UNIVERSITY OF CAPE TOWN

EEE3100S

POWER ENGINEERING

PWS Assignment

84

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GROUP 11

Due: 23 September 2022

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1 Abstract 2

To design a power system project by performing power system analysis. Power flow, balanced fault calculations and PowerWorld Simulations are performed to ensure that the power system, together with its component parts, is appropriately configured to function as expected.

We were able to create various data tables by simulating the 7 Bus power system with PowerWorld simulation and carrying out several procedures related to power flow and fault analysis concepts. The simulation allowed us to determine the amount of generating capacity needed to fulfil system demand as well as how to better account for unexpected changes in system load, voltage magnitudes, and MVA limitations.

The design is built to ensure that the generator supplies the load demand while also making sure that the transformers and transmission lines are within their rated MVA limits and voltage magnitudes.

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2 Introduction

3

The steady-state solution of a power system network is referred to as power flow (load flow) in power system terminology. Studies of power flow (load flow) are crucial for power system functioning, system extension, and planning. One-line diagrams and per-unit systems are frequently used in power-flow studies, which concentrate on several elements of AC power characteristics as voltages, voltage angles, real power, and reactive power.

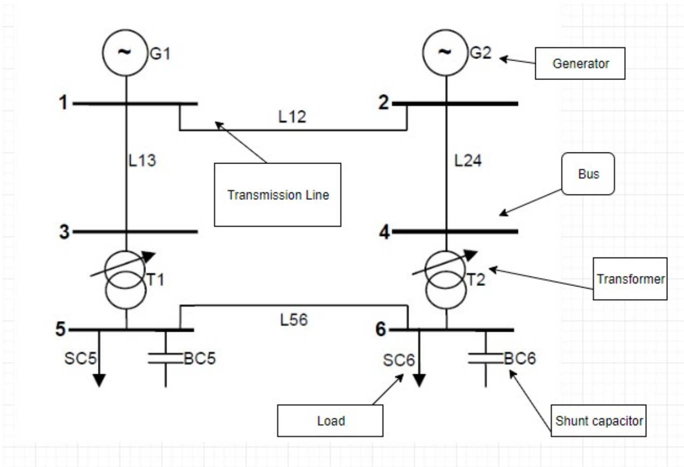

Figure 1: Single-Line Diagram of a Balanced Three-Phase 6-Bus Power System [7]

The power-flow study's main findings include the amount and phase angle of voltage at each bus as well as the actual and reactive power flowing through each line. A load bus is a bus that is not connected to any generators (PQ bus). A bus is referred to as a Slack (Swing) Bus if it has at least one generator connected to it. PV bus refers to a bus that is specified with the active power and voltage magnitudes that correspond to its rating.

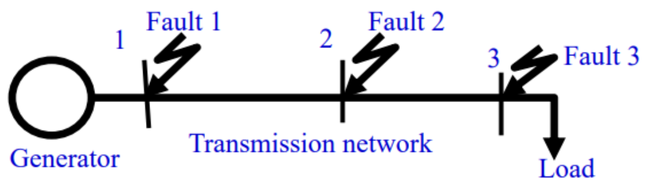

Figure 2: Faulted power system. [4]

When the power system operates under balanced conditions, all the equipment is operating at typical load currents, and the bus voltages are kept within the set parameters. A flaw in the system has the potential to disturb this state. The results could be disastrous if the electrical fault current exceeds the protective device's interrupting rating. It has the potential to seriously endanger human life and harm while severely damaging equipment.

Any malfunction in the system that prevents current from flowing normally is referred to as a fault. Faults cause abnormal operational conditions, which are typically high currents and voltages at specific system points. The two types of faults that occur in power systems are three-phase balanced (symmetrical) faults and unbalanced faults. Only symmetrical faults are analysed in this project.

A power system's fault analysis is necessary to give data for switchgear selection, relay configuration, and the stability of system operation. The goal of fault analysis is to identify the root causes of potential faults. The analysis of balanced three-phase faults can be done with an equivalent single-phase circuit.

For Impedance of parallel network:

$$z_{th} = Z_1 || Z_2$$

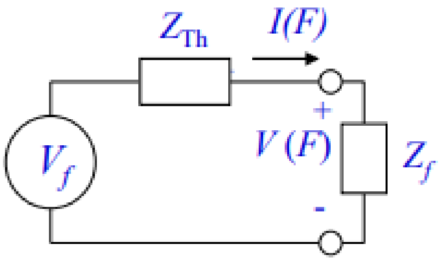

Figure 3: Thevenin equipment circuit for faulted network. [4]

Where Z_1 is the total impedance of the preceding components before where the fault occurs, while Z_2 is the total impedance on the other side of the fault.

The p.u fault current is given by:

$$I_{f_k} = \frac{V_k(0)}{|Z_{kk}|}$$

And the Voltage at the buses during a fault can be found using the Zbus where $Z_{bus} = Y_{bus}^{-1}$

$$V_j = \left(1 - \frac{Z_{jk}}{Z_{kk}}\right) * V_f$$

3 Task 1: Power Flow Preparation

From the single line diagram [**2**], all positive-sequence impedances, load, and voltage data is converted to per-unit.

The common $S_{base} = 10MVA$ (three-phase), while the $V_{base} = 13.8kV$(line-to-line) in the zone of the lines.

The Z_{base} of the transmission lines is given by:

$$Z_{base} = \frac{(V_{base})^2}{S_{base}} \tag{1}$$

While the per-unit value is given by:

$$Z_{p.u} = \frac{Z_{nominal}\,[\Omega]}{Z_{base}} \tag{2}$$

Since we know that $Z = zl$, the given z_1 must first be multiplied by the lengths of the line to find the total impedances along each line. Table 1

Transmission Lines

Table 1: Impedances & Per-Unit Values Of Transmission Lines

Line	Length (km)	$Z\,[\Omega]$	Z_{pu}
L1	2	0.38 + 0.76j	0.02 + 0.04j
L2	1	0.19 + 0.38j	0.01 + 0.02j
L3	2	0.38 + 0.76j	0.02 + 0.04j
L4	2	0.38 + 0.76j	0.02 + 0.04j
L5	2	0.38 + 0.76j	0.02 + 0.04j

Alternatively, PowerWorld Simulator may be used to calculate the per unit impedances of the transmission lines of different lengths as shown in Figure 1.

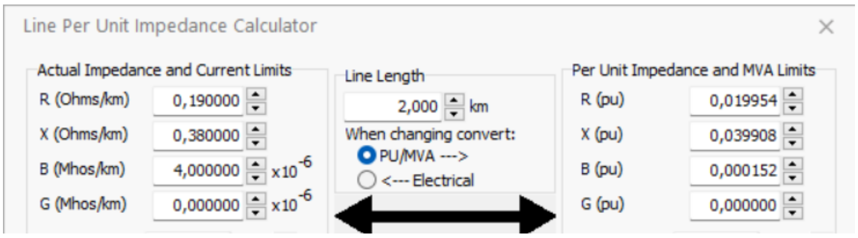

Figure 4: P.U Impedances of Transmission Lines Calculated using PowerWorld Simulator

For the transformer and generator, the change of $Sbase$ has to be reflected in the new per unit values where:

$$X_{p.u.n} = X_{p.u.o} \left(\frac{V_{bo}}{V_{bn}} \right)^2 \frac{S_{bn}}{S_{bo}} \tag{3}$$

Transformer T1

$$X_{p.u} = 0.1 * \left(\frac{10MVA}{5MVA} \right) = 0.2p.u$$

Generator G1

$$X_{p.u} = 0.15 * \left(\frac{10MVA}{50MVA} \right) = 0.03p.u$$

Loads

$$S_{p.u} = \frac{(800 + 380j)kVA}{10MVA} = (0.08 + 0.038j)p.u$$

The line, bus, and transformer input data tables are then shown below.

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Table 2: Bus Input Data

Bus	Bus Type	V [p.u]	$\delta°$	P_G [p.u]	Q_G [p.u]	P_L [p.u]	Q_L [p.u]	Q_{max} [p.u]	Q_{min} [p.u]
1	Swing	1.0	0	-	-	0	0	-	-
2	Load	-	-	0	0	0.08	0.038	-	-
3	Load	-	-	0	0	0.08	0.038	-	-
4	Load	-	-	0	0	0.08	0.038	-	-
5	Load	-	-	0	0	0.08	0.038	-	-
6	Load	-	-	0	0	0.08	0.038	-	-
7	Load	-	-	0	0	0.08	0.038	-	-

10

Table 3: Line Input Data

Bus-to-Bus	R' [p.u]	X' [p.u]	G' [p.u]	B' [p.u]	MVA_{max} [p.u]
2-3	0.02	0.04	-	$1.5 * 10^{-4}$	0.2
3-4	0.01	0.02	-	$7.6 * 10^{-5}$	0.2
4-5	0.02	0.04	-	$1.5 * 10^{-4}$	0.2
5-6	0.02	0.04	-	$1.5 * 10^{-4}$	0.2
6-7	0.02	0.04	-	$1.5 * 10^{-4}$	0.2

4

Table 4: Transformer Input Data

Bus-to-Bus	R [p.u]	X [p.u]	G_c [p.u]	B_m [p.u]	MVA_{max} [p.u]	Max TAP setting [p.u]
1-2	-	0.2			0.2	-

4 Task 2: Power Flow

4.1 Case 1

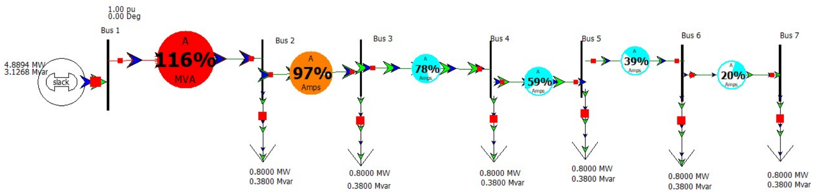

Figure 5: One Line Diagram After Gauss-Seidel Solver 2

Table 5: Bus Output Data Task 2 Case 1 2

Bus	Nominal Voltage	V [p.u]	Voltage [kV]	$\delta°$	P_L [MW]	Q_L [MVar]	P_G [MW]	Q_G [MVar]
1	345	1.0	345	0	-	-	4.89	3.13
2	13.8	0.94255	13.007	-5.96	0.8	0.38	-	-
3	13.8	0.92520	12.768	-6.76	0.8	0.38	-	-
4	13.8	0.91827	12.627	-7.08	0.8	0.38	-	-
5	13.8	0.90786	12.528	-7.59	0.8	0.38	-	-
6	13.8	0.90092	12.433	-7.93	0.8	0.38	-	-
7	13.8	0.89745	12.385	-8.10	0.8	0.38	-	-

Table 6: Line Output Data For Task 2 Case 1 2

Bus-to-Bus	MW From	MVar From	MVA From	Limit MVA	% MVA_{max} Limit	MW Loss	MVar Loss
2-3	4.1	2.1	4.6	5	91.7	0.05	0.09
3-4	3.2	1.6	3.6	5	72.3	0.02	0.03
4-5	2.4	1.2	2.7	5	54.1	0.02	0.03
5-6	1.6	0.8	1.8	5	35.7	0.01	0.01
6-7	0.8	0.4	0.9	5	17.8	0.00	0.00

2

Table 7: Transformer Output Data For Task 2 Case 1

Bus-to-Bus	MW From	MVar From	MVA From	Limit MVA	% MVA_{max} Limit	MW Loss	MVar Loss
1-2	4.9	3.1	5.8	5	116.1	0.00	0.67

From the output data, it is evident that the transformer overloads after the Gauss-Seidel solver. The voltage values from bus 3-7 are also not within 5% of the nominal values.

4.2 Case 2

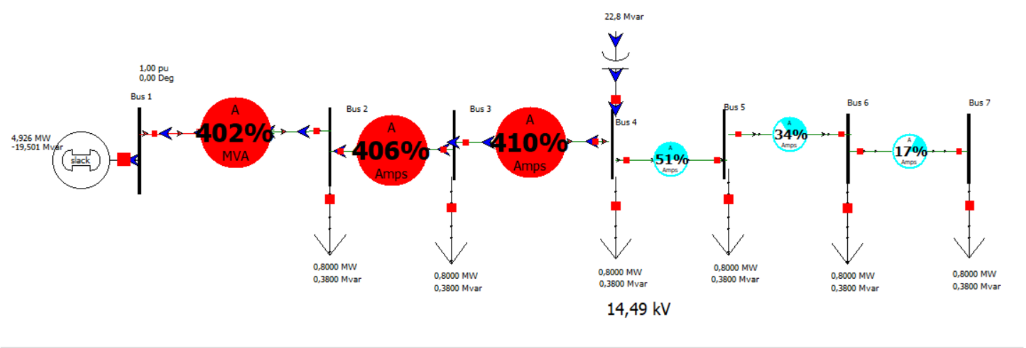

Figure 6: Method 1 To Increase Voltage At Bus 4 by 5%

2, There is a better method

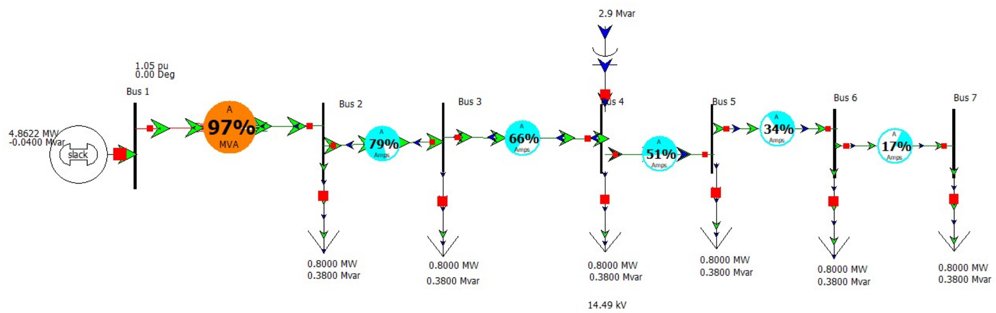

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Figure 7: Method 2 To Increase Voltage At Bus 4 by 5%

Two methods were tried to increase the voltage at bus 4 by 5%. The first method was to add a shunt capacitor at Bus 4, but this overloads the Transformer and the transmission lines from bus 2 to bus 4. In the second method, By increasing the Voltage of the Generator at the Slack bus from 1.0 p.u to 1.05 p.u, the voltage at Bus 4 will also increase by 5%, but since the transformer overloads, a shunt capacitor is added at bus 4 to compensate for the reactive power. The output data tables can be seen below.

Table 8: Bus Output Data Task 2 Case 2 2

Bus	Nominal Voltage	V [p.u]	Voltage [kV]	$\delta°$	P_G [MW]	Q_G [MVar]	P_L [MW]	Q_L [MVar]
1	345	1.0	345	0	4.89	3.13	-	-
2	13.8	0.94255	13.007	-5.96	-	-	0.8	0.38
3	13.8	0.92520	12.768	-6.76	-	-	0.8	0.38
4	13.8	0.91827	12.627	-7.08	-	-	0.8	0.38
5	13.8	0.90786	12.528	-7.59	-	-	0.8	0.38
6	13.8	0.90092	12.433	-7.93	-	-	0.8	0.38
7	13.8	0.89745	12.385	-8.10	-	-	0.8	0.38

2

Table 9: Line Output Data For Task 2 Case 2

Bus-to-Bus	MW From	MVar From	MVA From	Limit MVA	% MVA_{max} Limit	MW Loss	MVar Loss
2-3	4.1	2.1	4.6	5	91.7	0.05	0.09
3-4	3.2	1.6	3.6	5	72.3	0.02	0.03
4-5	2.4	1.2	2.7	5	54.1	0.02	0.03
5-6	1.6	0.8	1.8	5	35.7	0.01	0.01
6-7	0.8	0.4	0.9	5	17.8	0.00	0.00

2

Table 10: Transformer Output Data For Task 2 Case 2

Bus-to-Bus	MW From	MVar From	MVA From	Limit MVA	% MVA_{max} Limit	MW Loss	MVar Loss
1-2	4.9	3.1	5.8	5	116.1	0.00	0.67

4.3 Case 3

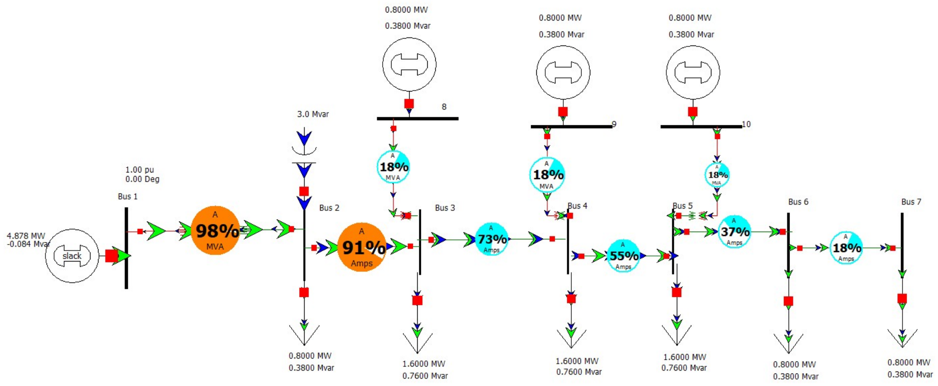

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Figure 8: Loads Increased by 100% At Bus 3-5

Table 11: Bus Output Data Task 2 Case 3 2

Bus	Nominal Voltage	V [p.u]	Voltage [kV]	$\delta°$	P_G [MW]	Q_G [MVar]	P_L [MW]	Q_L [MVar]	Switched Shunts [Mvar]
1	345	1.0	345	0	4.88	-0.08	-	-	-
2	13.8	1.00641	13.888	-5.56	-	-	0.8	0.38	3.04
3	13.8	0.99007	13.663	-6.26	-	-	1.6	0.76	-
4	13.8	0.98345	13.573	-6.54	-	-	1.6	0.76	-
5	13.8	0.97376	13.438	-6.98	-	-	1.6	0.76	-
6	13.8	0.96729	13.349	-7.28	-	-	0.8	0.38	-
7	13.8	0.96405	13.304	-7.43	-	-	0.8	0.38	-
8	345	0.99756	344.159	-5.33	0.8	0.38	-	-	-
9	345	0.99108	341.921	-5.60	0.8	0.38	-	-	-
10	345	0.98137	338.572	-6.02	0.8	0.38	-	-	-

Table 12: Line Output Data For Task 2 Case 3 2

Bus-to-Bus	MW From	MVar From	MVA From	Limit MVA	% MVA_{max} Limit	MW Loss	MVar Loss
2-3	4.1	2.1	4.6	5	91.7	0.04	0.08
3-4	3.2	1.6	3.6	5	72.3	0.01	0.03
4-5	2.4	1.2	2.7	5	54.1	0.02	0.03
5-6	1.6	0.8	1.8	5	35.7	0.01	0.01
6-7	0.8	0.4	0.9	5	17.8	0.00	0.00

2

Table 13: Transformer Output Data For Task 2 Case 3

Bus-to-Bus	MW From	MVar From	MVA From	Limit MVA	% MVA_{max} Limit	MW Loss	MVar Loss
1-2	4.9	-0.1	4.9	5	98.2	0.00	0.48
8-3	0.8	0.4	0.9	5	17.7	0.00	0.02
9-4	0.8	0.4	0.9	5	17.7	0.00	0.02
10-5	0.8	0.8	0.9	5	17.8	0.00	0.02

2, expensive using generators

To improve the voltages at buses 3-5, adding generators of 0.8 + 0.38j MVA. This improvement is shown in Figure 3. The values are within 5% of their limits.

The biggest losses in case 1 and case 3 are the MVar losses in the transformer connected to bus 1 and 2. In case 3, adding the generators in buses 3-5 decreases these Mvar Losses from 0.67Mvar (Case 1) to 0.48Mvar (Case 3). Addition of the new generators also means addition of three more transformers to step down the generator voltages, this introduces more losses from the added transformers. Losses at the loads remain fairly the same for both cases.

5 Task 3: Fault Analysis

5.1 Case 1

To perform fault analysis, the input data from Tables 9, 10, and 11 was used. The sub-transient reactance for the generator has been chosen to be 0.15.

Table 14: Machine Input Data For Fault Analysis

Bus	$X_2[p.u]$	$X_1[p.u]$	$X_0[p.u]$
1	1	1	1

2 Table 15: Transmission Line Input Data For Fault Analysis

Bus-to-Bus	Zero-Sequence Impedance Z_0 [p.u]
2-3	0.049885 + 0.099770j
3-4	0.024942 + 0.049885j
4-5	0.049885 + 0.099770j
5-6	0.049885 + 0.099770j
6-7	0.049885 + 0.099770j

Table 16: Transformer Input Data For Fault Analysis

Bus-to-Bus	X_0 [p.u]
1-2	0.2

After performing fault analysis, the output tables below were created to show the per unit voltage and fault currents during the faults.

Table 17: Per Unit Voltage During Faults

Fault-Bus	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7
1	0	0	0	0	0	0	0
2	0.403	0	0	0	0	0	0
3	0.690	0.487	0	0	0	0	0
4	0.754	0.591	0.197	0	0	0	0
5	0.827	0.710	0.425	0.283	0	0	0
6	0.867	0.776	0.552	0.441	0.22	0	0
7	0.892	0.817	0.632	0.541	0.359	0.179	0

Table 18: Per Unit Fault Curents

Fault-Bus	Fault Current
1	33.586
2	20.152
3	10.926
4	8.824
5	6.341
6	4.930
7	4.020

10

No phases

5.2 Case 2

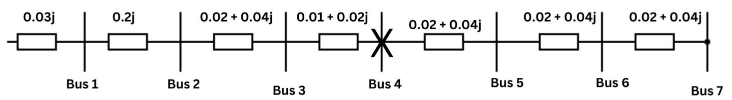

Figure 9: Reactance Diagram For Fault Analysis

$V_f = 1.0\angle 0^\circ$ p.u The Thevenin impedance Z_{th} at bus 4 is given by:

$$Z_{th} = [0.03j + 0.2j + (0.01 + 0.02j)] \,||\, [3 * (0.02 + 0.04j)]$$

$$Z_{th} = 0.032 + 0.0875j\Omega$$ 0

The fault current I_{f4} at bus 4 can be calculated as follows:

$$I_{f4} = \frac{V_4(0)}{|Z_{th}|} = \frac{1\angle 0^\circ}{0.032 + 0.0875j} = 10.73\angle -69.9p.u$$ 2, for method

Using the Zbus, the voltages at bus 3 and bus 5 can be calculated as follows:

Voltage at Bus 3

$$V_3 = \left(1 - \frac{Z_{34}}{Z_{44}}\right) * V_f$$

$$V_3 = \left(1 - \frac{0.1 + 0.25j}{0.03 + 0.29j}\right) * 1.0\angle 0 = 0.276\angle 66.16^\circ p.u$$

Voltage at Bus 5

$$V_5 = \left(1 - \frac{Z_{54}}{Z_{44}}\right) * V_f$$

3

$$V_5 = \left(1 - \frac{0.0300 + 0.29j}{0.0300 + 0.2900j}\right) * 1.0\angle 0^\circ = 0p.u$$

When comparing the Fault analysis done using PowerWorld Simulator versus hand calculations, the discrepancy between the voltages calculated at Bus 3 arise because a subtransient reactance of 0.15j was used for the machine, while 0.03j was used in the hand calculations. Voltage at Bus 5 is 0 p.u for both cases.

The fault current at bus 4 is found to be 8.824p.u in PowerWorld Simulator while it is 10.73p.u using hand calculations. This is because shunt admittances and loads are neglected when performing hand calculations. 4

6 Conclusions

The experiment was successfully executed. We obtained the required data tables to highlight the performance of our model through different tasks. We were able to increase the voltage at bus 4 by 5% from 13.8kv to 14.49kv by adding a shunt capacitor at bus 4 and increasing the voltage at bus 1 by 5%. We added three additional generators connected to each bus, increasing the loads at buses 3-5 by 100%, to ensure that the transformers and transmission lines are not overloaded while maintaining p.u voltages at each bus. The transformers accounted for most of the MVar losses due to their high leakage reactances compared to the generator and transmission lines.

Following a fault analysis, we discovered that the calculated fault current is 10.73p.u while the simulated fault current at bus 4 is 8.824p.u. acquired from PowerWorld simulation(Table 18). Consequently, we have 1.906p.u fault current difference, which is useful for identifying potential failure causes before they become apparent. We found the calculated voltages at bus 3 and 5 to be quite close to the values obtained in table 17.

When running our model, we may have neglected pre-fault load currents and all losses, which may have had an impact on the output results by causing them to consider the maximum fault current that may occur. 6

7 References

References

3

[1] Overbye T. Glover J. Sarma M. *Power System Analysis and Design*. Cengage Learning, 2012.

[2] Vula. *PowerWorld Assignment*. URL: https://vula.uct.ac.za/access/content/attachment/1e27edef-f635-4da5-802a-a1c5ea5018d5/Assignments/fe3cfbff-12ef-4118-8dac-24be9eec4e91/EEE3100S%20-%20PWS%20Assignment%20-%202022-%20KAF.pdf. (Accessed Sep. 22, 2022).

[3] Wikipedia Contributors. *Electrical fault*. URL: https://en.wikipedia.org/wiki/Electrical_faul. (Accessed Sep. 22, 2022).

[4] Vula. *Balanced Faults*. URL: https://vula.uct.ac.za/access/content/group/1e27edef-f635-4da5-802a-a1c5ea5018d5/03.%20Lessons/a.%20Slides/Week%205/KAF%20-%20Balanced%20faults-slides%20-%202022.pdf. (Accessed Sep. 22, 2022).

[5] N. Raphson. *Power Flow Newton Raphson Method - Matlab and Excel libraries for Omicron Devices (Nonofficial)*. URL: https://sites.google.com/site/omicronmatlablibraries/home/excel-vba-models-for-power-systems/newtonraphson. (Accessed Sep. 22, 2022).

3
Introduction and general report layout, make sure you do not start with a diagram or table without any explanation