# Power System Analysis

## B EE478: Simulation Project #4

**by**

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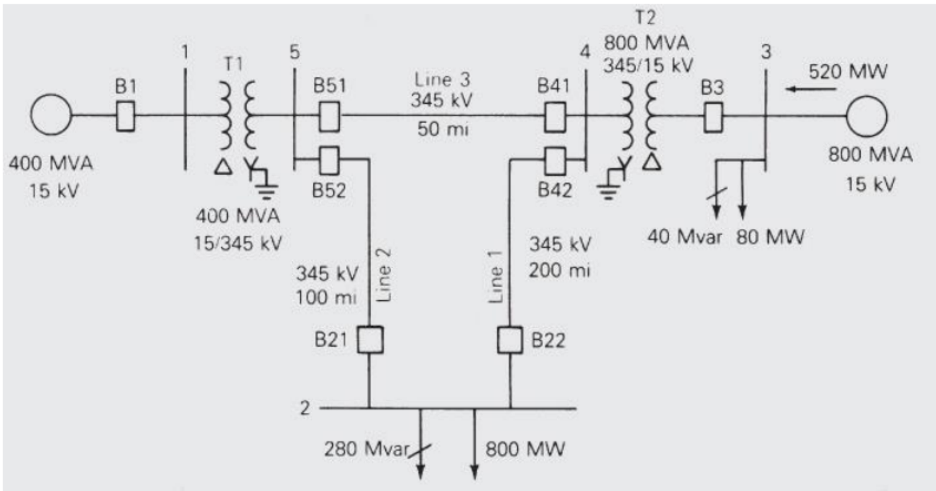
**Lab Due Date: 12/9/2023**

1. **The single line diagram of a five-bus power system is shown below. Machine, line and transformer data are given in the following tables. Note that the neutrals of both transformers and generator 1 are solidly grounded, as indicated by a neutral reactance of zero in Tables 1 and 3. However, a neutral reactance = 0.0025 per unit is connected to the generator 2 neutral. The system is initially unloaded. Prefault voltages at all buses are 1.05 per unit.**




**Single line diagram for the five-bus power system**

**Table 1: Synchronous machine data**

| Bus | $X_0$ per unit | $X_1 = X_d''$ per unit | $X_2$ per unit | Neutral Reactance $X_n$ per unit |
|---|---|---|---|---|
| 1 | 0.0125 | 0.045 | 0.045 | 0 |
| 3 | 0.005 | 0.0225 | 0.0225 | 0.0025 |

**Table 2: Line data**

| Bus-to-Bus | $X_0$ per unit | $X_1 = X_2$ per unit |
|---|---|---|
| L1 (2-4) | 0.3 | 0.1 |
| L2 (2-5) | 0.15 | 0.05 |
| L3 (4-5) | 0.075 | 0.025 |

**Table 3: Transformer data**

| Low-Voltage (connection) bus | High-Voltage (connection) bus | Leakage Reactance Per unit | Neutral Reactance per unit |
|---|---|---|---|
| 1 (Δ) | 5 (Y) | 0.02 | 0 |
| 3 (Δ) | 4 (Y) | 0.01 | 0 |

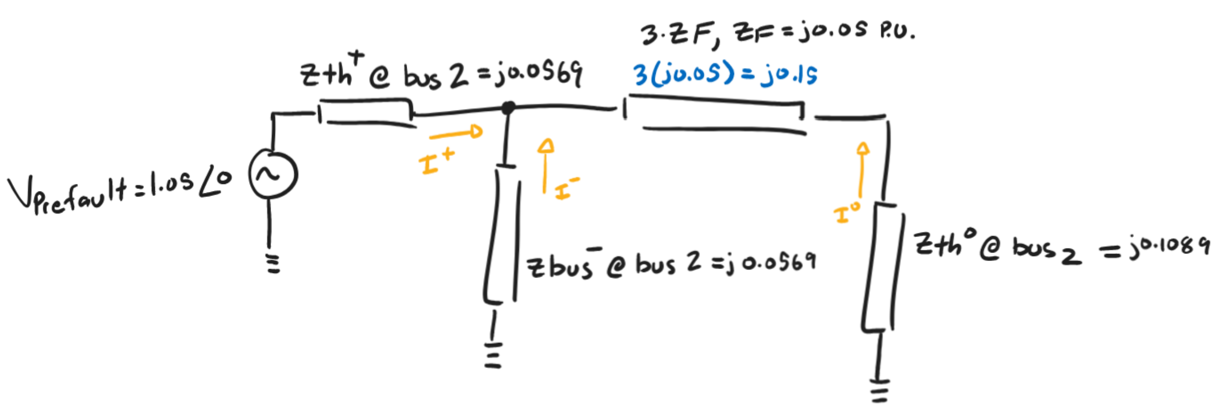
$$S_{base} = 100\ MVA$$

$$V_{base} = \begin{cases} 15\ kV\ at\ buses\ 1, 3 \\ 345\ kV\ at\ buses\ 2, 4, 5 \end{cases}$$

**Answer parts (a) to (d) for a double line-to-ground fault with $zf$ = $j$0.05 $pu$ at bus 2.**

**a) Use the sequence reactance diagrams of part (a) in Simulation Project #2 and determine the Thevenin equivalent of each sequence network as viewed form the fault bus. (20 Points)**

@ Double line to Ground Fault @ bus 2 $\left\{ \begin{array}{l} \text{Condition:} \\ I^0 = I^+ = I^- \\ V^0 - V^+ = (3 \cdot Z_F) I^0 \\ V^+ = V^- \end{array} \right.$




The thevenin from each sequence was calculated from project#2, which is used in the double line to ground fault at bus 2.

**b) Use the sequence Thevenin equivalent networks calculated in part (a) to calculate the sequence components of the fault current. Use the calculated sequence components and the transformation matrix to calculate the phase components of the fault currents. (20 Points)**

@ $I_{F_1}$ Segence

@ $I_{F_2}^{+}$

$$I_F^{+} = \frac{V_{Prefault}}{Z_{th}^{+} + \left[\frac{Z_{th}^{-}(Z_{th}^{0} + 3 \cdot Z_F)}{Z_{th}^{-} + Z_{th}^{0} + 3 \cdot Z_F}\right]}$$

$$I_{F_2}^{+} = \frac{1.05}{j0.0569 + \left[\frac{j0.0569\,\overbrace{[j0.1089 + j0.15]}^{j0.2589}}{\underbrace{[j0.0569 + j0.1089 + j0.15]}_{j0.3158}}\right]}$$

$$I_{F_1}^{+} = \frac{1.05}{\left[j0.0569 \left[\frac{j0.569\,(j0.2589)}{j0.318}\right]\right]} = -j10.14 \text{ P.U.}$$

@ $I_{F_2}^{-}$

$$I_F^{-} = (-I_F^{+})\left[\frac{Z_{th}^{0} + 3 \cdot Z_F}{Z_{th}^{0} + 3 \cdot Z_F + Z_{th}^{-}}\right]$$

$$I_{F_2}^{-} = -(-j10.14)\left[\frac{j0.1089 + (j0.15)}{j0.1089 + (j0.15) + j0.0569}\right]$$

$$I_{F_2}^{-} = j8.313 \text{ P.U.}$$

@ $I_{F_2}^{0}$

$$I_F^{0} = (-I_F^{+})\left[\frac{Z_{th}^{-}}{Z_{th}^{0} + 3 \cdot Z_F + Z_{th}^{-}}\right]$$

$$I_{F_2}^{0} \quad -(-j10.14)\left[\frac{j0.0569}{(j0.1089 + (j0.15) + j0.0569)}\right]$$

$$I_{F_2}^{0} = j1.827 \text{ P.U.}$$

@ $I_{F_1}$ Phase

$$\begin{bmatrix} I_{F_1}^{a} \\ I_{F_1}^{b} \\ I_{F_1}^{c} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} I_{F_1}^{0} = j1.827 \\ I_{F_1}^{+} = -j10.14 \\ I_{F_1}^{-} = j8.313 \end{bmatrix}$$

$$\begin{bmatrix} I_{F_1}^{a} \\ I_{F_1}^{b} \\ I_{F_1}^{c} \end{bmatrix} = \begin{bmatrix} 0 \text{ P.U.} \\ 16.21\angle 170^\circ \text{ P.U.} \\ 16.21\angle 9.7^\circ \text{ P.U.} \end{bmatrix}$$

**c) Use the sequence Thevenin equivalent networks interconnection to calculate the sequence components of the voltage at the faulted bus.**

**Use the calculated sequence components of the voltages and the transformation matrix to calculate the phase components of the voltage at the faulted bus**

@ Zero Seqence

@ $V_n^0(F)$, Fault @ bus 2

$$V_n^0(F) = (Zbus^0)(-I_F^0)$$

$$\begin{bmatrix} V_1^0(F) \\ V_2^0(F) \\ V_3^0(F) \\ V_4^0(F) \\ V_5^0(F) \end{bmatrix} = j\begin{bmatrix} 0.0125 & 0 & 0 & 0 & 0 \\ 0 & 0.1089 & 0 & 0.0043 & 0.0112 \\ 0 & 0 & 0.0125 & 0 & 0 \\ 0 & 0.0043 & 0 & 0.0089 & 0.0021 \\ 0 & 0.0112 & 0 & 0.0021 & 0.0157 \end{bmatrix}\begin{bmatrix} 0 \\ -(j1.827) \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} V_1^0(F) \\ V_2^0(F) \\ V_3^0(F) \\ V_4^0(F) \\ V_5^0(F) \end{bmatrix} = \begin{bmatrix} 0 \text{ P.U.} \\ 0.199 \text{ P.U.} \\ 0 \text{ P.U.} \\ 0.008 \text{ P.U.} \\ 0.020 \text{ P.U.} \end{bmatrix}$$

@ Positive Seqence

@ $V_n^+(F)$, Fault @ bus 2

$$V_n^+(F) = V_{Prefault} + Zbus^+(I_{F_1}^+)$$

$$\begin{bmatrix} V_1^+(F) \\ V_2^+(F) \\ V_3^+(F) \\ V_4^+(F) \\ V_5^+(F) \end{bmatrix} = \begin{bmatrix} 1.05 \\ 1.05 \\ 1.05 \\ 1.05 \\ 1.05 \end{bmatrix} + j\begin{bmatrix} 0.0279 & 0.0177 & 0.0085 & 0.0123 & 0.0204 \\ 0.0177 & 0.0569 & 0.0136 & 0.0197 & 0.0256 \\ 0.0085 & 0.0136 & 0.0182 & 0.0163 & 0.0123 \\ 0.0123 & 0.0197 & 0.0163 & 0.0236 & 0.0177 \\ 0.0204 & 0.0256 & 0.0123 & 0.0177 & 0.0294 \end{bmatrix}\begin{bmatrix} 0 \\ -(-j10.14) \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} V_1^+(F) \\ V_2^+(F) \\ V_3^+(F) \\ V_4^+(F) \\ V_5^+(F) \end{bmatrix} = \begin{bmatrix} 0.870 \text{ P.U.} \\ 0.472 \text{ P.U.} \\ 0.912 \text{ P.U.} \\ 0.850 \text{ P.U.} \\ 0.790 \text{ P.U.} \end{bmatrix}$$

@ Negative Seqence

@ $V_n^-(F)$, Fault @ bus 2

$$V_n^-(F) = Zbus^-(IF_1^-)$$

$$\begin{bmatrix} V_1^-(F) \\ V_2^-(F) \\ V_3^-(F) \\ V_4^-(F) \\ V_5^-(F) \end{bmatrix} = j \begin{bmatrix} 0.0279 & 0.0177 & 0.0085 & 0.0123 & 0.0204 \\ 0.0177 & 0.0569 & 0.0136 & 0.0197 & 0.0256 \\ 0.0085 & 0.0136 & 0.0182 & 0.0163 & 0.0123 \\ 0.0123 & 0.0197 & 0.0163 & 0.0236 & 0.0177 \\ 0.0204 & 0.0256 & 0.0123 & 0.0177 & 0.0294 \end{bmatrix} \begin{bmatrix} 0 \\ -(j8.313) \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

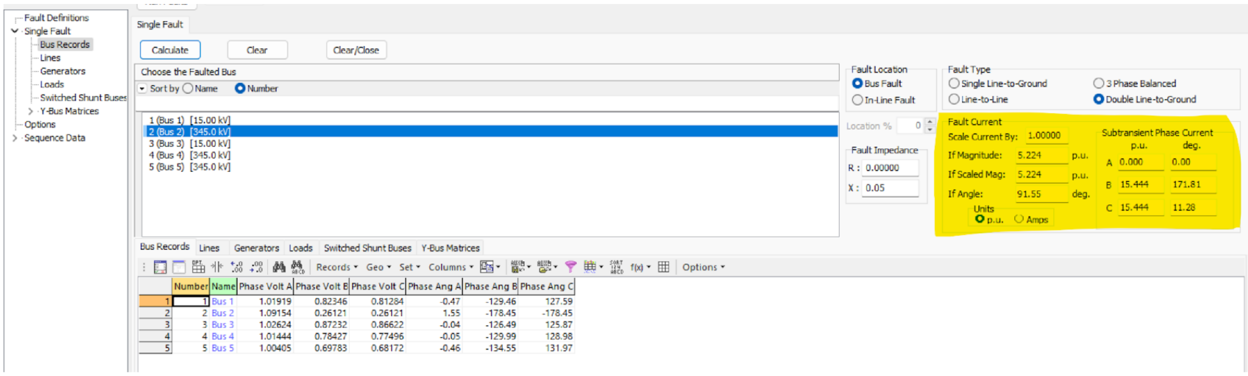
$$\begin{bmatrix} V_1^-(F) \\ V_2^-(F) \\ V_3^-(F) \\ V_4^-(F) \\ V_5^-(F) \end{bmatrix} = \begin{bmatrix} 0.147 \text{ P.U.} \\ 0.473 \text{ P.U.} \\ 0.113 \text{ P.U.} \\ 0.163 \text{ P.U.} \\ 0.212 \text{ P.U.} \end{bmatrix}$$

@ $V_2$-Phase

$$\begin{bmatrix} V_2^a(F) \\ V_2^b(F) \\ V_2^c(F) \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} V_2^0(F) = 0.199 \\ V_2^+(F) = 0.472 \\ V_2^-(F) = 0.473 \end{bmatrix} = \begin{bmatrix} V_2^a(F) = 1.144\angle 0^\circ \text{ P.U.} \\ V_2^b(F) = 0.273\angle 179.81^\circ \text{ P.U.} \\ V_2^c(F) = 0.273\angle -179.81^\circ \text{ P.U.} \end{bmatrix}$$

**d) Use the five-bus power system that you built in PowerWorld Simulator for Simulation Project #2 and simulate the fault to confirm the results of parts b and c. Take screenshots of the dialog boxes and paste them here.**

**Figure B.1 - Power World Simulation Phase Component of Double Line-to-ground Fault Per Unit  Current at Bus 2**

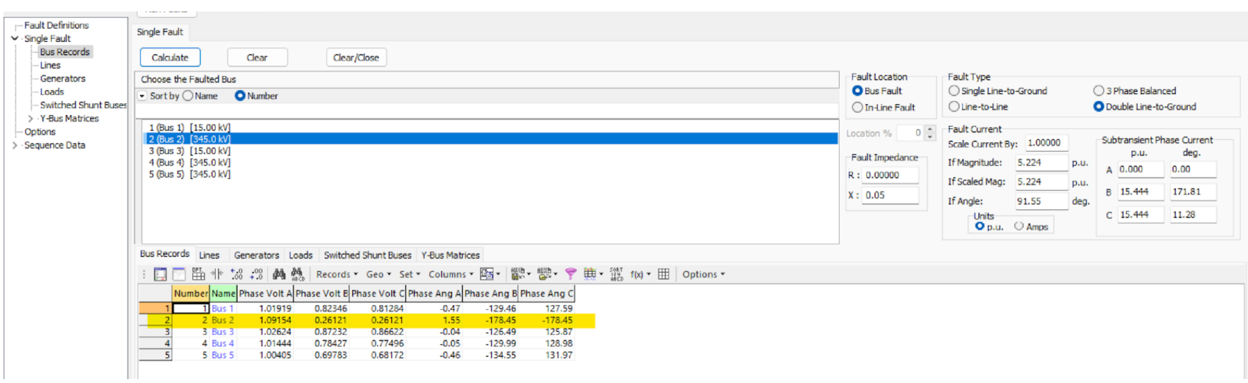



The fault current magnitude in the simulation has a magnitude of 15.44 while the calculated magnitude is 16.21. The value is accepted since the magnitude has a 4.75% error, less than 5%.

Phase B's Fault current angle simulation has an error of 1.06. Phase C's fault current simulation is 11.20 while the calculated has 9.7. Between those two values, there is a 15.46% error.

After comparing with another student the calculation value is very similar. However, the simulated values are a bit off. This error could be due to an issue in the simulation. For example, the bus value, magnitude 1.05 and angle 0m change when the simulation is simulated.

**Figure C.1 - Power World Simulation Phase Component of Double Line-to-ground Fault Per Unit Voltage at Bus 2**




The Power World simulated values and the calculated phase voltage at bus 2 have an error percentage of less than 5% making all those values acceptable.