Journal of Engineering, Management and Information Technology

ASPUR PUBLISHING

Vol. 04, No. 01 (2026) 9-24, doi: doi:10.61552/JEMIT.2026.01.002 - http://jemit.aspur.rs

SHORT CIRCUIT ANALYSIS IN SOLAR PV BASED MICRO-GRID USING ETAP

Salehin Haque Chowdhury
Md Kamrul Hassan
Mohammad Ragib Hasin
Tamim Ahmed
Md Al Araf [1]

Received 12.08.2024.
Revised 15.09.2024.
Accepted 18.10.2024.

Keywords:

Short Circuit Analysis, Solar PV Microgrid, ETAP, Protective Devices, Fault Current, Unsymmetrical Faults.

Original research

A B S T R A C T

This research investigates the critical role of protective equipment in mitigating unsymmetrical faults within a renewable energy-based power system. Focusing on a microgrid powered by five Q-Cell solar panels, the study simulates and analyzes various short circuit fault scenarios to determine optimal protection strategies. The research employs Electrical Transient Analyzer Program (ETAP) to simulate Line-to-Ground, Line-to-Line, and Line-to-Line-to-Ground faults at both the generation (Bus 1) and distribution (Bus 2) sides of the microgrid. Fault durations are varied from a single cycle up to the maximum breaking capacity of the system. Additionally, simultaneous fault scenarios affecting both Bus 1 and Bus 2 are investigated. Through extensive simulations, the study generates a comprehensive data table encompassing fault currents and system responses across all tested scenarios. This data serves as a critical foundation for selecting appropriately rated circuit breakers and relays, ensuring the safe and reliable operation of the microgrid. The research emphasizes the importance of accurately determining fault clearing times to minimize equipment damage and maintain system stability in the face of unsymmetrical faults.

1. INTRODUCTION

The integration of renewable energy sources, particularly solar photovoltaic (PV) systems, into microgrids presents both opportunities and challenges for ensuring reliable power delivery (Yan et al., 2017). While these systems offer a sustainable path towards a cleaner energy future, their inherent intermittency and distinct fault characteristics necessitate a rigorous approach to protection design (Gidiagbaa et al. 2023; Manditereza & Bansal, 2016). Unlike traditional power systems, microgrids often operate in a decentralized manner, with distributed generation sources like solar PV introducing unique fault current contributions and voltage profiles (Mondal et al., 2024). This complexity underscores the critical need for accurate short-circuit analysis (SCA) to safeguard equipment and maintain system stability under various fault conditions (Zhang & Zhang, 2024).

This research investigates the impact of unsymmetrical faults, commonly encountered in real-world power systems, on a solar PV-based microgrid (Altaf et al., 2022). Leveraging the capabilities of the Electrical Transient Analyzer Program (ETAP) software, we simulate and analyze the system's response to Line-to-Ground (L-G), Line-to-Line (L-L), and Line-to-Line-to-Ground (L-L-G) faults at different points within the

[1] Corresponding author: Md Al Araf
Email: md.al.araf.2001@gmail.com

microgrid. By varying fault durations and examining fault current magnitudes and voltage deviations, this study aims to:

1. Identify critical fault characteristics specific to the studied solar PV-based microgrid,
2. Determine appropriate ratings and types of protective devices, specifically circuit breakers, for ensuring reliable fault clearing and system protection,
3. Provide practical insights and recommendations for engineers designing similar microgrid systems.

The findings of this research contribute valuable data and knowledge to the field of microgrid protection, supporting the development of robust and resilient renewable energy-based power systems.

2. LITERATURE REVIEW

The growing incorporation of renewable energy sources, especially solar photovoltaic (PV) systems, into microgrids requires a comprehensive understanding of their performance during fault circumstances. Short circuit analysis (SCA) is essential for developing effective protection methods for these systems, guaranteeing their dependability and safety (Satpathi et al. 2017). This literature review analyzes recent studies on SCA in solar PV-based microgrids, emphasizing modeling techniques, fault situations, and the importance of protective equipment selection.

Microgrids, as characterized by Meena et al. (2024) and Mondal et al. (2024), are autonomous power systems capable of functioning independently or in tandem with the primary grid. The incorporation of renewable energy sources, although advantageous for sustainability, introduces intermittency and uncertainty into the microgrid's attributes (Meena et al., 2024; Zorumski et al., 2024). This unpredictability underscores the necessity of thorough SCA to guarantee system resilience against diverse fault circumstances. SCA entails analyzing the system's response to short circuit faults, computing fault currents, and evaluating the efficiency of protective mechanisms (Kadukar et al., 2018). This analysis is crucial for: Enhancing protection schemes: Establishing suitable ratings and configurations for circuit breakers, relays, and other protective apparatus (Chatterjee & Maklago, 2022; Kadukar et al., 2018; Zorumski et al., 2024). Enhancing system stability: Minimizing fault clearing times to prevent cascading failures and preserve stable operation (Kulkarni & Sontakke, 2015). Ensuring equipment safety: Restricting fault current magnitudes and durations to avert equipment damage (Chatterjee & Maklago, 2022).

Several studies emphasize the use of Electrical Transient Analyzer Program (ETAP) as an effective tool for simulating and studying microgrid behavior (Kulkarni & Sontakke, 2015). ETAP allows researchers to model multiple microgrid components, including distributed generation sources like solar PV systems, energy storage, and loads. The software offers complete analysis, including load flow studies, transient analysis, and short circuit calculations (Kadukar et al., 2018; Zorumski et al., 2024). For instance, (Kadukar et al., 2018) applied ETAP to model a 52.3 kW PV-based microgrid, simulating various transient situations such load flow changes, loss of generation, and short circuit faults. Similarly, (Chatterjee & Maklago, 2022) applied ETAP for load flow and transient analysis of a solar PV microgrid built for grid-tied operation. These studies highlight the adaptability of ETAP in studying microgrid performance under normal and fault scenarios.

Research underlines the significance of simulating multiple fault scenarios to build strong protection solutions (Al Araf et al., 2024; Ortiz et al., 2019). Zorumski et al. (2024) evaluated the impact of renewable energy source intermittency on protection coordination, underlining the need for adaptive protection methods in microgrids. Al Araf et al. (2024) concentrated on assessing symmetrical and unsymmetrical faults in transmission lines, highlighting the need of estimating fault current magnitudes for optimal equipment selection. While many studies focus on generic short circuit analysis, this research explicitly explores unsymmetrical faults (Line-to-Ground, Line-to-Line, and Line-to-Line-to-Ground) within a solar PV-based microgrid (Rasouli-Eshghabad et al., 2024). By simulating these precise events at varied locations and durations, this research seeks to offer thorough data on fault currents and system reactions. This extensive study forms the basis for selecting suitably rated circuit breakers and relays, ensuring optimal protection against unsymmetrical faults (Nsaif et al., 2021).

The literature stresses the crucial importance of SCA in developing reliable and safe solar PV-based microgrids. ETAP appears as a valuable tool for simulating various fault scenarios and studying system response (Shin et al., 2020). This research builds upon current knowledge by focusing specifically on unsymmetrical faults, intending to give comprehensive data for selecting optimal protection equipment and assuring the safe and stable functioning of the microgrid under different fault scenarios.

3. METHODOLOGY

3.1 Circuit Modelling and Simulation

Proposed Circuit Diagram

This entire system consists of five solar panels/PVA, Two Buses Bus 1 and Bus 2, in the middle of these two buses a transformer is used. A power grid is connected to the system by BUS 2. Five PVA named PVA1, PVA2, PVA3, PVA4, PVA5. Each PVA is of 6.85 KVA 6.6 KV and 599 A. BUS 2 is rated at 6.6 KV. Transformer T1 is rated at 2 MVA and 6.6/33 KV. BUS 2 is rated at 33 KV. Power Grid, U1 is rated at 1000 MVAsc (Mega Volt Amperes short circuit).

PV Panel Configuration

In this setting solar cell types can be selected. Q CELLS has been selected for this project which model number Q

BASE 215-230. Solar type poly-crystalline. Number of cells used is 60. DC voltage Vdc 1000v. Power Voltage P-V Curve and Current Voltage curve has been shown. All preset data are shown in below figures 1 and 2.

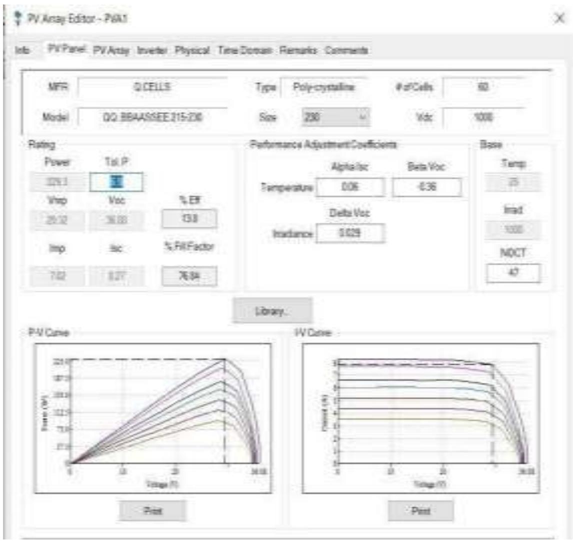


Figure 1. PV Panel Configuration

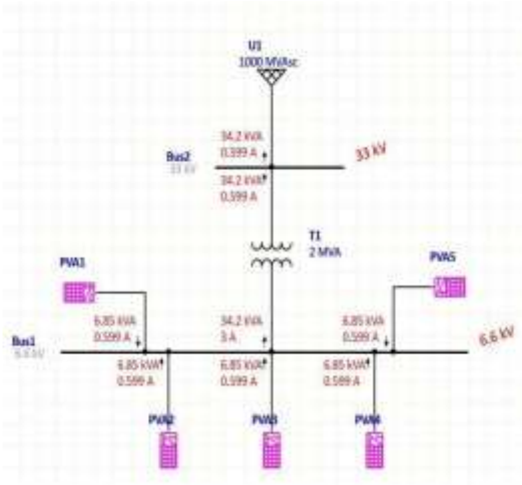


Figure 2. Power Flow Analysis Circuit Using ETAP

V Array Configuration

In this section number of cells and their connection type parallel or series is selected (Figure 3). We take 17 solar cells in series and 2 solar cells in parallel. Watt per panel 229.3 watt. Total PV Array 34. Voltage in DC 498.44 V. Kilowatt in DC 7.8kw. Current in DC 15.64 A. From the Irradiance calculation data, the system designed for 927 watts. This is variable with different condition normal, shutdown, emergency, standby, startup, accident, summer load, winter load.

Figure 3. PV Array Configuration

3.2 Inverter Ratings

DC Ratings, DC voltage 6.6 KV and 7.42 KVA where Vmax 110%

AC converted voltage 6.6 KV and 7.2 KVA. Minimum power factor 80 and maximum power factor 100. Minimum voltage 90% and maximum voltage 110%. At full load the efficiency is 97%, at 75% load the efficiency is 94%, at 50% load the efficiency is 93%, at 25% load the efficiency is 90%. This can consider as a very good power system. Load percentage and Efficiency with power factor also selected (Figure 4).

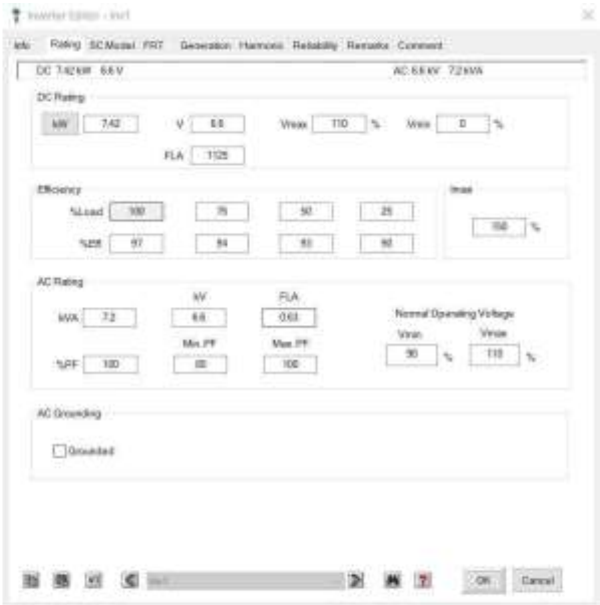


Figure 4. Inverter Rating

3.3 Fault Analysis

Condition 1: When Bus 1 Is Faulted

Table 1. For Case 1.1.1

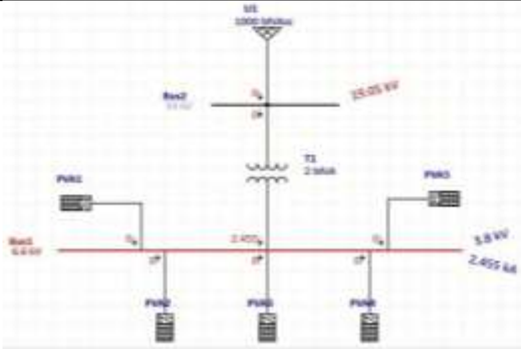
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-G	BUS 1	1	2.455 kA	3.8 kV	 **Figure 5**. L-G Fault on Bus 1 with One Cycle
No Fault	BUS 2	2	0 kA	19.05 kV	

Table 2. For Case 1.1.2

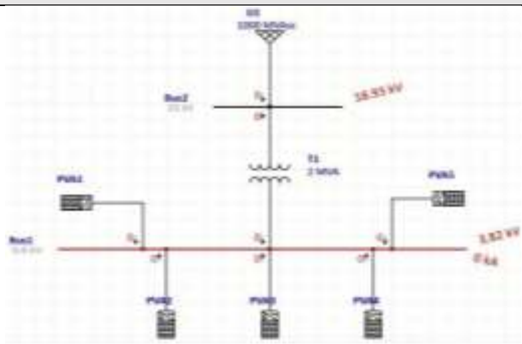
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-L	BUS 1	1	0 kA	3.82 kV	 **Figure 6**. L-L Fault on Bus 1 with One Cycle
No Fault	BUS 2	2	0 kA	18.93 kV	

Table 3. For Case 1.1.3

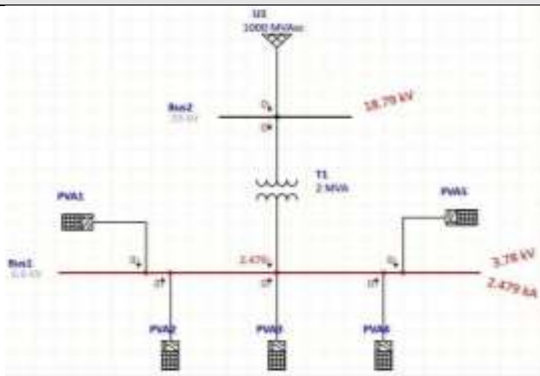
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-L-G	BUS 1	1	2.479 kA	3.78 kV	 **Figure 7**. L-L-G Fault on Bus 1 with One Cycle
No Fault	BUS 2	2	0 kA	18.79 kV	

Table 4: For Case 1.2.1

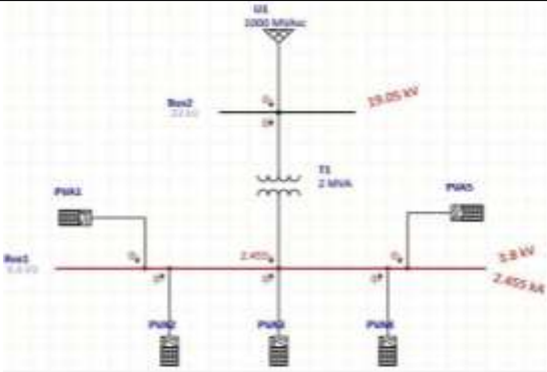
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-G	BUS 1	1.5-4	2.455 kA	3.8 kV	 **Figure 8**. L-G Fault on Bus 1 with 1.5-4 Cycle
No Fault	BUS 2	1.5-4	0 kA	19.05 kV	

Table 5. For Case 1.2.2

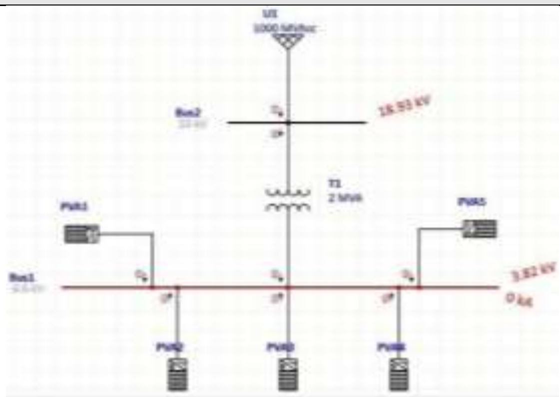
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-L	BUS 1	1.5-4	0 kA	3.82 kV	 **Figure 9**. L-L Fault on Bus 1 with 1.5-4 Cycle
No Fault	BUS 2	1.5-4	0 kA	18.93 kV	

Table 6. For Case 1.2.3

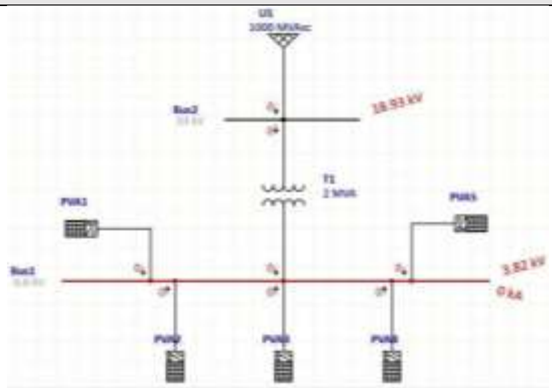
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-L	BUS 1	1.5-4	0 kA	3.82 kV	 **Figure 10**. L-L Fault on Bus 1 with 1.5-4 Cycle
No Fault	BUS 2	1.5-4	0 kA	18.93 kV	

Table 7. For Case 1.3.1

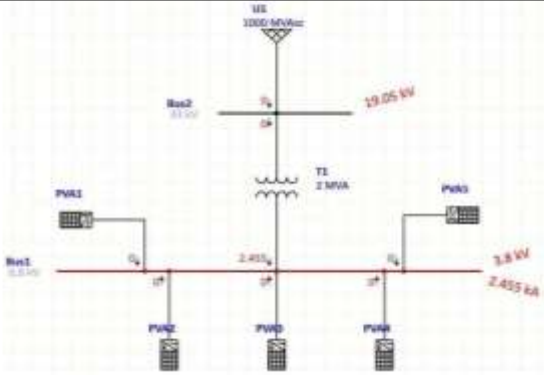
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-G	BUS 1	MAX	2.455 kA	3.8 kV	 **Figure 11.** L-G Fault on Bus 1 with MAX Cycle
No Fault	BUS 2	MAX	0 kA	19.05 kV	

Table 8. For Case 1.3.2

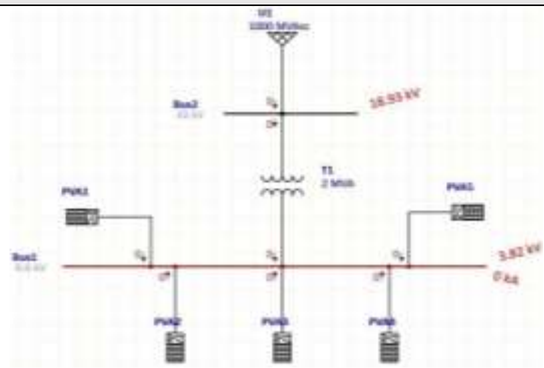
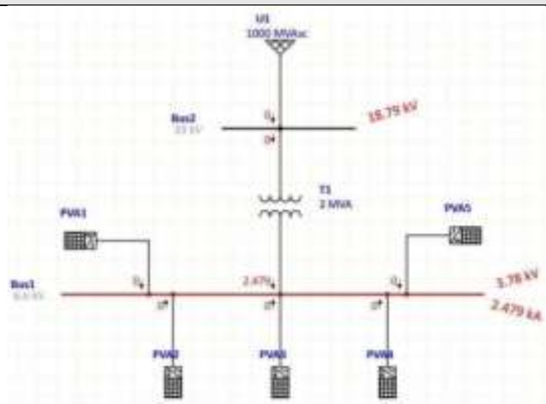
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-L	BUS 1	MAX	0 kA	3.82 kV	 **Figure 12**. L-L Fault on Bus 1 with MAX Cycle
No Fault	BUS 2	MAX	0 kA	18.93 kV	

Table 9. For Case 1.3.3

Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-L-G	BUS 1	MAX	2.479 kA	3.78 kV	 **Figure 13**. L-L-G Fault on Bus 1 with MAX Cycle
No Fault	BUS 2	MAX	0 kA	18.79 kV	

Condition 2: When Bus 2 Is Faulted

Table 10. For Case 2.1.1

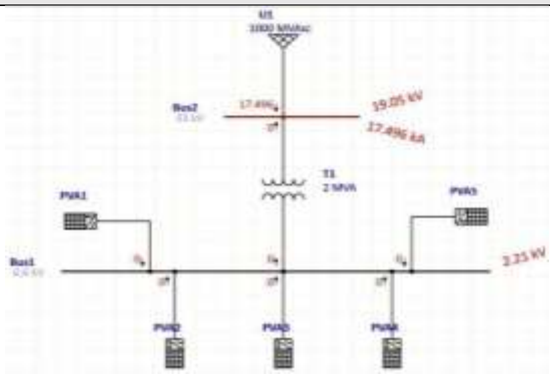
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-G	BUS 2	1	17.496 kA	19.05 kV	 **Figure 14**. L-G Fault on Bus 2 with 1 Cycle
No Fault	BUS 1	1	0 kA	2.21 kV	

Table 11. For Case 2.1.2

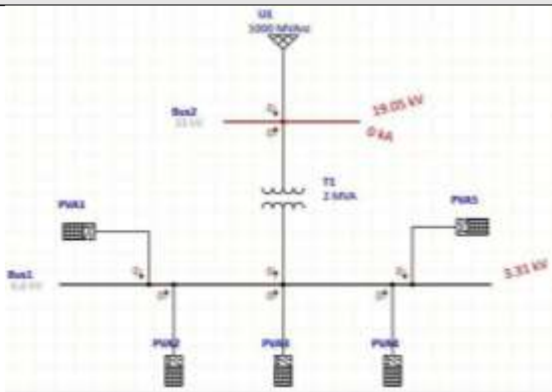
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L- L	BUS 2	1	0 kA	19.05 kV	 **Figure 15**. L-L Fault on Bus 2 with 1 Cycle
No Fault	BUS 1	1	0 kA	3.31 kV	

Table 12. For Case 2.1.3

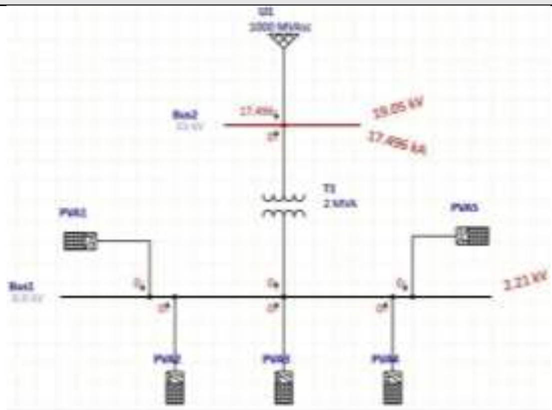
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-L-G	BUS 2	1	17.496 kA	19.05 kV	 **Figure 16**. L-L-G Fault on Bus 2 with 1 Cycle
No Fault	BUS 1	1	0 kA	2.21 kV	

Table 13. For Case 2.2.1

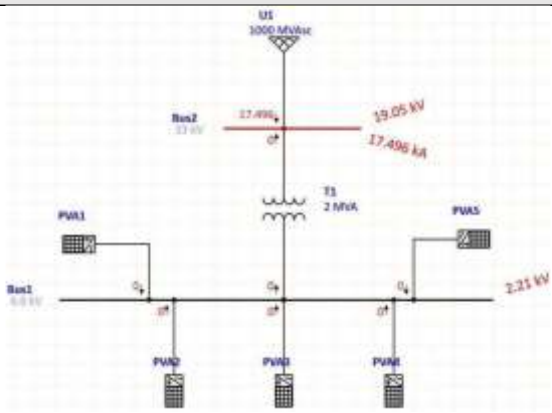
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-G	BUS 2	1.5-4	17.496 kA	19.05 kV	 **Figure 17**. L-G Fault on Bus 2 with 1.5-4 Cycle
No Fault	BUS 1	1.5-4	0 kA	2.21 kV	

Table 14. For Case 2.2.2

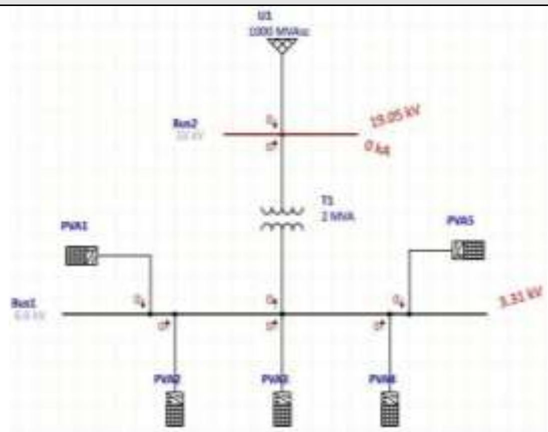
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-L	BUS 2	1.5-4	0 kA	19.05 kV	 **Figure 18**. L-L Fault on Bus 2 with 1.5-4 Cycle
No Fault	BUS 1	1.5-4	0 kA	3.31 kV	

Table 15. For Case 2.2.3

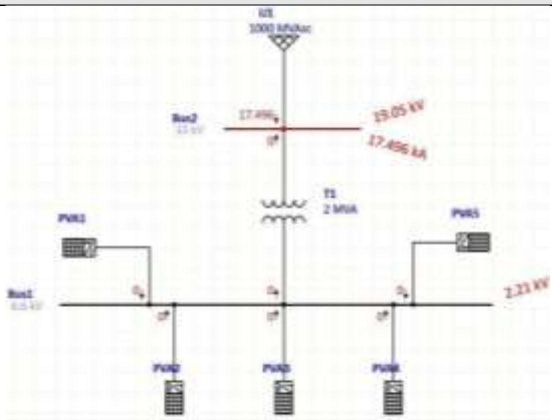
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-L-G	BUS 2	1.5-4	17.496 kA	19.05 kV	 **Figure 19**. L-L-G Fault on Bus 2 with 1.5-4 Cycle
No Fault	BUS 1	1.5-4	0 kA	2.21 kV	

Table 16. For Case 2.3.1

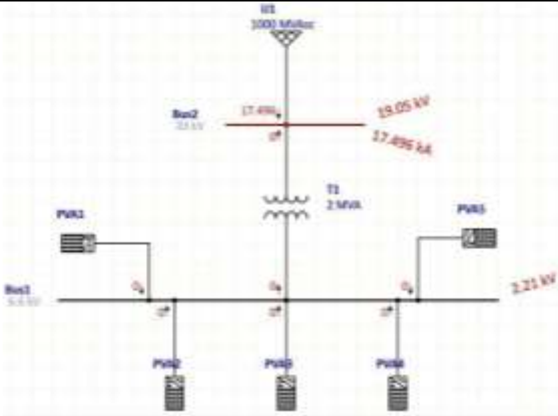
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-G	BUS 2	MAX	17.496 kA	19.05 kV	 **Figure 20**. L-G Fault on Bus 2 with MAX Cycle
No Fault	BUS 1	MAX	0 kA	2.21 kV	

Table 17. For Case 2.3.2

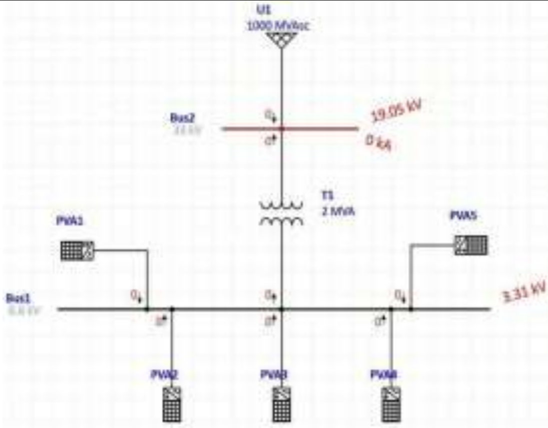
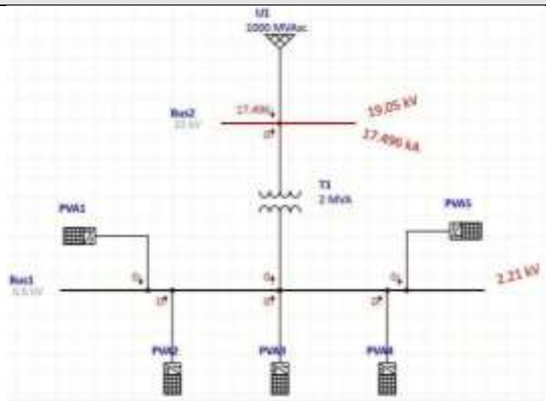
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L- L	BUS 2	MAX	0 kA	19.05 kV	 **Figure 21**. L-L Fault on Bus 2 with MAX Cycle
No Fault	BUS 1	MAX	0 kA	3.31 kV	

Table 18. For Case 2.3.3

Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-L-G	BUS 2	MAX	17.496 kA	19.05 kV	 **Figure 22**. L-L-G Fault on Bus 2 with MAX Cycle
No Fault	BUS 1	MAX	0 kA	2.21 kV	

Condition 3: When Bus 1 and Bus 2 both are Faulted

Table 19. For Case 3.1.1

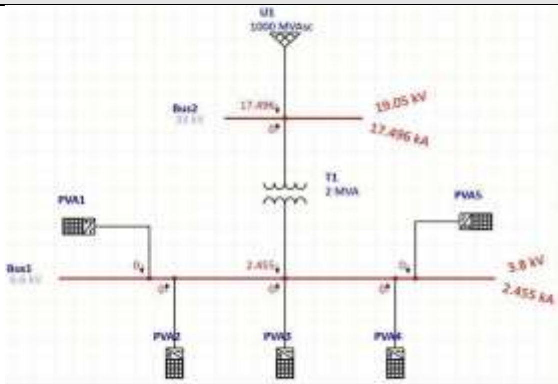
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-G	BUS 1	1	2.455 kA	3.8 kV	 **Figure 23**. L-G Fault on Bus 1, 2 with 1 Cycle
L-G	BUS 2	1	17.496 kA	19.05 kV	

Table 20. For Case 3.1.2

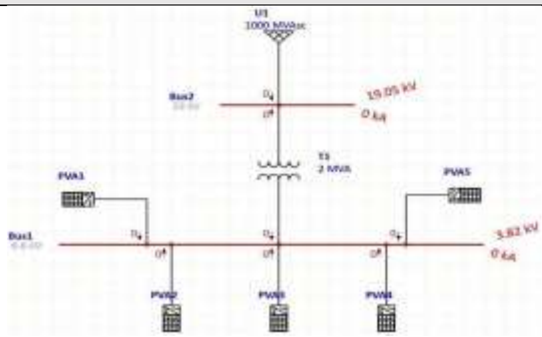
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-L	BUS 1	1	0 kA	3.82 kV	 **Figure 24**. L-L Fault on Bus 1, 2 with 1 Cycle
L-L	BUS 2	1	0 kA	19.05 kV	

Table 21. For Case 3.1.3

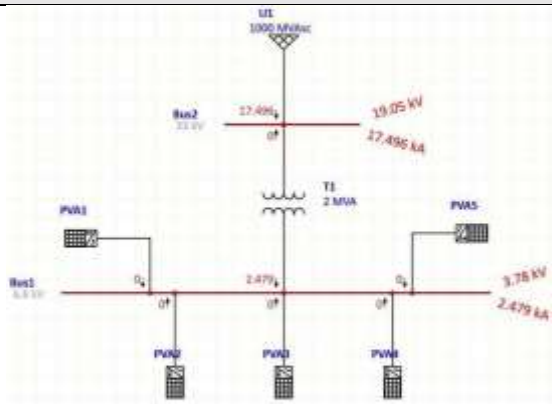
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-L-G	BUS 1	1	2.479 kA	3.78 kV	 **Figure 25**. L-L-G Fault on Bus 1, 2 with 1 Cycle
L-L-G	BUS 2	1	17.496 kA	19.05 kV	

Table 22. For Case 3.2.1

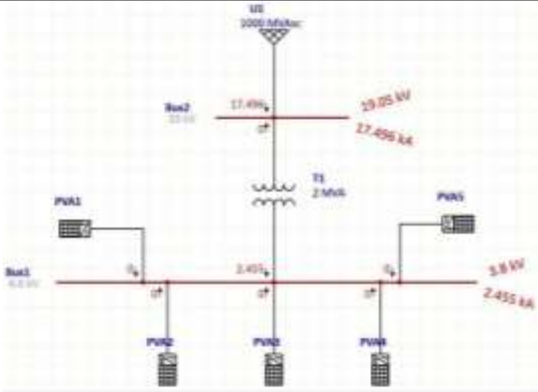
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-G	BUS 1	1.5-4	2.455 kA	3.8 kV	 **Figure 26**. L-G Fault on Bus 1, 2 with 1.5-4 Cycle
L-G	BUS 2	1.5-4	17.496 kA	19.05 kV	

Table 23. For Case 3.2.2

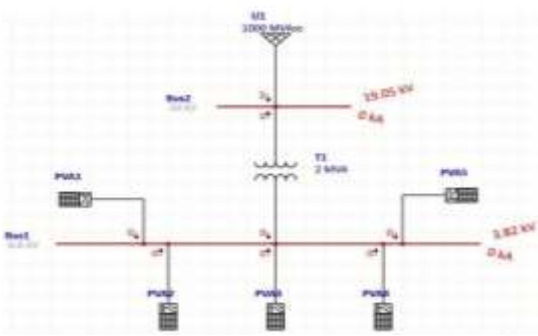
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-L	BUS 1	1.5-4	0 kA	3.82 kV	 **Figure 27**. L-L Fault on Bus 1, 2 with 1.5-4 Cycle
L-L	BUS 2	1.5-4	0 kA	19.05 kV	

Table 24. For Case 3.2.3

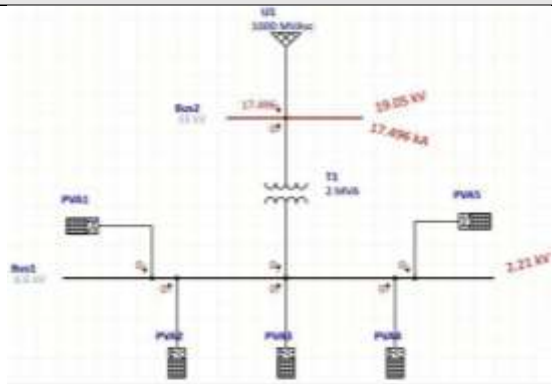
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-L-G	BUS 1	1.5-4	0 kA	2.21 kV	 **Figure 28**. L-L-G Fault on Bus 1, 2 with 1.5-4 Cycle
L-L-G	BUS 2	1.5-4	17.496 kA	19.05 kV	

Table 25. For Case 3.3.1

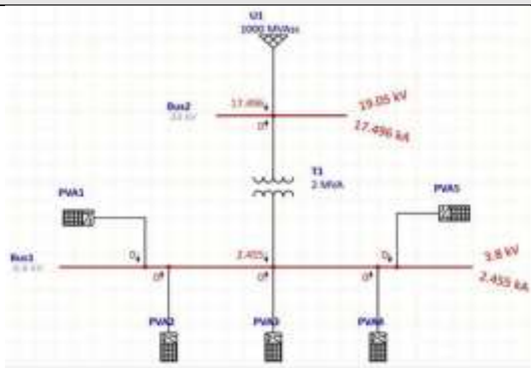
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-G	BUS 1	Max	2.455 kA	3.8 kV	 **Figure 29**. L-G Fault on Bus 1, 2 with MAX Cycle
L-G	BUS 2	Max	17.496 kA	19.05 kV	

Table 26. For Case 3.3.2

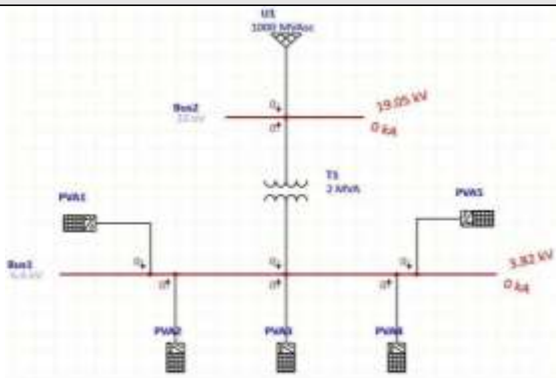
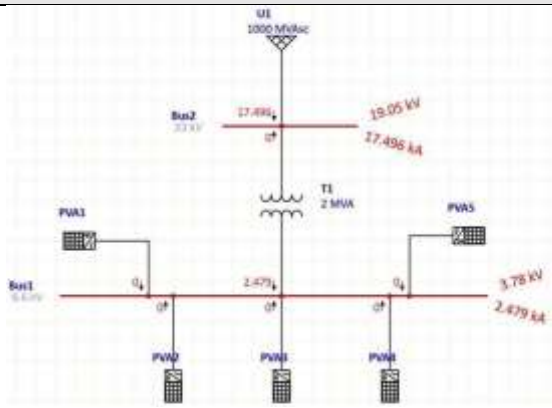
Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-L	BUS 1	Max	0 kA	3.82 kV	 **Figure 30.** L-L Fault on Bus 1, 2 with MAX Cycle
L-L	BUS 2	Max	0 kA	19.05 kV	

Table 27. For Case 3.3.3

Fault Type	Bus Number	Cycle	Short circuit current	Short circuit Voltage	Figure
L-L-G	BUS 1	Max	2.479 kA	3.78 kV	 **Figure 31**. L-L-G Fault on Bus 1, 2 with MAX Cycle
L-L-G	BUS 2	Max	17.496 kA	19.05 kV	

Different cases are presented on tables 1-27 and figures 5 – 31.

4. RESULTS AND DISCUSSION

4.1 Comparison among short circuit currents

Comparison among BUS 1 short circuit currents (BUS 1 is faulted and BUS 2 is at normal condition Figure 32):
As Bus 2 is at normal condition so BUS 2 has no fault current. BUS 1 Line to Ground (L-G), Line to Line (L-L) and Line to Line to Ground (L-L-G) fault currents are shown by graphical presentation for easy comparison and all the faults are denoted by different color in graph. Short Circuit Current values with three different cycles (1 cycle, 1.5-4 Cycle, MAX Cycle) also shown separately.

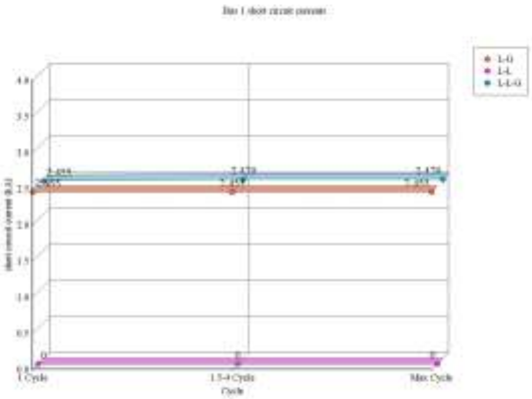


Figure 32. Bus 1 fault current's graph.

Comparison among BUS 1 short circuit voltages Figure 33, BUS 1 is faulted and BUS 2 is at normal condition):
As Bus 2 is at normal condition so BUS 2 has no fault current but an amount of voltage shown in meter for a little moment. BUS 1 Line to Ground (L-G), Line to Line (L-L) and Line to Line to Ground (L-L-G) fault voltages are shown by graphical presentation for easy comparison and all the faults are denoted by different color in graph. Short Circuit voltage values with three different cycles (1 cycle, 1.5-4 Cycle, MAX Cycle) also shown separately.

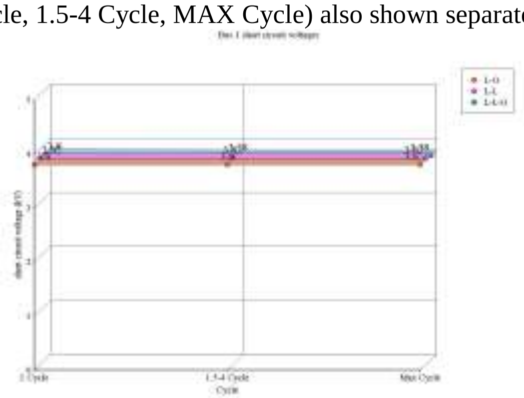


Figure 33. Bus 1 short circuit voltage graph.

Comparison among BUS 2 short circuit currents Figure 34, BUS 2 is faulted and BUS 1 is at normal condition):
As Bus 1 is at normal condition so BUS 1 has no fault current. BUS 1 Line to Ground (L-G), Line to Line (L-L) and Line to Line to Ground (L-L-G) fault currents are shown by graphical presentation for easy comparison and all the faults are denoted by different color in graph. Short Circuit Current values with three different cycles (1 cycle, 1.5-4 Cycle, MAX Cycle) also shown separately.

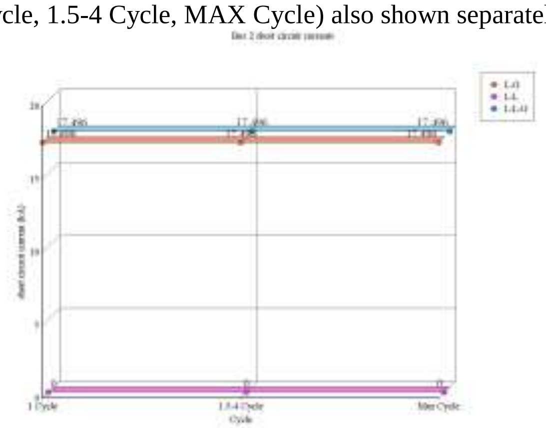


Figure 34. Bus 2 fault current's graph.

Comparison among BUS 2 short circuit voltages Figure 35 - BUS 2 is faulted and BUS 1 is at normal condition):
As Bus 1 is at normal condition so BUS 1 has no fault current but an amount of voltage shown in meter for a little moment. BUS 1 Line to Ground (L-G), Line to Line (L-L) and Line to Line to Ground (L-L-G) fault voltages are shown by graphical presentation for easy comparison and all the faults are denoted by different color in graph. Short Circuit voltage values with three different cycles (1 cycle, 1.5-4 Cycle, MAX Cycle) also shown separately.

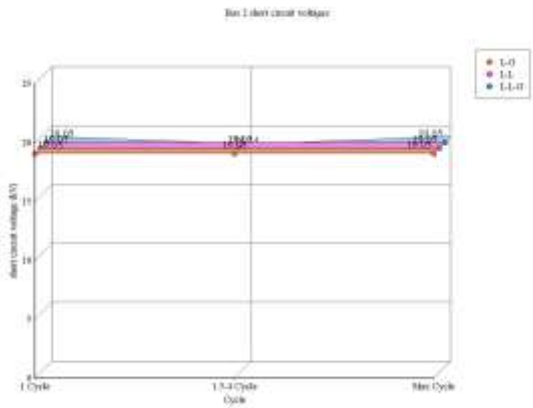


Figure 35. Bus 2 short circuit voltage graph

Comparison between BUS 1 short circuit currents and BUS 2 short circuit currents (Figure 36):
Here Bus 1 and BUS 2 Both are faulted. BUS 1 and BUS 2 Line to Ground (L-G), Line to Line (LL) and Line to Line to Ground (L-L-G) fault currents are shown by graphical presentation for easy comparison and all the faults are denoted by different color in graph. Short Circuit Current values with three different cycles (1 cycle, 1.5-4 Cycle, MAX Cycle) also shown separately.

Figure 36. Bus1 and BUS2 fault current's graph.

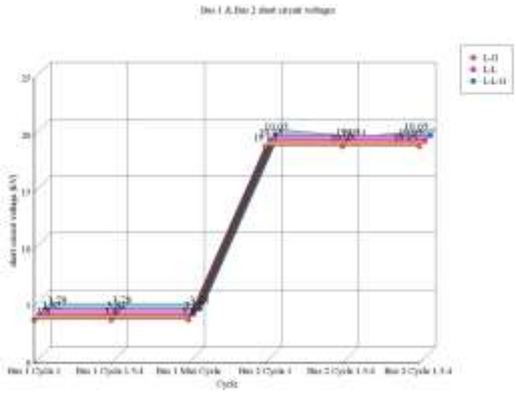


Figure 37. Bus1 and BUS2 short circuit voltage's graph.

Comparison between BUS 1 short circuit voltages and BUS 2 short circuit voltages (Figure 37):
Here Bus 1 and BUS 2 Both are faulted. BUS 1 and BUS 2 Line to Ground (L-G), Line to Line (LL) and Line to Line to Ground (L-L-G) short circuit voltages are shown by graphical presentation for easy comparison and all the faults are denoted by different color in graph. Short Circuit Current values with three different cycles (1 cycle, 1.5-4 Cycle, MAX Cycle) also shown separately.

4.2 Output Data Chart

In the chart below Table 28 where all the data are shown with three conditions. Conditions 1, 2, 3 are marked with yellow color. Condition 1 where BUS 1 is faulted and BUS 2 is in normal condition, Condition 2 where BUS 2 is faulted and BUS 1 is in normal condition and Condition 3 where BUS 1 is faulted and BUS 2 is also faulted. Short circuit current/ fault current in KA and short circuit voltage in kV is presented corresponding to their power cycles.

Table 28. Output Data

Condition	Fault Location	Current Type	1 Cycle (kA)	1.5-4 Cycle (kA)	Max Cycle (kA)	1 Cycle (kV)	1.5-4 Cycle (kV)	Max Cycle (kV)
Condition 1	Bus 1 Fault	L-G	2.455	2.455	2.455	3.8	3.8	3.8
		L-L	0	0	0	3.82	3.82	3.82
		L-L-G	2.455	2.479	2.479	3.8	3.78	3.78
	Bus 2 normal	L-G	0	0	0	19.05	19.05	19.05
		L-L	0	0	0	18.93	18.93	18.93
		L-L-G	0	0	0	19.05	18.79	18.79
Condition 2	Bus 2 Fault	L-G	17.496	17.496	17.496	19.05	19.05	19.05
		L-L	0	0	0	19.05	19.05	19.05
		L-L-G	17.496	17.496	17.496	19.05	18.44	19.05
	Bus 1 normal	L-G	0	0	0	2.21	2.21	2.21
		L-L	0	0	0	3.31	3.31	3.31
		L-L-G	0	0	0	2.21	2.21	2.21
Condition 3	Bus 1 Fault	L-G	2.455	2.455	2.455	3.8	3.8	3.8
		L-L	0	0	0	3.82	3.82	3.82
		L-L-G	2.479	2.479	2.479	3.78	3.78	3.78
	Bus 2 Fault	L-G	17.496	17.496	17.496	19.05	19.05	19.05
		L-L	0	0	0	19.05	19.05	19.05
		L-L-G	17.496	17.496	17.496	19.05	18.44	19.05

In Condition 1 where Bus 1 is faulted but Bus 2 is in normal condition. On BUS 1 Line to Ground (L-G) and Line to Line to Ground (L-L-G) Faults have similar values around 2.455-2.479 kA but not zero in other hand Line to Line (L-L) fault is zero because of the vector sum of the phase currents and must flow in the neutral or ground. Corresponding to their short circuit current, the short circuit voltage is around 3.78-3.82 kV. On BUS2 there are no fault current present because BUS 2 is not faulted.

Condition 2 where Bus 2 is faulted but Bus 1 is in normal condition. On BUS 2 Line to Ground (L- G) and Line to Line to Ground (L-L-G) Faults have similar values 17.496 kA each but not zero in other hand Line to Line (L-L) fault is zero because of the vector sum of the phase currents and must flow in the neutral or ground. Corresponding to their short circuit current, the short circuit voltage is 19.05 kV each. On BUS1 there are no fault current present because BUS 2 is not faulted.
Condition 3 where Bus 1 and Bus 2 both are faulted. On BUS 1 Line to Ground (L-G) and Line to Line to Ground

(L-L-G) Faults have similar values around 2.455-2.479 kA but not zero in other hand Line to Line (L-L) fault is zero because of the vector sum of the phase currents and must flow in the neutral or ground. Corresponding to their short circuit current, the short circuit voltage is around 3.78-3.82 kV. Now, On BUS 2 Line to Ground (L-G) and Line to Line to Ground (L-L-G) Faults have similar values 17.496 kA each but not zero in other hand Line to Line (L-L) fault is zero because of the vector sum of the phase currents and must flow in the neutral or ground.

Corresponding to their short circuit current, the short circuit voltage is 19.05 kV each. From those three conditions it is noticeable that fault current does not change much or do not have any large difference in their different segmented areas where BUS 1 and BUS 2 get faulted separately (Condition 1 and 2) or simultaneously (condition 3). So, there are no need to use different protection devices for different fault. A single calculated protection device can protect all over the system from various fault.

4.3 Circuit Breaker Selection

Now, from Table 28, at BUS 1 maximum fault current is 2.479KA and from Figure 2, regular current flow through Bus 1 is 3A. So, The Rated current for BUS 1 is more than 3A consider by adding 25% more, the value will be 3.75A. The Breaking capacity for BUS 1 is 2.479 kA, but the making current is 2.5 times than breaking current, so the breaking capacity will be at least 7.437 kA. As the maximum voltage at BUS 1 at the time of faulty condition is 3.8 kV. An Oil circuit Breaker or a Vacuum circuit breaker can be used at BUS 1 who’s Rated Current 3.75A and Breaking Capacity 7.437 kA.

At Bus 2 from table 28 at BUS 2 maximum fault current is 17.496 kA and from Figure 2 regular current flow through Bus 1 is 0.599 A. So, The Rated current for BUS 2 is more than 0.599 A consider by adding 25% more, the value will be 0.748 A. The Breaking capacity for BUS 2 is 17.496 kA, but the making current is 2.5 times than breaking current, so the breaking capacity will be at least 52.488 KA. As the maximum voltage at BUS 1 at the time of faulty condition is 19.05 kV. An Oil circuit Breaker or a Vacuum circuit breaker can be used at BUS 1 who’s Rated Current 0.748A and Breaking Capacity 52.488 kA.

5. CONCLUSION

This research provides a comprehensive analysis of unsymmetrical short circuit faults in a solar PV-based microgrid using ETAP simulation software. The study systematically modeled and simulated Line-to-Ground (L-G), Line-to-Line (L-L), and Line-to-Line-to-Ground (L-L-G) faults at both the generation (Bus 1) and distribution (Bus 2) sides of the microgrid under various fault durations.

The results, presented in detail through tables and graphs, reveal critical insights into the fault current magnitudes and voltage variations experienced at different points in the system during fault conditions. Notably, the study observed consistent fault current behavior across different fault scenarios, suggesting that a single, appropriately-rated protective device could provide adequate protection for the entire microgrid. This finding simplifies the protection scheme design and reduces the need for multiple, specialized devices.

Based on the maximum fault current and voltage levels identified, the research recommends specific types and ratings for circuit breakers to be installed at Bus 1 and Bus 2. These recommendations offer practical guidance for engineers designing and implementing protective schemes in similar microgrid systems, ensuring their resilience and safe operation during fault occurrences. By focusing on unsymmetrical faults, which are commonly encountered in real-world scenarios, this study contributes valuable data and insights to the field of microgrid protection. The systematic approach and detailed analysis conducted provide a robust framework for future research on fault analysis and protection coordination in renewable energy-based power systems.

Acknowledgement:
Funding: This research did not receive any specific grant from funding agencies in the public,commercial, or not-for-profit sectors.
Competing Interests: The authors declare that they have no competing interests.

Ethics Approval: Not applicable.

References:

Al Araf, M., Masum, Md. A. H., Siddiki, M., & Faruk, M. (2024). Integrative Fault Analysis of Transmission Lines using MATLAB and ETAP. *Journal of Electronics Computer Networking and Applied Mathematics*, 04, 54–65. DOI: 10.55529/jecnam.42.54.65

Altaf, M. W., Arif, M. T., Islam, S. N., & Haque, M. E. (2022). Microgrid protection challenges and mitigation approaches–A comprehensive review. *IEEE Access*, *10*, 38895-38922.

Chatterjee, A., & Maklago, F. O. (2022). Design and Analysis of a Microgrid System in Grid Tied Mode Using ETAP. 2022 IEEE Calcutta Conference (CALCON), 25–29. DOI: 10.1109/CALCON56258.2022.10060408

Gidiagbaa, J. O., Ninduwezuor-Ehiobub, N., Ojunjobic, O. A., Ofonagorod, K. A., & Daraojimbae, C. (2023). Ensuring the future of renewable energy: a critical review of reliability engineering applications in renewable energy systems. *Mater Corros Eng Manag*, *4*(2), 60-69.

Kadukar, P. R., Shete, P. S., & Gawande, S. P. (2018). Transient Analysis of Distributed Generation AC Microgrid using ETAP. 2018 International Conference on Current Trends towards Converging Technologies (ICCTCT), 1–8. DOI: 10.1109/ICCTCT.2018.8550987

Kulkarni, S., & Sontakke, S. (2015). Power System Analysis of a Microgrid using ETAP. 3(5).

Manditereza, P. T., & Bansal, R. (2016). Renewable distributed generation: The hidden challenges–A review from the protection perspective. *Renewable and Sustainable Energy Reviews*, *58*, 1457-1465.

Meena, G., Singh, V. P., Sundariyal, N., & Mathur, A. (2024). Component Model of AC Microgrid for Short-Circuit Analysis. 2024 1st International Conference on Innovative Sustainable Technologies for Energy, Mechatronics, and Smart Systems (ISTEMS), 1–6. https://ieeexplore.ieee.org/abstract/document/10560198/

Mondal, S., Bohre, A. K., Kolhe, M. L., & Thakkar, J. (2024). Steady State and Short Circuit Analysis of Microgrid with Renewables and EVs Using ETAP. In N. K. Dhote, M. L. Kolhe, & M. Rehman (Eds.), Recent Evolutions in Energy, Drives and e-Vehicles (pp. 503–523). Springer Nature. DOI: 10.1007/978-981-97-0763-8_42

Nsaif, Y. M., Lipu, M. H., Ayob, A., Yusof, Y., & Hussain, A. (2021). Fault detection and protection schemes for distributed generation integrated to distribution network: Challenges and suggestions. *IEEE Access*, *9*, 142693-142717.

Ortiz, L., Orizondo, R., Águila, A., González, J. W., López, G. J., & Isaac, I. (2019). Hybrid AC/DC microgrid test system simulation: Grid-connected mode. Heliyon, 5(12), e02862. DOI: 10.1016/j.heliyon.2019.e02862

Rasouli-Eshghabad, J., Shivaie, M., & Weinsier, P. D. (2024). A transfer-learning-based robust technique for multi-type fault detection and classification using Hilbert–Huang transform in low-voltage power distribution grids. *Neural Computing and Applications*, *36*(26), 16125-16139.

Satpathi, K., Ukil, A., & Pou, J. (2017). Short-circuit fault management in DC electric ship propulsion system: Protection requirements, review of existing technologies and future research trends. *IEEE Transactions on Transportation Electrification*, *4*(1), 272-291.

Shin, H., Chae, S. H., & Kim, E.-H. (2020). Design of microgrid protection schemes using PSCAD/EMTDC and ETAP programs. *Energies*, 13(21), 5784.

Yan, J., Zhai, Y., Wijayatunga, P., Mohamed, A. M., & Campana, P. E. (2017). Renewable energy integration with mini/micro-grids. In Applied Energy (Vol. 201, pp. 241–244). Elsevier. https://www.sciencedirect.com/science/article/pii/S0306261917307122

Zhang, C., & Zhang, X. (2024). Bus Short-Circuit Fault Detection and Repair Technology for Improving Inverter System Reliability. *Open Access Library Journal*, *11*(12), 1-15.

Zorumski, M., Keshtkar, H., & Mohammadi, F. D. (2024). Selective Coordination Study in a Renewable Energy-Based Microgrid. In K. Arai (Ed.), Intelligent Computing (pp. 1–15). Springer Nature Switzerland. DOI: 10.1007/978-3-031-62269-4_1

Salehin Haque Chowdhury
Web Business Technology Program (Global Entrepreneurship),
The Kyoto College of Graduate Studies for Informatics
Kyoto, Japan
salehinhaque41@gmail.com
ORCID: 0009-0004-7443-1994

Md Kamrul Hassan
Dept. of Electrical and Electronics Engineering (EEE)
Bangladesh University of Business and Technology (BUBT),
Dhaka 1216, Bangladesh
kamrulhasankiron0@gmail.com
ORCID: 0009-0003-8215-3392

Mohammad Ragib Hasin
Dept. of Electronic & Telecommunication Engineering,
International Islamic University Chittagong (IIUC),
Chittagong, Bangladesh
mohammadragibhasin@gmail.com
ORCID: 0009-0009-0167-9952

Tamim Ahmed
Dept. of Electrical and Electronics Engineering (EEE)
Bangladesh University of Business and Technology (BUBT),
Dhaka 1216, Bangladesh
mdtamimahmed42@gmail.com
ORCID: 0009-0003-9691-9192

Md Al Araf
Dept. of Electrical and Electronics Engineering (EEE)
Bangladesh University of Business and Technology (BUBT),
Dhaka 1216, Bangladesh
md.al.araf.2001@gmail.com
ORCID: 0009-0000-7058-8784