Transmission Lines can be Modeled according to their length as:

- Short Line Model ($l \leq 80$km)
- Medium Line Model (80km < l < 250km)
- Long Line Model ($l \geq 250$km)

Voltage regulation:

$$VR = \frac{|V_{R(NL)}| - |V_{R(FL)}|}{|V_{R(FL)}|} \times 100\% \tag{1}$$

ABCD for short line

$$\begin{pmatrix} V_S \\ I_S \end{pmatrix} = \begin{pmatrix} 1p.u & Z \\ 0 & 1p.u \end{pmatrix} \begin{pmatrix} V_R \\ I_R \end{pmatrix} \tag{2}$$

ABCD for medium line

$$\begin{pmatrix} V_S \\ I_S \end{pmatrix} = \begin{pmatrix} (1+\frac{YZ}{2}) & Z \\ Y(1+\frac{YZ}{4}) & (1+\frac{YZ}{2}) \end{pmatrix} \begin{pmatrix} V_R \\ I_R \end{pmatrix} \tag{3}$$

The propagation constant (γ) can be expressed as:

$$\gamma = \sqrt{ZY} = \alpha + j\beta = \sqrt{(R + j\omega L)(G + j\omega C)} \tag{4}$$

Z_C (the characteristic impedance) can be expressed as:

$$Z_C = \sqrt{\frac{Z}{Y}} \tag{5}$$

General form for TL

$$\begin{aligned} V(x) &= \cosh(\gamma x)V_R + Z_C \sinh(\gamma x)I_R \\ I(x) &= \frac{1}{Z_C}\sinh(\gamma x)V_R + \cosh(\gamma x)I_R \end{aligned} \tag{6}$$

ABCD for long line

$$\begin{pmatrix} V_S \\ I_S \end{pmatrix} = \begin{pmatrix} \cosh(\gamma l) & Z_C \sinh(\gamma l) \\ \frac{1}{Z_C}\sinh(\gamma l) & \cosh(\gamma l) \end{pmatrix} \begin{pmatrix} V_R \\ I_R \end{pmatrix} \tag{7}$$

Lossless line

The surge impedance:

$$Z_S = \sqrt{\frac{Z}{Y}} = \sqrt{\frac{L}{C}} \tag{8}$$

The propagation constant:

$$\gamma = \sqrt{ZY} = j\omega\sqrt{LC} = j\beta \tag{9}$$

ABCD Parameters for Lossless Line

$$A(x) = D(x) = \cos(\beta x)\, p.u \tag{10}$$

$$B(x) = j\sqrt{\frac{L}{C}}\sin(\beta x) \tag{11}$$

$$C(x) = \frac{j\sin(\beta x)}{\sqrt{L/C}} \tag{12}$$

π-Model for Lossless Line

$$X' = Z_S \sin(\beta l) \tag{13}$$

$$Z' = jX' \tag{14}$$

$$Y' = j\omega Cl\,\frac{\tan(\beta l/2)}{\beta l/2} = j\omega C'l \tag{15}$$

$$\begin{aligned} V(x) &= \cos(\beta x)V_R + jZ_S\sin(\beta x)I_R \\ I(x) &= j\frac{1}{Z_S}\sin(\beta x)V_R + \cos(\beta x)I_R \end{aligned} \tag{16}$$

Wave length (Lossless Line):

The velocity of propagation of voltage and current waves on lossless line can be expressed as:

$$v = \frac{\omega}{\beta} = \frac{2\pi f}{\beta} \tag{17}$$

Then, the wavelength of the wave is obtained by:

$$\lambda = \frac{2\pi}{\beta} = \frac{2\pi}{\omega\sqrt{LC}} = \frac{1}{f\sqrt{LC}} \tag{18}$$

Or

$$f\lambda = \frac{1}{\sqrt{LC}} = v \tag{19}$$

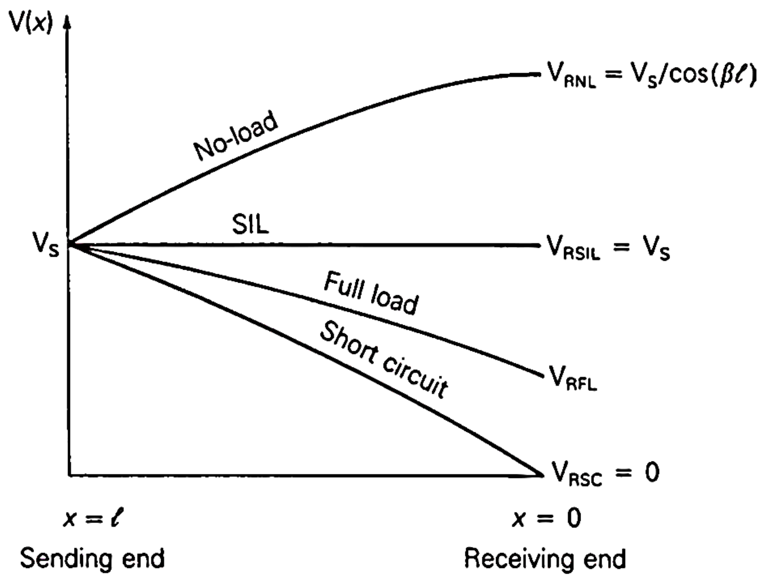
Surge Impedance Loading

$$SIL = \frac{V_{L-L(rated)}^2}{Z_S} \text{ MW} \tag{20}$$

Voltage profiles:

$$V_{NL}(x) = \cos(\beta x)V_{RNL} \tag{21}$$

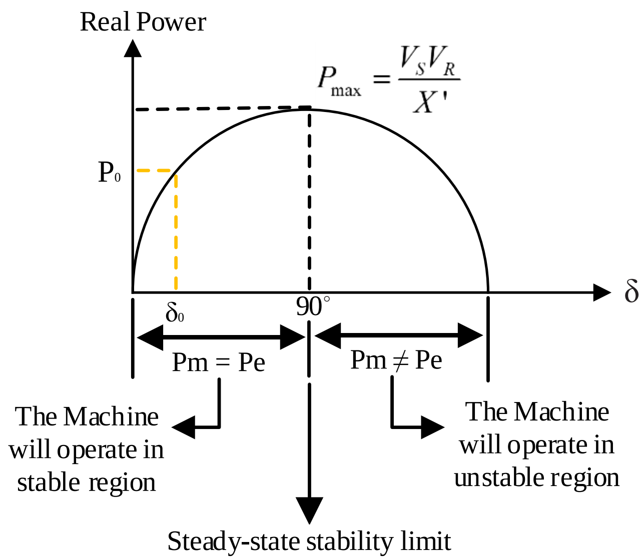
$$V_{SC}(x) = Z_S \sin(\beta x)I_{RSC} \tag{22}$$



Steady state stability limit

$$P = P_S = P_R = \frac{V_S V_R}{X'}\sin(\delta) \tag{23}$$

$$P_{\max} = \frac{V_S V_R}{X'} \text{ W} \tag{24}$$



The maximum power in terms of SIL

$$P = (V_{S.p.u})(V_{R.p.u})(SIL)\frac{\sin(\delta)}{\sin(\frac{2\pi}{\lambda}l)} \text{ Watt} \tag{25}$$

$$P_{\max} = \frac{(V_{S.p.u})(V_{R.p.u})(SIL)}{\sin(\frac{2\pi}{\lambda}l)} \text{ Watt} \tag{26}$$

Maximum Power Flow of Lossless Line

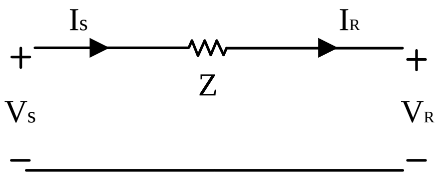
$$S_R = \frac{V_S V_R}{Z'} e^{j(\theta_Z - \delta)} - \frac{V_R^2 A}{Z'} e^{j(\theta_Z - \theta_A)} \tag{27}$$

$$P_R = \Re\{S_R\} = \frac{V_S V_R}{Z'} \cos(\theta_Z - \delta) - \frac{V_R^2 A}{Z'} \cos(\theta_Z - \theta_A) \tag{28}$$

$$Q_R = \Im\{S_R\} = \frac{V_S V_R}{Z'} \sin(\theta_Z - \delta) - \frac{V_R^2 A}{Z'} \sin(\theta_Z - \theta_A) \tag{29}$$

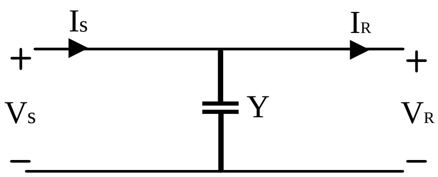
$$P_{R,\max} = \frac{V_S V_R}{Z'} - \frac{V_R^2 A}{Z'} \cos(\theta_Z - \theta_A) \tag{30}$$

ABCD Matrix



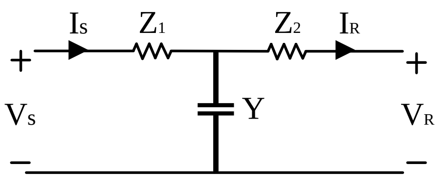
$$\begin{pmatrix} 1 & Z \\ 0 & 1 \end{pmatrix}$$

Short Line



$$\begin{pmatrix} 1 & 0 \\ Y & 1 \end{pmatrix}$$

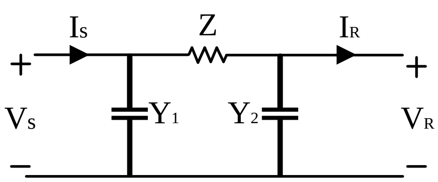
Compensate for reactive power



T-Circuit

$$\begin{pmatrix} (1+YZ_1) & Z_1+Z_2+YZ_1Z_2 \\ Y & (1+YZ_2) \end{pmatrix}$$

$$AD-BC=1$$

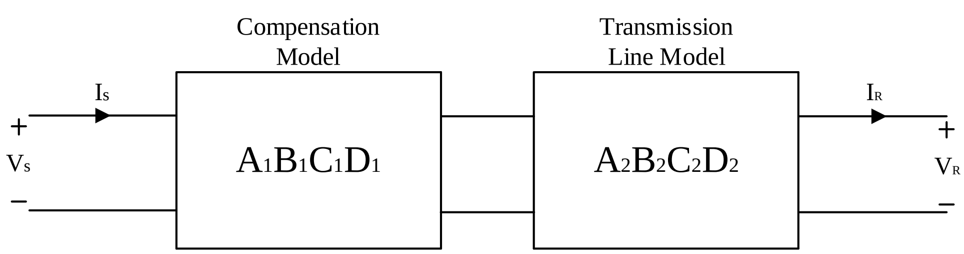


π-Circuit

$$\begin{pmatrix} (1+Y_2Z) & Z \\ Y_1+Y_2+Y_1Y_2Z & (1+Y_1Z) \end{pmatrix}$$

$$AD-BC=1$$

Cascaded Network



Cascaded Network

$$\begin{pmatrix} A_1 & B_1 \\ C_1 & D_1 \end{pmatrix}\begin{pmatrix} A_2 & B_2 \\ C_2 & D_2 \end{pmatrix}=\begin{pmatrix} A_1A_2+B_1C_2 & A_1B_2+B_1D_2 \\ C_1A_2+D_1C_2 & C_1B_2+D_1D_2 \end{pmatrix}$$