ECE 524

TRANSIENTS IN POWER SYSTEMS

SESSION no. 30
Steady-state models

Z' = L

- Short
  - Medium line model
    - with correction factors
    - for steady-state traveling wave effects

Z'' = \frac{Z}{2}

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Sequence components

\[ A_{12} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \]

convert to sequence domain

\[ A_{12}^{-1} \begin{bmatrix} R_{12} \end{bmatrix} A_{12} \]

\[ \begin{bmatrix} R_0 & 0 & 0 \\ 0 & R_1 & 0 \\ 0 & 0 & R_2 \end{bmatrix} \]

similar to \( L_{12} \) and \( C_{12} \)

either per length or total for line

\[ R_{ABC} = \begin{bmatrix} R_{AA} & R_{AB} & R_{AC} \\ R_{BA} & R_{BB} & R_{BC} \\ R_{CA} & R_{CB} & R_{CC} \end{bmatrix} \]

\( L_{ABC}, C_{ABC} \) small if untransposed
\[ [Z_{01z}] = [R_{01z}] + j\omega [L_{01z}] = \left( R_0 + jx_0 \right) Z_0 \begin{bmatrix} Z_{01} & Z_{02} \\ Z_{10} & R_1 + jx_1 & Z_{12} \\ Z_{20} & Z_{21} & R_2 + jx_2 \end{bmatrix} \]

Voltage steps across line:

\[ \begin{bmatrix} V_0 \\ V_1 \\ V_2 \end{bmatrix} = [Z_{01z}] \begin{bmatrix} I_0 \\ I_1 \\ I_2 \end{bmatrix} \]

Coupling terms between sequence components:

\[ A B C = \begin{bmatrix} A \\ B \\ C \end{bmatrix} \]
For transient analysis

1. Step 1 = get line model
   \[ Z_{ABC}, Y_{ABC} \]
   \[ R, L, C_{ABC}, C_{AB} \]

2. \( \rightarrow \) convert to sequence components
   \( \text{Pos., Neg., Zero} \)
   \( \rightarrow \) create modal domain model on coupled pi

3. Do steady state analysis to test model accuracy
   \( \rightarrow \) model in phase program
   \( \rightarrow \) model in your transients program
→ Simple power flow cases
- A few fault cases (SLG, LL, DLG at one or two locations)

→ If the steady-state results match then can go on to transient cases

If remote end open, or light loaded (radial) \(|v_{rl}| \geq |v_s|\)

\[
\begin{align*}
V_s & \rightarrow I = 1 \angle 90^\circ \\
V_r & \rightarrow I_r = \\
V_t & \rightarrow I_c = 
\end{align*}
\]
\[ \vec{V}_R = \vec{V}_S - \frac{\omega}{\omega (jX_L)} = \vec{V}_S + - 1 \|I\| X \cdot \angle 90^\circ + 90^\circ \]

\[ |I| L 90^\circ = \vec{V}_S + 1 |I| X \]

\[ |V_R| > |V_S| \Rightarrow \text{often referred to as Ferranti effect} \]

\[ \text{Ferranti Voltage rise} \]

\[ V_1 \]

\[ 0 \quad \text{distance} \quad d \]
\[ Q_{cap} = V^2 \gamma \]

\[ Q_{line} = I^2 X_L \text{ (pu)} \]
Sending end voltages

- Phases B and C show a zero mode response (same voltage on each).

Receiving end voltages:

- Note effect of two different propagation times for ground and line mode.
- Current

![Graph of Current](image)

Close 1 phase, with load 3 phase short.....

- Sending end currents:

![Graph of Sending end currents](image)
Voltages at sending end of the line when energize open circuited line:
- Energize line
- Then clear it
- Then reclose

The transient voltages in the trapped charge are largely due to residual effects of the initial closing transient.

And a receiving end

Note the larger transients for the reclose

Initial transient reclose into trapped charge
Options to Reduce Inrush

- Controlled breaker pole closing
- Pre-insertion resistor, bypass after a few travel times
- Secondary transient (small) when bypass
- Single phase case: size \( R = Z_c \)
- No reflection for return waves
  1. Voltage divider - apply 50% of voltage to the input of the line
  2. Reduces voltage and current
- Resistor sized for current loading and dissipation
- How about three phase line:
  1. Ideally size for the first line mode,
  2. Some mismatch if do single pole reclosing
  3. Many utilities just use one standard size resistor, rather than optimize for each line.
  4. Not ideal, but eliminates most of the transient