SHRI RAMDEOBABA COLLEGE OF ENGINEERING AND MANAGEMENT,NAGPUR

BASIC CONCEPT AND LINE PARAMETER OF POWER SYSTEM

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BASIC CONCEPTS

What is an Electric Power System?

"An **electrical power system** is a network of electrical component deployed to **generate, transfer and use electric power**."

OR

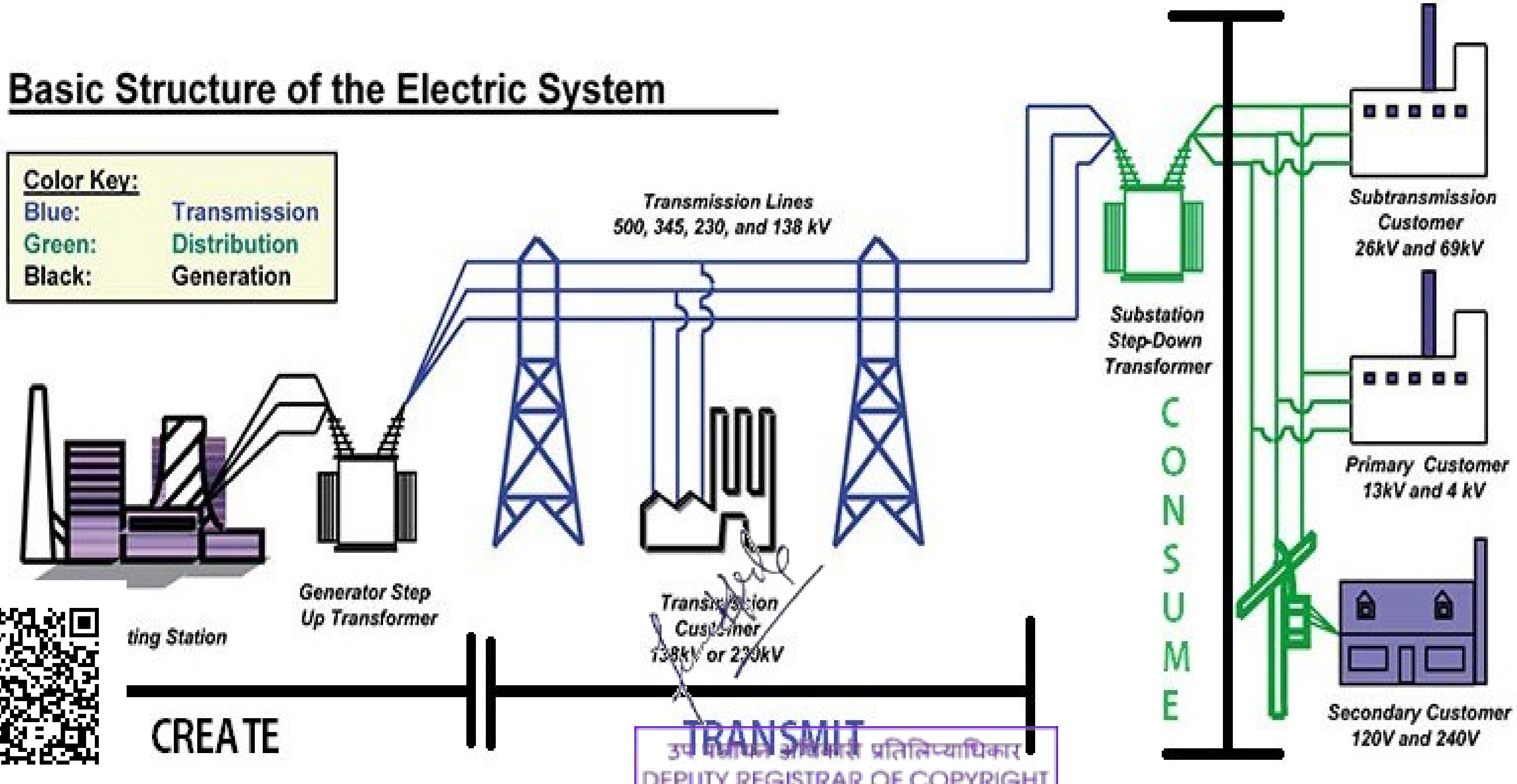
"An **electric power system** or electric grid is known as a **large network of power generating plants which connected to the consumer loads**.

The main task of Power System:

- Generation of Electricity
  - Conventional and Non-Conventional Energy sources
- Transmission of Electric Power
- tion of Transmitted Power.

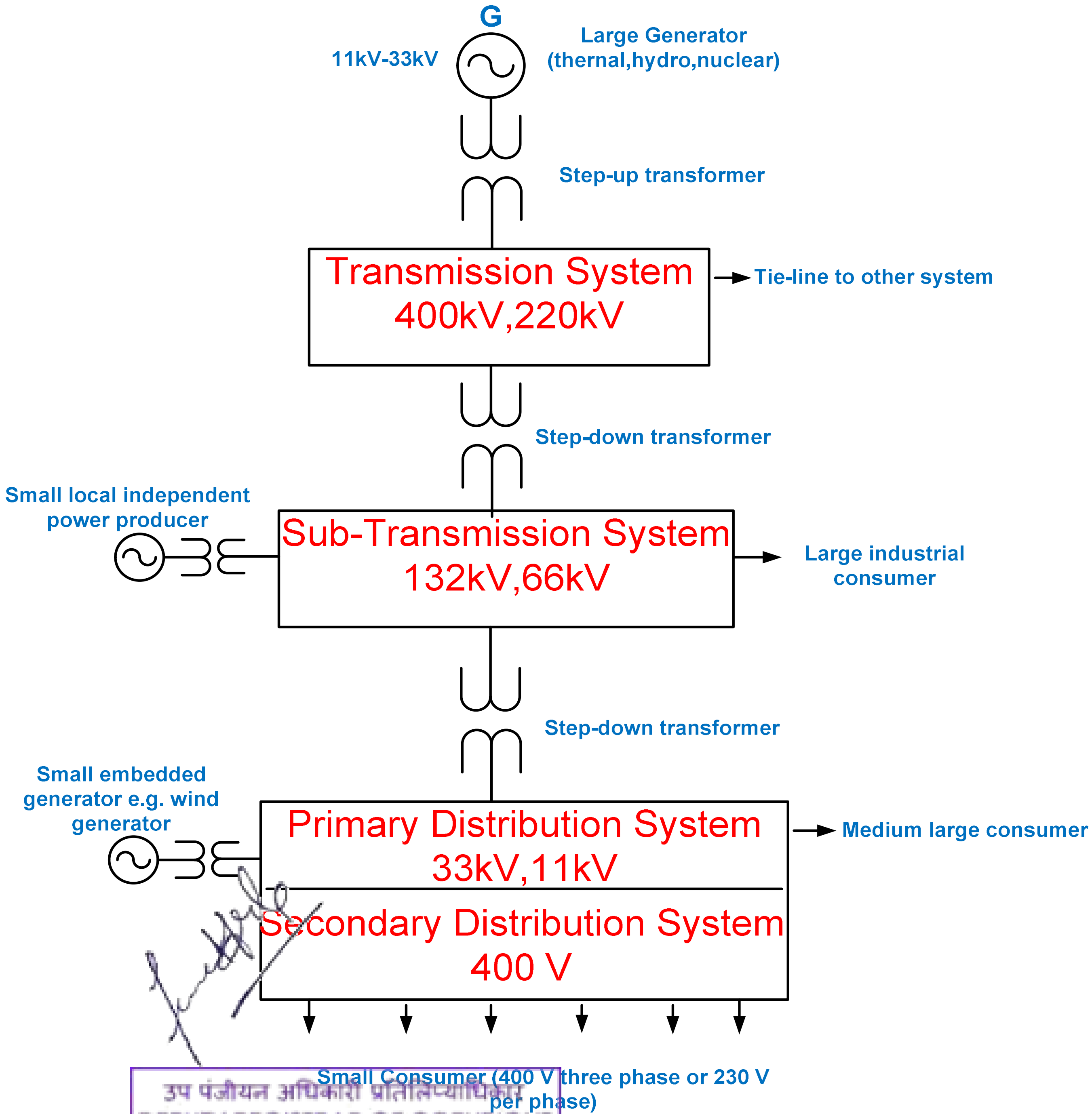
STRUCTURE OF POWER SYSTEM

- Generation ,transmission and distribution system are the main components of Electric Power System.

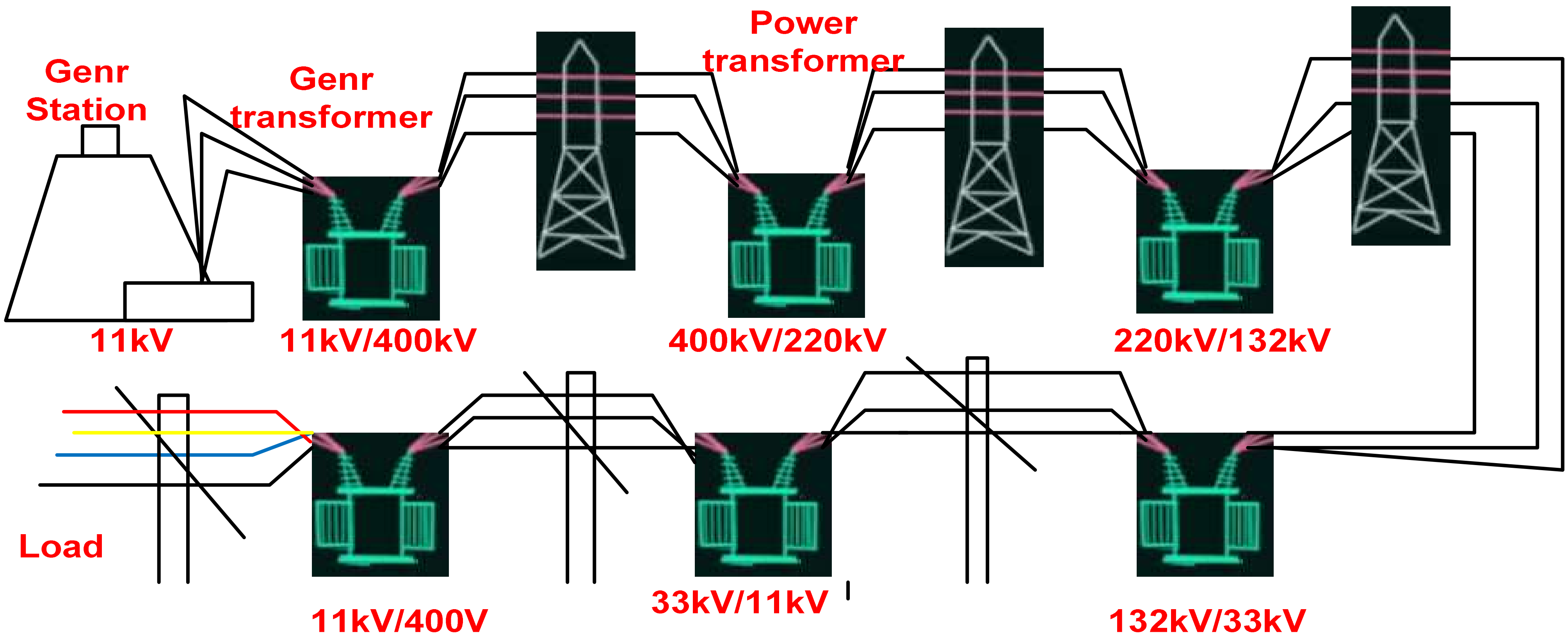


NGLE LINE DIAGRAM
' POWER SUPPLY
'STEM

gle line diagram is a simplified
tion of power system in which
ponents are represented by their
bols and the interconnection between
n is shown by straight line"



WORKING OF AC POWER SYSTEM



BRIEF DESCRIPTION

Generation or Generating station

he place where **electric power produced by the parallel connected three phase alternators/generators is called Generating Station** (i.e. power lant).

he maximum number of generators generate the power at voltage level around **11kV-33kV**. The increased voltage level leads to greater size of enerator required and hence the cost involved.

he generator and the transformer are the main components of the generating station. The generator converts the mechanical energy into electrical nergy.

he transformer transfers the power with very high efficiency from one level to another. But economically, it is good to step up the produced voltage o **132kV**, **220kV** or **400kV** or more by Step up transformer (power Transformer) which will reduce losses in the line and makes the transmission of ower over long distances.

erating stations employed mainly all over the world are as follows:

hermal power plant

lydel power plant(Hydro-electric)

Nuclear power plant

Diesel power plant

Gas power plant

ola

ida

Vinc

Transmission System

The electric supply (in **132kV**, **220 kV**, **400kV** or greater) is transmitted to load center by three phase three wire (3 **Phase – 3 Wires** also known as **Delta connection**) overhead transmission system.

It transports the energy from generating stations to bulk receiving stations.

It also interconnects the two or more generating stations. The neighbouring substations are also interconnected through the transmission lines.

Sub-Transmission System

The portion of the transmission system that connects the receiving substations through the step-down transformer to the distribution substations is called the sub-transmission system.

At receiving station, the **level of voltage reduced by step-down transformers** up to **132kV, 66 or 33 kV**, and elec[illegible] transferred by three phase three wire (**3 Phase – 3 Wires**) overhead system to different **sub stations**.

A su[illegible]on system has a higher voltage level than a distribution system and it supplies only bigger loads.

Distribution System

component of an electrical power system connecting all the consumers in an area to the bulk power sources is called a distribution em.

ary Distribution System

t a sub station, the level of **secondary transmission voltage** (**132kV, 66 or 33 kV**) reduced to **11kV** by **step down transforms**.

ectric supply is provided to those heavy load consumer (commercial power supply for industries) where the demands is 11 kV.

nese substations deliver power to smaller units called '**Feeders**'. This is done by either '**Overhead lines**' or '**Underground cables**'

ndary Distribution System

lectric power is transferred by (from primary distribution line i.e.11kV) to distribution sub station is known as secondar stribution.

nis sub station is located near by domestic & consumers areas where the level of **voltage reduced to 400V by step dow ansformers**.

nese transformers called **Distribution transformers**, **three phase four wire system** (3 Phase – 4 Wires also known as **Sta nnection**). So there is **400 Volts** (Three Phase Supply System) **between any two phases** and **230 Volts** (**Single Phase Supply etween a neutral and phase (live) wires**.

ELECTRIC SUPPLY SYSTEM

- The electric supply system can be broadly classified into:
  - AC and DC System
  - Overhead and Underground System

- Electric power can be transmitted in both AC and DC for short and long transmission and distribution systems.

AC Transmission

Generation, transmission and distribution of electric power has mostly been carried out in AC.

Advantage:

1. The level of AC voltage may be increased or decreased by using step up and Step down transformers.
2. Maintenance of AC substation is easier and cheaper than DC substation.
3. AC Circuit breakers are cheaper than DC Circuit breakers.

isadvantages:

- An AC line requires more copper than DC line
- Due to skin effect, effective resistance of line is increased and hence the losses in AC system are more.
- Due to the capacitance in AC transmission lines, a continuous power loss occurs because of charging current.
- There are some additional line losses due to inductance.
- More insulation are required in AC transmission system.
- The corona losses occur in an AC transmission line system.
- There are stability and synchronizing problems in AC System.
- The cost of AC transmission lines is greater than DC Transmission lines.

C Transmission

e electric power transmission was done in DC due to the following advantages over AC :

dvantage:

- Two conductors are used in DC transmission while three conductors are required in AC transmission.
- Due to the absence of inductance, there are very low voltage drop in
- DC transmission lines and no surge problem.
- There is no concept of Skin effect in DC transmission lines.
- Less corona loss and no interference with communication lines.
- There is no stability and synchronising difficulties.
- DC system is more efficient than AC, therefore, the rate of price of Towers, Poles, Insulators, and conductor are low so the system is economical.

sadvantages:

- Electric power cannot be generated at high DC voltage due to commutation problem.
- There is a limitation of DC switches and circuit breakers.
- It cannot be step up for transmission.

OVERHEAD AND UNDERGROUND TRANSMISSION

Point	Underground System	Overhead System
ic Safety	It is more safe	It is less safe
al Cost	It is more expensive	It is less expensive
bility	It is not flexible	It is flexible
king Voltage	It can work upto 66kV due to insulation problem	It can work upto 400 kV or high voltage
location and repair	Difficult to locate the fault and repair is difficult and expensive.	Fault can be easily located and c be easily repair
age due to lightning and derstrom	More chances of being subjected to lightining	Free from interruption
ference with Communication em	No interference	It interfere with communication system
uency of accident	Less chances of accident	More chances of accident
uency of fault	Very rare chances of fault	Fault occurs frequently.
earance	It appears good as wires are not visible	It gives shabby look
age	Less spacing between conductors, inductance is low therefore voltage drop is low	
gin	Less spacing between conductors, more capacitance ,therefore high charging current.	

ADVANTAGES OF HIGH VOLTAGE TRANSMISSION

ollowing are the advantages of high voltage transmission:

Reduces volume of conductor material:

onsider the transmission of electric power by a three-phase line.

et P = power transmitted in watts , V = line voltage in volts, cos Φ = power factor of the load,

l = length of the line in metres, R = resistance per conductor in ohms, ρ = resistivity of conductor material, a = area of cross-section of conductor

oad current I= $\frac{P}{\sqrt{3}V\cos\phi}$, Resistance/conductor = $\frac{\rho l}{a}$

otal Power loss W= $3I^2R = \frac{P^2\rho l}{v^2\cos^2\phi\, a}$, Area of cross section a= $\frac{P^2\rho l}{Wv^2\cos^2\phi}$

otal volume of material required is = 3al =$3\left(\frac{P^2\rho l}{Wv^2\cos^2\phi}\right)$l

is c... bove expression that for given values of *P, l, ρ* and *W*, the volume of conductor material

qu ... ely proportional to the square of transmission voltage and power factor. In other words,

e g ... ansmission voltage, the lesser is the conductor material required.

2. Increases transmission efficiency

Input Power = P + Total loss

$$P + \frac{P^2 \rho l}{V^2 \cos^2\phi\, a}$$

Assuming J to be current density

a= I/J

$$\text{Input Power} = P + \frac{P^2 \rho l J}{V^2 \cos^2\phi} \frac{1}{I} = P + \frac{P^2 \rho l J}{V^2 \cos^2\phi} \frac{\sqrt{3} V \cos\phi}{P}$$

Transmission Efficiency = Output Power/Input Power

$$\left[1 - \frac{\sqrt{3}\rho l J}{V \cos\phi}\right] \text{Approx.}$$

As J, ρ and l are constants, therefore transmission efficiency increases [illegible] line voltage is increased.

3. Decreases percentage line drop

Line Drop = I x R = I x $\frac{\rho l}{a}$ = I x $\frac{\rho l J}{I}$

% line drop = $\frac{\rho l J}{V}$ X 100

As J, ρ and l are constants, therefore, percentage line drop decreases when the transmission voltage increases.

Hence it is advisable to use the highest possible voltage for transmission of power in a bid to save conductor material. However, it must be realised that high transmission voltage results in

- **the increased cost of insulating the conductors**
- **the increased cost of transformers, switchgear and other terminal apparatus.**

Therefore, there is a limit to the higher transmission voltage which can be economically employed in a particular case.

PER UNIT SYSTEM

- The per unit(PU) system is used to analyse the three phase power system network.

- As you know that the entire power system network is all about the analysis of faults and stability that occurred through out from the generation and transmission to distribution.

- It involves the different voltage levels through out the system because of transformers.

- So it could be so inconvenient for any one to deal with ever changing voltage levels

- So to analyse this complex system to a common frame of reference, we need to convert different parameters of this system such as voltage, current on a common reference which can be referred as ltage and hence the system is called per unit(PU) system.

DEFINITION AND FORMULA

r unit is a scaling system to make calculation process in analysing an electrical network system easier, beca
antities expressed as per-unit do not change when they are referred from one side of a transformer to the other.
wer system quantities such as current, voltage, impedance and power are often expressed in per unit values.
r unit system is the ratio between the actual value in any unit and the base or reference value in the same unit.

$$per\ unit\ value\ of\ \ any\ quantity = \frac{Actual\ value\ of\ quantity(in\ any\ quantity)}{base\ or\ reference\ value\ of\ quantity(in\ same\ unit)}$$

customary to select two base quantities to define a given per unit system. The ones usually cted are voltage and power.

..... The rating of equipment in a power system are given in terms of operating voltage and acity in kVA.

FORMULA

Let:

V_b = base voltage (rated voltage)

kVA_b = base kilo volt ampere (rated power)

therefore $V_{p.u.} = \frac{\text{Actual voltage}}{\text{Base voltage}} = \frac{V_{actual}}{V_b}$

Base Current $I_b = \frac{kVA_b}{V_b}$

Per unit value of current $I_{p.u} = \frac{\text{Actual Current}}{\text{Base current}} = \frac{\text{Actual Current X } V_b}{kVA_b}$

Base Impedance $Z_b = \frac{\text{Base voltage}}{\text{Base current}} = \frac{V_b^2}{kVA_b}$

P[illegible]ue of impedance $Z_{p.u.} = \frac{\text{Actual Impedance}}{\text{Base Impedance}}$

Per unit value of impedance $Z_{p.u.} = \frac{\text{Actual Impedance}}{\text{Base Impedance}}$

$$Z_{p.u.} = Z(\Omega)\ X\ \frac{kVA_b}{{V_b}^2}$$

OR

$$Z_{p.u.} = Z\ (\Omega)\ X\ \frac{MVA_b}{(kV_b)^2}$$

When MVA_b is changed from MVA_b(old) to MVA_b(N) and kV_b (old) to kV_b(N) then the new p.u. impedance will be

$$Z_{p.u.}\ (O) = Z\ (\Omega)\ X\ \frac{MVA_b(O)}{(kV_b\ (O))^2} \text{.................................}(1)$$

$$Z_{p.u.}(N) = Z\ (\Omega)\ X\ \frac{MVA_b(N)}{(kV_b\ (N))^2} \text{.................................}(2)$$

Divide equation (2) by (1)

Z ... $(O)\ X\ \frac{MVA_b(N)}{MVA_b(O)}\ X\ \frac{(kV_b\ (O))^2}{(kV_b\ (N))^2}$

ADVANTAGES OF P.U. REPRESENTATION

- While performing calculations, referring quantities from one side of the transformer to the other side serious errors may be committed. This can be avoided by using per unit system.
- Voltages, currents and impedances expressed in per unit do not change when they are referred from one side of transformer to the other side. This is a great advantage.
- For transformers the p.u. of impedances are same for primary and secondary sides.
- Transformer connections do not affect the per unit values.
- Manufacturers usually specify the impedances of machines and transformers in per unit or percent of name plate ratings.
- Reduced calculations in three-phase systems.
- More usefully for digital computation.

STEPS TO SOLVE PER UNIT NUMERICAL

. Choose an appropriate common MVA_b for the system.

It is selected on following basis:

Either it is specified in the numerical OR

Take generator MVA as base value OR

Take max MVA of the given system or take any round figure.

. Choose an approximate reference kV_b for the system .Consider the system to be divided into number of ections by transformer. Choose an appropriate kV_b for one section .Calculate the kV_b of all section with he help of transformation ratio.

. Calculate per unit values of voltages and impedances in each section and connect them as per topology f single line diagram. The result is single phase per unit impedance diagram or reactance diagram.

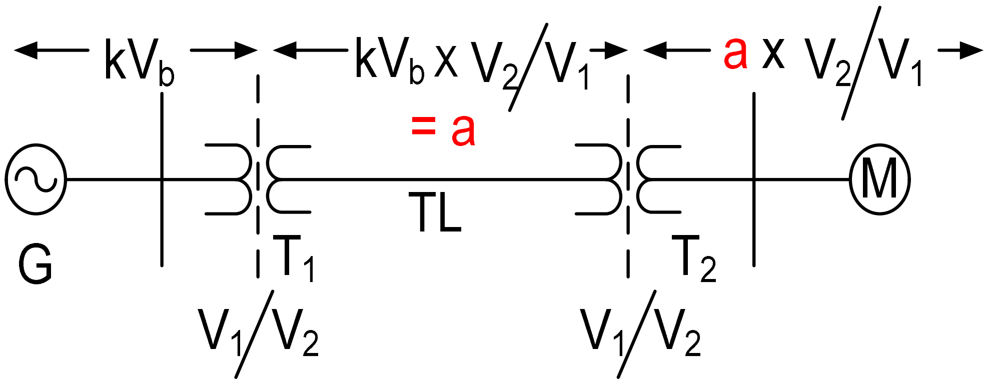
. MVA_b will be same for whole section i.e. for generator ,transformer, transmission line and load and V_b according to power system

Ass ıde:

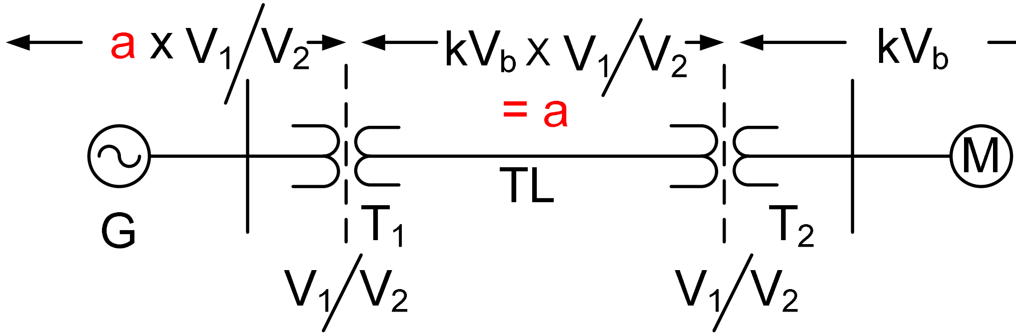
Lin ce and resistance are neglected so that it is represented as series reactance.

STEPS TO FIND kV_b FOR EACH SECTION

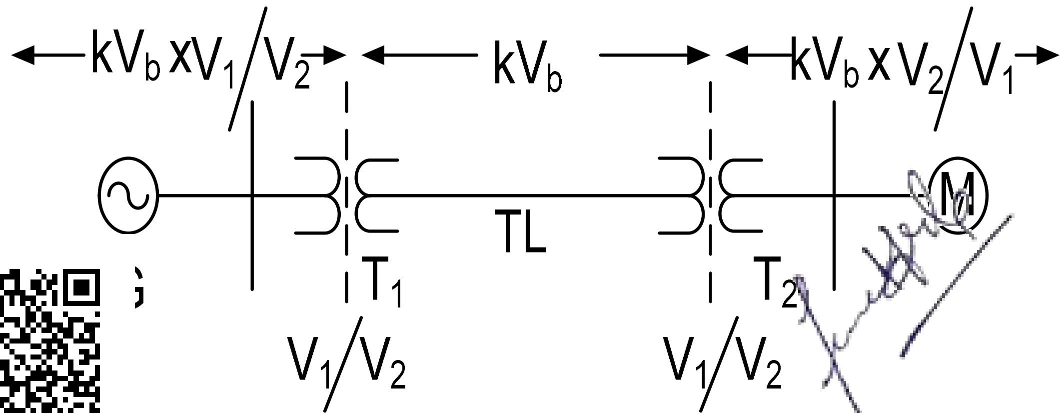
Case I : Generator rating is selected as base value



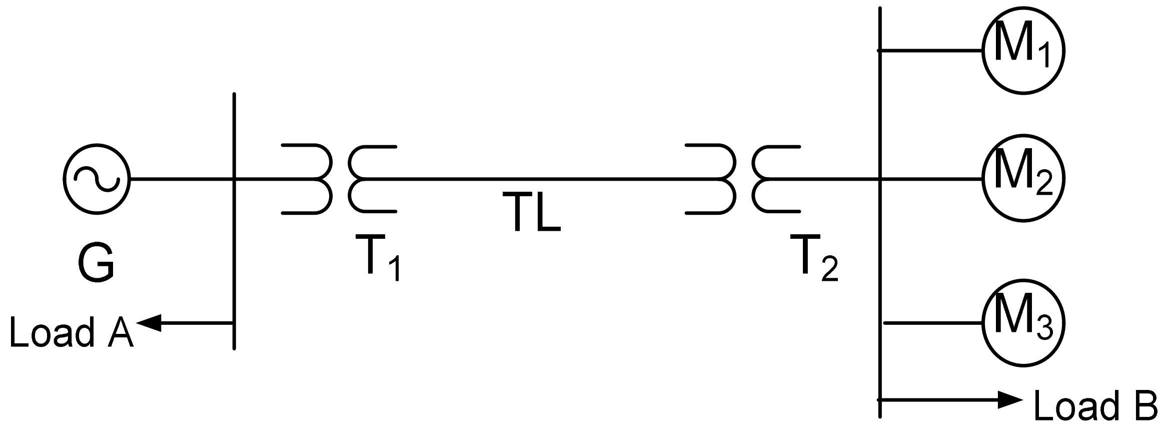
Case III : Selecting motor rating as base value



Case II : Selecting transmission line rating as base value



STEPS TO DRAW IMPEDANCE DIAGRAM



Step I: The generator and motor are represented as voltage source with series resistance and inductive reactance .

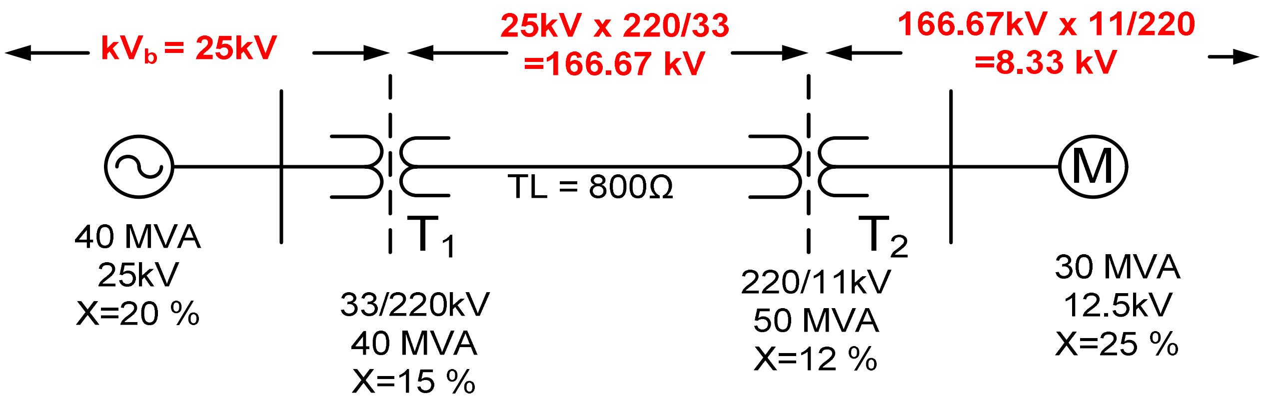
Step 2: Transformers are represented with series resistance and inductive reactance

Step 3 : Transmission line is represented by series resistance and inductive reactance

Load A and B are represented by series resistance and inductive reactance.

PROBLEMS

1. Draw pu reactance diagram and assume generator rating as base values?



Step 1: Selecting Generator rating as base value

$MVA_b = 40$ MVA , $KV_b = 25kV$

KV_b for transmission line = 25 x 220/33 = 166.67 kV

KV_b for motor side = 166.67 x 11/220 = 8.33 kV

Step 2: pu value of reactance on generator side

$$Xg_{p.u.}(N) = Xg_{p.u.}(O) \times \frac{MVA_b(N)}{MVA_b(O)} \times \frac{(kV_b\ (O))^2}{(kV_b\ (N))^2}$$

$$Xg_{p.u.}(N) = 0.2 \text{ p.u.}$$

p.u. value of reactance for T_1

$$X_{T1p.u} = 0.15 \times \frac{40}{60} \times \left(\frac{33}{25}\right)^2 = 0.1742 \text{ p.u.}$$

OR

$$X_{T1p.u} = 0.15 \times \frac{40}{60} \times \left(\frac{220}{166.67}\right)^2 = 0.1742 \text{ p.u.}$$

p.u. value of reactance for TL

$$X_{p.u.} = X\,(\Omega)\ X\ \frac{MVA_b}{(kV_b)^2}$$

$$X_{TLp.u.} = 800\ X\ \frac{40}{(166.67)^2} = 1.1519 \text{ p.u.}$$

p.u. value of reactance for T2

$$X_{T2p.u} = 0.12 \times \frac{40}{50} \times \left(\frac{220}{166.67}\right)^2 = 0.167 \text{ p.u.}$$

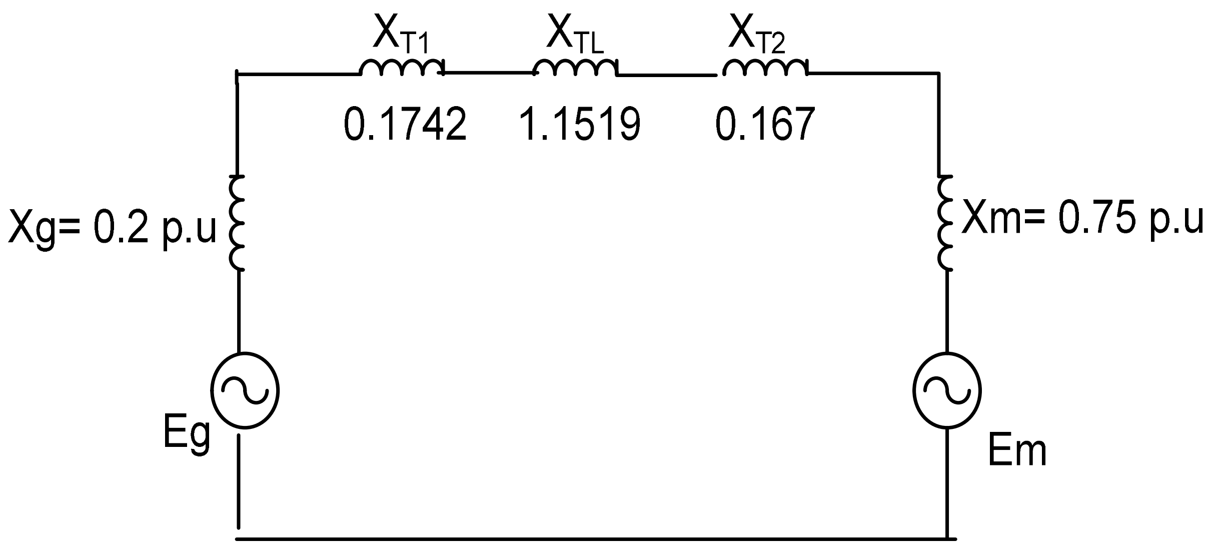
OR

$$\ldots \frac{40}{50} \times \left(\frac{11}{8.33}\right)^2 = 0.167 \text{ p.u.}$$

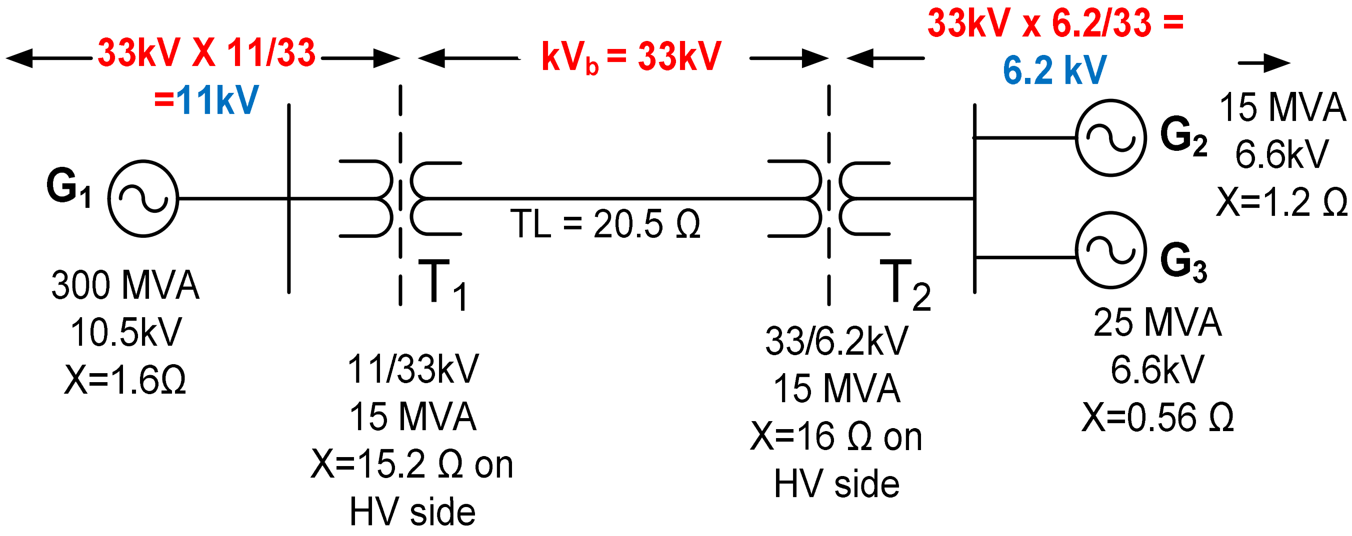
p.u. value of reactance for Motor

$$X_{mp.u} = 0.25 \times \frac{40}{30} \times \left(\frac{12.5}{8.33}\right)^2 = 0.75 \text{ p.u.}$$

Reactance Diagram:



2. Draw reactance diagram for given power system .Choose 30 MVA and 33kV as base value for transmission line



Selecting Transmission line rating rating as base value

MVA_b= 30 MVA , KV_b=33kV

Step 1: KV_b for Generator (G_1) side = 33 x 11/33 = 11 kV

KV_b for Generator (G_1 and G_2) side = 33 x 6.2/33 = 6.2 kV

X_{p} $\frac{MVA_b}{(kV_b)^2}$

ep 2: pu value of reactance of generator G_1

$Xg_{1p.u.} = 1.6 \times 30 / (11)^2 = 0.396$ p.u.

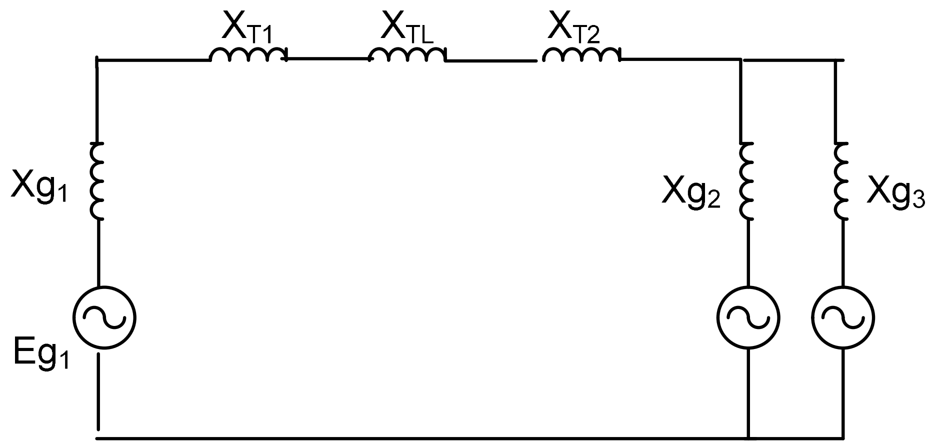
pu value of reactance of transformer T1

$X_{T1p.u.} = 15.2 \times 30 / (33)^2 = 0.418$ p.u.

hy 33? …… because X= 15.2 on HV side so we have to take KV_b from
/ side.

p.u. value of reactance of TL

$$X_{TLp.u.} = 20.5 \times \frac{30}{(33)^2} = 0.564 \text{ p.u.}$$



p.u. value of reactance of T2

$$X_{T2p.u} = 16 \times \frac{30}{(33)^2} = 0.44 \text{ p.u.}$$

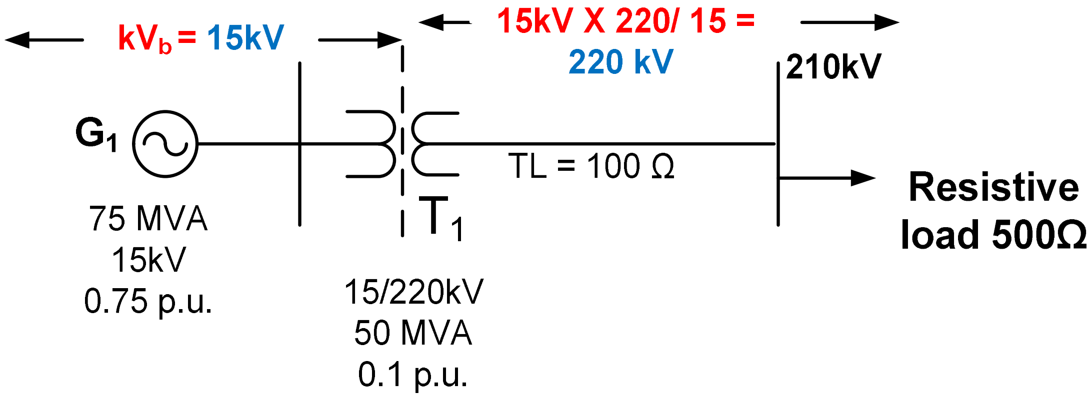
pu value of reactance of generator G_2

$$Xg_{2p.u.} = 1.2 \times \frac{30}{(6.2)^2} = 0.936 \text{ p.u.}$$

: of reactance of generator G_3

$$=0.56 \times \frac{30}{(6.2)^2} = 0.437 \text{ p.u.}$$

6. For the power system shown below determine generator voltage. Select generator rating as base value.



Step 1: Selecting generator rating as base value

MVA_b=75 MVA

KV_b= 15kV

kVb for transmission line and load is 220kV

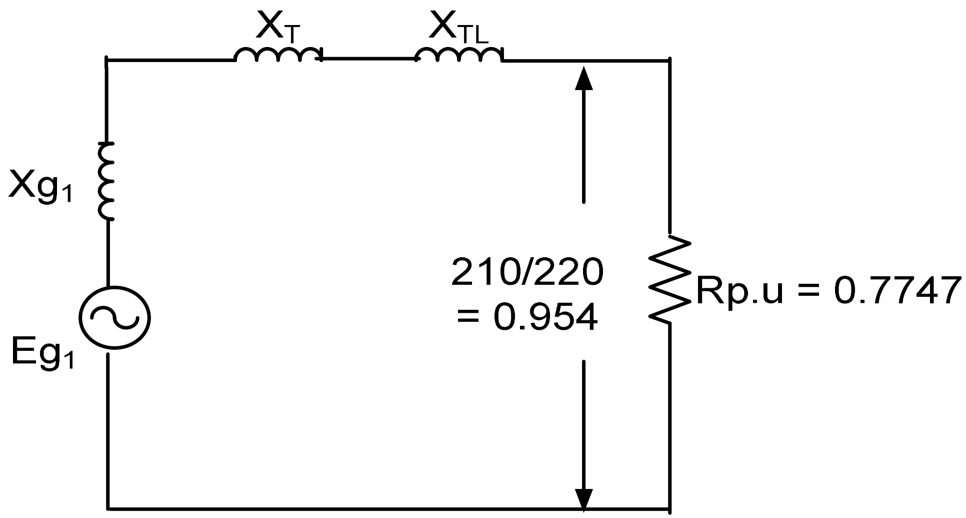
Step 2 : p.u. value of reactance

$$Xg_{1p.u.} = 0.75 \text{ x } \frac{75}{75} \text{ x } \left(\frac{15}{15}\right)^2 = j\ 0.75 \text{ p.u.}$$

$$X_{T1p.u.} = 0.1 \text{ x } \frac{75}{50} \text{ x } \left(\frac{15}{15}\right)^2 = j\ 0.15 \text{ p.u.}$$

$$X_{TL} = 100 \text{ x } \frac{75}{(220)^2} = j0.1549 \text{ p.u.}$$

$$= 500 \text{ x } \frac{75}{(220)^2} = j0.7747 \text{ p.u.}$$



Per unit value of voltage Vp.u = actual value / base valu

= 210/220 = 0.9545

I p.u. = Vp.u./ Rp.u. = 0.9545/0.7747 = 1.23 p.u.

Applying KVL in the loop

$E_{g1p.u.}$ =I p.u.[Rp.u +j(Xg+X_T +X_{TL})]

= 1.23 [0.7747 +j (0.75+ 0.15+0.1544)]

= 0.9528 + j 1.297

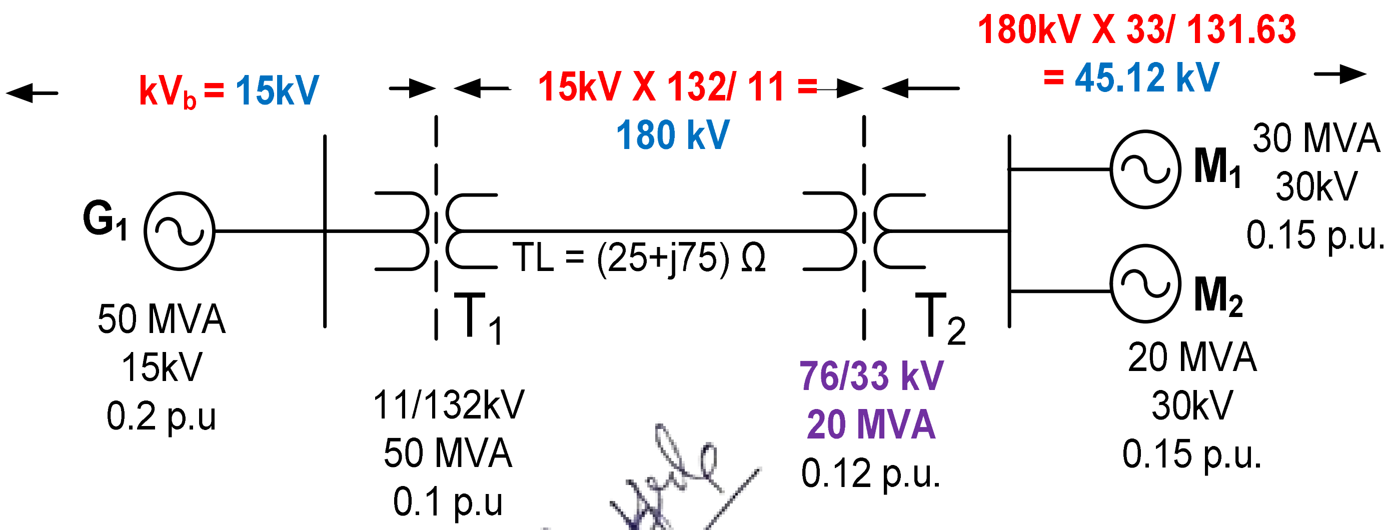
= 1.609 $\angle$53.73

E 15 x 1.609

= 24.135 kV

A 50 MVA,15kV,3-ph generator has sub-transient reactance of 0.2 p.u. The generator supplies the two otors over a transmission line having transformers at both end. The motor has rated input of 30 MVA and) MVA both 30kV with 0.15 p.u. subtransient reactance. The rating of sending end transformer T1 is 50 VA ,11/132kV,Δ/Y with leakage reactance of 0.1 pu. The transformer T2 at receiving end has three ngle phase unit .The rating of each individual transformer is 20 MVA,76/33 kV with leakage reactance ' 0.12 p.u. connected as Y/ Δ. Series impedance of a line is (25+j75)Ω. Draw impedance diagram. Select enerator rating as base value.

the motor have input of 24 MW and 16 MW respectively at 30 kV and both operated at unity power ctor ,find the voltage at the terminal of generator.



$$Xg_{p.u.} = 0.2 \times \frac{50}{50} \times \left(\frac{15}{15}\right)^2 = j\,0.2 \text{ p.u.}$$

$$X_{T1p.u.} = 0.1 \times \frac{50}{50} \times \left(\frac{11}{15}\right)^2 = j\,0.053 \text{ p.u.}$$

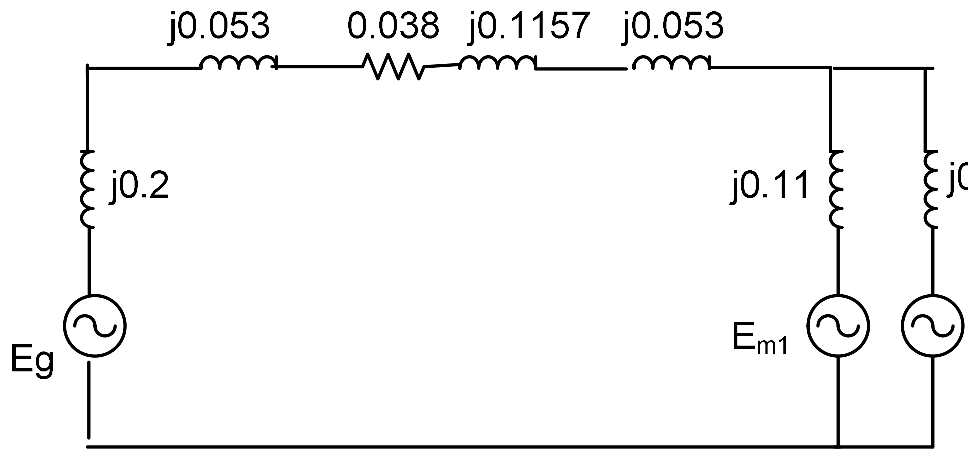
$Z_{TL} = 25 + j\,75 = 79.056 \angle 71.56\ \Omega$

$$= 79.056 \times \frac{50}{(180)^2} = 0.122 \angle 71.56 \text{ p.u.} = (0.038 + j\,0.1157)$$

$$X_{T2p.u.} = 0.12 \times \frac{50}{60} \times \left(\frac{131.63}{180}\right)^2 = j\,0.053 \text{ p.u.}$$

$$X_{m1p.u.} = 0.15 \times \frac{50}{30} \times \left(\frac{30}{45.13}\right)^2 = j\,0.1104 \text{ p.u.}$$

$$X_{m1p.u.} = 0.15 \times \frac{50}{20} \times \left(\frac{30}{45.13}\right)^2 = j\,0.165 \text{ p.u.}$$



Total input to the motor = 24+16 = 40MW

Base MVA= 50 MVA

Per unit value $P_{p.u.}$ = actual/base = 40/50 = 0.8

For voltage:

Base voltage $kV_b = 45.12$ kV

Actual value = 30 kV

$V_{p.u.} = 30/45.12 = 0.664$ p.u.

Therefore, $P_{pu} = V_{pu} I_{pu}$

$I_{pu} = 1.204$ p.u.

Applying KVL

$V_{tp.u} = Ip.u.(X_{T1} + Z_{TL} + X_{T2}) + V_{p.u}$

$= 1.204[j(0.053+0.1157+0.053) + 0.038] + 0.664$

$= 0.709 + j0.266 = 0.758 \angle 20.61$

$V_{actual} = V_{tp.u.}$ x base value

$= 0.758 \times 15$

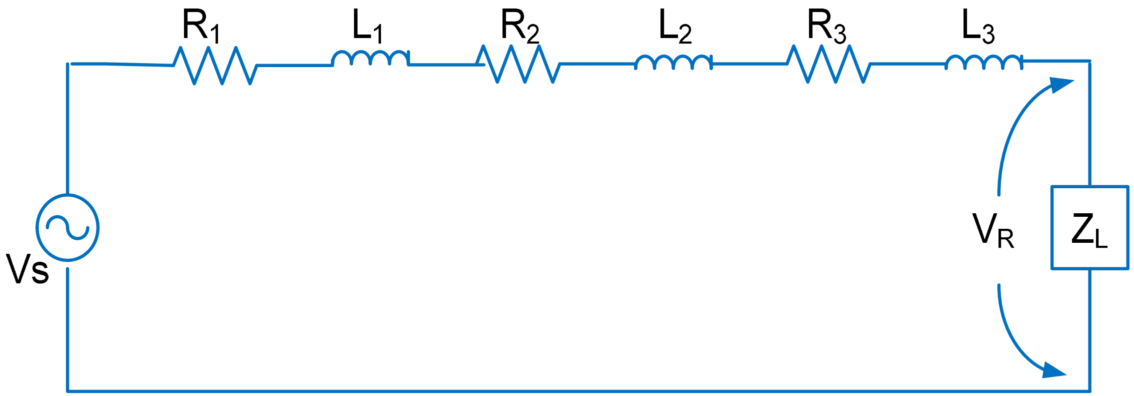
1.37kV

TRANSMISSION LINE PARAMETERS

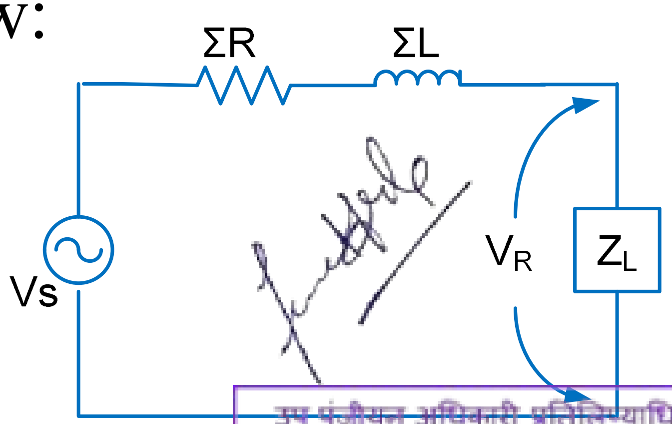
(ELECTRICAL DESIGN OF OVERHEAD TRANSMISSION LINE)

- Transmission of electric power is done by 3-phase 3-wire overhead line.
- An a.c. transmission line has resistance, inductance and capacitance uniformly distributed along its length. These are known as constants and parameter of the line.
- Performance of transmission line depends to the considerable extent upon these parameters.
- This constant determines whether the efficiency and voltage regulation of line is good or poor.
- Concept of these constant is necessary in order to make the electrical design of transmission line
- Out of these three parameters we will pay more attention in finding the value of inductance and capacitance as value of these parameter depends on conductor arrangement.
- Resistance is very simple to calculate.

- A transmission line has resistance ,inductance and capacitance distributed along the whole length of transmission line as shown in figure below:



- However performance of transmission line can be analysed conveniently if distributed parameters are considered lumped as shown in figure below:



Resistance:

- It is the opposition of line conductors to current flow.
- It is the most important cause for power loss in transmission line
- The resistance R of a line conductor having resistivity ρ ,length l and are of cross section a is given by:

$$R = \frac{\rho l}{a}$$

- In a single phase or 2-wire dc line,the total resistance(known as loop resistance) is equal to double the resistance of either conductor.
- In case of 3-phase transmission line, resistance per phase is the resistance of one conductor .

Inductance:

- When an alternating current flows through a conductor , a changing flux is set up which links with conductor.
- Due to these flux linkage ,the conductor posses inductance.
- Mathematically, inductance is defined as the flux linkages per ampere i.e.

ψ

where ψ = flux linkage in weber-turn

I = current in amperes

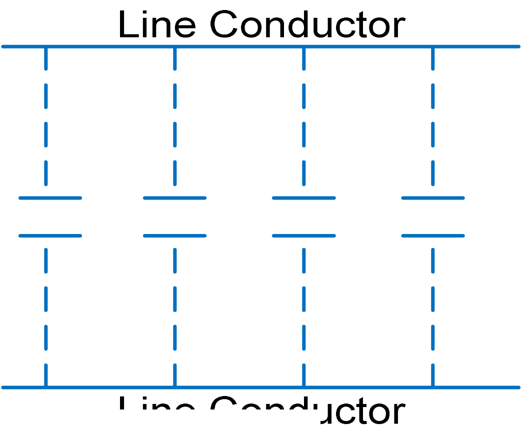
Capacitance:

- Any two conductor separated by an insulating material constitute capacitor.
- As any two conductors of an overhead line are separated by air which acts as an insulation ,therefore capacitance e between any two overhead line conductors.
- The capacitance between the conductor is the charge per unit potential difference.

i.e $C = \frac{q}{v}$ where q = charge on the line per column

v = p.d. between the conductors in volts.

- The capacitance is uniformly distributed along the whole length of the line and may be regarded as series of capa connected between the conductors as shown in Fig.1 below:



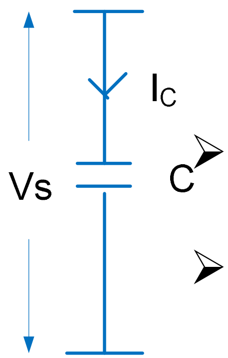


Fig.2

- When an alternating voltage is impressed on a transmission line ,the cha on the conductors at any point increases or decreases with increase a decrease of instantaneous value of the voltage between the conductors.
- The result is that the current known as charging current flows between conductors as shown in Fig.2 .
- This charging current flows in the line even it is open circuited supplying no load.

KIN EFFECT

The distribution of electric current over the entire cross section of the conductor is quite uniform in case of a DC system

When an alternating current passes through a conductor it does not flow uniformly all over the conductor. The concentration of current is higher on the surface of the conductor than at the centre, thus increasing the effective resistance. This effect is called the skin effect.

*ne tendency of alternating current to concentrate near the surface of a conductor is known as **skin effect.**"*

use of Skin Effect:

The solid conductor considered can be thought of having a number of strands one over the other, each carrying sor portion of the current.

Inductance of each strand will vary according to its position.

Thus, the strands near the centre are surrounded by a greater magnetic flux and hence have larger inductance than th near the surface.

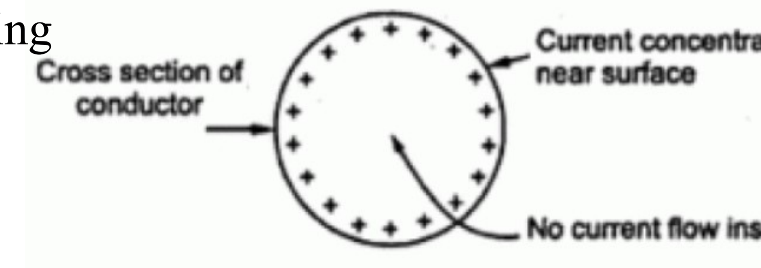
The high reactance of inner strands causes the alternating current to flow near the surface of conductor.

This crowding of current near the conductor surface is the skin effect.

ect:

Due to skin effect, the effective area of cross section of the conductor through which current flows is reduced.

Consequently the resistance of the conductor is slightly increased when carrying an alternating current.



Factors affecting it:

- Nature of material.
- It is directly proportional to diameter of conductor.
- It is proportional to frequency of supply. skin effect increases with the increase in frequency.
- It depends on the shape of the conductor. Skin effect less for stranded conductor than the solid conductor.

Skin effect is negligible when supply frequency is low(< 50 Hz) and conductor diameter is small (< 1 cm)

PROXIMITY EFFECT

Definition:

Proximity Effect is the phenomena of non-uniform current distribution on the surface of adjacent current carrying conductor due to the effect of another current carrying conductor in its proximity.

in cables, the conductors are very near to each other, this effect is dominant.

Whereas in overhead lines as lines are far apart when compared with cable, this effect can be neglected.

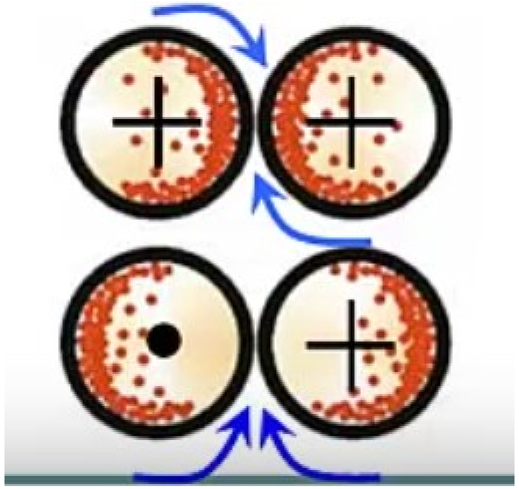
Cause of Proximity Effect:

The main reason for proximity effect is production of magnetic field in the surrounding of a current carrying conductor.

When this magnetic field links with the adjacent conductor, it gives rise to a circulating or eddy current in it.

Because of this eddy current, the current distribution on the nearby becomes non-uniform.

This leads to additional resistance to the flow of current in the nearby conductor. Hence due to proximity effect, the net ac resistance of conductor increases.



- If each conductor carries a current in same direction ,the halves of the conductor in close proximity are cut by more magnetic flux then the remote halves.
- Consequently the current distribution is not even through out the cross section, a least portion is carried out by the remote halves.
- If current are in opposite direction, the halves in close proximity will carry low density current.

Factors Affecting Poximity Effect

- **Frequency** – The proximity increases with the increases in the frequency.
- **Diameter** – The proximity effect increases with the increase in the conductor.
- **Structure** – This effect is more on the solid conductor as compared to the stranded conductor (i.e., ASCR) because the surface area of the stranded conductor is smaller than the solid conductor.
- **Material** – If the material is made up of high ferromagnetic material [illegible]ximity effect is more on their surface.

FLUX LINKAGES

1. Flux linkage due to a single current carrying conductor:

Consider a long straight cylindrical conductor of radius ‘r’ meters and carrying a current I amperes as shown in Fig(i)

This current will set up magnetic field.

This magnetic lines of force will exist inside the conductor as well as outside the conductor.

Both these fluxes will contribute to the inductance of the conductor.

i) Flux linkages due to internal flux:

Referring to Fig(ii) below, the magnetic field intensity at a point x meters from the centre is given by:

$H_x = \frac{I_x}{2\pi x}$ …. According to the amperes law.

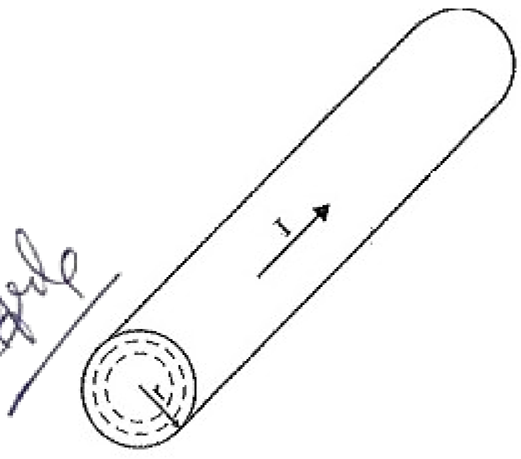
mmf around any closed path equals

the current enclosed by the path. The current

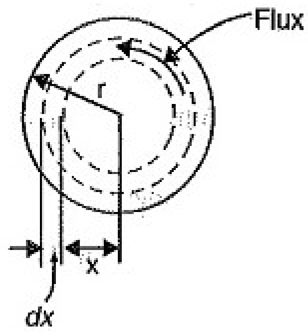
enclosed by the path is I_x and hence mmf

=

H



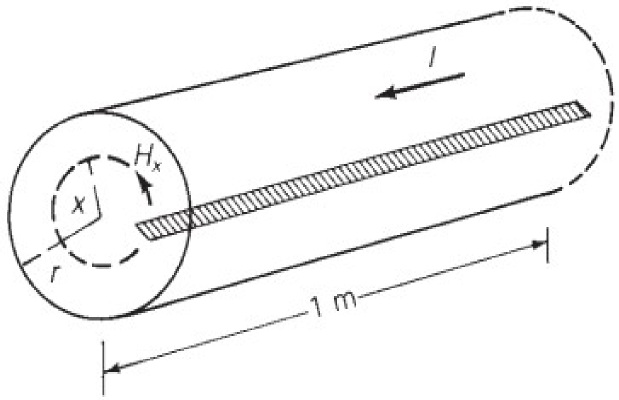
(i)



(ii)

Assuming current density to be uniform

$I_x = \frac{\pi x^2}{\pi r^2} I = \frac{x^2}{r^2} I$



Therefore, $H_x = \frac{x^2}{r^2}$ x I x $\frac{1}{2\pi x}$

$= \frac{x}{2\pi r^2} I \quad AT/m$

If μ (= $\mu_0 \mu_r$) is the permeability of conductor,then flux density at considered point is given by:

$B_x = \frac{\mu_0 \mu_r x}{2\pi r^2} I = \frac{\mu_0 \; x}{2\pi r^2} I \quad wb/m^2$ (μr = 1 for non-magnetic material)

For the finite element having thickness dx,area is equal to dx times the axial length.

Assuming axial length= 1 m

Flux per meter of the length is

$d\varphi = B_x * 1 * dx$ weber

$= \frac{\mu_0 \; x I}{2\pi r^2} dx$

T… links with the current I_x only. Lying within the circle of radius x.

tire cross sectional area of the conductor does not enclose the above expressed flux. e ratio of cross sectional area inside the circle of radius to the total cross section can thought as fractional turns the links the flux.

erefore the flux linkage per meter length of the conductor is

$$d\psi = \frac{x^2}{r^2}\, d\varphi$$

$$= \frac{x^2}{r^2}\, \frac{\mu_0\, x\, I}{2\pi r^2}\, \mathrm{dx}$$

$$= \frac{\mu_0\, I\, x^3}{2\pi r^4}\, \mathrm{dx}$$

erefore total flux linkage from centre of the conductor upto the surface of the nductor is

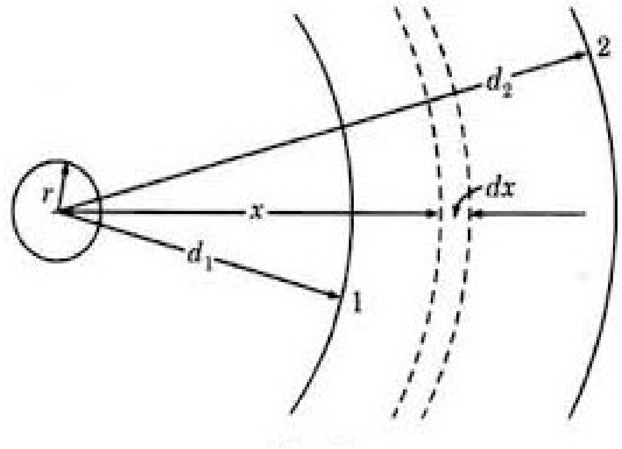
$${}_t = \int_0^r \frac{\mu_0\, I\, x^3}{2\pi r^4}\, \mathrm{dx}$$

$$= \frac{\mu_0\, I}{8\pi}\ \text{wb-T/m}$$

erefore L int $= \psi_{int} / I \ = \frac{1}{2} * 10^{-7}$ H/m

lux linkages due to external flux:

sider two points 1 and 2 at a distance of d_1 and d_2 from
entre of the conductor. Since the flux path are
entric circles around the conductor whole of the flux
ween 1 and 2 lies within the concentric cylindrical surface
ing through these points.



field strength at a distance x from the centre of conductor

$\frac{I}{2\pi x}$ AT/m

density is equal to $B_x = \mu_0 \mu_r H_x$ ($\mu_r = 1$ for non magnetic material)

$\frac{\mu_0 I}{2\pi x}$

refore the flux through cylindrical shell of radial thickness dx and axial length of 1 m is

$B_x * 1 * dx$ weber $= \frac{\mu_0 I}{2\pi x} dx$

li ter is equal to $d\varphi$. Since flux external to the conductor inks all the current in the conductor

= c

Therefore, the total flux linkage ψ *between points 1 and 2* $= \int_{d_1}^{d_2} d\psi$

$\Psi_{ext} = 2 * 10^{-7} * I * ln\ (d_2/d_1)$

Therefore $L_{ext} = 2 * 10^{-7}\ ln\ (d_2/d_1)$ $[\ L = \psi/I\ ]$

therefore ,total inductance of a conductor $L = L_{int} + L_{ext}$

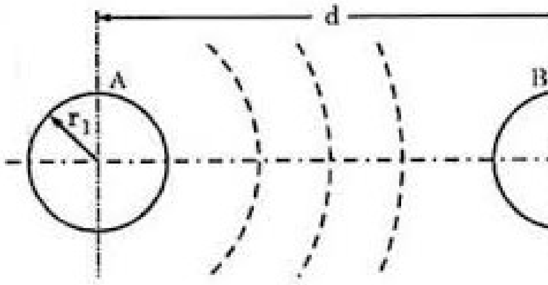
$= \frac{1}{2} * 10^{-7} + 2 * 10^{-7}\ ln\ (d_2/d_1)$

Substituting $d_1 = r$ and $d_2 = d$

$L = 2 * 10^{-7}\ ln \frac{d}{re^{-1/4}}$

Therefore $L = 2 * 10^{-7}\ ln \frac{d}{r'}$ $[r' = 0.7788 * r]$

INDUCTANCE OF SINGLE PHASE TWO WIRE LINE



A single phase line consist of two parallel conductors which form a rectangular loop of one turn.

When an alternating current flows through such a loop ,a changing magnetic flux is set up, and hence a loop possess inductance.

Consider a single phase overhead line consisting of two parallel conductors A and B spaced 'd' meters apart as shown in fig.

Conductor A and B carries same amount of current($I_A = I_B$) but in opposite direction because one forms th return circuit of the other.

i.e. $I_A + I_B = 0$

There will be flux linkage with conductor A due to its own current I_A and due to mutual inductance effect current I_B in conductor B.

Assuming that the flux produced by current in conductor A links all the current upto the centre of conduc and that flux beyond the centre of conductor B does not links any current.

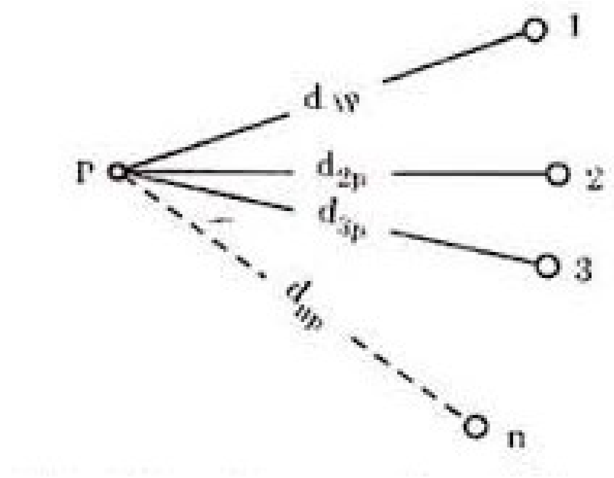
$2 * 10^{-7} \; ln \frac{d}{r_1'}$ $L_B = 2 * 10^{-7} \; ln \frac{d}{r_2'}$

op i ... $_A$ + L_B ....Substituting $r_1' = r_2' = r'$

$* \; 10^{-7} \; ln \frac{d}{r'}$

FLUX LINKAGE OF ONE CONDUCTOR IN A GROUP OF CONDUCTORS

Consider a group of parallel conductors 1, 2, 3, … n carrying currents I_1, I_2, I_3 … I_n respectively, as illustrated in Fig. 4.4. Let it be assumed that the sum of the currents in various conductors is zero i.e. $I_1 + I_2 + I_3 + \dots I_n = 0$



Theoretically, the flux due to a conductor extends from the centre of the conductor right up to infinity but let us assume that the flux linkages extend up to a remote point P and the respective distances are as marked in Figure.

The current in each conductor sets up a certain flux due its own current. The sum of all these fluxes is the total flux of the system and the total flux linkages of any one conductor is the sum of its linkages with all the individual fluxes set up by the conductors of the system.

he flux linkages of conductor 1 due to its own current I_1 (internal and external), up to point P,

$$\Psi_{1p1} = 2 \times 10^{-7} I_1 \log_e \frac{d_{1p}}{r'_1} \text{ Wb-turns/metre}$$

e f of conductor 1 due to current in conductor 2,

$$\times 10^{-7} I_2 \log_e \frac{d_{2p}}{d_{12}}$$

Thus the expression for flux linkages of conductor 1 due to currents in all conductors can be written as:

$$\psi_{1p} = 2 \times 10^{-7}\left[I_1 \log_e \frac{d_{1p}}{r_1'} + I_2 \log_e \frac{d_{2p}}{d_{12}} + I_3 \log_e \frac{d_{3p}}{d_{13}} + \ldots . I_n \log_e \frac{d_{np}}{d_{1n}}\right] \text{ Wb-turns/m}$$

The above equation may be written as:

$$\psi_{1p} = 2 \times 10^{-7}\left[I_1 \log_e \frac{1}{r_1'} + I_2 \log_e \frac{1}{d_{12}} + I_3 \log_e \frac{1}{d_{13}} + \ldots . I_n \log_e \frac{1}{d_{1n}}\right]$$

$$+ 2 \times 10^{-7}\,[I_1 \log_e d_{1p} + I_2 \log_e d_{2p} + I_3 \log_e d_{3p} + \ldots . I_n \log_e d_{np}] \text{ Wb-turns/m}$$

To account for the total flux linkages to conductor 1, the point P must approach infinity and in this condition,

$$d_{1p} \simeq d_{2p} \simeq d_{3p} \simeq d_{4p} \ldots d_{np} \simeq d \text{ (say)}$$

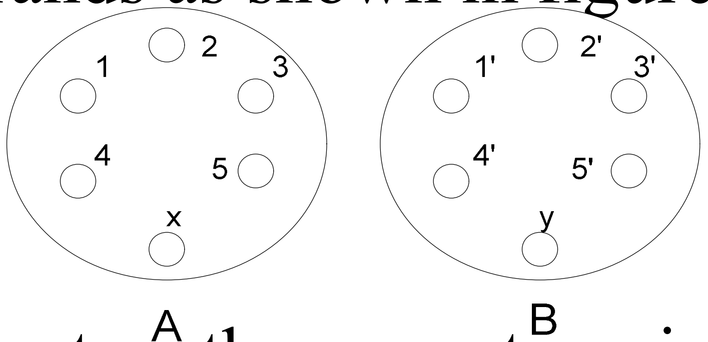
Then $$\lim_{d \to \infty} (I_1 + I_2 + I_3 + \ldots + I_n) \log_e d = 0 \qquad \because I_1 + I_2 + I_3 + \ldots I_n = 0$$

The equation for the flux linkages to conductor 1 becomes,

$$)^{-7}\left[I_1 \log_e \frac{1}{r_1'} + I_2 \log_e \frac{1}{d_{12}} + I_3 \log_e \frac{1}{d_{13}} + \ldots . I_n \log_e \frac{1}{d_{1n}}\right] \text{Wb-turns/m}$$

NDUCTANCE OF COMPOSITE CONDUCTOR LINES

nsider a single phase line consisting of two parallel conduc-tors A and B, ductor A consisting of x and conductor B of y strands as shown in figure . the conductors A and B carry currents I and – I pectively (since conductors of a 2-wire line ry the same current but in opposite directions).



suming uniform current density in both the conduc-tors the current carried b h strand of conductor A will be I/x while that carried by each strand of ductor B will be –I/y.

erefore, the flux linkages of strand 1 in conductor A can be written as:

$$\psi_1 = 2 \times 10^{-7}\frac{I}{x}\left[\log_e \frac{1}{r_1'} + \log_e \frac{1}{d_{12}} + \log_e \frac{1}{d_{13}} + \ldots + \log_e \frac{1}{d_{1x}}\right]$$

$$- 2 \times 10^{-7}\frac{I}{y}\left[\log_e \frac{1}{d11'} + \log_e \frac{1}{d12'} + \log_e \frac{1}{d13'} + \ldots + \log_e \frac{1}{d_{1y}}\right]$$

$$\psi_1 = 2 \times 10^{-7}\ I \log_e \frac{\sqrt[y]{\left(d_{11'}\ d_{12'}\ d_{13'}\ \ldots. d_{1y}\right)}}{\sqrt[x]{r_1'\ d_{12}\ d_{13} \ldots. d_{1x}}} \text{ Wb-turns/m}$$

Therefore, Inductance of strand 1 of conductor A,

$$L_1 = \frac{\psi_1}{I/x} = 2 \times 10^{-7} x \log_e \frac{\sqrt[y]{\left(d_{11'}\ d_{12'}\ d_{13'}\ d_{14'} \ldots. d_{1y}\right)}}{\sqrt[x]{r'\ d_{12}\ d_{13}\ d_{14} \ldots. d_{1x}}}$$

Similarly Inductance of strand 2 of conductor A,

$$L_2 = 2 \times 10^{-7} x \log_e \frac{y\sqrt{d_{21'}\ d_{22'}\ d_{23'}\ d_{24'}\ \ldots.\ d_{2y}}}{x\sqrt{d_{21}\ d_{22}\ d_{23}\ d_{24}\ \ldots.\ d_{2x}}} \text{ H/m}$$

Different strands of a conductor have different inductances. Therefore, average inductance of strands of conduct

$$L_{avg} = \frac{L_1 + L_2 + \cdots .. + L_x}{x}$$

Since x such strands of conductor A are electrically in parallel, therefore inductance of conductor A,

$$L_A = \frac{L_{av}}{x} = \frac{L_1 + L_2 + L_3 + \ldots L_x}{x^2}$$

$$0^{-7} \log_e \left[\frac{\sqrt[xy]{\left(d_{11'}\ d_{12'}\ d_{13'}\ d_{14'} \ldots d_{1y}\right)\left(d_{21'}\ d_{22'}\ d_{23'} \ldots d_{2y}\right) \ldots \left(d_{x1'}\ d_{x2'}\ d_{x3'} \ldots d_{xy}\right)}}{\sqrt[x^2]{\left(d_{11}\ d_{12}\ d_{13}\ d_{14} \ldots d_{1x}\right)\left(d_{21}\ d_{22}\ d_{23} \ldots d_{2x}\right)\left(d_{x1}\ d_{x2}\ d_{x3} \ldots dxx\right)}} \right]$$

In the above expression the numerator of argument of $\log_e$ is called the GMD (often called the mutual GMD) between conductors A and B and the denominator of argument $\log_e$ is called GMR (often called self GMD). GMD (Geometric Mean Distance) and GMR (Geometric Mean Radius) are denoted by D_m and D_s respectively.

$$\therefore L_A = 2 \times 10^{-7} \log_e \frac{D_m}{D_{sA}} \text{ H/m}$$

$$\text{Similarly } L_B = 2 \times 10^{-7} \log_e \frac{D_m}{D_{sB}} \text{ H/m}$$

If conductors A and B are identical

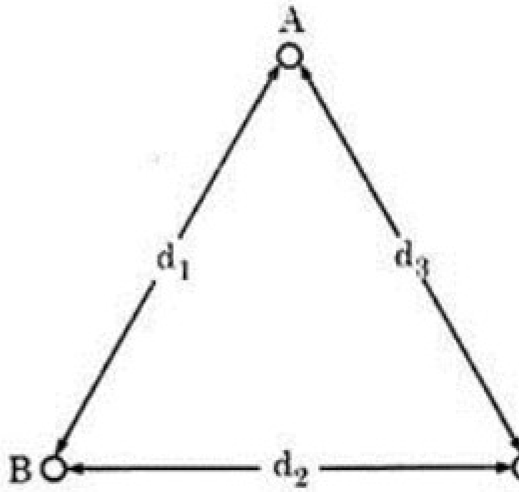
$$\therefore D_{sA} = D_{sB} = D_s \text{ (say)}$$

$$\text{Loop inductance, } L = L_A + L_B = 2 \times 10^{-7} \log_e \frac{D_m}{D_s} + 2 \times 10^{-7} \log_e \frac{D_m}{D_s}$$

$$= 4 \times 10^{-7} \log_e \frac{D_m}{D_s} \text{ H/m} \quad \text{or } 0.4 \log_e \frac{D_m}{D_s} \text{ mH/km}$$

INDUCTANCE OF THREE PHASE OVERHEAD LINE

A: With Unsymmetrical Spacing



- Consider a 3-ϕ line with conductors A, B, and C; each of radius r metres. Let the spacing between them be d_1, d_2 and d_3 and the current flowing through them be I_A, I_B and I_c respectively.
- The flux linkages of conductor A due to its own current I_A and other conductor currents I_B and I_c is

$$\psi_A = 2 \times 10^{-7}\left[I_A \log_e \frac{1}{r'} + I_B \log_e \frac{1}{d_1} + I_C \log_e \frac{1}{d_3} \right] \text{ Wb-turns/m}$$

Similarly

$$\psi_B = 2 \times 10^{-7}\left[I_B \log_e \frac{1}{r'} + I_A \log_e \frac{1}{d_1} + I_C \log_e \frac{1}{d_2} \right] \text{ Wb-turns/m}$$

and $$\psi_C = 2 \times 10^{-7}\left[I_C \log_e \frac{1}{r'} + I_A \log_e \frac{1}{d_3} + I_B \log_e \frac{1}{d_2} \right] \text{ Wb-turns/m}$$

If the system is balanced,

$I_A = I_B = I_c = I$ (say) in magnitude

Taking I_A as a reference phasor, the currents are represented, in symbolic form

(- 0.5 – j 0.866) and $I_c = I$ (- 0.5 + j 0.866)

Substituting these values of I_B and I_c in the expression for Ψ_A we get,

$$\psi_A = 2 \times 10^{-7}\left[I \log_e \frac{1}{r'} + I(-0.5 - j0.866)\log_e \frac{1}{d_1} + I(-0.5 + j0.866)\log_e \frac{1}{d_3}\right]$$

$$= 2 \times 10^{-7} I \left[\log_e \frac{1}{r'} + \log_e \sqrt{d_1 d_3} + j\sqrt{3}\log_e \sqrt{\frac{d_1}{d_3}}\right]$$

$$\text{and } L_A = \frac{\psi_A}{I_A} = 2 \times 10^{-7}\left[\log_e \frac{1}{r'} + \log_e \sqrt{d_1 d_3} + j\sqrt{3}\log_e \sqrt{\frac{d_1}{d_3}}\right] \text{ H/m} \quad ..$$

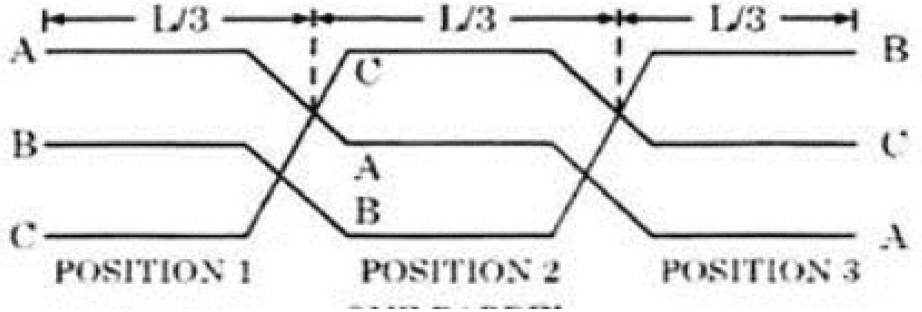
$$\text{Similarly } L_B = 2 \times 10^{-7}\left[\log_e \frac{1}{r'} + \log_e \sqrt{d_1 d_2} + j\sqrt{3}\log_e \sqrt{\frac{d_2}{d_1}}\right] \text{ H/m} \quad ..$$

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

Thus it is observed that when the conductors of a 3-phase transmission line are not equidistant from each other. i.e.. unsymmetrically spaced, the flux linkages and inductances of various phases are different wh[illegible]equal voltage drops in the three phases and transfer of power between phases due to mu[illegible]ces even if the currents in the conductors are balanced.

TRANSPOSITION OF CONDUCTORS

he unbalancing effect on account of irregular spac-ing of conductors is avoided by ransposition of conduc-tors, as shown in Fig. below. In practice the conductors are so ransposed that each of the three possible ar-rangements of conductors exists for one-hird of the total length of the line.



he effect of transposition is that each conduc-tor has the same average inductance, hich is given as:

$$\mathbf{L} = \frac{L_A + L_B + L_C}{3}$$

$$= 2 \times 10^{-7}\left[\log_e \frac{1}{r'} + \frac{1}{3}\left(\log_e \sqrt{d_1 d_3} + \log_e \sqrt{d_1 d_2} + \log_e \sqrt{d_2 d_3}\right) + j\frac{\sqrt{3}}{3}\left(\log_e \sqrt{\frac{d_1}{d_3}} + \log_e \sqrt{\frac{d_2}{d_1}} + \log_e \sqrt{\frac{d_3}{d_2}}\right)\right]$$

$$= 2 \times 10^{-7}\left[\log_e \frac{1}{r'} + \log_e \sqrt[3]{d_1 d_2 d_3} + 0\right] = 2 \times 10^{-7} \log_e \frac{\sqrt[3]{d_1 d_2 d_3}}{r'} \text{ H/m} \quad ...($$

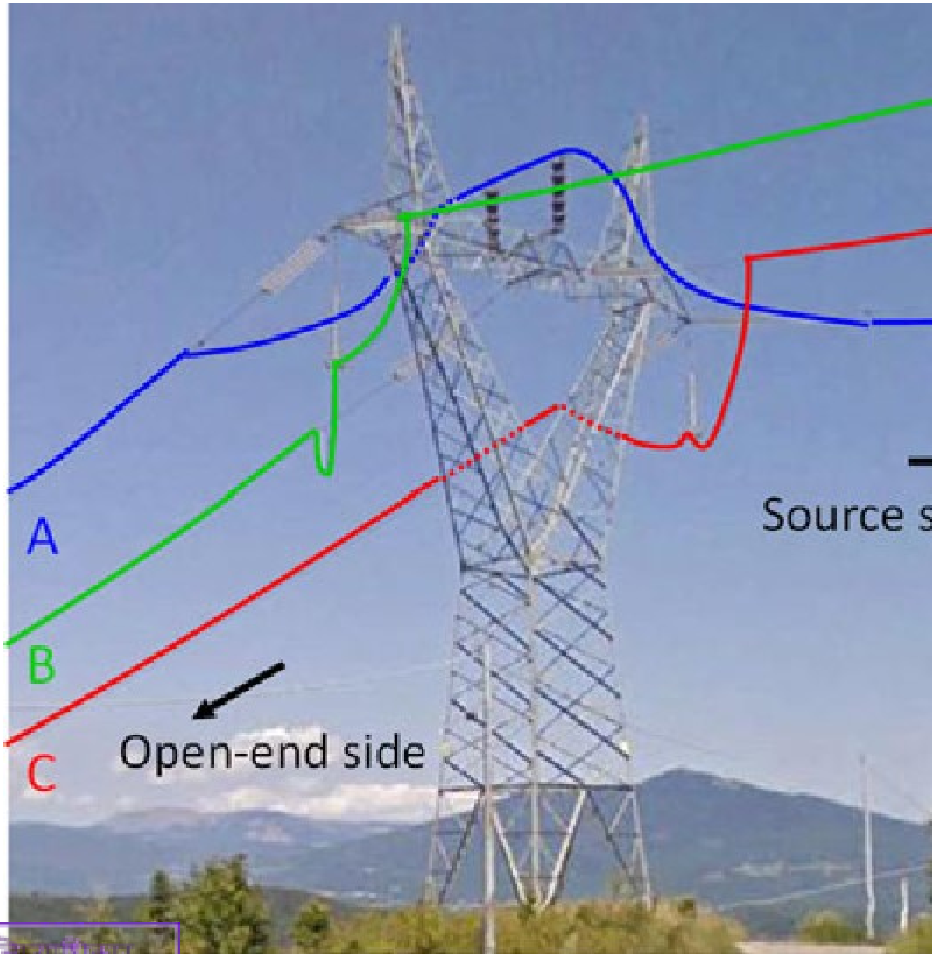
f the conductors are equi-spaced (let the spacing be equal to d), the inductance of each onductor will be same and can be obtained by substituting $d_1 = d_2 = d_3$ in above expressi

o inductance of each conductor:

$$\mathbf{L} = 2 \times 10^{-7} \log_e \frac{\sqrt[3]{d \times d \times d}}{r'} \text{ H/m}$$

$$= 2 \times 10^{-7} \log_e \frac{d}{r'} \text{ H/m}$$

For stranded conductor r’ will be replaced by D_s (self GMD).



PROBLEMS

Calculate the loop inductance per km of single phase transmission lin
comprising of two parallel conductors 1 m apart and 1.25 cm in diamete
Also calculate reactance of transmission line.

olution:

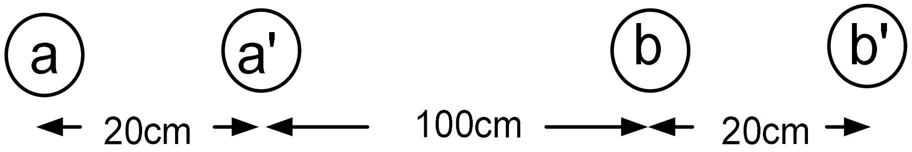
$_{oop} = 4 * 10^{-7} \ \ln \frac{d}{r'}$

$= 1 \text{ m} \quad , r = 1.25 \text{ cm}/2$

$= 0.7788 * r$

$_{oop} = 2.13 \text{ mH/Km}$

In a single phase line as shown below conductor a and a’ forms o
nductor while b and b’ in parallel forms a return path. Calculate to
ductance of line per km assuming current is equally shared by two paral
nductor. Conductor diameter is 2 cm.



$_{oop} = 4 * 10^{-7} \ln \frac{D_m}{D_s}$

both conductors are identical, $D_{SA}=D_{SB}=D_S$

$_n = \sqrt[4]{Dab\ Dab'\ Da'b\ Da'b'}$ ....p=q=2

$_n = \sqrt[4]{120 * 140 * 100 * 120} = 119.15$ cm

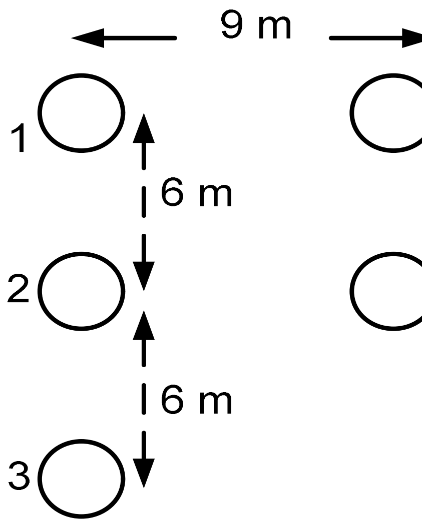
$= \sqrt[4]{Daa\ Daa'\ Da'a\ Da'a'}$

$= \sqrt[4]{0.7788 * 1 * 20 * 20 * 0.7788 * 1} = 3.94$ cm

$_{op} =$ 'Km

3. A single phase line consisting of bundle of three conductors of 5 m
diameter each of outgoing circuit and bundle of two conductors of 10 m
diameter each for return path. Find the inductance per km of line.

Solution:



$$L_{loop} = 4 * 10^{-7} \ln \frac{D_m}{D_s}$$

$$D_m = \sqrt[6]{D11' D12' D21' D22' D31' D32'}$$ ....p=3,q=2

$$= \sqrt[6]{9 * 10.81 * 10.81 * 9 * 15 * 10.81}$$

= 10.74 m

$$D_{SA} = \sqrt[9]{D11\ D12\ D13\ D21\ D22\ D23\ D31\ D32\ D33}$$

$$= \sqrt[9]{(0.7788 * 2.5 * 10^{-3}) * 6 * 12 * 6 * (0.7788 * 2.5 * 10^{-3}) * 6 * 12 * 6 * (0.7788 * 2.5 * 10^{-3})}$$

= 0.48 m

$$D_{SB} = \sqrt[4]{D1'1'\ D1'2' D2'1'\ D2'2'}$$

$$= \sqrt[4]{(0.7788 * 5 * 10^{-3}) * 6 * 6 * (0.7788 * 5 * 10^{-3})}$$

D_S = 2701

loc H/Km

CAPACITANCE OF A TRANSMISSION LINE

he capacitance between the conductor is the charge per unit potential.

.e $C = \frac{q}{v}$ where q = charge on the line per column

v = p.d. between the conductors in volts.

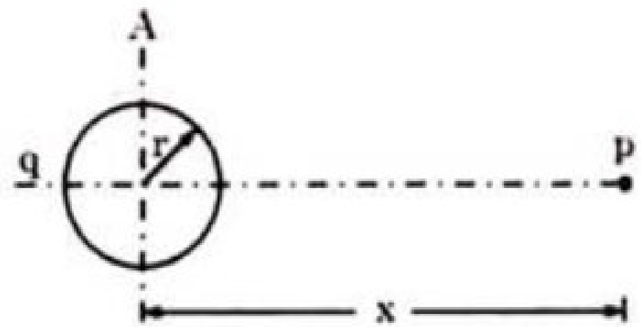
lectric potential at any point due to a charge is the work done in bringin
nit positive charge from infinity to that point.

. Potential at a Charged Single Conductor:

onsider a long straight cylindrical conductor A of radius r metres and havin
charge of q coulombs per metre of its length.

he electric field intensity at a distance x from

he centre of conductor,



$$E = \frac{q}{2\pi \epsilon_0 \epsilon_r x} \text{ volts/m}$$

ak s a medium $\varepsilon_r = 1$

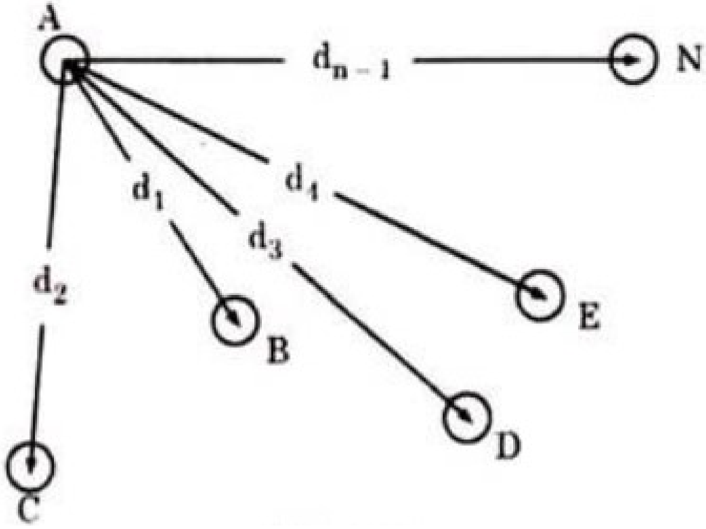
$$E = \frac{q}{2\pi \epsilon_0 x} \text{ volts/m}$$

potential difference between conductor A and infinity will be equal to work done in
ging a unit positive charge against E from infinity to conductor surface and is given

$$V_A = \int_r^{\infty} \frac{q}{2\pi \epsilon_0 x}\, dx = \frac{q}{2\pi \epsilon_0} \int_r^{\infty} \frac{dx}{x}$$

Potential at a Charged Conductor in a Group of Charged Conductors:

Consider a group of long straight conductors A, B, C, D, E … N having charges of q_1, q_2, q_3, q_4, q_5 … q_n coulombs
re length respectively as shown in Fig. below:



ntial of conductor A due to its own charge q_1

$$= \int_r^{\infty} \frac{q_1}{2\pi \epsilon_0} \frac{dx}{x} \text{ volts}$$

tential of conductor A due to charge q_2

$$= \int^{\infty} \frac{q_2}{2\pi \epsilon_0} \frac{dx}{x} \text{ volts}$$

th the charge q_2 extends from infinity up to a distance d_1 from conductor A.

Similarly potential of conductor A, due to charge q_3 of conductor C placed at a distance of d_2 metres from conductor A

$$= \int_{d_2}^{\infty} \frac{q_3}{2\pi \epsilon_0} \frac{dx}{x} \text{ volts}$$

Potential of conductor A due to charge qn of conductor N placed at a distance of dn – 1 metres from conductor A

$$= \int_{d_{n-1}}^{\infty} \frac{q_n}{2\pi \epsilon_0} \frac{dx}{x} \text{ volts}$$

So overall potential difference between conductor A and infinite

$$V_{AN} = \int_{r}^{\infty} \frac{q_1}{2\pi \epsilon_0} \frac{dx}{x} + \int_{d_1}^{\infty} \frac{q_2}{2\pi \epsilon_0} \frac{dx}{x} + \int_{d_2}^{\infty} \frac{q_3}{2\pi \epsilon_0} \frac{dx}{x} + \ldots + \int_{d_{n-1}}^{\infty} \frac{q_n}{2\pi \epsilon_0} \frac{dx}{x}$$

$$= \frac{1}{2\pi \epsilon_0} [q_1 (\log_e \infty - \log_e r) + q_2 (\log_e \infty - \log_e d_1) + q_3 (\log_e \infty - \log_e d_3) + \ldots + q_n (\log_e \infty - \log_e d_{n-1})]$$

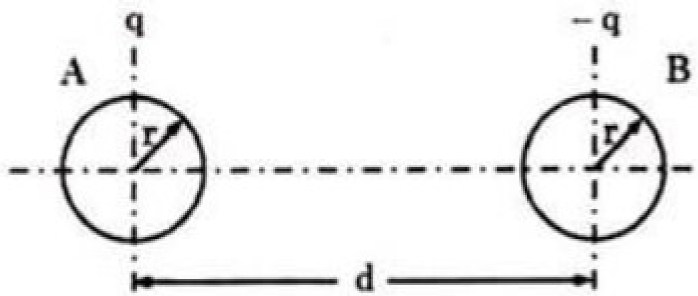
$$= \frac{1}{2\pi \epsilon_0} \left[q_1 \log_e \frac{1}{r} + q_2 \log_e \frac{1}{d_1} + q_3 \log_e \frac{1}{d_2} + \ldots + q_n \log_e \frac{1}{d_{n-1}} + \log_e \infty (q_1 + q_2 + q_3 + \ldots + q_n) \right]$$

Assuming balanced load *i.e.* $q_1 + q_2 + q_3 \ldots\ldots q_n = 0$

$$\text{or } V_{AN} = \frac{1}{2\pi \epsilon_0}\left[q_1 \log_e \frac{1}{r} + q_2 \log_e \frac{1}{d_1} + q_3 \log_e \frac{1}{d_2} + \ldots + q_n \log_e \frac{1}{d_{n-1}}\right] \text{ volts}$$

Capacitance of a Single Phase Overhead Line:

Consider a single phase overhead line with two parallel conductors, each of radiu
netres placed at a distance of d metres in air as shown in Fig. below. It is assumed that th
harge + q coulombs on conductor A and – q coulombs on conductor B are concentrated
he centres of the two conductors which are separated from each other by d metres.



PD between conductor A and neutral 'infinite' plane,

$$V_{AN} = \int_r^{\infty} \frac{q}{2\pi\epsilon_0} \cdot \frac{d}{dx} + \int_d^{\infty} \frac{-q}{2\pi\epsilon_0} \frac{dx}{x}$$

$$= \frac{q}{2\pi\epsilon_0}\left[\log_e \infty + \log_e \frac{1}{r} - \log_e \infty + \log\right.$$

$$= \frac{q}{2\pi\epsilon_0} \log_e \frac{d}{r}$$

Similarly p d between conductor B and neutral 'infinite' plane,

$$V_{BN} = \int_r^\infty \frac{-q}{2\pi\epsilon_0}\frac{dx}{x} + \int_d^\infty \frac{q}{2\pi\epsilon_0}\frac{dx}{x} = \frac{-q}{2\pi\epsilon_0}\log_e\frac{d}{r} \text{ volts}$$

PD between conductor A and B

$$V_{AB} = V_{AN} - V_{BN} = \frac{q}{2\pi\epsilon_0}\log_e\frac{d}{r} - \frac{-q}{2\pi\epsilon_0}\log_e\frac{d}{r} = \frac{q}{\pi\epsilon_0}\log_e\frac{d}{r} \text{ volts}$$

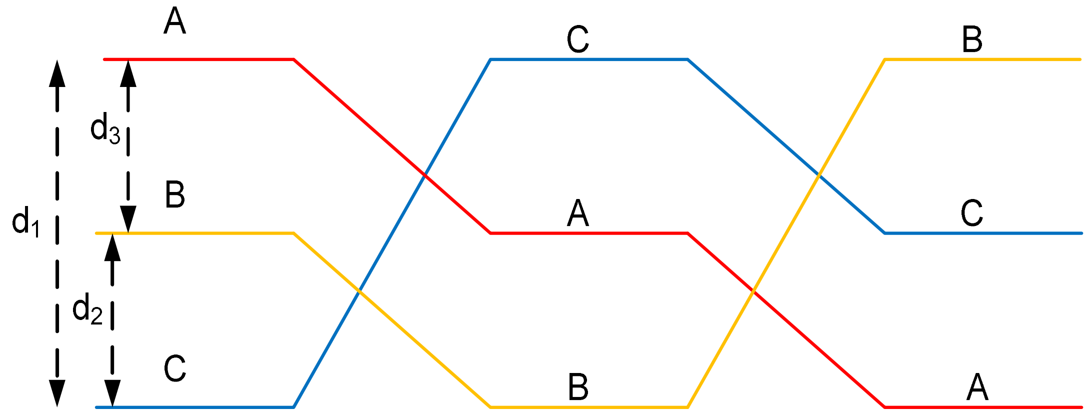
Capacitance of the single phase line,

$$C = \frac{q}{V_{AB}} = \frac{q}{\frac{q}{\pi\epsilon_0}\log_e\frac{d}{r}} = \frac{\pi\epsilon_0}{\log_e\frac{d}{r}} \text{ F/m}$$

apacitance of Three Phase Line

nsymmetrical Spacing

onsidering potential of conductor A
n 1st section as V_1



$$_1 = \frac{1}{2\pi\epsilon_0}\left[q_A \ln\frac{1}{r} + q_B \ln\frac{1}{d_3} + q_C \ln\frac{1}{d_2}\right]$$

milarly for section II

$$_2 = \frac{1}{2\pi\epsilon_0}\left[q_A \ln\frac{1}{r} + q_B \ln\frac{1}{d_1} + q_C \ln\frac{1}{d_3}\right]$$

milarly for section III

$$_3 = \frac{1}{2\pi\epsilon_0}\left[q_A \ln\frac{1}{r} + q_B \ln\frac{1}{d_2} + q_C \ln\frac{1}{d_1}\right]$$

herefore, average voltage of conductor A = $(V_1 + V_2 + V_3)/3$

$$_A = \ldots {}_A \ln\frac{1}{r} + q_B \ln\frac{1}{d_3} + q_C \ln\frac{1}{d_2} + q_A \ln\frac{1}{r} + q_B \ln\frac{1}{d_1} + q_C \ln\frac{1}{d_3} + q_A \ln\frac{1}{r} +$$

$$_B \ln \ldots \ln\frac{1}{d_1}]$$

$$V_A = \frac{1}{3}\frac{1}{2\pi\epsilon_0}\left[3q_A \ln\frac{1}{r} + (q_B + q_C)\ln\frac{1}{d_1 d_2 d_3}\right]$$

Assuming balanced condition

$$q_A + q_B + q_C = 0$$

$$q_B + q_C = -q_A$$

$$V_A = \frac{q_A}{2\pi\epsilon_0}\ln\frac{(d_1 d_2 d_3)^{1/3}}{r}$$

Capacitance per phase

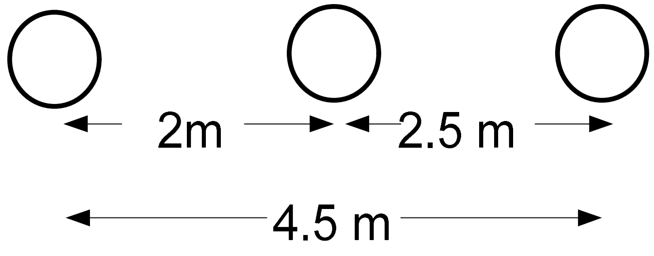
$$C_A = \frac{q_A}{V_A} = \frac{2\pi\epsilon_0}{\ln\frac{(d_1 d_2 d_3)^{1/3}}{r}} \text{ F/m}$$

roblems:

A three phase 50 Hz, 66kV overhead line conductors are placed in horizontal
ne. The conductor diameter is 1.25 cm .If the line length is 100 km, calculate:

Capacitance per phase

Charging current per phase



ume complete transposition of line

$$= \frac{2\pi\epsilon_0}{\ln\frac{\sqrt[3]{(d_1 d_2 d_3)}}{r}} \text{ F/m}$$

$=2$ m, $d_2=2{,}5$ m, $d_3 = 4.5$ m , $r = 1.25/2$, $\epsilon_0 = 8.85 * 10^{-12}$

$9.09 * 10^{-3}$ μF/km

100km line C= 0.909 μF

arging Current per phase I_c= V/Xc

en V_L = 66kV

erefore phase voltage $V_{ph} = 66/\sqrt{3} = 38.105$ kV

1(

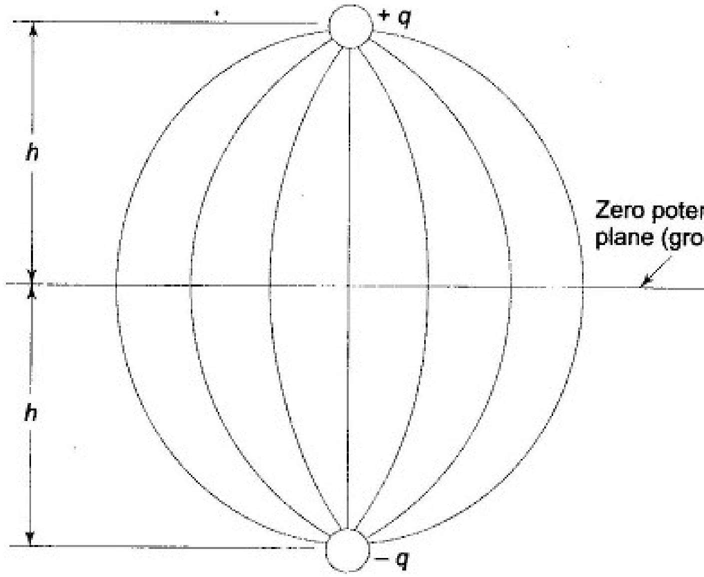
FFECT OF EARTH ON CAPACITANCE OF TRANSMISSION LINE

he effect of earth on Capacitance of Transmission Line can be conveniently taken into ccount by the method of images.

lethod of Images:

The earth may be assumed to be a perfectly conducting horizontal sheet of infinite exten which acts like an equipotential surface.

The electric field of two long, parallel conductors charged +q and -q per unit is such tha has a zero potential plane midway between the conductors



If a conducting sheet of infinite dimensions is placed at the zero potential plane, the electric field remains undistu

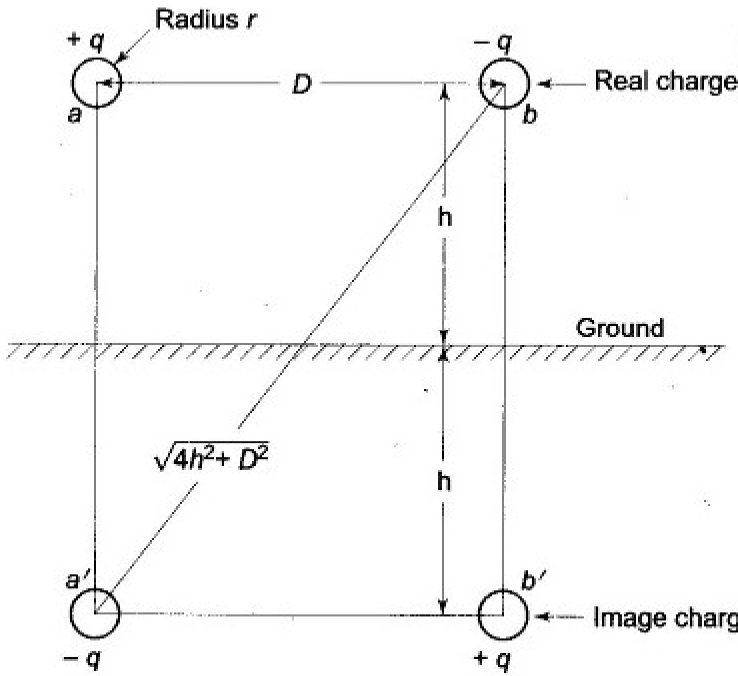
Further, if the conductor carrying charge -q is now remov e electric field above the conducting sheet stays intact, hile that below it vanishes.

ing these well known results in reverse, we may equivalently replace the presence of ground below a char nductor by a fictitious conductor having equal and opposite charge and located as far below the surface of ound as the overhead conductor above it—such a fictitious conductor is the mirror image of the overhead nductor.

is method of creating the same electric field as in the presence of earth is known as the **method of images**

acitance of a Single-Phase Line:

ider a single-phase line shown in Fig. below. The equation for the age drop Vab as determined by the two charged conductors a and b, heir images a' and b' can be written as follows:



$$= \frac{1}{2\pi k}\left[q_a \ln\frac{D}{r} + q_b \ln\frac{r}{D} + q_{a'} \ln\frac{(4h^2+D^2)^{1/2}}{2h} + q_{b'} \ln\frac{2h}{(4h^2+D^2)^{1/2}}\right]$$

$$= \frac{q}{\pi k}\ln\frac{2hD}{r(4h^2+D^2)^{1/2}}$$

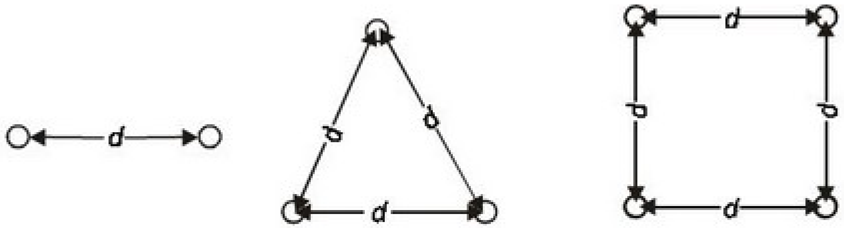
— ln - F/m line-to-line

$$C_n = \frac{2\pi k}{\ln\dfrac{D}{r(1+(D^2/4h^2))^{1/2}}}$$ F/m to neutral

It is observed from the above equation tha presence of earth modifies the radius r to $(D^2/4h^2))^{1/2}$. For h large compared to D (this i case normally), the effect of earth on line capaci is of negligible order.

BUNDLED CONDUCTORS

It is economical to transmit large amount of power over long distances by EHV lines and EHV lines are usually constructed with bundled conductors. Bundled conductors increase the self GMD and line inductance is reduced considerably which increase the power capability of the transmission line. Bundled conductors also reduce the corona loss, surge impedance and radio interference. The bundle usually comprises two, three or four conductors as shown in Fig.



Geometric mean radius of bundled conductors can be obtained in the same manner as that of stranded conductors.

For a two conductor arrangement,

$$D_S = (r'.\,d)^{\frac{1}{2}}$$

For a three conductor arrangement

$$D_S = (r'.\,d^2)^{\frac{1}{3}}$$

[illegible] conductor (quadruplex) arrangement,

$$D_S = (r'd.\,d.\,\sqrt{2}d)^{\frac{1}{4}} = (r'\sqrt{2}\,d^3)^{\frac{1}{4}}$$

[illegible] s the fictitious radius of each subconductor in the bundled.

ona Effect in Transmission Line

hen an alternating current is made to flow across two conductors of the transmission line whose spacing is l mpared to their diameters, then air surrounding the conductors (composed of ions) is subjected to di-electric stress.

t low values of supply end voltage, nothing really occurs as the stress is too less to ionize the air outside. But when tential difference is made to increase beyond some threshold value of around 30 kV known as the critical disrup ltage, then the field strength increases and then the air surrounding it experiences stress high enough to be dissoci o ions making the atmosphere conducting.

is results in electric discharge around the conductors due to the flow of these ions, giving rise to a faint lumines ow, along with the hissing sound accompanied by the liberation of ozone.

is phenomena of electrical discharge occurring in transmission line for high values of voltage is known as the **cor fect in power system**. If the voltage across the lines is still increased the glow becomes more and more intense al th hissing noise, inducing very high power loss into the system which must be accounted for.

ors Affecting Corona

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

tmosphere. As corona is formed due to ionisation of air surrounding the conductors, therefore, it is affected by the physical state of atmosphere. In the stormy weather, the number of ions is more than normal and as such corona occur much less voltage as compared with fair weather.

onductor size. The corona effect depends upon the shape and conditions of the conductors. The rough and irregular urfa ... ise to more corona because unevenness of the surface decreases the value of breakdown voltage. Thu str ... tor has irregular surface and hence gives rise to more corona that a solid conductor.

i) Spacing between conductors. If the spacing between the conductors is made very large as compared to their ameters, there may not be any corona effect. It is because larger distance between conductors reduces the electro-stati esses at the conductor surface, thus avoiding corona formation.

) Line voltage. The line voltage greatly affects corona. If it is low, there is no change in the condition of air rrounding the conductors and hence no corona is formed. However, if the line voltage has such a value that ectrostatic stresses developed at the conductor surface make the air around the conductor conducting, then corona is rmed.

dvantages and Disadvantages of Corona

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

dvantages

Due to corona formation, the air surrounding the conductor becomes conducting and hence virtual diameter of the nductor is increased. The increased diameter reduces the electrostatic stresses between the conductors.

) Corona reduces the effects of transients produced by surges.

sadvantages

Corona is accompanied by a loss of energy. This affects the transmission efficiency of the line.

) C ced by corona and may cause corrosion of the conductor due to chemical action.

i) T awn by the line due to corona is non-sinusoidal and hence non-sinusoidal voltage drop occurs in the e. se inductive interference with neighbouring communication lines.