ECE 325 – Electric Energy System Components
5- Transmission Lines

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Fall 2016
(Materials are from Chapter 25)

• Overview of power lines

• Equivalent circuit of a line

• Voltage regulation and power transmission of transmission lines
Overview

• Types of transmission lines
  – Overhead lines
  – Underground Cables (less than 1%)

• Properties
  – Series Resistance (stranding and skin effect)
  – Series Inductance (magnetic & electric fields; flux linkages within the conductor cross section and external flux linkages)
  – Shunt Capacitance (magnetic & electric fields; charge and discharge due to potential difference between conductors)
  – Shunt Conductance (due to leakage currents along insulators or corona discharge caused by ionization of air)

• Line-to-line voltage levels
  – 69kV, 115kV, 138kV and 161kV (sub-transmission)
  – 230kV, 345kV, and 500kV (EHV)
  – 765kV (UHV)
Overhead Transmission Lines

Shield wires (ground wires) are ground conductors used to protect the transmission lines from lightning strikes.
Overhead Transmission Lines

- Many strands to reduce series resistance
- Materials
  - AAC (All Aluminum Conductor),
  - AAAC (All Aluminum Alloy Conductor)
  - ACSR (Aluminum Conductor Steel Reinforced)
  - ACAR (Aluminum Conductor Alloy Reinforced)
  - ACCC (Aluminum Conductor Composite Core)
- Why not copper?
  - Relative lower costs and higher strength-to-weight ratios than copper
- Bundled conductors to reduce series reactance
  - Preferred for high voltages, e.g. 2-conductor bundles for 230kV, 3-4 for 345-500kV, and 6 for 765kV
**Equivalent circuit of a transmission line**

\[ GMR_L \text{ or } GMR_C \]

\[ GMD \]

\[ GMRL \text{ or } GMRC \]

\[ L \propto \ln \frac{GMD}{GMR_L} \]

\[ C \propto \ln \frac{GMR_C}{GMD} \]

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**Figure 25.13**
Distributed impedance of a transmission line.

**Figure 25.14**
Equivalent lumped circuit of a transmission line.

- \( R = r \times N, \ X_L = x_L \times N, \ X_C = x_C / N \): With the increase of \( N \) (i.e. the length of the line), \( R \) and \( X_L \) increase but \( X_C \) decreases.
- For HV lines, \( R << X_L \)

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**TABLE 25C**
TYPICAL IMPEDANCE VALUES PER KILOMETER FOR 3-PHASE, 60 HZ LINES

<table>
<thead>
<tr>
<th>Type of line</th>
<th>( x_L [\Omega] )</th>
<th>( x_C [\Omega] )</th>
</tr>
</thead>
<tbody>
<tr>
<td>aerial line</td>
<td>0.5</td>
<td>300 000</td>
</tr>
<tr>
<td>underground cable</td>
<td>0.1</td>
<td>3 000</td>
</tr>
</tbody>
</table>

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Simplifying the equivalent circuit

\[ R = r \times N, \quad X_L = x_L \times N, \quad X_C = x_C / N \]

HV lines: \( R \ll X_L \)

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**Figure 25.17**
Active and reactive powers of a transmission line.

**Figure 25.18**
Equivalent circuit of a short LV line.

**Figure 25.19**
Equivalent circuit of a long HV line.
Example 25-3

\[ r = 0.065 \ \Omega/km \]
\[ x_L = 0.5 \ \Omega/km \]
\[ x_C = 300 \ k\Omega \cdot km \]

\[ R = 0.065 \times 50 = 3.25 \Omega, \quad X_L = 0.5 \times 50 = 25 \Omega \]
\[ X_C = 300,000/50 = 6k\Omega, \text{ so } 2X_C = 12k \ \Omega \]

Note \( X_C = 480X_L \) and \( X_L = 7.7R \)

Consider one phase:
\[ P = 300/3 = 100MW \]
\[ |E| = 230/\sqrt{3} = 133kV \]
\[ |I| = 100MW/133kV = 750A \]
\[ P_J = |I|^2R = 1.83MW = 0.0183P \]
\[ Q_L = |I|^2X_L = 14.1Mvar \]
\[ Q_C = |E|^2/X_C = 3Mvar \ll Q_L \]