INSULATORS AND CABLES

What is an electric insulator

- An **electrical insulator** is a material whose internal electric charges do not flow freely, and therefore make it nearly impossible to conduct an electric current under the influence of an electric field. This contrasts with other materials, semiconductors and conductors, which conduct electric current more easily. The property that distinguishes an insulator is its resistivity; insulators have higher resistivity than semiconductors or conductors

- A perfect insulator does not exist, but some materials such as glass, paper and Teflon, which have high resistivity, are very good electrical insulators.
- Insulators are used in electrical equipment to support and separate electrical conductors without allowing current through themselves
- Insulators for overhead line provide insulation to power

Characteristics of solid insulator

- It must be mechanically strong enough to carry tension and weight of conductors.
- It must have very high dielectric strength to withstand the voltage stresses in High Voltage system.
- It must possesses high Insulation Resistance to prevent leakage current to the earth.
- The **insulating material** must be free from unwanted

Cont…

- It should not be porous.
- There must not be any entrance on the surface of electrical insulator so that the moisture or gases can enter in it.
- There physical as well as electrical properties must be less effected by changing temperature
- Withstand flashover phenomenon

Some terms

- **dielectric strength** has the following meanings: Of an insulating **material**, the maximum electric field that a pure **material**can withstand under ideal conditions without breaking down (i.e., without experiencing failure of its insulating properties).

  Compressive strength is the maximum compressive stress that, under a gradually applied load, a given solid material can sustain without fracture. Compressive strength is calculated by dividing the maximum load by the original cross-sectional area of a specimen in a compression test.

Insulators materials

Porcelain Insulator

Porcelain in most commonly used material for over head insulator in present days. The porcelain is aluminium silicate. The aluminium silicate is mixed with plastic kaolin, feldspar and quartz to obtain final hard and glazed **porcelain insulator** material. The surface of the insulator should be glazed enough so that water should not be traced on it. Porcelain also should

Cont..

- **Properties of Porcelain Insulator**

Property	Value(Approximate)
Dielectric Strength	60 KV / cm
Compressive Strength	70,000 Kg / cm^2

Glass Insulator

- Now days **glass insulator** has become popular in transmission and distribution system. Annealed tough glass is used for insulating purpose. Glass insulator has numbers of advantages over conventional porcelain insulator.

Advantages of Glass Insulator

- 1. It has very high dielectric strength compared to porcelain.
- 2. Its resistivity is also very high.
- 3. It has low coefficient of thermal expansion.
- 4. It has higher tensile strength compared to porcelain insulator.
- 5. As it is transparent in nature the is not heated up in sunlight as porcelain.
- 6. The impurities and air bubble can be easily detected inside

Disadvantages of Glass Insulator

- 1. Moisture can easily condensed on glass surface and hence air dust will be deposited on the wed glass surface which will provide path to the leakage current of the system.
- 2. For higher voltage glass can not be cast in irregular shapes since due to irregular cooling internal cooling internal strains are caused.

Properties of Glass Insulator

- **Property** **Value(Approximate)**

Property	Value(Approximate)
Dielectric Strength	140 KV / cm

Polymer Insulator

- In a **polymer insulator** has two parts, one is glass fiber reinforced epoxy resin rod shaped core and other is silicone rubber or EPDM (Ethylene Propylene Diene Monomer) made weather sheds. Rod shaped core is covered by weather sheds. Weather sheds protect the insulator core from outside environment. As it is made of two parts, core and weather sheds

Advantages of Polymer Insulator

1. It is very light weight compared to porcelain and glass insulator.
2. As the **composite insulator** is flexible the chance of breakage becomes minimum.
3. Because of lighter in weight and smaller in size, this insulator has lower installation cost.
4. It has higher tensile strength compared to porcelain insulator.
5. Its performance is better particularly in polluted areas.
6. Due to lighter weight polymer insulator imposes less load

Disadvantages of Polymer Insulator

- 1. Moisture may enter in the core if there is any unwanted gap between core and weather sheds. This may cause electrical failure of the insulator.
- 2. Over crimping in end fittings may result to cracks in the core which leads to mechanical failure of polymer insulator.

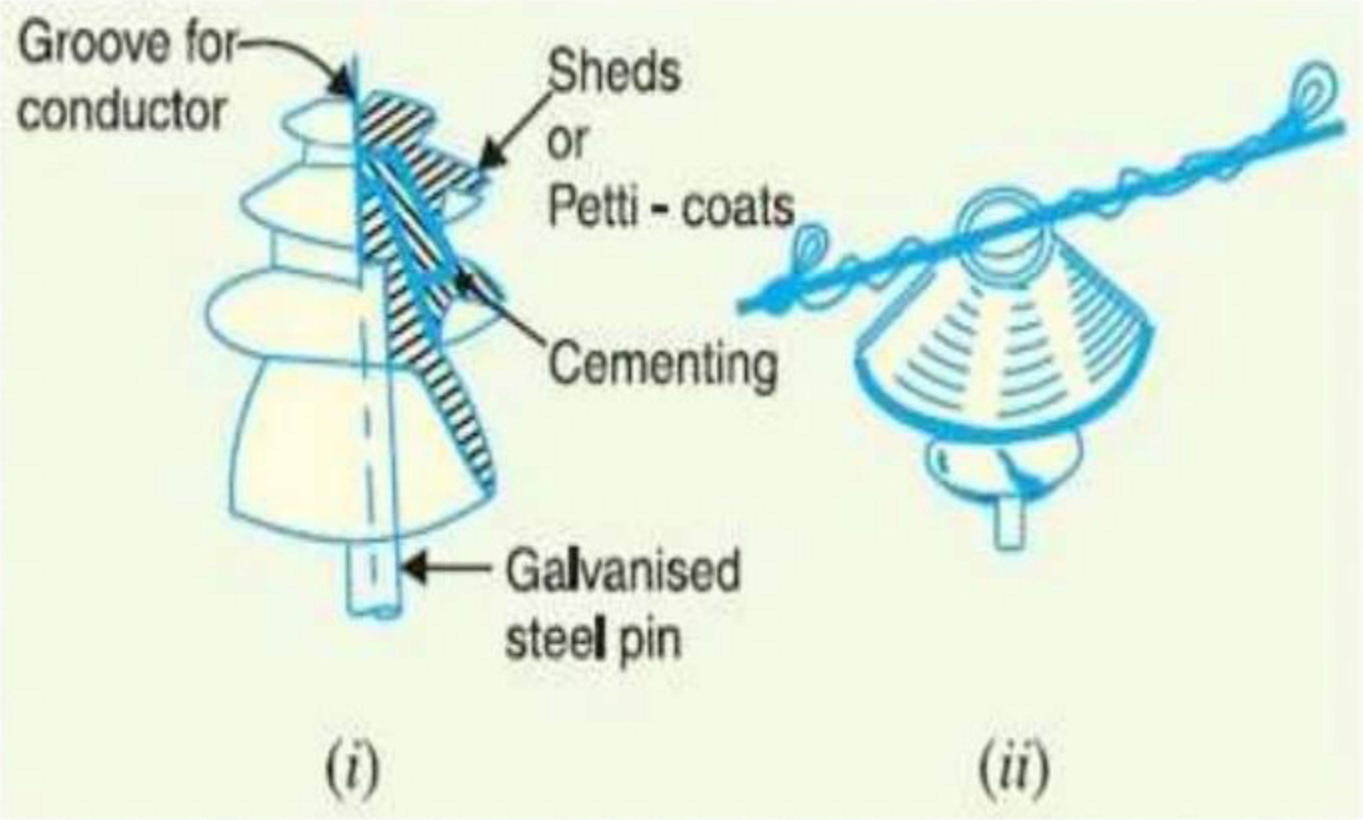
TYPES OF INSULATORS

There are several types of insulators but the most commonly used are :

1) Pin Insulator
2) Suspension Insulator
3) Strain Insulator and
4) Shackle insulator.

PIN INSULATOR

- A **pin insulator** consists of a nonconducting material such as porcelain, glass, plastic, polymer, or wood.
- 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 upto 33 kV.

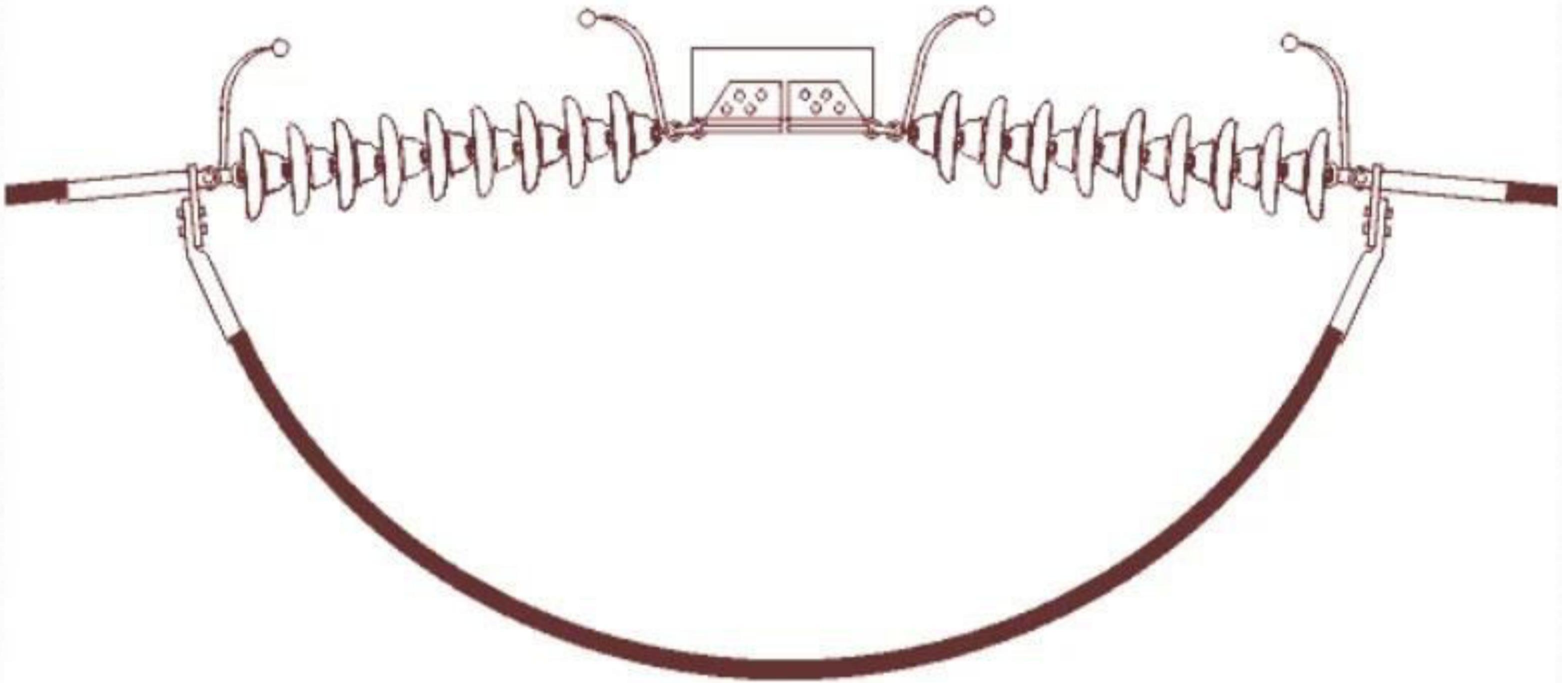

Groove for
conductor
Sheds
or
Petti - coats
Cementing
Galvanised
steel pin
(i)
(ii)

SUSPENSION INSULATOR

- For high voltages (>33 kV), it is a usual practice to use suspension type insulators 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

STRAIN INSULATOR

- 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

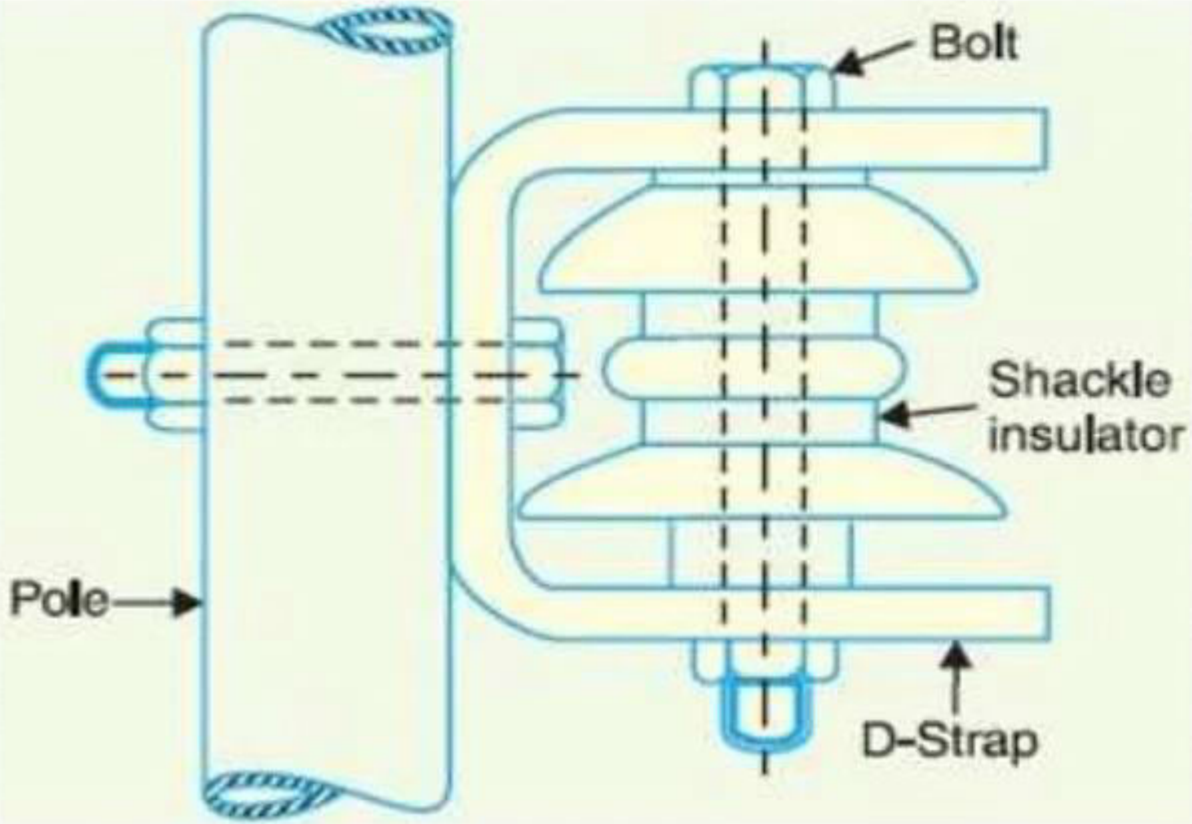


Efficiency of string

- efficiency = $\frac{\text{Voltage across the string}}{(n \times \text{Voltage across disc nearest to conductor})}$
- Where n = number of discs in the strin

Shackle insulators

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


Bolt
Shackle insulator
Pole
D-Strap

Causes of Insulator Failure

- There are different causes due to which **failure of insulation** in electrical power system may occur

1- <u>Cracking of Insulator</u>

- The porcelain insulator mainly consists of three different materials. The main porcelain body, steel fitting arrangement and cement to fix the steel part with porcelain. Due to changing climate conditions, these different materials in the insulator expand and contract in different rate. These unequal expansion and contraction of porcelain, steel and cement are the chief cause of cracking of insulator.

2- <u>Porosity in The Insulation Materials</u>

- If the porcelain insulator is manufactured at low temperatures, it will make it porous, and due to this reason it will absorb moisture from air thus its insulation will decrease and leakage current will start to flow through the insulator which will lead to **insulator failure**.

3-Improper Glazing on Insulator Surface

- If the surface of porcelain insulator is not properly glazed, moisture can stick over it. This moisture along with deposited dust on the insulator surface, produces a

4- Flash Over Across Insulator

- If flash over occurs, the insulator may be over heated which may ultimately results into shuttering of it.

5- Mechanical Stresses on Insulator

- If an insulator has any weak portion due to manufacturing defect, it may break from that weak portion when mechanical stress is applied on it by its conductor. These are the main causes of insulator failure. Now we will discuss the different **insulator test** procedures to ensure

Insulator Testing

the electrical insulator must undergo the following tests

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

Flashover Test

There are mainly 4 types of flashover test performed on an insulator

Power Frequency Dry Flashover Test of Insulator

- 1. First the insulator to be tested is mounted in the manner in which would be used practically.
- 2. Then terminals of variable power frequency voltage source are connected to the both electrodes of the insulator.
- 3. Now the power frequency voltage is applied and gradually increased up to the specified value. This specified value is below th

Cont..

Power Frequency Wet Flashover Test or Rain Test of Insulator

- 1. In this test also the insulator to be tested is mounted in the manner in which it would be used practically.
- 2. Then terminals of variable power frequency voltage source are connected to the both electrodes of the insulator.
- 3. After that the insulator is sprayed with water at an angle of 45^{o} 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 cm^3 at normal atmospheric pressure and temperature. In this way we create artificial raining condition.
- 4. Now the power frequency voltage is applied and gradually increased up to the specified value.

Cont…

Power Frequency Flashover Voltage test of Insulator

- 1. The insulator is kept in similar manner of previous test.
- 2. In this test the applied voltage is gradually increased in similar t
that of previous tests.
- 3. But in that case the voltage when the surroundings air breaks do
is noted.

Cont..

<u>Impulse Frequency Flashover Voltage Test of Insulator</u>

- The overhead outdoor insulator must be capable of sustaining high voltage surges caused by lightning etc. So this must be tested agains the high voltage surges.
- 1. The insulator is kept in similar manner of previous test.
- 2. Then several hundred thousands Hz very high impulse voltage generator is connected to the insulator.
- 3. Such a voltage is applied to the insulator and the spark over volt is noted.

The ratio of this noted voltage to the voltage reading collected from

Performance Test of Insulator

- Now we will discuss performance test of insulator one by one-
Temperature Cycle Test of Insulator
- 1. The insulator is first heated in water at 70°C for one hour.
- 2. Then this insulator immediately cooled in water at 7°C for anoth
one hour.
- 3. This cycle is repeated for three times.
- 4. After completion of these three temperature cycles, the insulator
dried and the glazing of insulator is thoroughly observed.
After this test there should not be any damaged or deterioration in t
glaze of the insulator surface.

Cont

Porosity Test of Insulator

- 1. The insulator is first broken into pieces.
- 2. Then These broken pieces of insulator are immersed in a 0.5 % alcohol solution of fuchsine dye under pressure of about 140.7 kg/ for 24 hours.
- 3. After that the sample are removed and examine.

  The presence of a slight porosity in the material is indicated by a de penetration of the dye into it.

Mechanical Strength Test of Insulator

Routine Test of Insulator

- Each of the insulator must undergo the following routine test before they are recommended for using at site.

Proof Load Test of Insulator

- In proof load test of insulator, a load of 20% in excess of specified maximum working load is applied for about one minute to each of t insulator.

Corrosion Test of Insulator

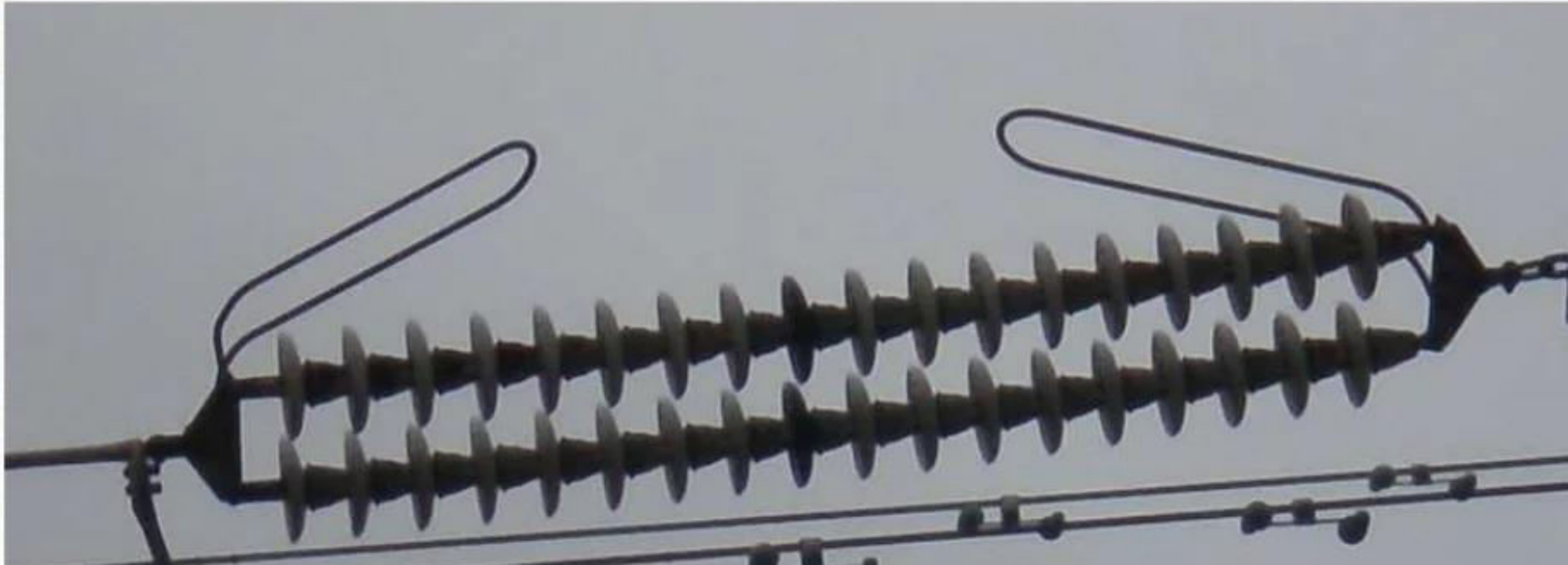
- In corrosion test of insulator,

1. The insulator with its galvanized or steel fittings is suspended int

Arcing horns

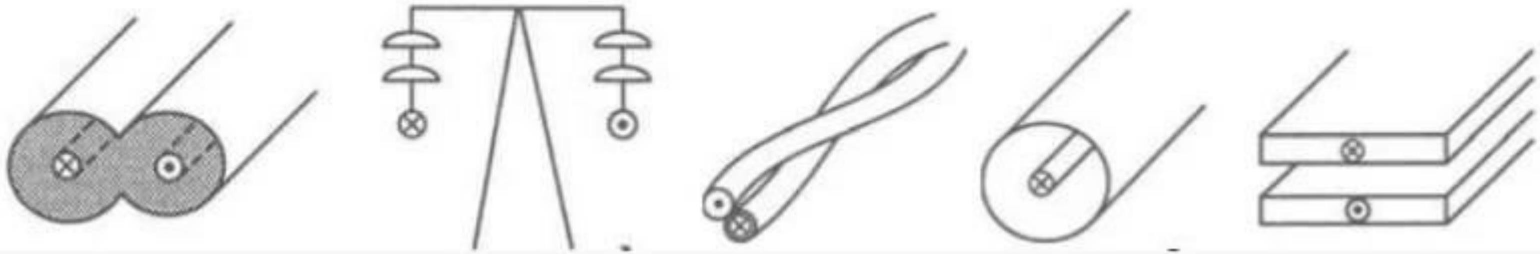
- "**Arcing horns**" are projecting conductors used to protect insulators on high voltage electric power transmission systems from damage during flashover. Overvoltages on transmission lines, due to atmospheric electricity, lightning strikes, or electrical faults, can cause arcs across insulators that can damage them

Arcing horns



The transmission line

- Physical connection between two locations through two conductors.
- The type of propagation used is TEM.



Transmission line parameters

1. Dimensional parameters: length, thickness, spacing and thickness of insulator.
2. Material parameters: conductivity, permittivities and permeabilities.
3. Electrical parameters: R,L,C & G.

R- series resistance of the line in ohms per unit length(Ω/m).

L- series inductance of the line in henrys per unit length(H/m).

C- Shunt capacitance of the line in farads per unit length(F/m).

Calculation of Line parameters

a) Resistance per unit length

- ✓ For dc current flow the surface current density is uniform
- ✓ For ac current flow the surface current density depends o
  skin depth.
- ✓ Series resistance is the small volume on the surface whe
  surface current exists. And conductor is assumed to hav
  infinite thickness.

a) Resistance per unit length(R) cont...

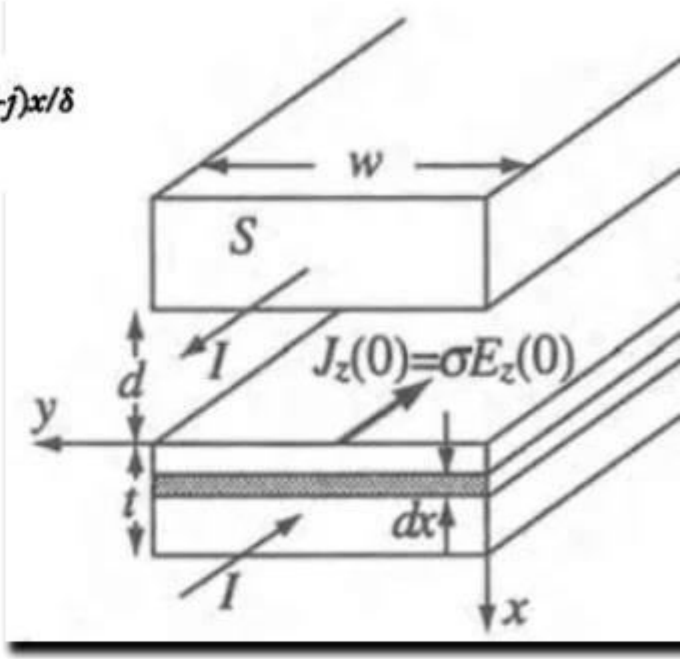
$$E_z(x) = E_z(0)e^{-\alpha x}e^{-j\beta x} = E_z(0)e^{-x/\delta}e^{-jx/\delta} = E_z(0)e^{-(1+j)x/\delta}$$

$$\alpha = \beta = \sqrt{\pi f \mu_c \sigma_c}, \qquad \delta = \frac{1}{\alpha} = \frac{1}{\sqrt{\pi f \mu_c \sigma_c}}$$

The current density in the conductor is

$$\mathcal{J}_z(x) = \sigma_c E_z(x) = \sigma_c E_z(0)e^{-(1+j)x/\delta}$$

an element of current $dI = \mathcal{J}(x) w\, dx$



$$\int^{x=\infty} \quad \int^{x=\infty} \quad w\sigma_c\delta E_z(0)$$

a) Resistance per unit length(R) cont

$$Z_s = \frac{E_z(0)}{I} = \frac{E_z(0)(1+j)}{w\delta\sigma_c E_z(0)} = \frac{(1+j)}{w\delta\sigma_c} = \frac{1}{w}\left(\frac{1}{\delta\sigma_c} + \frac{j}{\delta\sigma_c}\right)$$

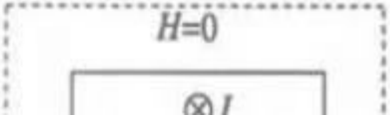
- The real part represents the series surface resistance which independent of dimension it is a property of conductor.
- Imaginary part represents the series inductance of low conductor which is negligible for high frequencies and in go conductors.
- The series resistance of the conductor per unit length obtained by doubling the resistance of a single conductor.

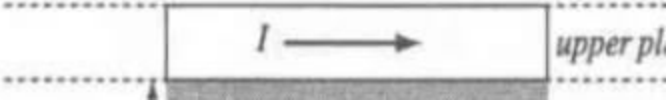
b) Inductance per unit length(L)

- Inductance of a conductor is ratio of flux linkage to the current flow.
- Current can be calculated by using Ampere's law and flux linkage from flux density.

$$I = Hw$$

$$\phi = Bs = Bd = \mu Hd$$





c) Capacitance per unit length(C)

- Capacitance ***C=Q/V***
- Two conductors form an capacitor with surface charge density each of ***Q/W***.

$$E = \frac{Q}{w\varepsilon}$$

$$V = \int_{0}^{d} E dl = Qd / w\varepsilon$$

d) Conductance per unit length(G)

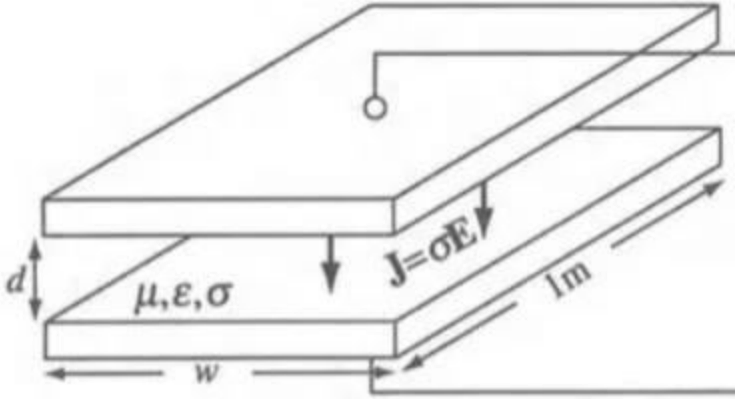
- Inverse of parallel resistance of the line.

$$E = \frac{V}{d}$$

$$J = \sigma E$$

$$I = JS = \sigma ES = \frac{\sigma V w}{d}$$

$$V = IR$$

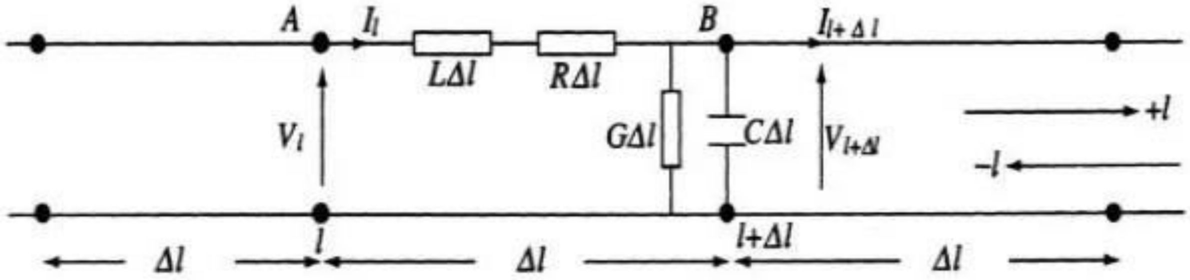


d

Line parameters

Two-wire line (**Fig. (14.5a)**).	Coaxial line (**Fig. (14.5d)**).	Parallel plate line (**Fig. (14.**
a = radius of conductor, d = distance between centers of conductors.	a = radius of inner conductor, b = inner radius of outer conductor.	w = width of plates, d = distance between plate
$R = \frac{1}{\pi a \delta \sigma_c}$	$R = \frac{1}{2\pi\delta\sigma_c}\left[\frac{1}{a} + \frac{1}{b}\right]$	$R = \frac{2}{w\delta\sigma_c}$ [Ω/m]
$L = \frac{\mu}{\pi}\cosh^{-1}\frac{d}{2a}$	$L = \frac{\mu}{2\pi}\ln\frac{b}{a}$	$L = \frac{\mu d}{w}$ [F/m]
$G = \frac{\pi\sigma}{\cosh^{-1}(d/2a)}$	$G = \frac{2\pi\sigma}{\ln(b/a)}$	$G = \frac{\sigma w}{d}$ [S/m]

Transmission line equations



$$Z = R\Delta l + jwL\Delta$$
$$Y = G\Delta l + jwC\Delta$$

- Line equations are derived by assuming large number of short segments.
- The total series impedance of the line segment is Z
- The total parallel line admittance of the line segment is Y
- By applying Kirchhoff's voltage and current law

$$V(l) = I(l)[R\Delta l + jwL\Delta l] + V(l+\Delta l) \quad \Rightarrow \quad \frac{dV(l)}{}$$

Transmission line equations cont...

- By using the taylor expansion for *V(l+Δl)* abou
l. *V(l+Δl)=V(l)*.

$$\frac{dI(l)}{dl} = -V(l)[R + jwL\Delta l]$$

- By combining the two differential equations

$$\frac{d^2V}{dl^2} - \gamma^2 V = 0$$

$$\frac{d^2I}{dl^2} - \gamma^2 I = 0$$

$$\gamma = \alpha + j\beta = \sqrt{(R + jwL)(G + jwC}$$

Transmission line equations cont...

- The characteristic quantities of the line are propagatic constant and line impedance.
- The characteristic line impedance of the transmission line ratio of forward propagating voltage and forwa propagating current. $Z_0 = \frac{V^+}{I^+}$
- Assuming only the forward propagating wave exis substitute the solution of voltage and current in first ord differential equation then line characteristic impedance is

$$Z_0 = \frac{R + jwL}{\gamma} = \frac{\gamma}{G + jwC}$$

Transmission line equations cont...

- The characteristic impedance of a line is independent location on the line and depends only on lin parameters.
- Characteristic impedance is a complex valued quantit Whereas the lumped parameters of the line are in pe unit length units.
- Wavelength and Phase velocity for any propagatin wave is

$$\lambda = \frac{2\pi}{\beta}[m]$$

Time-domain transmission line equation

$$V(l+\Delta l,t)-V(l,t)=-I(l,t)R\Delta l-L\Delta l\frac{dI(l,t)}{dt}$$

$$I(l+\Delta l,t)-I(l,t)=-V(l,t)G\Delta l-C\Delta l\frac{dV(l,t)}{dt}$$

$$\frac{dV(l,t)}{dl}=-I(l,t)R-L\frac{dI(l,t)}{dt}$$

$$\frac{dI(l,t)}{dl}=-V(l,t)G-C\frac{dV(l,t)}{dt}$$

Types of transmission lines

1. Lossless transmission line ($\alpha=0$).
2. Infinite long transmission line (No reflection from load).
3. Distortion-less transmission line (α,Z independent of frequency)
4. Low resistive transmission line ($R=0$).

1. Lossless transmission line

- R=0 and G=0 we leads to α=0.
- Line is made of pure conductor.
- Practically not existing only approximated line exist.
- The field components propagate along line with speed dictated by L and C.

$$\gamma = j\beta = jw\sqrt{LC}[rad/m]$$

$$Z_0 = \sqrt{\frac{L}{C}}[\Omega]$$

2. Infinite long transmission line

- Only forward propagation wave exists.
- Line can be a loss line or lossless line.

$$V(l) = V^{+}e^{-\gamma l}$$

$$I(l) = I^{+}e^{-\gamma l}$$

3. Distortion less transmission line

- This is line whose impact on propagation wave is independent of frequncy.
- General lossy line with attenuation constant, phase velocity and characteristic impedance independent of frequency.
- For a distortion less the line parameters must be designed so that R/L=G/C.

$$\gamma = R\sqrt{\frac{C}{L}} + jw\sqrt{LC}$$

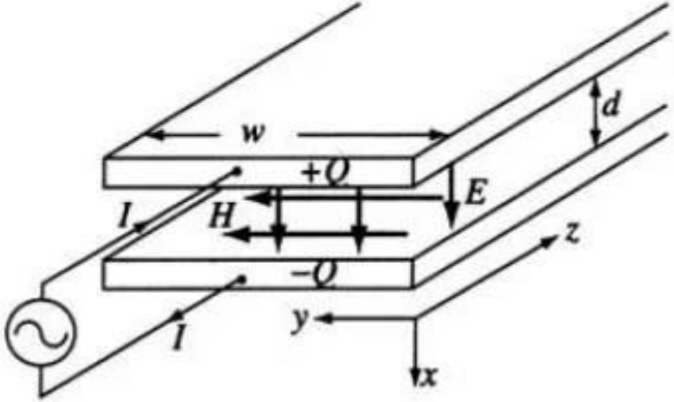
$$\alpha = R\sqrt{\frac{C}{L}} = \sqrt{RG}$$

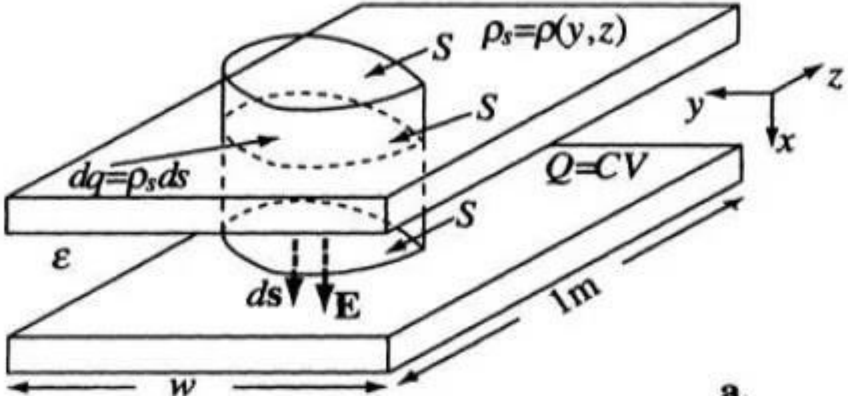
4. Low resistance transmission line

- R=0.
- These lines are made of pure conductors.
- The conducting nature of the line guides the wave but all the propagation parameters are effected by dielectric alone.
- These equations can holds for any line therefore by knowing one parameters remaining can be measured.

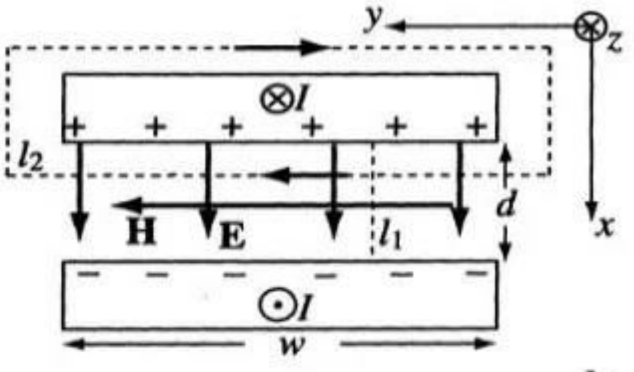
$$\gamma = jw\sqrt{LC}\sqrt{1+\frac{G}{jwC}}$$

The field approach to transmission lines





a.



b.

Finite Transmission Lines

- A finite line connected between the generator and load as shown in figure.
- For the analysis of line a reference point is needed on the line.
- The analysis till now are in terms of *l*, which is valid if generator is reference point and all analysis can be modified to *z* by considering load as a reference point.

$$V(l) = V^{+}e^{-\gamma l} + V^{-}e^{+\gamma l} \qquad V(z) = V^{+}e^{\gamma z} + V^{-}e^{-\gamma z}$$

$$I(l) = I^{+}e^{-\gamma l} + I^{-}e^{+\gamma l} \qquad I(z) = I^{+}e^{\gamma z} + I^{-}e^{-\gamma z}$$

1. The Load Reflection Coefficient

- Load Reflection coefficient is ratio of reflected voltage (bac propagated) to the incident voltage (forward propagated).
- Reflection coefficient can be calculated using characterist impedance and load impedance. Non-zero reflection coefficier represents mismatch of load impedance with line impedance.

$$Z_0 = \frac{V^+}{I^+} = -\frac{V^-}{I^-}$$

$$Z_L = \frac{V_L}{I_L} = \frac{V(0)}{I(0)}$$

$$V^+ + V^-$$

Load Reflection coefficient is

2. Line Impedance and generalized Reflection Coefficient

- Line impedance of line is important to connect a line to other in between generator and load.
- When a stub is connected to a line then the line impedance at that point acts as input impedance for the stub.
- Line impedance is ratio of line voltage to line current by taking load as reference point.

2. Line Impedance and generalized Reflection Coefficient cont…

- **Input line impedance**: the impedance at the input or generator side.
- **Line impedance**: impedance at any point on the line

$$Z(z) = Z_0 \frac{Z_L \cosh \gamma z + Z_0 \sinh \gamma z}{Z_0 \cosh \gamma z + Z_L \sinh \gamma z} [\Omega]$$

$$Z(z) = Z_0 \frac{Z_L + Z_0 \tanh \gamma z}{Z_0 + Z_L \tanh \gamma z} [\Omega]$$

- The generalized reflection coefficient is the reflection coefficient at any location on the line

3. The Lossless, Terminated Transmission Line

- R=0 and G=0 we leads to α=0.

$$V(z) = V^{+}(e^{j\beta z} + \Gamma_L e^{-j\beta z})$$

$$I(z) = \frac{V^{+}}{Z_0}(e^{j\beta z} - \Gamma_L e^{-j\beta z})$$

$$Z(z) = Z_0 \frac{Z_L \cosh\beta z + jZ_0 \sinh\beta z}{Z_0 \cosh\beta z + jZ_L \sinh\beta z} [\Omega]$$

$$Z(z) = Z_0 \frac{Z_L + jZ_0 \tanh\beta z}{Z_0 + jZ_L \tanh\beta z} [\Omega]$$

3. The Lossless, Terminated Transmissio Line cont...

- Because of phase variation of reflection coefficient it varies from maximum(+1) to minimum(-1) along the line.
- Therefore the line voltage and current also varies from maximum to minimum along the line.

$$V(z) = V^+ e^{j\beta z}(1+\Gamma(z))$$

$$I(z) = \frac{V^+}{Z_0} e^{j\beta z}(1-\Gamma(z))$$

3. The Lossless, Terminated Transmissio Line cont…

- The ratio between the maximum and minimum voltage (or current) is called **standing wave ratio.**

$$SWR = \frac{V_{max}}{V_{min}} = \frac{I_{max}}{I_{min}} = \frac{1+|\Gamma(z)|}{1-|\Gamma(z)|}$$

$$|\Gamma(z)| = \frac{SWR-1}{SWR+1}$$

$$V_{max} = |V^+|(1+|\Gamma(z)|) = |V^+|\left(\frac{2SWR}{SWR+1}\right)$$

3. The Lossless, Terminated Transmissio Line cont...

- The larger the SWR, the larger the maximum voltage and the lower the minimum voltage on the line.
- If SWR=1, the reflection coefficient is zero. In this, the magnitude of the voltage on the line does not vary. The phase varies. $V_{\max} = V_{\min} = |V^{+}|$
- If SWR is infinite, the magnitude of reflection coefficients equals to 1 that is the load either short

3. The Lossless, Terminated Transmissio Line cont…

- A number of particular loads are as follow:
  1. Matched load: $Z_L = Z_0; \Gamma_L = 0$
  2. Short-circuited load: $Z_L = 0; \Gamma_L = -1$
  3. Open circuit load: $Z_L = \infty; \Gamma_L = +1$
  4. Resistive load: $Z_L = R_L + j0; -1 < \Gamma_L < +1$

4. Lossless matched transmission line

- The line voltage and current have only forwar propagating wave.
- No standing wave in the line and all power on lin transferred to load.

$$Z_L = Z_0$$

$$\Gamma_L = 0$$

$$Z(z) = Z_0$$

$$V(z) = V^+ e^{j\beta z}$$

5. Lossless shorted transmission line

- The line impedance is purely imaginary and varies from –infinite to infinite.
- Load reflection coefficient is -1.
- Standing wave ratio is infinite.

$$Z_L = 0$$

$$\Gamma_L = -1$$

$$SWR = \infty$$

$$Z(z) = jZ_0 \tan(\beta z)$$

$$V(z) = V^+ e^{j\beta z}(1 - e^{-j2\beta z})$$

5. Lossless shorted transmission line cont

Line impedance properties

It is zero at the load and at any value $\beta z = n\pi$, $n = 1, 2$. In terms of wavelengt
the line impedance is zero at $z = n\lambda/2$, $n = 0, 1, 2, \ldots$.

The line impedance is purely imaginary and alternates between positive an
negative values, as shown in **Figure 14.20**. The impedance is positive (inductiv
for $n\lambda/2 < z < n\lambda/2 + \lambda/4$ and negative (capacitive) between $n\lambda/2 + \lambda/4 < z$
$n\lambda/2 + \lambda/2$, $n = 0, 1, 2, \ldots$. The line impedance changes from $+\infty$ to $-\infty$
$z = n\lambda/2 + \lambda/4$.

A shorted transmission line behaves as an inductor or a capacitor, dependin
on the location on the line. A capacitance or an inductance may be designed b
simply cutting a line of appropriate length. In this sense, shorted transmissio
lines are viewed as circuit elements.

5. Lossless shorted transmission line cont.

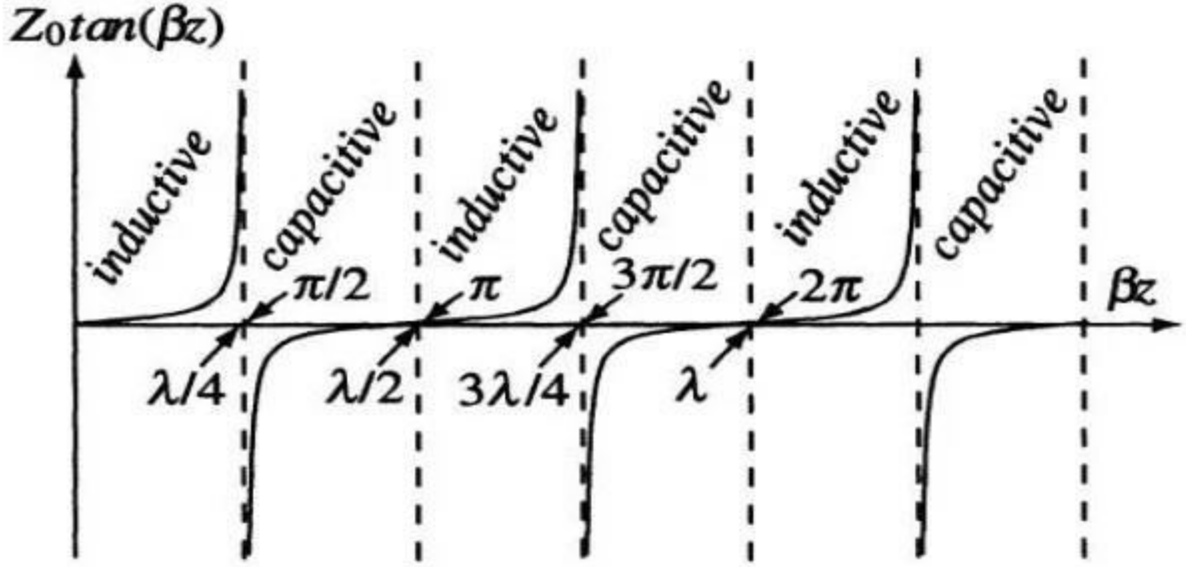


FIGURE 14.20 Line impedance on a shorted transmission line.

6. Lossless open transmission line

- The line impedance is purely imaginary an
varies from –infinite to infinite.
- Load reflection coefficient is +1.
- Standing wave ratio is infinite.

$$Z_L = \infty$$

$$\Gamma_L = +1$$

$$SWR = \infty$$

$$Z(z) = -jZ_0 \cot(\beta z)$$

6. Lossless open transmission line cont..

Line impedance properties

(1) $\Gamma_L = +1$, SWR $= \infty$.

(2) The line impedance is infinite at the load and at any value $\beta z = n\pi$, $n = 1, 2, \ldots$. In terms of wavelength, the line impedance is infinite at $z = n\lambda/2$, $n = 0, 1, 2, \ldots$. The line impedance is zero at $z = \lambda/4 + n\lambda/2$, $n = 0, 1, 2, \ldots$.

(3) The line impedance is purely imaginary and alternates between positive and negative values, as shown in **Figure 14.21**. The impedance is negative (capacitive) for $n\lambda/2 < z < n\lambda/2 + \lambda/4$ and positive (inductive) between $n\lambda/2 + \lambda/4 < z < n\lambda/2 + \lambda/2$, $n = 0, 1, 2, \ldots$. The line impedance changes from $+\infty$ to $-\infty$ at $z = n\lambda/2$.

(4) An open transmission line behaves as an inductor or a capacitor, depending on the location on the line. A capacitance or an inductance may be designed by simply cutting a line of appropriate length. Open transmission lines may also be viewed as circuit elements.

6. Lossless open transmission line cont..

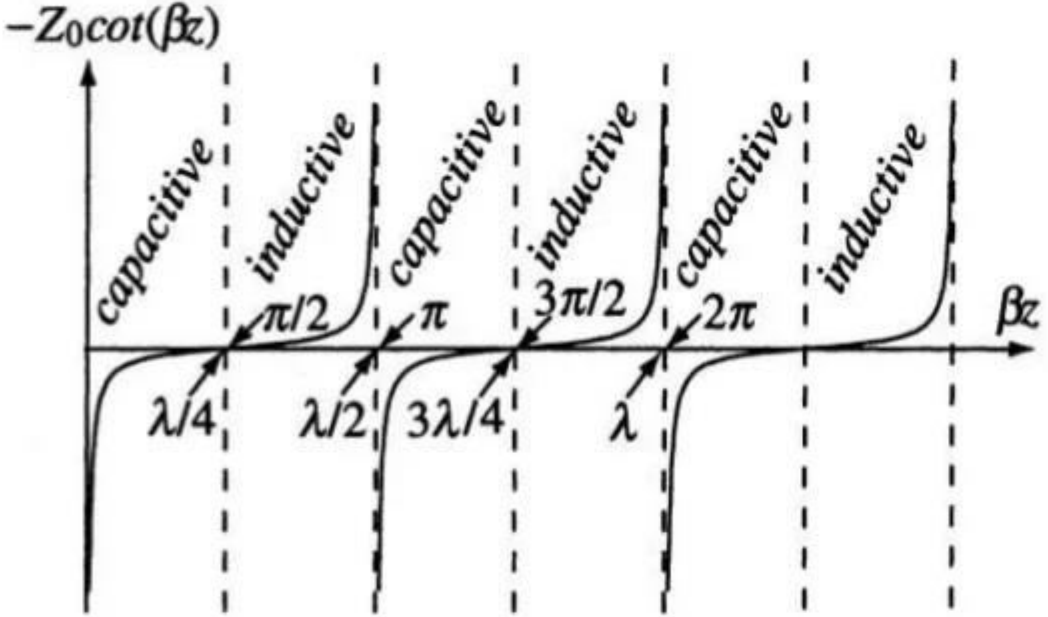


FIGURE 14.21 Line impedance on an open transmission line.

7. Lossless resistively loaded transmissio line

$$Z_L = R_L + j0$$

$$\Gamma_L = \frac{R_L - Z_0}{R_L + Z_0}$$

$$Z(z) = Z_0 \frac{R_L \cos(\beta z) + jZ_0 \sin(\beta z)}{Z_0 \cos(\beta z) + jR_L \sin(\beta z)} = Z_0 \frac{R_L + jZ_0 \tan(\beta z)}{Z_0 + jR_L \tan(\beta z)}$$

- The reflection coefficient is real and can be positive or negative depending relative magnitude of load and intrinsic impedance.
- Therefore the reflection coefficient phase on the line is either 0 or -180 degrees

7. Lossless resistively loaded transmissio line cont…

- Case 1: $R_L > Z_0$
- Reflection coefficient is always positive with phase of 0 degrees.

$$\Gamma_L = \frac{R_L - Z_0}{R_L + Z_0} = |\Gamma_L| e^{j0}$$

$$V(z) = V^+ e^{j\beta z}(1 + \Gamma_L e^{-j2\beta z})$$

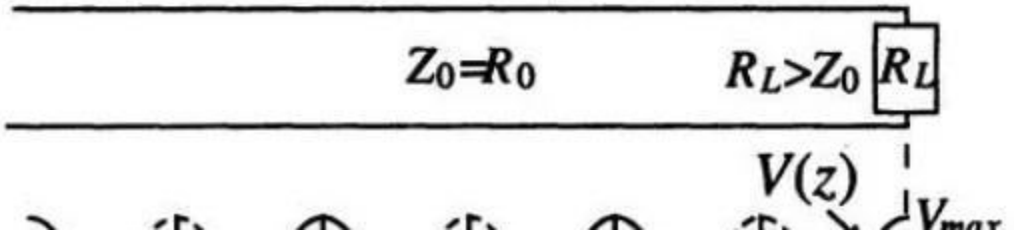
$$I(z) = \frac{V^+}{\ } e^{j\beta z}(1 - \Gamma_L e^{-j2\beta z})$$

7. Lossless resistively loaded transmission line cont...

- The locations of voltage minima and maxima are as follow.

$$z_{\min} = \frac{\lambda}{4\pi}(2n+1)\pi = \frac{(2n+1)\lambda}{4}$$

$$z_{\max} = \frac{\lambda}{4\pi}(2n+1)\pi + \frac{\lambda}{4} = \frac{n\lambda}{2} \qquad n = 0,1,2,\ldots$$



7. Lossless resistively loaded transmissio line cont…

- Case 2: $R_L < Z_0$
- Reflection coefficient is always negative with phase of -180 degrees.

$$\Gamma_L = \frac{R_L - Z_0}{R_L + Z_0} = |\Gamma_L| e^{-j\pi}$$

$$V(z) = V^+ e^{j\beta z}(1 + \Gamma_L e^{-j(2\beta z + \pi)})$$

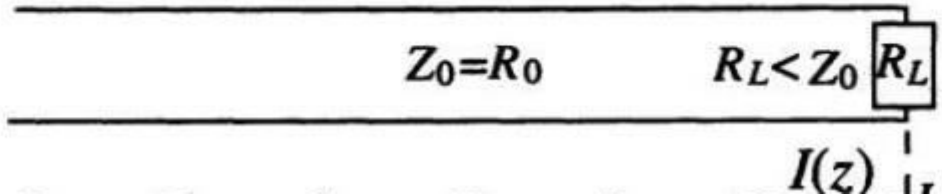
$$I(z) = \frac{V^+}{\ } e^{j\beta z}(1 - \Gamma_L e^{-j(2\beta z + \pi)})$$

7. Lossless resistively loaded transmissio line cont…

- The locations of voltage minima and maxima are as follow.

$$z_{\max} = \frac{\lambda}{4\pi}(2n+1)\pi = \frac{(2n+1)\lambda}{4}$$

$$z_{\min} = \frac{\lambda}{4\pi}(2n+1)\pi + \frac{\lambda}{4} = \frac{n\lambda}{2} \qquad n = 0,1,2,\ldots$$



7. Lossless resistively loaded transmissio line cont...

- The properties of line impedance are as follow:

The line impedance can be complex as can be seen from **Eq. (14.129)**, but it always real at locations of voltage maxima and voltage minima for any lossle line. The impedance at voltage maxima is $Z_{max} = Z_0 SWR$, whereas at volta minima (current maxima), it is $Z_{min} = Z_0/SWR$.

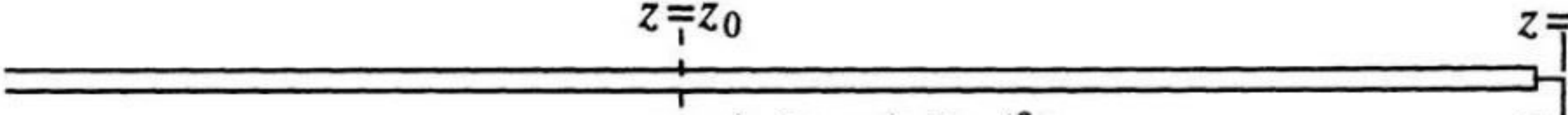
For $R_L > Z_0$, the first voltage maximum occurs at the load ($z = 0$) and the fir voltage minimum at a distance $\lambda/4$ from the load. All conditions on the lin repeat at intervals of $\lambda/2$.

Power relations on a general transmissio line

- The power at any location on the line can be calculated assuming the input at that location.
- Power at any location is due to both forward and backwa propagating waves.

$$V(z_0) = V^+(e^{\gamma z_0} + \Gamma_L e^{-\gamma z_0})$$

$$I(z_0) = \frac{V^+}{Z_0}(e^{\gamma z_0} - \Gamma_L e^{-\gamma z_0})$$



Power relations on a general transmissio line cont...

- The power entering this section of transmissio line is

$$P_i = \frac{1}{2}\mathrm{Re}\{V_{z0} I_{z0}^{*}\}$$

$$P_{z0} = \frac{|V^{+}|^{2}}{2|Z_0|}(e^{2\alpha z0} - |\Gamma_L|^{2} e^{-2\alpha z0})\cos(\theta_{z0})$$

$$P_{load} = \frac{|V^{+}|^{2}}{2|Z_0|}(1 - |\Gamma_L|^{2})\cos(\theta_{z0})$$

Power relations on a general transmissio line cont...

- If only the forward propagating wave exist:

$$V^+(z0) = V^+ e^{\gamma z0}, I^+(z0) = \frac{V^+}{Z_0} e^{\gamma z0}$$

$$P^+(z0) = \frac{|V^+|^2}{2Z_0} e^{2\gamma z0} \cos(\theta_{z0})$$

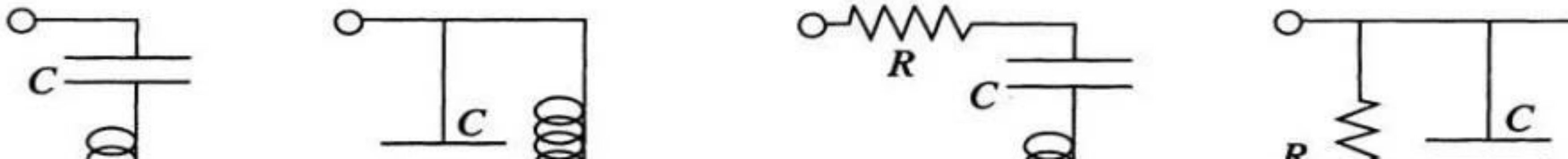
- If only the backward propagation wave exist:

$$V^-(z0) = \Gamma_L V^+ e^{-\gamma z0}, I^+(z0) = -\frac{\Gamma_L V^+}{Z_0} e^{-\gamma z0}$$

$$P^+(z0) = \frac{|V^+|^2 |\Gamma_L|^2}{2Z_0} e^{-2\gamma z0} \cos(\theta_{z0})$$

Resonant transmission line circuits

- Because of inductive and capacitive nature of the line impedance section of line segments can form various resonant circuits.
- Lossy and lossless series and parallel resonant circuits can be formed by using transmission line segments.
- At resonant frequency the transmission line segments have only real impedance.



Resonant transmission line circuits cont..

- The resonant circuit can be formed by using eithe open circuit line or short circuit line.
- The selection of line segments type depends on th application where it is used, practically the coaxia type resonators are used with open circuit an parallel plate are used with short circuit.
- In resonant circuits if the resonant frequency is give then the length of the line sections has to b calculated

Resonant transmission line circuits cont..

- Parallel resonant circuit using transmission line.
- The resonant condition can be calculated using admittance.

$$Z_{in1} = jZ_{01}\tan(\beta_1 d_1)$$

$$Z_{in2} = jZ_{02}\tan(\beta_2 d_2)$$

$$\frac{1}{Z_{in1}} + \frac{1}{Z_{in2}} = 0$$

$$Z_{01}\tan(\beta_1 d_1) + Z_{02}\tan(\beta_2 d_2) = 0$$

→ Resonant conditio

Resonant transmission line circuits cont..

- Series resonant circuit using transmission line.
- The resonant condition can be calculated using admittance.

$$Z_{in1} = jZ_{01}\tan(\beta_1 d_1)$$
$$Z_{in2} = jZ_{02}\tan(\beta_2 d_2)$$
$$Z_{in1} + Z_{in2} = 0$$
$$Z_{01}\tan(\beta_1 d_1) + Z_{02}\tan(\beta_2 d_2) = 0$$

Resonant conditi

MECHANICAL DESIGN OF OVERHEAD LINES

8.1 INTRODUCTION

- Electric power can be transmitted or distributed either by means of ***underground cables or by overhead lines.***
- The underground cables are ***rarely used*** for power transmission due to two main reasons.
  - Firstly, power is generally transmitted over ***long distances*** to load centers. Obviously, the ***installatio***

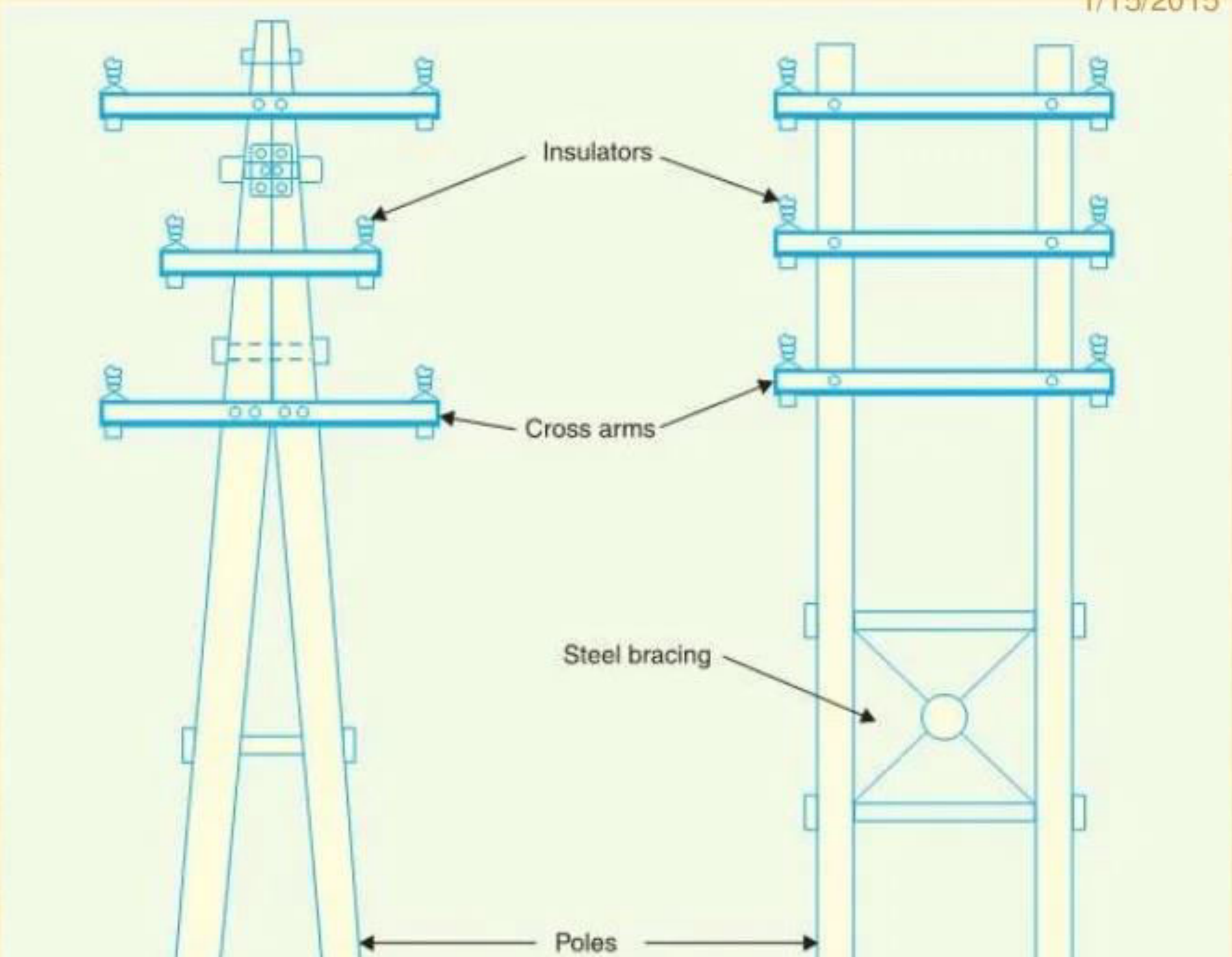
8.1 INTRODUCTION

- An overhead line is subjected to ***uncertain weather*** conditions and other ***external interferences***.
- This calls for the use of proper mechanical factors of safety in order to ***ensure the continuity of operation in the line***. In general, the ***strength of the line*** should be

8.1 MAIN COMPONENTS OF OVERHEAD LINES

- In general, the main components of an overhead line ar

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


Insulators
Cross arms
Steel bracing
Poles

8.2 CONDUCTOR MATERIAL

- The conductor material used for transmission and distribution of electric power should have the following properties :

1. ***high electrical conductivity***.
2. ***high tensile strength*** in order to withstand mechanical stresses.
3. ***low cost*** so that it can be used for long

COMMONLY USED CONDUCTOR MATERIALS.

- The most commonly used conductor materials for overhead lines are
  - Copper
  - aluminium
  - steel-cored aluminium
  - galvanized steel
  - cadmium copper.

8.3 LINE SUPPORTS

- The supporting structures for overhead line conductors are various types of poles and towers called line supports. In general, the line supports should have the following properties :

1. ***High mechanical strength*** to withstand the weight of conductors and wind loads etc.
2. without the loss of mechanical strength.
3. ***Cheap in cost*** and economical to maintain.

8.3 LINE SUPPORTS

- The line supports used for transmission and distribution of electric power are of various types including
  1. wooden poles
  2. steel poles
  3. R.C.C. poles

8.3 LINE SUPPORTS

The choice of supporting structure for a particular case depends upon the

i. line span
ii. X-sectional area
iii. line voltage
iv. Cost
v. local conditions

8.4 INSULATORS

- The overhead line conductors should be supported on the poles or towers in such a way that currents from conductors do not flow to earth through supports i.e., line conductors mu be properly insulated from supports. This is achieved by securing line conductors to supports with the help of insulators. The insulators provide necessary insulation betwee

8.4 INSULATORS

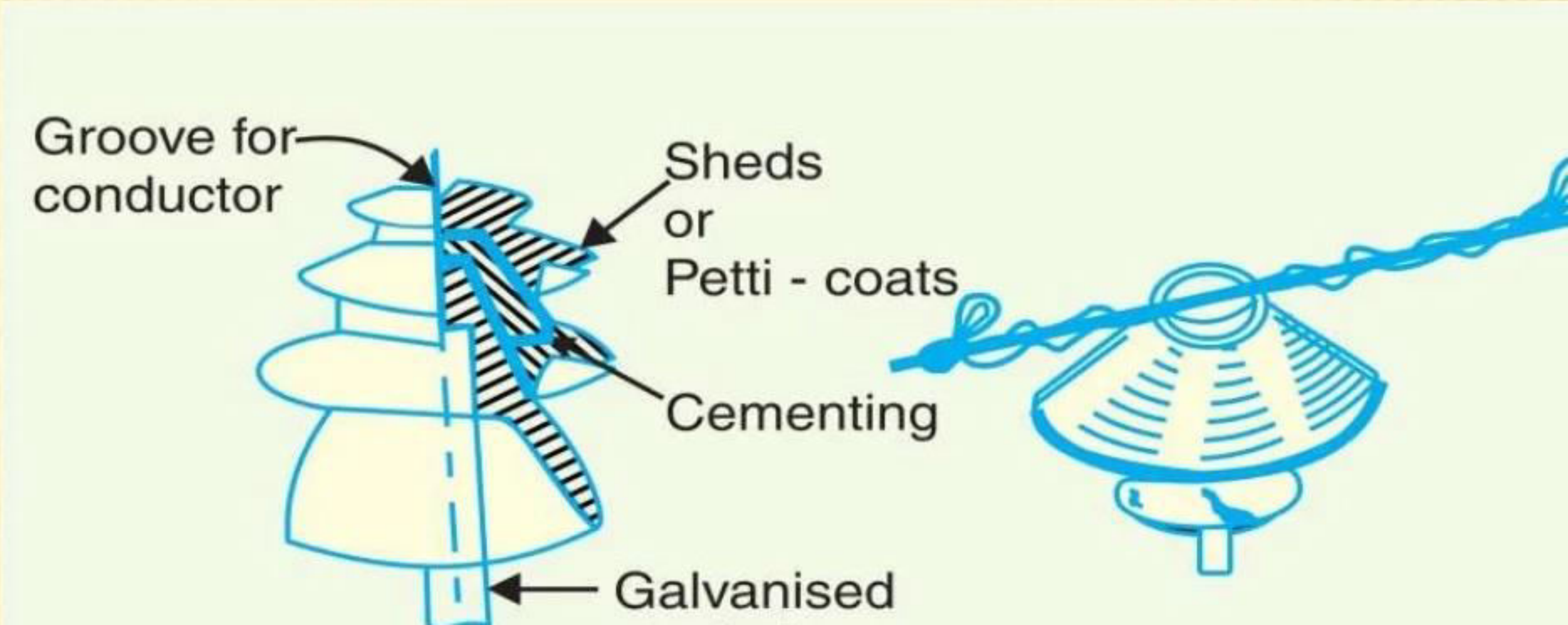
- In general, the insulators should have the following desirable properties :

1. ***High mechanical strength*** in order to withstand conductor load, wind load etc.
2. ***High electrical resistance*** of insulator material in order to avoid leakage currents to earth.
3. ***High relative permittivity*** of insulator material in order that dielectric strength is high.
4. The insulator material should be ***non-porous, free***

8.5 TYPES OF INSULATORS

The successful operation of an overhead line depends to a considerable extent upon the proper selection of insulators. There are several types of insulators but the most commonly used are

1. pin type
2. suspension type


Groove for
conductor
Sheds
or
Petti - coats
Cementing
Galvanised

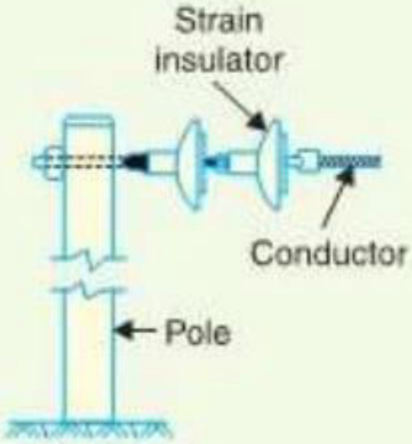


Fig. 8.8. Strain insulator.

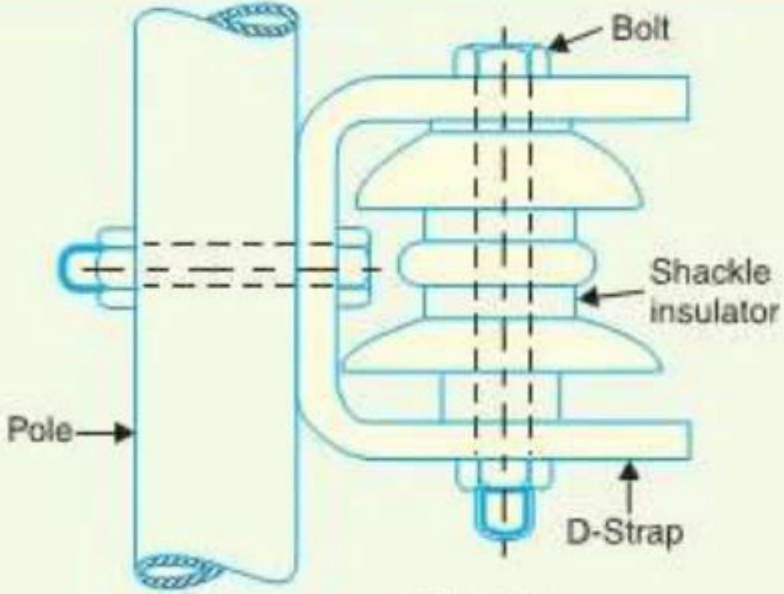


Fig. 8.9

8.10 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, whe the ***applied voltage exceeds*** a certain value, called ***critical disruptive voltage*** ,the conductors are ***surrounded by a faint violet glow*** called corona.
- The phenomenon of corona is accompanied by a hiss

8.10 CORONA

- If the applied voltage ***is increased to breakdown*** value, a flash-over will occur between the conductor due to the breakdown of air insulation.
- The phenomenon ***of violet glow, hissing noise an production of ozone gas*** in an overhead transmission line is known as corona.
- If the conductors are polished and smooth, the corona glow will be uniform throughout the length of the conductors, otherwise the rough points will

THEORY OF CORONA FORMATION

- Some ionised particles (i.e.,free electrons and +ve ions) and neutral molecules always prese in air
- When p.d. is applied between the conductors, potential gradient is set up in the air which will have maximum value at the conductor surfaces
- Under the influence of potential gradient, the

THEORY OF CORONA FORMATION

- When the potential gradient at the conductor surface reaches about 30 kV per cm (max. value), the velocity acquired by the free electrons is sufficient to strike a neutral molecule with enough force to dislodge one or more electrons from it. This produces another ion and one or more free electrons, which is tu are accelerated until they collide with other neutral molecules, thus producing other ions.

8.11 FACTORS AFFECTING CORONA

- The phenomenon of corona is affected by the physical state of the atmosphere as well as by the conditions of the line. The following are the factors upon which corona depends :

1. ***Atmosphere:*** As corona is formed due to ionization of air surrounding the conductors, therefore, it is affected by the physical state of atmosphere. In the ***stormy weather***, the number of ***ions is more*** than normal and as such corona ***occurs at much less voltage*** as compared with fair weather.
2. ***Conductor condition:*** The corona effect depends upon the shape and conditions of the conductors. The ***rough and irregular*** surface will give rise to ***more corona*** because ***unevenness*** of the surface ***decreases*** the value of

8.11 FACTORS AFFECTING CORONA

3. ***Spacing between conductors:*** If the ***spacing*** between the conductors is made ***very large*** as compared to their diameters, there ***may not be an*** ***corona*** effect. It is because larger distance betwee conductors reduces the electro-static stresses at th conductor surface, thus avoiding corona formation.
4. ***Line voltage:*** The line voltage greatly affects corona. If it is ***low***, there is no change in the condition of air surrounding the conductors and

8.13 ADVANTAGES AND DISADVANTAGES OF CORONA

- Corona has many advantages and disadvantages. In the correct design of a high voltage overhead line, a balance should be struck between the advantages and disadvantages.

Advantages

1. Due to corona formation, the air surrounding the conductor becomes conducting and hence ***virtual diameter of the conductor is increased***. The

8.13 ADVANTAGES AND DISADVANTAGES OF CORONA

Disadvantage

1. Corona is accompanied by a ***loss of energy***. This affects the transmission efficiency of the line.
2. ***Ozone*** is produced by corona and may cause ***corrosion*** of the conductor due to ***chemical action.***
3. The ***current*** drawn by the line due to corona i

8.14METHODS OF REDUCING CORONA EFFECT

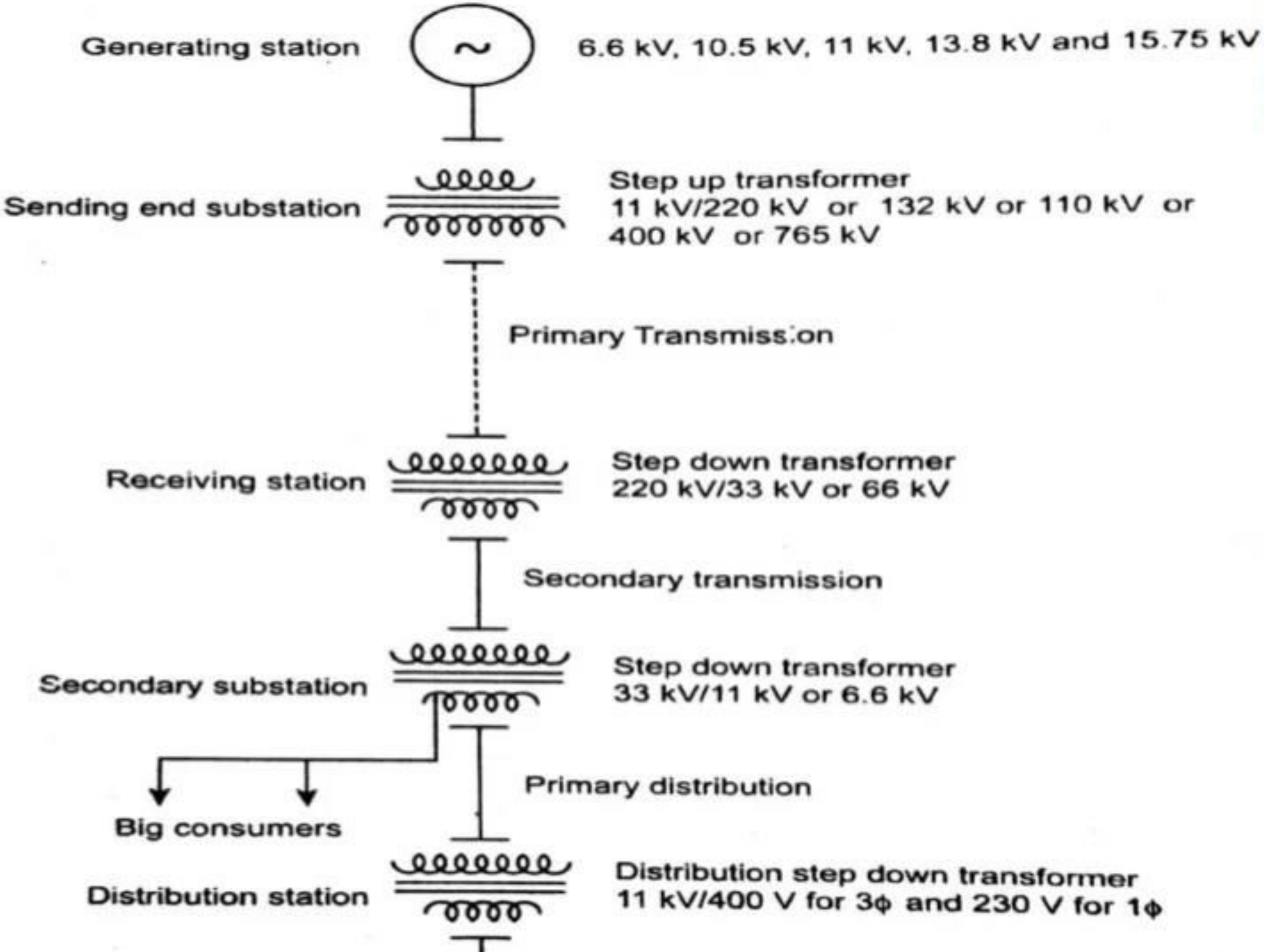
- The corona effects can be reduced by the following methods :

1. ***By increasing conductor size***, the voltage at which corona occurs is raised and hence corona effects are considerably reduced. This is one of the reasons that ACSR conductors which have a ***larger cross-sectional area*** are used in transmission lines.
2. ***By increasing the spacing*** between conductors, the voltage at which corona occurs is raised and hence corona effects can be eliminated. However, spacing

STRUCTURE OF POWER SYSTEM

Introduction

- An electrical power system consists of generation, transmission and distribution.
- The transmission systems supply bulk power and the distribution systems transfer electric power to the ultimate consumers.
- The generation of the electric energy is nothing but the conversion of one form energy into electrical energy.
- Electrical energy is generated in hydro, thermal and nuclear power stations.


Generating station
6.6 kV, 10.5 kV, 11 kV, 13.8 kV and 15.75 kV
Sending end substation
Step up transformer
11 kV/220 kV or 132 kV or 110 kV or
400 kV or 765 kV
Primary Transmission
Receiving station
Step down transformer
220 kV/33 kV or 66 kV
Secondary transmission
Secondary substation
Step down transformer
33 kV/11 kV or 6.6 kV
Primary distribution
Big consumers
Distribution station
Distribution step down transformer
11 kV/400 V for 3ϕ and 230 V for 1ϕ

Components of an electric power system:

- Generators: A device used to convert one form of energy into electric energy.
- Transformer: Transfer power or energy from one circuit to other witho the change of frequency.(to increase or decrease the voltage level)
- Transmission lines: Transfer power from one location to another
- Control Equipment: Used for protection purpose
- Primary Transmission: 110kV, 132kV or 220kV or 400kV or 765kV, hi voltage transmission, 3 phase 3-wire system.
- Secondary transmission: 3 phase 3-wire system, 33kV or 66kV feede are used
- Primary distribution: 3 phase 3-wire system, 11kV or 6.6kV, 3 phase

Generators:

- Generator is a device which converts mechanical energy into electrical energy. Generating voltages are normally 6.6 kV,10.5 kV or 11 kV.
- This generating voltage can be step up to 110 kV/132 kV/220kV at the generating(indoor or outdoor) to reduce the current in transmission line and to reduce transmission losses.
- Generators produce real power (MV) and reactive power (MVAR).

Transformers:

- It is a static device which transfers power or energy from one circuit to another circuit without change of frequency.
- The main function of transformers is step up voltages from lower generation levels to the higher generation voltage levels and also step down voltages from higher transmission voltage levels to lower distribution levels.
- When we are increasing the transmission voltage, current flowing through the current flowing through

Control Equipment

- Circuit Breaker (CB): Circuit breakers are used for opening or closing a circuit normal and abnormal (fault) condition.
- Different types of circuit breaker are oil circuit breaker, air-blast circuit breaker, vacuum circuit breaker, SF6 circuit breaker.
- During fault conditions relay will give command to the circuit breaker to operate.
- Isolators: Isolators are placed in substations to isolate the part of system during maintenance.
- It can operate only during no-load condition. Isolated switches

Contd…

- Busbar: Busbars are used to connect number of lines operating at the same voltage electrically.
- It is made up of copper or aluminium. Different types of busbar arrangements are –single busbar arrangement, single bus bar with sectionalisation, double bus bar arrangements, ring bus bar scheme etc.

Transmission System

- It supplies only large blocks of power to bulk power stati or very big consumers.
- It interconnects the neighbouring generating stations in t power pool i.e, interconnection of two or more generati stations.
- Tolerance of transmission line voltage is ±5 to ± 10% due the variation of loads.

Primary Transmission

- If the generated power is transmitted through transmissi line without stepping up the generated voltage, the li current and power loss would be very high.

Contd…

- The high voltage transmission lines transmit power from sending end substation to the receiving end substation.
- Primary transmission voltages are 110KV, 132 KV or 220KV 0r 400KV or 760KV.It uses 3phase, and 3wire system.

Secondary Transmission

- At the receiving end substation, the voltage is stepped down to a value of 66 or 33 or 22 KV using step down transformers.
- The secondary transmission line forms the link between the

Distribution System

- The component of an electrical power system connecting all the consumers in an area to the bulk power sources or transmission lin is called a distribution system.
- A distribution station distributes power to domestic, commercial a relatively small consumers.
- Distribution transformers are normally installed on poles or on plinth mounted or near the consumers

Primary Distribution

- At the secondary substations, the voltage is stepped down to 11 K or 6.6 KV using step down transformers.

Secondary Distribution

- At the distribution substation the voltage is stepped down to 400V (for 3phase) or 230V (for 1 phase) using step down transformers.
- The distribution lines are drawn along the roads and service connections to the consumers are tapped off from the distributors.
- It uses 3 phase, 4 wire system.
- Single phase loads are connected between one phase wire

Conclusion:

The basic structure of power system and its various components , their role are discussed.

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PRESENTATION TOPIC IS

TRANSMISSION LINE

INDEX

TRANSMISSION LINES

A transmission line is used for the transmission of electrical power from generating substation to the various distribution units. It transmits the wave of voltage and current from one end to another. The transmission line is made up of a conductor having a uniform cross-section along the line. Air act as an insulating or dielectric medium between the conductors.

CLASSIFICATION OF TRANSMISSION LINES

1. Overhead transmission lines
   - Short transmission lines
   - Medium transmission lines
   - Long transmission lines
2. Underground cables

OVERHEAD POWER LINE

An overhead power line is a structure used in electric power transmission and distribution to transmit electrical energy along large distances. It consists of one or more conductors (commonly multiples of three) suspended by towers or poles. Since most of the insulation is provided by air, overhead power lines are generally the lowest-cost method of power transmission for large quantities of electric energy.

Short transmission lines

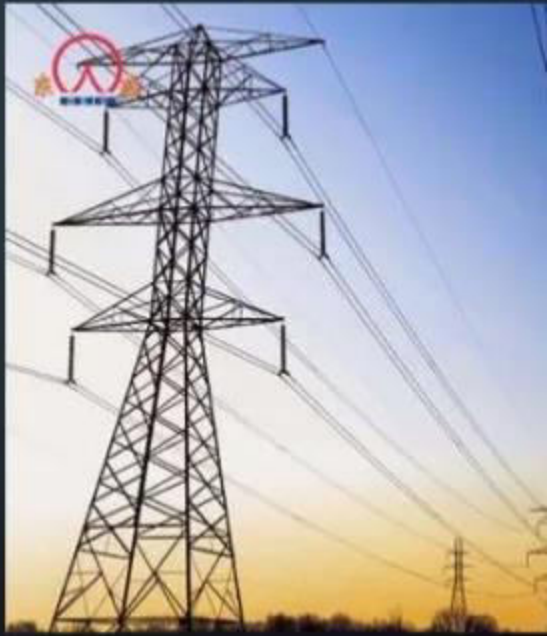
- Line voltage is less than 20KV
- Length of transmission line is up to about 80Km
- Capacitance effect are small or negligible

MEDIUM TRANSMISSION LINES

- Line voltage is moderately high.
- It is greater than 20KV but less than 100KV.
- Length of lines is about 50 Km to 150Km.
- Capacitance is significant.

LONG TRANSMISSION LINES

- Line voltage is very high (>100KV).
- Length of an overhead line is more than 150Km.
- Line constants are considered uniformly distributed over the whole length of the line.



ADVANTAGES OF OVERHEAD TRANSMISSION LINES

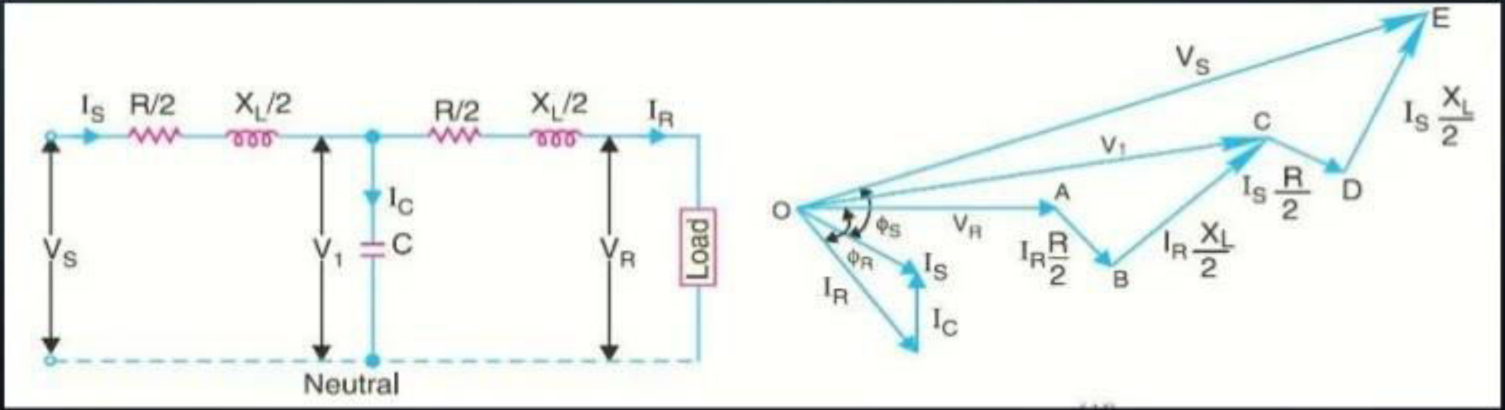
- Cheaper to install and maintain than underground cables
- They have large transmission capacity.
- Good cooling conditions
- Quicker to fix whenever fault develops.

Disadvantages Of Overhead Transmission Lines

- Not Very Safe To Be Erected In Densely Populated Area Of The City.
- Affected By Environmental Conditions Such As Temperature, Wind, Rain Etc.
- Difficult To Be Erected In The Area Where The Network Is Complex And Concentrate.
- Influenced By Thunder And Lightening.

NOMINAL "T" METHOD

Nominal "T" Method : In this method, the whole line capacitance is assumed to be concentrated at the middle point of the line and half the line resistance & reactance are lumped on its either side as shown in fig. There fore in this arrangement full charging current flows over half the line. In fig one phase of 3 phase transmission line is shown as it is advantageous to work in phase instead of line to line values



NOMINAL "T" MODEL OF A TRANSMISSION LINE

Here,

Series impedance of the line Z = R + jX
Shunt admittance of the line Y = jwc
Receiving end voltage = V_r
Receiving end current = I_r
Current in the capacitor = I_{ab}
Sending end voltage = V_s
Sending end current = I_s

Sending end voltage and current can be obtained by application of KVL and KCL. to the circuit shown below

$$V_{ab} = V_r + \frac{Z}{2} I_r$$

Current in the capacitor can be given as,

NOMINAL "T" MODEL OF A TRANSMISSION LINE

$$I_{ab} = \frac{V_{ab}}{Z_{ab}} = YZ_{ab}$$

By Kirchoff's current law at node a,

$$I_s = I_r + I_{ab}$$

$$I_s = I_r + YV_{ab}$$

$$I_s = I_r + Y\left(V_r + \frac{Z}{2}I_r\right)$$

By Kirchoff's voltage law

$$V_s = V_{ab} + \frac{Z}{2}I_s$$

$$V_s = V_r + \frac{Z}{2}I_r + \frac{Z}{2}\left[YV_r + \left(1 + \frac{ZY}{2}\right)I_r\right]$$

equation of sending end voltage v_s and current i_s can be written in the matrix form as

$$\begin{bmatrix} \frac{V_s}{I_s} \end{bmatrix} = \begin{bmatrix} 1 + \frac{ZY}{2} & Z\left(1 + \frac{ZY}{4}\right) \\ Y & 1 + \frac{ZY}{2} \end{bmatrix} \begin{bmatrix} \frac{V_r}{I_r} \end{bmatrix}$$

Also,

$$\begin{bmatrix} V_r \\ I_r \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix}$$

Hence, the ABCD constant of the nominal T-circuit model of a medium line are

$$A = D = 1 + \frac{ZY}{2}$$

$$B = Z\left(1 + \frac{ZY}{4}\right)$$

$$C = Y$$

EQUATION OF NOMINAL "T" METHOD

Let,

I_R = Receiving end Current per phase

V_R = Receiving end voltage per phase

X_L = Inductive Reactance per phase

R = Resistance per phase

C = Capacitance per Phase

Z = Impedance per Phase

V_1 = Voltage of capacitor

V_S = Sending end Voltage per phase

I_S = Sending end Current per phase

$COS\emptyset_R$ = Receiving end power factor (Lagging)

$COS\emptyset_S$ = Sending end Power factor (Lagging)

Tacking the receiving end voltage $\overrightarrow{V_R}$ as the reference phasor we have

Receiving end voltage, $\overrightarrow{V_R} = V_R + J0$

Receiving end Current, $\overrightarrow{I_R} = I_R(COS\emptyset_R - jSin\emptyset_R)$

Line loss of receiving end, = $\vec{I}_R \frac{\vec{Z}}{2}$

Voltage of capacitor, $V_1 = V_R + I_R \frac{Z}{2}$

Current of Capacitor, $\overrightarrow{I_C} = j\omega C\overrightarrow{V_1}$

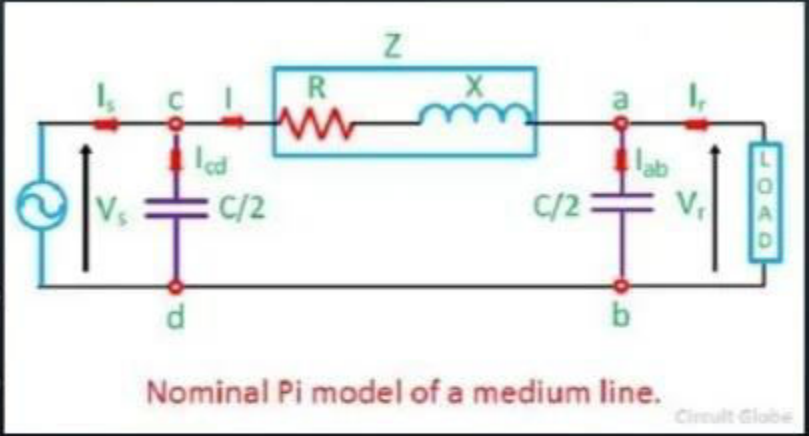
Sending end Current, $\overrightarrow{I_S} = \overrightarrow{I_R} + \overrightarrow{I_C}$

Line loss sending end, = $\vec{I}_S \frac{\vec{Z}}{2}$

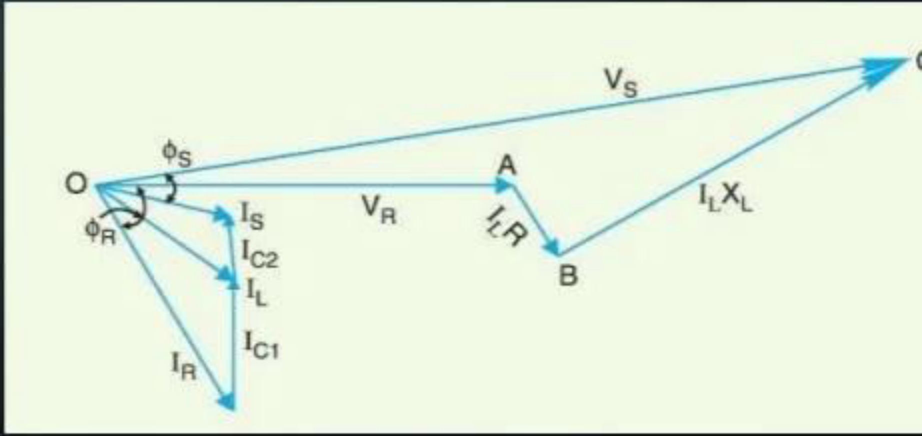
Sending end Voltage, $V_S = \vec{I}_S \frac{\vec{Z}}{2} + \overrightarrow{V_1}$

NOMINAL "PI" MODEL OF A MEDIUM TRANSMISSION LINE

In the nominal pi model of a medium transmission line, the series impedance of the line is concentrated at the centre and half of each capacitance is placed at the centre of the line. The nominal Pi model of the line is shown in the diagram below



Nominal Pi model of a medium line.



Equation of Nominal "∏" Method

In this circuit,

$$V_{ab} = V_r, \quad Z_{ab} = \frac{1}{Y_{ab}}$$

By Ohm's law

$$I_{ab} = \frac{V_{ab}}{Z_{ab}} = \frac{Y}{2} V_r$$

By KCL at node a,

$$I = I_r + I_{ab} = I_r + \frac{Y}{2} V_r$$

Voltage at the sending end

$$V_s = V_{cd} = V_{ab} + ZI = V_r + Z\left(I_r + \frac{Y}{2} V_r\right)$$

$$V_s = \left(1 + \frac{ZY}{2}\right) V_r + Z I_r$$

EQUATION OF NOMINAL "∏" METHOD

By ohm's law

$$I_{cd} = \frac{V_{cd}}{Z_{cd}} = \frac{Y}{2}V_s = \frac{Y}{2}\left[\left(1 + \frac{ZY}{2}\right)V_r + ZI_r\right]$$

Sending-end current is found by applying KCL at node c

$$I_S = I + I_{cd} = I_r + \frac{Y}{2}V_r + \frac{Y}{2}\left[\left(1 + \frac{ZY}{2}\right)V_r + ZI_r\right]$$

Or

$$I_s = Y\left(1 + \frac{ZY}{4}\right)V_r + \left(1 + \frac{ZY}{2}\right)I_r$$

Equations can be written in matrix form as

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} \left(1 + \frac{ZY}{2}\right) & Z \\ Y\left(1 + \frac{ZY}{4}\right) & \left(1 + \frac{ZY}{2}\right) \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix}$$

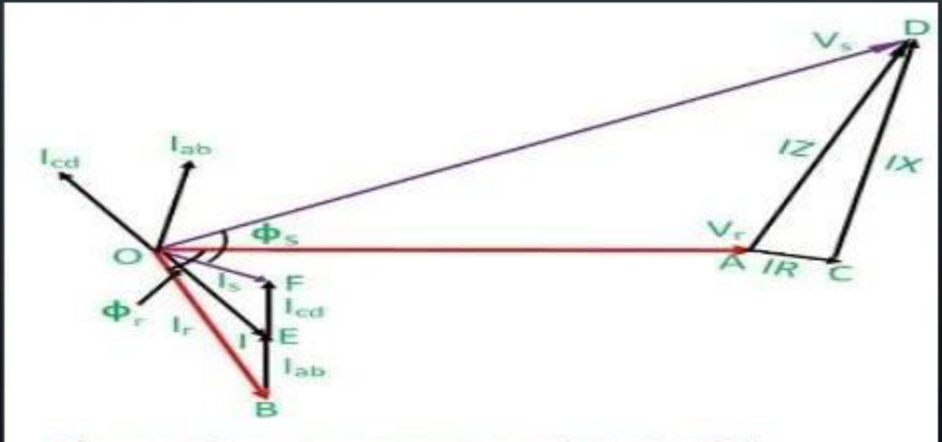
Also,

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix}$$

Hence, the ABCD constants for nominal pi-circuit model of a medium line are

$$A = D = 1 + \frac{ZY}{2}; \; B = Z \; C = Y\left(1 + \frac{ZY}{4}\right)$$

Phasor diagram of nominal pi model



The phasor diagram of a nominal pi-circuit is shown in the figure below.
It is also drawn for a lagging power factor of the load. In the phasor diagram the quantities shown are as follows;

OA = V_r – receiving end voltage. It is taken as reference phasor.

OB = I_r – load current lagging V_r by an angle $\emptyset_r$.

BE = I_{ab} – current in receiving-end capacitance. It leads V_r by 90°.

The line current I is the phasor sum of I_r and I_{ab}. It is shown by OE in the diagram.

AC = IR – voltage drop in the resistance of the line. It is parallel to I.

CD = IX -inductive voltage drop in the line. It is perpendicular to I.

AD = IZ – voltage drop in the line impedance.

OD = V_s – sending–end voltage to neutral. It is phasor sum of V_r and IZ.

The current taken by the capacitance at the sending end is I_{cd}. It leads the sending–end voltage V_s by 90

OF = I_s – the sending–end current. It is the phasor sum of I and I_{cd}.

Øs – phase angle between V_s and I_s at the sending end, and cosØs will give the sending-end power factor.

MATH & SOLUTION

Example 10:13

A 3-phase, 50Hz 150 km line has a resistance , inductive reactance and capacitive shunt admittance of 0.1Ω , 0 .5Ω and 3× 10^{-6} S per km per phase. If the line delivers 50 MW at 110 kV and 0.8 p.f. lagging , determine the sending and voltage and current. Assume a nominal π circuit for the line.

Total resistance /phase, $R = 0.1 \times 150 = 15\ \Omega$

Total reactance/phase, $X_L = 0.5 \times 150 = 75\ \Omega$

Capacitive admittance/phase, $Y = 3 \times 10^{-6} \times 150 = 45 \times 10^{-5}$ S

Receiving end voltage/phase, $V_R = 110 \times 10^3 / \sqrt{3} = 63{,}508\ V$

Load current , $I_R = \frac{50 \times 10^6}{\sqrt{3} \times 110 \times 10^3 \times 0.8} = 328\ A$

$\cos \emptyset_R = 0.8\ ;\ \sin \emptyset_R = 0.6$

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

$$\vec{V_R} = V_R + j0 = 63{,}508\ V$$

Load current , $\vec{I_R} = I_R\ (\cos\ \emptyset_R - j\ \sin \emptyset_R) = 328\ (0.8\text{-}j0.6)$

$= 262.4\ \text{-}j196.8$

Charging Current at the Load end is

$$\vec{I_{C1}} = \vec{V_R}\, j\, \frac{Y}{2} = 63{,}508 \times j\, \frac{45 \times 10^{-5}}{2} = j\ 14.3$$

Line current , $\vec{I_L} = \vec{I_R} + \vec{I_{C1}} = (262.4 - j\ 196.8) + J\ 14.3$

$= 262.4 - j\ 182.5$

$$\vec{V_S} = \vec{V_R} + \vec{I_L}\,\vec{Z} = \vec{V_R} + \vec{I_L}\ (R + j\, X_L)$$

$= 63{,}508 + (262.4 - j\ 182.5)(15 + j75\ )$

$= 63{,}508 + 3936 + j19{,}680 - j\ 2737.5 + 13{,}687$

$= 81{,}131 + j\ 16{,}942.5 = 82{,}881\ \angle 11^{\circ}47'\ V$

∴Line to line sending end voltage $= 82{,}881 \times \sqrt{3} = 1{,}43{,}550\ V$

$= 143.55\ kV$

Charging current at the sending end is

$$I_{C2} = j\ \vec{V_S}\ Y / 2 = (81{,}131 + j\ 16{,}942.5)\ j\ \frac{45 \times 10^{-5}}{2}$$

$= -3.81 + j\ 18.25$

Sending in current , $\vec{I_S} = \vec{I_L} + \vec{I_{C2}} = (262.4 - j182.5) + (-3.81 + j\ 18.25)$

$= 258.6 - j\ 164.25 = 306.4 \angle -32.4^{\circ}$ A

∴ Sending end current $= 306.4$ A

UNDERGROUND TRANSMISSION LINES

Undergrounding is the replacement of overhead cables providing electrical power or telecommunications, with underground cables. This is typically performed for aesthetic purposes, but also serves the additional significant purpose of making the power lines less susceptible to outages during high wind thunderstorms or heavy snow or ice storms. Undergrounding can increase the initial costs of electric power transmission and distribution but may decrease operational costs over the lifetime of the cables.

CLASSIFICATION OF UNDERGROUND CABLES

❑ BY VOLTAGE

- LT cables: Low-tension cables with a maximum capacity of 1000 V
- HT Cables: High-tension cables with a maximum of 11KV
- ST cables: Super-tension cables with a rating of between 22 KV and 33 KV
- EHT cables: Extra high-tension cables with a rating of between 33 KV and 66 KV
- Extra super voltage cables: with maximum voltage ratings beyond 132 KV

❑ BY CONSTRUCTION

- Belted cables: Maximum voltage of 11KVA
- Screened cables: Maximum voltage of 66 KVA
- Pressure cables: Maximum voltage of more than 66KVA

ADVANTAGES OF UNDERGROUND CABLES

- Low chances of developing faults.
- Low maintenance cost.
- Not influenced by environmental conditions.
- More durable in comparison to overhead transmission lines.
- Underground cables are more safer fore mankind.
- Requires a narrow band of length to install.

DISADVANTAGES OF UNDERGROUND CABLES

- Very expensive. It costs four times the overhead lines.
- Repairing of underground cables is not easy and it takes more time to repair than overhead lines.
- Maintenance cost is also very high.

THANK YOU ALL