Journal of Engineering Applications June 2024 Vol.11 No.31 9-15
Article

Fault detection in photovoltaic systems using IoT

Detección de fallas en sistemas fotovoltaicos utilizando IoT

Sánchez-Tiburcio, Luis Augusto*[a], Garrido-Meléndez, Javier[b], Rueda-Martinez, Fernando[c], Sevilla-Romero, Jorge Uriel[d]

[a] Universidad Veracruzana • KDO-3164-2024 • 0009-0004-4006-6933
[b] Universidad Veracruzana • C-9373-2018 • 0000-0001-9143-408X
[c] Universidad Veracruzana • KDO-3138-2024 • 0000-0003-3988-8695
[d] Universidad Veracruzana • 0000-0002-6144-0996 • 167238

CONAHCYT classification:

Area: VII Engineering
Field: Engineering
Discipline: Electronic Engineering
Subdiscipline: Automation and control

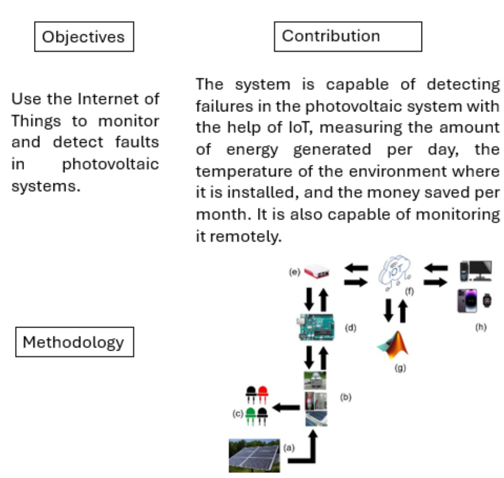
https://doi.org/10.35429/ JEA.2024.31.11.9.15

History of the article:
Received: January 15, 2024
Accepted: June 30, 2024

* ✉ [jgarrido@uv.mx]

Abstract

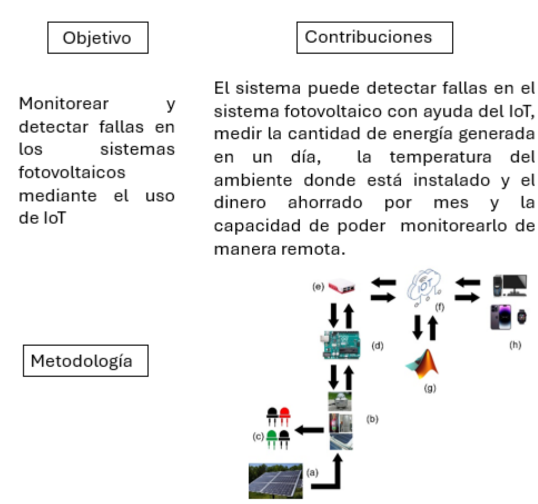
Fault detection in photovoltaic (PV) systems using the Internet of Things (IoT) allows monitoring variables that may be of interest to users who do not have technical knowledge and wish to measure: current, voltage, temperature, power generated, and money saved by the energy generated. This study aims to present a methodology for implementing a low-cost Internet of Things (IoT) to an FS in order to identify recurring faults using the Exponentially Weighted Moving Average (EWMA) statistical technique. The system was applied to a 3500 W PV located at the Universidad Veracruzana Campus Cotzacoalcos.



Internet of things, Photovoltaic systems

Resumen

El sistema de detección de fallas en sistemas fotovoltaicos (SF) utilizando el internet de las cosas (iot) permite monitorear las variables que pueden ser de interés para los usuarios que no tienen conocimientos técnicos y deseen medir el estado del SF, para lo anterior es necesario medir: Corriente, Voltaje, Temperatura, Potencia Generada, Dinero Ahorrado por la energía generada y tener la capacidad de detectar fallas en los SF. La contribución de este trabajo es presentar una metodología para aplicar el IoT de bajo costo a un SF para identificar la existencia de fallas recurrentes mediante la técnica estadística de Exponentially Weighted Moving Average (EWMA medias móviles ponderados exponencialmente). El sistema se aplicó a un SF de 3500 W ubicado en la Universidad Veracruzana Campus, Cotzacoalcos.



Internet de las cosas, Sistemas fotovoltaicos

Citación: Sánchez-Tiburcio, Luis Augusto, Garrido-Meléndez, Javier, Rueda-Martinez, Fernando, Sevilla-Romero, Jorge Uriel. Fault detection in photovoltaic systems using IoT. Journal of Engineering Applications. 2024. 11-31:9-15.

Journal of Engineering Applications June 2024 Vol.11 No.31 9-15
Article

Introduction

Photovoltaic (PV) systems are currently one of the most widely used renewable energy sources globally, with almost 164 Gigawatts (GW) of solar PV being commissioned in 2021 (Renewables 2021).

The use of PV system in households is more feasible because the costs of PV panels and their installation have been reduced over the years, the massive use of these systems has shown that it is necessary for them to receive preventive and corrective maintenance, but because users are not experts in this area they do not schedule or request this type of maintenance in time.

Fault Detection Systems in Photovoltaic Systems (FDSPS) are a solution to extend their life cycle, by detecting faults in real time and correcting faults in the shortest possible time, it is possible to make these systems more efficient.

There are different works related to fault detection systems, in Hassan, Rabhi, El hajjaji, and Tina, 2016, a method for real-time monitoring is proposed, based on setting a normality threshold and a failure threshold, calculated based on the Euclidean norm between the ideal measurement and the failure mode, the work of Benítez, Proenza, Vazquez, Núñez, and Diaz, 2020, explains a fault diagnosis methodology to contribute to the improvement of efficiency, maintenance and availability indicators of Grid-Connected PV system and an intelligent FDSPS system using the fuzzy logic method is proposed by Castellanos, 2021, capable of detecting shading, short-circuit and open-circuit faults within the PV system.

The use of the Internet of Things (IoT) is increasingly applied in home automation, in industries, and helps in the collection of data (Big Data) for various purposes. There are different IoT works applied to PV system, as in Dos, Gomes, Carvalho, and Fernandez, 2022, explain their design to monitor a PV system, based on the use of the ESP32 board. In Barbaran, 2021, an automated monitoring and control system with telemetry is designed for PV system preventive maintenance in industries.

IoT applied to measure grid energy consumption and CO_2 emissions is shown in Sujon, Nallapaneni and Ankit, 2023, proving a 17.59% reduction in conventional grid consumption.

An IoT application is carried out in Jaeeun and Sanghyun, 2022, where a day-ahead PV power prediction scheme based on neural networks is proposed, this method presents a prediction error reduction of 27% compared to the conventional method.

The objective of this work is to present a methodology to apply low-cost IoT to a PV to identify the existence of recurring faults using the Exponentially Weighted Moving Average (EWMA) statistical technique.

This paper is structured as follows: Section 1 describes the PV systems, the IoT and the EWMA method, Section 2 describes the methodology to implement the IoT in the SDFSF, Section 3 shows the results and finally the conclusions are presented.

Components of the fault detection system in a PV system.

Photovoltaic Systems

A photovoltaic installation is an array composed of one or more panels which in turn are composed of interconnected photovoltaic cells within each module, as shown in Figure 1.

Box 1

Figure 1
12-panel photovoltaic system.
Source: Own elaboration

To compare the current generated by the panel, the following equation is used.

$$I_{ph} = I_o e^{\frac{V_{oc}}{n_s V_t}} + \frac{V_{oc}}{R_{sh}} \quad (1)$$

ISSN: 2410-3454
RENIECYT-CONAHCYT: 1702902

Where: I_o is the saturation current in Standar Test Condition (STC)

V_{oc} is the open circuit voltage, n_s is the number of cells in the panel V_t is the Thermal Voltage, R_{sh} is the parallel resistance

Internet of Things (IoT)

IoT is defined as the collective network of connected devices and the technology that facilitates communication between devices and the cloud [AWS and ORACLE] where devices can be: appliances, cars, thermostats, light bulbs, PV or industrial equipment. This communication can be leveraged in low-cost computing, cloud technology, giant databases (big data) and mobile computing devices.

For example, public or private industries can benefit from IoT to manufacture products in a smart way, connect their assets, provide predictive maintenance by preventing breakdowns, work with power grids and smart utility networks, connect all their logistics, among others.

IoT is defined as the collective network of connected devices and the technology that facilitates communication between devices and the cloud [AWS and ORACLE] where devices can be: appliances, cars, thermostats, light bulbs, PV or industrial equipment. This communication can be leveraged in low-cost computing, cloud technology, giant databases (big data) and mobile computing devices.

For example, public or private industries can benefit from IoT to manufacture products in a smart way, connect their assets, provide predictive maintenance by preventing breakdowns, work with power grids and smart utility networks, connect all their logistics, among others.

EWMA control charts

They are used when you want to obtain moving averages which are based on establishing a weight to the historical information that decay exponentially over time [3]. which is defined as γ_i and is defined by the following equation:

$$\gamma_i = \lambda \chi_i + (1-\lambda)\gamma_{i-1} \quad (2)$$

Where γ_i is the moving average, λ is the smoothing constant, χ_i is the current observation, γ_{i-1} is the value of the previous moving average. In the first iteration of the moving average, in the absence of a previous moving average value, the previous moving average value is used as a substitute for this value. (μ_0) of all observations. The parameter λ is defined in a range of $0 < \lambda \leq 1$.

In this type of control chart, limits are used to define whether it is in a stable operation or not, as well as a central line, and these are defined by the following equations:

$$LCS = \mu_0 + 3\sigma\sqrt{\frac{\lambda[1-(1-\lambda)^{2i}}{2-\lambda}}$$

$$LC = \mu_0$$

$$LCI = \mu_0 - 3\sigma\sqrt{\frac{\lambda[1-(1-\lambda)^{2i}}{2-\lambda}}$$

The values used for the lambda factor are low because the aim is to be able to detect small changes in the system.

Methodology

Using the IoT to read sensors mounted on the SF and connected to the Arduino board which communicates to a Raspberry Pi to establish a connection to an internet server, thus generating a database that can be used to analyse it with the help of Matlab software and the EWMA control graph, and turn on a LED to indicate whether the system is working properly or has a fault.

The methodology used for the fault detection system in photovoltaic systems using IoT is described in the diagram in figure 1, the stages are explained below:

1.a) The PV system with 14 PV panels and a capacity of 3500 W, are located at the Coatzacoalcos campus of the Universidad Veracruzana.

1.b) The sensors measure voltage, current, irradiance and temperature signals.

1.c) The LED actuators indicate if the SF is working correctly or if there is a failure.

ISSN: 2410-3454
RENIECYT-CONAHCYT: 1702902

1.d) The Arduino board receives the information generated by the sensors and activates the actuators depending on the state of the SF.

1.e) The Raspberry Pi microcomputer is connected to the Arduino board to send and receive data through the Node-RED software and from this point the IoT connectivity begins.

1.f) MQTT servers are in the cloud that allow the exchange of information over the Internet. In this case, these servers receive information from the Raspberry Pi and the computer that feeds back the status of the fault to the SF.

1.g). A computer with Matlab software installed which requests the information to process it in real time and send the results to the IoT.

1.h) Computational devices (mobile phones, tablets, PCs, etc.) are connected to the IoT to visualise the status of the FS, as well as the variables of interest.

Fault detection system of a PV system

In the following, the functions of the components of the SF Fault Detection System with IoT are described.

An Arduino board was used which was programmed to read every minute the physical variables: irradiance, temperature, current and voltage by means of sensors, the outputs of the Arduino were used to activate or deactivate actuators to turn on the LEDs that work as indicators of the status of the SF. An RS-232 serial communication was configured to send the value of the physical variables and receive the information from the Raspberry Pi.

Box 2

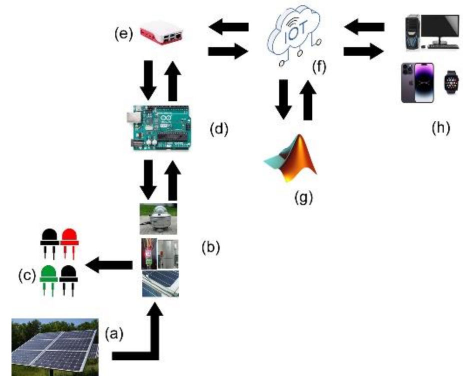


Figure 2
Fault detection system in a Photovoltaic System with IoT

Source: Own elaboration

The Raspberry Pi was programmed to send and receive information through the IoT, in addition to functioning as a web server for the virtual visualisation of the status of the photovoltaic panels and the graphs of the variables.

The Node-RED software was programmed with various flow diagrams (flows) that allowed the sending and receiving of information through the light messaging protocol Message Queuing Telemetry Transport (MQTT), which is used within the IoT.

The flows performed within the Node-RED tool are shown in figures 3 to 8, which are as follows:

a) Sending IP address of the Raspberry Pi.

b) Obtaining IP address of the Raspberry Pi

c) Request data from the sensors.

d) Send SF variables to the MQTT server.

e) Generation of a database.

f) SF failure status.

Each of the flows is described below:

a) Sending the IP address of the Raspberry Pi: This flow allows sending the IP address obtained to a topic of a public MQTT broker so that it can be worked remotely.

ISSN: 2410-3454
RENIECYT-CONAHCYT: 1702902

Sánchez-Tiburcio, Luis Augusto, Garrido-Meléndez, Javier, Rueda-Martinez, Fernando, Sevilla-Romero, Jorge Uriel. Fault detection in photovoltaic systems using IoT. Journal of Engineering Applications. 2024. 11-31:9-15
https://doi.org/10.35429/ JEA.2024.31.11.9.15

Box 3

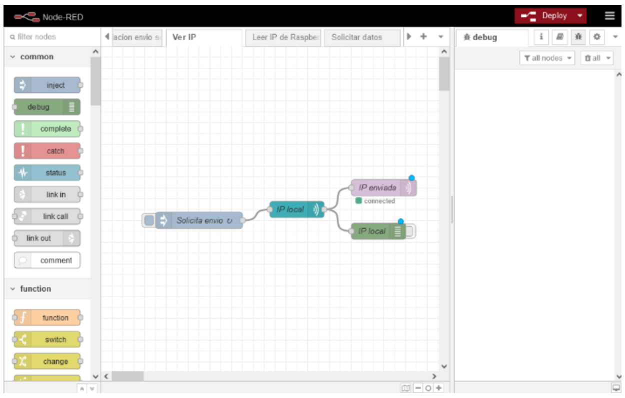


Figure 3
Sending IP address from Raspberry Pi

Source: Own

Box 4

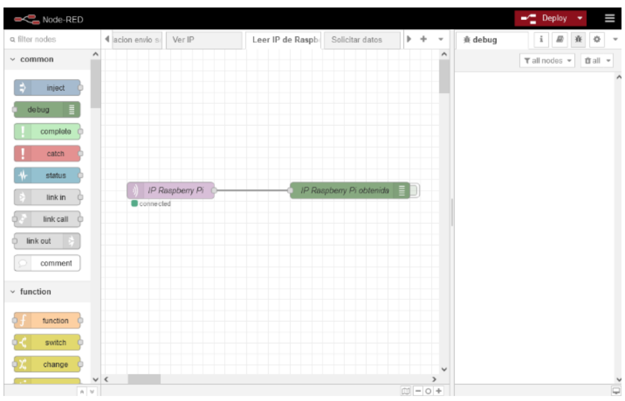


Figure 4
Gtetting IP address from Raspberry Pi.

Source: Own

Box 5

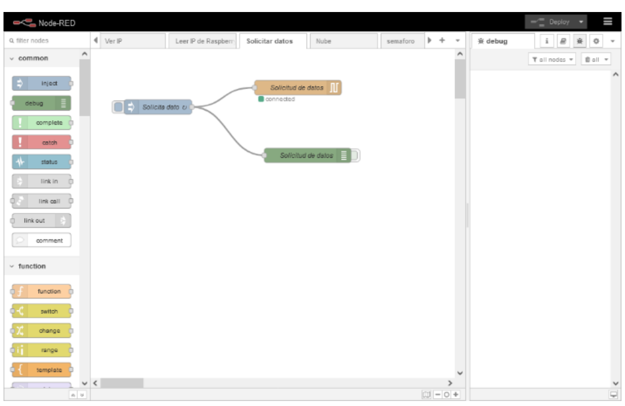


Figure 5
Request sensor data.

Source: Own

b) Obtain IP address of the Raspberry Pi, allowing administrators to work remotely to edit, generate or delete flows and users to view graphs.

Box 6

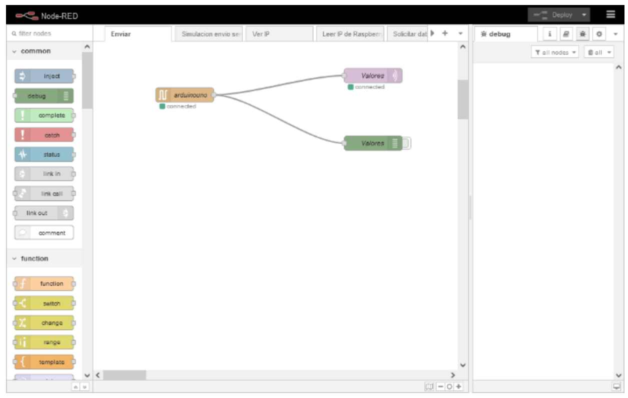


Figure 6
Send SF variables to the MQTT server

Source: Own

Box 7

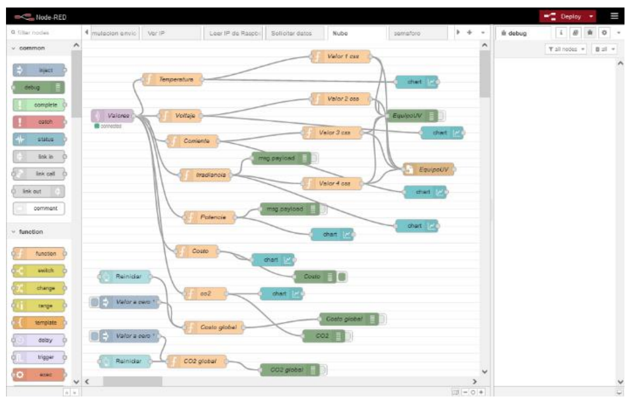


Figure 7
Generation of a database

Source: Own

Box 8

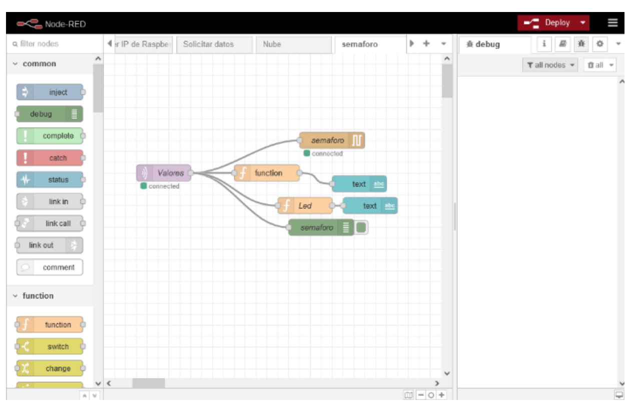


Figure 8
Failure status of the SF.

Source: Own

c) Requesting sensor data: This was used as the communication protocol between the Raspberry Pi and the Arduino one.

ISSN: 2410-3454
RENIECYT-CONAHCYT: 1702902

Sánchez-Tiburcio, Luis Augusto, Garrido-Meléndez, Javier, Rueda-Martinez, Fernando, Sevilla-Romero, Jorge Uriel. Fault detection in photovoltaic systems using IoT. Journal of Engineering Applications. 2024. 11-31:9-15
https://doi.org/10.35429/ JEA.2024.31.11.9.15

d) Send SF variables to the MQTT server: The Raspberry Pi is the computational device used to transmit and receive information from the public brokers test.mosquitto.org and broker.emqx.io.

e) Database generation: This was run on a server on the Internet, with the aim of generating a database in a csv file that could be used by a MATLAB script to analyse the data and with the help of the statistical tool EWMA know if there is a failure in the SF and issue a status of 0 if it is working correctly or a status of 1 if it has a failure.

f) SF failure status: The status value that is sent through the MQTT topic to the Raspberry Pi, which will transmit this information to the Arduino one board to control the indicator lights (green to indicate that everything is OK and red to indicate that there is a failure).

Results

The graphs displayed on the Dashboard were programmed to generate a web page showing real-time graphs of temperature, voltage, current, irradiance, cost, CO2 and power, as well as displaying two LEDs representing the status of the SF.

To test the SDFSF, it is analysed with and without failure as described below:

- The SF variables are measured when there are no faults and a database is generated which is stored to keep a statistical record, which is analysed by the EWMA and indicates that the system is within normal operating rates, lighting the green led as shown in Fig. 9.

- An open circuit fault is generated in the DC part of the SF, so that the measured voltage and current are equal to zero, by means of the EWMA analysis this variation is detected and generates an output that indicates that the system has a fault so that the red led on the Dahsboard is activated as shown in Fig. 10.

For the analysis of the data generated by the SF, it is stored in a CSV file which contains the new data and using the Matlab software and applying the EWMA algorithm, it is detected whether or not there is a fault, which is sent to the MQTT as shown in the code in figure 11.

Box 9

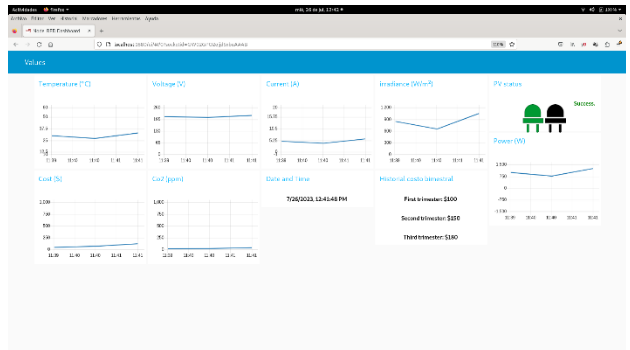


Figure 9
Dashboard without fail.
Source: Own

Box 10

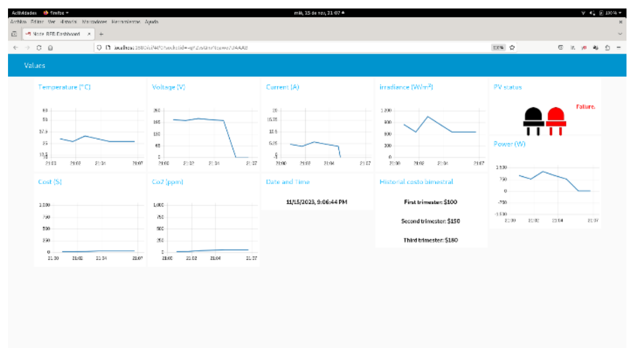


Figure 10
Dashboard with failure.
Source: Own

Box 11

```
%%% se detrmina si el sistema esta trabajando
mqttClient = mqttclient("tcp://broker.emqx.io",ClientID="myClient",Port=1883);
topicToWrite = "equipouv/javierjesusluis/valor2";

 M = csvread('Datos.csv',0,2);
n=length(M(:,1));
while (true)
    Iact = csvread('Datos.csv',0,2,[0,2,n,2]);

    if (Iact >LCS) | (Iact <LCI)

    msg = "1";
    write(mqttClient, topicToWrite, msg);
    else

    msg = "0";
    write(mqttClient, topicToWrite, msg);

    end
    n=n+1;
end
```

Figure 11
Fault status sending function to MQTT.
Source: Own

ISSN: 2410-3454
RENIECYT-CONAHCYT: 1702902

Journal of Engineering Applications June 2024 Vol.11 No.31 9-15
Article

Conclusions

In this work we presented the methodology to apply the Internet of Things for the detection of faults in a photovoltaic system, with the help of the weighted statistical mean (EWMA), which was tested experimentally, for this work a fault was generated, which was detected by the system.

One of the great advantages is that the more data, the more reliable the system becomes.

Conflict of interest

The authors declare that they have no conflicts of interest. They have no known competing financial interests or personal relationships that could have influenced what is reported in this article.

Availability of data and materials

The data and programmes used in this article are available on request.

Funding

This article did not receive any funding.

Abbreviations

AWS: Amazon Web Services.
CSV: Comma Separated Values.
EWMA: Exponentially Weighted Moving Average.
GW: Gigawatts.
IoT: Internet Of Things.
IP: Internet Protocol.
MQTT: Message Queuing Telemetry Transport.
PC: Personal Computer.
SF: Photovoltaic Systems.
SDFSF: Fault Detection Systems in Photovoltaic Systems.
STC: Standard Test Condition.

References

Differences

Barbaran V. L. (2021). Diseño de sistema automatizado de monitoreo y control con telemetría para mantenimiento preventivo de sistemas fotovoltaicos en las industrias de 3 a 50 kW. Universidad César Vallejo.

Benítez P., I., Proenza, R., Vazquez S., L., Núñez A., J. y Diaz M., D. (2020). Fault Diagnostic Methodology for Grid-Connected Photovoltaic Systems. Revista Iberoamericana de Automatica e Informatica Industrial (RIAI).

Castellanos C., J. E. (2021). Detección de fallas en sistemas fotovoltaicos basados en un controlador: EWMA o Lógica Difusa. Tesis de licenciatura. Coatzacoalcos Veracruz. Universidad Veracruzana.

Dos S., T. A., Gomes de F., F., Carvalho G., D. L. y Fernández R., L. M. (2022). Diseño IOT y validación de sistema de medida para generación fotovoltaica. Ingenius. Revista de Ciencia y Tecnología.

Hassan A., M., Rabhi, A., El hajjaji, A. y Tina, G. (2016). Real Time FaultDetection in Photovoltaic Systems. Energy Procedia.

Support

Jaeeun P., J. K. y Sanghyun L., J. K. C. (2022). Machine learning based photovoltaic energy prediction scheme by augmentation of on-site IoT data, Future Generation Computer Systems.

Background

Renewables 2021 - Renewables 2021 de la Agencia Internacional de Energía (AIE).

ISSN: 2410-3454
RENIECYT-CONAHCYT: 1702902