PPT ON
TRANSMISSION AND DISTRIBUTION SYSTEMS
B. Tech V SEM (IARE-R16)

UNIT 1

TRANSMISSION LINE PARAMETERS

GENERAL CONSIDERATIONS

Electrical Considerations for T.L. Design:

- Low voltage drop
- Minimum power loss for high efficiency of power transmission.
- The line should have sufficient current carrying capacity so that the power can be transmitted without excessive voltage drop or overheating.

---CONT'D

Conductivity of Conductor:

$R = \rho . L/A$, or

$R = L/\sigma . A$

Where:

L: Conductor length.

A: Conductor cross sectional area.

ρ: resistivity

Ϭ: Conductivity ($\sigma = 1/\rho$)

The conductor conductivity must be very high

to reduce Conductor resistance R and hence reduce losses

$$P_L = 3 I^2 .R$$

---CONT'D

- Heat expansion coefficient must be very small.

$R_t = R_0. (1 + \alpha_0 .t)$

$\alpha_t = \alpha_0/(1+ \alpha_0.t)$

α_t is the heat expansion coefficient at t.

MECHANICAL CONSIDERATIONS FOR T.L. DESIGN:

- The conductors and line supports should have sufficient mechanical strength:
- to withstand conductor weight, Conductor Tension and weather conditions (wind, ice).
- The Spans between the towers can be long.
- Sag will be small.
- Reducing the number and height of towers and the number of insulators.

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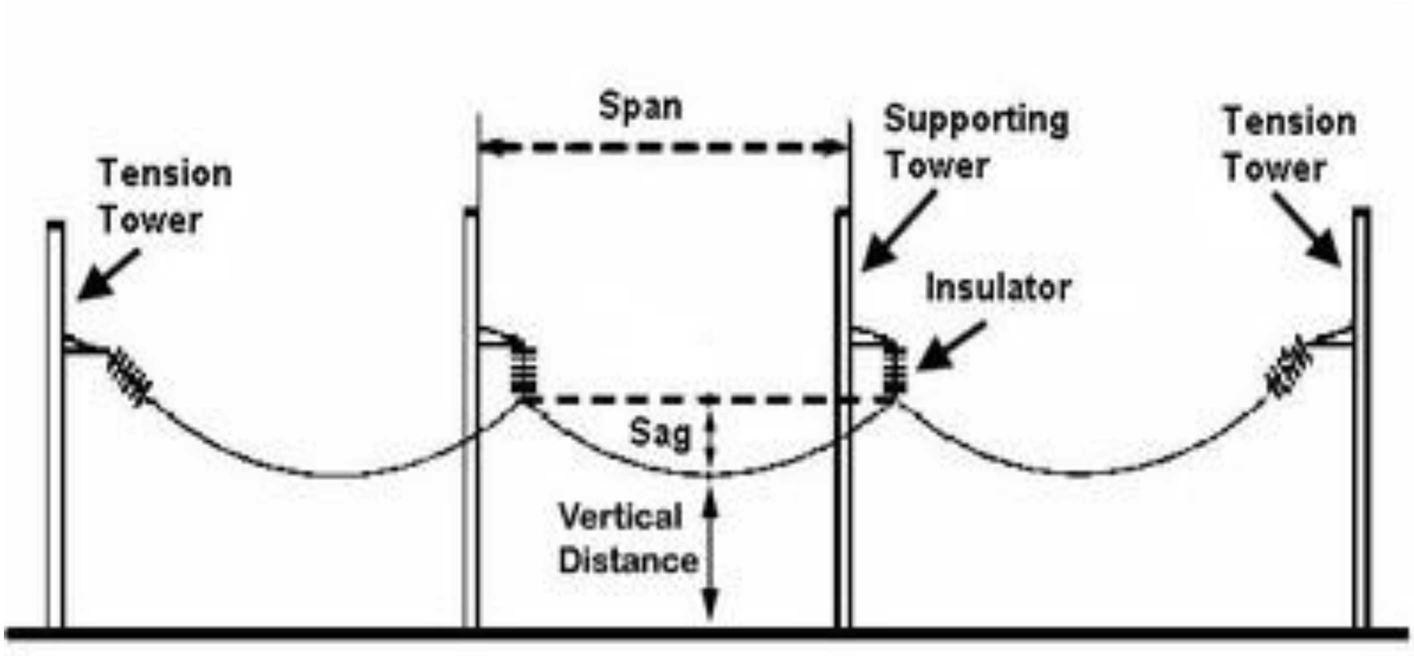


Fig: An overhead transmission line

MAIN COMPONENTS OF OVERHEAD LINES:

1) Conductors
2) Supports
3) Insulators
4) Cross arms
5) Miscellaneous

CONDUCTOR MATERIALS

Properties :

(i) High electrical conductivity.

(ii) High tensile strength in order to withstand mechanical stresses.

(iii) Low cost so that it can be used for long distances

(iv) Low specific gravity so that weight per unit volume is small.

Commonly used conductor materials:-

a)Copper

b) Aluminium

c)Steel-cored aluminium

d) Galvanised steel

e)Cadmium copper

Conductors are preferably stranded to increase flexibility.

COPPER

- High electrical conductivity
- Greater tensile strength
- Hard drawn copper used
- High current density
- Smaller cross-sectional area required

  High cost & non availability

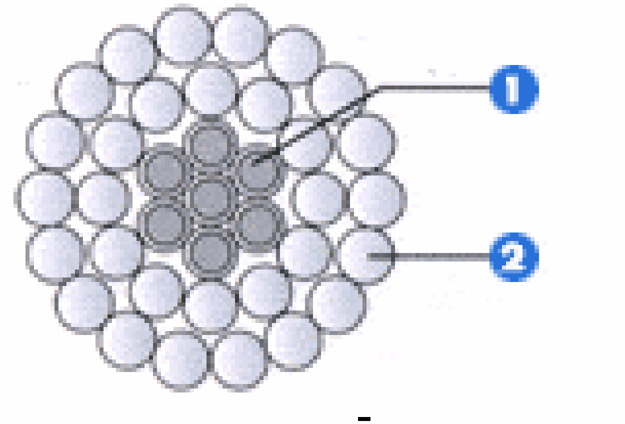
ALUMINIUM

- Cheaper & light in weight, for small span
- Small conductivity & tensile strength (60% of copper)
- Cross-sectional area of conductor larger than copper(Aluminium diameter= 1.26 times of copper)
- Higher tower with greater sag
- Specific gravity lower than copper
- Larger cross-arms required
- Not suitable for long distance transmission

All Aluminum Conductors (AAC)

Fig: All Aluminium Conductors

Aluminum Conductor Steel Reinforced (ACSR)



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1- Steel strands

2- Aluminum strands

ACSR (26/7)

Fig: Aluminum Conductor Steel Reinforced (ACSR)

Aluminum Conductor Steel Reinforced (ACSR)

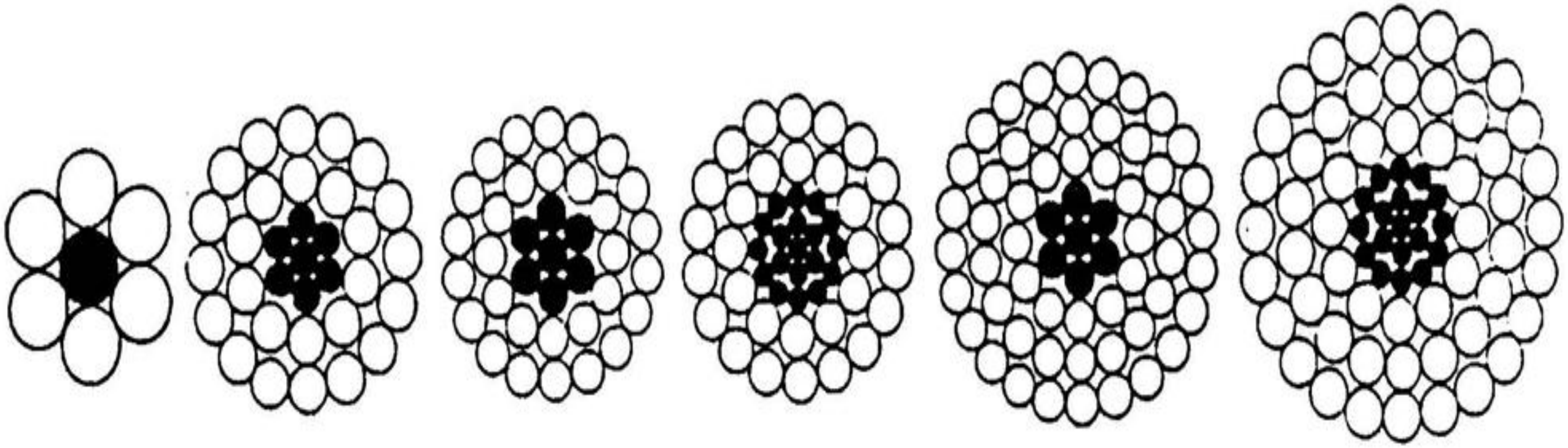

Fig: Aluminum Conductor Steel Reinforced (ACSR)

STEEL CORED ALUMINIUM

- To increase stregth of aliminium conductors reinforced with a core of galvanised steel wires.
- Abbreviated as ACSR(Aluminium condutor steel reinforced).

Advantages of ACSR

- High mechanical strength can be utilized by using spans of larger lengths.
- Tower of smaller height can be used
- A reduction in the number of supports also include reduction in insulators and the risk of lines outage due to flash over or faults is reduced.
- losses are reduced due to larger diameter of conductor.
- High current carrying capacity.

GALVANIZED STEEL

- Very high tensile strength
- Long spans
- Rural areas
- Cheap
- Poor conductivity & high resistance
- Not suitable for transmitting large power over a long distance

CADMIUM COPPER

- Addition of 1% or 2% cadmium to copper
- Increased tensile strength by 50% than pure copper
- Conductivity reduced by 15% below that of pure copper
- Economical for lines of small cross-section due to high cost of cadmium

LINE SUPPORTS

Properties:

- High mechanical strength to withstand weight of conductor
- Light in weight
- Cheap in cost
- Longer life
- Easy accessibility of conductor for maintenance

TYPES OF LINE SUPPORTS

- Wooden poles
- Steel poles
- RCC poles
- Lattice steel towers

WOODEN POLES

- Shorter span upto 50 m
- Less cost & used for distribution purpose in rural areas
- Pesticides required e.g creosote oil
- Used for voltage upto 20 kv
- Smaller life(20-25 years)
- Less mechanical strength
- Made of Sal or Chir
- Moderate cross-sectional area

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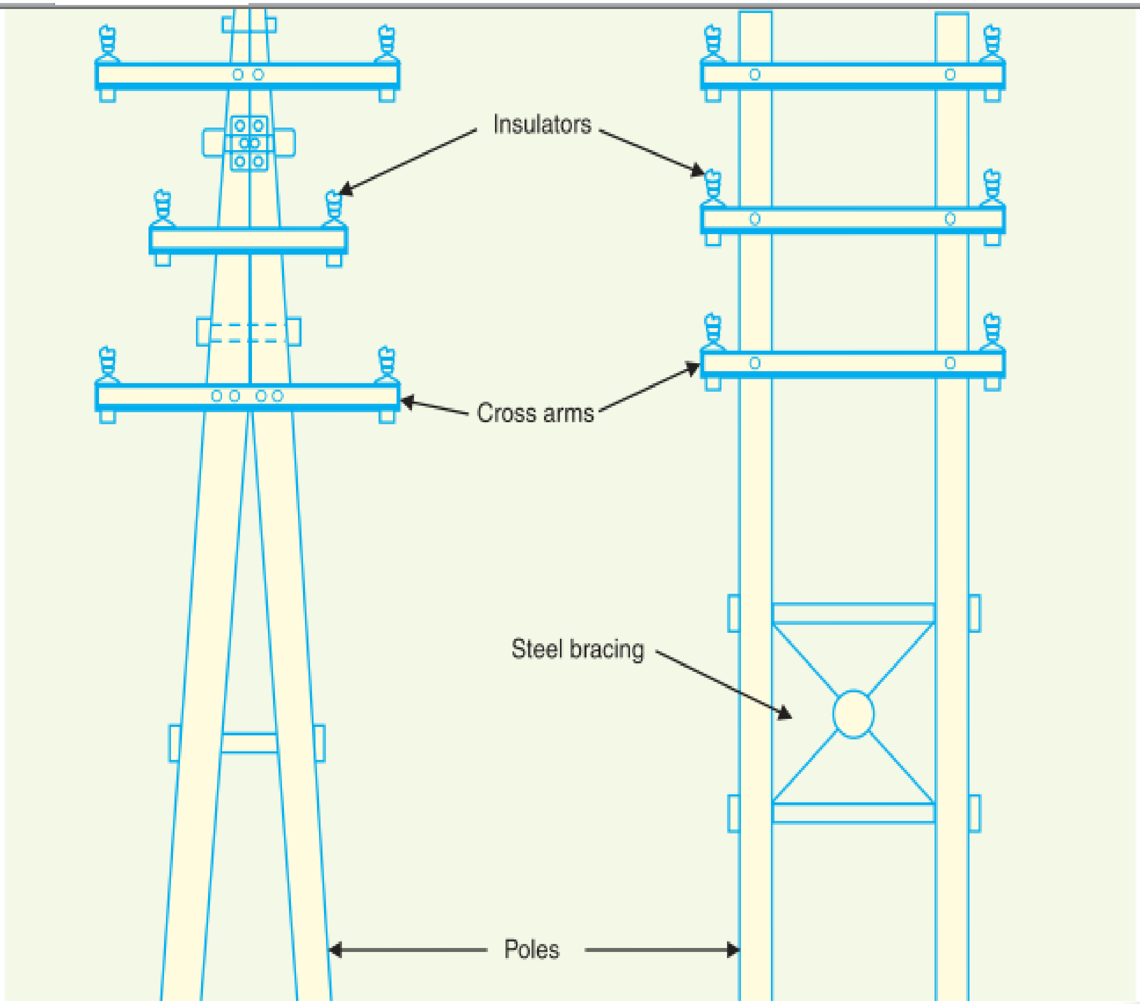

Fig: Wooden Poles

Wooden Poles

Fig: Wooden Poles

Steel Poles

Fig: Steel Poles

RCC(REINFORCED CONCRETE POLES)

- Greater mechanical strength
- Longer life
- Longer spans
- Good outlook
- Little maintenance
- Good insulating properties

Two Types:-

- Single pole
- Double poles

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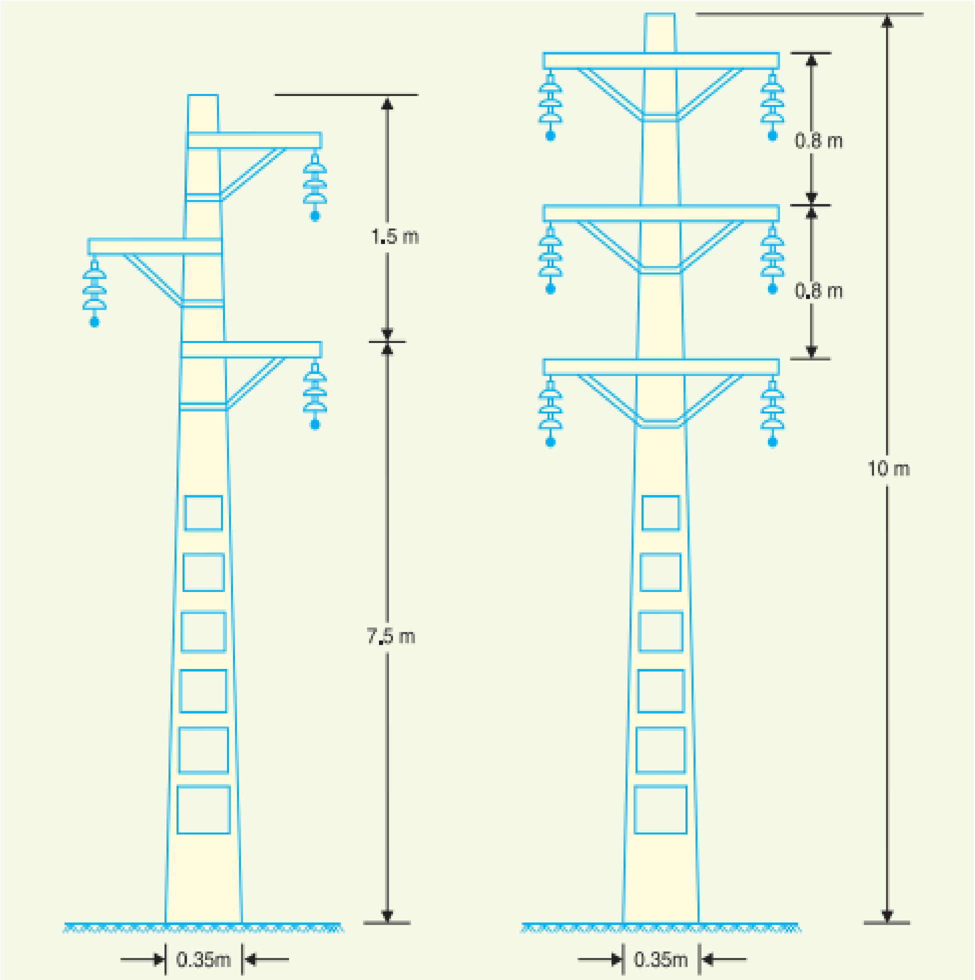

Fig: Reinforced Concrete Poles

Reinforced Concrete Poles

Fig: Reinforced Concrete Poles

---CONT'D

Fig: Reinforced Concrete Poles

STEEL TOWERS

- Longer life
- Longer span
- Greater mechanical strength
- For long distance at high voltage
- Tower footings are usually grounded by driving rods into the earth .This minimizes lightning troubles as each tower acts as lightning conductor.

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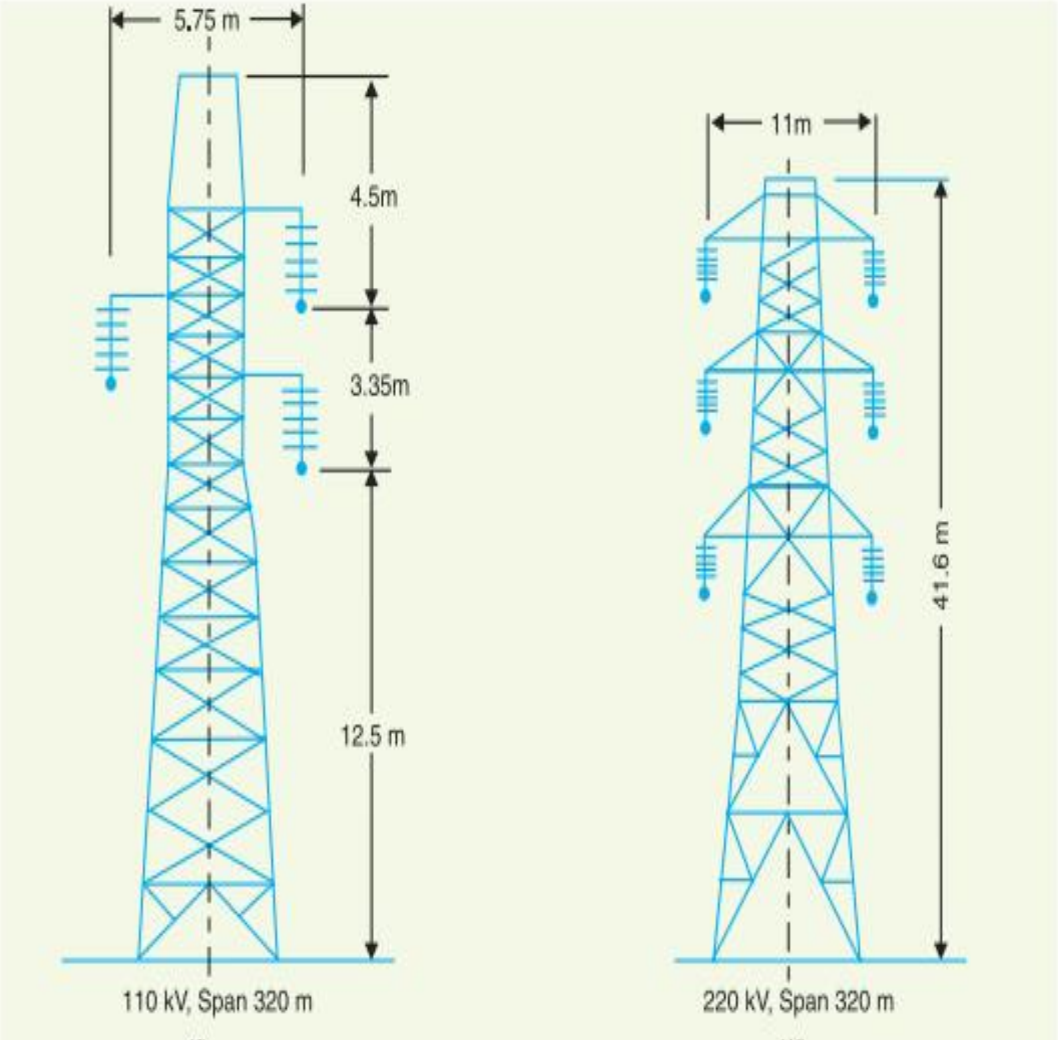

Fig: Steel Towers

Types of Towers

1- Suspension Tower

2- Tension Tower

3- Angle Tower

4- End Tower

SUSPENSION TOWER

Fig: Suspension Tower

Tension Tower

Fig: Tension Tower

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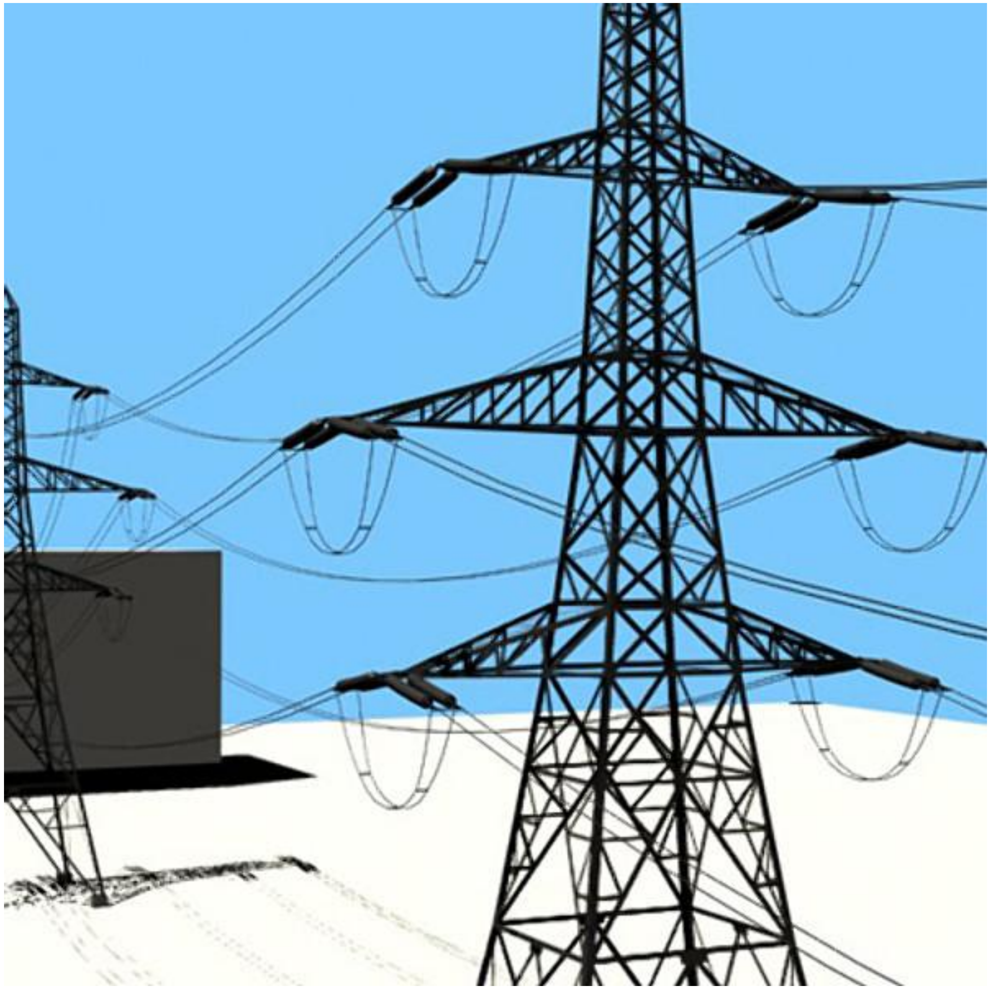

Fig: Tension Tower

Angle Tower

Fig: Angle Tower

End Towers

This type of towers exists in the beginning and at the end of the line which exposed to tension in one side.

INSULATORS

Properties of Insulators:

- High mechanical strength
- High electrical resistance to avoid leakage currents to earth
- Insulator material should be porous,free from impurities & cracks

Types of Insulators

- Pin type :- For transmission and distribution upto 33 KV
- Suspension type :- For voltage greater than 33 KV
- Strain type:- For dead ends, corner or sharp curve
- Shackle type:- For low voltage distribution lines & can be used either in a horizontal or vertical position

---CONT’D

Pin type insulator

Suspension insulator

---CONT'D

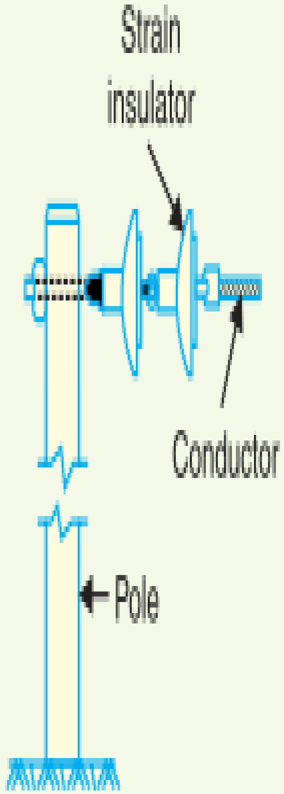

Fig. 8.8. Strain insulator.

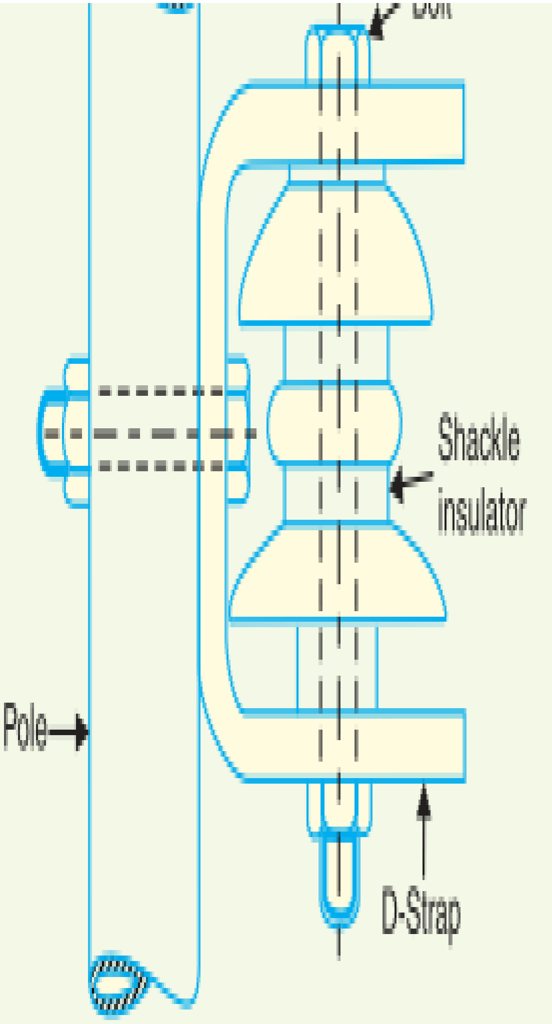

Fig. 8.9

BUNDLED CONDUCTOR

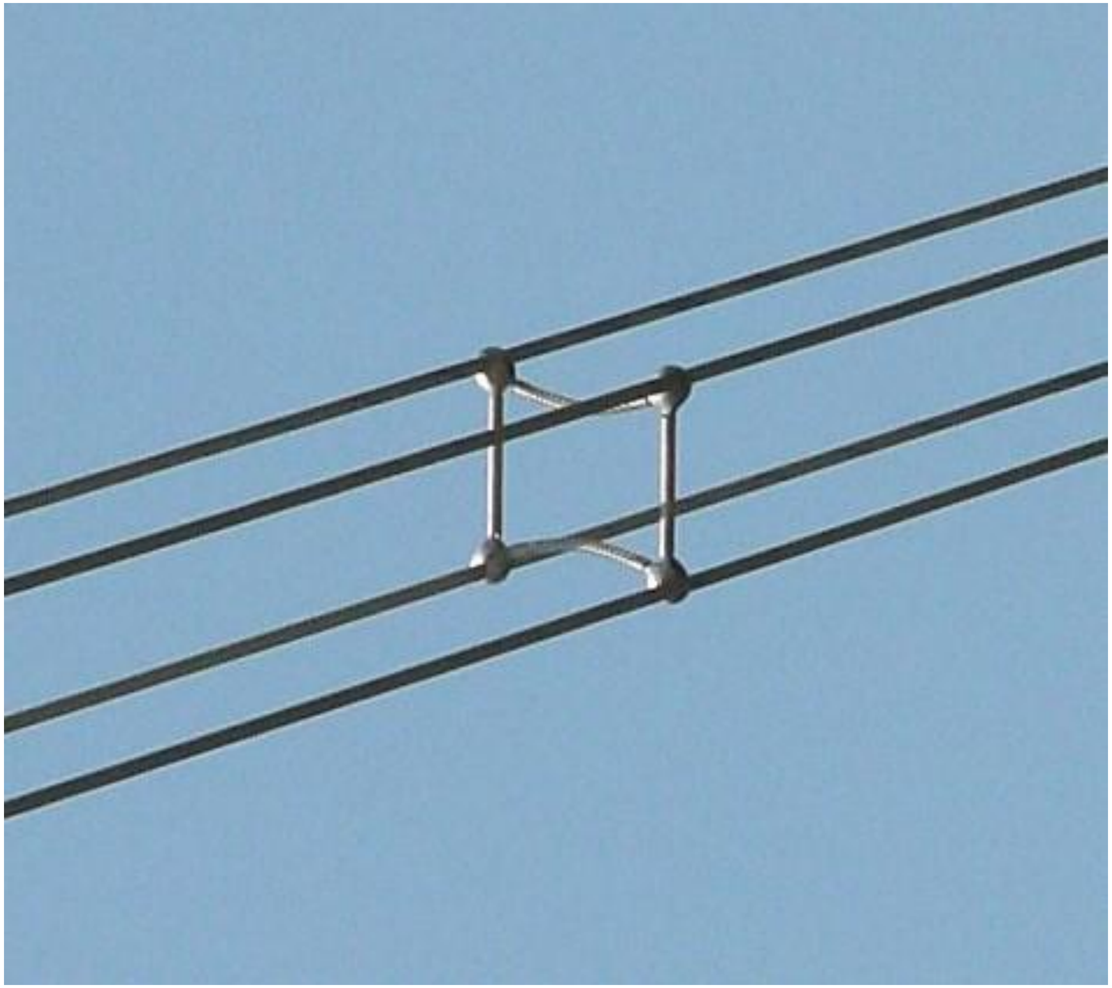

Fig: Bundled Conductor

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Fig: Bundled Conductor

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EDUCATION FOR LIBERATION

UNIT 2

MODELING AND PERFORMANCE OF TRANSMISSION LINES

TRANSMISSION LINE MODELS

- Previous lectures have covered how to calculate the *distributed* series inductance, shunt capacitance, and series resistance of transmission lines:
  - That is, we have calculated the inductance L, capacitance C, and resistance r per unit length,
  - We can also think of the shunt conductance g per unit length,
  - Each infinitesimal length dx of transmission line consists of a series impedance $r\mathrm{d}x + j\omega L\mathrm{d}x$ and a shunt admittance $g\mathrm{d}x + j\omega C\mathrm{d}x$,
- In this section we will use these distributed parameters to develop the transmission line models used in power system analysis.

TRANSMISSION LINE EQUIVALENT CIRCUIT

- Our model of an infinitesimal length of transmission line is shown below:

Units on

z and y are

per unit

length!

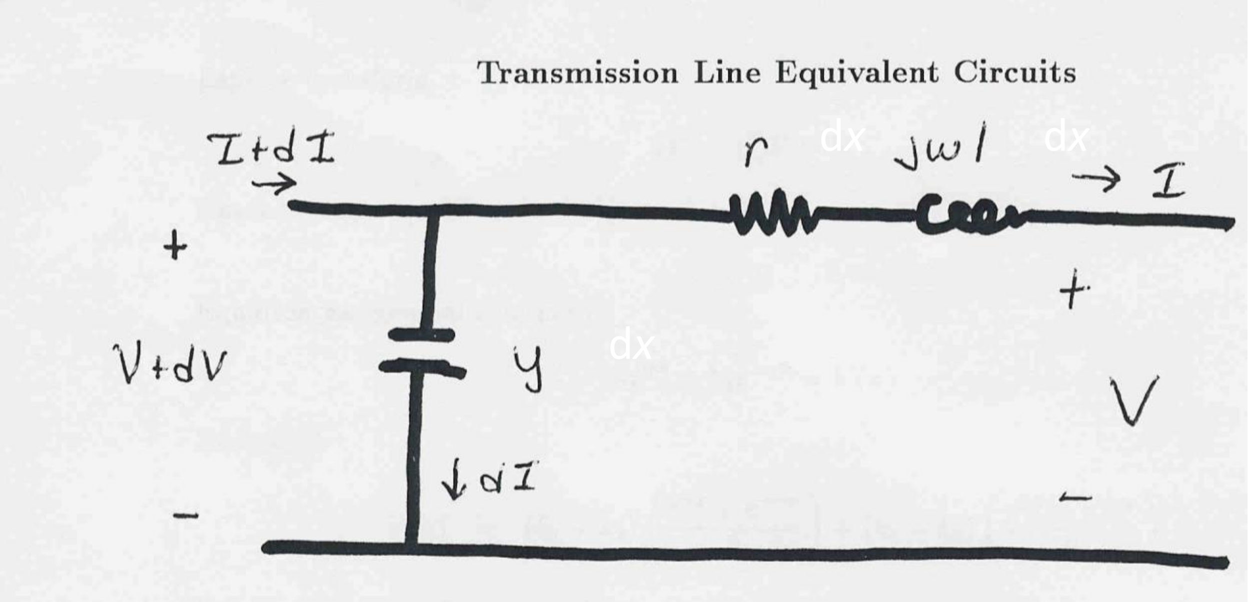


Fig.1: Transmission Line Equivalent Circuit

For operation at frequency ω, let $z = r + j\omega L$

and $y = g + j\omega C$ (with g usually equal to 0)

DERIVATION OF V, I RELATIONSHIPS

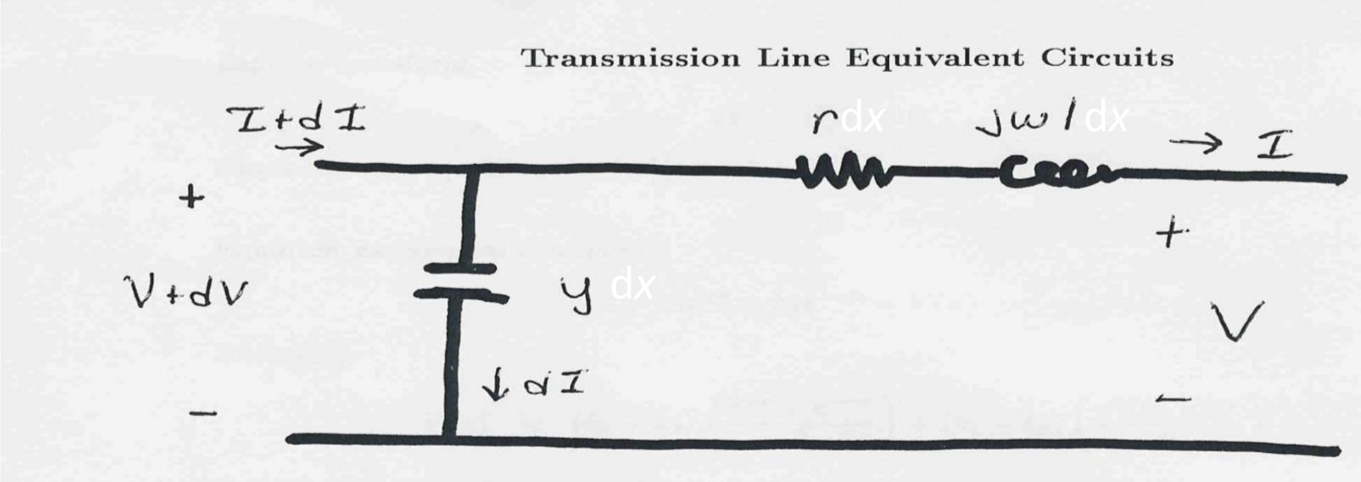


Fig.2: Transmission Line Equivalent Circuit

We can then derive the following relationships:

$$\mathrm{d}V = I(x)\, z\, \mathrm{d}x$$

$$\mathrm{d}I = (V(x) + \mathrm{d}V)\, y\, \mathrm{d}x \approx V(x)\, y\, dx,$$

on neglecting the $\mathrm{d}V\mathrm{d}x$ term,

$$\frac{\mathrm{d}V(x)}{\mathrm{d}x} = z\, I(x) \qquad \frac{\mathrm{d}I(x)}{\mathrm{d}x} = yV(x)$$

SETTING UP A SECOND ORDER EQUATION

$$\frac{\mathrm{d}V(x)}{\mathrm{d}x} = zI(x) \qquad \frac{\mathrm{d}I(x)}{\mathrm{d}x} = yV(x)$$

We can rewrite these two, first order differential equations as a single second order equation

$$\frac{\mathrm{d}^2V(x)}{\mathrm{d}x^2} = z\frac{\mathrm{d}I(x)}{\mathrm{d}x} = zyV(x)$$

$$\frac{\mathrm{d}^2V(x)}{\mathrm{d}x^2} - zyV(x) = 0$$

V, I RELATIONSHIPS, CONT'D

Define the propagation constant γ as

$$\gamma = \sqrt{yz} = \alpha + j\beta$$

where

α = the attenuation constant

β = the phase constant

EQUATION FOR VOLTAGE

The general equation for V is

$$V(x) = k_1 e^{\gamma x} + k_2 e^{-\gamma x},$$

which can be rewritten as

$$V(x) = (k_1 + k_2)(\frac{e^{\gamma x} + e^{-\gamma x}}{2}) + (k_1 - k_2)(\frac{e^{\gamma x} - e^{-\gamma x}}{2})$$

Let $K_1 = k_1 + k_2$ and $K_2 = k_1 - k_2$. Then

$$\begin{aligned} V(x) &= K_1(\frac{e^{\gamma x} + e^{-\gamma x}}{2}) + K_2(\frac{e^{\gamma x} - e^{-\gamma x}}{2}) \\ &= K_1 \cosh(\gamma x) + K_2 \sinh(\gamma x) \end{aligned}$$

REAL HYPERBOLIC FUNCTIONS

For real $\gamma x,$ the cosh and sinh functions have the following form:

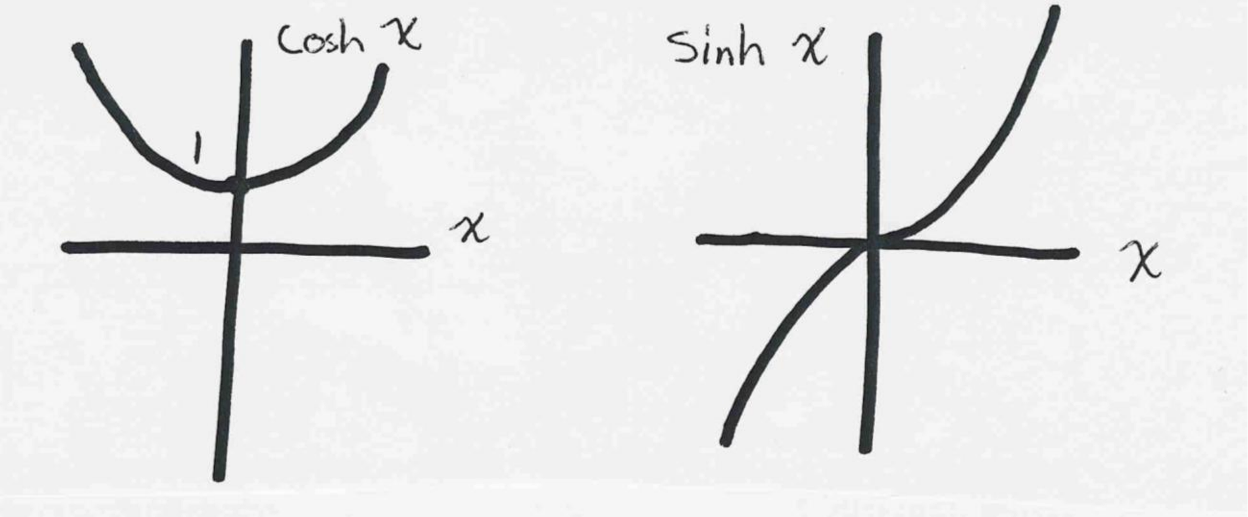


Fig.3: Real Hyperbolic Functions

$$\frac{d\cosh(\gamma x)}{dx} = \gamma \sinh(\gamma x) \qquad \frac{d\sinh(\gamma x)}{dx} = \gamma \cosh(\gamma x)$$

COMPLEX HYPERBOLIC FUNCTIONS

For complex $\gamma x = \hat{\alpha} + j\hat{\beta}$

$$\cosh(\gamma x) = \cosh\hat{\alpha}\cos\hat{\beta} + j\sinh\hat{\alpha}\sin\hat{\beta}$$

$$\sinh(\gamma x) = \sinh\hat{\alpha}\cos\hat{\beta} + j\cosh\hat{\alpha}\sin\hat{\beta}$$

Make sure your calculator handles sinh and cosh of complex numbers.

You will need this for homework and for the mid-term!

DETERMINING LINE VOLTAGE

The voltage along the line is determined based upon the current/voltage relationships at the terminals. Assuming we know V and I at one end (say the "receiving end" with V_R and I_R where $x = 0$) we can determine the constants K_1 and K_2, and hence the voltage at any point on the line.

We will mostly be interested in the voltage and current at the other, "sending end," of the line.

DETERMINING LINE VOLTAGE, CONT’D

$$V(x) = K_1\cosh(\gamma x) + K_2\sinh(\gamma x)$$

$$V(0) = V_R = K_1\cosh(0) + K_2\sinh(0)$$

$$\text{Since } \cosh(0) = 1 \ \& \ \sinh(0) = 0 \Rightarrow K_1 = V_R$$

$$\frac{dV(x)}{dx} = zI(x) = K_1\gamma\sinh(\gamma x) + K_2\gamma\cosh(\gamma x)$$

$$\Rightarrow K_2 = \frac{zI_R}{\gamma} = \frac{I_R\,z}{\sqrt{yz}} = I_R\sqrt{\frac{z}{y}}$$

$$V(x) = V_R\cosh(\gamma x) + I_R Z_c\sinh(\gamma x)$$

$$\text{where } Z_c = \sqrt{\frac{z}{y}} = \text{characteristic impedance}$$

DETERMINING LINE CURRENT

By similar reasoning we can determine $I(x)$

$$I(x) \quad = \quad I_R \cosh(\gamma x) + \frac{V_R}{Z_c} \sinh(\gamma x)$$

where x is the distance along the line from the receiving end.

Define transmission efficiency as $\eta \quad = \quad \frac{P_{out}}{P_{in}};$

that is, efficiency means the real power out (delivered) divided by the real power in.

TRANSMISSION LINE EXAMPLE

Assume we have a 765 kV transmission line with a receiving end voltage of 765 kV (line to line), a receiving end power $S_R = 2000 + j1000$ MVA and

$$z = 0.0201 + j0.535 = 0.535\angle 87.8^\circ \ \Omega/\text{mile}$$

$$y = j7.75\times 10^{-6} = 7.75\times 10^{-6}\angle 90.0^\circ \ \text{S}/\text{mile}$$

Then

$$\gamma = \sqrt{zy} = 2.036\times 10^{-3}\angle 88.9^\circ \ /\ \text{mile}$$

$$Z_c = \sqrt{\frac{z}{y}} = 262.7\ \angle\text{-}1.1^\circ\ \Omega$$

TRANSMISSION LINE EXAMPLE, ---CONT'D

Do per phase analysis, using single phase power and line to neutral voltages. Then

$$V_R = {765}/{\sqrt{3}} = 441.7\angle 0^\circ \text{ kV}$$

$$I_R = \left[\frac{(2000 + j1000)\times 10^6}{3\times 441.7\angle 0^\circ \times 10^3}\right]^* = 1688\angle -26.6^\circ \text{ A}$$

$$\begin{aligned} V(x) &= V_R \cosh(\gamma x) + I_R Z_c \sinh(\gamma x) \\ &= 441{,}700\angle 0^\circ \cosh(x\times 2.036\times 10^{-3}\angle 88.9^\circ) + \\ &\quad 443{,}440\angle -27.7^\circ \times \sinh(x\times 2.036\times 10^{-3}\angle 88.9^\circ) \end{aligned}$$

TRANSMISSION LINE EXAMPLE, ---CONT'D

- Squares and crosses show real and reactive power flow, where a positive value of flow means flow to the *left*.

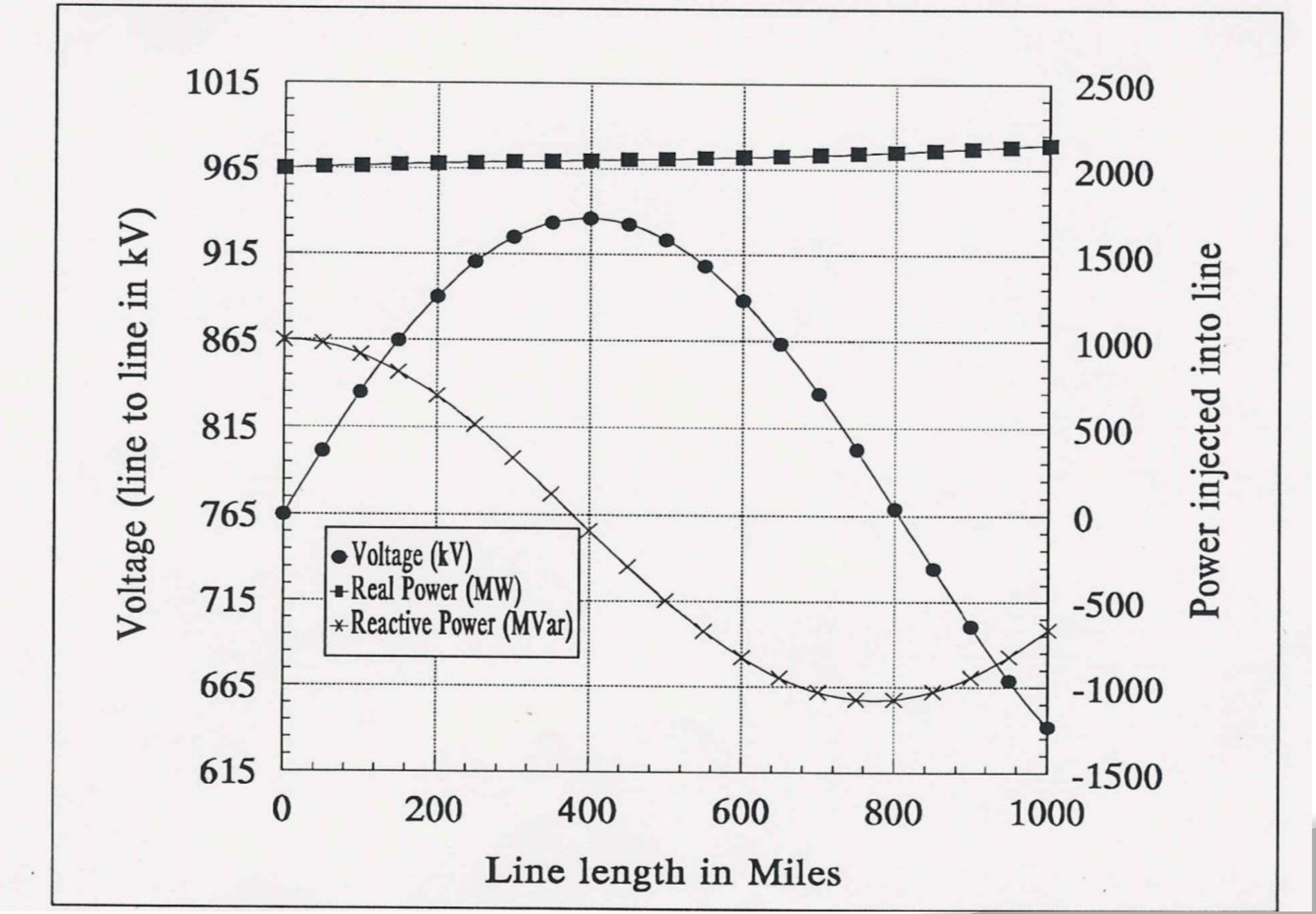


Fig.4: Transmission Line Example

LOSSLESS TRANSMISSION LINES

For a lossless line the characteristic impedance, Z_c, is known as the surge impedance.

$$Z_c = \sqrt{\frac{j\omega L}{j\omega C}} = \sqrt{\frac{L}{C}}\ \Omega \text{ (a real value)}$$

If a lossless line is terminated in impedance Z_c then:

$$Z_c = \frac{V_R}{I_R}$$

Then $I_R Z_c = V_R$ so we get...

LOSSLESS TRANSMISSION LINES

$$\begin{aligned} V(x) &= V_R\cosh(\gamma x) + I_R Z_c \sinh(\gamma x), \\ &= V_R\cosh\gamma x + V_R\sinh\gamma x, \\ &= V_R(\cosh\gamma x + \sinh\gamma x). \end{aligned}$$

$$\begin{aligned} I(x) &= I_R\cosh(\gamma x) + \frac{V_R}{Z_c}\sinh(\gamma x) \\ &= \frac{V_R}{Z_c}\cosh\gamma x + \frac{V_R}{Z_c}\sinh\gamma x, \\ &= \frac{V_R}{Z_c}(\cosh\gamma x + \sinh\gamma x) \end{aligned}$$

That is, for every location x, $\dfrac{V(x)}{I(x)} = Z_c.$

LOSSLESS TRANSMISSION LINES

Since the line is lossless this implies that for every location x, the real power flow is constant. Therefore:

Real power flow $= \Re(V(x)I(x)^*) = \Re(Z_c I(x)I(x)^*) =$

$\Re(Z_c\,|I(x)|^2) = Z_c\,|I(x)|^2$ is constant and equals $Z_c\,|I(0)|^2$.

Therefore, at each x, $|I(x)| = |I(0)| = |I_R|$.

So, since $\dfrac{V(x)}{I(x)} = Z_c$, $|V(x)| = |V(0)| = |V_R|$ and

Define $\dfrac{|V(x)|^2}{Z_c}$ to be the "surge impedance loading" (SIL).

If load power P > SIL then line consumes VArs; otherwise, the line generates VArs.

TRANSMISSION MATRIX MODEL

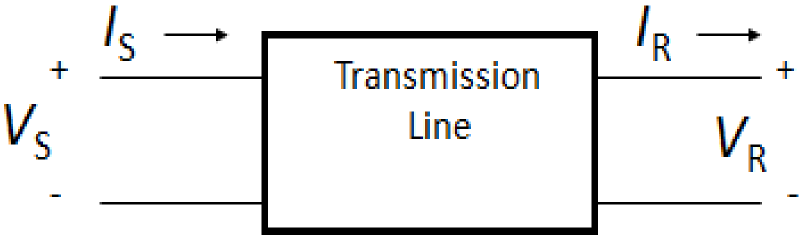


Fig.5: Transmission Matrix Model

With $\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$,

where A, B, C, D are determined from general equation noting that V_S and I_S correspond to x equaling length of line. Assume length of line is l.

TRANSMISSION MATRIX MODEL, ---CONT'D

With $\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$

Use voltage/current relationships to solve for A, B, C, D

$$V_S = V(l) = V_R \cosh \gamma l + Z_c I_R \sinh \gamma l$$

$$I_S = I(l) = I_R \cosh \gamma l + \frac{V_R}{Z_c} \sinh \gamma l$$

$$\mathbf{T} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cosh \gamma l & Z_c \sinh \gamma l \\ \frac{1}{Z_c} \sinh \gamma l & \cosh \gamma l \end{bmatrix}$$

EQUIVALENT CIRCUIT MODEL

A circuit model is another "black box" model.

We will try to represent as a π equivalent circuit.

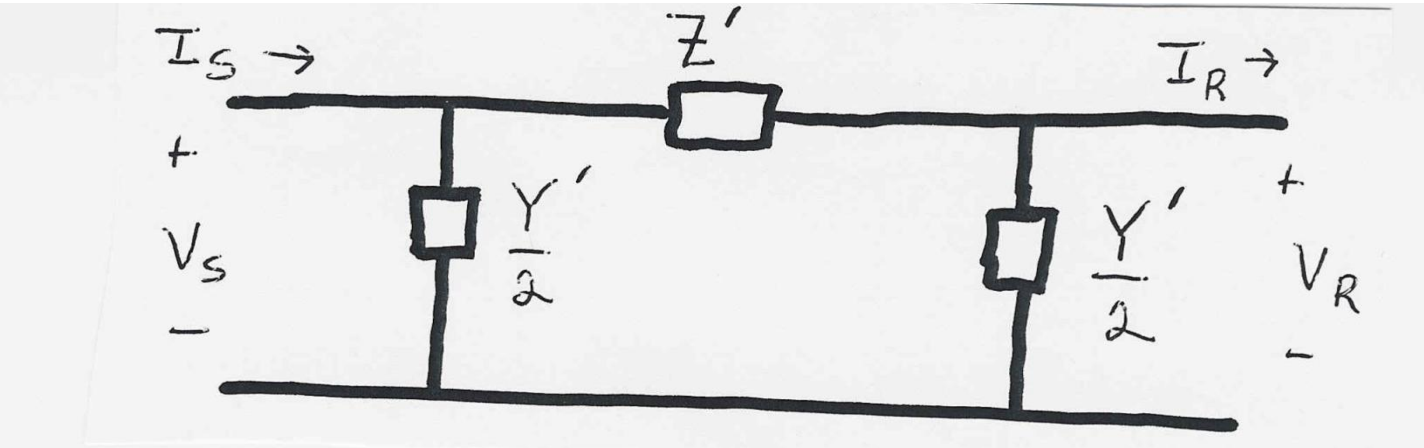


Fig.6: Equivalent Circuit Model

To do this, we'll use the **T** matrix values to derive the parameters *Z'* and *Y'* that match the behavior of the equivalent circuit to that of the **T** matrix.

We do this by first finding the relationship between sending and receiving end for the equivalent circuit.

EQUIVALENT CIRCUIT PARAMETERS

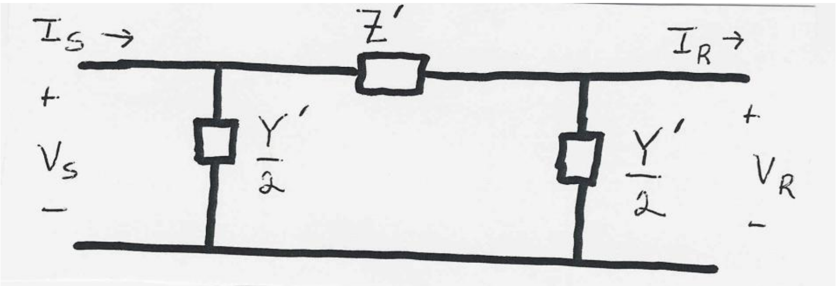


Fig.7: Equivalent Circuit Parameters

$$\frac{V_S - V_R}{Z'} - V_R \frac{Y'}{2} = I_R$$

$$V_S = \left(1 + \frac{Z'Y'}{2}\right) V_R + Z' I_R$$

$$I_S = V_S \frac{Y'}{2} + V_R \frac{Y'}{2} + I_R$$

$$I_S = Y'\left(1 + \frac{Z'Y'}{4}\right) V_R + \left(1 + \frac{Z'Y'}{2}\right) I_R$$

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} 1 + \frac{Z'Y'}{2} & Z' \\ Y'\left(1 + \frac{Z'Y'}{4}\right) & \left(1 + \frac{Z'Y'}{2}\right) \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

EQUIVALENT CIRCUIT PARAMETERS

We now need to solve for Z' and Y'.

Solve for Z' using B element:

$$B = Z_C \sinh \gamma l = Z'$$

Then using A we can solve for Y'

$$A = \cosh \gamma l = 1 + \frac{Z'Y'}{2}$$

$$\frac{Y'}{2} = \frac{\cosh \gamma l - 1}{Z_c \sinh \gamma l} = \frac{1}{Z_c} \tanh \frac{\gamma l}{2}$$

SIMPLIFIED PARAMETERS

These values can be simplified as follows:

$$Z' = Z_C \sinh \gamma l = \sqrt{\frac{z\,l\,zl}{y\,l\,zl}} \sinh \gamma l$$

$$= Z \frac{\sinh \gamma l}{\gamma l} \quad \text{with } Z \triangleq zl \quad (\text{recalling } \gamma = \sqrt{zy})$$

$$\frac{Y'}{2} = \frac{1}{Z_c} \tanh \frac{\gamma l}{2} = \sqrt{\frac{y\,l\,yl}{z\,l\,yl}} \tanh \frac{\gamma l}{2}$$

$$= \frac{Y}{2} \frac{\tanh {}^{\gamma l}\!/_{2}}{{}^{\gamma l}\!/_{2}} \quad \text{with } Y \triangleq yl$$

SIMPLIFIED PARAMETERS

For medium lines make the following approximations:

$$Z' = Z \qquad \left(\text{assumes } \frac{\sinh \gamma l}{\gamma l} \approx 1\right)$$

$$\frac{Y'}{2} = \frac{Y}{2} \qquad \left(\text{assumes } \frac{\tanh(\gamma l/2)}{\gamma l/2} \approx 1\right)$$

Length	$\frac{\sinh\gamma l}{\gamma l}$	$\frac{\tanh(\gamma l/2)}{\gamma l/2}$
50 miles	$0.998\angle 0.02°$	$1.001\angle -0.01°$
100 miles	$0.993\angle 0.09°$	$1.004\angle -0.04°$
200 miles	$0.972\angle 0.35°$	$1.014\angle -0.18°$

THREE LINE MODELS

Long Line Model (longer than 200 miles)

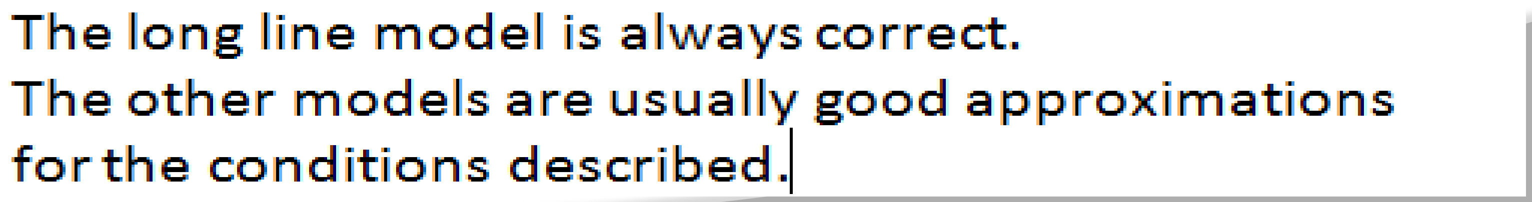
$$\text{use} \quad Z' = Z\frac{\sinh \gamma l}{\gamma l}, \qquad \frac{Y'}{2} = \frac{Y}{2}\frac{\tanh \gamma l/2}{\gamma l/2}$$

Medium Line Model (between 50 and 200 miles)

$$\text{use} \quad Z \text{ and } \frac{Y}{2}$$

Short Line Model (less than 50 miles)

use Z (i.e., assume Y is zero)



The long line model is always correct.
The other models are usually good approximations for the conditions described.

POWER TRANSFER IN SHORT LINES

- Often we'd like to know the maximum power that could be transferred through a short transmission line

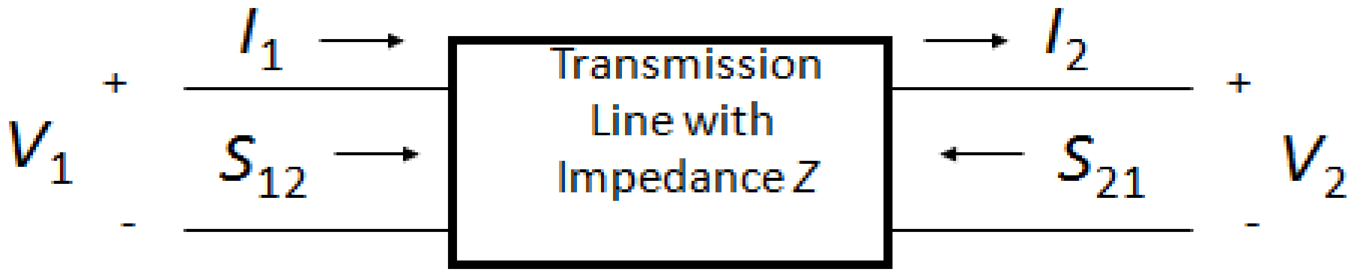


Fig.8: Short Transmission Line Matrix Model

$$S_{12} = V_1 I_1^* = V_1\left(\frac{V_1 - V_2}{Z}\right)^*$$

$$\text{with } V_1 = |V_1|\angle\theta_1, \quad V_2 = |V_2|\angle\theta_2, \quad Z = |Z|\angle\theta_Z$$

$$S_{12} = \frac{|V_1|^2}{|Z|}\angle\theta_Z - \frac{|V_1||V_2|}{|Z|}\angle(\theta_Z + \theta_{12})$$

POWER TRANSFER IN LOSSLESS LINES

If we assume a line is lossless with impedance jX and are just interested in real power transfer then:

$$P_{12} + jQ_{12} = \frac{|V_1|^2}{|Z|}\angle 90^\circ - \frac{|V_1||V_2|}{|Z|}\angle(90^\circ + \theta_{12})$$

Since $-\cos(90^\circ + \theta_{12}) = \sin\theta_{12}$, we get

$$P_{12} = \frac{|V_1||V_2|}{X}\sin\theta_{12}$$

Hence the maximum power transfer is

$$P_{12}^{Max} = \frac{|V_1||V_2|}{X},$$

This power transfer limit is called the steady-state stability limit.

LIMITS AFFECTING MAX. POWER TRANSFER

- Thermal limits
  - limit is due to heating of conductor and hence depends heavily on ambient conditions.
  - For many lines, sagging is the limiting constraint.
  - Newer conductors/materials limit can limit sag.
  - Trees grow, and will eventually hit lines if they are planted under the line,
  - Note that thermal limit is different to the steady-state stability limit that we just calculated:
    - Thermal limits due to losses,
    - Steady-state stability limit applies even for lossless line!

TREE TRIMMING: BEFORE

Fig.9: Transmission Line Before Tree Trimming

TREE TRIMMING: AFTER


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Fig.10: Transmission Line after Tree Trimming

OTHER LIMITS AFFECTING POWER TRANSFER

- Angle limits
  - while the maximum power transfer (steady-state stability limit) occurs when the line angle difference is 90 degrees, actual limit is substantially less due to interaction of multiple lines in the system
- Voltage stability limits
  - as power transfers increases, reactive losses increase as I^2X. As reactive power increases the voltage falls, resulting in a potentially cascading voltage collapse.

INTRODUCTION TO WAVE PROPAGATION

- Waves on transmission lines
- Plane waves in one dimension
- Reflection and transmission at junctions
- Spatial variations for harmonic time dependence
- Impedance transformations in space
- Effect of material conductivity

WAVES ON TRANSMISSION LINES

- Equivalent circuits using distributed C and L
- Characteristic wave solutions
- Power flow

EXAMPLES OF TRANSMISSION LINES

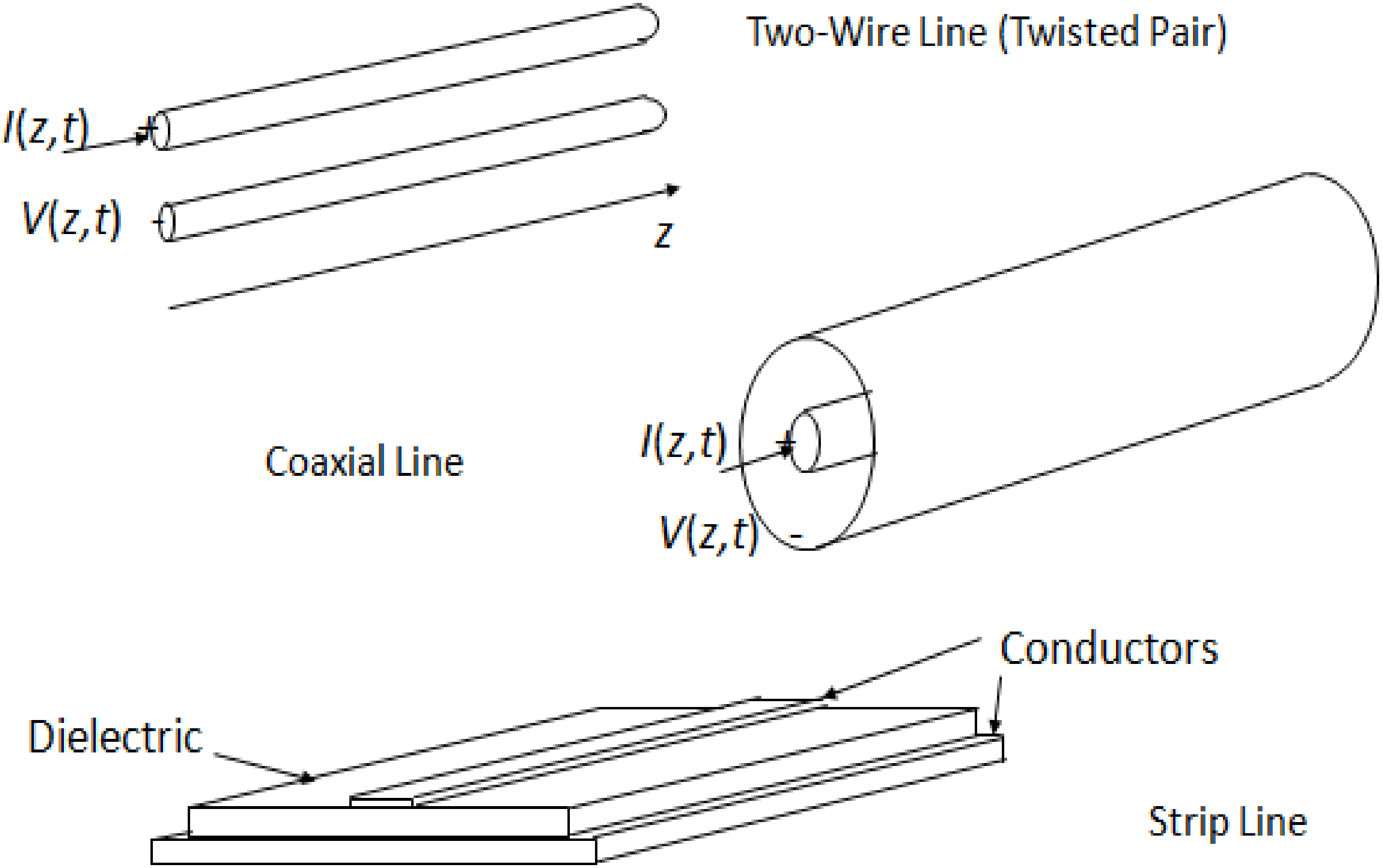


Fig: Transmission Lines Examples

PROPERTIES OF TRANSMISSION LINES (TL'S)

- Two wires having a uniform cross-section in one (*z*) dimension
- Electrical quantities consist of voltage *V*(*z*,*t*) and current *I*(*z*,*t*) that are functions of distance z along the line and time *t*
- Lines are characterized by distributed capacitance *C* and inductance *L* between the wires

  \- *C* and *L* depend on the shape and size of the conductors and the material between them

CAPACITANCE OF A SMALL LENGTH OF LINE

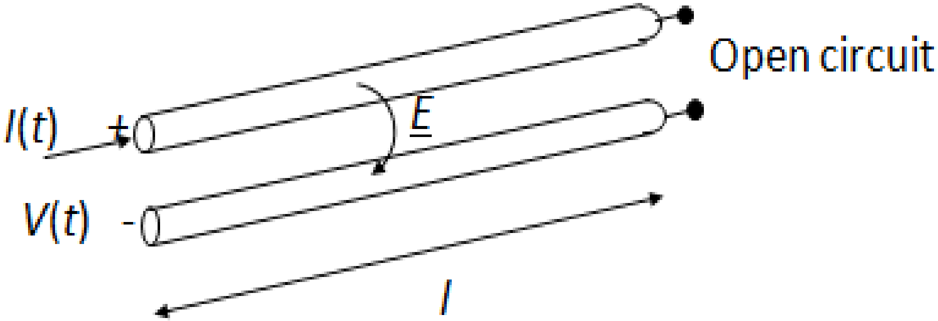


Fig: Transmission Line Small Length Capacitance

The two wires act as a capacitor. Voltage applied to the wires induces a charge on the wires, whose time derivative is the current. Since the total charge, and hence the current, is proportional to the length l of the wires. Let the constant of proportionality be C Farads/meter. Then

$$I(t) = Cl\frac{dV(t)}{dt}$$

INDUCTANCE OF A SMALL LENGTH OF LINE

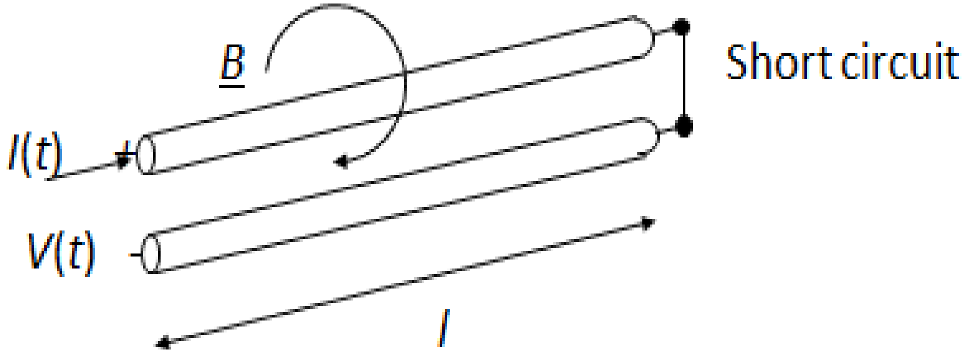


Fig: Transmission Line Small Length Inductance

The wire acts as a one - turn coil. Current applied to the wires induces a magnetic field throught the loop, whose time derivative generates the voltage. The amount of magnetic flux (magnetic field × area), and hence the voltage, is proportional to the length l of the wires. Let the constant of proportality be L Henrys/meter. Then

$$V(t) = Ll\frac{dI(t)}{dt}$$

TRANSMISSION LINE EQUATIONS

Taking the limit as $\Delta z \to 0$ gives the Transmission Line Equations

$$\frac{\partial V(z,t)}{\partial z} = -L\frac{\partial I(z,t)}{\partial t} \qquad \frac{\partial I(z,t)}{\partial z} = -C\frac{\partial V(z,t)}{\partial t}$$

These are coupled, first order, partial differential equations whose solutions are in terms of functions $F(t - z/v)$ and $G(t + z/v)$ that are determined by the sources. The solutions for voltage and current are of the form

$$V(z,t) = F(t - z/v) + G(t + z/v) \qquad I(z,t) = \frac{1}{Z}\left[F(t - z/v) - G(t + z/v)\right]$$

Direct substitution into the TL Equations, and using the chain rule gives

$$-\frac{1}{v}\left[F'(t - z/v) - G'(t + z/v)\right] = -L\frac{1}{Z}\left[F'(t - z/v) - G'(t + z/v)\right]$$

$$-\frac{1}{vZ}\left[F'(t - z/v) + G'(t + z/v)\right] = -C\left[F'(t - z/v) + G'(t + z/v)\right]$$

where the prime (') indicates differentiation with respect to the total variable inside the parentheses of F or G.

CONDITIONS FOR EXISTENCE OF TL SOLUTION

For the two equations to be satisfied

$$\frac{1}{v} = \frac{L}{Z} \qquad \text{and} \qquad \frac{1}{vZ} = C$$

Multiplying both sides of the two equations gives $\frac{1}{v^2 Z} = \frac{LC}{Z}$ or

$$v = \frac{1}{\sqrt{LC}} \ \text{m/s}$$

Dividing both sides of the two equations gives $\frac{vZ}{v} = \frac{L}{ZC}$ or

$$Z = \sqrt{\frac{L}{C}} \ \Omega$$

v and Z are interpreted as the wave velocity and wave impedance.

REFLECTION AND TRANSMISSION AT JUNCTIONS

- Junctions between different propagation media
- Reflection and transmission coefficients for 1-D propagation
- Conservation of power, reciprocity
- Multiple reflection/transmission

JUNCTIONS BETWEEN TWO REGIONS

Terminal condtions for the Junction of two TL's

$$V(0^-,t) = V(0^+,t)$$

$$I(0^-,t) = I(0^+,t)$$

Boundary conditions at the interface of two media

$$E_x(0^-,t) = E_x(0^+,t)$$

$$H_y(0^-,t) = H_y(0^+,t)$$

Plane wave propagation and boundary conditions are analogus to junctioning of two TL's

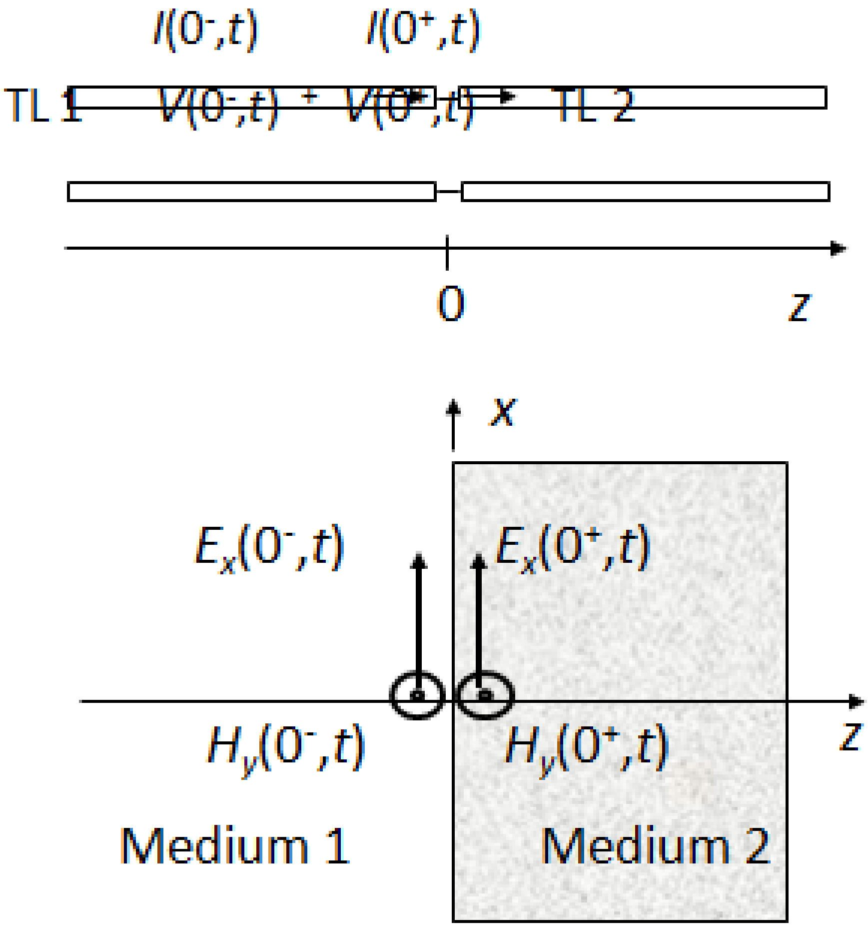


Fig: Reflection and Transmission at Junctions

REFLECTION AND TRANSMISSION

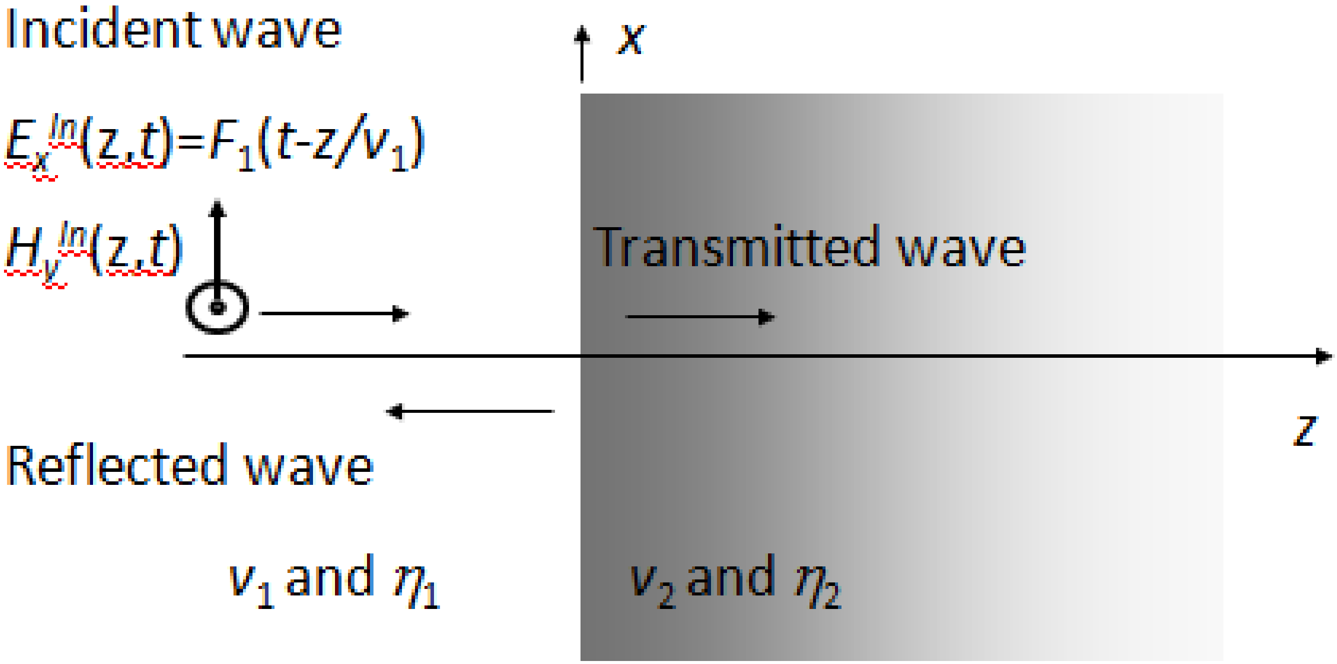


Fig: Reflection and Transmission

A source creates an incident wave whose electric field is given by the known function $F_1(t - z/v_1)$. Using the boundary conditions we solve for the unknown functions $G_1(t + z/v_1)$ and $F_2(t - z/v_2)$ for the electric fields of the reflected and transmitted waves:

$$E_x(0^-,t) = F_1(t) + G_1(t) = F_2(t) = E_x(0^+,t)$$

$$H_y(0^-,t) = \frac{1}{\eta_1}\left[F_1(t) - G_1(t)\right] = \frac{1}{\eta_2}F_2(t) = H_y(0^+,t)$$

SUMMARY OF REFLECTION AND TRANSMISSION

- The planar interface between two media is analogous to the junction of two transmission lines
- At a single interface (junction) the equation T = 1 + G is a statement of the continuity of electric field (voltage)
- The ratio of reflected to incident power = $G^{\square}$
- Power is conserved so that the ratio of transmitted to incident power = 1 - $G^{\square}$
- The reciprocity condition implies that reflected and transmitted power are the same for incidence from either medium
- At multiple interfaces, delayed multiple interactions complicate the description of the reflected and transmitted fields for arbitrary time dependence

UNIT 3

OVERHEAD INSULATORS AND UNDERGROUND CABLES

OVERHEAD INSULATORS

If overhead power lines are not properly insulated from their support poles/towers, the current will flow towards the ground through the poles/towers which also become hazardous. Of course, the power line won't even work in that case! Hence, overhead power lines are always supported on insulators mounted on their support poles/towers.

Overhead line insulators should have the following properties

- High mechanical strength in order to withstand the conductor load, wind load etc.
- High electrical resistance in order to minimize the leakage currents
- High relative permittivity of insulating material so that the dielectric strength is high
- High ratio of puncture strength to flashover

Most commonly used material for overhead line insulators is porcelain. But glass, steatite and some other special composite material may also be used sometimes.

TYPES OF OVERHEAD INSULATORS

For the successful operation of power lines, proper selection of insulators is very essential. There are several **types of overhead line insulators**.

Most commonly used types are

- Pin type insulators
- Suspension type insulators
- Strain insulators
- Shackle insulators

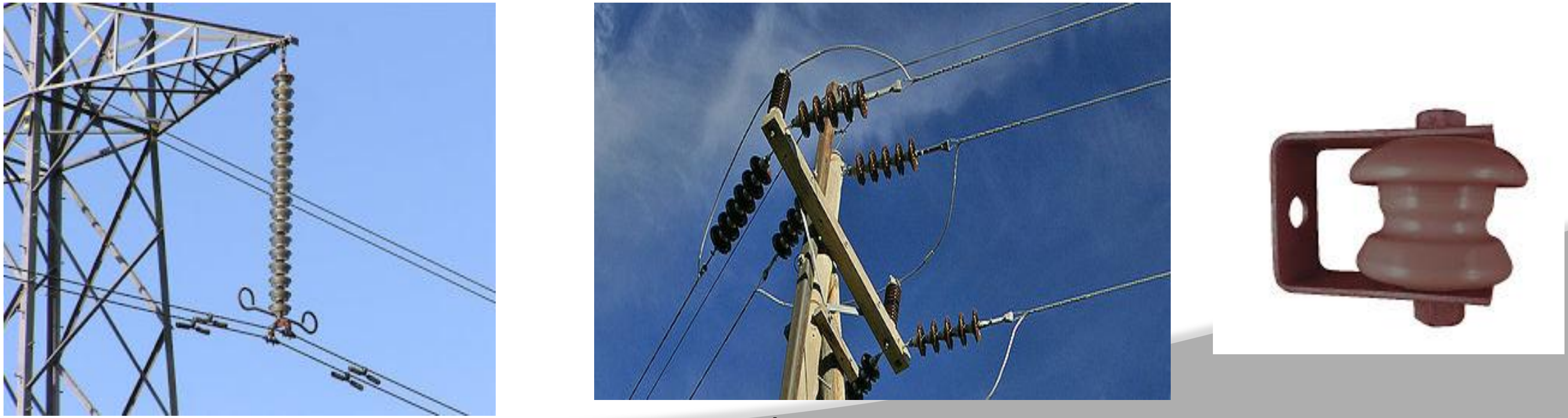


Fig.1: Various Insulators

VOLTAGE DISTRIBUTION OVER SUSPENSION INSULATOR

Let, there are 5 nos. disc insulators which are connected in series through metallic link and suspense from line tower which is shown in the figure. From the figure, it is seen that porcelain portion of each disc is in between two metal links.

Therefore each disc forms a capacitor C as shown in fig. It is known as mutual capacitance or self-capacitance. And capacitance also exists between metal fitting of each disc and tower or earth. This is known as shunt capacitance mc. Due to the shunt capacitance, the charging current is not the same though all the disc of string. Hence, the voltage across each disc will be different. And voltage across to the nearest conductor will have the maximum voltage. The reference to Fig. V5 will be more than V4 or V3 or V2 or V1.

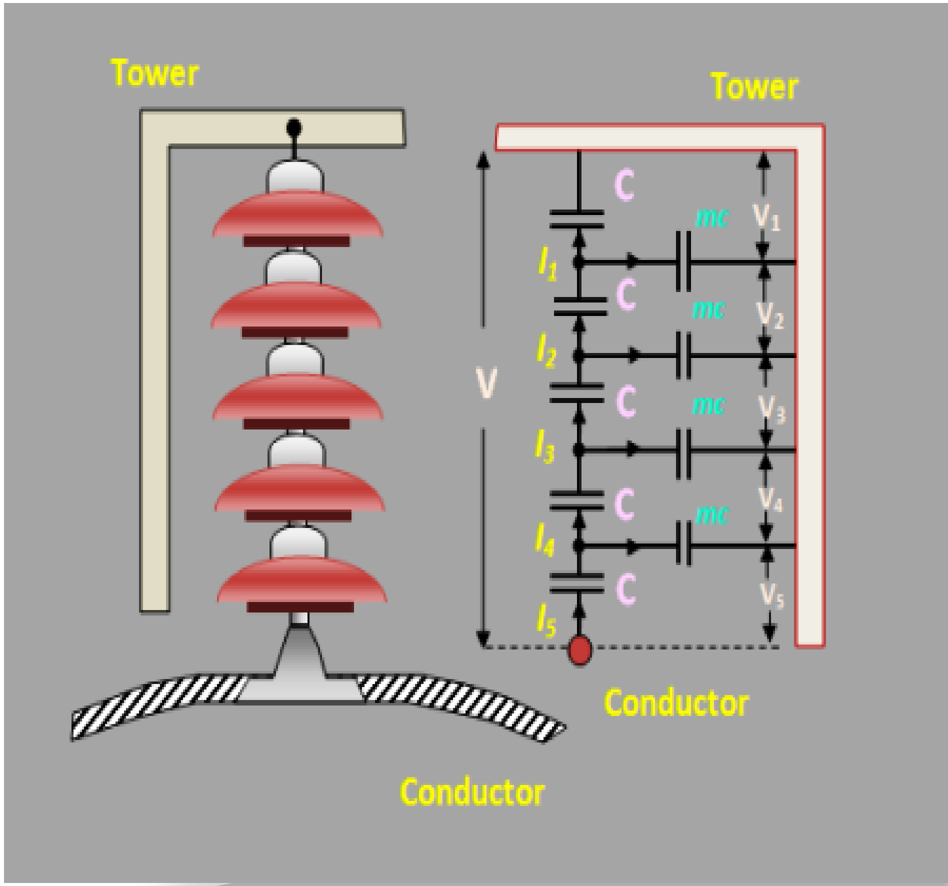


Fig.2: Voltage Distribution in a String

VOLTAGE DISTRIBUTION OVER SUSPENSION INSULATOR

The following points may be noted regarding the potential distribution over a string of suspension insulators:

- Due to the presence of shunt capacitor, the voltage across the suspension insulators does not distribute itself uniformly across the each disc.
- The voltage across the nearest disc to the conductor is maximum than others disc.
- The unit nearest to the conductor is under maximum electrical stress and is likely to be punctured.
- In the case of D.C voltage, the voltage across each unit would be the same. It is because insulator capacitance are ineffective for D.C.

STRING EFFICIENCY

The Ratio of the voltage across the whole string to the product of numbers of discs and the voltage across the disc nearest to the conductor is known as string efficiency.

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

N = number of disc insulator.

String efficiency is important for the overhead transmission line. The greater the string efficiency, the more uniform is the voltage distribution in the each disc insulator. In the ideal case, the value of string efficiency will be 100%, but, in a normal case, it is impossible to achieve 100% string efficiency, yet effort should be made to improve it as close to this value as possible.

MATHEMATICAL EXPRESSION OF STRING EFFICIENCY

- Applying Kirchhoff's current law to node A, we get ,
  $I_2 = I_1 + i_1$
  Or, $V_2\omega C = V_1\omega C + V_1\omega C_1$
  Or, $V_2\omega C = V_1\omega C + V_1\omega KC$
  $V_2 = V_1(1+K)$.................(i)
- Applying Kirchhoff's current law to node B, we get ,
  $I3 = I2 + i2$
  Or $V_3\omega C = V_2\omega C + (V_1+V_2)\,\omega C_1$
  Or $V_3\omega C = V_2\omega C + (V_1+V_2)\,\omega KC$
  Or $V_3 = V_2 + (V_1+V_2)\,K$
  $= KV_1 + V_2(1+K)$
  $= KV_1 + V_1(1+K)^2$
  $= V_1[K+(1+K)^2]$
  $V_3 = V_1[1+3K+K^2]$.................(ii)
- Voltage between conductor and earth (i,e., tower)
  $V = V_1 + V_2 + V_3$
  $= V_1 + V_1(1+K) + V_1(1+3K+K^2)$
  $= V_1(3+4K+K^2)$ ....(iii)

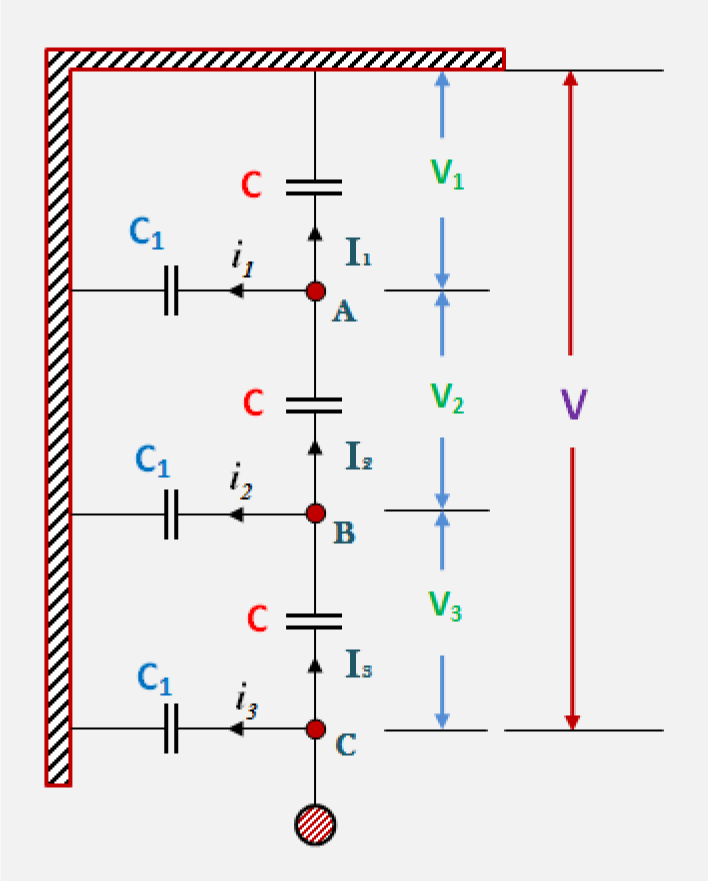


Fig.3: Efficiency of a String

MATHEMATICAL EXPRESSION OF STRING EFFICIENCY

Voltage across second unit from top ,

$V_2 = V_1 (1 + K)$

Voltage across third unit from top,

$V_3 = V_1(1 + 3K + K^2)$

$$\% \text{ String efficiency} = \frac{\textit{Voltage across the string}}{n \ X \ \textit{Voltage across disc nearest to conductor}} \ X \ 100$$

$$= \frac{V}{(3+V3)} \ X \ 100$$

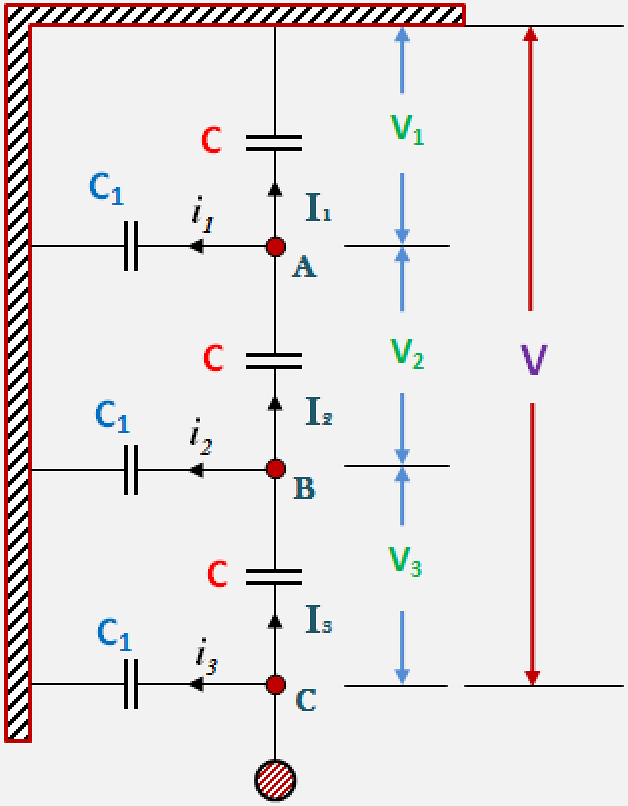


Fig.4: Efficiency of a String

The following points may be noted from the above mathematical analysis:

- If K=0.2 (Say) , then we get , $V_2 = 1.2 V_1$, and $V_3 = 1.64 V_1$. This clearly shows that disc nearest to the conductor has maximum voltage across it, the voltage across other discs decreasing progressively as the cross arm in approached.
- The greater the value of **K, (= C_1/C)**, the more non-uniform is the voltage across the discs and lesser the value of string efficiency.
- The unequally in voltage distribution increase with the increase of numbers of discs. Hence, the shorter string has more efficiency than the larger one.

UNDERGROUND CABLES

Introduction

Since the loads having the trends towards growing density. This requires the better appearance, rugged construction, greater service reliability and increased safety. An underground cable essentially consists of one or more conductors covered with suitable insulation and surrounded by a protecting cover. The interference from external disturbances like storms, lightening, ice, trees etc. should be reduced to achieve trouble free service. The cables may be buried directly in the ground, or may be installed in ducts buried in the ground.

CABLE STRUCTURE

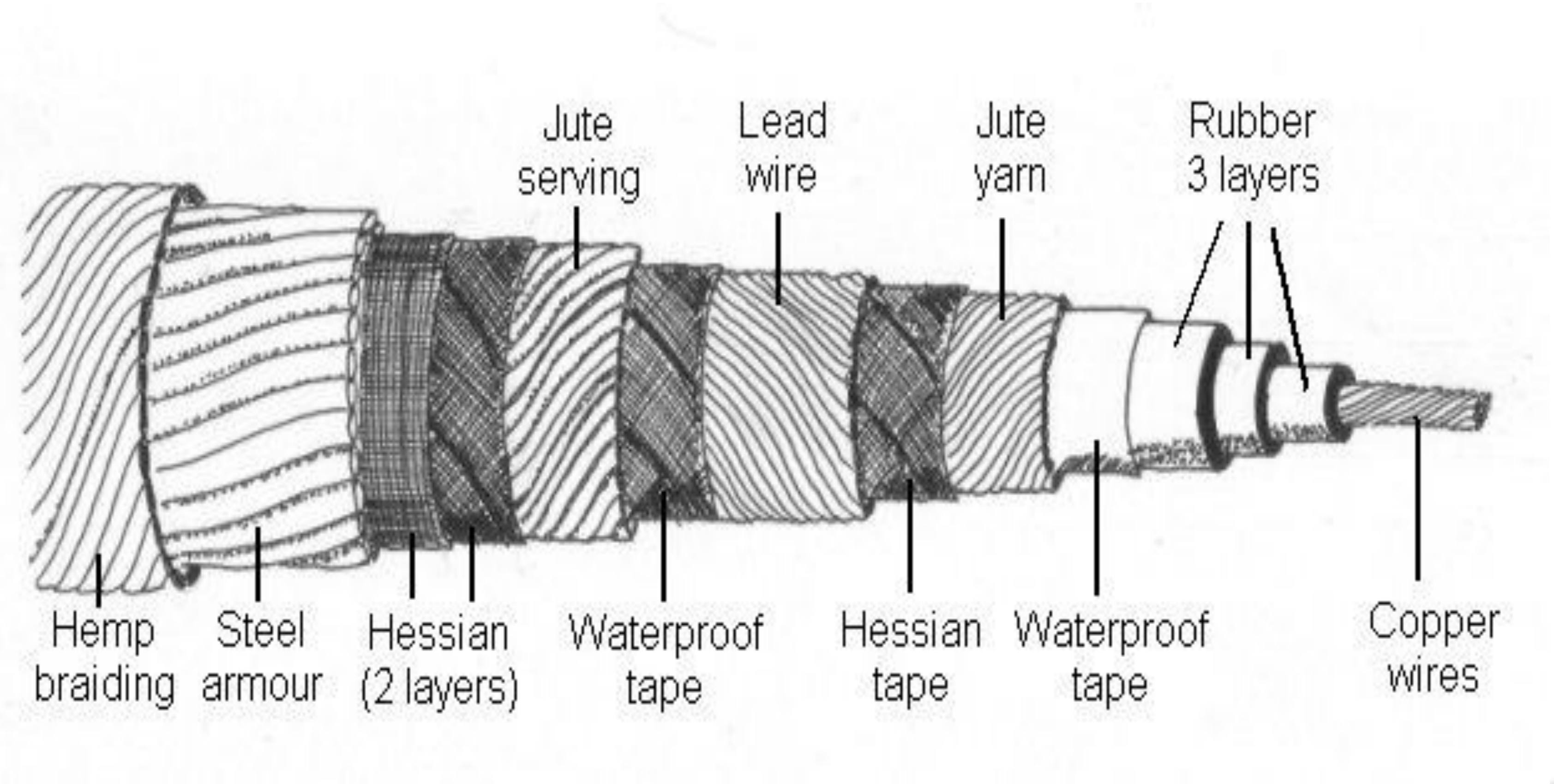


Fig.5: Structure of a Cable

Advantages & Disadvantages

Advantages

- Better general appearance
- Less liable to damage through storms or lighting
- Low maintenance cost
- Less chances of faults
- Small voltage drops

Disadvantages

- The major drawback is that they have greater installation cost and introduce insulation problems at high voltages compared with equivalent overhead system.

Construction of Cables

- Core or Conductor

  A cable may have one or more than one core depending upon the type of service for which it is intended. The conductor could be of aluminum or copper and is stranded in order to provide flexibility to the cable.

- Insulation

  The core is provided with suitable thickness of insulation, depending upon the voltage to be withstood by the cable.

  The commonly used material for insulation are impregnated paper, varnished cambric or rubber mineral compound.

---CONT'D

- Metallic Sheath

  A metallic sheath of lead or aluminum is provided over the insulation to protect the cable from moisture, gases or others damaging liquids

- Bedding

  Bedding is provided to protect the metallic sheath from corrosion and from mechanical damage due to armoring. It is a fibrous material like jute or hessian tape.

---Cont'd

- Armouring

  Its purpose is to protect the cable from mechanical injury while laying it or during the course of handling. It consists of one or two layers of galvanized steel wire or steel tape.

- Serving

  To protect armouring from atmospheric conditions, a layer of fibrous material is provided.

Properties of Insulating Material

- High resistivity.
- High dielectric strength.
- Low thermal co-efficient.
- Low water absorption.
- Low permittivity.
- Non – inflammable.
- Chemical stability.
- High mechanical strength.
- High viscosity at impregnation temperature.
- Capability to with stand high rupturing voltage.
- High tensile strength and plasticity.

Properties of Insulating Material

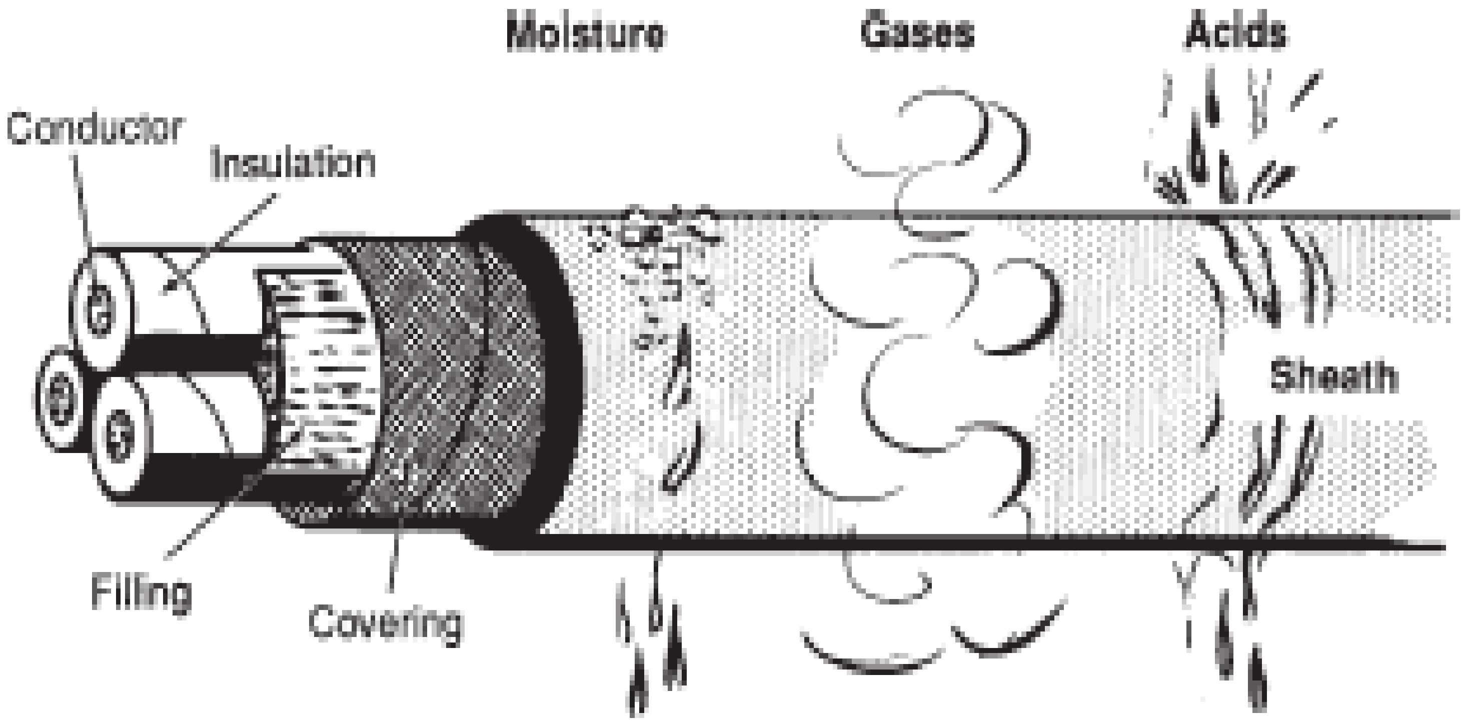


Fig.6: Insulation Properties

CLASSIFICATION OF CABLES

- Low tension (L.T) ----- up to 1000V
- High tension (H.T) ----- up to 11, 000V
- Super tension (S.T) ---- from 22KV to 33KV
- Extra high tension (E.H.T) cables --- from 33KV to 66KV
- Extra super voltage cables ------beyond 132KV

3- CORE CABLES

Belted Cables

- In these cables the conductors are wrapped with oil impregnated paper, and then cores are assembled with filler material. The assembly is enclosed by paper insulating belt.
- These can be used for voltages up to 11KV or in some cases can be used up to 22KV.
- High voltages beyond 22KV, the tangential stresses becomes an important consideration.
- As the insulation resistance of paper is quite small along the layer, therefore tangential stress set up, hence, leakage current along the layer of the paper insulation.
- This leakage current causes local heating, resulting breaking of insulation at any moment

---CONT'D

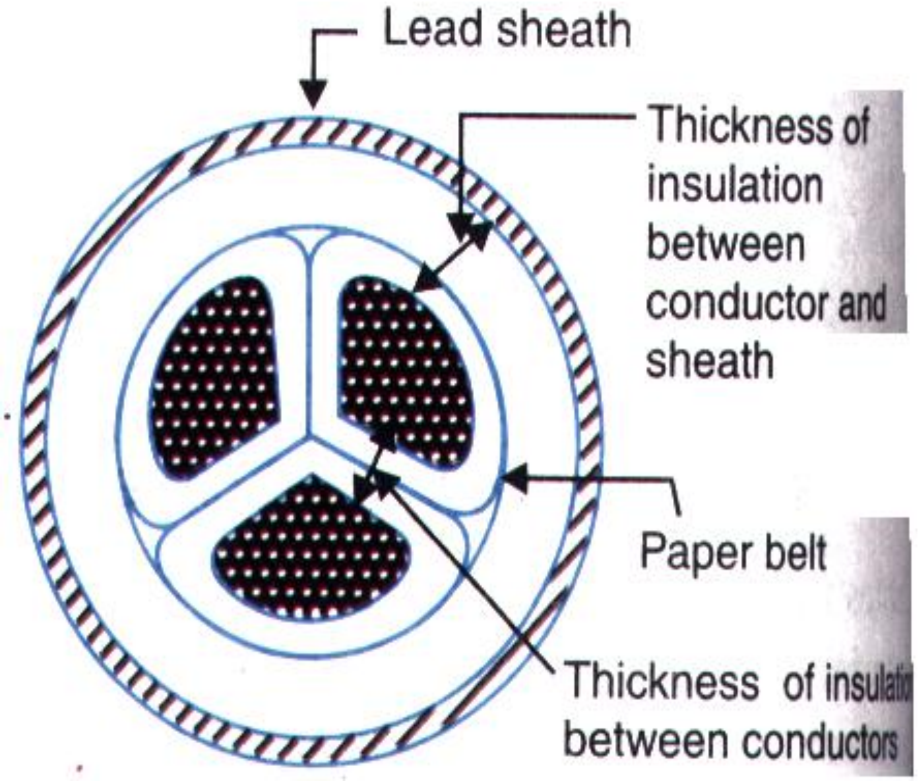


Fig.7: 3-Core Cable

DIRECT LAYING

Fig.8: Cable Direct Laying

GRADING OF CABLES

- Since the stresses are maximum at surface of the conductor or inner most part of the dielectric.
- The stress goes on decreasing as outer most layer is reached.
- Since the process of achieving the uniform electrostatic stresses on the dielectric of cables is known as Grading of cables

- The unequal distribution of stresses is undesirable because,
- if dielectric is chosen according to maximum stress the thickness of cable increases or either this may lead to breakdown of insulation.
- The following are the two main methods of grading
- ➢ Capacitance grading
- ➢ Inter sheath grading

SUMMARY OF COSTS: OVERHEAD VS. UNDERGROUND

- Transmission: Underground may be 4-20 times Overhead.
- Sub transmission: Underground may be 4-20 times Overhead
- Distribution: Underground may be 2-10 times Overhead
- New underground may be cheaper than overhead in special conditions and costs vary greatly from utility to utility and place to place.

UNIT 4

MECHANICAL DESIGN OF TRANSMISSION LINES

SAG AND TENSION

Definition of Sag:

Sag in overhead Transmission line conductor refers to the difference in level between the point of support and the lowest point on the conductor.

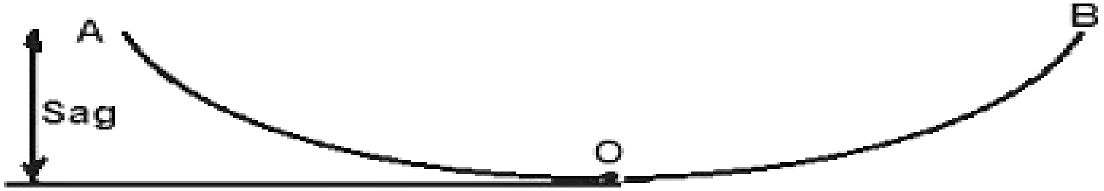


Fig.1: Sag in a transmission line

As shown in the figure above, a Transmission line is supported at two points A and B of two different Transmission Towers. It is assumed that points A and B are at the same level from the ground. Therefore as per our definition of Sag, difference in level of point A or B and lowest point O represents the Sag.

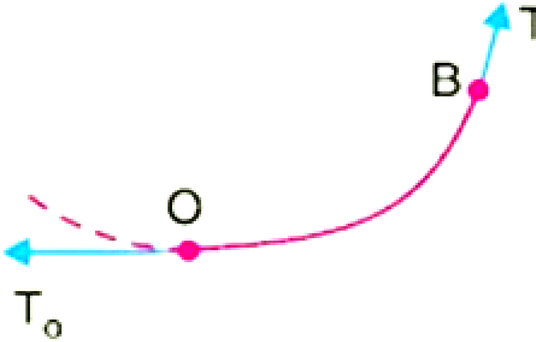
SAG AND TENSION

- Sag in Transmission line is very important. While erecting an overhead Transmission Line, it should be taken care that conductors are under safe tension.
- If the conductors are too much stretched between two points of different Towers to save conductor material, then it may happen so that the tension is conductor reaches unsafe value which will result conductor to break.
- Therefore, in order to have safe tension in the conductor, they are not fully stretched rather a sufficient dip or Sag is provided.
- The dip or Sag in Transmission line is so provided to maintain tension in the conductor within the safe value in case of variation in tension in the conductor because of seasonal variation

SAG AND TENSION

Some very basic but important aspects regarding Sag are as follows:

1) As shown in the figure above, if the point of support of conductor is at same level from the ground, the shape of Sag is Catenary. Now we consider a case where the point of support of conductor are at same level but the Sag is very less when compared with the span of conductor. Here **span** means the horizontal distance between the points of support. In such case, the Sag-span curve is parabolic in nature.



2) The tension at any point on the conductor acts tangentially as shown in figure above. Thus the tension at the lowest point of the conductor acts horizontally while at any other point we need to resolve the tangential tension into vertical and horizontal component for analysis purpose. The horizontal component of tension remains constant throughout the span of conductor.

CALCULATION OF SAG

- Enough sag shall be provided in overhead transmission line to keep the tension within the safe limit. The tension is generally decided by many factors like wind speed, ice loading, temperature variations etc.
- Normally the tension in conductor is kept one half of the ultimate tensile strength of the conductor and therefore safety factor for the conductor is 2.

Now, we will calculate the Sag in an overhead transmission line for two cases.

Case 1 : When the conductor supports are at equal level.

Case 2 : When the conductor supports are at unequal level.

Case 1: When the Conductor Supports are at Equal Level

Let us consider an overhead line supported at two different towers which are at same level from ground. The point of support are A and B as shown in figure below. O in the figure shows the lowest point on the conductor. This lowest point O lies in between the two towers i.e. point O bisects the span equally.

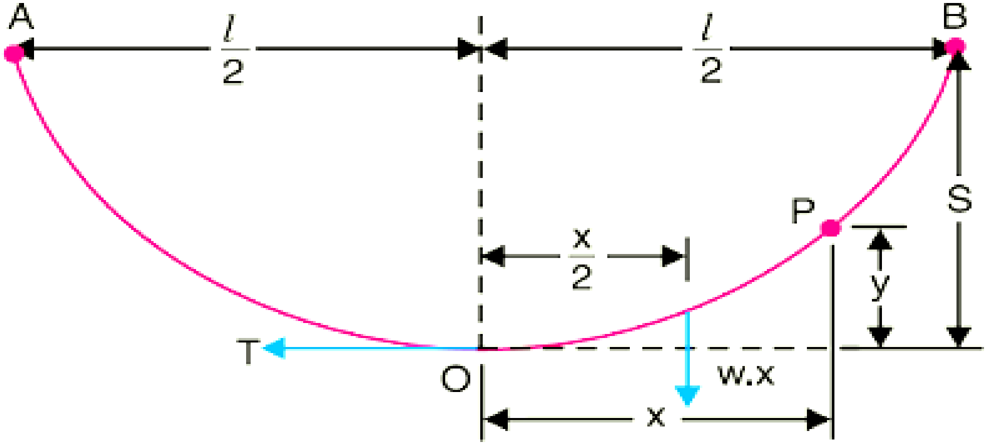


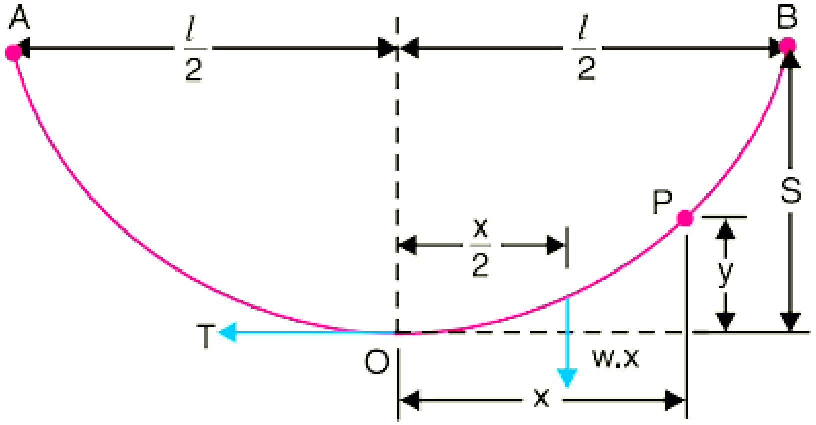
Fig.2: Supports at Equal Levels

Let,

- L = Horizontal distance between the towers i.e. Span
- W = Weight per unit length of conductor
- T = Tension in the conductor

---CONT'D

- Let us take any point P on the conductor. Assuming O as origin, the coordinate of point P will be (x,y).
- Therefore, weight of section OP = Wx acting at distance of x/2 from origin O.
- As this section OP is in equilibrium, hence net torque w.r.t point P shall be zero.



- Torque due to Tension T = Torque due to weight Wx

$$Ty = Wx(x/2)$$

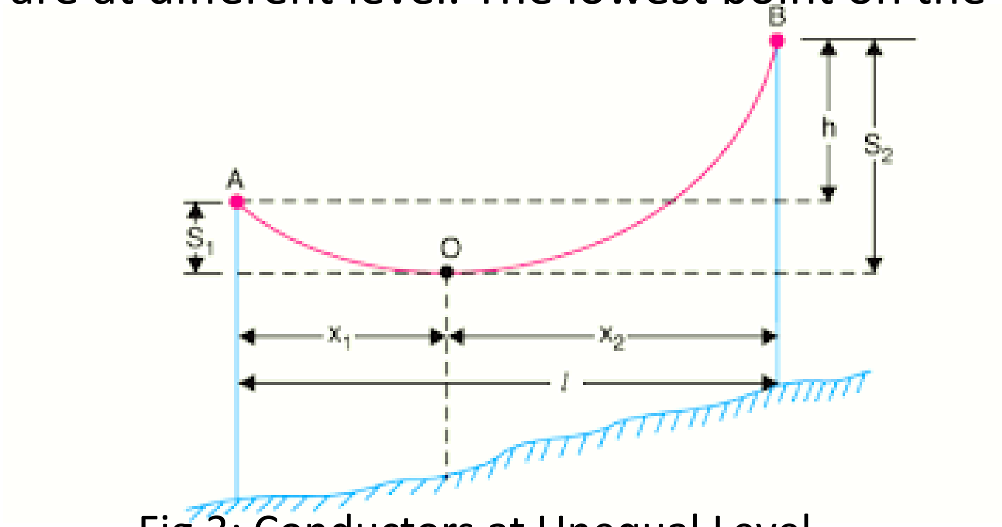
Therefore, $\mathbf{y = Wx^2 / 2T}$ **.......(1)**

For getting Sag, put x = L/2

$$\mathbf{Sag = WL^2/8T}$$

Case 2: When the Conductor Supports are at Unequal Level

In hilly area, the supports for overhead transmission line conductor do not remain at the same level. Figure below shows a conductor supported between two points A and B which are at different level. The lowest point on the conductor is O.



Let,

Fig.3: Conductors at Unequal Level

- L = Horizontal distance between the towers i.e. Span
- H = Difference in level between the two supports
- T = Tension in the conductor
- X_1 = Horizontal distance of point O from support A
- X_2 = Horizontal distance of point O from support B
- W = Weight per unit length of conductor

---CONT’D

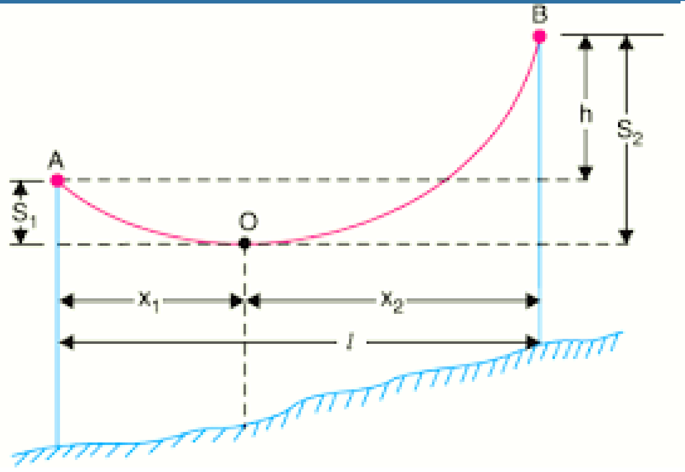


Fig.4: Conductors at Unequal Level

From equation (1),

Sag $S_1 = WX_1^2/2T$

and Sag $S_2 = WX_2^2/2T$

Now,

$S_1 – S_2 = (W/2T)[X_1^2 – X_2^2]$

$= (W/2T)(X_1 – X_2)(X_1 + X_2)$

But $X_1 + X_2 = L$ ……………………..(2)

So, $S_1 – S_2 = (WL/2T)(X_1 – X_2)$

$X_1 – X_2 = 2(S_1 – S_2)T / WL$

$X_1 – X_2 = 2HT / WL$ (As $S_1 – S_2 = H$)

$X_1 – X_2 = 2HT / WL$ ………………..(3)

Solving equation (2) and (3) we get,

$X_1 = L/2 – TH/WL$

$X_2 = L/2 + TH/WL$

By putting the value of X_1 and X_2 in Sag equation, we can easily find the value of S_1 and S_2.

EFFECT OF WIND AND ICE LOADING ON SAG:

- The above equations for Sag are only valid in ideal situation. Ideal situation refers to a condition when no wind is flowing and there is no any effect of ice loading.
- But in actual practise, there always exists a wind pressure on the conductor and as far as the ice loading is concerned, it is mostly observed in cold countries. In a country like India, ice loading on transmission line is rarely observed.

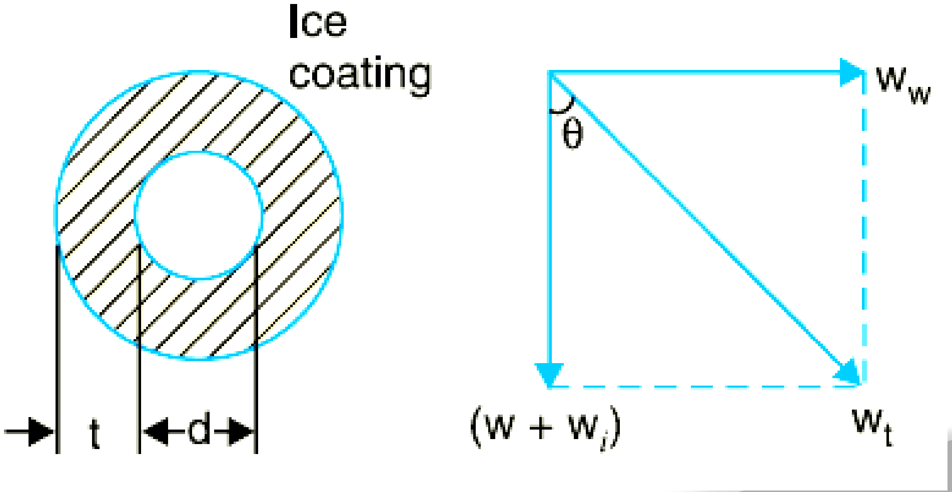


Fig.5: Ice Coating on Conductor

EFFECT OF WIND AND ICE LOADING ON SAG:

Coating of ice on conductor (it is assumed that ice coating is uniformly distributed on the surface of conductor) increases the weigh of the conductor which acts in vertically downward direction. But the wind exerts a pressure on the conductor surface which is considered horizontal for the sake of calculation.

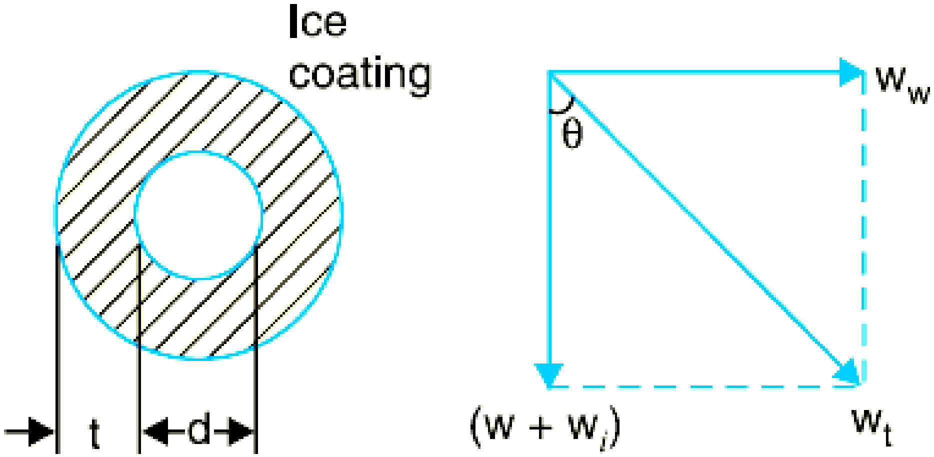


Fig.6: Ice Coating on Conductor

- As shown in figure above, net weight acting vertically downward is sum of weight of ice and weight of conductor. Therefore,

Net weight of conductor per unit length $W_t = \sqrt[2]{(Wi + W)^2 + Ww^2}$

EFFECT OF WIND AND ICE LOADING ON SAG:

Net weight of conductor per unit length $W_t = \sqrt[2]{(Wi + W)^2 + Ww^2}$

Here,

W = Weight of conductor per unit length

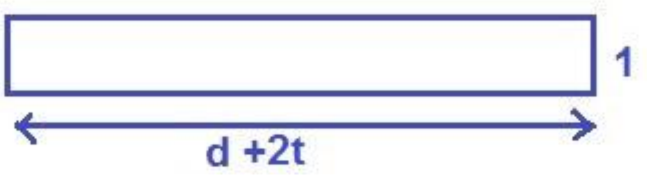
W_i = Weight of ice per unit length

W_w = Wind force per unit length

= Wind PressurexArea

= Wind Presuurex(2d+t)x1

Note the way of calculation of Area of conductor. What I did, I just stretched the conductor along the diameter to make a rectangle as shown in figure below.



Thus from equation (1),

Sag = $W_tL^2/2T$

and the angle made by conductor from vertical = tanϴ

= $W_w / (W+W_i)$

STRINGING CHART

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.

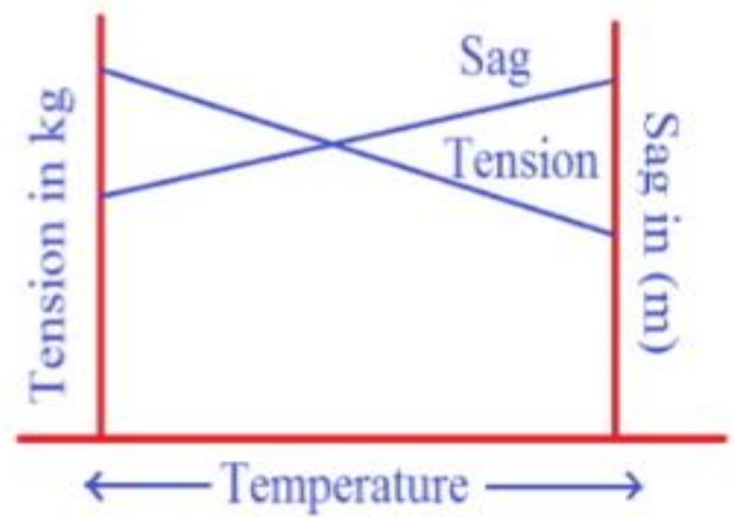


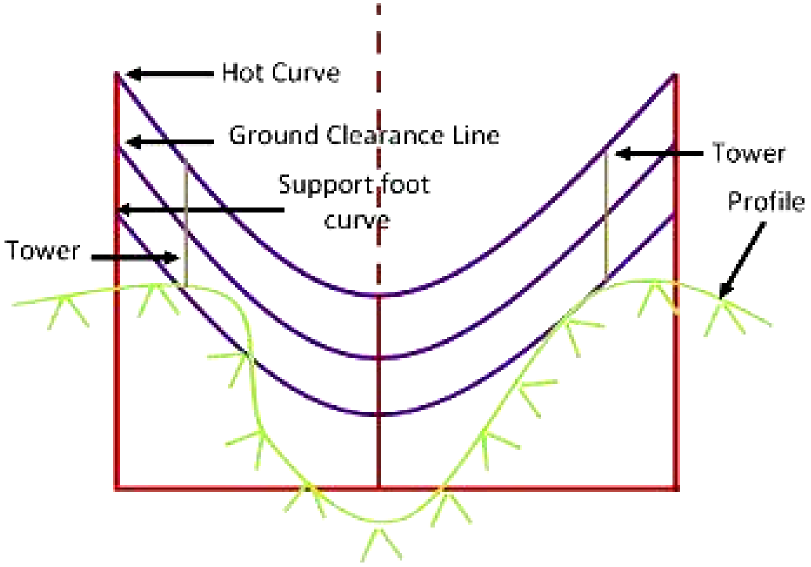
Fig.7: Stringing Chart

As Temperature increases then sag will increase but sag is inversely proportional to Tension so Tension will decrease.

SAG TEMPLATE

- **Definition:** 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 marked on it.

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



Sag Template

SAG TEMPLATE

The curves are explained below in details

- **Hot Curve –** The hot curve is obtained by plotting the sag at maximum temperature against span length. It shows where the supports must be located to maintain the prescribed ground clearance.
- **Ground Clearance Curve –** The clearance curve is below the hot curve. It is drawn parallel to the hot curve and at a vertical distance equal to the ground clearance as prescribed by the regulation for the given line.
- **Support Foot Curve –** This curve is drawn for locating the position of the supports for tower lines. It shows the height from the base of the standard support to the point of attachment of the lower conductor. For wood or concrete line, pole line this curve is not required to be drawn since they can be put in any convenient position.
- **Cold Curve or Uplift Curve –** Uplift curve is obtained by plotting the sag at a minimum temperature without wind price against span length. This curve is drawn to determine whether uplift of conductor occurs on any support. The uplift conductor may occur at low temperature when one support is much lower than either of the adjoining ones.
- Preparation of the Sag Template

UNIT 5

DISTRIBUTION SYSTEMS

ELECTRICAL POWER DISTRIBUTION SYSTEM

- **Electric power distribution** is the final stage in the delivery of electric power; it carries electricity from the transmission system to individual consumers. Distribution substations connect to the transmission system and lower the transmission voltage to medium voltage ranging between 2 kV and 35 kV with the use of transformers.
- ***Primary* distribution lines** carry this medium voltage power to distribution transformers located near the customer's premises. Distribution transformers again lower the voltage to the utilization voltage used by lighting, industrial equipment or household appliances.
- Often several customers are supplied from one transformer through ***secondary* distribution lines**. Commercial and residential customers are connected to the secondary distribution lines through service drops. Customers demanding a much larger amount of power may be connected directly to the primary distribution level or the sub transmission level.

ELECTRICAL POWER DISTRIBUTION SYSTEM

Distribution of electric power is done by distribution networks. Distribution networks consist of following main parts

- Distribution substation,
- Primary distribution feeder,
- Distribution Transformer,
- Distributors,
- Service mains.

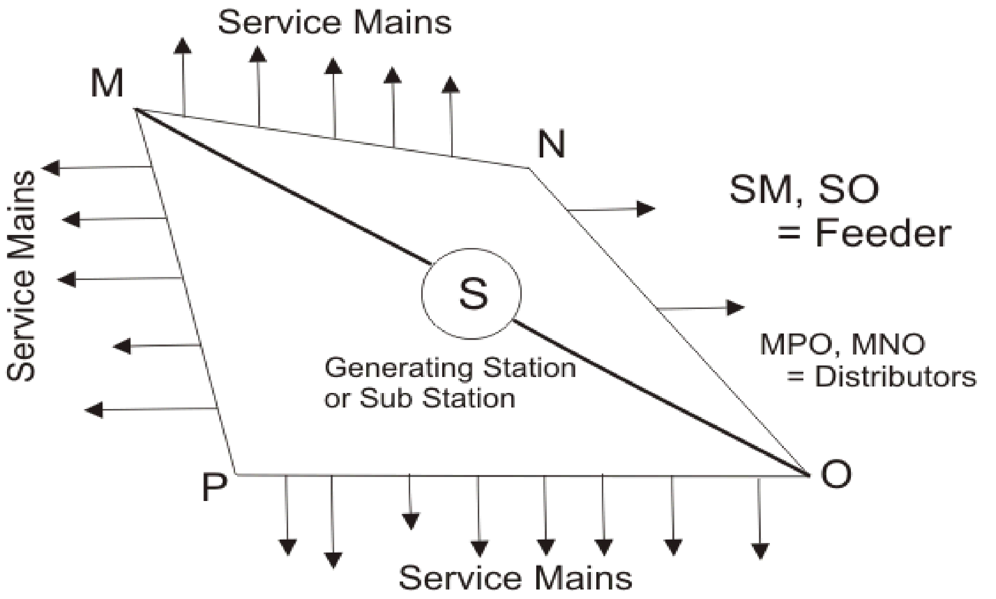


Fig. 1 : Distribution System

CLASSIFICATION OF DISTRIBUTION SYSTEMS

A distribution system may be classified according to ;

- ***Nature of current:*** According to nature of current, distribution system may be classified as (*a*) D.C. distribution system (*b*) A.C. distribution system.

  Now-a-days, A.C. system is universally adopted for distribution of electric power as it is simpler and more economical than direct current method.

- **Type of construction:** According to type of construction, distribution system may be classified as
  - Overhead System
  - Underground System.

The overhead system is generally employed for distribution as it is 5 to 10 times cheaper than the equivalent underground system. In general, the underground system is used at places where overhead construction is impracticable or prohibited by the local laws.

- **Scheme of connection:** According to scheme of connection, the distribution system may be classified as (a) radial system (b) ring main system (c) inter-connected system. Each scheme has its own advantages and disadvantages

COMPARISON OF A.C DISTRIBUTION WITH D.C DISTRIBUTION

A.C distribution	D.C. distribution
3 phase A.C distribution system requires 4 wires.	D.C distribution system requires only one wire with the ground as a return path.
The voltage at the far end is a less i.e. voltage drop in the distributor is more to the presence of inductance.	Therefore the cost of erection is less than the A.C system.
The efficiency of power transmission is less .	Voltage drop is less in the distributor due to the absence of inductance voltage regulation is good.
3phase 3 wire 4 wire are the types of the A.C distribution system.	The transformer cannot be used for improving voltage level.

OVERHEAD VERSUS UNDERGROUND SYSTEM

- The distribution system can be overhead or underground. Overhead lines are generally mounted on wooden, concrete or steel poles which are arranged to carry distribution transformers in addition to the conductors. The underground system uses conduits, cables and manholes under the surface of streets and sidewalks.

  The choice between overhead and underground system depends upon a number of widely differing factors.

- ***Public safety.*** The underground system is more safe than overhead system because all distribution wiring is placed underground and there are little chances of any hazard.

- ***Initial cost.*** The underground system is more expensive due to the high cost of trenching, conduits, cables, manholes and other special equipment. The initial cost of an underground system may be five to ten times than that of an overhead system.

OVERHEAD VERSUS UNDERGROUND SYSTEM

- ***Flexibility.*** The overhead system is much more flexible than the underground system. In the latter case, manholes, duct lines etc., are permanently placed once installed and the load expansion can only be met by laying new lines. However, on an overhead system, poles, wires, transformers etc., can be easily shifted to meet the changes in load conditions.
- ***Faults.*** The chances of faults in underground system are very rare as the cables are laid underground and are generally provided with better insulation.
- ***Appearance.*** The general appearance of an underground system is better as all the distribution lines are invisible. This factor is exerting considerable public pressure on electric supply companies to switch over to underground system.
- ***Fault location and repairs.*** In general, there are little chances of faults in an underground system. However, if a fault does occur, it is difficult to locate and repair on this system. On an overhead system, the conductors are visible and easily accessible so that fault locations and repairs can be easily made.

OVERHEAD VERSUS UNDERGROUND SYSTEM

- ***Current carrying capacity and voltage drop.*** An overhead distribution conductor has a considerably higher current carrying capacity than an underground cable conductor of the same material and cross-section. On the other hand, underground cable conductor has much lower inductive reactance than that of an overhead conductor because of closer spacing of conductors.
- ***Useful life.*** The useful life of underground system is much longer than that of an over head system. An overhead system may have a useful life of 25 years, whereas an underground system may have a useful life of more than 50 years.
- ***Maintenance cost.*** The maintenance cost of underground system is very low as compared with that of overhead system because of less chance of faults and service interruptions from wind, ice, and lightning as well as from traffic hazards.
- ***Interference with communication circuits.*** An overhead system causes electromagnetic interference with the telephone lines

DESIGN CONSIDERATIONS IN DISTRIBUTION SYSTEM

Good voltage regulation of a distribution network is probably the most important factor responsible for delivering good service to the consumers. For this purpose, design of feeders and distributors requires careful consideration.

- ***Feeders.*** A feeder is designed from the point of view of its current carrying capacity while the voltage drop consideration is relatively unimportant. It is because voltage drop in a feeder can be compensated by means of voltage regulating equipment at the substation.

- ***Distributors.*** A distributor is designed from the point of view of the voltage drop in it. It is because a distributor supplies power to the consumers and there is a statutory limit of voltage variations at the consumer’s terminals (± 6% of rated value). The size and length of the distributor should be such that voltage at the consumer’s terminals is within the permissible limits.

REQUIREMENTS OF A DISTRIBUTION SYSTEM

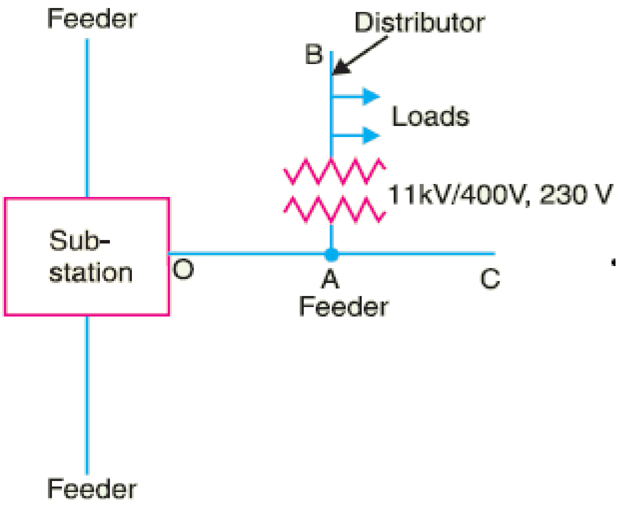
Requirements of a good distribution system are

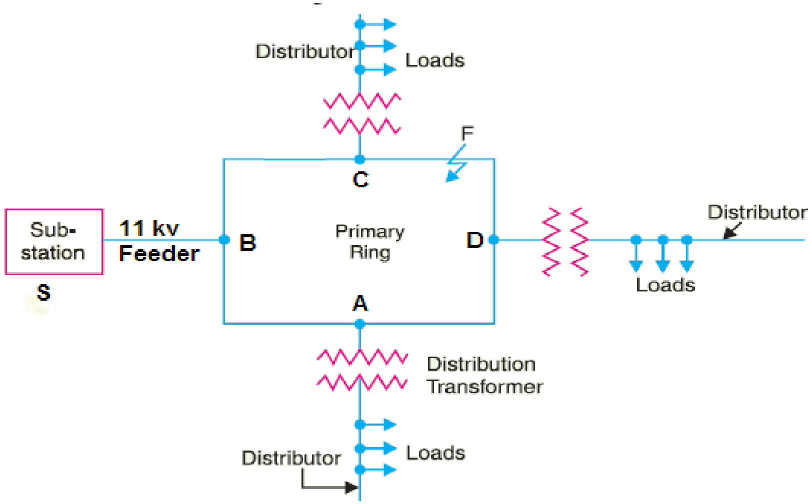
- Proper voltage
- Availability of power on demand.
- Reliability.

CONNECTION SCHEMES OF DISTRIBUTION SYSTEM

The following connection schemes of distribution system are generally employed:

- Radial Distribution System
- Parallel Distribution System
- Ring Main Distribution System
- Interconnected Distribution System





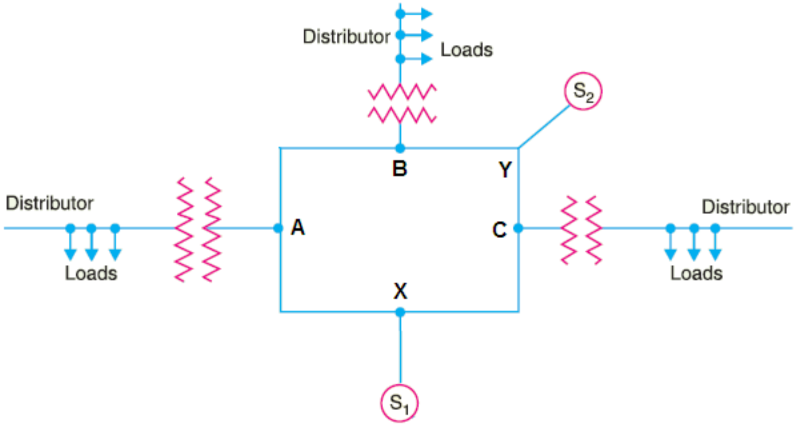


Fig.2 : Various Connection Schemes

KELVIN’S LAW

The cost of conductor material is a vital part of the total cost of a transmission line. Therefore, calculation of conductor size of a transmission line is very important.

Kelvin’s law in power system is used to find out the most economical area of x-section of a conductor for which the total annual cost of the transmission line is minimum.

Kelvin’s law can be stated as: The most economical area of x-section of a conductor is that for which the variable part of annual charges (i.e. annual charges on account of interest and depreciation) is equal to the cost of energy wasted per year.

PRACTICAL LIMITATIONS OF KELVIN’S LAW

Although theoretically Kelvin’s law holds good, there is often considerable difficulty in applying it to a proposed scheme of power transmission. In practice, the limitations of this law are :

- It is not easy to estimate the energy loss in the line without actual load curves, which are not available at the time of estimation.
- The assumption that annual cost on account of interest and depreciation on the capital outlay is in the form P1 + P2a is strictly speaking not true. For instance, in cables neither the cost of cable dielectric and sheath nor the cost of laying vary in this manner.
- This law does not take into account several physical factors like safe current density, mechanical strength, corona loss etc.
- The conductor size determined by this law may not always be practicable one because it may be too small for the safe carrying of necessary current.
- Interest and depreciation on the capital outlay cannot be determined accurately.

VARIOUS VOLTAGE LEVELS OF TRANSMISSION AND DISTRIBUTION SYSTEMS

Voltage levels for Transmission:

- The primary transmission voltages are 110KV, 132KV, 220KV and 400KV.
- Secondary transmission voltages are of the order of 11KV or 33KV.

These transmission voltages are designed based on the distance to which power is to be delivered, amount of power to be transmitted and the system stability.

Voltage levels for Distribution:

The role of distribution station is to deliver power from substation to the consumer terminals.

- The primary distribution voltages are 11, 6.6, or 3.3KV connected to bulk consumers (Industries).
- Secondary distribution voltage constitutes 415 or 230V.

INDIAN GRID SCENARIO

- The Indian Power system for planning and operational purposes is divided into five regional grids. The integration of regional grids, and thereby establishment of National Grid, was conceptualised in early nineties. The integration of regional grids which began with asynchronous HVDC back-to-back inter-regional links facilitating limited exchange of regulated power was subsequently graduated to high capacity synchronous links between the regions.
- The initial inter-regional links were planned for exchange of operational surpluses amongst the regions. However, later on when the planning philosophy had graduated from Regional self-sufficiency to National basis, the Inter-regional links were planned associated with the generation projects that had beneficiaries across the regional boundaries.
- By the end of 12th plan the country has total inter-regional transmission capacity of about 75,050 MW which is expected to be enhanced to about 1,18,050 MW at the end of XIII plan.
- Synchronisation of all regional grids will help in optimal utilization of scarce natural resources by transfer of Power from Resource centric regions to Load centric regions. Further, this shall pave way for establishment of vibrant Electricity market facilitating trading of power across regions. One Nation One Grid shall synchronously connect all the regional grids and there will be one national frequency.

INDIAN GRID SCENARIO

Evolution of National Grid:

- Grid management on regional basis started in sixties.
- Initially, State grids were inter-connected to form regional grid and India was demarcated into 5 regions namely Northern, Eastern, Western, North Eastern and Southern region.
- In October 1991 North Eastern and Eastern grids were connected.
- In March 2003 WR and ER-NER were interconnected .
- August 2006 North and East grids were interconnected thereby 4 regional grids Northern, Eastern, Western and North Eastern grids are synchronously connected forming central grid operating at one frequency.
- On 31st December 2013, Southern Region was connected to Central Grid in Synchronous mode with the commissioning of 765kV Raichur-Solapur Transmission line thereby achieving 'ONE NATION'-'ONE GRID'-'ONE FREQUENCY'.

Thank you