IoT based MPPT techniques for photovoltaic frameworks management under different environmental conditions: a review

Mohammad Junaid Khan[1,2], Md. Naqui Akhtar[3], Afroj Alam[4], Asyraf Afthanorhan[1]
[1]Universiti Sultan Zainal Abidin (UniSZA), Gong Badak Campus, Gong Badak, Malaysia
[2]Department of Electrical and Electronics Engineering, Mewat Engineering College (Waqf), Haryana, India
[3]Department of Electrical Engineering, Government Polytechnic Sahibganj, Jharkhand, India
[4]Department of CSE, School of Engineering, Presidency University, Bangalore, India

Article Info

Article history:

Received Jan 5, 2024
Revised May 2, 2024
Accepted May 12, 2024

Keywords:

DC-DC power converters
Internet of things
MPPT Controllers
PV panels
Solar energy

ABSTRACT

Solar energy (SE) is the most attractive form of renewable energy (RE) source for electrification. To harness SE, the photovoltaic (PV) system is required towards converting sunlight into direct electricity. The PV frameworks can be placed in areas with high energy potential. The performance of PV frameworks is complex work which depends on various parameters of the frameworks and their operations. The performance of PV frameworks can be evaluated using MATLAB/Simulink platform and real-time implementation. In this research article, the internet of things (IoT) is investigated to regulate and monitor PV system performance in various environments. IoT-based maximum power point tracking (MPPT) technology improves the response of real-time operating characteristics which makes it possible to control remote PV systems management, quickly diagnose problems and maintain them effectively. Additionally, it allows for recording production and performance data for analysis.

Corresponding Authors:

Asyraf Afthanorhan
Universiti Sultan Zainal Abidin (UniSZA), Gong Badak Campus
Gong Badak, 21300 Kuala Nerus Terengganu Darul Iman, Malaysia
Email: asyrafafthanorhan@unisza.edu.my

1. INTRODUCTION

In recent years, solar photovoltaic (PV) frameworks have emerged as one of the primary sources of clean energy worldwide. The most crucial potential to be emphasized is that of a solar PV system's ability to generate electricity. These potentials could change depending on a variety of factors from technology to technology and location to location. The cost of electricity per unit returns on investments, and paybacks would rely on the electricity potentials. Therefore, every solar PV framework is installed with the highest energy potential which is implemented for sufficient safeguard. During the installation of the PV frameworks, there is a chance of failing the PV framework. These problems can be more common in PV systems installed in remote areas. Consequently, these problems are reduced systematically using the proper strategy. The primary challenges that humans realize are those of concentration, undivided attention and accuracy needed for problem identification and solution presentation [1].

The most advanced technology available is the internet of things (IoT) which can be used to remotely control the frameworks to address this problem. The IoT is the system that combines every information and device of communication technology. Using tools like microcontrollers, with the use of transceivers, information and network protocols, digital communication tools, and the IoT, most everyday objects can be interacted with fastly and easily such as cameras, household utilizations, displays, automobiles, actuators, and sensors [2], [3]. This technology will assist in gathering a lot of specific information on things in order to provide a variety of new developmental opportunities. A few of the uses for the IoT include healthcare, home-automation, industrial and home energy management, RE frameworks, traffic-maintenance, medical-aids, automotive-industry, and smart-grids [2], [3].

The solar PV industry is highlighted as one of the wide-area IoT applications. This is a result of solar PV' widespread use in distributed-level generation and the energy sector today. The widespread use of solar PV systems presents a significant opportunity to combine it with IoT systems. For both IoT users and service providers, this would result in enormous indirect business. A PV system is made up of electric power converters, storage devices, and PV modules. It simply harvests energy using solar energy (SE) to generate electricity [4]. The conventional technique of employing fossil fuels differs significantly from the generation of PV power systems. However, similar techniques are used for transmitting and distributing the energy. PV generators are PV panels which consist of PV modules connected in parallel and series. The location of these generators is to appear in direct sunshine. The PV generators produce DC electricity which transforms into AC electricity using a power converter (inverter). The energy can either be used directly by a particular load or supplied to the AC grid using a transmission link. PV frameworks are divided into two categories such as off-grid and on-grid. It can be used as per the demand of the user. The battery bank is a storage device which is an essential part of some situations where on-grid is not available. The schematic block diagram of a PV framework operation is shown in Figure 1.

The PV array characteristics are non-linear due to changes in temperature and SR. This response can not be usable for any device. Therefore, the maximum power point tracking (MPPT) technique is necessary to achieve continuous constant power to the load. MPPT techniques are used to enhance the output power production of the solar PV framework at the load. It adjusts the duty cycle of the DC-DC power converter to find the maximum power point (MPP) from the solar PV arrays. The perturb and observe (P&O) MPPT technique produces maximum power with oscillations which is a simple and widely used MPPT technique for PV framework management. This method adjusts the operating point of the solar PV system by gradually altering the solar PV voltage and observing the response change in the output power [5].

Similarly, another incremental conductance (IC) MPPT method is widely used. This technique adjusts the power voltage curve slope and the incremental conductance at the specified operating point. It produces a fast and robust output response of the PV framework as compared to the conventional P&O MPPT technique. Artificial intelligence (AI) based MPPT techniques such as artificial neural network (ANN) technique which is trained neural network to the model that demonstrates the relationship between input and output of the PV panel voltage, current and power respectively. It produces the maximum power with fewer fluctuations in the MPP as compared to conventional MPPT techniques [6].

Various MPPT techniques are investigated and used to yield the MPP from solar PV arrays in the literature. Some important MPPT techniques are reviewed and evaluated for PV arrays under various conditions [7]–[33]. Investigated below are the following points:

i) To research IoT-based MPPT controllers that produce DC-DC converters with the best duty cycle.
ii) To use the MPPT controller to investigate the MPP from the SPV system.
iii) To investigate the less transient state of the entire system.
iv) A comparison of different MPPT methods for SPV frameworks under various environmental conditions.

The sections listed below make up the organization of this manuscript. Section 2 discusses an overview of IoT-based solar PV frameworks. Section 3 provides a comparative analysis of these frameworks. Section 4 discusses research trends, and section 5 offers conclusions.

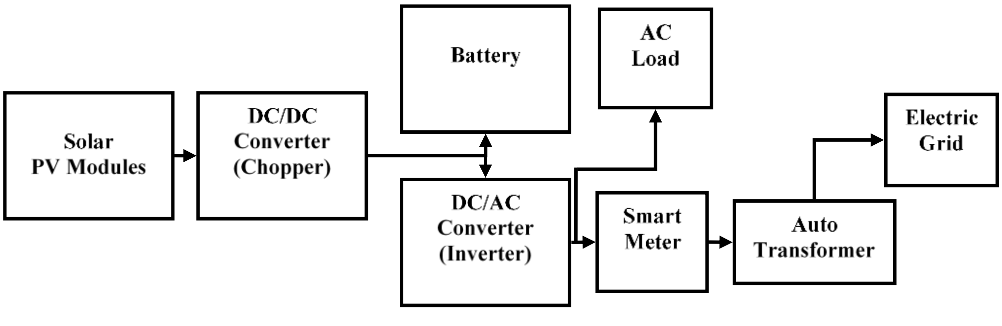

Figure 1. Schematic block diagram of a PV framework operation

2. OVERVIEW OF IOT BASED SOLAR PV FRAMEWORKS MANAGEMENT

The IoT doesn't directly play an important role in the vastness of the solar PV framework, but it does play an increasingly important role in technology. In this regard, the use of IoT technology on earth to harness the power of the sun. IoT devices are small computers with sensors that can collect data and communicate wirelessly. In the scope of solar energy, devices are being used to control and optimize solar PV framework performance. There are some of the following ways are used in the SE.

- Real-time monitoring-sensors can track things such as power production, voltage, current, and temperature of solar PV panels. These data are sent to the central location where they can be observed and analyzed. This allows for fast detection and resolution of any difficulties.
- Predictive maintenance – to control the performance data and their maintenance can be anticipated before a failure occurs. It can save time and money.
- Optimizing energy production-data on factors such as sunlight intensity can be used to tilt solar PV arrays to enhance efficiency.
- Smart grids-IoT can help integrate solar PV power into the electric grid by providing data on power production and consumption. It allows for improved balancing of power supply and demand.

Due to recent developments in energy sources, it is now possible to make IoT devices energy independent. These technologies are based on radio frequency (RF), heat, vibration, piezoelectric, and PV generators. These energy sources have been employed singly or in combination in numerous studies to generate energy for IoT applications. Many IoT applications leverage PV technology to become autonomous. Numerous studies are pertinent to this subject, and each one differs in terms of the methodology used for MPPT and its component parts. Because of their massive size, inductors which are used in basic converters can become external components while capacitors can take up a lot of space in microprocessors. Due to the lack of a large inductor, charge pumps which are made up of switches and capacitors have taken over as the favored option in several works [34]–[37].

There have been a number of recent studies and articles that have explored the connection between IoT and PV systems. There are a few examples of the most recent references on IoT-enabled smart PV system [38]. It has reviewed and provided an overview of the various IoT technologies and applications that can be used to enhance the output power response and monitoring of solar PV frameworks. Real-time monitoring and control of a PV system using IoT describes a system and presents the results of experiments conducted to test the system's performance. And also proposed a system for integrating IoT and PV systems for energy management, and presents a simulation of the system's performance [39].

The present centres on the installation of a new, cost-effective IoT technology to remotely control a solar PV array in order to analyze its performance, defect diagnosis and real-time implementation that will be made simpler by this [40]. IoT technology was created by combining of internet, micro-electro-mechanical frameworks, wireless equipment and micro-services. It provides the coordination of physical-objects, mechanical-machines, computational-devices and digital-machines with unique IDs. By eliminating the need for computer-to-human (human-to-human) interaction and bridging the gap between information and operational technologies, this coordination aids in the transmission of data across the network. The IoT in solar PV systems has enabled several new components of the present trend in the solar PV sector. This feature provides ongoing monitoring, efficient operations, quick and prompt fault resolution, promising analytics of business using historical generating data, potential income increases etc. To gain a better understanding, a few discussions focused on the work related to the monitoring and remote control of solar PV frameworks using IoT. In order to improve the energy efficiency in domestic houses (home energy management), IoT based solar PV frameworks are being developed as interoperable, scalable and reusable home energy management frameworks over the continually changing home energy patterns. It is decisively assisted in the saving of the system's cost [41].

Used for remote supervising and control a smart solar PV framework built on the IoT is being investigated by researchers. This technology uses IoT to make PV systems more energy efficient and to enable remote data transmission from the plant to the supervisory server. The existing approach reduces the amount of time that manual supervision is needed using wireless devices and a web console-based interface which both use less electricity [40]. It is suggested to use IoT technology to monitor solar power plants' power conditioning units. The parameters of the solar power conditioning unit are monitored, the energy outputs are shown and reported, and the monitored parameters are stored in the cloud for chronological study [42].

According to the researchers, IoT based smart PV frameworks need little maintenance and excellent monitoring performance. A single power supply a battery storage integrated with primary renewable energy (RE) sources are used in the smart hybrid frameworks. If one energy source is provided, therefore, IoT technology allows this intelligent device to function and charge its battery banks. Furthermore, it provides the facility of transition from an energy source into a battery storage system as a supply power unit [43]. The best opportunities for gathering different system parameters based on researchers have proposed that an isolated platform using the IoT which can be used to control the various aspects of solar PV framework operation including humidity and ambient temperature, voltage, and current levels of the solar PV frameworks. The cloud platform is used to store, process, and display this monitored data [44].

The most difficult problems that modern scientific and engineering systems will encounter can be resolved through IoT. The PV system, which is used to generate electricity, consists of a number of components, each of which operates differently [45]. More specifically, SR fluctuates with time and is dependent on weather which means powe cannot be continually generated during framework operation [46].

Perovskite solar cells (PSCs) have gotten better at what they do over time. For interior applications, solar PV arrays are utilized to generate power using IoT devices. This work builds a continuous IoT device that uses a standby battery to power a perovskite solar PV framework [47].

Indirect effects also extend to other components such as voltage levels of power converters, the state of charge of the battery and the energy demands of the load. Sometimes, the PV system may not perform well due to dust buildup and other environmental factors, leading to long-term system failure. It can be difficult for humans to keep track of these failures. Thus, they must visit the plant location regularly and maintain a log of the operating data. This task becomes even more challenging when the plant is located far away. Humans must therefore invest a great deal of time and energy in resolving these problems, and occasionally their incapacity stems from a lack of understanding of the frameworks's malfunction (or subpar operation). A continuous monitoring framework that records system parameters and stores them on a cloud platform should be included with the solar PV framework in order to address these issues. The performance of the framework and the reasons behind any deficit can be understood using the recorded data, facilitating troubleshooting and maintenance procedures as needed. IoT is essential for remote configuration optimization and monitoring of system performance.

Three levels make up the IoT architecture for PV framework management:

1) The first layer is the design environment of the solar PV framework, the second layer is the gateway linkage, and the third layer is the remote monitoring and control layer. Figure 2 depicts the IoT architecture for the solar PV framework management.
2) The initial layer is the design environment for the PV framework, and every component was connected in line with the required setup to fully satisfy the user's needs. In this case, the parts of the PV frameworks are connected to the Arduino server which is the second layer of the IoT structure.
3) Using a router equipped with an internet firewall feature, this second layer, sometimes referred to as gateway linkage, links the web server and the hardware designs of the solar PV frameworks. An ethernet (or wireless router module) can be integrated with the web server primarily using the Arduino server. The hardware components of the solar PV framework are operated and controlled by the Arduino server's micro-controller.
4) The data will be sent from the server to the third layer which is the remote monitoring and control layer. The collected solar PV framework data will be sent by the server to storage devices to produce reports regularly.
5) The data is available to users in the form of reports (or visual graphs) through the Android interface and the cloud through a Wi-Fi network.

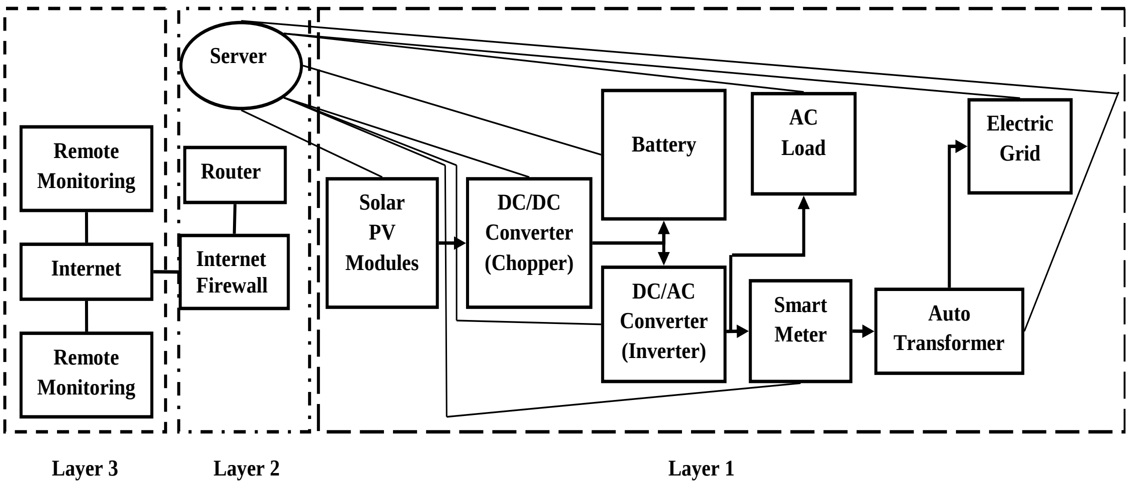

Figure 2. Proposed block diagram of an IoT based PV framework management

3. COMPARATIVE ANALYSIS OF IOT BASED SOLAR PV FRAMEWORKS MANAGEMENT

An IoT application for a PV system would involve using sensors and connected devices to monitor and control the performance of the system. Some examples of how this could be implemented include:

- Using temperature sensors to monitor the temperature of the PV panels and using this information to adjust the angle of the panels to optimize their efficiency.
- Using weather forecasts to predict when clouds will block the sun and adjusting the output power of the framework accordingly.
- Using sensors to monitor the output of the system, and sending alerts to the homeowner or maintenance team when something is not working correctly.
- Using a mobile app or web portal to allow the homeowner to monitor the performance of the system and adjust settings such as the power output or the angle of the panels.
- Connecting the system to the smart grid, allowing it to feed excess energy back into the grid during times of high demand and drawing energy from the grid during times of low solar output.

In general, the IoT application for PV systems is to improve the efficiency and reliability of the framework, as well as provide the data to help the owner who operates the system more effectively. IoT provides greater monitoring and controlling choices for all the works than human control (or human inspection) of solar PV frameworks. Therefore, it is important to encourage the use of IoT in PV array for prospective business analytics and a better knowledge of the system over time. Information on IoT utilization in PV frameworks used for different purposes is provided in Table 1.

IoT is a fast-developing technology which controls the various MPPT systems management for constant PV power production. It monitors the performance of the PV systems by a remote device in real-time with IoT technology. IoT-based MPPT technique produces the maximum power from the PV array under variable weather conditions like SR and abundant temperature. It also enhances the efficiency of the PV framework using various MPPT systems. IoT-based systems can used to significantly improve maintenance and management in solar PV arrays. Using this technology, to detect and diagnose framework problems early and proactively maintain through sensors and IoT systems before a failure takes place. IoT technology provides better performance in the PV system under modifications in the forecasting. In this regard, it helps to find the maximum output power production from the PV panels. To produce renewable energy in the future, it is a technology that merits investigation.

Table 1. Information on IoT utilization in PV frameworks management

Reference	IoT application in PV frameworks	Device used as micro-controller	IoT platform/remarks
[41]	System for managing home energy using dynamic home area networks	A 16-bit micro-controller is used in the proposed prototype	ZigBee
[40]	PV system remote monitoring and management	PIC micro-controller (PIC18F46K22) is used	ZigBee (250 Kbps)
[42]	Solar power conversion system	Arduino UNO R3	ZigBee
[44]	Solar manager application for monitoring data visualization	Arduino Mega	Xbee Modules
[48]	Lifetime solar panel detection	Arduino Uno	Wi-Fi Module-ESP8266
[43]	Optimization of output response of PV panel under partial shading conditions	Arduino Uno	Thinkspeak is used as IoT platform
[49]	Controlling of light intensity and PV power management	Arduino Uno	Thinkspeak is used as IoT platform
[50]	Inspection of solar PV arrays	DSP-TMS320F28335	ZigBee (IoT platform)

4. RESEARCH TRENDS

The investigation described above produced the following points:

- IoT simplifies the difficult task of regularly visiting the plant site, gathering performance data, and looking for flaws.
- The time spent interacting with computers and other people while monitoring the PV system will be reduced with the use of IoT.
- With minimal effort, IoT enables the detection of defects in solar PV frameworks and the root causes of subpar performance.
- IoT enables the analytics for predicting and projecting the potential for generating the power by providing the continuous recording of performance data and failure data. It also eliminates the need for PV system maintenance regularly.
- IoTs will be essential for gaining access to control over PV systems that are situated in remote sites (or far from the control centre).

5. CONCLUSION

In this paper, the IoT-based MPPT controoler for solar PV systems has been studied and analyzed. Because there are not enough traditional resources available, there is an energy crisis. Governments and numerous organizations are looking to SE as a workable solution to this problem. It is not only an unrestricted, free source of energy, but it is also safe for the environment and can be used on vacant land. Solar power plants can be remotely accessed and continuously monitored by the IoT and machine learning. In the method described above, a PV system must be designed, analogue circuitry must be built for accurate voltage and current readings, and a web server must be constructed to display the monitored data in an approachable manner. With an internet connection, the web server can be accessed from anywhere in the world, enabling effective management and increased power production. In order to enhance the efficiency of power production, servomotors can be used to control the rotation of solar panels using IoT-based AI and machine learning.

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BIOGRAPHIES OF AUTHORS

Dr. Mohammad Junaid Khan is working as a Post-Doctoral Researcher at UniSZA, Malaysia and Assistant Professor in the Department of Electrical and Electronics Engineering, Mewat Engineering College (Waqf), Nuh, Haryana (Haryana Waqf Board, Government of Haryana). He has more than 12 years of experience in teaching and research. He has been awarded the following awards such as 1) Best Paper Award, IEEE CENCON 2023 at Imperial Hotel Kuching, Kuching, Sarawak, Malaysia. 2) Outstanding Scientist Award, ScienceFather (Scifax company, Reg. No. 130116, Approved and Registered by Ministry of Corporate Affairs (MCA), Government of India). 3) Best Paper Award in International Conference at RPIIT, Karnal, Haryana. 4) Best Young Scientist at ITSR Rajasthan. 5) UGC Fellowship under MANF Scheme. He was selected for the Institute Post-Doctorate Fellowship (IPDF) at IIT Guwahati. He has granted 01 Indian patent and 04 patents filed and published in IPR. He has published 57 research articles in reputable international journals and conferences. He has also published a book and three chapters in international publishers. He completed four projects in favour of conferences and workshops, sanctions by HAREDA, Government of Haryana. He has organized many events such as conferences and workshops. He is a member of different technical committees and professional societies. He can be contacted at email: mohammadjunaid@unisza.edu.in.

Md. Naqui Akhtar received his Master of Engineering Degrees in Electrical Engineering (Instrumentation and Control Engineering) from National Institute of Technical Teacher's Training and Research (NITTTR), Panjab University, Chandigarh, India and B. Tech. Degree in Electrical Engineering from National Institute of Technology (NIT), Jamshedpur, Ranchi University, Jharkhand, India. He is currently working as Lecturer, Department of Electrical Engineering in Government Polytechnic, Sahibganj, Under the Control of Department of Higher and Technical Education, Government of Jharkhand, Ranchi, India since April, 2021. It is guided by Jharkhand University of Technology (JUT), Ranchi, India. He is having 12 years of teaching experience and 03 years of administrative experience, worked as Assistant Director, Department of Science and Technology, Jharkhand, Nepal House, Doranda, Ranchi. He has one year of Industrial Experience in Ambuja Cement Limited Bhatapara Unit, Raigarh, Chattishgarh, India. He has done his M. Tech research work on NN based hybrid model for the detection of maximum power point tracking in PV system. He has published 02 research articles in reputed international journals. He can be contacted at email: naqui.nit@gmail.com.

Afroj Alam is an assistant professor in Computer Science and Engineering dDepartment in Presidency University Yelahanka, Bengaluru, Karnataka 560064. He has overall 14+ years' experience in the field of Academics. Currently also he is a Ph.D. Scholar in Integral University Lucknow India. His area of research in on data mining technique with machine learning algorithm in smart healthcare for prediction of disease. He is actively involved in research activities and have published over 12 research articles and book chapters in refereed international journals, five papers of them in Scopus indexed. He has done his Master and Bachelor degree in Computer science. He can be contacted at email: alamafroj@gmail.com.

Associate Prof. Dr. Asyraf Afthanorhan is a distinguished academic who commenced his tenure at Universiti Sultan Zainal Abidin (UniSZA) in October 2018. Since October 2021, he has served as the Deputy Dean for Research and Development, demonstrating his leadership and commitment to advancing academic research. He boasts an impressive publication record, with over 120 research papers to his name. Notably, more than 80 of these papers have been indexed in prestigious databases such as Scopus and Web of Science (WoS). Additionally, he has authored 3 books and contributed 4 chapters to collective volumes, showcasing his expertise in his field. In terms of research grants, he has secured a remarkable total of 30 grants, with 6 of them appointing him as the principal investigator. These grants encompass various sectors, including governmental, industrial, and academic, highlighting his versatility and collaborative spirit. His contributions extend beyond publications and grants, as evidencedby his 5 copyrighted works. Moreover, he dedication and excellence have earned him 38 awards at the faculty, university, national, and international levels, underscoring the recognition and esteem he commands within the academic community. Furthermore, he has shared his expertise through consultancy services to more than 10 universities, organizations, and industries. This extensive consulting experience reflects his commitment to knowledge exchange and practical application of research findings, benefiting both academia and society at large. He can be contacted at email: asyrafafthanorhan@unisza.edu.my.