

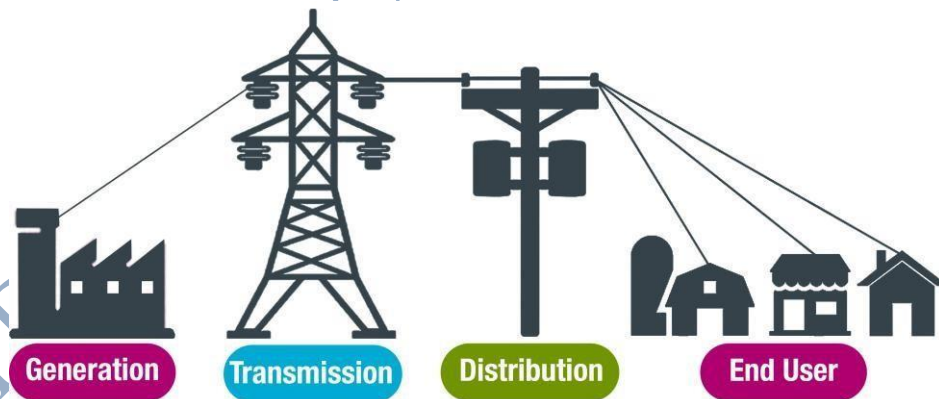


**GANESH INSTITUTE OF ENGINEERING &
TECHNOLOGY, POLYTECHNIC,
ANDHARUA, BHUBANESWAR.**

Electric Power Transmission and Distribution

(EEPC204)

(As per the 2025-26 syllabus of the SCTE&VT,
Bhubaneswar, Odisha.)



Fourth Semester

Electrical Engg.

Prepared by: *Er. Madhusmita Sahoo*

Th4. ELECTRIC POWER TRANSMISSION & DISTRIBUTION

SYLLABUS

1. BASICS OF TRANSMISSION AND DISTRIBUTION

- 1.1 Single line diagrams with components of the electric supply transmission and distribution systems
- 1.2 Classification of transmission lines
- 1.3 Primary and secondary transmission
- 1.4 Standard voltage level used in India
- 1.5 Classification of transmission lines: based on type of voltage, voltage level, length and others
- 1.6 Characteristics of high voltage for power transmission
- 1.7 Method of construction of electric supply transmission system- 110 kV, 220 kV, 400 kV
- 1.8 Method of construction of electric supply distribution systems- 220 V, 400V, 11 kV, 33 kV

2. TRANSMISSION LINE PARAMETERS AND PERFORMANCE

- 2.1 Line Parameters: Concepts of R, L and C of line parameters and types of lines
- 2.2 Performance of short line: Efficiency, regulation and its derivation, effect of power factor, vector diagram for different power factor
- 2.3 Performance of medium line: representation, nominal 'T', nominal 'π' and end condenser methods
- 2.4 Transposition of conductors and its necessity
- 2.5 Skin effect and proximity effect

3. EXTRA HIGH VOLTAGE TRANSMISSION

- 3.1 Extra High Voltage AC (EHVAC) transmission line: Necessity, high voltage substation components such as transformers and other switchgears
 - 3.1.1 Advantages, limitations and applications of EHVAC
 - 3.1.2 EHVAC lines in India
- 3.2 Ferranti and Corona effect
- 3.3 High Voltage DC (HVDC) Transmission Line: Necessity components, advantages, limitations and applications
 - 3.3.1 Layout of monopolar, bi-Polar and homo-polar transmission lines of HVDC
 - 3.3.2 HVDC Lines in: India
- 3.4 Features of EHVAC and HVDC transmission line
- 3.5 Flexible AC Transmission line Features, types of FACTS controller
- 3.6 New trends in wireless transmission of electrical power

4. AC DISTRIBUTION SYSTEM

- 4.1 AC distribution: Components classification, requirements of an ideal distribution system, primary and secondary distribution system
- 4.2 Feeder and distributor, factors to be considered in design of feeder and distributor
- 4.3 Types of different distribution schemes: radial, ring, and grid, layout, advantages, disadvantages and applications
- 4.4 Voltage drop, sending end and receiving end voltage
- 4.5 Distribution Sub-Station: Classification, site selection, advantages, disadvantages and applications

4.6 Single Line diagram (layout) of 33/11KV Sub-Station, 11KV/400V sub-station

4.7 Symbols and functions of their components

5. COMPONENTS OF TRANSMISSION AND DISTRIBUTION LINES

5.1 Overhead Conductors: Properties of material, types of conductor with trade names, significance of sag

5.2 Line supports: Requirements, types of line structures and their specifications, methods of erection

5.3 Line material

5.3.3 Types of insulators Insulators

5.3.1 Properties of insulating material

5.3.2 Selection of and their applications

5.3.4 Causes of insulator failure

5.3.5 Derivation of equation of string efficiency for string of three suspension insulator

5.3.6 Methods of improving string efficiency

5.4 Underground Cables: Requirements, classification, construction, comparison with overhead lines, cable laying and cable jointing.

BOOKS RECOMMENDED:

1. **Utilization of Electric Power & Electric Traction** by G.C. Garg, Khanna Book Publishing Co., New Delhi.
2. **Principles of Power System** by V.K. Mehta, S. Chand and Co. New Delhi.
3. **A Course in Electrical Power** by Soni; Gupta; Bhatnagar, Dhanpat Rai and Sons New Delhi.
4. **A Course in Power Systems** by J.B. Gupta, S.K. Kataria and sons, New Delhi.
5. **A Textbook of Electrical Technology Vol. III**, by B.L Theraja; A.K. Theraja, S.Chand and Co. New Delhi.

UNIT 1: BASICS OF TRANSMISSION AND DISTRIBUTION

Single line diagrams with components of the electric supply transmission and distribution systems:

A **Single Line Diagram** is a simplified graphical representation of a **three-phase electrical power system**. A single line diagram (SLD) for electric supply systems uses one line to represent three-phase power, showing key components like **generators, transformers (step-up/step-down), transmission lines (HV/EHV), substations (bulk/distribution), feeders, switches, circuit breakers, and loads**, illustrating power flow from generation (e.g., 11kV) up to transmission (e.g., 220kV/400kV) and down to distribution (e.g., 66kV to 11kV/415V/230V) for consumers.

Purpose of a Single Line Diagram

- Shows **generation, transmission, and distribution** of electrical power
- Helps in **system planning, operation, and maintenance**
- Easy to understand and saves drawing time
- Used by engineers, technicians, and electricians

Components of Single Line Diagram

1. **Generation:** Power is produced at generating stations, often at lower voltages (e.g., 11kV).
2. **Step-Up Transformers:** Voltage is increased (stepped up) for efficient long-distance transmission (e.g., to 132kV, 220kV, 400kV).
3. **Transmission System:** High-voltage lines carry power to load centres.
4. **Bulk Substations:** Receive high voltage and step it down for sub-transmission (e.g., to 66kV).
5. **Sub-Transmission:** Further steps down voltage for distribution substations.
6. **Distribution Substations:** Step down voltage (e.g., to 11kV/33kV) for primary distribution.
7. **Distribution Feeders & Lines:** Deliver power to industrial (primary 11kV) and residential areas (secondary 415V/230V).
8. **Distribution Transformers:** Step down medium voltage to final consumer voltage (e.g., 415V to 230V).
9. **Loads:** Homes, businesses, industries consuming power.
10. **Lines:** Transmission/Distribution lines (single line shows all phases).
11. **Symbols:** Transformers (X), Circuit Breakers (CB), Switches (S), Generators (G), Buses (bars connecting components).

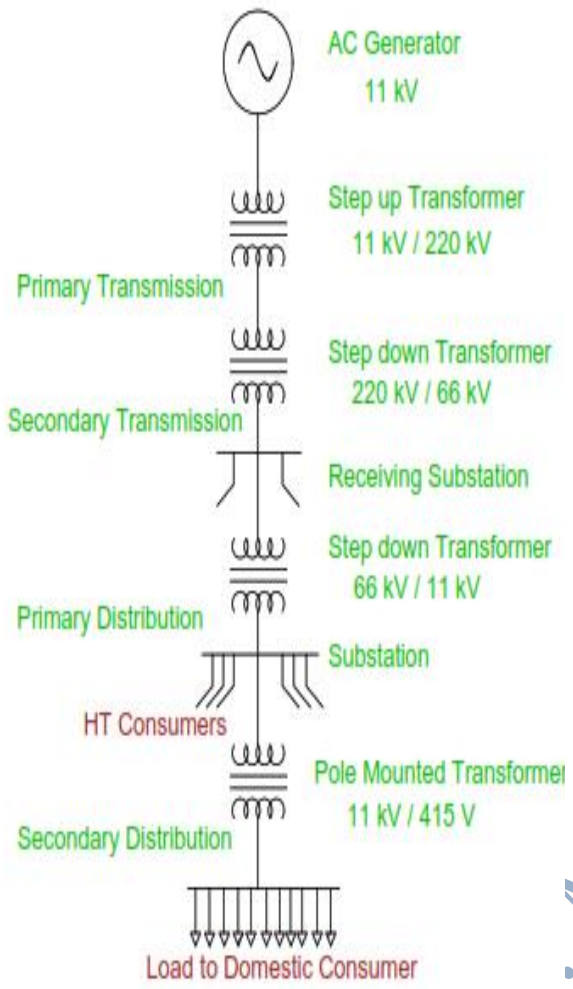
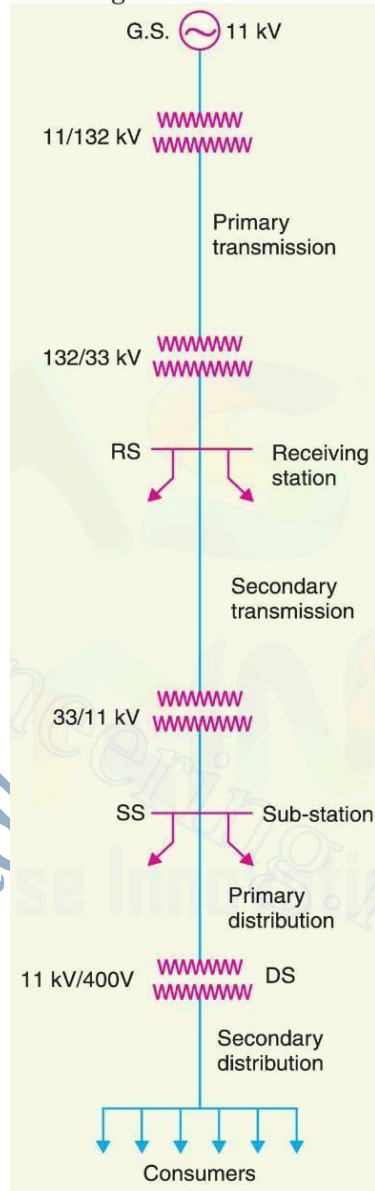


FIG : Single Line Diagram of Power Supply System



EPTD Notes

Madh

100

The conveyance of electric power from a power station to consumers Premises is known as electric supply system.

(i) **Generating station:** The generating station where electric power is produced by 3-phase alternators operating in parallel. The usual generation voltage is 11 kV. For economy in the transmission of electric power, the generation voltage (i.e., 11 kV) is stepped up to 132 kV (or more) at the generating station with the help of 3-phase transformers.

(ii) **Primary transmission.** The electric power at 132 kV is transmitted by 3-phase, 3-wire overhead system to the outskirts of the city. This forms the primary transmission. Generally the primary transmission is carried at 66 kV, 132 kV, 220 kV or 400 kV.

(iii) **Secondary transmission.** At the receiving station, the voltage is reduced to 33kV by step-down transformers. From this station, electric power is transmitted at 33kV by 3-phase, 3-wire overhead system to various sub-stations (SS) located at the strategic points in the city. This forms the secondary transmission.

(iv) **Primary distribution.** The secondary transmission line terminates at the sub-station (SS) where voltage is reduced from 33 kV to 11kV, 3-phase, 3-wire. The 11 kV lines run along the important road sides of the city. This forms the primary distribution.

(v) **Secondary distribution.** The electric power from primary distribution line (11 kV) is delivered to distribution sub-stations (DS). These sub-stations are located near the consumers' localities and step down the voltage to 400 V, 3-phase, 4-wire for secondary distribution.

The voltage between any two phases is 400 V and between any phase and neutral is 230 V. The single-phase residential lighting load is connected between any one phase and neutral, whereas 3-phase, 400 V motor load.

In transmission line determination of voltage drop, transmission efficiency, line loss etc. are important things to design. These values are affected by line parameter R, L and C of the transmission line. Length wise transmission lines are three types.

Short Transmission Line

A short transmission line is classified as a transmission line with:

- A length less than 80km (50 miles)
- Voltage level less than 69 kV
- Capacitance effect is negligible
- Only resistance and inductance are taken in calculation capacitance is neglected.

Medium Transmission Line

A medium transmission line is classified as a transmission line with:

- A length more than 80 km (50 miles) but less than 250 km (150 miles)
- Operational voltage level is from 69 kV to approx. 133 kV

- Capacitance effect is present
- Distributed capacitance form is used for calculation purpose.

Long Transmission Line

A long transmission line is classified as a transmission line with:

- A length more than 250 km (150 miles)
- Voltage level is above 133 kV
- Line constants are considered as distributed over the length of the line.

Primary Transmissions

Primary transmission is the **first stage of power transmission** after generation. Electrical power is transmitted at **very high voltage** from the generating station to **main receiving (grid) substations**.

Voltage Levels: **66 kV, 110 kV, 132 kV, 220 kV & 400 kV.**

Secondary Transmissions

Secondary transmission is the **next stage after primary transmission**, where power is transmitted from **receiving/grid substations** to **main distribution substations**.

Voltage Levels: **33 kV, 22 kV & 11 kV.**

Difference Between Primary and Secondary Transmission

Feature	Primary Transmission	Secondary Transmission
Voltage Level	Very high (66–400 kV)	Medium (11–33 kV)
Distance	Long	Medium
Transformer	Step-up	Step-down
Main Function	Bulk power transfer	Supply to distribution substations
Losses	Very low	Low
Line Type	Mostly overhead	Overhead / Underground

Standard voltage level used in India:

In India, the standard household voltage for single-phase supply is **230 Volts (V)** at a frequency of **50 Hertz (Hz)**, with acceptable variations typically between 207V to 253V. For three-phase systems, it's around 400V (230V Line to Neutral). This is consistent with many other countries using 220-240V ranges.

- **Domestic (Single Phase):** 230V AC, 50Hz.
- **Range:** The voltage can fluctuate within $\pm 6\%$ (207V to 253V) as per Indian Standards (IS 12360).
- **Three-Phase:** Typically 400V (Line-to-Line).

- **Transmission:** Higher voltages like 11kV, 33kV, 132kV, 220kV, 400kV are used for efficient power transmission before stepping down for local distribution.

Characteristics of high voltage for power transmission:

Characteristics include high dielectric strength for insulation, needing specialized equipment (transformers, insulators), and allowing greater power capacity per line, with Ultra-High Voltage (UHV) pushing limits for intercontinental grids.

- **Efficiency:** Higher voltage means lower current for the same power.
- **Cost Savings:** Lower current allows for smaller, lighter conductors, reducing material costs and the need for massive towers, saving on infrastructure.
- **Long Distance Transport:** Essential for moving large blocks of power from renewable sources (wind farms) or power plants to cities far away.
- **Reduced Line Drop:** Lower current results in less voltage drop, improving voltage regulation and system stability.
- **Increased Capacity:** Fewer HV lines are needed to carry the same total power, maximizing right-of-way use.

Long Questions:

- Explain with block diagram the Single Line Diagram.
- Compare Primary transmission with Secondary transmission.
- What are the standard voltage level used in India?
- Discuss the characteristics of high voltage for power transmission.

UNIT-2: TRANSMISSION LINE PARAMETERS AND PERFORMANCE

Line Parameters: Concepts of R, L and C of line parameters and types of lines:

Transmission line parameters R (Resistance), L (Inductance), C (Capacitance), and G (Conductance) define line performance, representing energy loss (R, G) and storage (L, C) distributed along the line, while types range from simple (short lines) to complex (long lines).

Types of Transmission Lines:

- **By Length / Modelling:**
 - **Short Lines:** Negligible capacitance, mainly R & L.
 - **Medium Lines:** Accounts for R, L, and some C (e.g., Nominal π Model).
 - **Long Lines:** Considers all distributed R, L, C, G (e.g., Equivalent π Model).
 - *Short transmission lines.*
 - When the length of an overhead transmission line is up to about 50 km and the line voltage is comparatively low (< 20 kV) is called as short transmission line.
 - Due to smaller length and lower voltage, the capacitance effects are small and hence can

be neglected.

- Here only resistance and inductance of the line are taken into account.

• *Medium transmission lines.*

- When the length of an overhead transmission line is about 50-150 km and the line voltage is moderately high ($>20 \text{ kV} < 100 \text{ kV}$), it is considered as a medium transmission line.
- Due to sufficient length and voltage of the line, the capacitance effects are taken into account.
- Three parameters i.e. Resistance, inductance and capacitance are taken into account while calculating performance of the transmission line.

• *Long transmission lines.*

- When the length of an overhead transmission line is more than 150km and line voltage is very high ($> 100 \text{ kV}$), it is considered as a long transmission line.
- For the treatment of such a line, the line constants are considered uniformly distributed over the whole length of the line and rigorous methods are employed for solution.

• By Physical Construction:

- **Overhead Lines:** Conductors on towers (e.g., parallel conductors).
- **Underground Cables:** Insulated conductors in ducts.
- **Coaxial Cables:** Inner conductor surrounded by dielectric and shield.
- **Planar Lines:** Microstrip, Stripline (used in PCBs).

Performance of short line: Efficiency, regulation and its derivation, effect of power factor, vector diagram for different power factor

i. Voltage regulation.

The ratio between difference in voltage ($V_S - V_R$) to the receiving end voltage is called as voltage regulation.

Mathematically, % age Voltage regulation = $\frac{V_S - V_R}{V_R} * 100$

Where V_S = Sending end voltage, V

V_R = Receiving end voltage,

V

Voltage regulation refers to the change in voltage magnitude between sending and receiving line terminals. It is an important consideration as excessive voltage drop could make the received voltage fall outside tolerance bands, disrupting loads.

$$\% \text{ Voltage regulation} = \frac{\text{Sending end voltage} - \text{Receiving end voltage}}{\text{Sending end voltage}} \times 100$$

Voltage regulation is influenced by line impedance, current, and power factor and is calculated as the percentage ratio of sending voltage to receiving voltage. Lower impedance and higher power factors improve regulation. It must be maintained within permissible limits, usually $\pm 5\%$ of the rated voltage.

ii. **Transmission efficiency:**

The ratio of receiving end power to the sending end power of a transmission line is known as the transmission efficiency of the line.

i.e.

$$\begin{aligned} \text{\% age Transmission efficiency, } \eta_T &= \frac{\text{Receiving end power}}{\text{Sending end power}} \times 100 \\ &= \frac{V_R I_R \cos \phi_R}{V_S I_S \cos \phi_S} \times 100 \end{aligned}$$

where V_R , I_R and $\cos \phi_R$ are the receiving end voltage, current and power factor while V_S , I_S and $\cos \phi_S$ are the corresponding values at the sending end.

Transmission efficiency indicates the effectiveness of power transfer over lines. It is defined as the ratio of power received to power sent and quantified as a percentage.

$$\text{\% Transmission line efficiency} = \frac{\text{Power delivered at receiving end}}{\text{Power sent from the sending end}} \times 100$$

Higher efficiency means lower transmission losses. Primary loss mechanisms include Joule heating due to line resistance and corona/dielectric losses from conductor surface irregularities. Efficiency is optimized by choosing conductor and insulator materials to minimize resistive losses and withstand higher operating voltages with reduced corona.

Efficiencies over 95% are typically achieved for practical distances.

Performance of medium line: representation, nominal 'T', nominal 'π' and end condenser methods

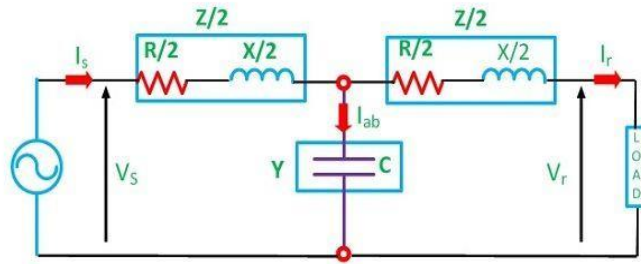
Performance of single phase medium transmission line:

There are three methods are used for the solution of medium transmission line, that are:

- (i) End condenser method
- (ii) Nominal T method
- (iii) Nominal π method

Nominal 'T' method:

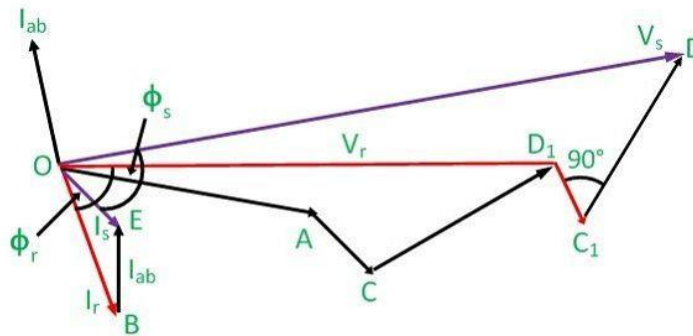
This method is used for the analysis of medium transmission line. In this method the total line capacitance is lumped or concentrated at the mid-point of the line. The resistance and reactance of the line are divided with half the resistance and reactance on one side and remaining half on other side of capacitor. Half of the line carries full charging current with this arrangement. Fig. shows the arrangement used in nominal T method for one phase. It is desirable to work in phase instead of line values.



Nominal T model of a Medium Line

Circuit Globe

The corresponding phasor diagram is represented as:



Phasor diagram of a nominal T network

Circuit Globe

Here the receiving end voltage V_R is taken as reference. The drop PQ ($I_R \cdot R / 2$) is phase with I_R . The drop QR ($I_R \cdot X_L / 2$) is leading I_R by 90° . The phasor sum of these drops with V_R gives the voltage V_1 which is the voltage across the capacitor. The capacitor current leads V_C by 90° . The phasor sum of I_R and gives I_S . The drop $Rg f IS \cdot R$ is in phase with Ig whereas drop ST ($I_S \cdot X_L / 2$) is leading I_S by 90° . The phasor sum of these drops along with V_1 gives the sending end voltage V_S .

Sum of these drops along with V_1 gives the sending end voltage V_S

Let I_R = Receiving end load current per phase

R = Resistance per phase, X_L = Inductive reactance

C = Capacitance per phase, $\cos \phi_R$ = p.f. at receiving end

V_S = Sending end voltage, V_1 = Voltage across capacitor

Receiving end voltage, $\bar{V}_R = V_R + j0$

Load current, $\bar{I}_R = I_R (\cos \phi_R - j \sin \phi_R)$

Voltage across capacitor, $\bar{V}_1 = \bar{V}_R + \bar{I}_R \left(\frac{\bar{Z}}{2} \right)$
 $= [V_R + j0] + [I_R (\cos \phi_R - j \sin \phi_R)] \left[\frac{R}{2} + j \frac{X_L}{2} \right]$

Current through capacitor,	$\bar{I}_C = j\omega C \bar{V}_1 = j2\pi fC \bar{V}_1$
Sending end current,	$I_S = \bar{I}_R + \bar{I}_C$
Sending end voltage,	$\bar{V}_S = \bar{V}_1 + \bar{I}_S \left(\frac{\bar{Z}}{2} \right) = \bar{V}_1 + \bar{I}_S \left[\frac{R}{2} + j \frac{X_L}{2} \right]$

Nominal 'π' method:

This is also a localized capacitance method in which capacitance is divided into two halves with one half lumped near sending end and other half near the receiving end. The capacitor near the sending end does not contribute any line voltage drop but it should be added with line current to get total sending end current.

The current \bar{I}_R lags behind V_R by angle ϕ_R . The current through capacitor C_1 is leading the voltage V_R by an angle of 90° . The phasor sum of I_R and I_{C1} gives the line current I_L . The drop $I_L R$ is in phase with I whereas drop $I_L X_L$ is leading by 90° . The phasor sum of these drops with V_R gives the sending end voltage V_S . The capacitor current I_{C2} is leading voltage V_S by 90° . The phasor sum of I_S and I_{C2} gives the sending end line current I_S .

Let V_S = Sending end voltage, V_R = Receiving end voltage

I_R = Load current or receiving end current

R = Resistance per phase,

X_L = Inductive reactance per phase

C = Capacitance per phase, $\cos \phi_R = \text{p.f. at receiving end}$

We have, $\bar{V}_R = V_R + j0$

Load current, $\bar{I}_R = I_R (\cos \phi_R - j \sin \phi_R)$

Charging current at receiving end, $\bar{I}_{C1} = j\omega \left(\frac{C}{2} \right) \bar{V}_R = j\pi f C \bar{V}_R$

We get the line current as, $\bar{I}_L = \bar{I}_R + \bar{I}_{C1}$

Thus sending end voltage is given as,

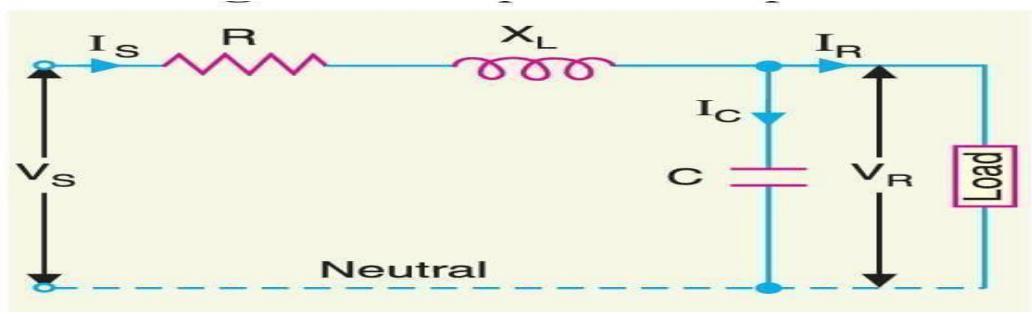
$$\bar{V}_S = \bar{V}_R + \bar{I}_L \bar{Z} = \bar{V}_R + \bar{I}_L [R + j X_L]$$

Charging current at sending end is,

$$\bar{I}_{C2} = j\omega \left(\frac{C}{2} \right) \bar{V}_S = j\pi f C \bar{V}_S$$

$$\text{Sending end current, } \bar{I}_S = \bar{I}_L + \bar{I}_{C2}$$

EPTD Notes by



- Let I_R = load current per phase
 R = resistance per phase
 X_L = inductive reactance per phase
 C = capacitance per phase
 $\cos \phi_R$ = receiving end power factor (*lagging*)

V_S = sending end voltage per phase

The phasor diagram for the circuit is shown in Fig 1

Taking the receiving end voltage \vec{V}_R as the reference phasor,

we have, $\vec{V}_R = V_R + j0$

Load current, $\vec{I}_R = I_R (\cos \phi_R - j \sin \phi_R)$

Capacitive current, $\vec{I}_C = j \vec{V}_R \omega C = j 2 \pi f C \vec{V}_R$

The sending end current \vec{I}_S is the phasor sum of load current \vec{I}_R and capacitive current \vec{I}_C i.e.,

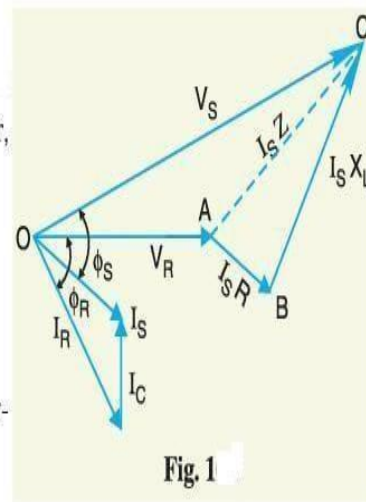


Fig. 1

$$\begin{aligned} \vec{I}_S &= \vec{I}_R + \vec{I}_C \\ &= I_R (\cos \phi_R - j \sin \phi_R) + j 2 \pi f C V_R \\ &= I_R \cos \phi_R + j (-I_R \sin \phi_R + 2 \pi f C V_R) \end{aligned}$$

Voltage drop/phase $= \vec{I}_S \vec{Z} = \vec{I}_S (R + j X_L)$

Sending end voltage, $\vec{V}_S = \vec{V}_R + \vec{I}_S \vec{Z} = \vec{V}_R + \vec{I}_S (R + j X_L)$

Thus, the magnitude of sending end voltage V_S can be calculated.

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

$\% \text{ Voltage transmission efficiency} = \frac{\text{Power delivered / phase}}{\text{Power delivered / phase} + \text{losses / phase}} \times 100$

$$= \frac{V_R I_R \cos \phi_R}{V_R I_R \cos \phi_R + I_S^2 R} \times 100$$

1. End condenser method

In this method the line capacitance is lumped or concentrated near the load or at the receiving end. This method overestimates the effect of capacitance.

Let V_S = Sending end voltage

V_R = Receiving end voltage

I_R = Load current per phase

X_L = Inductive reactance per phase

C = Capacitance per phase

$\cos \phi_R$ = Receiving end power factor

V_R is the reference vector,

- I_R = load current per phase
- R = resistance per phase
- X_L = inductive reactance per phase
- C = capacitance per phase
- $\cos \phi_R$ = receiving end power factor (*lagging*)
- V_S = sending end voltage per phase

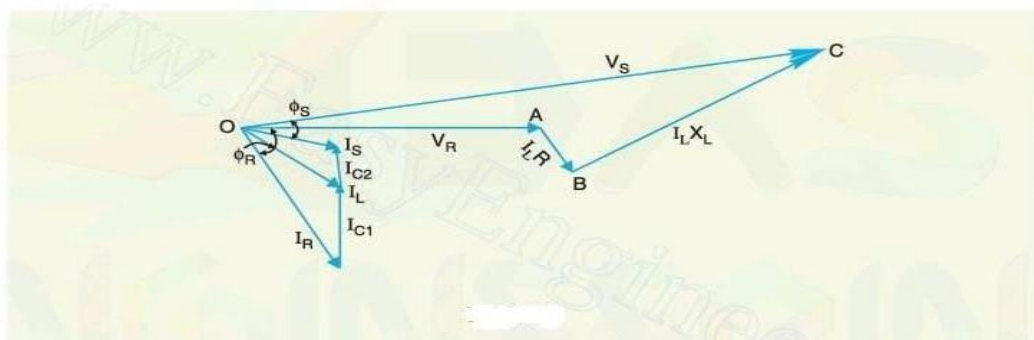
Taking the receiving end voltage as the reference phasor, we have,

$$\vec{V}_R = V_R + j0$$

Load current,
$$\vec{I}_R = I_R (\cos \phi_R - j \sin \phi_R)$$

Charging current at load end is

$$\vec{I}_{C1} = j \omega (C/2) \vec{V}_R = j \pi f C \vec{V}_R$$



Line current,
$$\vec{I}_L = \vec{I}_R + \vec{I}_{C1}$$

Sending end voltage,
$$\vec{V}_S = \vec{V}_R + \vec{I}_L \vec{Z} = \vec{V}_R + \vec{I}_L (R + jX_L)$$

Charging current at the sending end is

$$\vec{I}_{C2} = j \omega (C/2) \vec{V}_S = j \pi f C \vec{V}_S$$

\therefore Sending end current,
$$\vec{I}_S = \vec{I}_L + \vec{I}_{C2}$$

$\bar{V}_R = V_R + j0$ The load current I_R is lagging behind V_R by an angle of ϕ_R

$$\therefore \bar{I}_R = I_R (\cos \phi_R - j \sin \phi_R)$$

$$\text{Capacitive current, } \bar{I}_C = \frac{\bar{V}_R}{-jX_C} = \frac{\bar{V}_R}{\left[\frac{1}{j2\pi f C} \right]} = j 2\pi f C \bar{V}_R = j \omega C \bar{V}_R$$

From the phasor diagram it can be seen that the phasor sum of \bar{I}_R and \bar{I}_C gives the sending end current \bar{I}_S

$$\begin{aligned} \bar{I}_S &= \bar{I}_R + \bar{I}_C \\ &= I_R (\cos \phi_R - j \sin \phi_R) + j \omega C V_R \\ &= I_R \cos \phi_R + j (-I_R \sin \phi_R + \omega C V_R) \end{aligned}$$

The voltage drop in each phase is given by,

$$\text{Voltage drop/phase} = \bar{I}_S \bar{Z} = \bar{I}_S (R + jX_L)$$

$$\begin{aligned} \text{Sending end voltage, } \bar{V}_S &= \bar{V}_R + Z \cdot \bar{I}_S \\ &= \bar{V}_R + \bar{I}_S (R + jX_L) \end{aligned}$$

The voltage regulation is given as,

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

Similarly efficiency of transmission line is,

$$\begin{aligned} \% \text{ Transmission efficiency} &= \frac{\text{Power delivered / phase}}{\text{Power sent / Phase} + \text{Losses / Phase}} \times 100 \\ &= \frac{V_R I_R \cos \phi_R}{V_R I_R \cos \phi_R + I_S^2 R} \times 100 \end{aligned}$$

It can be seen that this method is having some limitations although this method is simple to operate. The disadvantages are:

i) This method assumes the capacitance to be lumped near the receiving end although in actual practice it is distributed along its length. Due to this there is considerable error of about 10 % in the calculations.

ii) The effects of line capacitance are overestimated in this method.

Skin effect and proximity effect

The **skin effect** and **proximity effect** are both phenomena that affect the flow of alternating current (AC) in conductors. They are particularly important in the context of electrical engineering, especially when dealing with high-frequency signals or power transmission.

1. Skin Effect

- The skin effect is the tendency of AC to flow primarily near the surface of a conductor, causing the current density to decrease exponentially with depth from the surface.
- **Cause:** As AC flows through a conductor, it generates a changing magnetic field, which, by Lenz's law, induces eddy currents in the conductor. These eddy currents oppose the flow of the main current, pushing the current towards the surface of the conductor.
- **Impact:** This leads to a reduction in the effective cross-sectional area of the conductor carrying the current, increasing the **resistance** of the conductor at higher frequencies.
- **Frequency Dependence:** The skin effect becomes more pronounced as the frequency of the AC increases. For low-frequency currents (like in power transmission), the skin effect is minimal, but at high frequencies (such as in radio frequency circuits), the current flows only on the outer surface of the conductor.
- **Formula for Skin Depth:** The skin depth is a measure of how deep the current penetrates into the conductor. The skin depth decreases as the frequency increases, which is why high-frequency signals tend to travel along the surface.

2. Proximity Effect

- The proximity effect occurs when alternating currents flow through nearby conductors, influencing each other's current distribution. The current tends to crowd towards the side of the conductor that is closest to another conductor.
- **Cause:** When multiple conductors are placed near each other (e.g., in a cable or coil), the magnetic field produced by the current in one conductor affects the current distribution in adjacent conductors. This causes the current to concentrate more on the parts of the conductors that are closest to each other, resulting in increased resistance.
- **Impact:** Like the skin effect, the proximity effect increases the effective resistance of a conductor. However, it is more pronounced when multiple conductors are involved, especially in tightly packed cables or coils.
- **Frequency Dependence:** The proximity effect also becomes more significant as the frequency increases, since the magnetic fields change more rapidly at higher frequencies.

Differences:

- **Skin Effect** primarily deals with the **current distribution** within a single conductor.
- **Proximity Effect** deals with how the current distribution in one conductor is influenced by the presence of nearby conductors.

Both effects increase the effective resistance at higher frequencies, which can lead to power loss and heating in electrical systems. Engineers mitigate these effects by using **litz wire** (a type of wire where many thin strands are woven together) or **multi-layer insulation** to reduce losses.

LONG QUESTION :

Classify types of transmission lines.

Discuss Explain Skin effect and Proximity effect.

Explain end condenser methods.

UNIT-3: EXTRA HIGH VOLTAGE TRANSMISSION

Extra High Voltage AC (EHVAC) transmission line

EHV AC transmission:

- A transmission system is to transfer electrical power from one place to another or from one network to another network.
- In order to transmit large amounts of electric power over long distances extra high voltage (EVH) transmission lines are adopted.
- Extra-high voltage (EHV) facilitate transmission at 300Kv to 765KV.
- High voltage up to 300KV.
- Ultra high voltage(UHV) above 765KV.
- In India the transmission voltages in use are 33, 66, 110, 132, 220 and 400KV.

Reasons for adoption of EHV AC transmission.

The reasons for adoption of EHV AC transmission line are:

- Increase in transmission efficiency.
- Reduction of electrical power loss.
- Decrease in voltage drop and Improvement of voltage regulation.
- Reduction in conductor material requirement.
- Flexibility for future system growth.
- Increase in transmission capacity of the line.
- Possibility of interconnections of power systems.

Limitations in EHV transmission.

The problem associated with EHV transmission line are:

- There is high amount of power loss due to corona.
- Radio – interference occurs in EHV transmission line.
- Heavy supporting structure and erection difficulties arises.
- Level of insulation requirement increases.
- Erection difficulties.
- The cost of transformers, switchgear equipment's and protective equipment's increases with increase in transmission line voltage.
- The EHV lines generates electrostatic effects which are harmful to human beings and animals.

Ferranti and Corona effect

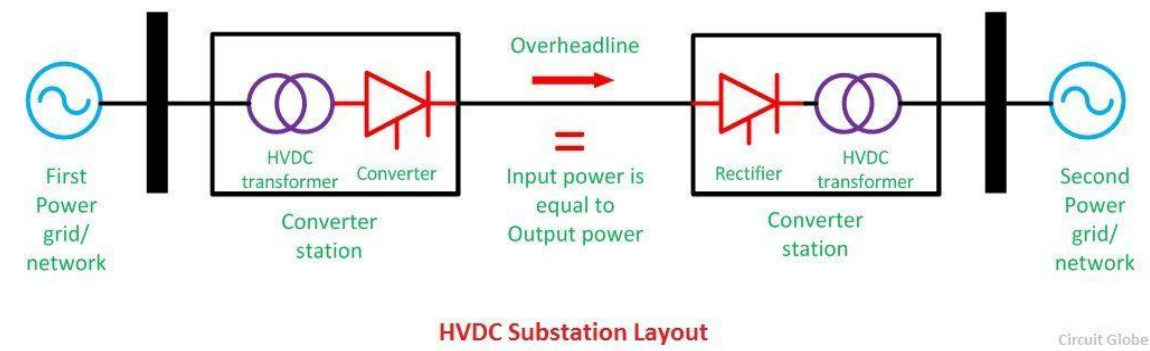
The **Ferranti effect** occurs in long high-voltage transmission lines, where under light load or no-load conditions, the voltage at the receiving end becomes higher than at the sending end. This happens because of the line's inductive reactance and its capacitive nature, which causes reactive

power to accumulate, leading to an increase in voltage. The effect is more pronounced in long-distance transmission lines, where the line's inductance and capacitance have a greater impact, and can result in dangerously high voltages at the receiving end if not managed with equipment like shunt reactors.

Corona: The phenomenon of violet glow, hissing noise and production of ozone gas in an overhead transmission line is known as corona.

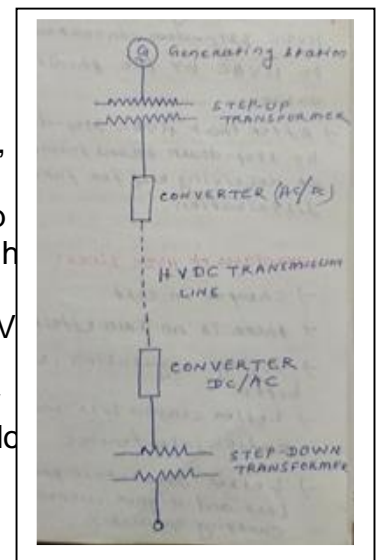
The **Corona effect** happens when the voltage on a conductor is high enough to ionize the surrounding air, creating a discharge of energy that results in a visible blue or violet glow, audible noise, and power loss. This effect occurs more easily in high-voltage lines, especially in areas with high humidity or polluted air, and can lead to inefficiencies, signal interference, and damage to the transmission equipment over time. Both effects are crucial to consider in electrical power systems, as they impact the efficiency, stability, and longevity of long-distance transmission lines.

High Voltage DC (HVDC) Transmission Line:



The single line diagram of HVDC transmission line is drawn:

- For HVDC transmission line the following points should be noted,
- The generating station generates 11KV AC voltage.
 - The 11KV voltage is step up to 132KV(AC) by step transformer. Then the high voltage AC is converted to high voltage DC by converter (rectifier).
 - The HVDC power transmitted by bipolar lines called as HVDC transmission line.
 - At the receiving end the HVDC converted to HVAC by converter(inverter). After that HVAC stepped down by step-down transformer at receiving end for further distribution



Advantages of HVDC transmission system.

The advantages of HVDC transmission system are:

- These systems are economical for bulk transmission of power for long distances as the cost of conductor reduces since d.c. system requires only two conductors.
- The cost of supporting towers and insulation is also reduced.

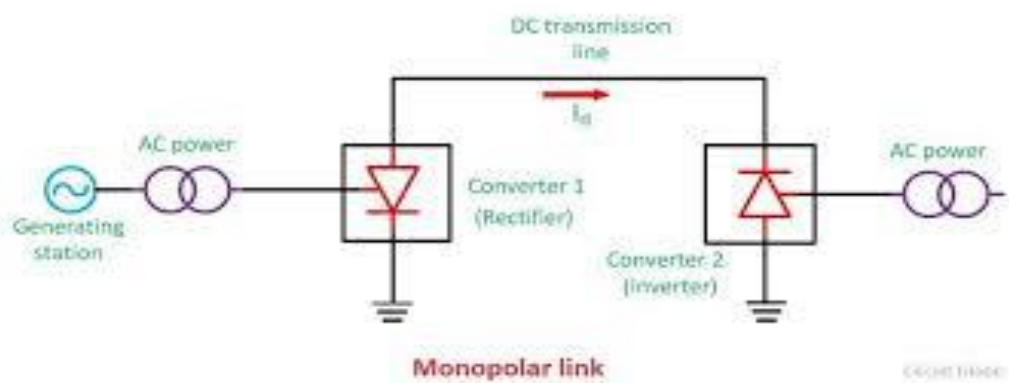
- The transmission losses are reduced.
- There are no stability problems with d.c. system. Hence asynchronous operation of transmission link is possible.
- Skin effect is also low in d.c. system.
- Greater power transmission per conductor is possible with d.c. system.
- The corona loss is low in d.c. systems.
- The radio interference with HVDC is less.
- Voltage regulation is better.
- The losses are less in transmission with d.c.
- With HVDC link there is easy reversibility and controllability of power flow.
- Intermediate substations are not required with HVDC transmission.
- Greater reliability than HVAC line.

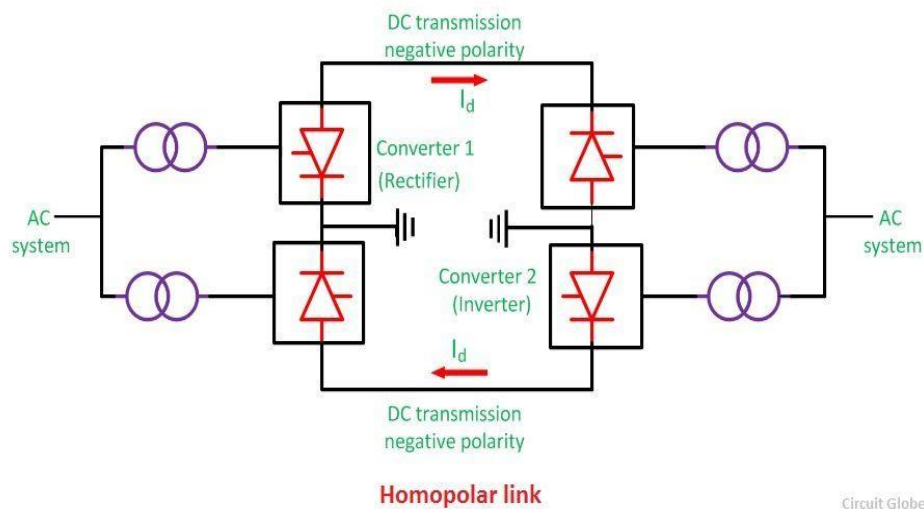
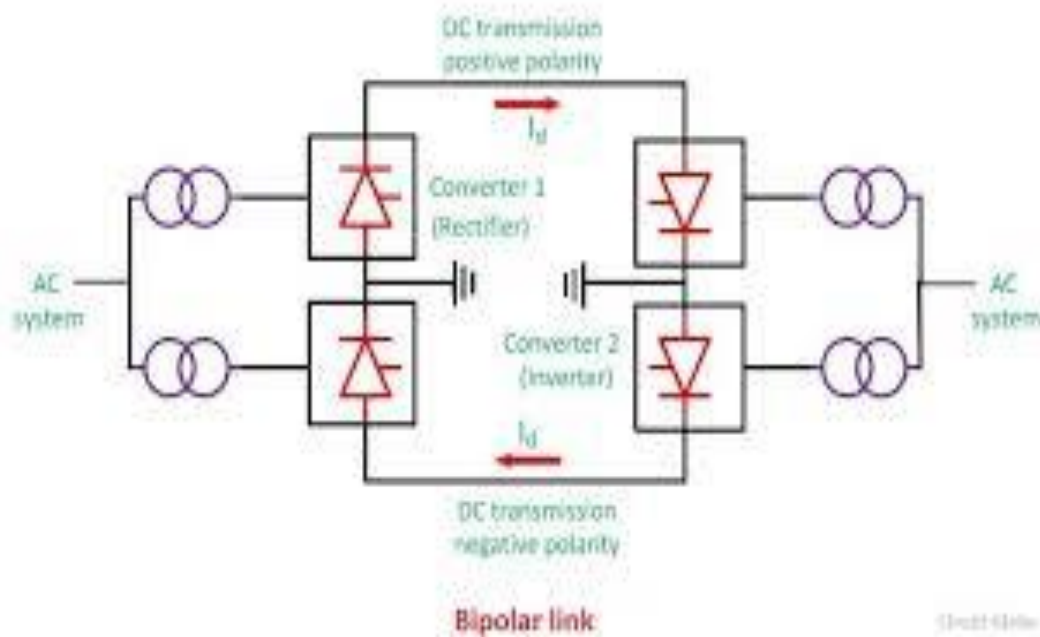
Limitations of HVDC transmission system.

The limitation or dis-advantages of HVDC transmission system are:

- With multi terminal d.c. the circuit breaking is difficult and expensive.
- Overload capacity of HVDC converters is low.
- The maintenance of insulators in HVDC system is more.
- Voltage transformation is not easier in case of dc.
- There are additional losses in converter transformers and valves.

Layout of monopolar, bi-Polar and homo-polar transmission lines of HVDC





Flexible AC Transmission line

Flexible AC Transmission Systems (FACTS) are a set of power electronic-based systems used to improve the controllability, stability, and efficiency of AC transmission lines. They provide the ability to control various parameters of the transmission system, such as voltage, current, power flow, and impedance, in real-time. FACTS devices help in enhancing the performance of the power grid, especially under varying load conditions, reducing transmission losses, and improving power system stability.

Features of FACTS controller:

- **Voltage Regulation:** Maintaining stable voltage profiles, even under fluctuating loads.
- **Power Flow Control:** Optimizing the flow of active and reactive power, preventing line congestion, and maximizing the use of existing transmission lines.
- **System Stability:** Enhancing system stability during transient disturbances, voltage sags, or system faults.

- **Flexibility:** FACTS controllers can be used in a wide range of power systems and can be added to existing infrastructure to improve its performance.
- **Efficiency:** Reducing losses, improving system efficiency, and enhancing the capacity of transmission lines without the need for major physical upgrades.

Types of FACTS controller:

Type of FACTS Controller	Function	Example
Shunt Controllers	Control reactive power, voltage regulation	SVC, STATCOM
Series Controllers	Control power flow, reduce line congestion	TCSC, SMES
Combined Controllers	Control both power flow and voltage	UPFC, IPFC
Hybrid Controllers	Improve power quality and system stability	UPQC

QUESTIONS:

Write notes on EHVAC lines.

With neat diagram explain about HVDC transmission line.

What is corona and Ferranti effect?

Explain the features of FACTS.

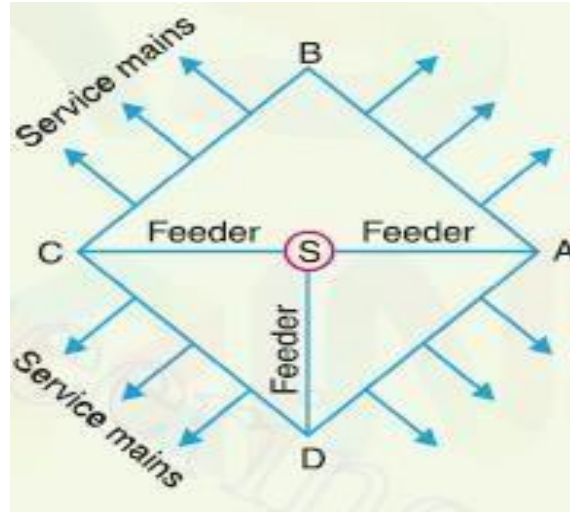
UNIT-4: AC DISTRIBUTION SYSTEM

AC distribution:

Introduction to Distribution System.

That part of power system which distributes electric power for local use is known as distribution system.

- It generally consists of feeders, distributors and the service mains.
- The single line diagram of a typical low tension distribution system is shown below.



(i) **Feeders.**

- A feeder is a conductor which connects the sub-station to the area where power is to be distributed.
- Generally, no tapings are taken from the feeder so that current in it remains the same throughout.
- The main consideration in the design of a feeder is the current carrying capacity.

(ii) **Distributor.**

- A distributor is a conductor from which tapings are taken for supply to the consumers.
- In above Fig. AB, BC, CD and DA are the distributors. The current through a distributor is not constant because tapings are taken at various places along its length.
- A distributor is designed from the point of view of the voltage drop in it.
- Here the limit of voltage variations is $\pm 6\%$ of rated value at the consumers' terminals.

(iii) **Service mains.**

- A service main is generally a small cable which connects the distributor to the consumers' terminals.

A.C distribution system.

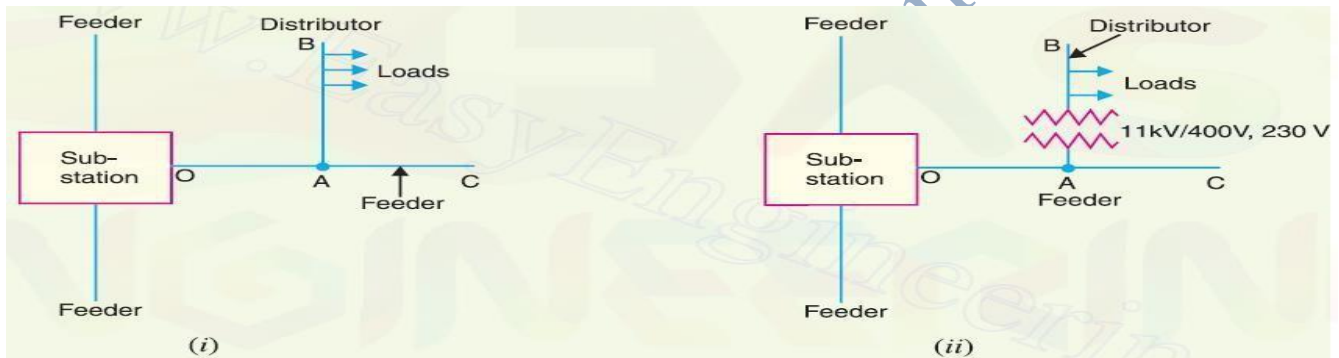
- The electrical energy produced at the power station is transmitted at very high voltages by 3-phase, 3-wire system to step-down sub-stations for distribution.
- The distribution system consists of two parts i.e. primary distribution and secondary distribution.
- The primary distribution circuit is 3-phase, 3-wire and operates at voltages (3.3 or 6.6 or 11kV) somewhat higher than general utilization levels.
- It delivers power to the secondary distribution circuit through distribution transformers situated near consumers' localities. Each distribution transformer steps down the voltage to 400 V and power is distributed to ultimate consumers by 400/230 V, 3-phase, 4-wire system.

Connection Schemes of Distribution System:

All distribution of electrical energy is done by constant voltage system. The following distribution circuits are generally used:

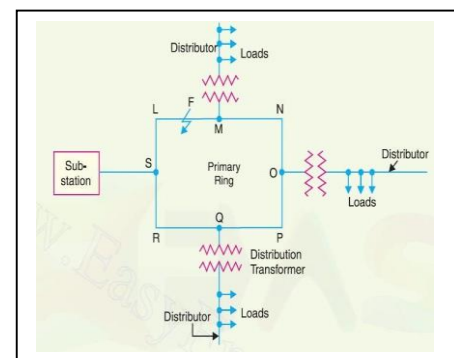
(i) Radial System.

- In this system, separate feeders radiate from a single substation and feed the distributors at one end only.
- The single line diagram of a radial system for d.c. distribution where a feeder OC supplies a distributor AB at point A is shown in fig.-(i).
- The single line diagram of radial system for a.c. distributor is fed at one end only is shown in fig.(ii)
- The radial system is employed only when power is generated at low voltage and the substation is located at the center of the load.
- This is the simplest distribution circuit and has the lowest initial cost.
- The end of the distributor nearest to the feeding point will be heavily loaded.
- This system is used for short distances only.



(ii) Ring main system.

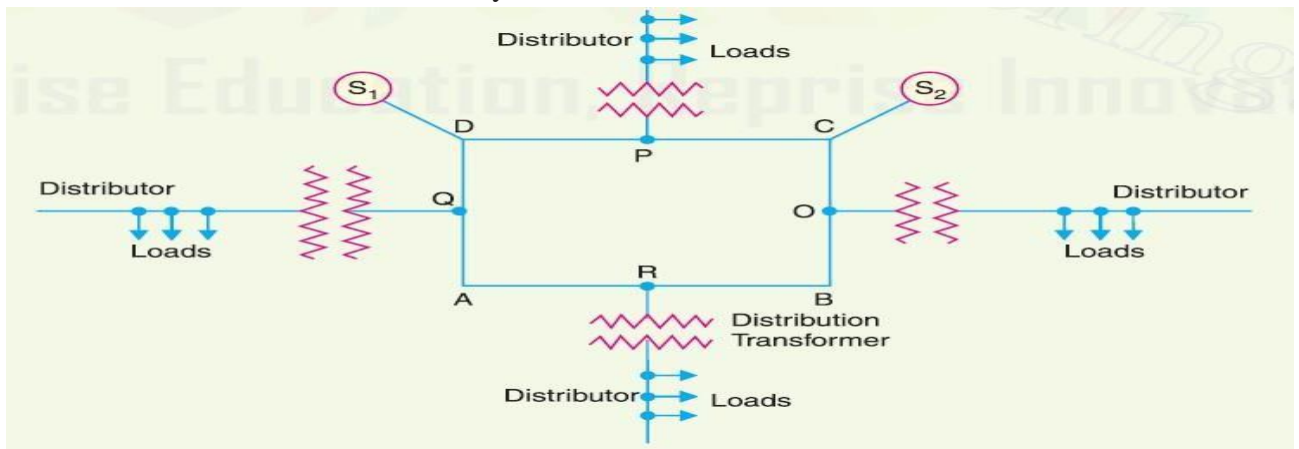
- In this system, the primaries of distribution transformers form a loop.
- The loop circuit starts from the substation busbars, makes a loop through the area to be served, and returns to the substation.
- The single line diagram of ring main system for a.c. distribution where substation supplies to the closed feeder LMNOPQRS is shown below.
- The distributors are tapped from different points M, O and Q of the feeder through distribution transformers.
- There are less voltage fluctuations at consumer's terminals.
- The system is very reliable as each distributor is fed via two feeders.



(iii) Interconnected system.

- When the feeder ring is energized by two or more than two generating stations or substations, it is called inter-connected system.
- The single line diagram of interconnected system where the closed feeder ring ABCD is supplied by two substations S1 and S2 at points D and C respectively shown below.

- Distributors are connected to points O, P, Q and R of the feeder ring through distribution transformers.
- It increases the service reliability.



Distribution Sub-Station:

A **distribution sub-station** is an essential part of the electrical distribution network that steps down the voltage from high transmission levels to the lower voltage levels used for local distribution to homes, businesses, and industries. It typically performs voltage transformation, switching, and protection.

Advantages of Distribution Sub-Stations

- **Voltage Regulation:**
They ensure the voltage supplied to consumers remains stable and within the required levels.
- **Improved Efficiency:**
By stepping down voltage, these substations reduce energy loss that typically occurs in high-voltage transmission lines.
- **Safety:**
With proper protection systems, distribution sub-stations help prevent electrical accidents, short circuits, and overloads.
- **Load Management:**
They help in distributing the electrical load efficiently to various parts of the grid and balance the supply-demand ratio.
- **Reduced Transmission Losses:**
When the voltage is reduced to a lower level, transmission losses (which increase with higher voltage) are minimized.

Disadvantages of Distribution Sub-Stations

- **High Initial Cost:**
The construction of a distribution sub-station, including the necessary transformers, protective devices, and switches, can be expensive.
- **Land Requirement:**
Some types of sub-stations, especially conventional ones, require a large amount of land space, which may not always be available in urban areas.

- **Maintenance Complexity:**
Continuous maintenance and monitoring are required to keep sub-stations running efficiently and safely. The failure of any component can disrupt the entire grid.
- **Noise Pollution:**
Electrical equipment, especially transformers, can generate noise, which can be disturbing, particularly in residential areas.
- **Environmental Concerns:**
Sub-stations can impact local wildlife and vegetation, especially if they are not properly designed or maintained.

QUESTIONS:

Draw the single line diagram of ring main system.

Define feeder and Distributor.

Write the advantages and disadvantages of distribution substation.

UNIT-5: COMPONENTS OF TRANSMISSION AND DISTRIBUTION LINES

Main Components of Overhead Lines

An overhead line may be used to transmit or distribute electric power. The successful operation of an overhead line depends to a great extent upon the mechanical design of the line. While constructing an overhead line, it should be ensured that mechanical strength of the line is such so as to provide against the most *probable* weather conditions. In general, the main components of an overhead line are:

- Conductors** which carry electric power from the sending end station to the receiving end station.
- Supports** which may be poles or towers and keep the conductors at a suitable level above the ground.
- Insulators** which are attached to supports and insulate the conductors from the ground.
- Cross arms** which provide support to the insulators.
- Miscellaneous items** such as phase plates, danger plates, lightning arrestors, anti-climbing wires etc.

Conductor Materials

The conductor is one of the important items as most of the capital outlay is invested for it. Therefore, proper choice of material and size of the conductor is of considerable importance. The conductor material used for transmission and distribution of electric power should have the following properties:

- high electrical conductivity.
- high tensile strength in order to withstand mechanical stresses.
- low cost so that it can be used for long distances.
- low specific gravity so that weight per unit volume is small.

All above requirements are not found in a single material. Therefore, while selecting a conductor material for a particular case, a compromise is made between the cost and the required electrical and mechanical properties.

Commonly used conductor materials. The most commonly used conductor materials for over-head lines are *copper, aluminum, steel-cored aluminum, galvanized steel* and

cadmium copper. The choice of a particular material will depend upon the cost, the required electrical and mechanical properties and the local conditions.

1. **Copper.** Copper is an ideal material for overhead lines owing to its high electrical conductivity and greater tensile strength. It is always used in the hard drawn form as stranded conductor. Copper has high current density *i.e.*, the current carrying capacity of copper per unit of X-sectional area is quite large. This leads to two advantages. Firstly, smaller X-sectional area of conductor is required and secondly, the area offered by the conductor to wind loads is reduced. Moreover, this metal is quite homogeneous, durable and has high scrap value.

There is hardly any doubt that copper is an ideal material for transmission and distribution of electric power. However, due to its higher cost and non-availability, it is rarely used for these purposes. Now-a-days the trend is to use aluminium in place of copper.

2. **Aluminium.** Aluminium is cheap and light as compared to copper but it has much smaller conductivity and tensile strength. The relative comparison of the two materials is briefed below:

(i) The conductivity of aluminium is 60% that of copper. The smaller conductivity of aluminum means that for any particular transmission efficiency, the X-sectional area of conductor must be larger in aluminium than in copper. For the same resistance, the diameter of aluminum conductor is about 1.26 times the diameter of copper conductor.

The increased X-section of aluminium exposes a greater surface to wind pressure and, therefore, supporting towers must be designed for greater transverse strength. This often requires the use of higher towers with consequence of greater sag.

(ii) The specific gravity of aluminium (2.71 gm/cc) is lower than that of copper (8.9 gm/cc). Therefore, an aluminum conductor has almost one-half the weight of equivalent copper conductor. For this reason, the supporting structures for aluminium need not be made so strong as that of copper conductor.

(iii) Aluminium conductor being light, is liable to greater swings and hence larger cross-arms are required.

(iv) Due to lower tensile strength and higher co-efficient of linear expansion of aluminum, the sag is greater in aluminum conductors.

Considering the combined properties of cost, conductivity, tensile strength, weight etc., aluminum has an edge over copper. Therefore, it is being widely used as a conductor material. It is particularly profitable to use aluminum for heavy-current transmission where the conductor size is large and its cost forms a major proportion of the total cost of complete installation.

3. **Steel cord aluminum.** Due to low tensile strength, aluminum conductors produce greater sag. This prohibits their use for larger spans and makes them unsuitable for long distance transmission. In order to increase the tensile strength, the aluminium conductor is reinforced with a core of galvanized steel wires. The *composite conductor thus obtained is known as *steel cored aluminium* and is abbreviated as A.C.S.R. (aluminium conductor steel reinforced).

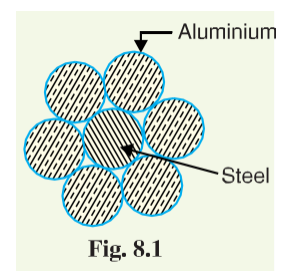


Fig. 8.1

Steel-cored aluminium conductor consists of central core of galvanized steel wires surrounded by a number of aluminium strands. Usually, diameter of both steel and aluminium wires is the same. The X-section of the two metals are generally in the ratio of 1 : 6 but can be modified to 1 : 4 in order to get more tensile strength for the conductor.

Fig. shows steel cored aluminium conductor having one steel wire surrounded by six wires of aluminium. The result of this composite conductor is that steel core takes greater percentage of mechanical strength while aluminium strands carry the bulk of current. The steel cored aluminium conductors have the following advantages:

- (i) The reinforcement with steel increases the tensile strength but at the same time keeps the composite conductor light. Therefore, steel cored aluminium conductors will produce smaller sag and hence longer spans can be used.
- (ii) Due to smaller sag with steel cored aluminium conductors, towers of smaller heights can be used.

4. Galvanized steel. Steel has very high tensile strength. Therefore, galvanized steel conductors can be used for extremely long spans or for short line sections exposed to abnormally high stresses due to climatic conditions. They have been found very suitable in rural areas where cheapness is the main consideration. Due to poor conductivity and high resistance of steel, such conductors are not suitable for transmitting large power over a long distance. However, they can be used to advantage for transmitting a small power over a small distance where the size of the copper conductor desirable from economic considerations would be too small and thus unsuitable for use because of poor mechanical strength.

5. Cadmium copper. The conductor material now being employed in certain cases is copper alloyed with cadmium. An addition of 1% or 2% cadmium to copper increases the tensile strength by about 50% and the conductivity is only reduced by 15% below that of pure copper. Therefore, cadmium copper conductor can be useful for exceptionally long spans. However, due to high cost of cadmium, such conductors will be economical only for lines of small X-section *i.e.*, where the cost of conductor material is comparatively small compared with the cost of supports.

Sag in Overhead Lines

While erecting an overhead line, it is very important that conductors are under safe tension. If the conductors are too much stretched between supports in a bid to save conductor material, the stress in the conductor may reach unsafe value and in certain cases the conductor may break due to excessive tension. In order to permit safe tension in the conductors, they are not fully stretched but are allowed to have a dip or sag.

*The difference in level between points of supports and the lowest point on the conductor is called **sag**.*

Line Supports

The supporting structures for overhead line conductors are various types of poles and towers called

line supports. In general, the line supports should have the following properties:

- (vi) High mechanical strength to withstand the weight of conductors and wind loads etc.
- (vii) Light in weight without the loss of mechanical strength.
- (viii) Cheap in cost and economical to maintain.
- (ix) Longer life.

- (x) Easy accessibility of conductors for maintenance.

The line supports used for transmission and distribution of electric power are of various types including *wooden poles, steel poles, R.C.C. poles* and *lattice steel towers*. The choice of supporting structure for a particular case depends upon the line span, X-sectional area, line voltage, cost and local conditions.

1. Wooden poles. These are made of seasoned wood (sal or chir) and are suitable for lines of moderate X-sectional area and of relatively shorter spans, say up to 50 meters. Such supports are cheap, easily available, provide insulating properties and, therefore, are widely used for distribution purposes in rural areas as an economical proposition. The wooden poles generally tend to rot below the ground level, causing foundation failure. In order to prevent this, the portion of the pole below the ground level is impregnated with preservative compounds like *creosote oil*. Double pole structures of the 'A' or 'H' type are often used to obtain a higher transverse strength than could be economically provided by means of single poles.

The main objections to wooden supports are:

- (i) tendency to rot below the ground level
- (ii) comparatively smaller life (20-25 years)
- (iii) cannot be used for voltages higher than 20 kV
- (iv) less mechanical strength and
- (v) require periodical inspection.

2. Steel poles. The steel poles are often used as a substitute for wooden poles. They possess greater mechanical strength, longer life and permit longer spans to be used. Such poles are generally used for distribution purposes in the cities. This type of supports need to be galvanized or painted in order to prolong its life. The steel poles are of three types viz., (i) rail poles (ii) tubular poles and (iii) rolled steel joints.

3. RCC poles. The reinforced concrete poles have become very popular as line supports in recent years. They have greater mechanical strength, longer life and permit longer spans than steel poles. Moreover, they give good outlook, require little maintenance and have good insulating properties. The holes in the poles facilitate the climbing of poles and at the same time reduce the weight of line supports.

The main difficulty with the use of these poles is the high cost of transport owing to their heavy weight. Therefore, such poles are often manufactured at the site in order to avoid heavy cost of transportation.

- 4. Steel towers.** In practice, wooden, steel and reinforced concrete poles are used for distribution purposes at low voltages, say up to 11 kV. However, for long distance transmission at higher voltage, steel towers are invariably employed. Steel towers have greater mechanical strength, longer life, can withstand most severe climatic conditions and permit the use of longer spans. The risk of interrupted service due to broken or punctured insulation is considerably reduced owing to longer spans. Tower footings are usually grounded by driving rods into the earth. This minimizes the lightning troubles as each tower acts as a lightning conductor.

Insulators

The overhead line conductors should be supported on the poles or towers in such a way that currents from conductors do not flow to earth through supports *i.e.*, line conductors

must be properly insulated from supports. This is achieved by securing line conductors to supports with the help of *insulators*. The insulators provide necessary insulation between line conductors and supports and thus prevent any leakage current from conductors to earth. In general, the insulators should have the following desirable properties:

- (i) High mechanical strength in order to withstand conductor load, wind load etc.
- (ii) High electrical resistance of insulator material in order to avoid leakage currents to earth.
- (iii) High relative permittivity of insulator material in order that dielectric strength is high.
- (iv) The insulator material should be non-porous, free from impurities and cracks otherwise the permittivity will be lowered.
- (v) High ratio of puncture strength to flashover.

The most commonly used material for insulators of overhead line is *porcelain* but glass, steatite and special composition materials are also used to a limited extent. Porcelain is produced by firing at a high temperature a mixture of kaolin, feldspar and quartz. It is stronger mechanically than glass and is less affected by changes of temperature.

Types of Insulators

The successful operation of an overhead line depends to a considerable extent upon the proper selection of insulators. There are several types of insulators but the most commonly used are pin type, suspension type, strain insulator and shackle insulator.

Pin type insulators. The part section of a pin type insulator is shown in Fig. 8.5. As the name suggests, the pin type insulator is secured to the cross-arm on the pole. There is a groove on the upper end of the insulator for housing the conductor. The conductor passes through this groove and is bound by the annealed wire of the same material as the conductor.

Pin type insulators are used for transmission and distribution of electric power at voltages up to 33 kV. Beyond operating voltage of 33 kV, the pin type insulators become too bulky and hence uneconomical.

Causes of insulator failure. Insulators are required to withstand both mechanical and electrical stresses. The latter type is primarily due to line voltage and may cause the breakdown of the insulator. The electrical breakdown of the insulator can occur either by *flash-over* or *puncture*. In case of flash-over, the insulator will continue to act in its proper capacity unless extreme heat produced by the arc destroys the insulator.

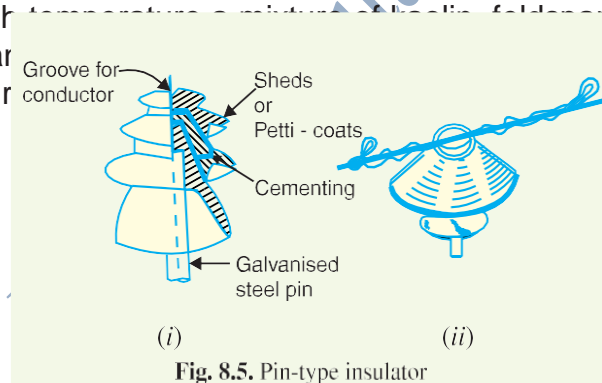


Fig. 8.5. Pin-type insulator

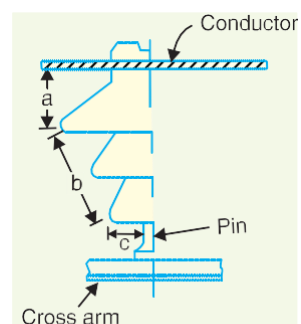


Fig. 8.6

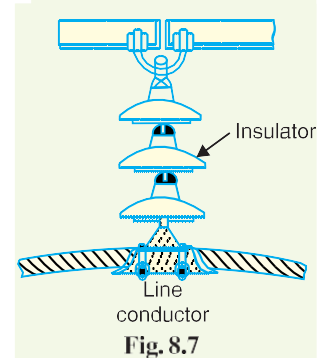


Fig. 8.7

In case of puncture, the discharge occurs from conductor to pin through the body of the insulator. When such breakdown is involved, the insulator is permanently destroyed due to excessive heat. In practice, sufficient thickness of porcelain is provided in the insulator to avoid puncture by the line voltage. The ratio of puncture strength to flash-over voltage is known as safety factor *i.e.*,

$$\text{Safety factor of insulator} = \frac{\text{Puncture strength}}{\text{Flash - over voltage}}$$

It is desirable that the value of safety factor is high so that flash-over takes place before the insulator gets punctured. For pin type insulators, the value of safety factor is about 10.

2 Suspension type insulators. The cost of pin type insulator increases rapidly as the working voltage is increased. Therefore, this type of insulator is not economical beyond 33 kV. For high voltages (>33 kV), it is a usual practice to use suspension type insulator. They consist of a number of porcelain discs connected in series by metal links in the form of a string. The conductor is suspended at the bottom end of this string while the other end of the string is secured to the cross-arm of the tower. Each unit or disc is designed for low voltage, say 11 kV. The number of discs in series would obviously depend upon the working voltage. For instance, if the working voltage is 66 kV, then six discs in series will be provided on the string.

Advantages

- (i) Suspension type insulators are cheaper than pin type insulators for voltages beyond 33 kV.
- (ii) Each unit or disc of suspension type insulator is designed for low voltage, usually 11 kV. Depending upon the working voltage, the desired number of discs can be connected in series.
- (iii) If any 1 disc is damaged, the whole string does not become useless because the damaged disc can be replaced by the sound one.
- (iv) The suspension arrangement provides greater flexibility to the line. The connection at the cross arm is such that insulator string is free to swing in any direction and can take up the position where mechanical stresses are minimum.
- (v) In case of increased demand on the transmission line, it is found more satisfactory to supply the greater demand by raising the line voltage than to provide another set of conductors. The additional insulation required for the raised voltage can be easily obtained in the suspension arrangement by adding the desired number of discs.
- (vi) The suspension type insulators are generally used with steel towers. As the conductors run below the earthed cross-arm of the tower, therefore, this arrangement provides partial protection from lightning.

3. Strain insulators. When there is a dead end of the line or there is corner or sharp curve, the line is subjected to greater tension. In order to relieve the line of excessive tension, strain insulators are used. For low voltage lines (< 11 kV), shackle insulators are used as strain insulators. However, for high voltage transmission lines, strain insulator consists of an assembly of suspension insulator. The discs of strain insulators are used in the vertical plane. When the tension in lines is exceedingly high, as at long river spans, two or more strings are used in parallel.

4. Shackle insulators. In early days, the shackle insulators were used as strain insulators. But now-a-days, they are frequently used for low voltage distribution lines. Such insulators can be used either in a horizontal position or in a vertical position. They can be directly fixed to the pole with a bolt or to the cross arm. The conductor in the groove is fixed with a soft binding wire.

String Efficiency

The voltage applied across the string of suspension insulators is not uniformly distributed across various units or discs. The disc nearest to the conductor has much higher potential than the other discs. This unequal potential distribution is undesirable and is usually expressed in terms of string efficiency.

The ratio of voltage across the whole string to the product of number of discs and the voltage across the disc nearest to the conductor is known as **string efficiency** i.e.,

$$\text{String efficiency} = \frac{\text{Voltage across the string}}{n \times \text{Voltage across disc nearest to conductor}}$$

where

$$n = \text{number of discs in the string.}$$

String efficiency is an important consideration since it decides the potential distribution along the string. The greater the string efficiency, the more uniform is the voltage distribution. Thus 100% string efficiency is an ideal case for which the voltage across each disc will be exactly the same. Although it is impossible to achieve 100% string efficiency, yet efforts should be made to improve it as close to this value as possible.

Mathematical expression. Fig. shows the equivalent circuit for a suppose that self-capacitance of each disc is C . Let us further assume that is some fraction K of self- capacitance i.e., $C_1 = KC$. Starting from the c

volt- age across each unit is V_1, V_2 and V_3 respectively as shown.

Applying Kirchoff's current law to node A, we get,

$$\begin{aligned} I_2 &= I_1 + i_1 \\ \text{or } V_2 \omega C^* &= V_1 \omega C + V_1 \omega C_1 \\ \text{or } V_2 \omega C &= V_1 \omega C + V_1 \omega K C \\ \therefore V_2 &= V_1 (1 + K) \quad \dots(i) \end{aligned}$$

Applying Kirchoff's current law to node B, we get,

$$\begin{aligned} I_3 &= I_2 + i_2 \\ \text{or } V_3 \omega C &= V_2 \omega C + (V_1 + V_2) \omega C_1 \\ \text{or } V_3 \omega C &= V_2 \omega C + (V_1 + V_2) \omega K C \\ \text{or } V_3 &= V_2 + (V_1 + V_2)K \\ &= KV_1 + V_2 (1 + K) \\ &= KV_1 + V_1 (1 + K)^2 \\ &= V_1 [K + (1 + K)^2] \\ \therefore V_3 &= V [1 + 3K + K^2] \quad \dots(ii) \end{aligned}$$

Voltage between conductor and earth (i.e., tower) is

$$\begin{aligned} V &= V_1 + V_2 + V_3 \\ &= V_1 + V_1(1 + K) + V_1 (1 + 3K + K^2) \\ &= V_1 (3 + 4K + K^2) \\ \therefore V &= V_1(1 + K) (3 + K) \quad \dots(iii) \end{aligned}$$

From expressions (i), (ii) and (iii), we get,

$$\begin{aligned} \text{Voltage across second unit from top, } V_2 &= V_1 (1 + K) \\ \text{Voltage across third unit from top, } V_3 &= V_1 (1 + 3K + K^2) \end{aligned}$$

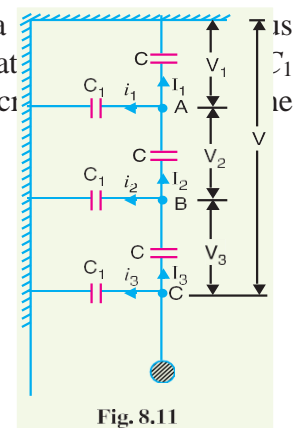


Fig. 8.11

$$\begin{aligned} \text{\% age String} &= \frac{\text{Voltage across string}}{n \times \text{Voltage across disc nearest to conductor}} \times 100 \\ &= \frac{V}{3 \times V_3} \times 100 \end{aligned}$$

Methods of Improving String Efficiency

It has been seen above that potential distribution in a string of suspension insulators is not uniform.

The maximum voltage appears across the insulator nearest to the line conductor and decreases progressively as the cross-arm is approached. If the insulation of the highest stressed insulator (*i.e.* nearest to conductor) breaks down or flash over takes place, the breakdown of other units will take place in succession. This necessitates to equalize the potential across the various units of the string *i.e.* to improve the string efficiency. The various methods for this purpose are:

(xi) *By using longer cross-arms.* The value of string efficiency depends upon the value of K *i.e.*, ratio of shunt capacitance to mutual capacitance. The lesser the value of K , the greater is the string efficiency and more uniform is the voltage distribution. The value of K can be decreased by reducing the shunt capacitance. In order to reduce shunt capacitance, the distance of conductor from tower must be increased *i.e.*, longer cross-arms should be used. However, limitations of

cost and strength of tower do not allow the use of very long cross-arms. In practice, $K = 0.1$ is the limit that can be achieved by this method.

(xii) *By grading the insulators.* In this method, insulators of different dimensions are so chosen that each has a different capacitance. The insulators are capacitance graded *i.e.* they are assembled in the string in such a way that the top unit has the minimum capacitance, increasing progressively as the bottom unit (*i.e.*, nearest to conductor) is reached. Since voltage is inversely proportional to capacitance, this method tends to equalize the potential distribution across the units in the string. This method has the disadvantage that a large number of different-sized insulators are required. However, good results can be obtained by using standard insulators for most of the string and larger units for that near to the line conductor.

(xiii) *By using a guard ring.* The potential across each unit in a string can be equalized by using a guard ring which is a metal ring electrically connected to the conductor and surrounding the bottom insulator as shown in the Fig. The guard ring introduces capacitance between metal fittings and the line conductor. The guard ring is contoured in such a way that shunt capacitance currents i_1, i_2 etc. are equal to metal fitting line capacitance currents i_{c1}, i_{c2} etc. The result is that same charging current I flow through each unit of string. Consequently, there will be uniform potential distribution across the units.

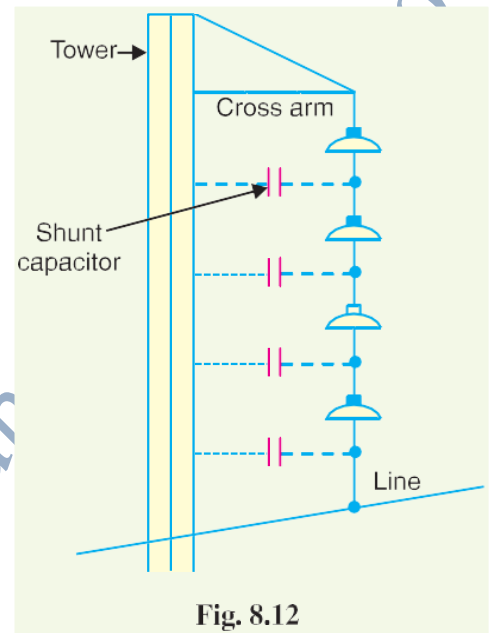


Fig. 8.12

UNDERGROUND CABLES

Underground Cables:

An underground cable essentially consists of one or more conductors covered with suitable insulation and surrounded by a protecting cover.

The type of cable to be used will depend upon the working voltage and service requirements. A cable must fulfill the following necessary requirements:

- (i) The conductor used in cables should be tinned stranded copper or aluminium of high conductivity.
- (ii) Stranding is done so that conductor may become flexible and carry more current.
- (iii) The conductor size should be such that the cable carries the desired load current without overheating and causes voltage drop within permissible limits.
- (iv) The cable must have proper thickness of insulation in order to give high degree of safety and reliability.
- (v) The cable must be provided with suitable mechanical protection.

Classification of Cables

Cables for underground service may be classified in two ways according to (i) the type of insulating material (ii) the voltage for which they are manufactured. according to which cables can be divided into the following groups:

- (i) Low-tension (L.T.) cables — up to 1000 V
- (ii) High-tension (H.T.) cables — up to 11,000 V
- (iii) Super-tension (S.T.) cables — from 22 kV to 33 kV
- (iv) Extra high-tension (E.H.T.) cables — from 33 kV to 66 kV
- (v) Extra super voltage cables — beyond 132 kV

- A cable may have one or more than one core depending upon the type of service for which it is intended. It may be (i) single-core (ii) two-core (iii) three-core (iv) four-core etc.

Types of L. T. & H.T. cables with constructional features.

Underground cables are generally deliver 3-phase power. For the purpose, either three-core cable or three single core cables may be used.

The following types of cables are generally used for 3-phase service:

1. Belted cables — up to 11 kV
2. Screened cables — from 22 kV to 66 kV
3. Pressure cables — beyond 66 kV.

1. Belted cables.

- These cables are used for voltages up to 11kV but in extraordinary cases, their use may be extended up to 22kV.

- The cores are insulated from each other by layers of impregnated paper.
- Another layer of impregnated paper tape, called paper belt is wound round the grouped insulated cores.
- The gap between the insulated cores is filled with fibrous insulating material (jute etc.) so as to give circular cross-section to the cable.
- The belt is covered with lead sheath to protect the cable against ingress of moisture and mechanical injury.

2. Screened cables.

- These cables are meant for use up to 33 kV, but in particular cases their use may be extended to operating voltages up to 66 kV.
- Two principal types of screened cables are H type cables and S.L. type cables.

(i) H-type cables.

- This type of cable was first designed by H. Hochstadter and hence the name.
- Each core is insulated by layers of impregnated paper.
- The insulation on each core is covered with a metallic screen which usually consists of a perforated aluminium foil.
- The cores are laid in such a way that metallic screens make contact with one another.
- The cable has no insulating belt but lead sheath, bedding, armouring and serving follow as usual.

(ii) S.L. type cables.

- It is basically H-type cable but the screen round each core insulation is covered by its own lead sheath.
- There is no overall lead sheath but only armouring and serving are provided.
- The three lead sheaths of S.L. cable are much thinner than the single sheath of H- cable.

3. Pressure cables

- When the operating voltages are greater than 66 kV, pressure cables are used.
- In such cables, voids are eliminated by increasing the pressure of compound and for this reason they are called pressure cables.

Two types of pressure cables i.e. oil-filled cables and gas pressure cables.

(i) Oil-filled cables.

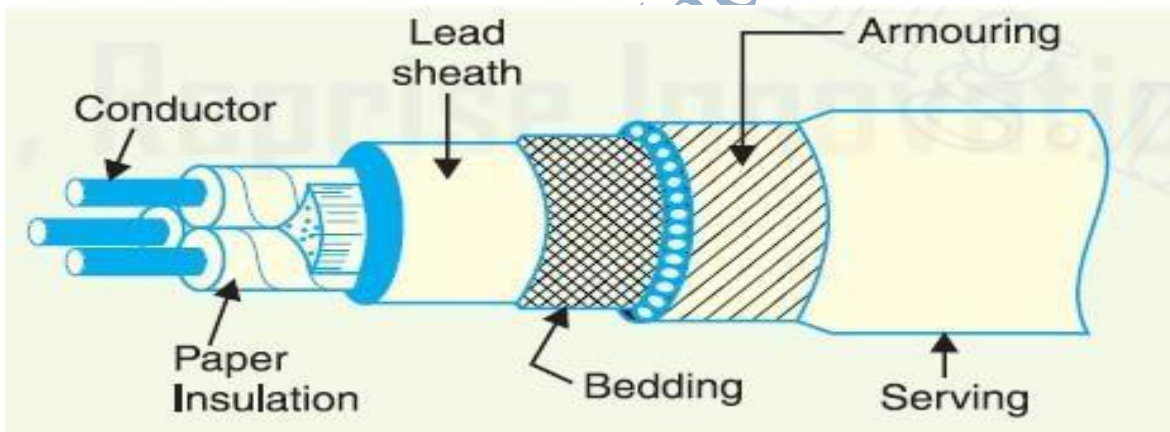
- In such types of cables, channels or ducts are provided in the cable for oil circulation.
- The oil under pressure is kept constantly supplied to the channel by means of external reservoirs placed at suitable distances (say 500 m) along the route of the cable.
- Oil under pressure compresses the layers of paper insulation and is forced into any voids that may have formed between the layers.
- Due to the elimination of voids, oil-filled cables can be used for higher voltages, the range being from 66 kV upto 230 kV.
- Oil-filled cables are of three types i.e. single-core conductor channel, single-

core sheath channel and three-core filler-space channels.

(ii) **Gas pressure cables.**

- The voltage required to set up ionization inside a void increase as the pressure is increased. Therefore, if ordinary cable is subjected to a sufficiently high pressure, the ionization can be altogether eliminated.
- The increased pressure produces radial compression which tends to close any voids. This is the underlying principle of gas pressure cables.
- The construction of the cable is similar to that of an ordinary solid type except that it is of triangular shape and thickness of lead sheath is 75% that of solid cable.
- The triangular section reduces the weight and gives low thermal resistance but the main reason for triangular shape is that the lead sheath acts as a pressure membrane.
- The sheath is protected by a thin metal tape.
- The cable is laid in a gas-tight steel pipe.
- The pipe is filled with dry nitrogen gas at 12 to 15 atmospheres.

Construction of Cables



The various parts of construction of a 3-conductor cable are:

1) **Cores or Conductors.**

- A cable may have one or more than one core (conductor) depending upon the type of service for which it is intended.
- The conductors are made of tinned copper or aluminium and are usually stranded in order to provide flexibility to the cable.

2) **Insulation.**

- Each core or conductor is provided with a suitable thickness of insulation, the thickness of layer depending upon the voltage to be withstood by the cable.
- The commonly used materials for insulation are impregnated paper, varnished cambric or rubber mineral compound.

- 3) **Metallic sheath.**
 - In order to protect the cable from moisture, gases or other damaging liquids (acids or alkalis) in the soil and atmosphere, a metallic sheath of lead or aluminium is provided over the insulation.
- 4) **Bedding.**
 - Over the metallic sheath is applied a layer of bedding which consists of a fibrous material like jute or hessian tape.
 - The purpose of bedding is to protect the metallic sheath against corrosion and from mechanical injury due to armouring.
- 5) **Armouring.**
 - Over the bedding, armouring is provided which consists of one or two layers of galvanized steel wire or steel tape.
 - Its purpose is to protect the cable from mechanical injury while laying it and during the course of handling.
 - Armouring may not be done in the case of some cables.
- 6) **Serving.**
 - In order to protect armouring from atmospheric conditions, a layer of fibrous material (like jute) similar to bedding is provided over the armouring is known as serving.

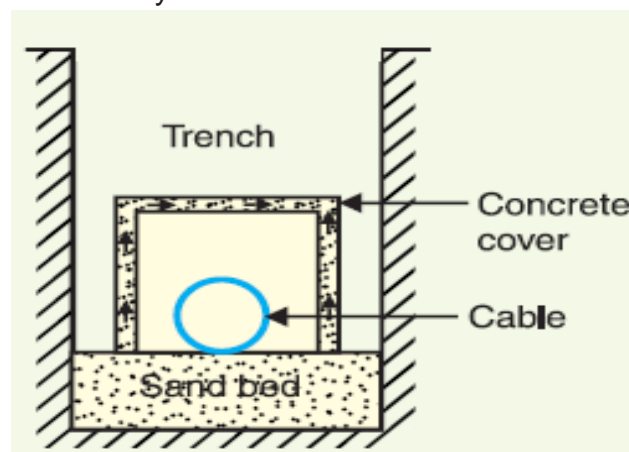
Methods of cable laying.

The reliability of underground cable network depends to a considerable extent upon the proper laying and attachment of fittings i.e., cable end boxes, joints, branch connectors etc.

There are three main methods of laying underground cables i.e., direct laying, draw-in system and the solid system.

1. **Direct laying.**

- In this method, a trench of about 1.5 meter deep and 45 cm wide is dug.
- The trench is covered with a layer of fine sand and the cable is laid over this sand bed.
- The sand prevents the entry of moisture from the ground and thus protects the cable from decay.



- The trench is then covered with bricks and other materials in order to protect the cable from mechanical injury. When more than one cable is to be laid in the same trench, a horizontal or vertical inter axial spacing of at least 30 cm is provided in order to reduce the effect of mutual heating.

Advantages

- (i) It is a simple and less costly method.
- (ii) It gives the best conditions for dissipating the heat generated in the cables.
- (iii) It is a clean and safe method as the cable is invisible and free from external disturbances.

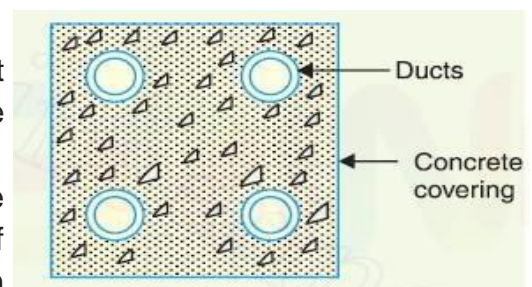
Disadvantages

- (i) The alterations in the cable network cannot be made easily.
- (ii) The maintenance cost is very high.
- (iii) Localization of fault is difficult.
- (iv) It cannot be used in congested areas where excavation is expensive and inconvenient.

- This method of laying cables is used in open areas where excavation can be done conveniently and at low cost.

2. Draw-in system.

- In this method, conduit or duct of glazed stone or cast iron or concrete are laid in the ground with manholes at suitable positions along the cable route.
- The diagram shows four-way underground duct line. Three of the ducts carry transmission cables and the fourth duct carries relay protection connection, pilot wires.
- The duct line changes direction; depths, dips and offsets be made with a very long radius.
- The distance between the manholes should not be too long so as to simplify the pulling in of the cables.
- The cables to be laid in this way need not be armoured but must be provided with serving of hessian and jute in order to protect them when being pulled into the ducts.



Advantages

- (i) Repairs, alterations or additions to the cable network is easy.
- (ii) As the cables are not armoured, therefore, joints become simpler and maintenance cost is low.
- (iii) There are very less chances of fault occurrence due to strong mechanical protection provided by the system.

Disadvantages

- (i) The initial cost is very high.
- (ii) The current carrying capacity of the cables is reduced.

- This method is generally used for short length cable routes such as in workshops, road crossings where frequent digging is costlier or impossible.

3. Solid system.

- In this method of laying, the cable is laid in open pipes or troughs dug out in earth along the cable route.
- The toughing is of cast iron, stoneware, asphalt or treated wood.
- When the cable is laid in position, the toughing is filled with a bituminous or asphaltic compound and covered over.
- Cables laid in this manner are usually plain lead covered because toughing affords good mechanical protection.

Disadvantages

- (i) It is more expensive than direct laid system.
- (ii) It requires skilled labor and favorable weather conditions.
- (iii) Due to less heat dissipation facilities, the current carrying capacity of the cable is reduced.

QUESTIONS

What is armouring and why it is used?

Why metallic sheathing is provided in underground cable?

Explain the various methods of cable laying.

Give in details the general construction of a cable.

Briefly describe about cable laying.

EPTD Notes by Er. Madhusmita Sahoo