SSRG International Journal of Electronics and Communication Engineering
ISSN: 2348-8549/ https://doi.org/10.14445/23488549/IJECE-V11I5P110

Volume 11 Issue 5, 99-107, May 2024

Original Article

Intelligent Fault Detection Algorithm of PV System Based on Cloud Computing

Laith A. Abdul-Rahaim[1], Ahmed Swadi Rahi[2]

[1]*Department of Electrical Engineering, College of Engineering, University of Babylon, Babil, Iraq.*
[2]*Babylon Technical Institute, Al-Furat Al-Awsat Technical University, (ATU), Kufa, Iraq.*

[2]*Corresponding Author : ahmed.rahi.bi21@atu.edu.iq*

Received: 14 March 2024 Revised: 17 April 2024 Accepted: 11 May 2024 Published: 31 May 2024

Abstract - *Using Photovoltaic (PV) panel systems is increasingly gaining popularity as a viable alternative energy source. In order to optimize the utilization of dependable energy resources, the photovoltaic panel system must be maintained in an optimal state. Continuous maintenance and monitoring are necessary in this context. However, in the event of fluctuations in weather patterns affecting the reliability of energy production, it becomes necessary to determine if these changes are within the expected range owing to environmental factors or if they deviate from the norm due to issues such as malfunctioning equipment, shading, or accumulation of dust on solar panels. To address this need, the implementation of an intelligent monitoring system is essential. This research includes an integrated system for remote monitoring via the use of cloud computing techniques for remote monitoring through temperature, radiation, voltage, and current sensors, as well as analyzing the type of fault using Artificial Neural Network (ANN) and fuzzy theory in the MATLAB program. Ensuring energy continuity and reducing time, effort, and cost for maintenance through early fault detection and diagnosis are crucial for maintaining the performance and longevity of PV systems and for rapid decision-making.*

Keywords - *Photovoltaic (PV), Fault detection and diagnosis, Cloud computing, Fuzzy theory, DC-DC converter.*

1. Introduction

In recent years, Photovoltaic (PV) systems have become an increasingly popular means of harnessing clean, renewable energy, helping fight against climate change and the shift towards a more sustainable energy future. However, they are just as prone to errors and breakdowns as any other sophisticated electrical system, which can severely reduce their performance and efficiency. In order to ensure the best performance and longevity of PV systems, fault detection and diagnosis are essential. In order to maximize energy production, minimize maintenance costs, and eliminate unscheduled downtime, timely defect detection is essential. Manual inspection and routine maintenance are commonplace in conventional approaches to defect identification, but these procedures can be both time-consuming and expensive. Monitoring power plants, detecting faults, and analyzing them remotely via cloud computing for photovoltaic systems is essential to reduce maintenance costs and ensure energy continuity. Figure 1 represents the remote monitoring of a PV plant via cloud computing. Solar cell stations are briefly summarized with their principal parts: the cells, the constant voltage converters, and the control circuit that controls the converter by the duty cycle to raise and lower the output voltage [1, 2]. Moreover, the core of the converter's work came through the urgent need to raise the DC-DC voltage to high levels for storage and energy transfer because storing power in batteries requires high currents and high voltage [3-7].

The main contributions of this paper are:

1. Proposed a modified algorithm for monitoring and fault detection based on an artificial neural network.
2. Compare the proposed algorithm with the fuzzy logic system to validate the superiority of the proposed monitoring and fault detection system.

This paper is organized into fourteen sections, including the Introduction, Related Work, and detailed explorations of system components and fault detection techniques. It covers the Positive Output Super Lift Luo Converter (POSLC) [14], Cloud Computing in PV Systems, Data Treatment, and Sensor implementation in PV Systems. Specific fault scenarios such as PV Array Ground Fault, PV Array Line-Line Fault, PV Array Arc Fault, and PV Array Open-Circuit Fault are thoroughly analyzed. The paper discusses fault detection methods on the DC side of PV systems and presents the proposed intelligent fault detection algorithm for PV systems using cloud computing. The implementation of these technologies and their results are detailed before concluding with the overall findings and implications of the research.

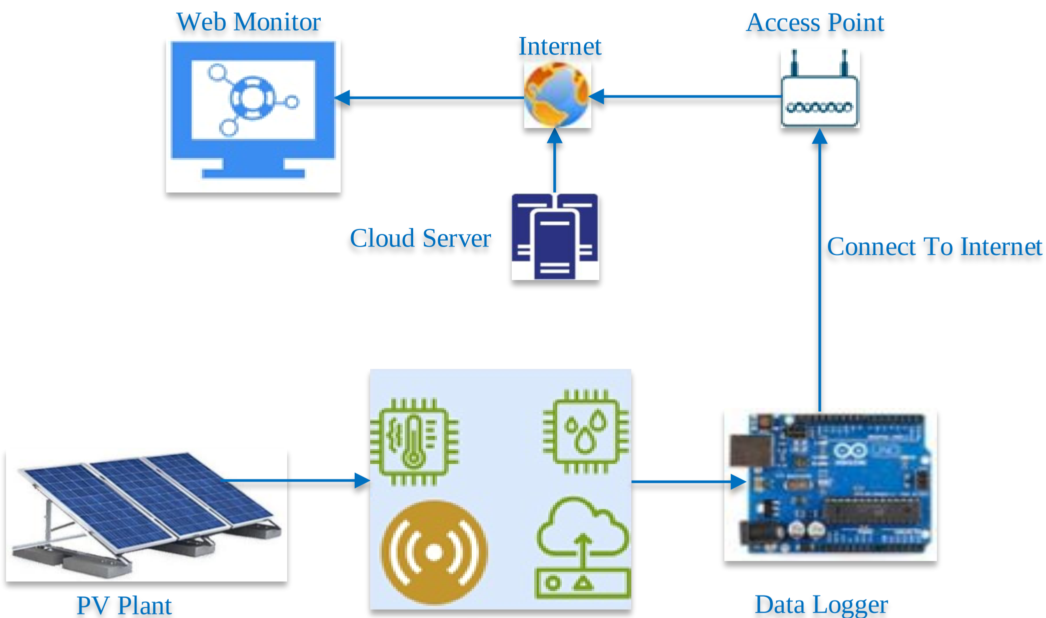

Fig. 1 Overview of intelligent system controlled by cloud

2. Related Work

The proposed system integrates Artificial Neural Networks (ANN) and fuzzy logic to create a robust framework for monitoring and fault detection in Photovoltaic (PV) systems, emphasizing high accuracy and precision. The system leverages the strengths of previous research efforts that have explored various aspects of PV system monitoring and fault detection. For instance, references such as [16, 27] focus on real-time monitoring using data loggers and neural networks, respectively, providing crucial baseline data that supports anomaly detection. The security and reliability aspects are enhanced by methodologies from references [17, 19], which address IoT security for smart grids and cybersecurity challenges. Fault detection techniques are further refined by incorporating insights from references [21, 22], which cover protection challenges, systems for PV fault monitoring, and DC arc faults, respectively.

Moreover, the proposed system builds on comprehensive approaches from references [23-25], which integrate both monitoring and fault detection capabilities using advanced technologies such as machine learning and IoT frameworks. These sources provide a broad spectrum of methodologies that enhance the system's ability to detect and diagnose faults effectively.

Combining these techniques, the proposed system aims to offer an unmatched operational reliability and efficiency level in PV system management, distinguishing itself through its advanced analytical capabilities and real-time response mechanisms. Table 1 presents the comparison of the proposed monitoring system with related work.

Table 1. Comparison of related work with the proposed system

Ref	Monitoring, Fault Detection, or Both
[16]	Monitoring (PV system monitoring with data loggers)
[17]	Both (IoT security for smart grids and PV systems)
[19]	Fault Detection (cybersecurity for smart grids)
[21]	Fault Detection (DC arc faults in PV systems, protection challenges and diagnosis)
[22]	Fault Detection (systems for PV fault monitoring)
[23]	Both (fault detection and diagnosis methods in PV systems)
[24]	Both (intelligent monitoring system using cloud and ML)
[25]	Both (IoT-based fault detection system for PV panels)
[26]	Monitoring (real-time monitoring using neural networks)
[27]	Fault Detection (intelligent fault detection model)
Proposed	Both monitoring and fault detection are based on ANN and fuzzy systems.

3. Positive Output Super Lift Luo Converter (POSLC)

There are many techniques for boosting the voltage to several levels in the DC-DC converters [8, 9]. The positive super lift Luo converters are among the best DC-DC converters due to their many advantages [10, 11].

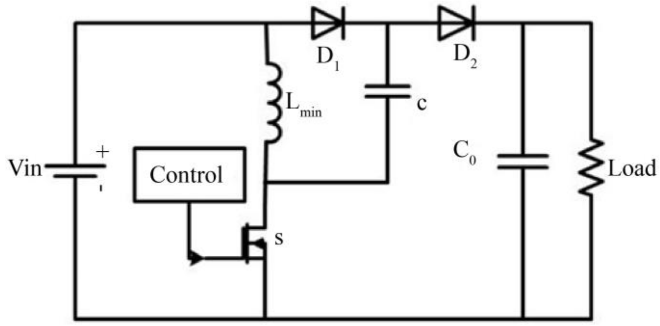

Fig. 2 Positive Output Super Lift Luo Converter (POSLC)

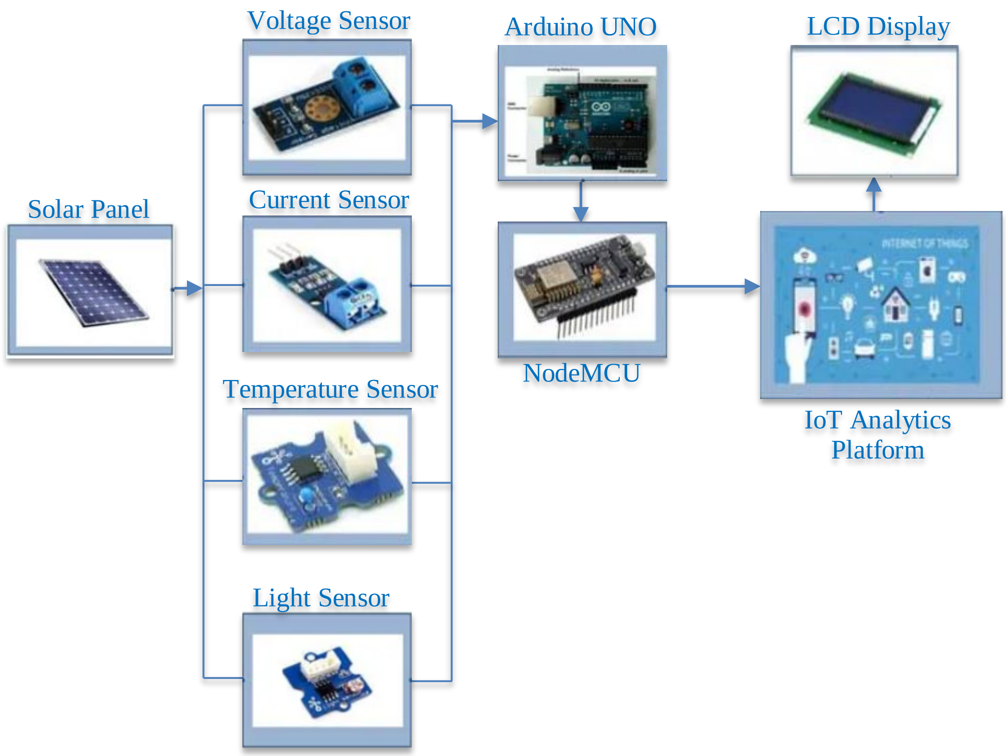

Fig. 3 The different sensors

The super lift Luo converter has a high voltage lift ratio and a geometric progression. The MOSFET switch, connected in low side mode, is used in a wide range of applications such as renewable energy, for example, Solar cells and wind energy Figure 2 shows the primary circuit for (POLC) [12]. As is known, the performance of all DC-DC converters is based on chopping the input voltage through an electronic switch. The switch has two operating modes: switch on and off states [13, 14].

4. Cloud Computing in PV Systems

Sensors and local computers connect machines, robots, and other physical things to collect and share data wirelessly. The cloud is crucial for PV system real-time monitoring and data collection. Internet sensors and gadgets in PV installations give operators vital information on system efficiency, environment, and equipment. This information helps identify and fix issues quickly. Some sensors are depicted in Figure 3.

5. Data Treatment

Solar power plant growth has generated a large, diversified data stream. This complicates data monitoring with standard methods and data treatment units. Large-scale solar power plants create too much data for PLC and Arduino modules [15, 18]. The Raspberry Pi Wi-Fi microcontroller can handle vast and complicated data but lacks real-time clock processing. Thus, an authoritative unit that can obtain much real-time information must be replaced. Figure 4 shows a two-classification monitoring system survey.

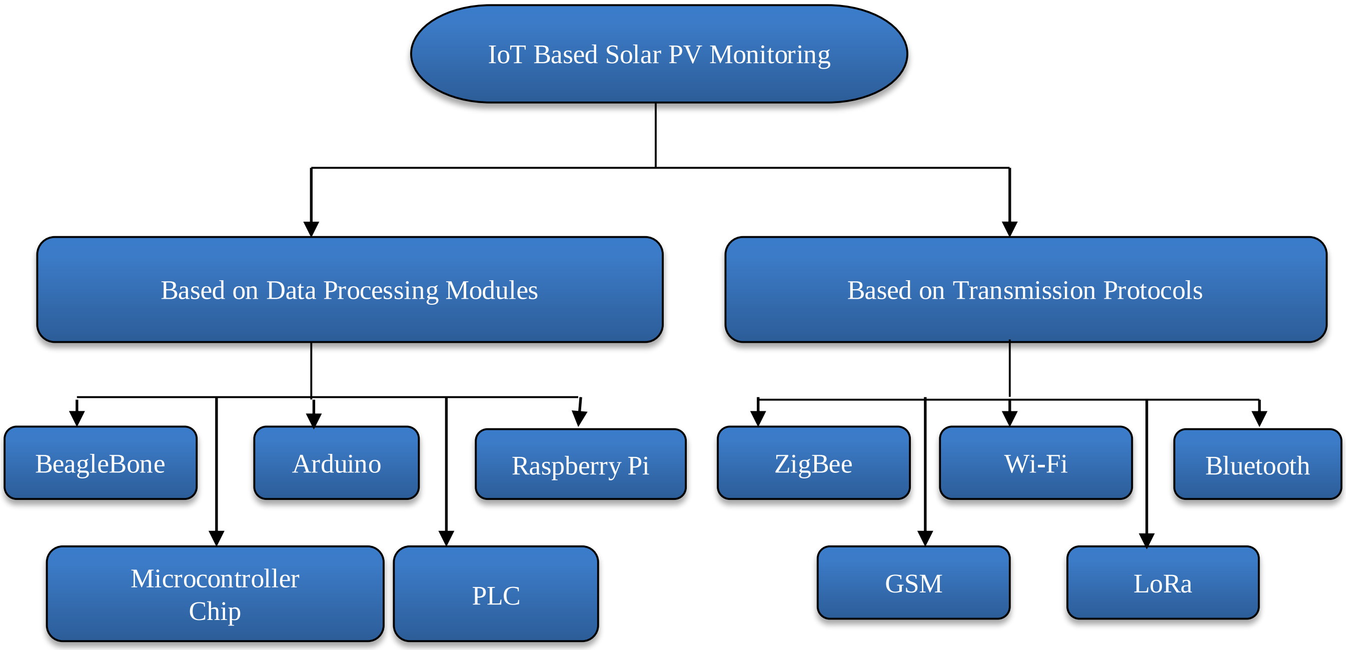

Fig. 4 PV monitoring techniques based-IoT [15]

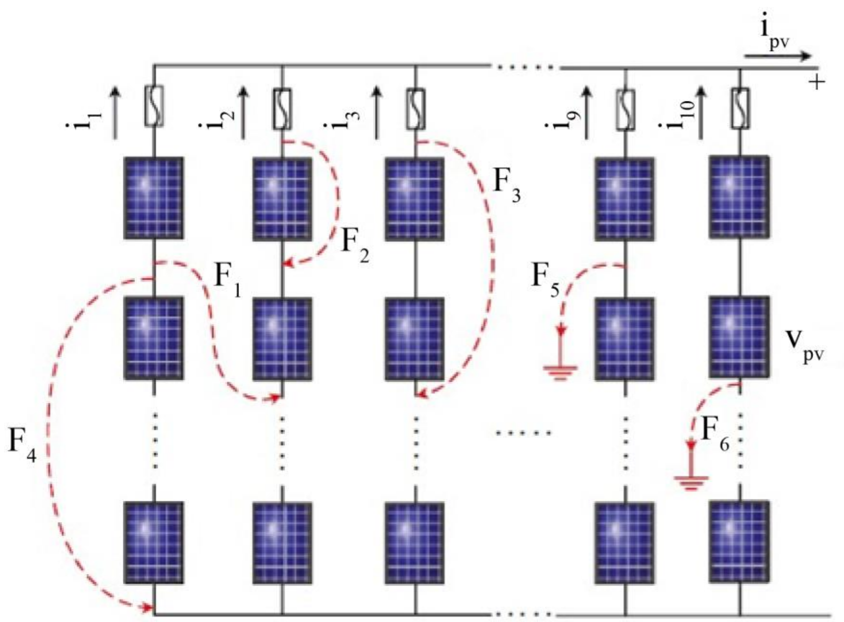

Fig. 5 The possible faults of the PV array

This includes authorization to ensure only authentic employers can access the system and step-by-step encryption for security and secrecy. Only authorized users should access data and act confidently [17-19].

6. Sensors in PV Systems

MATLAB can strategically deploy sensors for radiation, heat, voltage, current, and some metrics in PV systems connected to the cloud.

- Sensors measure sunlight reaching PV panels to assess system performance.
- Monitoring PV module, inverter, and other critical component temperatures can detect overheating and thermal imbalances, which can cause failures.
- Voltage and current: Sensors can consistently measure the photovoltaic (PV) system's electrical output, making it easier to spot changes.

7. PV Array Ground Fault

The usual practice in electrical installations is to link all NNUM (Normally Nonconducting Uninsulated Metallic) components to a third conductor known as an Equipment-Grounding Conductor (EGC) [20]. To prevent electric shock, it is standard practice to route any stray current via the NNUM components to the ground; any inadvertent connection between a current-carrying conductor and an EGC that results in a current flow to the ground is characterized as a Ground Fault (GF), which is the source of such errant current flow in the NNUM components. Figure 5 shows the possible faults of the PV array.

Depending on where the fault is, GF damage can vary. Figure 5 depicts GFs as F5 and F6. F5 and lower F6 GFs suggest higher location-wise GFs. The large potential difference between F5 and the ground causes rapid current flow. Low Voltage between F6 and ground reduces fault current. GF severity metrics include percentage mismatch, which counts the number of solar modules affected [21]. F5 and F6 contain 10% and 20% mismatches, respectively, assuming 10 PV modules per string (Figure 5). Lower fault current magnitude and a large percentage of misfit GF make detection harder.

8. PV Array Line-Line Fault

Line-line faults occur when locations of various voltage levels are accidentally linked. A short circuit between PV strings creates interesting LLF, while interesting LLF is caused by a short circuit anywhere in the string. F1, F2, F3, and F4 form an interesting LLF (Figure 5). LLF, like GF, is proportional to fault position or mismatch percentage. F1 and F2 have a 10% mismatch, whereas F3 and F4 have 20% and 90%, respectively, since each string of the PV array in Figure 5 has 10 PV modules. LLFs cause damaged PV array strings to drop in voltage, causing back-feeding current from unaffected strings. Unlike in a GF, a high fault current in an LLF results from a significant percentage mismatch. LLFs can be caused by water entry, animal nibbling of cable insulation, mechanical damage, and DC junction box corrosion.

9. PV Array Arc Fault

Electricity discharged at high voltage over an air gap between two conductors causes an arc fault (AF). High electric fields created an arc across the air gap by ionizing air molecules and blowing them toward the opposite electrode. Ionization creates additional ions through high-velocity particle collisions. The air between electrodes becomes conductive when an ion passes from one to the other. A series AF fault occurs when a current-carrying conductor breaks, starting an arc. The second type of AF is a parallel arc between two wires. Figure 6 shows photovoltaic array AF placements. The following points explain series and parallel arc fault causes, according to Wang and Balog [22].

- Series arc fault: Caused by a damaged current path, loose connection, or corrosion that raises connection impedance.
- Parallel arc faults: Caused by mechanical damage, rodent infestation, or malfunctioning PV module components.

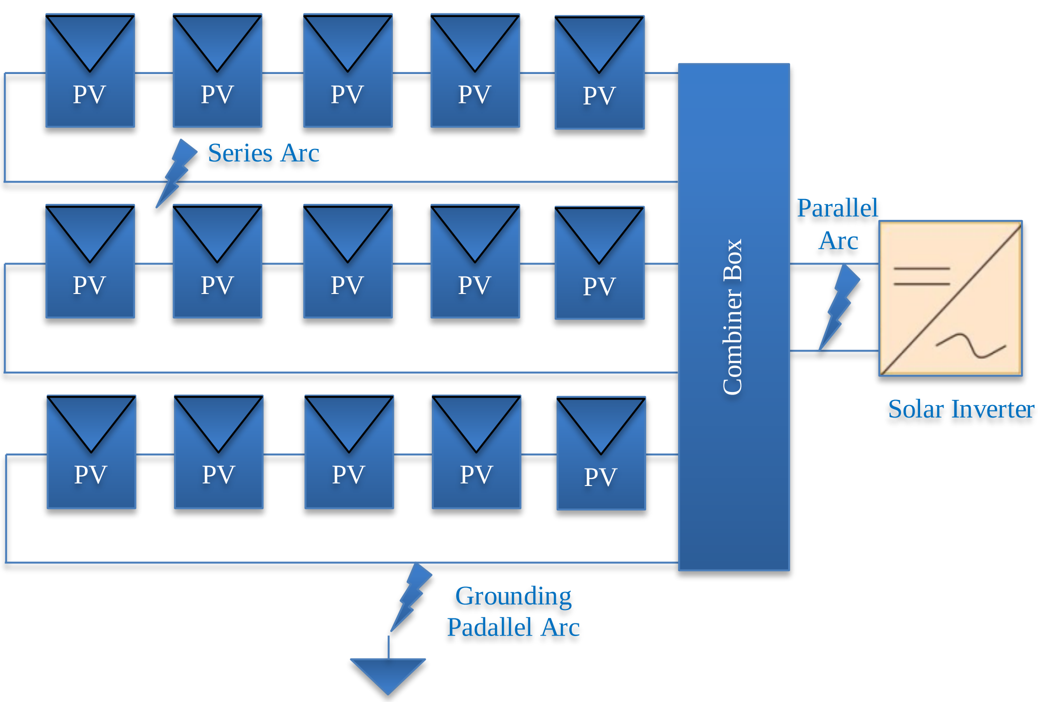

Fig. 6 The various af positions in a photovoltaic array [22]

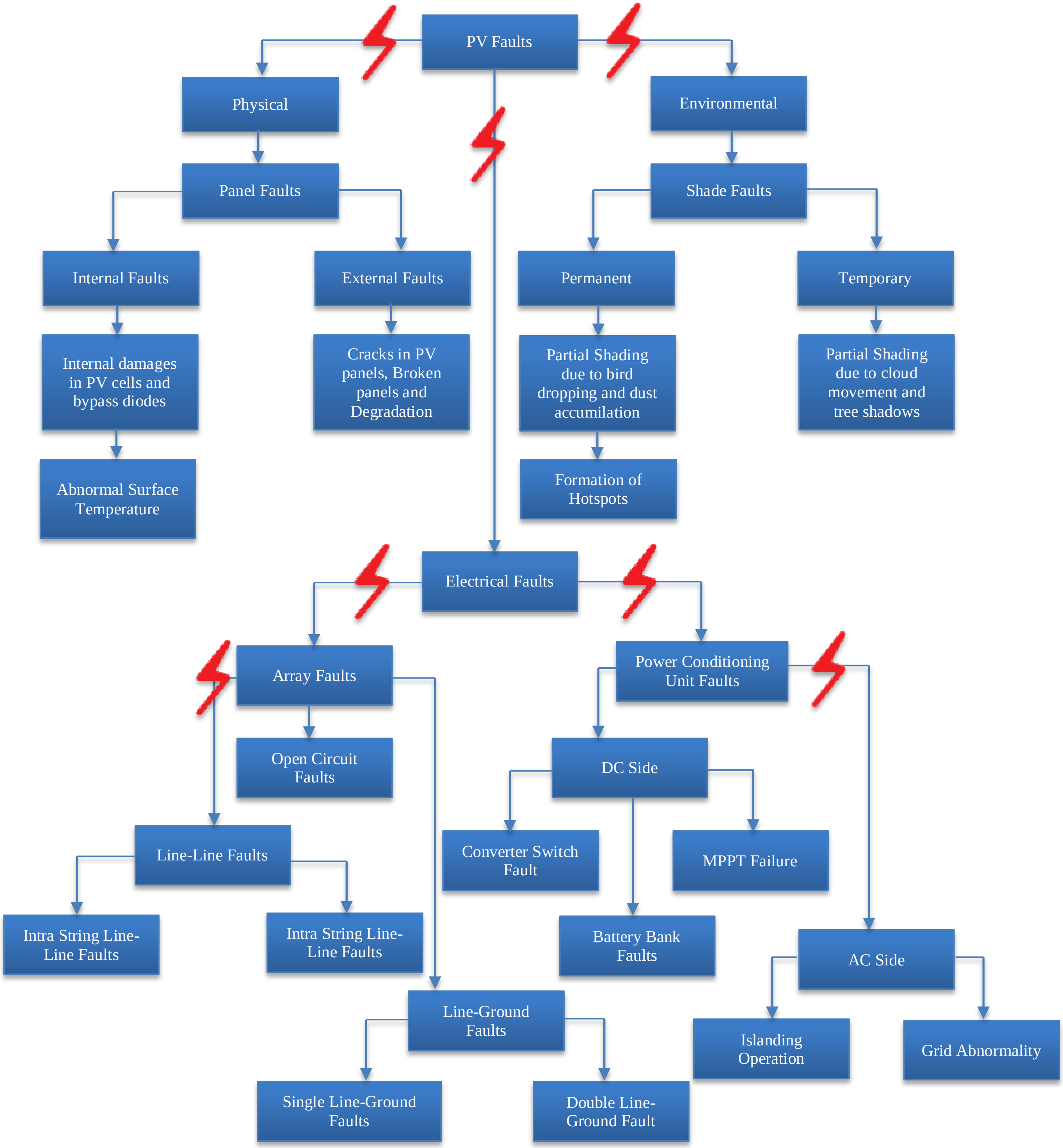

Fig. 7 Classification of various fault detection methods [21]

Direct Current (DC) arcs do not have zero crossings like AC systems. An arc can be kept in a PV array. A big voltage potential difference creates a significant fault current in parallel AF compared to serial AF. Thus, parallel AF's substantial fault current is more straightforward to detect than series AF's.

10. PV Array Open-Circuit Fault

Disconnection difficulties in PV strings cause this fault. Additionally, weak string soldering is the leading cause of disconnection. While the open-circuit defect reduces short-circuit current and maximum power, the open voltage remains constant.

11. Fault Detection Methods on the DC Side of PV Systems

The fault detection methods in the PV system are divided into two main parts, the DC side and the AC side, and this thesis illustrates the fault detection methods that occur on the DC side, as shown in Figure 7.

12. The Proposed Intelligent Fault Detection Algorithm of PV System by Cloud Computing

The research objective is to develop an accurate malfunction monitoring system for PV plants. An advanced and implemented Intelligent Management System (IMS) has been devised to enhance the functioning of the Photovoltaic (PV) plant by forecasting the power generated by PV modules to identify any malfunctioning occurrences.

In Matlab**,** the photovoltaic units are interconnected using a microcode method, which minimizes damage in case of failure and isolates the panel from the system. The system evaluates a photovoltaic electrical system using a computer based on the fuzzy theory in the MATLAB application. The system uses accurately calibrated sensors to measure radiation intensity, temperature, electric current, and voltage. Figure 8 represents a curve describing energy and radiation, as it is considered one of the main components for monitoring, understanding, and analyzing the station's production with radiation ether, which is considered the primary influence on the amount of energy generated from solar cells.

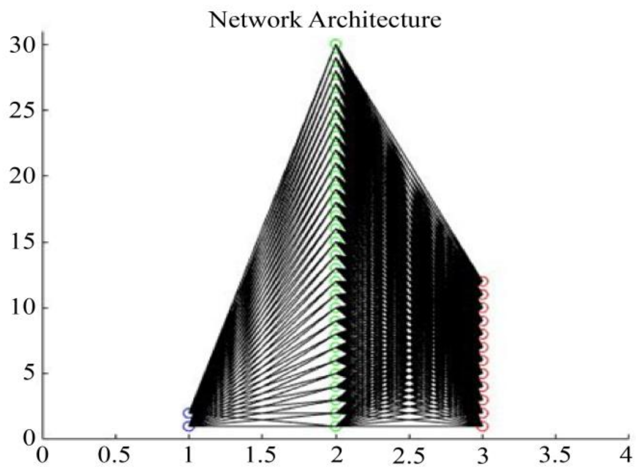

Fig. 8 A curve described by energy and radiation

To detect out-of-the-ordinary events, the machine learning model diligently monitors data collected by cloud sensors, drawing on patterns that have been previously learned.

13. Implementation Results

A cloud-based platform is used to implement the intelligent failure detection technique, with historical PV plant data used to train a machine learning model and real-time data from cloud sensors constantly fed into the system. Over several months, the algorithm successfully detected and diagnosed various faults and issues in the PV plant.

Figures 9 to 13 demonstrate the monitoring system's outcomes depending on the IoT system.

The PV monitoring system displays a consistent irradiance level at 1000 W/m², as shown in Figure 9, suggesting either a steady environmental condition or a static reading from the sensor. The power output graph shows a sharp decline from 1000W to approximately 950W, as depicted in Figure 10, correlating with a similar drop in the current from around 16A to 15A, as illustrated in Figure 11. This simultaneous decrease in power and current could indicate a sudden change in system conditions or potential partial shading affecting the panels. The voltage graph exhibits volatility with a dip and a recovery, as indicated in Figure 12, which might reflect an issue with the system's electrical connections or an external factor influencing the PV system's voltage stability. The power amount displayed as 946W, as shown in Figure 13, might result from the fluctuations seen in power, current, and voltage, potentially highlighting the momentary impact of the fault or anomaly detected by the system.

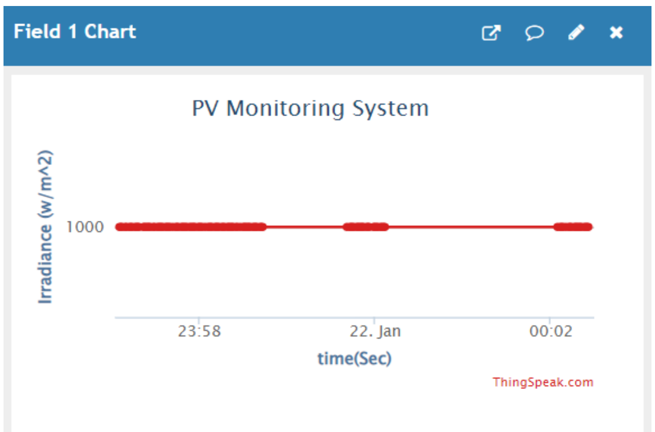

Fig. 9 Radiation sunlight incident on the PV system

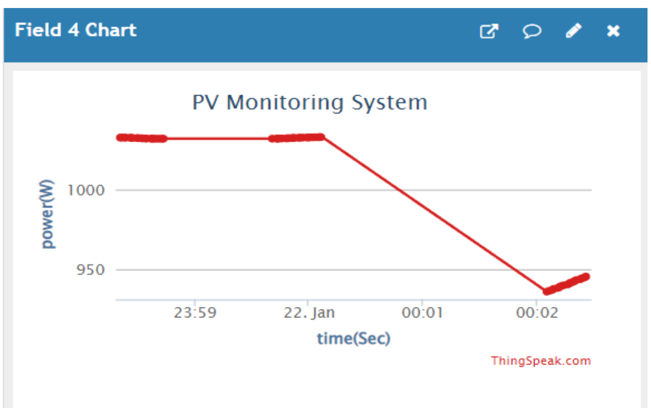

Fig. 10 Power with time for the PV system

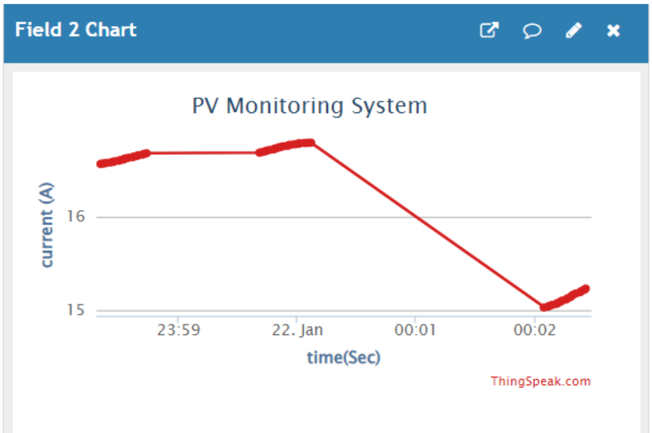

Fig. 11 Monitor the current wave through the cloud

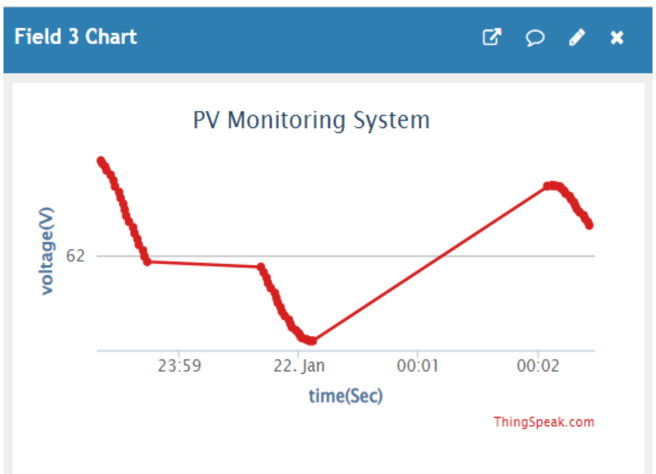

Fig. 12 Monitor the voltage wave through the cloud

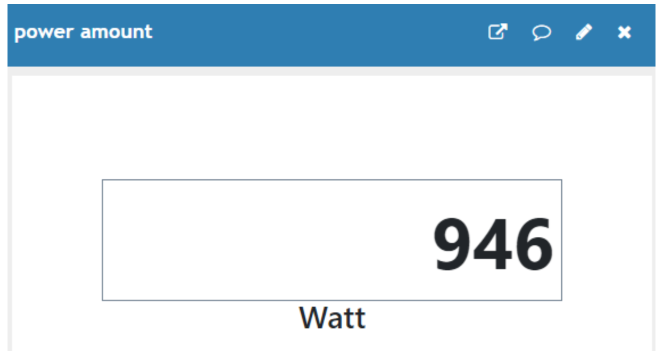

Fig. 13 Monitor electrical capacity digitally via the cloud

14. Conclusion

Integrating Photovoltaic (PV) systems into the energy landscape has ushered in a new era of sustainable energy production. However, ensuring the optimal performance and reliability of PV systems is essential to maximize their potential. Based on cloud computing, this paper's intelligent fault detection algorithm offers a comprehensive solution for timely fault detection and diagnosis in PV systems. By harnessing the sensor's cloud-based monitoring for the PV system and analytics fault detection by the MATLAB algorithm, the computer can continuously monitor system parameters, detect anomalies, and provide detailed diagnostic information to operators. This proactive approach enhances system reliability, reduces downtime, Reduces the number of working engineers, reduces costs and maintaining equipment and infrastructure, and ultimately maximizes energy production. As the adoption of PV systems continues to grow, intelligent fault detection algorithms like the one proposed here will play a pivotal role in ensuring the sustainability and efficiency of renewable energy sources.

References

[1] Mojtaba Forouzesh et al., "Step-Up DC–DC Converters: A Comprehensive Review of Voltage-Boosting Techniques, Topologies, and Applications," *IEEE Transactions on Power Electronics*, vol. 32, no. 12, pp. 9143-9178, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[2] Fang Lin Luo, and Hong Ye, *Advanced DC-DC Converters*, 1st ed., CRC Press: Boca Raton, pp. 1-792, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[3] Ebrahim Babaei et al., "Extendable Nonisolated High Gain DC–DC Converter Based on Active–Passive Inductor Cells," *IEEE Transactions on Industrial Electronics*, vol. 65, no. 12, pp. 9478-9487, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[4] Farzad Mohammadzadeh Shahir, Ebrahim Babaei, and Murtaza Farsadi, "Extended Topology for a Boost DC–DC Converter," *IEEE Transactions on Power Electronics*, vol. 34, no. 3, pp. 2375-2384, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[5] B. Axelrod et al., "Steep Conversion Ration Ćuk, Zeta, and Sepic Converters Based on a Switched Coupled-Inductor Cell," *2008 IEEE Power Electronics Specialists Conference*, Rhodes, Greece, pp. 3009-3014, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[6] Nishtha Bajoria et al., "Overview of Different Control Schemes used for Controlling of DC-DC Converters," *2016 International Conference on Electrical Power and Energy Systems (ICEPES)*, Bhopal, India, pp. 75-82, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[7] Raja Basak et al., "High Gain Boost Converter with Reduced Switching Stress," *2015 International Conference on Computation of Power, Energy, Information and Communication (ICCPEIC)*, Melmaruvathur, India, pp. 393-399, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[8] Thomas Salvatierra, and Marian K. Kazimierczuk, "DC Analysis, and Design of a PWM Buck Converter Operated as a Dynamic Power Supply," *International Journal of Circuit Theory and Applications*, vol. 45, no. 5, pp. 681-706, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[9] F. Mohammadzadeh Shahir, E. Babaei, and M. Farsadi, "Voltage-Lift Technique Based Nonisolated Boost DC–DC Converter: Analysis and Design," *IEEE Transactions on Power Electronics*, vol. 33, no. 7, pp. 5917-5926, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[10] Adrian Ioinovici, *Power Electronics and Energy Conversion Systems: Fundamentals and Hard-switching Converters*, John Wiley & Sons, pp. 1-872, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[11] Fang Lin Luo, and Hong Ye, "Positive Output Super-Lift Converters," *IEEE Transactions on Power Electronics*, vol. 18, no. 1, pp. 105-113, 2003. [CrossRef] [Google Scholar] [Publisher Link]

[12] Yefim Berkovich et al., "Improved Luo Converter Modifications with Increasing Voltage Ratio," *IET Power Electronics*, vol. 8, no. 2, pp. 202-212, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[13] Kerui Li, Yafei Hu, and Adrian Ioinovici, "Generation of the Large DC Gain Step-Up Nonisolated Converters in Conjunction with Renewable Energy Sources Starting from a Proposed Geometric Structure," *IEEE Transactions on Power Electronics*, vol. 32, no. 7, pp. 5323-5340, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[14] Miao Zhu, and Fang Lin Luo, "Analysis of Positive Output Super-Lift Converter in Discontinuous Conduction Mode," *2004 International Conference on Power System Technology*, Singapore, pp. 828-833, 2004. [CrossRef] [Google Scholar] [Publisher Link]

[15] Shaheer Ansari et al., "A Review of Monitoring Technologies for Solar PV Systems Using Data Processing Modules and Transmission Protocols: Progress, Challenges, and Prospects," *Sustainability*, vol. 13, no. 15, pp. 1-34, 2021, [CrossRef] [Google Scholar] [Publisher Link]

[16] M. Fuentes et al., "Design of an Accurate, Low-Cost Autonomous Data Logger for PV System Monitoring Using Arduino™ that Complies with IEC Standards," *Solar Energy Materials and Solar Cells*, vol. 130, pp. 529-543, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[17] Bhabendu Kumar Mohanta et al., "Survey on IoT Security: Challenges and Solution Using Machine Learning, Artificial Intelligence, and Blockchain Technology," *Internet of Things*, vol. 11, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[18] Ferran Adelantado et al., "Understanding the Limits of LoRaWAN," *IEEE Communications Magazine*, vol. 55, no. 9, pp. 34-40, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[19] Salsabeel Shapsough et al., "Smart Grid Cyber Security: Challenges and Solutions," *2015 International Conference on Smart Grid and Clean Energy Technologies (ICSGCE)*, Offenburg, Germany, pp. 170-175, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[20] Rashmi Mishra, Shimpy Ralhan, and Khaja Mohiddin, "A Review on Frequency Stability Enhancement and Effective Energy Storage Through Various Optimization Techniques," *Mobile Information Systems*, vol. 2022, pp. 1-8, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[21] Dhanup S. Pillai, and N. Rajasekar, "A Comprehensive Review on Protection Challenges and Fault Diagnosis in PV Systems," *Renewable and Sustainable Energy Reviews*, vol. 91, pp. 18-40, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[22] Shibo Lu, B.T. Phung, and Daming Zhang, "Study on DC Series Arc Fault in Photovoltaic Systems for Condition Monitoring Purpose," *2017 Australasian Universities Power Engineering Conference (AUPEC)*, Melbourne, VIC, Australia, pp. 1-6, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[23] A. Mellit, G.M. Tina, and S.A. Kalogirou, "Fault Detection and Diagnosis Methods for Photovoltaic Systems: A Review," *Renewable and Sustainable Energy Reviews*, vol. 91, pp. 1-17, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[24] Masoud Emamian et al., "Cloud Computing and IoT Based Intelligent Monitoring System for Photovoltaic Plants Using Machine Learning Techniques," *Energies*, vol. 15, no. 9, pp. 1-25, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[25] D. Balakrishnan et al., "An IoT-Based System for Fault Detection and Diagnosis in Solar PV Panels," *International Conference on Smart Engineering for Renewable Energy Technologies (ICSERET-2023)*, vol. 387, no. 5009, pp. 1-10, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[26] Sufyan Samara, and Emad Natsheh, "Intelligent Real-Time Photovoltaic Panel Monitoring System Using Artificial Neural Networks," *IEEE Access*, vol. 7, pp. 50287-50299, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[27] Barun Basnet, Hyunjun Chun, and Junho Bang, "An Intelligent Fault Detection Model for Fault Detection in Photovoltaic Systems," *Journal of Sensors*, vol. 2020, pp. 1-11, 2020. [CrossRef] [Google Scholar] [Publisher Link]