Department of Electrical and Computer Engineering

Transmission Line Models

Presenter: Udoka Chile Nwaneto

Course instructor: Seyed Pouyan (Yani) Jazayeri

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Outline

- Lecture 1:
  - Review of lectures on transmission line parameters
  - Representation of transmission lines
  - The short transmission line model
  - Voltage regulation
  - In-class example
  - The medium transmission line model (if we have time)
- Lecture 2:
  - Review of lectures on short line and medium line models
  - The long transmission line model
  - Equivalent pi-model

- Lecture 3:
  - Review of lectures 1 and 2.
  - Peer grading
  - Tutorial

Lecture 1

Review of lectures on transmission line parameters

- We are interested in knowing how to leverage the line parameters we calculated last week to model a transmission line.
- We will first discuss about charging current and then review transmission parameters by answering quick questions
- Afterwards, we will introduce short line models, voltage regulation, and if time permits, medium line models.

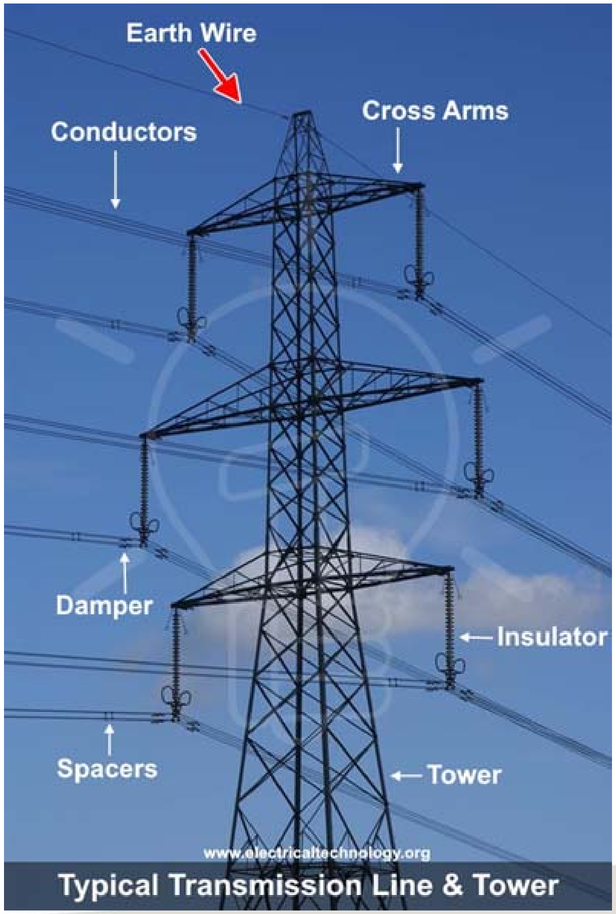

Fig. 1. A transmission tower supporting an overhead line [credit: www.electricaltechnology.org]

Quick Questions ????

Quick question 1: *Imagine as a third year engineering student, you are contracted by AESO to design a transmission line. Then, a Business Manager in AESO decides to ask you to name parameters of a transmission line and also state the parameters that are usually considered in transmission line design. What will be your response?*

Answer:

(a) Four parameters of a transmission line are resistance, inductance, capacitance and conductance.
(b) Resistance, inductance and capacitance are the parameters usually considered.

Quick question 2: *How do we keep the leakage current very negligible in overhead transmission lines?*

Answer:

First, for very high voltage lines, the conductors are bundled in order to reduce corona loss. Also, the insulators supporting the conductors are usually designed to have many ‘insulator skirts” or high insulation strength to minimize leakage currents during adverse weather conditions.

Quick question 3: *Is there any limit to the extent we can go in increasing the area of a conductor in order to accommodate larger amounts of current?*

Answer:

Yes, there is a limit. For AC overhead lines, increasing the area of one conductor might not result in increased current-carrying capacity because skin effect reduces the effective area of the conductor. To alleviate this problem, bundling of conductors or making the transmission line a double-circuit type are the two methods used to increase the current-carrying capacity (or ampacity) of a transmission line.

Quick question 4: *What if the line conductors are not symmetrically aligned, will the phase inductances be equal? If the phase inductances are not equal, what will be the effect on voltage across each phase even with balanced currents?*

Answer:

(a) If the line conductors are not symmetrically aligned, the phase inductances will not be equal due to unequal distances between phase conductors.

(b) Even if the current in the three phases are equal, the voltage drop due to line inductance will be unequal for the three phases.

Quick question 5: *For an n-phase transmission line of length l, with unsymmetrically aligned conductors, what is the distance between two points along the line where transposition is performed?*

Answer:

The distance between two points along the transmission line where transposition is performed is given by $= \boldsymbol{l/n}$. For a three-phase line, it is $\boldsymbol{l/3}$

Quick question 6: *What are the benefits of using (i) stranded conductors (ii) bundled conductors, in transmission lines?*

Answer:

(a) Stranding conductors increases its flexibility which consequently permits easy bending and transportation. In addition, it permits larger cross-sectional area.

(b) Bundling conductors reduces the line reactance which leads to improved line power transfer capability. It also reduces voltage gradient around the conductor surface and this leads to lower corona loss, radio interference and surge impedance.

Quick question 7: A drake conductor with the following parameters: *R* per conductor = 0.15 ohm/km, ampacity per conductor = 800 A, is used to construct a three-phase transmission line feeding a load at Fort Hills. If each phase of the transmission line has three-conductor bundle, calculate the equivalent resistance of each bundle as well as the bundle's ampacity.

Answer:

Since the conductors in a bundle are linked by spacers, they are connected in parallel. For parallel-connected conductors, the total ampacity (or current carrying capacity) per phase is equal to the **product of number of conductors per bundle and the ampacity of each conductor.** Thus ampacity of the three conductor bundle is: $800 \times 3 = 2400\ \mathrm{A}$

The equivalent resistance of the bundle can be found by **treating the conductors in the bundle as parallel-connected resistors.** For this question, the equivalent resistance is $\frac{0.15\frac{\Omega}{\mathbf{km}}}{3} = 0.05\,\frac{\Omega}{\mathbf{km}}$.

Quick question 8: *Why is the capacitance per phase for a three phase line is twice the capacitance calculated for a single phase line assuming they have the same dimensions?*

Answer:

The reason is that for a three phase line, the capacitance per phase is calculated to be the capacitance due to voltage difference between a conductor and the neutral point. However, for single-phase lines, the capacitance per phase is essentially line-to-line capacitance and it is determined by calculating the potential difference between the two conductors. In order to get line-to-line capacitance in a three phase line, we have to combine two capacitance per neutral in series. When we do that, recall that the total capacitance C_t for two capacitors in series (let's assume C_a for phase 'a' and C_b for phase 'b') is:

$$C_t = (C_a * C_b)/C_a + C_b)$$

For balanced lines, $C_a = C_b = C$

Thus, $C_t = \frac{C}{2} = \frac{C_a}{2} = \frac{C_b}{2}$ or $C_a = C_b = C = 2C_t$

Quick question 9: *Why do we use r instead of r' (i.e. GMR of a conductor) in calculating capacitance?*

Answer:

The reason is that in conductors, the internal magnetic flux is nonzero so we use r' while calculating inductance. However, in conductors, the internal electric field in zero, thus we use r while calculating capacitance.

Quick question 10: *Is it feasible to transmit power over long distances with an AC underground cable? Note that distance between conductors in underground cables is small.*

Answer:

No, it is not. Recall, that the capacitance per length per phase of a three phase symmetrically-aligned line is given by:

$$C_{an} = 2\pi\epsilon/(\ln\frac{D}{D_{sc}})$$

For underground cables, the geometric mean distance, D between conductors is very small compared to the conductor's geometric mean radius D_{sc}, thus the capacitance of underground cables are much higher than capacitance of overhead lines. Moreover, with increasing length of line, the line capacitance will become much more amplified in value.

Also recall that **charging current** is directly proportional to line capacitance. Therefore, with increased line capacitance in underground cables, **the resulting large charging current** takes up significant capacity of the cable leaving little for actual power transmission. For this reason, AC is not preferred for underground transmission line when the distance is more than 80 km. DC is preferred instead.

In-class example

1. A 60 km three-phase overhead line that draws power from Edmonton Load Centre is used to transmit 1800 MW to a load in Fort McMurray whose power factor is 0.8 lagging. If the voltage at Fort McMurray end is 400 kV at full load and the phase parameters of the line are given as r = 0.0191 Ω/km at 50°C; x_L = 0.25 Ω/km, calculate:

(a) The magnitude of the required sending-end voltage.
(b) Voltage regulation of the line.

Before solving the question, do you expect the sending-end voltage to be larger than the receiving end voltage or not?

Homework

1. An 18 km three-phase overhead line in Calgary Downtown is composed of drake conductors equilaterally spaced. Manufacturer tables list the drake conductor as having a resistance of 0.2357 ohm/km, and an inductive reactance of 0.4139 ohm/km. If the line delivers 2500 kW at 11 kV to a balanced star-connected load at Suncor Towers, determine

(a) The per-phase series impedance of the line.

(b) The sending-end voltage when the load power factor is 0.9 lagging.

(c) The percent voltage regulation of the line

Redo the (b) and (c) when the power factor is 0.9 leading and unity.

2. Assess your learning by reflecting on what you understood clearly during the lecture and things you would like the instructor to clarify more on in the next class

Please come with a hard copy of your homework when coming for the next lecture

Lecture 2

Review of last lectures

Quick question 11:

(a) Name the line parameters usually considered for the short line model? Why are other parameters neglected for the short line model?
(b) Name the line parameters used in modeling medium transmission lines? Are these parameters considered lumped or distributed?

Answer:

(a) Resistance and Inductance. Capacitance is neglected because as the short lines are usually less than 80 km, the line charging current is small and thus can be neglected.
(b) The parameters considered for medium lines are resistance, inductance and capacitance. The parameters are considered lumped.

Quick question 12:

(a) What happens to the percent V.R. when the load power factor is lagging?
(b) What happens to the percent V.R. when the load power factor is leading?
(c) Do electricity utility operators (e.g. AESO, ENMAX) prefer a smaller or larger value for the percent voltage regulation?

Answer:

(a) The percent V.R. will become larger
(b) The percent V.R. will become smaller
(c) Electricity utility operators prefer smaller percent V.R. as it entails lesser voltage drop (and by extension power loss) occurs along the line. It is for this reason that utility operators incentivize people with lower power factor equipment to install capacitors to improve their power factor.

Quick question 13: *Do the ABCD constants for a medium line satisfy the equation: AD-BC=1?*

Answer:

For a medium line, the ABCD constants are as follows:

$$A = D = 1 + (YZ)/2; \quad B = Z; \; C = Y(1 + \frac{YZ}{4})$$

Then, $AD - BC$ is given by:

$$AD - BC = \left(1 + \frac{YZ}{2}\right)\left(1 + \frac{YZ}{2}\right) - ZY(1 + \frac{YZ}{4})$$

$$= 1 + YZ + (\frac{YZ}{2})^2 - YZ - (\frac{YZ}{2})^2$$

Thus, $AD - BC = 1$ Proved.