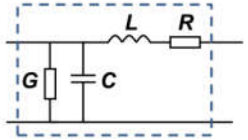
Department of Electrical and Electronics Engineering

EEE 415
Power System Analysis I

Transmission Line Models

Introduction

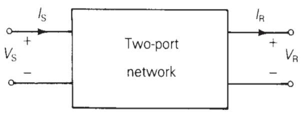
- The transmission line parameters are R, L, C and G.
  - R respresents the real power loss in the conductor.
  - L represents the magnetic field effect.
  - C represents the electric field effect.
  - G represents the real power loss caused by the leakage currents and corona loss.



- These parameters are derived as per unit length of the transmission line. They are not lumped and are uniformly distributed along the length of the line.
- The transmission line models used in power system analysis are developed using these distributed parameters.

Introduction: Two Port Network

- Generally, power system engineers deal with only the terminal characteristics of transmission lines.
- Therefore, it is convenient to represent a transmission line by the two-port network for the simplicity of calculations.
- V_S and I_S are the sending-end voltage and current.
- V_R and I_R are the receiving-end voltage and current.



Introduction: Two Port Network

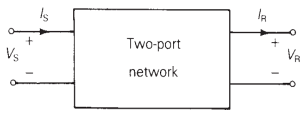
- The relation between the sending-end and receiving-end quantities can be written as;

$$V_S = AV_R + BI_R \quad \text{volts}$$

$$I_S = CV_R + DI_R \quad \text{A}$$

or in matrix format;

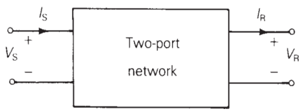
$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \left[\begin{array}{c|c} 1 & Z \\ \hline 0 & 1 \end{array}\right] \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$



- A, B, C, and D are parameters that depend on the transmission-line constants R, L, C, and G.

Introduction: Two Port Network

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



- From the circuit network theory, ABCD parameters apply to linear, passive, bilateral two-port networks, with the following general relation:

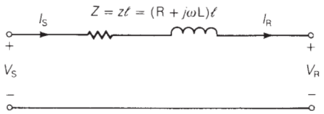
$$AD - BC = 1$$

Types of Transmission Line Models

- The transmission line models can be classified in three types with respect to the length of transmission lines;
  - Short Transmission Lines
  - Medium Transmission Lines
  - Long Transmission Lines

Short Transmission Line Model

- 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.



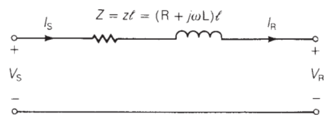
Short Transmission Line Model

- By appliying KVL to the short transmission line equivalent circuit, it is written as;

$$V_S = V_R + ZI_R$$
$$I_S = I_R$$

and in matrix format;

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \left[\begin{array}{c|c} 1 & Z \\ \hline 0 & 1 \end{array}\right] \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

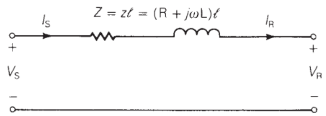


Short Transmission Line Model

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \left[\begin{array}{c|c} 1 & Z \\ \hline 0 & 1 \end{array}\right] \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

- The ABCD parameters for a short line are

$$A = D = 1$$
$$B = Z \quad \Omega$$
$$C = 0 \quad \text{S}$$



Medium Transmission Line Model

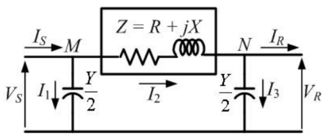
- The transmission lines above 80km and below 250km in length are referred as medium length transmission lines.
- As the length of transmission line increases, the line charging current becomes appreciable and the shunt capacitance must be considered.
- For this reason the modelling of a medium length transmission line is represented 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 modelled using two different models as;
  - Nominal π network model
  - Nominal T network model

Medium Transmission Line Model: Nominal π Network Model

- In nominal π network representation, the lumped series impedance is placed in the middle while the shunt admittance is divided into two equal parts and placed at the two ends.
- By applying KVL to the middle mesh of equivalent model and applying KCL to Node N;

$$V_s = ZI_2 + V_R = Z\left(V_R \frac{Y}{2} + I_R\right) + V_R$$

$$= \left(\frac{YZ}{2} + 1\right)V_R + ZI_R \qquad \text{Eq. 1}$$



Medium Transmission Line Model: Nominal π Network Model

- By applying KCL at nodes *M* and *N*;

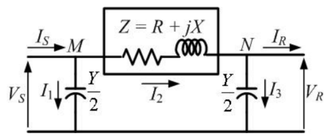
$$I_s = I_1 + I_2 = I_1 + I_3 + I_R$$

$$= \frac{Y}{2}V_s + \frac{Y}{2}V_R + I_R \qquad \text{Eq. 2}$$

- By substituting Eq. 1 to Eq. 2, Eq. 2 can be reorganized as;

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

$$= Y\left(\frac{YZ}{4} + 1\right)V_R + \left(\frac{YZ}{2} + 1\right)I_R$$



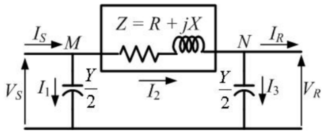
Medium Transmission Line Model: Nominal π Network Model

- By applying KCL at nodes *M* and *N*;

$$I_s = I_1 + I_2 = I_1 + I_3 + I_R$$
$$= \frac{Y}{2}V_s + \frac{Y}{2}V_R + I_R \quad \text{Eq. 2}$$

- By substituting Eq. 1 to Eq. 2, Eq. 2 can be reorganized as;

$$I_s = \frac{Y}{2}\left[\left(\frac{YZ}{2}+1\right)V_R + ZI_R\right] + \frac{Y}{2}V_R + I_R$$
$$= Y\left(\frac{YZ}{4}+1\right)V_R + \left(\frac{YZ}{2}+1\right)I_R \quad \text{Eq. 3}$$



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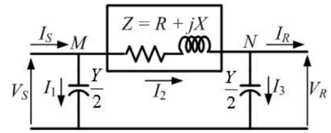
Medium Transmission Line Model: Nominal T Network Model

- From Eq. 1 and Eq. 3, the ABCD parameters of nominal π representation are written as;

$$A = D = \left(\frac{YZ}{2}+1\right)$$
$$B = Z\,\Omega$$
$$C = Y\left(\frac{YZ}{4}+1\right)\text{m S}$$



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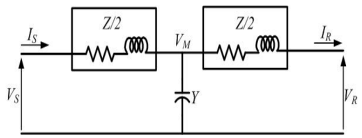
Medium Transmission Line Model: Nominal T Network Model

- In nominal T network representation, the shunt admittance is placed in the middle and the series impedance is divided into two equal parts and these parts are placed on either side of the shunt admittance.
- By applying KCL at the midpoint results in

$$\frac{V_S - V_M}{Z/2} = YV_M + \frac{V_M - V_R}{Z/2} \quad \text{Eq. 4}$$



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Medium Transmission Line Model: Nominal T Network Model

- By rearranging Eq.4, it can be written as;

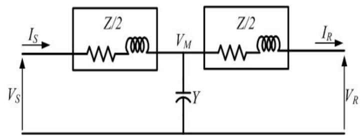
$$V_M = \frac{2}{YZ+4}\left(V_S + V_R\right) \quad \text{Eq. 5}$$

- The receiving end current I_R is written as;

$$I_R = \frac{V_M - V_R}{Z/2} \quad \text{Eq. 6}$$

- By substituting the value of VM from Eq. 5 into Eq. 6;

$$V_s = \left(\frac{YZ}{2}+1\right)V_R + Z\left(\frac{YZ}{4}+1\right)I_R \quad \text{Eq. 7}$$



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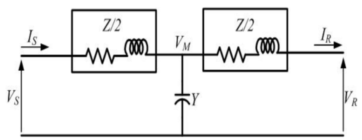
Medium Transmission Line Model: Nominal T Network Model

- The sending end current is

$$I_S = YV_M + I_R \quad \text{Eq. 8}$$

- By substituting the value of V_M from Eq. 5 into Eq. 8

$$I_R = YV_R + \left(\frac{YZ}{2} + 1\right) I_R \quad \text{Eq. 9}$$



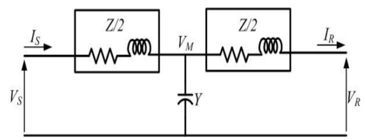
Medium Transmission Line Model: Nominal T Network Model

- From Eq. 7 and Eq. 9, the ABCD parameters of nominal T representation are written as;

$$A = D = \left(\frac{YZ}{2} + 1\right)$$

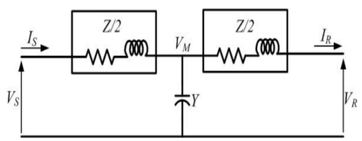
$$B = Z\left(\frac{YZ}{4} + 1\right)\Omega$$

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



Medium Transmission Line Model: Nominal T Network Model

- In the power system analysis such as, power flow and short circuit calculations, the nominal π represenation is preferred instead of nominal T representation because, the nominal T representation adds an additional node into network and it increases the dimensions of bus matrices.

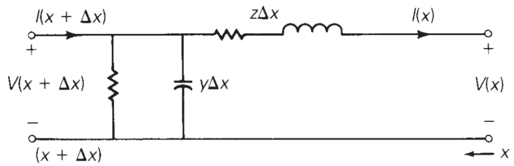


Long Transmission Line Model

- The transmission lines equal to or longer than 250 km are referred as long transmission lines.
- For an accurate calculations, the shunt capacitance and the series impedance of the long transmission lines should be modeled using distributed quantities.
- In the distributed model of the long transmission lines, the voltages and currents on the line are caluclated by solving differential equations of the line.

Long Transmission Line Model

- In order to account for the distributed nature of transmission-line parameters, the following equivalent circuit which represents a transmission line section of length Δx is used.



- V(x) and I(x) denote the voltage and current at position x, which is measured in meters from the right, or receiving end of the line. Similarly, V(x +Δx) and I(x +Δx) denote the voltage and current at position (x +Δx).

Transmission Line Performance Parameters

Long Transmission Line Model

- The circuit constants are

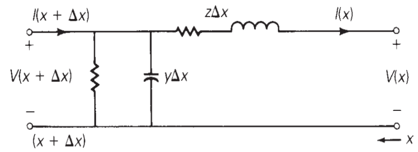
$$z = \mathrm{R} + j\omega\mathrm{L} \quad \Omega/\mathrm{m}$$

$$y = \mathrm{G} + j\omega\mathrm{C} \quad \mathrm{S/m}$$

where G is usually neglected for overhead transmission lines.

- Writing a KVL equation for the circuit

$$V(x+\Delta x) = V(x) + (z\Delta x)I(x) \quad \text{Eq. 10}$$



Transmission Line Models

Long Transmission Line Model

- By rearranging Eq. 10,

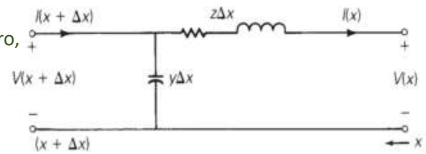
$$\frac{V(x+\Delta x) - V(x)}{\Delta x} = zI(x)$$

- Taking the limit of Eq. 10 as Δx approaches zero,

$$\frac{dV(x)}{dx} = zI(x) \quad \text{Eq. 11}$$

- Applying KCL to the circuit

$$I(x+\Delta x) = I(x) + (y\Delta x)V(x+\Delta x) \quad \text{Eq. 12}$$



Transmission Line Models

Long Transmission Line Model

- By rearranging Eq. 12,

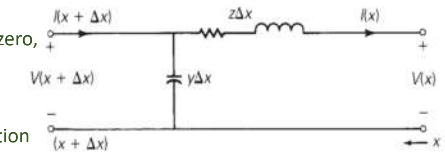
$$\frac{I(x+\Delta x) - I(x)}{\Delta x} = yV(x) \quad \text{Eq. 13}$$

- Taking the limit of Eq. 13 as Δx approaches zero,

$$\frac{dI(x)}{dx} = yV(x) \quad \text{Eq. 14}$$

- Using Eq. 11 and Eq. 14, the following equation is obtained,

$$\frac{d^2V(x)}{dx^2} - zyV(x) = 0 \quad \text{Eq. 15}$$



Transmission Line Models

Long Transmission Line Model

- The solution of Eq. 15 is,

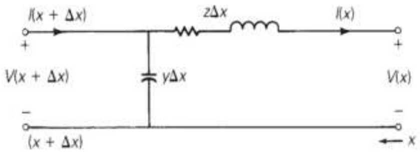
$$V(x) = A_1 e^{\gamma x} + A_2 e^{-\gamma x} \quad \text{Eq. 16}$$

where A_1 and A_2 are integration constants and γ called as propagation constant is equal to,

$$\gamma = \sqrt{zy}$$

- Using Eq. 11 and Eq 16,

$$\frac{dV(x)}{dx} = \gamma A_1 e^{\gamma x} - \gamma A_2 e^{-\gamma x} = zI(x) \quad \text{Eq. 17}$$



Transmission Line Models

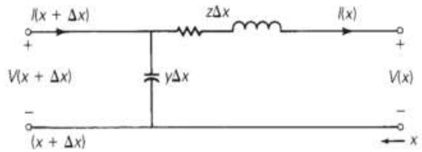
Long Transmission Line Model

- Solving Eq. 17 for I(x),

$$I(x) = \frac{A_1 e^{\gamma x} - A_2 e^{-\gamma x}}{Z_c} \quad \text{Eq. 18}$$

where Z_C is called as characteristic impedance and is equal to;

$$Z_c = \sqrt{\frac{z}{y}} \quad \Omega$$



Transmission Line Models

Long Transmission Line Model

- The integration constants A_1 and A_2 are evaluated from the boundary conditions. At x=0, the receiving end of the line, the receiving end voltage and current are equal to;

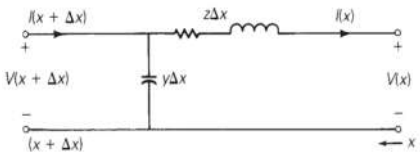
$$V_R = V(0)$$

$$I_R = I(0)$$

and Eq. 16 and Eq. 18 become as;

$$V_R = A_1 + A_2 \quad \text{Eq. 19}$$

$$I_R = \frac{A_1 - A_2}{Z_c} \quad \text{Eq. 20}$$



Transmission Line Models

Long Transmission Line Model

- Solving Eq. 19 and Eq. 20 for A_1 and A_2;

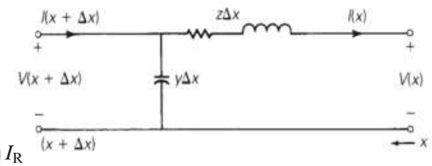
$$A_1 = \frac{V_R + Z_c I_R}{2}$$

$$A_2 = \frac{V_R - Z_c I_R}{2}$$

Substituting A_1 and A_2 into Eq. 16 and Eq. 18 and arranging these equations;

$$V(x) = \left(\frac{e^{\gamma x} + e^{-\gamma x}}{2}\right) V_R + Z_c \left(\frac{e^{\gamma x} - e^{-\gamma x}}{2}\right) I_R$$

$$I(x) = \frac{1}{Z_c}\left(\frac{e^{\gamma x} - e^{-\gamma x}}{2}\right) V_R + \left(\frac{e^{\gamma x} + e^{-\gamma x}}{2}\right) I_R$$

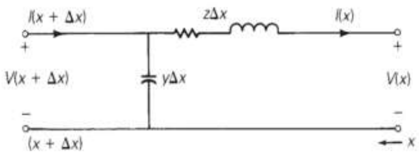


Transmission Line Models

Long Transmission Line Model

$$V(x)=\left(\frac{e^{\gamma x}+e^{-\gamma x}}{2}\right)V_R+Z_c\left(\frac{e^{\gamma x}-e^{-\gamma x}}{2}\right)I_R$$

$$I(x)=\frac{1}{Z_c}\left(\frac{e^{\gamma x}-e^{-\gamma x}}{2}\right)V_R+\left(\frac{e^{\gamma x}+e^{-\gamma x}}{2}\right)I_R$$



- By recognizing hyperbolic functions cosh and sinh;

$$V(x)=\cosh(\gamma x)V_R+Z_c\sinh(\gamma x)I_R \quad \text{Eq. 21}$$

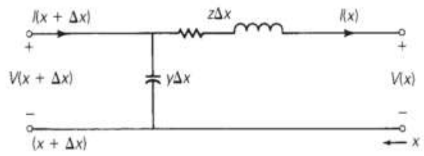
$$I(x)=\frac{1}{Z_c}\sinh(\gamma x)V_R+\cosh(\gamma x)I_R \quad \text{Eq. 22}$$

Transmission Line Models

Long Transmission Line Model

- Using Eq. 21 and Eq. 22, the ABCD paramters of long transmission line for any point x along the line is equal to;

$$\begin{bmatrix}V(x)\\I(x)\end{bmatrix}=\left[\begin{array}{c|c}A(x)&B(x)\\ \hline C(x)&D(x)\end{array}\right]\begin{bmatrix}V_R\\I_R\end{bmatrix}$$



where

$$A(x)=D(x)=\cosh(\gamma x) \quad \text{per unit}$$

$$B(x)=Z_c\sinh(\gamma x) \quad \Omega$$

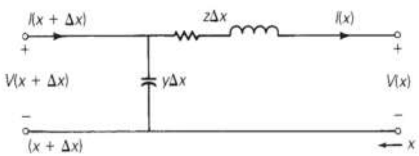
$$C(x)=\frac{1}{Z_c}\sinh(\gamma x) \quad \text{S}$$

Transmission Line Models

Long Transmission Line Model

- At sending end where *x=l*, $V(l)=V_S$ and $I(l)=I_S$, the ABCD paramters of long transmission line is equal to;

$$\begin{bmatrix}V_S\\I_S\end{bmatrix}=\left[\begin{array}{c|c}A&B\\ \hline C&D\end{array}\right]\begin{bmatrix}V_R\\I_R\end{bmatrix}$$



where

$$A=D=\cosh(\gamma l) \quad \text{per unit}$$

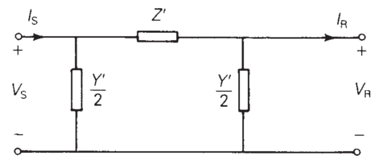
$$B=Z_c\sinh(\gamma l) \quad \Omega$$

$$C=\frac{1}{Z_c}\sinh(\gamma l) \quad \text{S}$$

Transmission Line Models

Long Transmission Line Model

- The long transmission line model can be respresented by the equivalent π circuit.
- Z' and Y' are used for the equivalent π circuit of the long line model instead of Z and Y in the nominal π circuit representation.



Transmission Line Models

Long Transmission Line Model

- The ABCD paramters of the equivalent π circuit of long transmission line is equal to;

$$A = D = 1 + \frac{Y'Z'}{2}$$

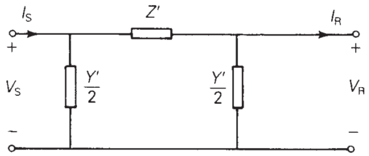
$$B = Z' \quad \Omega$$

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

where

$$Z' = Z_c \sinh \gamma\ell = Z \frac{\sinh \gamma\ell}{\gamma\ell}$$

$$\frac{Y'}{2} = \frac{1}{Z_c} \tanh \frac{\gamma\ell}{2} = \frac{Y}{2} \frac{\tanh \gamma\ell/2}{\gamma\ell/2}$$



Note that Z=zl and Y=yl, z and y are per unit length parameters.

Transmission Line Performance

Voltage Regulation

- The variation of line voltage with different loading conditions is called '*voltage regulation*'.
  - About 10% voltage change between no load and full load operation is a usual practice for reliable operation.
  - Voltage regulation measures the degree of change in voltage when load varies from no-load to full load at a specific power factor

$$\text{Percent regulation} = \frac{|V_{R,NL}| - |V_{R,FL}|}{|V_{R,FL}|} \times 100$$

Transmission Line Performance

Efficiency

- The transmission line efficiency can be calculated from the ratio of the real power at the receiving end to real power at the sending end.

$$\eta = \frac{P_{R,3\Phi}}{P_{S,3\Phi}} \times 100$$

$$S_{R,3\Phi} = 3V_{R,\text{line-to-neutral}} I_R^* = P_{R,3\Phi} + jQ_{R,3\Phi}$$

$$S_{S,3\Phi} = 3V_{S,\text{line-to-neutral}} I_S^* = P_{S,3\Phi} + jQ_{S,3\Phi}$$

Transmission Line Performance

Lossess Lines

- The conductane, G which represents the power loss caused by leakage current and the corona are generally neglected for the power system analyses.
- Transmission and distribution lines for power transfer generally are designed to have low losses so, the series resistance can be neglected to simplify the calculations for the surge impedance loading, voltage profiles and steady-state stability limit of transmission lines.
- For the losses line, R=G=0 and

$$z = j\omega \mathrm{L} \quad \Omega/\mathrm{m}$$

$$y = j\omega \mathrm{C} \quad \mathrm{S/m}$$

- The characteristic impedance becomes as;

$$Z_c = \sqrt{\frac{z}{y}} = \sqrt{\frac{j\omega \mathrm{L}}{j\omega \mathrm{C}}} = \sqrt{\frac{\mathrm{L}}{\mathrm{C}}} \quad \Omega$$

Transmission Line Performance

Losess Lines

- The characteristic impedance becomes as;

$$Z_c = \sqrt{\frac{z}{y}} = \sqrt{\frac{j\omega L}{j\omega C}} = \sqrt{\frac{L}{C}} \quad \Omega$$

and the propagation constant is,

$$\gamma = \sqrt{zy} = \sqrt{(j\omega L)(j\omega C)} = j\omega\sqrt{LC} = j\beta$$

- For losess lines;
  - The characteristic impedance is called as surge impedance and it is pure real, resistive.
  - The propagation constant is pure imaginary.

Transmission Line Performance

Losess Lines

- The ABCD parameters of losess line are;

$$A(x) = D(x) = \cosh(\gamma x) = \cosh(j\beta x)$$

$$= \frac{e^{j\beta x} + e^{-j\beta x}}{2} = \cos(\beta x) \quad \text{per unit}$$

$$\sinh(\gamma x) = \sinh(j\beta x) = \frac{e^{j\beta x} - e^{-j\beta x}}{2} = j\sin(\beta x) \quad \text{per unit}$$

$$B(x) = Z_c \sinh(\gamma x) = jZ_c \sin(\beta x) = j\sqrt{\frac{L}{C}} \sin(\beta x) \quad \Omega$$

$$C(x) = \frac{\sinh(\gamma x)}{Z_c} = \frac{j\sin(\beta x)}{\sqrt{\frac{L}{C}}} \quad S$$

- A(x) and D(x) are pure real; B(x) and C(x) are pure imaginary.

Transmission Line Performance

Surge Impedance Loading - SIL

- Surge impedance loading (SIL) is the power delivered by a lossless line to a load resistance equal to the surge impedance Z=√(L/C).
- At SIL;

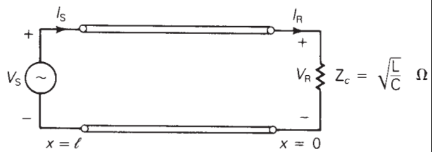
$$V(x) = \cos(\beta x)V_R + jZ_c \sin(\beta x) I_R$$

$$= \cos(\beta x)V_R + jZ_c \sin(\beta x)\left(\frac{V_R}{Z_c}\right)$$

$$= (\cos\beta x + j\sin\beta x)V_R$$

$$= e^{j\beta x} V_R \quad \text{volts}$$

$$|V(x)| = |V_R| \quad \text{volts}$$



- **The voltage magnitude at any point x along a lossless line at SIL is constant.**

Transmission Line Performance

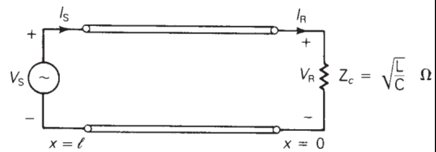
Surge Impedance Loading - SIL

- At SIL, the current in any x point is equal to;

$$I(x) = \frac{j\sin(\beta x)}{Z_c} V_R + (\cos\beta x)\frac{V_R}{Z_c}$$

$$= (\cos\beta x + j\sin\beta x)\frac{V_R}{Z_c}$$

$$= (e^{j\beta x})\frac{V_R}{Z_c} \quad A$$



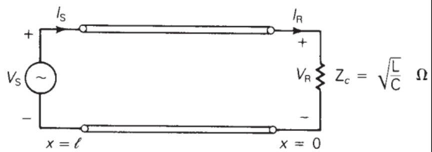
Transmission Line Performance

Surge Impedance Loading - SIL

- At SIL, the complex power in any x point is equal to;

$$S(x) = P(x) + jQ(x) = V(x)I^*(x)$$
$$= (e^{j\beta x}V_R)\left(\frac{e^{j\beta x}V_R}{Z_c}\right)^*$$
$$= \frac{|V_R|^2}{Z_c}$$

- Thus the real power flow along a lossless line at SIL remains constant from the sending end to the receiving end. The reactive power flow is zero.
- If P > SIL then line consumes vars; otherwise line generates vars.



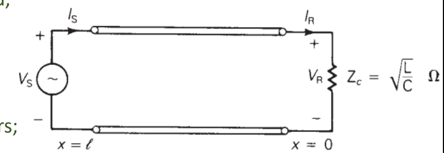
Transmission Line Performance

Surge Impedance Loading - SIL

- At rated line voltage, the real power delivered, or SIL, is

$$SIL = \frac{V_{rated}^2}{Z_c}$$

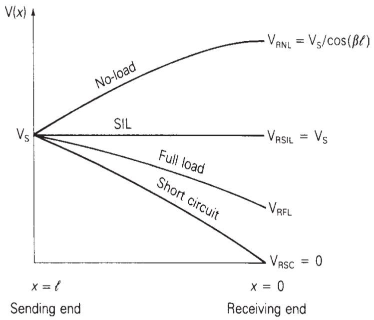
- If P > SIL then transmission line consumes vars; otherwise it generates vars.



Transmission Line Performance

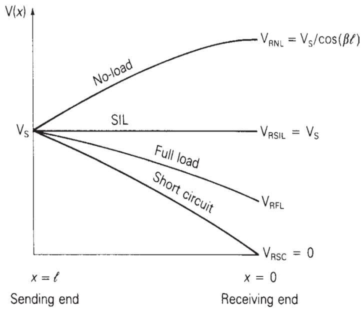
Voltage Profiles

- In practice, power lines are not terminated by their surge impedance.
- Loadings can vary from a small fraction of SIL during light load conditions up to multiples of SIL, depending on line length and line compensation, during heavy load conditions.
- If a line is not terminated by its surge impedance, then the voltage profile is not flat.
- Figure shows voltage profiles of lines with a fixed sending-end voltage magnitude V_S for line lengths l up to a quarter wavelength.



Transmission Line Performance

Voltage Profiles



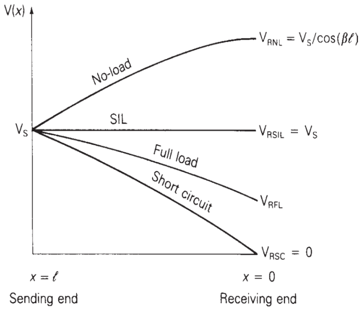
- At no-load, I_{RNL}=0 and

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

The no-load voltage increases from V_S=$V_{NL}(l)$ at the sending end to V_{RNL} at the receiving end (where x=0).

- The voltage profile at SIL is flat.

Transmission Line Performance
Voltage Profiles



- For a short circuit at the load, V_{RSC}=0 and

$$V_{SC}(x) = (Z_c \sin \beta x) I_{RSC}$$

The voltage decreases from $V_S=V_{SC}(l)$ at the sending end to V_{RSC}=0 at the receiving end.

- The full-load voltage profile, which depends on the specification of full-load current, lies above the short-circuit voltage profile.

Transmission Line Performance
Reactive Power Compensation

- Objectives of reactive power compensation are to control voltage and/or improve maximum power transfer capability.
- Achieved by modifying effective line parameters:
  - Characteristic impedance
  - Propagation constant
- The voltage profile is determined by Z_C
- The maximum power that can be transmitted depends on Z_C as well as β.
- There are two main reactive power compensation technique;
  - Shunt Compensation
  - Series Compensation

Transmission Line Performance
Reactive Power Compensation

Shunt Reactors

- Used to compensate the undesirable voltage effects associated with line capacitance and limit voltage rise on open circuit or light load.
- Shunt compensation with reactors increases effective Z_C and reduces SIL.
- They are connected directly to the lines at the ends.
- In very long lines, at least some reactors are required to be connected to lines

Transmission Line Performance
Reactive Power Compensation

Shunt Capacitors

- Used in transmission systems to compensate for I^2X losses
- Normally distributed throughout the system so as to minimize losses and voltage drops.
- Shunt capacitor compensation of transmission lines in effect
  - decreases Z_C
  - increases propagation constant
- Advantages: low cost and flexibility of installation and operating.
- Disadvantages: Q output is proportional to square of the voltage; hence Q output reduced at low voltages.
- Shunt capacitors are used extensively in subtransmission or distribution systems for power factor correction and feeder voltage control.

Transmission Line Performance

Reactive Power Compensation

Series Capacitors

- Connected in series with the line
- Used to reduce effective inductive reactance of line and reduces I^2X losses.
- Series capacitive compensation in effect reduces both:
  - characteristic impedance Z_C
  - Propagation constant
- Reactive power produced increases with increasing power transfer so it has self regulating ability.

Examples

Example 1

A three-phase, 60-Hz, completely transposed 345-kV, 200-km line has two 795,000-cmil (403-mm^2) 26/2 ACSR conductors per bundle and the following positive-sequence line constants:

$$z = 0.032 + j0.35 \quad \Omega/\text{km}$$

$$y = j4.2 \times 10^{-6} \quad \text{S/km}$$

Full load at the receiving end of the line is 700 MW at 0.99 p.f. leading and at 95% of rated voltage. Assuming a medium-length line, determine the following:

a. *ABCD* parameters of the nominal π circuit

b. Sending-end voltage V_S, current I_S, and real power P_S

c. Percent voltage regulation

d. Transmission-line efficiency at full load

Examples

Example 2

A 50 Hz transmission line 300 km long has a total series impedance of 40 + j125 ohms and a total shunt admittance of 10^{-3} mho. The receiving-end load is 50 MW at 220 kV with 0.8 lagging power factor. Find the sending-end voltage, current, power and power factor using

(a) short line approximation,

(b) nominal-π method,

(c) exact transmission line equation

Examples

Example 3

A three-phase, 60-Hz, 500-kV transmission line is 300 km long. The line inductance is 0.97 mH/km per phase and its capacitance is 0.0115 μF/km per phase. Assume a lossless line.

(a) Determine the line phase constant β, the surge impedance Z_C,

(b) The receiving end rated load is 800 MW, 0.8 power factor lagging at 500 kV. Determine the sending end quantities and the voltage regulation.