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Tracking and Shading Identification of Issues in PV for a using Neural Network Approach

Mr. G.Umamaheswaran¹, P. Jency Henin²

Associate Professor, Department of Electronics and Communication Engineering, Er.Perumal Manimekalai College of Engineering, Hosur, Tamil Nadu, India¹

PG Scholar, Department of Applied Electronics, Er.Perumal Manimekalai College of Engineering, Hosur, Tamil Nadu, India²

ABSTRACT: A photovoltaic (PV) system is highly sensitive to sudden changes in weather conditions, necessitating continuous monitoring of its maximum power point to enhance its operational efficiency. Various errors and defects can arise during production, adversely affecting both the quality and quantity of energy generated. One prevalent issue is partial shading, where certain modules within the array receive uneven levels of sunlight. This study introduces a streamlined approach to fault detection, utilizing transient signals that respond to such defects. Partial shading occurs when different segments of the array experience fluctuations in light intensity. By monitoring weather parameters and electrical variables such as voltage and current, the effects of partial shading—with and without the use of bypass diodes—are analyzed on the I-V and P-V characteristics of the PV array. The PV module model integrates observed module temperature and solar irradiation as inputs to accurately compute the power output of the PV array in real-time. To identify and pinpoint shading defects in the PV system, a novel approach employing convolutional neural networks (CNNs) and Internet of Things (IoT) technology is proposed. Data including current, voltage, temperature, and radiation readings from the PV panels are transformed into three-dimensional images before being fed into a machine learning system. Simulation of the PV system and fault detection techniques was conducted using MATLAB.

KEYWORDS: Partial Shading, Fault Identification, Maximum Power Point (MPP), Deep Learning, Internet of Things (IoT)

I. INTRODUCTION

Photovoltaic (PV) system maintenance and evaluation are increasingly essential for maximizing power output, boosting PV power plant dependability, and extending plant life. When PV plants are operating under suboptimal conditions, especially when shaded, their current–voltage (I-V) characteristics exhibit a noteworthy form when compared with the reference situation (healthy 1 functioning). PV systems have grown frequently, but they still have many obstacles to overcome, including defect detection, to improve system performance and reduce maintenance costs and repair times.

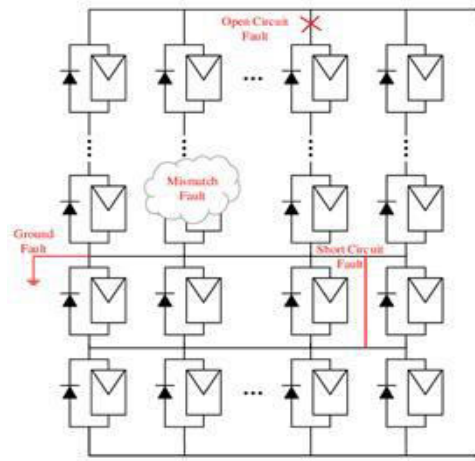


Figure 1 Basic fault detection of the PV model.

Various issues with PV systems have surfaced because of this concern, leading to complete or partial loss of energy output. In PV systems, frequent problems include electric arc errors, hot spots, bypass imbalance, ground faults, and line-to-line failures. Real-time variable measurements and comprehensive PV system modeling and simulation form the foundation of the problem detection process. Enhancing a photovoltaic system's efficiency and dependability requires fault investigation. Nevertheless, the conventional approaches currently employed for PV array failure identification and repair remain inadequate.

The partial shadowing condition (PSC), in which a PV array is partially shadowed by passing clouds and surrounding structures, is a primary issue. PV performance is negatively impacted by a large increase in temperature in the watched portion if this flaw is left undiscovered. The hot spot phenomenon causes degradation of the cell encapsulate and subsequent falling apart.

Enhancing the dependability, security, and effectiveness of the system requires online fault detection of the PV arrays. This study outlines a method for identifying common issues in photovoltaic (PV) arrays, such as open-circuit, short-circuit, degradation, and shading faults. The approach relies on observing and assessing voltage and current behavior. Initially, fault-specific parameters are determined, such as voltage in an open circuit, short-circuit current, and voltage and current at the maximum power point (MPP) of the PV array. These parameters serve as indicators for detecting faults. Subsequently, fault-detection thresholds are established based on these indicators, tailored to the specific characteristics of each fault type. PV systems installed outside are susceptible to certain dangers.

To tackle these challenges, a pioneering method is suggested, aimed at distinguishing between faults and instances of partial shading, while also considering the number of mismatched modules and strings to accommodate dynamic changes in irradiation. The proposed approach hinges on analyzing basic data extracted from the current-voltage (I-V) characteristic curve of the photovoltaic (PV) array during Line-Line (LL) faults, and it unfolds through two key phases. Firstly, utilizing continuously updated variables derived from PV array voltage, current, and irradiation, the type of defect is identified. Subsequently, it quantifies the count of mismatched strands (commonly referred to as open-circuited blocking diodes) and mismatched components (also known as short-circuited bypass diodes) by comparing them against the anticipated values derived from the PV array's I-V characteristic curves.

1.1 Objective

- Maximizing power output, ensuring reliability, and extending lifespan are key objectives in maintaining and evaluating photovoltaic (PV) systems.
- Suboptimal conditions like shading significantly alter PV system performance.
- Challenges persist in defect detection, which is crucial for system performance improvement and cost reduction.
- Common issues include electric arc errors, hot spots, and ground faults, leading to energy loss.

- Real-time measurements and comprehensive modeling are crucial for fault identification.

II. LITERATURE SURVEY

A method for detecting defects in solar modules utilizes unmanned aerial vehicles (UAVs) equipped with visible light and thermal imagers. The approach enables real-time monitoring and evaluation of solar panels, identifying anomalies with high accuracy. The necessity of conducting drone inspections under specific conditions, such as an irradiance level of $I \geq 700 \text{ W/m}^2$ and proper temperature measurements, is emphasized to ensure precise readings for image analysis. The probability density histogram of each pixel's temperature value shows a beta distribution in normal operating conditions, providing detailed statistics for mean and variance temperatures [1].

String-level monitoring is pivotal for automatic fault detection, localization, and identification within photovoltaic (PV) systems. Through the analysis of residuals or fault indicator signals vis-à-vis predefined thresholds, anomalies are pinpointed and categorized according to deviations in string current profiles. This methodology strives to preclude latent defects, thereby bolstering the dependability and durability of PV modules in expansive solar installations. The strategy responds to the escalating demand for automated safeguarding techniques, fostering sustained operational efficiency and mitigating the potential hazards posed by protracted, undetected malfunctions [2].

Examining techniques for fault analysis, detection, and protection in solar PV systems underscores the significance of vigilant monitoring. Despite the lack of moving parts, PV systems can experience various faults in their components. Faults are categorized based on duration—transitory or permanent. The study discusses the importance of accurate placement of measurement devices depending on the fault type being investigated. Effective monitoring systems are crucial for maintaining system efficiency and preventing unexpected failures that could impact energy production [3].

Utilizing the Internet of Things (IoT) technology and Extreme Learning Machine (ELM) models identify faults in PV systems with high classification accuracy. The method achieves real-time monitoring of environmental and electrical parameters. The ELM model outperforms traditional methods like Support Vector Machines (SVM), providing a robust approach to detecting faults and minimizing risks to power production and safety. The advanced technique enhances the efficiency of fault detection and ensures the reliable operation of PV systems [4].

Long Short-Term Memory (LSTM) neural networks are used to detect high impedance faults (HIF) in solar PV systems. A 300 kW solar PV system is modeled, and features are extracted using discrete wavelet transform for classifier training. The LSTM classifier achieves over 91% accuracy in identifying HIFs, demonstrating the effectiveness of combining advanced signal processing techniques with machine learning for fault detection. The methodology significantly improves the accuracy and reliability of identifying complex faults in PV systems [5].

Investigating methods to improve efficiency in aging PV plants involves detecting solar module faults using thermal imaging. The study identifies six common fault types in deteriorated panels and emphasizes timely replacement to reduce output loss. A decision tree classifier with specific parameters enhances fault detection accuracy, contributing to better maintenance practices. The approach ensures efficient management of aging PV plants and helps in maintaining optimal energy production levels [6].

A comparative analysis of photovoltaic faults evaluates detection techniques, covering acute and chronic faults. The study highlights technological challenges in identifying and mitigating these issues, discussing the single-diode model of solar cells and the relevance of both internal and external factors in fault occurrence. Comprehensive detection strategies are necessary to address various fault scenarios effectively, ensuring the reliability and performance of PV systems [7].

A statistical methodology is employed in a real-time fault detection system designed for large-scale solar photovoltaic (PV) plants. Real-time PV module data is compared with theoretical predictions to identify faults, providing graphical alerts for timely intervention. The method is validated in a large solar PV facility, demonstrating its effectiveness in minimizing energy loss and enhancing green energy production. The system's fast reaction time and accurate fault location capabilities support prompt corrective actions [8].

A method differentiates between partially shaded conditions and faults in grid-tied solar PV systems by analyzing the PV array's current-voltage characteristics. The approach identifies fault types and the extent of module mismatches, providing a detailed fault classification and detection mechanism. Essential for maintaining the efficiency of large-scale power plants, the algorithm ensures reliable fault identification and supports optimal system performance [9].

A fault-tolerant control approach is implemented for inverters within PV systems to ensure consistent functionality even under abnormal circumstances. This method enables PV systems to remain operational during faults, thereby enhancing resilience and sustaining power output. The study delves into the hierarchical structure of PV systems, underscoring the necessity for sturdy control mechanisms capable of efficiently managing both internal and external faults. Such an approach serves to bolster the endurance and dependability of PV systems across a range of operating conditions [10].

The Group Teaching Optimization (GTO) technique is utilized to design an MPPT (Maximum Power Point Tracking) controller tailored for photovoltaic (PV) systems operating in scenarios of partial and intricate shading. The methodology includes modeling PV arrays under various shading scenarios, simulating their performance, and implementing the GTO algorithm to optimize the MPPT process. The system's efficiency is enhanced through iterative adjustments, ensuring robust power extraction despite varying shading conditions. Extensive testing and validation confirm the algorithm's effectiveness in real-world applications [11].

The Group Teaching Optimization (GTO) algorithm is applied for Maximum Power Point Tracking (MPPT) control in photovoltaic (PV) systems experiencing shading effects. This approach entails thorough simulations of PV arrays under partial shading conditions, integrating the GTO algorithm to attain peak power output. The process includes modeling different shading scenarios, applying the algorithm, and conducting extensive testing to validate its robustness. Results demonstrate significant improvements in power efficiency, confirming the GTO algorithm's suitability for complex shading conditions [12].

A machine learning-driven global Maximum Power Point Tracking (MPPT) approach tackles partial shading challenges in photovoltaic (PV) arrays. The approach entails training a machine learning algorithm to forecast the global maximum power point across diverse shading scenarios. This algorithm is seamlessly incorporated into the PV system to guarantee optimal power harvesting, even when encountering numerous local maxima in the power-voltage characteristic curve. The efficacy of this strategy is confirmed through both simulation and practical experimentation [13].

Numerous nature-inspired optimization techniques are investigated for addressing partial shading challenges in photovoltaic (PV) systems. The methodology includes a comprehensive literature review, classification of different optimization techniques, and critical analysis of their effectiveness in handling shading issues. The study provides a detailed comparison of performance metrics, identifies the strengths and weaknesses of each algorithm, and offers recommendations for future research directions [14].

Focuses on nature-inspired algorithms with an emphasis on systematic comparison and evaluation. The methodology encompasses collecting relevant studies, categorizing algorithms based on their operational principles, and analyzing their performance in mitigating the effects of partial shading on PV systems. The review provides insights into the most promising techniques and their practical applications [15].

This study presents a novel Maximum Power Point Tracking (MPPT) algorithm tailored for photovoltaic (PV) systems functioning in scenarios of both uniform and partial shading. The approach entails constructing a mathematical model of the PV system, integrating the devised algorithm, and subjecting it to rigorous testing across diverse shading conditions. Performance is evaluated through simulations and real-world experiments, demonstrating its ability to maintain optimal power output and improve overall system efficiency [16].

Presents a model to determine losses in PV yield due to soiling, shading, and thermal effects. The methodology includes collecting PV yield data from various sources, analyzing it to identify patterns of losses, and developing a predictive model that quantifies the impact of these factors on overall system performance. The model is validated through extensive testing, providing a comprehensive tool for optimizing PV yield and improving system efficiency [17].

Analyzing various Maximum Power Point Tracking (MPPT) methods for photovoltaic (PV) systems operating in partially shaded environments. The methodology involves a detailed review of existing MPPT methods, a comparative analysis of their effectiveness, and an identification of key challenges and limitations associated with each technique. The study offers insights into potential improvements and innovations, providing recommendations for enhancing the performance of MPPT controllers in shaded PV systems [18].

A suggested solution involves an IoT-driven framework enhanced with artificial intelligence to identify hot spots within photovoltaic (PV) modules, capable of spanning diverse irradiance levels. The methodology includes designing an IoT architecture, developing AI algorithms for hot spot detection, and implementing the system in a real-world PV setup. The efficacy of this method is confirmed through practical field trials, showcasing its capacity to pinpoint and address hot spots, consequently enhancing the efficiency and dependability of PV systems [19].

Focusing on developing a robust MPPT optimization framework that incorporates accurate shadow detection for solar photovoltaic setups. The methodology involves developing a shadow detection algorithm, integrating it with the MPPT control system, and testing the combined model under various shading conditions. System performance is evaluated through simulations and practical experiments, showing significant improvements in power output and efficiency, highlighting the model's potential for real-world applications [20].

III. PROPOSED METHODOLOGY

In the proposed method essential to understand how current and voltage behave under various conditions outside in order to identify faults in photovoltaic systems. To ensure precise characterization of the PV system within the simulation framework and to facilitate precise measurement of electrical and atmospheric parameters, it is essential to develop a reliable simulation package tailored to the specific PV system under investigation. Established benchmarks are utilized to establish protocols for identifying defects by comparing the model's performance with real-time data during normal operation or potential malfunctions.

In reality, the task of detecting flaws in photovoltaic (PV) systems has transformed into a software module heavily reliant on utilizing convolutional neural networks (CNNs), which analyze data gathered via the Internet of Things to construct predictive models for PV components. In addition, on the DC side, there are three different kinds of problems that might happen: faults with PV arrays, faults with multiple parameter predictive modules, and faults with the cabling system. The output voltage and output power will drop if there is a multiple-parameter predictive module failure. While the majority of potential cable systems and transmission of energy lines will clearly result in a reduction in output voltage and power delivered.

Analyzing potential weaknesses in the photovoltaic (PV) system enhances maintenance procedures and enhances system reliability. Input each string's representation into the deep learning model. Deep learning aims to identify distinct features, extract them, and then establish an average value for each category. Upon receiving an update, the standard deviation of the newly obtained image is calculated and aligned with a classification method similar to the new technique to pinpoint the fault location.

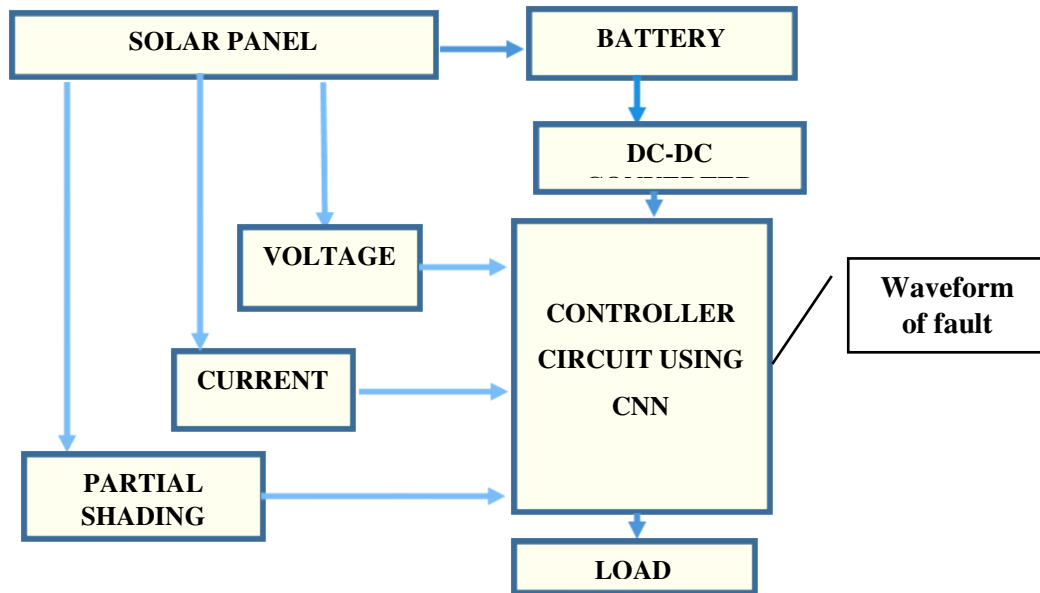


Figure 2 Proposed Block diagram

3.1 Hardware Components

A. Solar Panel

Solar cells, or photovoltaic (PV) cells, convert sunlight into energy using a semiconductor material. When photons, or light particles, hit the PV cell, they can be absorbed, reflected, or passed through. Only absorbed photons generate electricity by dislodging electrons from the semiconductor atoms. These freed electrons move towards the cell's front surface, creating a voltage potential similar to that of a battery.

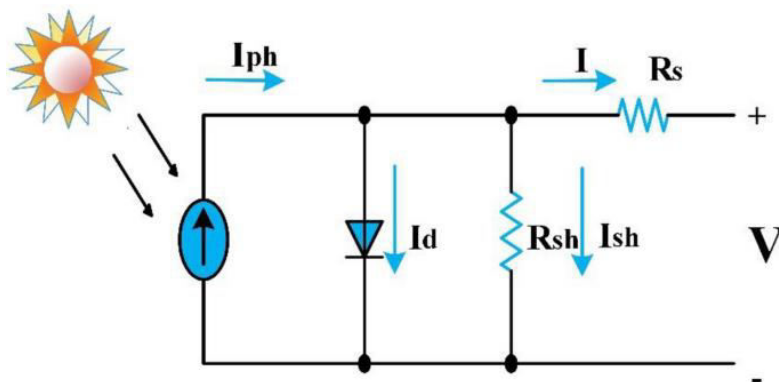


Figure 3 Equivalent circuit of photovoltaic system

Conductors on the cell then capture these electrons, generating an electrical circuit when connected to an external load, like a battery. A photovoltaic (PV) cell comprises a p-n junction diode with a slender p-type semiconductor layer atop a thicker n-type layer. It is shielded by a delicate glass sheet. Numerous cells assemble to create a photovoltaic module, which may be linked either in series or in parallel to construct arrays within solar energy facilities. Detecting defects in solar panels is crucial for maintenance, but differentiating between true defects and production issues due to weather or operating conditions can be challenging.

B. Voltage Measurement

A voltage assessment is capable of identifying, overseeing, and gauging PV voltage levels. The input comprises the voltage, and potential outputs include analog voltage signals, switches, audible signals, analog current levels, frequency, or frequency-modulated outputs. Certain voltage assessments furnish sine or pulse trains, whereas others present amplitude modulation, pulse width modulation, or frequency modulation outputs. This evaluation relies on a voltage divider. There exist two main categories of voltage assessments: capacitive and resistive.

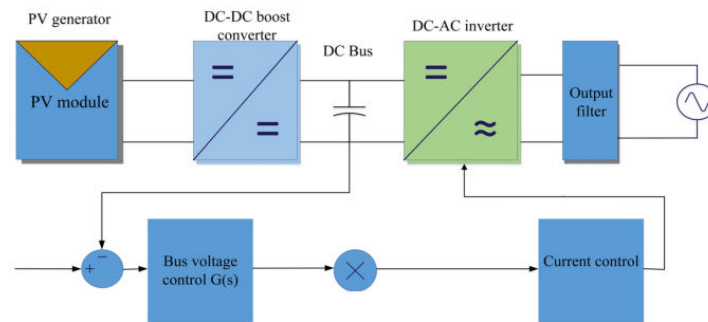


Figure 4 Circuit diagram of Voltage Measurement

Figure 4 shows a setup of two resistors with a non-conductor (dielectric) placed between two plates. When AC voltage is applied, electrons are attracted or repelled by the voltage of the opposing plate, causing current to flow. The field between the plates generates a connection without any hardware relationships.

Voltage measurement can detect, track, and measure the voltage supply. Its input is the voltage, and outputs can be frequency-modulated, switches, auditory signals, analog voltage signals, or analog current levels. Voltage measurements can yield various outputs, including sine or pulse trains, amplitude modulation, pulse width modulation, or frequency modulation. These measurements rely on a voltage divider as their fundamental basis. The two main types of voltage measurements are resistive and capacitive.

C. Current Measurement

Photovoltaic (PV) systems employ a range of fault detection techniques, such as electrical characterization, visual inspection, ultrasonic examination, infrared imaging, and imaging analysis. The techniques require tools, like thermal cameras. Visual and thermal inspections involve periodic checks for signs of failure, such as browning, mechanical damage, or hot spots. Electrical diagnosis monitors the PV module's performance, identifying issues through changes in output. The first sign of deterioration is a drop in output power, indicated by I-V curves.

Measuring current in photovoltaic (PV) systems typically entails monitoring the current passing through the PV output voltage, which correlates directly with the current intensity. One prevalent technique utilizes a resistor as a converter, transforming current into voltage. Various technologies are employed for current measurement, including direct sensing, which relies on Ohm's law, and indirect sensing, based on Ampere's and Faraday's principles. Direct sensing involves measuring voltage changes across electrical elements, whereas indirect sensing detects magnetic fields surrounding conductors. These measurements are used for control purposes. The measuring range can reach up to 120A, with a voltage activation of +5V, a frequency range of 20Hz to 20kHz, and a response time of less than 20ns.

D. Partial Shading Fault

The resilience of solar PV modules against intense heat caused by hotspots resulting from partial shading, soiling, cracked or mismatched cells, and connector issues is noteworthy. Partial shading can lead to shaded cells experiencing reverse bias, exacerbating the challenge. Without bypass diodes, this reverse bias current can cause overheating, sometimes exceeding 150°C or even 300°C, damaging the module. Traditional fault detection in PV arrays relies on thresholds but doesn't differentiate between partial shading and short-circuits. A decision tree method was used to identify PV array failures, using data on current, voltage, irradiance, and temperature. A challenge is obtaining a comprehensive training dataset.

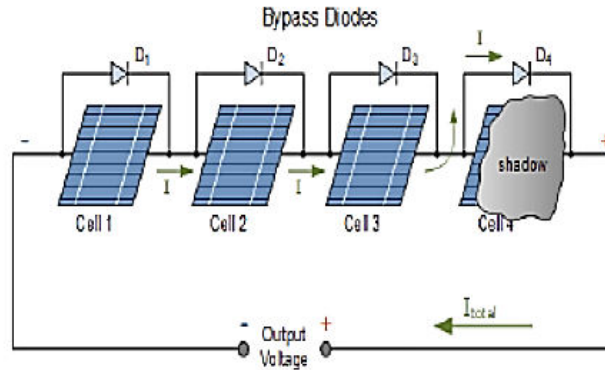


Figure 5 PV Fault Condition

Power loss in PV panels is mainly due to shading, current mismatch, and voltage imbalance. Bypass diodes protect shaded cells from reverse bias damage, allowing current to bypass less productive cells, preventing overheating and power loss. Partial shading causes power fluctuations, with less productive modules absorbing power from others, leading to increased losses.

3.2 Software Description

A. MATLAB (Matrix Laboratory)

MATLAB, short for Matrix Laboratory, stands as a premier software environment tailored for high-performance numerical computation, visualization, and programming tasks. Crafted by MathWorks, it seamlessly blends a desktop interface optimized for iterative analysis and design workflows with a programming language specifically geared towards expressing matrix and array operations. Its arsenal boasts robust tools for linear algebra, data analysis, algorithmic development, and cutting-edge graphics for data visualization. Embraced across academia and industry, MATLAB finds applications in signal processing, image processing, communications, control systems, and computational finance, among others. Its adaptability shines through an array of toolboxes catering to diverse specialized needs. Moreover, the Simulink platform within MATLAB facilitates model-based design for dynamic and embedded systems. With its intuitive interface, extensive documentation, and strong community support, MATLAB emerges as an indispensable asset for engineers, scientists, and researchers tackling intricate mathematical challenges and crafting inventive solutions.

IV. RESULT AND DISCUSSION

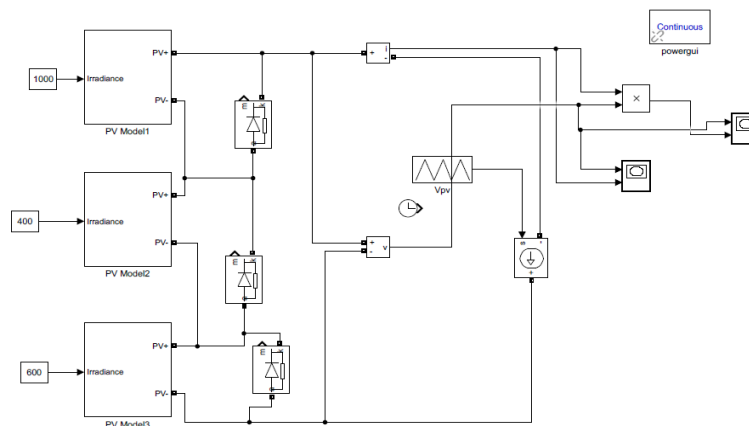


Figure 6 Matlab Simulation output

Figure 6 Simulated output of PV output power is impacted by a three different set of parameters, including partial shading, solar insolation, temperature, Convolutional Neural Network (CNN) and PV array layout. The study delved into how various shading scenarios, caused by trees, buildings, and clouds, affect photovoltaic (PV) arrays. It examined the power-voltage (P-V) characteristic curves of the PV system under full sunlight, revealing nonlinearities centered around a maximum power point (MPP). These complexities are exacerbated by fluctuations in sunlight. In instances of partial shading, specific solar cells receiving uniform irradiance can operate at peak efficiency because of their series arrangement, guaranteeing a steady supply to each cell.

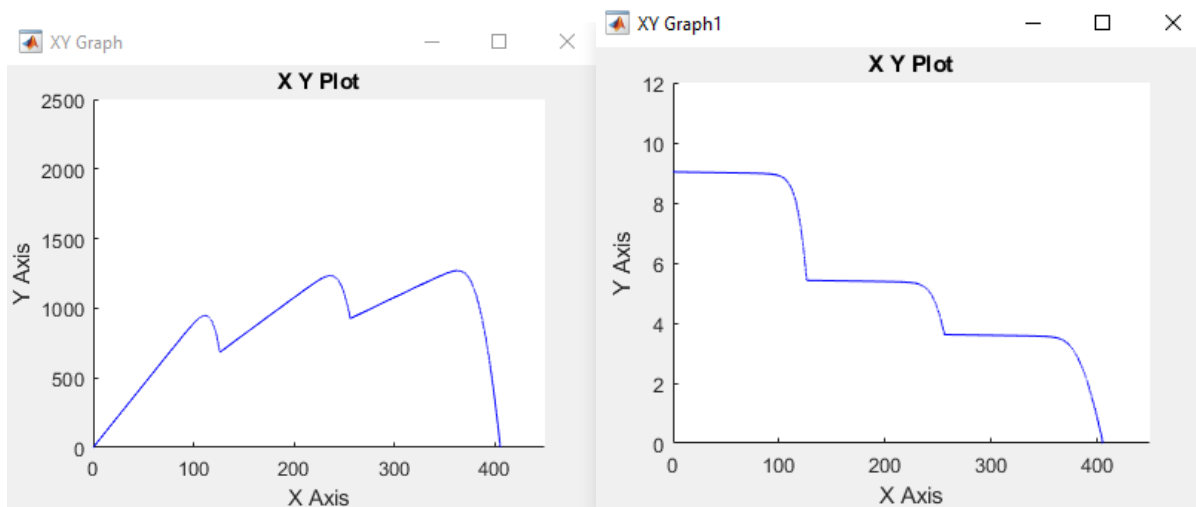


Figure 7 P-V curve in PV cell and I-V curve in PV cell

Figure 7 illustrates the results, demonstrating that partial shading significantly impacts the maximum power output of photovoltaic (PV) systems. Notably, two distinct local peaks emerge in both the power-voltage (P-V) and current-voltage (I-V) characteristics. The magnitude and position of these peaks fluctuate depending on the extent of partial shading. This phenomenon occurs because each module within the PV system is subjected to varying levels of irradiance during partial shading conditions.

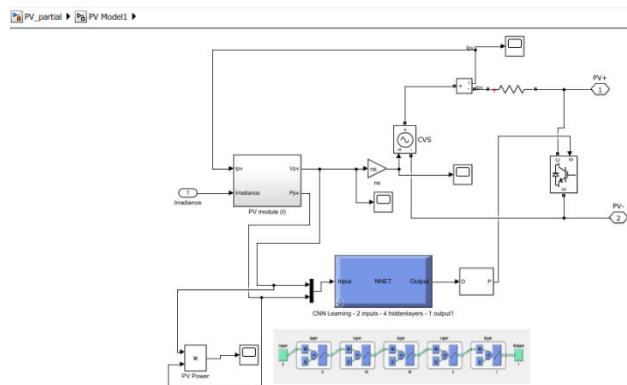


Figure 8 Circuit of closed loop pv in Matlab simulink output

The input sample dataset for Figure 8 was gathered from the PV simulation model during both normal and abnormal conditions as part of the training process.

V. CONCLUSION

Partial shadowing can have significant effects on the maximum power output of a solar system. The PV panel of shade, as well as the Interconnecting structure applied to connect the individual solar panels, all influence how susceptible a solar system is to partial shadowing. The bypass diode is essential for an efficient functioning of the solar system in a range of partially shaded conditions. Our understanding of how shadows effect solar panels may be enhanced by connecting photovoltaic modules under partially shadowed and/or mismatching situations to achieve maximum power output. The results also demonstrated that defect identification in simulink model was more improvements than previous approaches. The suggested technique detects shading problems with better efficiency, which is one of the major issues facing PV system

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