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EEPS401 2025: Lab 1

Simulation and Validation of an 11-bus Power System Network in PowerWorld Simulator

Due Date: 17 April 2025

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1. Introduction

In this lab task, an 11-bus power system network (Figure 1) connected to a ring feed load is modelled and simulated in PowerWorld Simulator. The objective is to confirm the calculations that were made in Class Test 1 in which this network was analysed in depth. This validation process is crucial in power system engineering as it ensures the accuracy of both manual calculations and software simulations before these models can be relied upon for system planning, protection design, or operational decisions.

The validation focuses on several critical aspects of power system analysis: Y-bus matrix formation, fault current calculations, voltage profiles during fault conditions, and generator contribution to fault currents.

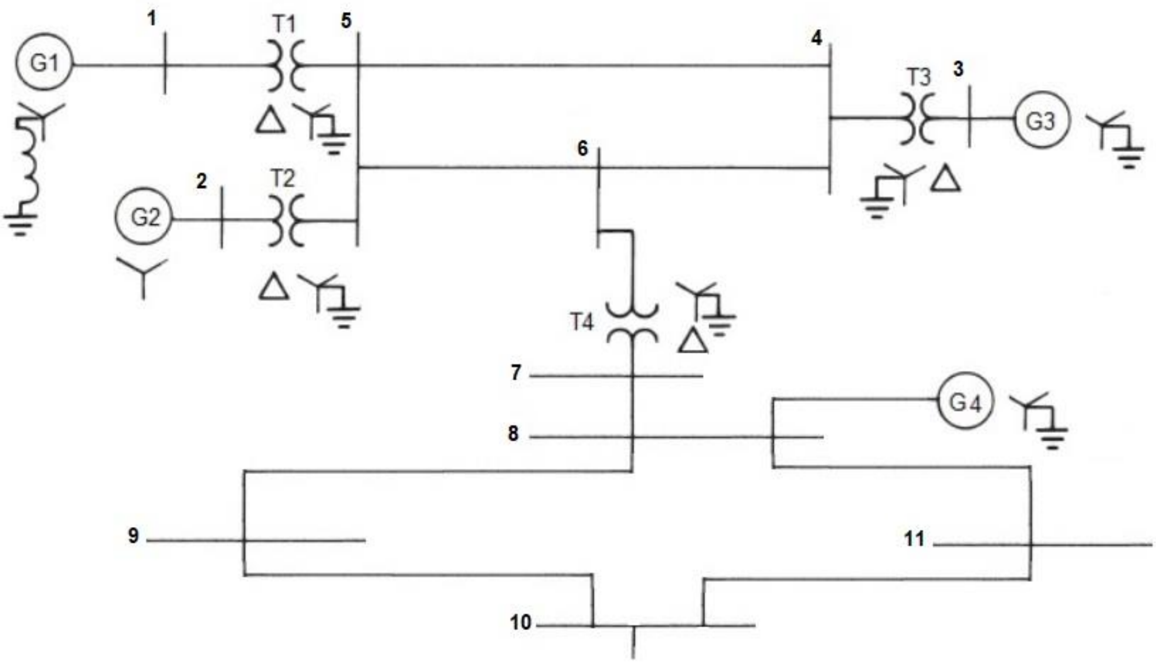


Figure 1: The 11-bus Network Diagram

Generator 4 (G4) is said to be a standby generator, therefore, G4 is excluded from this analysis.

2. Converting Parameters to a Common Base

The Network's given parameters are shown in Figure 2.

Use the information given below for the electrical system shown:

G1 and T1 rated **MVA** are the first two non-zero digits of your student number

G2 and T2 rated **MVA** are the next two non-zero digits of your student number

G3 and T3 rated **MVA** are the next two non-zero digits of your student number

Assume G4 is a standby generator that is not connected to the grid.

T4 rated **kVA** is the last three non-zero digits of your student number

Other ratings

Item:	Voltages:	Impedances:
G1	12 kV	1+j18 %
G2	13.8 kV	2+j20 %
G3	20 kV	1.4+j25 %
T1	12/132 kV	0.7+j6.5 %
T2	13.8/132 kV	0.9+j7.5 %
T3	20/132 kV	0.5+j4.5 %
T4	132/11 kV	1,5+j10.5 %
Line 5-4	132 kV	20+j175 ohm
Line 5-6	132 kV	29+j225 ohm
Line 6-4	132 kV	8+j153 ohm
Line 7-8	11 kV	1+j4.3 ohm
Line 8-9	11 kV	3+j8.6 ohm
Line 9-10	11 kV	2+j6.2 ohm
Line 10-11	11 kV	1+j3.8 ohm
Line 8-11	11 kV	1.2+j5.1 ohm

Figure 2: Provide Network Parameters.

And based on my student number (220702330), the following MVA ratings were used for the generators and transformers:

- **G1 and T1**: 22 MVA (the first two non-zero digits of my student number)
- **G2 and T2**: 72 MVA (the next two non-zero digits of my student number)
- **G3 and T3**: 33 MVA (the next two non-zero digits of my student number)
- **T4: 233 kVA** (the last three non-zero digits of my student number)

These parameters are however at different bases due to the transformers which are present in the network. To effectively and efficiently simulate the network model in PowerWorld Simulator, all the parameters must be converted to a common base per unit (pu).

2.1. Converting Line Impedances to the Common base per unit

To convert line impedances from ohms to per-unit, the following equation was used:

$$Zpu = Zactual * \left(\frac{Sbase}{V_{Line}^2}\right) \dots (1)$$

Where:

- Zpu is the calculated per-unit impedance
- $Zactual$ is the given impedance in ohms from Figure 2
- $Sbase$ is the base apparent power (100 MVA)
- V_{Line} is the line voltage at the respective line

The following figures show my calculations for these line impedances:

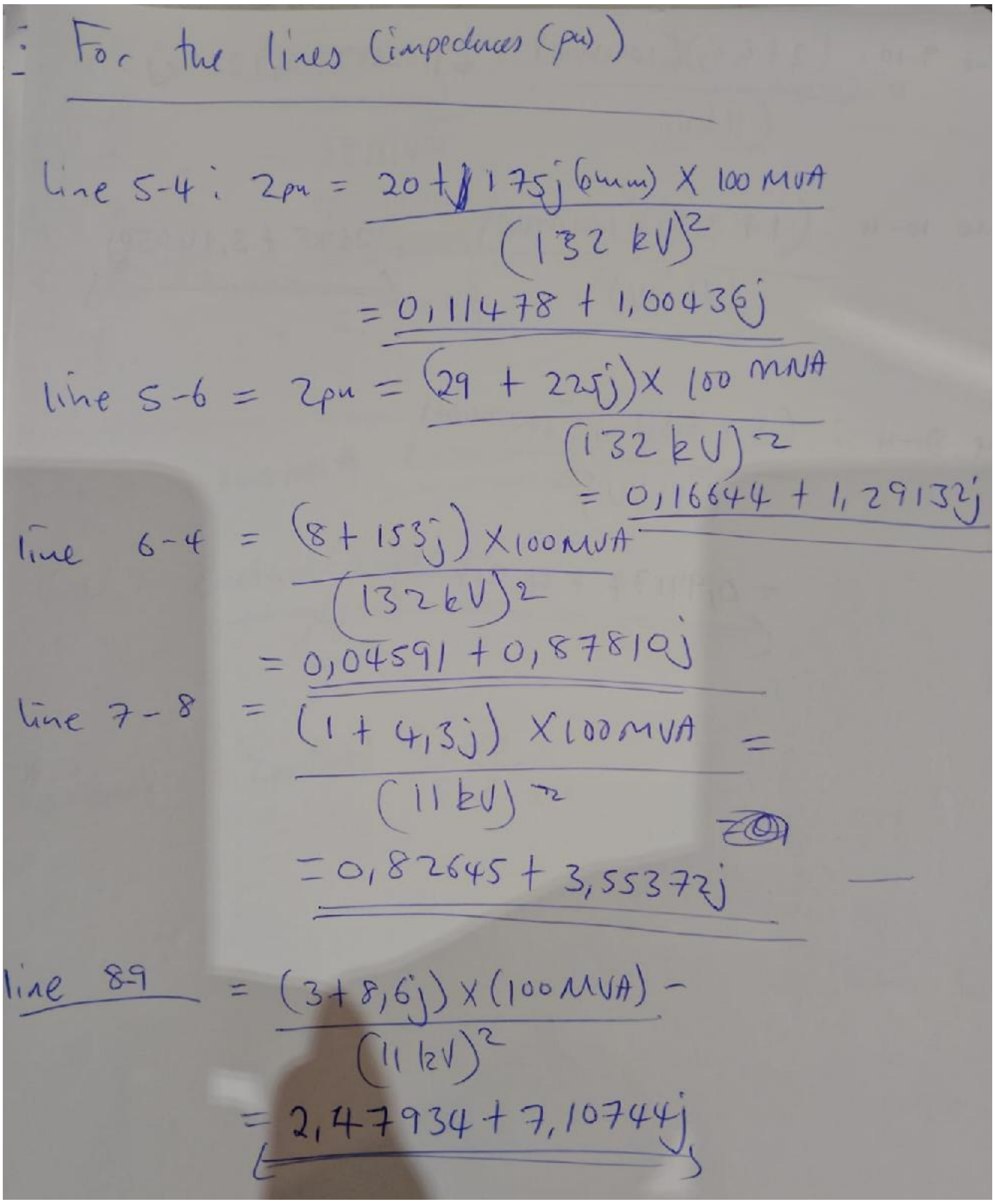


Figure 3: Line Impedance Calculations 1

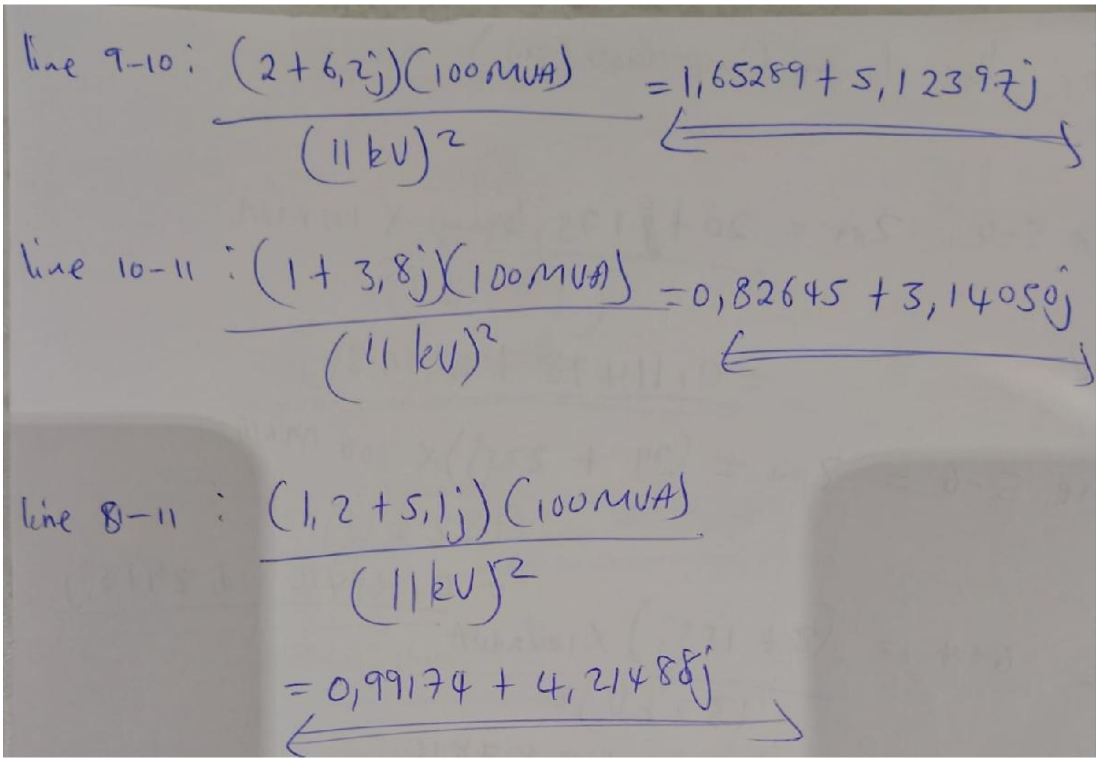


Figure 4: Line Impedance Calculations 2

2.2. Converting Generator and Transformer Impedances to the common base per unit

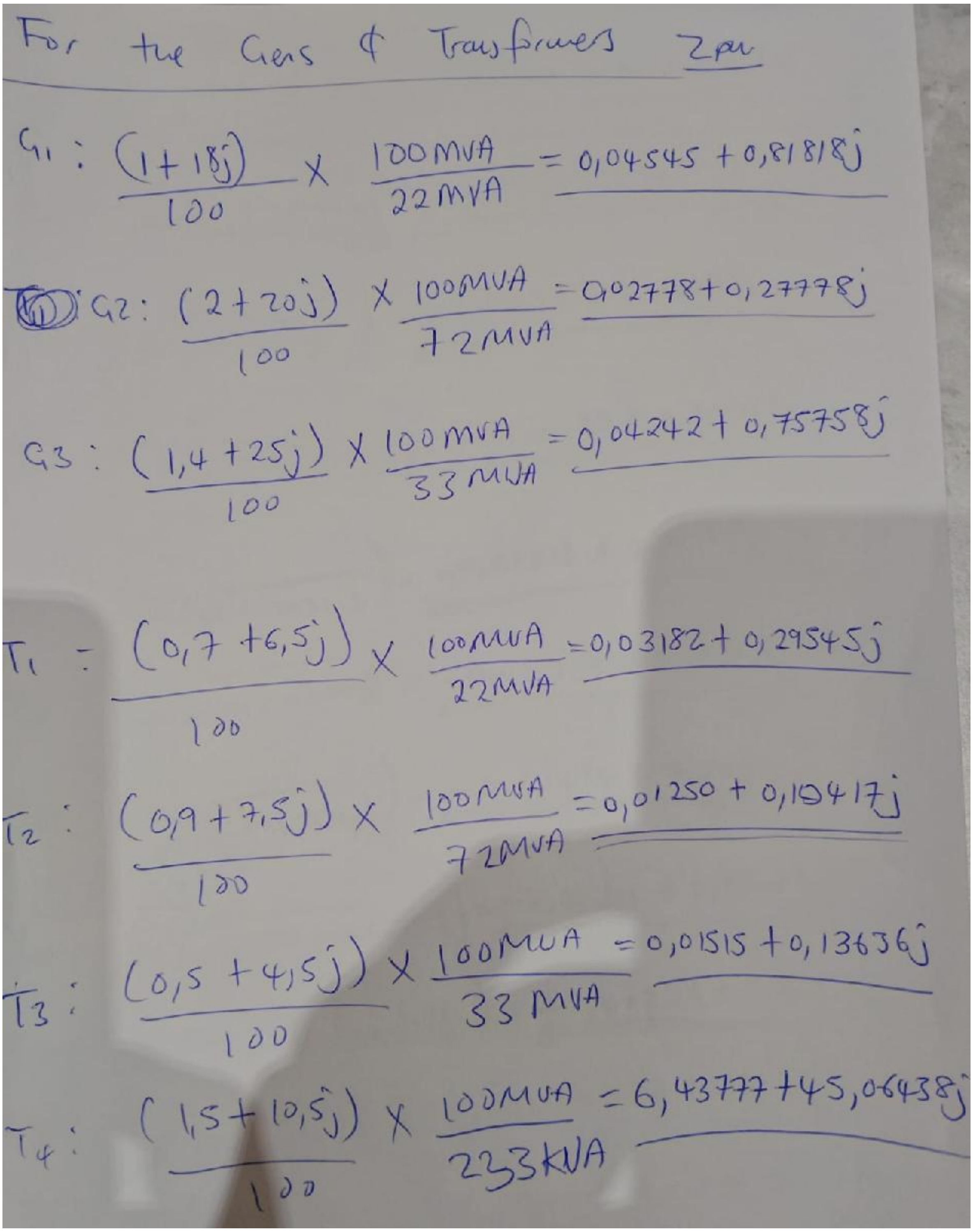
For generators and transformers, the given percentage impedances were first divided by 100 to convert to per-unit, then adjusted to the common base using:

$$Zpu_{new} = Zpu_{rated} * \left(\frac{Sbase_{new}}{Srated}\right) \ldots (2)$$

Where:

- Zpu_{new} is the calculated common base per-unit impedance
- Zpu_{rated} is the given percentage impedance divided by 100
- $Sbase_{new}$ is the chosen base power (100 MVA)
- $Sbase_{rated}$ is the component's rated MVA value

The figures below show my calculations for these component impedances:



For the Gens & Transformers Zpu

$G_1: \frac{(1+18j)}{100} \times \frac{100MVA}{22MVA} = 0{,}04545 + 0{,}81818j$

$G2: \frac{(2+20j)}{100} \times \frac{100MVA}{72MVA} = 0{,}02778 + 0{,}27778j$

$G3: \frac{(1{,}4+25j)}{100} \times \frac{100MVA}{33MVA} = 0{,}04242 + 0{,}75758j$

$T_1: \frac{(0{,}7+6{,}5j)}{100} \times \frac{100MVA}{22MVA} = 0{,}03182 + 0{,}29545j$

$T_2: \frac{(0{,}9+7{,}5j)}{100} \times \frac{100MVA}{72MVA} = 0{,}01250 + 0{,}10417j$

$T3: \frac{(0{,}5+4{,}5j)}{100} \times \frac{100MVA}{33MVA} = 0{,}01515 + 0{,}13636j$

$T_4: \frac{(1{,}5+10{,}5j)}{100} \times \frac{100MVA}{233kVA} = 6{,}43777 + 45{,}06438j$

Figure 5: Generator and Transformer Impedance Calculations

Summary of the calculated common base pu parameters:

Common Base	100MVA		
Line	**New Impedance**	**Generator/ Transforme**	**New Impedance**
Line 5 - 4	0.11475 + 1.00436i	G1	0.04545 +0.81818i
Line 5 - 6	0.16644 + 1.29132i	G2	0.02778 + 0.27778i
Line 6 - 4	0.04591 + 0.87810i	G3	0.04242 + 0.75758i
Line 7 - 8	0.82645 + 3.55372i	T1	0.03182 + 0.29545i
Line 8 - 9	2.47934 + 7.10744i	T2	0.01250 + 0.10417i
Line 9 - 10	1.65289 + 5.12397i	T3	0.01515 + 0.13636i
Line 10 - 11	0.82645 +3.14050i	T4	6.43777 + 45.06438i
Line 8 - 11	0.99174 + 4.21488i		

Figure 6: Summary of Network impedances adjust to the common base per unit

Note: *I performed my hand calculations to 5 decimal places, this would improve the accuracy of my model as well as its correlation with the MATLAB results.*

3. Developing the Network Diagram

Figure 7 shows the network diagram as designed in PowerWorld. The impedances calculated in the previous section are then used to model the actual power system. Since all the impedances have been adjusted to the common base pu, all generators in the model have been modelled at 100 MVA generator MVA base. Also note that the ‘load’ appearing in Figure 7 is only illustrative (and is set to 0 W, 0 Mvar).

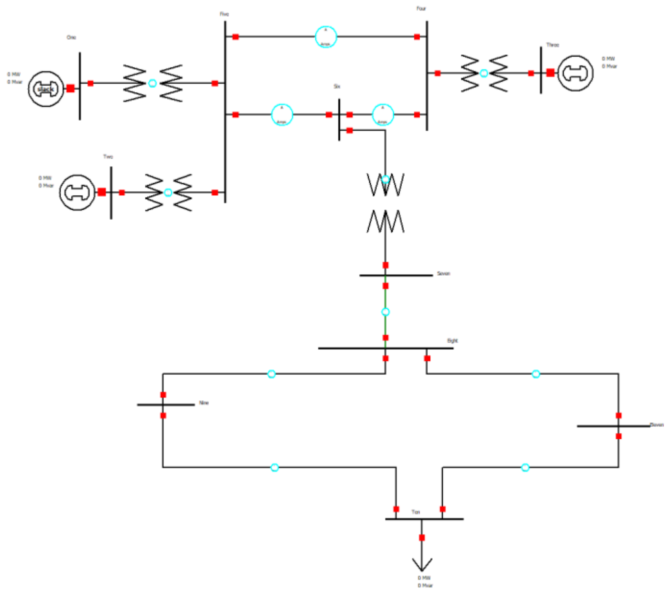


Figure 7: The Network Diagram in PowerWorld Simulator

Each bus bar is set to the actual voltage provided in the assignment brief (refer to transformer primary and secondary voltages as well as the volage ratings for the lines in Figure 2) i.e. :

- Bus bar 1 : 12 kV (system slack)
- Bus bar 2 : 13.8 kV
- Bus bar 3 : 20 kV
- Bus bar 4, 5, 6 : 132 kV
- Bus bar 6 – 11 : 11 kV

After configuring the bus bars, the rest of the components were placed and modelled accordingly. Note also, that bus bar 1 was set as the system slack bus.

3.1. Modelling Generators

The important generator parameters to adjust were the 'generator base MVA' and the 'positive sequence impedances' under the 'fault parameters' tab.

Generator 1:

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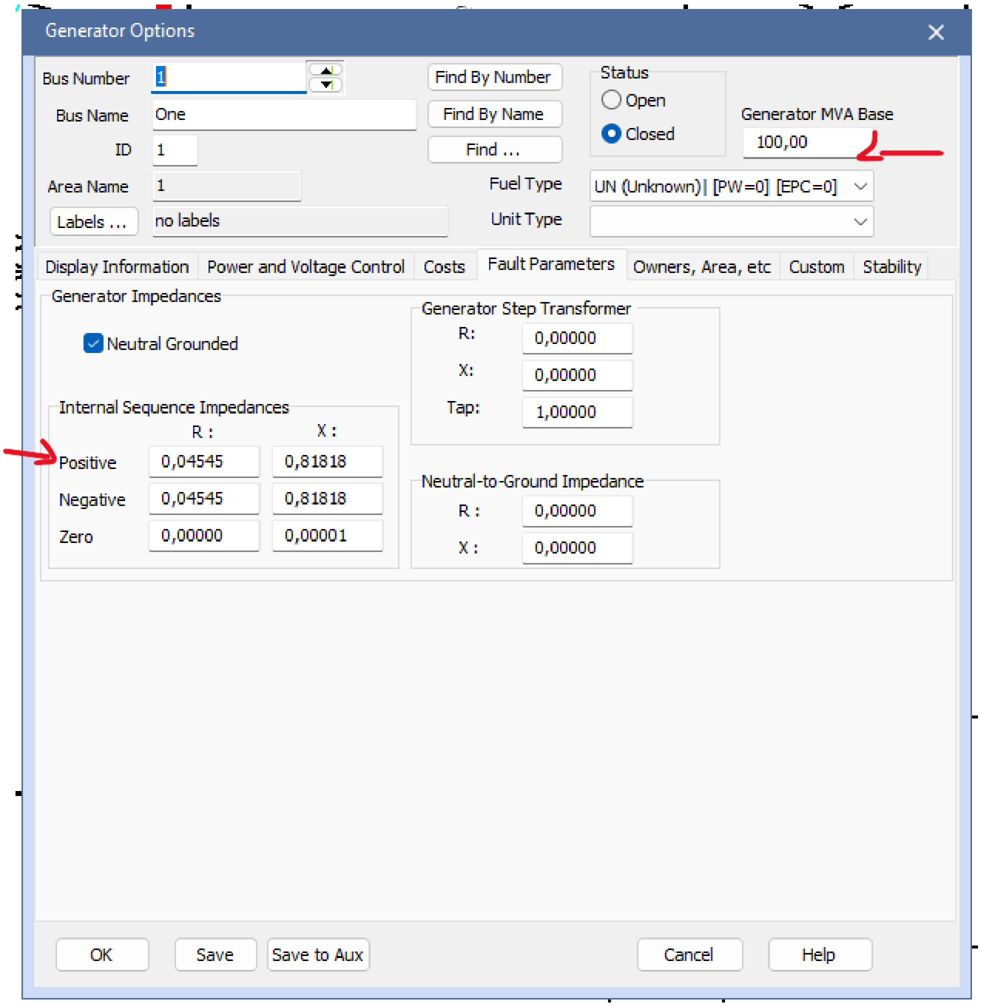

Figure 8: Modelling generator 1. Important parameters marked in red.

Generator 2:

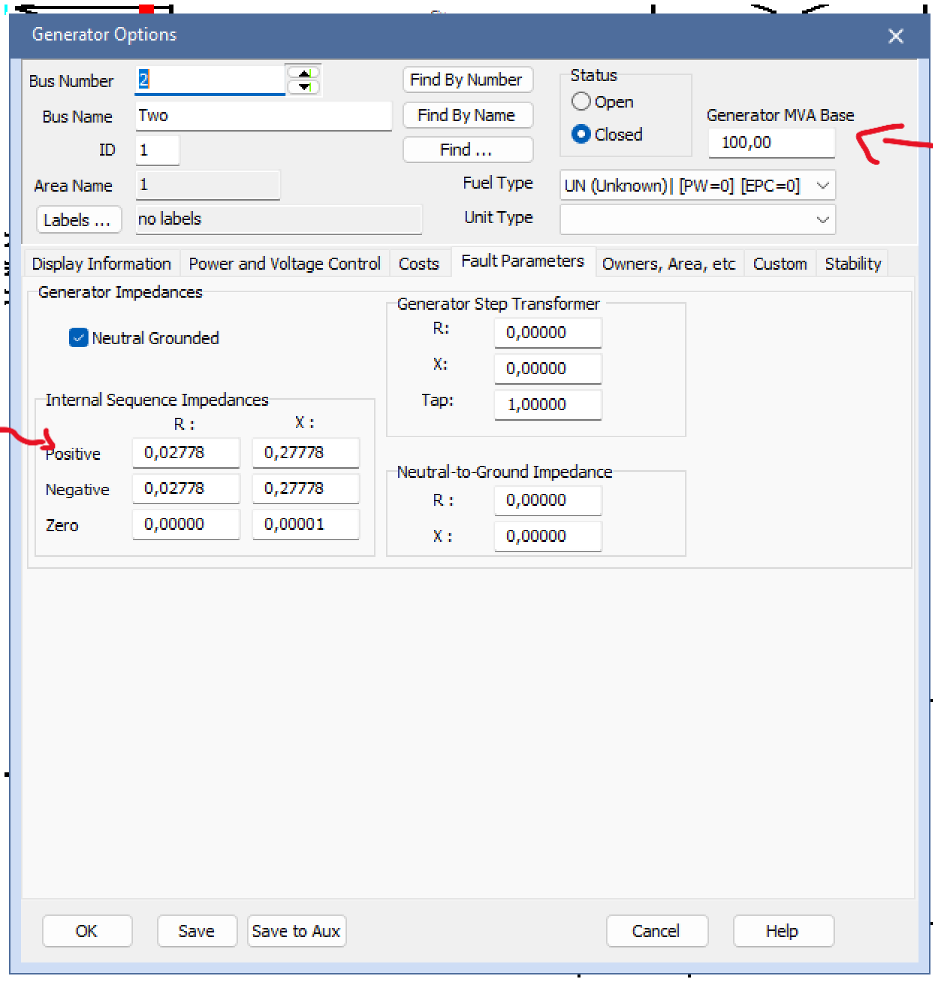

Figure 9: Modelling generator 2. Important parameters marked in red.

Generator 3:

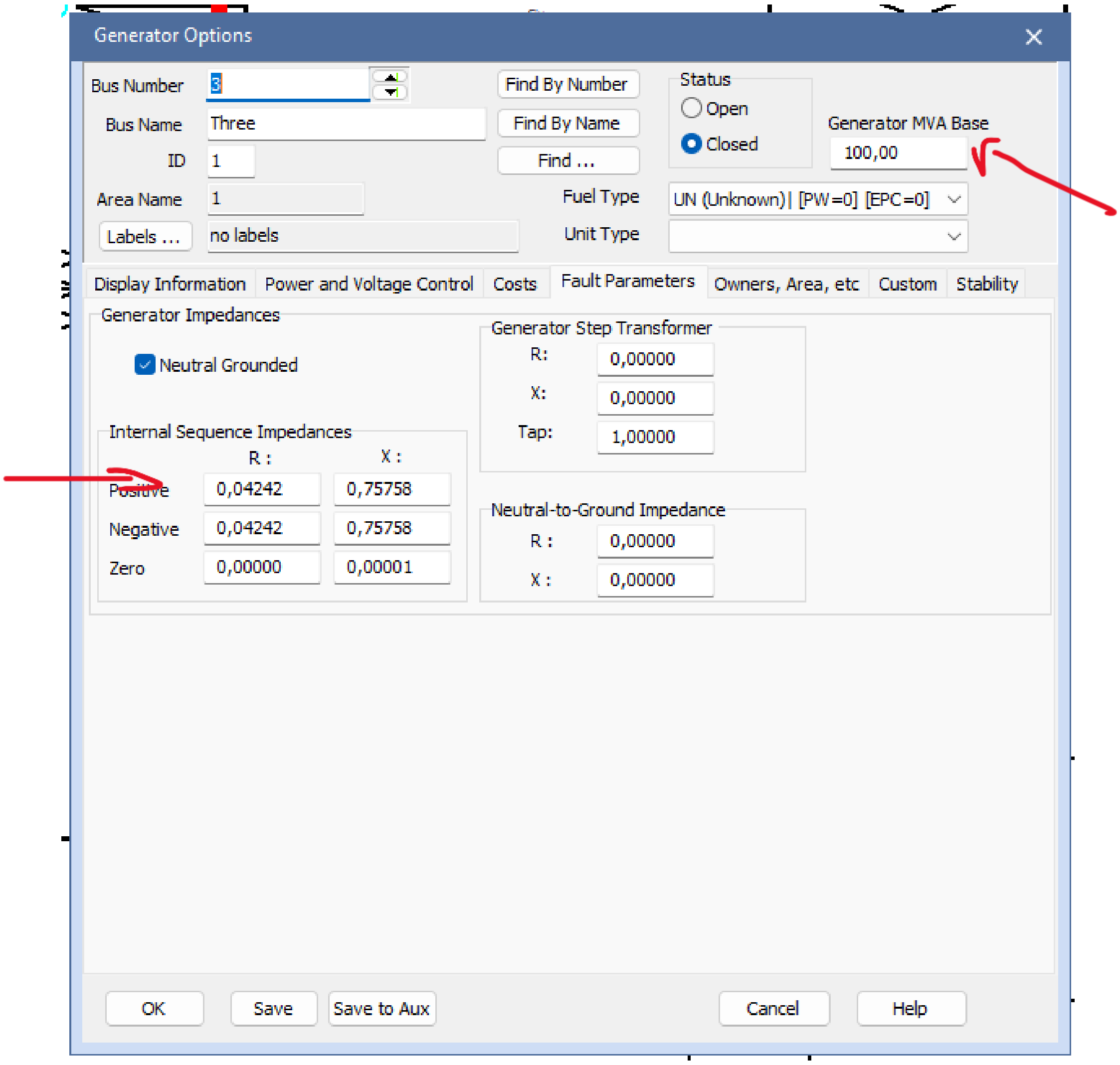

Figure 10: Modelling generator 3. Important parameters marked in red.

3.2. Modelling Transformers

For transformers the important parameters to adjust were:

- Parameters tab: ‘Per Unit impedance Parameters’ (set the calculated ‘Series Resistance (R) and ‘Series Reactance (X).
- Nominal kV: Setting the “From Bus” and the “To Bus” voltages according to the bus bars to which the transformer is connected.

MVA limits were not set, hence all values under this tab are 0s.

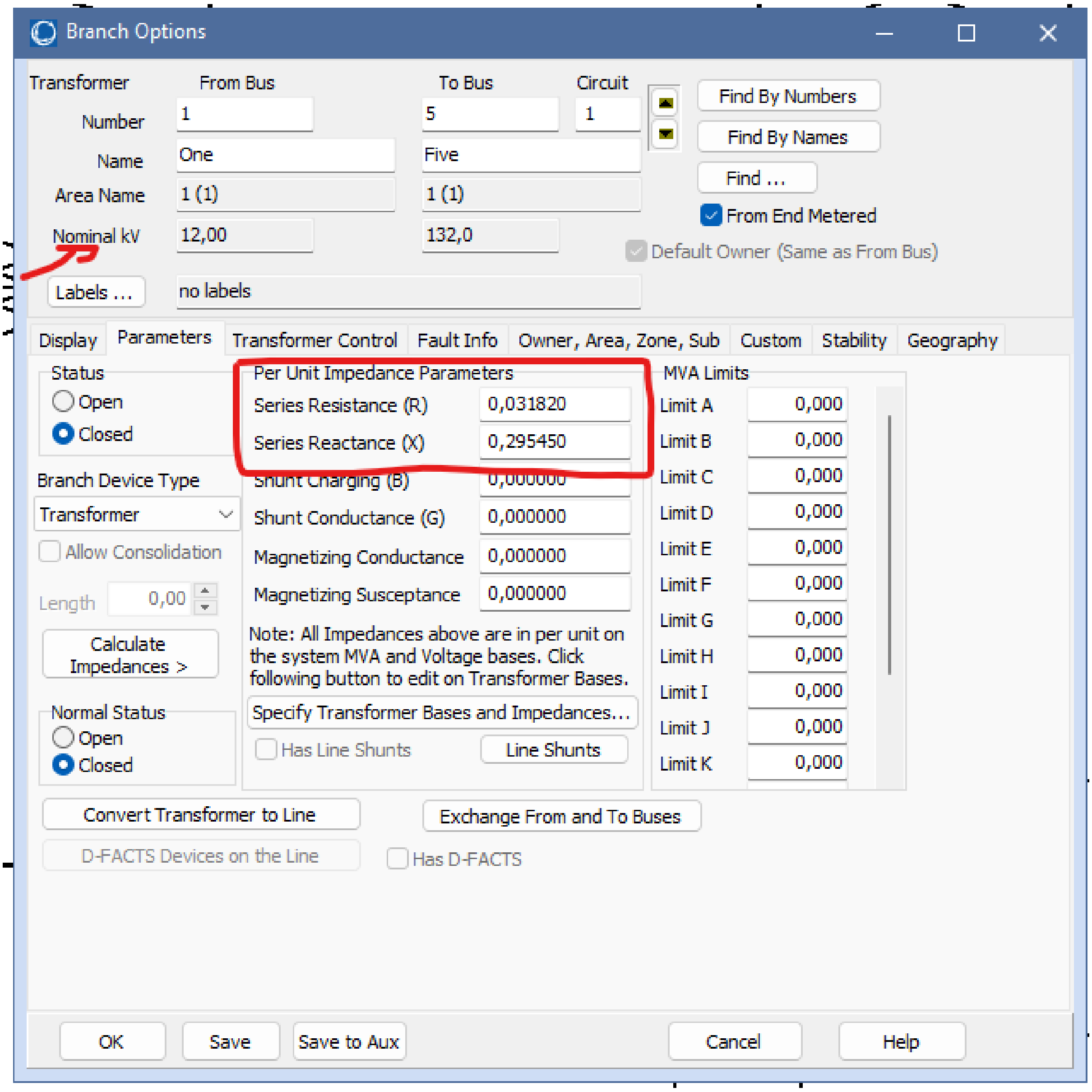

Figure 11: Transformer 1 parameter configuration. Important parameters are highlighted in red

The same procedure was followed for the rest of the transformers in the network.

3.3. Modelling Transmission lines

For transmission lines, the important parameters were:

- The nominal voltage
- Parameters tab: ‘Per Unit Impedance parameters’ (adjusting the ‘Series Resistance (R)’ and the ‘Series Reactance (X)’

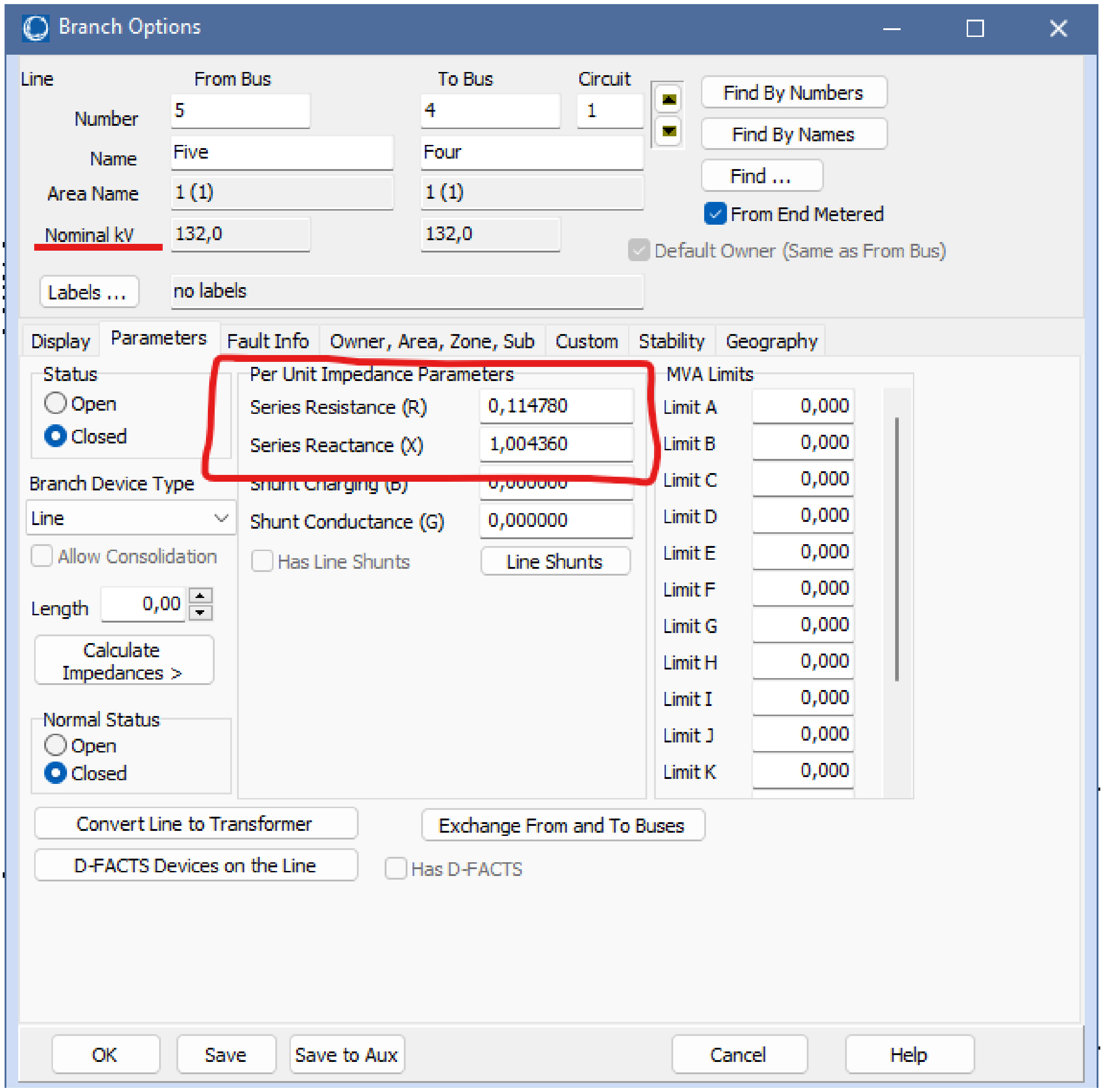

Figure 12: Configuring parameters for line 5 -4. The important parameters are highlighted in red

Again, no MVA limits were set for the lines, and this procedure was repeated for all the line in the network.

Once all the parameters were set. The 'case' was set to 'Run Mode' and the system/network was simulated. The following sections show various simulation results and how they correlate with the MATLAB calculations from Class Test 1.

4. Ybus Confirmation

In ‘Run Mode’, under the ‘Tools’ tab, under ‘Fault Analysis’, under ‘Single Fault’, various fault analysis tools can be explored. Under the ‘Y-Bus matrices’ tab, when the calculate button is clicked on, the network’s Y-bus matrix is displayed. Figure 13 shows the generated Y-Bus matrix.

	Number	Name	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11
1	1	One	0,43 - j4,56				-0,36 + j3,35						
2	2	Two		1,49 - j13,03			-1,14 + j9,46						
3	3	Three			0,88 - j8,56	-0,80 + j7,24							
4	4	Four			-0,80 + j7,24	0,98 - j9,36	-0,11 + j0,98	-0,06 + j1,14					
5	5	Five	-0,36 + j3,35	-1,14 + j9,46		-0,11 + j0,98	1,71 - j14,55	-0,10 + j0,76					
6	6	Six				-0,06 + j1,14	-0,10 + j0,76	0,16 - j1,92	-0,00 + j0,02				
7	7	Seven						-0,00 + j0,02	0,07 - j0,29	-0,06 + j0,27			
8	8	Eight							-0,06 + j0,27	0,16 - j0,62	-0,04 + j0,13		-0,05 + j0,22
9	9	Nine								-0,04 + j0,13	0,10 - j0,30	-0,06 + j0,18	
10	10	Ten									-0,06 + j0,18	0,14 - j0,47	-0,08 + j0,30
11	11	Eleven								-0,05 + j0,22		-0,08 + j0,30	0,13 - j0,52

Figure 13: Y-Bus matrix generated in PowerWorld simulator.

Figure 14 shows the Y-bus matrix generated in MATLAB based on hand calculated admittances.

Test1_220702330.mlx | Ybus = 11×11 complex

	1	2	3	4	5	6	7	8	9	10	11
1	0.4280 - 4.5643i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	-0.3604 + 3.3459i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i
2	0.0000 + 0.0000i	1.4920 -13.0277i	0.0000 + 0.0000i	0.0000 + 0.0000i	-1.1356 + 9.4634i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i
3	0.0000 + 0.0000i	0.0000 + 0.0000i	0.8785 - 8.5600i	-0.8048 + 7.2441i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i
4	0.0000 + 0.0000i	0.0000 + 0.0000i	-0.8048 + 7.2441i	0.9765 - 9.3627i	-0.1123 + 0.9828i	-0.0594 + 1.1357i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i
5	-0.3604 + 3.3459i	-1.1356 + 9.4634i	0.0000 + 0.0000i	-0.1123 + 0.9828i	1.7064 -14.5539i	-0.0982 + 0.7618i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i
6	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	-0.0594 + 1.1357i	-0.0982 + 0.7618i	0.1607 - 1.9192i	-0.0031 + 0.0217i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i
7	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	-0.0031 + 0.0217i	0.0652 - 0.2887i	-0.0621 + 0.2670i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i
8	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	-0.0621 + 0.2670i	0.1587 - 0.6172i	-0.0438 + 0.1254i	0.0000 + 0.0000i	-0.0529 + 0.2248i
9	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	-0.0438 + 0.1254i	0.1008 - 0.3022i	-0.0570 + 0.1768i	0.0000 + 0.0000i
10	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	-0.0570 + 0.1768i	0.1354 - 0.4746i	-0.0784 + 0.2978i
11	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	-0.0529 + 0.2248i	0.0000 + 0.0000i	-0.0784 + 0.2978i	0.1313 - 0.5226i

Figure 14: Y-Bus matrix generated in MATLAB based on hand calculations of Y

Figure 15 shows the how much the % difference between the two sets of results.

$$diff_{percent} = abs\left(\frac{PowerWorld_{YBus} - MATLAB_{YBus}}{PowerWorld_{YBus}}\right) * 100$$

Table 3: Percentage Difference Between PowerWorld and MATLAB Y-Bus Matrices

	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11
Bus 1	0.10357	0	0	0	0.12331	0	0	0	0	0	0
Bus 2	0	0.023107	0	0	0.058716	0	0	0	0	0	0
Bus 3	0	0	0.017201	0.087171	0	0	0	0	0	0	0
Bus 4	0	0	0.087171	0.046309	0.3703	0.37883	0	0	0	0	0
Bus 5	0.12331	0.058716	0	0.3703	0.035889	0.32938	0	0	0	0	0
Bus 6	0	0	0	0.37883	0.32938	0.053765	17.843	0	0	0	0
Bus 7	0	0	0	0	0	17.843	1.6702	1.3318	0	0	0
Bus 8	0	0	0	0	0	0	1.3318	0.47952	4.351	0	2.4895
Bus 9	0	0	0	0	0	0	0	4.351	0.73813	2.3162	0
Bus 10	0	0	0	0	0	0	0	0	2.3162	1.3222	0.88187
Bus 11	0	0	0	0	0	0	0	2.4895	0	0.88187	0.54071

Figure 15: Tabulation of % differences between the PowerWorld and MATLAB Y-buses

Figure 16 tabulates the correlation values for the same sets of results.

$$correlation_{percent} = 100 - diff_{percent}$$

Table 4: Correlation Percentage Between PowerWorld and MATLAB Y-Bus Matrices

	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11
Bus 1	99.896	100	100	100	99.877	100	100	100	100	100	100
Bus 2	100	99.977	100	100	99.941	100	100	100	100	100	100
Bus 3	100	100	99.983	99.913	100	100	100	100	100	100	100
Bus 4	100	100	99.913	99.954	99.63	99.621	100	100	100	100	100
Bus 5	99.877	99.941	100	99.63	99.964	99.671	100	100	100	100	100
Bus 6	100	100	100	99.621	99.671	99.946	82.157	100	100	100	100
Bus 7	100	100	100	100	100	82.157	98.33	98.668	100	100	100
Bus 8	100	100	100	100	100	100	98.668	99.52	95.649	100	97.51
Bus 9	100	100	100	100	100	100	100	95.649	99.262	97.684	100
Bus 10	100	100	100	100	100	100	100	100	97.684	98.678	99.118
Bus 11	100	100	100	100	100	100	100	97.51	100	99.118	99.459

Figure 16: Tabulation of the correlation between the two sets of values

Figure 17 gives a more intuitive heatmap of the correlation which makes analysis easier.

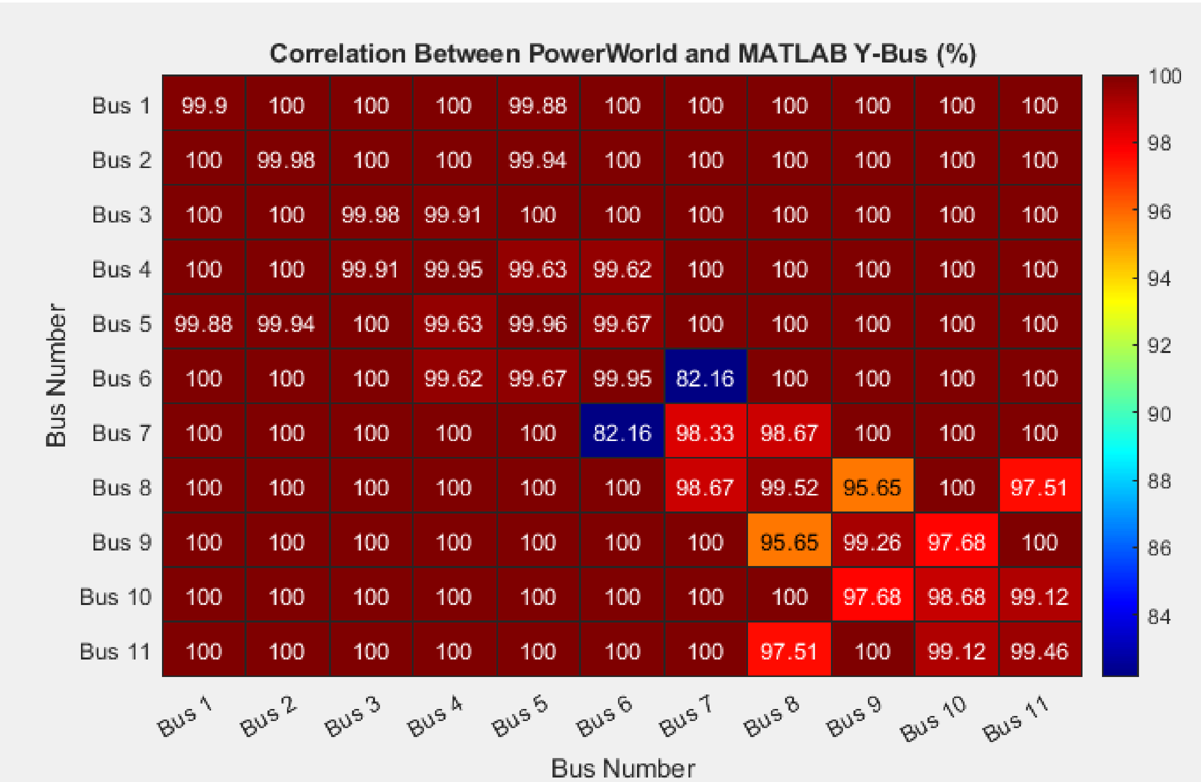

Figure 17: PowerWorld and MATLAB Ybus correlation Heatmap

Summary of results:

- Maximum percentage difference: 17.842786%
- Average percentage difference: 0.546713%
- Minimum correlation: 82.157214%
- Average correlation: 99.453287%

The outlier at Y-Bus(6,7) is due to the precision between the two software, where the MATLAB value is $-0.0031 + 0.0217i$ and that from PowerWorld is $0.00 + 0.02i$.

PowerWorld tend to round to 2 decimal places which might have tremendous negative effects on the accuracy of the model in representing the actual network especially when dealing with very small numbers like $-0.0031 + 0.0217i$ (at the scale $\leq 10^{-3}$). This is also evident on all the non-zero elements of the Ybus matrix; none of them have a correlation of 100%. This is due to the less precision of the PowerWorld Simulator.

Overall, the PowerWorld and MATLAB Y-Bus matrices are well correlated (>99%) which confirms good Ybus hand and MATLAB calculations as well as a good simulation in PowerWorld Simulator.

5. Fault Currents and Voltage Confirmation

In 'Run Mode', under the 'Tools' tab, under 'Fault Analysis', under 'Single Fault', under the 'Bus Records' tab, when the calculate button is clicked on, network's voltage profile when there is a fault at the selected bus is displayed in pu. Corresponding fault currents are displayed at the top right of the window and can be toggled between pu and Amps values. Figure 18 shows the interface.

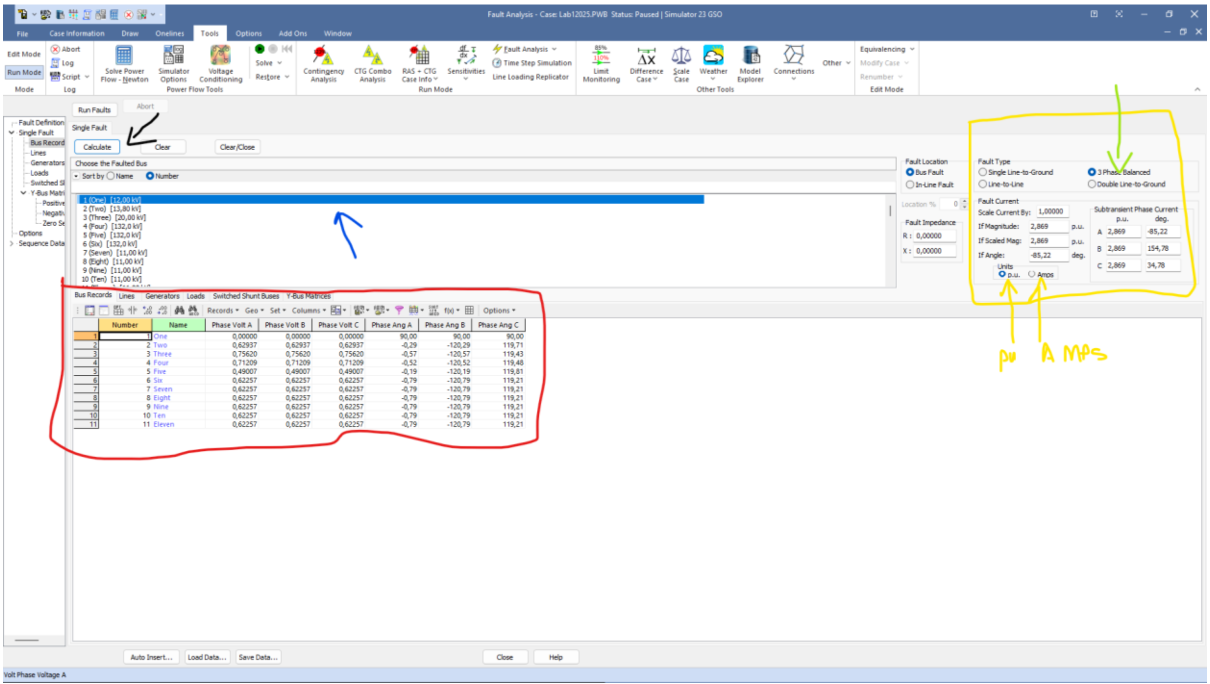

Figure 18: The PowerWorld Interface to explore fault currents and voltages. The Blue arrow shows the current selected bus. The red box highlights where the fault voltage profile for the network when there is a fault at the selected bus is displayed. The back arrow point to the "calculate" button which is pressed every time the user moves to a new bus and wants to calculate that bus's faults. The yellow box is where the fault currents are displayed when user presses the calculate button, the yellow arrows point to the toggle buttons to switch between pu and Amps values. The green arrow highlights an important setting which must be selected since this assignment is investigating 3 phase balanced faults.

Figure 19 tabulates the fault currents in pu obtained from the PowerWorld Simulator.

Table 1: PowerWorld Fault Currents (per unit)

	PowerWorld_Ifault_pu
Bus 1	2.869
Bus 2	4.898
Bus 3	2.215
Bus 4	2.14
Bus 5	4.13
Bus 6	1.255
Bus 7	0.022
Bus 8	0.02
Bus 9	0.018
Bus 10	0.018
Bus 11	0.019

Figure 19: Per Unit Fault currents at all the bus bars, as simulated in PowerWorld Simulator

Figure 20 shows the corresponding pu MATLAB values.

Table 2: MATLAB Fault Currents (per unit)

	MATLAB_Ifault_pu
Bus 1	2.8687
Bus 2	4.8977
Bus 3	2.2152
Bus 4	2.14
Bus 5	4.1295
Bus 6	1.255
Bus 7	0.021572
Bus 8	0.020002
Bus 9	0.018281
Bus 10	0.018267
Bus 11	0.018727

Figure 20: Per Unit Fault Currents as calculated in MATLAB

Figure 21 shows the percentage difference between the two sets of values.

Table: Percentage Difference for Fault Currents (per unit)

	Difference_Percent
Bus 1	0.01082
Bus 2	0.0065901
Bus 3	0.010947
Bus 4	0.0017102
Bus 5	0.011453
Bus 6	4.0477e-05
Bus 7	1.9433
Bus 8	0.0098141
Bus 9	1.5596
Bus 10	1.4815
Bus 11	1.4367

Figure 21: % difference between the MATLAB value and the PowerWorld Simulator per unit fault currents for each bus

Figure 22 shows the percentage correlation between the two sets of values as well.

Table: Correlation for Fault Currents (per unit)

	Correlation_Percent
Bus 1	99.989
Bus 2	99.993
Bus 3	99.989
Bus 4	99.998
Bus 5	99.989
Bus 6	100
Bus 7	98.057
Bus 8	99.99
Bus 9	98.44
Bus 10	98.519
Bus 11	98.563

Figure 22: % correlation between the MATLAB calculated per unit fault currents and those calculated by the PowerWorld Simulator

Therefore, for the fault currents values;

Summary of results:

- Maximum Difference: 1.943255%
- Average Difference: 0.588406%
- Minimum Correlation: 98.056745%
- Average Correlation: 99.411594%

Figure 23 gives an intuitive summarised visualisation of these results:

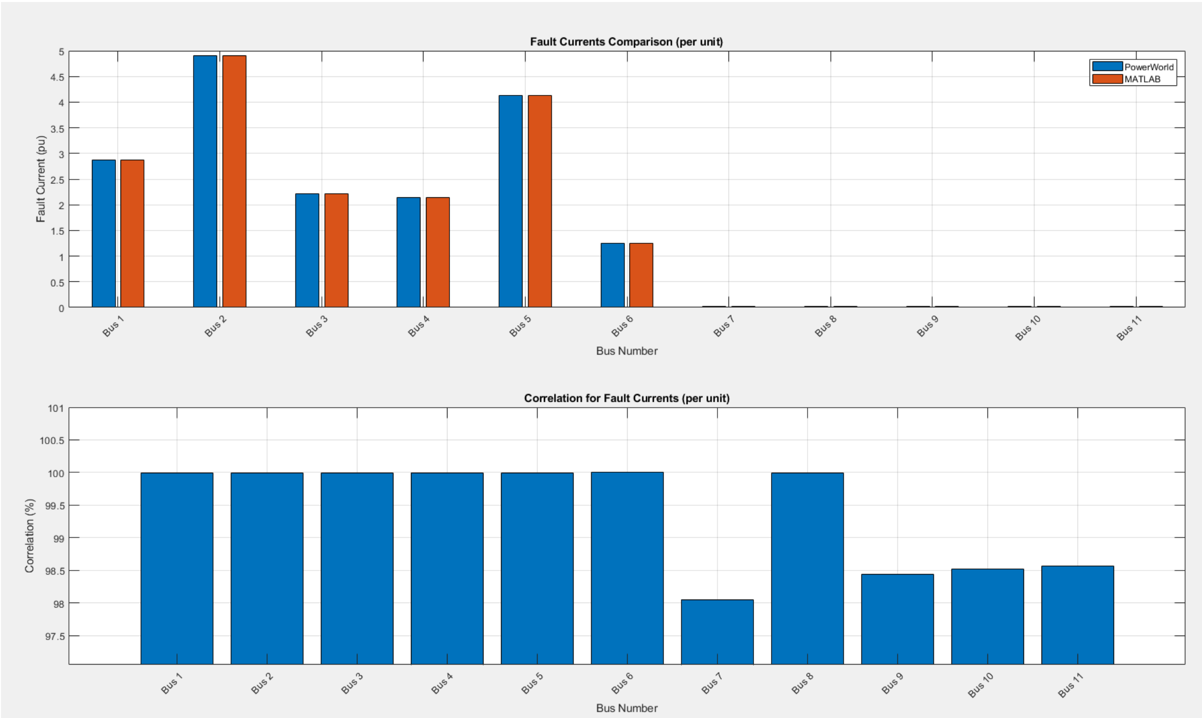

Figure 23: Per Unit fault currents comparison and correlation visualisation

The same process was repeated for actual current values (in PowerWorld this is achieved by toggling the radio buttons highlighted in Figure 18). The resulting values for PowerWorld were tabulated in Figure 24 below.

Table 3: PowerWorld Fault Currents (Amps)

	PowerWorld_Ifault_Amps
Bus 1	13802
Bus 2	20490
Bus 3	6394.9
Bus 4	936.03
Bus 5	1806.2
Bus 6	548.93
Bus 7	113.32
Bus 8	105.07
Bus 9	96.028
Bus 10	95.958
Bus 11	98.375

Figure 24: Actual Fault Current in Amperes as calculated by PowerWorld

The corresponding MATLAB values are tabulated in Figure 25.

Table 4: MATLAB Fault Currents (Amps)

	MATLAB_Ifault_Amps
Bus 1	13802
Bus 2	20490
Bus 3	6394.9
Bus 4	936.02
Bus 5	1806.2
Bus 6	548.92
Bus 7	113.23
Bus 8	104.98
Bus 9	95.949
Bus 10	95.875
Bus 11	98.291

Figure 25: Actual fault currents in Amps calculated in MATLAB

Figure 26 tabulates the % difference between these two sets of values for each bus.

Table: Percentage Difference for Fault Currents (Amps)

	Difference_Percent
Bus 1	7.8857e-05
Bus 2	0.0019543
Bus 3	0.00040372
Bus 4	0.00071986
Bus 5	0.00057372
Bus 6	0.0023018
Bus 7	0.081032
Bus 8	0.083678
Bus 9	0.0823
Bus 10	0.08637
Bus 11	0.085023

Figure 26: % difference between the MATLAB and PowerWorld sets of actual fault currents results.

And then Figure 27 tabulates the % correlation between the two sets of results:

Table: Correlation for Fault Currents (Amps)

	Correlation_Percent
Bus 1	100
Bus 2	99.998
Bus 3	100
Bus 4	99.999
Bus 5	99.999
Bus 6	99.998
Bus 7	99.919
Bus 8	99.916
Bus 9	99.918
Bus 10	99.914
Bus 11	99.915

Figure 27: % correlation between actual fault currents from PowerWorld and MATLAB.

Summary of actual fault currents results:

- Maximum Difference: 0.086370%
- Average Difference: 0.038585%
- Minimum Correlation: 99.913630%
- Average Correlation: 99.961415%

This set of results show better correlation that those of per unit values. This is attributed to PowerWorld's precision, which is more accurate when working with large numbers and not so reliable when working with very small numbers (like 10^{-3} scale for per unit values e.g. at bus 7 in Figure 23 where correlation is below 99%).

Figure 28 gives a clear visualization to summarize these results.

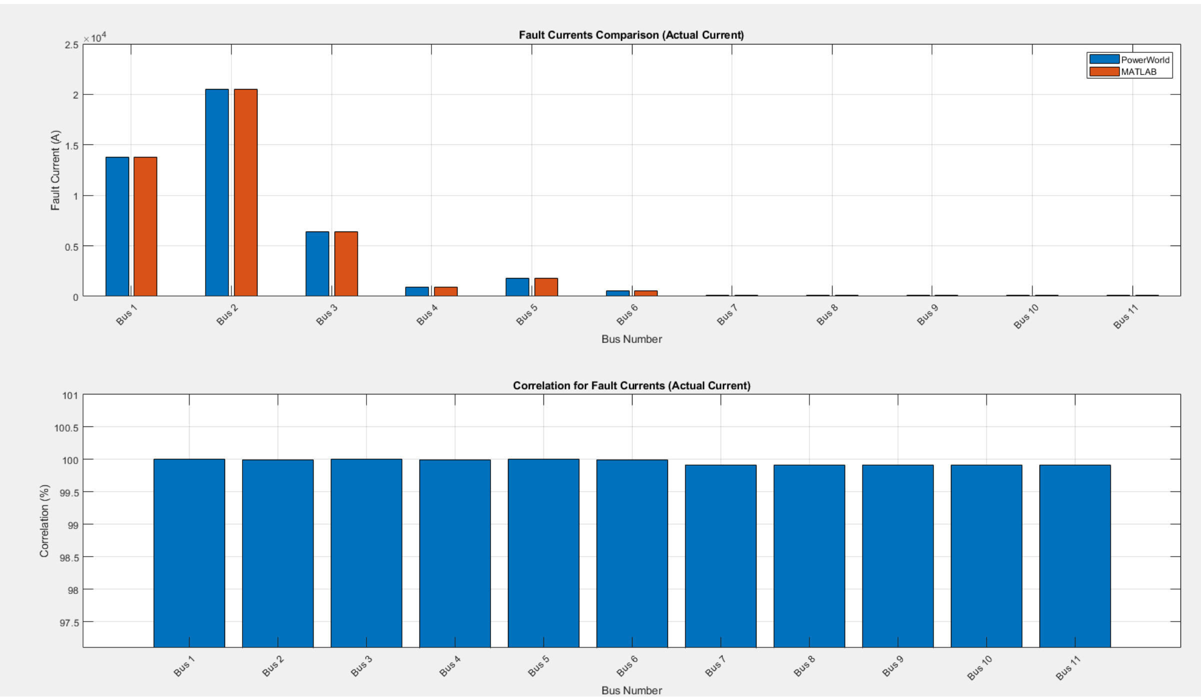

Figure 28: Actual fault comparison and correlation graphs between PowerWorld and MATLAB calculated results

After all the recording all the voltage profiles for faults at all the buses separately, figure 29 tabulates the voltage profiles from PowerWorld simulator, while Figure 30 tabulates those obtained from MATLAB in Class Test 1.

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PowerWorld Fault Voltage Profiles (per unit):

Each column represents the voltage profile when there is a fault at that bus

	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11
Bus 1	0	0.62937	0.7562	0.71209	0.49007	0.62257	0.62257	0.62257	0.62257	0.62257	0.62257
Bus 2	0.36753	0	0.58798	0.51341	0.13805	0.36226	0.36226	0.36226	0.36226	0.36226	0.36226
Bus 3	0.81168	0.81349	0	0.1232	0.74338	0.37328	0.37328	0.37328	0.37328	0.37328	0.37328
Bus 4	0.78522	0.78728	0.15316	0	0.70732	0.28533	0.28533	0.28533	0.28533	0.28533	0.28533
Bus 5	0.2662	0.27317	0.52195	0.43545	0	0.26009	0.26009	0.26009	0.26009	0.26009	0.26009
Bus 6	0.8349	0.83647	0.64482	0.58072	0.775	0	0	0	0	0	0
Bus 7	0.99717	0.99719	0.9939	0.99279	0.99614	0.98282	0	0	0	0	0
Bus 8	0.99738	0.9974	0.99434	0.99332	0.99642	0.98408	0.07304	0	0	0	0
Bus 9	0.9976	0.99763	0.99483	0.9939	0.99673	0.98546	0.15377	0.08714	0	0.03622	0.05805
Bus 10	0.99761	0.99763	0.99484	0.9939	0.99673	0.98547	0.15403	0.08736	0.03643	0	0.03744
Bus 11	0.99754	0.99757	0.99471	0.99375	0.99665	0.9851	0.13241	0.06403	0.03421	0.01287	0

Figure 29: Per unit fault voltage profiles for all bus bars as calculated from PowerWorld

MATLAB Fault Voltage Profiles (per unit):

Each column represents the voltage profile when there is a fault at that bus

	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11
Bus 1	9.9182e-18	0.62936	0.7562	0.71209	0.49007	0.62256	0.6222	0.62219	0.62218	0.62217	0.62218
Bus 2	0.36752	0	0.58798	0.51341	0.13804	0.36225	0.36165	0.36162	0.3616	0.36159	0.3616
Bus 3	0.81168	0.81349	0	0.1232	0.74338	0.37327	0.37266	0.37263	0.37261	0.3726	0.37261
Bus 4	0.78521	0.78728	0.15316	0	0.70732	0.28531	0.28461	0.28458	0.28456	0.28454	0.28455
Bus 5	0.2662	0.27317	0.52195	0.43544	0	0.26008	0.25938	0.25935	0.25933	0.25932	0.25933
Bus 6	0.8349	0.83647	0.64482	0.58072	0.775	0	0.0010188	0.001069	0.0011009	0.0011237	0.0011105
Bus 7	0.99717	0.99719	0.9939	0.99279	0.99614	0.98282	0	5.1602e-05	8.2544e-05	0.00010512	9.4961e-05
Bus 8	0.99737	0.9974	0.99434	0.99332	0.99642	0.98407	0.073019	0	3.1936e-05	5.4773e-05	4.3444e-05
Bus 9	0.9976	0.99763	0.99483	0.9939	0.99673	0.98546	0.15371	0.087102	0	0.036173	0.058001
Bus 10	0.9976	0.99763	0.99484	0.9939	0.99673	0.98546	0.15399	0.087339	0.036421	0	0.037432
Bus 11	0.99754	0.99757	0.9947	0.99375	0.99665	0.98509	0.13237	0.064012	0.03418	0.012845	0

Figure 30: per unit fault voltage profiles for all buses as from MATLAB calculations

Figure 31 and Figure 32 tabulates the % differences and % correlations between the two sets of values respectively.

Table: Percentage Difference for Fault Voltage Profiles (per unit)

	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11
Bus 1	0	0.00082061	0.0005499	0.00023644	0.00069351	0.00083694	0.058696	0.061292	0.063158	0.064483	0.063343
Bus 2	0.0018406	0	3.9958e-05	0.00054004	0.0044118	0.0038176	0.16963	0.17699	0.18236	0.18616	0.18278
Bus 3	0.00039555	0.00041519	0	0.0005409	8.2818e-05	0.0023454	0.1668	0.17435	0.17962	0.18336	0.18037
Bus 4	0.0008176	0.00026705	0.00015068	0	0.00019279	0.0058527	0.2523	0.26366	0.27154	0.27715	0.27274
Bus 5	0.0011753	0.001264	0.00080308	0.0020128	0	0.0038264	0.27122	0.28307	0.29172	0.29786	0.29238
Bus 6	0.00053313	0.0004279	7.8251e-05	0.00069172	0.00016143	0	0	0	0	0	0
Bus 7	0.00030188	0.00029823	0.00037705	0.00012607	0.00032793	0.00030253	0	0	0	0	0
Bus 8	0.00054879	0.00015367	0.00022779	0.00023637	5.7404e-05	0.00072576	0.028521	0	0	0	0
Bus 9	0.00036235	0.00048319	0.00036426	0.00027524	0.00012119	0.00034498	0.040989	0.04362	0	0.13103	0.083588
Bus 10	0.00054018	0.00037752	0.00037095	6.1082e-05	0.00027262	0.00060546	0.027003	0.024294	0.023551	0	0.022268
Bus 11	0.00032273	0.00045214	0.00053069	0.00046172	8.1269e-05	0.00066596	0.028406	0.028772	0.087803	0.1961	0

Figure 31: Voltage profile % difference between MATLAB and PowerWorld set of per unit fault voltage values

Table: Correlation for Fault Voltage Profiles (per unit)

	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11
Bus 1	100	99.999	99.999	100	99.999	99.999	99.941	99.939	99.937	99.936	99.937
Bus 2	99.998	100	100	99.999	99.996	99.996	99.83	99.823	99.818	99.814	99.817
Bus 3	100	100	100	99.999	100	99.998	99.833	99.826	99.82	99.817	99.82
Bus 4	99.999	100	100	100	100	99.994	99.748	99.736	99.728	99.723	99.727
Bus 5	99.999	99.999	99.999	99.998	100	99.996	99.729	99.717	99.708	99.702	99.708
Bus 6	99.999	100	100	99.999	100	100	100	100	100	100	100
Bus 7	100	100	100	100	100	100	100	100	100	100	100
Bus 8	99.999	100	100	100	100	99.999	99.971	100	100	100	100
Bus 9	100	100	100	100	100	100	99.959	99.956	100	99.869	99.916
Bus 10	99.999	100	100	100	100	99.999	99.973	99.976	99.976	100	99.978
Bus 11	100	100	99.999	100	100	99.999	99.972	99.971	99.912	99.804	100

Figure 32: % correlation between MATLAB and PowerWorld fault voltage profiles

For easier analysis, Figure 33 Visualises this correlation through a heatmap.

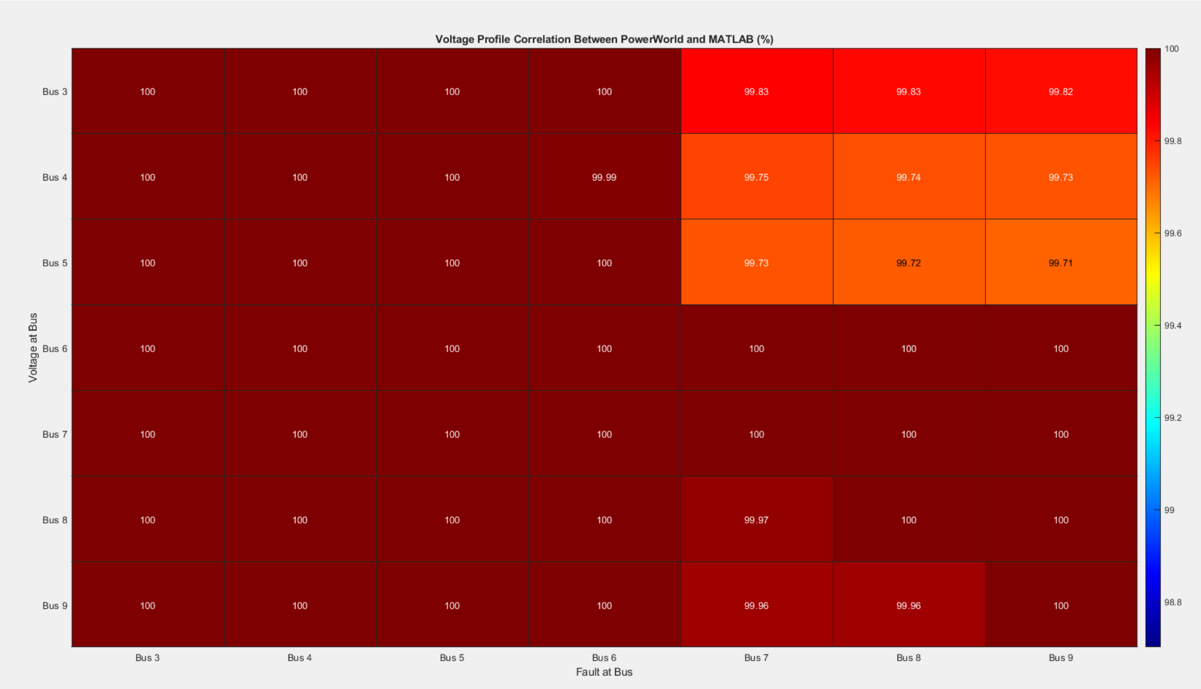

Figure 33: Heatmap visualising the % correlation between MATLAB and PowerWorld sets of results for the per unit fault voltage profiles for all the buses

Summary of results for per unit fault voltage profiles:

- Maximum Difference: 0.297858%
- Average Difference: 0.046935%
- Minimum Correlation: 99.702142%
- Average Correlation: 99.953065%

This set of results show the highest correlation (above 99%) for all the buses. The reason for this is that PowerWorld seems to do a good job when calculating per unit fault voltage profiles. As shown in Figure above, all fault voltage profile values are rounded to the nearest 5 decimal places which is the same precision that I used in my MATLAB file. Correlation was low however from bus 7 onwards where the fault voltages are relatively smaller than the rest of the network. However, this result (the correlation between my MATLAB calculations and PowerWorld calculations) is special because it signifies how accurate my MATLAB calculations are and that had PowerWorld been more precise in all it's readings, almost all the calculations would have a correlation of 100%.

There is no direct way to generate actual fault voltage profiles (in kV) in PowerWorld therefore, a comparison of actual fault voltages could not be conducted.

6. Generator Contribution Confirmation

In PowerWorld Simulator, in ‘Run Mode’, under the ‘Tools’ tab, under ‘Fault Analysis’, under ‘Single Fault’, under the ‘Generators’ tab, when the calculate button is clicked on, the network’s generators’ individual contribution to the selected bus’s fault current is displayed either in per unit or Amps (depending on the radio button selected in the fault current section at the top right corner). Figure 34 shows the PowerWorld interface under the ‘Generators’ tab when the selected bus is Bus 1.

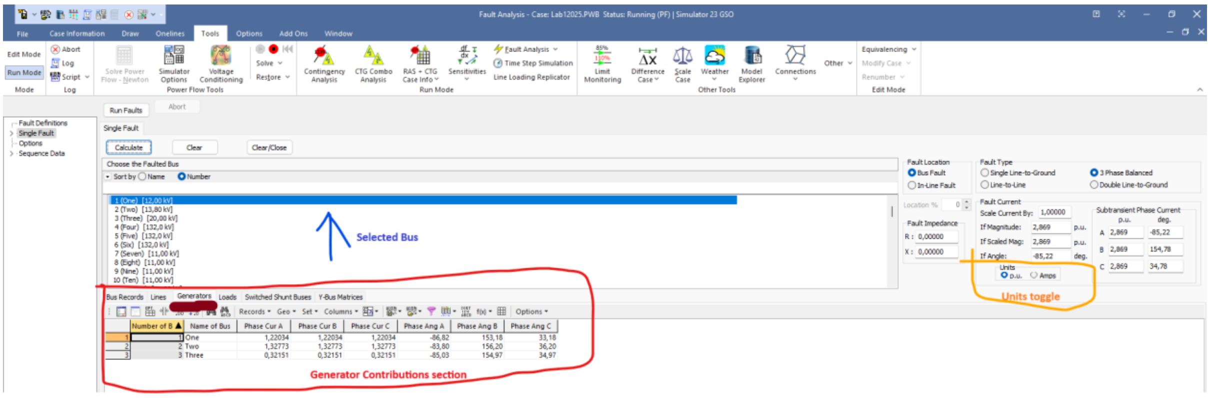

Figure 34: Getting generator contribution to fault currents at a selected bus (bus 1 in this case). The user must select a different bus to get the generators' contributions to that bus's fault current

After iterating this process for all the buses, Figure 35 summarises the generator contributions as obtained from PowerWorld both per unit and in Amperes.

PowerWorld Generator Contributions (Per Unit):

Faulted_Bus	G1	G2	G3
1	1.2203	1.3277	0.32151
2	0.77225	3.5821	0.54353
3	0.2299	0.6682	1.3179
4	0.2622	0.76209	1.1163
5	0.89581	2.6037	0.6305
6	0.20159	0.58592	0.4681
7	0.00347	0.01008	0.00805
8	0.00322	0.00935	0.00747
9	0.00294	0.00854	0.00682
10	0.00294	0.00854	0.00682
11	0.00301	0.00875	0.00699

PowerWorld Generator Contributions (Amperes):

Faulted_Bus	G1	G2	G3
1	5871.4	5554.8	928.13
2	3715.5	14986	1569
3	1106.1	2795.5	3804.5
4	1261.5	3188.3	3222.6
5	4310	10893	1820.1
6	969.89	2451.3	1351.3
7	16.68	42.17	23.25
8	15.47	39.1	21.55
9	14.14	35.74	19.7
10	14.13	35.71	19.68
11	14.48	36.61	20.18

Figure 35: PowerWorld generator contribution profile for all the fault currents at all the buses.

Figure 36 summarises the results obtained from MATLAB in test 1.

MATLAB Generator Contributions (Per Unit):

===

Faulted_Bus	G1_pu	G2_pu	G3_pu
1	1.2203	1.3277	0.32152
2	0.77225	3.5821	0.54354
3	0.2299	0.6682	1.3179
4	0.2622	0.76209	1.1163
5	0.89581	2.6037	0.6305
6	0.20159	0.58592	0.4681
7	0.0034685	0.010081	0.0080541
8	0.0032161	0.0093477	0.0074681
9	0.0029394	0.0085436	0.0068256
10	0.0029373	0.0085372	0.0068205
11	0.0030112	0.0087522	0.0069923

MATLAB Generator Contributions (Amperes):

==

Faulted_Bus	G1_Amps	G2_Amps	G3_Amps
1	5871.4	5554.8	928.14
2	3715.5	14986	1569.1
3	1106.1	2795.6	3804.5
4	1261.5	3188.4	3222.6
5	4310	10893	1820.1
6	969.89	2451.3	1351.3
7	16.688	42.177	23.25
8	15.474	39.108	21.558
9	14.142	35.744	19.704
10	14.132	35.717	19.689
11	14.488	36.617	20.185

Figure 36: Generator contributions as calculated from MATLAB

Figure 37 tabulates the generator contributions to the per unit fault current as generated in PowerWorld and Figure 38 shows the corresponding MATLAB tabulation.

PowerWorld Generator Contributions (Percentage):

Faulted_Bus	G1	G2	G3
1	42.527	46.269	11.204
2	15.767	73.136	11.097
3	10.374	30.153	59.473
4	12.249	35.601	52.15
5	21.69	63.044	15.266
6	16.055	46.664	37.281
7	16.065	46.667	37.269
8	16.068	46.657	37.275
9	16.066	46.667	37.268
10	16.066	46.667	37.268
11	16.053	46.667	37.28

Figure 37: Each generator's contribution to the fault current as a percentage of the pu fault current at that bus

Generator Contributions (Percentage of Total Fault Current):

Faulted_Bus	G1_Percent	G2_Percent	G3_Percent
1	42.527	46.269	11.204
2	15.767	73.136	11.097
3	10.374	30.153	59.473
4	12.249	35.601	52.15
5	21.69	63.043	15.266
6	16.055	46.664	37.281
7	16.055	46.664	37.281
8	16.055	46.664	37.281
9	16.055	46.664	37.281
10	16.055	46.664	37.281
11	16.055	46.664	37.281

Figure 38: Corresponding % generator contributions as calculated in MATLAB

Figure 39 tabulates the percentage difference and correlation between the two sets of results respectively.

```
Percentage Difference in Generator Contribution Percentages:
```

Faulted_Bus	G1	G2	G3
1	0.00012325	0.00041008	0.0021613
2	0.0002287	0.00027844	0.0015101
3	0.0011742	0.00061797	0.00010848
4	0.00016439	0.00022887	0.00011763
5	0.00013662	0.00019067	0.00059327
6	0.0012321	0.00013694	0.0003592
7	0.061427	0.0052105	0.033003
8	0.080394	0.016179	0.014404
9	0.066148	0.0052105	0.03504
10	0.066148	0.0052105	0.03504
11	0.01005	0.0052105	0.0021947

```
Correlation in Generator Contribution Percentages:
```

Faulted_Bus	G1	G2	G3
1	100	100	99.998
2	100	100	99.998
3	99.999	99.999	100
4	100	100	100
5	100	100	99.999
6	99.999	100	100
7	99.939	99.995	99.967
8	99.92	99.984	99.986
9	99.934	99.995	99.965
10	99.934	99.995	99.965
11	99.99	99.995	99.998

Figure 39: % difference and % correlation between the PowerWorld set of generator contributions and the MATLAB set

The heatmap in Figure 40 summarises the correlation between the % contribution of each generator to the fault current at each bus in the network, comparing MATLAB calculations and PowerWorld generated results.

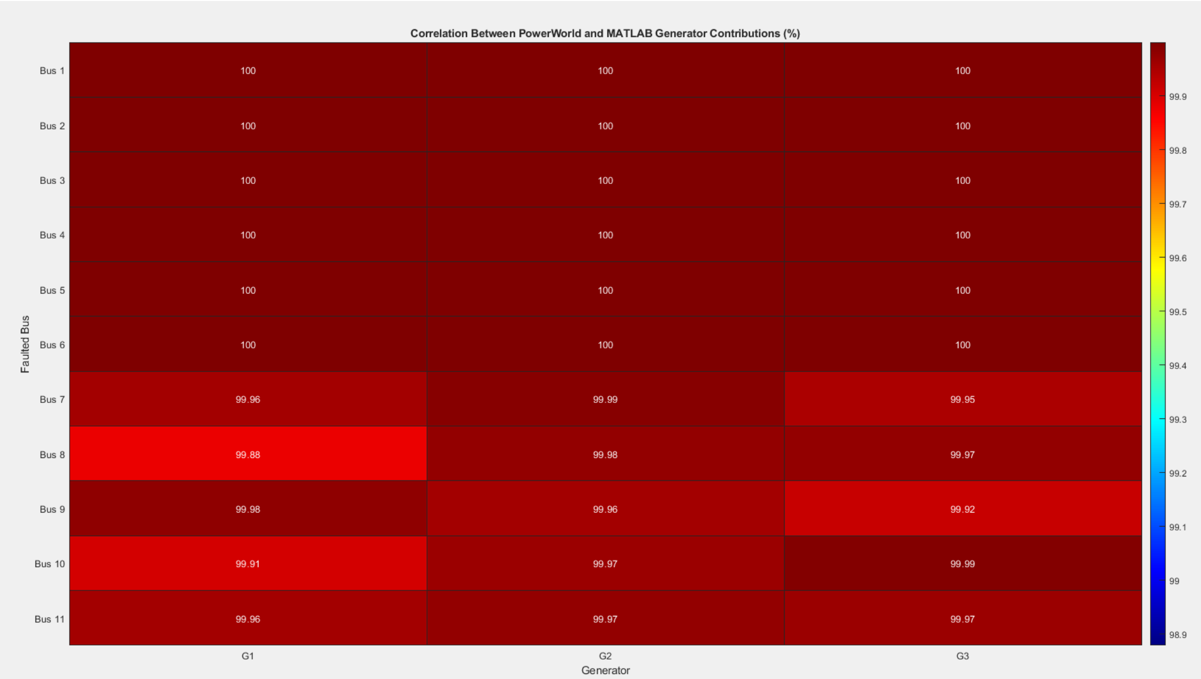

Figure 40: Correlation heatmap between the MATLAB and PowerWorld sets of results

For buses (electrically) further from the generators, the generator contributions to their fault currents are relatively low and since I used per unit fault current contributions in my comparison, the values tend to be very small and PowerWorld is not very generous with precision, hence the lower correlation observed from bus 7 onwards.

An important observation from the generator contribution analysis is that the sum of individual generator current contributions in actual amperes is less than the total fault current at each bus. This is not an error but reflects how fault currents combine in interconnected networks, including effects from charged line capacitances, mutual coupling, and the redistribution of pre-fault load currents. [1] The non-identical phase angles of generator contributions also prevent simple arithmetic summation of their magnitudes. Interestingly, when analysing the same contributions using per-unit values, the sum does equal the total per-unit fault current at each bus. This contrast demonstrates the normalizing effect of the per-unit system, which removes the complications of different voltage levels and transformer configurations to allow linear combination of contributions. For this reason, I deliberately chose to present generator contributions in per-unit values for my comparative analysis between PowerWorld and MATLAB results, as they provide a more accurate representation of each generator's relative contribution to fault currents, even though the actual ampere values in both simulation environments don't sum to 100% of the total fault current. This approach ensures a clearer picture of each generator's role during fault conditions while validating both the mathematical consistency of our per-unit calculations and the accurate modelling of complex network interactions.

7. Conclusion

This lab report has demonstrated the successful modelling and simulation of an 11-bus power system network in PowerWorld Simulator based on my student number parameters (220702330). The simulation results have been systematically validated against previously calculated values from MATLAB, showing excellent correlation across multiple aspects of the power system analysis.

The Y-bus matrix validation showed an average correlation of 99.45%, with minor discrepancies attributed to precision differences between the software platforms. Fault current comparisons revealed even stronger agreement, with an average correlation of 99.96% for actual fault currents and 99.41% for per-unit values. Voltage profiles during faults demonstrated the highest consistency, with an average correlation of 99.95%.

The generator contribution analysis yielded particularly valuable insights into power system behaviour during fault conditions. The observation that per-unit generator contributions sum to total per-unit fault current, while actual ampere contributions do not, confirms the theoretical soundness of the per-unit system while also demonstrating the complex interactions that occur in real power networks. This careful analysis of generator contributions verified that the PowerWorld model accurately represents generator behaviour during faults, though correlation decreased slightly for buses electrically distant from the generators due to precision limitations when working with very small values.

Overall, this verification process confirms the accuracy of both the PowerWorld simulation and the original MATLAB calculations from Class Test 1. The high degree of correlation between the two methods (consistently above 99% on average) validates the modelling approach and parameter conversions used. This simulation now provides a reliable platform for further power system studies including load flow analysis, contingency analysis, and stability studies.

The slight discrepancies observed highlight the importance of understanding software precision limitations when conducting power system analysis, particularly when working with per-unit values at very small scales. Additionally, the contrasting behaviour between per-unit and actual current calculations underscores the importance of choosing appropriate analysis methods when evaluating different aspects of power system performance during fault conditions.

8. References

[1] G. Heydt and N. Nimpitiwan, “Fault Current Contribution From Synchronous Machine and Inverter Based Distributed Generators,” *IEEE Transactions on Power Delivery,* vol. 1, no. 22, pp. 643 - 641, 2007.