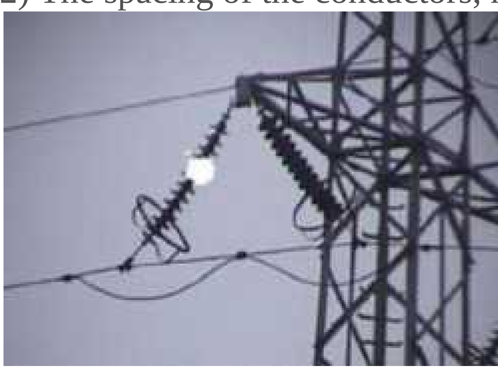
Corona Effect in Power System

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

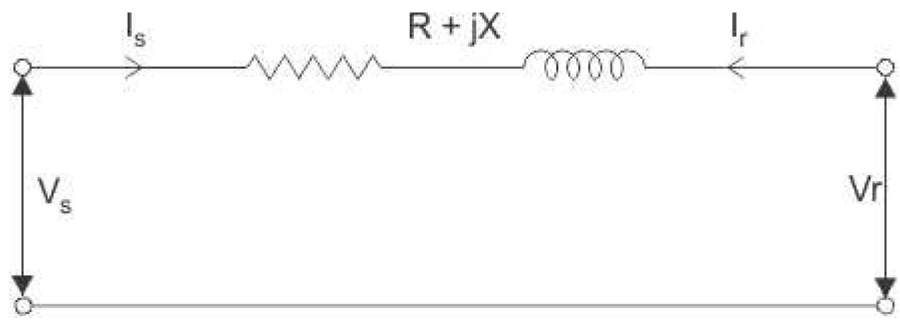
As already mentioned, for corona to occur effectively the spacing between the lines should be much higher compared to its diameter, but if the length is increased beyond a certain limit, the di-electric stress on the air reduces and consequently the effect of corona reduces as well. If the spacing is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

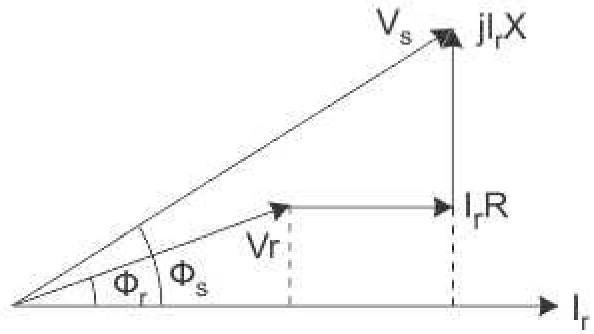
Short Transmission Line

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.

$I_s = I_r$.

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

V_s is approximately equal to

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

That means,

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

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,

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

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

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

Here, v_r and v_x are 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 ,

$$V_s = AV_r + BI_r \cdots\cdots\cdots\cdots\cdots\cdots (1)$$
$$I_s = CV_r + DI_r \cdots\cdots\cdots\cdots\cdots\cdots (2)$$

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.

$$C = \left.\frac{I_s}{V_r}\right|_{I_r = 0}$$

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

$$D = \left.\frac{I_s}{I_r}\right|_{V_r = 0}$$

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,

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

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

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

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

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-

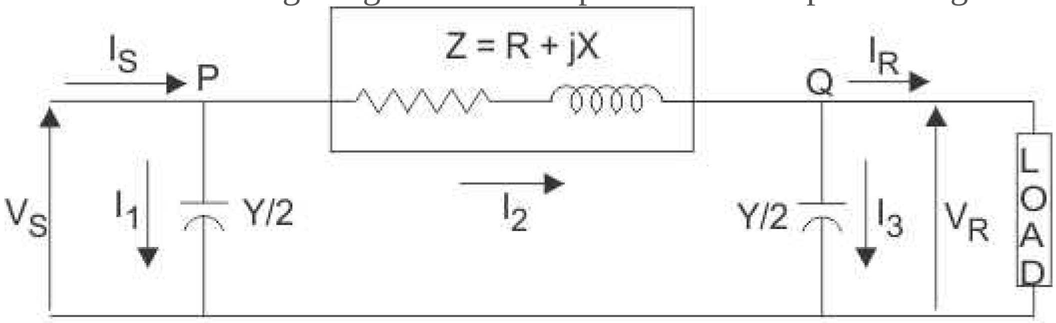
1)Nominal **Π** representation.

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.

$$I_S = I_1 + I_2 \cdots\cdots\cdots\cdots (1)$$

Similarly applying KCL, to node Q.

$$I_2 = I_3 + I_R \cdots\cdots\cdots\cdots (2)$$

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) with the standard ABCD parameter equations

$$V_S = AV_R + BI_R$$

$$I_S = CV_R + DI_R$$

We derive the parameters of a medium transmission line as:

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

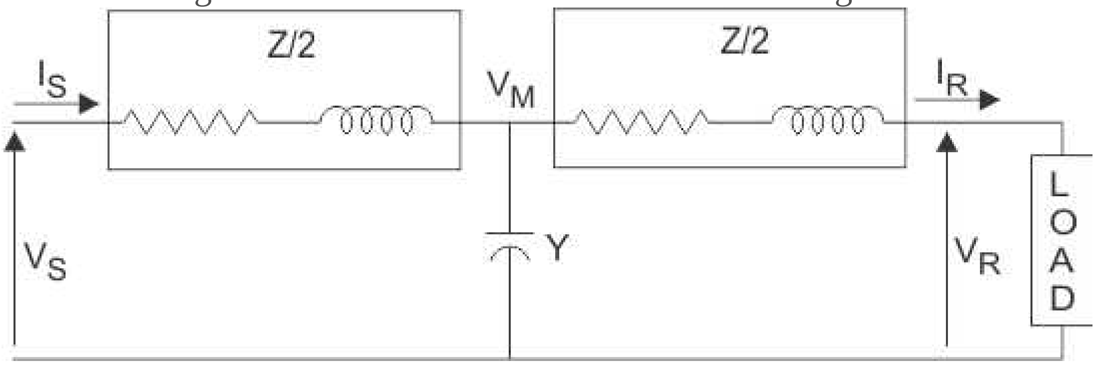
$$B = Z\ \Omega$$

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

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

Nominal T Representation of a Medium Transmission Line

In 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

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

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

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

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

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

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

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

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

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.