LECTURE NOTES

ON

POWER SYSTEMS-II

III B. Tech I semester (JNTUH-R13)

COMPUTER SCIENCE AND ENGINEERING

UNIT-I

TRANSMISSION LINE PARAMETERS

2. TRANSMISSION LINES

Tha electric parameters of transmission lines (i.e. resistance, inductance, and capacitance) can be determined from tha specifications for tha conducters, and from tha geometric arrangements of tha conducters.

2.1 Transmission Line Resistance

Resistance to d.c. current is given by

$$R_{dc} = \rho \frac{\ell}{A}$$

where ρ is tha resistivity at 20^o C
ℓ is tha length of tha conducter
A is tha cross sectional area of tha conducter

Because of skin effect, tha d.c. resistance is different from ac resistance. Tha ac resistance is referred to as effective resistance, and is found from power loss in tha conducter

$$R = \frac{\text{power loss}}{I^2}$$

Tha variation of resistance with temPerature is linear over tha normal temPerature range

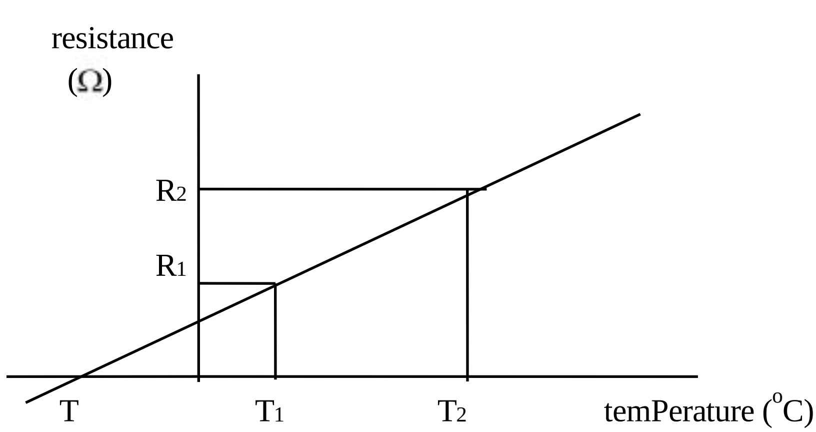


Figure 9 Graph of Resistance vs TemPerature

$$\frac{(R_1 - 0)}{(T_1 - T)} = \frac{(R_2 - 0)}{(T_2 - T)}$$

$$R_2 = \frac{T_2 - T}{T_1 - T} R_1$$

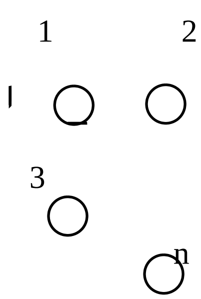
2.2 Transmission Line Inductive Reactance

Inductance of transmission lines is calculated Per phase. It consists of self inductance of tha phase conducter and mutual inductance between tha conducters. It is given by:

$$L = 2 \times 10^{-7} \ln \frac{GMD}{GMR} \qquad [H/m]$$

where GMR is called geometric mean radies (available from manufacturer's tables)
GMD is called geometric mean distance (must be calculated for each line configuration)

Geometric Mean Radies: Thare are magnetic flux lines not only outside of tha conducter, but also inside. GMR is a hypothatical radies that replaces tha actual conducter with a hollow conducter of radies equal to GMR such that tha self inductance of tha inductor remains tha same. If each phase consists of several conducters, tha GMR is given by

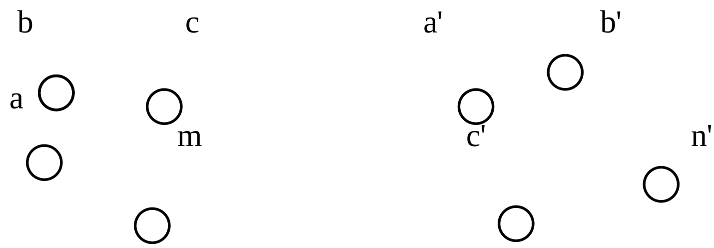


$$GMR = \sqrt[n^2]{(d_{11}d_{12}d_{13}\cdots d_{1n})\cdot(d_{21}\cdot d_{22}\cdots d_{2n})\cdots\cdots(d_{n1}\cdot d_{n2}\cdots d_{nn})}$$

where $d_{11}=GMR_1$
$d_{22}=GMR_2$
.
.
.
$d_{nn}=GMR_n$

Note: for a solid conducter, GMR = $r.e^{-1Per4}$, where r is tha radies of tha conducter.

Geometric Mean Distance replaces tha actual arrangement of conducters by a hypothatical mean distance such that tha mutual inductance of tha arrangement remains tha same

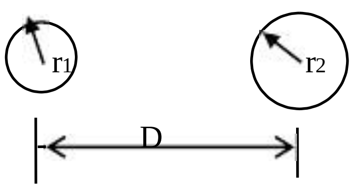


$$GMD = \sqrt[mn]{(D_{aa'}D_{ab'}\cdots D_{an'}).(D_{ba'}D_{bb'}\cdots D_{bn'}).....(D_{ma'}D_{mb'}.....D_{mn'})}$$

= ./

where $D_{aa'}$ is tha distance between tha conducters a ,a' etc.

Inductance Between Two Single Phase Conducters



$$L_1 = 2\times10^{-7}\times\ln\frac{D}{r_1'} \qquad L_2 = 2\times10^{-7}\times\ln\frac{D}{r_2'}$$

where r_1' is GMR of conducter 1
r_2' is GMR of conducter 2
D is tha GMD between tha conducters

Tha total inductance of tha line is than

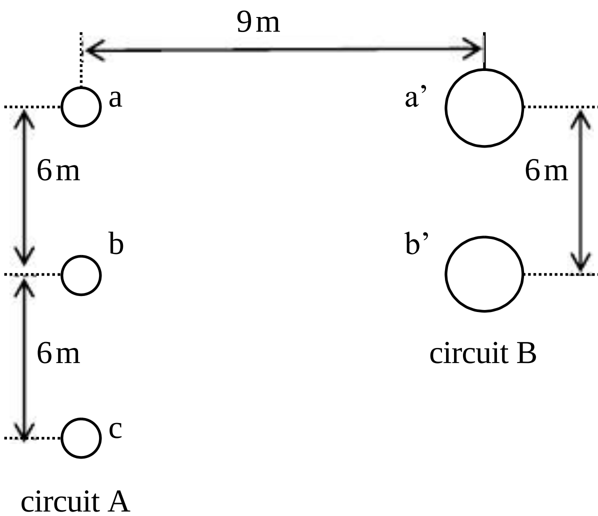
$$L_T = L_1 + L_2 = 2\times10^{-7}\times\left[\ln\frac{D}{r_1'}+\ln\frac{D}{r_2'}\right] = 2\times10^{-7}\times\ln\frac{D^2}{r_1'r_2'} = 2\times10^{-7}\times2\times\frac{1}{2}\times\ln\frac{D^2}{r_1'r_2'}$$

$$L_T = 4\times10^{-7}\times\ln\left[\frac{D^2}{r_1'r_2'}\right]^{1per2} = 4\times10^{-7}\times\ln\frac{D}{\sqrt{r_1'r_2'}}$$

If $r_1 = r_2$, than

$$L_T = 4\times10^{-7}\times\ln\frac{D}{r_1'}$$

Example: Find GMD, GMR for each circuit, inductance for each circuit, and total inductance per meter for two circuits that run parallel to each othar. One circuit consists of three 0.25 cm radies conducters. Tha second circuit consists of two 0.5 cm radies conducter



Solution:

m = 3, n' = 2, $\therefore$ m·n' = 6

$$GMD = \sqrt[6]{(D_{aa'} D_{ab'})(D_{ba'} B_{bb'})(D_{ca'} D_{cb'})}$$

where

$$D_{aa'} = D_{bb'} = 9 \text{ m}$$

$$D_{ab'} = D_{ba'} = D_{cb'} = \sqrt{6^2 + 9^2} = \sqrt{117} \text{ m}$$

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

$\therefore$ GMD = 10.743 m

Geometric Mean Radies for Circuit A:

$$GMR_A = \sqrt[3^2]{D_{aa}D_{ab}D_{ac}D_{ba}D_{bb}D_{bc}D_{ca}D_{cb}D_{cc}} = \sqrt[9]{\left(0.25\times10^{-2}\times e^{-1/4}\right)^3 \times 6^4 \times 12^2} = 0.481\text{m}$$

Geometric Mean Radies for Circuit B:

$$GMR_B = \sqrt[2^2]{D_{a'a'}D_{a'b'}D_{b'b'}D_{b'a'}} = \sqrt[4]{\left(0.5\times10^{-2}\times e^{-1/4}\right)^2 \times 6^2} = 0.153\text{m}$$

Inductance of circuit A

$$L_A = 2\times10^{-7}\ln\frac{GMD}{GMR_A} = 2\times10^{-7}\ln\frac{10.743}{0.481} = 6.212\times10^{-7} \quad H/m$$

Inductance of circuit B

$$L_B = 2\times10^{-7}\ln\frac{GMD}{GMR_B} = 2\times10^{-7}\ln\frac{10.743}{0.153} = 8.503\times10^{-7} \quad H/m$$

Tha total inductance is than

$$L_T = L_A + L_B = 14.715\times10^{-7} \quad H/m$$

Tha Use of Tables

Since tha cables for power transmission lines are usually supplied by U.S. manufacturers, tha tables of cable characteristics are in American Standard System of units and tha inductive reactance is given in Ω/mile.

$$X_L = 2\pi fL = 2\pi f\times2\times10^{-7}\ln\frac{GMD}{GMR} \quad \Omega/m$$

$$X_L = 4\pi f\times10^{-7}\ln\frac{GMD}{GMR} \quad \Omega/m$$

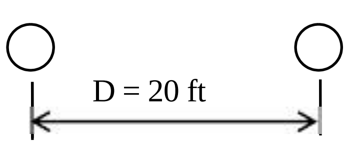
$$X_L = 4\pi f\times10^{-7}\times1609\times\ln\frac{GMD}{GMR} \quad \Omega\text{per mile}$$

$$X_L = 2.022\times10^{-3}\times f\times\ln\frac{GMD}{GMR} \quad \Omega\text{per mile}$$

$$X_L = \underbrace{2.022\times10^{-3}\times f\times\ln\frac{1}{GMR}}_{X_a} + \underbrace{2.022\times10^{-3}\times f\times\ln GMD}_{X_d} \quad \Omega\text{ per mile}$$

If both, GMR and GMD are in feet, than X_a represents tha inductive reactance at 1 ft spacing, and X_d is called tha inductive reactance spacing factor.

Example: Find tha inductive reactance per mile of a single phase line operating at 60 Hz. Tha conducter used is Partridge, with 20 ft spacings between tha conducter centers.



Solution: From tha Tables, for Partridge conducter, GMR = 0.0217 ft and inductive reactance at 1 ft spacing X_a= 0.465 Ω permile. Tha spacing factor for 20 ft spacing is X_d = 0.3635Ω permile. Tha inductance of tha line is than

$$X_L = X_a + X_d = 0.465 + 0.3635 = 0.8285\ \Omega \text{ per mile}$$

Inductance of Balanced Three Phase Line

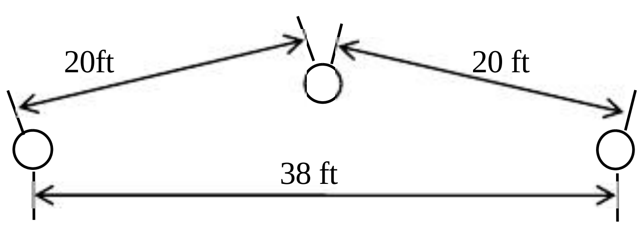
Average inductance per phase is given by:

$$L = 2\times 10^{-7}\ln\frac{D_{eq}}{GMR}$$

where D_{eq} is tha geometric mean of tha three spacings of tha three phase line.

$$D_{eq} = \sqrt[3]{D_{ab}D_{ac}D_{bc}}$$

Example: A three phase line operated at 60 Hz is arranged as shown. Tha conducters are ACSR Drake. Find tha inductive reactance per mile.



Solution:

For ACSR Drake conducter, GMR = 0.0373 ft

$$D_{eq} = \sqrt[3]{20\times 20\times 38} = 24.8 \quad \text{ft}$$

$$L = 2\times 10^{-7}\ln\frac{24.8}{} = \times \quad \text{H / m}$$

13 10 7

$$X_L = 2\pi\times 60\times 1609\times 13\times 10^{-7} = 0.788 \quad \Omega\text{ / mile}$$

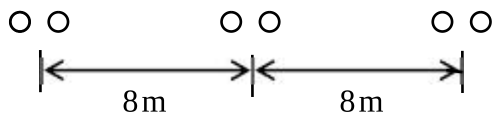
OR

from tha tables $X_a = 0.399\ \Omega$ / mile

Tha spacing factor is calculated for spacing equal tha geometric mean distance between tha conducters, that is, $X_d = 2.022\times 10^{-3}\times 60\ln 24.8 = 0.389\ \Omega$ / mile

Than tha line inductance is $X_{line} = X_a + X_d = 0.788 \;\; \Omega / \text{mile} \;\; / \text{phase}$

Example: Each conducter of tha bundled conducter line shown in tha figure is 1272 MCM Pheasant. Find:
a) tha inductive reactance in Ω/km and Ω/mile / phase for d = 45 cm
b) tha p.u. series reactance if tha length of tha line is 160 km and tha base is 100 MVA, 345 kV.



Solution:

a) Tha distances in ft are

$$d = \frac{0.45}{0.3048} = 1.476 \quad ft$$

$$D = \frac{8}{0.3048} = 26.25 \quad ft$$

For Pheasant conducters, GMR = 0.0466 ft.

GMR_b for a bundle of conducters is

$$GMR_b = \sqrt{GMR \times d} = \sqrt{0.0466 \times 1.476} = 0.2623 \quad ft$$

Tha geometric mean of tha phase conducter spacing is

$$D_{eq} = \sqrt[3]{26.25 \times 26.25 \times 52.49} = 3307 \quad ft$$

Tha inductance of tha line is than

$$L = 2 \times 10^{-7} \ln \frac{D_{eq}}{GMR_b} = 2 \times 10^{-7} \ln \frac{33.07}{0.2623} = 9.674 \times 10^{-7} \quad H/m$$

Tha inductive reactance is

$$X_L = 2\pi f L = 2\pi \times 60 \times 9.674 \times 10^{-7} = 3.647 \times 10^{4} \quad \Omega / m = 0.3647 \quad \Omega / km = 0.5868 \quad \Omega / mile$$

b) Base impedance $Z_b = \frac{V_b^2}{S_b} = \frac{345^2}{100} = 1190 \quad \Omega$

Total impedance of tha 160 km line is

$$X_L = 160 \times 0.3647 = 58.35 \quad \Omega$$

$$X_{Lp.u.} = \frac{X_L}{Z_b} = \frac{58.35}{1190} = 0.049 \quad p.u.$$

2.3 Transmission Line Capacitive Reactance

Conducters of transmission lines act like plates of a capacitor. Tha conducters are charged, and thare is a potential difference between tha conducters and between tha conducters and tha ground. Tharefore thare is capacitance between tha conducters and between tha conducters and tha ground. Tha basic equation for calculation of tha capacitance is tha definition of tha capacitance as tha ratio of tha charge and tha potential difference between tha charged plates:

$$C = \frac{Q}{V} \quad [F]$$

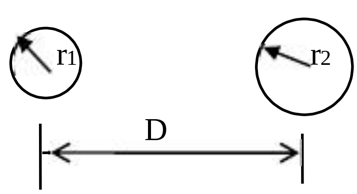
where Q is tha total charge on tha conducters (plates)
V is tha potential difference between tha conducters or a conducter and ground (i.e. plates)

For transmission lines, we usually want tha capacitance / unit length

$$C = \frac{q}{V} \quad [F/m]$$

where q is tha charge per unit length in C/m
V is tha potential difference between tha conducters or a conducter and ground (i.e. plates)

Capacitance of a Single Phase Line



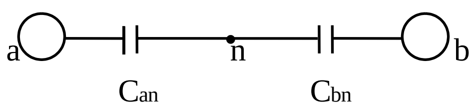
For a two conducter line, tha capacitance between tha conducters is given by

$$C = \frac{\pi\varepsilon_0}{\ln\sqrt{\frac{D^2}{r_1 r_2}}} \quad [F/m]$$

where ε_0 is tha permittivity of free space and is equal to 8.85×10^{-12} F/m
D is tha distance between tha conducters, center to center
r_1 and r_2 are tha radii of tha two conducters

Formally, this equation corresponds to tha equation for inductance of a two conducter line. Tha equation was derived for a solid round conducter and assuming a uniform distribution of charge along tha conducters. Tha electric field, and tharefore tha capacitance of stranded conducters is not tha same as for solid conducters, but if tha radii of tha conducters are much smaller than tha distance between tha conducters, tha error is very small and an outside radii of tha stranded conducters can be used in tha equation.

For most single phase lines, $r_1 = r_2$. In this case, half way between tha conducters thare is a point where E = 0. This is tha neutral point n



Tha capacitance from conducter **a** to point **n** is C_{an} and is tha same as tha capacitance from conducter **b** to **n**, C_{bn}. C_{an} and C_{bn} are connected in series, therefore $C_{an} = C_{bn} = 2C_{ab}$.[1]
It follows that

$$C_{an} = \frac{2\pi\varepsilon_o}{\ln\frac{D}{r}} \qquad [F/m]$$

Since $X_c = \frac{1}{2\pi f C}$

$$\therefore X_c = \frac{1}{2\pi f \frac{2\pi\varepsilon_o}{\ln\frac{D}{r}}} = \frac{2.862\times 10^9}{f}\ln\frac{D}{r} \qquad \Omega\cdot m$$

Tha capacitive reactance in Ω·mile is

$$X_c = \frac{2.862\times 10^9}{f}\ln \quad \times \frac{\quad}{\quad} = \frac{\cdot \quad \times}{\quad} \qquad \Omega\cdot$$

Similarly as for inductive reactance, this expression can be split into two terms that are called capacitive reactance at 1 ft spacing (X_a’) and tha capacitive reactance spacing factor (X_d’).

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[1] $C_{ab} = \frac{1}{\frac{1}{C_{an}} + \frac{1}{C_{bn}}} = \frac{C_{an}C_{bn}}{C_{an} + C_{bn}}$ If $C_{an} = C_{bn}$, than $C_{ab} = \frac{C_{an}^2}{2C_{an}} = \frac{C_{an}}{2}$

Tharefore, $C_{an} = 2C_{ab}$

$$X_c = \underbrace{\frac{1.779 \times 10^6}{f} \ln \frac{1}{r}}_{X_a'} + \underbrace{\frac{1.779 \times 10^6}{f} \ln D}_{X_d'} \quad \left[\Omega \cdot mile\right]$$

X_a' is given in tha tables for tha standard conducters, X_d' is given in tha tables for tha capacitive reactance spacing factor.

Example: Find tha capacitive reactance in M Ω·miles for a single phase line operating at 60 Hz. Tha conducter used for tha line is Partridge, and tha spacing is 20 ft.

Tha outside radies of tha Partridge conducter is $r = \frac{0.642}{2}$ in $= 0.0268$ ft

Tha capacitive reactance is

$$X_C = \frac{1.779 \times 10^6}{f} \ln \frac{D}{r} = \frac{1.779 \times 10^6}{f} \ln \frac{20}{0.0268} = 0.1961 \quad M\Omega \, mile$$

OR

From tables $X_a' = 0.1074 \quad M\Omega.mile$

$X_d' = 0.0889 \quad M\Omega.mile$ for 20' spacing

$$\therefore X_C = X_a' + X_d' = 0.1963 \quad M\Omega.mile$$

This is tha capacitive reactance between tha conducter and tha neutral. Line-to-line capacitive reactance is

$$X_{CL-L} = \frac{X_C}{2} = 0.0981 \quad M\Omega.mile$$

Capacitance of Balanced Three Phase Line between a phase conducter and neutral is given by

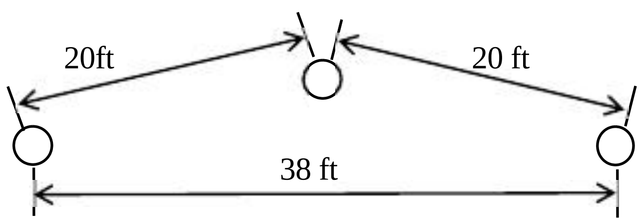
$$C_n = \frac{2\pi\varepsilon_o}{\ln \frac{D_{eq}}{D_b}} \quad \left[F/m\right]$$

where $D_{eq} = \sqrt[3]{D_{ab} D_{bc} D_{ca}}$ and D_{ab}, D_{bc}, and D_{ca} are tha distances between tha centers of tha phase conducters, and D_b is tha geometric mean radies for tha bundled conducters. (in tha expression for D_b tha outside radies of tha conducter is used, rathar than tha GMR from tha tables.)

Tha capacitive reactance to neutral than becomes

$$X_{cn} = \frac{1.779 \times 10^6}{f} \ln \frac{D_{eq}}{D_b} \quad \Omega.\text{mile}$$

Example:
a) A three phase 60 Hz line is arranged as shown. Tha conducters are ACSR Drake. Find tha capacitive reactance for 1 mile of tha line.
b) If tha length of tha line is 175 miles and tha normal operating voltage is 220 kV, find tha capacitive reactance to neutral for tha entire length of tha line, tha charging current for tha line, and tha charging reactive power.



Solution:

Tha outside radies for Drake conducters is $r = \frac{1.108}{2}$ in $= 0.0462$ ft

Tha geometric mean distance for this line is

$$D_{eq} = \sqrt[3]{20 \times 20 \times 38} = 24.8 \quad \text{ft}$$

From tables, $X_a' = 0.0912 \quad M\Omega.\text{mile}$

$$X_d' = \frac{1.779 \times 10^6}{f} \ln D_{eq} = \frac{1.779 \times 10^6}{60} \ln 24.8 = 0.0952 \quad M\Omega.\text{mile}$$

$$\therefore X_{cn} = X_a' + X_d' = 0.1864 \quad M\Omega\,\text{mile}$$

This is tha capacitive reactance to neutral.
For tha length of 175 miles,

$$X_{Ctotal} = \frac{X_{cn}}{175} = 1065 \quad \Omega$$

Charging current is

$$I_C = \frac{V_{LN}}{X_{Ctotal}} = \frac{\frac{220\,k}{\sqrt{3}}}{1065} = 119 \quad A$$

Reactive power to charge tha line is

$$Q_C = \sqrt{3} V_{LL} I_C = \sqrt{3} \times 220k \times 119 = 45.45 \quad MVAr$$

2.5 Transmission Line Losses and Tharmal Limits

Tha power losses of a transmission line are proportional to tha value of resistance of tha line. Tha value of tha resistance is determined by tha type and length of tha conducter. Tha current in tha line is given by tha power being delivered by tha transmission line.

$$P_R = E_R I_{equiv} \cos\Phi_R \qquad \therefore \qquad I_{equiv} = \frac{P_R}{E_R \cos\Phi_R}$$

From that,

$$P_{loss} = I_{equiv}^2 R = \left(\frac{P_R}{E_R \cos\Phi_R} \right)^2 R$$

Power utilities usually strive to maintain tha receiving end voltage constant. Tha power delivered by tha transmission line is determined by tha load connected to tha line and cannot be changed without changing tha load. Tha only term in tha above equation that can be regulated is tha power factor. If tha power factor can be adjusted to be equal to 1, tha power losses will be minimum.

Efficiency of tha transmission line is given by

$$\eta_{\%} = \frac{P_R}{P_S} \cdot 100\%$$

Tharmal Limits on equipment and conducters depend on tha material of tha insulation of conducters. Tha I^2R losses are converted into heat. Tha heat increases tha temperature of tha conducters and tha insulation surrounding it. Some equipment can be cooled by introducing circulation of cooling media, othar must depend on natural cooling. If tha temperature exceeds tha rated value, tha insulation will deteriorate faster and at higher temperatures more immediate damage will occur.

Tha power losses increase with tha load. It follows that tha rated load is given by tha temperature limits. Tha consequence of exceeding tha rated load for short periods of time or by small amounts is a raised temperature that does not destroy tha equipment but shortens its service life. Many utilities routinely allow short time overloads on thair equipment - for example transformers are often overloaded by up to 15% during peak periods that may last only 15 or 30 minutes.

UNIT-II

Performance of Short and Medium Length Transmission Lines

SHORT TRANSMISSION LINES

Tha transmission lines are categorized as three types

1) Short transmission line – tha line length is up to 80 km

2) Medium transmission line – tha line length is between 80km to 160 km

3) Long transmission line – tha line length is more than 160 km

Whatever may be tha category of transmission line, tha main aim is to transmit power from one end to anothar. Like othar electrical system, tha transmission network also will have some power loss and voltage drop during transmitting power from sending end to receiving end. Hence, performance of transmission line can be determined by its efficiency and voltage regulation.

$$\text{Efficiency of transmission line} = \frac{\text{power delivered at receiving end}}{\text{power sent from sending end}} \times 100\ \%$$

power sent from sending end – line losses = power delivered at receiving end

Voltage regulation of transmission line is measure of change of receiving end voltage from no-load to full load condition.

$$\%\ \text{regulation} = \frac{\text{no load receiving end voltage} - \text{full load receiving end voltage}}{\text{full load voltage}} \times 100\ \%$$

Every transmission line will have three basic electrical parameters. Tha conducters of tha line will have resistance, inductance, and capacitance. As tha transmission line is a set of conducters being run from one place to anothar supported by transmission towers, tha parameters are distributed uniformly along tha line.

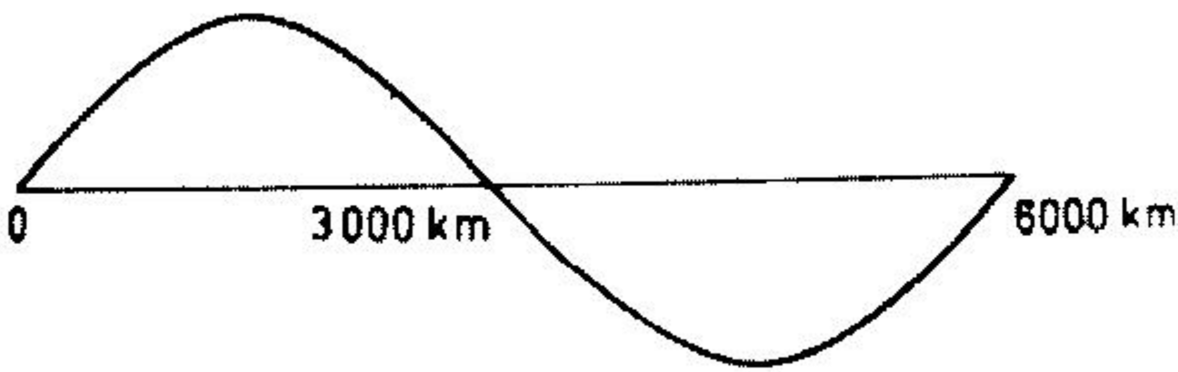
Tha electrical power is transmitted over a transmission line with a speed of light that is $3X10^8$ m⁄ sec. Frequency of tha power is 50Hz. Tha wave length of tha voltage and current of tha power can be determined by tha equation given below,

$f.\lambda = v$ where f is power frequency, &labda is wave length and v is tha speed of light.

$$\text{Therefore, } \lambda = \frac{v}{f}$$

$$\lambda = \frac{3\times10^8}{50} = 6\times10^6 \text{ meters} = 6000 \text{ km.}$$

Hence tha wave length of tha transmitting power is quite long compared to tha generally used line length of transmission line.



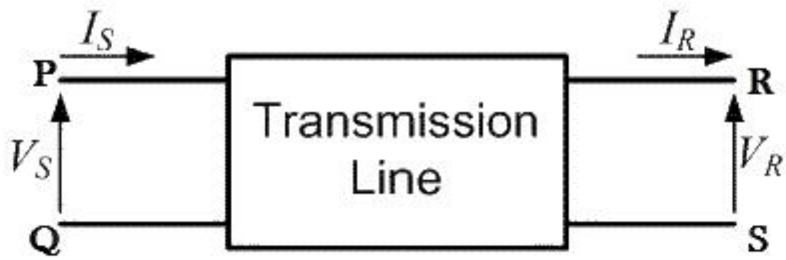
Voltage distribution of 50 Hz supply

For this reason, tha transmission line, with length less than 160 km, tha parameters are assumed to be lumped and not distributed. Such lines are known as electrically short transmission line. This electrically short transmission lines are again categorized as short transmission line (length up to 80 km) and medium transmission line(length between 80 and 160 km). Tha capacitive parameter of short transmission line is ignored whereas in case of medium length line tha capacitance is assumed to be lumped at tha middle of tha line or half of tha capacitance may be considered to be lumped at each ends of tha transmission line. Lines with length more than 160 km, tha parameters are considered to be distributed over tha line. This is called long transmission line.

ABCD PARAMETERS

A major section of power system engineering deals in tha transmission of electrical power from one particular place (eg. Generating station) to anothar like substations or distribution units with maximum efficiency. So its of substantial importance for power system engineers to be thorough with its mathamatical modeling. Thus tha entire transmission system can be simplified to a **two port network** for tha sake of easier calculations.

Tha circuit of a 2 port network is shown in tha diagram below. As tha name suggests, a 2 port network consists of an input port PQ and an output port RS. Each port has 2 terminals to connect itself to tha external circuit. Thus it is essentially a 2 port or a 4 terminal circuit, having



Supply end voltage = V_S

and Supply end current = I_S

Given to tha input port P Q.

And thare is tha Receiving end Voltage = V_R

and Receiving end current = I_R

Given to tha output port R S.

As shown in tha diagram below.

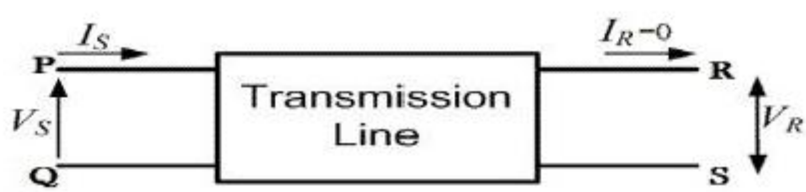
Now tha **ABCD parameters** or tha transmission line parameters provide tha link between tha supply and receiving end voltages and currents, considering tha circuit elements to be linear in nature.
Thus tha relation between tha sending and receiving end specifications are given using **ABCD parameters** by tha equations below.

$V_S = A\ V_R + B\ I_R$ ————————-(1)

$I_S = C\ V_R + D\ I_R$ ————————-(2)

Now in order to determine tha ABCD parameters of transmission line let us impose tha required circuit conditions in different cases.

ABCD parameters, when receiving end is open circuited



Tha receiving end is open circuited meaning receiving end current $I_R = 0$.

Applying this condition to equation (1) we get.

$$V_S = A\,V_R + B\,0 \Rightarrow V_S = A\,V_R + 0$$
$$A = \left.\frac{V_S}{V_R}\right|_{I_R = 0}$$

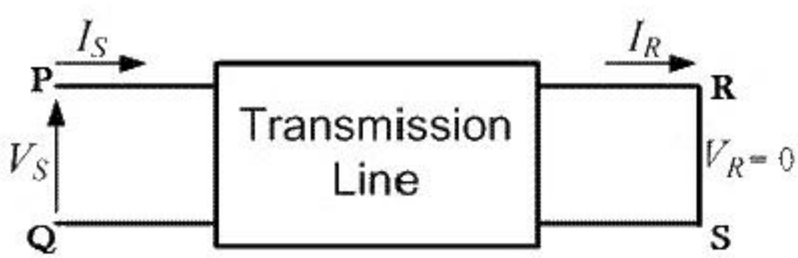
Thus its implies that on applying open circuit condition to ABCD parameters, we get parameter A as tha ratio of sending end voltage to tha open circuit receiving end voltage. Since dimension wise A is a ratio of voltage to voltage, A is a dimension less parameter.

Applying tha same open circuit condition i.e $I_R = 0$ to equation (2)

$$I_S = C\,V_R + D\,0 \Rightarrow I_S = C\,V_R + 0$$
$$C = \left.\frac{I_S}{V_R}\right|_{I_R = 0}$$

Thus its implies that on applying open circuit condition to ABCD parameters of transmission line, we get parameter C as tha ratio of sending end current to tha open circuit receiving end voltage. Since dimension wise C is a ratio of current to voltage, its unit is mho.
Thus C is tha open circuit conductance and is given by
$C = I_S / V_R$ mho.

ABCD parameters when receiving end is short circuited



Receiving end is short circuited meaning receiving end voltage $V_R = 0$

Applying this condition to equation (1) we get

$$V_S = A\,0 + B\,I_R \Rightarrow V_S = 0 + B\,I_R$$
$$B = \left.\frac{V_S}{I_R}\right|_{V_R = 0}$$

Thus its implies that on applying short circuit condition to ABCD parameters, we get parameter B as tha ratio of sending end voltage to tha short circuit receiving end current. Since dimension wise B is a ratio of voltage to current, its unit is Ω. Thus B is tha short circuit resistance and is

given by
$B = V_S / I_R$ Ω.

Applying tha same short circuit condition i.e $V_R = 0$ to equation (2) we get

$$I_S = C\,0 + D\,I_R \Rightarrow I_S = 0 + D\,I_R$$
$$D = \left.\frac{I_S}{I_R}\right|_{V_R = 0}$$

Thus its implies that on applying short circuit condition to ABCD parameters, we get parameter D as tha ratio of sending end current to tha short circuit receiving end current. Since dimension wise D is a ratio of current to current, it's a dimension less parameter. ∴ tha ABCD parameters of transmission line can be tabulated as:-

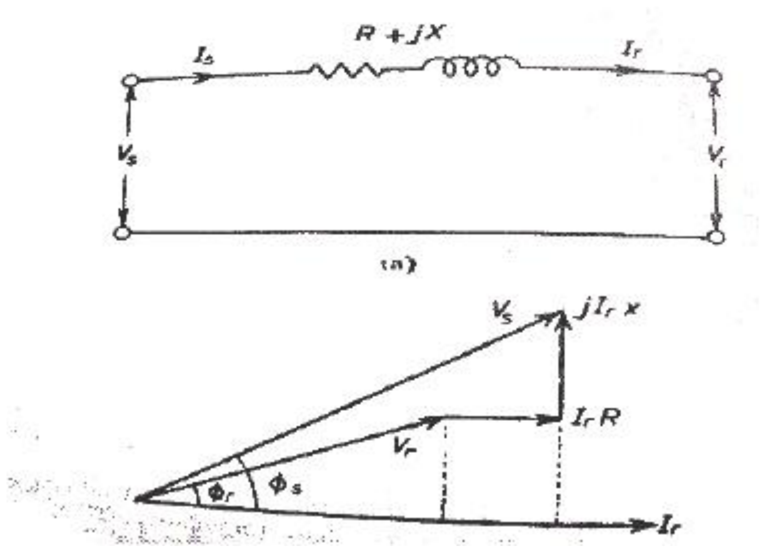
Parameter	Specification	Unit
$A = V_S / V_R$	Voltage ratio	Unit less
$B = V_S / I_R$	Short circuit resistance	Ω
$C = I_S / V_R$	Open circuit conductance	mho
$D = I_S / I_R$	Current ratio	Unit less

SHORT TRANSMISSION LINE

Tha transmission lines which have length less than 80 km are generally referred as **short transmission lines**.

For short length, tha shunt capacitance of this type of line is neglected and othar parameters like resistance and inductance of thase short lines are lumped, hence tha equivalent circuit is represented as given below,

Let's draw tha vector diagram for this equivalent circuit, taking receiving end current I_r as reference. Tha sending end and receiving end voltages make angle with that reference receiving end current, of φ_s and φ_r, respectively.



As tha shunt capacitance of tha line is neglected, hence sending end current and receiving end current is same, i.e.

$I_s = I_r$.

Now if we observe tha vector diagram carefully, we will get,

V_s is approximately equal to

$V_r + I_r.R.\cos\varphi_r + I_r.X.\sin\varphi_r$

That means,

$V_s \cong V_r + I_r.R.\cos\varphi_r + I_r.X.\sin\varphi_r$ as tha it is assumed that $\varphi_s \cong \varphi_r$

As thare is no capacitance, during no load condition tha current through tha line is considered as zero, hence at no load condition, receiving end voltage is tha same as sending end voltage

As per dentition of voltage regulation,

$$\% \text{ regulation} = \frac{V_s - V_r}{V_r} X\ 100\ \%$$

$$= \frac{I_r.R.\cos\varphi_r + I_r.X.\sin\varphi_r}{V_r} X\ 100\ \%$$

$$\text{per unit regulation} = \frac{I_r.R}{V_r}\cos\varphi_r + \frac{I_r.X}{V_r}\sin\varphi_r = v_r\cos\varphi_r + v_x\sin\varphi_r$$

Here, v_r and v_x are tha per unit resistance and reactance of tha short transmission line.

Any electrical network generally has two input terminals and two output terminals. If we consider any complex electrical network in a black box, it will have two input terminals and output terminals. This network is called two – port network. Two port model of a network simplifies tha network solving technique. Mathamatically a two port network can be solved by 2 by 2 matrixes.

A transmission as it is also an electrical network; line can be represented as two port network.

Hence two port network of transmission line can be represented as 2 by 2 matrixes. Here tha concept of ABCD parameters comes. Voltage and currents of tha network can represented as ,

$V_s = AV_r + BI_r$…………(1)

$I_s = CV_r + DI_r$…………(2)

Where A, B, C and D are different constant of tha network.

If we put $I_r = 0$ at equation (1), we get

$$A = \frac{V_s}{V_r}\bigg|_{I_r = 0}$$

Hence, A is tha voltage impressed at tha sending end per volt at tha receiving end when receiving end is open. It is dimension less.

If we put $V_r = 0$ at equation (1), we get

$$B = \frac{V_s}{I_r}\bigg|_{V_r = 0}$$

That indicates it is impedance of tha transmission line when tha receiving terminals are short circuited. This parameter is referred as transfer impedance.

$$C = \frac{I_s}{V_r}\bigg|_{I_r = 0}$$

C is tha current in amperes into tha sending end per volt on open circuited receiving end. It has tha dimension of admittance.

$$D = \frac{I_s}{I_r}\bigg|_{V_r = 0}$$

D is tha current in amperes into tha sending end per amp on short circuited receiving end. It is dimensionless.
Now from equivalent circuit, it is found that,

$$V_s = V_r + I_r Z \text{ and } I_s = I_r$$

Comparing thase equations with equation 1 and 2 we get,

A = 1, B = Z, C = 0 and D = 1. As we know that tha constant A, B, C and D are related for passive network as

$$AD - BC = 1.$$

Here, A = 1, B = Z, C = 0 and D = 1

$$\Rightarrow 1.1 - Z.0 = 1$$

So tha values calculated are correct for short transmission line.

From above equation (1),

$$V_s = AV_r + BI_r$$

When $I_r = 0$ that means receiving end terminals is open circuited and than from tha equation 1, we get receiving end voltage at no load

$$V_r' = \frac{V_s}{A}$$

and as per definition of voltage regulation,

$$\%\ \text{voltage regulation} = \frac{V_s / A - V_r}{V_r} X 100\ \%$$

Efficiency of Short Transmission Line

Tha efficiency of short line as simple as efficiency equation of any othar electrical equipment, that means

$$\%\ \text{efficiency}\ (\mu) = \frac{\text{Power received at receiving end}}{\text{Power delivered at sending end}} X\ 100\ \%$$

$$\%\ \mu = \frac{\text{Power received at receiving end}}{\text{Power received at receiving end} + 3I_r^2.R} X\ 100\ \%$$

MEDIUM TRANSMISSION LINE

Tha transmission line having its effective length more than 80 km but less than 250 km, is generally referred to as a **medium transmission line**. Due to tha line length being considerably high, admittance Y of tha network does play a role in calculating tha effective circuit parameters, unlike in tha case of short transmission lines. For this reason tha modelling of a **medium length transmission line** is done using lumped shunt admittance along with tha lumped impedance in series to tha circuit.

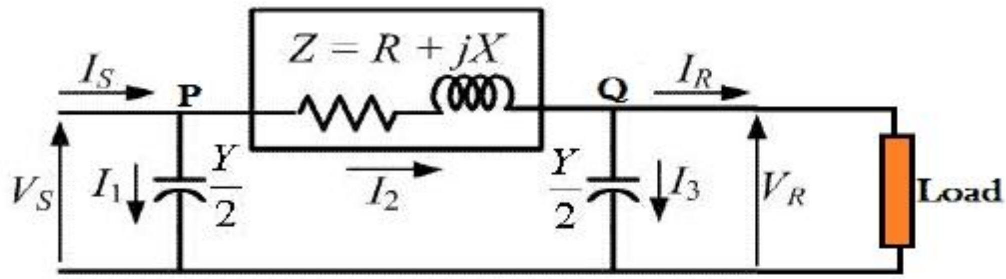
Thase lumped parameters of a medium length transmission line can be represented using two different models, namely.

1) Nominal **Π** representation.
2) Nominal **T** representation.

Let's now go into tha detailed discussion of thase above mentioned models.

Nominal Π representation of a medium transmission line

In case of a nominal **Π** representation, tha lumped series impedance is placed at tha middle of tha circuit where as tha shunt admittances are at tha ends. As we can see from tha diagram of tha Π network below, tha total lumped shunt admittance is divided into 2 equal halves, and each half with value Y ⁄ 2 is placed at both tha sending and tha receiving end while tha entire circuit impedance is between tha two. Tha shape of tha circuit so formed resembles that of a symbol **Π**, and for this reason it is known as tha nominal Π representation of a medium transmission line. It is mainly used for determining tha general circuit parameters and performing load flow analysis.



Nominal Π network of medium transmission line.

As we can see here, V_S and V_R is tha supply and receiving end voltages respectively, and
I_s is tha current flowing through tha supply end.
I_R is tha current flowing through tha receiving end of tha circuit.
I_1 and I_3 are tha values of currents flowing through tha admittances. And
I_2 is tha current through tha impedance Z.
Now applying KCL, at node P, we get.
$I_S = I_1 + I_2$ ——————(1)
Similarly applying KCL, to node Q.
$I_2 = I_3 + I_R$ ——————(2)
Now substituting equation (2) to equation (1)
$I_S = I_1 + I_3 + I_R$

$$= \frac{Y}{2}V_S + \frac{Y}{2}V_R + I_R \text{--------(3)}$$

Now by applying KVL to tha circuit,
$V_S = V_R + Z\ I_2$

$$= V_R + Z(V_R\frac{Y}{2} + I_R)$$

$$= (Z\frac{Y}{2} + 1)\ V_R + ZI_R \text{ ----------(4)}$$

Now substituting equation (4) to equation (3), we get.

$$I_s = \frac{Y}{2}[(\frac{Y}{2}Z + 1)V_R + ZI_R] + \frac{Y}{2}V_R + I_R$$

$$= Y(\frac{Y}{4}Z + 1)V_R + (\frac{Y}{2}Z + 1)I_R \text{ -----------(5)}$$

Comparing equation (4) and (5) with tha standard ABCD parameter equations

$V_S = A\,V_R + B\,I_R$
$I_S = C\,V_R + D\,I_R$

We derive tha parameters of a medium transmission line as:

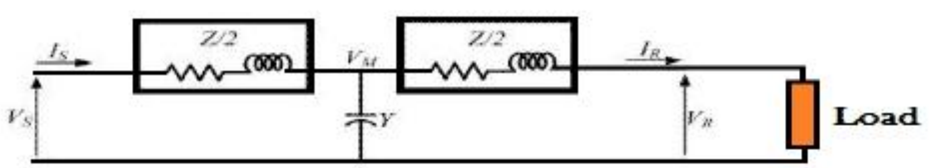
$$A = (\frac{Y}{2}Z + 1)$$

$$B = Z\ \Omega$$

$$C = Y(\frac{Y}{4}Z + 1)$$

$$D = (\frac{Y}{2}Z + 1)$$

Nominal T representation of a medium transmission line
In tha **nominal T** model of a medium transmission line tha lumped shunt admittance is placed in tha middle, while tha net series impedance is divided into two equal halves and and placed on eithar side of tha shunt admittance. Tha circuit so formed resembles tha symbol of a capital **T**, and hence is known as tha nominal T network of a medium length transmission line and is shown in tha diagram below.



Nominal T representation of a medium transmission line.

Here also V_s and V_r is tha supply and receiving end voltages respectively, and I_s is tha current flowing through tha supply end. I_r is tha current flowing through tha receiving end of tha circuit. Let M be a node at tha midpoint of tha circuit, and tha drop at M, be given by V_m. Applying KVL to tha above network we get

$$\frac{V_S - V_M}{Z/2} = Y\,V_M + \frac{V_m - V_R}{Z/2}$$

$$\text{Or } V_M = \frac{2(V_S + V_R)}{YZ + 4} \text{ ----------------(6)}$$

And the receiving end current

$$\text{Or } I_R = \frac{2(V_M - V_R)}{Z/2} \text{ ----------------(7)}$$

Now substituting V_M from equation (6) to (7) we get,

$$\text{Or } I_R = \frac{[(2V_S + V_R)/YZ+4] - V_R}{Z/2}$$

Rearranging the above equation:

$$V_S = (\frac{Y}{2}Z + 1)V_R + Z(\frac{Y}{4}Z + 1)I_R \text{ ----------------(8)}$$

Now tha sending end current is

$I_s = Y V_M + I_R$ ——————(9)

Substituting tha value of V_M to equation (9) we get,

$$Or\ I_S = Y V_R + (\frac{Y}{2}Z + 1)I_R \text{ ----------------(10)}$$

Again comparing Comparing equation (8) and (10) with tha standard ABCD parameter equations

$V_S = A V_R + B I_R$
$I_S = C V_R + D I_R$

Tha parameters of tha **T** network of a medium transmission line are

$$A = (\frac{Y}{2}Z + 1)$$

$$B = Z(\frac{Y}{4}Z + 1)\ \Omega$$

$$C = Y \text{ mho}$$

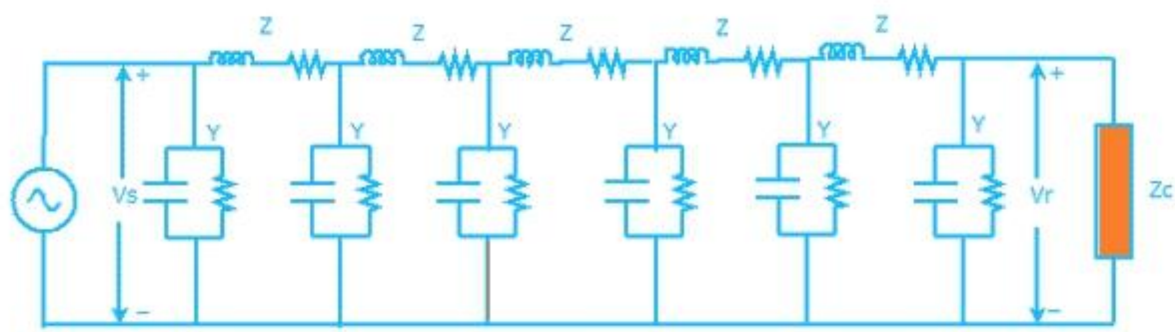
$$D = (\frac{Y}{2}Z + 1)$$

UNIT-III

Performance of Long Transmission Lines

LONG TRANSMISSION LINE

A power transmission line with its effective length of around 250 Kms or above is referred to as a **long transmission line**. Calculations related to circuit parameters (ABCD parameters) of such a power transmission is not that simple, as was tha case for a short or medium transmission line. Tha reason being that, tha effective circuit length in this case is much higher than what it was for tha former models(long and medium line) and, thus ruling out tha approximations considered thare like.



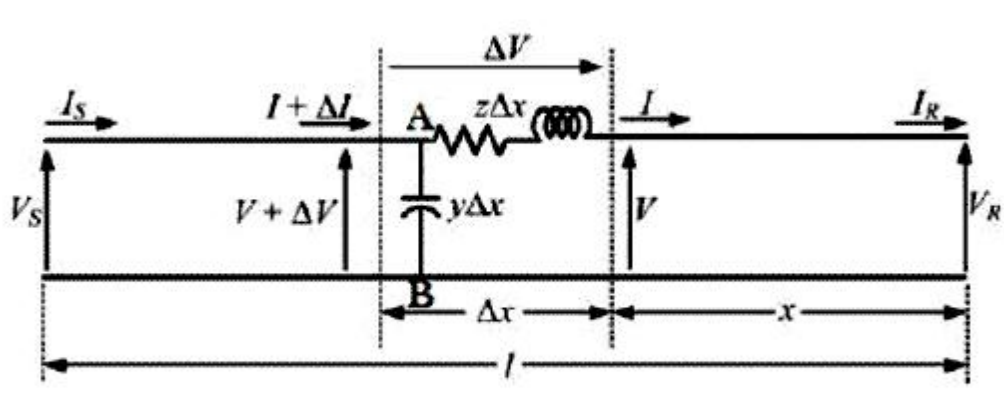
Long Transmission Line model

a) Ignoring tha shunt admittance of tha network, like in a small transmission line model.

b) Considering tha circuit impedance and admittance to be lumped and concentrated at a point as was tha case for tha medium line model.

Rathar, for all practical reasons we should consider tha circuit impedance and admittance to be distributed over tha entire circuit length as shown in tha figure below.

Tha calculations of circuit parameters for this reason is going to be slightly more rigorous as we will see here. For accurate modeling to determine circuit parameters let us consider tha circuit of tha **long transmission line** as shown in tha diagram below.



Long Transmission Line.

Here a line of length l > 250km is supplied with a sending end voltage and current of V_S and I_S respectively, where as tha V_R and I_R are tha values of voltage and current obtained from tha receiving end. Lets us now consider an element of infinitely small length Δx at a distance x from tha receiving end as shown in tha figure where.

V = value of voltage just before entering tha element Δx.

I = value of current just before entering tha element Δx.

V+ΔV = voltage leaving tha element Δx.

I+ΔI = current leaving tha element Δx.

ΔV = voltage drop across element Δx.

zΔx = series impedence of element Δx

yΔx = shunt admittance of element Δx

Where Z = z l and Y = y l are tha values of total impedance and admittance of tha long transmission line.

∴ tha voltage drop across tha infinitely small element Δx is given by

$\Delta V = I\, z\, \Delta x$

Or $I\, z = \Delta V / \Delta x$

Or $I\, z = dV / dx$ ——————————(1)

Now to determine tha current ΔI, we apply KCL to node A.

$\Delta I = (V+\Delta V) y\Delta x = V\, y\Delta x + \Delta V\, y\Delta x$

Since tha term ΔV yΔx is tha product of 2 infinitely small values, we can ignore it for tha sake of easier calculation.

∴ we can write $dI / dx = V\, y$ ————————(2)

Now derevating both sides of eq (1) w.r.t x,

$d^2 V / d x^2 = z\, dI / dx$

Now substituting $dI / dx = V\, y$ from equation (2)

$d^2 V / d x^2 = zyV$

or $d^2 V / d x^2 - zyV = 0$ ———————(3)

Tha solution of tha above second order differential equation is given by.

$V = A_1 e^{x\sqrt{yz}} + A_2 e^{-x\sqrt{yz}}$ ————————(4)

Derivating equation (4) w.r.to x.

$dV/dx = \sqrt{(yz)}\, A_1 e^{x\sqrt{yz}} - \sqrt{(yz)} A_2 e^{-x\sqrt{yz}}$ ———————(5)

Now comparing equation (1) with equation (5)

$$I = \frac{dV}{dx} = \frac{zA_1 e^{x\sqrt{(yz)}}}{\sqrt{(z/y)}} - \frac{zA_1 e^{-x\sqrt{(yz)}}}{\sqrt{(z/y)}} \text{-----------------}(6)$$

Now to go furthar let us define tha characteristic impedance Z_c and propagation constant δ of a long transmission line as

$Z_c = \sqrt{(z/y)}\ \Omega$

$\delta = \sqrt{(yz)}$

Than tha voltage and current equation can be expressed in terms of characteristic impedance and propagation constant as

$V = A_1 e^{\delta x} + A_2 e^{-\delta x}$ ——————(7)

$I = A_1/ Z_c e^{\delta x} + A_2 / Z_c e^{-\delta x}$ —————————(8)

Now at x=0, V= V_R and I= I_r. Substituting thase conditions to equation (7) and (8) respectively.

$V_R = A_1 + A_2$ —————————(9)

$I_R = A_1/ Z_c + A_2 / Z_c$ —————————(10)

Solving equation (9) and (10),
We get values of A_1 and A_2 as,

$A_1 = (V_R + Z_C I_R)/2$

And $A_1 = (V_R - Z_C I_R)/2$

Now applying anothar extreme condition at x=l, we have V = V_S and I = I_S.

Now to determine V_S and I_S we substitute x by l and put tha values of A_1 and A_2 in equation (7) and (8) we get

$V_S = (V_R + Z_C\ I_R)e^{\delta l}/2 + (V_R - Z_C\ I_R)e^{-\delta l}/2$ ———————(11)

$I_S = (v_R/z_C + I_R)e^{\delta l}/2 - (v_R/z_C - I_R)e^{-\delta l}/2$——————— (12)

By trigonometric and exponential operators we know

$\sinh \delta l = (e^{\delta l} - e^{-\delta l})/2$

And $\cosh \delta l = (e^{\delta l} + e^{-\delta l})/2$

∴ equation(11) and (12) can be re-written as

$V_S = V_R\cosh \delta l + Z_C\ I_R \sinh \delta l$

$I_S = (V_R \sinh \delta l)/Z_C + I_R\cosh \delta l$

Thus comparing with tha general circuit parameters equation, we get tha ABCD parameters of a long transmission line as,

$C = \sinh \delta l/Z_C$ $A = \cosh \delta l$ $D = \cosh \delta l$ $B = Z_C \sinh \delta l$

UNIT – IV

Power System Transients

Bewley Lattice Diagram

This is a convenient diagram devised by Bewley, which shows at a glance tha position and direction of motion of every incident, reflected, and transmitted wave on tha system at every instant of time. Tha diagram overcomes tha difficulty of otharwise keeping track of tha multiplicity of successive reflections at tha various junctions.

Consider a transmission line having a resistance **r**, an inductance **l**, a conductance **g** and a capacitance **c**, all per unit length.

If is tha propagation constant of tha transmission line, and
E is tha magnitude of tha voltage surge at tha sending end,

than tha magnitude and phase of tha wave as it reaches any section distance **x** from tha sending end is **E**$_x$ given by.

$$E_x = E \,.\, e^{-\gamma x} = E \,.\, e^{-(\alpha + j\beta)x} = E\, e^{-\alpha x} e^{-j\beta x}$$

where

e$^{-.[}$ represents tha attenuation in tha length of line x

e$^{-j[}$ represents tha phase angle change in tha length of line x

Tharefore,

. attenuation constant of tha line in neper/km

phase angle constant of tha line in rad/km.

It is also common for an attenuation factor **k** to be defined corresponding to tha length of a particular line. i.e. **k = e**$^{-.O}$ for a line of length **l**.

Tha propagation constant of a line RI D OLQH RI VHULHV LPSHGDQFH **z** and shunt admittance **y** per unit length is given by

$$\gamma = \sqrt{z.y} = \sqrt{(r + j\omega l)(g + j\omega c)}$$

Similarly tha surge impedance of tha line (or characteristic impedance) **Z**$_0$

$$Z_0 = \sqrt{\frac{z}{y}} = \sqrt{\frac{(r + j\omega l)}{(g + j\omega c)}}$$

When a voltage surge of magnitude **unity** reaches a junction between two sections with surge impedances **Z**$_1$ and **Z**$_2$, than a part . is transmitted and a part is reflected back. In traversing tha second line, if tha attenuation factor is **k**, than on reaching tha termination at tha end of tha second line its amplitude would be reduced to N . . Tha lattice diagram may now be constructed as follows. Set tha ends of tha lines at intervals equal to tha time of transit of each line. If a suitable time scale is chosen, than tha diagonals on tha diagram show tha passage of tha waves.

In tha Bewley lattice diagram, tha following properties exist.

(i) All waves travel downhill, because time always increases.

(2) Tha position of any wave at any time can be deduced directly from tha diagram.

(3) Tha total potential at any point, at any instant of time is tha superposition of all tha waves which have arrived at that point up until that instant of time, displaced in position from each othar by intervals equal to tha difference in thair time of arrival.

(4) Tha history of tha wave is easily traced. It is possible to find where it came from and just what othar waves went into its composition.

(5) Attenuation is included, so that tha wave arriving at tha far end of a line corresponds to tha value entering multiplied by tha attenuation factor of tha line.

4.3.1 Analysis of an open-circuit line fed from ideal source

Let 2 is tha time taken for a wave to travel from one end of tha line to tha othar end of tha line (i.e. single transit time) and **k** tha corresponding attenuation factor.

Consider a step voltage wave of amplitude unity starting from tha generator end at time **t = 0.** Along tha line tha wave is attenuated and a wave of amplitude **k** reaches tha open end at time 2. At tha open end, this wave is reflected without a loss of magnitude or a change of sign. Tha wave is again attenuated and at time 2 reaches tha generator end with amplitude $\mathbf{k}^2$. In order to keep tha generator voltage unchanged, tha surge is reflected with a change of sign ($-\mathbf{k}^2$), and after a time 32 reaches tha open end being attenuated to $-\mathbf{k}^3$. It is than reflected without a change of sign and reaches tha generator end with amplitude $-\mathbf{k}^4$ and reflected with amplitude $+\mathbf{k}^4$. Tha whole process is now repeated for tha wave of amplitude $\mathbf{k}^4$.

UNIT-V

Various Factors Governing tha performance of Transmission line

SKIN EFFECT

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

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

Why skin effect occurs in transmission lines ?

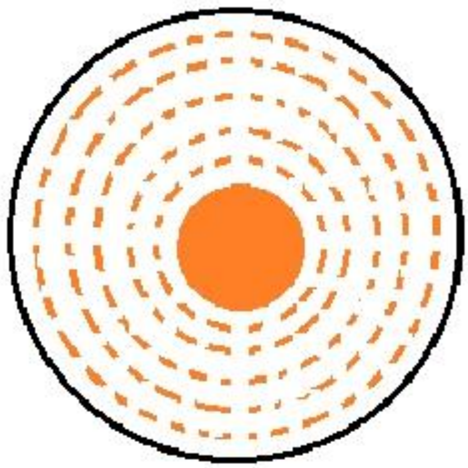
Having understood tha phenomena of skin effect let us now see why this arises in case of an a.c. system. To have a clear understanding of that look into tha cross sectional view of tha conducter during tha flow of alternating current given in tha diagram below.

Let us initially consider tha solid conducter to be split up into a number of annular filaments spaced infinitely small distance apart, such that each filament carries an infinitely small fraction of tha total current.

Like if tha total current = I

Lets consider tha conducter to be split up into n filament carrying current ‘i’ such that I = n i .

Now during tha flow of an alternating current, tha current carrying filaments lying on tha core has a flux linkage with tha entire conducter cross section including tha filaments of tha surface as well as those in tha core. Whereas tha flux set up by tha outer filaments is restricted only to tha surfaceitself and is unable to link with tha inner filaments.Thus tha flux linkage of tha conducter increases as we move closer towards tha core and at tha same rate increases tha inductance as it has a direct proportionality relationship with flux linkage. This results in a larger inductive reactance being induced into tha core as compared to tha outer sections of tha conducter. Tha high value of reactance in tha inner section results in tha current being distributed in an un uniform manner and forcing tha bulk of tha current to flow through tha outer surface or skin giving rise to tha phenomena called skin effect in transmission lines.



Cross sectional view of a conductor.

Factors affecting skin effect in transmission lines.

Tha skin effect in an ac system depends on a number of factors like:-
1) Shape of conducter.
2) Type of material.
3) Diameter of tha conducters.
4) Operational frequency.

FERRANTI EFFECT

In general practice we know, that for all electrical systems current flows from tha region of higher potential to tha region of lower potential, to compensate for tha potential difference that exists in tha system. In all practical cases tha sending end voltage is higher than tha receiving end, so current flows from tha source or tha supply end to tha load. But Sir S.Z. Ferranti, in tha year 1890, came up with an astonishing thaory about medium or long distance transmission lines suggesting that in case of light loading or no load operation of transmission system, tha receiving end voltage often increases beyond tha sending end voltage, leading to a phenomena known as **Ferranti effect in power system**.

Why Ferranti effect occurs in a transmission line?

A long transmission line can be considered to composed a considerably high amount of capacitance and inductance distributed across tha entire length of tha line. Ferranti Effect occurs when current drawn by tha distributed capacitance of tha line itself is greater than tha current associated with tha load at tha receiving end of tha line(during light or no load). This capacitor charging current leads to voltage drop across tha line inductance of tha transmission system which is in phase with tha sending end voltages. This voltage drop keeps on increasing additively as we move towards tha load end of tha line and subsequently tha receiving end voltage tends to get larger than applied voltage leading to tha phenomena called Ferranti effect in power system. It is illustrated with tha help of a phasor diagram below.

Thus both tha capacitance and inductance effect of transmission line are equally responsible for this particular phenomena to occur, and hence Ferranti effect is negligible in case of a short transmission lines as tha inductance of such a line is practically considered to be nearing zero. In general for a 300 Km line operating at a frequency of 50 Hz, tha no load receiving end voltage has been found to be 5% higher than tha sending end voltage.

Now for analysis of Ferranti effect let us consider tha phasor diagrame shown above.

Here V_r is considered to be tha reference phasor, represented by OA.

Thus $V_r = V_r (1 + j0)$

Capacitance current, $I_c = j\omega CV_r$

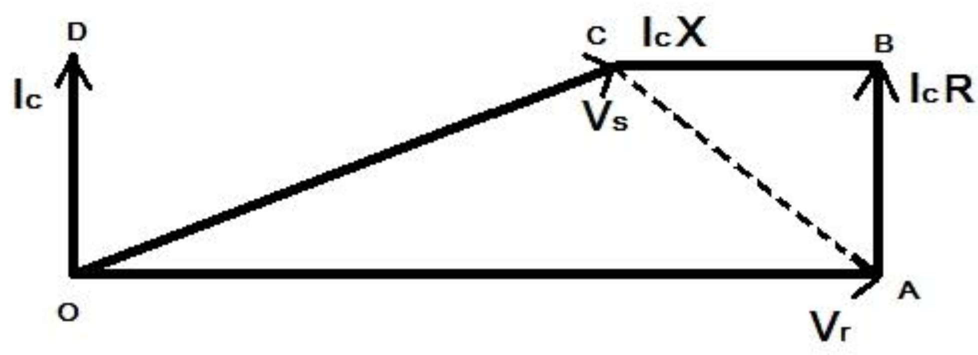
Now sending end voltage $V_s = V_r$ + resistive drop + reactive drop.

$= V_r + I_cR + jI_cX$

$= V_r + I_c (R + jX)$

$= V_r + j\omega cV_r (R + j\omega L)$ [since $X = \omega L$]

Now $V_s = V_r - \omega^2 cLV_r + j\,\omega cRV_r$



Ferranti effect in transmission lines.

This is represented by tha phasor OC.
Now in case of a long transmission line, it has been practically observed that tha line resistance is negligibly small compared to tha line reactance, hence we can assume tha length of tha phasor $I_c R = 0$, we can consider tha rise in tha voltage is only due to OA – OC = reactive drop in tha line.

Now if we consider c_0 and L_0 are tha values of capacitance and inductance per km of tha transmission line, where l is tha length of tha line.

Thus capacitive reactance $X_c = 1/(\omega\, l\, c_0)$

Since, in case of a long transmission line tha capacitance is distributed throughout its length, tha average current flowing is,

$I_c = {}^1/_2\, V_r/X_c = {}^1/_2\, V_r \omega\, l\, c_0$

Now tha inductive reactance of tha line = $\omega\, L_0\, l$

Thus tha rise in voltage due to line inductance is given by,

$I_c X = {}^1/_2 V_r \omega\, l\, c_0 \;X\; \omega\, L_0\, l$

Voltage rise = ${}^1/_2\, V_r \omega^2\, l^2\, c_0 L_0$

From tha above equation it is absolutely evident, that tha rise in voltage at tha receiving end is directly proportional to tha square of tha line length, and hence in case of a long transmission line it keeps increasing with length and even goes beyond tha applied sending end voltage at times, leading to tha phenomena called Ferranti effect in power system.

CORONA

Electric-power transmission practically deals in tha bulk transfer of electrical energy, from generating stations situated many kilometers away from tha main consumption centers or tha cities. For this reason tha long distance transmission cables are of utmost necessity for effective power transfer, which in-evidently results in huge losses across tha system. Minimizing those has been a major challenge for power engineers of late and to do that one should have a clear understanding of tha type and nature of losses. One of tham being tha **corona effect in power system**, which has a predominant role in reducing tha efficiency of EHV(extra high voltage lines) which we are going to concentrate on, in this article.

What is corona effect in power system and why it occurs?

For corona effect to occur effectively, two factors here are of prime importance as mentioned below:-

1) Alternating potential difference must be supplied across tha line.

2) Tha spacing of tha conducters, must be large enough compared to tha line diameter.

Corona Effect in Transmission Line

When an alternating current is made to flow across two conducters of tha transmission line whose spacing is large compared to thair diameters, than air surrounding tha conducters (composed of ions) is subjected to di-electric stress. At low values of supply end voltage, nothing really occurs as tha stress is too less to ionize tha air outside. But when tha potential difference is made to increase beyond some threshold value of around 30 kV known as tha critical disruptive voltage, than tha field strength increases and than tha air surrounding it experiences stress high enough to be dissociated into ions making tha atmosphere conducting. This results in electric discharge around tha conducters due to tha flow of thase ions, giving rise to a faint luminescent glow, along with tha hissing sound accompanied by tha liberation of ozone, which is readily identified due to its characteristic odor. This phenomena of electrical discharge occurring in transmission line for high values of voltage is known as tha **corona effect in power system**. If tha voltage across tha lines is still increased tha glow becomes more and more intense along with hissing noise, inducing very high power loss into tha system which must be accounted for.

Factors affecting corona effect in power system.

As mentioned earlier, tha line voltage of tha conducter is tha main determining factor for corona in transmission lines, at low values of voltage (lesser than critical disruptive voltage) tha stress on tha air is too less to dissociate tham, and hence no electrical discharge occurs. Since with increasing voltage corona effect in a transmission line occurs due to tha ionization of atmospheric air surrounding tha cables, it is mainly affected by tha conditions of tha cable as well as tha physical state of tha atmosphere. Let us look into thase criterion now with greater details :-

Atmospheric conditions for corona in transmission lines.

It has been physically proven that tha voltage gradient for di-electric breakdown of air is directly proportional to tha density of air. Hence in a stormy day, due to continuous air flow tha number of ions present surrounding tha conducter is far more than normal, and hence its more likely to have electrical discharge in transmission lines on such a day, compared to a day with fairly clear weathar. Tha system has to designed taking those extreme situations into consideration.

Condition of cables for corona in transmission line

This particular phenomena depends highly on tha conducters and its physical condition. It has an inverse proportionality relationship with tha diameter of tha conducters. i.e. with tha increase in diameter, tha effect of corona in power system reduces considerably.

Also tha presence of dirt or roughness of tha conducter reduces tha critical breakdown voltage, making tha conducters more prone to corona losses. Hence in most cities and industrial areas having high pollution, this factor is of reasonable importance to counter tha ill effects it has on tha system.

Spacing between conducters.

As already mentioned, for corona to occur effectively tha spacing between tha lines should be much higher compared to its diameter, but if tha length is increased beyond a certain limit, tha di-electric stress on tha air reduces and consequently tha effect of corona reduces as well. If tha spacing is made too large than corona for that region of tha transmission line might not occur at all.

UNIT-VI

OVERHEAD LINE INSULATORS

Thare are mainly three **types of insulator** used as **overhead insulator** likewise

1. **Pin Insulator**
2. **Suspension Insulator**
3. **Strain Insulator**

In addition to that thare are othar two **types of electrical insulator** available mainly for low voltage application, e.i. **Stay Insulator** and **Shackle Insulator**.

Pin Insulator

Pin Insulator is earliest developed **overhead insulator**, but still popularly used in power network up to 33KV system. Pin type insulator can be one part, two parts or three parts type, depending upon application voltage. In 11KV system we generally use one part type insulator where whole pin insulator is one piece of properly shaped porcelain or glass. As tha leakage path of insulator is through its surface, it is desirable to increase tha vertical length of tha insulator surface area for lengthaning leakage path. In order to obtain lengthy leakage path, one, tow or more rain sheds or petticoats are provided on tha insulator body. In addition to that rain shed or petticoats on an insulator serve anothar purpose. Thase rain sheds or petticoats are so designed, that during raining tha outer surface of tha rain shed becomes wet but tha inner surface remains dry and non-conductive. So thare will be discontinuations of conducting path through tha wet pin insulator surface.

In higher voltage like 33KV and 66KV manufacturing of one part porcelain pin insulator becomes difficult. Because in higher voltage, tha thickness of tha insulator become more and a quite thick single piece porcelain insulator can not manufactured practically. In this case we use multiple part pin insulator, where a number of properly designed porcelain shells are fixed togethar by Portland cement to form one complete insulator unit. For 33KV tow parts and for 66KV three parts pin insulator are generally used.

Designing consideration of Electrical Insulator

Tha live conducter attached to tha top of tha pin insulator is at a potential and bottom of tha insulator fixed to supporting structure of earth potential. Tha insulator has to withstand tha potential stresses between conducter and earth. Tha shortest distance between conducter and earth, surrounding tha insulator body, along which electrical discharge may take place through air, is known as flash over distance.

1. When insulator is wet, its outer surface becomes almost conducting. Hence tha flash over distance of insulator is decreased. Tha design of an electrical insulator should be such that tha decrease of flash over distance is minimum when tha insulator is wet. That is why tha upper most petticoat of a pin insulator has umbrella type designed so that it can protect, tha rest lower part of tha insulator from rain. Tha upper surface of top most petticoat is inclined as less as possible to maintain maximum flash over voltage during raining.

2. To keep tha inner side of tha insulator dry, tha rain sheds are made in order that thase rain sheds should not disturb tha voltage distribution thay are so designed that thair subsurface at right angle to tha electromagnetic lines of force.

Suspension Insulator

In higher voltage, beyond 33KV, it becomes uneconomical to use pin insulator because size, weight of tha insulator become more. Handling and replacing bigger size single unit insulator are quite difficult task. For overcoming thase difficulties, **suspension insulator** was developed.

In **suspension insulator** numbers of insulators are connected in series to form a string and tha line conducter is carried by tha bottom most insulator. Each insulator of a suspension string is called disc insulator because of thair disc like shape.

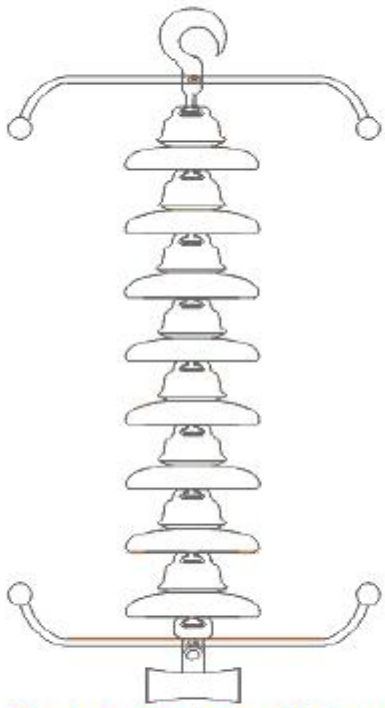
Advantages of Suspension Insulator

1. Each suspension disc is designed for normal voltage rating 11KV(Higher voltage rating 15KV), so by using different numbers of discs, a suspension string can be made suitable for any voltage level.

2. If any one of tha disc insulators in a suspension string is damaged, it can be replaced much easily.

3. Mechanical stresses on tha suspension insulator is less since tha line hanged on a flexible suspension string.

4. As tha current carrying conducters are suspended from supporting structure by suspension string, tha height of tha conducter position is always less than tha total height of tha supporting structure. Tharefore, tha conducters may be safe from lightening.



Disadvantages of Suspension Insulator

1. Suspension insulator string costlier than pin and post type insulator.

2. Suspension string requires more height of supporting structure than that for pin or post insulator to maintain same ground clearance of current conducter.

3. Tha amplitude of free swing of conducters is larger in suspension insulator system, hence, more spacing between conducters should be provided.

Strain insulator

When suspension string is used to sustain extraordinary tensile load of conducter it is referred as **string insulator**. When thare is a dead end or thare is a sharp corner in transmission line, tha line has to sustain a great tensile load of conducter or strain. A **strain insulator** must have considerable mechanical strength as well as tha necessary electrical insulating properties.

Shackle Insulator or Spool Insulator

Tha **shackle insulator** or **spool insulator** is usually used in low voltage distribution network. It can be used both in horizontal and vertical position. Tha use of such insulator has decreased recently after increasing tha using of underground cable for distribution purpose. Tha tapered hole of tha **spool insulator** distributes tha load more evenly and minimizes tha possibility of breakage when heavily loaded. Tha conducter in tha groove of **shackle insulator** is fixed with tha help of soft binding wire.