TRANSMISSION OVER HEAD LINE SYSTEM

January 17

2016

Transmission over head line system; conductor, tower, foundation , insulator…etc

Design & Type

Prepared by :-

Electrical Engineering

Saman Saber Ismael

ID No : 3782

Mobile NO :07701563974

Contents

Introduction

Transmission of Electrical Energy

High Voltage Transmission Lines

Flexible AC Transmission Systems (FACTS)

Reactive Power Compensation in Power Transmission System

Electrical Power Transmission System

Performance of Transmission Line

Short Transmission Line

Medium Transmission Line

Long Transmission Line

Ferranti Effect in Power System

Corona Effect in Power System

ABCD Parameters of Transmission Line

Electrical Transmission Tower Types and Design

Methods of Transmission Tower Erection

Basic Concept of Transmission Tower Foundation

Design of Foundation of Transmission Towers in Different Soils

Types of Overhead Conductor

Skin Effect in Transmission Lines

Insulation Coordination in Power System

Types of Electrical Insulator | Overhead Insulator

Electrical Insulator | Insulating Material | Porcelain Glass Polymer Insulator

Electrical Insulator Testing | Cause of Insulator failure

Introduction

Electrical power is generated at different generating stations. These generating stations are not necessarily situated at the load center. During construction of generating station number of factors to be considered from economical point of view. These all factors may not be easily available at load center, hence generating stations are not normally situated very nearer to load center. Load center is the place where maximum power is consumed. Hence there must be some means by which the generated power must be transmitted to the load center. Electrical transmission system is the means of transmitting power from generating station to different load centers.

Factor to be Considered for Constructing a Generating Station

During planning of construction of generating station the following factors to be considered for economical generation of electrical power.

1) Easy availability of water for thermal power generating station.

2) Easy availability of land for construction of power station including it's staff township.

3) For hydro power station there must be a dam on river.

So proper place on the river must be chosen in such a way that the construction of the dam can be done in most optimum way.

4) For thermal power station easy availability of fuel is one of the most important factors to be considered.

5) Better communication for goods as well as employees of the power station also to be kept into consideration.

6) For transporting very big spare parts of turbines, alternators etc, there must be wide road ways, rain communication, and deep and wide river must pass away nearby the power station.

7) For nuclear power plant, it must be situated in such a distance from common location so that there may be any effect from nuclear reaction the heath of common people.

Many other factors also to be considered, but there are beyond the scope of our discussion. All the factors listed above are very difficult to be available at load center. The power station or generating station must be situated where all the facilities are easily available. This place may not be necessarily at the load center. The power generated at generating station then transmitted to the load center by means of electrical power transmission system as we said earlier. The power generated at generating station is in low voltage level as low voltage power generation has some economical values. Low voltage power generation is more economical than high voltage power generation. At low voltage level, bot weight and wide of insulation is less in the alternator, this directly reduces the cost and size of alternator. But this low voltage level power can not be transmitted directly to the consumer end as because this low voltage power transmission is not at all economical. Hence although low voltage power generation is economical but low voltage electrical power transmission is not economical. Electrical power is directly proportional to the product of electrical current and voltage of system. So for transmitting certain electrical power from one place to another, if the voltage of the power is increased then associated current of this power is reduced. Reduced current means less I^2R loss in the system, less cross sectional area of the conductor means less capital involvement and decreased current causes improvement in voltage regulation of power transmission system and improved voltage regulation indicates quality power. Because of these three reasons electrical power mainly transmitted at high voltage level. Again at distribution end for efficient distribution of the transmitted power, it is stepped down to its desired low voltage level. So it can be concluded that first the electrical power is generated at low voltage level then it stepped up to high voltage for efficient transmission of electrical energy. Lastly for distribution of electrical energy or power to different consumers it is stepped down to desired low voltage level. This brief discussion of electrical transmission system and network, but now we will discussed little bit more details about transmission of electrical energy.

Transmission of Electrical Energy

Fundamentally there are two systems by which electrical energy can be transmitted.

(1) High voltage DC electrical transmission system.

(2) High voltage AC electrical transmission system. There are some advantages in using DC transmission system-

i) Only two conductor are required for Dc transmission system. It is further possible to use only one conductor of DC transmission system if earth is utilized as return path of the system.

ii) The potential stress on the insulator of DC transmission system is about 70% of same voltage AC transmission system. Hence less insulation cost is involved in DC transmission system.

iii) Inductance, capacitance, phase displacement and surge problems can be eliminated in DC system. Even having these advantages in DC system, generally electrical energy is transmitted by three(3) phase AC transmission system.

i)The alternating voltages can easily be stepped up & down, which is not possible in DC transmission system.

ii) Maintenance of AC substation is quite easy and economical compared to DC syte.

iii) The transforming in AC electrical sub station is much easier than motor-generator sets in DC system.

But AC transmission system also have some disadvantages like,

- **i) The volume of conductor used in AC system is much higher than that of DC.**
- **ii) ii)The reactance of the line, affects the voltage regulation of electrical power transmission system.**
- **iii) Problems of skin effects and proximity effects only found in AC system.**
- **iv) AC transmission system is more likely to be affected by corona effect than DC system.**

v) **Construction of AC electrical power transmission network is more completed than DC system.**

vi) **Proper synchronizing is required before inter connecting two or more transmission lines together, synchronizing can totally be omitted in DC transmission system.**

High Voltage Transmission Lines

Distribution in simple words means to make available a number of product or services to end customers. Same is the case when we are talking about electrical distribution system. Means making available that 415v or 240v to a number of end consumers through a distribution system. The generation normally takes place around 11 Kv to 25 Kv which is generally termed as medium voltage. Since we all aware of the fact that this is not the proper voltage for transmission. So this volage is the stepped up to a level of 220 kv or 400 kv or 132 kv depending on the power transmitted or we can say that depends upon the distance. This power is carried away through a transmission network of high voltage lines. These transmission lines are of hundreds of kilometers. These lines are then terminated to some substations which step down the desired voltage to either 11kv or 33 kv or 66 kv. This can be termed as sub transmission network.

Now if we are particularly taking about distribution network then everything below 33kv i.e 11 kv feeders emarates from 33 kv is branched into several 11 kv feeders. The main moto of these 11 kv feeders is to carry power close to the nearby localities which include industrial area, villages etc. here the transformer further reduce the 11 kv to 415v or 240v and it provides the voltage through 415v feeders which inturn gives 415v or 240 v. now 415v is a three phase supply so this is given to the places where we have to give three phase supply. Similarly you all are aware of 220 v supply, its a single phase and is used in homes. Example of Simple distribution system Let it there are 4 generating unit generating a total of 20kv this is step up to 400kv and transmitted to the distribution network as explained above The distributing substation receive it as either 66/33/11Kv there may be chance that there are seperate 66kv feeders but at the end..those 11 kv or 33 kv are directly given to DISCOMS. So in short if i am saying distribution system then it starts from 33or 11 kv downwards this is step down to 430/250 v for the customers by considering the fact that there is voltage drop in transmission lines

A simple example demonstates this Input HT lines 11kv from X grid 11 kv from Y grid transformer rated primary voltage 11kv secondary voltage 416/240 v For domestic users a phase and a neutral connection is supplied and for heavy load 3 wire connection is supplied For the distribution to the consumer end, we can use either overhead line or underground line. Underground one are good in appearance and safe but they are costly one. A typical lenght of 11 kv feeder on city os around 3 km. where as in rural areas this lenghth is upto 15-18 kms. A 415 feeder normally is of 0.5m to 1 km max Ring Main Unit - RMU It is mainly used by distributors when more than one feeder is supplying input and in case of failure from any feeder, powers can be fed uninteruptlily from other feeders at same point. Now a days it is of SF6 type. It is used for two inputs or one outgoing to the load or one input or two outgoing to the load.

Electricity supply to consumersThe secondary winding of the transformer is mostly of wye connection type.This supply system with a neutral wire is termed as 4 wire 3 phase supply.4 wire supplies are normally used to distribute domestic supplies since they can provide an earthed neutral. The three phase wires together give a 3-phase 3-wire supply (240x1.73=415Volts) suitable or heavy machinery such as 3-phase motors.

Isuues in distribution Power system Lack of priority is given to 33kv substations related to load and maintanance also the health status of 11KV/415V Absence of monitoring, overloading, reult in the improper voltage distribution which also leads to the breakdown of equipment at consumer end We are currently using circuit breakers for load management moreover we don't have switches in distribution network, in order to isolate certain loads for loadshedding purpose.what we know have CB(circuit breakers) for 11kv feeders. So when desired it will leads to the isolation of that particular network .

Flexible AC Transmission Systems (FACTS) – What and why?

FACTS is the acronym for "Flexible AC Transmission Systems" and refers to a group of resources used to overcome certain limitations in the static and dynamic transmission capacity of electrical networks. The IEEE defines FACTS as "alternating current transmission systems incorporating power-electronics based and other static controllers to enhance control ability and power transfer ability". The main purpose of these systems is to supply the network as quickly as possible with inductive or capacitive reactive power that is adapted to its particular requirements, while also improving transmission quality and the efficiency of the power transmission system.

Features of Flexible AC Transmission Systems (FACTS)

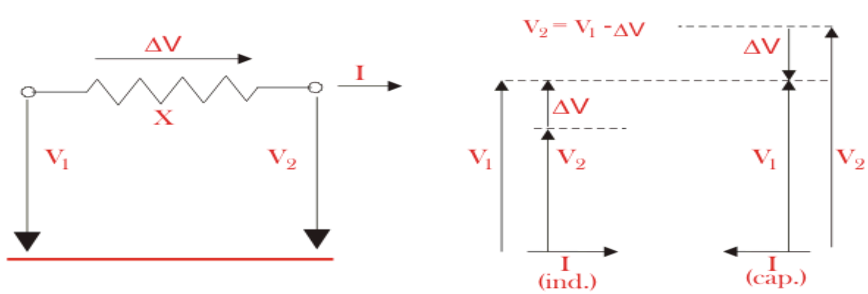
Fast voltage regulation,

Increased power transfer over long AC lines,

Damping of active power oscillations, and

Load flow control in meshed systems,

Thereby significantly improving the stability and performance of existing and future transmission systems. This means that with Flexible AC Transmission Systems (FACTS), power companies will be able to better utilize their existing transmission networks, substantially increase the availability and reliability of their line networks, and improve both dynamic and transient network stability while ensuring a better quality of supply.



Influence of reactive power flow on system voltage

Influence of Reactive Power Flow on Power System Voltage

Reactive Power Compensation in Power Transmission System

Consumer load requires reactive power that varies continuously and increases transmission losses while affecting voltage in the transmission network. To prevent unacceptably high voltage fluctuations or the Reactive power compensation consumer load requires reactive power that varies continuously and increases transmission losses while affecting voltage in the transmission network. To prevent unacceptably high voltage fluctuations or the power failures that can result, this reactive power must be compensated and kept in balance. This function has always been performed by passive elements such as reactors or capacitors, as well as combinations of the two that supply inductive or capacitive reactive power. The more quickly and precisely the reactive power compensation can be accomplished, the more efficiently the various transmission characteristics can be controlled. For this reason, slow mechanically switched components have been almost completely replaced by fast thyristor-switched and thyristor controlled components. Owner failures that can result, this reactive power must be compensated and kept in balance. This function has always been performed by passive elements such as reactors or capacitors, as well as combinations of the two that supply inductive or capacitive reactive power. The more quickly and precisely the reactive power compensation can be accomplished, the more efficiently the various transmission characteristics can be controlled. For this reason, slow mechanically switched components have been almost completely replaced by fast thyristor-switched and thyristor controlled components.

Effects of Reactive Power Flow

Reactive power flow has the following effects:

Increase in transmission system losses

Adding to power plant installations

Adding to operating costs

Major influence on system voltage deviation

Degradation of load performance at under voltage

Risk of insulation breakdown at over-voltage

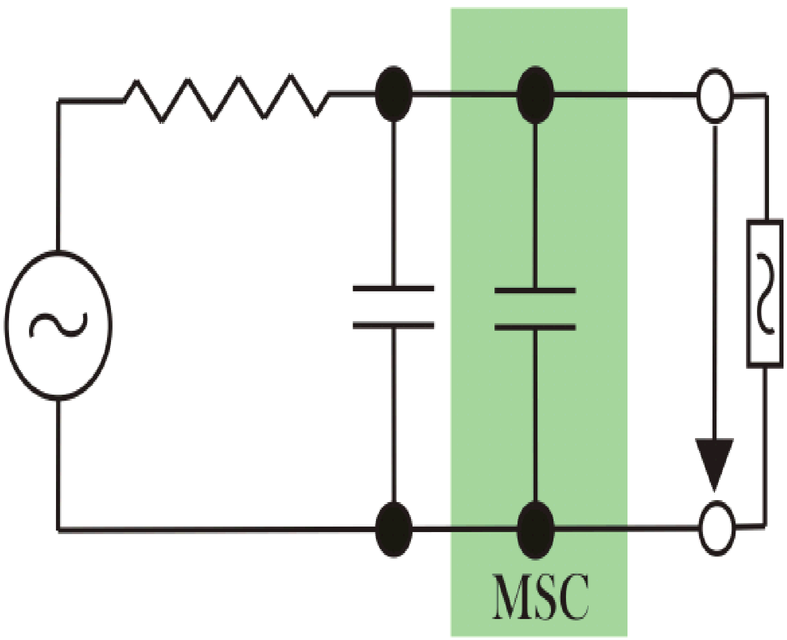
Limitation of power transfer

Steady-state and dynamic stability limits

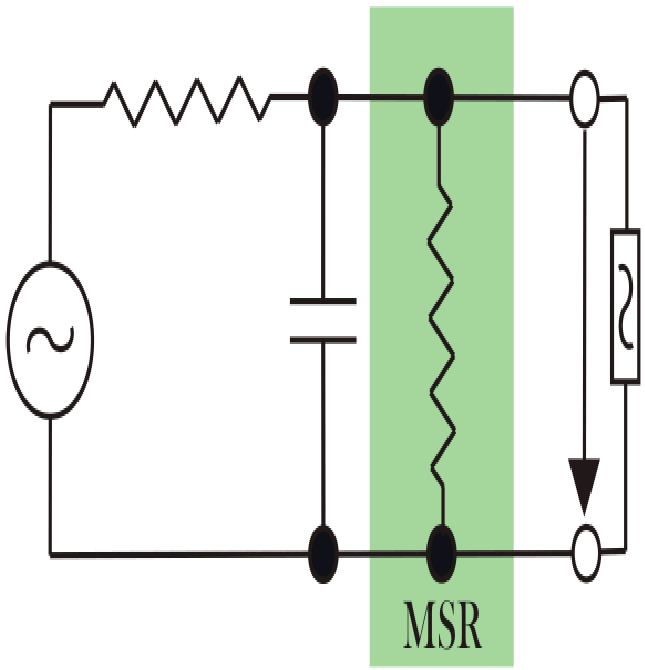
Parallel and Series

Type:-

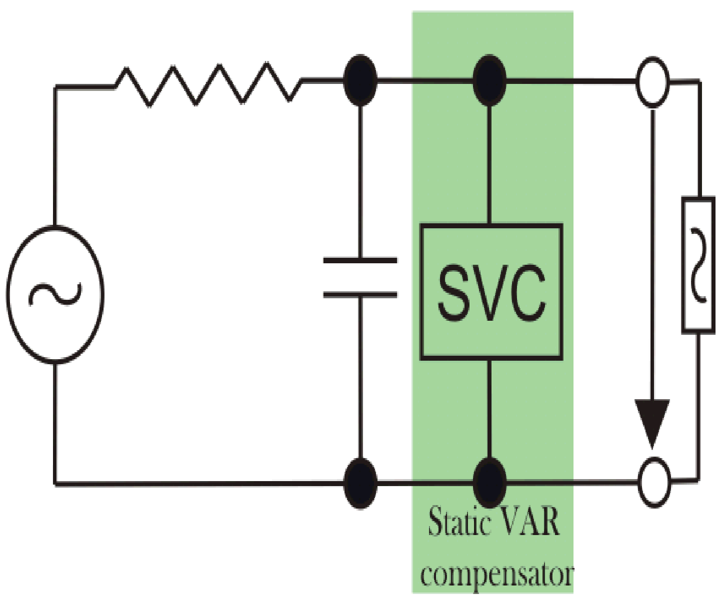
Shor-circuit level Transmission phase angle Steady-state voltage Voltage after load rejection Application



nearly unchangedslightly increased high voltage stabilization at heavy load



nearly unchanged slightly increased decreased low voltage stabilization at light load



nearly unchanged controlled controlled limited by control fast voltage control reactive power control damping of power swings

Fig. Shows today's most common shunt compensation devices, their influence on the most important transmission parameters, and typical applications.

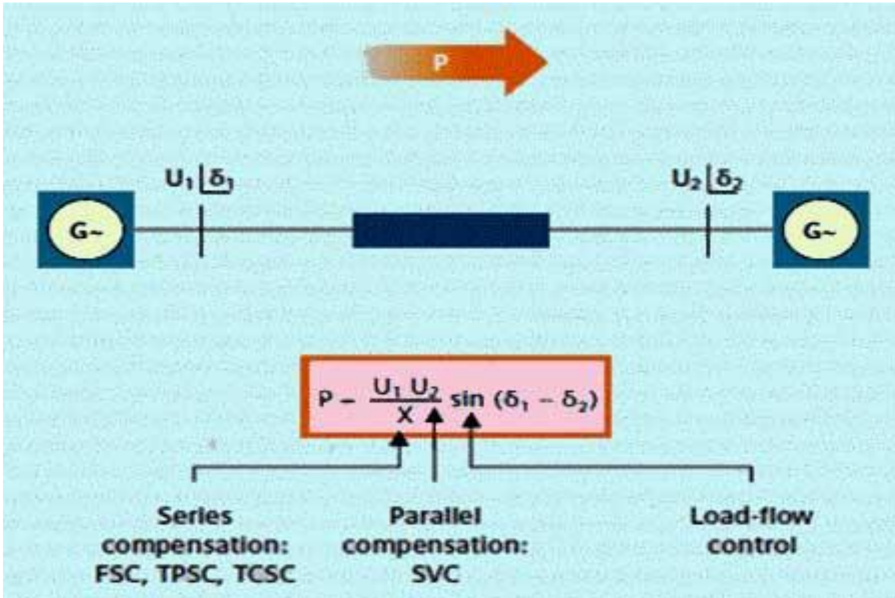


Fig.: The active power/ transmission angle equation illustrates which FACTS components selectively influence which transmission parameters.

Electrical Power Transmission System

Electrical power is generated at different generating stations. These generating stations are not necessarily situated at the load center. During construction of generating station number of factors to be considered from economical point of view. These all factors may not be easily available at load center, hence generating stations are not normally situated very nearer to load center. Load center is the place where maximum power is consumed. Hence there must be some means by which the generated power must be transmitted to the load center. Electrical transmission system is the means of transmitting power from generating station to different load centers.

Factor to be Considered for Constructing a Generating Station

During planning of construction of generating station the following factors to be considered for economical generation of electrical power.

1) Easy availability of water for thermal power generating station.

2) Easy availability of land for construction of power station including it's staff township.

3) For hydro power station there must be a dam on river. So proper place on the river must be chosen in such a way that the construction of the dam can be done in most optimum way.

4) For thermal power station easy availability of fuel is one of the most important factors to be considered.

5) Better communication for goods as well as employees of the power station also to be kept into consideration.

6) For transporting very big spare parts of turbines, alternators etc, there must be wide road ways, rain communication, and deep and wide river must pass away nearby the power station.

7) For nuclear power plant, it must be situated in such a distance from common location so that there may be any effect from nuclear reaction the heath of common people.

Many other factors also to be considered, but there are beyond the scope of our discussion. All the factors listed above are very difficult to be available at load center. The power station or generating station must be situated where all the facilities are easily available. This place may not be necessarily at the load center. The power generated at generating station then transmitted to the load center by means of electrical power transmission system as we said earlier.

The power generated at generating station is in low voltage level as low voltage power generation has some economical values. Low voltage power generation is more economical than high voltage power generation. At low voltage level, bot weight and wide of insulation is less in the alternator, this directly reduces the cost and size of alternator. But this low voltage level power can not be transmitted directly to the consumer end as because this low voltage power transmission is not at all economical. Hence although low voltage power generation is economical but low voltage electrical power transmission is not economical. Electrical power is directly proportional to the product of electrical current and voltage of system. So for transmitting certain electrical power from one place to another, if the voltage of the power is increased then associated current of this power is reduced. Reduced current means less I^2R loss in the system, less cross sectional area of the conductor means less capital involvement and decreased current causes improvement in voltage regulation of power transmission system and improved voltage regulation indicates quality power. Because of these three reasons electrical power mainly transmitted at high voltage level. Again at distribution end for efficient distribution of the transmitted power, it is stepped down to its desired low voltage level. So it can be concluded that first the electrical power is generated at low voltage level then it stepped up to high voltage for efficient transmission of electrical energy. Lastly for distribution of electrical energy or power to different consumers it is stepped down to desired low voltage level. This brief discussion of electrical transmission system and network, but now we will discussed little bit more details about transmission of electrical energy.

Performance of Transmission Line

The transmission lines are categorized as three types-

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

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

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

Whatever may be the category of transmission line, the main aim is to transmit power from one end to another. Like other electrical system, the 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.

$$Efficiency\,of\;transmission\;line = \frac{Power\;delivered\;at\;receiving\;end}{Power\;sent\;from\;sending\;end}\,100\%$$

$$Power\;sent\;from\;sending\;end - line\;losses = Power\;delivered\;at\;receiving\;end$$

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

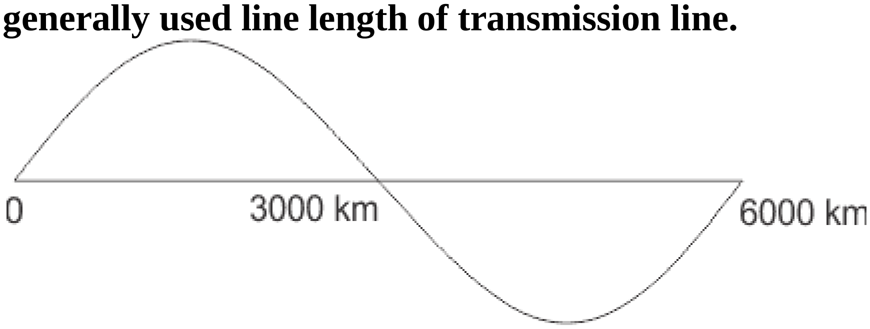
$$\%regulation = \frac{No\ load\ receiving\ end\ voltage\ -\ Full\ load\ receiving\ end\ voltage}{Full\ load\ receiving\ end\ voltage}100\%$$

Every transmission line will have three basic electrical parameters. The conductors of the line will have electrical resistance, inductance, and capacitance. As the transmission line is a set of conductors being run from one place to another supported by transmission towers, the parameters are distributed uniformly along the line. The electrical power is transmitted over a transmission line with a speed of light that is 3X108 m/sec. Frequency of the power is 50 Hz. The wave length of the voltage and current of the power can be determined by the equation given below, f.λ = v where f is power frequency, λ is wave length and υ is the speed of light.

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

$$\Rightarrow \lambda = \frac{3 \times 10^8}{50} = 6 \times 10^6\ mtr = 6,000\ mtr$$

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



Voltage distribution of 50 Hz supply

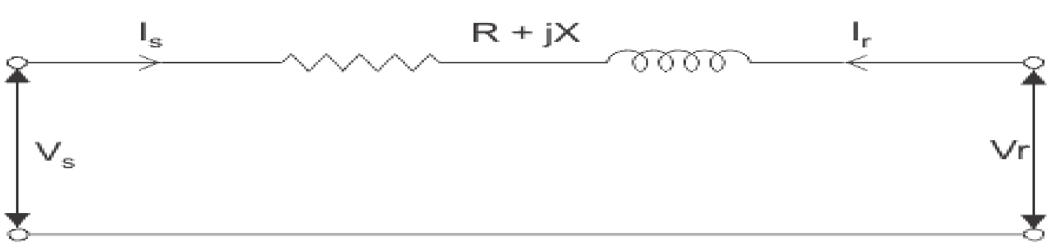
For this reason, the transmission line, with length less than 160 km, the parameters are assumed to be lumped and not distributed. Such lines are

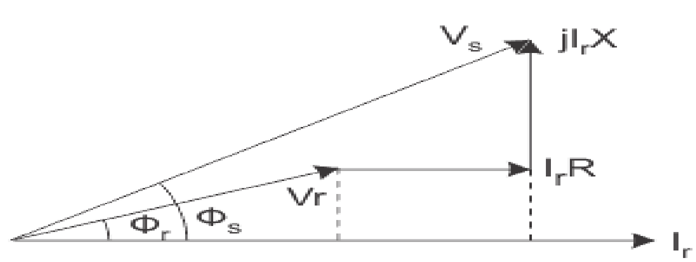
known as electrically short transmission line. This electrically short transmission lines are again categorized as short transmission line(length up to 80 km) and medium transmission line(length between 80 and 160 km). The capacitive parameter of short transmission line is ignored whereas in case of medium length linethe , capacitance is assumed to be lumped at the middle of the line or half of the capacitance may be considered to be lumped at each ends of the transmission line. Lines with length more than 160 km, the parameters are considered to be distributed over the line. This is called long transmission line.

Short Transmission Line

The transmission lines which have length less than 80 km are generally referred as short transmission lines. For short length, the shunt capacitance of this type of line is neglected and other parameters like electrical resistance and inductor of these short lines are lumped, hence the equivalent circuit is represented as given below,

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





As the shunt capacitance of the line is neglected, hence sending end current and receiving end current is same, i.e. Is = Ir. Now if we observe the vector diagram carefully, we will get, Vs is approximately equal to Vr + Ir.R.cosφr + Ir.X.sinφr That means, Vs ≅ Vr + Ir.R.cosφr + Ir.X.sinφr as the it is assumed that φs ≅ φr As there is no capacitance, during no load condition the current through the line is considered as zero, hence at no load condition, receiving end voltage is the same as sending end voltage. As per dentition of voltage regulation of power transmission line,

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

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

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

Here, v_r and v_x are the per unit resistance and reactance of the 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 the network solving technique. Mathematically a two port network can be solved by 2 by 2 matrix. 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 the concept of ABCD parameters comes. Voltage and currents of the network

can represented as ,

$$V_s = AV_r + BI_r \quad \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

$$I_s = CV_r + DI_r \quad \cdots\cdots\cdots\cdots\cdots\cdots (2)$$

Where A, B, C and D are different constant of the network. If we put I_r = 0 at equation (1), we get,

$$A = \left.\frac{V_s}{V_r}\right| I_r = 0$$

Hence, A is the voltage impressed at the sending end per volt at the receiving end when receiving end is open. It is dimension less. If we put V_r = 0 at equation (1), we get

$$B = \left.\frac{V_s}{I_r}\right| V_r = 0$$

That indicates it is

impedance of the transmission line when the receiving terminals are short circuited. This parameter is referred as transfer impedance.

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

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

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

D is the current in amperes into the 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 these equations with equation 1 and 2

we get, A = 1, B = Z, C = 0 and D = 1. As we know that the 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 the 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 then from the equation 1, we get receiving end voltage at no load.

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

and as per definition of voltage regulation of power transmission line,

$$\%\text{ voltage regulation} = \frac{V_s / A - V_r}{V_r} X100\ \%$$

Efficiency of Short Transmission Line

The efficiency of short line as simple as efficiency equation of any other electrical equipment, that means

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

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

R is per phase electrical resistance of the transmission line.

Medium Transmission Line

The 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 the line length being considerably high, admittance Y of the network does play a role in calculating the effective circuit parameters, unlike in the case of short transmission lines. For this reason the modelling of a medium length transmission line is done using lumped shunt admittance along with the lumped impedance in series to the circuit.

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

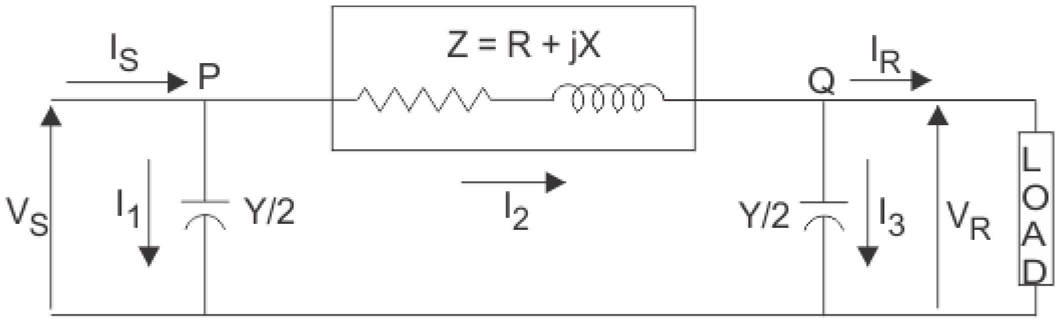
1)Nominal Π representation.

2)Nominal T representation. Let's now go into the detailed discussion of these above mentioned models.

Nominal Π Representation of a Medium Transmission Line

In case of a nominal Π representation, the lumped series impedance is placed at the middle of the circuit where as the shunt admittances are at the ends. As we can see from the diagram of the Π network below, the total lumped shunt admittance is divided into 2 equal halves, and each half with value Y/2 is placed at both the sending and the receiving end while the entire circuit impedance is between the two. The shape of the circuit so formed resembles that of a symbol Π, and for this reason it is known as the nominal Π

representation of a medium transmission line. It is mainly used for determining the general circuit parameters and performing load flow analysis.



Nominal network of medium transmission line

As we can see here, V_S and V_R is the supply and receiving end voltages respectively, and I_s is the current flowing through the supply end. I_R is the current flowing through the receiving end of the circuit. I_1 and I_3 are the values of currents flowing through the admittances. And I_2 is the current through the impedance Z. Now applying KCL, at node P, we get.

$I_S = I_1 + I_2 \cdots\cdots\cdots (1)$ **Similarly applying KCL, to node Q.**

$I_2 = I_3 + I_R \cdots\cdots\cdots (2)$ **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 the circuit, $V_S = V_R + ZI_2$

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

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

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)

$$V_S = AV_R + BI_R$$

with the standard ABCD parameter equations $I_S = CV_R + DI_R$ **We derive the parameters of a medium transmission line as:**

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

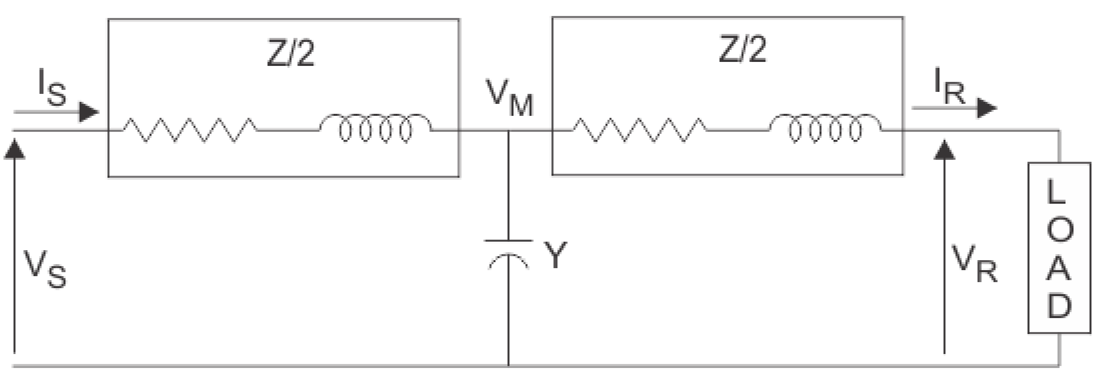
$$B = Z\ \Omega$$

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

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

Nominal T Representation of a Medium Transmission Line

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



Nominal T representation of a medium transmission line

Here also V_s and V_r is the supply and receiving end voltages respectively, and I_s is the current flowing through the supply end. I_r is the current flowing through the receiving end of the circuit.

Let M be a node at the midpoint of the circuit, and the drop at M, be given by V_m. Applying KVL to the 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 the sending end current is,

$$I_s = YV_M + I_R \cdots\cdots\cdots(9)$$

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

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

Again comparing equation (8) and (10) with the standard ABCD parameter equations,

$$V_S = AV_R + BI_R$$

$$I_S = CV_R + DI_R$$

The parameters of the T network of a medium transmission line are

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

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

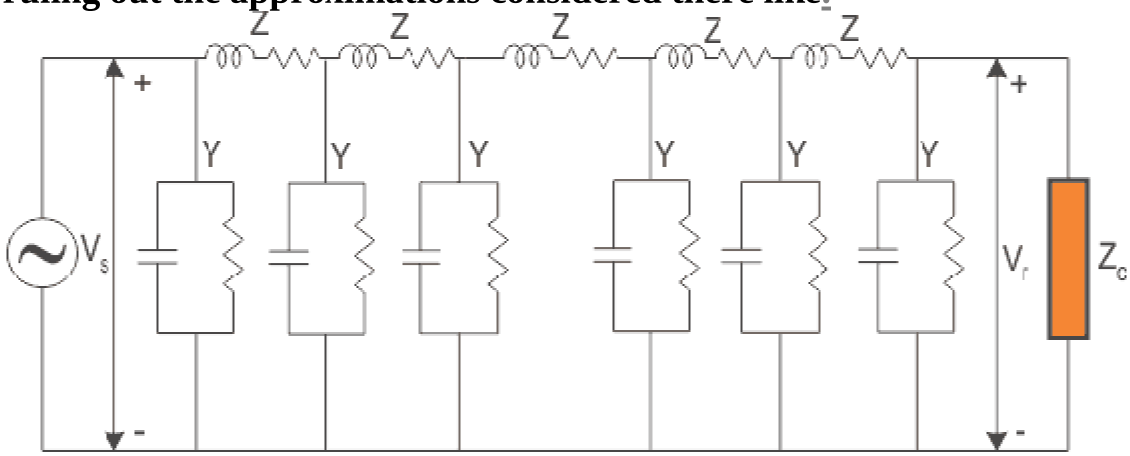
$$C = Y \text{ mho}$$

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

Long Transmission Line

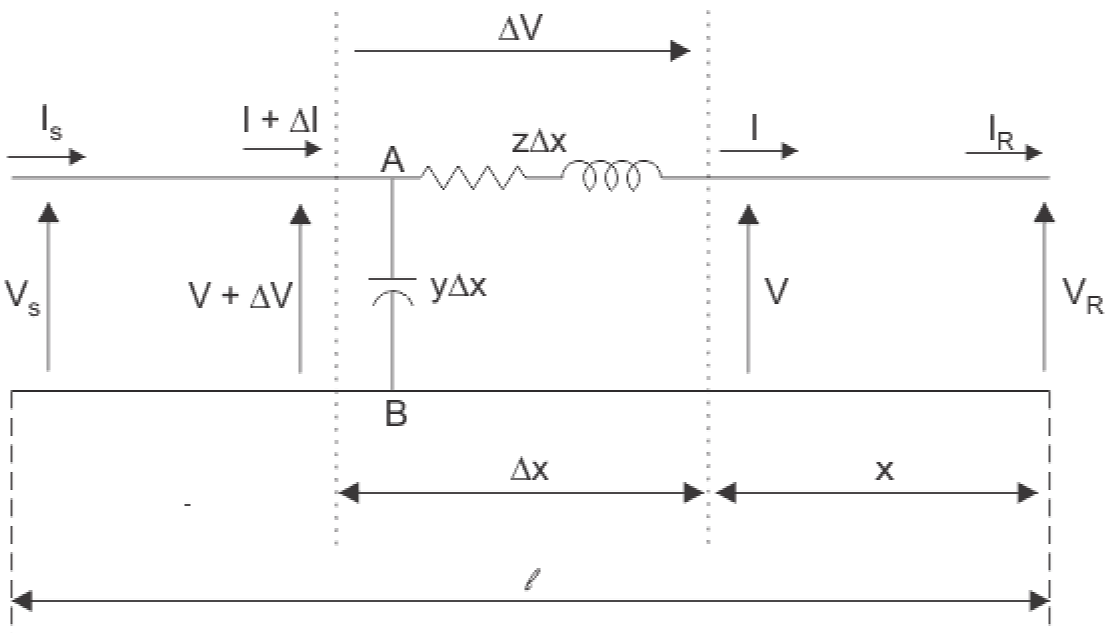
A power transmission line with its effective length of around 250 Kms or above is referred to as a long transmission line. Calculations related to circuit parameters (ABCD parameters) of such a power transmission is not that simple, as was the case for a short transmission line or medium transmission line.

The reason being that, the effective circuit length in this case is much higher than what it was for the former models (long and medium line) and, thus ruling out the approximations considered there like.



Long Transmission Line Model

a) Ignoring the shunt admittance of the network, like in a small transmission line model. b) Considering the circuit impedance and admittance to be lumped and concentrated at a point as was the case for the medium line model. Rather, for all practical reasons we should consider the circuit impedance and admittance to be distributed over the entire circuit length as shown in the figure below. The 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 the circuit of the long transmission line as shown in the 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 the V_R and I_R are the values of voltage and current obtained from the receiving end. Lets us now consider an element of infinitely small length Δx at a distance x from the receiving end as shown in the figure where.

V = value of voltage just before entering the element Δx. I = value of current just before entering the element Δx. V+ΔV = voltage leaving the element Δx. I+ΔI = current leaving the 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 the values of total impedance and admittance of the long transmission line. Therefore, the voltage drop across the infinitely small element Δx is given by

$$\Delta V = Iz\Delta x$$

$$Or\ Iz = \frac{\Delta V}{\Delta x}$$

$$Or\ Iz = \frac{dV}{dx} \cdots\cdots\cdots (1)$$

Now to determine the current ΔI, we apply KCL to node A. ΔI = (V+ΔV)yΔx = V yΔx + ΔV yΔx Since the term ΔV yΔx is the product of 2 infinitely small values, we can ignore it for the sake of easier calculation. Therefore, we can write dI ⁄ dx = V y -----------------(2) Now derivating both sides of eq (1) w.r.t x, $d^2V/dx^2 = z\,dI/dx$ Now substituting dI ⁄ dx = V y from equation (2) $d^2V/dx^2 = zyV$ or $d^2V/dx^2 - zyV = 0$ ------------(3)

The solution of the 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 further let us define the characteristic impedance Z_c and propagation constant δ of a long transmission line as

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

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

Then the 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 these 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 another 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 the 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)**

$I_S = ({}^{V}{}_R/{}_{ZC} + I_R)e^{\delta l}/2 - ({}^{V}{}_R/{}_{ZC} - I_R)e^{-\delta l}/2$**--------------- (12)**

By trigonometric and exponential operators we know

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

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

Therefore, 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 the general circuit parameters equation, we get the ABCD parameters of a long transmission line as,

$A = \cosh \delta l$

$B = Z_C \sinh \delta l$

$C = \sinh \delta l / Z_C$

$D = \cosh \delta l$

Ferranti Effect in Power System

In general practice we know, that for all electrical systems current flows from the region of higher potential to the region of lower potential, to compensate for the electrical potential difference that exists in the system. In all practical cases the sending end voltage is higher than the receiving end, so current flows from the source or the supply end to the load. But Sir S.Z. Ferranti, in the year 1890, came up with an astonishing theory about medium distance transmission line or long distance transmission lines suggesting that in case of

light loading or no load operation of transmission system, the receiving end voltage often increases beyond the 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 inductor distributed across the entire length of the line. Ferranti Effect occurs when current drawn by the distributed capacitance of the line itself is greater than the current associated with the load at the receiving end of the line(during light or no load). This capacitor charging current leads to voltage drop across the line inductor of the transmission system which is in phase with the sending end voltages. This voltage drop keeps on increasing additively as we move towards the load end of the line and subsequently the receiving end voltage tends to get larger than applied voltage leading to the phenomena called Ferranti effect in power system. It is illustrated with the help of a phasor diagram below.

Thus both the capacitance and inductor 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 the inductor 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, the no load receiving end voltage has been found to be 5% higher than the sending end voltage.

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

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

$$Thus\ V_r = V_r(1 + j0)$$

$$Capacitance\ current,\ I_c = j\omega C V_r$$

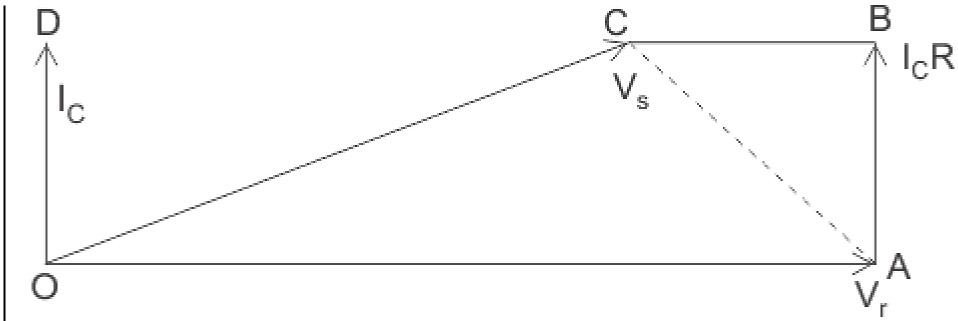
$$Now\ sending\ end\ voltage\ V_s = V_r + resistive + reactive\ drop.$$

$$= V_r + I_c R + j I_c X$$

$$= V_r + I_c(R + jX)$$

$$= V_r + j\omega C V_r(R + j\omega L)[\ Since\ X = \omega L\ ]$$

$$Now\ V_s = V_r - \omega^2 C L V_r + j\omega C R V_r$$



Ferranti effects in transmission line

This is represented by the phasor OC.

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

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

$$Thus\ capacitive\ reactance\ X_c\ =\ \left(\frac{1}{\omega l c_0}\right)$$

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

$$I_c\ =\ \left(\frac{V_r}{2X_c}\right)\ =\ \left(\frac{1}{2}\right)\ V_r \omega l c_0$$

$$Now\ the\ inductive\ reactance\ of\ the\ line\ =\ \omega L_0 l$$

Thus the rise in voltage due to line inductor is given by,

$$I_c X\ =\ \left(\frac{1}{2}\right)\ V_r \omega l c_0 X \omega l$$

$$Voltage\ rise\ =\ \left(\frac{1}{2}\right)\ V_r \omega^2 l^2 c_0 L_0$$

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

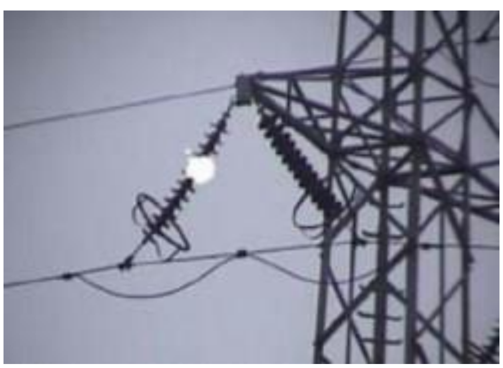
Corona Effect in Power System

Electric power transmission practically deals in the bulk transfer of electrical energy, from generating stations situated many kilometers away from the main consumption centers or the cities. For this reason the long distance transmission cables are of utmost necessity for effective power transfer, which in-evidently results in huge losses across the system. Minimizing those has been a major challenge for power engineers of late and to do that one should have a clear understanding of the type and nature of losses. One of them being the corona effect in power system, which has a predominant role in reducing the 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 electrical potential difference must be supplied across the line.
2) The spacing of the conductors, must be large enough compared to the line diameter.



When an alternating current is made to flow across two conductors of the transmission line whose spacing is large compared to their diameters, then air surrounding the conductors (composed of ions) is subjected to di-electric stress. At low values of supply end voltage, nothing really occurs as the stress is too less to ionize the air outside. But when the potential difference is made to increase beyond some threshold value of around 30 kV known as the

critical disruptive voltage, then the field strength increases and then the air surrounding it experiences stress high enough to be dissociated into ions making the atmosphere conducting. This results in electric discharge around the conductors due to the flow of these ions, giving rise to a faint luminescent glow, along with the hissing sound accompanied by the 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 the corona effect in power system. If the voltage across the lines is still increased the glow becomes more and more intense along with hissing noise, inducing very high power loss into the system which must be accounted for.

Factors Affecting Corona Effect in Power System.

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

Atmospheric Conditions for Corona in Transmission Lines
It has been physically proven that the voltage gradient for di-electric breakdown of air is directly proportional to the density of air. Hence in a stormy day, due to continuous air flow the number of ions present surrounding the conductor 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 weather. The system has to designed taking those extreme situations into consideration.

Condition of Cables for Corona in Transmission Line.
This particular phenomena depends highly on the conductors and its physical condition. It has an inverse proportionality relationship with the diameter of

the conductors. i.e. with the increase in diameter, the effect of corona in power system reduces considerably. Also the presence of dirt or roughness of the conductor reduces the critical breakdown voltage, making the conductors more prone to corona losses. Hence in most cities and industrial areas having high pollution, this factor is of reasonable importance to counter the ill effects it has on the system.

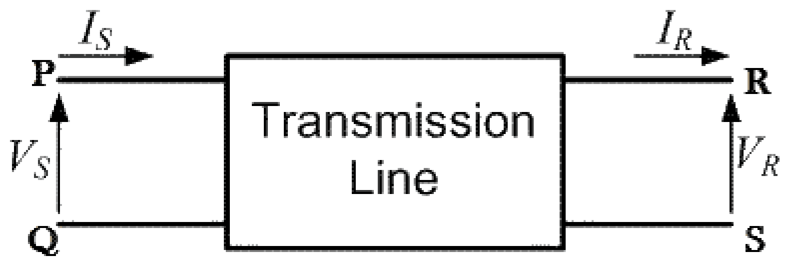
Spacing between Conductors
As already mentioned, for corona to occur effectively the spacing between the lines should be much higher compared to its diameter, but if the length is increased beyond a certain limit, the di-electric stress on the air reduces and consequently the effect of corona reduces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

ABCD Parameters of Transmission Line

Show/Hide Page Index

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

The circuit of a 2 port network is shown in the diagram below. As the 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 the 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 the input port P Q.**

$And\ there\ is\ the\ Receiving\ end\ voltage = V_R$

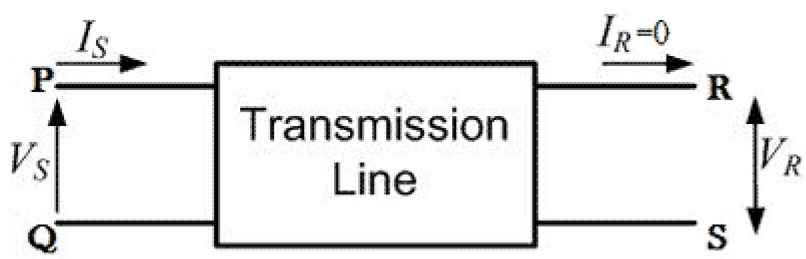
$and\ Receiving\ end\ current = I_R$ **Given to the output port R S. As shown in the diagram below. Now the ABCD parameters or the transmission line parameters provide the link between the supply and receiving end voltages and currents, considering the circuit elements to be linear in nature. Thus the relation between the sending and receiving end specifications are given using ABCD parameters by the equations below.**

$$V_S = AV_R + BI_R \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

$$I_S = CV_R + DI_R \cdots\cdots\cdots\cdots\cdots\cdots (2)$$

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

ABCD Parameters, When Receiving End is Open Circuited



The 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 the ratio of sending end voltage to the open circuit receiving end voltage.

Since dimension wise A is a ratio of voltage to voltage, A is a dimension less parameter.

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

$$I_S = C V_R + D\,0 \Rightarrow I_S = C V_R + 0$$

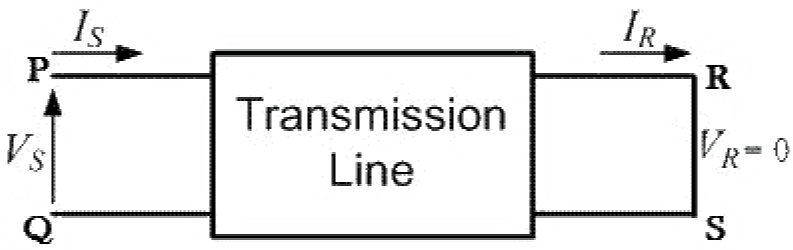
$$C = \left.\frac{I_S}{V_R}\right|_{I_R = 0}$$

Thus its implies that on applying open circuit condition to ABCD parameters of transmission line, we get parameter C as the ratio of sending end current to the open circuit receiving end voltage.

Since dimension wise C is a ratio of current to voltage, its unit is mho.

Thus C is the 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 the ratio of sending end voltage to the short circuit receiving end current. Since dimension wise B is a ratio of voltage to current, its unit is Ω. Thus B is the short circuit resistance and is given by $B = V_S / I_R$ Ω. Applying the 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 the ratio of sending end current to the short circuit receiving end current. Since dimension wise D is a ratio of current to current, it's a dimension less parameter. ∴ the 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

Electrical Transmission Tower Types and Design

The main supporting unit of overhead transmission line is transmission tower. Transmission towers have to carry the heavy transmission conductor at a sufficient safe height from ground. In addition to that all towers have to sustain all kinds of natural calamities. So transmission tower designing is an important engineering job where all three basic engineering concepts, civil, mechanical and electrical engineering concepts are equally applicable.

A power transmission tower consists of the following parts,

1) Peak of transmission tower

2) Cross arm of transmission tower

3) Boom of transmission tower

4) Cage of transmission tower

5) Transmission Tower Body

6) Leg of transmission tower

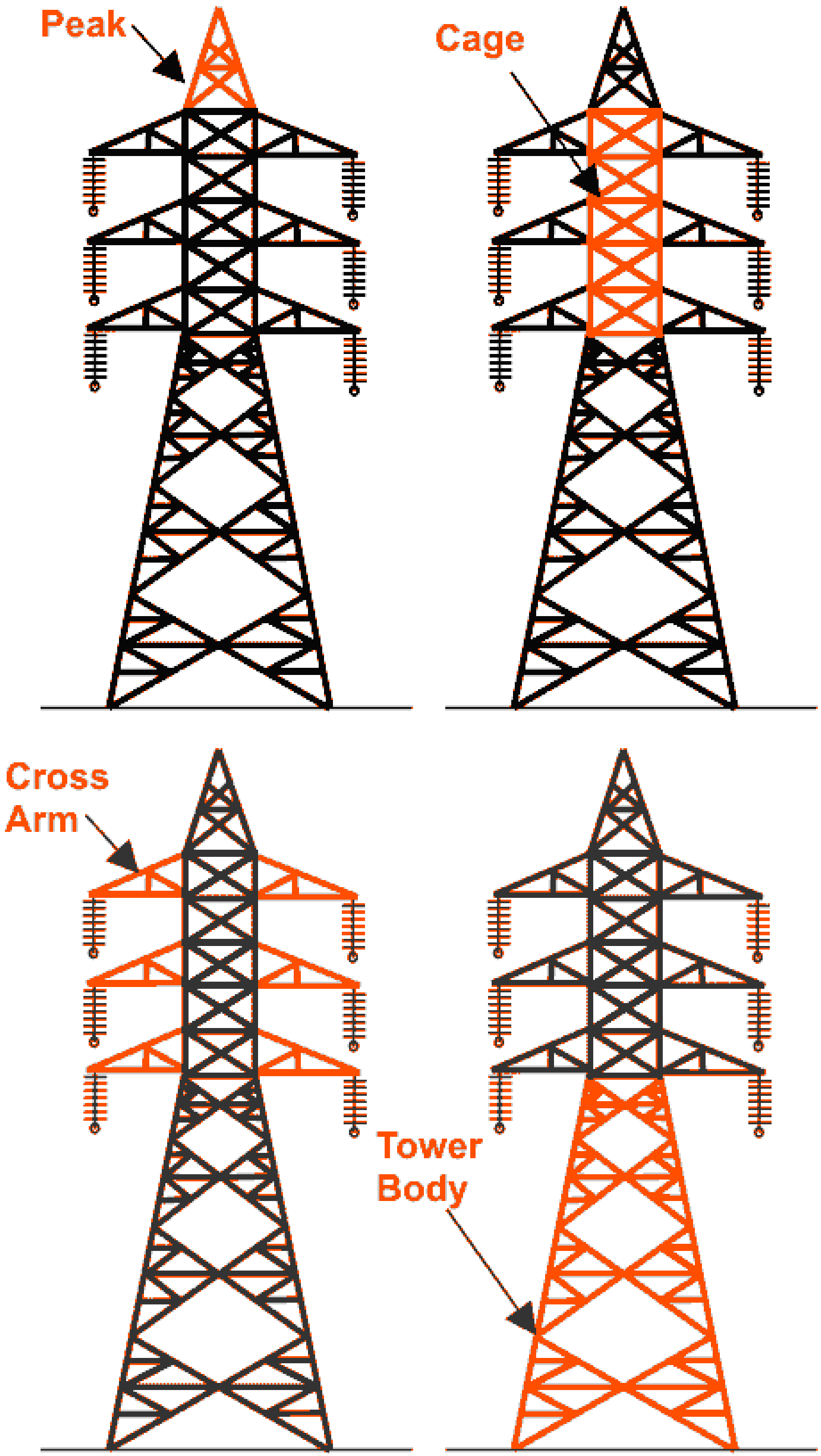
7) Stub/Anchor Bolt and Base plate assembly of transmission tower. The main parts among these are shown in the pictures.

Peak of Transmission Tower
The portion above the top cross arm is called peak of transmission tower. Generally earth shield wire connected to the tip of this peak.

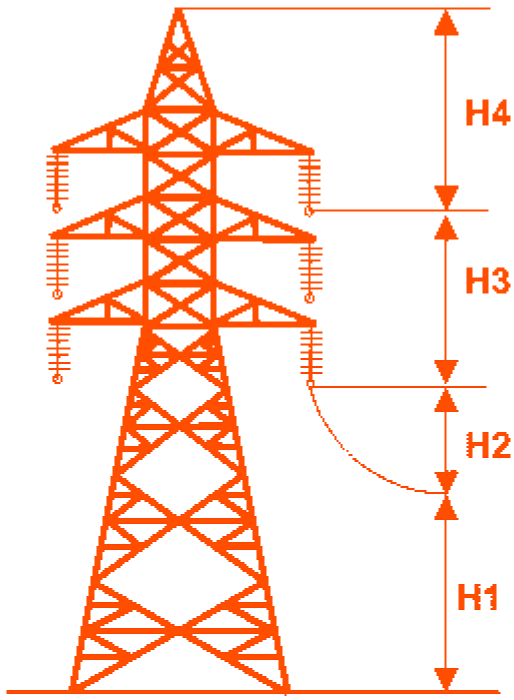
Cross Arm of Transmission Tower
Cross arms of transmission tower hold the transmission conductor. The dimension of cross arm depends on the level of transmission voltage, configuration and minimum forming angle for stress distribution.

Cage of Transmission Tower
The portion between tower body and peak is known as cage of transmission tower. This portion of the tower holds the cross arms.

Transmission Tower Body
The portion from bottom cross arms up to the ground level is called transmission tower body. This portion of the tower plays a vital role for maintaining required ground clearance of the bottom conductor of the transmission line.


Peak
Cage
Cross Arm
Tower Body

Design of Transmission Tower



During design of transmission tower the following points to be considered in mind, a) The minimum ground clearance of the lowest conductor point above the ground level. b) The length of the insulator string. c) The minimum clearance to be maintained between conductors and between conductor and tower. d) The location of ground wire with respect to outer most conductors. e) The mid span clearance required from considerations of the dynamic behavior of conductor and lightening protection of the line. To determine the actual transmission tower height by considering the above points, we have divided the total height of tower in four parts,

1. Minimum permissible ground clearance (H1)

2. Maximum sag of the conductor (H2)

3. Vertical spacing between top and bottom conductors (H3)

4. Vertical clearance between ground wire and top conductor (H4).

Types of Transmission Tower

According to different considerations, there are different types of transmission towers. The transmission line goes as per available corridors. Due to unavailability of shortest distance straight corridor transmission line has to deviate from its straight way when obstruction comes. In total length of a long transmission line there may be several deviation points. According to the angle of deviation there are four types of transmission tower- 1. A – type tower – angle of deviation 0^o to 2^o. 2. B – type tower – angle of deviation 2^o to 15^o. 3. C – type tower – angle of deviation 15^o to 30^o. 4. D – type tower – angle of deviation 30^o to 60^o.

As per the force applied by the conductor on the cross arms, the transmission towers can be categorized in another way-

1. Tangent suspension tower and it is generally A - type tower.

2. Angle tower or tension tower or sometime it is called section tower. All B, C and D types of transmission towers come under this category.

Apart from the above customized type of tower, the tower is designed to meet special usages listed below,

These are called special type tower

1. River crossing tower

2. Railway/ Highway crossing tower

3. Transposition tower

Based on numbers of circuits carried by a transmission tower, it can be classisfied as-

1. Single circuit tower

2. Double circuit tower

3. Multi circuit tower.

Methods of Transmission Tower Erection

There are four main methods of erection of steel transmission towers which a re described below: (i) Build-up method or Piecemeal method. (ii) Section method. (iii) Ground assembly method. (iv) Helicopter method.

Build Up Method of Transmission Tower Erection

This method is most commonly used in India for the erection of 6.6 kV, 132 kV, 220 kV and 400 kV transmission line towers due to the following advantages :

- **(i) Tower materials can be supplied to site in knowckced down condition which facilitates easier and cheaper transportation.**
- **(ii) It does not require any heavy machinery such as cranes etc.**
- **(iii) Tower erection activity can be done in any kind of terrain and mostly throughout the year.**
- **(iv) Availability of workmen at cheap rates. This method consists of erecting the towers, member by member.**

The tower members are kept on ground serially according to erection sequence to avoid search or time loss. The erection progresses from the bottom upwards. The four main corner leg members of the first section of the tower are first erected and gaud off. Sometimes more than one contiguous leg sections of each corner leg are bolted together at the ground and erected. The cross braces of the first section which are already assembled on the ground are raised one by one as a unit and bolted to the already erected corner leg angles. First section of the lower thus built and horizontal struts (belt members) if any, are bolted in position. For assembling the second section of the tower, two gin poles are placed one each on the top of diagonally opposite corner legs. These two poles are used, for raising parts of second section.
The leg members and braces of this section are then hoisted and assembled. The gin poles are then shifted to the corner leg members on the top of second section to raise the parts of third section of the lower in position for assembly.
Gin poles are thus moved up as the tower grows. This process is continued till the complete tower is erected. Cross-arm members are assembled on the ground and raised up and fixed to the main body of the tower. For heavier towers, a small boom is rigged on one of the tower legs for hoisting purposes. The members / sections are hoisted either manually or by winch machines operated from the ground.
For smaller base towers / vertical configuration towers one gin pole is used instead of two gin poles. In order to maintain speed and efficiency, a small assembly party goes ahead of the main erection gang and its purpose is to sort out the tower members, keeping the members in correct position on the ground and assembling the panels on the ground which can be erected as a complete unit.

Section Method of Transmission Tower Erection

In the section method, major sections of the tower are assembled on the ground and the same are erected as units. Either a mobile crane or a gin pole is used. The gin pole used is approximately 10 m long and is held in place by means of guys by the side of the tower to be erected.

The two opposite sides of the tower section of the tower are assembled on the ground. Each assembled side is then lifted clear of the ground with the gin or derrick and is lowered into position on bolts to stubs or anchor bolts.

One side is h held in place with props while the other side is being erected. The two opposite sides are then laced together with cross members and diagonals; and the assembled section is lined up, made square to the line. After completing the first section, gin pole is set on the top of the first section. The gin rests on a strut of the tower immediately below the leg joint. The gin pole then has to be properly guyed into position.

The first face of the second section is raised. To raise the second face of this section it is necessary to slide the foot of the gin on the strut of the opposite face of the tower.

After the two opposite faces are raised, the lacing on the other two sides is bolted up. The last lift raises the top of the towers.

After the tower top is placed and all side lacing have been bolted up all the guyed are thrown off except one which is used to lower the gin pole. Sometimes whole one face of the tower is assembled on the ground, hoisted and supported in position.

The opposite face is similarly assembled and hoisted and then the bracing angles connecting these two faces are fitted.

Ground Assembly Method of Tower Erection

This method consists of assembling the tower on ground, and erecting it as a complete unit. The complete tower is assembled in a horizontal position on even ground. The tower is assembled along the direction of the line to allow the cross arms to be fitted. One slopping ground, however, elaborate packing of the low side is essential before assembly commences.

After the assembly is complete the tower is picked up from the ground with the help of a crane and carried to its location, and set on its foundation.

For this method of erection, a level piece of ground close to footing is chosen from the tower assembly.

This method is not useful when the towers are large and heavy and the foundations are located in arable land where building and erecting complete towers would cause damage to large areas or in hilly terrain where the assembly of complete tower on sloping ground may not be possible and it may be difficult to get crane into position to raise the complete tower.

In India, this method is not generally adopted because of prohibitive cost of mobile crane, and non-availability of good approach roads to tower locations.

Helicopter Method of Transmission Tower Erection

In the helicopter method, the transmission tower is erected in section.

For example bottom section is first lifted on to the stubs and then the upper section is lifted and bolted to the first section and the process is repeated till the complete tower is erected. Sometimes a completely assembled tower is raised with the help of helicopter. Helicopters are also used for lifting completely assembled towers with guys from the marshaling yards where these are fabricated and then transported one by one to line locations. Helicopter hovers over the line location while the tower is securely guyed.

The ground crew men connect and tighten the tower guys.

As soon as the guy wires are adequately tensioned the helicopter disengages and files to the marshaling yard.

This method is adopted where approach is v very difficult or to speed up the construction of the transmission line.

Tightening of Nuts and Punching of Threads and Tack Welding of Nuts of Transmission Towers

All nuts shall be tightened properly using correct sized spanners. Before tightening it is ensured that filter washers and plates are placed in relevant gaps between members, bolt of proper size and length are inserted and one

spring washer is inserted under e each nut. In case of step bolts, spring washer shall be placed under the outer nut. The tightening shall be carried on progressively from the top downwards, care being taken that all bolts at every level are tightened simultaneously.

It may be better to employ four persons, each covering one leg and the face to his right.

The threads of bolts shall be projected outside the nuts by one to two threads and shall be punched at three positions on the top inner periphery of the nut and bolt to ensure that the nuts are not loosened in course of time.

If during tightening a nut is found to be slipping or running over the bolt threads, the bolt together with the nut shall be changed outright.

Painting of Joints of Transmission Tower

For galvanized towers is coastal or highly polluted areas, the joints shall be painted with zinc paint on all contact surfaces during the course of erection.

Checking the Verticality of Erected Transmission Towers

The finally erected tower shall be truly vertical after erection and no straining is permitted to bring it in alignment. Tolerance limit for vertical shall be one in 360 of the tower height.

Basic Concept of Transmission Tower Foundation

Foundation of any structure plays an important role in safety and satisfactory performance of the structure as it transmits mechanical loads of the electrical transmission system to earth. A transmission structure Without having a sound and safe foundation, it cannot perform the functions for which it has been designed. The foundations in various types of soils have to be designed to suit the soil conditions of particular type.

In addition to foundations of normal towers, there are situations where considering techno-economical aspect for special towers required or river crossing which may be located either on the bank of the river or in the mind

stream or both, pile foundation may be provided. Type of loads on foundation : The foundation of towers are normally subjected to three types of forces. These are:

(a) The compression or downward thrust.

(b) The tension or uplift.

(c) The lateral forces of side thrusts in both transverse and longitudinal directions. The magnitude or limit loads for foundations should be taken 10% higher than these for the corresponding towers. The base slab of the foundation shall be designed for additional moments developing due to eccentricity of the loads. The additional weight of concrete in the footing below ground level over the earth weight and the full weight of concrete above ground level in the footing and embedded steel parts also be taken into account; adding to the down-thrust. Soil parameters For designing the foundations, following parameters are required.

(a) Limit bearing capacity of soil.

(b) Density of soil.

(c) Angle of earth frustum. The above values are available from soil test report.

Stability Analysis of Transmission Tower Foundation

In addition to the strength design, stability analysis of the foundation shall be done to check the possibility of failure by over turning, uprooting of stubs, sliding and tilting of foundation etc. The following primary type of soil resistance shall be assumed to act in resisting the loads imposed on the footing in earth.

Resistance Against Uplift of Transmission Tower Foundation

The uplift loads shall be assumed to be resisted by the weight of earth in an inverted frustum of a pyramid of earth whose sides make an angle equal to the angle of report of the earth with the vertical in average soil. The volume of earth computation shall be as per enclosed drawing (Fig.3) The weight of concrete embedded in earth and that above the ground level shall also be

considered for resisting the uplift. In case where the frustum of earth pyramid of two adjoining legs overlaps each other, the earth frustum shall be assumed truncated by a vertical plane passing through the center line of the tower base. Over load factor (OLF) of 10% (Ten percent) shall be considered over the design load i.e. OLF = 1.10 for suspension tower and 1.15 for angle including dead end and anchor tower. However, for special tower OLF shall be 1.20.

Resistance Against Down Thrust of Transmission Tower Foundation
The following load combinations shall be resisted by the bearing strength of the soil:

(1) The down thrust loads combined with an additional weight of concrete above earth are assumed to be acting on the total area of the bottom of the footing.

(2) The moment due to side thrust forces at the bottom of the footing.

The structural design of the base slab shall be developed for the above load combination. In case of toe(&toe;) pressure calculation due to above load combination allowable bearing pressure to be increased by 25%.

Resistance Against Side Thrust of Transmission Tower Foundation
The chimney shall be designed as per limit state method for the combined action of axial forces, tension and compression and the associated maximum bending moment. In these calculations, the tensile strength of concrete shall be ignored.

Resistance Against Uprooting of Stub of Transmission Tower Foundation
OLF of 10% (Ten percent) shall be considered i.e. OLF = 1.10 for normal suspension towers and 1.15 for angle tower including Dead end / anchor tower. For special towers OLF shall be 1.20.

Design of Foundation of Transmission Towers in Different Soils

1. All foundation shall be of RCC. The design and construction of RCC structures shall be carried out as per IS:456 and minimum grade of concrete shall be M-20.

2. Limit state method of design shall be adopted.

3. Cold twisted deformed bars as per IS:1786 or TMT bars shall be used as reinforcement.

4. Foundations shall be designed for the critical loading combination of the steel structure and or equipment and/or superstructure.

5. If required protection to the foundation, shall be provided to take care of any special requirements for aggressive alkaline soil, black cotton soil or any soil which is detrimental/harmful to the concrete foundations.

6. All structures shall be checked for sliding and overturning stability during both construction and operating conditions for various combination of loads.
7. For checking against overturning, weight of soil vertically above footing shall be taken and inverted frustum of pyramid of earth on foundation should not be considered.

8. Base slab of any underground enclosure shall also be designed for maximum ground water table. Minimum factor of safety of 1.5 against bouncy shall be ensured.

9.The tower and equipment foundations shall be checked for a factor of safety of 2.2 for normal condition and 1.65 for short circuit condition against sliding, overturning and pullout.

Guidelines for Classification of Foundations of Transmission Towers in Different Soils

The transmission tower may be situated in different locations. Power System transmission networks are being sprading all over the world. The soil condition of different places are also different. Depending upon the nature of soil, the types foundation of transmission towers should be selected and constructed accordingly.

We have tried to give you a clear and brief Guidelines for classification of Foundations of transmission towers in different Soil conditions.

SL	Name of soil encountered	Type of foundation to be adopted
1	In good soil (silty sand mixed with clay)	Normal Dry
2	Where top layer of Black Cotton soil extends upto 50% of the depth with good soil there after.	Partial Black Cotton
3	Where top layer of black cotton soil exceeds 50% and extends upto full depth or is followed by good soil.	Black Cotton
4	Where top layer is good soil upto 50% of the depth but the lower layer is a black cotton soil	Black Cotton
5	Where subsoil water is met at 1.5 ml or more below the ground level in good soil	Wet
6	Good soil locations which are in surface water for long period with water penetration not exceeding 1.0 m below ground level (e.g. paddy fields).	Wet
7	In good soil where subsoil water is encountered between 0.75m and 1.5m depth from ground level.	Partially submerged

8	In good soil where subsoil water is encountered within 0.75 m depth from ground level	Fully Submerged
9	Where top layer of normal dry soil extends upto 85% of the depth followed by fissured rock without presence of water.	Dry Fissured Rock
10	Where top layer is lissured rock followed by good soil/sandy soil with/without presence of water	Special foundation
11	Where normal soil/tissured rock extends upto 85% of the depth followed by hard rock	Dry fissured Rock with under cut in Fisured Rock combined with anchor bar for hard rock design
12	Where fissure rock os encountered with subsoil water within 0.75m or below 0.75m from G.L. (Top layer may be either a good soil or black cotton soil)	Submerged Fissured Rock
13	Where Hard Rock is encountered at 1.5 m or less below ground level.	Hard Rock
14	Where Hard Rock is encountered from 1.5 m to 2.5m below G.L. (Top layer being good soil)	with chimney for Normal Soil Hard Rock Foundation
15	Where hard rock is encountered from 1.5m to 2.5 m below G./L. (Top layer either in Black cotton) soil or fissured Rock	Hard Rock Foundation design with chimneys designed for wet black cotton soil.
16	Where fissured rock is encountered at the bottom of pit (with black cotton soil at top)	Composite Foundation

17	**Where hard rock is encountered at bottom with water and black cotton soil at top and hard rock layer depth is less than 1.5 m.**	**Hard Rock**
18	**Sandy soil with clay content not exceeding 10%**	**Dry Sandy soil foudation**
19	**Sandy soil with water table in the pits**	**Wet sandy soil design to be developed considering the depth of water**
20	**Where top layer upto 1.5 m below G.L. is normal dry soil and thereafter hard soil/murrum**	**Normal dry with undercut**
21	**Where bottom layer is marshy soil with top layer of good soil/fissured rock/black cotton**	**Soil investigation is to be carried out and special foundation design to be developed.**
22	**Where the top layers are a combination of clinker mixed with firm soil, gravel and stone chips upto 60% of foundation deapth from ground level followed by hard murrum**	**Normal dry with undercut**
23	**Where top layers are combination of hard murrum, soft rock etc. followed by yellow/black clayee soil**	**Special foundation design is to be developed after carrying out soil investigation.**

Any other combination of soil not covered above shall require development of special foundation design.

Types of Overhead Conductor

Conductor is a physical medium to carry electrical energy form one place to other. It is an important component of overhead and underground electrical transmission and distribution systems. The choice of conductor depends on the cost and efficiency. An ideal conductor has following features

1. **It has maximum conductivity**
2. **It has high tensile strength**
3. **It has least specific gravity i.e. weight / unit volume**
4. **It has least cost without sacrificing other factors**

Types of Overhead Conductor

In early days copper 'Cu' was used for transmitting energy in stranded hard drawn form to increase tensile strength. But now it has been replaced by aluminum 'Al' due to following reasons:

1. **It has lesser cost than copper.**
2. **It offers larger diameter for same amount of current which reduces corona.**

Corona: is ionization of air due to higher voltage (usually voltage above critical voltage) which causes violating light around the conductor and hissing sound. It also produce ozone gas therefor it is undersirable condition

Aluminium also has some disadvantages over copper i.e.

1. **It has lesser conductivity**
2. **It has larger diameter which increase surface area to air pressure thus it swings more in air than copper so larger cross arms required which increases the cost.**
3. **It has lesser tensile strength ultimately larger sag**
4. **It has lesser specific gravity (2.71gm/cc) than copper (8.9 gm/cc) cc = cubic centimeter**

Due to lower tensile strength aluminium is used with some other materials or its alloys

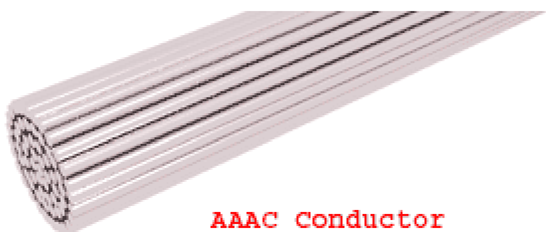
AAC (All Aluminium Conductor)

• It has lesser strength and more sag per span length than any other category • Therefore, it is used for lesser span i.e. it is applicable at distribution level
• It has slightly better conductivity at lower voltages than ACSR i.e. at distribution level • Cost of ACSR is equal to AAC.

ACAR (Aluminium Conductor, Aluminium Reinforce)

• It is cheaper than AAAC but pro to corrosion.
• It is most expansive.

AAAC (All Aluminium Alloy Conductor)



• It has same construction as AAC except the alloy.
• Its strength is equal to ACSR but due to absence of steel it is light in weight.
• The presence of formation of alloy makes it expensive.
• Due to stronger tensile strength than AAC, it is used for longer spans.
• It can be used in distribution level i.e. river crossing.
• It has lesser sag than AAC.
• The difference between ACSR and AAAC is the weight. Being lighter in weight, it is used in transmission and sub-transmission where lighter support structure is required such as mountains, swamps etc.

ACSR (Aluminium Conductor Steel Reinforced)

- **it is used for longer spans keeping sag minimum.**
- **It may consists of 7 or 19 strands of steel surrounding by aluminium strands concentrically. The number of strands are shown by x/y/z, where 'x' is number of aluminium strands, 'y' is number of steel strands and 'z' is diameter of each strand.**
- **Strands provide flexibility, prevent breakage and minimize skin effect.**
- **The number of strands depends on the application, they may be 7, 19, 37, 61, 91, or more**
- **If the Al and St strands are separated by a filler such as paper then this kind of ACSR is used in EHV lines and called expanded ACSR.**
- **Expanded ACSR has larger diameter and hence lower corona losses.**

IACS (International Annealed Copper Stand)

- **It is 100% pure conductor and it is standard for reference.**

Skin Effect in Transmission Lines

The phenomena arising due to unequal distribution of current over the entire cross section of the conductor being used for long distance power transmission is referred as the skin effect in transmission lines.

Such a phenomena does not have much role to play in case of a very short line, but with increase in the effective length of the conductors, skin effect increases considerably.

So the modifications in line calculation needs to be done accordingly.

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

Why Skin Effect Occurs in Transmission Lines ?

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

Let us initially consider the solid conductor 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 the total current.

Like if the total current = I Lets consider the conductor to be split up into n filament carrying current 'i' such that I = n i .

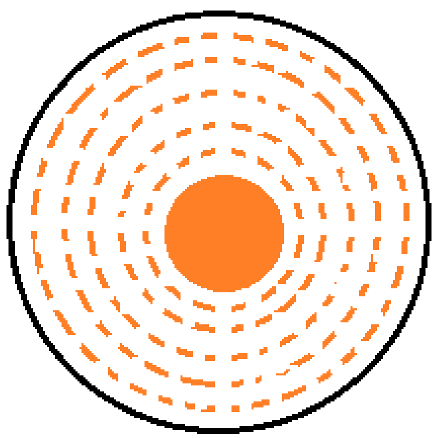
Now during the flow of an alternating current, the current carrying filaments lying on the core has a flux linkage with the entire conductor cross section including the filaments of the surface as well as those in the core.

Whereas the flux set up by the outer filaments is restricted only to the surface itself and is unable to link with the inner filaments.

Thus the flux linkage of the conductor increases as we move closer towards the core and at the same rate increases the inductor as it has a direct proportionality relationship with flux linkage.

This results in a larger inductive reactance being induced into the core as compared to the outer sections of the conductor.

The high value of reactance in the inner section results in the current being distributed in an un-uniform manner and forcing the bulk of the current to flow through the outer surface or skin giving rise to the phenomena called skin effect in transmission lines.



Cross sectional view of a conductor.

Factors Affecting Skin Effect in Transmission Lines

The skin effect in an ac system depends on a number of factors like:-

1) Shape of conductor.

2) Type of material.

3) Diameter of the conductors.

4) Operational frequency.

Insulation Coordination in Power System

Insulation Coordination in Power System was introduced to arrange the electrical insulation levels of different components in the electrical power system including transmission network, in such a manner, that the failure of insulator, if occurs,

confindes to the place where it would result in the least danmage of the system, easy to repair and replace, and results least disturbance to the power supply. When any over voltage appears in the electrical power system, then there may be a chance of failure of its insulation system. Probability of failure of insulation, is high at the weakest insulation point nearest to the source of over voltage. In power system and transmission networks, insulation is provided to the all equipment and components. Insulators in some points are easily replaceable and repairable compared to other. Insulation in some points are not so easily replaceable and repairable and the replacement and repairing may be highly expensive and require long interruption of power. Moreover failure of insulator at these points may causes bigger part of electrical network to be out of service. So it is desirable that in situation of insulator failure, only the easily replaceable and repairable insulator fails. The overall aim of insulation coordination is to reduce to an economically and operationally acceptable level the cost and disturbance caused by insulation failure. In insulation coordination method, the insulation of the various parts of the system must be so graded that flash over if occurs it must be at intended points. For proper understanding the insulation coordination we have to understand first, some basic terminologies of the electrical power system. Let us have a discussion.

Nominal System Voltage

Nominal System Voltage is the phase to phase voltage of the system for which the system is normally designed. Such as 11KV, 33KV, 132KV, 220KV, 400KV systems.

Maximum System Voltage

Maximum System Voltage is the maximum allowable power frequency voltage which can occurs may be for long time during no load or low load condition of the power system. It is also measured in phase to phase manner.

List of different nominal system voltage and their corresponding maximum system voltage is given below for reference,

Nominal System Voltage in KV 11 33 66 132 220 400

Maximum System Voltage in KV 12 36 72.5 145 245 420

NB - It is observed from above table that generally maximum system voltage is 110% of corresponding nominal system voltage up to voltage level of 220 KV, and for 400 KV and above it is 105%.

Factor of Earthing

This is the ratio of the highest rms phase to earth power frequency voltage on a sound phase during an earth fault to the rms phase to phase power frequency voltage which would be obtained at the selected location without the fault.

This ratio characterizes, in general terms, the earthing conditions of a system as viewed from the selected fault location.

Effectively Earthed System

A system is said to be effectively earthed if the factor of earthing does not exceed 80% and non-effectively earthed if it does. Factor of earthing is 100% for an isolated neutral system, while it is 57.7% ($1/\sqrt{3} = 0.577$) for solidly earthed system.

Insulation Level

Every electrical equipment has to undergo different abnormal transient over voltage situation in different times during its total service life period. The equipment may have to withstand lightning impulses, switching impulses and/or short duration power frequency over voltages.

Depending upon the maximum level of impulse voltages and short duration power frequency over voltages that one power system component can withstand, the insulation level of high voltage power system is determined.

During determining the insulation level of the system rated less than 300 KV, the lightning impulse withstand voltage and short duration power frequency

withstand voltage are considered. For equipment rated more or equal 300 KV, switching impulse withstand voltage and short duration power frequency withstand voltage are considered.

Lightning Impulse Voltage

The system disturbances occur due to natural lightning, can be represented by three different basic wave shapes.

If a lightning impulse voltage travels some distance along the transmission line before it reaches to a insulator its wave shaped approaches to full wave, and this wave is referred as 1.2/50 wave. If during travelling, the lightning disturbance wave causes flash over across an insulator the shape of the wave becomes chopped wave.

If a lightning stroke hits directly on the insulator then the lightning impulse voltage may rise steep until it is relieved by flash over, causing sudden, very steep collapse in voltage.

These three waves are quite different in duration and in shapes.

Switching Impulse

During switching operation there may be uni-polar voltage appears in the system.

The wave form of which may be periodically damped or oscillating one. Switching impulse wave form has steep front and long damped oscillating tale.

Short Duration Power Frequency Withstand Voltage

Short duration power frequency withstand voltage is the prescribed rms value of sinusoidal power frequency voltage that the electrical equipment shall withstand for a specific period of time normally 60 seconds.

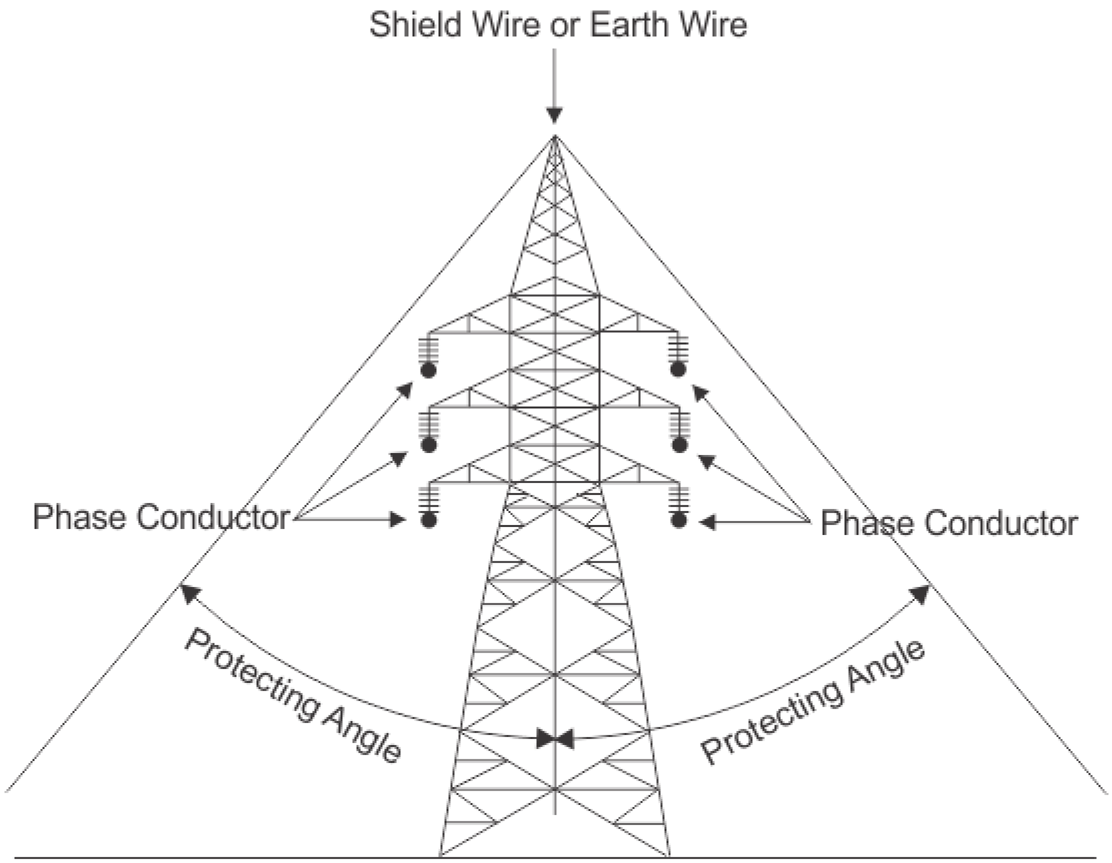
Protection Level Voltage of Protective Device

Over voltage protective device like surge arrestors or lightning arrestors are designed to withstand a certain level of transient over voltage beyond which the devices drain the surge energy to the ground and therefore maintain the level of transient over voltage up to a specific level. Thus transient over voltage can not exceed that level. The protection level of over voltage

protective device is the highest peak voltage value which should not be exceeded at the terminals of over voltage protective device when switching impulses and lightening impulses are applied.

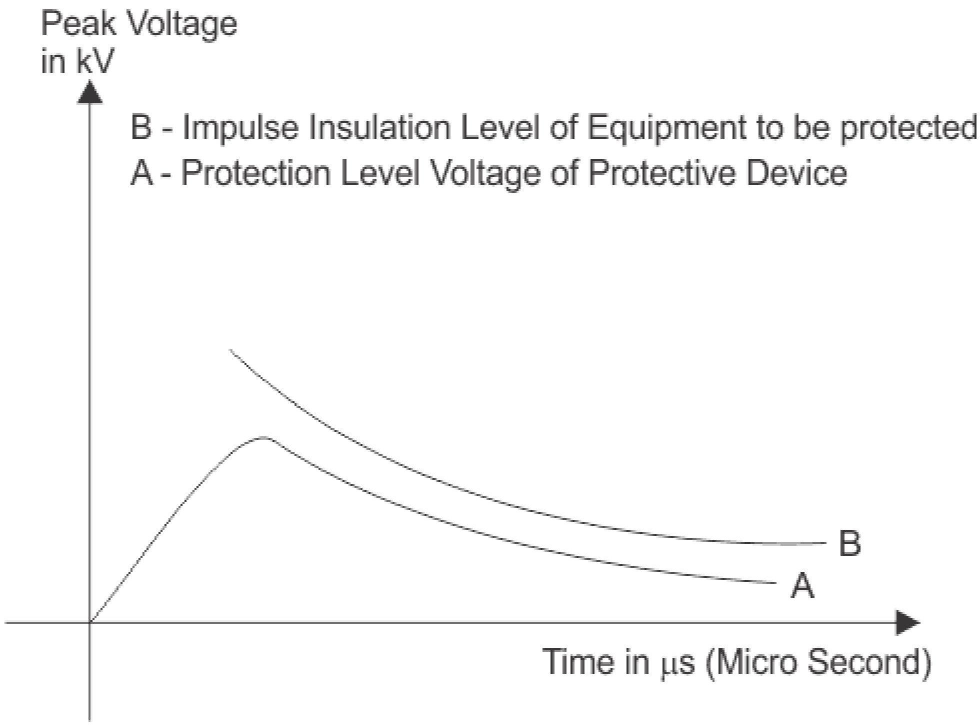
Now let us discuss the insulation coordination methods one by one-

Using Shield Wire or Earth Wire



Lightning surge in over head transmission line may be caused due to direct hits of lightening strokes. It can be protected by providing a shield wire or earth wire at a suitable height from the top conductor of transmission line. If the conducting shield wire is properly connected to transmission tower body and the tower is properly earthed then direct lightning strokes can be avoided from all the conductors come under the protective angle of earth wire. Over head earth wire or ground wire or shield wire is also used to over the electrical substation to protect different electrical equipment from lightning strokes.

Conventional Method of Insulation Coordination

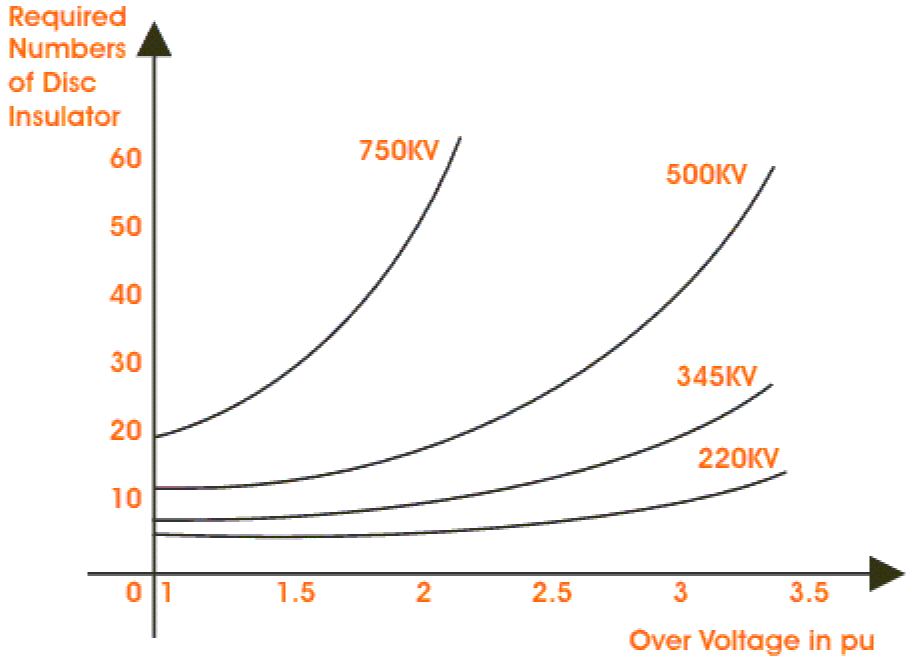


Voltage - Time Curved Used for Insulation Coordination

As we discussed above that a component of electrical power system may suffer from different level of transient voltage stresses, switching impulse voltage and lightning impulse voltage. The maximum amplitude of transient over voltages reach the components, can be limited by using protecting device like lightning arrestor in the system. If we maintain the insulation level of all the power system component above the protection level of protective device, then ideally there will be no chance of breakdown of insulation of any component. Since the transient over voltage reaches at the insulation after crossing the surge protective devices will have amplitude equals to protection level voltage and protection level voltage < impulse insulation level of the components.

Generally, the impulse insulation level is established at 15 to 25% above the protective level voltage of protective devices.

Statistical Methods of Insulation Coordination



Required Number of Disc Insulator in Different Voltages

At higher transmission voltages, the length of the insulator strings and the clearance in air do not increase linearly with voltage but approximately to $V^{1.6}$.

The required number of insulator disc in suspension string for different over voltages is shown below. It is seen that increase in the number of disc is only slight for 220 KV system, with the increase in the over voltage factor from 2 to 3.5 but that there is a rapid increase in the 750 kV system. Thus, while it may be economically feasible to protect the lower voltage lines up to an over voltage factor of 3.5(say), it is definitely not economically feasible to have an over voltage factor of more than about 2 to 2.5 on the higher voltage lines.

In the higher voltage systems, it is the switching over voltages that is predominant. However, these may be controlled by proper design of switching devices.

Types of Electrical Insulator | Overhead Insulator

There are mainly three types of insulator used as overhead insulator likewise
1. Pin Insulator

2. Suspension Insulator

3. Strain Insulator In addition to that there are other two types of electrical insulator available mainly for low voltage application, e.i. Stay Insulator and Shackle Insulator.

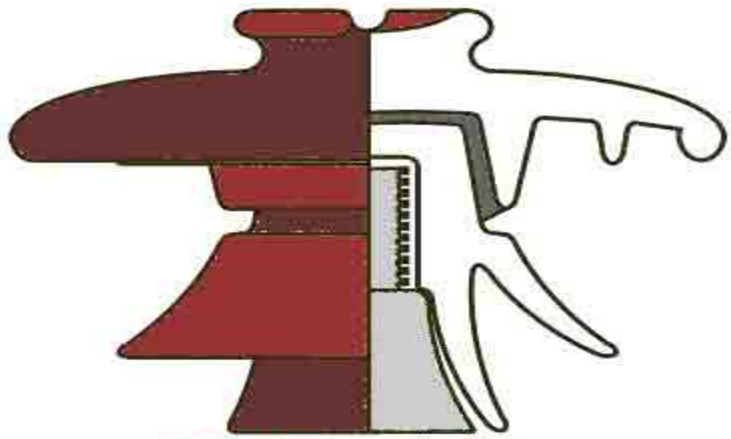
Pin Insulator

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 the leakage path of insulator is through its surface, it is desirable to increase the vertical length of the insulator surface area for lengthening leakage path. In order to obtain lengthy leakage path, one, tow or more rain sheds or petticoats are provided on the insulator body.

In addition to that rain shed or petticoats on an insulator serve another purpose. These rain sheds or petticoats are so designed, that during raining the outer surface of the rain shed becomes wet but the inner surface remains dry and non-conductive. So there will be discontinuations of conducting path through the wet pin insulator surface. In higher voltage like 33KV and 66KV manufacturing of one part porcelain pin insulator becomes difficult. Because in higher voltage, the thickness of the 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 together by Portland cement to form one complete insulator unit.



33KV Pin Insulator

For 33KV tow parts and for 66KV three parts pin insulator are generally used

Designing Consideration of Electrical Insulator

The live conductor attached to the top of the pin insulator is at a potential and bottom of the insulator fixed to supporting structure of earth potential. The insulator has to withstand the potential stresses between conductor and earth. The shortest distance between conductor and earth, surrounding the 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 the flash over distance of insulator is decreased. The design of an electrical insulator should be such that the decrease of flash over distance is minimum when the insulator is wet. That is why the upper most petticoat of a pin insulator has umbrella type designed so that it can protect, the rest lower part of the insulator from rain. The upper surface of top most petticoat is inclined as less as possible to maintain maximum flash over voltage during raining.

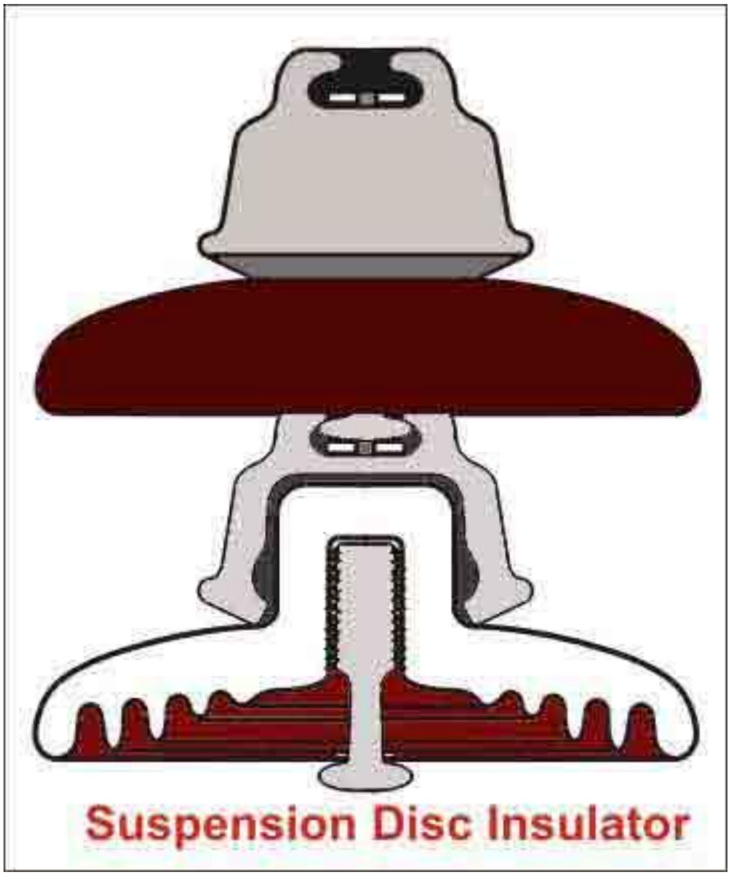
2. To keep the inner side of the insulator dry, the rain sheds are made in order that these rain sheds should not disturb the voltage distribution they are so designed that their subsurface at right angle to the electromagnetic lines of force.

Post Insulator

Post insulator is more or less similar to Pin insulator but former is suitable for higher voltage application. Post insulator has higher numbers of petticoats and has greater height. This type of insulator can be mounted on supporting structure horizontally as well as vertically. The insulator is made of one piece of porcelain but has fixing clamp arrangement are in both top and bottom end. The main differences between pin insulator and post insulator are,

SL	Pin Insulator	Post Insulator
1	It is generally used up to 33KV system	It is suitable for lower voltage and also for higher voltage
2	It is single stag	It can be single stag as well as multiple stags
3	Conductor is fixed on the top of the insulator by binding	Conductor is fixed on the top of the insulator with help of connector clamp
4	Two insulators cannot be fixed together for higher voltage application	Two or more insulators can be fixed together one above other for higher voltage application
5	Metallic fixing arrangement provided only on bottom end of the insulator	Metallic fixing arrangement provided on both top and bottom ends of the insulator

Suspension Insulator



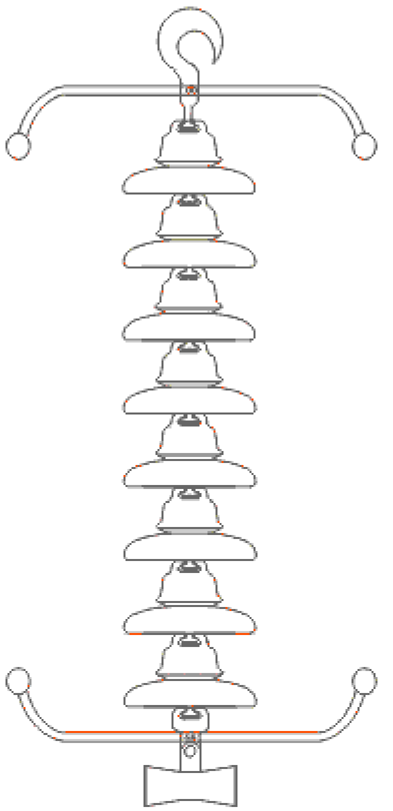
In higher voltage, beyond 33KV, it becomes uneconomical to use pin insulator because size, weight of the insulator become more. Handling and replacing bigger size single unit insulator are quite difficult task. For overcoming these difficulties, suspension insulator was developed. In suspension insulator numbers of insulators are connected in series to form a string and the line conductor is carried by the bottom most insulator. Each insulator of a suspension string is called disc insulator because of their 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 the disc insulators in a suspension string is damaged, it can be replaced much easily.

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



4. As the current carrying conductors are suspended from supporting structure by suspension string, the height of the conductor position is always less than the total height of the supporting structure.

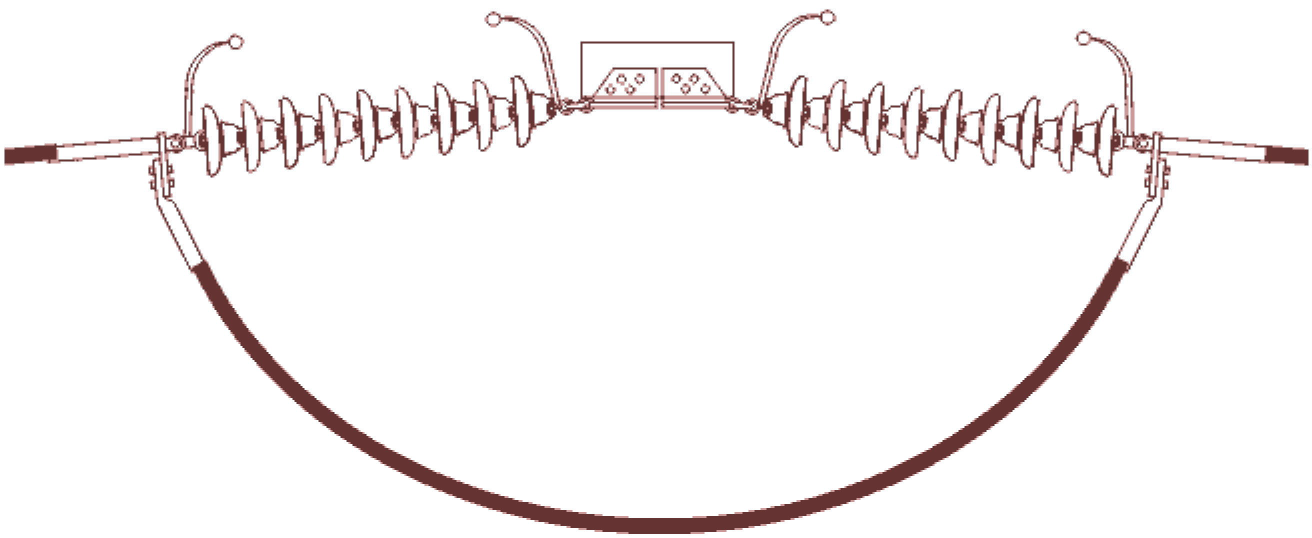
Therefore, the conductors may be safe from lightening.

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

Strain Insulator

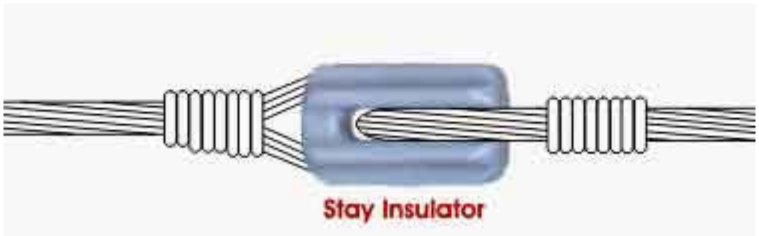
When suspension string is used to sustain extraordinary tensile load of conductor it is referred as string insulator. When there is a dead end or there is a sharp corner in transmission line, the line has to sustain a great tensile load of conductor or strain. A strain insulator must have considerable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



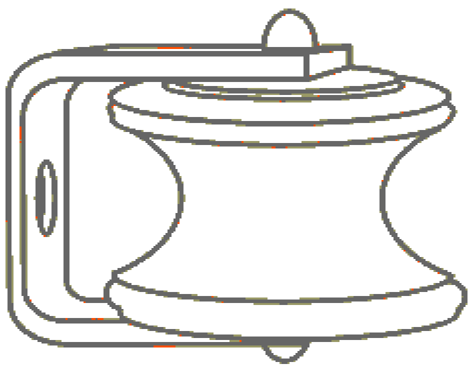
STRAIN INSULATOR

Rated System Voltage	Number of disc insulator used in strain type tension insulator string	Number of disc insulator used in suspension insulator string
33KV	3	3
66KV	5	4
132KV	9	8
220KV	15	14

Stay Insulator



For low voltage lines, the stays are to be insulated from ground at a height. The insulator used in the stay wire is called as the stay insulator and is usually of porcelain and is so designed that in case of breakage of the insulator the guy-wire will not fall to the ground.



Shackle Insulator or Spool Insulator

The shackle insulator or spool insulator is usually used in low voltage distribution network. It can be used both in horizontal and vertical position. The use of such insulator has decreased recently after increasing the using of underground cable for distribution purpose.

The tapered hole of the spool insulator distributes the load more evenly and minimizes the possibility of breakage when heavily loaded. The conductor in the groove of shackle insulator is fixed with the help of soft binding wire.

Electrical Insulator | Insulating Material | Porcelain Glass Polymer Insulator

Electrical Insulator must be used in electrical system to prevent unwanted flow of current to the earth from its supporting points. The insulator plays a vital role in electrical system. Electrical Insulator is a very high resistive path through which practically no current can flow. In transmission and distribution system, the overhead conductors are generally supported by supporting towers or poles. The towers and poles both are properly grounded. So there must be insulator between tower or pole body and current carrying conductors to prevent the flow of current from conductor to earth through the grounded supporting towers or poles.

Insulating Material

The main cause of failure of overhead line insulator, is flash over, occurs in between line and earth during abnormal over voltage in the system. During this flash over, the huge heat produced by arcing, causes puncher in insulator body.

Viewing this phenomenon the materials used for electrical insulator, has to posses some specific properties.

Properties of Insulating Material
The materials generally used for insulating purpose is called insulating material. For successful utilization, this material should have some specific properties as listed below-

1. It must be mechanically strong enough to carry tension and weight of conductors.

2. It must have very high dielectric strength to withstand the voltage stresses in High Voltage system.

3. It must possesses high Insulation Resistance to prevent leakage current to the earth.

4. The insulating material must be free from unwanted impurities.

5. It should not be porous.

6. There must not be any entrance on the surface of electrical insulator so that the moisture or gases can enter in it.

7. There physical as well as electrical properties must be less effected by changing temperature.

Porcelain Insulator

Porcelain in most commonly used material for over head insulator in present days.

The porcelain is aluminium silicate.

The aluminium silicate is mixed with plastic kaolin, feldspar and quartz to obtain final hard and glazed porcelain insulator material. The surface of the insulator should be glazed enough so that water should not be traced on it. Porcelain also should be free from porosity since porosity is the main cause of deterioration of its dielectric property.

It must also be free from any impurity and air bubble inside the material which may affect the insulator properties.

Properties of Porcelain Insulator

Property	Value(Approximate)
Dielectric Straingth	60 KV / cm
Compressive Strength	70,000 Kg / cm^2
Tensile Strength	500 Kg / cm^2

Glass Insulator

Now days glass insulator has become popular in transmission and distribution system. Annealed tough glass is used for insulating purpose.

Glass insulator has numbers of advantages over conventional porcelain

insulator<

Glass Insulator (Disc)

Advantages of Glass Insulator

1. It has very high dielectric strength compared to porcelain.

2. Its resistivity is also very high.

3. It has low coefficient of thermal expansion.

4. It has higher tensile strength compared to porcelain insulator.

5. As it is transparent in nature the is not heated up in sunlight as porcelain.

6. The impurities and air bubble can be easily detected inside the glass insulator body because of its transparency.

7. Glass has very long service life as because mechanical and electrical properties of glass do not be affected by ageing.

8. After all, glass is cheaper than porcelain.

Disadvantages of Glass Insulator

1. Moisture can easily condensed on glass surface and hence air dust will be deposited on the wed glass surface which will provide path to the leakage current of the system.

2. For higher voltage glass can not be cast in irregular shapes since due to irregular cooling internal cooling internal strains are caused.

Properties of Glass Insulator

Property	**Value(Approximate)**
Dielectric Straingth	**140 KV / cm**
Compressive Strength	**10,000 Kg / cm^2**
Tensile Strength	**35,000 Kg / cm^2**

Polymer Insulator
(Supension)

Polymer Insulator

In a polymer insulator has two parts, one is glass fiber reinforced epoxy resin rod shaped core and other is silicone rubber or EPDM (Ethylene Propylene Diene Monomer) made weather sheds.

Rod shaped core is covered by weather sheds. Weather sheds protect the insulator core from outside environment.

As it is made of two parts, core and weather sheds, polymer insulator is also called composite insulator.

The rod shaped core is fixed with Hop dip galvanized cast steel made end fittings in both sides.

Advantages of Polymer Insulator

1. It is very light weight compared to porcelain and glass insulator.
2. As the composite insulator is flexible the chance of breakage becomes minimum.

3. Because of lighter in weight and smaller in size, this insulator has lower installation cost.

4. It has higher tensile strength compared to porcelain insulator.

5. Its performance is better particularly in polluted areas.

6. Due to lighter weight polymer insulator imposes less load to the supporting structure.

7. Less cleaning is required due to hydrophobic nature of the insulator.

Disadvantages of Polymer Insulator
1. Moisture may enter in the core if there is any unwanted gap between core and weather sheds. This may cause electrical failure of the insulator.

2. Over crimping in end fittings may result to cracks in the core which leads to mechanical failure of polymer insulator.

In addition to these, some other disadvantages might be experienced. Let us give a practical example where many difficulties are faced in maintaining a distribution network in Victoria Australia due to polymeric insulator.

There are many Cockatoos, Galahs & Parrots in that area of Australia, which love to chew on polymeric strain insulators. Here, the 22KV network has many of polymeric strain insulators installed and now after a few years of installing polymeric strain insulators, the authority is now replacing many of them back with Glass disc insulators.

Another disadvantage is that they have had post type polymeric insulators melt and bend in bushfire areas. They have a concrete pole and a steel cross

arm that survives a bushfire, however the polymers in some cases fail. This would not be the case with glass or porcelain insulators.

They have also had polymeric insulators fail in areas close to the ocean coastline where there are high salt levels in the air.

1. **Subject to bird attack by Parrots, Cockatoos & Galahs.**
2. **Not resilient to bushfire temperatures.**
3. **Not recommended for location near surf beaches due to salt spray.**

   The information is contributed by Robert Lancaster of Australian Electricity Supply Industry

Types of Insulator

There are mainly three types of insulator likewise

1. Pin Insulator

2. Suspension Insulator

3. Stray Insulator

In addition to that there are other two types of electrical insulator available mainly for low voltage application, e.i. stay insulator and shackle insulator.

Electrical Insulator Testing | Cause of Insulator failure

To ensure the desired performance of an electrical insulator, that is for avoiding unwanted insulator failure, each insulator has to undergo numbers of insulator test.

Before going through testing of insulator we will try to understand different causes of insulator failure.

Because insulator testing ensures the quality of electrical insulator and chances for failure of insulation depend upon the quality of insulator.

Causes of Insulator Failure

There are different causes due to which failure of insulation in electrical power system may occur. Let's have a look on them one by one-

Cracking of Insulator

The porcelain insulator mainly consists of three different materials. The main porcelain body, steel fitting arrangement and cement to fix the steel part with porcelain. Due to changing climate conditions, these different materials in the insulator expand and contract in different rate.

These unequal expansion and contraction of porcelain, steel and cement are the chief cause of cracking of insulator.

Defective Insulation Material

If the insulation material used for insulator is defective anywhere, the insulator may have a high chance of being puncher from that place.

Porosity in The Insulation Materials

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

Improper Glazing on Insulator Surface

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

As a result the flash over distance of the insulator is reduced.

As the flash over distance is reduced, the chance of failure of insulator due to flash over becomes more.

Flash Over Across Insulator

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

Mechanical Stresses on Insulator

If an insulator has any weak portion due to manufacturing defect, it may break from that weak portion when mechanical stress is applied on it by its conductor.

These are the main causes of insulator failure. Now we will discuss the different insulator test procedures to ensure minimum chance of failure of insulation.

Insulator Testing

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

1. Flashover tests of insulator,

2. Performance tests and

3. Routine tests Let's have a discussion one by one- Flashover Test

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

Power Frequency Dry Flashover Test of Insulator

1. First the insulator to be tested is mounted in the manner in which it would be used practically.

2. Then terminals of variable power frequency voltage source are connected to the both electrodes of the insulator.

3. Now the power frequency voltage is applied and gradually increased up to the specified value. This specified value is below the minimum flashover voltage.

4. This voltage is maintained for one minute and observe that there should not be any flash-over or puncher occurred.

The insulator must be capable of sustaining the specified minimum voltage for one minute without flash over.

Power Frequency Wet Flashover Test or Rain Test of Insulator

1. In this test also the insulator to be tested is mounted in the manner in which it would be used practically.

2. Then terminals of variable power frequency voltage source are connected to the both electrodes of the insulator.

3. After that the insulator is sprayed with water at an angle of 45^o in such a manner that its precipitation should not be more 5.08 mm per minute. The resistance of the water used for spraying must be between 9 kΩ 10 11 kΩ per cm^3 at normal atmospheric pressure and temperature. In this way we create artificial raining condition.

4. Now the power frequency voltage is applied and gradually increased up to the specified value.

5. This voltage is maintained for either one minute or 30 second as specified and observe that there should not be any flash-over or puncher occurred. The insulator must be capable of sustaining the specified minimum power frequency voltage for specified period without flash over in the said wet condition.

Power Frequency Flashover Voltage test of Insulator

1. The insulator is kept in similar manner of previous test.

2. In this test the applied voltage is gradually increased in similar to that of previous tests.

3. But in that case the voltage when the surroundings air breaks down, is noted.

Impulse Frequency Flashover Voltage Test of Insulator

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

1. The insulator is kept in similar manner of previous test.

2. Then several hundred thousands Hz very high impulse voltage generator is connected to the insulator.

3. Such a voltage is applied to the insulator and the spark over voltage is noted.
The ratio of this noted voltage to the voltage reading collected from power frequency flashover voltage test is known as impulse ratio of insulator.

$$\therefore \text{Impulse Ratio} = \frac{\text{Impulse Frequency Flashover Voltage}}{\text{Power Frequency Flashover Voltage}}$$

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

Performance Test of Insulator
Now we will discuss performance test of insulator one by one-

Temperature Cycle Test of Insulator
1. The insulator is first heated in water at 70^{o}C for one hour.

2. Then this insulator immediately cooled in water at 7^{o}C for another one hour.

3. This cycle is repeated for three times.

4. After completion of these three temperature cycles, the insulator is dried and the glazing of insulator is thoroughly observed.
After this test there should not be any damaged or deterioration in the glaze of the insulator surface.

Puncture Voltage Test of Insulator
1. The insulator is first suspended in an insulating oil.

2. Then voltage of 1.3 times of flash over voltage, is applied to the insulator.
A good insulator should not puncture under this condition.

Porosity Test of Insulator

1. The insulator is first broken into pieces.

2. Then These broken pieces of insulator are immersed in a 0.5 % alcohol solution of fuchsine dye under pressure of about 140.7 kg/cm^2 for 24 hours.

3. After that the sample are removed and examine.
The presence of a slight porosity in the material is indicated by a deep penetration of the dye into it.

Mechanical Strength Test of Insulator

1. The insulator is applied by 2½ times the maximum working strength for about one minute.
2.The insulator must be capable of sustaining this much mechanical stress for one minute without any damage in it.

Routine Test of Insulator

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

Proof Load Test of Insulator

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

Corrosion Test of Insulator

In corrosion test of insulator,
1. The insulator with its galvanized or steel fittings is suspended into a copper sulfate solution for one minute.

2. Then the insulator is removed from the solution and wiped, cleaned.

3. Again it is suspended into the copper sulfate solution for one minute.

4.The process is repeated for four times.
Then it should be examined and there should not be any disposition of metal on it.