Lecture 7
Performance of Transmission Lines

Analysis of Transmission lines (1)

The technical analysis of transmission line is done to know its Performance to transfer Power from the sending end to the receiving end. Performance of a transmission line includes efficiency and regulation. For bulk Power transfer, three phase transmission lines are used but for analysis purposes, line can be represented by its single-phase equivalent using the phase resistance, phase Inductance and line to neutral capacitance with assumption that supply and load are balanced in transmission line.

Since resistance, inductance, capacitance and conductance are distributed over the line length, the performance of the line depends on the manner how these are accounted for. General definition of efficiency and regulation in per unit are

$$\text{Efficiency} = \frac{\text{output}}{\text{Input}} = \frac{\text{output}}{\text{output} + \text{losses}}$$

&

$$\text{Regulation} = \frac{\text{change in output Voltage}}{\text{Rated Voltage}}$$

For the transmission lines, η is defined as the ratio of Power delivered at the receiving end to the Power sent at sending end.

Regulation of transmission line is defined as the ratio of change in Voltage at the receiving end, from no Load to full Load keeping the Sending-end Voltage and f constant, i.e. to full Load Voltage.

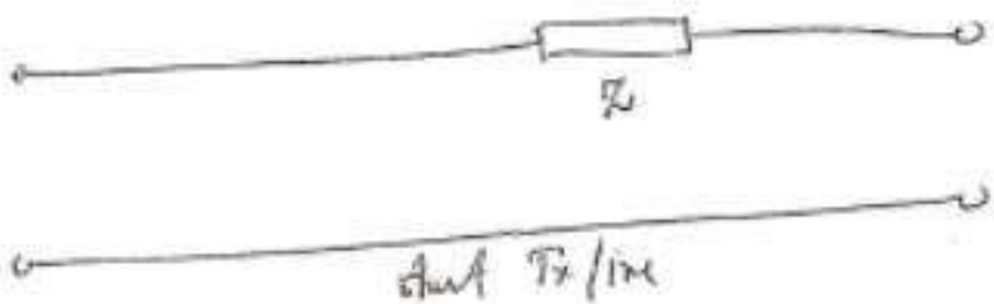
$$\% \text{ Regulation} = \frac{\text{No-Load Voltage} - \text{Full Load Voltage}}{\text{Full Load Voltage}} \times 100$$

$$\% R = \frac{V_{(no\text{-}load)} - V_{(full\ load)}}{V_{(full\ load)}}$$

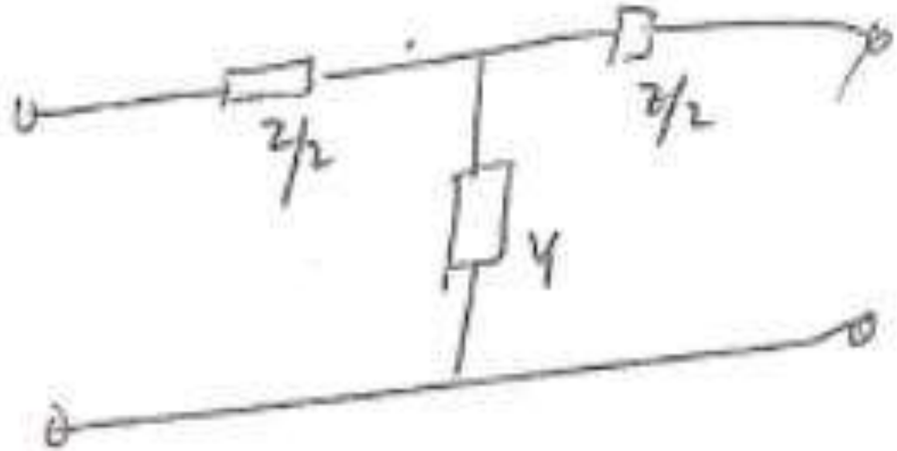
Classification of Lines

Transmission lines are represented into three categories Short lines, medium lines and Long lines. A line having length less than 80 Km is called short line, the charging of C (shunt) can be ignored in the analysis and series r & L can be treated as lumped parameters.
if Tx line is between (80 Km and 200 Km), the charging (current) capacitance of the line cannot be ignored however the series impedance can be taken as lumped parameters. charging capacitance is also considered as lumped parameters. r can be either represented as nominal -T and nominal π circuits. These are called so because line parameters are considered lumped which is not accurate.

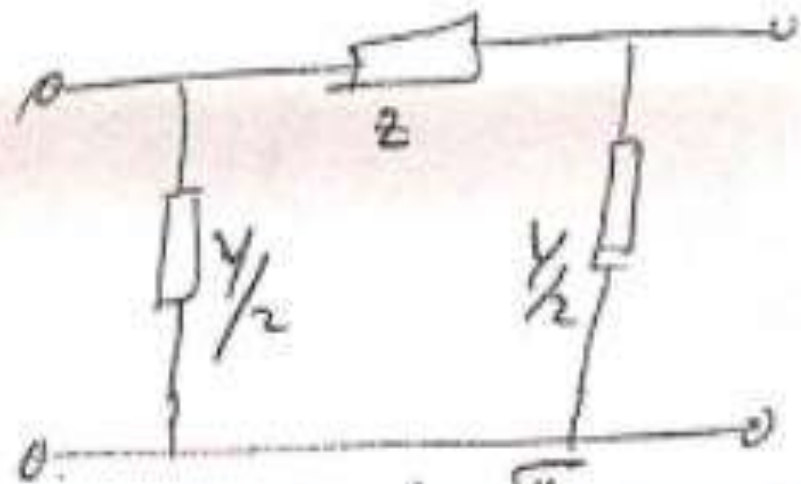
∴ The line more than 200 Km is called (iii) long lines, whose exact representation is required. The line can be represented as T or π but since line parameters are taken as distributed parameters, they are known as equivalent-T & equivalent-π representation.



Medium Tr line



nominal T



nominal - π

Performance of Short Tx lines

Short Tx line

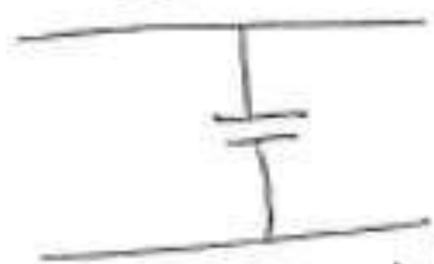
Introduction:- A transmission line always have resistance and reactance (both C & L). The resistance is dependent upon the material from which the conductor is made. → The Inductance is due to the fact that conductor is surrounded by the magnetic lines of force.
→ The Capacitance of the line is due to the fact that the conductor carrying current forms a capacitor with the earth, which is always at lower potential than the conductor and the air between them forms a dielectric medium.
The sending end station, in addition to the receiving end voltage, has to provide extra potential to overcome the drops in the line, which is due to resistance, capacitance and ... of the performance of the

which ... Thus the performance of the transmission lines is dependent upon these three line Constant, however the effect of capacitance in short lines (50 km to 60 km) is negligible and usually not taken into account.

<u>Effect of lines Capacitance:</u> when the potential is applied to the line, an electric flux exists between the two lines, and it forms a uniformly distributed condenser. The line capacitance causes a charging current to flow in the line

, even if it is not loaded from the generating station. This current leads from the supply voltage by 90° and is maximum at the sending end and is uniformly consumed as the receiving end approaches. Although the loading is similar to that of a uniformly distributed load, but for practical purposes the whole of the capacitance can be assumed to be concentrated at the middle of the line as represented in figure below.

(a) Uniformly distributed capacitance of line



(b) Concentrated c of the line.

Capacitance of the

(b) Uniformly distributed charge current

(d) concentrated charge current.

Effect of line Inductance

As the Load current flow through the line conductors are surrounded by magnetic flux causing self-inductance which in turn generates an emf of self-induction. The self-induced emf is in quadrature with the current and opposes the supply voltage. In addition to this IX drop than in resistance drop IR, Although the inductance of the line is distributed throughout the line the inductance can be assumed

AC Line Performance

When ac flows through a line cell, changes in magnetic flux give rise to an emf of self-inductance (back emf). This emf lags 90° behind the current. Its value is

$e = \omega L I = I X$ volts $X = \omega L$, $\omega = 2\pi f$

L = Inductance (Henry) X = Reactance of cell

$L = \frac{2}{10^7}\left(\frac{1}{4} + \log_e \frac{D}{r}\right)$

The voltage impressed on the line at the sending end has thus to provide a compt in phase with the current to compensate for the resistance drop and component in quadrature ahead of the current to compensate for the reactance drop. The precise ... value depends to compensation of

effect on the receiving end voltage depends
upon the difference of phase b/w the voltage
& current at this end of line when the
load has either lagging or unity P.f, the
receiving end voltage (Er) is < (Es) sending end voltage
But when the load is leading p.f, there may
be a rise of voltage at receiving end.

The effect of capacitance is to produce a current in
quadrature ahead of the impressed voltage. The capacitance
current does not flows when the line is open
extend at the receiving end and its value
at any point is that required to charge the

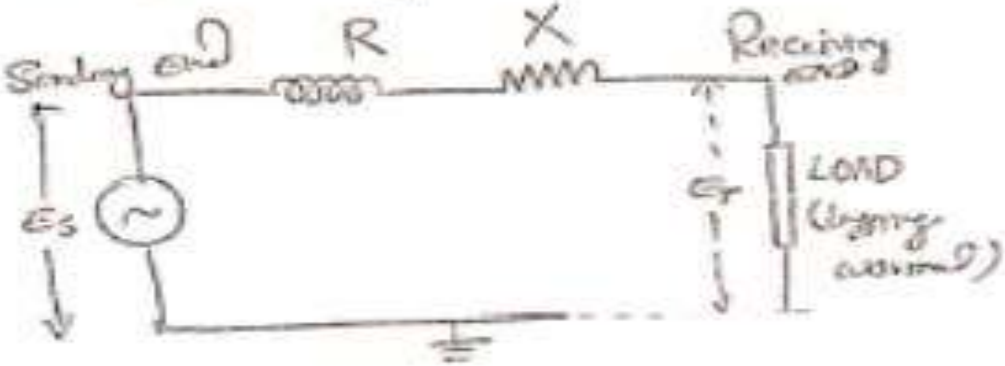
Section of the line between the given point ('x') and the receiving end. Hence the current has its max value at the sending end of the line, where it is known as the charging current and decreases continuously to zero at the receiving end. The charging current

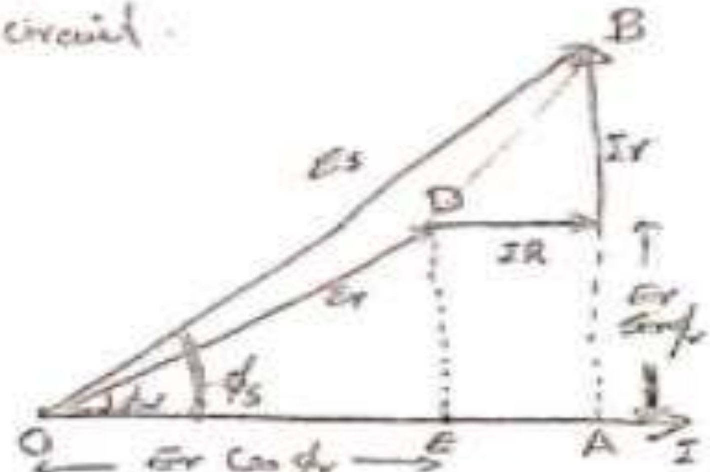
$I_c = \omega C E = E B$ amp

$B = \omega C = 1/X_c$ susceptance of cell mhos

Performance of Short line

In case of 50 cycle overhead line not exceeding 80 km in length, the effect of capacitance is small and can be usually be neglected. The T/x circuit then reduced to the single series-impedance circuit.





Let the conditions at the receiving end known

$E_r, I, (P.f)_r$

$\cos\phi_r \rightarrow$ Load P.f lagging (assume)

$\phi_s \rightarrow$ phase angle at sending end

$\phi_r \rightarrow$ " " " Receiving end

From ΔODE

$$OE = \overline{OD}\cos\phi_r = E_r\cos\phi_r$$

$$ED = \overline{OD}\sin\phi_r = E_r\sin\phi_r$$

From Right angled triangle $\triangle OAB$ $OB \rightarrow E_s$ (S)

$OA = E_r \cos\phi_r + IR$ & $AB = E_r \sin\phi_r + IX$

$(OB)^2 = (OA)^2 + (AB)^2$

$$E_s = \sqrt{(E_r \cos\phi_r + IR)^2 + (E_r \sin\phi_r + IX)^2}$$

or

$$E_s = E_r \sqrt{(\cos\phi_r + IR/E_r)^2 + (\sin\phi_r + IX/E_r)^2}$$

expanding & using $E_r >> IR$, $E_r >> IX$, $(IR/E_r)^2 << 1$

$\cos^2\phi_r + \sin^2\phi_r = 1$

we get

$$E_s = E_r \sqrt{1 + \frac{2I}{E_r}(R\cos\phi_r + X\sin\phi_r)}$$

& $$\phi_s = \tan^{-1} \frac{E_r \sin\phi_r + IX}{E_r \cos\phi_r + IR}$$

Transmission efficiency = $\frac{(P)_{o/p}}{(P)_{I/p}} \times 100 = \frac{E_r I \cos\phi_r}{E_s I \cos\phi_s} \times 100$

$P_{I/p} = P_{o/p} + \text{losses}$

Regulation it is the change of Voltage at the receiving end when full load is thrown off, the sending end Voltage being kept constant. Arithmetically

$$Reg = (E_r)_{no\text{-}Load} - (E_r)_{full\ Load}$$

as $(E_r)_{no\ load} = E_s$

So Regulation $= E_s - (E_r)_{full\ load}$

% age Regulation $= \frac{(E_r)_{no\ load} - (E_r)_{full\ load}}{E_r} \times 100$

As we calculated

$$E_s = E_r \sqrt{1 + \frac{2I}{E_r}(R\cos\phi_r + X\sin\phi_r)}$$

$$E_r > (2IR\cos\phi_r + 2IX\sin\phi_r)$$

Applying Binomial theorem & taking

$$E_s = E_r \left\{1 + \frac{1}{2}\frac{2I}{E_r}(R\cos\phi_r + X\sin\phi_r)\right]$$

$$E_s = E_r + IR\cos\phi_r + IX\sin\phi_r$$

$E_s - E_r =$

% age Regulation $= \frac{E_s - E_r}{E_r} \times 100$

$$\boxed{\%\ \text{age}\ R = \frac{(IR\cos\phi_r + IX\sin\phi_r)}{E_r} \times 100}$$