Real-Time Fault Identification of Photovoltaic Systems Based on Remote Monitoring with IoT

Original Scientific Paper

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Abstract *– The increase in energy demand, as well as the need to protect the environment, has led to the promotion of new forms of generation, including photovoltaic energy. In this scenario, new challenges arise in the field of real-time monitoring of the characteristic variables of this type of system to determine correct operation. This paper presents the methodology of remote monitoring to detect faults in real-time in a photovoltaic system, taking advantage of the variables values that can be obtained from it, and estimating an operating state based on the behavior of these variables. The study used IoT technology for remote data acquisition, and by analyzing them, an estimate of the panel's operating status was made in real time by comparing the values of the variables registered. The study resulted in a real-time remote monitoring system that allows the estimation of the state of operation of a photovoltaic system and the classification of different types of failures that could occur in it. The study concludes that complex monitoring systems can be configured in real-time by technology based on IoT and with an adequate treatment of these variables, it is possible to estimate the photovoltaic systems' state of operation and identify electrical failures in them.*

Keywords*:* *Photovoltaic System, Faults, IoT, Electrical Variables*

Received: July 20, 2023; Received in revised form: December 24, 2023; Accepted: December 29, 2023

1. INTRODUCTION

The increase in demand for energy has caused the photovoltaic energy market to strengthen in recent years, in addition to this, a lot of research has been carried out to increase the efficiency of photovoltaic panels and batteries, thereby reducing the costs of the components of these systems, making the implementation of these generation systems increase their profitable. [1]. With this growth in photovoltaic generation, new challenges are presented for network operators and users who implement these systems, both for self-consumption and for distributed generation. These new challenges are not only related to the installations and the implications that this would present both to the external and internal networks but also to the possible failures that these systems would have in implementation for continuous use, affecting the security and reliability of the network. In this context, new monitoring techniques are necessary to visualize in some way the photovoltaic systems components state. [2].

In [3-5] a classification of all possible faults that could occur in a photovoltaic system is made, among which are those related to line-to-ground contacts, line-to-line contacts, faults due to short circuits, short circuits, etc. internal faults, open circuit faults, arc flash faults, hot spot faults, shading/partial shading faults, bypass diode faults, and degradation faults. Also, four basic principles of fault detection, model-based detection (MBD), real-time detection (RTD), output signal analysis (OSA), and a machine learning technique (MLT) are analyzed. Additionally, mathematical formulations of each failure are detailed, which may be useful for possible analysis of their detection with other types of techniques [3, 4]. In [5] a classification of faults is made according to their location in the photovoltaic system, these may be on the DC side of the system or the AC side. In addition, a failure detection technique is proposed based on the comparison between the results measured in real-time and the prediction results of the model of the efficiency of the photovoltaic array and the inverter to detect energy losses. If the values are lower than the predefined threshold, then the photovoltaic system is considered to be operating normally, otherwise, an anomaly is considered to be present in the system. System efficiency thresholds are established when the system is working under normal conditions without failure. In [6] a review of the multiple failures that could occur in a photovoltaic panel is carried out and a way of classifying them according to the nature of the failure is proposed, having in this classification of failures of physical, electrical or environmental causes. Furthermore, considering the bibliographic reviews carried out in the article, the main characteristics of some fault detection algorithms available for photovoltaic systems that have proven to be effective and feasible to implement are reviewed. The study presents an analysis of some fault detection techniques such as Model-Based Difference Measurement (MBDM), which compares real-time parameters with calculated model data based on the detected instantaneous irradiance and temperature levels to identify system failures. Real-time difference measurement (RDM), which compares real-time values with threshold limits defined based on photovoltaic models or real-time experiments. Output Signal Analysis (OSA) where analysis is applied to the output signal to identify faults, especially transients in the voltage and current waveforms. Machine learning techniques (MLT) where machine learning algorithms are trained to learn the relationship between the input and output parameters of a photovoltaic system and, based on this learning, identify faulty behavior. Infrared thermography (ITH) bases its analysis on the determination of a thermal imbalance in the panel structure; particularly due to the formation of hot spots as a result of some malfunction in the photovoltaic array. In this same way, there is the studio [7] where classification of the faults that can occur in the photovoltaic arrays is carried out and some advanced fault detection techniques analysis is carried out such as Comparison-Based Techniques (CBTs), Statistical and Signal Processing-Based Techniques (SSPBTs), Reflectometry-Based Techniques (RBTs) and Machine Learning-Based Techniques (MLBTs).

The reviews carried out on the monitoring techniques of photovoltaic systems show a constant evolution, from being manual to being carried out through automatic processes using advanced devices and complex processing procedures, both for the acquisition and for the analysis of the data. In [8] a review of the development of some data monitoring techniques for the diagnosis of the state of photovoltaic panels is carried out. The methods are classified into three groups. Manual methods (visual inspection, reflectometry methods, ground capacitance measurements). Semi-automatic methods (thermal cameras, infrared or electroluminescent images for fault location). Automatic methods use data as input to detect failures through algorithms based on modern analysis and prediction techniques such as advanced algorithms and machine and deep learning. Currently, automatic methods have taken a leading role in detecting photovoltaic system faults.

The advantage of these processes is the efficiency for detecting an anomaly in the photovoltaic system as well as the speed of identification and showing them, however, there are still limitations with the fact of going from an experimental context to a real context. This is due to the costs that this type of system implies. In this context, IoT based applications could have a great impact on the development of remote fault detection systems, very useful in places where performing monitoring with other manual techniques is difficult due to the lack of the necessary infrastructure. [9, 10].

The devices used are sensors, Arduinos and Raspberry Pi microcomputers that, depending on the configuration, obtain data from a photovoltaic system which are presented on displays and/or mobile applications or saved in a physical database or a cloud. Initially, these methodologies have been developed for the monitoring of electrical variables, but later they have been used for other applications such as estimates of operating states. [9, 11-14].

IoT-based methodologies have been developed as automatic techniques for fault detection in photovoltaic systems by remotely acquiring data from the panel. In this way, multiple advances have been made in this field through the development of algorithms and prototypes that have allowed the validation of these procedures. In [15] a low cost prototype based on IoT is developed to monitor data from an autonomous photovoltaic system. In this study, current, voltage, temperature, and solar radiation data are monitored.

Through these data, faults related to short circuits, open circuit faults, dust accumulation faults and shading effects are detected. The fault detection process is carried out by comparing the measured magnitudes of voltages and currents with magnitudes calculated through the data obtained from other parameters such as radiation and temperature. The methodology is applied to a laboratory photovoltaic system. The study [16] presents a methodology to detect various types of failures in photovoltaic panels through thermography and artificial intelligence systems. A multilayer neural network is used to identify the type of failure produced in the panel, the input information for neural network training is obtained from data obtained from multiple thermographic analyses. In this same way, studies [17], [18] analyze different methodologies based on Machine Learning (ML) and Ensemble Learning (EL) that could be used to detect complex faults in photovoltaic panels such as multiple faults that most proposed methodologies cannot identify. The study presents a comparative analysis of the possible methodologies to use both ML and EL, for this it uses data from solar panels under certain fault conditions. The studies present the estimates made with these algorithms and their level of precision, concluding that all of them can be used for the proposed purposes. In the studies [19-23] an analysis of the Artificial Neural Networks application is presented depending on the type of failures to be detected, the types of data used, the ANN model and the performance in the diagnosis of failures. Additionally, the study analyzes the challenge of having sufficient data to be able to train the ANNs used. In this way, is recommended to exchange information between researchers and/or research centers to have common data repositories that can serve as input for the realization of this type of predictive model based on ANN.

The main objective of this work is to monitor and estimate a photovoltaic system operation state through real-time measurements, as well as the monitoring of its failures according to the measurements taken directly in the photovoltaic system. For this study, the historical data from the photovoltaic system parameters will be used to determine normal operating intervals of the photovoltaic system and using them to estimate the operating status of the photovoltaic system in different operating scenarios. The process takes as a reference the advances made in the field of fault detection through parameter comparison and the acquisition of remote data in real-time through IoT processes. For this purpose, the process has been divided into three stages: Obtaining and saving data from the photovoltaic system, analysis of data for detection and identification of failures and visualization of results. The main contribution of this project is:

- Integration of a real-time data acquisition process using IoT technology and its use to determine the operational status of a photovoltaic system in real-time through intervals of the system parameters in normal operation.
- The use of historical data generated by the remote monitoring system to determine intervals in the normal operating parameters of the system to determine a fault operating state.
- Identification of faults at specific points of the photovoltaic system based on the comparison of real values in real-time and the intervals of the operating parameters.

With the increase of monitored variables, it has been possible to identify failures not only in the photovoltaic panel but also failures in different points of the photovoltaic system.

2. METHODOLOGY

The methodology is based on a comparative analysis of the variables that describe the photovoltaic system operation. The monitoring of these variables was carried out by a complete remote data acquisition system with IoT technology. The data acquisition procedure is shown in Fig. 1. This document shows the data management by the remote monitoring system to determine the operating status of the photovoltaic system from the comparison of the real-time parameters of the photovoltaic system with the data of the intervals in normal operation, the process is carried out in a Raspberry Pi microcomputer, later these results are sent by the Internet to a display device that can be a mobile or a server.

2.1. OBTAINING AND SAVING DATA FROM THE PHOTOVOLTAIC SYSTEM

The initial stage of the project consists of obtaining the data from the photovoltaic system for its analysis by the developed methodology to estimate the operation state and determine the type of possible failure. This stage consists of the following stage:

Measurement of variables: It is carried out by sensors located at specific points in the photovoltaic system. The variables taken are Voltages, Current, Irradiance and Temperature in the photovoltaic panel and Current in the battery.

Data acquisition and sending: It is done by an Arduino device that is responsible for converting the sensor's analog signals to digital for later sending them by the Raspberry Pi 4 device to a storage cloud through IoT technology.

The stage of obtaining and storing data can be visualized in the graph of Fig. 1.

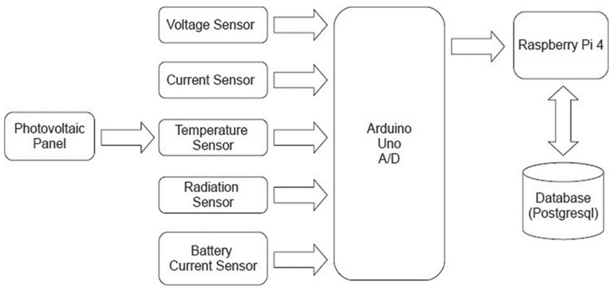

Fig. 1. Monitoring System block diagram using IoT

2.2. DATA ANALYSIS FOR FAULT DETECTION AND IDENTIFICATION

Data processing, for visualization and determining a possible fault in the system, is done by IoT processes directly on the Raspberry Pi, which works as a central node that receives, processes, and sends. the data. Data collected from sensors and monitoring devices are processed in the Raspberry Pi using specific algorithms and models designed to identify patterns of normal and potential failure.

Fault analysis is performed based on measured values. For this purpose, scenarios with different faults and the effect of each of them on the monitored parameters have been analyzed based on their standard values. The monitored variables are Radiation, Solar Panel Voltage, Solar Panel Current, Solar Panel Temperature, and Battery Current. These values represent the optimal system operation in normal conditions, any deviation in the values and according to the analysis proposed in the methodology will represent a possible fault that has occurred in some part of the photovoltaic system.

The data processing from sensors begins through a fixed window width average filtering whose size is ten samples, to eliminate any form of noise that alters the signal coming from the sensors. In addition, the values coming from the PR-300AL solar irradiation sensor were compared using a commercial meter model TES 132. Likewise, the values from the FZ0430 voltage sensor and the ACS712 current sensor were validated using a digital multimeter Proskit MT-3109.

The methodology proposed in the present work focuses on the analysis of seven possible failures in the photovoltaic system.

- Data acquisition process fault.
- Radiation measurement fault.
- Voltage drops in the photovoltaic panel fault.
- Current drop in the photovoltaic panel fault.
- Photovoltaic panel temperature measurement fault.
- General photovoltaic panel fault.
- General battery fault.

The results of this analysis are sent to the results visualization stage.

The data methodology analysis for fault detection can be seen in Fig. 2, in which different faults can be analyzed by simulation of seven possible scenarios.

<u>Data acquisition process fault</u>

In this paper, this scenario has been taken as the first possible fault, if it were to occur, none of the subsequent failures or the actual operating state of the photovoltaic system could be identified. In this fault scenario, it will be considered that none of the variables coming from the monitoring system are within the allowed limits. In this case, a general fault in the photovoltaic system can be considered for some reason that must be verified in the system.

<u>Radiation measurement fault</u>

In the present methodology, radiation measurement failure is considered when the panel voltage, current and temperature variables are within a normal operation, but there is a problem with the radiation measurements.

The main effect of the errors in the measurement of solar radiation occurs in the determination of the performance of the photovoltaic system and in the determination of the climatic and atmospheric conditions that influence the energy production of the photovoltaic system.

<u>Voltage drops in the photovoltaic panel fault</u>

A voltage drop failure scenario in the photovoltaic panel is identified when the radiation and current variables of the photovoltaic panel are within their normal values but the voltage values of the photovoltaic panel present any anomaly.

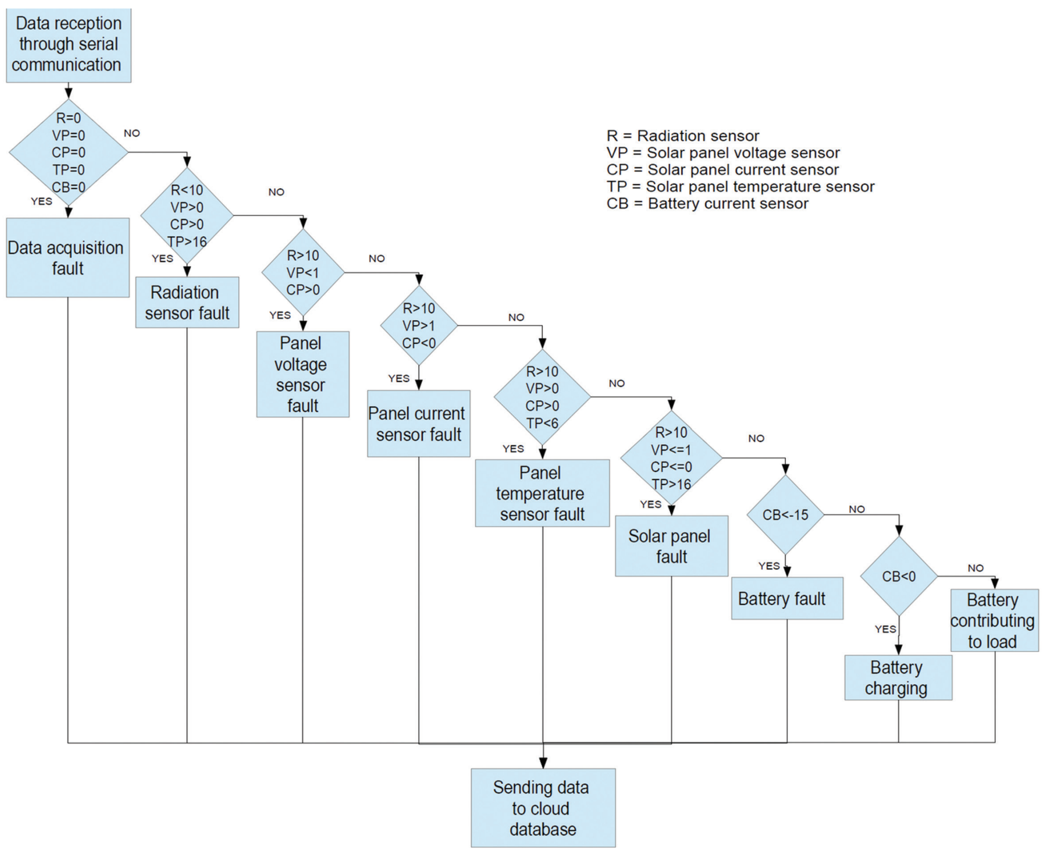

Fig. 2. Diagram of possible faults analysis in a Photovoltaic System

This type of fault is a problem that can occur when the solar panels' generation voltage decreases significantly, which shows that the panels are not producing enough energy even with adequate radiation levels.

Current drop in the photovoltaic panel fault

The fault of the current drop in the photovoltaic panel is a type of fault that can affect the general performance of the photovoltaic system and decrease its energy production. In this methodology, a scenario with a failure by current quality in the photovoltaic panel is identified when the measurements of the current variable are not within their normal operating limits while the radiation and voltage variables of the photovoltaic panel present normal operating values.

Photovoltaic panel temperature measurement fault

The temperature variable is a panel performance indicator. The correct measurement of this parameter can determine the existence of a possible fault in the photovoltaic panel that will affect the energy production of the photovoltaic system. In the present methodology, the identification of some anomaly in the panel temperature is proposed when the measurements of the temperature variables present some anomaly while the values of the radiation parameters, panel voltage and panel current have adequate values.

General photovoltaic panel fault

General faults in photovoltaic panels can be identified in different ways, especially with the decrease in power generation, drops in voltage and output current. To diagnose a general failure, it is necessary to monitor the voltage and current parameters of the photovoltaic panel, as well as the parameters of incident radiation on the panel and its temperature. With these values, a general failure of the panel can be identified and the energy production of the photovoltaic system when all these parameters present some anomaly.

General battery fault

General battery faults can be identified in many ways, such as a decrease in charge capacity or a complete battery fault. To identify this type of fault, a current sensor in the battery has been considered. If the battery current parameter presents null values while other system parameters such as radiation, temperature, panel voltage and current are present.

2.3. RESULTS VISUALIZATION

The treatment of the data for the possible faults visualization in the photovoltaic system is done by processes in IoT, in the case of saving it was done by an open-source relational database AWS-PostgreSQL.

This database management system is known for its open source, reliability, scalability, and ability to manage large volumes of data. AWS-PostgreSQL ensures secure and efficient storage of collected data in the system.

For the visualization of the results, the Qlik Sense application has been used, which is a tool that allows the creation of interactive dashboards and graphs to analyze and visualize the data effectively, with Qlik Sense, this tool allows users to perform analysis, identify patterns, trends, and anomalies, making it easier to spot potential system failures and make informed decisions.

2.4. PHOTOVOLTAIC SYSTEM TEST PROTOTYPE

The methodology has been applied in a real test photovoltaic system located in the Rumiñahui University Institute building in the Pichincha province Fig. 6. The test system consists of the following elements:

- **Photovoltaic panel**: 200W photovoltaic panel, open circuit voltage of 21V and short circuit current of 12.82A
- **Battery unit**: Gel battery, capacity of 100Ah at 12V
- **Charge regulator**: Solar Charge Controller PWM, nominal voltage of 12-24V and maximum current of 20A
- **Voltage Inverter**: 1KW DC/AC inverter, nominal voltage 12VDC/110VAC
- **Current sensors**: ACS712
- **Loads**: 4 9W LED spotlights

Fig. 3. Photovoltaic system test prototype

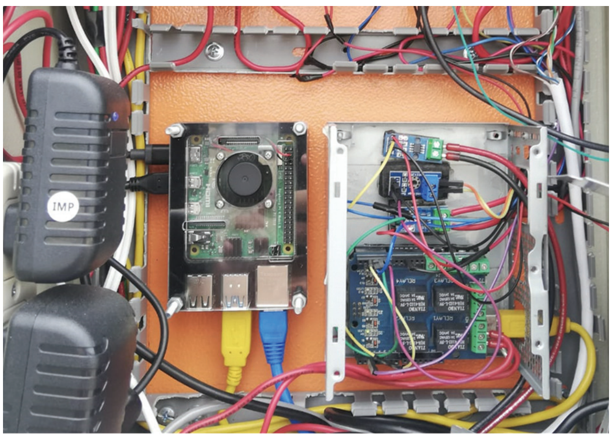

Fig. 4. Raspberry Pi, Arduino, Current sensor and Voltage Sensor

Monitoring and data storage system: This system consists of: Raspberry Pi, Arduino, Current sensor, Voltage Sensor, Temperature Sensor, and Radiation Sensor.

Fig. 5. Photovoltaic system test prototype.

Fig. 6. Temperature Sensor

Fig. 7. Radiation Sensor.

The standard values of the parameters monitored in the test photovoltaic system are presented in Table 1.

Component	Value
Radiation	0 - 1000W/m2
Solar Panel Voltage	0 - 21V
Solar Panel Current	0 - 12.82 A
Solar Panel Temperature	0 - 60°C
Battery current	0 - 100A

3. RESULTS

The present work is based on the application of a data acquisition system for monitoring the characteristic parameters of a photovoltaic system. The project is based on IoT technology for the acquisition of data for the supervision of the state of operation of a photovoltaic system, as well as the identification of some possible faults that can occur in some parts of the photovoltaic system. The results of remote monitoring of the variables of the photovoltaic system, as well as its operating state, detail any possible failure in it.

The analysis of all the variables monitored and saving them in the database allows the estimation of the photovoltaic panel operation state. In the case of any anomaly that exists, the comparison of all these parameters will be able to estimate the possible type of fault that has occurred in some part of the photovoltaic system. The methodology applied to achieve this objective is detailed in section II. Here the results obtained from different fault scenarios in the test system are presented.

Based on the values indicated in Table 1, and with the application of the methodology proposed in section II in the test photovoltaic system, the following results are obtained.

The Fig. 8. Shows a fault scenario for data acquisition. These types of faults can occur due to technical monitoring devices faults or by human faults due to errors in their connection or configuration.

This scenario can cause many negative effects, such as inadequate monitoring of the photovoltaic system parameters, causing that would not be possible to know its operating state or the existence of a possible fault in any components, which would not present adequate information to users for taking the correct decisions.

Radiation measurement fault.

The fault in the radiation measurement can be caused by different technical or atmospheric reasons, in the case of technical faults it could be by damage in the measurement sensors due to factory defects or aging, in the case of atmospheric factors it could be by extreme climatic conditions that do not allow the correct radiation measurement by the sensors. The result presented by the graphical interface in a fault event scenario by radiation measurement is shown in Fig. 9.

	Voltage double precision	Current double precision	Radiation double precision	Temperature double precision	Date text	Hour text	Battery double precision	Fault text
25	0	0	0	0	19 06 2023	11:17:33	0	Data acquisition fault
26	0	0	0	0	19 06 2023	11:17:34	0	Data acquisition fault
27	0	0	0	0	19 06 2023	11:17:36	0	Data acquisition fault
28	0	0	0	0	19 06 2023	11:17:37	0	Data acquisition fault
29	0	0	0	0	19 06 2023	11:17:39	0	Data acquisition fault

Fig. 8. Data acquisition process fault messages

	Voltage double precision	Current double precision	Radiation double precision	Temperature double precision	Date text	Hour text	Battery double precision	Fault text
53	11794	0.049	-0.003	16.125	29 05 2023	18:22:34	3.111	Radiation sensor fault
54	0.156	0.007	-0.003	16.062	29 05 2023	19:10:39	2.241	Radiation sensor fault
55	0.013	0.067	0.337	16.062	29 05 2023	19:28:14	3.138	Radiation sensor fault
56	0.056	0.026	0.167	16.062	29 05 2023	19:28:45	2.985	Radiation sensor fault
57	0.158	0.026	0.167	16.062	29 05 2023	19:29:01	2.26	Radiation sensor fault

Fig. 9. Radiation measurement fault messages

Voltage drops in the photovoltaic panel fault

Faults by voltage drop in the photovoltaic panel can be caused by different factors such as lack of sunlight, partial or total shading of the panels, dirt or dust accumulated on the surface of the panels, faulty connections, cable problems or damage to panel components. These types of faults affect the amount of electrical energy generated and the performance of the photovoltaic system decreases, causing a decrease in the energy production provided by the system. A scenario with fault by voltage drop in the photovoltaic panel is shown in Fig. 10.

	Voltage double precision	Current double precision	Radiation double precision	Temperature double precision	Date text	Hour text	Battery double precision	Fault text
53	11794	0.049	-0.003	16.125	29 05 2023	18:22:34	3.111	Radiation sensor fault
54	0.156	0.007	-0.003	16.062	29 05 2023	19:10:39	2.241	Radiation sensor fault
55	0.013	0.067	0.337	16.062	29 05 2023	19:28:14	3.138	Radiation sensor fault
56	0.056	0.026	0.167	16.062	29 05 2023	19:28:45	2.985	Radiation sensor fault
57	0.158	0.026	0.167	16.062	29 05 2023	19:29:01	2.26	Radiation sensor fault

Fig. 10. Voltage drops in the photovoltaic panel fault messages

Current drop in the photovoltaic panel fault

A fault by Current Drop in the photovoltaic panel can be caused by different factors, especially the effect of shadows. These faults affect directly the production of the photovoltaic panel and the electricity production of the photovoltaic system. They can also be caused by dirt or dust accumulated on the surface of the panel. Dirt acts as a barrier that blocks sunlight and reduces, the energy output of the panel, resulting in less current being generated. In addition, faulty electrical connections, cable problems, or damage to panel components can also cause a decrease in the generated current.

A scenario with a failure by Current Drop in the photovoltaic panel is shown in Fig. 11.

	Voltage double precision	Current double precision	Radiation double precision	Temperature double precision	Date text	Hour text	Battery double precision	Fault text
37	11.717	-0.19	37.26	19.312	15 06 2023	17:51:17	2.707	Panel current sensor fault
38	11.701	-0.203	33.91	18.937	15 06 2023	17:56:18	2.811	Panel current sensor fault
39	11.717	-0.144	30.39	18.812	15 06 2023	18:01:18	2.846	Panel current sensor fault
40	11.737	-0.199	26.34	18.562	15 06 2023	18:06:19	2.887	Panel current sensor fault
41	11.724	-0.252	21.94	18.375	15 06 2023	18:11:20	3.196	Panel current sensor fault

Fig. 11. Current drop in the photovoltaic panel fault messages.

Photovoltaic panel temperature measurement fault

Fig. 12 presents a scenario in which a panel temperature measurement error has occurred. This type of error can be by technical defects in the sensors, due to the existence of some damage in the panel or due to climatic conditions that do not allow them to generate the foreseen energy by the system. In any case, the temperature is a parameter that can show some damage in the photovoltaic system, so it is a variable to be considered.

	Voltage double precision	Current double precision	Radiation double precision	Temperature double precision	Date text	Hour text	Battery double precision	Fault text
45	6.625	0.935	343.1	0	09 06 2023	10:29:00	-1.207	Panel temperature sensor fault

Fig. 12. Photovoltaic panel temperature measurement fault messages

General photovoltaic panel fault

A general fault in a photovoltaic panel refers to a general malfunction that affects the energy production of the photovoltaic panel. It can be caused by different factors, such as damage to internal components, aging, damage from adverse environmental conditions, or installation problems. Fig. 13 shows a general failure scenario in the photovoltaic panel.

	Voltage double precision	Current double precision	Radiation double precision	Temperature double precision	Date text	Hour text	Battery double precision	Fault text
58	0	-3.451	0.17	16.562	02 05 2023	19:06:04	2.932	Solar panel fault
59	0	-0.302	0.34	17.812	08 05 2023	19:12:13	3.016	Solar panel fault
60	0	-0.318	478.5	41.25	09 06 2023	10:05:31	-0.064	Solar panel fault
61	0	-0.339	676.45	41.187	09 06 2023	10:05:46	0.891	Solar panel fault
62	0	-0.373	773.533	41.312	09 06 2023	10:06:02	2.01	Solar panel fault

Fig. 13. General photovoltaic panel fault messages

General battery fault

A general fault in a battery refers to a general malfunction that affects its storage capacity. It can be caused by various factors, such as battery aging, overcharging, deep discharge, or extreme environmental conditions.

Fig. 14 shows a general fault scenario in the photovoltaic system.

	Voltage double precision	Current double precision	Radiation double precision	Temperature double precision	Date text	Hour text	Battery double precision	Fault text
17	21.387	0.701	912.1	41.25	09 06 2023	10:14:19	-22.565	Battery fail
18	21.941	0.244	907	41.75	09 06 2023	10:14:35	-24.439	Battery fail
19	18.515	4.557	975.1	44.187	09 06 2023	10:15:52	-26.615	Battery fail
20	20.434	2.32	974.57	44.625	09 06 2023	10:16:08	-26.667	Battery fail
21	21.18	1.134	953.1	44.625	09 06 2023	10:16:23	-26.695	Battery fail

Fig. 14. General battery fault messages.

4. CONCLUSIONS

The implementation of systems based on IoT technology used for real-time monitoring of photovoltaic systems has proven to be an effective and promising solution. The ability to remotely monitor, record, save data and analyze it in real-time enables constant monitoring of system variables, making it easy to detect optimal or failed operating states early.

The continuous monitoring of the variables of the photovoltaic system helps to guarantee optimal operation and prevent possible problems caused by failures in the system. The ability to observe the variability of these parameters in real-time provides a complete view of the system and makes it easy to identify significant deviations in operating parameters that could indicate the presence of faults or abnormal conditions. By establishing thresholds and comparison criteria for normal operation, abnormal conditions can be quickly identified and corrective measures can be taken to address the identified failure on time avoiding loss of system efficiency and prolonged damage to photovoltaic system components in general.

The results of this study establish the basis for the development of more advanced and sophisticated real-time monitoring systems in the field of alternative energies. These technologies have the potential to significantly improve the efficiency and reliability of photovoltaic systems, promoting their large-scale adoption and contributing to the transition to cleaner and more sustainable energy sources. In addition, the proposed methodology can be generalized for other types of unconventional generation systems such as wind power, for which it will be necessary to make adaptations to the methodology according to the type of generation to be analyzed.

The results showed that the proposed methodology allows it to be proposed for a large-scale system, however, some points must be considered to achieve this scaling, mainly due to the large amount of data that would be managed, firstly the system should use a scalable IoT platform, which provides the ability to process and collect large amounts of data efficiently. Additionally, a cloud storage system should be implemented, which provides reliable and scalable storage capacity for the data generated by the system, finally, it should be implemented appropriate security measures such as authentication and encryption that help protect the system from possible cyber-attacks.

5. ACKNOWLEDGMENT.

The present document is part of the research project entitled Remote Monitoring of electrical variables and Estimation Faults in photovoltaic systems, financed by the Rumiñahui Universitary Technological Institute.

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