ECE 523: Homework #1

Due Session 6 (Sept. 7)

1. Sketch a per phase, per unit equivalent circuit for the system below. Use a system MVA base of 100MVA, and a voltage base of 220 kV on the high voltage transmission line section.

Using the following equipment nameplate data:

G1: 50 MVA, 13.8 kV, X = 15%
G2: 25 MVA, 14.4 kV, X = 15%
T1: 60 MVA, 13.8 : 230 kV, X = 10%
T2: 30 MVA, 230 : 13.8 kV, X = 10%
Line 1: 10 + j100 Ohm
Line 2: 5 + j50 Ohm
Line 3: 5 + j50 Ohm
Load: 75 MVA, 0.9pf lagging

2. A three-phase generator feeds three large synchronous motors over a 16km, 115kV transmission line, through a 115kV:13.8kV transformer bank, as shown below.
   (a) Draw a per unit, per phase equivalent circuit with all reactances indicated in per unit on a 100 MVA base and 13.8kV or 115kV base.

   (b) The generator is controlled to maintain the voltage at the motor bus at 1.0pu at an angle of 0 degrees. The three motors are operating at full rating and 90% PF lagging. Determine the voltage required at the generator terminals assuming that there is no voltage regulating taps or similar equipment in this system.

   (c) Calculate the voltage required behind the subtransient reactance for the generator and each of the motors

   (d) Calculate the line current in Amperes
3. Draw the per unit, Thevenin equivalent circuit for the system below looking out from the load bus if:

(a) The generator internal voltages are equal in magnitude and angle (label both as $E_1$ and present your results as a function of $E_1$)

(b) The generator internal voltages are not equal (label one as $E_1$ and the other $E_2$ in your solution, and present your results as a function of $E_1$ and $E_2$)

Impedance values (all on consistent bases, no change of base needed):

G1: $X = 0.1$ pu
G2: $X = 0.1$ pu
Line 1: $X = 0.1$ pu
Line 2: $X = 0.1$ pu
Load: $Z = j 0.1$ pu
Often people neglect load in fault studies.

**Reasoning**

1. Load current small compared to fault currents.
2. Difficult to get up to date values to be exact.
- Fixed loads at a given location

\[ Z \rightarrow \begin{align*}
& \cdot \text{Fixed impedance} \\
& \cdot \text{P, Q} \\
& \cdot \text{constant current} \\
& \cdot \text{motor}
\end{align*} \right\} \text{ZIP}

Fault occurs

Fault: Induced Voltage Delayed Recovery

Breaker clears
Phasor Based Fault Analysis

- Load converted to constant
  \[ Z (R + jX \text{ or } R \parallel jX) \]

- Series

- Transients program
Impedance change of base calculation

\[ X_{T1\text{new}} := X_{T1} \left( \frac{V_{T1\text{Low}}}{V_{B1}} \right)^2 \left( \frac{S_B}{S_{T1}} \right) \]

\[ X_{T1\text{new}} = 0.229 \cdot \text{pu} \]

Transformer 2:

\[ S_{T2} := 25 \text{ MVA} \quad V_{T2\text{Low}} := 13.2 \text{kV} \quad V_{T2\text{hi}} := 161 \text{kV} \quad X_{T2} := 0.10 \text{pu} \]

Impedance change of base calculation

\[ X_{T2\text{new}} := X_{T2} \left( \frac{V_{T2\text{Low}}}{V_{B3}} \right)^2 \left( \frac{S_B}{S_{T2}} \right) \]

\[ X_{T2\text{new}} = 0.366 \cdot \text{pu} \]

Load Model

\[ \text{mag} S_{\text{load}} := 45 \text{ MVA} \quad \text{pf}_{\text{load}} := 0.8 \quad \text{lagging} \quad V_{\text{load\text{rated}}} := 161 \text{kV} \]

\[ \phi_{\text{load}} := \cos(\text{pf}_{\text{load}}) \]

\[ \phi_{\text{load}} = 36.87 \cdot \text{deg} \]

\[ S_{\text{load}} := \text{mag} S_{\text{load}} e^{j \phi_{\text{load}}} \quad S_{\text{load}} = (36 + 27i) \cdot \text{MVA} \]

Since the load is wye connected with parallel impedances:

\[ R_{\text{load}} := \frac{(V_{\text{load\text{rated}}}^2)}{\text{Re}(S_{\text{load}})} \]

\[ R_{\text{load}} = 720.028 \Omega \]

\[ X_{\text{load}} := \frac{(V_{\text{load\text{rated}}}^2)}{\text{Im}(S_{\text{load}})} \]

\[ X_{\text{load}} = 960.037 \Omega \]

As a check:

\[ Z_{\text{equivload}} := \left( \frac{1}{R_{\text{load}}} + \frac{1}{j \cdot X_{\text{load}}} \right)^{-1} \]

\[ |Z_{\text{equivload}}| = 576.022 \Omega \quad \text{arg}(Z_{\text{equivload}}) = 36.87 \cdot \text{deg} \]

\[ \bar{S} = \frac{|V|^2}{Z^*} \cdot \frac{R}{Z} \quad S = \bar{V} \bar{I}^{*} = \bar{V}(\frac{V}{Z})^{*} = \frac{V V^{*}}{Z^{*}} = \frac{|V|^2}{Z^{*}} \]
Power flow with angle differences (and magnitude)

Flat: $\vec{V}_1 = 1 \angle 0$

Power flow

$\vec{V}_1 = 1V_1 \angle 0$

Fault

$\vec{V}_c = 1 \angle 0$

$\vec{V}_2 = 1|V_c| \angle 0$
- Shunt Faults
  - We don't necessarily need to represent load flow

  - However, if evaluating an event after it happened.

- Series Faults
Generators

Synch generators

\[ E = x_0 \text{ or } x_1 \]

\[ x_0, x_1 \]

Motor loads

Size of motor

Induction motors

Synchronous motors

Direct connected

\[ x'' \text{ or } x_a \]

1000 HP motor, \( x'' = 0.1 \text{ pu} \)

\[ E \]

\[ 35 \text{ MVA} \]
Adjustable speed drive?
Representing external system

Point of interconnection

System under study

POI, ZTH, VTH often 1.0pu

Neighbor
Data Exchange

1. E-nH on

2. I_{sc} = \frac{x}{1+x} \Rightarrow \frac{n_{d}}{V_{ol}} \Rightarrow \frac{1}{2m}
3. MVA short circuit

\[ V \cdot I_{sc} = V \cdot \frac{V}{|Z_{th}|} = \frac{V^2}{|Z_{th}|} \]

\[ \frac{\text{MVA}_{sc}}{\text{MVA}_{sc}} = \frac{V^2}{|Z_{th}|} \sim 1 \text{pu} \]

3Ø

X/R to get angle of \( Z_{th} \)
\[ \text{MVA} \times \text{SC} = 3 \Phi, \quad \text{MVA} \times \text{SLC} \]

\[ Z_1 \] almost always \[ Z_1 = Z_2 \]

\[ Z \] use to find \[ Z_0 \]

\[ I_0 = \frac{V}{Z_1 + Z_2 + Z_0} \]

\[ \text{MVA} \times \text{SLC} = V \times I_{\text{AF}} \]

\[ I_{\text{AF}} = 3I_0 \]

\[ I_1 = I_2 = I_0 \]
\[ \frac{3V}{\sqrt{3} + Z + Z_0} = \text{MVA}_{\text{sc SLG}} \]

Know from \( \text{MVA}_{\text{sc 50}} \)

Solve for this

\[ \text{MVA}_{\text{sc}} = 10000 \text{ MVA} \]

\[ \text{TO pu using 50} \]

\[ \frac{\text{MVA}_{\text{sc pu}}}{30} = \frac{l^2}{|Z_{TH}|} \]

\[ l = \frac{l^2}{\text{MVA}_{\text{sc pu}}} \]
Symmetrical Components

(Theory)

- Derived in a paper by Fortesque ~ 100 years ago

N-phase system
- Unbalanced set of phases

Superposition:
1. N-1 balanced N-phase sets
2. A single zero sequence set
Example

Node equation for 0, 1, 2

I_{B1} \rightarrow I_{B2} \rightarrow I_{B0}

I_0 \rightarrow I_{A0} \rightarrow I_{A1} \rightarrow I_{A2}

I = 0

I_{B} = I_{B0} + I_{B1} + I_{B2} = 0

I_{C0} = I_{B0} = I_{A0}

I_{C} = I_{C0} + I_{C1} + I_{C2} = 0