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EEPS401 2025: Lab 2

Simulation and Validation of an 11-bus Power System Network in PowerWorld Simulator for Asymmetrical Fault Analysis

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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 for asymmetrical fault analysis. The primary objective is to validate the theoretical fault analysis calculations from Class Test 2 (through PowerWorld simulation) in which the faults were calculated using theoretical methods with the help of MATLAB for complex matrix manipulation. 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 and voltage profiles during fault conditions.

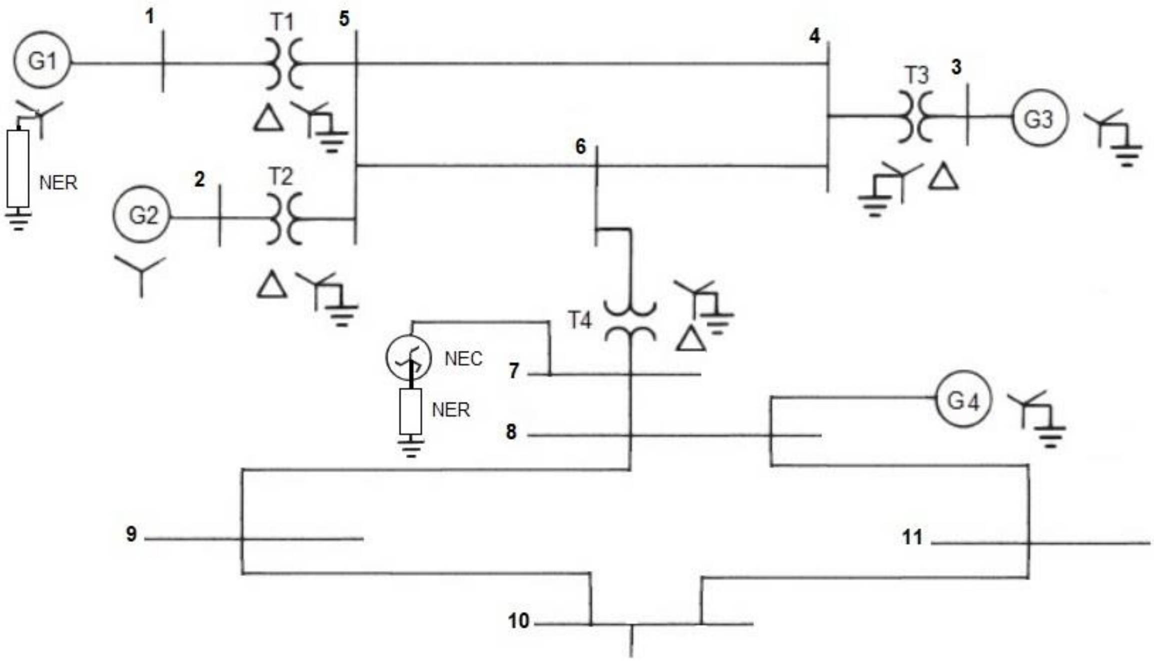

Figure 1: The 11-bus Network Diagram

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

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2. PowerWorld Simulator: Network Modelling

2.1. Converting Network Parameters to Common Base Per Unit

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

Use the information from Test 1 and note the changes given below for the electrical system of Test 1:

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 **8 MVA** plus the last non-zero digit of your student number (edited from last 3 nonzero digits in kVA to give realistic faults)

In addition note the changes to the impedances of the 11kV cables downstream of T4 (also for more realistic faults).

G1 has a Neutral Earthing Resistor (NER). **Select a suitable ohmic value** for the resistor to limit the magnitude of the earth fault occurring in the generator to about 1/10th of the Symmetrical Fault Current magnitude.

G2 **should have a suitably valued** NER **if** your student number ends with an **even number, otherwise leave it as is.**

G3 **should have a suitably valued** NER **if** your student number ends with an **odd number, otherwise leave it as is.**

G4 is a standby generator (ignore for this study).

Bus 7: Install an NEC (Neutral Earthing Compensator) rated 11kV 1.5 MVA X1=X2=90%; X0=5%

The NEC has a NER (Neutral Earthing Resistor) rated 10 ohm on its neutral.

Other ratings

Item:	Voltages:	Z1=Z2:	Z0:
G1	12 kV	1+j18 %	j5%
G2	13.8 kV	2+j20 %	j7%
G3	20 kV	1.4+j25 %	j4%
T1	12/132 kV	0.7+j6.5 %	j6.5%
T2	13.8/132 kV	0.9+j7.5 %	j7.5%
T3	20/132 kV	0.5+j4.5 %	j4.5%
T4	132/11 kV	1,5+j10.5 %	j10.5%
Line 5-4	132 kV	20+j175 ohm	j300 ohm
Line 5-6	132 kV	29+j225 ohm	j250 ohm
Line 6-4	132 kV	8+j153 ohm	j175 ohm
Line 7-8	11 kV	0.06+j0.114 ohm	j0.18 ohm
Line 8-9	11 kV	0.03+j0.186 ohm	j0.21 ohm
Line 9-10	11 kV	0.07+j0.262 ohm	j0.32 ohm
Line 10-11	11 kV	0.05+j0.31 ohm	j0.43 ohm
Line 8-11	11 kV	0.012+j0.151 ohm	j0.54 ohm

Figure 2: Provided Network Parameter Guidelines.

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: 8 MVA + 3 MVA = 11 MVA** (**8 MVA** plus the last non-zero digit of my student number (edited from last 3 nonzero digits in kVA to give realistic faults)

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).

2.2. Converting Line Impedances to the Common base per unit

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

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

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 for the positive/negative sequence networks and then for the zero-sequence network as well:

For the lines (impedances (pu))

Line 5-4: $Zpu = \frac{20 + 175j \text{ (ohm)} \times 100 \text{ MVA}}{(132 \text{ kV})^2}$

$= \underline{0,11478 + 1,00436j}$

line 5-6 = $Zpu = \frac{(29 + 225j) \times 100 \text{ MVA}}{(132 \text{ kV})^2}$

$= \underline{0,16644 + 1,29132j}$

line 6-4 = $\frac{(8 + 153j) \times 100 \text{ MVA}}{(132 \text{ kV})^2}$

$= \underline{0,04591 + 0,87810j}$

Figure 3: Positive/Negative Sequence Line Impedances 1

~~Line 7/8/~~ : Line 7–8:

$$Z_{pu} = \frac{0{,}06 + 0{,}114j \times 100\ MVA}{11\ kV^2}$$

$$= 0{,}04959 + 0{,}09421j$$

Line 8–9: $\frac{0{,}03 + 0{,}186j \times 100\ MVA}{11\ kV^2}$

$$= 0{,}02479 + 0{,}15372j$$

Line 9–10: $\frac{0{,}07 + 0{,}262j \times 100\ MVA}{11\ kV^2}$

$$= 0{,}05785 + 0{,}21653j$$

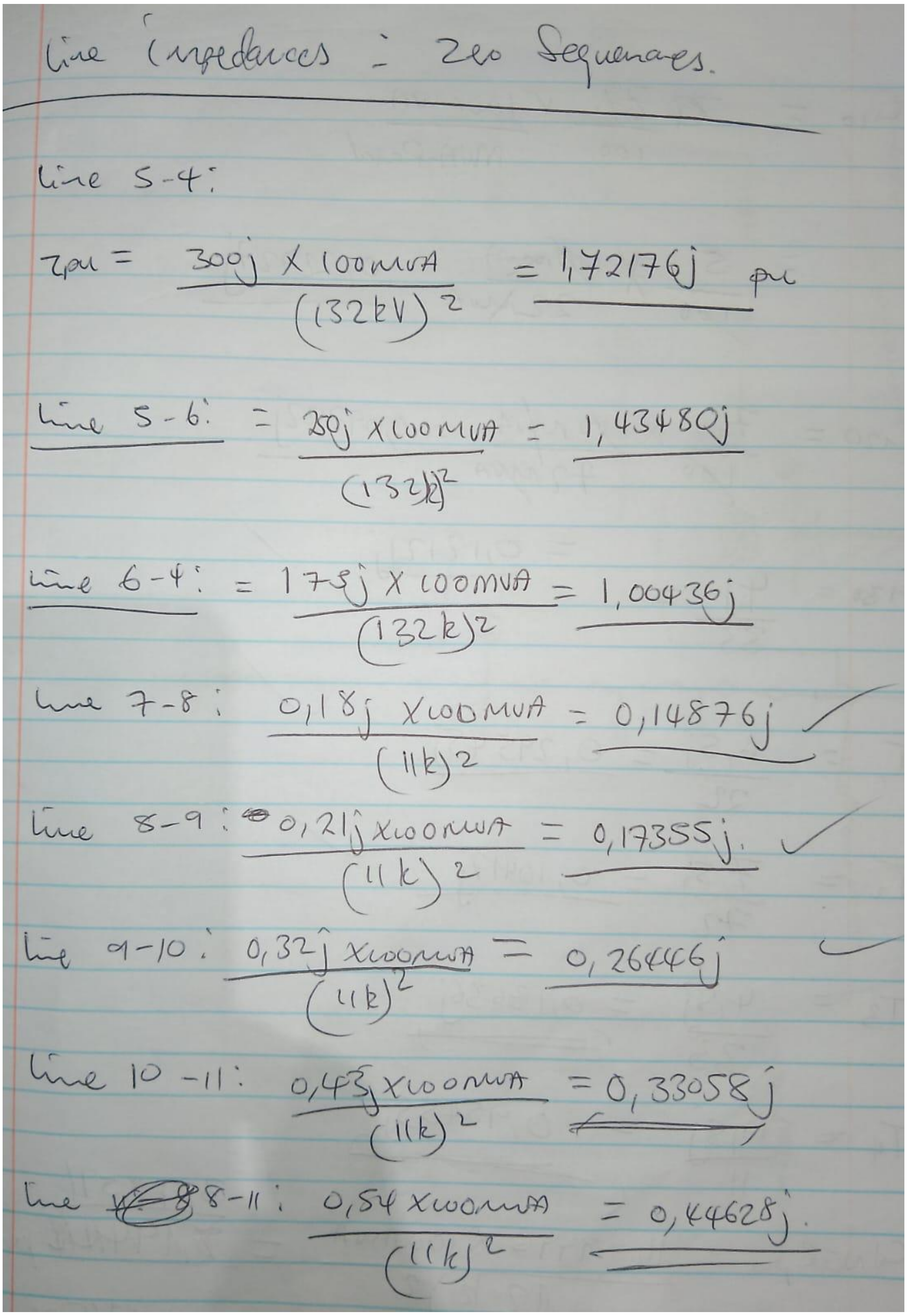
Line 10–11: $\frac{0{,}05 + 0{,}31j \times 100\ MVA}{11\ kV^2}$

$$= 0{,}04132 + 0{,}25620j$$

Line 8–11: $\frac{0{,}012 + 0{,}151j \times 100\ MVA}{11\ kV^2}$ $= 0{,}0092 + 0{,}12479j$

Figure 4:Positive/Negative Sequence Line Impedances 2

Note: Line impedances from bus 7 downstream had to be adjusted (lowered) so that symmetrical fault currents in that section of the network can be more realistic. The industry standard is that 5pu <= Ifault <= 20pu, where Ifault is the symmetrical fault current which is expected to be within those limits of the full load current at the particular bus bar in question. In Test 1, these downstream fault currents were unrealistically small (below reasonable limits).



Line impedances : Zero Sequences.

Line 5-4:

$$Z_{pu} = \frac{300j \times 100MVA}{(132kV)^2} = 1{,}72176j \text{ pu}$$

Line 5-6: $$= \frac{250j \times 100MVA}{(132k)^2} = 1{,}43480j$$

Line 6-4: $$= \frac{175j \times 100MVA}{(132k)^2} = 1{,}00436j$$

Line 7-8: $$\frac{0{,}18j \times 100MVA}{(11k)^2} = 0{,}14876j$$

Line 8-9: $$\frac{0{,}21j \times 100MVA}{(11k)^2} = 0{,}17355j.$$

Line 9-10: $$\frac{0{,}32j \times 100MVA}{(11k)^2} = 0{,}26446j$$

Line 10-11: $$\frac{0{,}43j \times 100MVA}{(11k)^2} = 0{,}35058j$$

Line 8-11: $$\frac{0{,}54 \times 100MVA}{(11k)^2} = 0{,}44628j.$$

Figure 5: Zero-Sequence Line Impedances

2.3. 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 Z_{pu}

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

$$G_2: \frac{(2+20j)}{100} \times \frac{100MVA}{72MVA} = \underline{0{,}02778 + 0{,}27778j}$$

$$G_3: \frac{(1{,}4+25j)}{100} \times \frac{100MVA}{33MVA} = \underline{0{,}04242 + 0{,}75758j}$$

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

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

$$T_3: \frac{(0{,}5+4{,}5j)}{100} \times \frac{100MVA}{33MVA} = \underline{0{,}01515 + 0{,}13636j}$$

Figure 6: Positive/Negative Sequence Generator and Transformer Impedance Calculations 1

Note: Alongside the adjusted line impedances for the lines from bus bars 7-11, Transformer 4 impedances were reduced from the Test 1 values to increase fault current magnitudes in the downstream network (buses 7-11), ensuring fault currents fall within the practical range of 5-20 pu for effective protection coordination.

$$T4: \frac{1{,}5 + 10{,}5j}{100} \times \frac{100 \times 10^6}{11 \times 10^6}$$

$$= 0{,}13636 + 0{,}95455j$$

Figure 7: Transformer 4 Negative/Positive Sequence Impedance

$$G_{10} = \frac{Z\%}{100} \times \frac{100\,\text{MVA}}{\text{MVA-Rated}}$$

$$= \frac{5j}{100} \times \frac{100\,\text{MVA}}{22\,\text{MVA}} \quad \underline{0,22727j}$$

$$G_{20} = \frac{7j}{100} \times \frac{100\,\text{MVA}}{72\,\text{MVA}} = \underline{0,09722j}$$

$$G_{30} = \frac{4j}{33} = \underline{0,12121j}$$

$$T_1 = \frac{6,5j}{22} = \underline{0,29545j}$$

$$T_2 = \frac{7,5j}{72} = \underline{0,10417j}$$

$$T_3 = \frac{4,5j}{33} = \underline{0,13636j}$$

$$T_4 = \frac{10,5j}{11} = \underline{0,95455j}$$

$$G1NER_{pu} = \frac{11,79996 \times 100\,\text{MVA}}{(12k)^2} = \cancel{8,19444}\ \underline{3,48591}\ \text{pu}$$

$$G3NER_{pu} = \frac{30,35060 \times 100\,\text{MVA}}{(20k)^2} = \cancel{7,58765\,\text{pu}}\ \ 4,51416\ \text{pu}$$

Figure 8: Zero-Sequence Generator and Transformer Impedance Calculations

The Neutral Earthing Compensator (NEC) and the Neutral Earthing Resistor (NER) for bus bar 7 as well as the NER for G1 are calculated as per the provided guidelines. Based on my student number, G3 also required a NER value, and the same criterion applied for G1 (selecting an ohmic value for the resistor to limit the magnitude of the earth fault occurring in the generator to about 1/10th of the Symmetrical Fault Current magnitude) was applied.

Bus 7 NEC

$$\frac{5\%}{100} \times \frac{100MVA}{1,5MVA} = 3,3333pu.$$

Bus 7 NER:

$$\cancel{10} \cancel{\times} \frac{10 \text{ ohms} \times 100MVA}{(11kV)^2} = 8,26446 \cancel{pu}.pu$$

G1 NER

$$Z_{NER} = \frac{V_{Line}}{(I_{fault} \times 0,1)} = \frac{12k}{(\sqrt{3} \cdot I_{fault} \times 0,1)}$$

$I_{fault} = 13802A$

$$\therefore Z_{NER} = 5,01971\Omega.$$

G3 NER

$$\frac{20k}{(\sqrt{3} \times 3804,54 \times 0,1)} = 18,05604\Omega.$$

$$G1NER_{pu} = \frac{5,01971 \times 100MVA}{(12k)^2} = 3,48591$$

$$G3NER_{pu} = \frac{18,05604 \times 100MVA}{(20k)^2}$$

$$= 4,51416pu.$$

Figure 9: NEC and NER Calculations

Summary of the calculated common base pu parameters:

Common Base	100MVA						
Line	**New Impedance(+/-)**	**New Impedance(0)**	**Generator/Transformer**	**New Impedance(+/-)**	**New Impedance(0)**	**NER**	**NEC**
Line 5 - 4	0.11475 + 1.00436i	1.72176i	**G1**	0.04545 +0.81818i	0.22727i	3.48591	
Line 5 - 6	0.16644 + 1.29132i	1.43480i	**G2**	0.02778 + 0.27778i	0.09722i	4.51416	
Line 6 - 4	0.04591 + 0.87810i	1.00436i	**G3**	0.04242 + 0.75758i	0.12121i		
Line 7 - 8	0.04959 + 0.09421i	0.14876i	**T1**	0.03182 + 0.29545i	0.29545i		
Line 8 - 9	0.02479 + 0.15372i	0.17355i	**T2**	0.01250 + 0.10417i	0.10417i		
Line 9 - 10	0.05785 + 0.21653i	0.26446i	**T3**	0.01515 + 0.13636i	0.13636i		
Line 10 - 11	0.04132 + 0.25620i	0.33058i	**T4**	0.13636 + 0.95455i	0.95455i		
Line 8 - 11	0.00920 + 0.12479i	0.44628i	**Bus Bar 7**			8.26446	3.3333i

Figure 10: 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.*

2.4. PowerWorld Modelling

The existing PowerWorld model from Lab 1 had to undergo a few modifications to allow for the asymmetrical fault analysis:

- Adjusting the updated positive/negative impedances
- Setting up the zero-sequence impedances as well as the NER and NEC values

2.4.1. Adjusting generator models to add zero-sequence impedances

To update generator models to add zero-sequence impedances, the important parameters to adjust are highlighted in the Figure below. Similar changes were made for respective generators using the values calculated ion the previous section.

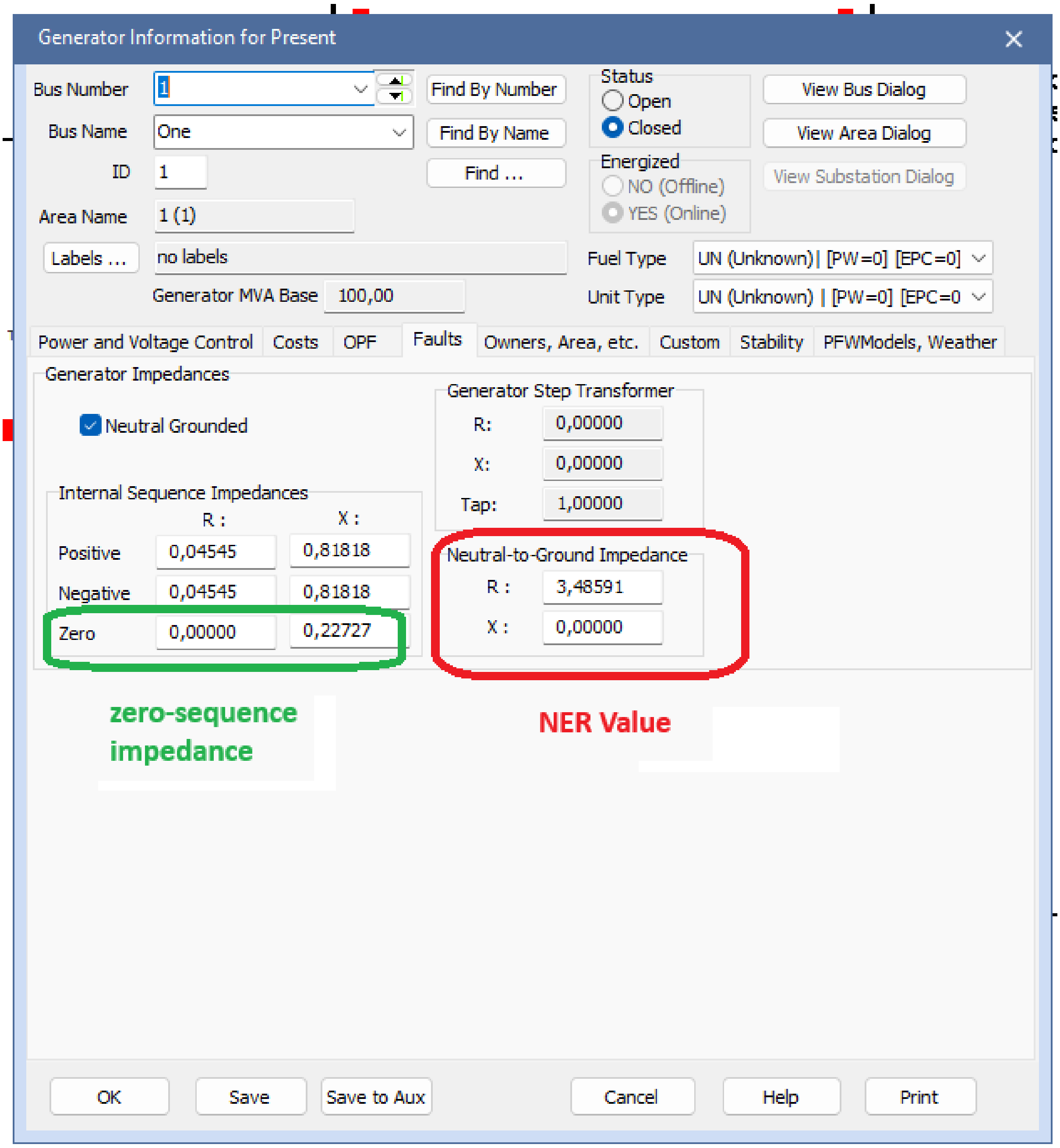


Figure 11: Important parameter fields to adjust for generator models (generator 1 shown)

2.4.2. Adjusting transformer models to add zero-sequence impedances

For transformer models Figure 12 below shows the parameter fields to add the zero-sequence impedances.

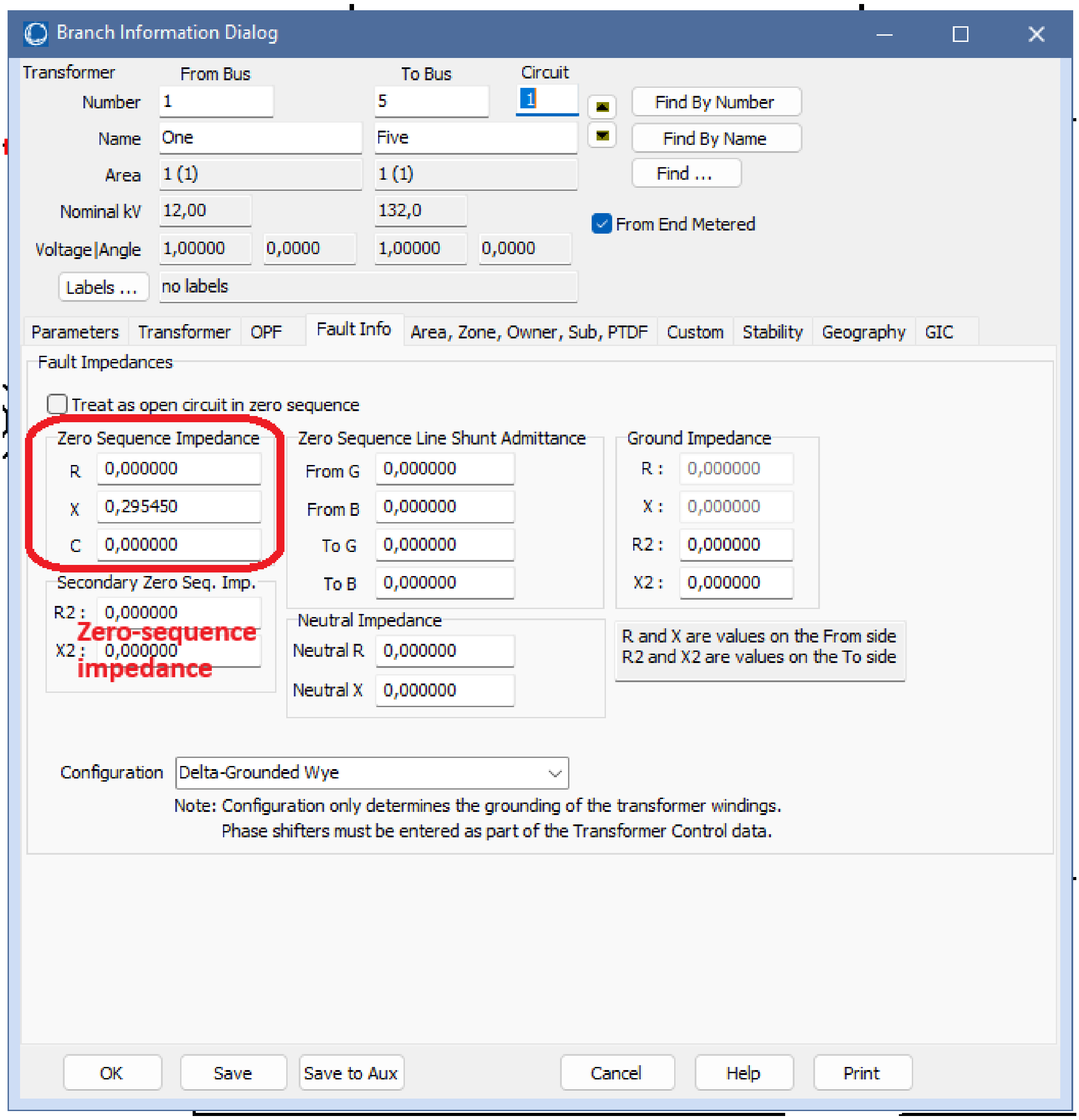


Figure 12: Adding zero-sequence impedances to a transformer model

A special scenario occurs at bus bar 7; the bus bar is supposed to have a ground path via a Neutral Earthing Compensator and a Neutral Earthing Resistor. To model this in PowerWorld, the values must be added to the model of transformer 4 as highlighted in Figure 13 below.

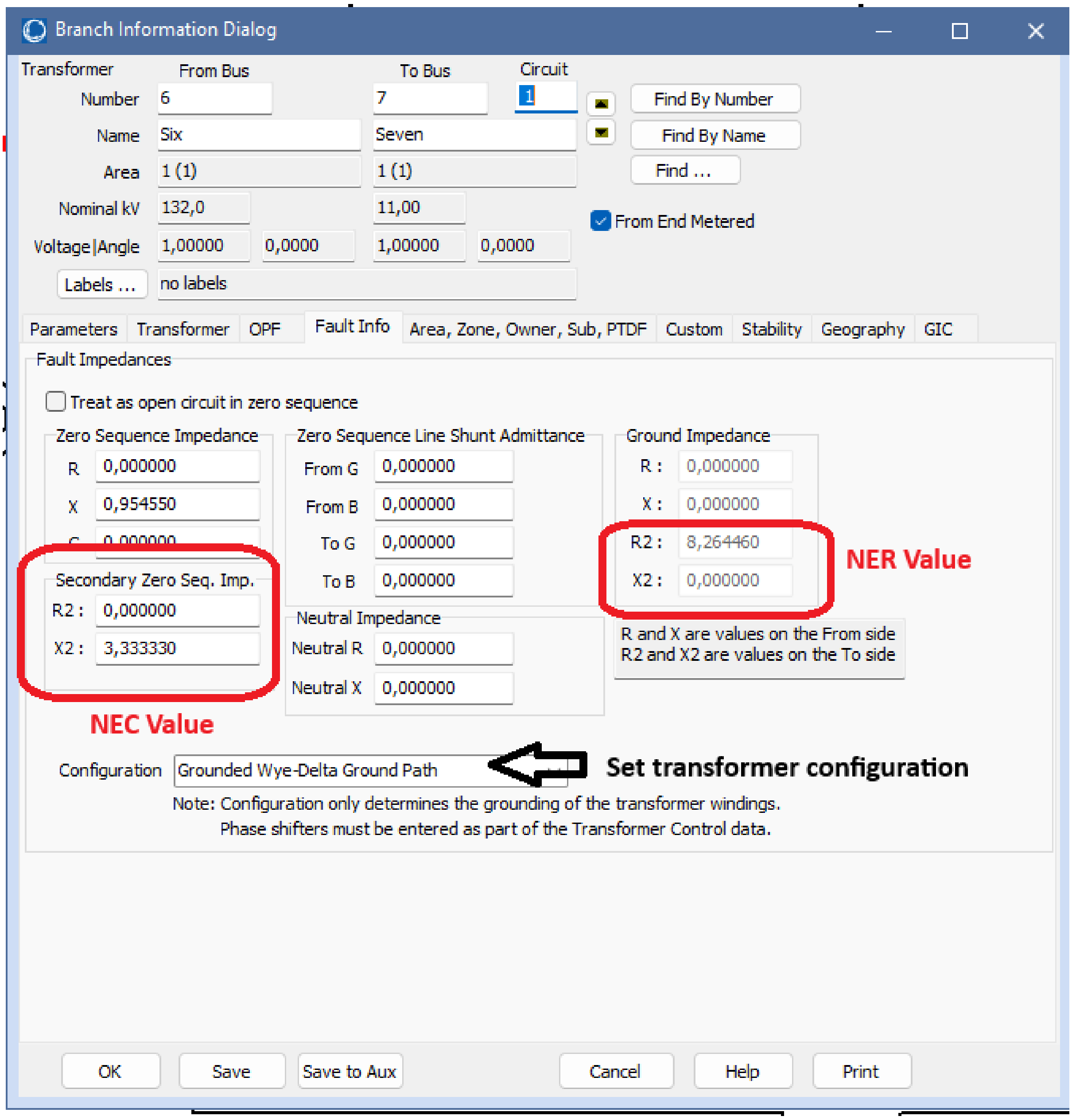


Figure 13: Setting up the NER and NEC values at transformer 4 secondary side for bus bar 7

2.4.3. Adjusting transmission line models to add zero-sequence impedances

On the transmission line model only the zero-sequence impedance field needed to be adjusted as highlighted in Figure 14 below.

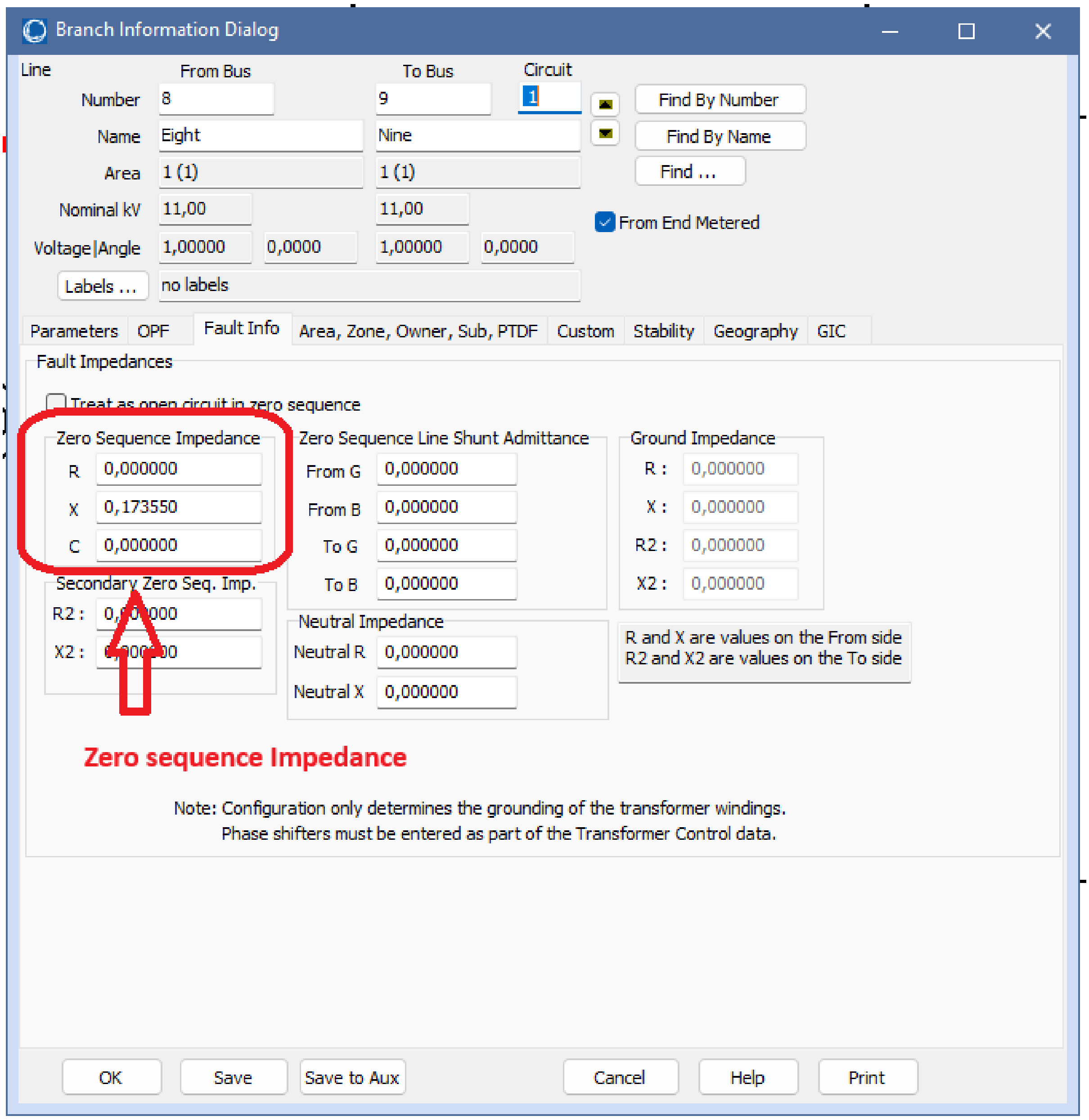


Figure 14: Adjusting transmission line model to add zero-sequence impedance

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 2.

1. Ybus Correlation

In ‘Run Mode’, under the ‘Tools’ tab, under ‘Fault Analysis’, under ‘Single Fault’, various fault analysis tools can be explored as demonstrated in Lab 1.

For asymmetrical fault analysis, 3 different Ybus matrices are available. The Ybus matrix for the positive sequence is exactly the same as that of the negative sequence. The zero-sequence matrix is different. Figure 15 shows the positive sequence (as well as negative sequence) Ybus matrix as simulated by the PowerWorld simulator.

Bus Records | Lines | Generators | Loads | Switched Shunt Buses | Y-Bus Matrices

Positive Sequence | Negative Sequence | Zero Sequence

Records ▾ Geo ▾ Set ▾ Columns ▾ f(x) ▾ Options ▾

	Number	Name	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6	Bus 7	Bus 8	Bus 9	Bus 10	Bus 11
1	1	One				-0,36035 + j3,34586						
2	2	Two	1,49203 - j13,02775			-1,13558 + j9,46343						
3	3	Three		0,87852 - j8,55998	-0,80484 + j7,24411							
4	4	Four		-0,80484 + j7,24411	0,97654 - j9,36265	-0,11232 + j0,98282	-0,05938 + j1,13572					
5	5	Five	-1,13558 + j9,46343		-0,11232 + j0,98282	1,70643 - j14,55386	-0,09818 + j0,76175					
6	6	Six			-0,05938 + j1,13572	-0,09818 + j0,76175	0,30422 - j2,92413	-0,14666 + j1,02666				
7	7	Seven					-0,14666 + j1,02666	4,52173 - j9,33831	-4,37506 + j8,31165			
8	8	Eight						-4,37506 + j8,31165	5,98516 - j22,62223	-1,02250 + j6,34044		-0,58759 + j7,97014
9	9	Nine							-1,02250 + j6,34044	2,17416 - j10,65105	-1,15166 + j4,31061	
10	10	Ten								-1,15166 + j4,31061	1,76521 - j8,11486	-0,61355 + j3,80425
11	11	Eleven							-0,58759 + j7,97014		-0,61355 + j3,80425	1,20114 - j11,77439

Figure 15: Positive/Negative sequence matrix as generated by the PowerWorld Simulator

Figure 16 shows the corresponding Y-bus matrix generated in MATLAB based on hand calculated admittances.

Test1_220702330.mlx | Ybus1 = 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	0.3042 - 2.9241i	-0.1467 + 1.0267i	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	-0.1467 + 1.0267i	4.5217 - 9.3383i	-4.3751 + 8.3117i	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	-4.3751 + 8.3117i	5.9852 -22.6222i	-1.0225 + 6.3404i	0.0000 + 0.0000i	-0.5876 + 7.9701i
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	-1.0225 + 6.3404i	2.1742 -10.6510i	-1.1517 + 4.3106i	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	-1.1517 + 4.3106i	1.7652 - 8.1149i	-0.6136 + 3.8043i
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	-0.5876 + 7.9701i	0.0000 + 0.0000i	-0.6136 + 3.8043i	1.2011 -11.7744i

Figure 16: Positive/negative sequence Ybus matrix calculated by MATLAB based on the theoretical Y calculations

Figure 17 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	0	0	0	0	0	0	0	0	0	0
Bus 2	0	0	0	0	0	0	0	0	0	0	0
Bus 3	0	0	0	0	0	0	0	0	0	0	0
Bus 4	0	0	0	0	0	0	0	0	0	0	0
Bus 5	0	0	0	0	0	0	0	0	0	0	0
Bus 6	0	0	0	0	0	0	0	0	0	0	0
Bus 7	0	0	0	0	0	0	0	0	0	0	0
Bus 8	0	0	0	0	0	0	0	0	0	0	0
Bus 9	0	0	0	0	0	0	0	0	0	0	0
Bus 10	0	0	0	0	0	0	0	0	0	0	0
Bus 11	0	0	0	0	0	0	0	0	0	0	0

Figure 17: Tabulation of % differences between the positive/negative sequence PowerWorld and MATLAB Y-buses

Figure 18 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	100	100	100	100	100	100	100	100	100	100	100
Bus 2	100	100	100	100	100	100	100	100	100	100	100
Bus 3	100	100	100	100	100	100	100	100	100	100	100
Bus 4	100	100	100	100	100	100	100	100	100	100	100
Bus 5	100	100	100	100	100	100	100	100	100	100	100
Bus 6	100	100	100	100	100	100	100	100	100	100	100
Bus 7	100	100	100	100	100	100	100	100	100	100	100
Bus 8	100	100	100	100	100	100	100	100	100	100	100
Bus 9	100	100	100	100	100	100	100	100	100	100	100
Bus 10	100	100	100	100	100	100	100	100	100	100	100
Bus 11	100	100	100	100	100	100	100	100	100	100	100

Figure 18: Tabulation of the correlation between the two sets of values

The correlation is visualised for even better analysis using the heatmap in Figure 19.

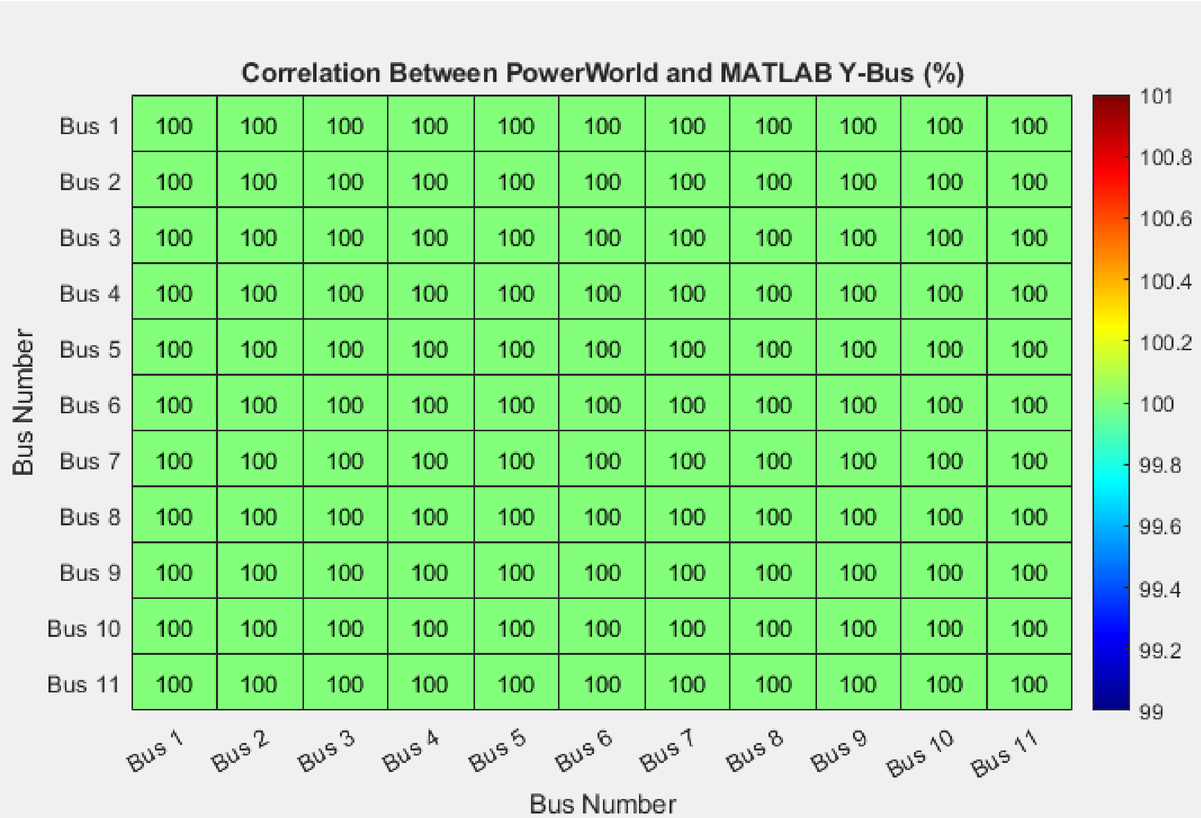


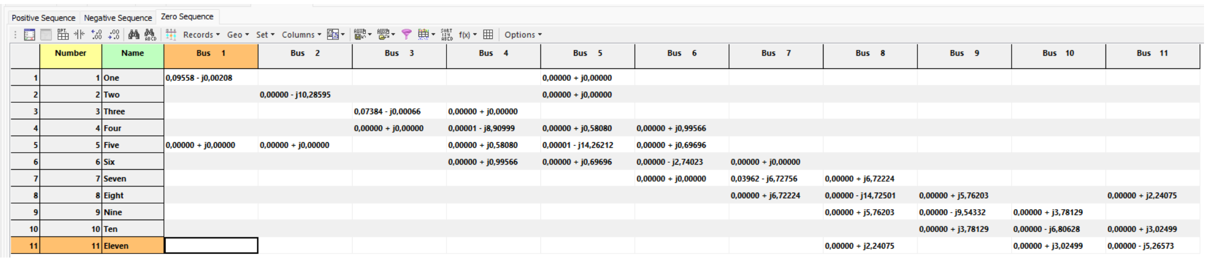
Figure 19:PowerWorld and MATLAB Ybus (positive and negative sequence) correlation Heatmap

Summary of results:

- Maximum percentage difference: 0.000000%
- Average percentage difference: 0.000000%
- Minimum correlation: 100.000000%
- Average correlation: 100.000000%

The same procedure is repeated but for the zero-sequence Ybus matrices.

Figure 20 shows the zero-sequence Ybus matrix generated by the PowerWorld simulator.


Positive Sequence | Negative Sequence | Zero Sequence

Records Geo Set Columns f(x) Options

	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	0,09558 - j0,00208				0,00000 + j0,00000						
2	2	Two		0,00000 - j10,28595			0,00000 + j0,00000						
3	3	Three			0,07384 - j0,00066	0,00000 + j0,00000							
4	4	Four			0,00000 + j0,00000	0,00001 - j8,90999	0,00000 + j0,58080	0,00000 + j0,99566					
5	5	Five	0,00000 + j0,00000	0,00000 + j0,00000		0,00000 + j0,58080	0,00001 - j14,26212	0,00000 + j0,69696					
6	6	Six				0,00000 + j0,99566	0,00000 + j0,69696	0,00000 - j2,74023	0,00000 + j0,00000				
7	7	Seven						0,00000 + j0,00000	0,03962 - j6,72756	0,00000 + j6,72224			
8	8	Eight							0,00000 + j6,72224	0,00000 - j14,72501	0,00000 + j5,76203		0,00000 + j2,24075
9	9	Nine								0,00000 + j5,76203	0,00000 - j9,54332	0,00000 + j3,78129	
10	10	Ten									0,00000 + j3,78129	0,00000 - j6,80628	0,00000 + j3,02499
11	11	Eleven								0,00000 + j2,24075		0,00000 + j3,02499	0,00000 - j5,26573

Figure 20: PowerWorld simulator zero-sequence Ybus matrix

Figure 21 shows the corresponding hand calculated Ybus matrix.

Test1_220702330.mlx | Ybus0 = 11×11 complex

	1	2	3	4	5	6	7	8	9	10	11
1	0.0956 - 0.0021i	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	0.0000 + 0.0000i	0.0000 + 0.0000i
2	0.0000 + 0.0000i	0.0000 -10.2859i	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	0.0000 + 0.0000i
3	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0738 - 0.0007i	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
4	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 - 8.9100i	0.0000 + 0.5808i	0.0000 + 0.9957i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i
5	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.5808i	0.0000 -14.2621i	0.0000 + 0.6970i	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	0.0000 + 0.9957i	0.0000 + 0.6970i	0.0000 - 2.7402i	0.0000 + 0.0000i	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	0.0000 + 0.0000i	0.0396 - 6.7276i	0.0000 + 6.7222i	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	0.0000 + 6.7222i	0.0000 -14.7250i	0.0000 + 5.7620i	0.0000 + 0.0000i	0.0000 + 2.2407i
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	0.0000 + 5.7620i	0.0000 - 9.5433i	0.0000 + 3.7813i	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	0.0000 + 3.7813i	0.0000 - 6.8063i	0.0000 + 3.0250i
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	0.0000 + 2.2407i	0.0000 + 0.0000i	0.0000 + 3.0250i	0.0000 - 5.2657i

Figure 21: Hand calculated zero-sequence Ybus matrix

Figure 22 tabulates the % differences between the two sets of values.

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	0	0	0	0	0	0	0	0	0	0
Bus 2	0	0	0	0	0	0	0	0	0	0	0
Bus 3	0	0	0	0	0	0	0	0	0	0	0
Bus 4	0	0	0	0.00011223	0	0	0	0	0	0	0
Bus 5	0	0	0	0	7.0116e-05	0	0	0	0	0	0
Bus 6	0	0	0	0	0	0	0	0	0	0	0
Bus 7	0	0	0	0	0	0	0	0	0	0	0
Bus 8	0	0	0	0	0	0	0	0	0	0	0
Bus 9	0	0	0	0	0	0	0	0	0	0	0
Bus 10	0	0	0	0	0	0	0	0	0	0	0
Bus 11	0	0	0	0	0	0	0	0	0	0	0

Figure 22: Tabulation of % differences between PowerWorld and MATLAB zero-sequence Ybus matrices

The % correlation of these values is tabulated in Figure 23 below.

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	100	100	100	100	100	100	100	100	100	100	100
Bus 2	100	100	100	100	100	100	100	100	100	100	100
Bus 3	100	100	100	100	100	100	100	100	100	100	100
Bus 4	100	100	100	100	100	100	100	100	100	100	100
Bus 5	100	100	100	100	100	100	100	100	100	100	100
Bus 6	100	100	100	100	100	100	100	100	100	100	100
Bus 7	100	100	100	100	100	100	100	100	100	100	100
Bus 8	100	100	100	100	100	100	100	100	100	100	100
Bus 9	100	100	100	100	100	100	100	100	100	100	100
Bus 10	100	100	100	100	100	100	100	100	100	100	100
Bus 11	100	100	100	100	100	100	100	100	100	100	100

Figure 23:% correlation between MATLAB and PowerWorld zero-sequence Ybus values

The correlation matrix is visualised in the Figure 24 heatmap.

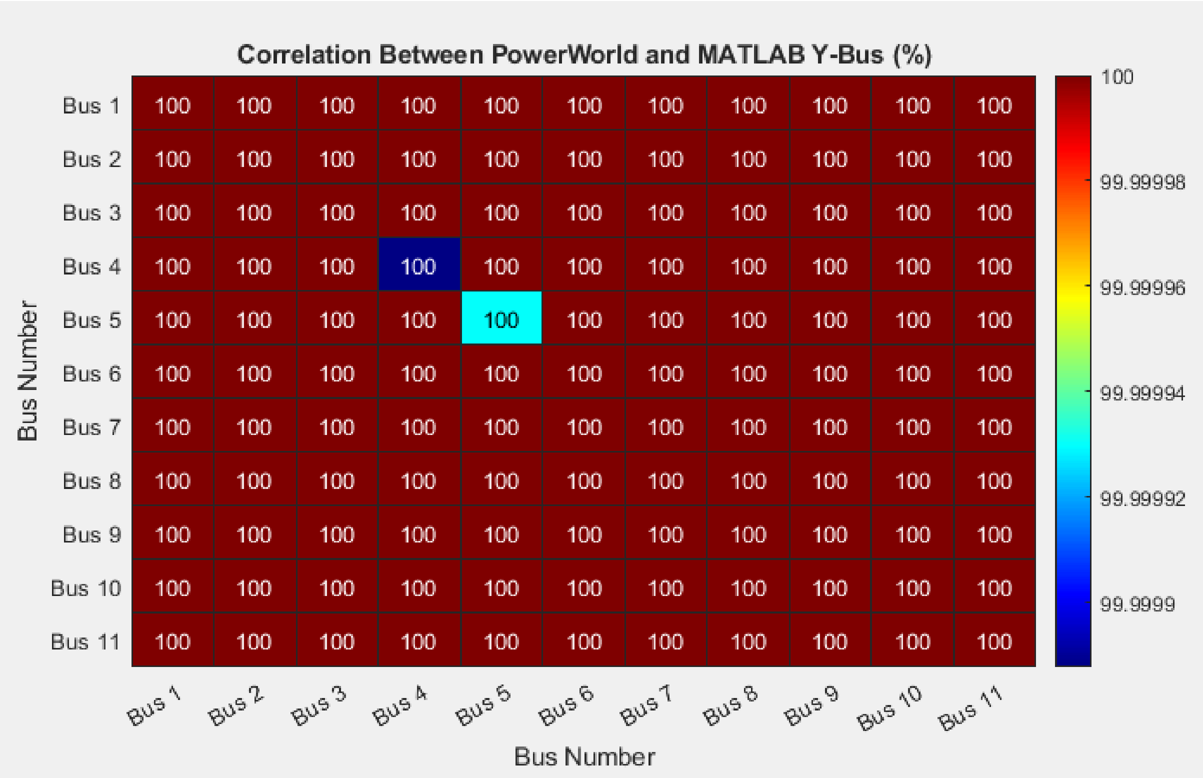


Figure 24: Zero-sequence Ybus correlation matrix

Summary of results:

- Maximum percentage difference: 0.000112%
- Average percentage difference: 0.000002%
- Minimum correlation: 99.999888%
- Average correlation: 99.999998%

Overall, both Ybus matrix sets show exceptional correlation of almost 100% with negligible % differences at Y55 and Y45 of way below 1%. This shows that the PowerWorld Simulator network was modelled accurately and that the hand/theoretical calculations were performed correctly and precisely. It is important to note that the improved correlation in Lab 2 relative to Lab 1 (although both sets of Ybus matrices were correct) is due to the fact that this time, both sets of values were set to the same number of decimal points (5 d.p).

2. Fault Currents and Voltages Correlation

Two types of faults were simulated in this lab, single-phase-to-earth faults and phase-to-phase faults. The single fault currents when a fault occurs at each and the corresponding voltage profiles in the entire network are compared between PowerWorld values and those calculated in MATLAB based on the Ybus matrices calculated in the previous section. Figure 25 demonstrates the PowerWorld settings to calculate the fault values in the PowerWorld simulator.

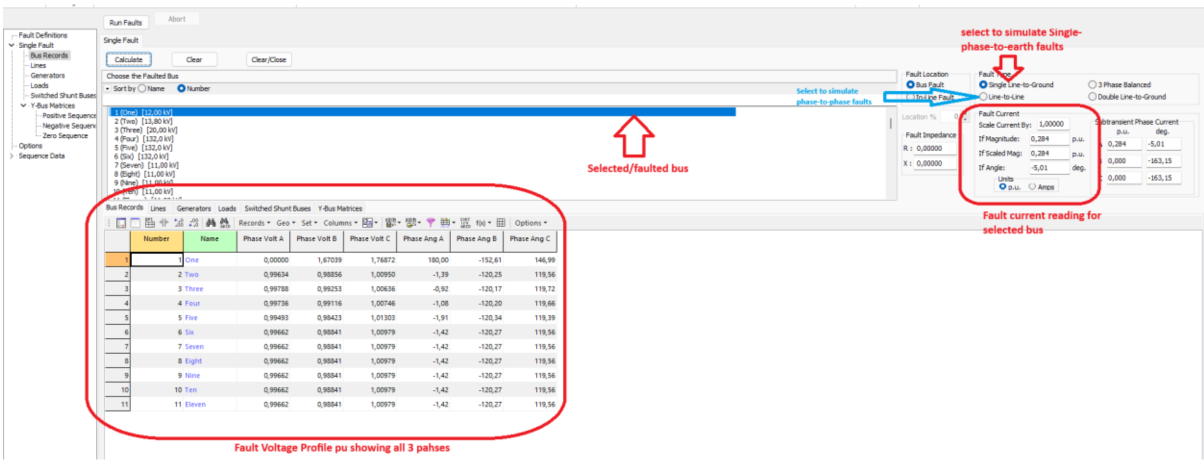


Figure 25: PowerWorld Interface to calculate different types of fault currents and voltages

The following sections compare the magnitudes of fault currents (A) and voltages (pu) for the different types of faults.

2.1. Single-earth-to-phase Faults

For fault currents comparison, with phase A being the faulted phase, this section compares phase A currents whenever there is a fault at each bus. If there is a good correlation between the A phase currents then the assumption is that currents in the B and C phases also correlate, since the 3 phase are related by the A operator (1 angle 120 deg). The same assumption is used for the fault voltage profile. Therefore, this section will only compare the A phase fault currents and voltage profiles.

Figure 26 tabulates a comparison of single-phase-to-earth fault currents (A) when there is a fault at each of the 11 buses. The table also tabulates the % differences and the correlation between MATLAB and PowerWorld.

--- SLG Phase A Fault Current COMPARISON ---

Bus	MATLAB_Val	PowerWorld_Val	Percent_Diff	Percent_Corr
1	1367.4	1367.3	0.0022114	99.998
2	24843	24843	0.00018439	100
3	634.52	634.48	0.0057249	99.994
4	1247.5	1247.5	0.00035816	100
5	2362.3	2362.3	0.0001297	100
6	663.14	663.14	0.0003008	100
7	602.91	602.87	0.0059977	99.994
8	598.66	598.62	0.006096	99.994
9	595.3	595.26	0.0067622	99.993
10	593.02	592.98	0.0071972	99.993
11	595.11	595.08	0.0066611	99.993

Figure 26: Comparison of fault currents (A) between MATLAB and PowerWorld

Summary Statistics:

- Maximum Difference: 0.007197%
- Average Difference: 0.003784%
- Minimum Correlation: 99.992803%
- Average Correlation: 99.996216%

Figure 27 visualises the summary of results for easier visual analysis.

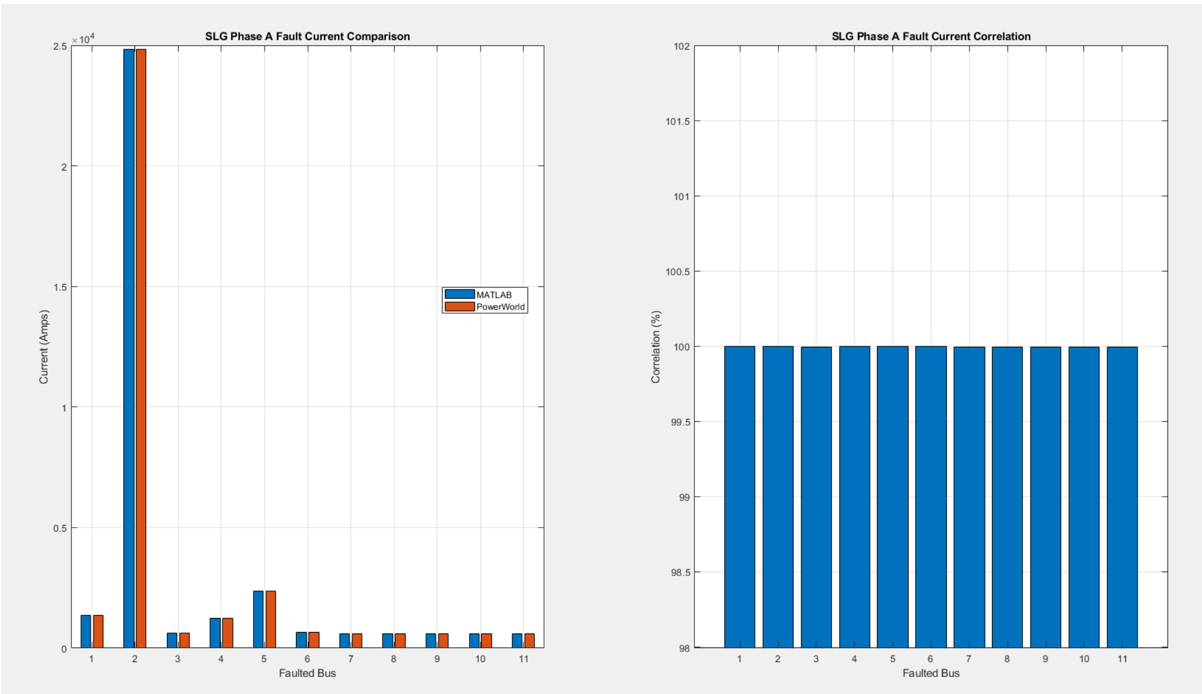


Figure 27: Summary of fault currents comparison and correlation

Figures 28 - 31 tabulates the 2 sets of voltage profiles from MATLAB and PowerWorld as well as the comparisons.

=== SLG Phase A Voltage Profile - MATLAB VALUES (Magnitudes Only) ===
MATLAB Voltage Magnitudes (per unit):

Faulted_Bus	Bus1_Mag	Bus2_Mag	Bus3_Mag	Bus4_Mag	Bus5_Mag	Bus6_Mag	Bus7_Mag	Bus8_Mag	Bus9_Mag	Bus10_Mag	Bus11_Mag
1	0	0.9963	0.9979	0.9974	0.9949	0.9966	0.9966	0.9966	0.9966	0.9966	0.9966
2	0.4885	0	0.6667	0.6065	0.3034	0.4841	0.4841	0.4841	0.4841	0.4841	0.4841
3	0.9985	0.9984	0	0.993	0.9978	0.994	0.994	0.994	0.994	0.994	0.994
4	0.8091	0.811	0.2474	0	0.7333	0.323	0.3653	0.3653	0.3653	0.3653	0.3653
5	0.3599	0.3663	0.583	0.4951	0	0.3174	0.3544	0.3544	0.3544	0.3544	0.3544
6	0.867	0.8683	0.714	0.64	0.8083	0	0.1953	0.1953	0.1953	0.1953	0.1953
7	0.9968	0.9968	0.9927	0.9912	0.9955	0.9805	0	0	0	0	0
8	0.9967	0.9967	0.9925	0.991	0.9954	0.98	0.0134	0	0	0	0
9	0.9966	0.9966	0.9922	0.9907	0.9953	0.9793	0.0281	0.0149	0	0.0049	0.0106
10	0.9966	0.9965	0.9921	0.9905	0.9952	0.9788	0.0379	0.0248	0.0148	0	0.0141
11	0.9966	0.9966	0.9922	0.9906	0.9952	0.9791	0.0316	0.0186	0.0142	0.0078	0

Figure 28: Tabulation of MATLAB calculated voltage profile

=== SLG Phase A Voltage Profile - POWERWORLD VALUES (Magnitudes Only) ===
PowerWorld Voltage Magnitudes (per unit):

Faulted_Bus	Bus1_Mag	Bus2_Mag	Bus3_Mag	Bus4_Mag	Bus5_Mag	Bus6_Mag	Bus7_Mag	Bus8_Mag	Bus9_Mag	Bus10_Mag	Bus11_Mag
1	0	0.9963	0.9979	0.9974	0.9949	0.9966	0.9966	0.9966	0.9966	0.9966	0.9966
2	0.4885	0	0.6667	0.6065	0.3034	0.4841	0.4841	0.4841	0.4841	0.4841	0.4841
3	0.9985	0.9984	0	0.993	0.9978	0.994	0.994	0.994	0.994	0.994	0.994
4	0.8091	0.811	0.2474	0	0.7333	0.323	0.3653	0.3653	0.3653	0.3653	0.3653
5	0.36	0.3663	0.583	0.4951	0	0.3174	0.3544	0.3544	0.3544	0.3544	0.3544
6	0.867	0.8683	0.714	0.64	0.8083	0	0.1953	0.1953	0.1953	0.1953	0.1953
7	0.9968	0.9968	0.9926	0.9912	0.9955	0.9805	0	0	0	0	0
8	0.9967	0.9967	0.9925	0.991	0.9954	0.98	0.0134	0	0	0	0
9	0.9966	0.9966	0.9922	0.9907	0.9953	0.9793	0.0281	0.015	0	0.0049	0.0106
10	0.9966	0.9965	0.9921	0.9905	0.9952	0.9788	0.0379	0.0249	0.0148	0	0.0141
11	0.9966	0.9966	0.9922	0.9906	0.9952	0.9791	0.0316	0.0186	0.0142	0.0078	0

Figure 29: Tabulation of PowerWorld calculated voltage profile

=== SLG Phase A Voltage Profile - PERCENTAGE DIFFERENCE MATRIX ===
Percentage Difference (%):

Faulted_Bus	Bus1	Bus2	Bus3	Bus4	Bus5	Bus6	Bus7	Bus8	Bus9	Bus10	Bus11
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	100	100	100	100
8	0	0	0	0	0	0	0.03	0	0	100	100
9	0	0	0	0	0	0	0.01	0.01	0	0.08	0.04
10	0	0	0	0	0	0	0	0	0.02	0	0.03
11	0	0	0	0	0	0	0.03	0.01	0.01	0.05	0

Figure 30: Tabulation of the % differences between corresponding values of the two sets

```
=== SLG Phase A Voltage Profile - CORRELATION MATRIX ===
Correlation (%):
=====================================
```

Faulted_Bus	Bus1	Bus2	Bus3	Bus4	Bus5	Bus6	Bus7	Bus8	Bus9	Bus10	Bus11
1	100	100	100	100	100	100	100	100	100	100	100
2	100	100	100	100	100	100	100	100	100	100	100
3	100	100	100	100	100	100	100	100	100	100	100
4	100	100	100	100	100	100	100	100	100	100	100
5	100	100	100	100	100	100	100	100	100	100	100
6	100	100	100	100	100	100	100	100	100	100	100
7	100	100	100	100	100	100	100	0	0	0	0
8	100	100	100	100	100	100	99.97	100	100	0	0
9	100	100	100	100	100	100	99.99	99.99	100	99.92	99.96
10	100	100	100	100	100	100	100	100	99.98	100	99.97
11	100	100	100	100	100	100	99.97	99.99	99.99	99.95	100

Figure 31: Correlation matrix of the two sets of values

Summary statistics:

- Maximum Difference: 100.000000%
- Average Difference: 4.961840%
- Minimum Correlation: 0.000000%
- Average Correlation: 95.038160%

Figure 32 visualises this summary.

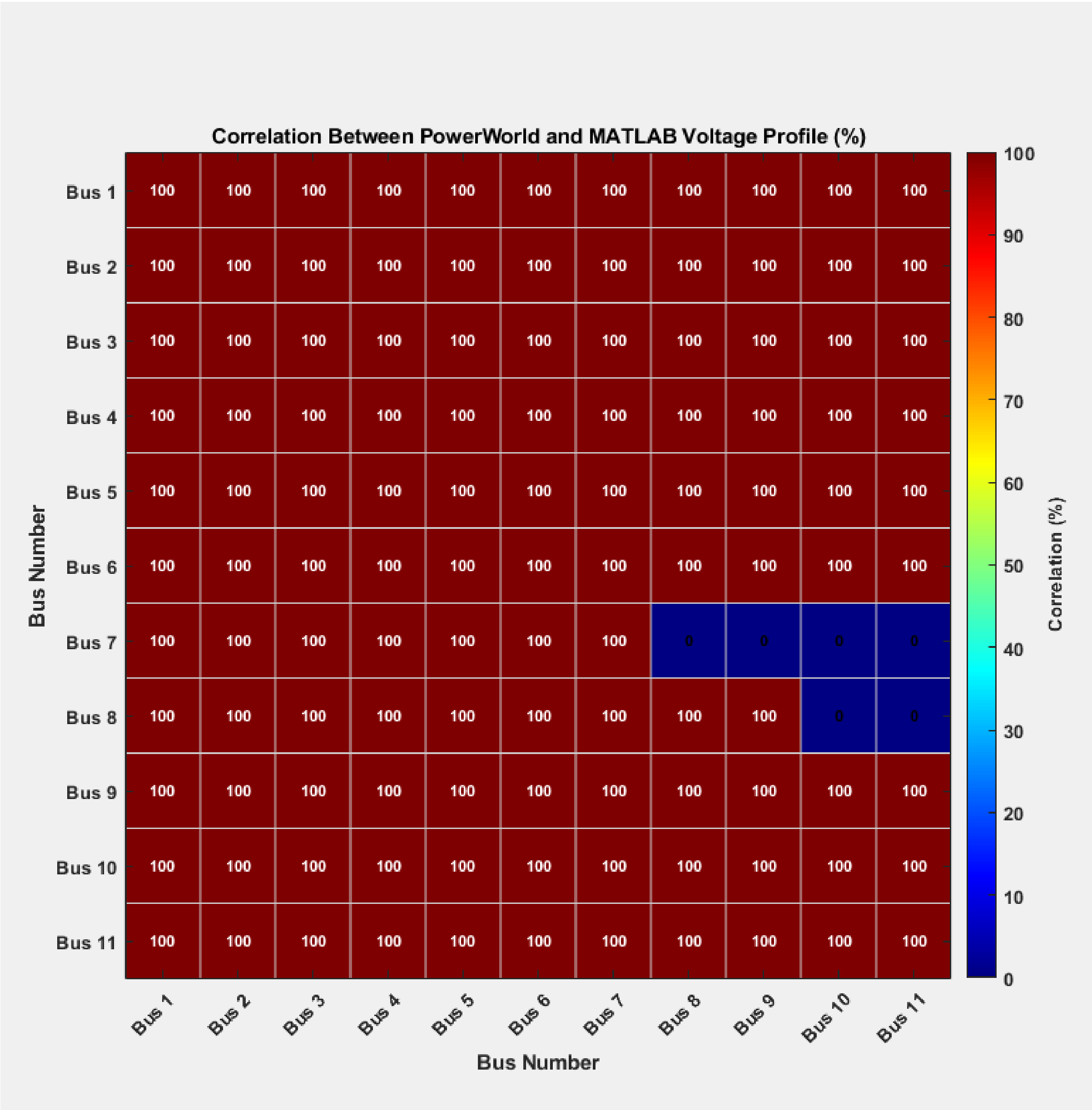


Figure 32: Correlation matrix heatmap for easier visual analysis

The zero correlation around bus bars 7 and 8 is unacceptable since both sets have zero values at those specific points. This is definitely a bug in my correlation calculation code which did not handle division by zero properly. To prove this, I have tested correlation in the same region but for the B phases.

=== SLG Phase B Voltage Profile - MATLAB VALUES (Magnitudes Only) ===
MATLAB Voltage Magnitudes (per unit):

Faulted_Bus	Bus1_Mag	Bus2_Mag	Bus3_Mag	Bus4_Mag	Bus5_Mag	Bus6_Mag	Bus7_Mag	Bus8_Mag	Bus9_Mag	Bus10_Mag	Bus11_Mag
1	1.6704	0.9886	0.9925	0.9912	0.9842	0.9884	0.9884	0.9884	0.9884	0.9884	0.9884
2	0.8994	0.9336	0.9255	0.9162	0.8834	0.8974	0.8974	0.8974	0.8974	0.8974	0.8974
3	0.9943	0.9943	1.6719	0.9731	0.9921	0.9806	0.9806	0.9806	0.9806	0.9806	0.9806
4	0.9547	0.9558	0.8752	0.8943	0.9449	0.9057	0.8931	0.8931	0.8931	0.8931	0.8931
5	0.884	0.8872	0.9107	0.9053	0.9025	0.8928	0.8816	0.8816	0.8816	0.8816	0.8816
6	0.9678	0.9685	0.9393	0.9413	0.9633	0.9341	0.8785	0.8785	0.8785	0.8785	0.8785
7	0.9951	0.9951	0.9893	0.9874	0.9933	0.9699	1.5778	1.5778	1.5778	1.5778	1.5778
8	0.9951	0.9951	0.9894	0.9874	0.9933	0.9701	1.5661	1.566	1.566	1.566	1.566
9	0.9951	0.9951	0.9894	0.9875	0.9933	0.9702	1.554	1.5539	1.554	1.5545	1.5549
10	0.9951	0.9952	0.9894	0.9875	0.9933	0.9703	1.5459	1.5459	1.5464	1.5473	1.5482
11	0.9951	0.9951	0.9894	0.9875	0.9933	0.9702	1.5516	1.5516	1.5525	1.5539	1.5558

Figure 33: MATLAB phase B SLG voltage profile

=== SLG Phase B Voltage Profile - POWERWORLD VALUES (Magnitudes Only) ===
PowerWorld Voltage Magnitudes (per unit):

Faulted_Bus	Bus1_Mag	Bus2_Mag	Bus3_Mag	Bus4_Mag	Bus5_Mag	Bus6_Mag	Bus7_Mag	Bus8_Mag	Bus9_Mag	Bus10_Mag	Bus11_Mag
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0
7	0.9951	0.9951	0.9893	0.9874	0.9933	0.9699	1.5778	1.5778	1.5778	1.5778	1.5778
8	0.9951	0.9951	0.9894	0.9874	0.9933	0.9701	1.566	1.5659	1.5659	1.5659	1.5659
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0

Figure 34:PowerWorld phase B SLG voltage profile (only when there is a fault at bus bars 7 and 8)

Figure 35 shows the B phase correlation.

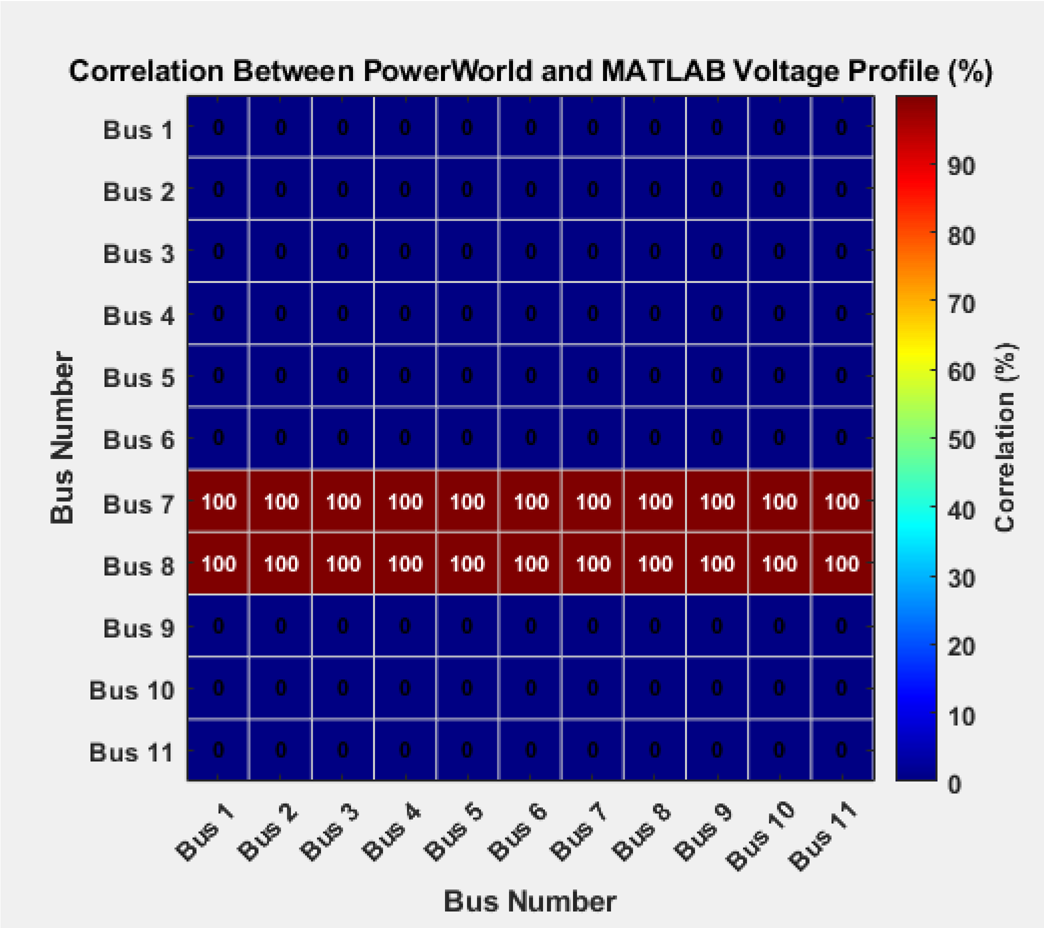


Figure 35: B Phase correlation when there is a fault at bus bar 7 and bus bar 8

Overall, my MATLAB single-phase-to-earth fault currents (A), and the corresponding voltage profile (pu) calculations have a very correlation with the simulated PowerWorld simulator results (all > 99% correlation i.e. less that 1% difference).

2.2. Phase-to-phase Faults

In this section, phase A is unfaulted and the phase-to-phase fault is between phase A to phase B. The comparisons between PowerWorld and MATLAB is done between phase B fault currents (which is the same for phases B and C) and the voltage profiles will be compared for phase B (if these correlate, phase C values should also correlate since they are related by the A operator).

Figure 36 tabulates the phase-to-phase fault current comparison and the % difference and correlation as well.

--- LL Phase B Fault Current COMPARISON ---

Bus	MATLAB_Val	PowerWorld_Val	Percent_Diff	Percent_Corr
1	11953	11953	6.9487e-05	100
2	17745	17745	0.00026196	100
3	5538.1	5538.1	0.00015664	100
4	810.63	810.63	4.6258e-05	100
5	1564.2	1564.2	8.549e-05	100
6	475.39	475.39	0.00027904	100
7	2582	2582	0.00023109	100
8	2443.5	2443.5	0.00024359	100
9	2290.9	2290.9	0.00023843	100
10	2216	2216	0.00030431	100
11	2313.4	2313.3	0.00035515	100

Figure 36: Phase to phase fault currents comparison summary

Summary statistics:

- Maximum Difference: 0.007197%
- Average Difference: 0.003784%
- Minimum Correlation: 99.992803%
- Average Correlation: 99.996216%

For easier visual analysis the summary is visualised in Figure 37.

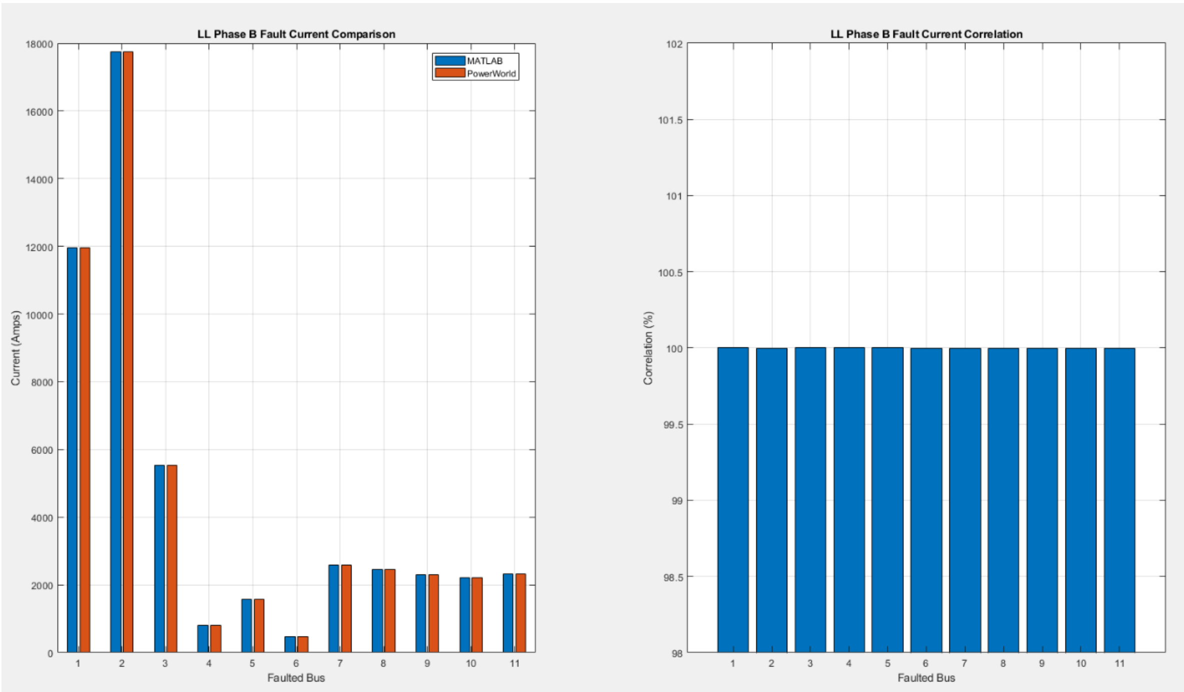


Figure 37: Statistics summary visualisation

Figures 38 – 41 tabulates MATLAB and PowerWorld voltage profiles, the %difference and % correlation matrices.

=== LL Phase B Voltage Profile - MATLAB VALUES (Magnitudes Only) ===
MATLAB Voltage Magnitudes (per unit):
======================================

Faulted_Bus	Bus1_Mag	Bus2_Mag	Bus3_Mag	Bus4_Mag	Bus5_Mag	Bus6_Mag	Bus7_Mag	Bus8_Mag	Bus9_Mag	Bus10_Mag	Bus11_Mag
1	0.5	0.7415	0.8279	0.7974	0.6569	0.7403	0.7403	0.7403	0.7403	0.7403	0.7403
2	0.6018	0.5	0.722	0.6771	0.5185	0.6022	0.6021	0.6021	0.6021	0.6021	0.6021
3	0.8648	0.8653	0.5	0.5118	0.8165	0.5881	0.5881	0.5881	0.5881	0.5881	0.5881
4	0.8466	0.8471	0.5232	0.5	0.7922	0.5484	0.5484	0.5484	0.5484	0.5484	0.5484
5	0.5585	0.5562	0.6825	0.6338	0.5	0.5597	0.5597	0.5597	0.5597	0.5597	0.5597
6	0.8815	0.8819	0.7492	0.7065	0.8387	0.5	0.5	0.5	0.5	0.5	0.5
7	0.9466	0.9468	0.8843	0.8633	0.9268	0.6972	0.5	0.5	0.5	0.5	0.5
8	0.9501	0.9503	0.892	0.8723	0.9317	0.7169	0.5189	0.5	0.5	0.5	0.5
9	0.9533	0.9534	0.8986	0.8802	0.936	0.7327	0.5261	0.5042	0.5	0.5025	0.504
10	0.9548	0.955	0.902	0.8841	0.9381	0.7409	0.5322	0.5091	0.5058	0.5	0.5063
11	0.9527	0.9528	0.8974	0.8787	0.9352	0.7294	0.5219	0.5001	0.5001	0.4989	0.5

Figure 38: MATLAB phase-to-phase (B-C) voltage profile

=== LL Phase B Voltage Profile - POWERWORLD VALUES (Magnitudes Only) ===
PowerWorld Voltage Magnitudes (per unit):
======================================

Faulted_Bus	Bus1_Mag	Bus2_Mag	Bus3_Mag	Bus4_Mag	Bus5_Mag	Bus6_Mag	Bus7_Mag	Bus8_Mag	Bus9_Mag	Bus10_Mag	Bus11_Mag
1	0.5	0.7415	0.8279	0.7974	0.6569	0.7404	0.7404	0.7404	0.7404	0.7404	0.7404
2	0.6018	0.5	0.7221	0.6771	0.5185	0.6022	0.6022	0.6022	0.6022	0.6022	0.6022
3	0.8648	0.8653	0.5	0.5118	0.8165	0.5881	0.5881	0.5881	0.5881	0.5881	0.5881
4	0.8466	0.8471	0.5232	0.5	0.7922	0.5484	0.5484	0.5484	0.5484	0.5484	0.5484
5	0.5585	0.5562	0.6825	0.6338	0.5	0.5597	0.5597	0.5597	0.5597	0.5597	0.5597
6	0.8815	0.8819	0.7492	0.7065	0.8388	0.5	0.5	0.5	0.5	0.5	0.5
7	0.9466	0.9468	0.8843	0.8633	0.9268	0.6972	0.5	0.5	0.5	0.5	0.5
8	0.9501	0.9503	0.892	0.8723	0.9317	0.7169	0.5189	0.5	0.5	0.5	0.5
9	0.9533	0.9534	0.8986	0.8802	0.936	0.7327	0.5261	0.5042	0.5	0.5025	0.504
10	0.9548	0.955	0.902	0.8842	0.9381	0.7409	0.5322	0.5091	0.5058	0.5	0.5063
11	0.9527	0.9528	0.8974	0.8787	0.9352	0.7294	0.5219	0.5002	0.5001	0.4989	0.5

Figure 39: PowerWorld phase-to-phase(B-C) voltage profile

=== LL Phase B Voltage Profile - PERCENTAGE DIFFERENCE MATRIX ===
Percentage Difference (%):
======================================

Faulted_Bus	Bus1	Bus2	Bus3	Bus4	Bus5	Bus6	Bus7	Bus8	Bus9	Bus10	Bus11
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0

Figure 40: phase-phase voltage profile % difference matrix

=== LL Phase B Voltage Profile - CORRELATION MATRIX ===
Correlation (%):
==

Faulted_Bus	Bus1	Bus2	Bus3	Bus4	Bus5	Bus6	Bus7	Bus8	Bus9	Bus10	Bus11
1	100	100	100	100	100	100	100	100	100	100	100
2	100	100	100	100	100	100	100	100	100	100	100
3	100	100	100	100	100	100	100	100	100	100	100
4	100	100	100	100	100	100	100	100	100	100	100
5	100	100	100	100	100	100	100	100	100	100	100
6	100	100	100	100	100	100	100	100	100	100	100
7	100	100	100	100	100	100	100	100	100	100	100
8	100	100	100	100	100	100	100	100	100	100	100
9	100	100	100	100	100	100	100	100	100	100	100
10	100	100	100	100	100	100	100	100	100	100	100
11	100	100	100	100	100	100	100	100	100	100	100

Figure 41: phase-to-phase voltage profile correlation matrix

Summary Statistics:

- Maximum Difference: 0.003470%
- Average Difference: 0.000834%
- Minimum Correlation: 99.996530%
- Average Correlation: 99.999166%

Figure 42 visualises the summary statistics.

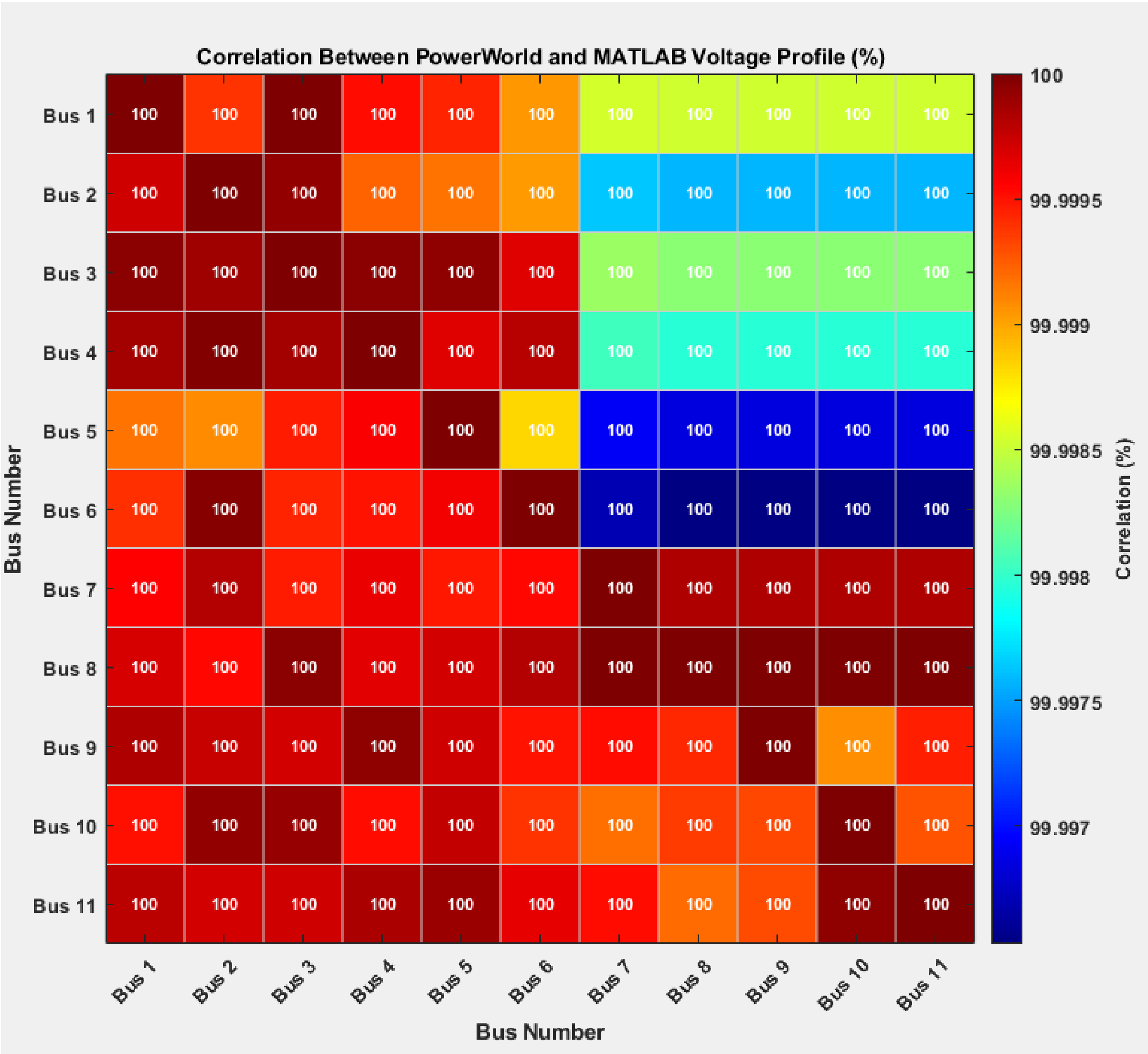


Figure 42: correlation matrix heatmap

Overall, the phase-to-phase fault calculations from MATLAB have a very high correlation (>99%). The subtle variations (most evident in Figure 42) are merely due to slight precision differences.

3. Conclusion

This laboratory exercise successfully validated the theoretical asymmetrical fault analysis calculations performed in Class Test 2 through PowerWorld Simulator modelling of the 11-bus power system network. The validation demonstrated exceptional correlation between hand calculations and software simulation results across all key parameters analysed.

The Y-bus matrix correlation analysis yielded outstanding results with perfect 100% correlation for positive/negative sequence networks and 99.999998% correlation for zero-sequence networks with maximum differences of only 0.000112%.

Both fault types analysed showed exceptional validation accuracy, with single-phase-to-earth faults achieving 99.996% average correlation across all 11 bus locations and phase-to-phase faults demonstrating 99.996% correlation for fault currents and 99.999% for voltage profiles.

The consistently high correlation values (>99%) confirm the accuracy of both theoretical fault analysis methods and PowerWorld Simulator for power system studies

This validation exercise confirms that manual fault analysis calculations, when performed with appropriate precision, achieve results comparable to commercial software. The PowerWorld Simulator proved reliable for complex sequence network analysis and comprehensive fault studies. The exceptional correlation provides confidence in both the theoretical methods taught and the software tools used for power system engineering applications, successfully bridging theoretical learning with practical engineering applications and providing a solid foundation for advanced power system analysis and professional practice.