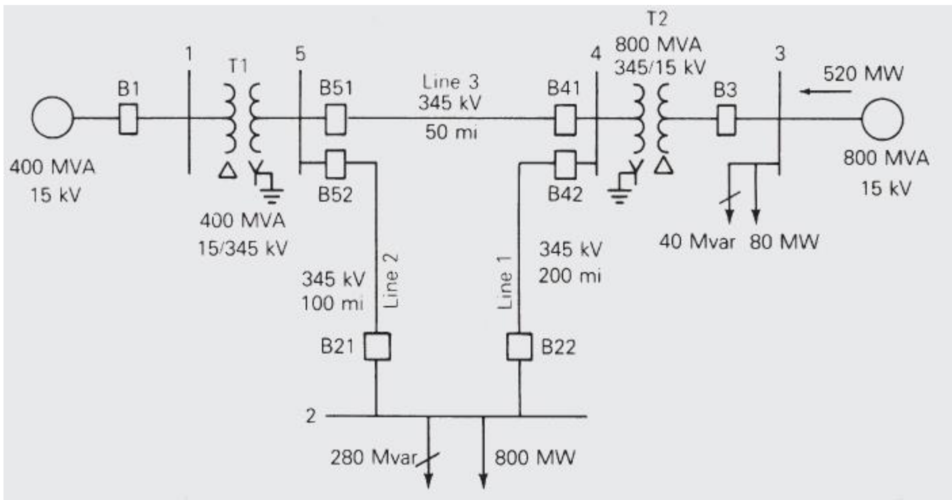
B EE 478

Power System Analysis

Simulation Project #2

Due date: 12/2/2023 (11:59 PM)

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

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

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

a) Draw the zero-, positive-, and negative-sequence reactance diagrams neglecting the transformer phase-shifts. **(5 Points)**

b) Calculate the bus admittance matrices for the sequence networks ($Y_{bus}^{0}, Y_{bus}^{+}, Y_{bus}^{-}$). Clearly show how different elements of the bus admittance matrices are calculated. **(5 Points)**

c) Use the sequence bus admittance matrices to calculate the sequence bus impedance matrices ($Z_{bus}^{0}, Z_{bus}^{+}, Z_{bus}^{-}$). **(5 Points)**

For a bolted single line-to-ground fault at bus 1, then bus 2, and so on to bus 5, do the following:

d) Use the appropriate elements of the sequence bus impedance matrices to determine the Thevenin equivalent of each sequence network as viewed form the fault bus and calculate the sequence components of the fault current for each fault.
Use the calculated sequence components and the transformation matrix to calculate the phase components of the fault currents. **(15 Points)**

e) Use the sequence bus impedance matrices calculated in part (c) and the vector of sequence bus injected currents using the sequence fault currents calculated in part (d) to calculate the per-unit sequence bus voltages during each fault

$$\left(\begin{bmatrix} V_1(F) \\ V_2(F) \\ V_3(F) \\ V_4(F) \\ V_5(F) \end{bmatrix}^0, \begin{bmatrix} V_1(F) \\ V_2(F) \\ V_3(F) \\ V_4(F) \\ V_5(F) \end{bmatrix}^+, \begin{bmatrix} V_1(F) \\ V_2(F) \\ V_3(F) \\ V_4(F) \\ V_5(F) \end{bmatrix}^- \right).$$

Use the calculated sequence components of the voltages for each bus and the transformation matrix to calculate the phase components of the bus voltages during each fault ($\begin{bmatrix} V_1^a(F) \\ V_1^b(F) \\ V_1^c(F) \end{bmatrix}, \begin{bmatrix} V_2^a(F) \\ V_2^b(F) \\ V_2^c(F) \end{bmatrix}, \begin{bmatrix} V_3^a(F) \\ V_3^b(F) \\ V_3^c(F) \end{bmatrix}, \begin{bmatrix} V_4^a(F) \\ V_4^b(F) \\ V_4^c(F) \end{bmatrix}, \begin{bmatrix} V_5^a(F) \\ V_5^b(F) \\ V_5^c(F) \end{bmatrix}$). **(20 Points)**

f) Use the sequence bus voltages calculated in part (e) and the sequence reactance diagrams calculated in part (a) to calculate the sequence components of the contributions to the fault current for each fault as follows:

f1) Sequence components of the fault current contributions from Generator 1 and Transformer 1 ($I_{G_1}^0(F), I_{G_1}^+(F), I_{G_1}^-(F),\ I_{T_1}^0(F), I_{T_1}^+(F), I_{T_1}^-(F)$) for the fault at bus 1.

f2) Sequence components of the fault current contributions from Line 1 and Line 2 ($I_{L1}^0(F), I_{L1}^+(F), I_{L1}^-(F),\ I_{L2}^0(F), I_{L2}^+(F), I_{L2}^-(F)$) for the fault at bus 2.

f3) Sequence components of the fault current contributions from Generator 2 and Transformer 2 ($I_{G_2}^0(F), I_{G_2}^+(F), I_{G_2}^-(F),\ I_{T_2}^0(F), I_{T_2}^+(F), I_{T_2}^-(F)$) for the fault at bus 3.

f4) Sequence components of the fault current contributions from Line 1, Line 3, and Transformer 2 ($I_{L1}^0(F), I_{L1}^+(F), I_{L1}^-(F),\ I_{L3}^0(F), I_{L3}^+(F), I_{L3}^-(F), I_{T_2}^0(F), I_{T_2}^+(F), I_{T_2}^-(F)$) for the fault at bus 4.

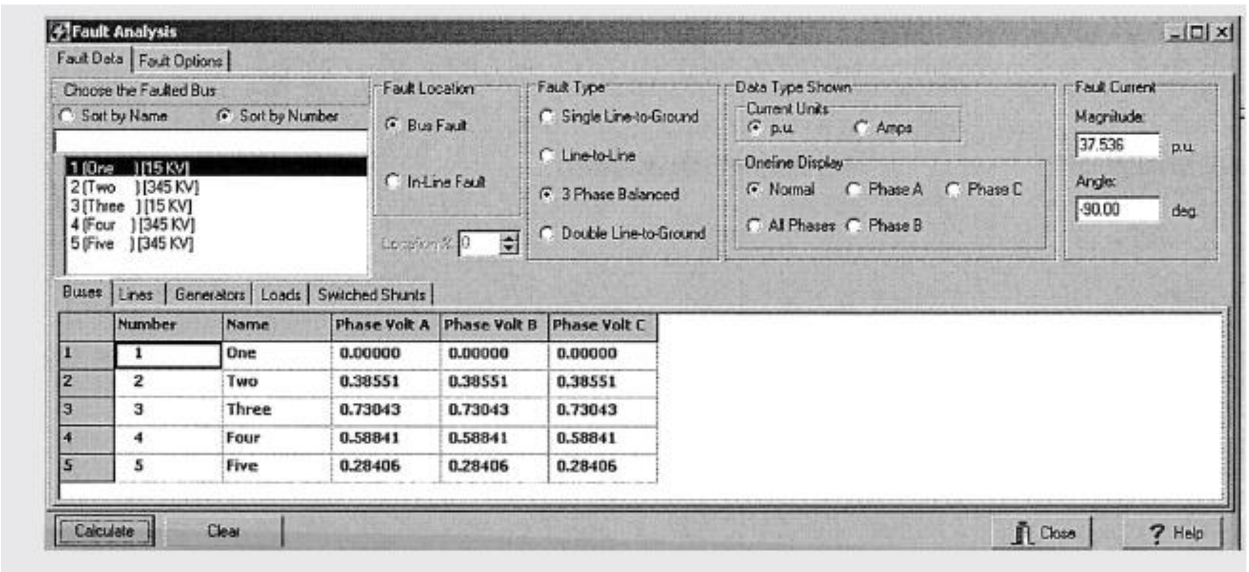
f5) Sequence components of the fault current contributions from Line 2, Line 3, and Transformer 1 ($I_{L2}^0(F), I_{L2}^+(F), I_{L2}^-(F),\ I_{L3}^0(F), I_{L3}^+(F), I_{L3}^-(F), I_{T_1}^0(F), I_{T_1}^+(F), I_{T_1}^-(F)$) for the fault at bus 5.

Use the calculated sequence components and the transformation matrix to calculate the phase components of the fault current contributions in parts (f1)-(f5). **(20 Points)**

g) Use the data given in Tables 1-3 to modify the five-bus power system that you built in PowerWorld Simulator for Simulation Project #1. Use the modified system to confirm the results of parts d, e and f. Take screenshots of the dialog boxes and paste them here. **(30 Points)**

Guideline for fault analysis in PowerWorld Simulator:

To fault a bus from the one-line, first right-click on the bus symbol to display the local menu, and then select “Fault.” This opens a dialog box where you will click on the “Single Fault” option on the top left to display the **Fault** dialog (see Figure below). Verify that the fault location is “Bus Fault” and the Fault Type is “Single Line-to-Ground.” Then select “Calculate,” located in the top left corner of the dialog, to determine the fault currents and voltages. Take a screenshot of this dialog box to provide the confirmation for the results of parts d and e.



Then select “Generators” or “Lines” located above the fault voltages in the dialog to find the generators’/transformers’ or lines’ contributions to the fault current. Take a screenshot of the dialog box to provide the confirmation for the results of part f.

Note: **<u>Your solution will include the screenshots of the fault currents and voltages as well as the screenshots of the generators’ and lines’ fault current contributions for each fault. (Total 5 screenshots for the fault currents and voltages, 5 screenshots for the generators’ fault current contributions, and 5 screenshots for the lines’ currents during each fault.)</u>**

You will turn in the hard copy or electronic copy of your solutions for parts (a) to (g) and upload your PowerWorld files (both .pwb and .pwd) on Canvas.

F.A.

Fault Bus	Single Line-to-Ground Fault Current (Phase A) per unit/degrees	GEN LINE OR TRSF	Bus-to-Bus	Contributions to Fault Current Phase A	Current Phase B	Phase C
				per unit/degrees		
1	46.02/−90.00	G1	GRND–1	34.41/ −90.00	5.804/ −90.00	5.804/ −90.00
		T1	5–1	11.61/ −90.00	5.804/ 90.00	5.804/ 90.00
2	14.14/−90.00	L1	4–2	5.151/ −90.00	0.1124/ 90.00	0.1124/ 90.00
		L2	5–2	8.984/ −90.00	0.1124/ −90.00	0.1124/ −90.00
3	64.30/−90.00	G2	GRND–3	56.19/ −90.00	4.055/ −90.00	4.055/ −90.00
		T2	4–3	8.110/ −90.00	4.055/ 90.00	4.055/ 90.00
4	56.07/−90.00	L1	2–4	1.742/ −90.00	0.4464/ 90.00	0.4464/ 90.00
		L3	5–4	10.46/ −90.00	2.679/ 90.00	2.679/ 90.00
		T2	3–4	43.88/ −90.00	3.125/ −90.00	3.125/ −90.00
5	42.16/−90.00	L2	2–5	2.621/ −90.00	0.6716/ 90.00	0.6716/ 90.00
		L3	4–5	15.72/ −90.00	4.029/ 90.00	4.029/ 90.00
		T1	1–5	23.82/ −90.00	4.700/ −90.00	4.700/ −90.00

$V_{prefault} = 1.05 \angle 0$		Bus Voltages during Fault		
Fault Bus	Bus	Phase A	Phase B	Phase C
1	1	$0.0000 \angle 0.00$	$0.9537 \angle -107.55$	$0.9537 \angle 107.55$
	2	$0.5069 \angle 0.00$	$0.9440 \angle -105.57$	$0.9440 \angle 105.57$
	3	$0.7888 \angle 0.00$	$0.9912 \angle -113.45$	$0.9912 \angle 113.45$
	4	$0.6727 \angle 0.00$	$0.9695 \angle -110.30$	$0.9695 \angle 110.30$
	5	$0.4239 \angle 0.00$	$0.9337 \angle -103.12$	$0.9337 \angle 103.12$
2	1	$0.8832 \angle 0.00$	$1.0109 \angle -115.90$	$1.0109 \angle 115.90$
	2	$0.0000 \angle 0.00$	$1.1915 \angle -130.26$	$1.1915 \angle 130.26$
	3	$0.9214 \angle 0.00$	$1.0194 \angle -116.87$	$1.0194 \angle 116.87$
	4	$0.8435 \angle 0.00$	$1.0158 \angle -116.47$	$1.0158 \angle 116.47$
	5	$0.7562 \angle 0.00$	$1.0179 \angle -116.70$	$1.0179 \angle 116.70$
3	1	$0.6851 \angle 0.00$	$0.9717 \angle -110.64$	$0.9717 \angle 110.64$
	2	$0.4649 \angle 0.00$	$0.9386 \angle -104.34$	$0.9386 \angle 104.34$
	3	$0.0000 \angle 0.00$	$0.9942 \angle -113.84$	$0.9942 \angle 113.84$
	4	$0.3490 \angle 0.00$	$0.9259 \angle -100.86$	$0.9259 \angle 100.86$
	5	$0.5228 \angle 0.00$	$0.9462 \angle -106.04$	$0.9462 \angle 106.04$
4	1	$0.5903 \angle 0.00$	$0.9560 \angle -107.98$	$0.9560 \angle 107.98$
	2	$0.2309 \angle 0.00$	$0.9401 \angle -104.70$	$0.9401 \angle 104.70$
	3	$0.4387 \angle 0.00$	$0.9354 \angle -103.56$	$0.9354 \angle 103.56$
	4	$0.0000 \angle 0.00$	$0.9432 \angle -105.41$	$0.9432 \angle 105.41$
	5	$0.3463 \angle 0.00$	$0.9386 \angle -104.35$	$0.9386 \angle 104.35$
5	1	$0.4764 \angle 0.00$	$0.9400 \angle -104.68$	$0.9400 \angle 104.68$
	2	$0.1736 \angle 0.00$	$0.9651 \angle -109.57$	$0.9651 \angle 109.57$
	3	$0.7043 \angle 0.00$	$0.9751 \angle -111.17$	$0.9751 \angle 111.17$
	4	$0.5209 \angle 0.00$	$0.9592 \angle -108.55$	$0.9592 \angle 108.55$
	5	$0.0000 \angle 0.00$	$0.9681 \angle -110.07$	$0.9681 \angle 110.07$

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