



**R. C. Patel College of Engineering and Polytechnic,
Shirpur**

Class: SYEE (EE3K)

Course:

**ELECTRICAL POWER GENERATION,
TRANSMISSION AND DISTRIBUTION**

(Course Code: 313333)

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Unit - III

Transmission Line Components, Parameters and Performance

(16 Marks)

Course Outcome:

**CO3 - Interpret the normal
operation and parameters of the
electric transmission system.**

and performance.

* Introduction:

- Electrical energy plays a very important role in our daily life.
- The development of a country depends on the adequate availability of electrical energy, its reliability, uninterrupted supply and affordable cost per unit of energy.
- Electrical energy is generated at the Generating station and transmitted to the Receiving station through High voltage (Hv) or Extra High voltage (EHV) Transmission lines.

* Electric power transmission system: (single line diagram):

- The main objective of an Electric power system is to generate electrical energy and deliver it safely and efficiently to the consumers where it is required.
- The electrical energy passes through the following five stages before reaching the consumers:
 1. Generating station
 2. primary Transmission
 3. secondary Transmission
 4. primary Distribution
 5. Secondary Distribution.

1) Generating station:

- Electrical energy is generated at Generating station at a vtg level of 11 kv.
- In some cases, the generated vtg may be 3.3 kv, 6.6 kv, 11 kv

or 33 kV depending on the type and capacity of the power plant.

2) primary Transmission:

- To transmit electrical energy over long distances, High voltage (HV) Transmission lines are used.
- These transmission lines may carry power over hundreds of km.
- Therefore, the transmission v_tg is increased to 110 kV, 132 kV, 220 kV, or 400 kV as required.
- primary Transmission is carried out using overhead 3 phase 3 wire system.

3) secondary Transmission:

- At the receiving station, the v_tg is stepped down using a step down transformer from 132 kV or 66 kV.
- The electrical energy is then transmitted from the receiving station to different load centers located within cities.
- secondary transmission is also carried out using an overhead 3 phase, 3 wire system.

*4) primary Distribution:

- The secondary transmission lines terminates at the distribution substation.
- At the substation, the v_tg is stepped down to 11 kV using a step-down transformer.
- The electrical energy is then distributed to various load centers through the 11 kV distribution network.

- (2)
- The v_{tg} level used for primary distribution depends on the amount of power to be supplied and the distance beth substations.

* 5) secondary Distribution:

- Distribution substations are located near the consumer area.
- for secondary distribution, the v_{tg} is stepped down from 11 kV to 400 kV using a distribution Transformer.
- A 3 phase, 4 wire low tension (LT) feeder is used for supplying power to consumers.
- The advantage of the 3 phase, 4 wire system is that both 3 phase supply and 1 phase supply can be provided according to the load requirement.
- From these lines, service lines are connected to consumers.

* Single line Diagram (SLD) of Electrical power system:

- A single line diagram (SLD) is a simplified representation of an electrical power system.
- It shows the main electrical components and their connections in the system using a single line instead of showing all conductors separately.
- The single line diagram provides important details about the arrangement of system components and their electrical ratings, such as v_{tg}, output rating, Resistance (R) and reactance (X).
- In power engineering, the SLD is a simplified notation used to represent a three-phase power system.
- Various electrical components such as circuit breaker, Transformers, capacitors, Bus bars, conductors, Generators and loads are represented by standard symbols in the diagram.

- The SLD helps engineers understand the structure, operation and interconnection of an electrical power system easily and quickly.

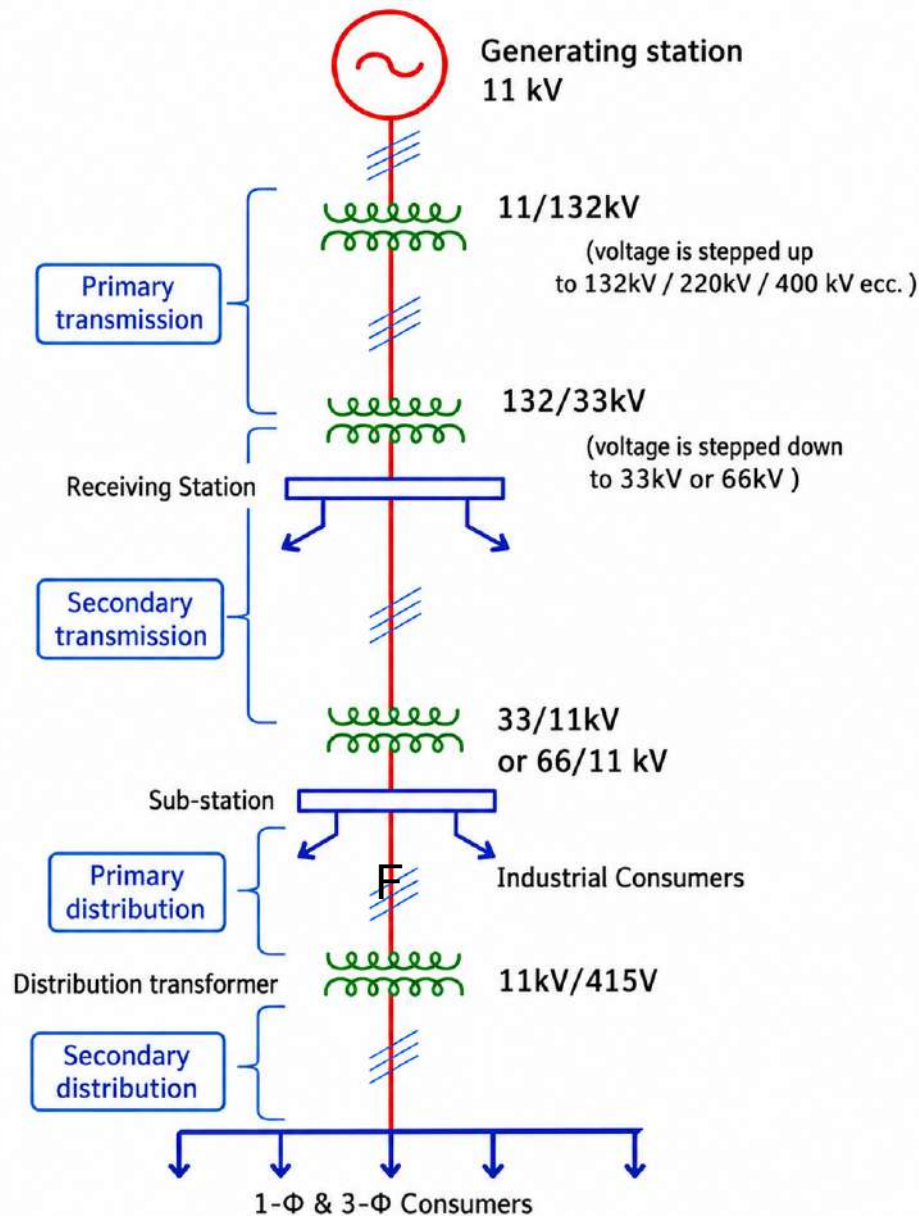


Fig. Single Line Diagram

- Fig above represents the SLD of an electrical power system.
- It can be simplified using a block diagram given below that shows the flow of electrical energy from Generation, Transmission, and distribution up to the consumers.
- This representation helps in understanding the overall structure and operation of the electrical power system.

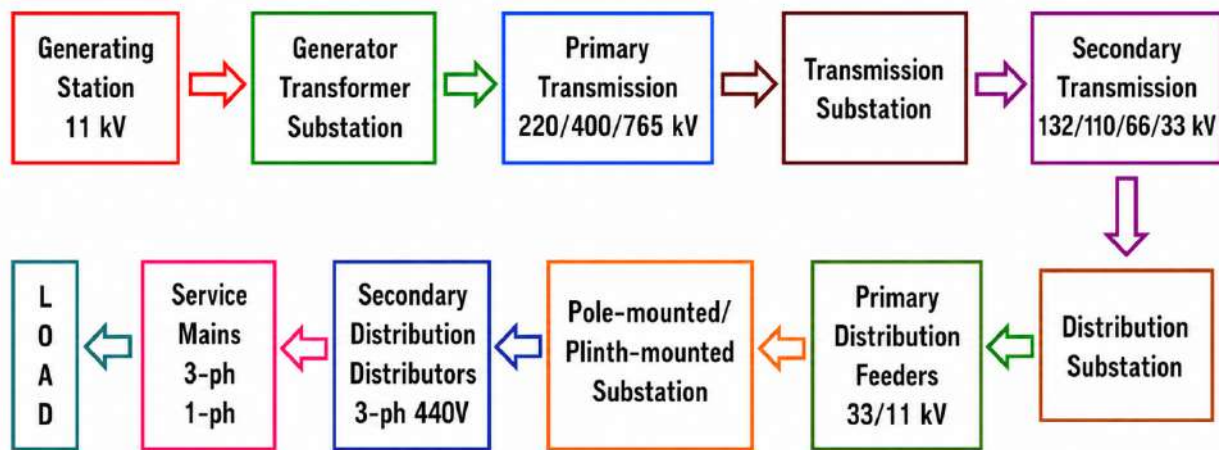


Fig. Block Diagram of Single Line Diagram

* Classification of Transmission Lines:

- Transmission lines can be classified in different ways depending on Voltage Level, length of the transmission line, Types of voltage, and Method of construction.

1) According to Voltage level:

Transmission lines are classified into the following types based on their operating voltage.

a) High voltage (HV) Transmission line:

- operates at vtg upto 33 kV.
- Used for transmitting electrical power over short distances.

b) Extra. High voltage (EHV) Transmission line:

- operates at vtg above 33 kV and up to 400 kV.
- used for transmitting large amount of power over long distances with lower power losses.

c) Ultra High voltage (UHV) Transmission line:

- operates at vtg above 400 kV
- used for transmitting very large amount of electrical power over very long distances with maximum efficiency.

2) According to the Length of the Transmission Line:

Transmission lines are classified into three types based on their length.

a) short Transmission line:

- Length: Up to 50 km
- Used for supplying power over short distances
- The effect of line capacitance is usually neglected.

b) Medium Transmission line:

- Length: 50 km to 150 km
- Used for medium distance power transmission.
- line capacitance is considered during analysis.

c) Long Transmission line:

- Length: More than 150 km
- Used for transmitting electrical power over long distances.
- All transmission line parameters (R, L, C) are considered for accurate analysis.

3) According to type of voltage:

Transmission lines are classified based on the type of electrical v_tg used.

a) AC Transmission:

- Uses Alternating Current (AC)
- It is the most commonly used transmission system because v_tg can be increased or decreased easily using transformers.

b) DC Transmission:

- DC transmission uses direct current.

⑤
- Mainly used for very long-distance transmission, underwater cables and interconnecting different power systems.

4) According to Method of Construction:

Transmission lines are classified according to the way they are installed.

a) Overhead Transmission:

- Conductors are supported on poles or transmission towers above the ground.
- It is less expensive, easy to install and simple to maintain.
- It is most commonly used transmission system.

b) Underground Transmission:

- Conductors are laid below the ground using underground cables.
- It provides better safety and improve the appearance of cities.
- It is more expensive than overhead transmission and is mainly used in urban areas where overhead lines are not suitable.

* Standard Voltage Levels used in India:

- The standard voltage level used in India are as follows:

1) Generation voltage:

- The electricity produced at generating station is called Generation voltage.
- standard Generation voltage:
3.3 kV, 6.6 kV, 11 kV, 17.5 kV, 21 kV
- Nowadays, most generating stations produce electricity in the range of 11 kV to 33 kV.

2) Primary Transmission Voltage:

- After generation, the voltage is increased using a step-up transformer and transmitted over long distance.
- standard primary transmission voltages:
220 kV, 400 kV, 765 kV.

3) Secondary Transmission Voltage:

- Near the receiving station, the voltage is reduced for further transmission.
- standard secondary transmission voltage:
220 kV, 132 kV, 110 kV, 66 kV.

4) Primary Distribution Voltage:

- The voltage is further reduced at the distribution substation and supplied to local distribution networks.
- standard primary distribution voltages: 33 kV, 22 kV, 11 kV.

5) Secondary Distribution Voltage:

- Finally, the voltage is reduced to the level required by consumers.
- standard secondary distribution voltages:
Three phase: 400 V
single phase: 230 V

* Need of Transmission Line:

- Transmission lines are required for the following reasons:
1. Electricity is generated at generating stations, which are

generally located far away from cities and load centers. (3)

2. Therefore, electrical energy must be transmitted from generating station to the receiving station through transmission lines.

3. The transmission system consists of:

- primary transmission lines
- High-voltage secondary transmission lines.

4. High voltage transmission reduces power loss ($I^2 R$ loss) and improves the efficiency of power transmission.

5. Since the current becomes smaller at high voltage, conductors of smaller cross-sectional area can be used, making the transmission system more economical.

* Difference between primary transmission and secondary transmission:

Sr. No.	Primary Transmission	Secondary Transmission
1	Primary Transmission uses 220 kV, 400 kV, and 765 kV voltage levels.	Secondary Transmission uses 132 kV, 110 kV, 66 kV, and 33 kV voltage levels.
2	The voltage level is increased using a Step-up Transformer before transmission.	The voltage level is reduced using a Step-down Transformer before further transmission.
3	It transfers electrical power from the Generating Station to the Primary Substation (Receiving Station).	It transfers electrical power from the Primary Substation to the Receiving (Secondary) Substation.
4	The load center is far away from the Generating Station.	The load center is nearer to the Primary Substation.
5	The height of transmission towers is higher than that of Secondary Transmission towers.	The height of transmission towers is lower than that of Primary Transmission towers.
6	It is used to transmit a large amount of electrical power over long distances.	It is used to transmit electrical power in comparatively smaller quantity than Primary Transmission.
7	It is used when the distance to the load center is long.	It is used when the substation is located closer to the load center.
8	The power handling capacity is higher.	The power handling capacity is lower than Primary Transmission.
9	Grid interconnection is generally used in Primary Transmission.	Grid interconnection is generally not used in Secondary Transmission.

* Difference between overhead transmission system and underground transmission system:

Sr. No.	Parameter	Overhead Transmission	Underground Transmission
1	Capital Cost	Low	High
2	Erecting Cost (Installation Cost)	Low	High
3	Time Required for Installation	Less	More
4	Flexibility	High. It is easy to modify or extend the system.	Low. Modification or extension is difficult.
5	Future Expansion	The system voltage can be increased easily, and future expansion is simple.	Future expansion and increasing the system voltage are difficult.
6	Overload Capacity	High. It can carry overload for a short period.	Low. It cannot carry overload for a long time.
7	Fault Finding	Easy. Faults can be located and repaired quickly.	Difficult. Locating and repairing faults takes more time.
8	Chances of Fault	High because conductors are exposed to the environment.	Low because cables are protected underground.
9	Chances of Accident	High due to exposed conductors.	Very Low (Almost Nil) because cables are buried underground.
10	Safety	Low	High
11	Maintenance	Requires frequent (more) maintenance because conductors are exposed to the environment.	Requires less frequent maintenance because cables are protected underground.
12	Cost of Maintenance	Low because faults are easy to locate and repair.	High because fault location and repair are difficult and expensive.
13	Radio Interference	High due to corona discharge and exposed conductors.	No Radio Interference because cables are installed underground.
14	Life (Service Life)	Shorter due to exposure to weather conditions such as rain, wind, and sunlight.	Longer because cables are protected from atmospheric conditions.
15	Appearance	Poor because conductors and towers are visible.	Good because cables are hidden underground, giving a neat appearance.
16	Atmospheric Effect	High because it is affected by rain, wind, storms, lightning, and pollution.	No Atmospheric Effect because cables are laid below the ground.
17	Reliability	Low because faults occur more frequently due to environmental conditions.	High because underground cables are well protected and have fewer faults.

* Other Transmission systems:

- Transmission systems are mainly classified into DC system and AC system.

A) DC (Direct current) system:

1. DC Two-wire system:

- This system has two conductors (wires):
 - one positive (+) wire
 - one negative (-) wire
- It is simplest DC distribution system
- It is mainly used for small DC power supply applications.

2. DC Two-wire Mid-point Earthed system:

- This system has two conductors and the mid-point is connected to Earth (Ground).
- Mid-point Earthing improves the safety of the system.

3. DC Three-wire system:

- This system has three conductors:
 1. one positive (+) wire
 2. one negative (-) wire
 3. one Neutral wire.
- It provides two different voltage levels from the same supply.
- It reduces voltage drop and improves the efficiency of the distribution system.

B) AC (Alternating current) system:

1) Single phase AC two wire system:

- This system has two wires:
 - one phase (live) wire
 - one neutral wire
- It is mainly used for domestic and residential electricity supply.
- Ex: 230V single phase supply.

2) Single phase AC two-wire system with Mid-point Earthed:

- This system is similar to the single phase AC two wire system, but mid-point is connected to Earth (Ground).
- Mid-point earthing provides better system and is rarely used today, safety and improves system protection.

3) Two phase AC four-wire system:

- This system has four conductors (wires).
- It supplies two-phase AC power.
- It was used in older power system and is rarely used today.

4) Two phase AC Three-wire system:

- This system has three conductors.
- It is another method of supplying two-phase AC power.
- It is also rarely used in modern electrical power systems.

5) Three phase AC Three-wire system:

- This system has three phase conductors.
- It does not use a neutral wire.
- It is commonly used for power transmission and three-phase industrial loads.

6) Three phase AC four wire system:

- This system has four conductors:
 - Three phase wires (R, Y, B)
 - One ~~Neutral~~ wire (N)
Neutral
- It is the most widely used AC distribution system.
- It can supply both:
 - Three phase loads (415V)
 - Single phase loads (230V)

* Advantage and Disadvantage of AC Transmission:

* Advantages of AC Transmission:

1. High voltage can be produced easily:

- Using a step up transformer, AC voltage can be increased to a high voltage level.

- High voltage transmission reduces power loss during transmission. ⑦

2) Voltage level can be changed easily:

- The AC voltage can be increased or decreased easily using transformers according to the requirement.
- This makes AC transmission more flexible and economical.

3) Maintenance is Easy and Economical:

- Compared to DC transmission, the maintenance of AC transmission systems is easier and less expensive.
- AC equipment is simple to maintain.

4) AC substations are more efficient:

- AC substations are generally more efficient than DC substations.
- They provide reliable operation with lower operating costs.

* Disadvantages of AC Transmissions:

1. Efficiency is affected by Inductance and Capacitance:

- The efficiency of AC transmission lines is affected by inductance and capacitance.
- These parameters cause voltage drop and reactive power losses.

2. More Conducting Material Required:

- Compared to DC transmission, AC transmission requires more conducting material.
- Therefore, the cost of conductor is higher.

3. Skin Effect and Proximity Effect:

- In AC transmission, skin effect and proximity effect are present.
- These effects increase the effective resistance of conductors and reduce efficiency.

4. Corona Effect is Higher:

- The corona effect is greater in AC transmission than in DC transmission.
- Corona causes power loss, noise, and radio interference.

5. Construction is More Complex:

- The construction of an AC transmission system is more complex than a DC system.
- More equipment such as transformers, circuit breakers and protection devices are required.

* Advantages and Disadvantages of DC Transmission:

* Advantages of DC Transmission:

1. Requires fewer conductors
2. No inductance, capacitance or surge problems.
3. Better voltage regulation.
4. No skin effect
5. less insulation requirement
6. Economical for underground cables.

* Disadvantages of DC Transmission:

1. High voltage DC voltage cannot be generated easily.
2. Voltage conversion is difficult
3. High initial cost
4. Limitations of switches and circuit breakers

* Advantages of High Voltage AC (HVAC) Transmission:

1. Low transmission current
2. Smaller conductor cross-section.
3. Lighter Transmission Towers
4. Smaller size of Electrical Equipment
5. Reduction in power loss.
6. Lower cost per kWh of transmission
7. Reduced copper losses.
8. Higher transmission efficiency.
9. Lower voltage drop
10. Improved voltage regulation
11. Better transmission line performance.
12. Increased power Handling capacity.
13. possibility of Interconnection.
14. suitable for long-distance transmission.

* Transmission line components:

- These components help in the safe, reliable, and efficient transmission of electrical energy from the generating station to the receiving station.

The main components are:

- Line conductors
- Line support
- Insulators
- overhead conductors
- underground cables.

* 1) Line Conductor:

- Line conductor is a conducting material used to carry electrical energy from generating station to receiving station through transmission line.

- The conductor should have high conductivity and good mechanical strength.
- ACSR (Aluminium conductor steel reinforced) is commonly used as a transmission line conductor.
- In an ACSR conductor, the steel core provides mechanical strength, while the aluminium strands carry the electrical current.

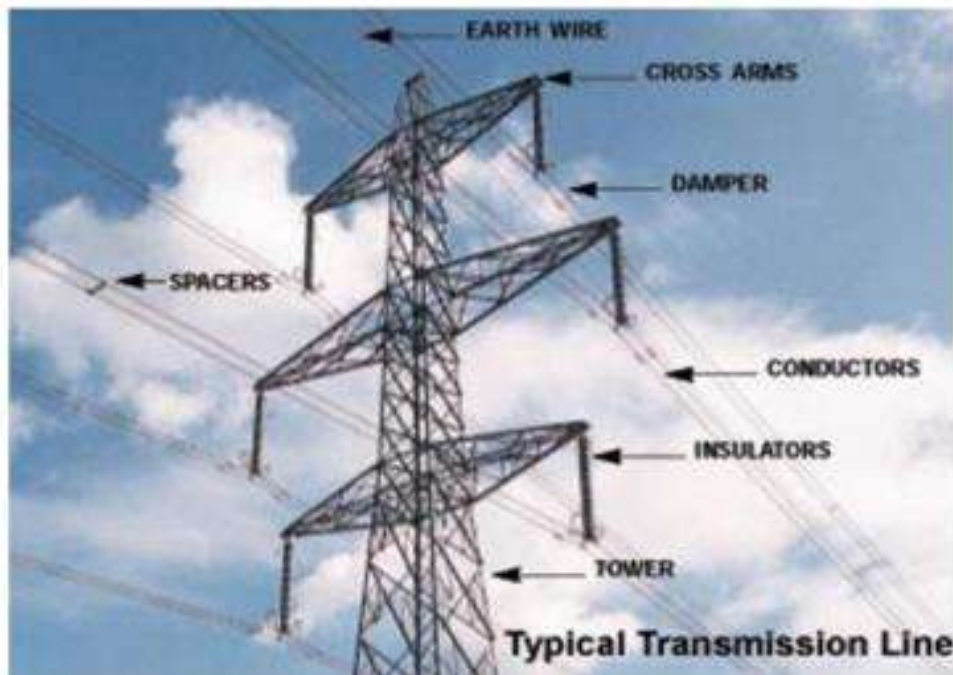


Fig Line Conductor

* 2) Line support (pole):

- A line support (pole) is used to support the overhead conductors of transmission line.

* Function of line support:

- It supports the conductor and keeps them at a safe height from the ground.

- It maintains the required distance between conductors.
- It carries the weight of the conductors and other line components.
- It must withstand wind, rain, snow and other environmental forces.
- It provides sufficient mechanical strength and stability to the transmission line.

- Types of line support:

1. Wooden pole
2. Steel pole
3. RCC pole
4. Lattice steel tower.

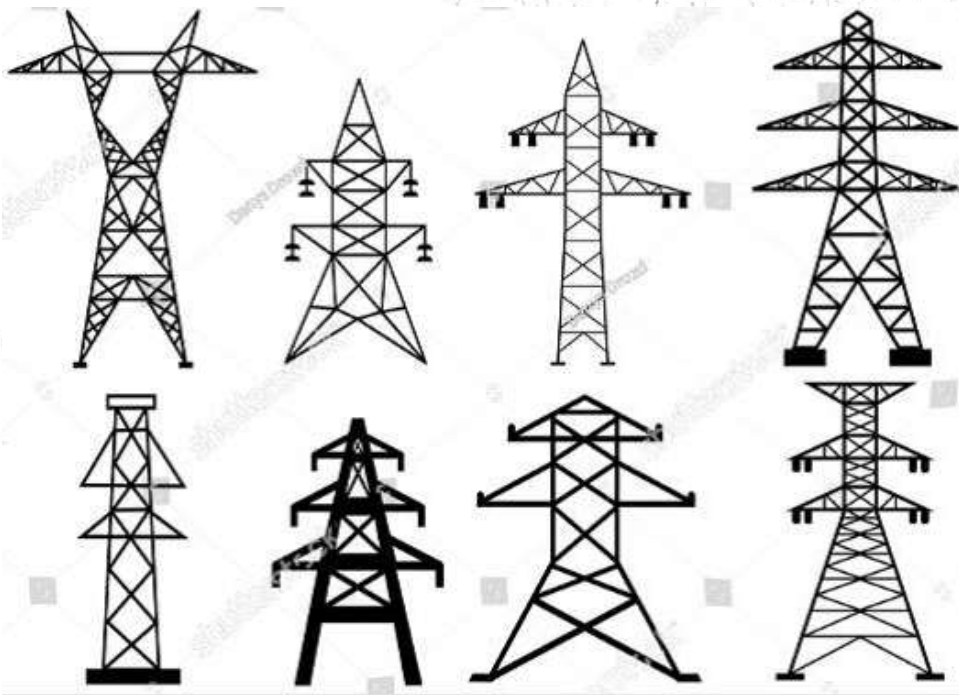


Fig Line Support

3) Insulator:

- An insulator is a device used to electrically isolate the conductor from the line support while mechanically supporting the conductor.

- Function of Insulator:

1. It provides electrical insulation between the conductor and pole/tower.
2. It provides mechanical support to the conductor.
3. It prevents leakage current from flowing from conductor to the tower or ground.

4. It helps maintain the required clearance between conductors and the supporting structure.

* Types of Insulators:

- pin insulator
- suspension insulator
- strain insulator
- shackle insulator

4) Cross Arms:

- Cross arm are horizontal members fixed on the pole/tower to support the insulators and conductors.

- Function of Cross-Arms:

- They provide mechanical support to the insulators.
- They maintain the required spacing between conductors.
- They help keep the conductors at a safe distance from the pole.
- Cross-arm are generally made of steel or RCC depending on the type of line support.

5) Other components of transmission line:

1. Danger plate:

- It is fixed on pole or tower to give a warning about the high voltage electrical line.
- It helps to prevent accidents.

2. Lightning Arrester:

- It protects the transmission line and electrical equipment from high voltage surges caused by lightning.
- It provides a path for the surge current to flow safely to earth.

3. Anti-climbing wire:

- It provided on pole/towers to prevent unauthorized climbing.
- It improves the safety of people near the transmission line.

4. Stay wire:

- It provides additional mechanical support and stability to the pole.
- It prevents the pole from tilting due to the pull of conductors and external forces.

5. Jumper:

- A jumper is a short conductor used to provide electrical continuity between two sections of a transmission line.

* Types of line supports:

- The main types of line supports are:

1. Wooden pole
2. Steel pole
3. RCC pole
4. Steel tower.

* Types of line Insulators:

1. pin Insulator
2. suspension Insulator
3. strain insulator
4. Shackle insulator
5. stay insulator

* Types of line Conductors:

1. AAC:- All Aluminium Conductor

- Made entirely of Aluminium
- Good electrical conductivity,
- low mechanical strength.

2. AAAC - All Aluminium Alloy Conductor:

- Made of Aluminium Alloy
- Better mechanical strength than AAC.
- It has good corrosion resistance.

3. ACSR - Aluminium Conductor Steel Reinforced:

- It consists of Aluminium strands around a steel core.
- Aluminium carries the electrical current
- The steel core provides high mechanical strength.
- It is widely used for overhead transmission lines.

4. ACAR - Aluminium Conductor Alloy Reinforced:

- It consists of Aluminium strands reinforced with Aluminium alloy.
- It provides good combination of electrical conductivity and mechanical strength.
- It is used for overhead transmission lines.

5. Copper Conductor:

- Made of Copper
- Copper has very high electrical conductivity
- It has good mechanical properties but it is more expensive than Aluminium.

6. Aluminium Conductor:

- Made of Aluminium
- It is ~~the~~ light in weight and economical
- It is commonly used in overhead transmission lines.

7. CCC - Cadmium copper conductor:

- Made of Copper with Cadmium
- It has good electrical conductivity and improved mechanical strength.

- It can withstand mechanical stress better than ordinary copper. ⑪

8. Gsc: Galvanized steel conductor:

- Made of Galvanized steel
- It has high mechanical strength
- It is used where high mechanical strength is required.

* Method of construction of Electric supply transmission systems

- 110kV, 220kV and 400kV
- For bulk power transmission and power distribution, HV, EHV and suitable distribution lines are required.
- The method of construction of transmission lines is selected mainly considering:
 - Reliability
 - Cost
 - Required transmission voltage
 - Safety and operating conditions.

* Important voltage levels:

- 110 kV
- 220 kV
- 400 kV
- These high voltage transmission systems are used for transmitting large amounts of electrical power over long distances.

* Survey work for overhead transmission line:

- Before construction of overhead transmission line, a proper survey of the proposed route is necessary.
- The survey helps in selecting the most suitable route and reduces the construction cost.

- The main components of an overhead lines are:

- pole
 - Insulator
 - cross-Arm
 - Tower
 - Related components such as insulator Hardware, pole brackets, and pole earthing.
- A proper study of survey work is important for deciding:
- Route of the transmission line
 - location of tower/poles
 - Required conductor sag
 - clearance
 - Tools and equipment
 - safety requirements
 - Cost of Construction.

* Survey works

- survey work includes following things:
 1. Selection of route
 2. Detailed survey
 3. proposed route should be short and straight.
 4. Avoid sharp turns.
 5. Study of topography
 6. Detailed survey for material requirements.

* Things to avoid to reduce Construction Cost:

- The following conditions should be avoided as far as possible because they increase the cost of construction:
 1. Excessive deviation
 2. Rank Crossing
 3. Special foundation

3. proper Guards and clearance
4. Right angle crossing
5. Avoid Highway and railway Crossings
6. Study of river Flood levels
7. Excessive Deviation should be avoided.
8. Guard wire size
9. Guy wire size.

* Transmission line parameters: R, L and C

- The performance of a transmission line depends mainly on its electrical parameters.
- The important parameters of a transmission line are:
 - Resistance (R)
 - Inductance (L)
 - Capacitance (C)
 - Conductance (G)

* parameters of transmission lines:

1. Resistance (R):

- Resistance (R) is the loop resistance of the transmission line per unit length.
 - It is mainly due to the resistance of the conductors.
 - It causes power loss in the transmission line.
- Unit - Ω/km .

2. Inductance (L)

- Inductance (L) is the loop inductance of the transmission line per unit length.
- It is produced due to the magnetic field around the current carrying conductor.

4. Difficult Access

5. Other important obstacles: As far as possible, Avoid:

- Forest areas
- Canals
- Rivers
- Railway crossings
- Road crossings
- Telephone lines
- Existing power lines
- Buildings
- Rocky areas etc.

* Types / stages of survey:

- The survey is generally carried out in two stages:

1. Primary walk-over survey:

- First, a primary walk-over survey is carried out
- The survey team physically examines the proposed route
- The purpose is to study the topography, obstacles, accessibility and general conditions of the area.

2. Detailed survey:

- After the primary walk-over survey, a detailed survey is carried out.
- It provides accurate information required for final design and construction of the transmission line.
- It helps determine the exact location of poles/towers, route alignment, clearance and material requirement.

* Points Considered During Route Selection of transmission line:

1. Transportation facility
2. Minimum angle poles

- Inductance causes reactive voltage drop in the transmission line.

unit: Henry/km (H/km)

3. Capacitance (C)

- capacitance (C) is the shunt capacitance of the transmission line per unit length.

- It exists both the conductors and both the conductor and earth.

- It is important in the analysis of long transmission lines.

unit: Farad/km (F/km)

4. Conductance (G):

- Conductance (G) is the shunt conductance of the transmission line per unit length.

- It represents the leakage current through the insulation both the conductor and earth.

- It depends mainly on the condition of the insulation and surrounding environment.

unit: Siemens/km (S/km)

* Inductance (L) of transmission line:

- It is mainly due to the magnetic field produced around a current carrying conductor.



Fig. Transmission line inductance and magnetic effect

Explanation:

- When current flows through a conductor, a magnetic field is produced around the conductor.
- When the current changes, the magnetic field also changes.
- This changing magnetic field produces an induced EMF that opposes the change in current.
- This property of the conductor is called inductance.

Defn: Inductance of a transmission line is the property by which a change in current produces an induced EMF that opposes the change in current.

unit: Henry per km (H/km).

* Capacitance (C) of transmission line:



Fig Transmission line capacitance

- In transmission line, the two parallel conductors act like the two plates of a capacitor.
- The air/insulating medium between the conductors acts as the dielectric.
- Therefore, capacitance exists between the two conductors.
- The capacitance of the transmission line is due to the electric field between the conductors.
- Capacitance is generally considered as shunt capacitance.
- The capacitance is expressed as capacitance per unit length.
- unit: microfarad/km ($\mu\text{F/km}$)

Defn: capacitance of a transmission line is the capacitance betw its conductors due to the electric field existing betw them.

* Resistance of transmission line (R):

- It is the electrical resistance offered by the conductor to the flow of current.



Fig Electric Resistance

- A transmission line conductor has a certain electrical resistance.
- Resistance opposes the flow of current through the conductor.
- The resistance depends mainly on:
 - length of conductor
 - cross-sectional area
 - Resistivity of conductor material
 - Temperature.

Unit: Ω / km .

- for a conductor:

$$R = \frac{\rho l}{a}$$

Where: R = Resistance (Ω)

ρ = Resistivity of conductor material

l = length of conductor

a = cross-sectional area of conductor.

- Effect of resistance:

- Resistance causes power loss in the transmission line:

$$P_{\text{loss}} = I^2 R$$

- $\therefore$ Higher resistance leads to higher power loss and lower transmission efficiency.

* Conductance (G) of transmission line:

Defn: Conductance is the ability of an imperfect insulator to allow a small amount of leakage current to flow between the conductors or between conductor and earth.

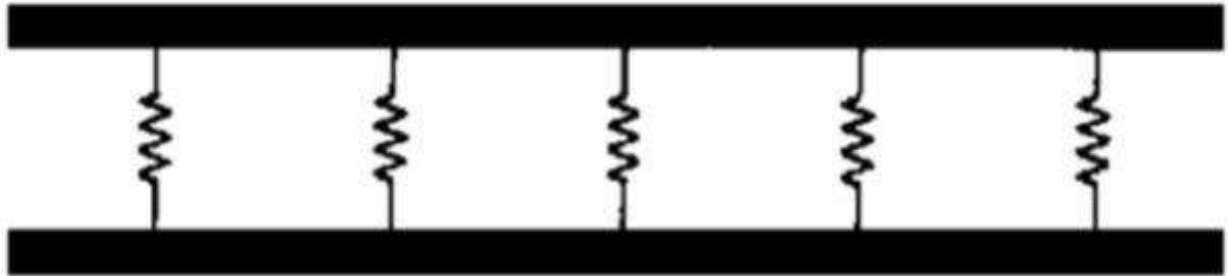


Fig | Conductance (G) of Transmission Line

Explanation:

- In an ideal transmission line, the insulator is a perfect insulator, so there is no current flow through it.
- In practice, an insulator is not perfectly insulating.
- Therefore, a small amount of leakage current flows through the insulation between the two conductors.
- This leakage current provides a leakage path between the conductors.
- This leakage path can be represented by a resistance connected between the conductors.
- Conductance (G) is the reciprocal of this resistance.
$$G = \frac{1}{R}$$
 where G = conductance
 R = leakage resistance.

Unit: Siemens (S).

* Equivalent diagram of a transmission line:

Defn: The equivalent diagram of a transmission line represents the distributed parameters R, L, C and G along the entire length of the transmission line. R and L are series parameters while C and G are shunt parameters.

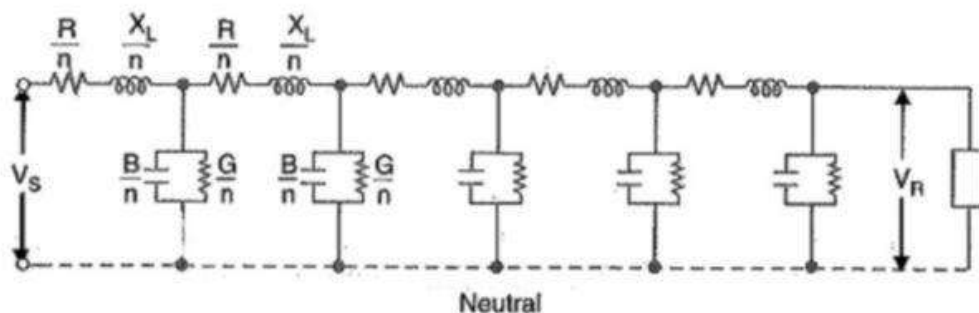


Fig Equivalent Diagram of Long Transmission Line

* Effect of transmission line components on performance:

- The performance of a transmission line is mainly affected by its electrical parameters R, L, C and G .

1. Effect of Resistance (R):

- Resistance (R) causes voltage drop in the transmission line.
- It also causes copper loss:

$$P_{\text{loss}} = I^2 R$$

- Therefore, resistance reduces the efficiency of the transmission line.

2. Effect of Inductance (L):

- Inductance (L) causes reactive voltage drop in the transmission line.
- It affects the voltage regulation and power factor.

3. Effect of capacitance (C):

- capacitance (C) produces charging currents.
- This charging current flows through the transmission line even when the load current is small.

- Therefore, capacitance affects the current and voltage conditions of the transmission line.

4. Effect of conductance (G):

- Conductance (G) represents the leakage current through the insulation.
- In practical transmission line, this current is very small.
- Therefore, G is generally neglected in many transmission line calculations.

5. Effect on Efficiency:

- The above parameters affect the efficiency (η) of the transmission line.

$$\eta = \frac{\text{Receiving end power}}{\text{Sending end power}} \times 100$$

- Higher losses result in lower transmission efficiency.

6. Effect on voltage Regulation:

- The parameters also affect the voltage regulation of the transmission line

$$\% \text{ Voltage Regulation} = \frac{V_s - V_R}{V_R} \times 100$$

where V_s = Sending end voltage

V_R = Receiving end Vtg.

7. Effect on power factor:

- The Inductance (L) and other line parameters affect the power factor of the transmission system.

* Performance of short Transmission Line:

- The performance of a transmission line is mainly evaluated using:
 1. Efficiency
 2. Voltage Regulation.
- The following factors are important while studying transmission-line performance:
 - Sending-end voltage
 - Sending-end current
 - Sending-end power factor
 - Receiving-end voltage
 - Receiving-end current
 - Receiving-end power factor
 - Transient conditions
 - Limitations of the transmission system.
- The performance of a transmission line is mainly determined by its

1. Efficiency:

- Efficiency tells us how effectively electrical power is transmitted from the sending end to the receiving end.

$$\eta = \frac{P_R}{P_S} \times 100$$

where, P_R = Receiving end power
 P_S = Sending-end power.

2. Voltage Regulation:

- Voltage regulation indicates the change in receiving-end v_tg when the load changes.

$$\% \text{ Vtg regulation} = \frac{V_S - V_R}{V_R} \times 100$$

Where V_s = Sending end voltage

V_R = Receiving end vty.

Defn: Voltage Regulation is the change in the Receiving end vty of a transmission line when the load changes from No load to Full load, while the sending end vty is kept constant.

$$\% V.R. = \frac{V_s - V_R}{V_R} \times 100$$

Where

V_s = Sending End vty

V_R = Receiving End vty at Full load.

or

$$\% \text{ Voltage Regulation (V.R.)} = \frac{V_{RNL} - V_{RFL}}{V_{RFL}} \times 100$$

Where V_{RNL} = Receiving End vty at No load

V_{RFL} = Receiving end vty at Full load.

* Efficiency of Transmission line:

Defn: Transmission line efficiency is the ratio of Receiving end power to Sending End power, expressed as a percentage.

$$\eta_T = \frac{\text{Receiving end power}}{\text{sending end power}} \times 100$$

for three phase ac transmission line:

$$\eta_T = \frac{\sqrt{3} V_R I_R \cos \phi_R}{\sqrt{3} V_s I_s \cos \phi_s} \times 100$$

∴ Therefore

$$\eta_T = \frac{V_R I_R \cos \phi_R}{V_s I_s \cos \phi_s} \times 100$$

Where: V_R = Receiving End Vtg

(17)

I_R = Receiving End current

$\cos\phi_R$ = Receiving End Power factor

V_S = Sending End Vtg

I_S = sending End current

$\cos\phi_S$ = sending End Power factor.

* Formula of transmission Efficiency in terms of line loss:

We know that

$$\therefore \eta_T = \frac{\text{Power Delivered}}{\text{Power Sent}} \times 100$$

Therefore

$$\eta_T = \frac{P_R}{P_S} \times 100$$

Where P_R = Receiving End power (power delivered)

P_S = Sending End power.

Here, $P_S = P_R + \text{Loss}$

$$\therefore \eta_T = \frac{P_R}{P_R + \text{Loss}} \times 100$$

$$\text{Alternatively, } \eta_T = \frac{P_S - \text{Loss}}{P_S} \times 100$$

For 3 ϕ AC transmission line:

$$P_R = \sqrt{3} V_R I_R \cos\phi_R$$

If the line loss is mainly Copper loss

$$P_{\text{loss}} = I^2 R$$

$$\text{Hence, } \boxed{\eta_T = \frac{V_R I_R \cos\phi_R}{V_R I_R \cos\phi_R + I^2 R} \times 100}$$

* Types OF Transmission lines According to length:

Transmission lines are classified according to their length into three types:

1. short transmission line - up to 50 km
2. Medium Transmission line - 50 to 150 km
3. Long Transmission line - Above 150 km.

1. short Transmission line:

- A short transmission line is a transmission line having a length of up to 50 km.
- Important characteristics:
- The length of line is less than or equal to 50 km.
- The operating voltage is generally less than 20 kV.
- The capacitive effect is very small and is therefore neglected.
- The line charging current is very small.
- Therefore, the shunt capacitance is generally neglected.
- The transmission line is mainly represented by Series Resistance (R) and series Inductance (L).
- Hence, the analysis of a short transmission line is comparatively simple.

2. Medium Transmission:

- A Medium Transmission line is transmission line having a length from 50 km to 150 km.
- Important characteristics:
- length is 50 km to 150 km.
- Operating voltage: 20 kV to 100 kV
- Capacitance effect cannot be neglected.

- Therefore, Resistance (R), Inductance (L) and capacitance (C) are (18) considered in analysis.
- The line parameters are considered to be uniformly distributed along the length of the line.
 - The capacitance can be represented at a particular location in the equivalent circuit.
 - Different methods are used to represent the capacitance, such as:
 - Nominal T Method
 - Nominal- π Method.

2. Long transmission line:

- A long transmission line is a line having a length above 150 km.
- It is generally used for transmission at high V_{tg} , usually above 100 kV.
- Important characteristics:
 - length of line is more than 150 km.
 - operating v_{tg} : above 100 kV.
 - The effect of Resistance (R), Inductance (L), capacitance (C) and Conductance (G) are considered.
 - These parameters are treated as uniformly distributed throughout the entire length of line.
 - for accurate efficiency calculation and performance analysis, the distributed parameters must be considered.
 - Therefore, the analysis of a long transmission line involves complex mathematical calculations.
 - The charging current due to capacitance is significant and can ~~be~~ not be neglected.

* Equivalent Diagram of Long Transmission Line:

- In a long transmission line R, L, C and G are distributed continuously along the complete length of the line.
 - Defn: A long transmission line is a transmission line having a length above 150 km. In this line, R, L, C and G are considered as uniformly distributed parameters along the entire length.
- Therefore, complex mathematical methods are required for accurate analysis.

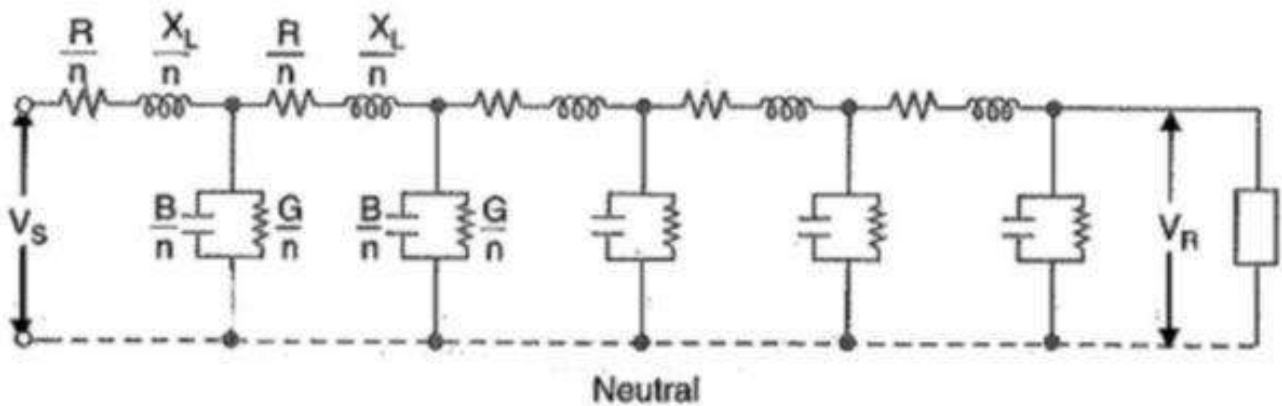


Fig Equivalent Diagram of Long Transmission Line

* Short Transmission Line:

- A short transmission line has a length up to 50 km.

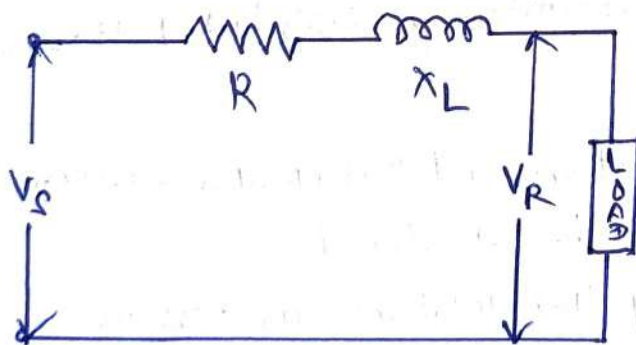


Fig. Equivalent diagram

I_r = Receiving end current
 R = Resistance per phase
 X_L = Reactance per phase
 V_R = Receiving End voltage
 $\cos \phi_R$ = Receiving end power factor

V_s = Sending end voltage.

$\cos \phi_s$ = Sending End Power Factor

For a short transmission line, the sending end vty is given by

$$V_s = V_R + IR + jIX_L$$

Also, $I_S = I_R = I$

Therefore, $V_S = V_R + IR + jIX_L$

where, V_S = sending end vtg

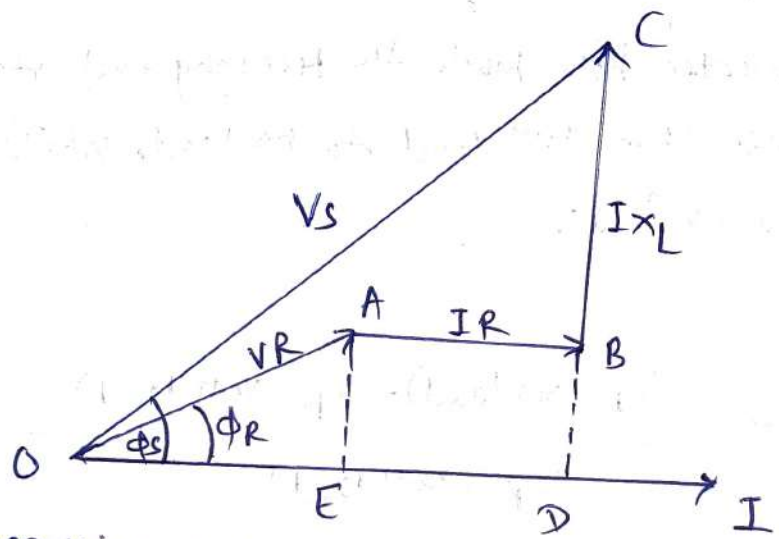
V_R = Receiving End vtg

IR = Resistive vtg drop

jIX_L = Inductive vtg drop.

I = Line current

* phasor diagram for Lagging power factor load



- The receiving end current I_R is taken as reference phasor for drawing the phasor diagram of a short transmission line.
- If the load has a lagging p.f. the current lags the receiving end vtg V_R by an angle ϕ_R .
- Draw the phasor V_R (OA)
- Since the current is lagging, draw the current phasor I at an angle ϕ_R clockwise from V_R .
- The current phasor is represented by AB.
- Draw the resistive vtg drop IR in the same direction as current I .
- Draw the inductive vtg drop jIX_L .
- jIX_L is drawn 90° ahead of current I .

- The total line v_{tq} drop is:

$$IZ = IR + jIX_L$$

- By adding the v_{tq} drops IR and jIX_L vectorially to the receiving end v_{tq} V_R , we obtain the sending end v_{tq} V_S .

- Finally, the angle betw V_S and I is called the sending end power factor angle ϕ_S .

$$V_S = V_R + IR + jIX_L$$

* Voltage Regulation

- v_{tq} regulation indicates how much the receiving end v_{tq} changes when the load changes from full load to no load, while keeping the sending-end v_{tq} constant.

The formula is:

$$\text{v_{tq} Regulation} = \frac{V_R(\text{No load}) - V_R(\text{Full load})}{V_R(\text{Full load})}$$

Percentage v_{tq} Regulation

$$\% V_R = \frac{V_S - V_R}{V_R} \times 100$$

for a lagging load:

$$\% V_R = \frac{IR \cos \phi_R + IX_L \sin \phi_R}{V_R} \times 100$$

Therefore

$$\% V_R = \left[\frac{IR}{V_R} \cos \phi_R + \frac{IX_L}{V_R} \sin \phi_R \right] \times 100$$

Since $\frac{IR}{V_R} = \text{P.u. resistance (R.p.u.)}$

and $\frac{IX_L}{V_R} = \text{P.u. reactance (X.p.u.)}$

We can write:

$$\%VR = [R_{p.u.} \cos\phi_R + X_{p.u.} \sin\phi_R] \times 100$$

for leading power factor

$$\%VR = [R_{p.u.} \cos\phi_R - X_{p.u.} \sin\phi_R] \times 100$$

1. Efficiency of short Transmission line:

- The efficiency of a transmission line is defined as the ratio of power output to power input.

$$\% \text{ Efficiency} = \frac{\text{Power output}}{\text{Power input}} \times 100$$

for 3ϕ transmission line

$$\% \text{ efficiency} = \frac{V_R I_R \cos\phi_R}{V_S I_S \cos\phi_S} \times 100$$

since, for short transmission line,

$$I_S = I_R = I$$

Therefore

$$\% \text{ efficiency} = \frac{V_R I \cos\phi_R}{V_R I \cos\phi_R + I^2 R} \times 100$$

2. Effect of power Factor on vrg regulation and Efficiency:

- When the load has a lagging p.f.

$$\%VR = \frac{IR \cos\phi_R + IX_L \sin\phi_R}{V_R} \times 100 \quad \text{--- (1)}$$

- When the load has a leading p.f.

$$\%VR = \frac{IR \cos\phi_R - IX_L \sin\phi_R}{V_R} \times 100 \quad \text{--- (2)}$$

Using equation ① and ②, the following important conclusions can be obtained:

* Effect of load power factor on vtg regulation:

Case 1: Lagging power factor

- When the load p.f. $\cos\phi_R$ is lagging and is sufficiently low, such that $IR \cos\phi_R > IX_L \sin\phi_R$
the vtg regulation is positive. Therefore $V_R < V_S$.
- That means the receiving end vtg V_R is less than the sending end vtg V_S .

Case 2: Leading power factor

- When the p.f. is leading and $IR \cos\phi_R < IX_L \sin\phi_R$
the vtg regulation becomes negative.
In this case $V_R > V_S$
- That means the receiving end vtg V_R becomes greater than sending end vtg V_S .

Case 3: Same Receiving End vtg and Line current

- For a lagging load power factor, if power factor is decreased, the vtg regulation increases.
- Therefore a lower lagging power factor results in a larger vtg drop.

Case 4: Leading load power factor

- If the receiving end vtg V_R and line current I are kept constant then:

- For a leading load power factor, if the P.F. is decreased, the vrg regulation decreases.
- Therefore, leading power factor can reduce the vrg regulation of the transmission line.

* EFFECT OF load power factor on Transmission Efficiency:

- The amount of power delivered to the load depends on the load power factor.
- The electrical power supplied to a 3ϕ load is:

$$P = \sqrt{3} V_L I_L \cos \phi$$

Where P = Electrical power

V_L = line vrg

I_L = line current

$\cos \phi$ = load power factor.

- Therefore, the efficiency of a transmission line is affected by the load power factor.