IGEE 402 Power System Analysis – Fall 2024

Experiment 3 Lab Report – Fault Analysis

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Objective:

The objective of this lab is to differentiate between symmetrical faults (involving all three phases equally) and asymmetrical faults (where one or more phases are affected differently). Symmetrical components and sequence networks are used to model asymmetrical faults. Additionally, design issues that arise from each type of fault are identified.

I. Introduction

In power systems, faults can disrupt normal operations and potentially damage equipment. Symmetrical faults impact all three phases equally, making them straightforward to analyze. Asymmetrical faults, however, affect phases unevenly and require more advanced analysis techniques. This lab introduces methods to model and simulate both fault types, aiming to understand fault currents and system stability. Through hands-on experiments, the team observed how different faults impact network performance and identified critical considerations for system protection and design.

II. Experiment and Analysis

Part 1 Preliminary Calculations

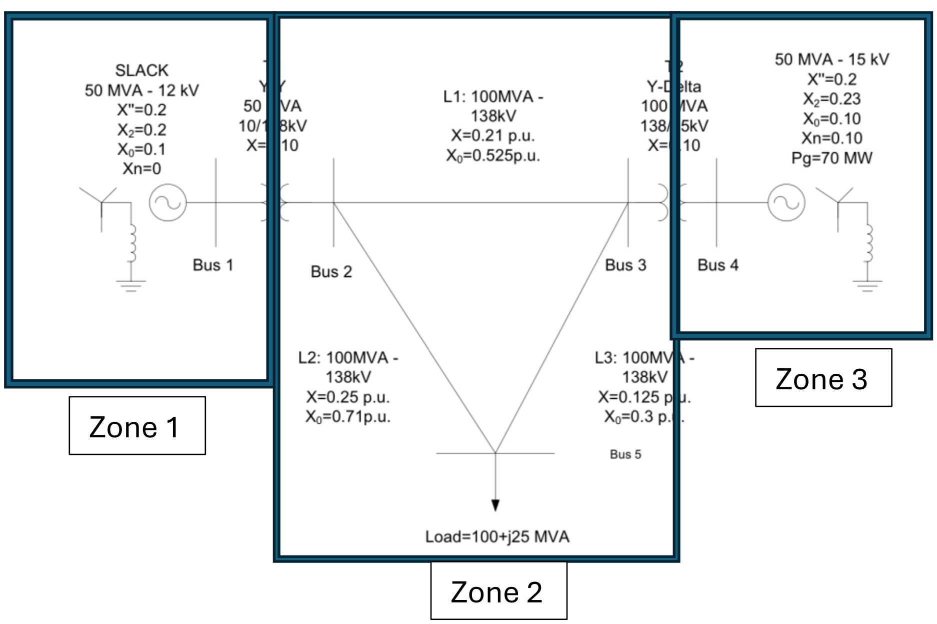


*Figure **Error! Use the Home tab to apply 0 to the text that you want to appear here.**. Meshed power System*

$$S_{base} = 100MVA.\ Zone3\ V_{base} = 15kV$$

Zone\Value	Base Voltage (kV)	Base Impedance(p.u.) = $Z_{base} = \frac{V^2}{S}$
Zone 1	10	1
Zone 2	138	190.44
Zone 3	15	2.25

Table ***Error! Use the Home tab to apply 0 to the text that you want to appear here.*** *. Base Voltage and Base Impedance of all Zones*

	Impedance X(p.u.)	Impedance X_0(p.u.)
L1	0.21	0.525
L2	0.25	0.71
L3	0.125	0.3

Table 1.2. p.u Impedance of all Lines

	X_n(p.u.)	X_0(p.u.)	X_2(p.u.)	X''(p.u.)	X(p.u.)
G1	0	$0.1 \times \frac{100M}{50M} = 0.2$	$0.2 \times \frac{100M}{50M} = 0.4$	$0.2 \times \frac{100M}{50M} = 0.4$	NaN
G2	0.1	0.1	0.23	0.1	NaN
T1	NaN	NaN	NaN	NaN	$0.1 \times \frac{100M}{50M} = 0.2$
T2	NaN	NaN	NaN	NaN	0.1

Table 1.3. p.u value of all generator and transformer impedance in consistent bases

Part 2 *Symmetrical Faults*

2.1 System Simulation to obtain the fault current magnitude

	Fault Name	Skip	Solved	Fault Object (File Format)	Fault Location	Type for Fault 1	Type for Fault 2	Fault Resistance	Fault Reactance	Fault 1 Current Mag
1	B_000001BUS1	NO	YES	Bus '1'		3PB	SLG	0.000	0.000	3.16861
2	B_000002BUS2	NO	YES	Bus '2'		3PB	SLG	0.000	0.000	3.17014
3	B_000003BUS3	NO	YES	Bus '3'		3PB	SLG	0.000	0.000	3.47469
4	B_000004BUS4	NO	YES	Bus '4'		3PB	SLG	0.000	0.000	3.88561
5	B_000005BUS5	NO	YES	Bus '5'		3PB	SLG	0.000	0.000	2.90597

Table 2.1.1 fault current magnitude of three phase fault at each bus

$$I_{base} = \frac{S_{base}}{\sqrt{3}V_{base}}$$

Based on the formula, we can calculated that the I base for each zone and get the corresponding ampere value for each bus which indicated in the below table(table2.2).

Bus	I_base(A)	Fault Current (p.u.)	Fault Current (A)
1	5774	3.16861	18295.55
2	418	3.17014	1325.11
3	418	3.47469	1452.42
4	3849	3.88561	14955.71
5	418	2.90597	1214.70

Table 2.1.2 fault current and its base of three phase fault at each bus

We can identify through the table that the worst-case fault current exists in Bus 1 which has fault current 18295.55 amperes.

2.2 Voltage magnitudes in the worst-case fault current

Using the simulation software, we obtained the network voltages magnitudes of the bus with worst case fault current in amperes.

	Phase A (pu)	Phase B (pu)	Phase C (pu)
Bus 1	0.00000	0.00000	0.00000
Bus 2	0.25443	0.25443	0.25443
Bus 3	0.43163	0.43163	0.43163
Bus 4	0.57380	0.57380	0.57380
Bus 5	0.36258	0.36258	0.36258

Table 2.2.1 Network voltage magnitude profile at Bus 1

2.3 Fault Current for the worst-case fault found in 2.1 after removing the connection bus 2 and 5

	Fault Objec (File Format	Fault Location	Type for Fault 1	Type for Fault 2	Fault Resistance	Fault Reactance	Fault 1 Current Mag	Fault 1 Current Ang	Fault 1 Subtrans Mag A (pu)	Fault 1 Subtrans Mag B (pu)	Fault 1 Subtrans Mag C (pu)	Fault 1 Thev R	Fault 1 Thev X
1	Bus '1'		3PB	SLG	0.000	0.000	3.02377	-85.11915	3.024	3.024	3.024	0.02814	0.32951
2	Bus '2'		3PB	SLG	0.000	0.000	2.94545	-84.67804	2.945	2.945	2.945	0.05107	0.32863
3	Bus '3'		3PB	SLG	0.000	0.000	3.48238	-79.98335	3.482	3.482	3.482	0.08245	0.26373
4	Bus '4'		3PB	SLG	0.000	0.000	3.93198	-81.19720	3.932	3.932	3.932	0.05277	0.24879
5	Bus '5'		3PB	SLG	0.000	0.000	2.52949	-79.98482	2.529	2.529	2.529	0.15629	0.32780

Table 2.3.1 fault current after removing the line connection between bus 2 and 5

From the 2.1, we know that the worst case happened on Bus 1. After removing the connection between the bus 2 and 5. The magnitude in p.u for Bus 1 is 3.02377 (Table 2.3.1) which is 17459.2 amperes. We can observe that the fault current decreased due to the disconnection.

2.4 The fault current of the worst case found in 2.1 after disconnecting the bus 5 load

	Fault Objec (File Format	Fault Location	Type for Fault 1	Type for Fault 2	Fault Resistance	Fault Reactance	Fault 1 Current Mag	Fault 1 Current Ang	Fault 1 Subtrans Mag A (pu)	Fault 1 Subtrans Mag B (pu)	Fault 1 Subtrans Mag C (pu)	Fault 1 Thev R	Fault 1 Thev X
1	Bus '1'		3PB	SLG	0.000	0.000	2.93427	-89.99999	2.934	2.934	2.934	0.00000	0.34080
2	Bus '2'		3PB	SLG	0.000	0.000	2.83049	-81.85503	2.830	2.830	2.830	0.00000	0.34911
3	Bus '3'		3PB	SLG	0.000	0.000	3.07204	-76.33633	3.072	3.072	3.072	0.00000	0.32277
4	Bus '4'		3PB	SLG	0.000	0.000	3.48950	-72.28822	3.490	3.489	3.489	0.00000	0.28657
5	Bus '5'		3PB	SLG	0.000	0.000	2.55118	-78.17099	2.551	2.551	2.551	0.00000	0.38783

Table 2.4.1 fault current disconnecting the load of bus 5

From 2.1, we know that the worst case happened on Bus 1. After reconnecting the line between bus 2 and 5 and disconnecting the load at bus 5, we obtained the fault current magnitude of bus 1 2.93427 in p.u. by timing the current base 5774 A, which results in 16942.48 amperes.

Part 3 *Asymmetrical Faults (Single-line-to-ground)*

1. The magnitude of the single line to ground fault current in per unit is shown in the table below under column of Fault 2 Current Mag.

	Fault Reactance	Fault 1 Current Mag	Fault 1 Current Ang	Fault 1 Subtrans Mag A (pu)	Fault 1 Subtrans Mag B (pu)	Fault 1 Subtrans Mag C (pu)	Fault 1 Thev R	Fault 1 Thev X	Fault 2 Current Mag	Fault 2 Current Ang	Fault 2 Subtrans Mag A (pu)	Fault 2 Subtrans Mag B (pu)	Fault 2 Subtrans Mag C (pu)	Fault 2 Thev R	Fault 2 Thev X
1	0.000	2.93427	-89.99999	2.934	2.934	2.934	0.00000	0.34080	3.36950	-89.99999	3.370	0.000	0.000	0.00000	0.89034
2	0.000	2.83049	-81.85503	2.830	2.830	2.830	0.00000	0.34911	3.12538	-81.85503	3.125	0.000	0.000	0.00000	0.94851
3	0.000	3.07204	-76.33633	3.072	3.072	3.072	0.00000	0.32277	3.92020	-76.33633	3.920	0.000	0.000	0.00000	0.75882
4	0.000	3.48950	-72.28822	3.490	3.489	3.489	0.00000	0.28657	2.13875	-72.28822	2.139	0.000	0.000	0.00000	1.40269
5	0.000	2.55118	-78.17099	2.551	2.551	2.551	0.00000	0.38783	2.71141	-78.17099	2.711	0.000	0.000	0.00000	1.09472

Table 3.1.1 Magnitude of the fault current

The corresponding ampere value for each bus is indicated in the below table(table2.2).

Bus	I_base(A)	Fault Current (p.u.)	Fault Current (A)
1	5774	3.36950	19455
2	418	3.12538	1306.4
3	418	3.92020	1638.6
4	3849	2.13875	8232.0
5	418	2.71141	1133.4

Table 3.1.2 fault current and its base of single line to ground fault at each bus

2. It is still Bus 1 with a fault current of 19455 A. It is the same bus found in previous case. Bus 1 is directly connected to the slack bus, where the impedance is minimized and fault current maximized. This behavior is consistent with all fault types due to the dominant role of the slack bus and its low impedance contribution. During the symmetrical fault case, fault current depends primarily on the positive sequence impedance. Bus 1 can draw unlimited fault current from the ideal voltage source and has lower impedance due to its direct connection to the slack bus, resulting in higher fault current. For the asymmetrical case, the fault depends on the positive, negative, and zero-sequence impedance. At bus 1, the slack's zero sequence impedance is negligible, allowing for a higher zero-sequence current contribution. This makes the fault current at Bus 1 higher than the rest.

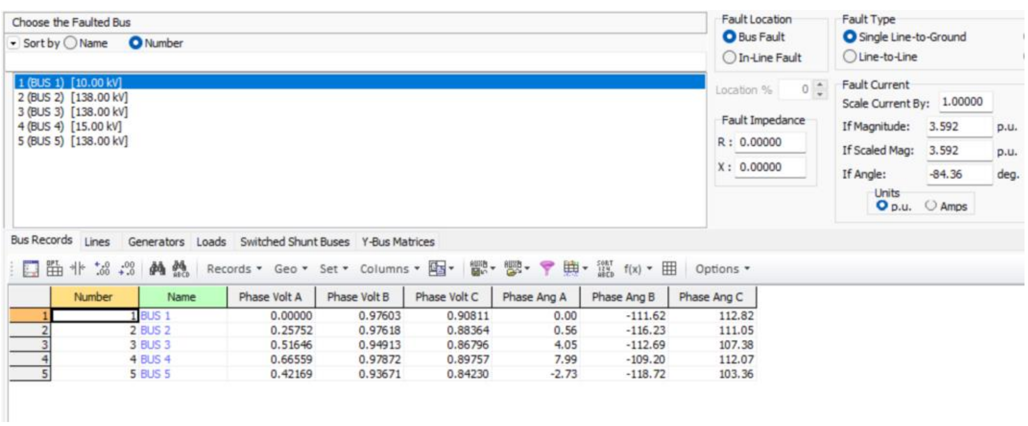


Figure 3.2.1 Bus 1 Single Line to Ground Fault

3. The bus has a base current of 5774 A. With a magnitude of 4.233 pu, the team found the current magnitude in amperes to be 24441 A. Three phase current has a fault of 18295.55 A, single line to ground fault current has a magnitude of 19455 A. The double line to ground fault is the largest out of the three.

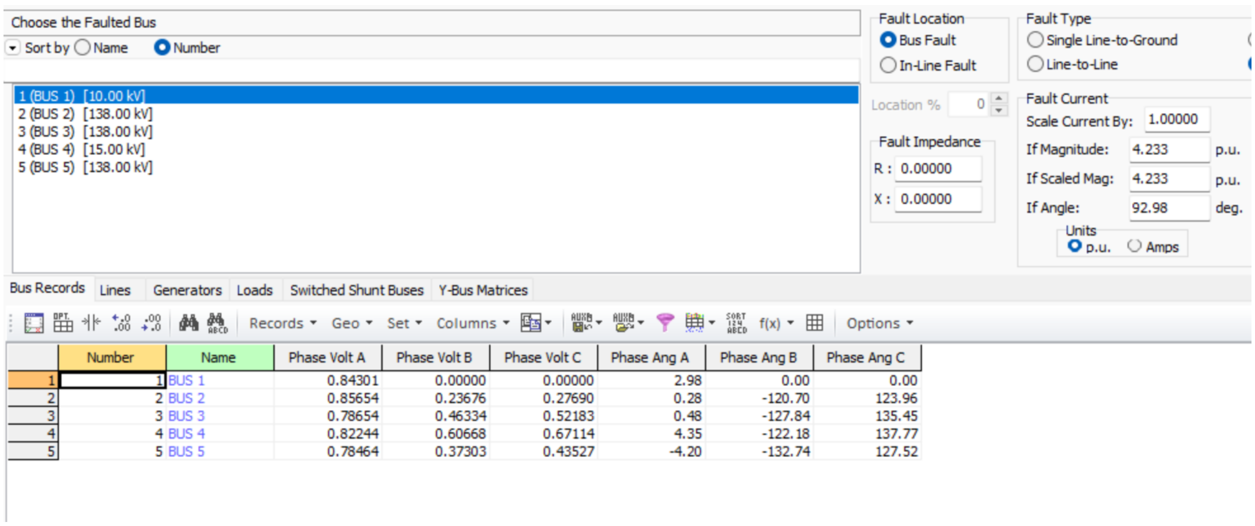


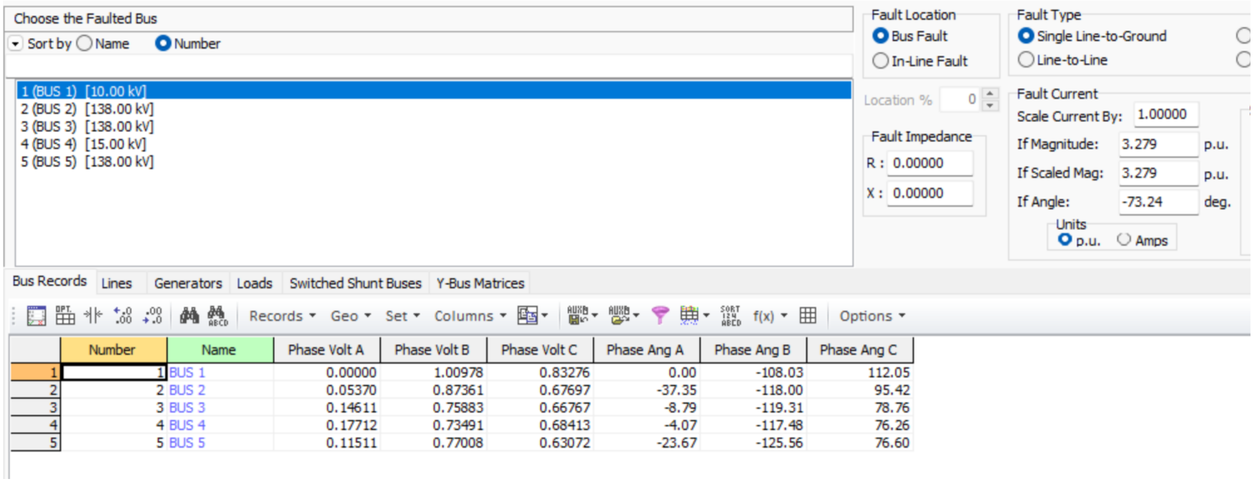
Figure 3.3.1 Bus 1 Double Line to Ground Fault

4. The voltage magnitudes at all buses for the worst-case fault current is shown in the table below. It is asymmetrical. The magnitudes of all three-phase voltages are not equal, and the phase relationships are not apart by 120 degrees. In SLG fault, one phase (the faulted phase) is grounded, causing its voltage to drop close to zero at the fault's bus while the other two phases remain nearly unaffected initially maintain their voltage magnitude close to pre-fault values but slightly imbalance due to the fault. This type of faults breaks the symmetry of the three-phase system.

	Phase A (pu)	Phase B (pu)	Phase C (pu)
Bus 1	0.00000	0.97603	0.90811
Bus 2	0.25752	0.97618	0.88364
Bus 3	0.51646	0.94913	0.86796
Bus 4	0.66559	0.97872	0.89757
Bus 5	0.42169	0.93671	0.84230

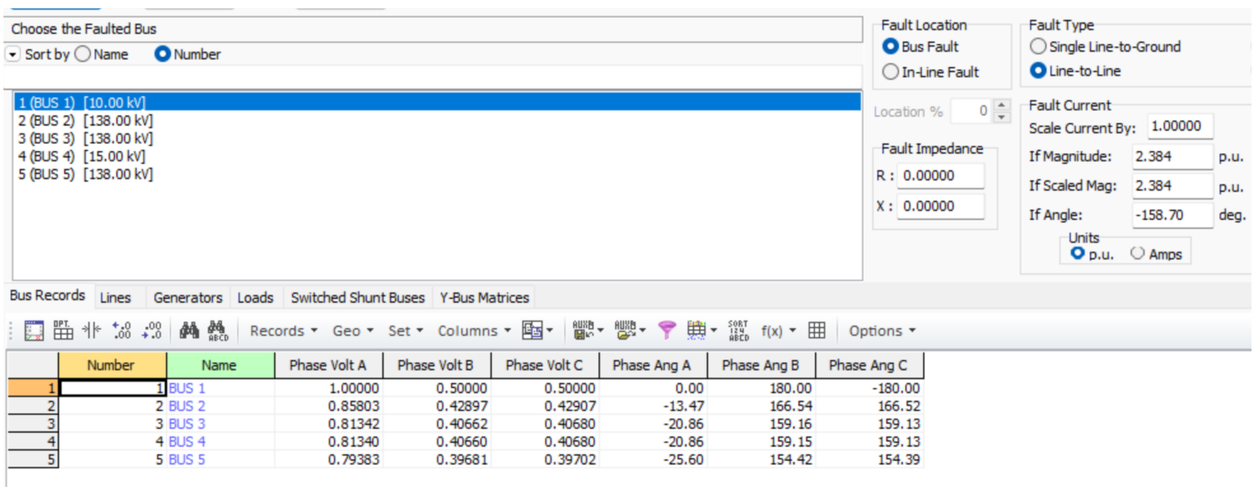
Table 3.4.1 Voltage magnitudes at all Bus for Worst Case Fault Current

5.Bus 1 has a base current of 5774 A. Using the software, the team obtained the per unit magnitude of 3.279 pu. Therefore, multiplying 3.279 pu by 5774 A, the team obtained the magnitude of single line to ground current to be 18933 A. The line-to-line fault current has a per unit magnitude of 2.384 pu, which is 13765 A.



	Number	Name	Phase Volt A	Phase Volt B	Phase Volt C	Phase Ang A	Phase Ang B	Phase Ang C
1	1	BUS 1	0.00000	1.00978	0.83276	0.00	-108.03	112.05
2	2	BUS 2	0.05370	0.87361	0.67697	-37.35	-118.00	95.42
3	3	BUS 3	0.14611	0.75883	0.66767	-8.79	-119.31	78.76
4	4	BUS 4	0.17712	0.73491	0.68413	-4.07	-117.48	76.26
5	5	BUS 5	0.11511	0.77008	0.63072	-23.67	-125.56	76.60

Figure 3.5.1 Single-Line-To-Ground Fault



	Number	Name	Phase Volt A	Phase Volt B	Phase Volt C	Phase Ang A	Phase Ang B	Phase Ang C
1	1	BUS 1	1.00000	0.50000	0.50000	0.00	180.00	-180.00
2	2	BUS 2	0.85803	0.42897	0.42907	-13.47	166.54	166.52
3	3	BUS 3	0.81342	0.40662	0.40680	-20.86	159.16	159.13
4	4	BUS 4	0.81340	0.40660	0.40680	-20.86	159.15	159.13
5	5	BUS 5	0.79383	0.39681	0.39702	-25.60	154.42	154.39

Figure 3.5.2 Line to Line Fault

III. Conclusion

This lab provided a comprehensive understanding of fault analysis in three-phase power systems by investigating symmetrical and asymmetrical faults. Symmetrical faults, affecting all three phases equally, were easier to analyze, with fault currents largely determined by positive-sequence impedance. Asymmetrical faults, such as single-line-to-ground faults, introduced system imbalances and required the use of symmetrical components and sequence networks to account for contributions from positive, negative, and zero-sequence impedances. The analysis revealed that the worst-case fault currents for both fault types occurred at Bus 1 due to its direct connection to the slack bus, which minimized impedance and maximized fault current contributions. These observations underscore the importance of understanding fault characteristics for designing reliable protection systems and maintaining power system stability.