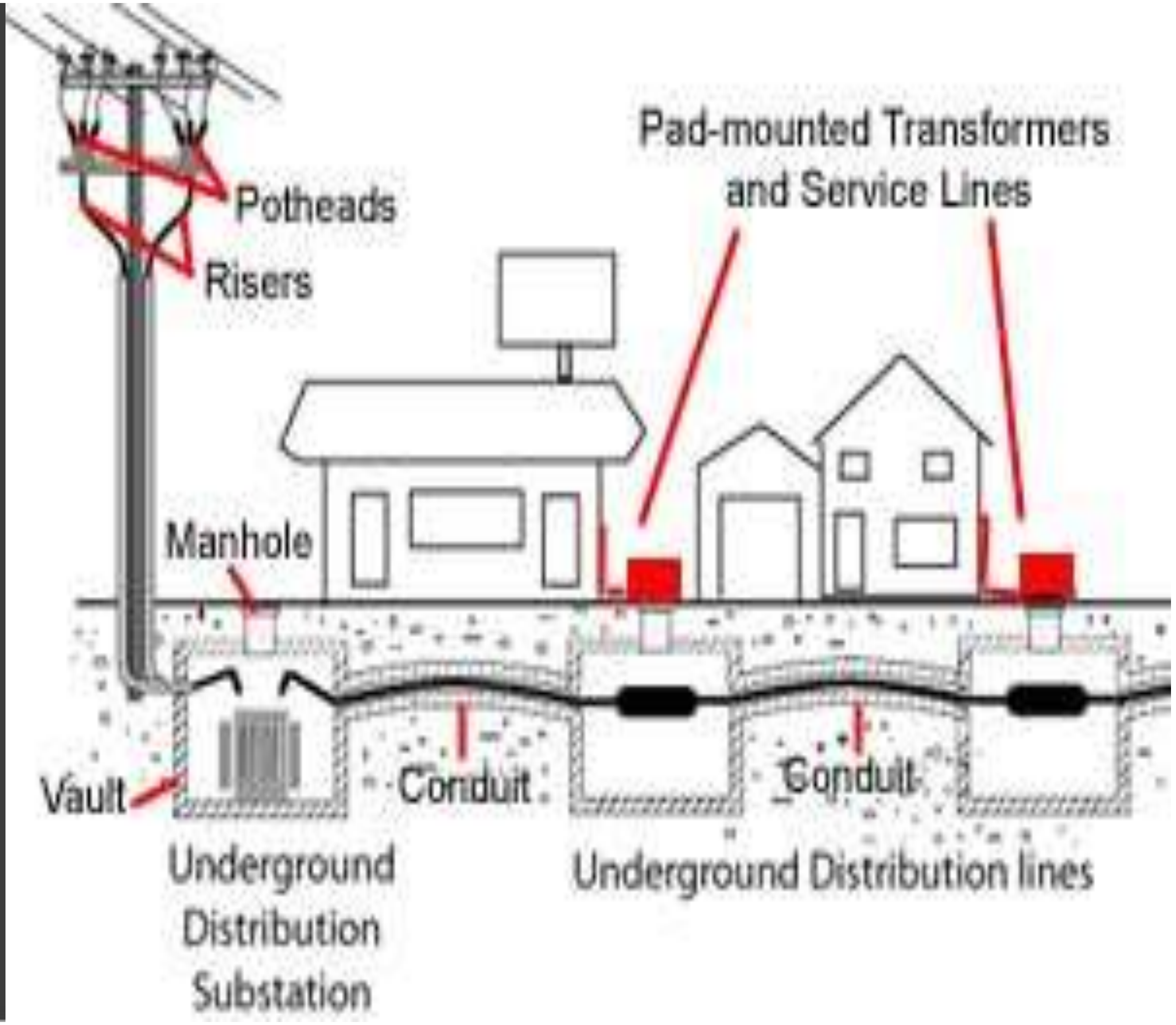
# SYMBOLS FOR EQUIPMENT IN SUBSTATION



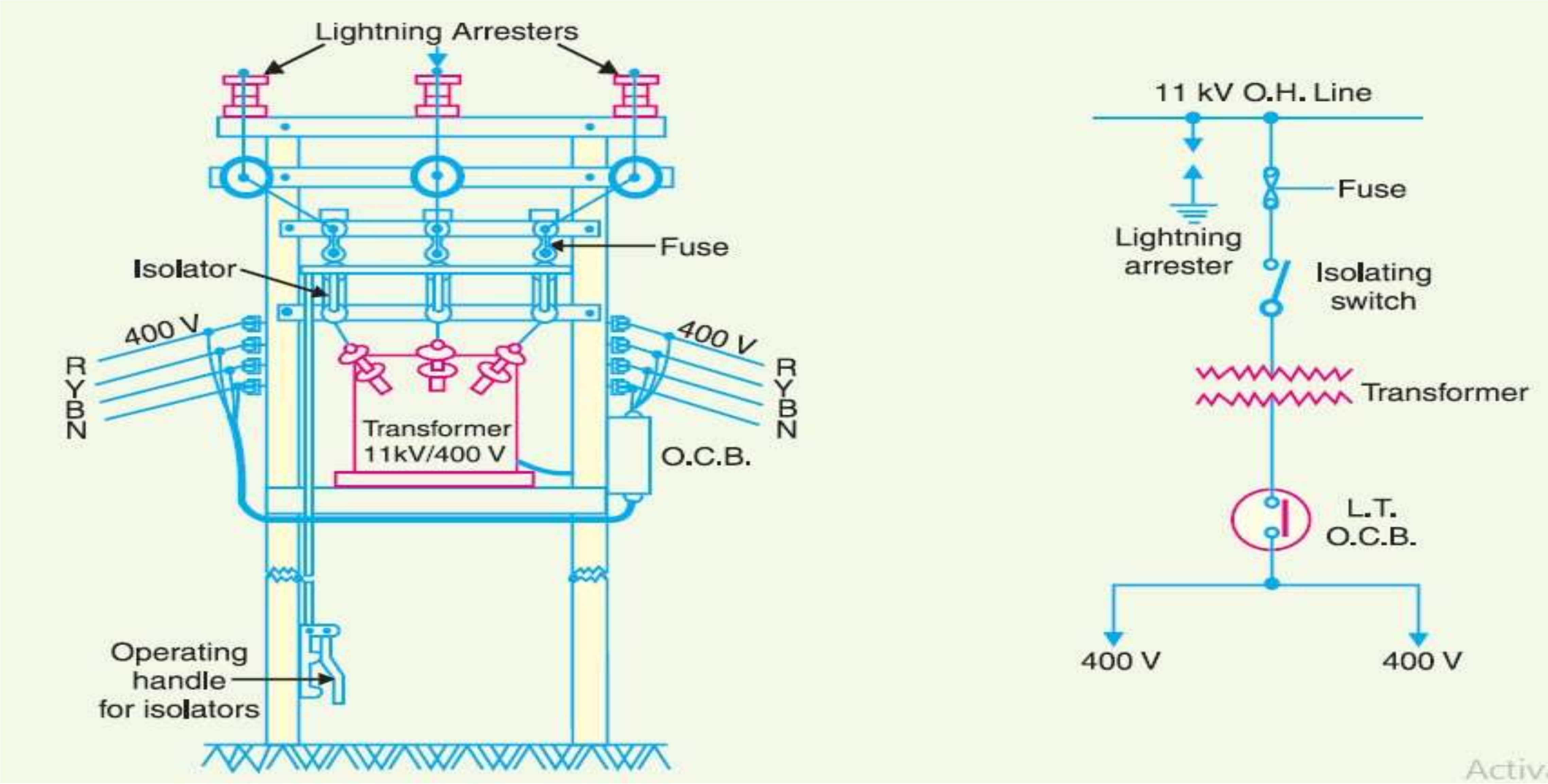
| Sl No | Electrical components | Symbols |
|---|---|---|
| 1 | AC Generator |  |
| 2 | Bus Bar |  |
| 3 | Power transformer -Two winding |  |
| 4 | Three winding transformer |  |
| 5 | Current Transformer (CT) |  |
| 6 | Voltage transformer or Potential transformer (PT) |  |
| 7 | Circuit Breaker (CB) |  |
| 8 | Circuit breaker with isolator |  |
| 9 | Isolator or Group Operating Switch(GOS) |  |
| 10 | Lighting Arrestor (LA) |  |
| 11 | Earth Switch (ES) |  |
| 13 | Wave or Line trap |  |

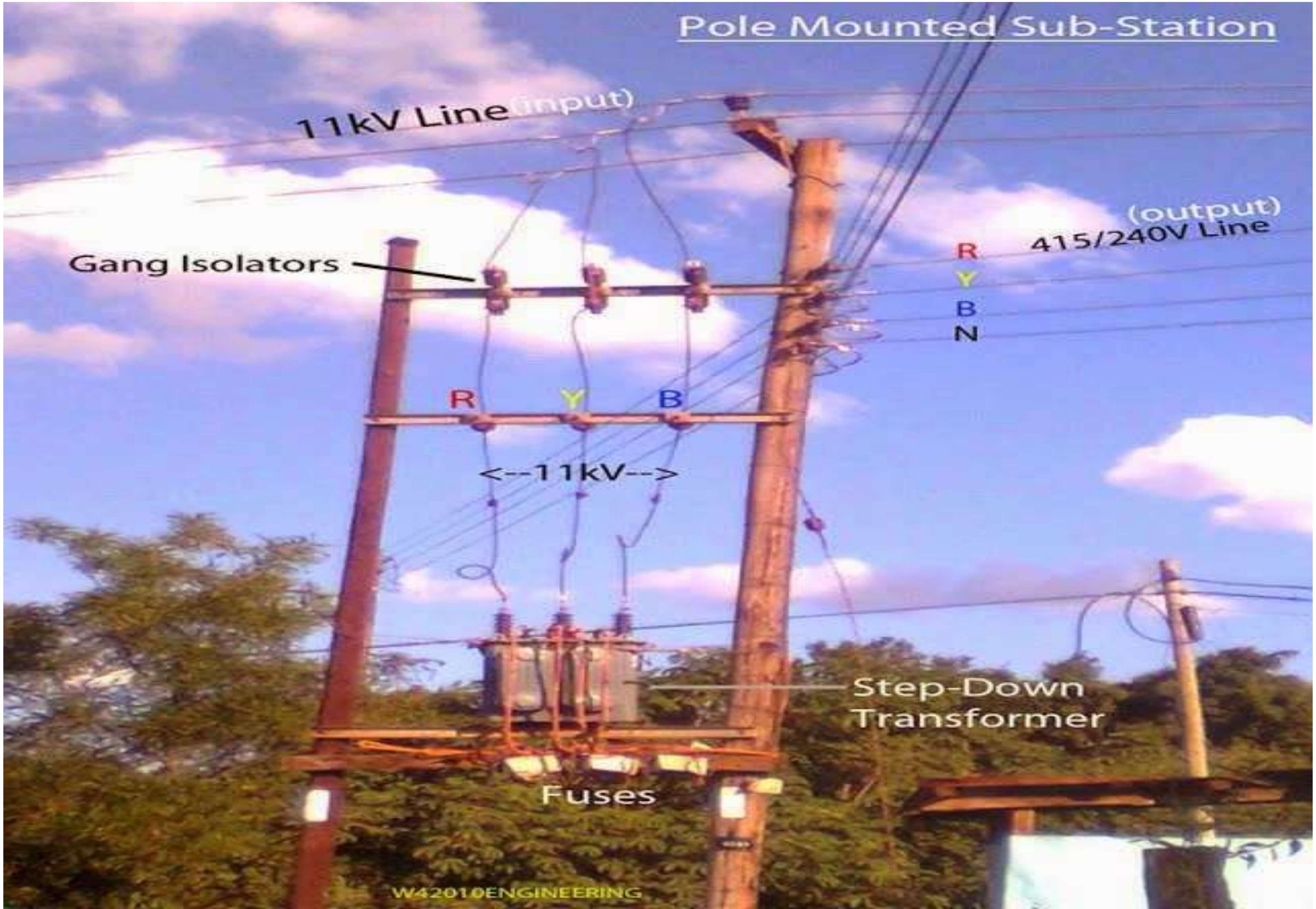

Lock Out Tags
ANSI Z535 and OSHA 1910.147 compliant.
Manufactured from durable plastic
Designed for outdoor use
Phase Markers
Subsurfacely printed polycarbonate
Custom colors available
A
B
C
Substation Signs
ANSI Z535 compliant, available
in polycarbonate or aluminum.
20 year warranty
Reflective Numbers & Letters
Available in engineering grade,
high visibility prismatic and
high intensity reflective
materials
UtiCarrier Pole Markers
Polycarbonate with UV inhibitors,
nail-thru installation, or pre-drilled.
Sizes accomodate up to 10 positions
for use with U2817 reflective markers
1 2 3 4 5 6
Slide in Pole Markers
Aluminum with reflective slide-in
characters. Sizes accommodate up
to 12 positionsfor use with U781916,
or U19678 reflective markers
1 2 3 4 5
WARNING
Keep out!
RML
Station 356
165 Wood Grove Way
Candraville, PA 19691
NOTICE
“No Scrap Value” Markers
Reflective markers identify copper clad
grounding devices as a theft deterrent
911 Substation Address Sign
Easily identifies 911 address to aid first responders
in locating the substation in case of emergency.
Signs can also be placed on the control house door.

# UNDER GROUND SUBSTATION

# OUTDOOR SUBSTATION LAYOUT

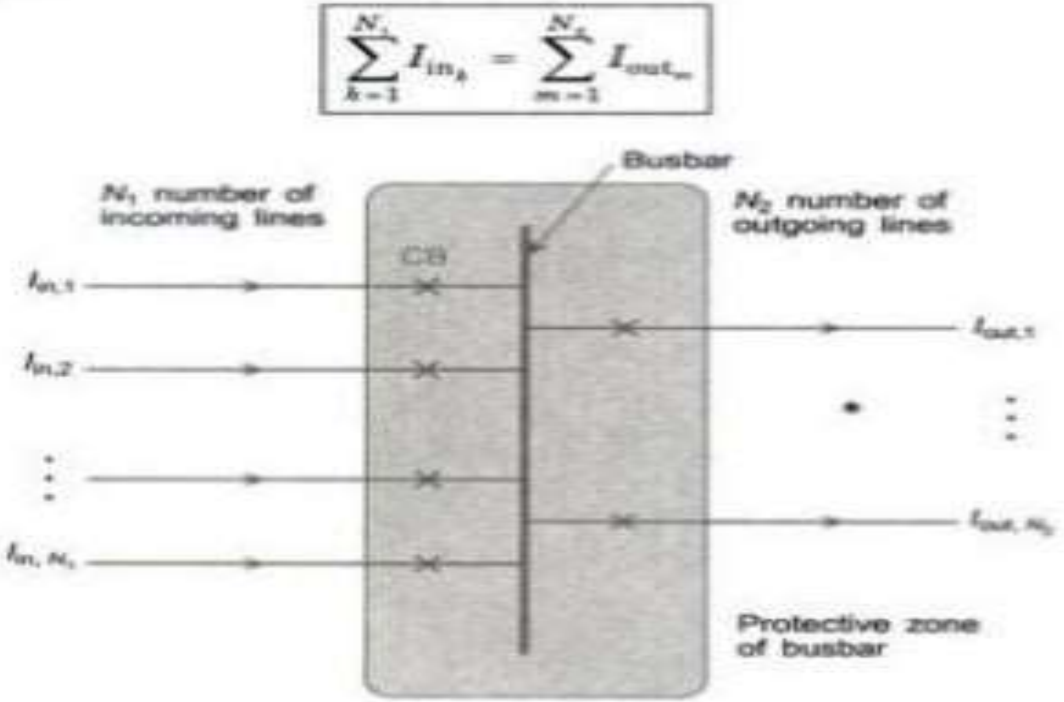


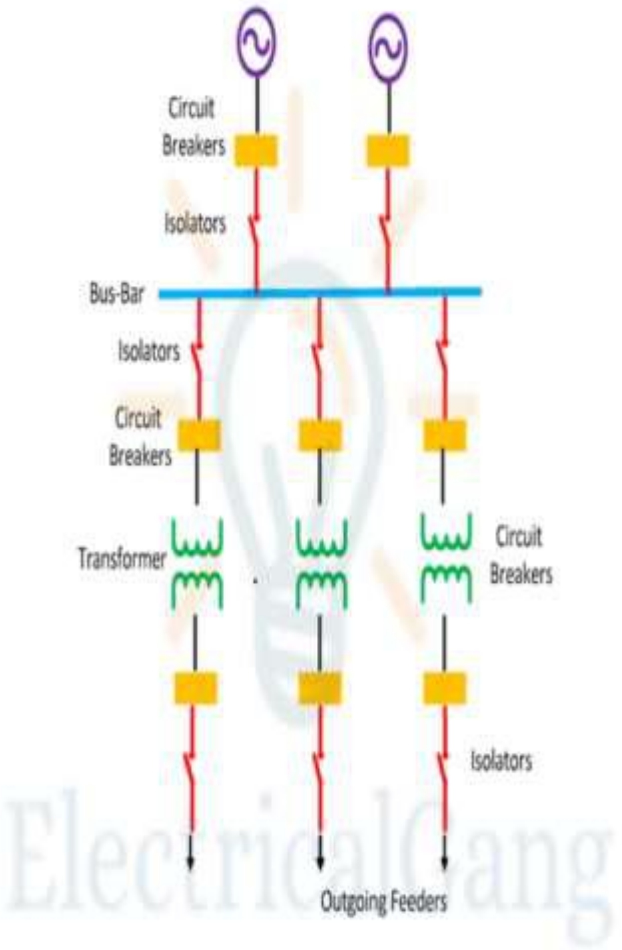

Pole Mounted Sub-Station
11kV Line (input)
(output)
415/240V Line
R
Y
B
N
Gang Isolators
R
Y
B
<--11kV-->
Step-Down
Transformer
Fuses
W42010ENGINEERING

# BUS BAR ARRANGEMENTS IN THE SUBSTATION

## What is a bus bar?

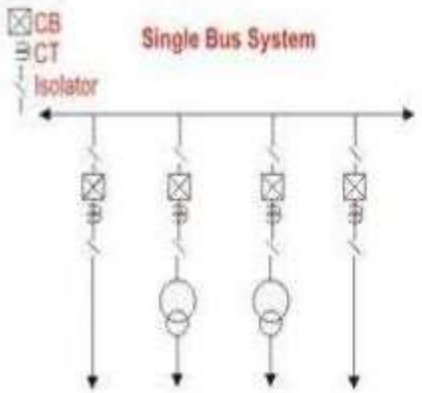
- Bus is derived from Latin word "OMNIBUS" (common for all)
- Nerve centre of the power system where various circuits are connected together.






Single Bus-Bar Arrangement

# SINGLE BUS SYATEM




**Advantages:**

**1.Simple in Design**

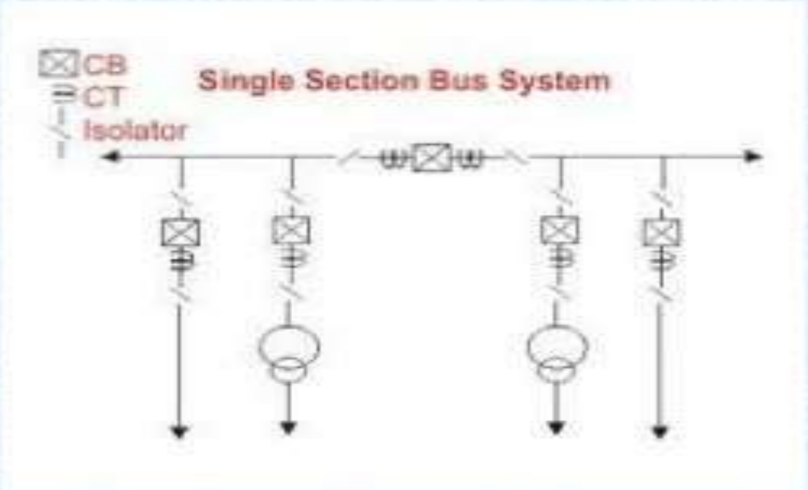
**2.Less Expenditure**

**Disadvantages:**

**1.In case of bus fault or bus bar isolator fault or maintenance total Substation is out of service.**

**2.In case of maintenance of transformer circuit breaker the associated transformer has also to be shut-down. Similarly for Line also.**

# SINGLE BUS WITH BUS SECTIONALISER



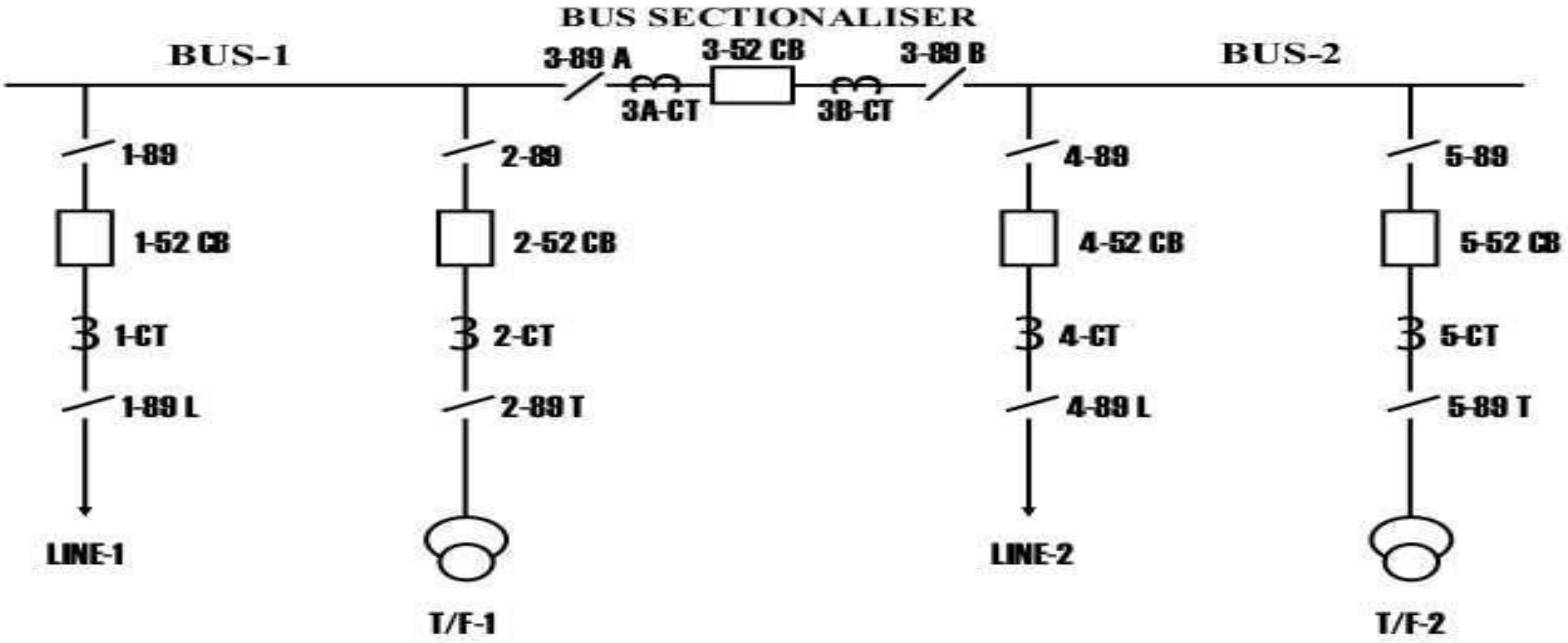

**Advantages:**

1. One complete section can be taken out for Maintenance without disturbing the continuity of other section.
2. If a fault occurs on one section of the Bus, that faulty section alone will be isolated.

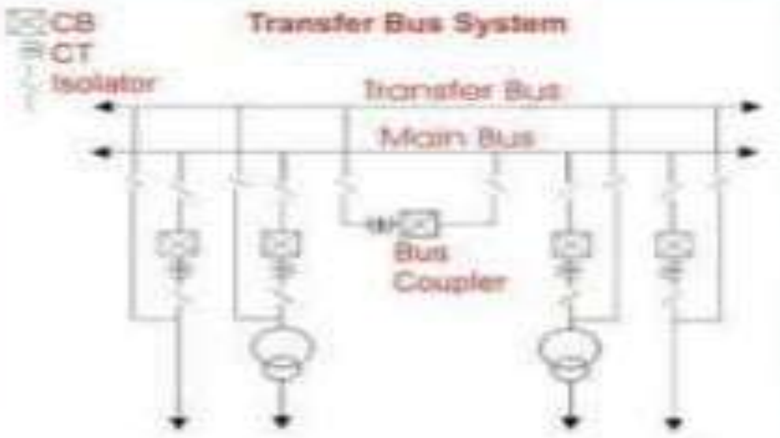
**Disadvantages:**

It will be a little more costly with the addition of one isolator and some cases with Circuit breaker, C.Ts and C&R panel.

# SINGLE BUS WITH CB SECTIONALISER SYSTEM



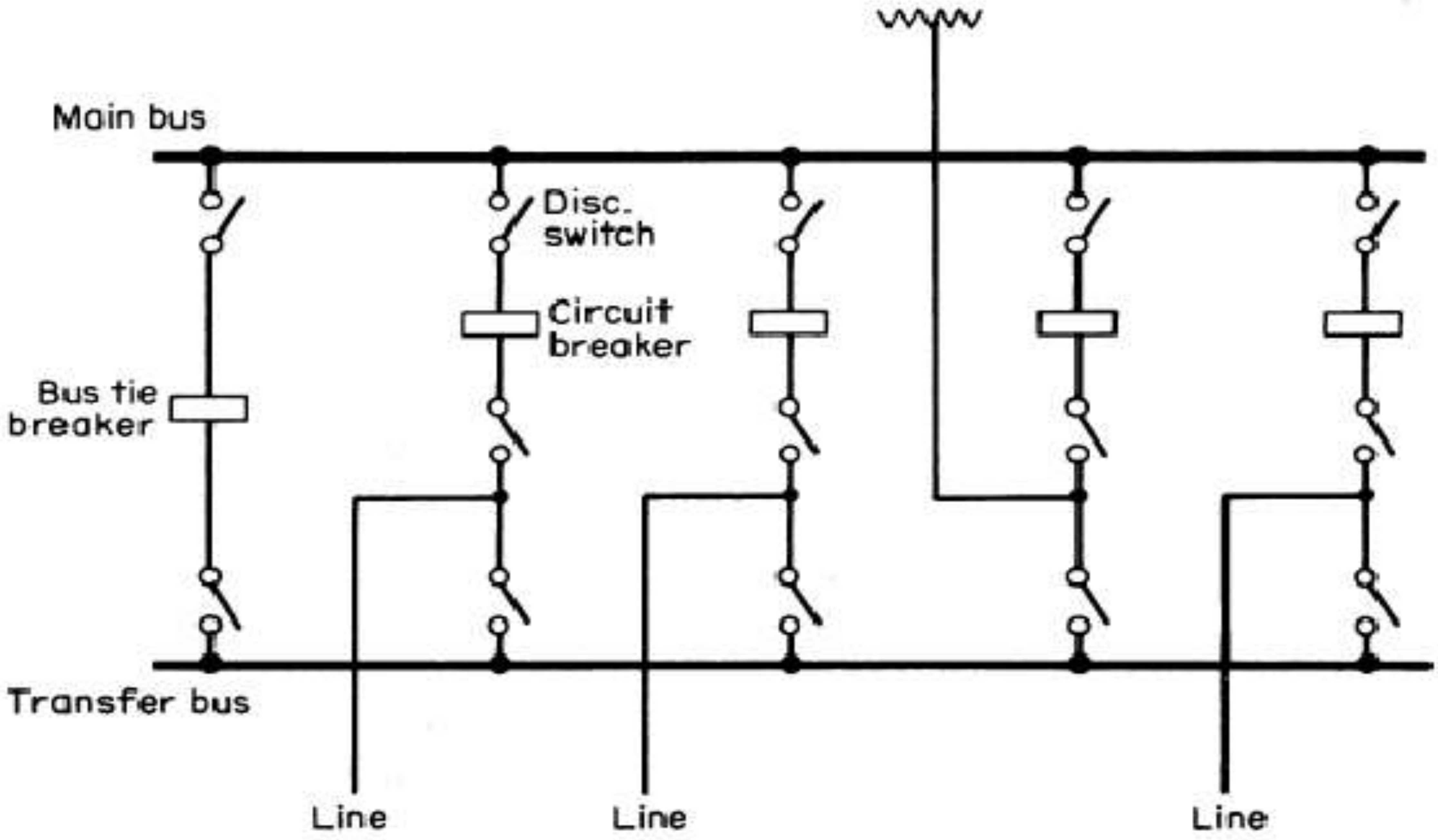
# MAIN AND TRANSFER BUS SYSTEM




## Switching operation:

1.First close the isolators at both side of the bus coupler breaker.
2. Then close the bypass isolator of the feeder which is to be transferred to transfer bus.
3. Now energized the transfer bus by closing the bus coupler circuit breaker from remote.

4.After bus coupler breaker is closed, now the power from main bus flows to the feeder line through its main breaker as well as bus coupler breaker viatransfer bus.
5. Now if main breaker of the feeder is switched off, total power flow will instantaneously shift to the bus coupler breaker and hence this breaker will serve the purpose of protection for the feeder.
6. At last the operating personnel open the isolators at both sides of the main circuit breaker to make it isolated from rest of the live system.



Main bus
Disc.
switch
Circuit
breaker
Bus tie
breaker
Transfer bus
Line
Line
Line

# GAS INSULATED SUBSTATIONS

# GIS – GAS INSULATED SUBSTATION

**Gas Insulated Substations (GIS)** is a compact, **multicomponent assembly** enclosed in a ground metallic housing in which the primary insulating medium is compressed **Sulphur hexafluoride (SF6)** gas.

**SF6** acts as an **insulation** between **live parts** & the **earthed metal closure.**

- The introduction of SF6 gas has revolutionized not only the technology of circuit breakers but also the layout of substations.
- The dielectric strength of SF6 gas at atmospheric pressure is approximately three times that of air.
- It is incombustible, non toxic, colorless and chemically inert.
- It has arc-quenching properties 3 to 4 times better than air at equal pressure.
- Space requirement is only 10 to 25 percent of what is required is a conventional substation.

# Components of GIS substation

1. Circuit breaker
2. Disconnector switch
3. Earthing switch
4. Current transfomer
5. Voltage transformer
6. Bus bar & connectors
7. Power transformer
8. Surge arrester
9. Cable termination
10. SF6 / air or SF6 / oil bushing

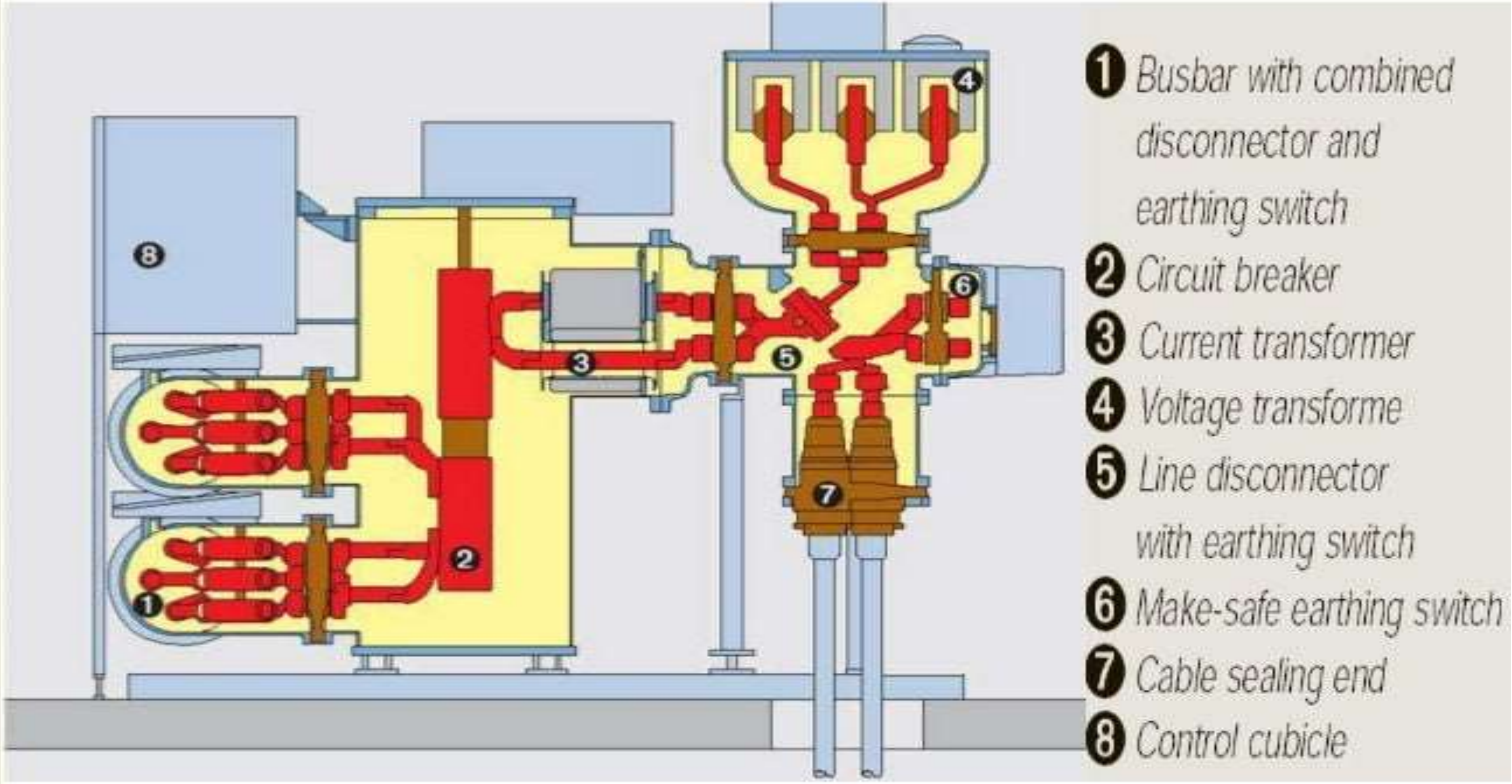
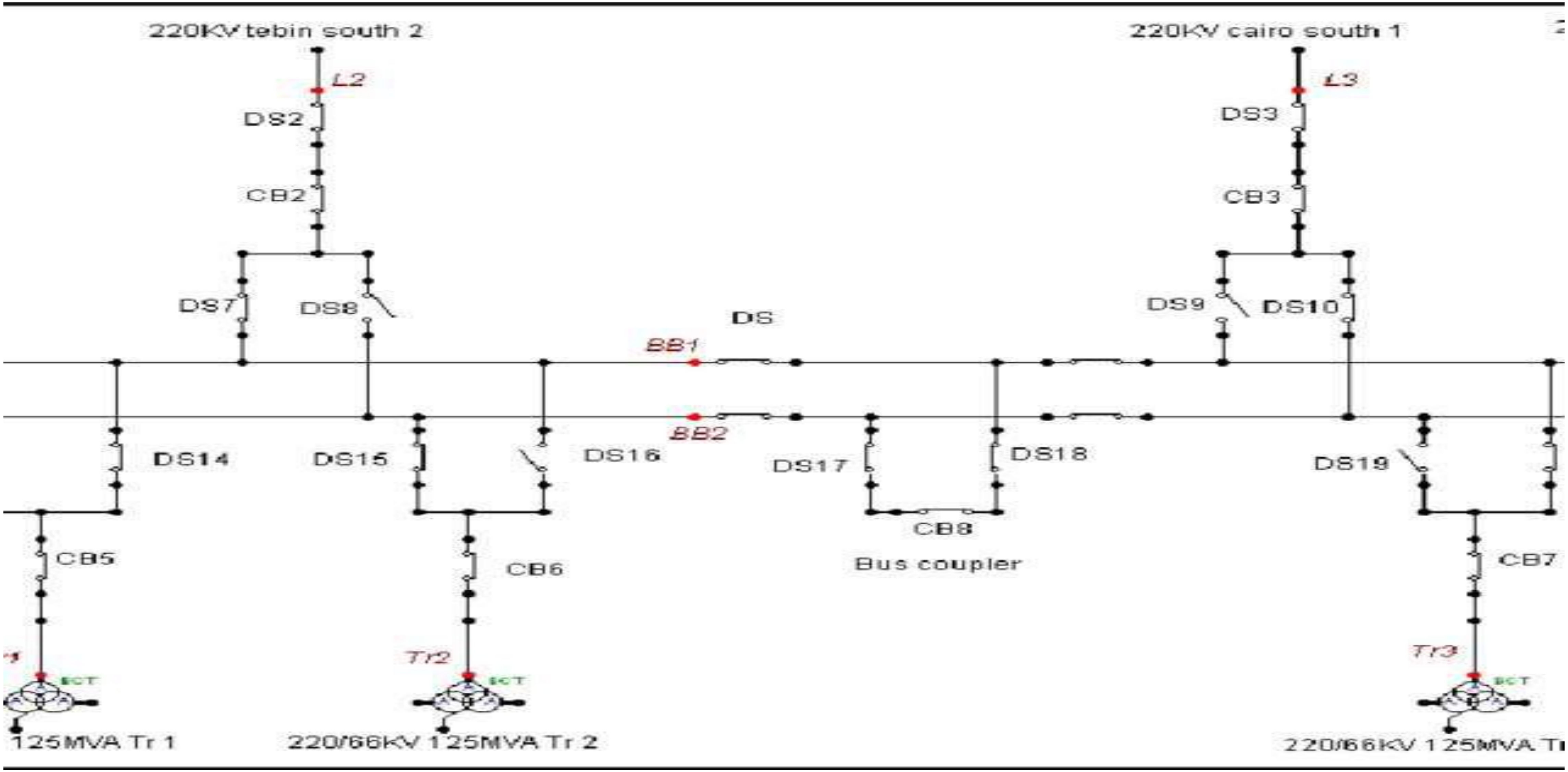



**Fig: essential parts of Gas insulated substation**

# SINGLE LINE DIAGRAM OF GIS



# COMPARISON BETWEEN AIS AND GIS

## On the basis of Construction

**Gas insulated**

- Uses SF6 for insulation
- use fixed, mounted circuit breakers
- Can be indoor as well as outdoor, compact

**Air insulated**

- Uses air for insulation
- uses three-position draw-out circuit breakers
- Mostly outdoors, covers large area

# On the basis of Maintenance

## Gas insulated

- visually inspected every four years or more
- GIS units being sealed, are protected from environmental damage

## Air insulated

- visually inspected every year to two years
- Inspections include having a technician torque, draw-out, clean, lubricate and vacuum the unit
- checked for visual signs of copper corrosion

# On the basis of Total Cost

Gas insulated

- units tend to cost between 10% to 40% more than
- their sealed technology means lower installation and maintenance costs AIS

Air insulated

- offer upfront cost savings
- lifelong maintenance required

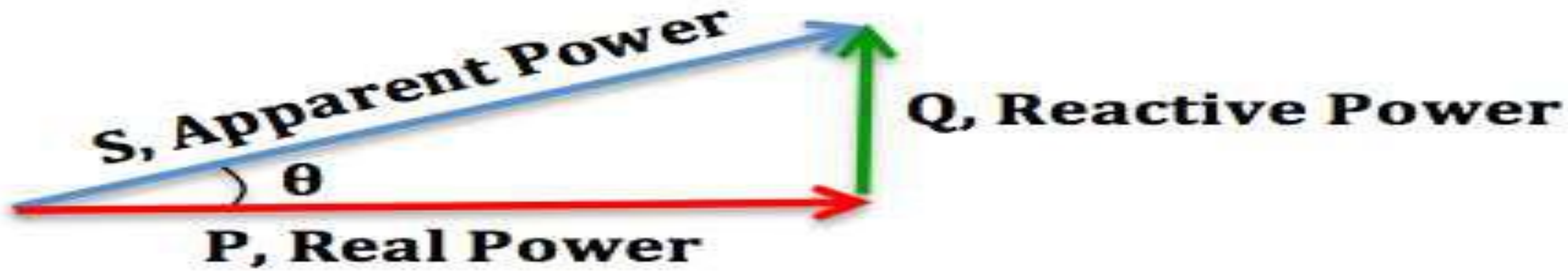
# UNIT-IV

# POWER FACTOR IMPROVEMENT
# AND
# VOLTAGE CONTROL

# Power Factor

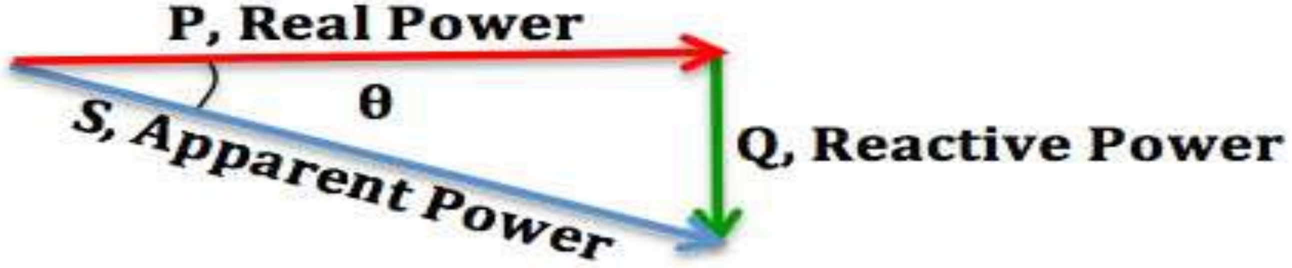
In electrical engineering, the power factor of an AC power system is defined as the ratio of the real power absorbed by the load to the apparent power flowing in the circuit.

Since the units are consistent, the power factor is by definition a dimensionless number between -1 and 1. When power factor is equal to 0, the energy flow is entirely reactive and stored energy in the load returns to the source on each cycle. When the power factor is 1, referred to as *unity* power factor, all the energy supplied by the source is consumed by the load. Power factors are usually stated as "leading" or "lagging" to show the sign of the phase angle. Capacitive loads are leading (current leads voltage), and inductive loads are lagging (current lags voltage).




Lagging Power Factor


Leading Power Factor



# *WHAT IS AN ELECTRICAL LOAD?*

An electrical load is any electrical appliance that consumes electrical energy and convert it into heat or in other form. Different electrical devices use electrical power to convert it into other form. For example resistive loads like heater convert electrical power into heat, industrial and domestic motors transform electrical energy into motion.

# ***TYPES OF LOADS***

1)Residential Loads
2)Commercial Loads
3)Industrial Loads
4)Agricultural Loads
5)Municipal Loads
6)Traction Loads

- AC electrical loads are referred to either as linear or non-linear depending on how they draw current from the mains power supply waveform.
- With a **linear load**, the relationship between the voltage and current waveforms are sinusoidal and the current at any time is proportional to the voltage (Ohm’s law). Examples of linear loads would include transformers, motors and capacitors.
- On the other hand, with a **non-linear load** the current isn’t proportional to the voltage and it fluctuates based on the alternating load impedance.
- Common examples of non-linear loads include rectifiers, variable-speed drives and electronic devices such as computers, printers, TVs, servers and telecoms systems that use switched-mode power supply (SMPS) power conversion technologies. They are also typically found with blade servers.
- Non-linear loads draw in currents in abrupt short pulses. These pulses distort the current waveforms, which in turn generates harmonics that can lead to power problems affecting both the distribution system equipment and the loads connected to it.
- Harmonics can cause problems such as distortion of the mains supply voltage, equipment overheating, nuisance tripping of circuit breakers, and misfiring of variable speed drives.

# Power factor

# Causes of Low Power Factor

**Low Lagging Power Factor** conditions can be caused by various combinations of the following **Inductive Devices**:

- Induction motors
- Induction generators
- Inductive loads of fluorescent ballasts
- Rectifiers providing a DC power supply
- Arc welders
- Solenoids
- Induction heaters
- Lifting magnets
- Transformers
- High Intensity Discharge (HID) Lighting

# Causes of Low Power Factor

- Single phase and three phase induction Motors(Usually, Induction motor works at poor power factor .
- Varying Load in Power System(As we know that load on power system is varying. During low load period, supply voltage is increased which increase the magnetizing current which cause the decreased power factor).
- Industrial heating furnaces.
- Electrical discharge lamps (High intensity discharge lighting) Arc lamps (operate a very low power factor)

# Effect of low poor power factor

- Line losses will be more.
- The useful load that can be transmitted is reduced.
- There will be a poor voltage regulation
- It reduces the handling capacity of the plant.

# Improving Power Factor

- Normally the power factor of the system ranges between 0.8 to 0.9, however in case of low P.F. there is a need of improving power factor.
- There are some methods used to improve the power factor of the system:
  i. Static Capacitor
  ii. Synchronous Condenser

## i. Static Capacitor

- The power factor can be improved by connecting capacitors in parallel with the equipment operating at lagging power factor.
- Static capacitors are invariably used for power factor improvement in factories.

# Static Capacitor


**Advantages:**

i. They have low losses.

ii. They require little maintenance as there are no rotating parts.

iii. They can be easily installed as they are light and require no foundation.

iv. They can work under ordinary atmospheric conditions.

**Disadvantages:**

i. They have short service life ranging from 8 to 10 years.

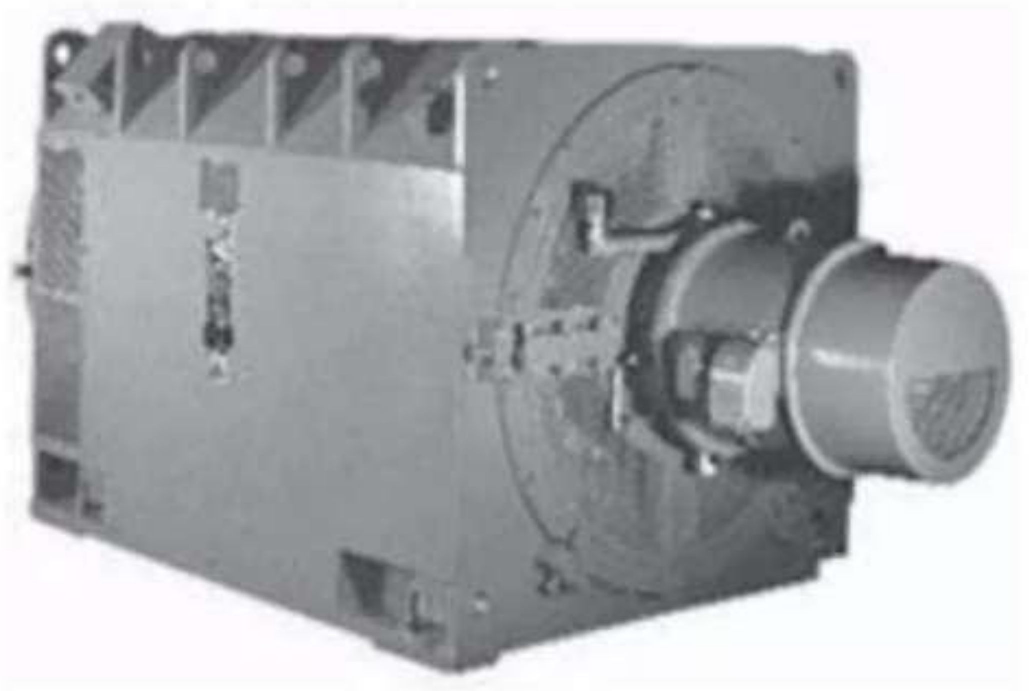
ii. They are easily damaged if the voltage exceeds the rated value.

iii. Once the capacitors are damaged, their repair is uneconomical.

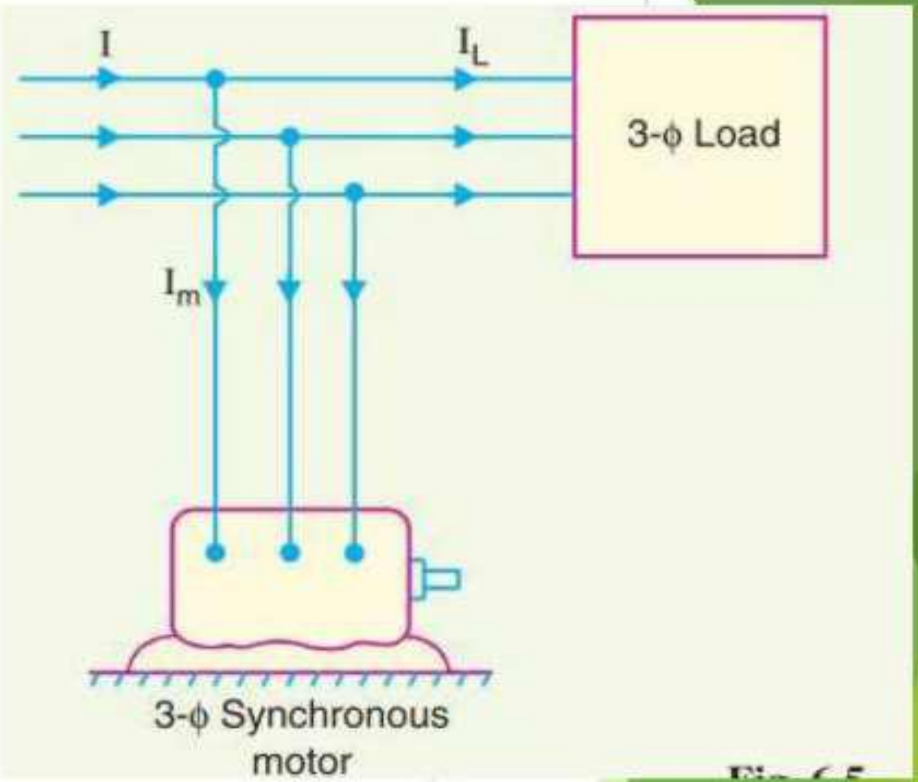
## ii) Synchronous Condenser

- A synchronous motor takes a leading current when over-excited and, therefore, behaves as a capacitor.
- An over-excited synchronous motor running on no load is known as "Synchronous condenser".
- Synchronous condensers are generally used at major bulk supply sub-stations for power factor improvement.

# Synchronous Condenser



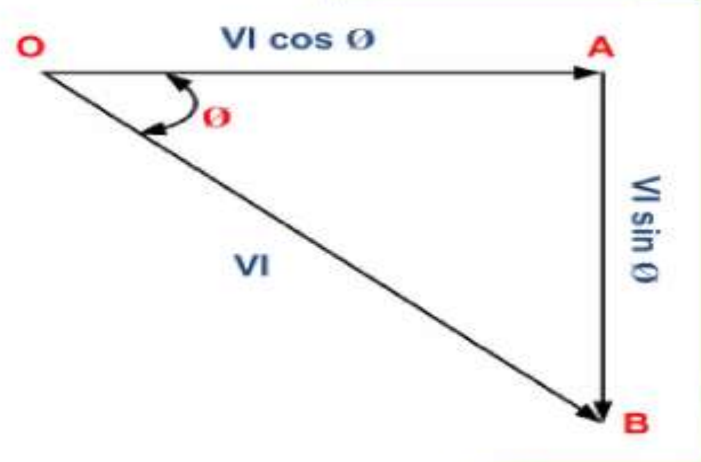
Synchronous Condenser



# Power Triangle:

The analysis of power factor can also made in terms of power drawn by a.c. circuit.

*OA = VI cos Ø* and represents the ***active power*** in the watts or *kW*.




*AB = VI sin Ø* and represents the ***reactive power*** in *VAR* or *kVAR*

*OB = VI* and represents the ***apparent power*** in *VA* or *kVA*.

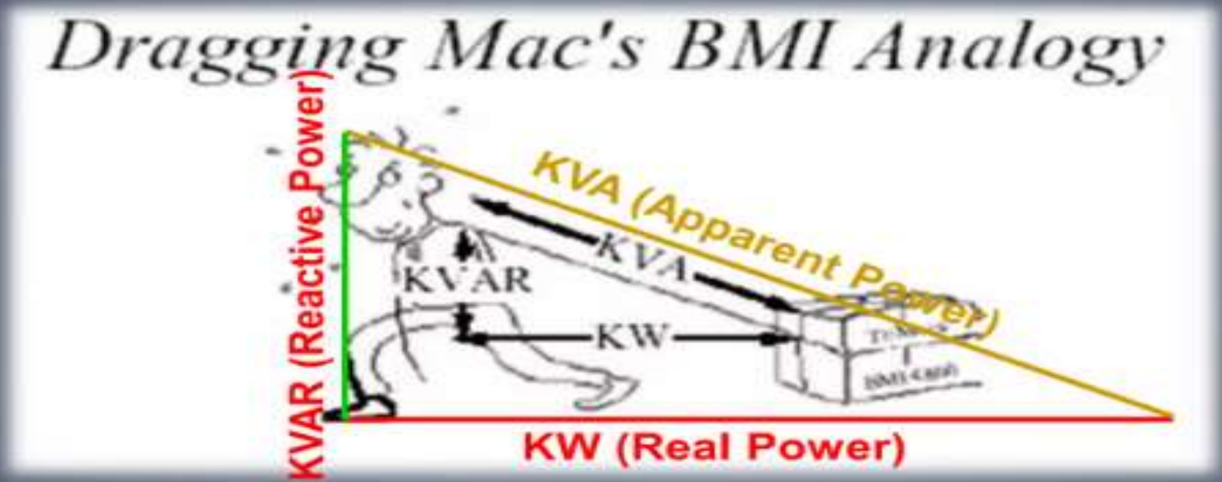
- The apparent power in an a.c. circuit has two components viz., active and reactive power at right angles to each other.

*OB2 = OA2 + AB2*

(Apparent power)2 = (Active power)2 + (Reactive power)2

*(kVA)2 = (kW)2 + (kVAR)2*

# Conti..

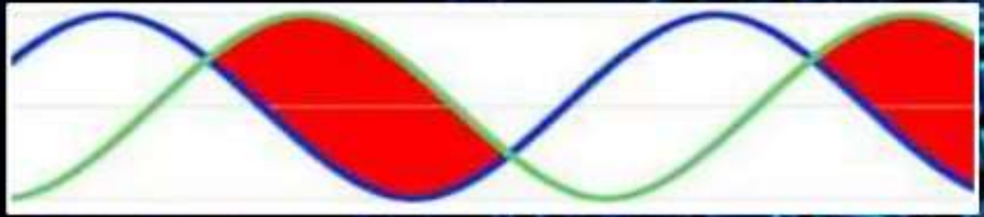



$$\text{Power Factor (pf)} = \frac{\text{kW (Real Power)}}{\text{kVA (Total Power)}} = \cos \text{Ø}$$

**Power Factor (COS Ø) should be close to unity**

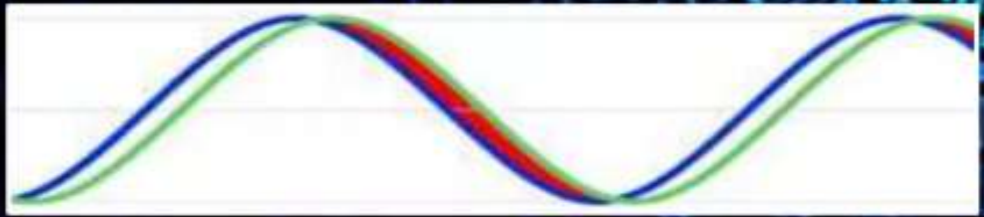
# Graph of PF Lag Vs PF Improvement

Low Lagging Power Factor



Lag Between Voltage and Current creates waste

Power Factor Improvement



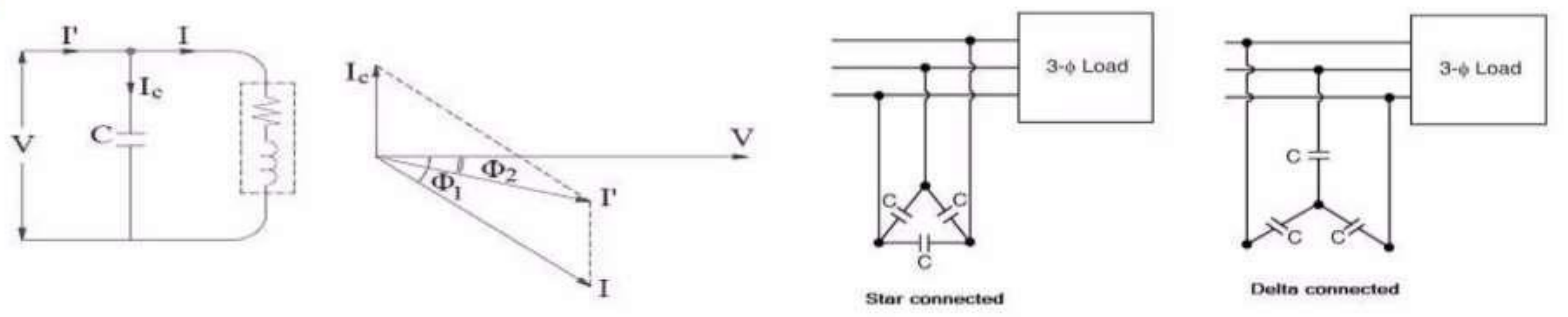
Wasteful lag is reduced to increase energy efficiency

Voltage Current Waste

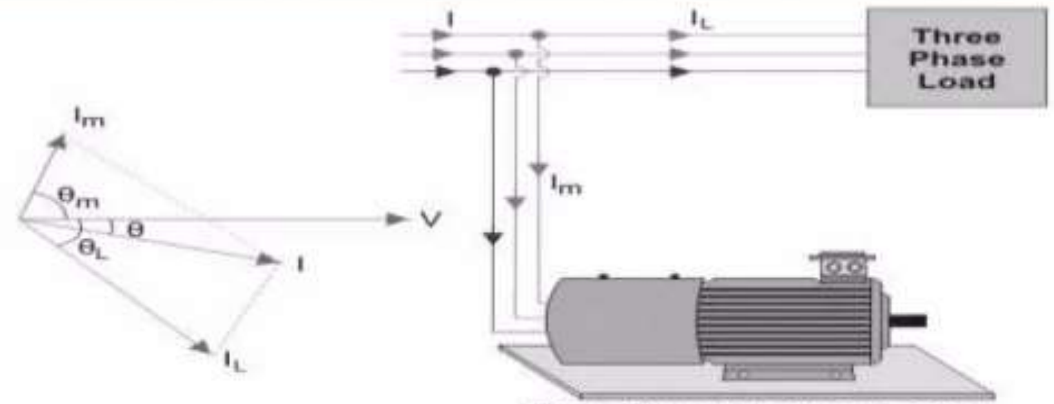
# Ways to Improve Power Factor

Certain ways to Improve Power Factor are :

- **Using Static Capacitor**

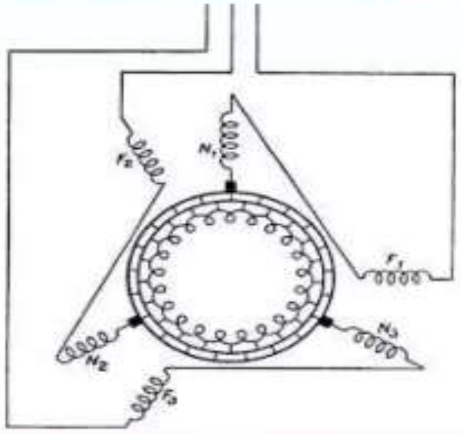


## ❖ Using Synchronous Condenser




Three Phase Synchronous Motor

## ❖ Phase Advancers



# VOLTAGE CONTROL

In power system networks, while supplying power through a transmission line, we keep the voltage constant at the sending end. The voltage at the receiving end undergoes a change that does not depend on the load and power factor. Voltage control should therefore be considered in power system networks as the voltage changes while transmitting power from sending end to end.

## *NEED OF VOLTAGE CONTROL*

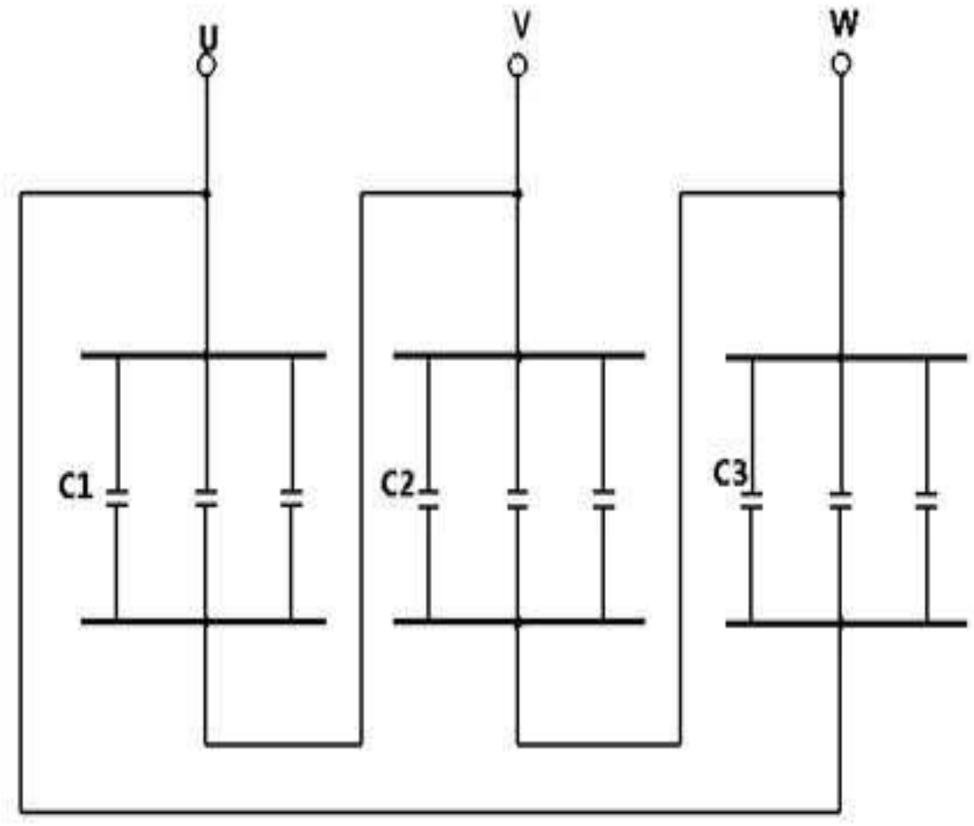
Variation of voltage while power is transmitted from one place to another in power system networks. In order to maintain the variations in voltage within a permissible limit, we employ methods to control voltage.

- The voltage must be set within the permissible limits since most electrical devices and appliances are designed to work at a specific voltage, the need for constant voltage is very important. Wide variations in voltage can cause errors in the operation and performance of electrical devices.
- In the context of Nepal, the voltage variation limit is ±10% for transmission and ±5% for the distribution systems.

# Methods of Voltage Control

## 1. Using Shunt Capacitor

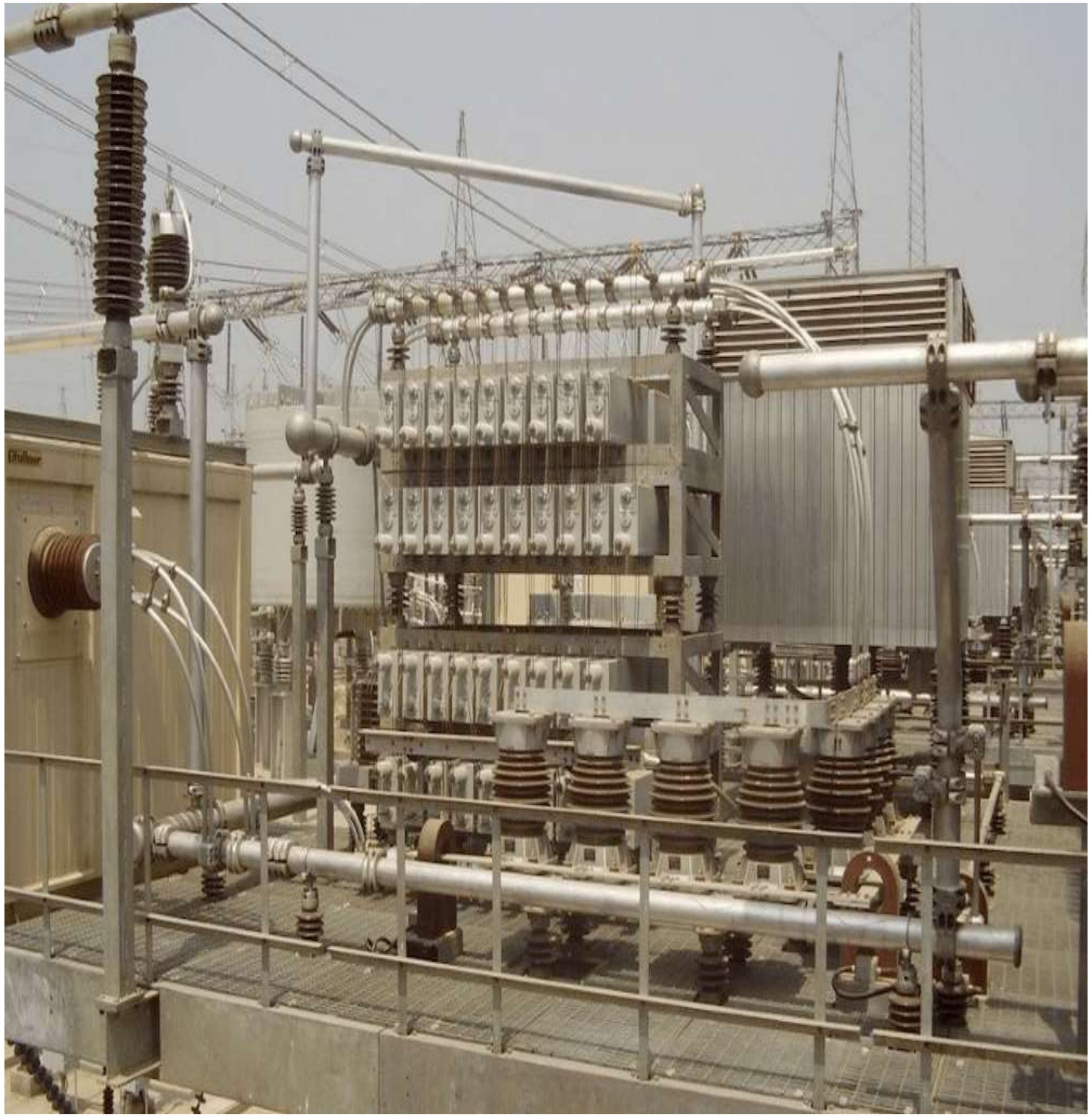
We use a shunt capacitor in the case of inductive load. Shunt capacitors are positioned near the receiving end of the substation or industrial loads. In the case of inductive loads, the system's power factor reduces, and $IX_L$ drop, i.e. inductive reactance drop, increases, causing voltage fluctuations. Shunt capacitors are suitably switched to compensate for the effect of inductive loads and line voltage is regulated.




Triangle wiring of shunt capacitor

## 2. Using Series Capacitors

- The use of a series capacitor reduces the transmission line's net reactance, thereby reducing the voltage drop between the sending end and receiving end.
- The main disadvantage of this method is the production of high voltage across the capacitor during the event of a fault or short circuit. Due to this reaction, there should be provision for additional protection of the capacitor.

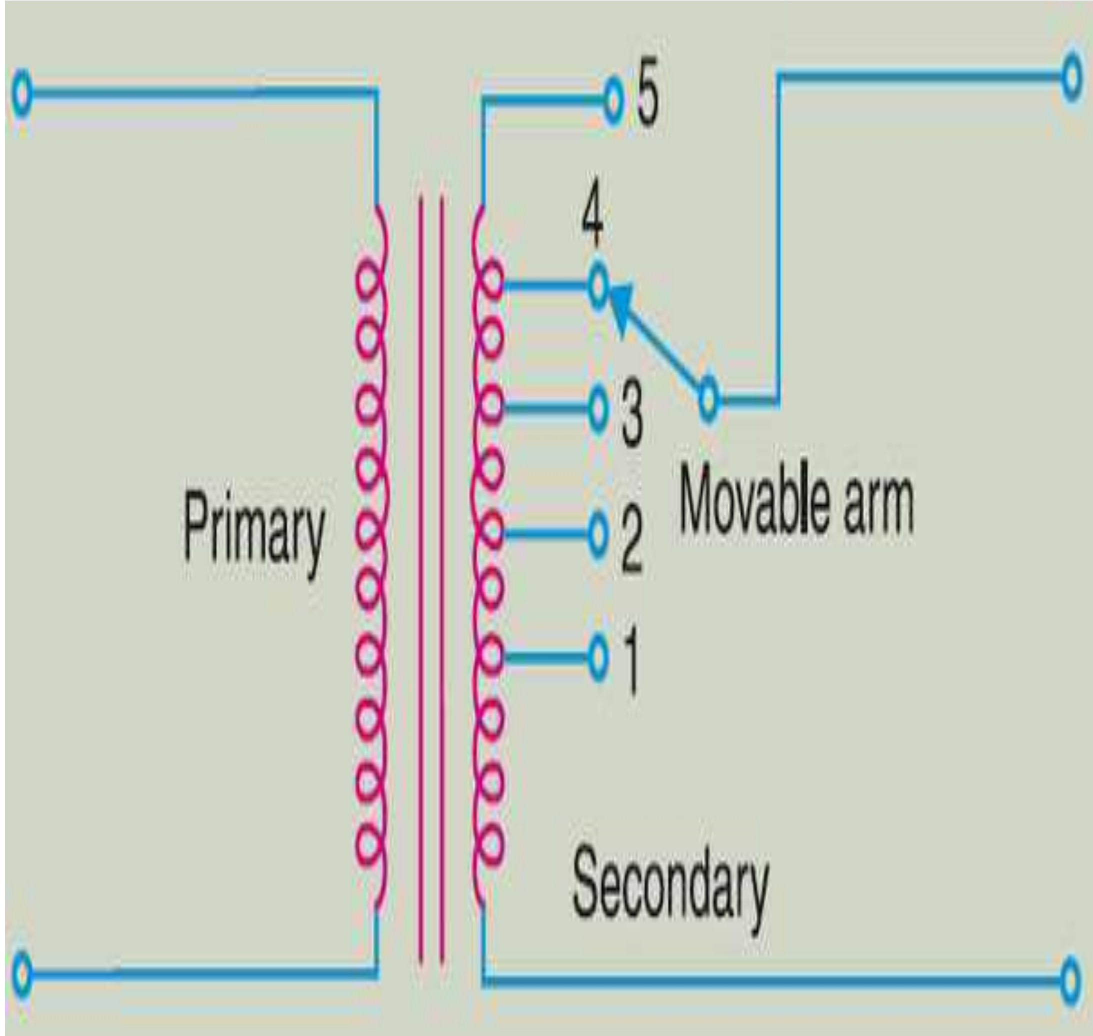


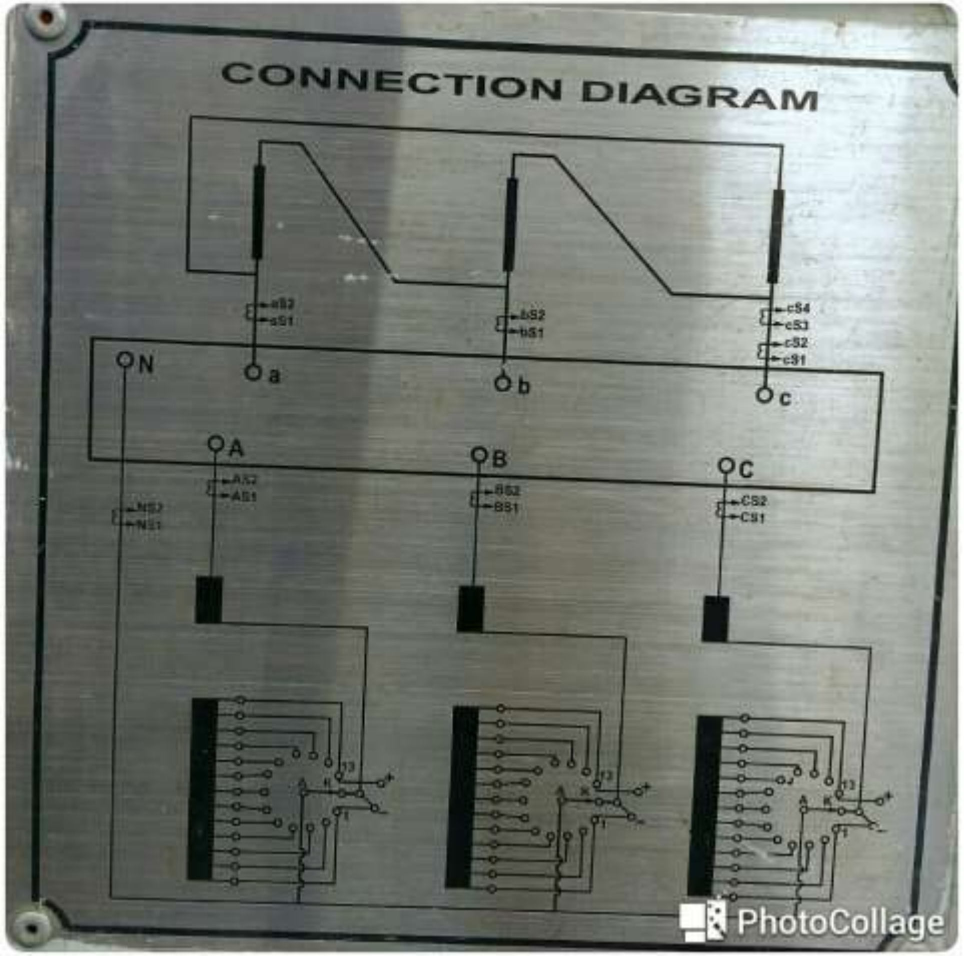
# Voltage Control by Synchronous Condensers:

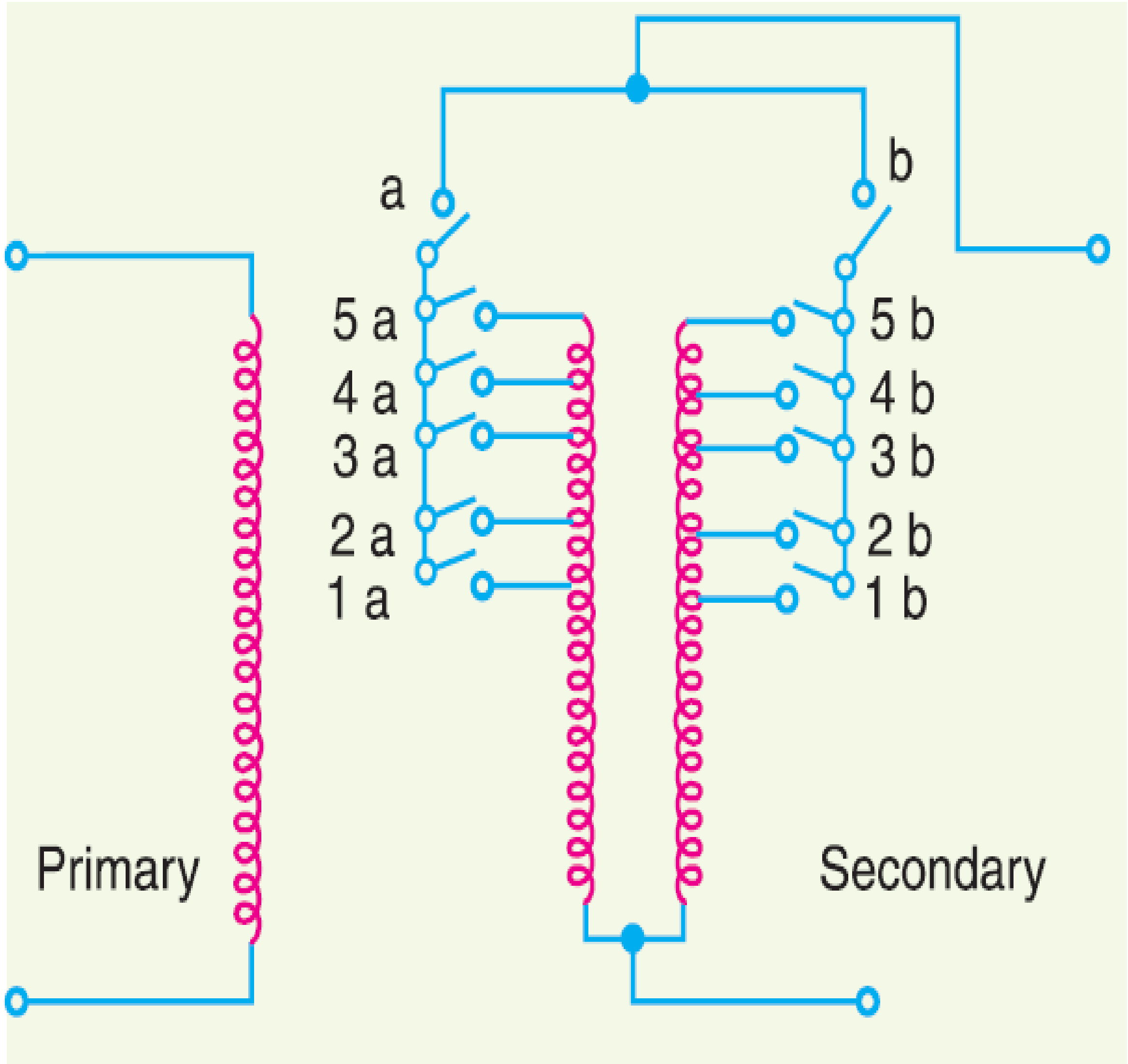
- Synchronous condensers are over excited synchronous motors installed in the power system to deliver the reactive power. These synchronous phase modifiers are located near the load improves the voltage profile of the power system. The main advantage of synchronous phase modifiers are the ability to deliver the reactive power can be adjusted unlike static shunt capacitors.

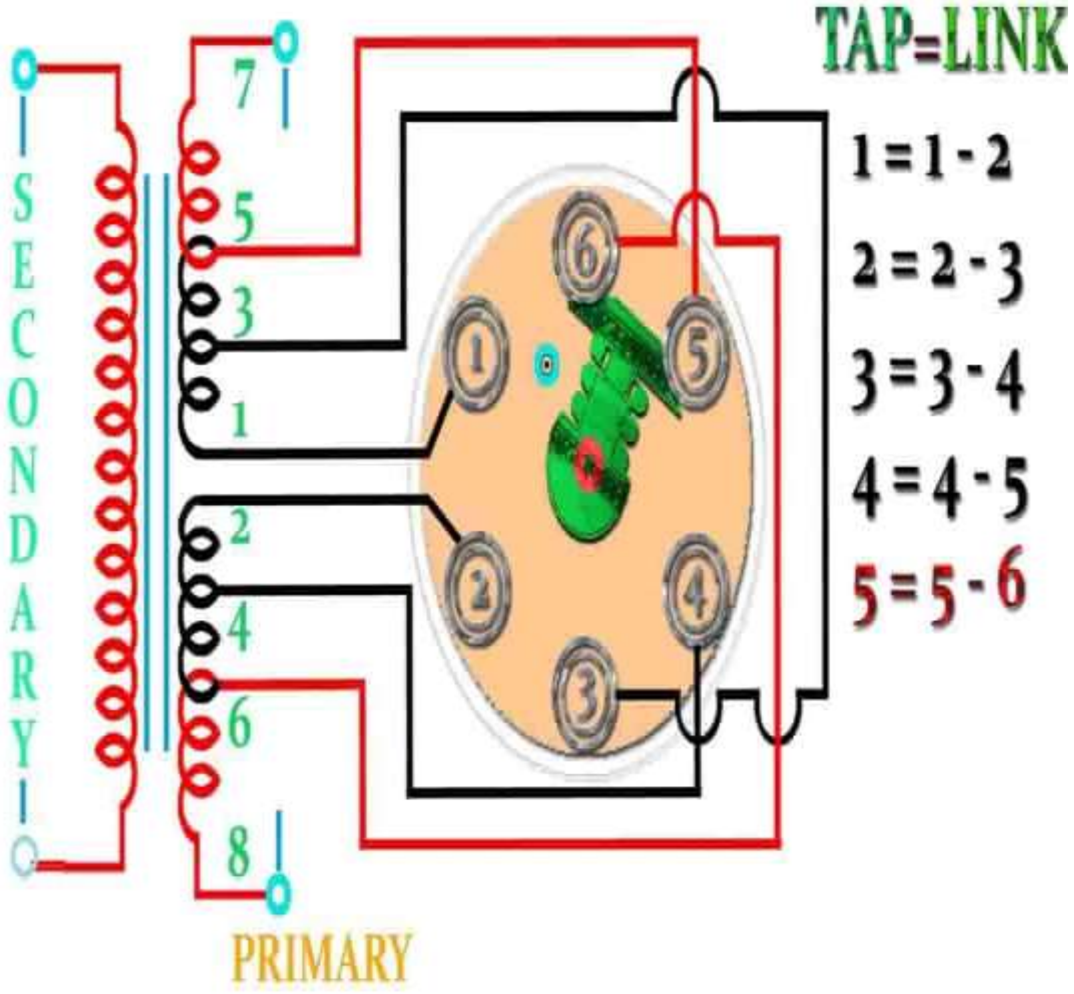
## 4. Using Tap Changing Transformer

- In transmission and distribution networks of power system networks, tap changing transformers are used for voltage control.
- In a tap changing transformer, the voltage on the secondary transformer can be adjusted by adjusting the tap or in other words, adjusting the number of spins on the transformer secondary emf.
- The charge in the tap of the transformer results in a change in the number of turns on the secondary side of the transformer and thereby voltage can be changed and adjusted.
- OFF-load and ON-load tap changing transformers are used for this purpose.


5
4
3
2
1
Primary
Movable arm
Secondary


CONNECTION DIAGRAM
N
a
b
c
A
B
C
PhotoCollage


a
b
5 a
4 a
3 a
2 a
1 a
5 b
4 b
3 b
2 b
1 b
Primary
Secondary

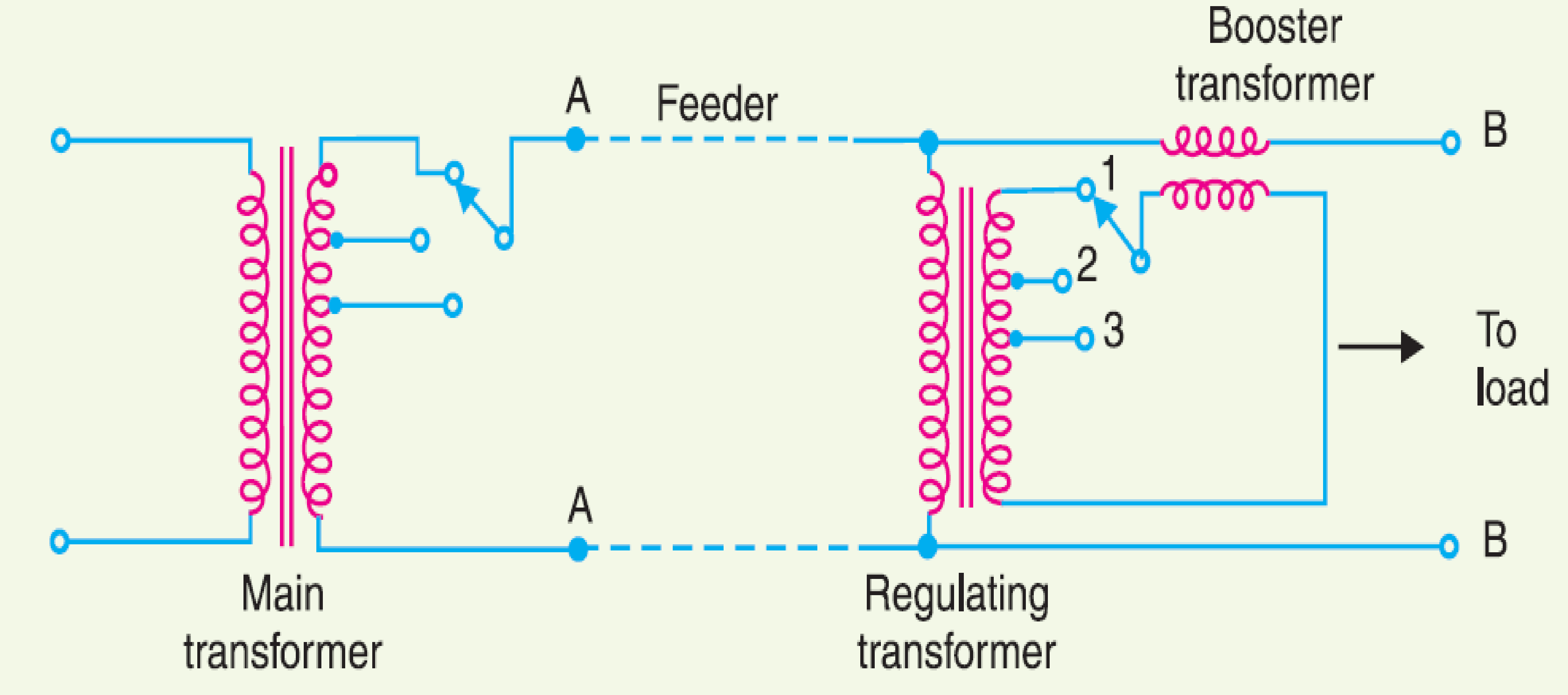

TAP=LINK
1 = 1 - 2
2 = 2 - 3
3 = 3 - 4
4 = 4 - 5
5 = 5 - 6
SECONDARY
PRIMARY
7
5
3
1
2
4
6
8

# NEED OF TAP CHANGER

- To supply a desired voltage to the load.
- To counter the voltage drops due to loads.
- To counter the input supply voltage changes on load.
- Additionally required to perform the task of regulation of active and reactive power flows.


Figure 42: Tap changing and Buck Boost arrangement

# Booster transformer



# ECONOMIC ASPECTS OF POWER GENRATION AND TARIFF

# What is Economics Of Power Generation?

- **Definition of Economics of Power Generation:** The art of determining the per unit (i.e. one kWh) cost of production of Electrical Energy is known as Economics of Power Generation.
- While designing and building a power station, efforts should be made to achieve overall economy so that the per unit cost of production is as low as possible.
- This will enable the electric supply company to sell electrical energy at a profit and ensure reliable service.

# Tariff and Economic aspects in power Generation

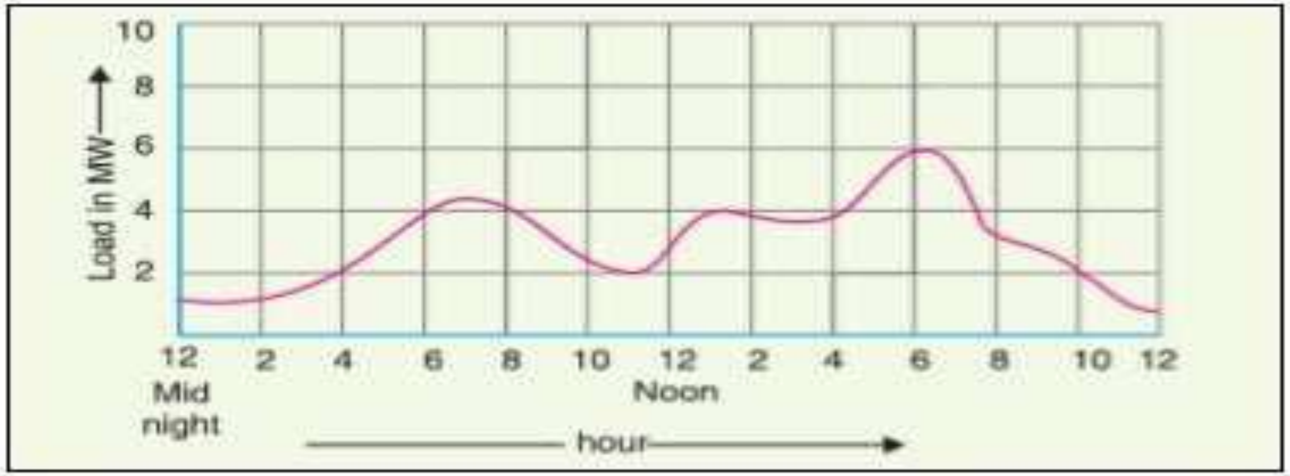
## Introduction

- The function of a power station is to deliver power to a large number of consumers. However, the power demands of different consumers vary in accordance with their activities.
- The result of this variation in demand is that load on a power station is never constant, rather it varies from time to time.
- The power demanded by the consumers is supplied by the power station through the transmission and distribution networks. As the consumers' load demand changes, the power supply by the power station changes accordingly.

# Load Curves

- *The curve showing the variation of load on the power station with respect to (w.r.t) time is known as a **load curve.***

- Load variations during the whole day (i.e., 24 hours) are recorded half-hourly or hourly and are plotted against time on the graph. The curve thus obtained is known as ***daily load curve*** as it shows the variations of load w.r.t. time during the day.



# Important Terms and Factors

***Demand Factor:*** *It is the ratio of maximum demand on the power station to its connected load.*

$$\text{Demand factor} = \frac{\text{Maximum demand}}{\text{Connected load}}$$

- The value of demand factor is usually less than 1. It is expected because maximum demand on the power station is generally less than the connected load.
- If the maximum demand on the power station is 80 MW and the connected load is 100 MW, then demand factor = 80/100 = 0·8.
- The knowledge of demand factor is vital in determining the capacity of the plant equipment.

# Important Terms and Factors

- ***Plant capacity factor:*** It is the ratio of actual energy produced to the maximum possible energy that could have been produced during a given period i.e.,

$$\text{Plant capacity factor} = \frac{\text{Actual energy produced}}{\text{Max. energy that could have been produced}} = \frac{\text{Average demand} \times T^{**}}{\text{Plant capacity} \times T} = \frac{\text{Average demand}}{\text{Plant capacity}}$$

- Thus if the considered period is one year,

$$\text{Annual plant capacity factor} = \frac{\text{Annual kWh output}}{\text{Plant capacity} \times 8760}$$

- The plant capacity factor is an indication of the reserve capacity of the plant. A power station is so designed that it has some reserve capacity for meeting the increased load demand in future.
- Therefore, the installed capacity of the plant is always somewhat greater than the maximum demand on the plant.

# Variable Load on Power Station

- *The load on a power station varies from time to time due to uncertain demands of the consumers and is known as **variable load on the station.***
- The consumers require their small or large block of power in accordance with the demands of their activities. Thus the load demand of one consumer at any time may be different from that of the other consumer.
- The result is that load on the power station varies from time to time.
- **Effects of variable load:** The variable load on a power station introduces many perplexities in its operation. Some of the important effects of variable load on a power station are :

1. ***Need of additional equipment***
2. ***Increase in production cost***

# TARIFF SYSTEM FEATURES

- Obtain a reasonable return to the supplier
- Appropriate and acceptable to the various types of users.
- Easily understood by all levels of users
- Suppliers will have little benefit with affordable rates paid by consumers

## Tariff – Introduction:

Electrical energy produced by the power system is delivered to a large no customers. The tariff becomes the attention for the electric supply company. The company has to ensured that the tariff such that it not only recovers total cost of producing electrical energy but also earns profit on the capital investment.

# Tariff

*The rate at which electrical energy is supplied to a consumer is known as* ***tariff.***

# Desirable Characteristics of a Tariff

- *Proper return*
- *Fairness*
- *Simplicity*
- *Reasonable profit*
- *Attractive*

# *Objectives of tariff*

(i) Recovery of cost of producing electrical energy at the power station.

(ii) Recovery of cost on the capital investment in transmission and distribution systems.

(iii) Recovery of cost of operation and maintenance of supply of electrical energy e.g., metering equipment, billing etc.

(iv) A suitable profit on the capital investment.

# Types of Tariff

**Simple tariff**

*When there is a fixed rate per unit of energy consumed, it is called a simple* tariff *or uniform rate tariff.*

**Disadvantages**

(*i*) *There is no discrimination between different types of consumers since every consumer has* to pay equitably for the fixed charges.

(*ii*) *The cost per unit delivered is high.*

(*iii*) *It does not encourage the use of electricity.*

# Flat rate tariff

*When different types of consumers are charged at different uniform per unit rates, it is called a flat rate tariff.*

**Disadvantages**

(*i*) *Since the flat rate tariff varies according to the way the supply is used, separate meters are* required for lighting load, power load etc. This makes the application of such a tariff expensive and complicated.

(*ii*) *A particular class of consumers is charged at the same rate irrespective of the magnitude of* energy consumed. However, a big consumer should be charged at a lower rate as in his case the fixed charges per unit are reduced.

# Block rate tariff

*When a given block of energy is charged at a specified rate and the succeeding blocks of energy are charged at progressively reduced rates, it is called a block rate* tariff.

In block rate tariff, the energy consumption is divided into blocks and the price per unit is fixed in each block. The price per unit in the first block is the highest** and it is progressively reduced for the succeeding blocks of energy. For example, the first 30 units may be charged at the rate of 60 paise per unit ; the next 25 units at the rate of 55 paise per unit and the remaining additional units may be charged at the rate of 30 paise per unit.

The advantage of such a tariff is that the consumer gets an incentive to consume more electrical energy. This increases the load factor of the system and hence the cost of generation is reduced. However, its principal defect is that it lacks a measure of the consumer's demand. This type of tariff is being used for majority of residential and small commercial consumers.

# Two-part tariff

*When the rate of electrical energy is charged on the basis of maximum demand of the consumer and the units consumed, it is called a two-part tariff.*

Total charges = Rs ($b \times kW + c \times kWh$)

where,

$b$ = *charge per kW of maximum demand*

$c$ = *charge per kWh of energy consumed*

This type of tariff is mostly applicable to industrial consumers who have appreciable maximum demand

## THREE PART TARIFF

Total charge = Rs $(a + b \times kW + c \times kWh)$

$a$ = fixed charge made during each billing period. It includes interest and depreciation on the cost of secondary distribution and labour cost of collecting revenues,

$b$ = charge per kW of maximum demand,

$c$ = charge per kWh of energy consumed.

# Types of Tariff

**Two-part tariff:** *When the rate of electrical energy is charged on the basis of maximum demand of the consumer and the units consumed, it is called a two-part tariff.*

- In two-part tariff, the total charge to be made from the consumer is split into two components *viz.*, fixed charges and running charges.
- The fixed charges depend upon the maximum demand of the consumer while the running charges depend upon the number of units consumed by the consumer.
- the consumer is charged at a certain amount per kW of maximum demand plus a certain amount per kWh of energy consumed

**Advantages**

(*i*) *It is easily understood by the consumers.*

(*ii*) *It recovers the fixed charges which depend upon the maximum demand of the consumer but* are *independent of the units consumed*.

**Disadvantages**

(*i*) *The consumer has to pay the fixed charges irrespective of the fact whether he has consumed* or *not consumed the electrical energy.*

(*ii*) *There is always error in assessing the maximum demand of the consumer.*

# Power factor tariff

*The tariff in which power factor of the consumer's load is taken into consideration is known as **power factor tariff***

- *k VA maximum demand tariff*
- *Sliding scale tariff*
- *kW and kVAR tariff*

# Types of Tariff

**Power factor tariff:** *The tariff in which power factor of the consumer's load is taken into consideration is known as power factor tariff.*

- In an a.c. system, power factor plays an important role. A low power factor increases the rating of station equipment and line losses.
- Therefore, a consumer having low power factor must be penalised.

# Maximum demand tariff.

similar to two-part tariff with the only difference that the maximum demand is actually measured by installing maximum demand meter in the premises of the consumer. This removes the objection of two-part tariff where the maximum demand is assessed merely on the basis of the rate able value. This type of tariff is mostly applied to big consumers.

However, it is not suitable for a small consumer (*e.g., residential consumer) as a separate maximum* demand meter is required.

# Types of Tariff

***kVA maximum demand tariff* :**

- It is a modified form of two-part tariff.
- In this case, the fixed charges are made on the basis of maximum demand in kVA and not in kW.
- As kVA is inversely proportional to power factor, therefore, a consumer having low power factor has to contribute more towards the fixed charges.
- This type of tariff has the advantage that it encourages the consumers to operate their appliances and machinery at improved power factor.