Power System Analysis

B EE478: Simulation Project #3

by

Timothy Caole **- 1920592**

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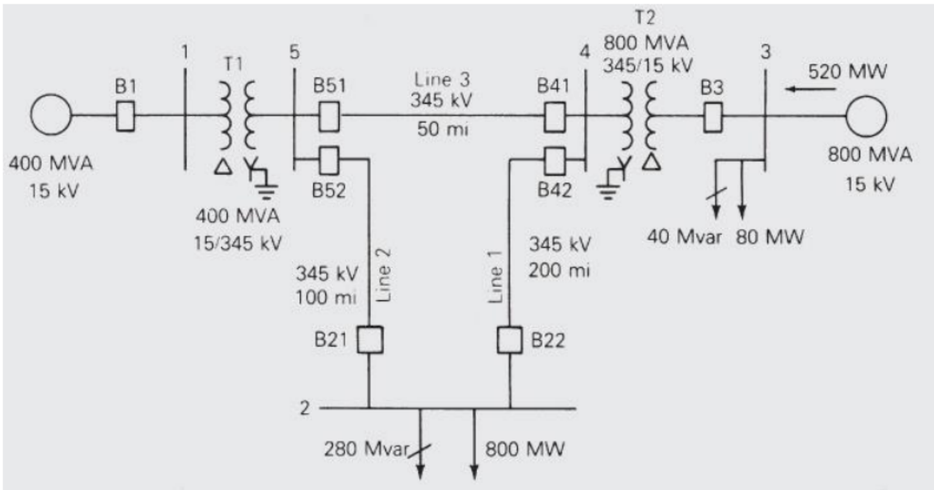
1. **The single line diagram of a five-bus power system is shown below. Machine, line and transformer data are given in the following tables. Note that the neutrals of both transformers and generator 1 are solidly grounded, as indicated by a neutral reactance of zero in Tables 1 and 3. However, a neutral 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

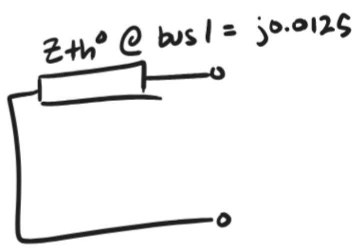
$\boldsymbol{S_{base}} = \mathbf{100\ MVA}$

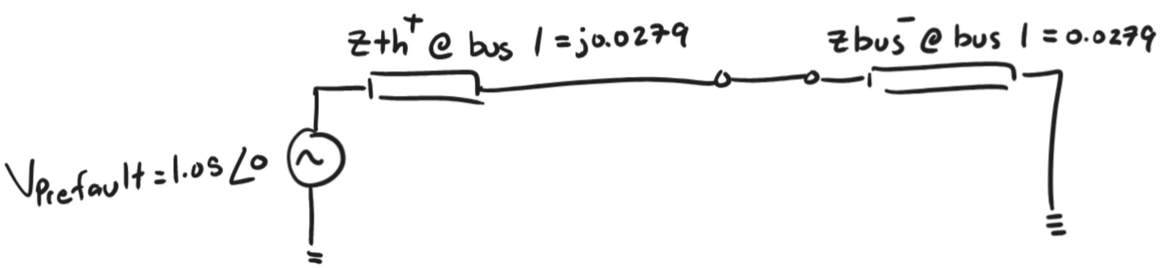
$$\boldsymbol{V_{base}} = \begin{cases} \mathbf{15\ kV\ at\ buses\ 1,3} \\ \mathbf{345\ kV\ at\ buses\ 2,4,5} \end{cases}$$

Answer parts (a) to (d) for a bolted line-to-line fault at bus 1.

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)

@ Line to line Fault @ bus 1 $\left\{ \begin{array}{l} \text{Condition:} \\ I^0 = 0 \\ I^+ = -I^- \\ V^+ - V^- = Z_F \cdot I^+ \end{array} \right.$





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

@ $I_{F_1}^0$

$I_{F_1}^0 = 0$

@ $I_{F_1}^+$

$$I^+ = \frac{V_{Prefault}}{Z_{th}^+ + Z_{th}^- + Z_F}$$

$$I_{F_1}^+ = \frac{1.05}{j(0.0279 + 0.0279)} = -j18.81 \text{ P.U.}$$

@ $I_{F_1}^-$

$I^+ = -I^-$

$I_{F_1}^- = j18.81$ P.U.

@ I_{F_1} Phase

$$\begin{bmatrix} I_{F_1}^a \\ I_{F_1}^b \\ I_{F_1}^c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} I_{F_1}^0 = 0 \\ I_{F_1}^+ = -j18.81 \\ I_{F_1}^- = j18.81 \end{bmatrix}$$

$$\begin{bmatrix} I_{F_1}^a \\ I_{F_1}^b \\ I_{F_1}^c \end{bmatrix} = \begin{bmatrix} 0 \text{ P.U.} \\ -j32.57 \text{ P.U.} \\ 32.57 \text{ P.U.} \end{bmatrix}$$

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 1

$$V_n^0(F) = (Zbus^0)(-IF_1^0)$$

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

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

@ Positive Seqence

@ $V_n^+(F)$, Fault @ bus 1

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

$$\begin{bmatrix} V_1^+(F) \\ V_2^+(F) \\ V_3^+(F) \\ V_4^+(F) \\ V_5^+(F) \end{bmatrix} = \begin{bmatrix} 1.05 \\ 1.05 \\ 1.05 \\ 1.05 \\ 1.05 \end{bmatrix} + j \begin{bmatrix} 0.027 & 0.017 & 0.008 & 0.012 & 0.020 \\ 0.017 & 0.056 & 0.013 & 0.019 & 0.025 \\ 0.008 & 0.013 & 0.018 & 0.016 & 0.012 \\ 0.012 & 0.019 & 0.016 & 0.023 & 0.017 \\ 0.020 & 0.025 & 0.012 & 0.017 & 0.029 \end{bmatrix} \begin{bmatrix} -(-j18.81) \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} V_1^+(F) \\ V_2^+(F) \\ V_3^+(F) \\ V_4^+(F) \\ V_5^+(F) \end{bmatrix} = \begin{bmatrix} 0.523 \text{ P.U} \\ 0.716 \text{ P.U.} \\ 0.889 \text{ P.U.} \\ 0.818 \text{ P.U.} \\ 0.666 \text{ P.U.} \end{bmatrix}$$

@ Negative Seqence

@ $V_n^-(F)$, Fault @ bus 1

$$V_n^-(F) = Z_{bus}^-(I_{F_1}^-)$$

$$\begin{bmatrix} V_1^-(F) \\ V_2^-(F) \\ V_3^-(F) \\ V_4^-(F) \\ V_5^-(F) \end{bmatrix} = j\begin{bmatrix} 0.027 & 0.017 & 0.008 & 0.012 & 0.020 \\ 0.017 & 0.056 & 0.013 & 0.019 & 0.025 \\ 0.008 & 0.013 & 0.018 & 0.016 & 0.012 \\ 0.012 & 0.019 & 0.016 & 0.023 & 0.017 \\ 0.020 & 0.025 & 0.012 & 0.017 & 0.029 \end{bmatrix} \begin{bmatrix} -(j18.81) \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} V_1^-(F) = 0.526 \text{ P.U.} \\ V_2^-(F) = 0.333 \text{ P.U.} \\ V_3^-(F) = 0.160 \text{ P.U.} \\ V_4^-(F) = 0.231 \text{ P.U.} \\ V_5^-(F) = 0.383 \text{ P.U.} \end{bmatrix}$$

@ $V_n(F)$ Phase

$$\begin{bmatrix} V_1^a(F) \\ V_1^b(F) \\ V_1^c(F) \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} 0 \\ 0.523 \\ 0.526 \end{bmatrix}$$

$\alpha = 1\angle 120^\circ$ $\qquad$ $\alpha^2 = 1\angle 240^\circ = 1\angle -120^\circ$

$$\begin{bmatrix} V_1^a(F) \\ V_1^b(F) \\ V_1^c(F) \end{bmatrix} = \begin{bmatrix} 1.046\angle 0^\circ \text{ P.U.} \\ 0.524\angle 180^\circ \text{ P.U.} \\ 0.524\angle -180^\circ \text{ P.U.} \end{bmatrix}$$

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 Line-to-Line Fault Per Unit Current at Bus 1

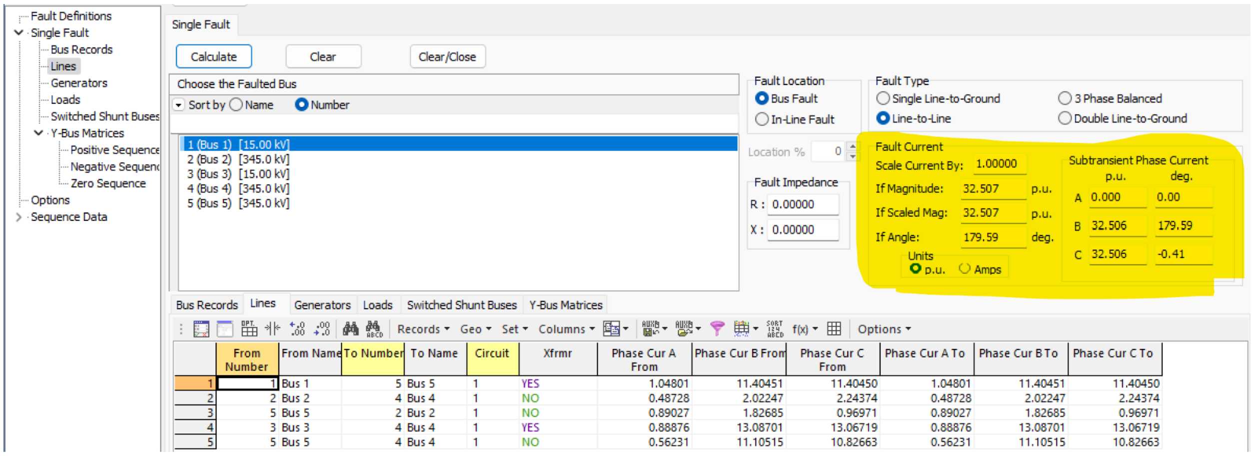


Figure C.1 - Power World Simulation Phase Component of Double Line-to-ground Fault Per Unit Voltage at Bus 2