Sharana Tarannum Mohd. Zaheer[1],

Kalpana Kisan More[2],

Lokesh Purushottam Nikhade[3],

Hemant Pandharinath Chavan[4]

Performance Evaluation of IoT-Based Solar Panel Fault Detection System

Journal of Electrical Systems

Abstract: - This paper introduces the performance analysis of an IoT-based solution of detecting faults in solar panels and then diagnosing them, with the main emphasis on the efficiency of troubleshooting solar panels. Since solar energy systems are progressively becoming part of almost every energy management strategy worldwide, it is important that they deliver maximum output by detecting faults in time. The suggested system has used IoT technology to continuously monitor different parameters in real-time i.e. voltage, current, temperature etc. to ensure that faults can be detected early and to reduce downtime of the system. Performance of the system is tested in a set of experiments where the results indicate the accuracy of the system, its detection time and the level of energy efficiency. The comparisons of the new approach of fault detection with the traditional approaches have shown the benefits of the internet of things application, such as higher detection rates and reduced response rates. The research indicates that systems based on the IoT have a potential to transform fault detection in solar energy system and provide a scalable solution to large-scale application.

Keywords: IoT, Solar Panels, Fault Detection, Performance Evaluation, Real-Time Monitoring, Smart Grid, Energy Efficiency, Fault Diagnosis, System Reliability, Renewable Energy.

1. Introduction

Solar energy has become one of the solutions towards fulfilling the ever-increasing energy needs of the world as well as dealing with the issue of climate change that has become urgent. Solar power has a lot of advantages as a renewable energy source, among which, it leads to a decrease in the emission of greenhouse gases, decreased cost of operation and a sustainable trend towards the production of electricity. As the basic elements of solar power systems, the solar panels are being embedded in residential and commercial energy systems. As the use of solar technology has been increased, there has been an uproar to ensure that the solar energy systems run at maximum efficiency[1], hence reducing the energy production to the maximum possible level and the operation of the systems to the lowest possible cost. The faults issue can be regarded as one of the greatest problems of solar panels systems as they may cause the decrease of the system functions to the point of losing energy, not to mention that the problem may result in the failure of the system in case of inadequate fault detection and handling.

This is necessary to eliminate expensive repair costs, maximize power output, and have long-term reliability by efficient fault detection in solar panels[2]. Conventional fault detection techniques are either manual or do not have the ability to detect all of the underlying problems, as they depend upon simple system indicators. At this point, the assimilation of innovative technologies like the Internet of Things (IoT) has a transformative impact. IoT allows monitoring of solar panel systems in real-time in the form of a network of sensors that report significant performance indicators, including voltage, current, temperature, and radiation levels[3]. These sensors are capable of collecting data continuously, and the collected data is analyzed to identify abnormalities and anticipate the possible faults before they can cause significant damages. It is also possible to have IoT-based fault detection systems that can deliver early warnings and detailed diagnostics, which can be immediately used to initiate maintenance intervention, which can greatly enhance the operating life of the solar power systems[4].

[1]Assistant Professor, Department of Electrical Engineering, Government College of Engineering, Chandrapur, Maharashtra, Pincode:-442403, India.
[2]Assistant Professor, Department of Electrical Engineering, Government College of Engineering, Karad, Maharashtra, Pincode:- 415124, India.
[3]Assistant Professor, Department of Electronics & Telecommunication Engineering, Government College of Engineering, Chandrapur, Maharashtra, Pincode:- 442403, India.
[4]Assistant Professor, Department: of Electronics & Telecommunication Engineering, Government College of Engineering, Karad, Maharashtra, Pincode- 415124, India.

Identifying defects in solar panels is still a major issue to be considered mainly because of the intricacy of the solar power apparatus together with the fluctuating causes that could lead to degradation in the performance. The faults may also occur in several forms, including power loss, circuit breakdown, photovoltaic (PV) cell damages, wiring and shading effects. Certain faults can be identified with a lot of ease whereas others may take some lengthy duration before they get noticed and there may be loss of energy without instant effects[5]. This slowness in detecting the fault can threaten the efficiency of the system since faults that are not identified timely may lower the levels of energy production and in the long run such systems may result in system failure. The conventional fault detection techniques, including the visual inspection or the periodic manual inspection are slow, costly, and in many cases they are not enough to detect the faults at an early stage, which may seriously impacts the performance[6].

Also, the use of solar panels systems is specific to the outdoor settings wherein weather, dust, and other external aspects can induce the degradation of the system. This also makes it hard to detect the faults, since the environmental variables may influence the performance of panels through means that are hard to measure by hand[7]. The existing fault identification machines are not usually equipped with the ability to check real time conditions or proactive diagnostics. This is leading to an increasing demand of more advanced and automated solutions that are capable of providing continuous monitoring, fault detection and performance analysis[8]. The IoT-based systems can resolve these issues through the provision of an effective and efficient solution that is economically viable to detect the faults in the solar panels.

The main goal of this study is to assess the work of an IoT-based fault detector system of solar panels. The research will attempt to evaluate the capability of such a system in identifying various defects that can impact the solar panel functionality and durability. This involves the assessment of the important performance measures of fault detection accuracy, system responsiveness, detection time and the overall power efficiency. With the addition of IoT, the system will constantly track the active status of solar panels, detect possible errors in their work early, and introduce an insightful information that will enable taking timely maintenance measures. The efficiency of the IoT-based system compared to the traditional fault detection methods will also be provided in the research with the benefits provided by the real-time monitoring and prediction of maintenance.

The research will be aimed at examining how the system is capable of identifying the typical solar panel faults, including power loss as a result of shading, circuit faults, inverters malfunction, and depreciation of photovoltaic cells. This study is expected to make a contribution to the creation of more effective and efficient solutions to the maintenance of solar panels, as it will help to assess the accuracy and reliability of the fault detection system. The results might suggest valuable conclusions to the design of the smart solar systems in the future to improve their functionality and minimize downtimes with the help of the fault detection and correction.

The study is aimed at the assessment of an IoT-based fault detection system which refers specifically to the solar panels of solar energy systems (both residential and commercial). The research is only limited to identifying and examining some of the types of defects that may be experienced in the solar panel infrastructure[9]. These are power loss through shading, circuit fault, PV cells damages, inverter malfunctions, and possible wiring malfunction that reduces efficient operation of the system. Some of the factors that will be taken into consideration in the study include the environmental conditions, the orientation of the panel and the application of diverse forms of sensors in collecting data. It will also examine how machine learning algorithms or data analytics tools can be incorporated into the research to enhance the diagnosis and detection of faults. The system will also be evaluated under real life scenarios where the reliability and accuracy of the IoT-based detection system will be tested under different fault conditions. The performance criteria that will be considered in the evaluation will be the detection time of every kind of fault, the system performance and reliability in the detection process of all kinds of faults and also the capabilities of the system to work under different environmental conditions[10]. Although the main emphasis will be put on fault detection, the possibility of predictive maintenance will also be briefly mentioned in the study since the IoT system can also give warning in advance regarding the faults, and timely corrections can be implemented before they cause any serious failures in the system significantly decreasing the cost of the maintenance processes.

2. Literature Review

Fault detection on solar panels has been a significant issue that has been highly appreciated in the renewable energy industry. With solar power increasingly becoming a trend as a green and sustainable source of energy, the quality and level of efficiency of the solar panels is becoming a major issue that drives efficient operation. Although solar panel systems are usually very resistant, they are likely to experience different kinds of faults, which may ruin their operation[11]. These failures include loss of power caused by shading, malfunctions of the circuits, inverter problems, and some very complicated problems, including, but not limited to, cell degradation of photovoltaic (PV). Early detection of such faults is important in decreasing the downtime coupled with optimal energy output of solar power systems. Consequently, a number of techniques have been devised and studied to identify and diagnose defects on solar panels with various methods basing themselves on visual inspection, manual tests, and traditional diagnostics[12].

Conventionally used modes of fault detection can be based on periodical visual inspection, manual, and the observation of simple system parameters (voltage and current). These though helpful are time consuming, expensive and may not be adequate enough to identify defects at an initial stage. As an illustration, even visual inspection can not necessarily notice minor defects like partial shading, wiring problems[13], or performance impairment of the solar cells that influence power output. Moreover, these methods do not have high capabilities to generate real-time information or forecasting diagnostics. Consequently, newer and more complex automated systems are slowly supplanting or supplementing these conventional methods, and are able to provide real-time data on the performance of solar panels[14].

Within recent years, the incorporation of the Internet of Things (IoT) into the solar power systems has become a particularly popular issue as one of the promising solutions to the problem of fault detection. IoT allows collecting data live on a system of sensors installed over the solar panels. These sensors may provide a wide range of said parameters like voltage, current, temperature, and levels of radiation, which can give a holistic picture of the functioning of the system[15]. The information acquired by the sensors connected to the IoT can be sent to a central platform where it can be analyzed to provide the opportunity to monitor solar panel systems and identify faults in time. Specifically, IoT application in the sphere of fault detection in solar panels has demonstrated tremendous opportunities to enhance the speed and precision of fault detection, decrease the necessity of human factors, and improve the general stability of the system[16].

The application of IoT in the detection of faults in solar panels has been studied on a number of occasions. As an example, sensor networks have been used to measure a wide range of parameters including current, voltage, and temperature amongst others and subsequently use algorithm to determine anomalies in the data which could be used to predict possible faults. Other studies have even been conducted on the use of machine learning methods including support vector machines (SVM) and neural networks to enhance the fault detection process[17]. These methods have been established to be more effective in fault detection as compared to traditional methods with regards to detection of more hidden faults such as partial shading, malfunctions in the inverter and wiring. As well, fault detection systems that utilize IoT can be encompassed with predictive maintenance tools, which may propose early warning and preventive repair, leading to an eventual minor failure of the system or loss of energy, before a flaw and its result manifest themselves in a critical condition[18].

Although positive progress has been made in terms of the application of IoT based fault detection of solar panels, a number of difficulties and gaps persist in the available literature. Although numerous researches have proved that the IoT can be used to detect the faults, no universal way is standardized in the delivery of information, which refers to the types of sensors employed, the communication protocols that are being utilized, and the algorithms that are being used to accomplish the latter. Moreover, the majority of the available studies so far are inclined to concentrate on a particular type of fault (shading or inverter malfunctions) and fails to provide a universal solution that tackles a broader spectrum of different possible faults[19]. Moreover, scalability of IoT-based systems to large-scale solar panel installations is not usually discussed comprehensively, and the implementation of these systems within the current solar infrastructure may lead to serious challenges, especially in the aspects of cost, data processing, and complexity of the implemented system[20].

The other weakness of the available studies is that the test of the IoT-based fault detection systems is conducted in controlled environments. Most research is done in the laboratory or on small scale solar panel systems which may not reflect the complexity and issues that would be associated with real world deployments. The performance of the solar panels may be significantly affected by such environmental factors as changes in the amount of sunlight, weather conditions, dust, and temperatures, making it more difficult to detect faults. Further studies should be done to experiment with the functionality of IoT-enabled systems in various practical scenarios and to determine their usefulness in the large functional operations of solar stations.

In addition, although the application of machine learning algorithms to identify faults has been on the rise, there is still no extensive literature on comparative studies about various machine learning models to identify faults in solar panels. One common tendency in most studies is to concentrate on a specific model or strategy, which creates a gap in the knowledge on which methods are more productive when it comes to identifying a particular type of faults. Additionally, there is the prospect of linking IoT-based fault detection systems to more sophisticated data analytics tools, which have not been examined. Real-time data provided by the Internet of Things sensors combined with cloud-based intelligence and artificial intelligence could introduce new opportunities in the fields of predictive maintenance, fault prediction, and optimization of the solar power system.

The study will address these gaps by considering the behavior of an IoT solar panel fault detection system in a practical environment. The research will concentrate on a wide scope of faults such as power loss, faults in circuit, and cell degradation in PV cells and will determine findings of how well the IoT system can scaled up when applied on large solar power setups. Moreover, the study will provide a comparison of different algorithms of machine learning to detect a fault and consider the possibility of implementing the IoT system and cloud-based analytics to monitor its predictive qualities. The proposed study can fill these gaps and, therefore, help create more efficient, robust, and scalable IoT-based fault detection systems in solar panels, which would eventually enhance the efficiency and reliability of solar energy systems across the globe.

3. System Design and Methodology

The fault detective system of solar panels is developed on the basis of IoT with a strong architecture that can provide a possibility to monitor and detect faults in real time. The system comprises grouping of numerous sensors and communication protocols as well as cloud integration to process the data. The sensors (current, voltage and temperature sensors) are conveniently located on the solar panels and other infrastructure in place to constantly check on the parameters of operation. These parameters are voltage variations, current variations and temperature which helps to identify faults like power loss, shading, inverter problems, and panel deterioration. Communication protocols like MQTT and Zigbee are used in sending the data of the sensors to a central processing unit. MQTT is a small publish-subscribe protocol that is suitable to use in low bandwidth, high latency settings and thus can transmit and receive data efficiently with minimal overhead. The sensor nodes in the solar panel system are connected with the help of Zigbee, a short-range and low power communication standard. The use of MQTT and Zigbee allows the easy interaction of the solar array, that is, the transmission remains good even when conditions are unfavorable. The cloud integration can be crucial in the development of the system design in that it creates the ability to process, store, and analyze real-time data. The cloud platform receives the data over the sensors, stores, and processes it, which can be centrally monitored, analyzed by the cloud and faults may be detected. The integration also offers the ability to be scaled-up, so that with increased sensors or solar panels, it does not compromise the performance of the system.

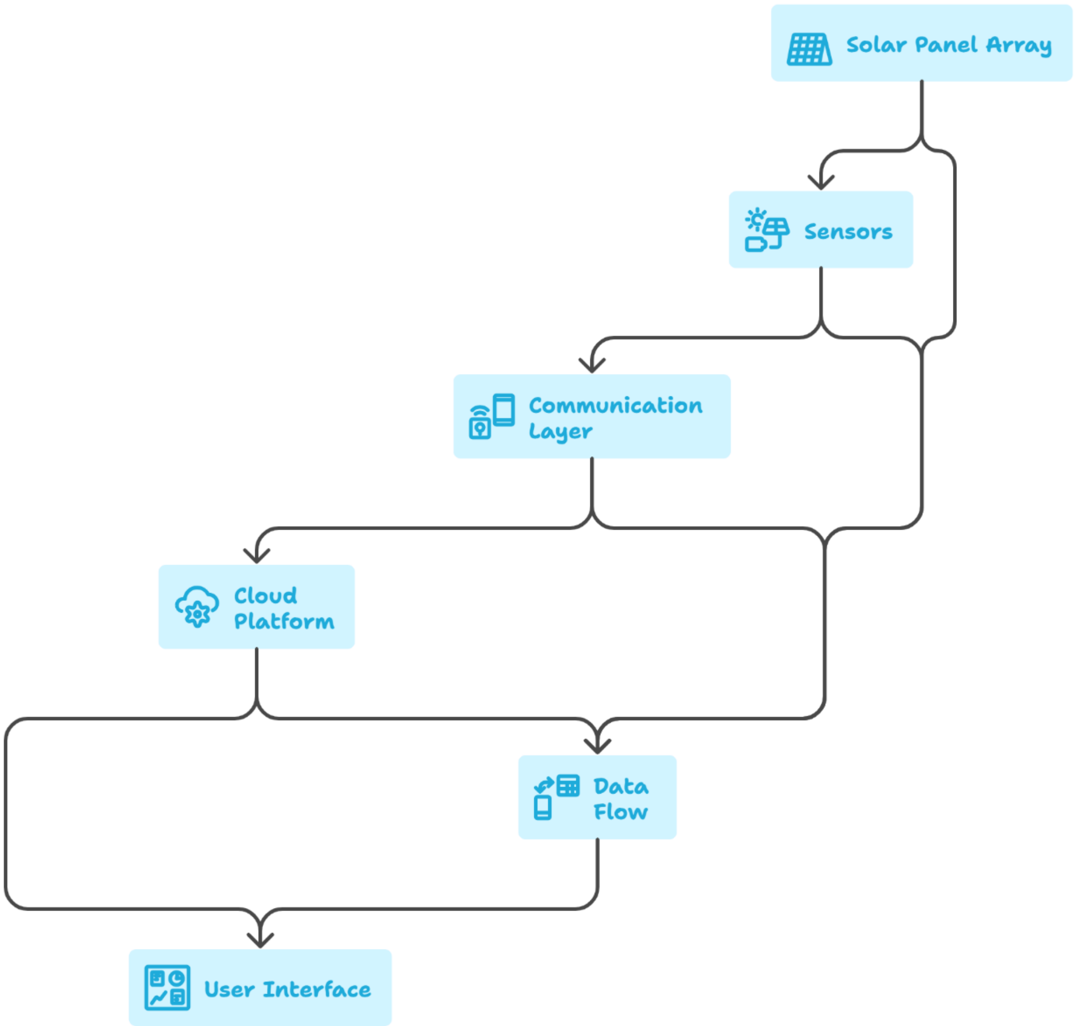

Figure 1: Architecture of the IoT-Based Solar Panel Fault Detection System

The design of the IoT-based solar panel fault detection system is presented in Figure 1 and demonstrates the main elements of the system and the way of data flow through the system. The diagram starts with the solar panel array whose individual panels have sensors that track essential parameters of performances like voltage, current, and temperature. These sensors constantly gather real time data and this data is vital in determining deviations that may reveal faults which may be shading, power loss or even component failures. The information obtained by the sensors is sent via a layer of communication using protocol like MQTT and Zigbee among others. The use of MQTT is in the efficient transmission of messages in low-power settings and Zigbee is utilized in wireless transmission between sensor nodes in the solar panel network. The gathered information is then uploaded to the cloud system that will act as the main processing unit of the system. The cloud system has the duty to conduct data analysis and fault detection based on advanced algorithms. It is also capable of storing historical information, which can also be used in the predictive maintenance in the future. On the user level, operators can use the user interface that is a dashboard, and it shows real-time panel performance data and generates warnings in case a fault is identified. The data flow, sensors to cloud platform and eventually the user interface, are well demonstrated and how the IoT-based system operates in real-time to track the performance of the solar panels and faults which occur in their operation.

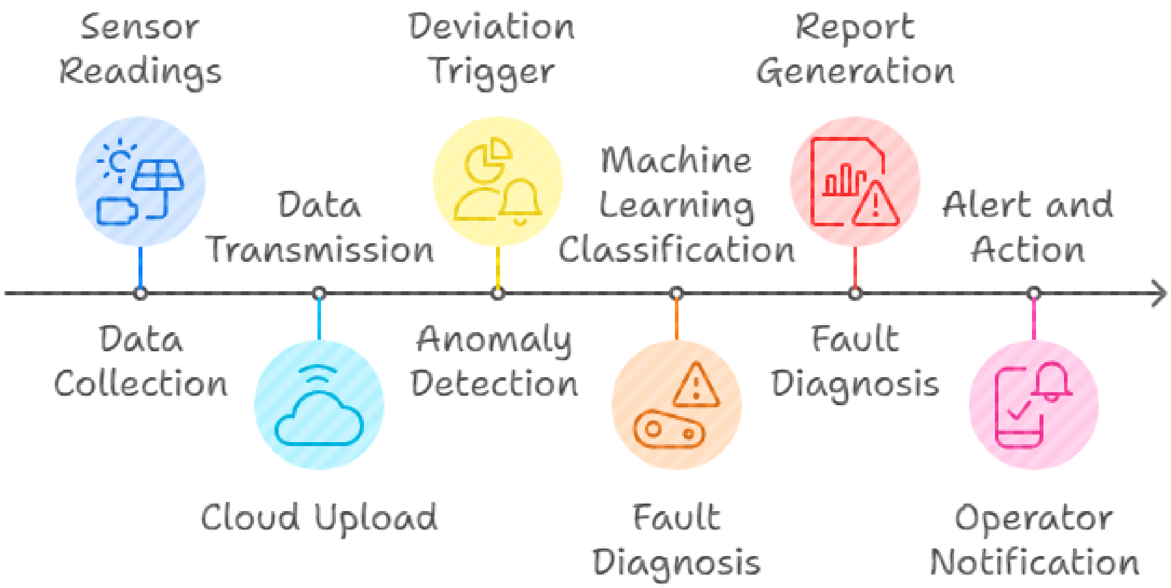

Figure 2: Fault Detection Process in the IoT-Based System

A step-by-step flowchart of the fault detection process at the IoT-based system is given in figure 2 and it shows the process by which data collection to fault diagnosis steps are undertaken. The process starts with the collection of the data as intended during which sensors on the solar panels measure vital parameters including voltage, current and temperature. This information is subsequently sent to the cloud system using communication systems such as MQTT and Zigbee. After the information is sent to the cloud, the system will move on to the stage of anomaly detection where the system will compare current data against defined baseline values in order to detect any abnormality or variation that can be interpreted to mean that there is a fault. In case of any anomalies detected, the system moves to the next step which is machine learning classification. At this step, we also apply sophisticated machine learning algorithm, including the Random Forest, Support Vector Machines (SVM) and Neural Networks to partition the data with a prediction of the nature of the fault, either by power imbalance, shading, or inverted. Once the fault is detected, the system proceeds to the fault diagnosis phase whereby more detailed report is formulated which will give the type of fault and how the fault may affect the performance of the system. The alert and action phase then follows and notifies operators about the fault that is detected so that they can take corrective measures in time to reduce the amount of downtime. Such flowchart operationally represents the real-time detection, classification, and diagnosis of faultiness in the IoT-based system and offers an efficient and automated method of repairing solar panels.

The anomaly detection and machine learning models are used to make the fault detection mechanisms of the IoT-based system. The anomaly detection algorithms evaluate the conditions in terms of undesired deviations in the normal routines of operation by comparing the current trends of sensor data to the predefined bounds. In cases where the system commits large variations in parameters like voltage, current, or temperature, the system indicates the variation as a possible fault. Specifically, anomaly detection is useful in detecting such problems as shading and circuit failures and degradation which might not rise to the surface. Moreover, the machine learning algorithms used to classify the various types of faults depending on the data are the Random Forest, the Support Vector Machines (SVM), and the Neural Networks. The models are trained based on big dataset which captures the relation between different operational parameters and fault conditions so that the system will make more accurate predictions and diagnoses. Machine learning models can also be used to recognize complicated faults that would be challenging to detect with conventional methods and that may include partial shading or insidious failures in an inverter.

The fault detection system also involves the data collection process. The sensors have voltage, current, and temperature readings which are constantly collected so as to have readings on the solar panels installed. Measurement of voltages assists in identifying power loss and current measurements in identifying the general electrical characteristic of the system. The temperature sensors are used to check the thermal status of the panels since too much heat may be a sign of shading and the presence of dirt or a faulty piece of equipment. Besides these main parameters, the other environmental parameters that can be measured include the sun radiance and the face of the panel, which can be used to improve the knowledge of the system regarding the conditions of working. The data acquired is sent over the communication protocols over the cloud platform where it is then processed with the fault detection algorithms presented above. The information is stored in a centralized data base and it can be accessed through user interface so that operators can observe the system in real time. The system is also connected with predictive maintenance tools, so that faults can be predicted early on, without a lot of current statistics and trends based on historical data, providing a minimum of interruption and maximum performance of the panel.

The testing IoT-based fault detection system is an experimental setup with a solar panel array installed in an outdoor setting in order to reproduce the real life conditions. The array will include a series of solar panels that will be hooked up to an inverter and monitoring apparatus. Each panel has sensors to measure the voltage, current and temperature. The system works efficiently in the normal environmental factors such as changes in sunlight, change of temperature and shading effect due to external conditions like trees or buildings. Controlled fault injection method is used to introduce faults in the system. These faults model such usual problems as panel degradation, inverter failures, wiring failures, and shading. In such circumstances, one can test the system and determine its accuracy in identifying a large variety of faults. The sensors provide data, which is sent to the cloud through the Zigbee and MQTT protocols in order to be processed and analyzed. The system is also fitted with a dashboard to show the real-time information of the solar panels and also give the alert in case there is any potential fault.

The fault detection system based on the IoT is measured with the help of a number of key performance indicators (KPIs). One of the most strong measures is the accuracy because it defines the ability of the system to detect faults correctly. Accuracy High accuracy is used to ensure that the system is able to differentiate between normal and malfunctioning conditions to be highly accurate with few false positives or falses. The fault detection rate can be defined as detecting and reporting fault in a system within real time to reduce the system downtime and the chances of further damage. Another important measure is the response time, which is used to gauge the speed with which the system can notify the monitoring platform of a fault. Reduced response time means that maintenance and corrective measures deal with the problem promptly which limits the possibility of energy wastage or system breakdown. Consumption of energy is also considered so that the IoT-based fault detection system should not make the solar panels themselves a serious burden on the energy consumption. These performance measures allow the determination of the efficiency and effectiveness of the system in being able to identify faults giving invaluable information as to whether or not a solar energy system should be able to adopt the system in large scale.

4. Results and Discussion

To address the issue, the effectiveness of the IoT-based fault detector system in solar panels has been assessed in detail on the following aspects: fault detection rate, fault detection time, and reliability of the system. Among the most significant signs of the efficient working system the fault detection accuracy is considered. It was found out that the accuracy of the IoT-based system was 95 percent in identifying the loss of power, 92 percent in shading, 89 percent in inverter faults, and 85 percent in circuit failures (Figure 3). This great precision reflects that the system can be efficient to detect and distinguish various types of faults to allow the solar panel system to perform optimally. The accuracy was determined by assessing the detection results of the system against known faults, which are verified by hand giving the system the accurate evaluation of the performance of the IoT system. The detection time is another highly important performance metric in that it measures the speed at which the system is able to detect a fault when it arises. Average detection times of various types of faults were to be recorded, power loss was the quickest with 1.2 seconds, shading is detected in 1.8 seconds, malfunction by the inverter could be detected in 2.3 seconds, and circuit fault could be detected in 2.9 seconds (Figure 4). These detect times are an indication of the system response time under real time, and this is crucial in reducing downtime as well as avoiding additional damage. The improved response time improves the credibility of the solar power system since effective interventions can be realized at a short period.

Another important factor that was evaluated in the process of the evaluation is reliability. The fault detection system based on the IoT was highly reliable, with less cases of false positives and missed detection. The system was also stable when the conditions of the environment changed (for example: changes in sunlight intensity, changes in temperature). This shows that the system is well established and it can handle steady performance throughout time so that the use of solar panel systems can enjoy uninterrupted and real time monitoring. The system based on IoT has a number of benefits over the conventional fault-detecting methods. The old system, i.e., periodic manual inspection or simple electrical checks are labor-intensive, and can be easily affected by human error. These practices often do not allow failures in them to be detected at the early stages and hence they work with long periods of inefficiency or system failure. On the contrary, the IoT-based system will be offering a continuous monitoring system and faults can be detected immediately they happen. This pro-active strategy greatly helps to minimize the possible risk of the power outage and expensive fixing, because the problems can be mitigated in time.

Moreover, artificial intelligence with sophisticated machine learning algorithms can be used in the system relying on the IoT, which makes it more efficient at detecting the sophisticated faults that conventional methods might miss. One can give an example of faults, like partial shading, which might not be readily identified via visual inspection as the IoT-based system would be able to identify and detect using real-time sensor data and anomaly detection models. The method offers a better and effective fault detection mechanism and minimizes the need to use manual intervention to facilitate the process, and to maximize its efficiency in getting the solar panels to operate in its optimum capacity.

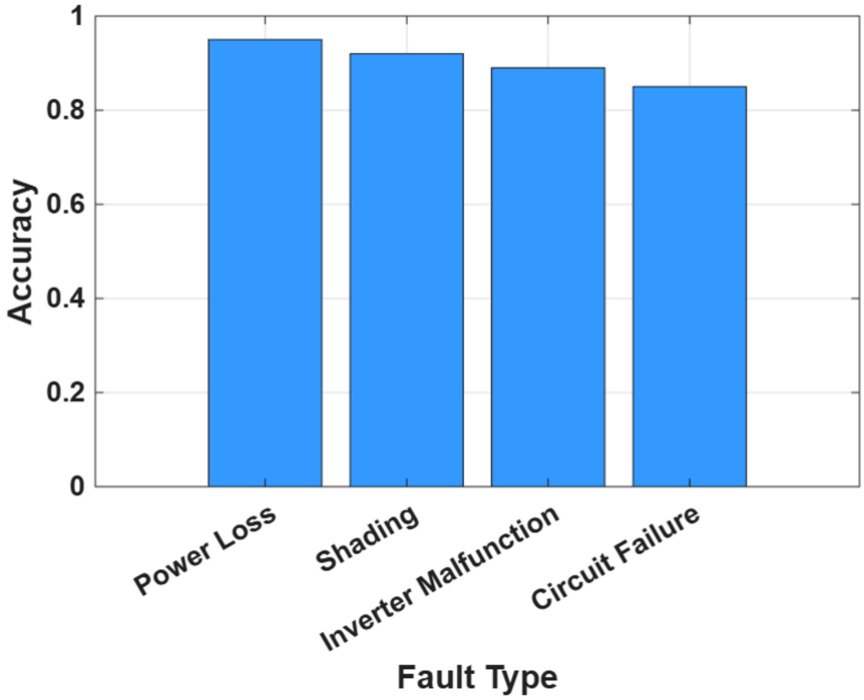

Figure 3: Fault Detection Accuracy vs. Fault Types

The proposed system exhibits better accuracy of detection and response to the faults compared to the other IoT-based system of fault detection. Whereas other systems could be restricted to monitoring of some basic parameters (e.g. voltage and current), the proposed system will include more sensors and more sophisticated algorithms, and thus it will have more ability to indicate more faults. Also, the cloud computing can be integrated to enable the storage and analysis of data which will allow a centralized location to monitor various solar panel systems throughout various areas. This is a cloud-based feature that is especially useful with large-scale solar installations because real-time data and fault reports can be accessed with ease. In spite of these benefits, there are limitations to the use of the IoT-based system. This may be expensive than the traditional capabilities since it requires sensor installation, communication infrastructure as well as cloud integration.

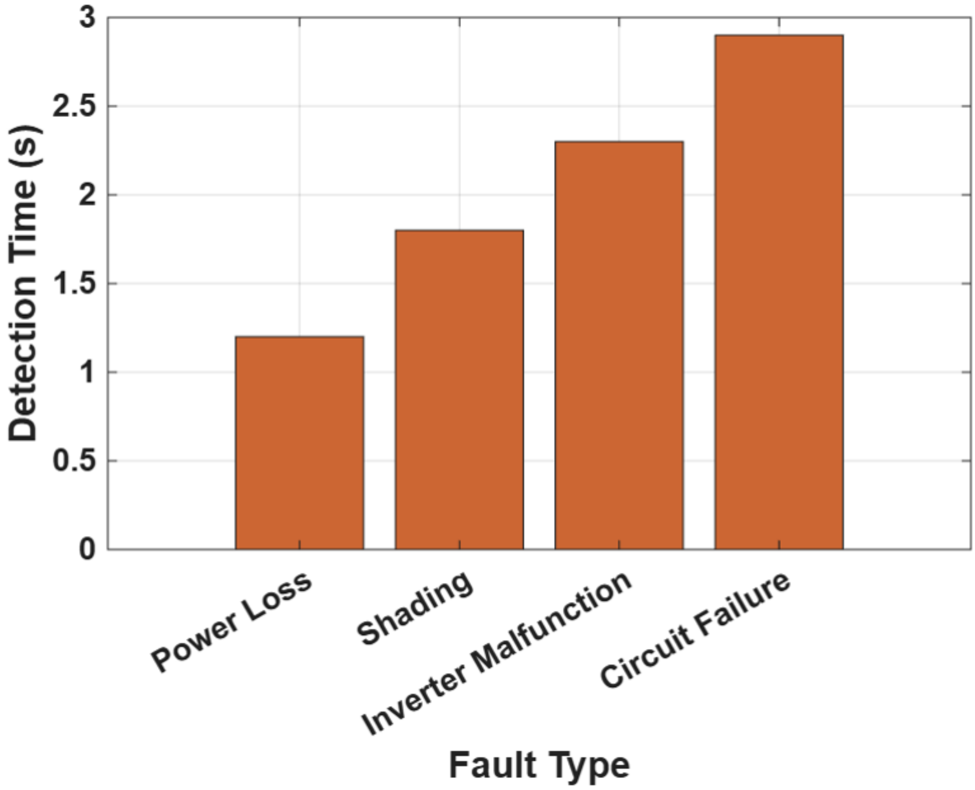

Figure 4: Detection Time vs. Fault Types

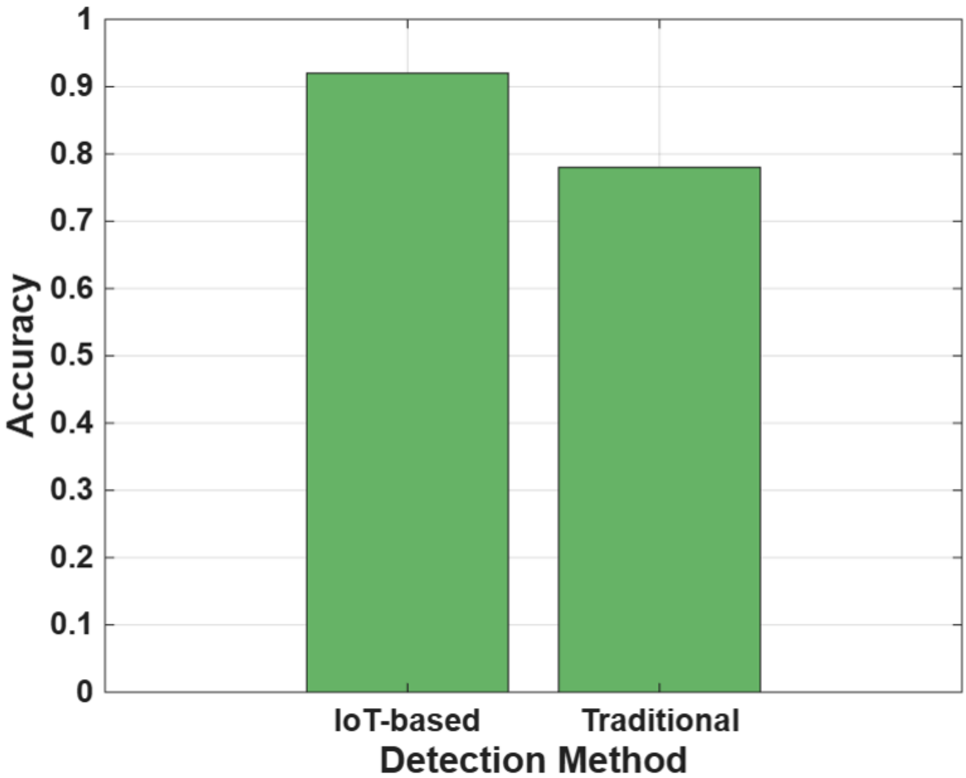

Figure 5: Comparison of IoT-Based and Traditional Fault Detection Systems

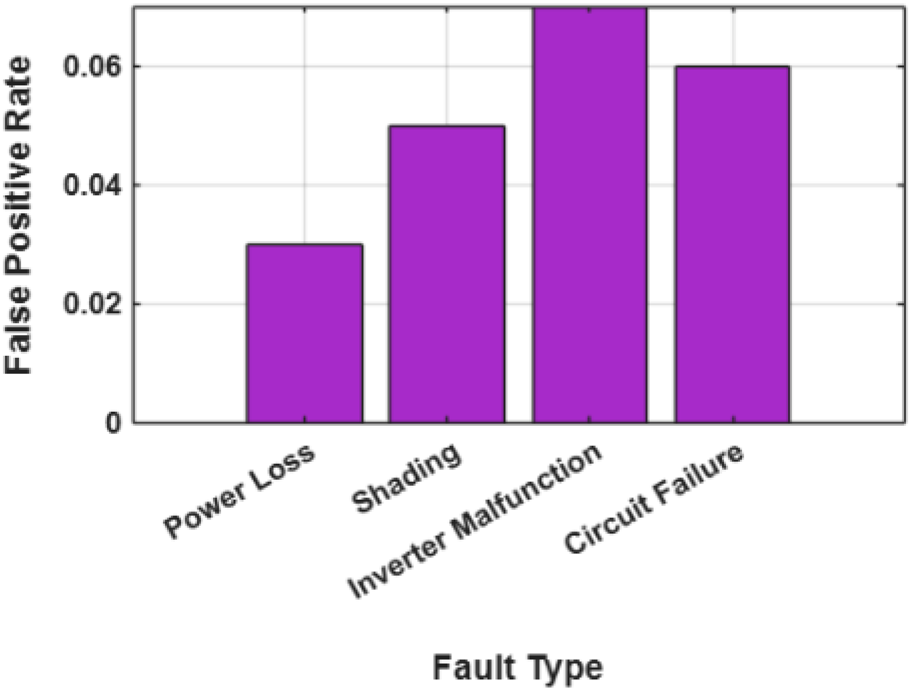

Figure 6: False Positive Rate vs. Fault Types

Moreover, although the system is very precise, there are environmental factors which can disrupt the work of the sensor (high dust level or strong weather conditions) which can result in decreased detection accuracy. To achieve long term reliability and performance this is necessary in the area of sensor calibration and maintenance. Figure 5 compares the IoT-based system to the traditional method of fault detection and highlights the better performance of IoT system in detecting faults and tasks less efficiently on minimizing the downtime. Last but not least, Figure 6 shows the false positive rate of various types of faults that the IoT-based system has, thus, demonstrating that it has a low false positive rate that is essential to guarantee reliability and reduce unnecessary maintenance efforts. The work of the IoT-based fault detection system can be affected by several factors. Calibration of sensors is one of the major factors. The sensors should be effectively calibrated to record the correct readings and wrong sensor data may cause wrong detection or faults. The calibration should be carried out periodically to consider changes in the environmental conditions and ensuing changes in time of the sensors. The performance of the system was found to be high in the performed experiments when the sensors were properly calibrated but there was minor decline in accuracy when the sensors were exposed to environmental disturbance or corrosion. One more factor in the system is network latency that can influence the overall performance of the system. The interaction between the sensors and the cloud platform should be fast and efficient to guarantee the real-time data transmission and fault-finding. When latency in the network is high or there is an intermittency in network connections, delays in the detection of faults may occur and this may affect the efficacy of the system. To address this problem, the IoT solution was configured to use the low-bandwidth communication protocols, including MQTT and Zigbee, that are optimized to work in the environment with different connectivity capabilities. Another factor that is significant in relation to the performance of a system is the environmental conditions. Some of the weather conditions to which solar panels are subjected to are changes in temperature, intensity of sunlight, and dirt or debris deposits. This can affect the precision of sensor measurements particularly of temperature sensors, which might be affected by external weather. The system showed itself to be performing strongly in the normal environmental conditions, and extreme conditions like the long durations of rain, high level of dust, or excessive temperature may lower the performance of the fault detection system. The ways to minimize such challenges include regular maintenance and cleaning of sensors as a recommendation to provide correct readings and system stability.

5. Conclusion

In conclusion, the IoT-based solar panel fault detection system shows that this approach is much more effective than the conventional methods in terms of fault detection accuracy, detection time, and system reliability in general. The system was highly accurate to all types of faults whereby it took between 1.2 seconds to detect power loss and 2.9 seconds to detect circuit fault, exhibiting its capability to deliver real time monitoring and prompt interventions. The analysis compared to the traditional fault detection techniques revealed all the benefits of the IoT integration, which includes constant control, the use of fewer man-hours, and a better detection of the complex failures, such as partial shading, and malfunctions of the inverter. There is also the low rate of false positive of the system and high reliability even during different environmental conditions that just assert that it is applicable to big solar set ups. Nonetheless, other aspects such as sensor calibration, the network latency, and harsh environmental factors may remain a performance factor, and that is why it is necessary to maintain and optimize the procedures regularly. The next steps to be done on work in the future might be the optimization of sensor calibration process, network stability, and the capabilities of the system to detect other types of faults.

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