DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

EE8402-TRANSMISSION AND DISTRIBUTION

(REGULATION 2017)

UNIT-I

TRANSMISSION LINE PARAMETERS

PART-A (2 Marks)

1. **Explain briefly the skin and proximity effects.**

   (Apr 2015, Nov 2016, Apr 2017, Apr 2018, Nov 2018, Nov 2019)

Steady current when flowing through the conductor, does not distribute uniformly, rather it has tendency to concentrate near surface of conductor. This phenomenon is called skin effect.

The alternating magnetic flux in a conductor caused by the current flowing in a neighboring conductor gives rise to circulating current in the former which cause an apparent increase in the resistance of the conductor this phenomenon is called proximity effect.

2. **What are the advantages of using bundled conductors? (Dec 2014) (Nov 2016)**
   - Minimization of interference with communication circuit.
   - Reduction in corona loss.
   - Reduction in voltage drop which increases circuit capacity and boosting operating voltage.
   - Low reactance, increase in capacitance and surge impedance loading.
3. **List out the parameters affecting skin effect in transmission line. (Apr 2019)**
   - **Frequency** – Skin effect increases with the increase in frequency.
   - **Diameter** – It increases with the increase in diameter of the conductor.
   - **The shape of the conductor** – Skin effect is more in the solid conductor and less in the stranded conductor because the surface area of the solid conductor is more.
   - **Type of material** – Skin effect increase with the increase in the permeability of the material (Permeability is the ability of material to support the formation of the magnetic field).
4. **What is a composite conductor? (Nov 2010)**

   A conductor which operates at high voltages and composed of 2 or more sub conductors and run electrically in parallel are called composite conductors.
5. **What is meant by transposition of line conductors? (Jun 2012, May 2016, Nov 2017)**

   Transposition means changing the positions of the three phases on the line supports twice over the total length of the line .the line conductors in practice ,are so transposed that each of the three possible arrangements of conductors exit for one-third of the total length of the line .
6. **What is bundling of conductors? (Nov 2014)**

   A bundle conductor is a conductor made up of two or more sub conductors and is used as one phase conductors. The Advantages of bundled conductor‘s are

   1. Reduced reactance
   2. Reduced voltage gradient
   3. Reduced corona loss
   4. Reduced radio interference
   5. Reduced surge impedance.
7. **How inductance and capacitance of a transmission line are affected by the spacing between the conductors?**

   If the conductors of a three phase transmission line are not equidistant from each other the flux linkages, inductances and capacitances of various phases are not different. This cause‘s unequal voltage drops in the three phases and transfer of power between phases due to mutual inductance even if the currents in the conductors are balanced. Thus spacing between the conductors play a major role in overhead transmission.

8. **What are the advantages of adopting EHV/UHV for transmission of ac electric power? / Why is electrical power preferably to be transmitted at a high voltage?**

   (Nov 2011, Nov 2018)

- Reduced line losses
- High transmission efficiency
- Improved voltage regulation
- Reduced conductor material requirement.

9. What are the advantages of FACTS controllers? (Apr 2018)

- It controls line impedance angle and voltage which helps in controlling the power flow in transmission lines.
- The power flow in transmission lines can be made optimum.

10. List out the objectives of FACTS. (Nov 2017, May 2016)

- Power transfer capability of transmission system is to be increased.
- Power flow is to be kept over the designated route.

11. What is ring main distributor? (May 2017)

In ring main distributor, the distributor is in the form of a closed ring. The distributor ring may be fed from one or more than one point.

12. State the applications of HVDC transmission. (Nov 2016)

i) Long distance bulk power transmission
ii) Underground or sub marine cables.
iii) Asynchronous connection of AC system with different frequencies.
iv) Control and stabilize the power systems with power flow control

13. Mention the transmission voltages that are followed in Tamilnadu. (May 2017)

AC: 765KV, 400KV, 230KV, 220KV, 132KV, 110KV and 66KV
DC: 500KV and 400KV

14. What is interconnected systems and state the advantages. (Nov 2017, Apr 2018)

The connection of several generating stations in a network of particular transmission voltage level. Any area fed from one generating station during overload hours can be fed from another power station and thus reserved capacity required is reduced, reliability of supply is increased and efficiency is increased.

15. Why high voltage is preferred for power transmission? (May, Nov2015, May 2016)

As voltage increases, current flow through the line decreases and I2R loss reduces. So transmission efficiency increases. Therefore high voltage is preferred for power transmission.

16. Distinguish between self and mutual GMD. (Nov 2015)

Self GMD:

It is the geometrical mean of the distance between the conductors belonging to same phase. Hence it is otherwise called as geometrical mean radius. It depends only upon the size & shape of the conductor and is independent of spacing between conductors.

Mutual GMD:

It is the geometrical mean of the distance between the phases. It depends only upon the spacing and is independent of the exact size, shape and orientation of the conductor.

17. Distinguish between feeder and distributor. (Apr 2015, Nov 2015, Nov 2016)

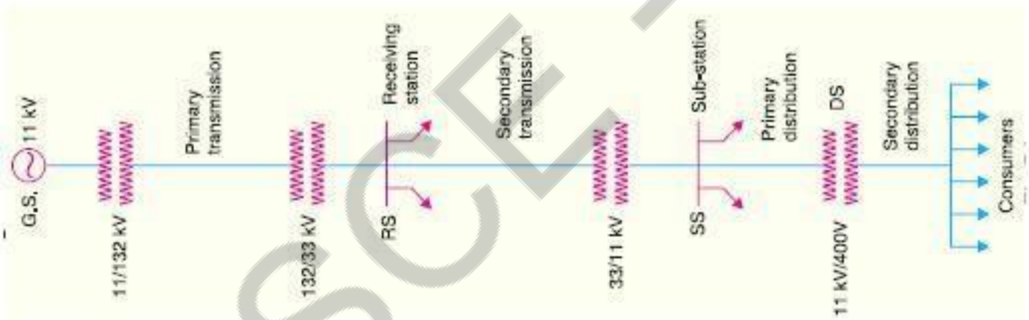
FEEDER	DISTRIBUTOR
Feeder is defined as lines, which connect the distribution station and distributor.	Distributor is defined as a common bus bar, which connect the service main and feeder.

PART-B

1. Explain with neat sketch, the structure of power system. (Nov 2015,May 2016, Nov 2017)

Introduction

- An electric power supply system consists of three principal components, the power station, transmission lines and distribution system.
- Electric power is generated at power stations, which are located at favorable places, generally quite away from the consumer.
- It is then transmitted over large distances to load centres with the help of conductors known as transmission lines. Finally, it is distributed to a large number of small and big consumers through a distribution network.
- The electric supply system can be broadly classified into (*i*) d.c. or a.c. system (*ii*) overhead or underground system. Now-a- days, 3-phase, 3-wire a.c. system is universally adopted for generation and transmission of electric power as an economical proposition. However, distribution of electric power is done by 3-phase, 4-wire a.c. system.
- The underground system is more expensive than the overhead system. Therefore, in our country, overhead system is mostly adopted for transmission and distribution of electric power.
- The large network of conductor between the power station and the consumers can be broadly divided into two parts; viz; Transmission and distribution system.
- Each part can further be sub divided into two, primary transmission and secondary transmission and primary distribution and secondary distribution.



1. Generating station:

i) Generating station represents the generating station, where electric power is produced by 3 phase alternator operating in parallel.

ii) The usual generation voltage is 11kV. The power generated at this voltage is stepped upto 132 kV, 220kV, 400 kV.

iii) As the transmission of electric power at high voltages have so many advantages, viz; saving of conducting material, high transmission efficiency and less sine loss.

2. Primary Transmission:

i) The electric power at high voltage (say 132 kV) is transmitted by 3 phase, 3 wire overhead system to the outskirts of the city. This form the primary transmission.

3. Secondary Transmission:

i) The primary transmission line terminates at the receiving station, which usually lies at the outsides of the city at the receiving station, the voltage is reduced is reduced to 33 kV by 3 phase, 3 wire over head system to various sub stations located at the strategic points in the city. This forms secondary transmission.

4. Primary Distribution :

i) The secondary transmission line terminates at the sub station where voltage is reduced from 33 kV to 11 kV 3 phase 3 wire.

ii) The 11 kV line runs along the important roadsides of the city. This forms the primary Distribution.

5. Secondary Distribution:

i) The electric power from primary distribution line is delivered to distribution sub stations.

ii) These sub stations are located near the consumer localities and step down the voltage to 400 V and between any phase and neutral is 230V.

iii) The 3 phase residential lighting load is connected between any one phase and neutral whereas 3 phase 400V motor loads are connected across 3 phase lines directly.

(v) has less corona loss and reduced interference with communication circuits.

(vii) The high voltage d.c. transmission is free from the dielectric losses, particularly in the case of cables.

(viii) In d.c. transmission, there are no stability problems and synchronising difficulties.

Disadvantages

(i) Electric power cannot be generated at high d.c. voltage due to commutation problems.

(ii) The d.c. voltage cannot be stepped up for transmission of power at high voltages.

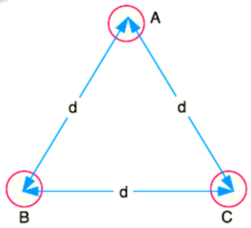
(iii) The d.c. switches and circuit breakers have their own limitations.

2. Derive the capacitance of 3ϕ overhead line for symmetrical and unsymmetrical spacing. (May 2014, Dec 2014, May 2016, Nov 2017, Nov 2018)

In a 3-phase transmission line, the capacitance of each conductor is considered instead of capacitance from conductor to conductor. Here, again two cases arise viz., symmetrical spacing and unsymmetrical spacing.

(i) Symmetrical Spacing

Fig shows the three conductors A, B and C of the 3-phase overhead transmission line having charges QA , QB and QC per meter length respectively. Let the conductors be equidistant (d meters) from each other. We shall find the capacitance from line conductor to neutral in this symmetrically spaced line. Referring to Fig,



Overall potential difference between conductor A and infinite neutral plane is given by

$$V_A = \int_r^\infty \frac{Q_A}{2\pi x\varepsilon_0}dx + \int_d^\infty \frac{Q_B}{2\pi x\varepsilon_0}dx + \int_d^\infty \frac{Q_C}{2\pi x\varepsilon_0}dx$$

$$= \frac{1}{2\pi\varepsilon_0}\left[Q_A \log_e \frac{1}{r} + Q_B \log_e \frac{1}{d} + Q_C \log_e \frac{1}{d}\right]$$

$$= \frac{1}{2\pi\varepsilon_0}\left[Q_A \log_e \frac{1}{r} + (Q_B + Q_C) \log_e \frac{1}{d}\right]$$

Assuming balanced supply, we have, $Q_A + Q_B + Q_C = 0$

$\therefore \quad Q_B + Q_C = -Q_A$

$$\therefore \quad V_A = \frac{1}{2\pi\varepsilon_0}\left[Q_A \log_e \frac{1}{r} - Q_A \log_e \frac{1}{d}\right] = \frac{Q_A}{2\pi\varepsilon_0} \log_e \frac{d}{r} \text{ volts}$$

∴ Capacitance of conductor A w.r.t neutral

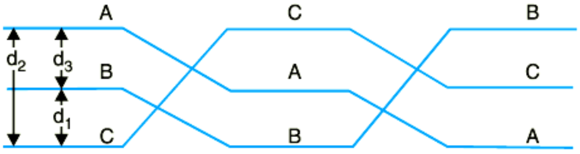
$$C_A = \frac{Q_A}{V_A} = \frac{Q_A}{\frac{Q_A}{2\pi\varepsilon_0}\log_e\frac{d}{r}} \text{ F/m} = \frac{2\pi\varepsilon_0}{\log_e\frac{d}{r}} \text{ F/m}$$

$$C_A = \frac{2\pi\varepsilon_0}{\log_e\frac{d}{r}} \text{ F/m}$$

Note that this equation is identical to capacitance to neutral for two-wire line. Derived in a similar manner, the expressions for capacitance are the same for conductors B and C.

(ii) Unsymmetrical spacing.

Fig. shows a 3-phase transposed line having unsymmetrical spacing. Let us assume balanced conditions i.e. QA + QB + QC = 0.



Considering all the three sections of the transposed line for phase A,

$$\text{Potential of 1st position,} \quad V_1 = \frac{1}{2\pi\varepsilon_0}\left(Q_A\log_e\frac{1}{r} + Q_B\log_e\frac{1}{d_3} + Q_C\log_e\frac{1}{d_2}\right)$$

$$\text{Potential of 2nd position,} \quad V_2 = \frac{1}{2\pi\varepsilon_0}\left(Q_A\log_e\frac{1}{r} + Q_B\log_e\frac{1}{d_1} + Q_C\log_e\frac{1}{d_3}\right)$$

$$\text{Potential of 3rd position,} \quad V_3 = \frac{1}{2\pi\varepsilon_0}\left(Q_A\log_e\frac{1}{r} + Q_B\log_e\frac{1}{d_2} + Q_C\log_e\frac{1}{d_1}\right)$$

Average voltage on condutor A is

$$V_A = \frac{1}{3}(V_1 + V_2 + V_3)$$

$$= \frac{1}{3\times 2\pi\varepsilon_0} * \left[Q_A\log_e\frac{1}{r^3} + (Q_B + Q_C)\log_e\frac{1}{d_1 d_2 d_3}\right]$$

As $Q_A + Q_B + Q_C = 0$, therefore, $Q_B + Q_C = -Q_A$

$$\therefore \quad V_A = \frac{1}{6\pi\varepsilon_0}\left[Q_A\log_e\frac{1}{r^3} - Q_A\log_e\frac{1}{d_1 d_2 d_3}\right]$$

$$= \frac{Q_A}{6\pi\varepsilon_0}\log_e\frac{d_1 d_2 d_3}{r^3}$$

$$= \frac{1}{3}\times\frac{Q_A}{2\pi\varepsilon_0}\log_e\frac{d_1 d_2 d_3}{r^3}$$

$$= \frac{Q_A}{2\pi\varepsilon_0}\log_e\left(\frac{d_1 d_2 d_3}{r^3}\right)^{1/3}$$

$$= \frac{Q_A}{2\pi\varepsilon_0}\log_e\frac{(d_1 d_2 d_3)^{1/3}}{r}$$

Capacitance from conductor to neutral is

$$C_A = \frac{Q_A}{V_A} = \frac{2\pi\varepsilon_0}{\log_e\frac{\sqrt[3]{d_1 d_2 d_3}}{r}} \; F/m$$

3. **Derive an expression for the inductance of a 3ϕ overhead transmission lines with unsymmetrical spacing. Also explain the concept of transportation of conductors.**

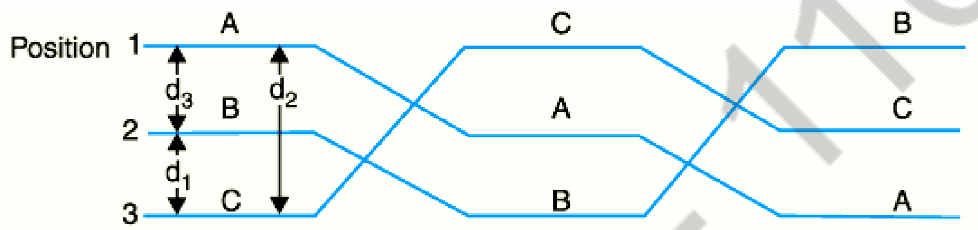
(M 2014) (Nov 2018)

When 3-phase line conductors are not equidistant from each other, the conductor spacing is said to be unsymmetrical. Under such conditions, the flux linkages and inductance of each phase are not the same. A different inductance in each phase results in unequal voltage drops in the three phases even if the currents in the conductors are balanced. Therefore, the voltage at the receiving end will not be the same for all phases. In order that voltage drops are equal in all conductors, we generally interchange the positions of the conductors at regular intervals along the line so that each conductor occupies the original position of every other conductor over an equal distance. Such an exchange of positions is known as transposition. Fig.shows the transposed line. The phase conductors are designated as A, B and C and the positions occupied are numbered 1, 2 and 3. The effect of transposition is that each conductor has the same average inductance.

Fig. shows a 3-phase transposed line having unsymmetrical spacing. Let us assume that each of the three sections is 1 m in length. Let us further assume balanced conditions i.e.,

IA + IB +IC = 0

Let the line currents be :



$$I_A = I(1 + j\,0)$$
$$I_B = I(-0{\cdot}5 - j\,0{\cdot}866)$$
$$I_C = I(-0{\cdot}5 + j\,0{\cdot}866)$$

Flux linkages with conductor A due to its own current

$$= \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4} + \int_r^{\infty}\frac{dx}{x}\right) \quad \ldots(i)$$

Flux linkages with conductor A due to current IB

$$= \frac{\mu_0 I_B}{2\pi}\int_{d_3}^{\infty}\frac{dx}{x}$$

Flux linkages with conductor A due to current IC

$$= \frac{\mu_0 I_C}{2\pi}\int_{d_2}^{\infty}\frac{dx}{x}$$

Total flux linkages with conductor A is

$$\psi_A = (i) + (ii) + (iii)$$

$$= \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4} + \int_r^{\infty}\frac{dx}{x}\right) + \frac{\mu_0 I_B}{2\pi}\int_{d_3}^{\infty}\frac{dx}{x} + \frac{\mu_0 I_C}{2\pi}\int_{d_2}^{\infty}\frac{dx}{x}$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} + \int_r^{\infty}\frac{dx}{x}\right) I_A + I_B\int_{d_3}^{\infty}\frac{dx}{x} + I_C\int_{d_2}^{\infty}\frac{dx}{x}\right]$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I_A - I_B \log_e d_3 - I_C \log_e d_2 + \log_e \infty\,(I_A + I_B + I_C)\right]$$

As $\quad I_A + I_B + I_C = 0,$

$$\therefore \quad \psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I_A - I_B \log_e d_3 - I_C \log_e d_2\right]$$

As proved above, the total flux linkages per metre length of conductor A is

$$= \frac{4\pi \times 10^{-7}}{2\pi}\left[\frac{1}{4} + \log_e \frac{\sqrt{d_2\, d_3}}{r} + j\,0{\cdot}866 \log_e \frac{d_3}{d_2}\right] \text{ H/m}$$

$$= 10^{-7}\left[\frac{1}{2} + 2\log_e \frac{\sqrt{d_2\, d_3}}{r} + j\,1{\cdot}732 \log_e \frac{d_3}{d_2}\right] \text{ H/m}$$

$$\psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I_A - I_B \log_e d_3 - I_C \log_e d_2\right]$$

Putting the values of I_A, I_B and I_C, we get,

$$\psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I - I(-0{\cdot}5 - j\,0{\cdot}866)\log_e d_3 - I(-0{\cdot}5 + j\,0{\cdot}866)\log_e d_2\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4} I - I\log_e r + 0{\cdot}5\, I \log_e d_3 + j\,0{\cdot}866 \log_e d_3 + 0{\cdot}5\, I \log_e d_2 - j\,0{\cdot}866\, I \log_e d_2\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4} I - I\log_e r + 0{\cdot}5\, I\left(\log_e d_3 + \log_e d_2\right) + j\,0{\cdot}866\, I\left(\log_e d_3 - \log_e d_2\right)\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4} I - I \log_e r + I^{*} \log_e \sqrt{d_2 d_3} + j\,0{\cdot}866\, I \log_e \frac{d_3}{d_2}\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4} I + I \log_e \frac{\sqrt{d_2\, d_3}}{r} + j\,0{\cdot}866\, I \log_e \frac{d_3}{d_2}\right]$$

$$= \frac{\mu_0 I}{2\pi}\left[\frac{1}{4} + \log_e \frac{\sqrt{d_2 d_3}}{r} + j\,0{\cdot}866 \log_e \frac{d_3}{d_2}\right]$$

$\therefore$ Inductance of conductor A is

$$L_A = \frac{\psi_A}{I_A} = \frac{\psi_A}{I}$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4} + \log_e \frac{\sqrt{d_2\, d_3}}{r} + j\,0{\cdot}866 \log_e \frac{d_3}{d_2}\right]$$

$$= \frac{4\pi \times 10^{-7}}{2\pi}\left[\frac{1}{4} + \log_e \frac{\sqrt{d_2\, d_3}}{r} + j\,0{\cdot}866 \log_e \frac{d_3}{d_2}\right] \text{ H/m}$$

$$= 10^{-7}\left[\frac{1}{2} + 2\log_e \frac{\sqrt{d_2\, d_3}}{r} + j\,1{\cdot}732 \log_e \frac{d_3}{d_2}\right] \text{ H/m}$$

Similarly inductance of conductors B and C will be :

$$L_B = 10^{-7}\left[\frac{1}{2} + 2\log_e \frac{\sqrt{d_3\, d_1}}{r} + j\,1{\cdot}732 \log_e \frac{d_1}{d_3}\right] \text{ H/m}$$

$$L_C = 10^{-7}\left[\frac{1}{2} + 2\log_e \frac{\sqrt{d_1\, d_2}}{r} + j\,1{\cdot}732 \log_e \frac{d_2}{d_1}\right] \text{ H/m}$$

Inductance of each line conductor

$$= \frac{1}{3}(L_A + L_B + L_C)$$

$$= \left[\frac{1}{2} + 2\log_e \frac{\sqrt[3]{d_1 d_2 d_3}}{r}\right] \times 10^{-7} \text{ H/m}$$

$$= \left[0 \cdot 5 + 2\log_e \frac{\sqrt[3]{d_1 d_2 d_3}}{r}\right] \times 10^{-7} \text{ H/m}$$

If we compare the formula of inductance of an un symmetrically spaced transposed line with that of symmetrically spaced line, we find that inductance of each line conductor in the two cases will be equal if $d = \sqrt[3]{d_1 d_2 d_3}$ The distance d is known as equivalent equilateral spacing for un symmetrically transposed line.

4. Explain about skin and proximity effects. (Dec 2013)

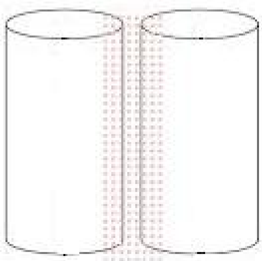
Skin Effect:

The phenomena arising due to unequal distribution of electric current over the entire cross section of the conductor being used for long distance power transmission is referred as the **skin effect in transmission lines.** Such a phenomena does not have much role to play in case of a very short line, but with increase in the effective length of the conductors, **skin effect** increases considerably. So the modifications in line calculation needs to be done accordingly.

The distribution of electric current over the entire cross section of the conductor is quite uniform in case of a DC system. But what we are using in the present era of power system engineering is predominantly an alternating electric current system, where the electric current tends to flow with higher density through the surface of the conductors (i.e skin of the conductor), leaving the core deprived of necessary number of electrons. In fact there even arises a condition when absolutely no electric current flows through the core, and concentrating the entire amount on the surface region, thus resulting in an increase in the effective electrical resistance of the conductor. This particular trend of an AC transmission system to take the surface path for the flow of electric current depriving the core is referred to as the **skin effect in transmission lines**.

Proximity Effect :-

Proximity means nearness in space or time, so as the name suggests, **proximity effect in transmission lines** indicates the effect in one conductor for other neighbouring conductors. When the alternating current is flowing through a conductor, alternating magnetic flux is generated surrounding the conductor. This magnetic flux associates with the neighbouring wires and generates a circulating current (it can be termed as ‘eddy current’ also). This circulating current increases the resistance of the conductor and push away the flowing current through the conductor, which causes the crowding effect.



When the gaps between two wires are greater the **proximity effect** is less and it rises when the gap reduces. The flux due to central conductor links with right side conductor. In a two wire system more lines of flux link elements farther apart than the elements nearest to each other as shown above. Therefore, the inductance of the elements farther apart is more as compared to the elements near to each other and hence the current density is less in the elements farther apart than the the current density in the element near to each other. As a result the effective resistance of the conductor is increased due to non uniform distribution of current. This phenomenon is actually referred as proximity effect. This effect is pronounced in the case of cables where the distance between the conductors is small whereas proximity effect in transmission lines in the case of overhead system, with usual spacing is negligibly small.

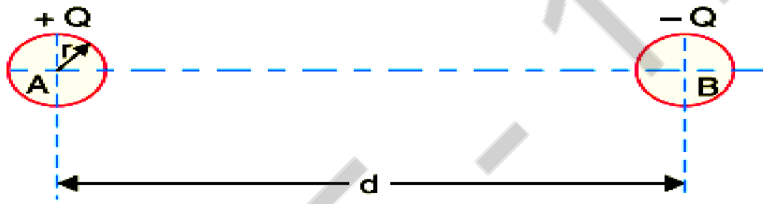
5. Derive the expression for line to line capacitance of a single phase two wire line and also find the capacitive reactance between one conductor to neutral. (Nov 2019)

Capacitance of a Single Phase Two-Wire Line

- Consider a single phase overhead transmission line consisting of two parallel conductors A and B spaced d metres apart in air. Suppose that radius of each conductor is r metres. Let their respective charge be + Q and − Q coulombs per metre length. The total p.d. between conductor A and neutral —infinitel plane is

$$V_A = \int_r^{\infty} \frac{Q}{2\pi x \varepsilon_0}\,dx + \int_d^{\infty} \frac{-Q}{2\pi x \varepsilon_0}\,dx$$

$$= \frac{Q}{2\pi \varepsilon_0}\left[\log_e \frac{\infty}{r} - \log_e \frac{\infty}{d}\right] \text{volts} = \frac{Q}{2\pi \varepsilon_0} \log_e \frac{d}{r} \text{ volts}$$



- Similarly, p.d. between conductor B and neutral -infinitel plane is

$$V_B = \int_r^{\infty} \frac{-Q}{2\pi x \varepsilon_0}\,dx + \int_d^{\infty} \frac{Q}{2\pi x \varepsilon_0}\,dx$$

$$= \frac{-Q}{2\pi \varepsilon_0}\left[\log_e \frac{\infty}{r} - \log_e \frac{\infty}{d}\right] = \frac{-Q}{2\pi \varepsilon_0} \log_e \frac{d}{r} \text{ volts}$$

- Both these potentials are w.r.t. the same neutral plane. Since the unlike charges attract each other, the potential difference between the conductors is

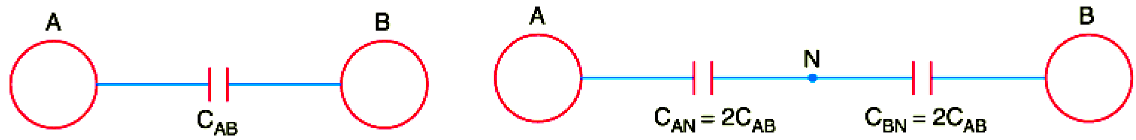
$$V_{AB} = 2V_A = \frac{2Q}{2\pi \varepsilon_0} \log_e \frac{d}{r} \text{ volts}$$

Capacitance, $$C_{AB} = Q/V_{AB} = \frac{Q}{\frac{2Q}{2\pi \varepsilon_0} \log_e \frac{d}{r}} \text{ F/m}$$

$$C_{AB} = \frac{\pi \varepsilon_0}{\log_e \frac{d}{r}} \text{ F / m}$$

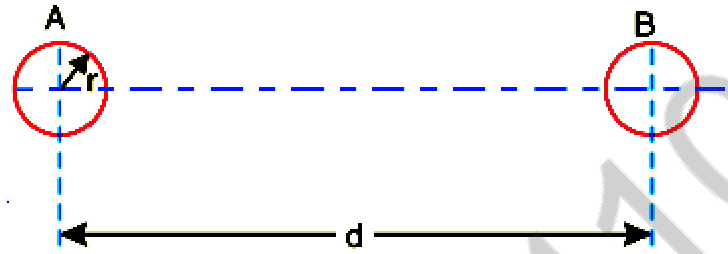
Capacitance to neutral

- Equation (i) gives the capacitance between the conductors of a two-wire line often it is desired to know the capacitance between one of the conductors and a neutral point between them. Since potential of the mid-point between the conductors is zero, the potential difference between each conductor and the ground or neutral is half the potential difference between the conductors. Thus the capacitance to ground or capacitance to neutral for the two-wire line is twice the line-to-line capacitance



6. Derive the expression for inductance of a single phase and three phase two- wire line (June 2013, Nov 2018)

A single phase line consists of two parallel conductors which form a rectangular loop of one turn. When an alternating current flows through such a loop, a changing magnetic flux is set up. The changing flux links the loop and hence the loop (or single phase line) possesses inductance. It may appear that inductance of a single phase line is negligible because it consists of a loop of one turn and the flux path is through air of high reluctance. But as the X –sectional area of the loop is very **large, even for a small flux density, the total flux linking the loop is quite large and hence the line has appreciable inductance



Consider a single phase overhead line consisting of two parallel conductors A and B spaced d metres apart as shown in Fig. Conductors A and B carry the same amount of current (i.e. IA = IB), but in the opposite direction because one forms the return circuit of the other.

IA+IB = 0

In order to find the inductance of conductor A (or conductor B), we shall have to consider the flux linkages with it. There will be flux linkages with conductor A due to its own current IA and also A due to the mutual inductance effect of current IB in the conductor B

Flux linkages with conductor A due to its own current

$$= \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4} + \int_r^\infty \frac{dx}{x}\right)$$

Flux linkages with conductor A due to current I_B

$$= \frac{\mu_0 I_B}{2\pi}\int_d^\infty \frac{dx}{x}$$

Total flux linkages with conductor A is

$$\psi_A = \text{exp. }(i) + \text{exp }(ii)$$

$$= \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4} + \int_r^\infty \frac{dx}{x}\right) + \frac{\mu_0 I_B}{2\pi}\int_d^\infty \frac{dx}{x}$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} + \int_r^\infty \frac{dx}{x}\right) I_A + I_B \int_d^\infty \frac{dx}{x}\right]$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} + \log_e \infty - \log_e r\right) I_A + \left(\log_e \infty - \log_e d\right) I_B\right]$$

$$= \frac{\mu_0}{2\pi}\left[\left(\frac{I_A}{4} + \log_e \infty \left(I_A + I_B\right) - I_A \log_e r - I_B \log_e d\right)\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{I_A}{4} - I_A \log_e r - I_B \log_e d\right] \quad (\because I_A + I_B = 0)$$

Now, $\quad I_A + I_B = 0 \quad \text{or} \quad -I_B = I_A$

$\therefore \quad -I_B \log_e d = I_A \log_e d$

$$\therefore \quad \psi_A = \frac{\mu_0}{2\pi}\left[\frac{I_A}{4} + I_A \log_e d - I_A \log_e r\right] \text{ wb-turns/m}$$

$$= \frac{\mu_0}{2\pi}\left[\frac{I_A}{4} + I_A \log_e \frac{d}{r}\right]$$

$$= \frac{\mu_0 I_A}{2\pi}\left[\frac{1}{4} + \log_e \frac{d}{r}\right] \text{ wb-turns/m}$$

$$\text{Inductance of conductor } A, L_A = \frac{\psi_A}{I_A}$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4} + \log_e \frac{d}{r}\right] \text{H/m} = \frac{4\pi \times 10^{-7}}{2\pi}\left[\frac{1}{4} + \log_e \frac{d}{r}\right] \text{H/m}$$

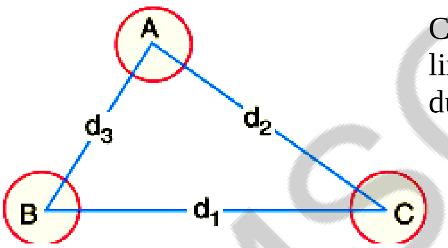
$$L_A = 10^{-7}\left[\frac{1}{2} + 2\log_e \frac{d}{r}\right] \text{H/m}$$

$$\text{Loop inductance} = 2L_A \text{ H/m} = 10^{-7}\left[1 + 4\log_e \frac{d}{r}\right] \text{H/m}$$

$$\text{Loop inductance} = 10^{-7}\left[1 + 4\log_e \frac{d}{r}\right] \text{H/m}$$

INDUCTANCE OF A 3-PHASE OVERHEAD LINE

Fig. shows the three conductors A, B and C of a 3-phase line carrying currents IA , IB and IC respectively. Let d1 , d2 and d3 be the spacing‘s between the conductors as shown. Let us further assume that the loads are balanced i.e. IA + IB + IC = 0.



Consider the flux linkages with conductor There will be flux linkages with conductor A due to its own current and also due to the mutual inductance effects of IB and IC

Flux linkages with conductor A due to its own current

$$= \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4} + \int_r^\infty \frac{dx}{x}\right)$$

Flux linkages with conductor A due to current I_B

$$= \frac{\mu_0 I_B}{2\pi}\int_{d_3}^\infty \frac{dx}{x}$$

Flux linkages with conductor A due to current I_C

$$= \frac{\mu_0 I_C}{2\pi}\int_{d_2}^\infty \frac{dx}{x}$$

Total flux linkages with conductor A is

Total flux linkages with conductor A is

$$
\begin{aligned}
\psi_A &= (i) + (ii) + (iii) \\
&= \frac{\mu_0 I_A}{2\pi}\left(\frac{1}{4} + \int_r^\infty \frac{dx}{x}\right) + \frac{\mu_0 I_B}{2\pi}\int_{d_3}^\infty \frac{dx}{x} + \frac{\mu_0 I_C}{2\pi}\int_{d_2}^\infty \frac{dx}{x} \\
&= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} + \int_r^\infty \frac{dx}{x}\right) I_A + I_B \int_{d_3}^\infty \frac{dx}{x} + I_C \int_{d_2}^\infty \frac{dx}{x}\right] \\
&= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I_A - I_B \log_e d_3 - I_C \log_e d_2 + \log_e \infty \left(I_A + I_B + I_C\right)\right]
\end{aligned}
$$

As $\qquad I_A + I_B + I_C = 0,$

$$\therefore \qquad \psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I_A - I_B \log_e d_3 - I_C \log_e d_2\right]$$

SYMMETRICAL SPACING

If the three conductors A, B and C are placed symmetrically at the corners of an equilateral triangle of side d, then, d1 = d2 = d3 = d. Under such conditions, the flux Derived in a similar way, the expressions for inductance are the same for conductors B

$$
\begin{aligned}
\psi_A &= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I_A - I_B \log_e d - I_C \log_e d\right] \\
&= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I_A - (I_B + I_C)\log_e d\right] \\
&= \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right) I_A + I_A \log_e d\right] \qquad (\because I_B + I_C = -I_A) \\
&= \frac{\mu_0 I_A}{2\pi}\left[\frac{1}{4} + \log_e \frac{d}{r}\right] \text{ werber-turns/m} \\
L_A &= \frac{\psi_A}{I_A} \text{ H/m} = \frac{\mu_0}{2\pi}\left[\frac{1}{4} + \log_e \frac{d}{r}\right] \text{ H/m} \\
&= \frac{4\pi \times 10^{-7}}{2\pi}\left[\frac{1}{4} + \log_e \frac{d}{r}\right] \text{ H/m} \\
L_A &= 10^{-7}\left[0 \cdot 5 + 2\log_e \frac{d}{r}\right] \text{ H/m}
\end{aligned}
$$

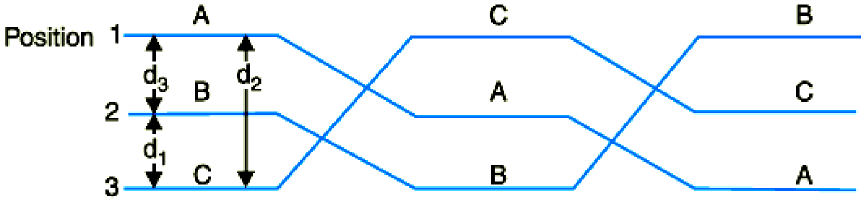
UNSYMMETRICAL SPACING

When 3-phase line conductors are not equidistant from each other, the conductor spacing is said to be unsymmetrical. Under such conditions, the flux linkages and inductance of each phase are not the same. A different inductance in each phase results in unequal voltage drops in the three phases even if the currents in the conductors are balanced. Therefore, the voltage at the receiving end will not be the same for all phases. In order that voltage drops are equal in all conductors, we generally interchange the positions of the conductors at regular intervals along the line so that each conductor occupies the original position of every other conductor over an equal distance. Such an exchange of positions is known as transposition. Fig.shows thetransposed line. The phase conductors are designated as A, B and C and the positions occupied are numbered 1, 2 and 3. The effect of transposition is that each conductor has the same average inductance.

Fig. shows a 3-phase transposed line having unsymmetrical spacing. Let us assume that each of the three sections is 1 m in length. Let us further assume balanced conditions i.e.,

IA + IB +IC = 0

Let the line currents be:



$$
\begin{aligned}
I_A &= I\,(1 + j\,0)\\
I_B &= I\,(-0{\cdot}5 - j\,0{\cdot}866)\\
I_C &= I\,(-0{\cdot}5 + j\,0{\cdot}866)
\end{aligned}
$$

As proved above, the total flux linkages per metre length of conductor A is

$$\psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right)I_A - I_B \log_e d_3 - I_C \log_e d_2\right]$$

Putting the values of I_A, I_B and I_C, we get,

$$\psi_A = \frac{\mu_0}{2\pi}\left[\left(\frac{1}{4} - \log_e r\right)I - I(-0\cdot5 - j\,0\cdot866)\log_e d_3 - I(-0\cdot5 + j\,0\cdot866)\log_e d_2\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4}I - I\log_e r + 0\cdot5\,I\log_e d_3 + j\,0\cdot866\log_e d_3 + 0\cdot5\,I\log_e d_2 - j\,0\cdot866\,I\log_e d_2\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4}I - I\log_e r + 0\cdot5\,I\left(\log_e d_3 + \log_e d_2\right) + j\,0\cdot866\,I\left(\log_e d_3 - \log_e d_2\right)\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4}I - I\log_e r + I\,^{*}\log_e\sqrt{d_2 d_3} + j\,0\cdot866\,I\log_e\frac{d_3}{d_2}\right]$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4}I + I\log_e\frac{\sqrt{d_2\,d_3}}{r} + j\,0\cdot866\,I\log_e\frac{d_3}{d_2}\right]$$

$$= \frac{\mu_0\,I}{2\pi}\left[\frac{1}{4} + \log_e\frac{\sqrt{d_2 d_3}}{r} + j\,0\cdot866\log_e\frac{d_3}{d_2}\right]$$

$\therefore$ Inductance of conductor A is

$$L_A = \frac{\psi_A}{I_A} = \frac{\psi_A}{I}$$

$$= \frac{\mu_0}{2\pi}\left[\frac{1}{4} + \log_e\frac{\sqrt{d_2\,d_3}}{r} + j\,0\cdot866\log_e\frac{d_3}{d_2}\right]$$

$$= \frac{4\pi\times10^{-7}}{2\pi}\left[\frac{1}{4} + \log_e\frac{\sqrt{d_2\,d_3}}{r} + j\,0\cdot866\log_e\frac{d_3}{d_2}\right]\ \text{H/m}$$

$$= 10^{-7}\left[\frac{1}{2} + 2\log_e\frac{\sqrt{d_2\,d_3}}{r} + j\,1\cdot732\log_e\frac{d_3}{d_2}\right]\ \text{H/m}$$

Similarly inductance of conductors B and C will be :

$$L_B = 10^{-7}\left[\frac{1}{2} + 2\log_e \frac{\sqrt{d_3 d_1}}{r} + j\,1\cdot 732 \log_e \frac{d_1}{d_3}\right] \text{ H/m}$$

$$L_C = 10^{-7}\left[\frac{1}{2} + 2\log_e \frac{\sqrt{d_1 d_2}}{r} + j\,1\cdot 732 \log_e \frac{d_2}{d_1}\right] \text{ H/m}$$

Inductance of each line conductor

$$= \frac{1}{3}(L_A + L_B + L_C)$$

$$= {}^{*}\left[\frac{1}{2} + 2\log_e \frac{\sqrt[3]{d_1 d_2 d_3}}{r}\right] \times 10^{-7} \text{ H/m}$$

$$= \left[0\cdot 5 + 2\log_e \frac{\sqrt[3]{d_1 d_2 d_3}}{r}\right] \times 10^{-7} \text{ H/m}$$

If we compare the formula of inductance of an un symmetrically spaced transposed line with that of symmetrically spaced line, we find that inductance of each line conductor in the two cases will be equal if $d = \sqrt[3]{d_1 d_2 d_3}$ The distance d is known as equivalent equilateral spacing for un symmetrically transposed line

7. **A Three -Phase , 50Hz, 132kV overhead line has conductors placed in a horizontal plane 4 m apart. Conductor diameter is 2cm. If the line length is 100km,calculate the charging current per phase assuming complete transposition.**

Apr 2018

Solution :

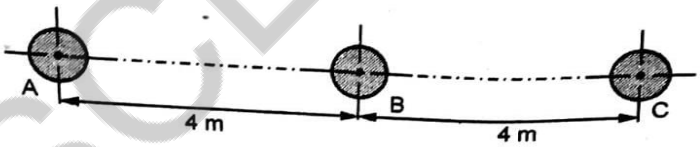


Fig. 1.29.5

$$D = 2 \text{ cm} = \text{Diameter of conductor}$$

$$r = \frac{D}{2} = \frac{2}{2} = 1 \text{ cm} = 1 \times 10^{-2} \text{ m}$$

Equivalent equilateral spacing is given by,

$$d = \sqrt[3]{d_{12} d_{23} d_{31}} = \sqrt[3]{(4)(4)(8)} = 5.0396 \text{ m}$$

Line to neutral capacitance is given by,

$$C_{an} = \frac{2\pi\varepsilon_0}{ln\left[\frac{d}{r}\right]} \text{ F/m} = \frac{2\pi \times 8.854 \times 10^{-12}}{ln\left[\frac{5.0396}{1 \times 10^{-2}}\right]} = 8.9403 \times 10^{-12}$$

For a line length of 100 km,

$$C_{an} = 8.9403 \times 10^{-12} \times 100 \times 10^3 = 8.9403 \times 10^{-7} \text{ F}$$

$$= 0.8940 \times 10^{-6} \text{ F} = 0.8940 \ \mu\text{F}$$

The charging current per phase is given by,

$$I_C = \frac{V_{ph}}{X_c} = \frac{(V_L/\sqrt{3})}{(1/2\pi fC)} = \frac{V_L}{\sqrt{3}} \times 2\pi f C$$

$$= \frac{132 \times 10^3}{\sqrt{3}} \times 2\pi \times 50 \times 0.8940 \times 10^{-6} = \mathbf{21.40 \text{ A}}$$

8. *Determine the inductance of a single phase transmission line consisting of tnree conauctors of 2.5 mm radii in the 'go' conductor and two conductors of 5 mm radii in the, return, conductor. The configuration of the line is as shown in Fig.*

Apr 2018

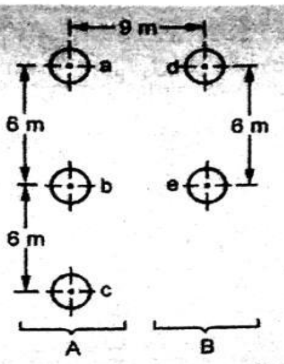


Fig. 1.21.3

Solution : Consider the side consisting of 3 wires.

$$r = 2.5 \text{ mm}, \quad r' = 0.7788\, r = 1.947 \text{ mm}$$

$$D_{aa} = D_{bb} = D_{cc} = r' = 1.947 \text{ mm}$$

$$D_{ae} = D_{ce} = \sqrt{6^2 + 9^2} = 10.817 \text{ m} = D_{bd}$$

$$D_{cd} = \sqrt{12^2 + 9^2} = 15 \text{ m}$$

$$D_{ab} = D_{ba} = 6 \text{ m}, \quad D_{ac} = D_{ca} = 12 \text{ m}, \quad D_{bc} = D_{cb} = 6 \text{ m}$$

The self GMD is given by,

$$D_{S1} = \sqrt[9]{(D_{aa} D_{bb} D_{cc})(D_{ab} D_{ac} D_{ba} D_{ca} D_{bc} D_{cb})}$$

$$= \sqrt[9]{(1.947 \times 10^{-3})^3 \times (6 \times 12 \times 6 \times 12 \times 6 \times 6)} = 0.4809 \text{ m}$$

The mutual GMD is given by,

$$D_{m1} = \sqrt[6]{(D_{ad} D_{ae})(D_{bd} D_{be})(D_{cd} D_{ce})}$$

$$= \sqrt[6]{(9 \times 10.817) \times (10.817 \times 9) \times (15 \times 10.817)} = 10.744 \text{ m}$$

The inductance of first side is,

$$L_1 = 2 \times 10^{-7}\, ln \left[\frac{D_{m1}}{D_{S1}} \right] = 6.212 \times 10^{-7} \text{ H/m} = 0.6212 \text{ mH/km}$$

The mutual GMD of return side remains same.

$$D_{m2} = D_{m1} = 10.744 \text{ m}$$

The self GMD of return side is,

$$D_{S2} = \sqrt[4]{D_{dd}\,D_{de}\,D_{ed}\,D_{ee}}$$

$$D_{dd} = D_{ee} = 0.7788 \times r = 0.7788 \times 5 = 3.894 \text{ mm}$$

$$\therefore \quad D_{S2} = \sqrt[4]{(3.894\times10^{-3})^2\times6^2} = 0.1528 \text{ m}$$

The inductance of return side is,

$$L_2 = 2\times10^{-7}\, ln\left[\frac{D_{m2}}{D_{S2}}\right] = 8.506\times10^{-7} \text{ H/m} = 0.8506 \text{ mH/km}$$

$$\therefore \quad \text{Total L} = L_1 + L_2 = \mathbf{1.4718\ mH/km}$$

9. Draw and explain a simple facility model of UPFC (Nov/Dec 2017)

Solution:

Unified Power Flow Controller (UPFC) is a combination of static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC) which are compiled through a DC link to allow bidirectional flow of real power between the series output terminals of SSSC and shunt output terminals of the STATCOM.

When a injecting variable voltage in series with the transmission like, it is positive to control real and reactive power flow through the line and also to control voltage, angle without an external energy source.

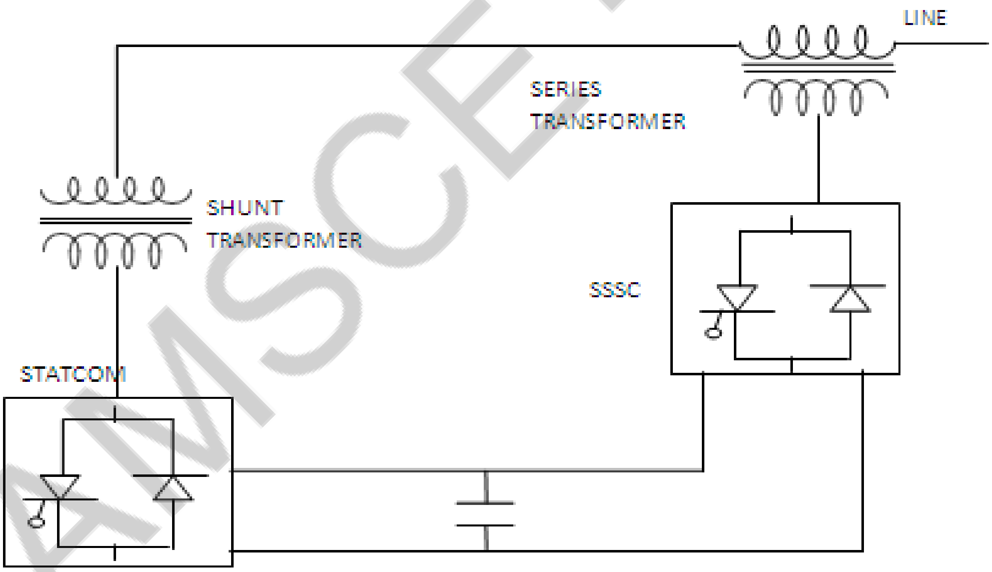


Fig: UPFC

UPFC has two branches (a) series branch (b) shunt branches. The series branches has a voltage source inverter, which injects a voltage is series, there by exchanging real power with the line. A shunt voltage control is provided using shunt transmission for shunt reactive companion. D. C link is used to support the power transfer there by enchanting the performance of UPFC.

10. *Determine the inductance of a 3 phase, line operating at 50 Hz and the conductors are arranged as shown in Fig. 1.19.8. The conductor diameter is 0.7 cm.*

Apr 2017

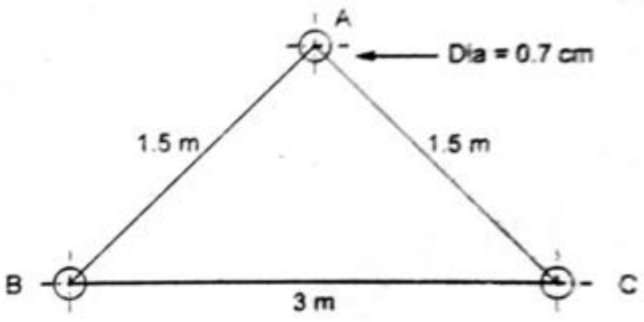


Fig. 1.19.8

Solution : Radius of conductor $= \frac{0.7}{2} = 0.35 \text{ cm} = 3.5 \times 10^{-3}\text{m}$

$$r' = 0.7788 \times 3.5 \times 10^{-3} = 2.7258 \times 10^{-3}\text{m}$$

$$D_{AB} = 1.5 \text{ m}$$

$$D_{BC} = 3 \text{ m}$$

$$D_{CA} = 1.5 \text{ m}$$

$$D_{eq} = \sqrt[3]{D_{AB} \cdot D_{BC} \cdot D_{CA}} = \sqrt[3]{(1.5)(3)(1.5)} = 1.8898 \text{ m}$$

Inductance per phase,

$$L_A = 2 \times 10^{-7}\, ln\left[\frac{D_{eq}}{r'}\right] \text{H/m} = 2 \times 10^{-7}\, ln\left[\frac{1.8898}{2.7258 \times 10^{-3}}\right]$$

$$= 1.3083 \times 10^{-6} \text{ H/m}$$

$$= 1.3083 \times 10^{-3} \text{ H/km}$$

$\therefore \quad L_A = $ **1.31 mH/km**

UNIT-II
MODELLING AND PERFORMANCE OF TRANSMISSION LINES
Part-A (2 Marks)

1. **What is Corona?(May 2016, Nov 2018)**

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

2. **Define Ferranti Effect.(Apr 2015, May 2016,Apr 2017,Nov 2017,Apr 2018)**

   In case of long transmission line under no load conditions, the voltage at the receiving end is found to be more then that at the sending end because of the effect of line capacitance. This is called Ferranti effect.

3. **What are the factors which affect corona? (May 2012)**
   - Electrical factors such as supply frequency
   - Line voltage
   - Atmospheric conditions like pressure, temperature, etc.,
   - Size of conductor
   - Surface conditions whether rough, smooth, dirty or wet.
   - Shape of conductor
   - Spacing between conductors

4. **What is the importance of voltage control? (May 2015)**

   When the load on the supply system changes, the voltage at the consumer terminals also changes. They must be kept within prescribed limit for the following reasons:
   - In case of lightning load, the lamp characteristics are very sensitive to changes of voltage. For instance, if the supply voltage to an incandescent lamp decreases by 6% of rated value, then illuminating power may decrease by 20% on the other handif the supply voltage is 6% above the rated value, the life of the lamp may be reduced by 50% due to the rapid deterioration of the filament.
   - Too wide variation of voltage cause excessive heating of distribution transformer. This may reduce their ratings to a considerable extent.
   - In case of power load consisting of induction motor, the voltage variation may cause erratic operation. If the supply voltage is above normal, the motor may operate with a saturated magnetic circuit, with large magnetizing current, heating and low power factor. On the other hand if the voltage is too low, it will reduce starting torque of the motor considerably.

5. **What are the methods used for voltage control of lines?(Nov 2016)**

   The methods used for voltage control of lines are i)by using over compound generator ii) by excitation control.

   Voltages regulating equipments

   Synchronous motors, tap changing transformers, series shut capacitors, booster transformers, compound generators, induction regulator.

   Methods used for voltage control of lines.

   Tap changing auto- transformer; b) Booster transformer.

6. **What is the importance of voltage control?(Nov 2014, April 2015)**

   In case of lighting load, the lamp characteristics are very sensitive to changes of voltage. For instance, if the supply voltage to an incandescent lamp decreases by 6% of rated value, then illuminating power may decrease by 20%. On the other hand, if the supply voltage is 6% above the rated value, the life of the lamp may be reduced by 50% due to rapid deterioration of the filament.

7. **What is the effect of leading power factor on voltage regulation of a transmission line? (Apr 2019)**

   When the load power factor (cos φ_R) is lagging or unity or leading that IRcos φ_R) > IXL sin φ_R) then voltage regulation is positive (receiving end voltage is lesser than the sending end voltage) and increases with the decrease in power factor for lagging loads (for a given V_R and I).

8. **Define voltage regulation.(Dec 2012, Dec 2013, May 2014)**

Defined as change in voltage at the receiving end from no load to full load, sending end voltage remaining the same. Usually expressed as percentage of receiving end voltage.

% regulation = $\frac{Vs-Vr}{Vr}$ x 100

Vs = sending end voltage

Vr = receiving end voltage

9. **What is surge impedance loading? (Apr 2017, Apr 2018)**

Surge impedance loading of a power transmission line is the power delivered by a line to a pure resistive load equal to its surge impedance.

10. **Distinguish between attenuation and phase constant. (May 2011)**

Attenuation constant	Phase constant.
• Real part of propagation constant γ • Denoted by symbol α • Represents the attenuation of an electromagnetic wave propagating through a medium per unit distance from source	• Imaginary part of propagation constant γ • Denoted by symbol β • Represents change in phase per meter along the path travelled by the wave at any insytant.

11. **Define the term critical disruptive voltage. (Dec 2011, May 2013, Dec 2013, Dec 2014)**

The minimum phase to neutral voltage at which corona effect occurs is called critical disruptive voltage. It is not visible at this voltage.

12. **What is the use of power circle diagram? (May 2012, Nov 2018)**

Useful in studying various aspects of power transmission at sending and receiving end. It aids in determining active power P, reactive power Q, power angle δ, power factor at give load conditions, also voltage conditions and impedance Z of the line.

13. **What is the difference between nominal T and nominal π method?(May 2014)**

NOMINAL T METHOD	NOMINAL Π METHOD
In this the whole line capacitance is assumed to be concentrated at the middle point of the line and half the line resistance, and reactance are lumped on its either side.	In this the whole line capacitance is assumed to be divided into two halves. One half being connected at the sending end and other half at the receiving end..
Full charging current flow over half the line.	Capacitance at the receiving end has no effect on the line drop, but the charging current of the second half capacitor is added to obtain the total sending current.

PART-B

1. **Explain the following with respect to corona**
   (i) Corona (ii) Effects (iii) Critical disruptive voltage
   (iv) Visual critical voltage (v) Corona power loss
   (Apr 2015, Apr 2019, Nov 2019)

Corona

When an alternating potential difference is applied across two conductors whose spacing is large as compared to their diameters, there is no apparent change in the condition of atmospheric air surrounding the wires if the applied voltage is low. However, when the applied voltage exceeds a certain value, called critical disruptive voltage, the conductors are surrounded by a faint violet glow called corona.

Effects:
- Corona is affected by atmospheric conditions, conductor size, spacing between conductors and line voltage.
- Die to Corona, the transmission line efficiency of the line is reduced.
Coron produces ozone and may cause corrosion of the conductor

Critical Disruptive Voltage:

It is the minimum phase-neutral voltage at which corona occurs. Consider two conductors of radii r cm and spaced d cm apart. If V is the phase-neutral potential, then potential gradient at the conductor surface is given by:

$$g = \frac{V}{r \log_e \frac{d}{r}} \text{ volts / cm}$$

In order that corona is formed, the value of g must be made equal to the breakdown strength of air. The breakdown strength of air at 76 cm pressure and temperature of 25ºC is 30 kV/cm (max) or 21·2 kV/cm (r.m.s.) and is denoted by go. If Vc is the phase-neutral potential required under these conditions, then,

$$g_o = \frac{V_c}{r \log_e \frac{d}{r}}$$

where g_o = breakdown strength of air at 76 cm of mercury and 25ºC
= 30 kV/cm (*max*) or 21·2 kV/cm (*r.m.s.*)

$\therefore$ Critical disruptive voltage, $V_c = g_o r \log_e \frac{d}{r}$

Visual critical voltage. It is the minimum phase-neutral voltage at which corona glow appears all along the line conductors.

It has been seen that in case of parallel conductors, the corona glow does not begin at the disruptive voltage Vc but at a higher voltage Vv, called visual critical voltage. The phase-neutral effective value of visual critical voltage is given by the following empirical formula :

$$V_v = m_v g_o \delta r \left(1 + \frac{0 \cdot 3}{\sqrt{\delta r}}\right) \log_e \frac{d}{r} \text{ kV/phase}$$

where mV is another irregularity factor having a value of 1·0 for polished conductors and 0·72 to 0·82 for rough conductors.

Power loss due to corona. Formation of corona is always accompanied by energy loss which is dissipated in the form of light, heat, sound and chemical action. When disruptive voltage is exceeded, the power loss due to corona is given by:

$$P = 242 \cdot 2 \left(\frac{f+25}{\delta}\right) \sqrt{\frac{r}{d}} \, (V - V_c)^2 \times 10^{-5} \text{ kW / km / phase}$$

where f = supply frequency in Hz
V = phase-neutral voltage (*r.m.s.*)
V_c = disruptive voltage (*r.m.s.*) per phase

2. **Explain different method of voltage control. (Nov 2019)**
Tap-Changing Transformers

The excitation control method is satisfactory only for relatively short lines. However, it is *not suitable for long lines as the voltage at the alternator terminals will have to be varied too much in order that the voltage at the far end of the line may be constant. Under such situations, the problem of voltage control can be solved by employing other methods. One important method is to use tap-changing transformer and is commonly employed where main transformer is necessary. In this method, a number of tappings are provided on the secondary of the transformer. The voltage drop in the line is supplied by changing the secondary e.m.f. of the transformer through the adjustment of its number of turns.

(i) Off load tap-changing transformer.

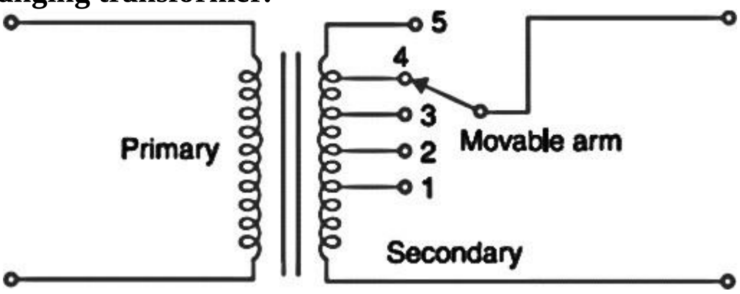


Fig. shows the arrangement where a number of tappings have been provided on the secondary. As the position of the tap is varied, the effective number of secondary turns is varied and hence the output voltage of the secondary can be changed. Thus referring to Figwhen the movable arm makes contact with stud 1, the secondary voltage is minimum and when with stud 5, it is maximum. During the period of light load, the voltage across the primary is not much below the alternator voltage and the movable arm is placed on stud 1. When the load increases, the voltage across the primary drops, but the secondary voltage can be kept at the previous value by placing the movable arm on to a higher stud. Whenever a tapping is to be changed in this type of transformer, the load is kept off and hence the name off load tap-changing transformer. The principal disadvantage of the circuit arrangement shown in Fig. is that it cannot be used for tap-changing on load. Suppose for a moment that tapping is changed from position 1 to position 2 when the transformer is supplying load. If contact with stud 1 is broken before contact with stud 2 is made, there is break in the circuit and arcing results. On the other hand, if contact with stud 2 is made before contact with stud 1 is broken, the coils connected between these two tapping's are short-circuited and carry damaging heavy currents. For this reason, the above circuit arrangement cannot be used for tap-changing on load.

Auto-Transformer Tap-changing

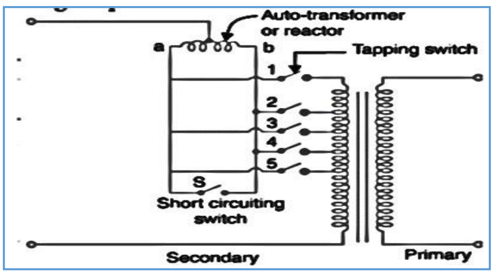
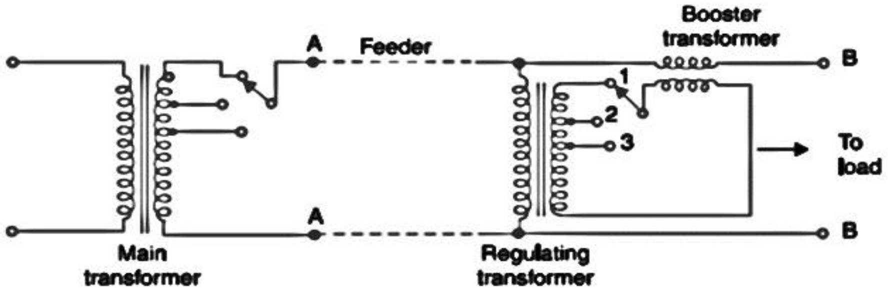


Fig. shows diagrammatically auto- transformer tap changing. Here, a mid- tapped auto-transformer or reactor is used. One of the lines is connected to its mid-tapping. One end, say a of this transformer is connected to a series of switches across the odd tappings and the other end b is connected to switches across even tappings. A short-circuiting switch S is connected across the auto-transformer and remains in the closed position under ormal operation. In the normal operation, there is *no inductive voltage drop across the auto- transformer Referring to Fig, it is clear that with switch 5 closed, minimum secondary turns are in the circuit and hence the output voltage will be the lowest. On the other hand, the output voltage will be maximum when switch 1 is closed.

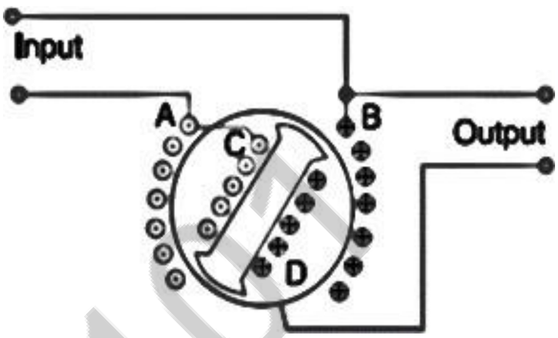
Booster Transformer

Sometimes it is desired to control the voltage of a transmission line at a point far away from the main transformer. This can be conveniently achieved by the use of a booster transformer as shown in Fig.

The secondary of the booster transformer is connected in series with the line whose voltage is to be controlled. The primary of this transformer is supplied from a regulating transformer *fitted with on-load tap-changing gear. The booster transformer is connected in such a way that its secondary injects a voltage in phase with the line voltage



Single-phase induction regulator.



An induction regulator is essentially a constant voltage transformer, one winding of which can be moved w.r.t. the other, thereby obtaining a variable secondary voltage. The primary winding is connected across the supply while the secondary winding is connected in series with the line whose voltage is to be controlled. When the position of one winding is changed w.r.t. the other, the secondary voltage injected into the line also changes. There are two types of induction regulators viz. single phase and 3-phase.

A single phase induction regulator is illustrated in Fig. In construction, it is similar to a single phase induction motor except that the rotor is not allowed to rotate continuously but can be adjusted in any position either manually or by a small motor. The primary winding A B is wound on the *stator and is connected across the supply line. The secondary winding CD is wound on the rotor and is connected in series with the line whose voltage is to be controlled.

The primary exciting current produces an alternating flux that induces an alternating voltage in the secondary winding CD. The magnitude of voltage induced in the secondary depends upon its position w.r.t. the primary winding. By adjusting the rotor to a suitable position, the secondary voltage can be varied from a maximum positive to a maximum negative value. In this way, the regulator can add or subtract from the circuit voltage according to the relative positions of the two windings.

3. **Determine the efficiency and regulation of a 3-phase, 100km, 50Hz, transmission line delivering 20MW at a p.f. of 0.8 lagging and 66 kV to a balanced load. The conductor are of copper, each having resistance 0.1 ohm per km, inductance 1.117mH per km and capacitance 0.9954 μF per km. Neglect leakage and use nominal pi-method. (May 2018)**

Solution : The nominal π circuit is shown in the Fig. 2.8.12.

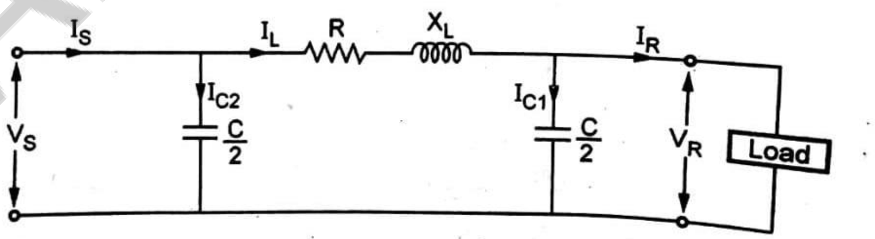


Fig. 2.8.12

$$R = 0.1 \times l = 0.1 \times 100 = 10\ \Omega \qquad \ldots\ l = 100 \text{ km}$$

$$X_L = 2\pi f L \times l = 2\pi \times 50 \times 1.117 \times 10^{-3} \times 100 = 35.1\ \Omega$$

$$Z_C = -jX_C = -j\frac{1}{2\pi f C} = -j\frac{1}{2\pi \times 50 \times 0.9954 \times 10^{-6}}$$

$$= -j\,3197.81\ \Omega/\text{km}$$

$$\therefore \quad Z_C = -j\,3197.81 \times (100 \text{ km}) = -j\,319781\ \Omega$$

$$\therefore \quad Y_C = \frac{1}{Z_C} = \frac{1}{-jX_C} = +j3.127 \times 10^{-6} \text{ mho} \qquad \ldots\ \frac{-1}{j} = +j$$

$$\therefore \quad Y_{C1} = Y_{C2} = \frac{Y_C}{2} = +j1.5635 \times 10^{-6} \text{ mho}$$

$$V_R = 66 \text{ kV},\ V_R(\text{ph}) = \frac{66}{\sqrt{3}} = 38.105 \text{ kV}$$

$$I_R = \frac{P_R}{\sqrt{3}\, V_R \cos\phi_R} = \frac{20 \times 10^6}{\sqrt{3} \times 66 \times 10^3 \times 0.8} = 218.693 \text{ A}$$

$$\therefore \quad \bar{I}_R = 218.693 \angle -\cos^{-1} 0.8 = 218.693 \angle -36.869° \text{ A}$$

$$\bar{I}_{C1} = \frac{\bar{V}_R}{Z_{C1}} = \bar{V}_R \times Y_{C1} = 38.105 \times 10^3 \angle 0° \times j1.5635 \times 10^{-6}$$

$$= j\,0.0595 \text{ A}$$

$$\bar{I}_L = \bar{I}_R + \bar{I}_{C1} = 174.956 - j\,131.21 + j\,0.0595$$

$$= 174.956 - j\,131.15 \text{ A} = 218.65 \angle -36.86° \text{ A}$$

$$\bar{V}_S = \bar{V}_R + \bar{I}_L (R + jX_L) = (38.105 \times 10^3 + j0) + \bar{I}_L (10 + j35.1)$$

$$= (38.105 \times 10^3 + j0) + [218.65 \angle -36.86° \times 36.496 \angle 74.09°]$$

$$= 38.105 \times 10^3 + j0 + 6353.66 + j4828$$

$$= 44458.66 + j\,4828 \text{ V} = 44.72 \angle 6.19° \text{ kV}$$

$$\therefore \quad V_S(\text{line}) = \sqrt{3} \times 44.72 = 77.45 \text{ kV}$$

$$\text{Total line losses} = 3I_L^2 R = 3 \times 218.65^2 \times 10 = 1.434 \times 10^6 \text{ W}$$

$$\therefore \text{ Transmission efficiency} = \frac{P_R}{P_R + \text{losses}} \times 100$$

$$= \frac{20 \times 10^6}{20 \times 10^6 + 1.434 \times 10^6} \times 100 = 93.31\ \%$$

$$\bar{V}_S = \left[1 + \frac{\bar{Z}\,\bar{Y}}{2}\right] \bar{V}_R + \bar{Z}\,\bar{I}_R$$

On no load $I_R = 0$ i.e. $\bar{V}_S = \left[1 + \frac{\bar{Z}\,\bar{Y}}{2}\right] \bar{V}_R(\text{NL})$

$$\therefore \quad \bar{V}_R(\text{NL}) = \frac{\bar{V}_S}{1 + \frac{\bar{Z}\,\bar{Y}}{2}}$$

$$1 + \frac{\bar{Z}\,\bar{Y}}{2} = 1 + \frac{(10 + j35.1)(j3.127 \times 10^{-6})}{2} = 0.999 \angle 8.96 \times 10^{-4}$$

$$\therefore \quad \bar{V}_R(\text{NL}) = \frac{49.72 \angle 6.19°}{0.999 \angle 8.96 \times 10^{-4}} = 44.724 \angle 6.189° \text{ kV}$$

$$\therefore \text{ Voltage regulation} = \frac{\bar{V}_R(\text{NL}) - V_R}{V_R} \times 100$$

$$= \frac{44.724 - 38.105}{38.105} \times 100 = 17.37\ \%$$

Example 2.5.1 A single phase 50 Hz generator supplies an inductive load of 6 MW at 0.8 pf lagging by means of an overhead line 15 km long. The line resistance and inductance are 0.02 ohm/km and 0.85 mH/km. The voltage at the receiving end is 11 kV. Determine the sending end voltage and voltage regulation. **AU : May-17, Marks 8**

Solution : $P = 6$ MW, $\cos\phi_R = 0.8$ lag, $\phi_R = 36.86°$, 15 km

$$\therefore \quad Z = R + jX_L = (0.02 \times 15) + j\,(2\pi \times 50 \times 0.85 \times 15 \times 10^{-3})$$

$$= 0.3 + j\,4\ \Omega = 4.0112 \angle 85.711°\ \Omega, \quad V_R = 11\text{ kV}$$

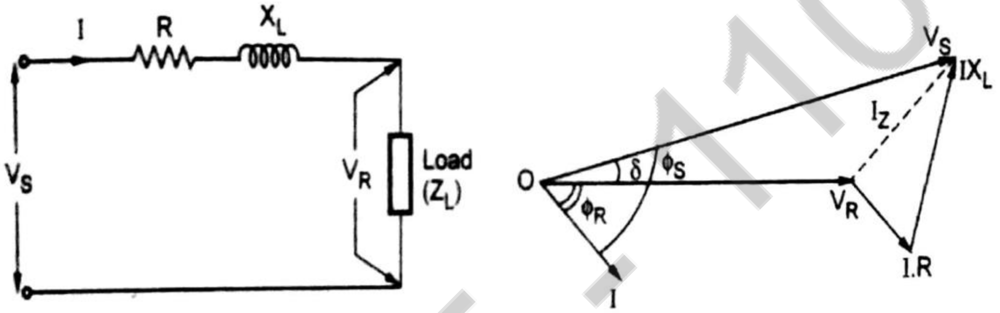


Fig. 2.5.5

$$I = \frac{P}{V_R \cos\phi_R} = \frac{6 \times 10^6}{11 \times 10^3 \times 0.8} = 681.818\text{ A} \qquad \text{...Single phase}$$

$$\therefore \quad I = 681.818 \angle -36.86°\text{ A} = 545.525 - j\,409\text{ A}$$

$$\therefore \quad \overline{V}_S = \overline{V}_R + \overline{I}\,\overline{Z} = [11 \times 10^3 \angle 0°] + [681.818 \angle -36.86°] \times 4.0112 \angle 85.711°$$

$$= 11 \times 10^3 + j\,0 + 1800 + j\,2059.388 = 12800 + j\,2059.388$$

$$= 12964.61 \angle 9.14°\text{ V}$$

$\therefore$ Sending end voltage = **12.9646 kV**

$$\%\,R = \frac{V_S - V_R}{V_R} \times 100 = \frac{12.9646 - 11}{11} \times 100 = \mathbf{17.86\ \%}$$

Example 7.13.4 *A 400 V, 3 phase 4 wire service mains supplies a star connected load. The resistance of each line is 0.1 ohm and that of the neutral 0.2 ohm. The load impedances are $Z_R = (6 + j9)$, $Z_y = 8$ ohms and $Z_B = (6 - j8)$. Calculate the vioitage across each load impedance and current in the neutral. Phase sequence RYB.* **AU : May-17, Marks 15**

Solution : The arrangement is shown in Fig. 7.13.7.

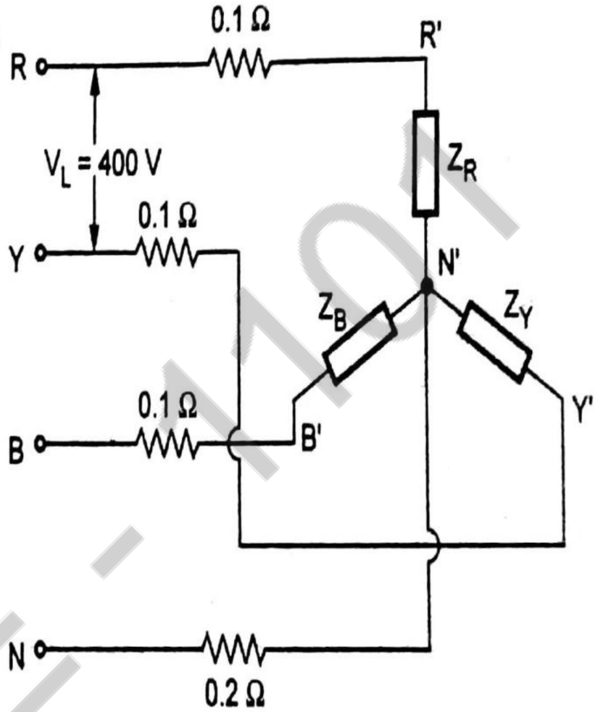


Fig. 7.13.7

Total line impedances are,

$$Z_R = (6+j9+0.1)$$

$$= 6.1+j9\,\Omega$$

$$Z_Y = (8+j0+0.1)$$

$$= 8.1+j0\,\Omega$$

$$Z_B = (6-j8+0.1) = 6.1-j8\,\Omega$$

$$Z_N = 0.2+j0$$

$$\therefore \quad Y_R = \frac{1}{Z_R} = \frac{1}{10.872\angle 55.871^\circ}$$

$$= 0.0919\angle -55.871^\circ = 0.05156 - j\,0.076\ \mho$$

$$\therefore \quad Y_Y = \frac{1}{Z_Y} = \frac{1}{8.1\angle 0^\circ} = 0.1234\angle 0^\circ = 0.1234 + j\,0\ \mho$$

$$\therefore \quad Y_B = \frac{1}{Z_B} = \frac{1}{10.06\angle -52.67^\circ} = 0.099\angle +52.67^\circ = 0.06 + j\,0.0787\ \mho$$

$$\therefore \quad Y_N = \frac{1}{Z_N} = \frac{1}{0.2\angle 0^\circ} = 5\angle 0^\circ = 5 + j\,0\ \mho$$

Supply voltages are,

$$V_R = \frac{400}{\sqrt{3}} \angle 0^\circ = 230.94 \angle 0^\circ \text{ V}$$

$$\therefore \quad V_Y = 230.94 \angle -120^\circ = -115.47 - j\,200 \text{ V}$$

$$\therefore \quad V_B = 230.94 \angle +120^\circ = -115.47 + j\,200 \text{ V}$$

The node voltage between the two neutrals NN′ is given by,

$$V_{N'N} = \frac{V_R Y_R + V_Y Y_Y + V_B Y_B}{Y_R + Y_Y + Y_B + Y_N}$$

$$= \frac{(230.94 \angle 0^\circ \times 0.0919 \angle -55.871^\circ) + (230.94 \angle -120^\circ \times 0.1234 \angle 0^\circ) + (230.94 \angle +120^\circ \times 0.099 \angle +52.67^\circ)}{0.05156 - j0.076 + 0.1234 + j0 + 0.06 + j0.0787 + 5 + j0}$$

$$= \frac{(11.907 - j17.57) + (-14.248 - j24.679) + (-22.676 + j2.917)}{5.2349 + j2.7 \times 10^{-3}}$$

$$= \frac{-25.017 - j39.332}{5.23496 + j2.7 \times 10^{-3}} = \frac{46.614 \angle -122.458^\circ}{5.235 \angle 0.03^\circ} = \mathbf{8.904 \angle -122.48^\circ \text{ V}}$$

$$= -4.781 - j\,7.511 \text{ V}$$

$\therefore$ Load phase voltages are,

$$V'_R = V_R - V_{N'N} = 230.94 + j\,0 - (-4.781 - j\,7.511)$$

$$= 235.721 + j\,7.511 \text{ V} = \mathbf{235.84 \angle 1.825^\circ} \text{ V}$$

$$V'_Y = V_Y - V_{N'N} = (-115.47 - j\,200) - (-4.781 - j\,7.511)$$

$$= -110.689 + j\,192.489 \text{ V} = \mathbf{222.045 \angle -119.9^\circ} \text{ V}$$

$$V'_B = V_B - V_{N'N} = (-115.47 + j\,200) - (-4.781 - j\,7.511)$$

$$= -110.689 + j\,207.511 \text{ V} = \mathbf{235.186 \angle 118.076^\circ} \text{ V}$$

$$I_N = V_{N'N}\, Y_N = (8.904 \angle -122.48^\circ)(5 \angle 0^\circ) = \mathbf{44.52 \angle -122.48^\circ} \text{ A}$$

Example 1.19.6 *Determine the inductance of a 3 phase, line operating at 50 Hz and the conductors are arranged as shown in Fig. 1.19.8. The conductor diameter is 0.7 cm.*

AU : May-05, May-17, Marks 8

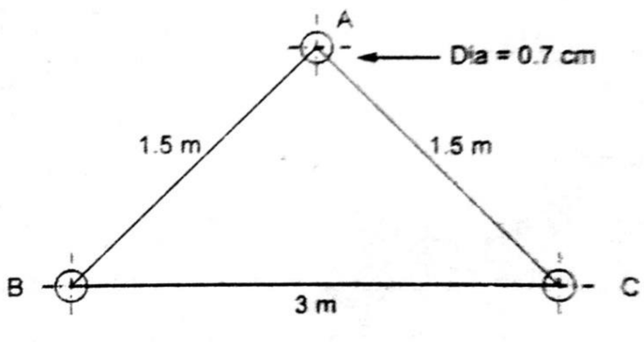


Fig. 1.19.8

Solution : Radius of conductor $= \frac{0.7}{2} = 0.35 \text{ cm} = 3.5 \times 10^{-3} \text{m}$

$$r' = 0.7788 \times 3.5 \times 10^{-3} = 2.7258 \times 10^{-3} \text{m}$$

$$D_{AB} = 1.5 \text{ m}$$

$$D_{BC} = 3 \text{ m}$$

$$D_{CA} = 1.5 \text{ m}$$

$$D_{eq} = \sqrt[3]{D_{AB} \cdot D_{BC} \cdot D_{CA}} = \sqrt[3]{(1.5)(3)(1.5)} = 1.8898 \text{ m}$$

Inductance per phase,

$$L_A = 2 \times 10^{-7} \ln\left[\frac{D_{eq}}{r'}\right] \text{H/m} = 2 \times 10^{-7} \ln\left[\frac{1.8898}{2.7258 \times 10^{-3}}\right]$$

$$= 1.3083 \times 10^{-6} \text{ H/m}$$

$$= 1.3083 \times 10^{-3} \text{ H/km}$$

$$\therefore \quad L_A = \mathbf{1.31 \text{ mH/km}}$$

7. A three phase, 50 Hz overhead transmission line 100 km long has the following constants: Resistance / km / phase = 0.1Ω ,Inductive reactance / km / phase = 0.2Ω, Capacitive susceptance / km /phase = 0.04×10-4 mho Determine i) Sending end current ii) Sending end voltage iii) Sending end power factor iv) Transmission efficiency when supplying a balanced load of 10,000 kW at 66 kV with p.f. of 0.8 lagging. Use nominal T method. (Apr2015)(May2014)

$$R = 0.1 \times 100 = 10 \ \Omega$$

$$X_L = 0.2 \times 100 = 20 \ \Omega$$

$$Y_C = 0.04 \times 10^{-4} \times 100 = 4 \times 10^{-4} \text{ mho}$$

$$\overline{V}_R = V_R \angle 0° = \frac{66000}{\sqrt{3}} \angle 0° = 38105.118 \angle 0° \text{ volts}$$

$$\text{Power delivered} = \sqrt{3} V_R I_R \cos \phi_R$$

$$I_R = \frac{10{,}000 \times 10^3}{\sqrt{3} \times 66000 \times 0.8} = 109.34 \text{ A}$$

$$\bar{I}_R = 109.34 \angle -\cos^{-1} 0.8 = 109.34 \angle -36.86° \text{ A}$$

$$V_1 = 39.202 \text{ kV}$$

$$\bar{I}_C = j\, Y_C\, \bar{V}_1 = j\,[4 \times 10^{-4}]\,[39202.241 \angle 0.7991°]$$

$$= j\,[4 \times 10^{-4}]\,[39198.428 + j\,546.77]$$

$$= -0.2187 + j\,15.67$$

$$= 15.68 \angle 90.79° \text{ A}$$

$$\bar{I}_S = \bar{I}_C + \bar{I}_R = [-0.2187 + j\,15.67] + [109.34 \angle -36.86°]$$

$$= [-0.2187 + j\,15.67] + [87.48 - j\,65.58]$$

$$= 87.2613 - j\,50.32 = 100.73 \angle -29.97° \text{ A}$$

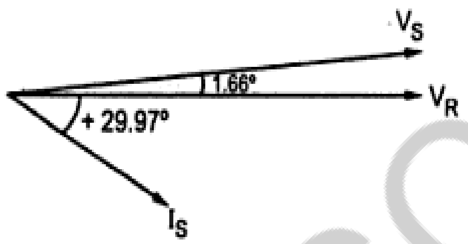
$$\bar{V}_S = \bar{V}_1 + \bar{I}_S\left(\frac{\bar{Z}}{2}\right) = \bar{V}_1 + \bar{I}_S\left[\frac{R}{2} + j\,\frac{X_L}{2}\right]$$

$$= [39198.428 + j\,546.77] + [100.73 \angle -29.97°] + [11.18 \angle 63.43°]$$

$$= [39198.428 + j\,546.77] + [939.52 + j\,620.91]$$

$$= 40137.948 + j\,1167.68 = 40154.929 \angle 1.66° \text{ volts}$$

$$V_S = 40154.929 \text{ V} = 40.154 \text{ kV}$$



p.f. angle between V_S and I_S

$$= 1.66 + 29.97°$$

p.f. at sending end = cos (31.63°)

$$= 0.853 \text{ lagging}$$

$$\text{Total line losses} = 3\,I_S^2\,\frac{R}{2} + 3\,I_R^2\,\frac{R}{2} = 3\,\frac{R}{2}\,[I_S^2 + I_R^2]$$

$$= 3 \times \frac{10}{2}\,[(100.73)^2 + (109.34)^2]$$

$$= 15\,[22101.76] = 331526.53 = 331.52 \text{ kW}$$

$$\%\ \text{Transmission efficiency} = \frac{\text{Power delivered}}{\text{Power delivered} + \text{Losses}} \times 100$$

$$= \frac{10000}{10000 + 331.52} \times 100$$

$$= 96.79$$

Transmission efficiency = 96.79 %

8. Explain the concept of real and reactive power. (April 2015)

In a simple alternating current (AC) circuit consisting of a source and a linear load, both the current and voltage are sinusoidal. If the load is purely resistive, the two quantities reverse their polarity at the same time. At every instant the product of voltage and current is positive or zero, with the result that the direction of energy flow does not reverse. In this case, only active power is transferred.

If the loads are purely reactive, then the voltage and current are 90 degrees out of phase. For half of each cycle, the product of voltage and current is positive, but on the other half of the cycle, the product is negative, indicating that on average, exactly as much energy flows toward the load as flows back. There is no net energy flow over one cycle. In this case, only reactive power flows—there is no net transfer of energy to the load.

Practical loads have resistance, inductance, and capacitance, so both active and reactive power will flow to real loads. Power engineers measure apparent power as the magnitude of the vector sum of active and reactive power. Apparent power is the product of the root-mean-square of voltage and current.

Electrical engineers have to take apparent power into account when designing and operating power systems, because even though the current associated with reactive power does no work at the load, it heats the conductors and wastes energy. Conductors, transformers and generators must be sized to carry the total current, not just the current that does useful work.

Another consequence is that adding the apparent power of two loads will not accurately result in the total apparent power unless the two circuits have the same displacement between current and voltage (the same power factor).

Conventionally, capacitors are considered to generate reactive power and inductors to consume it. If a capacitor and an inductor are placed in parallel, then the currents flowing through the inductor and the capacitor tend to cancel rather than add. This is the fundamental mechanism for controlling the power factor in electric power transmission; capacitors (or inductors) are inserted in a circuit to partially compensate reactive power 'consumed' by the load.

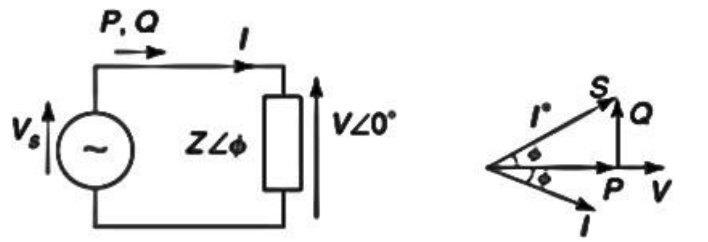
Upon energization, the ac networks and the devices connected to them create associated time-varying electrical fields related to the applied voltage, as well as magnetic fields dependent on the current flow. As they build up, these fields store energy that is released when they collapse. Apart from the energy dissipation in resistive components, all energy-coupling devices, including transformers and energy- conversion devices (e.g., motors and generators), operate based on their capacity to store and release energy.

The reactive power is essential for creating the needed coupling fields for energy devices. It constitutes voltage and current loading of circuits but does not result in an average (active) power consumption and is, in fact, an important component in all ac power networks. In high-power networks, active and reactive powers are measured in megawatts (MW) and MVAR, respectively.

Electromagnetic devices store energy in their magnetic fields. These devices draw lagging currents, thereby resulting in positive values of Q; therefore, they are frequently referred to as the absorbers of reactive power. Electrostatic devices, on the other hand, store electric energy in fields. These devices draw leading currents and result in a negative value of Q; thus they are seen to be suppliers of reactive power. The convention for assigning signs to reactive power is different for sources and loads, for which reason readers are urged to use a consistent notation of voltage and current, to rely on the resulting sign of Q, and to not be confused by absorbers or suppliers of reactive power.

―To make transmission networks operate within desired voltage limits and methods of making up or taking away reactive power is called reactive-power control‖.

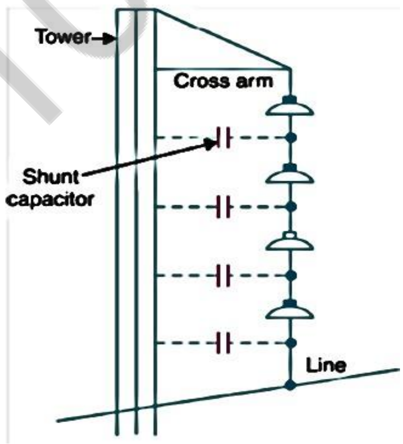
The AC networks and the devices connected to them create associated time-varying electrical fields related to the applied voltage and as well as magnetic fields dependent on the current flow and they build up these fields store energy that is released when they collapse‖.



Apart from the energy dissipation in resistive components, all energy-coupling devices (e.g: motors and generators) operate based on their capacity to store and release energy.
While the major means of control of reactive power and voltage is via the excitation systems of synchronous generators and devices may be deployed in a transmission network to maintain a good voltage profile in the system.
The shunt connected devices like shunt capacitors or inductors or synchronous inductors may be fixed or switched (using circuit breaker).
The **Vernier**or smooth control of reactive power is also possible by varying effective usceptance characteristics by use of power electronic devices. Example: Static VarComponsator(SVC)‖ and a Thyristor Controlled Reactor (TCR).

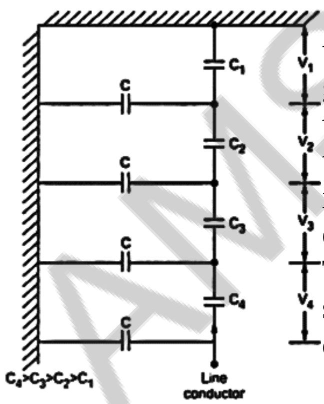
9. Explain the methods of improving string efficiency (Nov2012)(Apr2014) (May 2016, Nov 2019)

(I)By Using Longer Cross-Arms



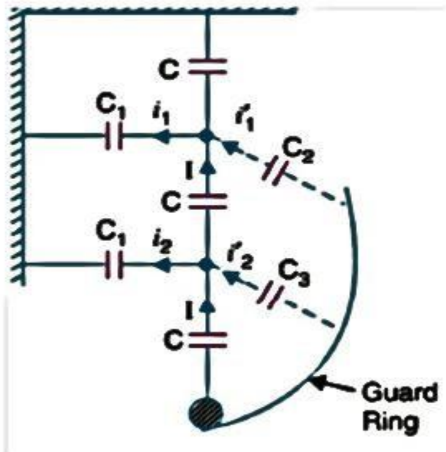
The value of string efficiency depends upon the value of K i.e., ratio of shunt capacitance to mutual capacitance. The lesser the value of K, the greater is the string efficiency and more uniform is the voltage distribution. The value of K can be decreased by reducing the shunt capacitance. In order 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.

(II) 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.

(III) 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 i1, i2 etc. are equal to metal fitting line capacitance currents i′1, i′2 etc.
The result is that same charging current I flows through each unit of string. Consequently, there will be uniform potential distribution across the units.

UNIT-III
MECHANICAL DESIGN OF LINES

1. What is string efficiency in a string of suspension type insulators?(Nov 2019)

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

String efficiency = $\frac{voltage\ across\ the\ string}{n*(voltage\ across\ the\ unit\ adjacent\ to\ the\ line\ conductor)}$

2.What are the main components of overhead transmission lines?(Nov 2019)

(i) Conductors which carry electric power from the sending end station to the receiving end station.

(ii) Supports which may be poles or towers and keep the conductors at a suitable level above the ground.

(iii) Insulators which are attached to supports and insulate the conductors from the ground.

(iv) Cross arms which provide support to the insulators.

(v) Miscellaneous items such as phase plates, danger plates, lightning arrestors, anti-climbing wires etc.

3. What are the types of line supports used in transmission and distribution systems?(Apr 2019)

The line support 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.

4. What are the factors affecting the sag in a transmission lines?
(Nov 2016, Apr 2017, Apr 2019)

Weight of the conductor, length of the span, working tensile strength and the temperature.

5. Why are insulators used with overhead lines? (Nov 2018)

Overhead line conductors are not covered with any insulating coating. They are secured to the supporting structures by means of insulating fittings, called insulators. These insulators impede the flow of current from the conductors to the earth through the conductor support. Thus insulators play an important in the successful operation of overhead line.

6. Explain the term 'Sag of a line'. (May 2016)

Sag is defined as the different in level between points of supports and the lowest point on the conductor.

7. State the advantages of suspension type insulators.(Apr 2018)

The advantages of suspension type insulators are:

- They are cheaper than pin type insulators beyond 11kV
- In the event of failure of an insulator one unit can be replaced instead of whole string.
- Each unit of suspension type insulators is designed for low voltage usually 11kV. Depending upon the working voltage, the desired number of units can be connected in series.

8. What are the main requirements of the insulating materials used for cable? (Apr 2018)

Some of the insulating materials used in the manufacture of cables are

i. Rubber
ii. Polyethylene
iii. Polyvinyl chloride
iv. Enamel
v. Gutta-percha
vi. Vulcanized Indian rubber
vii. Varnished cambric etc.

9. What is sag template? (Nov 2015, Apr 2018)

The sag template is used for allocating the position and height of the supports correctly on the profile.The sag template decided the limitations of vertical and wind load. It also limits the minimum clearance angle between the sag and the ground for safety purpose. The sag template is usually made up of transparent celluloid, perplex, or sometimes cardboard. The following curves are :

1. Hot Template Curve or Hot Curve
2. Ground Clearance Curve
3. Support Foot or Tower Curve
4. Cold Curve or Uplift Curve

10. What is meant by stringing chart and give the significance of stringing chart. (May 2016, Nov 2017)

Stringing chart is basically a graph between Sag, Tension with Temperature. As we want low Tension and minimum sag in our conductor but that is not possible as sag is inversely proportional to tension. It is because low sag means a tight wire and high tension whereas a low tension means a loose wire and increased sag. Therefore, we make compromise between two but if the case of temperature is considered and we draw graph then that graph is called Stringing chart. As Temperature increases then sag will increase but sag is inversely proportional to Tension so Tension will decrease and the significance are :

a. For finding the sag in the conductor
b. In the design of insulator string
c. In the design of tower
d. To find the distance between the towers

11. Specify the different types of insulators.(Apr 2017,

The different types of insulators used for overhead transmission lines are:

i. Pin type insulators
ii. Suspension type insulator
iii. Strain insulators
iv. Shackle insulators

12. What are the methods of improving string efficiency in line insulators? (Nov 2016)

The various methods for improving string efficiency are:

i. Longer cross - arms method
ii. Capacitance grading method
iii. Static shielding method or guard ring method

13. What are the tests performed on the insulators? (May 2016)

Testing of insulators can be classified into three types. They are,

i. Design tests
ii. Sample tests and
iii. Routine tests

14. What is meant by surge impedance and surge impedance loading of transmission line? (May 2015)

Surge impedance:

The characteristic impedance of a lossless line is known as surge impedance.

Surge impedance loading:

It is the power transmitted when a lossless line is terminated with a resistance equal to surge impedance of the line. This indicates the maximum power that can be delivered and it is useful in transmission line design.

PART-B

1. Explain the potential distribution over suspension insulator string. (Nov2014)

A string of suspension insulators consists of a number of porcelain discs connected in series through metallic links. Fig. shows 3-disc string of suspension insulators. The porcelain portion of each disc is in between two metal links. Therefore, each disc forms a capacitor C as shown in Fig. This is known as mutual capacitance or self-capacitance.

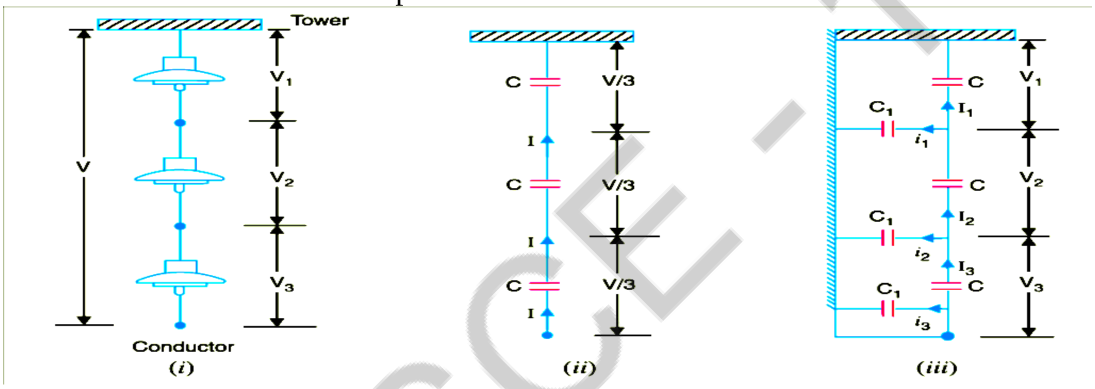
If there were mutual capacitance alone, then charging current would have been the same through all the discs and consequently voltage across each unit would have been the same i.e., V/3 as shown However, in actual practice, capacitance also exists between metal fitting of each disc and tower or earth. This is known as shunt capacitance C1. Due to shunt capacitance, charging current is not the same through all the discs of the string Therefore, voltage across each disc will be different. Obviously, the disc nearest to the line conductor will have the maximum* voltage. Thus referring to Fig V3 will be much more than V2 or V1. The following points may be noted regarding the potential distribution over a string of suspension insulators:

The voltage impressed on a string of suspension insulators does not distribute itself uniformly across the individual discs due to the presence of shunt capacitance.

The disc nearest to the conductor has maximum voltage across it. As we move towards the cross-arm, the voltage across each disc goes on decreasing.

The unit nearest to the conductor is under maximum electrical stress and is likely to be punctured. Therefore, means must be provided to equalize the potential across each unit.

If the voltage impressed across the string were d.c., then voltage across each unit would be the same. It is because insulator capacitances are ineffective for d.c.



As stated above, 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.,

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

N=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 3-disc string. Let us suppose that self-capacitance of each disc is C. Let us further assume that shunt capacitance C1 is some fraction K of self-capacitance i.e., C1 =KC. Starting from the cross-arm or tower, the voltage across each unit is V1, V2 and V3 respectively as shown

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

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

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

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

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

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

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

$$\frac{V_1}{1} = \frac{V_2}{1+K} = \frac{V_3}{1+3K+K^2} = \frac{V}{(1+K)(3+K)} \qquad \ldots(iv)$$

Therefore voltage across top unit $V_1 = \dfrac{V}{(1+k)(3+k)}$

Voltage across second unit from top $V_2=V_1(1+k)$ Voltage across third unit from top $V_3= V_1(1-3k+k^2)$

$$\% \text{ String Efficiency} = \frac{\text{Voltage Across string}}{n\times \text{voltage across disc nearest to conductor}} \times 100$$

$$= \frac{V}{n\times V_3} \times 100$$

2. Mention the different electrical tests on insulator and explain them.

According to the British Standard, the electrical insulator must undergo the following tests

1. Flashover tests of insulator
2. Performance tests
3. Routine tests

1. Flashover Test

There are mainly three types of flashover test performed on an insulator

Power Frequency Dry Flashover Test of Insulator

First the insulator to be tested is mounted in the manner in which it would be used practically. Then terminals of variable power frequency voltage source are connected to the both electrodes of the insulator. Now the power frequency voltage is applied and gradually increased up to the specified value. This specified value is below the minimum flashover voltage. This voltage is maintained for one minute and observe that there should not be any flash-over or puncher occurred. The insulator must be capable of sustaining the specified minimum voltage for one minute without flash over.

Power Frequency Wet Flashover Test or Rain Test of Insulator

In this test also the insulator to be tested is mounted in the manner in which it would be used practically. Then terminals of variable power frequency voltage source are connected to the both electrodes of the insulator. After that the insulator is sprayed with water at an angle of 45o in such a manner that its precipitation should not be more 5.08 mm per minute. The resistance of the water used for spraying must be between 9 kΩ 10 11 kΩ per cm3 at normal atmospheric pressure and temperature. In this way we create artificial raining condition. Now the power frequency voltage is applied and gradually increased up to the specified value. This voltage is maintained for either one minute or 30 second as specified and observe that there should not be any flash-over or puncher occurred. The insulator must be capable of sustaining the specified minimum power frequency voltage for specified period without flash over in the said wet condition.

Power Frequency Flashover Voltage test of Insulator

The insulator is kept in similar manner of previous test. In this test the applied voltage is gradually increased in similar to that of previous tests. But in that case the voltage when the surroundings air breaks down, is noted.

Impulse Frequency Flashover Voltage Test of Insulator

The overhead outdoor insulator must be capable of sustaining high voltage surges caused by lightning etc. So this must be tested against the high voltage surges.

The insulator is kept in similar manner of previous test. Then several hundred thousand Hz very high impulse voltage generator is connected to the insulator. Such a voltage is applied to the insulator and the spark over voltage is noted. The ratio of this noted voltage to the voltage reading collected from power frequency flashover voltage test is known as impulse ratio of insulator.

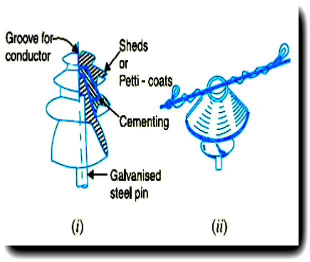
$$Impulse\ Ratio = \frac{Impulse\ frequency\ flashover\ voltage}{Power\ frequency\ flasover\ voltage}$$

This ratio should be approximately 1.4 for pin type insulator and 1.3 for suspension type insulators.

3. Draw the schematic diagram and explain the types of insulators. (April2015)

There are mainly three types of insulator likewise 1. Pin Insulator 2. Suspension Insulator 3. Stray Insulator In addition to that there are other two types of electrical insulator available mainly for low voltage application, e.i. stay insulator and shackle insulator.

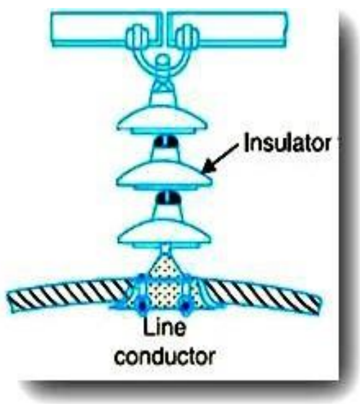
Pin Type Insulators



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 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 flashover, an arc occurs between the line conductor and insulator pin (i.e., earth) and the discharge jumps across the air gaps, following shortest distance. Figure shows the arcing distance (i.e. a + b + c) for the insulator. 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. 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 flashover voltage is known as safety factor.

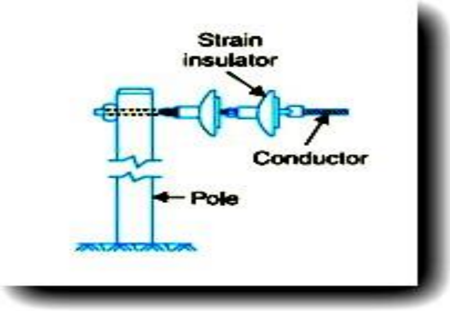
Suspension Type



For high voltages (>33 kV), it is a usual practice to use suspension type insulators shown in Figure.

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.

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 insulators as shown in Figure. The discs of strain insulators are used in the vertical plane. When the tension in lines is exceedingly high, at long river spans, two or more strings are used in parallel.

Shackle Insulators

In early days, the shackle insulators were used as strain insulators. But now a day, 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.

Stay Insulator

For low voltage lines, the stays are to be insulated from ground at a height. The insulator used in the stay wire is called as the stay insulator and is usually of porcelain and is so designed that in case of breakage of the insulator the guy-wire will not fall to the ground. There are several methods of increasing the string efficiency or improving voltage distribution across different units of a string.

Example 5.5.2 *An insulator string consists of three units, each having a safe working voltage of 15 kV. The ratio of self to shunt capacitance is 6 : 1. Find the maximum safe working voltage of the string and the string efficiency.*

AU : April-99, Oct.-01, April-05, May-11, 12, Dec.-17, Marks 16

Solution : Let C_1 = shunt capacitance and C = Self capacitance

$$\frac{C}{C_1} = \frac{6}{1}$$

$$\therefore \quad C_1 = \frac{1}{6} C = kC \quad \text{i.e. } k = \frac{1}{6} = 0.1667$$

Let voltage across line unit be 15 kV which is its safe working voltage i.e. $V_3 = 15 \times 10^3$ V. This is because the maximum voltage appears across the line unit.

For insulator string of 3 units we get,

$$V_2 = (1 + k)\, V_1$$

$$V_3 = (k^2 + 3k + 1)\, V_1$$

$$\therefore 15 \times 10^3 = \left(\frac{1}{36} + \frac{3}{6} + 1\right) V_1$$

$$\therefore \quad V_1 = 9.8181 \text{ kV}$$

$$\therefore \quad V_2 = \left(1 + \frac{1}{6}\right) \times 9.8181$$

$$= 11.454 \text{ kV}$$

$$\therefore \quad V = V_1 + V_2 + V_3 = 36.27 \text{ kV}$$

between line and earth

This is safe working voltage.

$$\therefore \text{ Line voltage } = \sqrt{3}\, V = 62.826 \text{ kV}$$

$$\text{String efficiency} = \frac{V}{n \times V_3} = \frac{36.27}{3 \times 15} = 80.605 \%$$

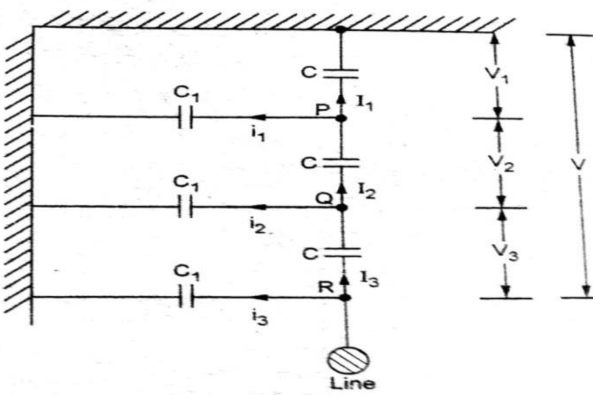


Fig. 5.5.3

Example 5.5.4 *In a 33 kV overhead line, there are three units in the string of insulators. If the capacitance between each insulator pin and earth is 11 % of self capacitance of each insulator, find the distribution of voltage over 3 insulators and string efficiency. Draw the equivalent circuit.*

AU : May-07, 18, Marks 16

Solution : Let, C_1 = Shunt capacitance

C = Self capacitance

$\therefore \quad C_1 = 11\ \%\ \text{of}\ C = 0.11\ C$

$\therefore \quad k = \dfrac{C_1}{C} = 0.11$

$V_L = 33\ \text{kV (line)}$

$\therefore \quad V = \dfrac{V_L}{\sqrt{3}} = 19.0525\ \text{kV (phase)}$

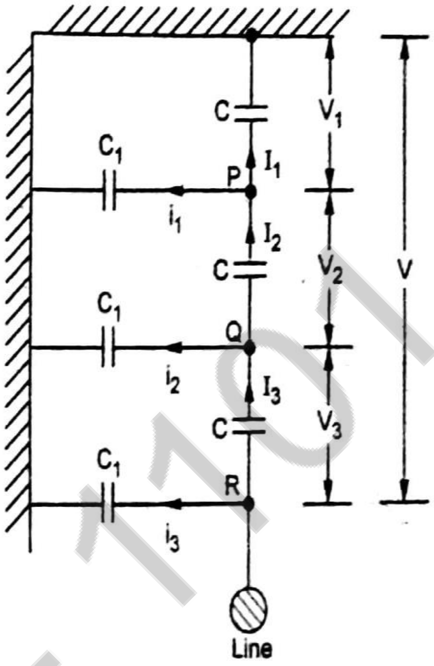


Fig. 5.5.5

Applying KCL at various nodes P, Q and R.

Node P, $I_2 = i_1 + I_1$

$$\therefore \quad \frac{V_2}{X_C} = \frac{V_1}{X_{C1}} + \frac{V_1}{X_C}$$

$$\therefore \quad V_2\, 2\pi f C = V_1\, 2\pi f C_1 + V_1\, 2\pi f C$$

$$\therefore \quad V_2 = V_1\left[\frac{C_1}{C} + 1\right] \quad \text{i.e.} \quad V_2 = (1+k)\, V_1 \qquad \dots (1)$$

Node Q, $I_3 = i_2 + I_2$

$$\therefore \quad \frac{V_3}{X_C} = \frac{(V_1 + V_2)}{X_{C1}} + \frac{V_2}{X_C}$$

$$\therefore \quad 2\pi f C V_3 = (V_1 + V_2)\, 2\pi f C_1 + 2\pi f C V_2$$

$$\therefore \quad V_3 = V_1\,[k^2 + 3k + 1] \qquad \dots \text{Using (1)}$$

And $\quad V = V_1 + V_2 + V_3$

$$\therefore \quad 19.0525 = V_1 + (1+k)\, V_1 + (k^2 + 3k + 1)\, V_1 = 3.4567\, V_1$$

$\therefore \quad V_1 =$ **5.511 kV** and $V_2 =$ **6.124 kV** and $V_3 =$ **7.4175 kV**

$$\text{String efficiency} = \frac{V}{n \times V_3} = \frac{19.0525}{3 \times 7.4175} = 0.8561 \text{ i.e. } \mathbf{85.61\ \%}$$

Example 4.4.8 *A transmission line conductor having a dia of 19.5 mm weights 0.85 kg/m. The span is 275 meters. The wind pressure is 39 kg/m² of projected area with ice coating of 13 mm. The ultimate strength of the conductor is 8000 kg. Calculate the maximum sag if the factor of safety is 2 and ice weighs 910 kg/m³*

AU : Dec.-07, 14, May-16,18, Marks 13

Solution :

$$w = 0.85 \text{ kg/m}, \quad d = 19.5 \text{ mm}, \quad t = 13 \text{ mm}$$

$$p = 39 \text{ kg/m}^2, \quad \text{Ultimate strength} = 8000 \text{ kg}, \quad S_f = 2$$

$$w_w = p \times [d + 2t] = 39 \times [19.5 + 2 \times 13] \times 10^{-3} = \mathbf{1.7745 \text{ kg/m}}$$

$$w_i = \text{ice density} \times \pi\, t(d+t)$$

$$= 910 \times \pi \times 13 \times 10^{-3} (19.5 + 13) \times 10^{-3} = \mathbf{1.208 \text{ kg/m}}$$

$$w_t = \sqrt{(w + w_i)^2 + (w_w)^2}$$

$$= \sqrt{(0.85 + 1.208)^2 + (1.7745)^2} = \mathbf{2.7174 \text{ kg/m}}$$

$$S_f = \frac{\text{Ultimate Strength}}{T}$$

$$\therefore \quad T = \frac{8000}{2} = \mathbf{4000 \text{ kg}}$$

$$S = \frac{w_t L^2}{8T} \qquad \ldots L = 275 \text{ m}$$

$$\therefore \quad S = \frac{2.7174 \times 275^2}{8 \times 4000} = \mathbf{6.422 \text{ m}}$$

Example 2.7.4 *A three - phase transmission line having a series impedance of (20 + j30) Ω delivers 7 MW at 33 kV and 0.8 lagging power factor. Find the sending end voltage, regulation and power angle. Neglect shunt capacitance.*

AU : Dec.-17, Marks 6

Solution :

$$\cos \phi_R = 0.8 \text{ lag}, \quad \phi_R = -36.869°$$

$$V_R(\text{line}) = 33 \text{ kV}, \quad V_R = \frac{33}{\sqrt{3}} = 19.052 \text{ kV(phase)}$$

$$Z = 20 + j30\ \Omega = 36.055 \angle 56.31°\ \Omega$$

$$I_L = \frac{P}{\sqrt{3}\, V_R(\text{line}) \cos\phi_R} = \frac{7 \times 10^6}{\sqrt{3} \times 33 \times 10^3 \times 0.8} = 153.085 \text{ A}$$

Take V_R(phase) as reference

$\therefore \quad \overline{V}_R = 19.052 \times 10^3 \angle 0° V$

$\overline{I}_L = 153.085 \angle -36.869° \text{ A}$

$\therefore \quad \overline{V}_S = \overline{V}_R + \overline{I}_L \overline{Z} = (19.052 \times 10^3 \angle 0°) + [153.085 \angle -36.869° \times 36.055 \angle 56.31°]$

$\therefore \quad \overline{V}_S = 19256.78 + j\,1837.08 \text{ V} = \mathbf{19.3442 \angle 5.45° \text{ kV}}$

$\therefore \quad V_R(\text{line}) = \sqrt{3} \times 19.3442 = \mathbf{33.5051 \text{ kV}}$

$\therefore \quad \% R = \frac{V_S - V_R}{V_R} \times 100 = \mathbf{1.5306\ \%}$

$\delta = \mathbf{5.45°}$ = Power angle ... From $\overline{V}_S$

8. Derive an Expression for sag and tension in a power conductor strung between two supports at equal heights taking into account the wind and ice loading also.(Nov2013)(Nov2018)

When supports are at equal levels .Consider a conductor between two equilevel supports A and B with O as the lowest point as shown in Fig.8.2. It can be proved that lowest point will be at a conductor between two equilevel supports A and B with O as the lowest point as shown in Fig. It can be proved that lowest point will be at the mid- span.
a conductor between two equilevel supports A and B with O as the lowest point as shown in Fig. It can be proved that lowest point will be at the mid-span.
Let
l = Length of span
w = Weight per unit length of conductor
T = Tension in the conductor.
Consider a point P on the conductor. Taking the lowest point O as the origin, let the co-ordinates of point P be x and y. Assuming that the curvature is so small that curved length is equal to its horizontal projection (i.e., OP = x), the two forces acting on the portion OP of the conductor are :
(a) The weight wx of conductor acting at a distance x/2 from O.
(b) The tension T acting at O.

Equating the moments of above two forces about point O, we get,

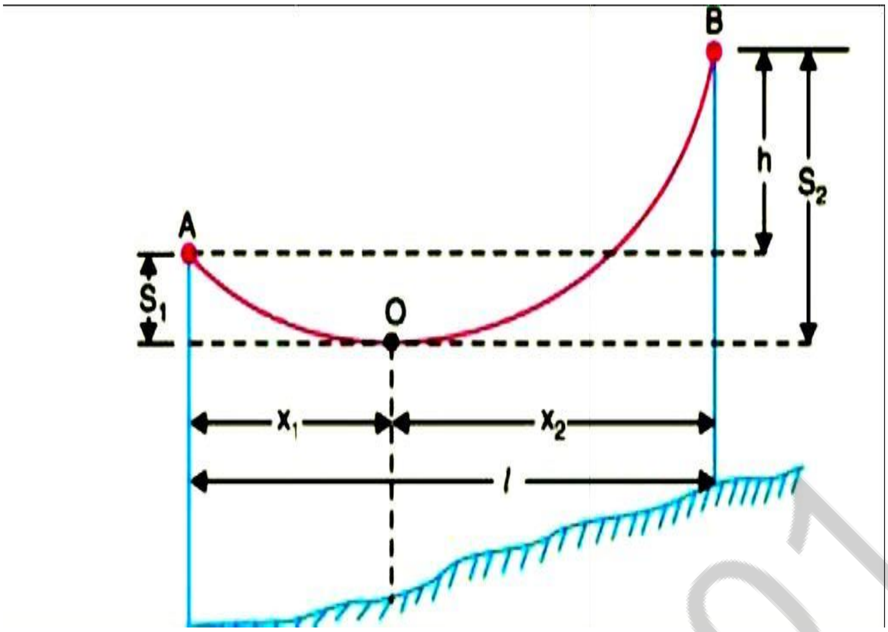
$Ty = wx \times \frac{x}{2}$

$y = \frac{wx^2}{2T}$

The maximum dip is represented by the value of y at either of the supports A and B At support A, $x = \frac{l}{2}$ and y=S

Sag, $S = \frac{w(\frac{l}{2})}{2T} = \frac{wl^2}{8T}$

When supports are at unequal levels.
In hilly areas, we generally come across conductors suspended between supports at unequal levels. Fig.3 shows a conductor suspended between two supports A and B which are at different levels. The lowest point on the conductor is O.



l = Span length
h = Difference in levels between two supports
x 1 = Distance of support at lower level (i.e., A) from O
x 2 = Distance of support at higher level (i.e. B) from O
T = Tension in the conductor

If the weight per unit length of the conductor then Sag $S_1 = \frac{wx_1^2}{2T}$

Sag $S_2 = \frac{wx_2^2}{2T}$

$x_1 + x_2 = l$

Now $\quad S_2 - S_1 = \frac{w}{2T}[x_2^2 - x_1^2] = \frac{w}{2T}(x_2 + x_1)(x_2 - x_1)$

$\therefore \quad S_2 - S_1 = \frac{w\,l}{2T}(x_2 - x_1) \qquad [\because x_1 + x_2 = l]$

But $\quad S_2 - S_1 = h$

$\therefore \quad h = \frac{w\,l}{2T}(x_2 - x_1)$

or $\quad x_2 - x_1 = \frac{2\,Th}{w\,l} \qquad ...(ii)$

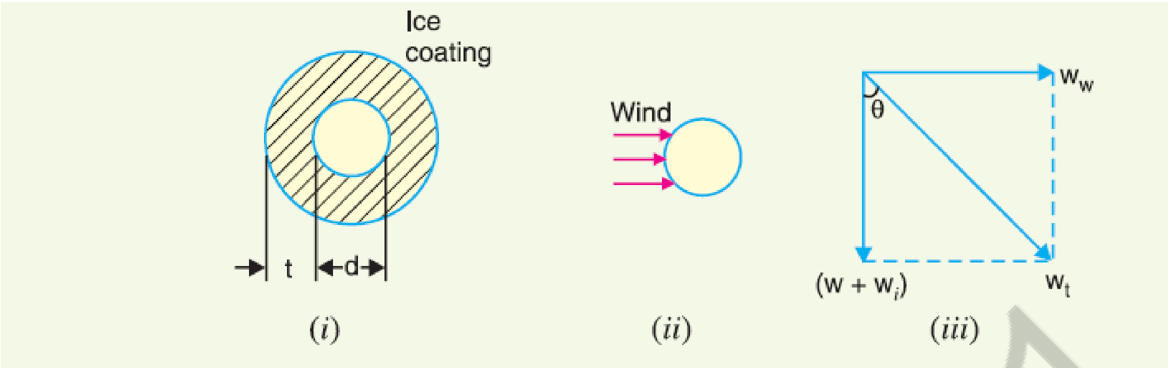
Solving exps. (*i*) and (*ii*), we get,

$$x_1 = \frac{l}{2} - \frac{T\,h}{w\,l}$$

$$x_2 = \frac{l}{2} + \frac{T\,h}{w\,l}$$

Having found x_1 and x_2, values of S_1 and S_2 can be easily calculated.

Effect of wind and ice loading:- The above formulae for sag are true only in still air and at normal temperature when the conductor is acted by its weight only. However, in actual practice, a conductor may have ice coating and simultaneously subjected to wind pressure. The weight of ice acts vertically downwards i.e., in the same direction as the weight of conductor. The force due to the wind is assumed to act horizontally i.e., at right angle to the projected surface of the conductor. Hence, the total force on the conductor is the vector sum of horizontal and vertical forces as shown in



Total weight of conductor per unit length is

$$w_t = \sqrt{(w + w_i)^2 + (w_w)^2}$$

Where w = weight of conductor per unit length

= conductor material density × volume per unit length w_i= weight of ice per unit length

= density of ice × volume of ice per unit length

$$= \text{density of ice} \times \frac{\pi}{4}\left[(d + 2t)^2 - d^2\right] \times 1$$

$$= \text{density of ice} \times \pi\, t\, (d + t)^*$$

w_W= wind force per unit length

= wind pressure per unit area × projected area per unit length

$$= \text{wind pressure} \times [(d + 2t) \times 1]$$

When the conductor has wind and ice loading also, the following points may be noted : **(i)** The conductor sets itself in a plane at an angle to the vertical where

$$\tan\theta = \frac{w_w}{w + w_i}$$

(ii) The sag in the conductor is given by

$$S = \frac{w_t\, l^2}{2T}$$

Hence S represents the slant sag in a direction making an angle to the vertical. If no specific mention is made in the problem, then slant slag is calculated by using the above formula.

(iii) The vertical sag =

$$S \cos\theta$$

9. An overhead transmission line has a span of 200m, between the supports, the supports are at the same level. The area of cross section of conductor is 1.9cm^2 while the ultimate strength is 5000kg/cm^2. The specific gravity of the conductor material is 8.9 gm/cm$^{2.}$ If the conductor is subjected to the wind pressure of 1.5kg/m length. Calculate the sag if factor of safety is 5. Also calculate the vertical sag.(April2015)(Nov2014)

$L = 200m$, $A = 1.9 cm^2$

Ultimate strength=$5000 kg/cm^2 = 5000 \times 1.9 kg = 9500 kg$ $S_f = \frac{\text{ultimate strength}}{\text{tension } T}$

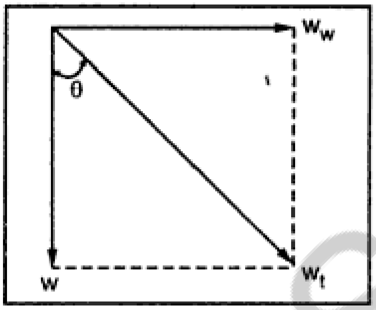
$S_f = \frac{9500}{T}$

$T = 1900 kg$

$$
\begin{aligned}
w &= \text{weight of conductor} = \text{area of c/s} \times \text{density} \\
&= 1.9 \text{ cm}^2 \times 8.9 \text{ gm/cm}^3 = 16.91 \text{ gm/cm} \\
&= \frac{16.91 \times 10^{-3}}{10^{-2}} \text{ kg/m} = 1.691 \text{ kg/m} \\
w_w &= \text{wind force} = 1.5 \text{ kg/m} \\
w_t &= \sqrt{w^2 + w_w^2} \quad \text{... ice loading absent} \\
&= \sqrt{(1.691)^2 + (1.5)^2} \\
&= 2.2604 \text{ kg/m}
\end{aligned}
$$

$$
\therefore \quad S = \frac{w_t L^2}{8T}
$$

$$
= \frac{2.2604 \times (200)^2}{8 \times 1900} = 5.9484 \text{ m}
$$



This acts along direction of θ with respect to vertical

$\tan\theta = \frac{w_w}{w} = \frac{1.5}{1.691}$

$\therefore \quad \theta = 41.574°$

$\therefore$ Vertical sag $= S\cos\theta$

$= 5.9484 \times \cos(41.574)$

$= 4.45$ m

UNIT-IV

UNDERGROUND CABILITYS

Part-A (2 Marks)

1. What are the limitaions of solid type cables? (Nov 2019)

For voltages beyond 66KV, solid type cables are unreliable, because there is no danger of breakdown of insulation due to the presence of voids.

But in pressure cables, voids are eliminated by increasing the pressure of the compound by using oil, gas etc**.**

2. What are the desirable characteristics of insulating marterials used in cables? (Apr 2019)

i. High insulation resistance to avoid leakage current
ii. High dielectric strength to avoid electrical breakdown of the cable
iii. High mechanical strength to withstand the mechanical handling of cables
iv. Non-hygroscopic i.e) it should mot absorb moisture from air or soil.
v. Non inflammable
vi. Unaffected by acids and alkalies

3. What are the sources of heat generation in an underground cable? (Apr 2019)

a. Copper loss in conductor
b. Dielectric losses in cable insulation
c. Losses in metallic sheathings and armouring

4. What are the main requirements of insulating materials used for a cable?(Apr 2018)

i. PVC
ii. Rubber
iii. Impregnated paper
iv. Polythene

5. What is a belted cable? (Nov 2017)

The conductors (usually three) are bunched together and then bounded with an insulating paper 'belt'. In such cables, each conductor is insulated using paper impregnated with a suitable dielectric. The gaps between the conductors and the insulating paper belt are filled with a fibrous dielectric material such as Jute or Hessian. This provides flexibility as well as a circular shape. As we discussed earlier (in Construction of Cables), the jute layer is then covered by a metallic sheath and armouring for protection. One particular speciality of this cable is that its shape may not be perfectly circular. It is kept non-circular to use the available space more effectively.

6. Classify the cables used for three phase service.(May 2016)

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

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

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7. What are the two different methods of grading of cables?(Apr 2017)

Uniform electrostatic stress in the dielectric of cable is achieved by grading of cables.

Methods of grading

i. Capacitance grading
ii. Intersheath grading

8. What is the main purpose of armouring? (Apr 2015)

The main purpose of armour is to provide mechanical protection, although it can also provide part of the earth fault path. For multi-core cables steel wire armour is most often used.

9. Define safety factor of insulator. Why it is desired to have this value be high?(MJ15)

It is defined as the ratio of puncture strength to the flashover voltage.

It is desirable to have high safety factor so that flashover takes place before the insulator gets punctured. For pin type insulators, the value of safety factor is above 10.

10. Define grading of cable. (Nov 2015)

The process of achieving uniform electrostatic stress in the dielectric of cables is known as grading of cables.

11. What is shackle insulator?(May 2014)

It is used in low voltage distribution line (11KV). This can be used either in a vertical position or horizontal position. In this type of construction, the conductor is placed between the clamp and the insulator and is fixed along the groove of the insulator using soft binding wires of same material as the conductor.

12. What is meant by dielectric stress in a cable? (May 2014)

Dielectric stress occurs, when the insulation of a cable is subjected to electrostatic forces under normal operating conditions. Dielectric stress at any point in a cable is the electric field intensity at that point.

13. What are the factors to be considered while selecting a cable for a particular service? (Nov 2014)

i) Operating voltage
ii) Current carrying capacity
iii) Voltage drop
iv) Site requirement
v) Economic evaluation

Part-B

1. What is grading of cables? Explain its types in detail.

(May2014, May 2016, Nov 2018, Apr 2019, Nov 2019)

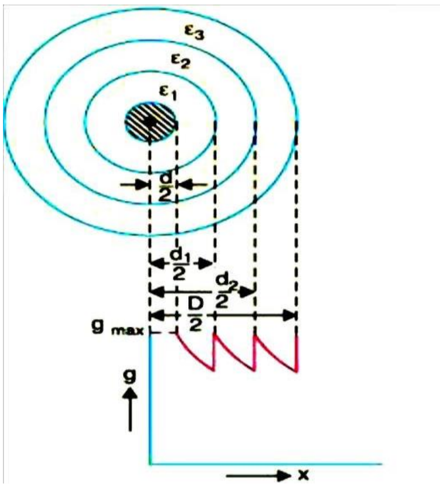
The process of achieving uniform electrostatic stress in the dielectric of cables is known as grading of cables.

It has already been shown that electrostatic stress in a single core cable has a maximum value (g_{max}) at the conductor surface and goes on decreasing as we move towards the sheath. The maximum voltage that can be safely applied to a cable depends upon g_{max} i.e., electrostatic stress at the conductor surface. For safe working of a cable having homogeneous dielectric, the strength of dielectric must be more than g_{max} .If a dielectric of high strength is used for a cable, it is useful only near the conductor where stress is maximum. But as we move away from the conductor, the electrostatic stress decreases, so the dielectric will be unnecessarily over strong. The unequal stress distribution in a cable is undesirable for two reasons. Firstly, insulation of greater thickness is required which increases the cable size.

Secondly, it may lead to the breakdown of insulation. In order to overcome above disadvantages, it is necessary to have a uniform stress distribution in cables. This can be achieved by distributing the stress in such a way that its value is increased in the outer layers of dielectric. This is known as grading of cables. The following are the two main methods of grading of cables:

(i) Capacitance grading
(ii) Intersheath grading

(i)Capacitance Grading



The process of achieving uniformity in the dielectric stress by using layers of different dielectrics is known as capacitance grading.

In capacitance grading, the homogeneous dielectric is replaced by a composite dielectric. The composite dielectric consists of various layers of different dielectrics in such a manner that relative permittivity r of any layer is inversely proportional to its distance from the center.

Under such conditions, the value of potential gradient any point in the dielectric is constant and is independent of its distance from the center. In other words, the dielectric stress in the cable is same everywhere and the grading is ideal one. However, ideal grading requires the use of an infinite number of dielectrics which is an impossible task. In practice, two or three dielectrics are used in the decreasing order of permittivity, the dielectric of highest permittivity being used near the core. The capacitance grading can be explained beautifully by referring to Fig. There are three dielectrics of outer diameter d1, d2 and D and of relative permittivity 1, 2 and 3 respectively. If the permittivity are such that 1 > 2 > 3 and the three dielectrics are worked at the same maximum stress, then,

$$\frac{1}{\varepsilon_1 d} = \frac{1}{\varepsilon_2 d_1} = \frac{1}{\varepsilon_3 d_2}$$

or

$$\varepsilon_1 d = \varepsilon_2 d_1 = \varepsilon_3 d_2$$

Potential difference across the inner layer is

$$V_1 = \int_{d/2}^{d_1/2} g\,dx = \int_{d/2}^{d_1/2} \frac{Q}{2\pi\varepsilon_0\varepsilon_1 x}dx$$

$$= \frac{Q}{2\pi\varepsilon_0\varepsilon_1}\log_e\frac{d_1}{d} = \frac{g_{max}}{2} d\log_e\frac{d_1}{d}\left[\because \frac{Q}{2\pi\varepsilon_0\varepsilon_1} = \frac{{}^{*}g_{max}}{2}d\right]$$

$$V_2 = \frac{g_{max}}{2} d_1 \log_e \frac{d_2}{d_1}$$

$$V_3 = \frac{g_{max}}{2} d_2 \log_e \frac{D}{d_2}$$

Total p.d. between core and earthed sheath is

$$V = V_1 + V_2 + V_3$$

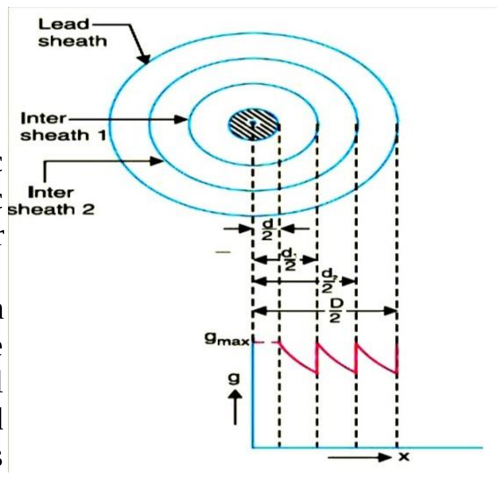
$$= \frac{g_{max}}{2}\left[d\log_e\frac{d_1}{d} + d_1\log_e\frac{d_2}{d_1} + d_2\log_e\frac{D}{d_2}\right]$$

$$V' = \frac{g_{max}}{2} d\log_e\frac{D}{d}$$

$$V = \frac{g_{1max}}{2} d\log_e\frac{d_1}{d} + \frac{g_{2max}}{2} d_1\log_e\frac{d_2}{d_1} + \frac{g_{3max}}{2} d_2\log_e\frac{D}{d_2}$$

if the cable had homogeneous dielectric, then, for the same values of d, D and gmax, the permissible potential difference between core and earthed sheath would have been

$$V' = \frac{g_{max}}{2} d\log_e\frac{D}{d}$$



Intersheath Grading

In this method of cable grading, a homogeneous dielectric is used, but it is divided into various layers by placing metallic inters heaths between the core and lead sheath. The inter sheaths are held at suitable potentials which are in between the core potential and earth potential. This arrangement improves voltage distribution in the dielectric of the cable and consequently more uniform potential gradient is obtained. Consider a cable of core diameter d and outer lead sheath of diameter D. Suppose that two inters heaths of diameters d1 and d2 are inserted into the homogeneous dielectric and maintained at somefixed potentials. Let V1, V2 and V3 respectively be the voltage between core and intersheath 1, between inter sheath 1 and 2 and between inter sheath 2 and outer lead sheath. As there is a definite potential difference between the inner and outer layers of each inter sheath, therefore, each sheath can be treated like a homogeneous single core cable Maximum stress

Between core and inter sheath 1is

$$g_{1max} = g_{2max} = g_{3max} = g_{max} \text{ (say)}$$

$$\therefore \quad \frac{V_1}{\frac{d}{2}\log_e \frac{d_1}{d}} = \frac{V_2}{\frac{d_1}{2}\log_e \frac{d_2}{d_1}} = \frac{V_3}{\frac{d_2}{2}\log_e \frac{D}{d_2}}$$

Similarly,

$$g_{1max} = \frac{V_1}{\frac{d}{2}\log_e \frac{d_1}{d}}$$

$$g_{2max} = \frac{V_2}{\frac{d_1}{2}\log_e \frac{d_2}{d_1}}$$

$$g_{3max} = \frac{V_3}{\frac{d_2}{2}\log_e \frac{D}{d_2}}$$

$\sqrt{3}$

Example 6.9.4 *The capacitance per kilometer of a 3 phase belted core cable is 0.2 micro farad/km between two cores with the third core connected to sheath. Calculate the kVA. The supply voltage 6.6 kV and 30 km long.* **AU : May-04, 17, Marks 8**

Solution : The capacitance between two cores with third core connected to sheath is $C_3 = 0.2\ \mu F/km$. In such a case; one of the capacitor C_s is eliminated and this gives,

$$C_3 = \frac{1}{2}C_N \quad \text{i.e.} \quad C_N = 2C_3 = 0.4\ \mu F/km$$

$$\therefore C_N \text{ for 30 km} = 0.4 \times 30 = 12\ \mu F$$

$$\therefore \quad I_C = 2\pi f V_{ph} C_N = 2\pi \times 50 \times \frac{6.6\times10^3}{\sqrt{3}} \times 12 \times 10^{-6} = \mathbf{14.3653\ A}$$

$$\therefore \quad kVA = 3 V_{ph} I_C = 3 \times \frac{6.6\times10^3}{\sqrt{3}} \times 14.3653 = \mathbf{164.2174\ kVA}$$

Example 6.7.7 *A single core cable has a conductor diameter of 1 cm and internal sheath diameter of 1.8 cm. If impregnated paper of relative permittivity 4 is used as the insulation calculate the capacitance for 1 km length of the cable.* **AU : May-18, Marks 5**

Solution :

$$D = 1.8 \text{ cm}, \ d = 1 \text{ cm}, \ l = 1 \text{ km}, \ \varepsilon_r = 4$$

$$C = \frac{2\pi\varepsilon_r l \varepsilon_0}{ln\left(\frac{D}{d}\right)} = \frac{2\pi\times4\times1\times10^3\times8.854\times10^{-12}}{ln\left(\frac{1.8}{1}\right)}$$

$$= \mathbf{0.3786\ \mu F}$$

4. Derive the expression for capacitance of a single core cable. (Apr 2018)

Capacitance of a Single-Core Cable

A single-core cable can be considered to be equivalent to two long co-axial cylinders. The conductor (or core) of the cable is the inner cylinder while the outer cylinder is represented by lead sheath which is at earth potential. Consider a single core cable with conductor diameter *d* and inner sheath diameter *D* (Fig. 4.27). Let the charge per metre axial length of the cable be *Q* coulombs and Ɛ be the permittivity of the insulation material between core and lead sheath.

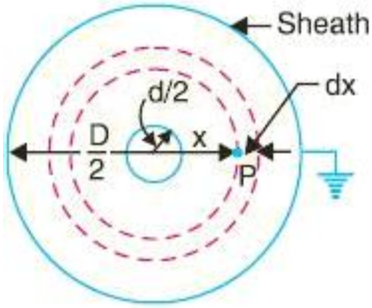


Fig. 4.27

Obviously *$\varepsilon = \varepsilon_0 \varepsilon_r$ where ε_r is the relative permittivity of the insulation.

Consider a cylinder of radius *x* metres and axial length 1 metre.

The surface area of this cylinder is = $2\pi x \times 1 = 2\pi x$ m^2

Electric flux density at any point *P* on the considered cylinder is

$$D_x = \frac{Q}{2\pi x}\ \text{C/m}^2$$

Electric intensity at point *P*, $E_x = \frac{D_x}{\varepsilon} = \frac{Q}{2\pi x \varepsilon} = \frac{Q}{2\pi x \varepsilon_0 \varepsilon_r}$ volts/m

The work done in moving a unit positive charge from point *P* through a distance *dx* in the direction of electric field is $E_x\,dx$. Hence, the work done in moving a unit positive charge from conductor to sheath, which is the potential difference *V* between conductor and sheath, is given by :

$$V = \int_{d/2}^{D/2} E_x\,dx = \int_{d/2}^{D/2} \frac{Q}{2\pi x \varepsilon_0 \varepsilon_r}\,dx = \frac{Q}{2\pi \varepsilon_0 \varepsilon_r}\log_e \frac{D}{d}$$

Capacitance of the cable is

$$C = \frac{Q}{V} = \frac{Q}{\frac{Q}{2\pi \varepsilon_0 \varepsilon_r}\log_e \frac{D}{d}}\ \text{F/m}$$

$$= \frac{2\pi \varepsilon_o \varepsilon_r}{\log_e(D/d)}\ \text{F/m}$$

$$= \frac{2\pi \times 8\cdot 854 \times 10^{-12} \times \varepsilon_r}{2\cdot 303\,\log_{10}(D/d)}\ \text{F/m}$$

$$= \frac{\varepsilon_r}{41\cdot 4\,\log_{10}(D/d)} \times 10^{-9}\ \text{F/m}$$

If the cable has a length of *l* metres, then capacitance of the cable is

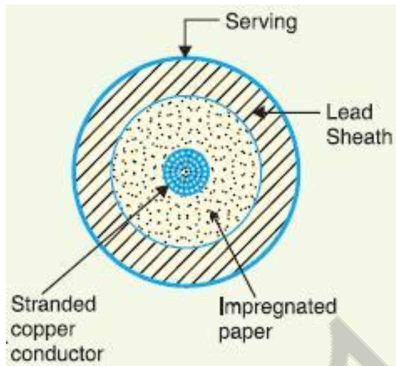
$$C = \frac{\varepsilon_r\,l}{41\cdot 4\,\log_{10}\frac{D}{d}} \times 10^{-9}\ \text{F}$$

5. With neat diagrams explain constructional features of various types of cables.

(Nov 2018, Nov 2019)

Classification of Cables:

Cables for underground service may be classified in two ways according to (i) the type of insulating material used in their manufacture (ii) the voltage for which they are manufactured. However, the latter method of classification is generally preferred, according to which cables can be divided into the following groups:



(i) Low-tension (L.T.) cables — upto 1000 V
(ii) High-tension (H.T.) cables — upto 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
(iv) Extra super voltage cables — beyond 132 kV

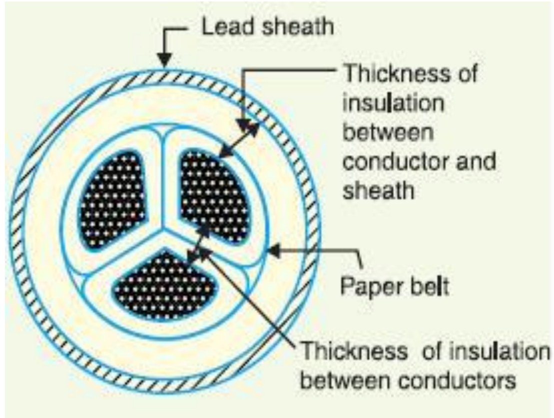
A cable may have one or more than one core depending upon the type of service for which it is intended. It may be (i) single-core (ii) two-core (iii) three-core (iv) four-core etc. For a 3-phase service, either 3-single-core cables or three-core cable can be used depending upon the operating voltage and load demand. Fig shows the constructional details of a single-core low tension cable. The cable has ordinary construction because the stresses developed in the cable for low voltages (up to 6600 V) are generally small. It consists of one circular core of tinned stranded copper (or aluminium) insulated by layers of impregnated paper. The insulation is surrounded by a lead sheath which prevents the entry of moisture into the inner parts. In order to protect the lead sheath from corrosion, an overall serving of compounded fibrous material (jute etc.) is provided. Single-core cables are not usually armoured in order to avoid excessive sheath losses. The principal advantages of single-core cables are simple construction and availability of larger copper section.

Cable for 3-phase :-

In practice, underground cables are generally required to deliver 3-phase power. For the purpose, either three-core cable or three single core cables may be used. For voltages upto 66 kV, 3-core cable (i.e., multi-core construction) is preferred due to economic reasons. However, for voltages beyond 66 kV, 3-core-cables become too large and unwieldy and, therefore, single-core cables are used. The following types of cables are generally used for 3-phase service :

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

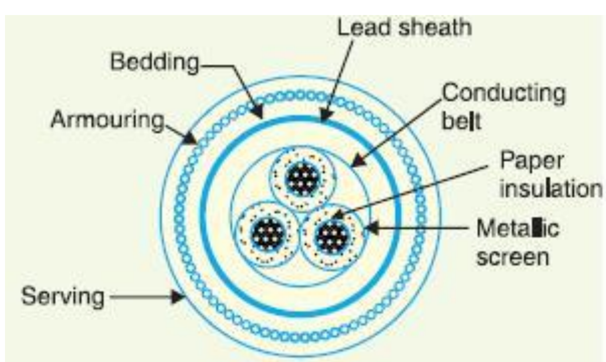
1. Belted cables. These cables are used for voltages upto 11kV but in extraordinary cases, their use may be extended upto 22kV. Fig. shows the constructional details of a 3-core belted cable. The cores are insulated from each other by layers



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 cores are generally stranded and may be of non circular shape to make better use of available space. The belt is covered with lead sheath to protect the cable against ingress of moisture and mechanical injury. The lead sheath is covered with one or more layers of armouring with an outer serving (not shown in the figure).The belted type construction is suitable only for low and medium voltages as the electro static stresses developed in the cables for these voltages are more or less radial i.e., across the insulation. However, for high voltages (beyond 22 kV), the tangential stresses also become important. These stresses act along the layers of paper insulation. As the insulation resistance of paper is quite small along the layers, therefore, tangential stresses set up leakage current along the layers of paper insulation. The leakage current causes local heating, resulting in the risk of breakdown of insulation at any moment. In order to overcome this difficulty, screened cables are used where leakage currents are conducted to earth through metallic screens.

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. Hochstetler and hence the name. Fig shows the constructional details of a typical 3-core, H-type cable. 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 aluminum foil. The cores are laid in such a way that metallic screens



Make contact with one another. An additional conducting belt (copper woven fabric tape) is Wrapped round the three cores. The cable has no insulating belt but lead sheath, bedding, armouring and serving follow as usual. It is easy to see that each core screen is in electrical contact with the conducting belt and the lead sheath. As all the four screens (3 core screens and one conducting belt) and the lead sheath are at earth potential, therefore, the electrical stresses are purely radial and consequently dielectric losses are reduced.

Two principal advantages are claimed for H-type cables. Firstly, the perforations in the metallic screens assist in the complete impregnation of the cable with the compound and thus the possibility of air pockets or voids (vacuous spaces) in the dielectric is eliminated. The voids if present tend to reduce the breakdown strength of the cable and may cause considerable damage to the paper insulation. Secondly, the metallic screens increase the heat dissipating power of the cable.

(ii) S.L. type cables.:-

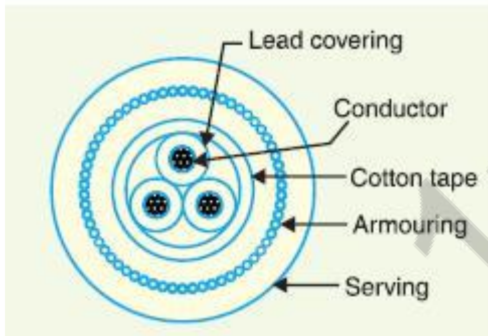


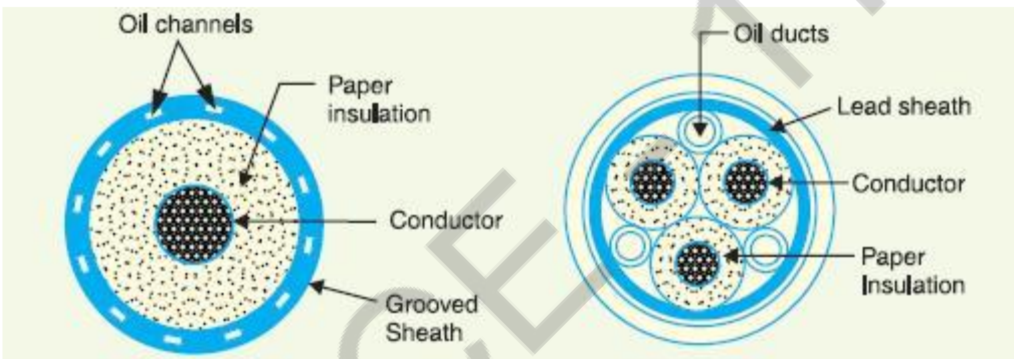
Fig. shows the constructional details of a 3-core S.L. (separate lead) type cable. It is basically H-type cable but the screen round each core insulation is covered by its own lead sheath. There is no overall lead sheath but only armouring and serving are provided. The S.L. type cables have two main advantages over H-type cables. Firstly, the separate sheaths minimize the possibility of core-to-core breakdown. Secondly, bending of cables becomes easy due to the elimination of overall lead sheath. However, the disadvantage is that the three lead sheaths of S.L. cable are much thinner than the single sheath of H-cable and, therefore, call for greater care in manufacture

3. Pressure cables :-For voltages beyond 66 kV, solid type cables are unreliable because there is a danger of breakdown of insulation due to the presence of voids. 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 viz oil-filled cables and gas pressure cables are commonly used.

(i) Oil-filled cables. In such types of cables, channels or ducts are provided in the cable for oil circulation. The oil under pressure (it is the same oil used for impregnation) 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 in to 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 up to 230 kV. Oil-filled cables are of three types viz., single-core conductor channel, single-core sheath channel and three-core filler-space channels.

Fig. shows the constructional details of a single-core conductor channel, oil filled cable. The oil channel is formed at the center by stranding the conductor wire around a hollow cylindrical steel spiral tape. The oil under pressure is supplied to the channel by means of external reservoir. As the channel is made of spiral steel tape, it allows the oil to percolate between copper strands to the wrapped insulation. The oil pressure compresses the layers of paper insulation and prevents the possibility of void formation. The system is so designed that when the oil gets expanded due to increase in cable temperature, the extra oil collects in the reservoir. However, when the cable temperature falls during light load conditions, the oil from the reservoir flows to the channel. The disadvantage of this type of cable is that the channel is at the middle of the cable and is at full voltage w.r.t. earth, so that a very complicated system of joints is necessary.

Fig. shows the constructional details of a single core sheath channel oil-filled cable. In this type of cable, the conductor is solid similar to that of solid cable and is paper insulated. However, oil ducts are provided in them etallic sheath as shown. In the 3-core oil-filler cable shown in Fig. the oil ducts are located in the filler spaces. These channels are composed of perforated metal-ribbon tubing and are at earth potential.



(ii) Gas pressure cable:-The voltage required to set up ionization inside a void increases as the pressure is increased. Therefore, if ordinary cable is subjected to a sufficiently high pressure, the ionization can be altogether eliminated. At the same time, the increased pressure produces radial compression which tends to close any voids. This is the underlying principle of gas pressure cables.

shows the section of external pressure cable designed by Hochstetler, Vogal and Bowden. 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. The gas pressure produces radial compression and closes the voids that may have formed between the layers of paper insulation. Such cables can carry more load current and operate at higher voltages than a normal cable. Moreover, maintenance cost is small and the nitrogen gas helps in quenching any flame. However, it has the disadvantage that the overall cost is very high.

UNIT-V

DISTRIBUTION SYSTEMS

Part-A(2 Marks)

1. What are the materials mainly used in bus bars?(May 2015)

Materials used for bus bars:

i) Aluminium

ii) Copper

Materials used for coating:

i) Tin

ii) Silver

2. What are the limitations of Kelvin's law? (Apr 2019)

1. It is quite difficult to estimate the energy loss in the line without actual load curves which are not available at the time of estimation.
2. Interest and depreciation on the capital cost cannot be determined accurately.
3. The conductor size determined using this law may not always be practicable one because it may not have sufficient mechanical strength.
4. This law does not take into account several factors like safe current carrying capacity, corona loss etc.
5. The economical size of a conductor may cause the voltage drop beyond the acceptable limits.

3. What are the advantages of FACTS Controllers? (Apr 2019)

FACTS controllers can be utilized to increase the transmission capacity, improve the stability and dynamic behavior or ensure better quality in modern power systems. Their main capabilities are reactive power compensation, voltage control and power flow control.

4. What is gas insulated substations?(Apr 2018)

A gas insulated substation (GIS) is a high voltage substation in which the major structures are contained in a sealed environment with sulfur hexafluoride gas as the insulating medium.

5. What are the major equipments of a substations? (Nov 2017)

i) Transformer

ii) Circuit breakers

iii) Isolating switches

iv) Protective relays

v) Bus bars

vi) Current and potential transformers

vii) Surge arresters

viii) Control room equipments

6. What are the classifications of substations according to service? (Apr 2015)

According to constructional features

i) Indoor substation

ii) Outdoor substation

iii) Underground substation

iv) Pole mounted substation

7. Discuss the importance of voltage control in power systems. (Nov 2019)

i) Lightning loads are very sensitive to change in voltage

ii) Voltage variations will cause erratic operation in inductive motors.

iii) Large variations of voltage cause excessive heating of distribution transformers.

8. What do you understand by induction regulators? (Nov 2019)

An induction regulator is an alternating current electrical machine, somewhat similar to an induction motor, which can provide a continuously variable output voltage. The induction regulator was an early device used to control the voltage of electric networks.

9. Write down the types of grounding.(Apr 2017)

(i) Solid or effective grounding
(ii) Resistance grounding
(iii) Reactance grounding
(iv) Peterson-coil grounding

10. What is the need for earthing?(Nov 2016)

i) To prevent accidents and damage to the equipment of the power system.

ii) To ensure the safety of the persons handling the equipment

iii) To maintain the continuity of supply at the same time

11. What is meant by tower spotting?(Nov 2015)

Tower spotting is the art of locating structures in the right way and selecting height and the type of towers to be used.

12. What is the purpose of terminal and through substations in the power system? (Nov 2014)

Terminal – To end or terminate the line supplying the substation
Through – To pass the incoming line through at the same voltage.

13. Mention any 4 bus schemes in the substation. (May 2013)

i) Single bus scheme
ii) Single bus bar with bus sectionalizer
iii) Double bus with double breaker
iv) Double bus with single breaker
v) Main and transfer bus
vi) Ring bus
vii) Breaker and half with two main buses
viii) Double bus bar with bypass isolators.

PART-B

1.

Example 7.11.8 *A 2-wire d.c. street mains AB, 600 m long is fed from both ends at 220 V. Loads of 20 A, 40 A, 50 A and 30 A are tapped at distances of 100 m, 250 m, 400 m and 500 m from the end A respectively. If the area of X-section of distributor conductor is 1 square centimeter, find the minimum consumer voltage. Take* $\rho = 1.7\times10^{-6}$ *ohm-cm.*

AU : May-18, Marks 15

Solution : Let E be the point of minimum potential. At 'E' let x A is supplied from point A while (50 – x) A is supplied from point B.

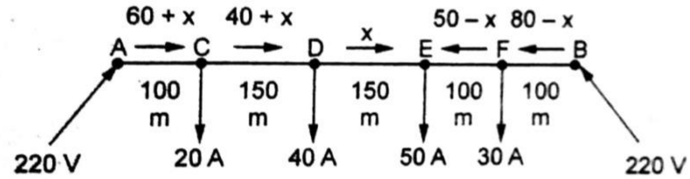


Fig. 7.11.15 (a)

$$\text{Drop(AE)} = \text{Drop(BE)}$$

$$220 - (60+x)r \times 100 - (40+x)r \times 150 - xr \times 150$$

$$= 220 - (80-x)\times r \times 100 - (50-x)\times r \times 100$$

$$\therefore -6000 - 100x - 6000 - 150x - 150x = -8000 + 100x - 5000 + 100x$$

$$\therefore \quad x = 1.667 \text{ A}$$

2.

Example 7.13.1 *A single phase distributor 'AB' 300 m long supplies a load of 200 A at 0.8 ... at 200 m from ... total resistance ... ohm. Calculate*

...y-18, Marks 15

Solution : The arrangement is shown in the Fig. 7.13.4.

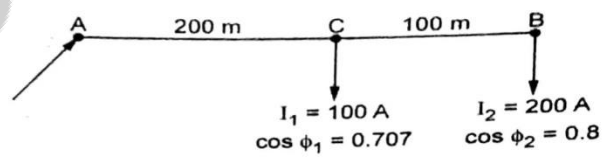


Fig. 7.13.4

$$Z/\text{km} = 0.2 + j\,0.1\ \Omega$$

$$\bar{Z}_{AC} = (Z/\text{km})\,L_{AC}$$

$$= (0.2+j0.1)\times 200\times10^{-3}$$

$$= 0.04 + j0.02\,\Omega$$

$$= 0.04472 \angle 26.565°\ \Omega$$

$$\bar{Z}_{CB} = (Z/\text{km})\,L_{CB} = (0.2+j0.1)\times100\times10^{-3}$$

$$= 0.02 + j\,0.01\ \Omega = 0.0223 \angle 26.565°\ \Omega$$

Taking voltage at the far end B as the reference vector we get,

$$\bar{I}_2 = 200\angle -\cos^{-1}0.8 = 200 \angle -36.86° = 160 - j\,120 \text{ A}$$

$$\bar{I}_1 = 100\angle -\cos^{-1}0.707 = 100 \angle -45° = 70.7 - j\,70.7 \text{ A}$$

$$\bar{I}_{CB} = \bar{I}_2,\quad \bar{I}_{AC} = \bar{I}_1 + \bar{I}_2$$

$$\bar{I}_{AC} = 230.7 - j\,190.7 \text{ A} = 299.314 \angle -39.578° \text{ A}$$

The various voltage drops are,

$$\bar{V}_{CB} = \bar{I}_{CB}\times\bar{Z}_{CB} = 200 \angle -36.86° \times 0.0223 \angle 26.565°$$

$$= 4.46 \angle -10.304° \text{ V} = 4.388 - j\,0.8 \text{ V}$$

$$\bar{V}_{AC} = \bar{I}_{AC}\times\bar{Z}_{AC} = 299.314 \angle -39.578° \times 0.04472 \angle 26.565°$$

$$= 13.3853 \angle -13.013° \text{ V} = 13.041 - j\,3.014 \text{ V}$$

Voltage drop in the distributor $= \bar{V}_{CB} + \bar{V}_{AC}$

$$= 4.388 - j\,0.8 + 13.014 - j\,3.014 = 17.429 - j\,3.814 \text{ V} = 17.841 \angle -12.343° \text{ V}$$

$\therefore$ **Magnitude of voltage drop in distributor = 17.841 V**

3. **Explain with the help of phasor diagram, the voltage control by synchronous condenser. (Nov 2018)**

Voltage Control by Synchronous Condenser

The voltage at the receiving end of a transmission line can be controlled by installing specially designed synchronous motors called *synchronous condensers at the receiving end of the line. The synchronous condenser supplies watt less leading kVA to the line depending upon the excitation of the motor. This watt less leading kVA partly or fully cancels the watt less lagging kVA of the line, thus controlling the voltage drop in the line. In this way, voltage at the receiving end of a transmission line can be kept constant as the load on the system changes.

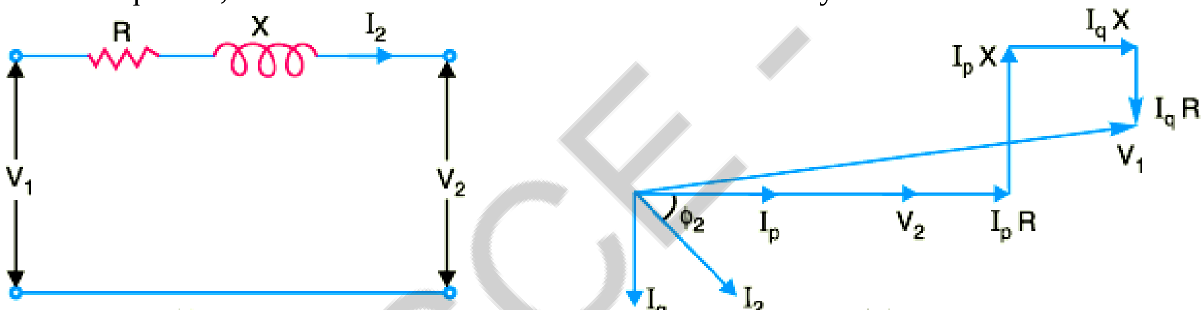
For simplicity, consider a short transmission line where the effects of capacitance are neglected. Therefore, the line has only resistance and inductance. Let V1 and V2 be the per phase sending end and receiving end voltages respectively. Let I2 be the load current at a lagging power factor of cos $\varphi 2$.

(i) Without synchronous condenser.

Fig. (i) shows the transmission line with resistance R and inductive reactance X per phase. The load current I can be resolved into two 2 rectangular components viz I in phase with V and I at right angles to V Each component will produce resistive and reactive drops ; the resistive drops being in phase with and the reactive drops in quadrature leading with the corresponding currents. The vector addition of these voltage drops to V gives the sending end voltage V

(ii) With synchronous condenser

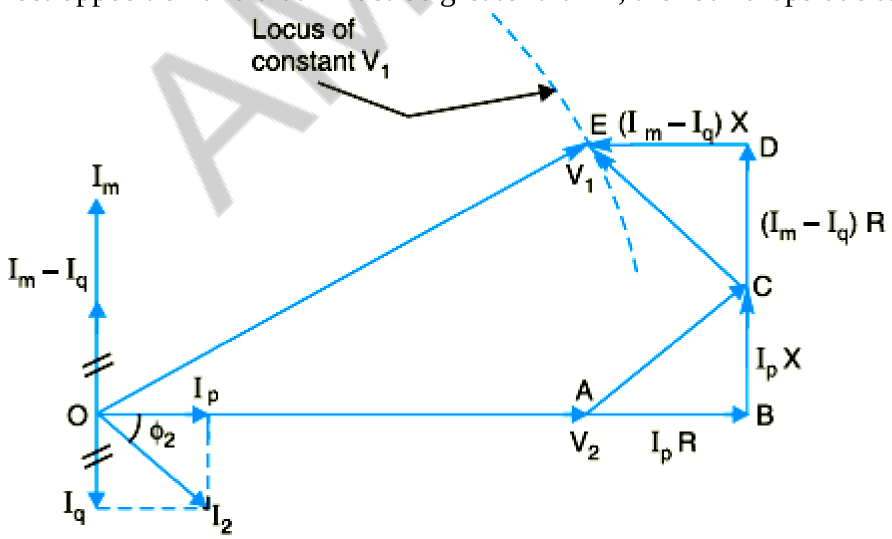
Now suppose that a synchronous condenser taking a leading current * *I is connected at the receiving end of the line. The vector diagram of the circuit becomes as shown in Fig. Note that since I and I are in direct opposition and that I must be greater than I , the four drops due to these two currents simplify to :
From this equation, the value of Im can be calculated to obtain any desired ratio of V1 / V2 for a m



(i) (ii)

ii) With synchronous condenser

Now suppose that a synchronous condenser taking a leading current * *I is connected at the receiving end of the line. The vector diagram of the circuit becomes as shown in Fig. Note that since I and I are in direct opposition and that I must be greater than I , the four drops due to these two currents simplify to



$(I_m - I_q)\, R$ in phase with I_m

and $(I_m - I_q)\, X$ in quadrature leading with I_m

From the vector diagram, the relation between V_1 and V_2 is given by ;

$$OE^2 = (OA + AB - DE)^2 + (BC + CD)^2$$

or

$$V_1^2 = [V_2 + I_p R - (I_m - I_q)\, X]^2 + [I_p X + (I_m - I_q)\, R]^2$$

From this equation, the value of Im can be calculated to obtain any desired ratio of V1 / V2 for a m

$$\text{kVAR capacity of condenser} = \frac{3\, V_2\, I_m}{1000}$$

4. Explain the following DC Distributor
   - (i) Distributor fed at both ends
   - (ii) Distridutor fed at one end (Nov 2018)

D.C. Distributor with Uniformly Distributed Load

This type of distributor is also classified as,

1. Distributor fed at one end and 2. Distributor fed at both the ends

Distributor Load Fed at One End

The Fig. 7.12.1 shows the single line diagram of uniformly distributed load on two wire distributor, fed at one end.

The distributed load is of i amperes per metre.

This indicates that at every metre length i amperes load is supplied through tapping on the distributor.

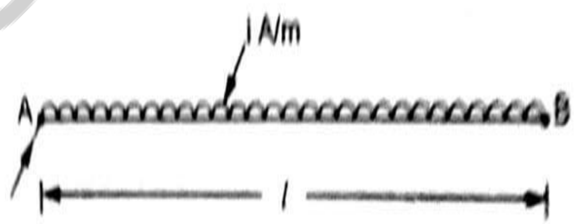


Fig. 7.12.1

Let l = Length of the distributor

r = Resistance per unit length in Ω

In such case, total voltage drop is to be obtained by considering a point C at a distance x from feeding end A. This is shown in the Fig. 7.12.2.

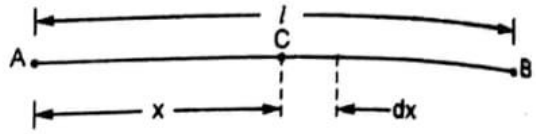


Fig. 7.12.2

The current tapped at point C is

$$= \text{Total current} - \text{Current up to point 'C'} = i \times l - i \times x = i\,(l - x)$$

Consider an elementary length dx near point C. Its resistance is r dx.

Hence the voltage drop over the length dx is,

$$dV = i\,(l - x)\, r\, dx$$

Thus total voltage drop upto point C is,

$$V_{AC} = \int_0^x i\,(l-x)\, r\, dx = ir \int_0^x (l-x)\, dx = ir \left[lx - \frac{x^2}{2} \right]_0^x$$

$$\therefore \quad \boxed{V_{AC} = ir \left(lx - \frac{x^2}{2} \right) \text{volts}}$$

This is the **equation of parabola.**

Thus the voltage drop upto point B can be obtained by putting $x = l$.

$$\therefore \quad V_{AB} = ir \left(l^2 - \frac{l^2}{2} \right) = ir\,\frac{l^2}{2} = \frac{1}{2}\,(il)\,(rl)$$

$$\therefore \quad \boxed{V_{AB} = \frac{1}{2}\, I\, R} \quad \text{... Maximum voltage drop}$$

where I = Total current fed at point A

R = Total resistance of the distributor

From this one important observation can be noted as :

Key Point *In a uniformly distributed load on the distributor fed at one end, the total voltage drop is equal to that produced by the whole of the load assumed to be concentrated at the middle point.*

This fact can be used to simplify the complicated load calculations.

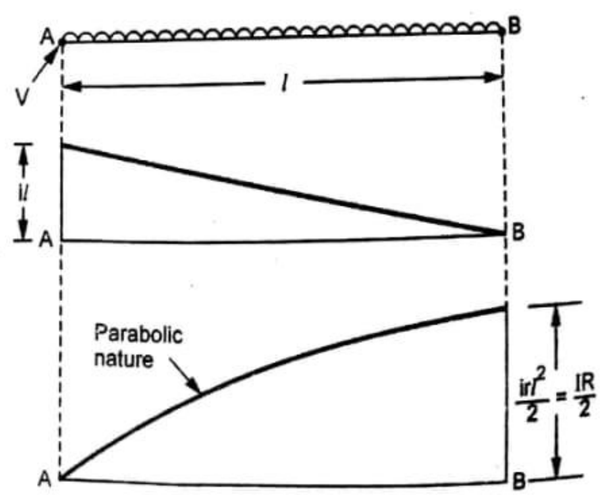


Fig. 7.12.3 Current loading and voltage drop diagram

Consider an elementary length dx near C whose resistance is rdx.

So voltage drop over length dx is,

$$dv = i\left(\frac{l}{2}-x\right) r\, dx$$

Hence voltage drop upto point C is,

$$V_{AC} = \int_0^x i\left(\frac{l}{2}-x\right) r\, dx = ir\left[\frac{lx}{2}-\frac{x^2}{2}\right] = \frac{i\,r}{2}\,[lx - x^2]$$

Now maximum voltage drop is at midpoint i.e. $x = \frac{l}{2}$ as the midpoint is the point of minimum potential.

$$\therefore \quad \text{Maximum drop} = ir\left[\frac{l}{2}\left(\frac{l}{2}\right)-\frac{(l/2)^2}{2}\right] = ir\left[\frac{l^2}{4}-\frac{l^2}{8}\right] = \frac{i\,r\,l^2}{8} = \frac{1}{8}\,(il)\,(rl)$$

$$\therefore \quad \boxed{\text{Maximum drop} = \frac{IR}{8}}$$

where I is total current and R is the total resistance.

It is $1/4^{th}$ of the drop in case of distributed load distributor fed at one end. The point of minimum potential is the farthest end from feeding end in case of distributor fed at one end while in this case, it is midpoint of the length of the distributor.

The Fig. 7.12.6 shows current loading and voltage drop diagrams.

The power loss in this case also can be obtained from the power loss over elementary length dx.

The current at any point C at distance x is $i\left(\frac{l}{2}-x\right)$

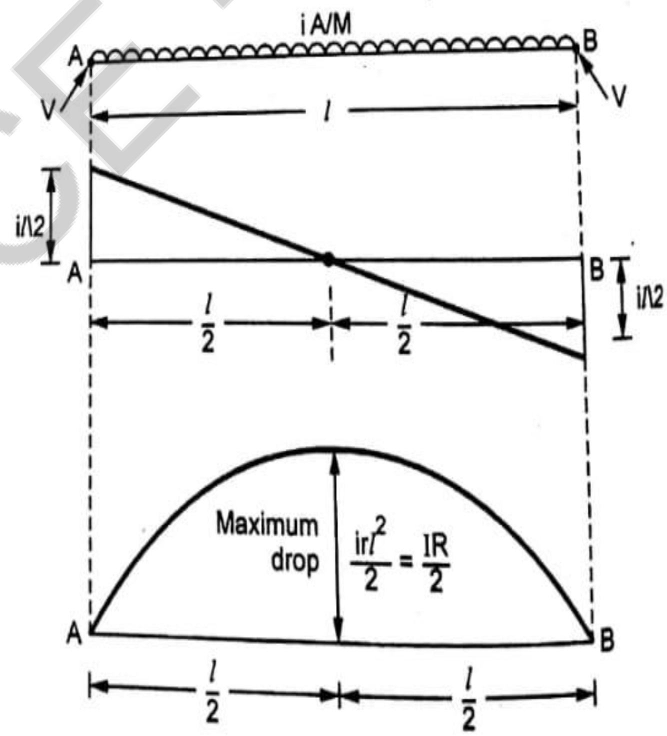


Fig. 7.12.6 Current loading and voltage drop diagram

$$dP = \left[i\left(\frac{l}{2}-x\right)\right]^2 r\,dx$$

$$P = \int_0^l \left[i\left(\frac{l}{2}-x\right)\right]^2 r\,dx = i^2 r \int_0^l \left[\frac{l^2}{4} - lx + x^2\right] dx$$

$$= i^2 r\left[\frac{l^2}{4}x - l\frac{x^2}{2} + \frac{x^3}{3}\right]_0^l = i^2 r\left[\frac{l^3}{4} - \frac{l^3}{2} + \frac{l^3}{3}\right]$$

$$\therefore \quad \boxed{P = \frac{i^2 r l^3}{12} \text{ watts}}$$

This is power loss over the entire length l of the distributor. Hence power loss in half length is half of the total power loss which is $\frac{i^2 r l^3}{24}$ watts.

2.2.2 Ends at Unequal Voltages

The Fig. 7.12.7 shows the uniformly distributed load on the distributor of length l. The load is i amperes/m while the distributor is fed at both the ends which are maintained at different voltages.

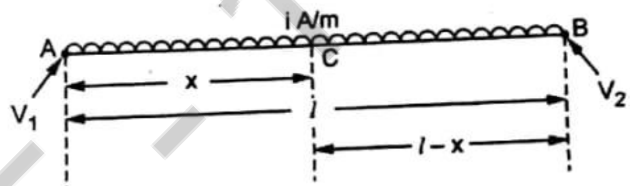


Fig. 7.12.7

To find the location of point of minimum potential :

Let point C be the point of minimum potential which is at a distance x from feeding point A.

The current supplied by the feeding point A is ix. While the current supplied by the feeding point B is i $(l - x)$.

Now, V_1 – Drop in section AC = V_2 – Drop in section BC.

Let r be the resistance per metre length.

In case of distributed load the drop is given by $\frac{i r l^2}{2}$ for a length of 'l'. Considering section AC as separate section fed at one end the drop in section AC can be written as,

$$V_{AC} = \frac{i r x^2}{2} \text{ volts}$$

Similarly, $$V_{BC} = \frac{i r (l-x)^2}{2} \text{ volts}$$

$$\therefore \quad V_1 - \frac{i r x^2}{2} = V_2 - \frac{i r (l-x)^2}{2}$$

Knowing V_1, V_2, i, r and l, the above equation can be solved for x which gives the point of minimum potential.

5. Find the voltage drop on a DC distributor having concentrated loads supplied at both ends with equal and unequal voltages. (Nov 2018)

7.11.2 Concentrated Loads Fed at Both Ends

This type is further classified depending upon the voltage levels at the two ends.

1. Ends fed with equal voltages and 2. Ends fed with unequal voltages

7.11.2.1 Ends at Equal Voltages

The Fig. 7.11.4 shows this type of distributor. The ends A and B are maintained at equal voltages.

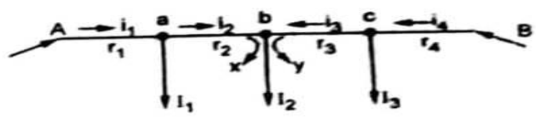


Fig. 7.11.4

Let r_1, r_2, r_3 and r_4 are the go and return resistances of the sections Aa, ab, bc and cB respectively.

Let point 'b' be the **point of minimum potential**.

As we move from point A towards B the potential goes on decreasing and at point b becomes minimum. All the currents between section Ab are supplied by point A. After b the voltage goes on increasing till it becomes feeding voltage at B. All the currents between Band b are supplied by the point B.

Now the current at minimum potential point b is supplied by both. Let x be supplied by point A while y be supplied by point B. It is obvious that $y = I_2 - x$.

As both the points A and B are maintained at same voltage, drop in section Aa must be equal to drop in section Bb.

$$i_1r_1 + i_2r_2 = i_3r_3 + i_4r_4$$

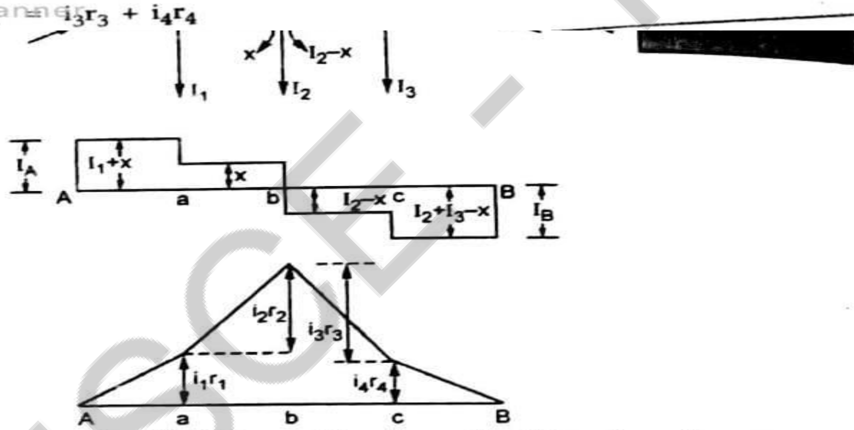


Fig. 7.11.5 Current loading and voltage drop diagrams

$$\therefore \quad (I_1 + x)\, r_1 + x r_2 = (I_2 - x)\, r_3 + (I_2 + I_3 - x)\, r_4$$

Thus knowing all the currents, x can be calculated and all the voltage drops can be obtained.

The Fig. 7.11.5 shows the current loading and voltage drop diagrams.

Key Point *The load point where the currents are coming from both the [illegible] is the point of minimum potential.*

7.11.2.2 Ends at Unequal Voltages

The Fig. 7.11.6 shows this type of distributor. The ends A and B are maintained at different voltages.

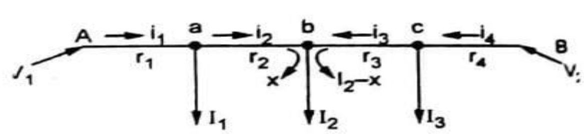


Fig. 7.11.6

Let the resistances of the sections Aa, ab, bc and cB are r_1, r_2, r_3 and r_4 respectively. Let point 'b' is the point of minimum potential.

In this case also the point b is fed by both the points A and B. The current from point A is x while from B it is $i_2 - x$. Now we can write the equation as,

Voltage drop between A and B = Voltage drop over AB

If voltage of A is V_1 and is greater than voltage of B which is V_2 then,

$$V_1 - V_2 = \text{Drops in all the sections of AB}$$

The same equation can be written as,

$$V_1 - \text{Drops over Ab} = V_2 - \text{Drops over Bb}$$

$$\therefore \quad V_1 - i_1 r_1 - i_2 r_2 = V_2 - i_3r_3 - i_4r_4$$

$$\therefore \quad V_1 - (I_1 + x) r_1 - x r_2 = V_2 - (x_2 - x) r_3 - (I_2 + I_3 - x) r_4$$

Solving this equation, as V_1 and V_2 are known, x can be obtained.

The Fig. 7.11.7 shows the current loading and voltage drop diagrams.

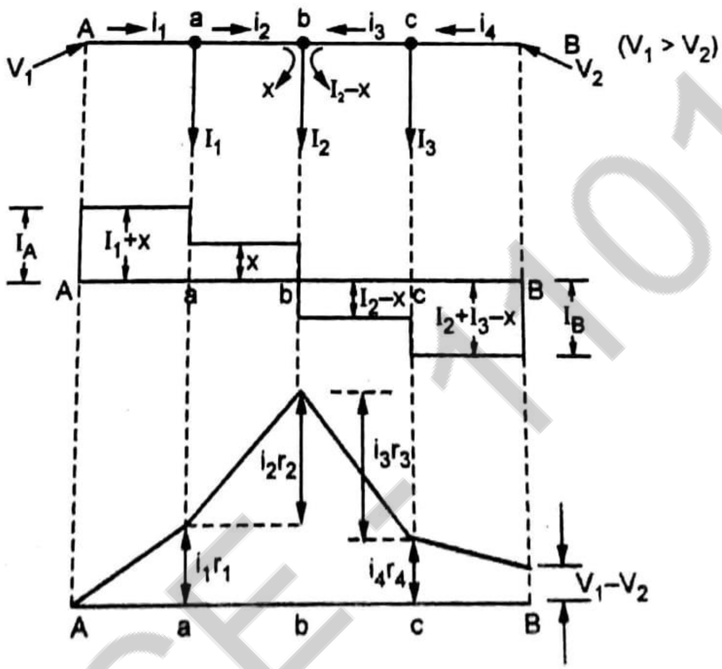


Fig. 7.11.7 Current loading and voltage drop diagrams

6. Explain the various types of grounding in detail with schematic diagram.

(Apr 2015, Apr 2018, Apr 2019)

Concept of Grounding

The process of connecting the metallic frame (i.e. non-current carrying part) of electrical equipment or some electrical part of the system (e.g. neutral point in a star- connected system, one conductor of the secondary of a transformer etc.) to earth (i.e. soil) is called grounding or earthing. It is strange but true that grounding of electrical systems is less understood aspect of power system. Nevertheless, it is a very important subject. If grounding is done systematically in the line of the power system, we can effectively prevent accidents and damage to the equipment of the power system and at the same time continuity of supply can be maintained. Grounding or earthing may be classified as

:(i) Equipment grounding (ii) System grounding. Equipment grounding deals with earthing the non-current-carrying metal parts of the electrical equipment. On the other hand, system grounding means earthing some part of the electrical system e.g. earthing of neutral point of star-connected system in generating stations and substations.

Neutral Grounding

The process of connecting neutral point of 3-phase system to earth (i.e. soil) either directly or through some circuit element is called neutral grounding. Neutral grounding provides protection to personal and equipment. It is because during earth fault, the current path is completed through the earthed neutral and the protective devices (e.g. a fuse etc.) operate to isolate the faulty conductor from the rest of the system. Fig shows a 3-phase, star-connected system with neutral earthed. Suppose a single line to ground fault occurs in line R at point F. This will cause the current to flow through ground path as shown in Fig.1. Note that current flows from R phase to earth, then to neutral point N and back to R-phase. Since the impedance of the current path is low, a large current flows through this path. This large current will blow the fuse in R-phase and isolate the faulty line R. This will protect the system from the harmful effects of the fault.

Advantages of Neutral Grounding

The following are the advantages of neutral grounding

(i) Voltages of the healthy phases do not exceed line to ground voltages i.e. they remain nearly constant.

(ii) The high voltages due to arcing grounds are eliminated.

(iii) The protective relays can be used to provide protection against earth faults. In case earth fault occurs on any line, the protective relay will operate to isolate the faulty line.

(iv) The over voltages due to lightning are discharged to earth.

Methods of Neutral Grounding

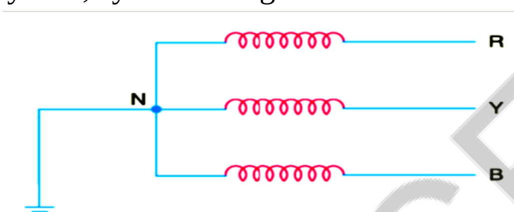
The methods commonly used for grounding the neutral point of a 3-phase system are : (i) Solid or effective grounding

(ii) Resistance grounding

(iii) Reactance grounding

(iv) Peterson-coil grounding

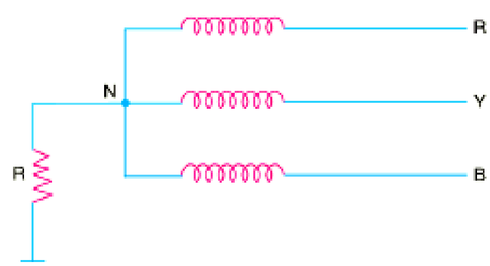
The choice of the method of grounding depends upon many factors including the size of the system, system voltage and the scheme of protection to be used.



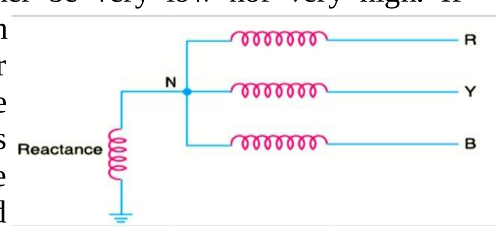
(i)Solid Grounding

When the neutral point of a 3-phase system (e.g. 3- phase generator, 3-phase transformer etc.) is directly connected to earth (i.e. soil) through a wire of negligible resistance and reactance, it is called solid grounding or effective grounding. Fig. shows the solid grounding of the neutral point. Since the neutral point is directly connected to earth through a wire, the neutral point is held at earth potential under all conditions. Therefore, under fault conditions, the voltage of any conductor to earth will not exceed the normal phase voltage of the system.

Resistance Grounding



In order to limit the magnitude of earth fault current, it is a common practice to connect the neutral point of a 3-phase system to earth through a resistor. This is called resistance grounding. When the neutral point of a 3-phase system (e.g. 3-phase generator, 3- phase transformer etc.) is connected to earth (i.e. soil) through a resistor, it is called resistance grounding. Fig shows the grounding of neutral point through a resistor R. The value of R should neither be very low nor very high. If the value of earthing resistance R is very low, the earth fault current will be large and the system becomes similar to the solid grounding system. On the other hand, if the earthing resistance R is very high, the system conditions become similar to ungrounded neutral system. The value of R is so chosen such that the earth fault current is limited to safe value but still sufficient to permit the operation of earth fault protection system.



Reactance Grounding

In this system, a reactance is nserted between the neutral and ground as shown in Fig. The purpose of reactance is to limit the earth faultcurrent. By changing the earthing reactance, the earth fault current can be changed to obtain the conditions similar to that of solid grounding. This method is not used these days because of the following

Disadvantages

(i) In this system, the fault current required to operate the protective device is higher than that of resistance grounding for the same fault conditions.

(ii) High transient voltages appear under fault conditions.

Arc Suspension Grounding (Or Resonant Grounding)

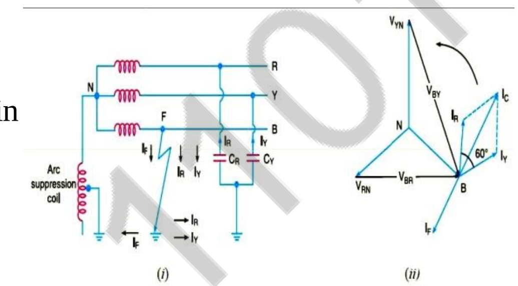
We have seen that capacitive currents are responsible for producing arcing grounds. These capacitive currents flow because capacitance exists between each line and earth. If inductance L of appropriate value is connected in parallel with the capacitance of the system, the fault current IF flowing through L will be in phase opposition to the capacitive current IC of the system. If L is so adjusted that IL= Ic then resultant current in the fault will be zero. This condition is known as resonant grounding. When the value of L of arc suppression coil is such that the fault current IF exactly balances the capacitive current Ic, it is called resonant grounding

Advantages

The Peterson coil grounding has the following advantages:

(i) The Peterson coil is completely effective in preventing any damage by an arcing ground.

(ii) The Peterson coil has the advantages of ungrounded neutral system.



Disadvantages

The Peterson coil grounding has the following disadvantages:

(i) Due to varying operational conditions, the capacitance of the network changes from time to time. Therefore, inductance L of Peterson coil requires readjustment.

(ii) The lines should be transposed.

7. What is Transformer substation? Discuss the role of major components in transformer substation? (Apr 2019)

There are several ways of classifying sub-stations. However, the two most important ways of classifying them are according to (1) service requirement and (2) constructional features.

1. According to service requirement

A sub-station may be called upon to change voltage level or improve power factor or convert a.c. power into d.c. power etc. According to the service requirement, sub- stations may be classified into :

i) Transformer sub-stations.

Those sub-stations which change the voltage level of electric supply are called transformer sub-stations. These sub-stations receive power at some voltage and deliver it at some other voltage. Obviously, transformer will be the main component in such sub- stations. Most of the sub-stations in the power system are of this type.

(ii) Switching sub-stations

These sub-stations do not change the voltage level i.e. incoming and outgoing lines have the same voltage. However, they simply perform the switching operations of power lines.

(iii) Power factor correction sub-stations.

Those sub-stations which improve the power factor of the system are called power factor correction sub-stations. Such sub-stations are generally located at the receiving end of transmission lines. These sub-stations generally use synchronous condensers as the power factor improvement equipment.

(iv) Frequency changer sub-stations

Those sub-stations which change the supply frequency are known as frequency changer sub-stations. Such a frequency change may be required for industrial utilization.

(v) Converting sub-stations

Those sub-stations which change a.c. power into d.c. power are called converting sub-stations. These sub-stations receive a.c. power and convert it into d.c power with suitable apparatus to supply for such purposes as traction, electroplating, electric welding etc.

(vi) Industrial sub-stations

Those sub-stations which supply power to individual industrial concerns are known as industrial sub-stations.

2. According to constructional features

A sub-station has many components (e.g. circuit breakers, switches, fuses, instruments etc.) which must be housed properly to ensure continuous and reliable service. According to constructional features, the sub-stations are classified as:

(i) Indoor sub-station

(ii) Outdoor sub-station

(iii) Underground sub-station (iv) Pole-mounted sub-station

(i) Indoor sub-stations

For voltages upto 11 kV, the equipment of the sub-station is installed indoor because of economic considerations. However, when the atmosphere is contaminated with impurities, these sub-stations can be erected for voltages upto 66 kV.

(ii) Outdoor sub-stations

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

(iii) Underground sub-stations

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

(iv) Pole-mounted sub-stations

This is an outdoor sub-station with equipment installed over- head on H-pole or 4-pole structure. It is the cheapest form of sub-station for voltages not exceeding 11kV (or 33 kV in some cases). Electric power is almost distributed in localities through such sub- stations. For complete discussion on pole-mounted sub-station.