DEPARTMENT OF ELECTRICAL &ELECTRONICS ENGINEERING

COURSE: POWER SYETMS-II

BRANCH: Electrical and Electronics Engineering

CLASS: III/I Sem.

YEAR: 2016-2017

LECTURE NOTES

UNIT-I

Performance of Short and Medium Length Transmission Lines

SHORT TRANSMISSION LINES

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.

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

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

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

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

Every transmission line will have three basic electrical parameters. The conductors of the line will have 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.

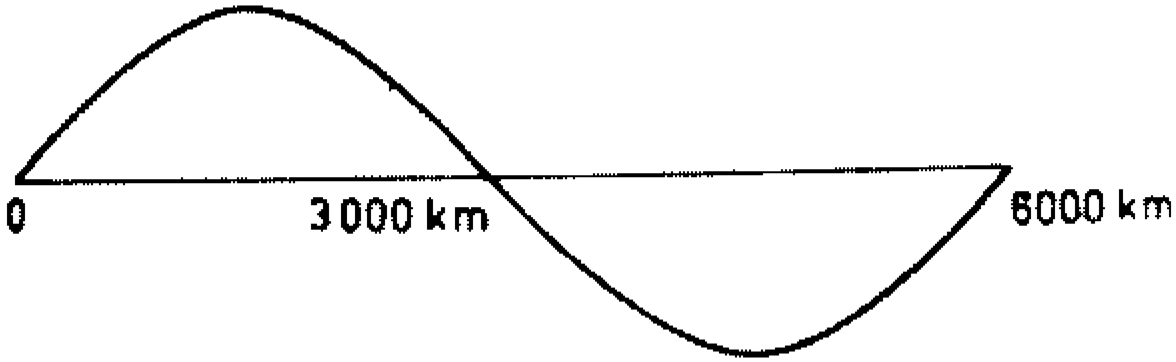
The electrical power is transmitted over a transmission line with a speed of light that is $3X10^8$ m/sec. Frequency of the power is 50Hz. The wave length of the voltage and current of the power can be determined by the equation given below,

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

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

$$\lambda = \frac{3X10^8}{50} = 6X10^6 \text{ meters} = 6000 \text{ km.}$$

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



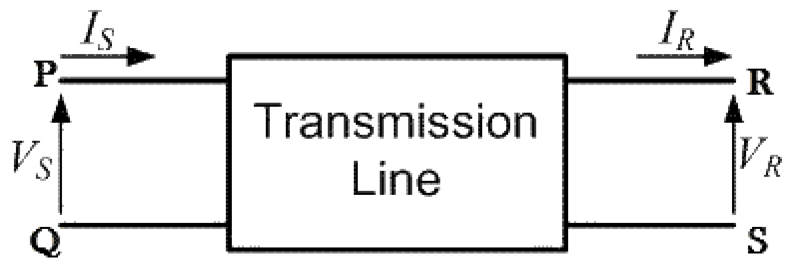
Voltage distribution of 50 Hz supply

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 line the 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.

ABCD PARAMETERS

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.

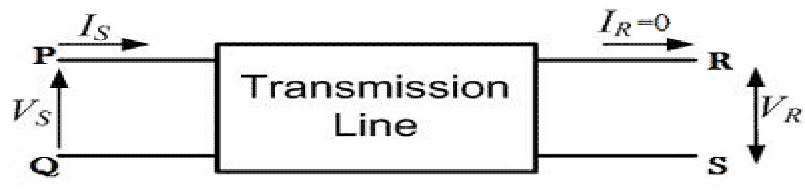
Now the **ABCD parameters** or the transmission line parameters provide the link between the supply and receiving end voltages and currents, considering the circuit elements to be linear in nature.
Thus the relation between the sending and receiving end specifications are given using **ABCD parameters**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

$V_S = A\ V_R + B\ I_R$ ————————-(1)

$I_S = C\ V_R + D\ I_R$ ————————-(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.

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

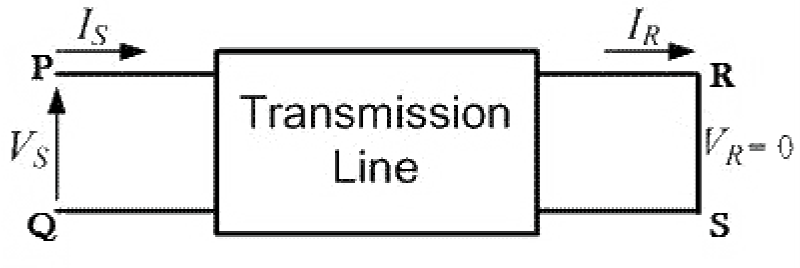
Thus its implies that on applying open circuit condition to ABCD parameters, we get parameter A as the ratio of sending end voltage to the open circuit receiving end voltage. Since dimension wise A is a ratio of voltage to voltage, A is a dimension less parameter.

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

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

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:-

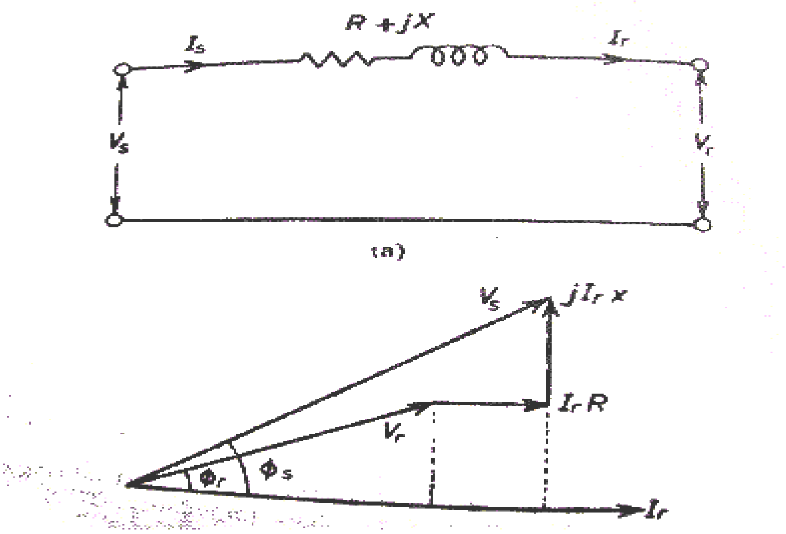
Parameter	Specification	Unit
$A = V_S / V_R$	Voltage ratio	Unit less
$B = V_S / I_R$	Short circuit resistance	Ω
$C = I_S / V_R$	Open circuit conductance	mho
$D = I_S / I_R$	Current ratio	Unit less

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 resistance and inductance 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,

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

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

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

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

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

$V_s = AV_r + BI_r$………..(1)

$I_s = CV_r + DI_r$………..(2)

Where A, B, C and D are different constant of 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,

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

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,

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

Efficiency of Short Transmission Line

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

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

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

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.

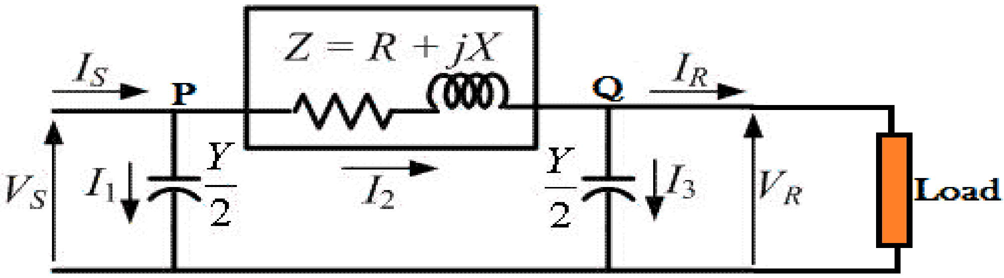
These lumped parameters of a medium length transmission line can be represented using two different models, namely.

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 Π 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.
$I_S = I_1 + I_2$ ————————(1)
Similarly applying KCL, to node Q.
$I_2 = I_3 + I_R$ ————————(2)
Now substituting equation (2) to equation (1)
$I_S = I_1 + I_3 + I_R$

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

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

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

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

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

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

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

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

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

We derive the parameters of a medium transmission line as:

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

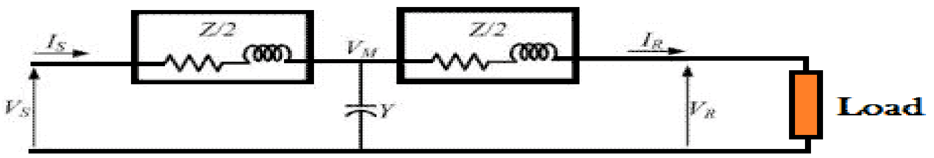
$$B = Z\ \Omega$$

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

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

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

$I_s = Y\,V_M + I_R$ ——————(9)

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

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

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

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

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

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

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

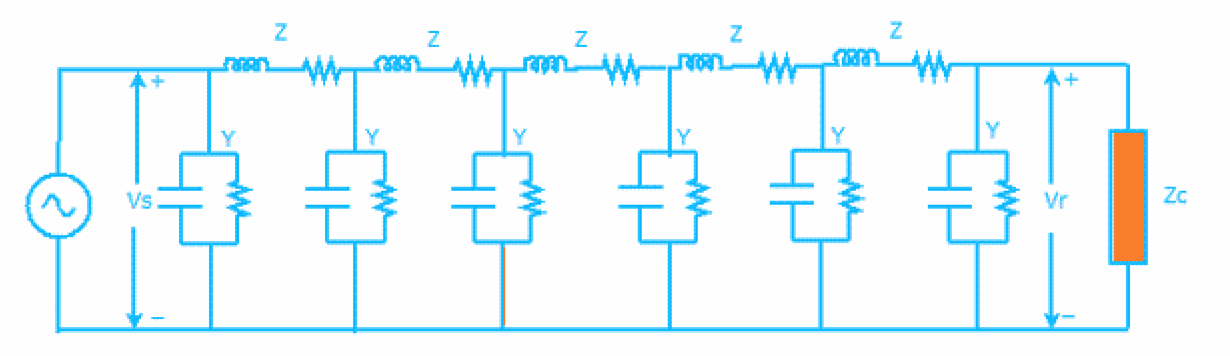
$$C = Y \text{ mho}$$

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

Performance of Long Transmission Lines

LONG TRANSMISSION LINE

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



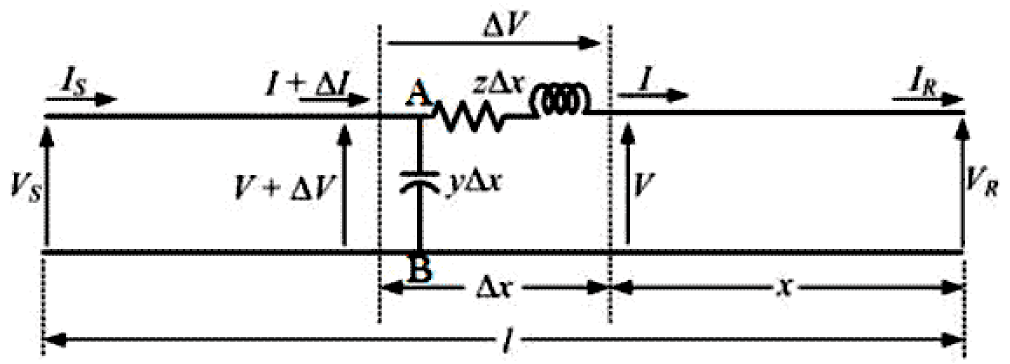
Long Transmission Line model

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.

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

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

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

Or $I z = dV / dx$ ——————————(1)

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

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

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

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

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

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

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

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

or $d^2 V / d x^2 - zyV = 0$ ————(3)

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

∴ 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,

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

Various Factors Governing the Performance of Transmission line

1) .

FERRANTI EFFECT

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 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 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 inductance 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 inductance 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 inductance effect of transmission line are equally responsible for this particular phenomena to occur, and hence Ferranti effect is negligible in case of a short transmission lines as the inductance of such a line is practically considered to be nearing zero. In general for a 300 Km line operating at a frequency of 50 Hz, 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, $I_c = j\omega CV_r$

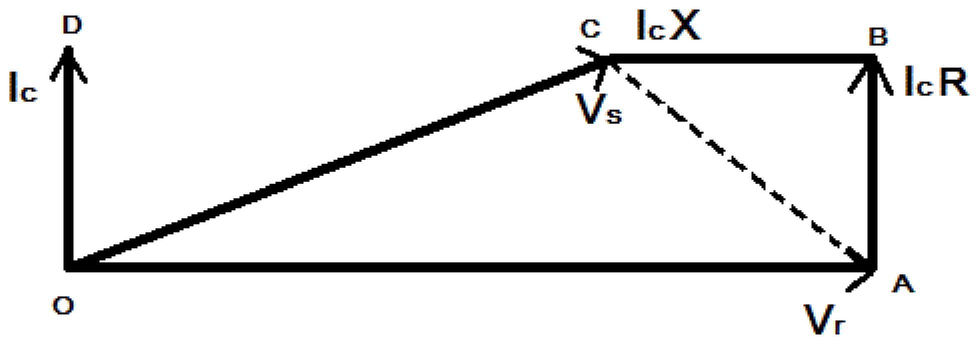
Now sending end voltage $V_s = V_r$ + resistive drop + reactive drop.

$= V_r + I_cR + jI_cX$

$= V_r + I_c (R + jX)$

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

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



Ferranti effect in transmission lines.

This is represented by the phasor OC.
Now in case of a long transmission line, it has been practically observed that the line 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 inductance per km of the transmission line, where l is the length of the line.

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

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

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

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

Thus the rise in voltage due to line inductance is given

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

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

From 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.

Voltage control and Line compensation:

Series and shunt compensation:

The demand of active power is expressing Kilo watt (kw) or mega watt (mw). This power should be supplied from electrical generating station. All the arrangements in electrical pomes system are done to meet up this basic requirement. Although in alternating power system, reactive power always comes in to picture. This reactive power is expressed in Kilo VAR or Mega VAR. The demand of this reactive power is mainly originated from inductive load connected to the system. These inductive loads are generally electromagnetic circuit of electric motors, electrical transformers, inductance of transmission and distribution networks, induction furnaces, fluorescent lightings etc. This reactive power should be properly compensated otherwise, the ratio of actual power consumed by the load, to the total power i.e. vector sum of active and reactive power, of the system becomes quite less. This ratio is alternatively known as electrical power factor, and fewer ratios indicates poor power factor of the system. If the power factor of the system is poor, the ampere burden of the transmission, distribution network, transformers, alternators and other equipments connected to the system, becomes high for required active power. And hence reactive power compensation becomes so important. This is commonly done by capacitor bank.

Let's explain in details,
we know that active power is expressed $=VI\cos\theta$
where,$\cos\theta$ is the power factor of the system. Hence, if this power factor has got less valve,
the corresponding current (I) increases for same active power P.

As the current of the system increases, the ohmic loss of the system increases. Ohmic loss means, generated electrical power is lost as unwanted heat originated in the system. The cross-section of the conducting parts of the system may also have to be increased for carrying extra ampere burden, which is also not economical in the commercial point of view. Another major disadvantage, is poor voltage regulation of the system, which mainly caused due to poor power factor.

The equipments used to compensate reactive power.
There are mainly two equipments used for this
purpose.
(1) Synchronous condensers
(2) Static capacitors or Capacitor Bank

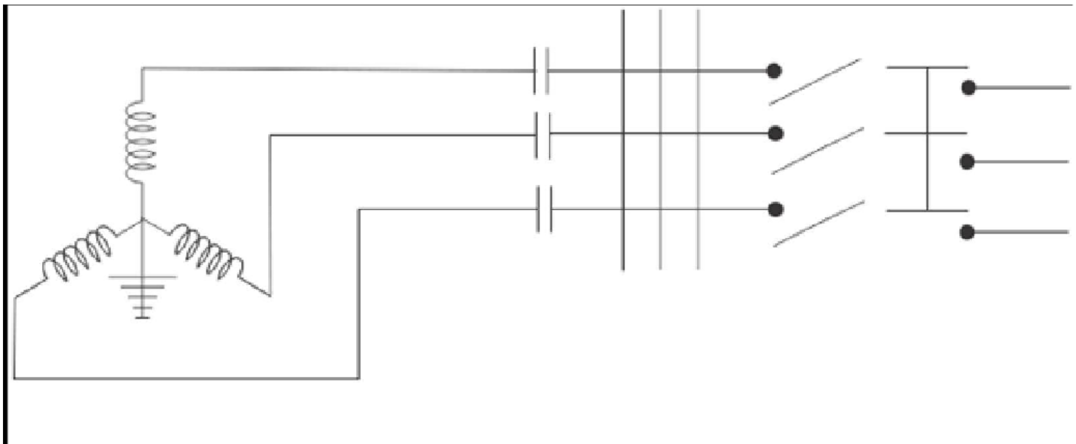
Synchronous condensers, can produce reactive power and the production of reactive power can be regulated. Due to this regulating advantage, the synchronous condensers are very suitable for correcting power factor of the system, but this equipment is quite expensive compared to static capacitors. That is why synchronous condensers, are justified to use only for voltage regulation of very high voltage transmission system.

The regulation in static capacitors can also be achieved to some extend by split the total capacitor bank in 3 sectors of ratio 1: 2:2. This division enables the capacitor to run in 1, 2, 1+2=3, 2+2=4, 1+2+2=5 steps. If still further steps are required, the division may be made in the ratio 1:2:3 or 1:2:4. These divisions make the static capacitor bank more expensive but still the cost is much lower them synchronous condensers. It is found that maximum benefit from compensating equipments can be achieved when they are connected to the individual load side. This is practically and economically possible only by using small rated capacitors with individual load not by using synchronous condensers. Static capacitor Bank.

Static capacitor can further be subdivided in to two categories,

(a) Shunt capacitors

(b) Series capacitor



Series Capacitor Bank

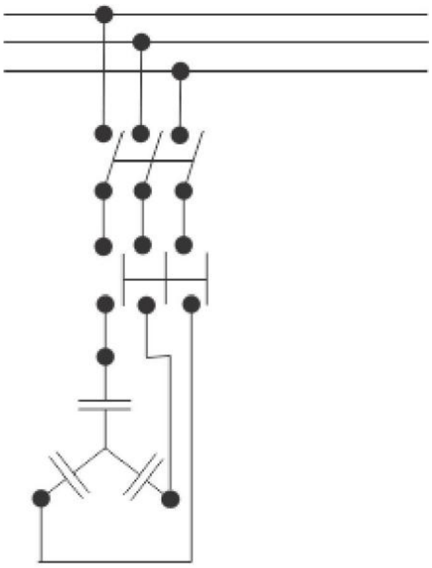


Fig.1. Series and Shunt Capacitor bank

These categories are mainly based on the methods of connecting capacitor bank with the system. Among these two categories, shunt capacitors are more commonly used in the power system of all voltage levels. There are some specific advantages of using shunt capacitors such as,

a) It reduces line current of the system.

b) It improves voltage level of the load.

c) It also reduces system Losses.

d) It improves power factor of the source current.

e) It reduces load of the alternator.

f) It reduces capital investment per mega watt of the Load.

All the above mentioned benefits come from the fact, that the effect of capacitor reduces reactive current flowing through the whole system. Shunt capacitor draws almost fixed amount of leading current which is superimposed on the load current and consequently reduces reactive components of the load and hence improves the power factor of the system. series capacitor on the other hand has no control over flow of current.

As these are connected in series with load , the load current always passes through the series capacitor bank. Actually, the capacitive reactance of series capacitor neutralizes the inductive reactance of the line hence, reduces, effective reactance of the line. Thereby, voltage regulation of the system is improved. But series capacitor bank has a major disadvantage. During faulty condition, the voltage across the capacitor maybe raised up to 15 times more than its rated value. Thus series capacitor must have sophisticated and elaborate protective equipments. Because of this, use of-series capacitor is confined in the extra high voltage system only.

TAP-CHANGING AND REGULATING TRANSFORMERS

Transformers which provide a small adjustment of voltage magnitude, usually in the range o f ± 10%, and others which shift the phase angle of the line voltages are important components of a power system. Some transformers regulate both the magnitude and phase angle.

Almost all transformers provide taps on windings to adjust the ratio of transformation by changing taps when the transformer is deenergized. A change in tap can be made while the transformer is energized and such transformers a recalled load-tap-changing (LTC) transformers or tap-changing-under-load (TCUL) transformers. The tap changing is automatic and operated by motors which respond to relays set to hold the voltage at the prescribed level. Special circuits allow the change to be made without interrupting the current.

A type of transformer designed for small adjustments of voltage rather than large changes in voltage levels is called a regulating transformer Each of the three windings to which taps are made is on the same magnetic core as the phase winding whose voltage is 90° out of phase with the voltage from neutral to the point connected to the center of the tapped winding. For instance, the voltage

to neutral V_{an} is increased by a component ΔV_{an} which is in phase or

180° out of phase with ΔV_{bc}.

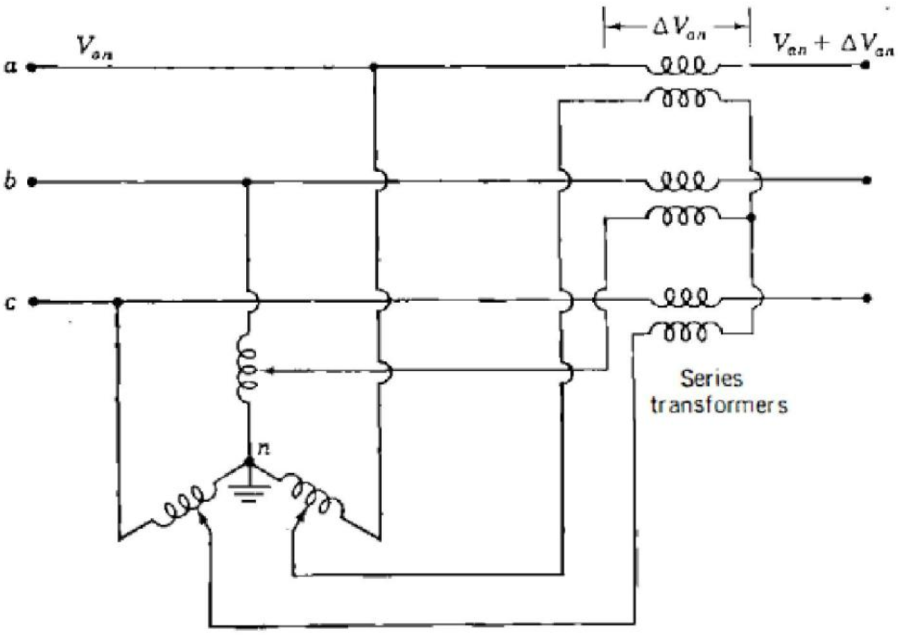


Fig. 1. Regulating t/f for control of voltage magnitude

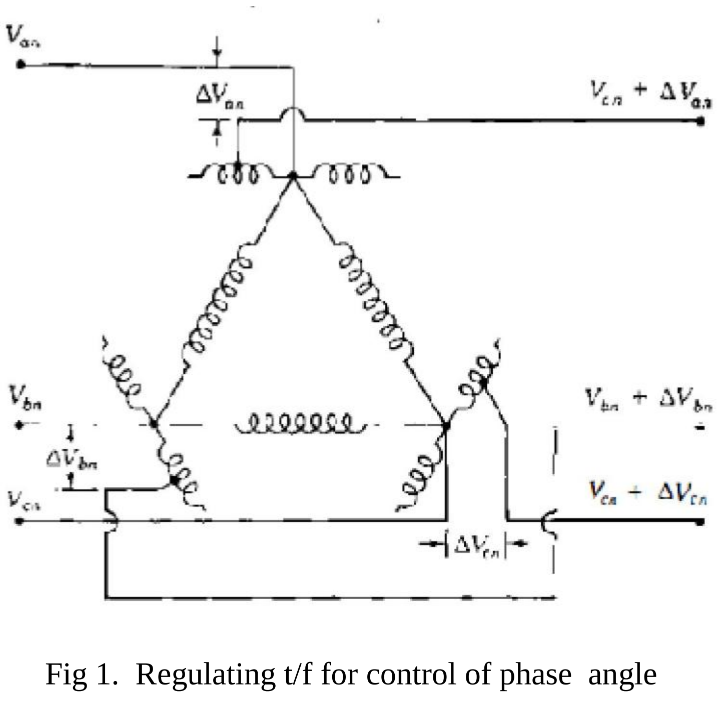


Fig 1. Regulating t/f for control of phase angle

PHASE-SHIFTING TRANSFORMER

The voltage drop in a transmission line is simulated in a line drop compensator, which senses the remote secondary voltage and adjusts the voltage taps. The voltage taps, however, do not change the phase angle of the voltages appreciably. A minor change due to change of the transformer impedance on account of tap adjustment and the resultant power flow through it can be ignored. The real power control can be affected through phase-shifting of the voltage. A phase-shifting transformer changes the phase angle without appreciable change in the voltage magnitude; this is achieved by injecting a voltage at right angles to the corresponding line-to-neutral voltage.

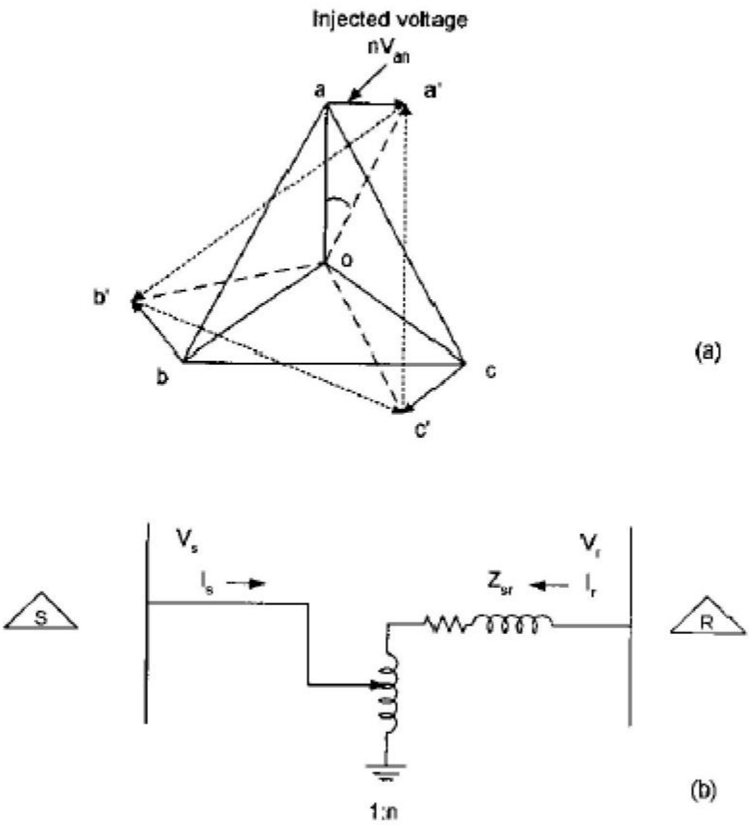


Fig. 1. (a) Voltage injection vector diagram of a phase shifting transformer; (b) schematic diagram of phase-shifting transformer.

Consider the equivalent circuit representation of Fig. 13. Let the regulating transformer be represented by an ideal transformer with a series impedance or admittance. Since it is an ideal transformer, the complex power input equals the complex power output, and for a voltage adjustment tap changing transformer we have already shown that

$$I_s = n^2 y V_s - n y V_r$$

where n is the ratio of the voltage adjustment taps (or currents). Also,

$$I_r = y(V_r - nV_s)$$

EFFECTS OF REGULATING TRANSFORMERS

The transformer with the higher tap setting is supplying most of t h e reactive power to the load. The real power is dividing equally between the transformers. If both transformers have the same impedance, they would share both the real and reactive power equally if they had the same turns ratio. When two transformers are in parallel, we can vary the distribution of reactive power between the transformers by adjusting the voltage-magnitude ratios. When two paralleled transformers of equal kilovolt amperes do not share the Kilovolt amperes equally because their impedances differ, the kilovolt amperes may be more nearly equalized by adjustment of the voltage-magnitude ratios through tap changing.