31730: Electric Power Engineering, fundamentals

Transmission Lines

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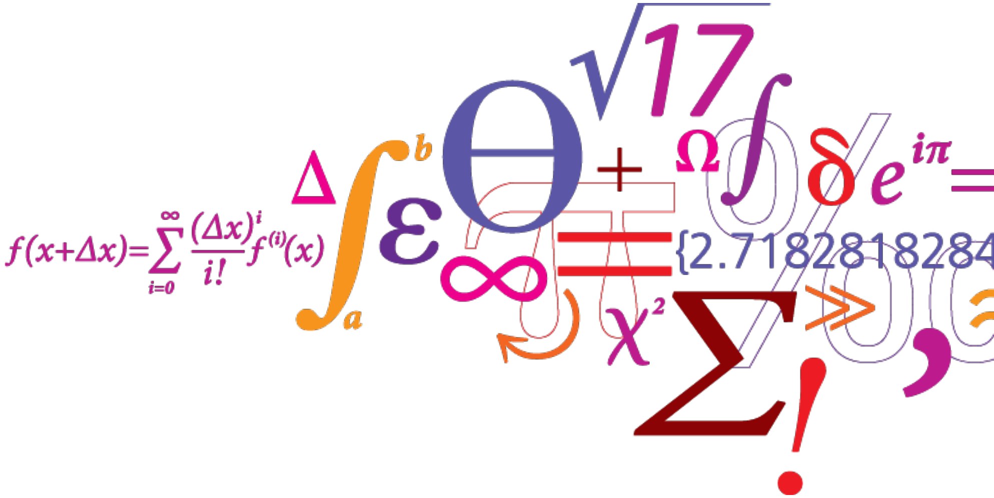

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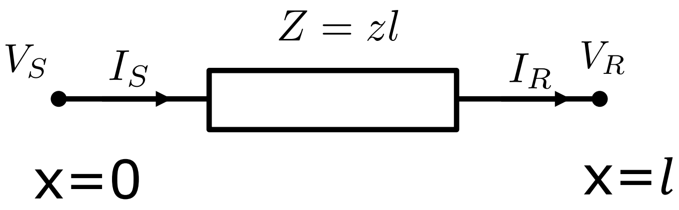
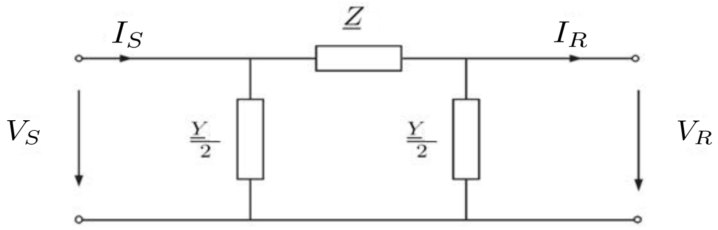
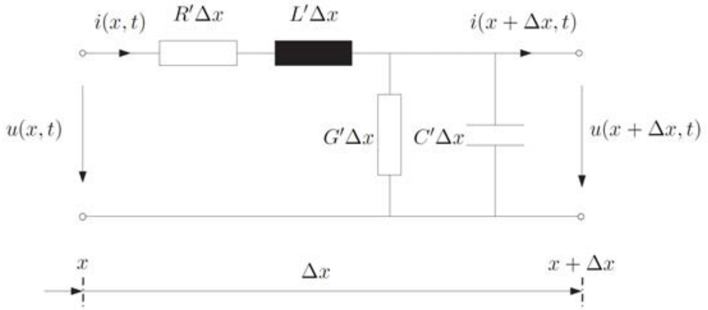
Line Models







$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

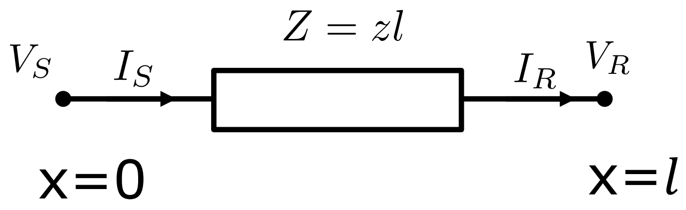
$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} 1 + \frac{YZ}{2} & Z \\ Y\left(1 + \frac{YZ}{4}\right) & 1 + \frac{YZ}{2} \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} \cosh(\gamma l) & Z_c \sinh(\gamma l) \\ \frac{1}{Z_c} \sinh(\gamma l) & \cosh(\gamma l) \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$$Y = 0$$

$$\gamma l << 1$$

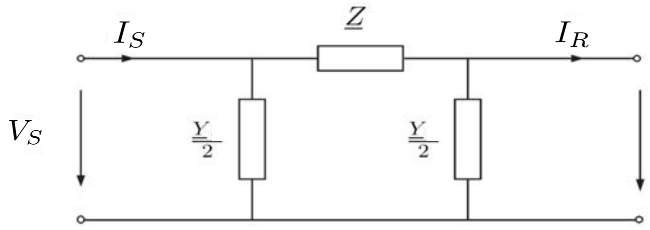
Line Models



$l \leq 25$ km

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

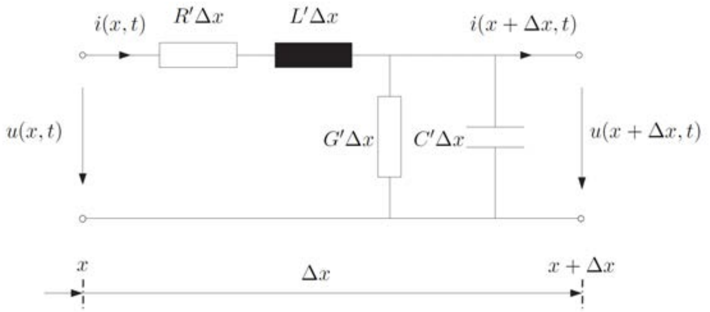
$Y = 0$



$l \leq 250$ km

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} 1 + \frac{YZ}{2} & Z \\ Y\left(1 + \frac{YZ}{4}\right) & 1 + \frac{YZ}{2} \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$\gamma l << 1$



$l > 250$ km

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} \cosh(\gamma l) & Z_c \sinh(\gamma l) \\ \frac{1}{Z_c}\sinh(\gamma l) & \cosh(\gamma l) \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

- How much is the surge impedance of a lossless line?

- What happens when we connect at the end of the line a load equal to the surge impedance of the line?

Surge impedance loading

- How much is the surge impedance of a lossless line?

- The surge impedance of a lossless line is pure resistive

$$Z_c = \sqrt{\frac{L}{C}}$$

- At surge impedance loading the power line is in a state of **reactive power balance**
  - Series inductances consume the same amount of reactive power as the shunt capacitances produce
  - Reactive power consumed on series inductance: dependent on current through the line
  - Reactive power consumed on shunt capacitance: dependent on voltage at line ends

Reactive power demand of a line

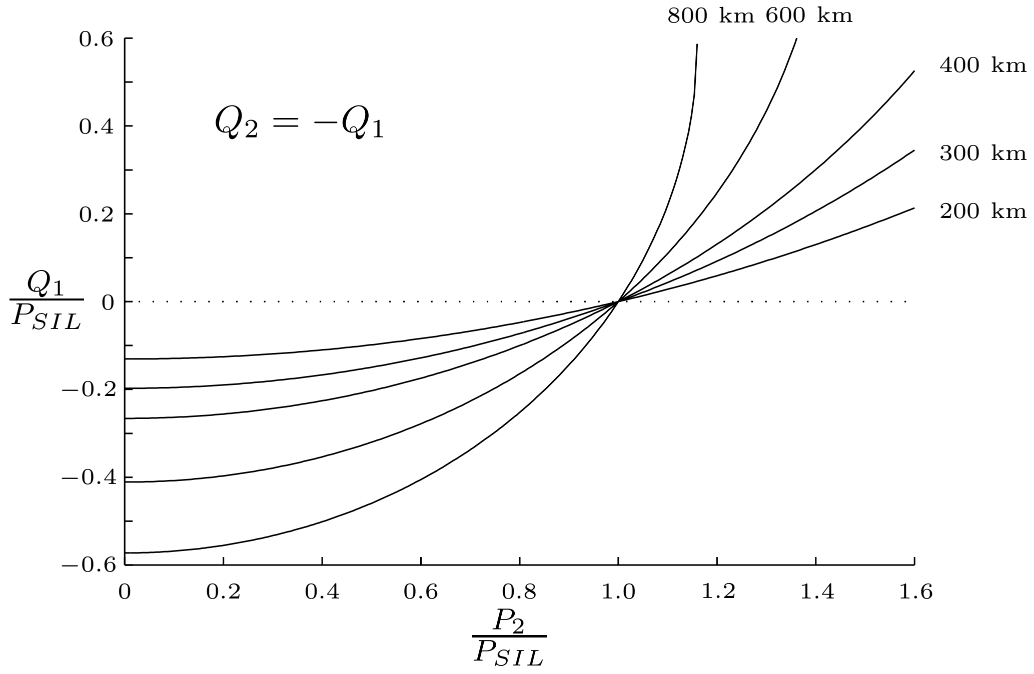


Figure 6.3. The reactive power demand at the beginning of the line, as a function of the active power at the end of the line ($U_1 = U_2$, lossless line).

Figure taken from:
G. Andersson and C. Franck, Electric Power Systems,
Lecture Notes, ETH Zurich, 2013

Voltage Profiles

FIGURE 5.10

Voltage profiles of an uncompensated lossless line with fixed sending-end voltage for line lengths up to a quarter wavelength

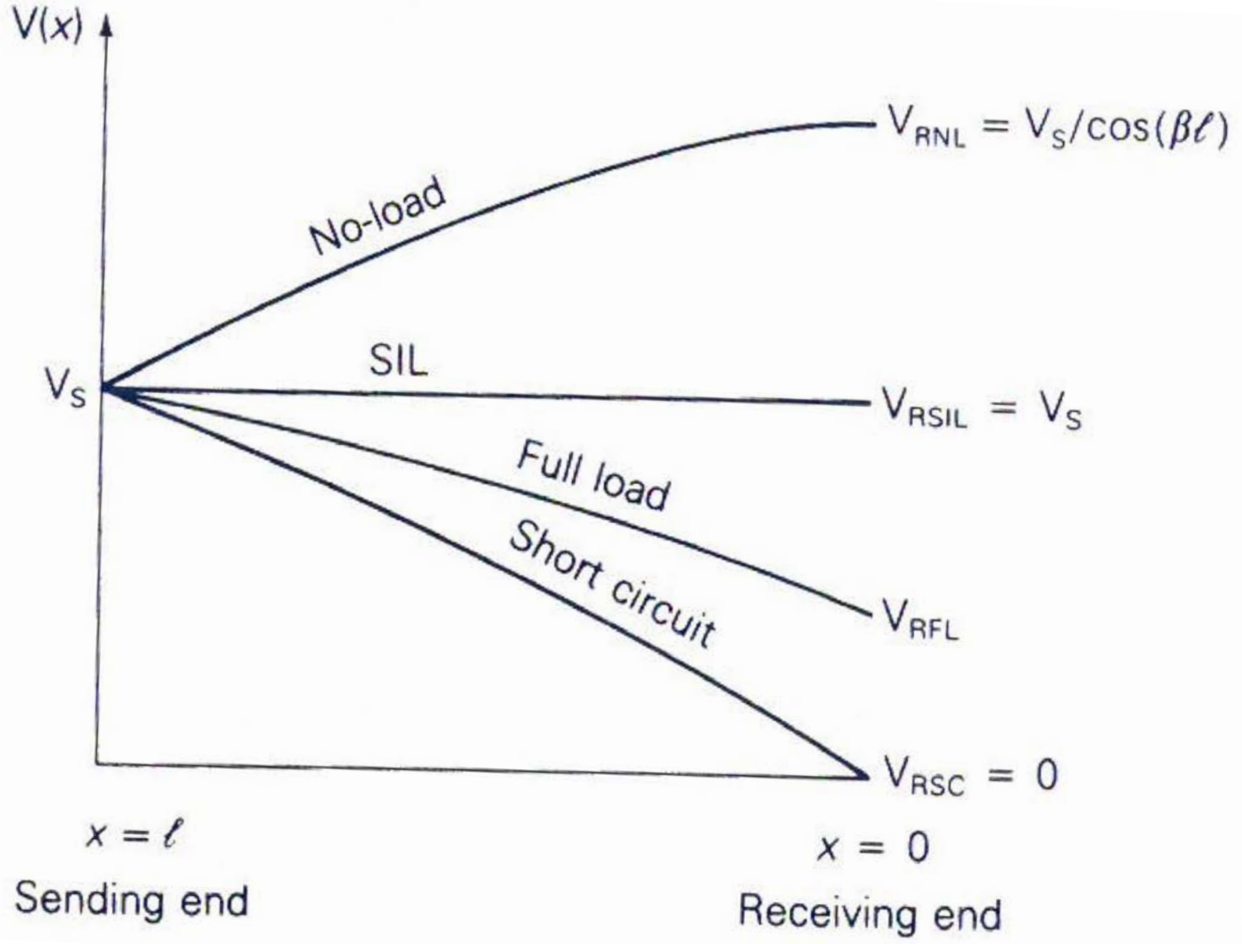
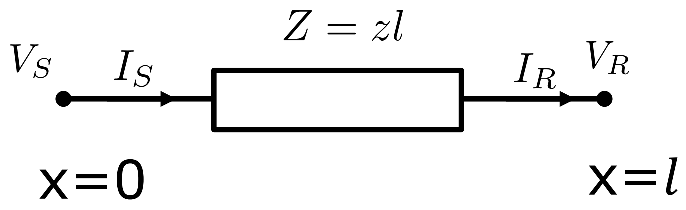


Figure taken from:
J. Glover, T. Overbye, M. Sarma, Power System Analysis and Design,
Cengage Learning, Sixth Edition, 2016

Voltage at the beginning of the line for different power factors



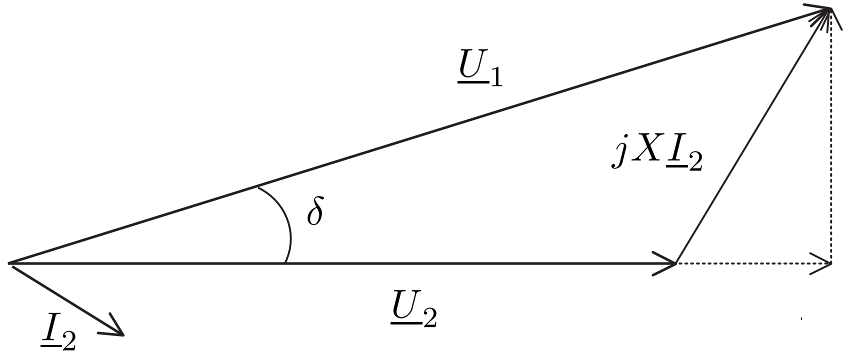


Figure 6.7. Simplified relation between the phasors $\underline{U}_1$ and $\underline{U}_2$.

- The above diagram shows the voltage and current phasors for an inductive load (lagging power factor) and a line modelled as a series inductance
- Draw the phasor diagrams and describe what happens with the voltage angle and magnitude for:
  1. cosφ = 1
  2. $P=P_{SIL}$ (here you must use the exact parameters/equations for the lossless lines)
  3. cosφ : leading

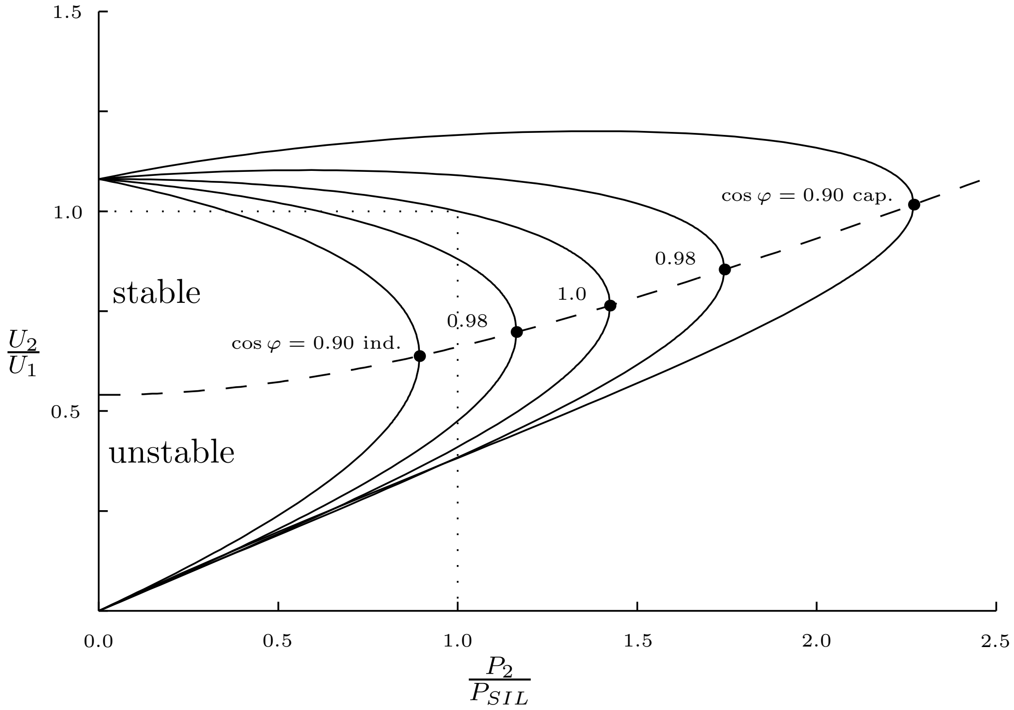


Figure 6.10. Voltage at the end of the line as a function of the delivered active power for different line loadings. U_1 is kept constant at 1.0 pu.

Figure taken from:
G. Andersson and C. Franck, Electric Power Systems,
Lecture Notes, ETH Zurich, 2013

Steady-state stability limit

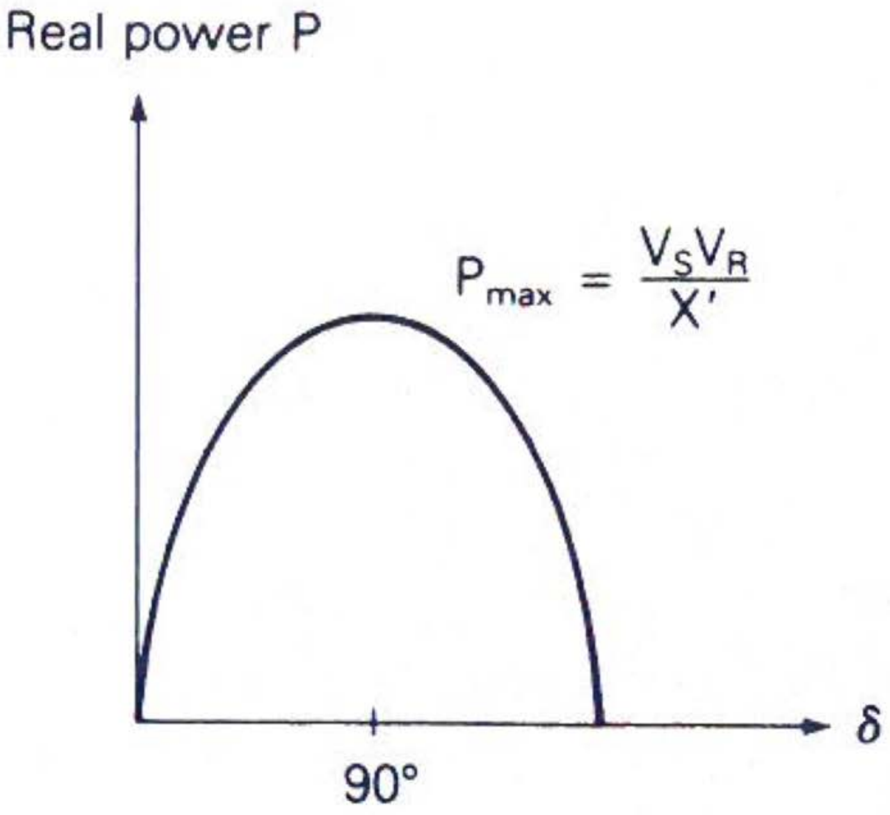


FIGURE 5.11

Real power delivered by a lossless line versus voltage angle across the line

Figure taken from:
J. Glover, T. Overbye, M. Sarma, Power System Analysis and Design,
Cengage Learning, Sixth Edition, 2016

Line Loadability

FIGURE 5.12

Transmission-line loadability curve for 60-Hz overhead lines—no series or shunt compensation

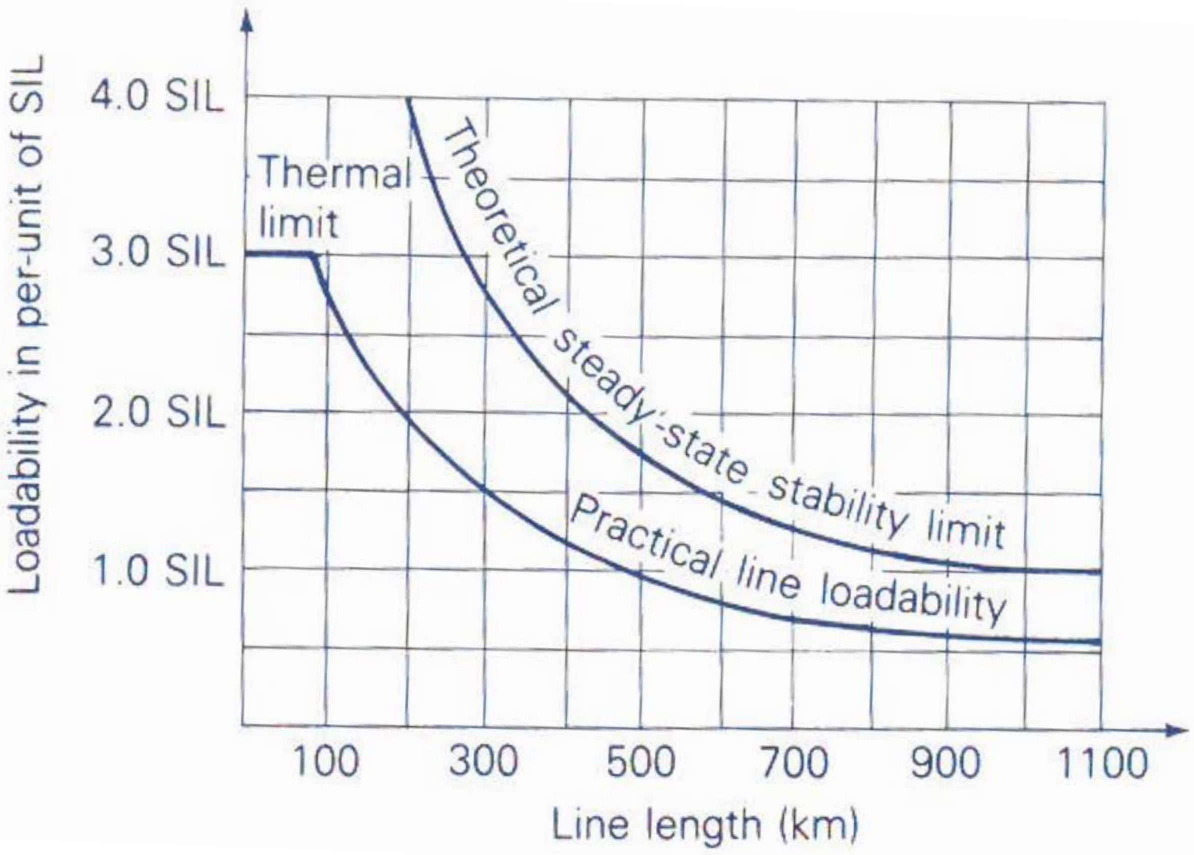


Figure taken from:
J. Glover, T. Overbye, M. Sarma, Power System Analysis and Design, Cengage Learning, Sixth Edition, 2016

Shunt Reactive Compensation

- You are given:
  1. Nominal voltage at full load conditions
  2. Current at full load conditions

- You need to determine
  - Nominal voltage at sending end
  - Percent voltage regulation at no-load conditions
  - Shunt reactive compensation to stay within limits