Lecture 6

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September 26, 2024

- Considering a network consisting of a generator, connected to a transmission network, with a distribution network:
  - The distribution network is generally low (or lower) voltage area
  - Distribution networks are generally connected by voltage drop-down transformers
  - Regulators are implemented — essentially transformers with really small turn radii

$$\alpha \cong 10 - 100$$

    * Where α is the turns ratio
  - For a regulator, we may write:

$$V_{a'n} = V_{an} + \Delta V_{an}$$

  - There will be a slight phase offset, which may be written as:

$$\hat{V}_2 = \hat{a}\hat{V}_1 = \hat{V}_1 e^{j\phi}$$

    * Where the exponential term is called a "phase shifter"
  - A phase shifter may be drawn as follows:

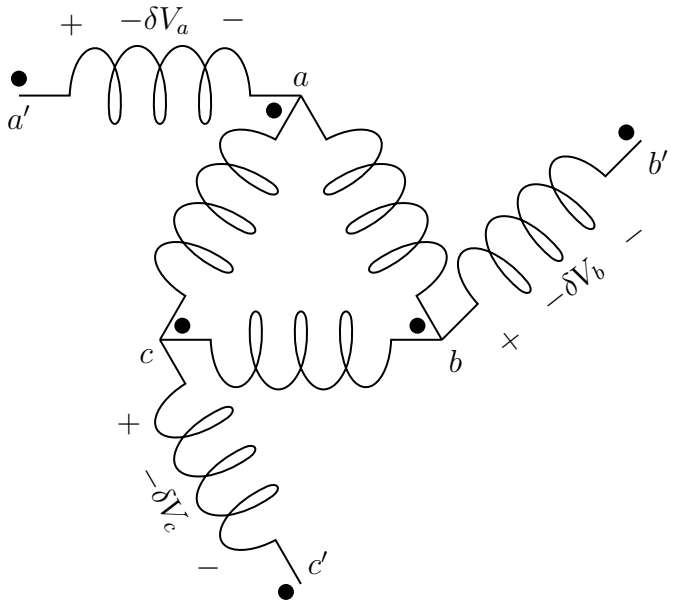

Figure 1: Phase Shifter Schematic

  - Dots added to transformer diagrams indicate that certain points are at the same phase, and show orientations of windings
  - Phase shift is determined by turns ratio → small turns ratio, small shift, and vice versa (usually at most a few degrees)
  - Note that the turns ratio acts as a "valve" which can switch reactive power flow from one transformer to the next (for regulators)
    * Higher turns in the second transformer would result in higher reactive power
  - The same "valve" logic applies to phase shifters; however, instead of affecting the reactive power this affects real power
  - In summary: Phase shifter used to change phase and modify real power flow, while regulators modify reactive power flow

- Nominal Tap Transformer:
  - Modeled by:

$$\begin{bmatrix} i_k \\ i_m \end{bmatrix} = \begin{bmatrix} y_t & -y_t \\ -y_t & y_t \end{bmatrix} \begin{bmatrix} V_k \\ V_m \end{bmatrix}$$

    * Where:

$$y_t = \frac{1}{r + jx_t}$$

- Off-Nominal Tap Transformer:
  - Modeled by:

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} y_t/a^2 & -y_t/a \\ -y_t/a & y_t \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

  - Note that, by setting $a \to 1$, we are essentially returning to a nominal tap transformer, as the regulator component is eliminated
  - Can be thought of as a regulating transformer equivalent circuit in per-unit