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Design and Analysis of Fault Detection in Photovoltaic Array Cable

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***Abstract*— The rapid expansion of photovoltaic (PV) systems for sustainable energy generation has increased the need for reliable fault detection mechanisms, particularly in PV array cables. Faults in PV cables, including open-circuit, short-circuit, insulation degradation, and ground faults, can significantly impact system efficiency, safety, and long-term performance. Effective fault detection and analysis are crucial for minimizing energy losses, preventing fire hazards, and reducing maintenance costs. This paper presents a comprehensive investigation into the design and analysis of fault detection methods for PV array cables, incorporating electrical parameter monitoring, machine learning techniques, and advanced signal processing methods. Various detection techniques, including voltage-current characteristics, impedance-based methods, and real-time thermal imaging, are explored to enhance fault diagnosis accuracy. The integration of Internet of Things (IoT) and edge computing for real-time fault monitoring is also discussed.**

Keywords*— Solar, Pulse, Renewable, Fault, Panel, Microgrid, Line, Ground, Cable, Photovoltaic Cable.

I. INTRODUCTION

The increasing global demand for renewable energy has led to the widespread adoption of photovoltaic (PV) systems as a sustainable energy source. PV technology offers numerous benefits, including low carbon emissions, scalability, and minimal operational costs. However, maintaining high efficiency and reliability in PV systems requires addressing various technical challenges, particularly in fault detection and monitoring. Among the critical components of a PV system, array cables play a vital role in transmitting electrical power from the solar panels to the inverter and the grid. Any fault occurring in PV cables can result in power losses, system inefficiencies, potential safety hazards, and increased operational costs. Thus, the development of effective fault detection and diagnosis techniques is essential for optimizing the performance and longevity of PV systems.

Faults in PV array cables can arise from multiple factors, including environmental stress, aging, mechanical damage, and manufacturing defects. The most common cable faults include open-circuit faults, short-circuit faults, ground faults, and insulation degradation. Open-circuit faults occur when the continuity of the cable is broken, leading to incomplete power transmission. Short-circuit faults, on the other hand, result in excessive current flow that can damage system components and pose fire hazards. Ground faults are particularly concerning as they may cause leakage currents that endanger both system integrity and human safety. Additionally, insulation degradation due to prolonged exposure to ultraviolet (UV) radiation, moisture, and temperature variations can lead to gradual performance decline and unexpected failures.

Conventional fault detection methods rely on periodic manual inspections, infrared thermal imaging, and electrical parameter monitoring. However, these approaches have limitations in terms of efficiency, scalability, and real-time fault localization. The growing complexity and scale of PV installations necessitate the adoption of advanced diagnostic techniques that can detect faults in real-time, reduce false alarms, and improve fault classification accuracy. Recent advancements in artificial intelligence (AI), machine learning (ML), and Internet of Things (IoT)-based monitoring have revolutionized fault detection in PV systems. By leveraging AI and ML algorithms, fault detection systems can analyze large volumes of real-time data, identify anomalies, and predict potential failures before they occur. Additionally, IoT-enabled sensors provide continuous monitoring of cable parameters such as voltage, current, impedance, and temperature, enabling early fault detection and proactive maintenance.

Another promising approach in fault detection is the use of signal processing and impedance-based methods. Techniques such as wavelet transforms, frequency domain analysis, and time-domain reflectometry (TDR) have shown significant potential in identifying and locating faults with high precision. These methods allow for non-intrusive fault diagnosis by analyzing the electrical signatures of cables and detecting deviations from normal operation. Moreover, integrating fault detection mechanisms with edge computing enhances real-time analysis by reducing latency and minimizing data transmission requirements. By processing fault-related data at the network edge, PV systems can achieve faster fault diagnosis and improve overall reliability.

Despite these technological advancements, several challenges remain in implementing efficient fault detection systems for PV array cables. Environmental factors such as shading, temperature fluctuations, and dust accumulation can introduce noise into measurement data, leading to difficulties in distinguishing actual faults from normal variations. Additionally, the high cost and complexity of deploying advanced sensors and AI-based monitoring systems present financial and logistical barriers, particularly for small-scale PV installations. The need for standardized fault detection protocols and interoperability among different PV monitoring systems also poses a challenge, as variations in system configurations can affect fault diagnosis accuracy.

the turnaround recuperation issue of the output diodes.

II. PROPOSED MODEL

The main objective is to design and fault analysis of solar photovoltaic cable array grid connected systems. Previously its analysis for single PV cable, but in some application, there is need to use PV cable array. Therefore, proposed model has PV cable array and fault analysis perform with accuracy.

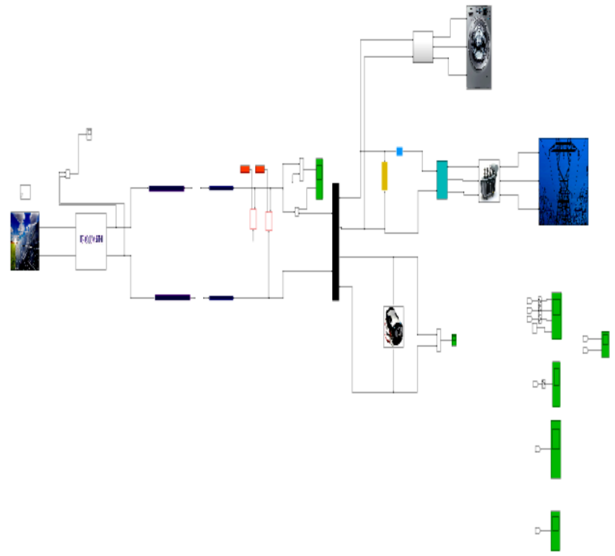

Figure 1: Proposed Model

Figure 1 shows proposed model of fault analysis of dc microgrid with PV cable. In this model, there are sub modules like three phase grid, DC-DC converter, pulse width modulation, Solar panel and MPPT.

Following sub module are used to design proposed model. Each module is connected as per flow block diagram.

- Three phase grids
- DC-DC converter and DC-AC converted
- pulse width modulation (PWM)
- Solar panel
- MPPT Technique

Standard Solar, Inc. as of late finished one of the principal solar microgrid systems with a gridinteractive battery bank in the nation. Being an originally was a test it took a very long time of devotion, inventive building and coordination with key accomplices, utilities and government workplaces to make this venture a reality. The primary portion of this paper will set the phase by clarifying how the microgrid is arrangement, its usefulness and what makes it uncommon. At that point I will investigate the stuff to plan and introduce a solar microgrid system, the exercises gained from this groundbreaking undertaking and what specialized contemplations ought to be made when actualizing this new innovation.

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Maximum power point tracking (MPPT) is a calculation actualized in photovoltaic (PV) inverters to constantly modify the impedance seen by the solar cluster to keep the PV system working at, or near, the pinnacle power purpose of the PV panel under fluctuating conditions, such as changing solar irradiance, temperature, and burden. Architects creating solar inverters execute MPPT calculations to expand the power produced by PV systems. The calculations control the voltage to guarantee that the system works at "greatest power point" (or pinnacle voltage) on the power voltage bend, as demonstrated as follows. MPPT calculations are commonly utilized in the controller plans for PV systems. The calculations account for factors, for example, factor irradiance (daylight) and temperature to guarantee that the PV system produces most extreme power consistently. Most extreme power point tracking is a technique utilized normally with wind turbines and photovoltaic (PV) solar systems to boost power extraction under all conditions.

An electrical grid is an interconnected system for conveying power from makers to buyers. It comprises of creating stations that produce electrical power, high voltage transmission lines that convey power from far off sources to demand focuses, and circulation lines that interface singular clients. An AC-AC converter with around sinusoidal info currents and bidirectional power flow can be acknowledged by coupling a heartbeat width modulation (PWM) rectifier and a PWM inverter to the DC-interface. The DC-connect amount is then intrigued by an energy stockpiling component that is regular to the two phases, which is a capacitor C for the voltage DC-interface or an inductor L for the current DC-connect. The PWM rectifier is controlled such that a sinusoidal AC line current is drawn, which is in phase or hostile to phase (for energy feedback) with the relating AC line phase voltage.

III. SIMULATION RESULTS

The simulation studies involve the fault analysis model as shown in Figure 1. The proposed model is implemented with MATLAB simulink.

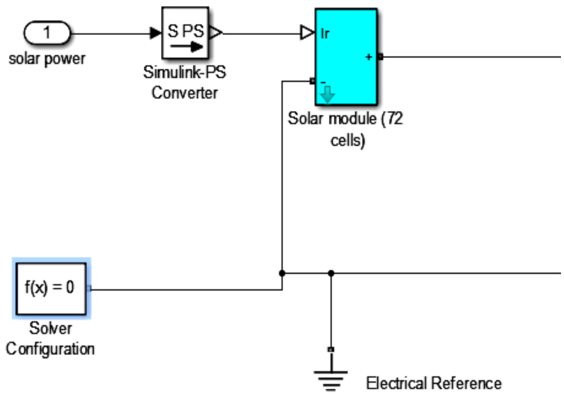

Figure 2: Solar panel

Figure 2 shows solar arrays; it begins with a single solar energy cell known as a photovoltaic cell. “Photo” essentially means light, and “voltaic” refers to voltage, which is a unit of potential electrical energy. When

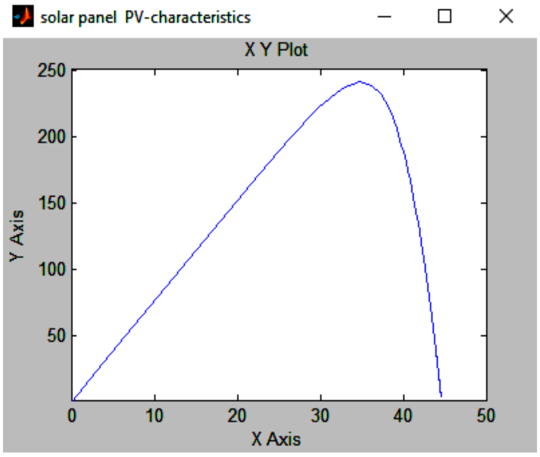

Figure 3: Voltage vs Power graph

Figure 3 shows voltage vs power graph of solar panel PV-characteristics. X axis show the MPPT value of voltage i.e approx. 32 while y axis shows the power i.e. 240W approx.

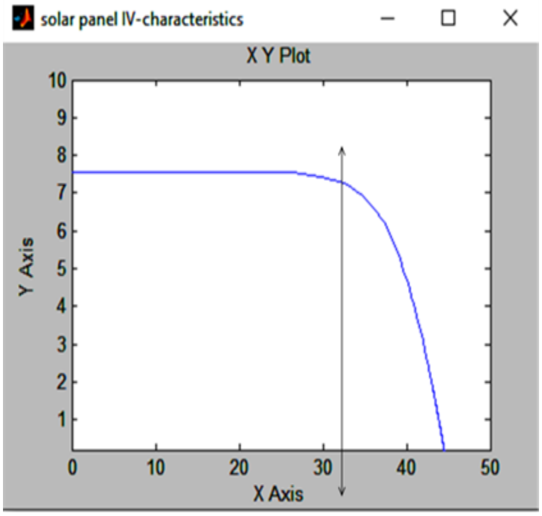

Figure 4: Voltage vs Current graph

Figure 4 presents voltage vs current graph of solar panel PV- characteristics. X axis show the value of voltage i.e approx. 32 while y axis shows the power i.e. 7.5A approx.

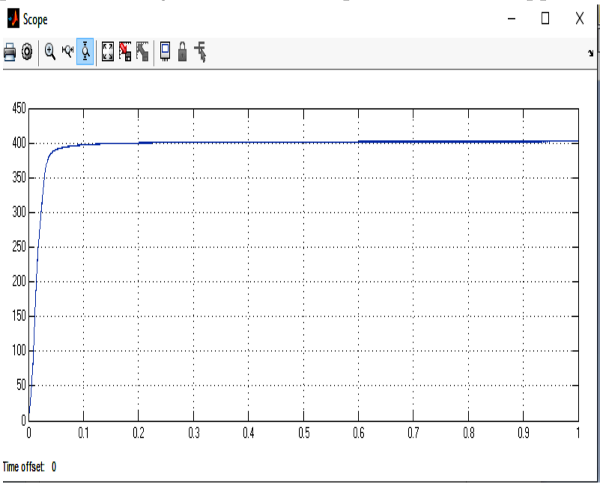

Figure 5: Voltage of DC-DC Converter

Figure 5 is showing voltage of DC-DC converter, it achieves 402.8 voltages. In previous model IGBT is used but in proposed model MOSFET is used instead of IGBT.

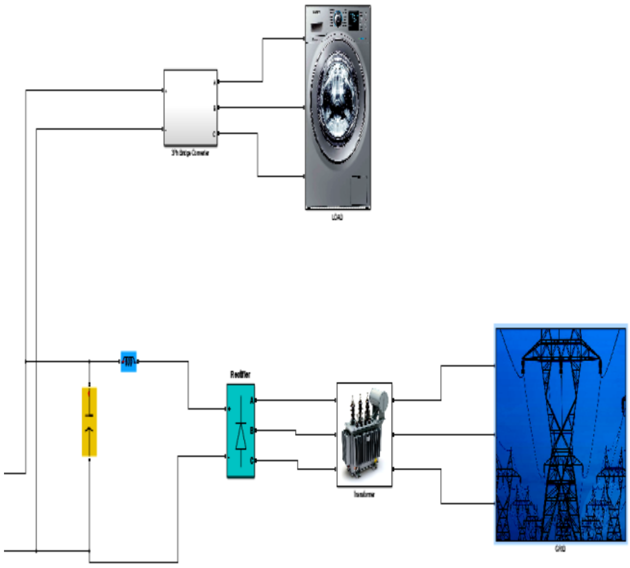

Figure 6: Load and AC Grid

Figure 6 presents the load element and AC grid. Here 2 phase power line is converted into 3 phase power line by using bridge converter and rectifier.

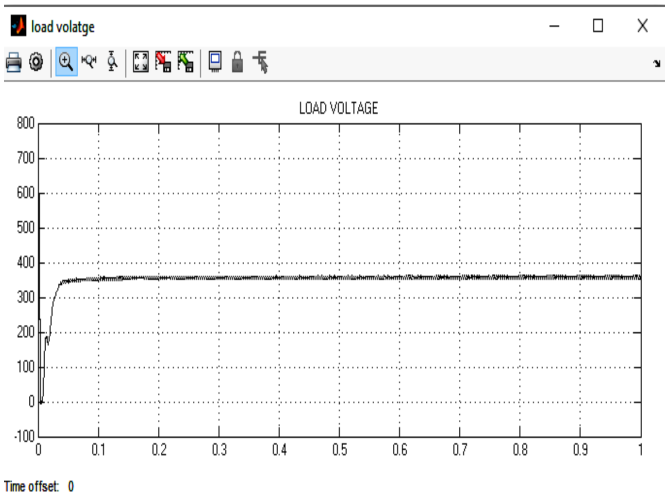

Figure 7: Load Voltage

Figure 7 is showing output of load. Here 380V is achieved at the output side in this model. So, this voltage can be used for any industrial or domestic application.

1. Line-to-Line fault

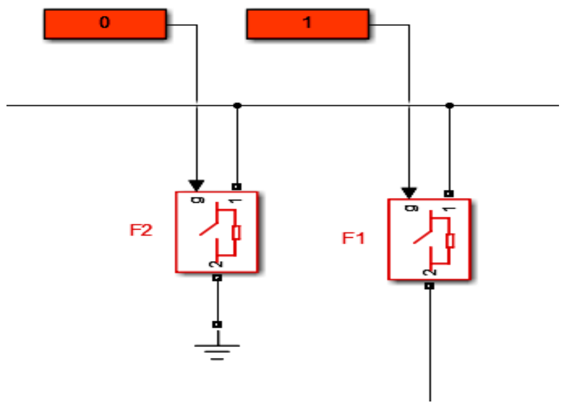

Figure 8: Line-to-Line fault

Figure 8 is showing line-to-line fault condition. In which line have fault while ground have no fault. A line-to-line fault is one where short circuiting occurs between two phases of a system.

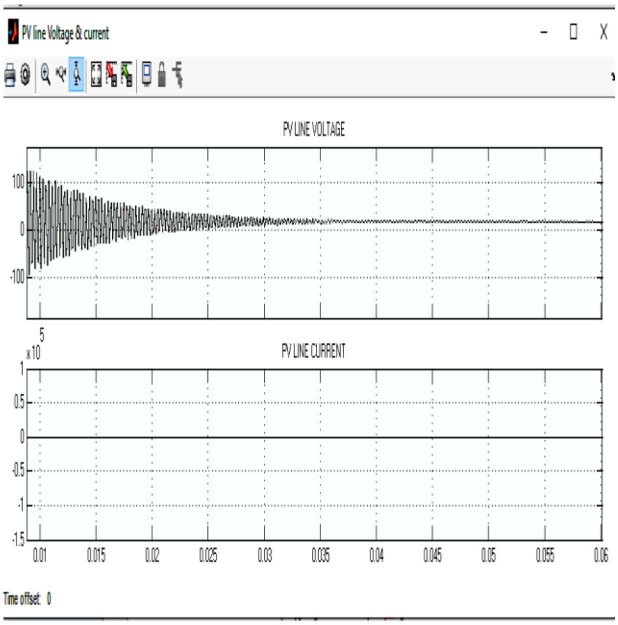

Figure 9: PV line voltage and current graph-2

Figure 9 is showing line-to-line fault voltage and current. The value of voltage is 12V and current is 0A

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2. Line to ground fault

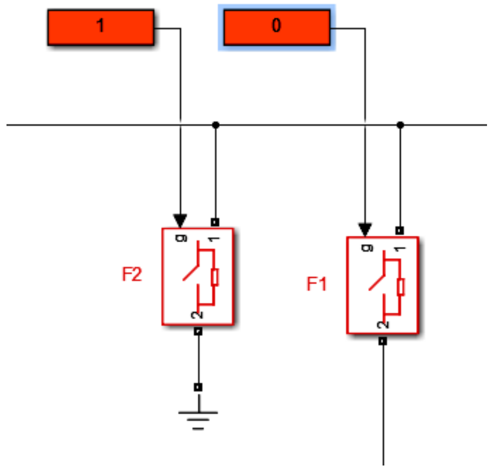

Figure 10: Line to ground fault

Figure 10 is showing line-to-ground Fault. Generally, a single line-to-ground fault on a transmission line occurs when one conductor drops to the ground in which line have fault while ground have no fault.

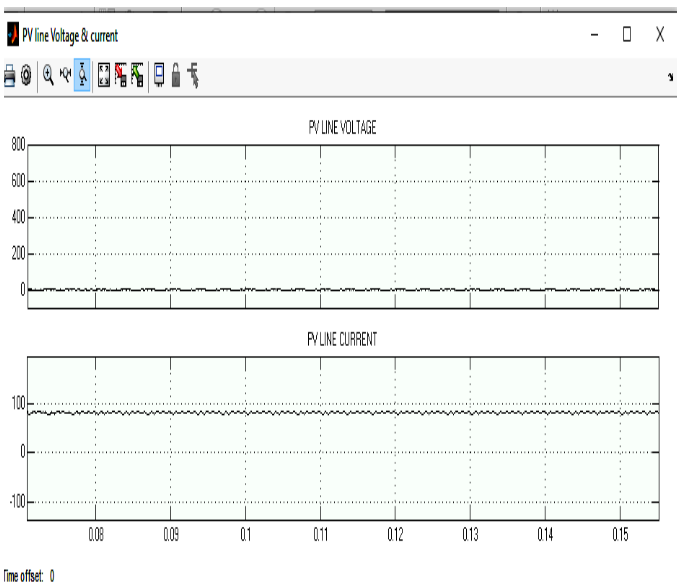

Figure 11: PV line voltage and current-3

Figure 11 is showing line-to-ground fault voltage and current. The value of voltage is 0V and current is 80A.

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Table 1: Simulation Result

Sr No.	Fault condition	Voltage (V)	Current (A)
1	No fault	202	80
2	Line to Line	12	0
3	Line to Ground	0	80
4	Combined Fault	0	0

Table 2: Result Comparison

Sr No.	Parameter	Previous Model	Proposed Model
1	Switch	IGBT	MOSFET
2	Output	DC Microgrid	DC & AC Microgrid
3	Fault	All case	All case
4	Load output voltage	Not Mention	230V
5	DC-DC converter Output Voltage	380 V	402.8 V
6	Software	PSCAD/EMTDC	MATLAB

Table 1 shows simulation results and table 2 showing comparison of proposed model analysis results with previous model results. Therefore, above result shows, proposed model gives significant improved analysis rather than the existing model.

IV. Conclusion

The design and analysis of fault detection in photovoltaic (PV) array cables are crucial for ensuring system efficiency, reliability, and safety. Various faults, including open-circuit, short-circuit, insulation degradation, and ground faults, can significantly impact energy generation and pose serious risks if undetected. Advanced fault detection techniques, such as electrical parameter monitoring, AI-driven analytics, IoT-based real-time monitoring, and signal processing methods, have emerged as effective solutions for improving fault diagnosis accuracy. However, challenges related to environmental variability, sensor costs, and data complexity must be addressed to enhance practical implementation. Future research should focus on developing cost-effective, adaptive, and hybrid fault detection frameworks that integrate multiple diagnostic techniques, ultimately leading to more resilient and self-sustaining PV energy systems.

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