Lecture Notes in Networks and Systems 1040

Marcelo Zambrano Vizuete ·
Miguel Botto-Tobar ·
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Innovation and Research – Smart Technologies & Systems

Proceedings of the CI3 2023, Volume 1

Springer

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Preface

The 4th edition of the International Research and Innovation Congress – Smart Technologies and Systems, CI3 2023, took place from August 30 to September 1, 2023, at the facilities of the Instituto Tecnológico Universitario Rumiñahui, located in the city of SangolquÍ, Pichincha, Ecuador.

The conference was organized by the Red de Investigación, Innovación y Transferencia de Tecnología RIT2, made up of the most relevant university institutes in Ecuador, among which are ITCA, BOLIVARIANO, ARGOS, VIDA NUEVA, ESPÍRITU SANTO, SUDAMERICANO, ISMAC, SAN ISIDRO, ARTES GRÁFICAS, ORIENTE, HUMANE, SUCRE, CENTRAL TÉCNICO, POLICÍA NACIONAL and RUMIÑAHUI.

Additionally, the event is sponsored by the Secretaría de Educación Superior, Ciencia, Tecnología e Innovación SENESCYT, Labortorio de Comunicación Visual de la Universidad Estatal de Campinas—Brazil, Universidad Ana G. Méndez—Puerto Rico, Centro de Investigaciones Psicopedagógicas y Sociológicas—Cuba, Instituto Superior de Diseño de la Universidad de La Habana—Cuba, GDEON and the Corporación Ecuatoriana para el Desarrollo de la Investigación y la Academia—CEDIA.

The main objective of CI3 2023 is to generate a space for dissemination and collaboration, where academia, industry and government can share their ideas, experiences and results of their projects and research.

"Research as a pillar of higher education and business improvement" is the motto of the Conference and suggests how research, innovation and academia must coincide with the productive sector to leverage social and economic development.

CI3 2023 had 145 papers submitted, of which 52 were accepted for publication and presentation. To guarantee the quality of the publications, the event has a staff of more than 70 experts, from different countries such as Spain, Argentina, Chile, Mexico, Peru, Brazil, Ecuador, among others, who carry out an exhaustive review of each proposal sent.

Likewise, during the event a series of keynote conferences were held, given by both national and international experts, allowing attendees to get in touch with the latest trends and technological advances around the world. Keynote speakers included: Ph.D. Carina González, University of La Laguna, Spain; Ph.D. Gabriel Gómez, State University of Campinas, Brazil; Ph.D. Carlos Sanchez, University of Zaragoza, Spain; Ph.D. Juan Minango, Instituto Tecnológico Superior Rumiñahui; Dr. Iván Cherrez, Universidad Espíritu Santo, Ecuador; and Ph.D. Nela Paustizaca, Escuela Politécnica del Litoral, Ecuador.

The content of this proceeding is related to the following topics:

- Smart Cities
- Innovation and Development
- Applied Technologies
- Economics and Management
- ICT for Educations.

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Contents

Real-Time Data Acquisition Based on IoT for Monitoring Autonomous Photovoltaic Systems

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Abstract. Technological development has made photovoltaic systems more accessible for applications in domestic self-generation microsystems. In this context, new monitoring techniques are necessary to visualize the operating status of photovoltaic systems components. The main objective of this work is to monitor the operation status of a photovoltaic system through remote measurements in real-time using IoT technology. The study used IoT technology for the remote acquisition of principal elements of a photovoltaic system data to show them in time series through a graphical interface. The study resulted in a real-time remote monitoring system that allows the observation of photovoltaic system variables. The study concludes that through IoT technology, complex real-time monitoring systems of photovoltaic system operating variables can be configured to store them in a database that allows the visualization and analysis of historical data behavior of photovoltaic systems.

Keywords: Photovoltaic System · Remote Monitoring · IoT · Electrical Variables

1 Introduction

Technological development has made photovoltaic systems more accessible for domestic self-generation microsystems. In this context, new challenges are presented for network operators and for end users who implement these systems, for self-consumption and for distributed generation. These new challenges not only have to do with the installations and their impacts but also with the monitoring and management systems of this type of equipment. In this context, new monitoring techniques are needed to visualize the state of the components of the photovoltaic systems [1].

The current technological advances in the field of monitoring techniques present a constant evolution, going from being manual to being carried out through automatic processes using advanced devices and complex processing procedures, both for the acquisition and analysis of data. In [2], a review of the development of some data monitoring techniques for the diagnosis of the state of photovoltaic panels is carried out.

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In this study, a general classification is made into three groups. Manual methods that are applied to small systems, these techniques include visual inspection, reflectometry methods, and ground capacitance measurements. Semi-automatic methods, in this group are thermal cameras, infrared or electroluminescent images for locating faults in a large-scale system. The automatic methods used in a general way with algorithms based on modern techniques of analysis and data treatment are also proposed.

One of the ways used in automatic methods is the development of monitoring systems based on IoT applications, these have become a viable alternative in remote monitoring systems development that could be very useful in places with difficult access and where is difficult to have the necessary infrastructure to carry out some type of manual or semi-automatic monitoring [3, 4]. IoT-based monitoring systems are mainly made up of sensors, Arduino brand prototype development boards and Raspberry Pi microcomputers which, depending on the configuration, obtain data from a photovoltaic system that are displayed on display screens and/or mobile applications or also stored. in a physical database or in a data cloud. Initially, these methodologies were developed for monitoring the variables of the photovoltaic panels, but later they have been used for other applications such as estimates of the operating state of the system in general [3, 5–8].

In other studies, new methodologies are developed to improve the processes of acquisition, presentation and treatment of data. In [9], a data acquisition methodology based on IoT technology is presented. This study develops a data acquisition scheme with three levels, in the first one the current, voltage, temperature and solar irradiance data are taken through sensors. At the next level, these data are sent through the internet to finally present them in a third phase on a web platform or stored in a database. The device is made with Arduino technology both for the data acquisition from the sensors and for the transmission of them for them to be presented in real-time. In this same context, the study [10], presents a methodology where the use of a SCADA system is proposed as a means of monitoring variables. This methodology also uses sensors, an Arduino device to receive the variables and Raspberry Pi to manage and send the data.

IoT-based methodologies have also been developed as automatic techniques for monitoring photovoltaic operating variables through remote data acquisition. In general, these methodologies use sensors, data acquisition devices such as Arduino and data processing through a Rasberry Pi, however, the last one is not always used, but a remote server can also be used for the analysis of the data obtained. The variables that are taken through sensors are voltages, currents, temperature and irradiance at certain points of a photovoltaic system, this can be variable depending on the study to be carried out [11–14].

The main objective of this work is to monitor a photovoltaic system operation state through remote measurements in real-time using IoT technology. For this, the process has been divided into four stages, data acquisition, data processing, sending the data to a cloud database and displaying them. The main contribution of the project is related to the unification of the data acquisition process, treatment and presentation of them in online visualization platforms, which makes this model a remote and real-time monitoring system, in addition to show of a backup of the monitored variables stored in time series data, all of this, based on IoT technology. These systems are suitable to be applied in autonomous photovoltaic systems, especially in those with difficult access and where the necessary infrastructure to establish conventional communication systems is not available.

2 Methodology

The proposed methodology consists of four stages as indicated in Fig. 1. The first consists of the variables measurement through the sensors installed in certain points of the photovoltaic system, the second consists of the acquisition of sensor data through an Arduino device and the sending to a cloud through a Rasberry Pi. The third consists of the treatment of the data obtained in a Rasberry Pi microcomputer and finally a fourth stage where the data from the sensors are sent through the Internet to a display device which can be a mobile or a server. Each of the stages is detailed below in Fig. 1.

For filtering of data obtained from the sensors, the Arduino MeanFilter library was used, which implements a moving average filter. This filter stores a certain number of samples to define the window used by the filter to later obtain the average. A window

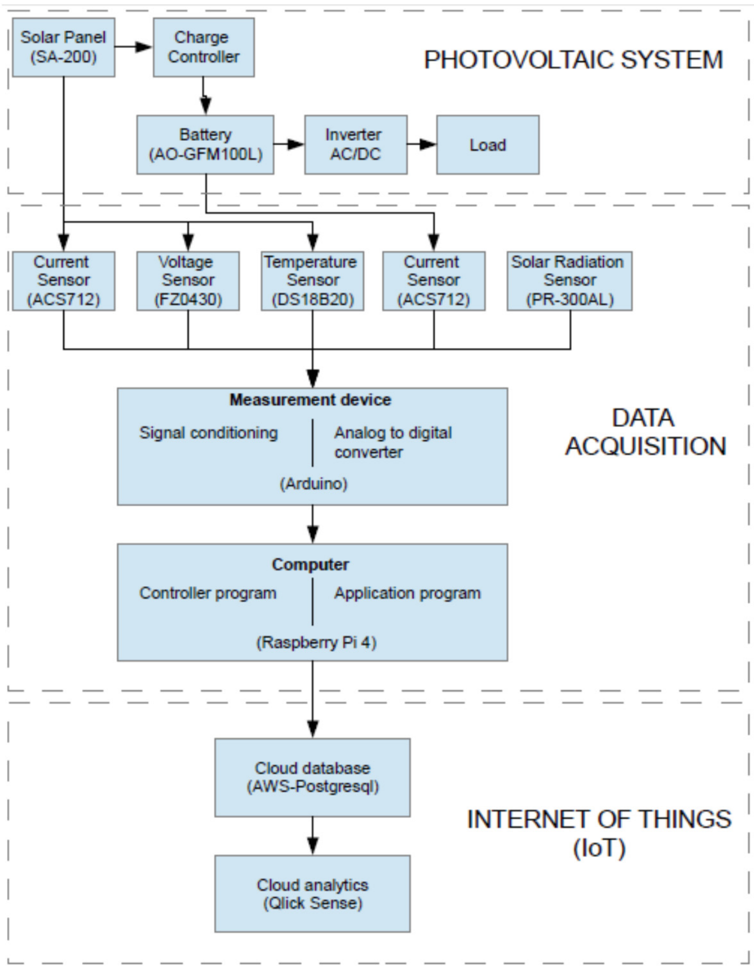

Fig. 1. Photovoltaic Monitoring System Diagram Using IoT.

of 10 samples was used. The moving average filter is widely used in signal acquisition systems and does not have a high computational cost to be implemented on a prototyping board such as Arduino.

2.1 Variable Measurement Process.

The measurement process is carried out through sensors located at specific points of the photovoltaic system. The variables taken are Voltages, Current, Irradiance, Temperature in the photovoltaic panel and Current in the battery. ACS712 Current [15], FZ0430 Voltage [16], DS18B20 Temperature [17] and Radiation PR-300AL [18] sensors are used.

To minimize the measurement error, the values from sensor of the solar irradiance variable were contrasted with a commercial solar irradiance meter such as the TES 132 DataLogging Solar Power Meter. In the same way, Current and voltage measurements were contrasted with Proskit MT-3109 Multimeter. TES 132 is showed in the Fig. 2.

Fig. 2. TES 132 Data-logging Solar Power Meter.

2.2 Data Acquisition and Sending

The data acquisition and filtering process is carried out through an Arduino device that is responsible for converting the analog signals of the sensors to digital signals and then sending them through the Raspberry Pi 4 device to a storage cloud and a visualization platform in real-time through IoT technology. In this stage, there is a remote measurement process through sensors, IoT devices and data storage in time series.

2.3 Data Processing

Data processing for visualization is done through IoT processes directly on the Rasberry Pi, which acts as a central node that receives, processes, and sends the data. The data collected from the sensors and monitoring devices is processed on the Raspberry Pi using specific algorithms and models designed to identify normal operation patterns and detect possible parameters whit any error that could affect the complete measurement process.

The monitored variables are Radiation, Solar Panel Voltage, Solar Panel Current, Solar Panel Temperature and Battery Current.

2.4 Results Visualization

Data processing for visualization is done through IoT processes; in the case of storage, it was done through an open-source relational database AWS-PostgreSQL. This database management system is known for its open source, reliability, scalability, and ability to manage a large volume of data. Choosing AWS-PostgreSQL ensures secure and efficient storage of collected data in the system.

For data visualization, the Qlik Sense application has been used, which is a tool that allows the interactive dashboards and graphics creation to analyze and visualize data effectively, with Qlik Sense.

The flow diagram of the proposed methodology is presented in Fig. 2.

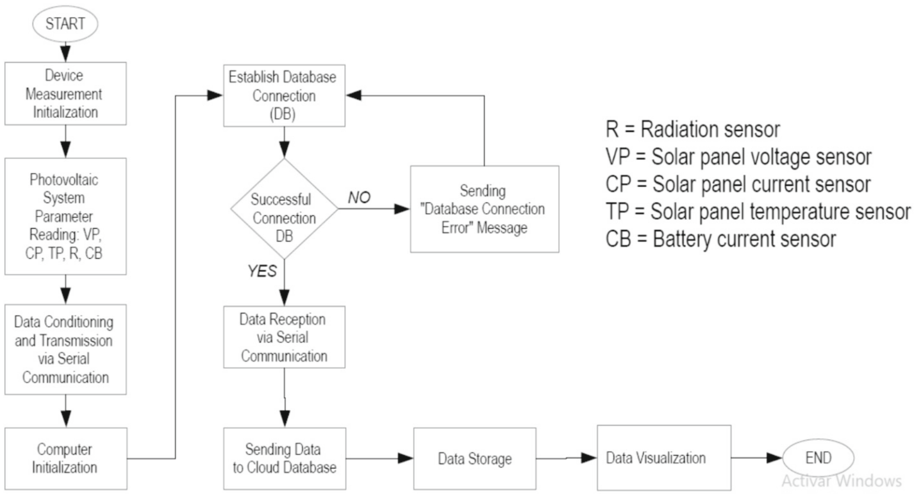

Fig. 3. Monitoring System Flowchart of photovoltaic system using IoT.

3 Results

The present work is based on the data acquisition system development for a photovoltaic system characteristic variables observation. The project is based on IoT technology for data acquisition from a photovoltaic system.

The methodology has been applied in a real test photovoltaic system located in the Instituto Superior Tecnológico Rumiñahui building located in the Pichincha province.

The test system consists of the next elements:

Photovoltaic module: 200 W photovoltaic panel, 21 V of open circuit voltage and 12.82 A of short circuit current.
Battery module: Gel battery, capacity of 100 Ah at 12 V.
Charge regulator: Solar Charge Controller PWM, nominal voltage of 12–24 V and maximum current of 20A.
Voltage Inverter: 1KW DC/AC inverter, nominal voltage 12 VDC/110 VAC.
Current sensors: ACS712.
Loads: 4 LED lights of 9 W.
Raspberry Pi: Model 4 with 8 GB of RAM and 32 GB of SSD.
Arduino: UNO R3 Model.
Voltage Sensor: FZ0430.
Temperature Sensor: DS18B20.
Radiation Sensor: PR-300AL.

The complete test of the Photovoltaic System is shown in Fig. 4.

Fig. 4. Test Photovoltaic System.

The application results of this methodology are detailed below:

The first process of the present study is focused on the remote acquisition of data through IoT technology use. This methodology allowed the collection of relevant information for the analysis of the test photovoltaic system state. These data are related to voltage, current, temperature in the solar panel and solar irradiation that it receives. For this, the system was configured to monitor, acquire and record the data every 5 min during an initial period of 3 months. This sampling frequency made it possible to obtain a large amount of data in a significant time interval, which is essential to perform a representative analysis and understand the behavior of the system in real-time. The results obtained were validated by real measurements with the respective equipment intended for these purposes.

The collection and storage of this data have two main purposes. To observe clearly the values of the photovoltaic system operating variables in real time to verify its operation, which allows observing the efficiency of the system and determining the need to carry out some type of maintenance in it.

The data obtained from the IoT system during the week of June 11 to June 15, 2023, are presented below. These data are of great importance because they will provide detailed information about the behavior of the system under specific conditions and will be useful as a guide for the analysis and estimation of the photovoltaic system operation state.

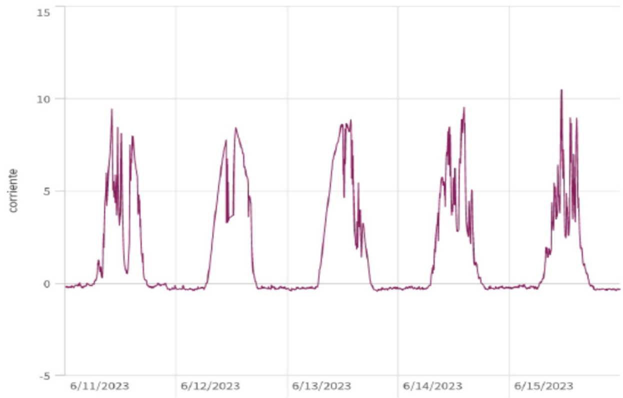

Fig. 5. Current at Photovoltaic Panel output obtained by the Monitoring System.

The graphic of Fig. 5 presents the current data obtained at the photovoltaic panel output of the test system, it clearly shows the variation of the current generated by the photovoltaic panel, which allows us to identify patterns, trends, and potential irregularities in panel performance. The fluctuations in the generated current values are influenced by solar radiation and ambient temperature. During the hours of maximum solar radiation, it is expected that the generated current reaches its highest values, while, in periods of less solar radiation, the current may decrease.

The graphic of Fig. 6 represents the voltage values recorded by the monitoring and measurement device for five days. This graphic provides detailed information on how the voltage varies in time, which helps us to identify patterns, trends and possible problems in the operation of the panel through the voltage values recorded in time series. The voltage variation in a day is directly influenced by solar radiation and ambient temperature. During the hours of greatest solar radiation, it is supposed that the voltage reaches its maximum values, while, at times of less solar radiation, the voltage can decrease to its minimum values.

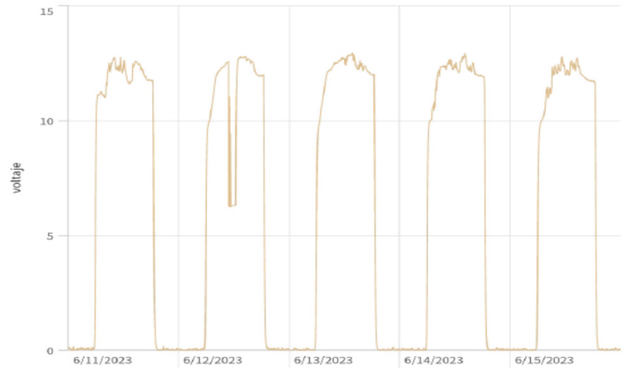

Fig. 6. Voltage at Photovoltaic Panel output obtained by the Monitoring System.

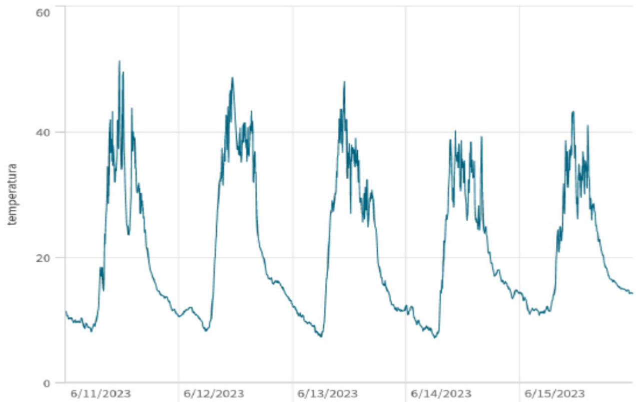

Fig. 7. Temperature on Photovoltaic Panel obtained by the Monitoring System.

The graphic in Fig. 7 provides detailed information about the temperature fluctuations produced on the photovoltaic panel throughout the day. The efficiency of the photovoltaic panel is influenced by its temperature, an increase in temperature can decrease the efficiency of solar cells and reduce energy production. Therefore, it is important to monitor this parameter to assess system performance and take corrective actions on time.

The graphic in Fig. 8 provides detailed information about the incident solar radiation on the photovoltaic panel and its variation during the day, which allows us to understand how solar radiation affects the energy production of the photovoltaic panel. The graphic shows how solar radiation varies throughout the day, with radiation peaking during the hours of greatest solar intensity, generally at noon. The graphic could also give radiation information based on seasonal patterns and differences in solar radiation between cloudy and clear days.

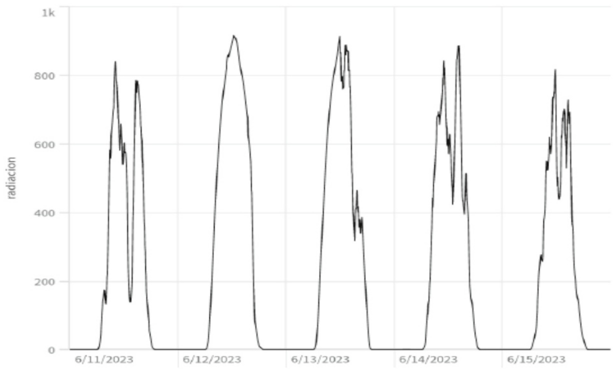

Fig. 8. Radiation on Photovoltaic Panel obtained by the Monitoring System.

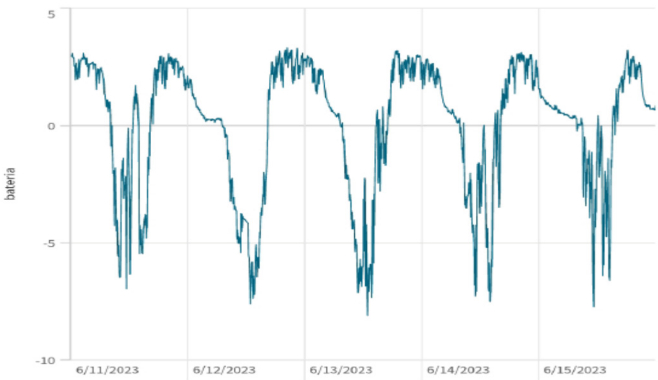

Fig. 9. Current from the battery obtained by the Monitoring System.

The graphic of Fig. 9 shows the current measurements in the battery throughout a week, in it, we can see positive values that represent an energy contribution to the load and negative values that correspond to the battery charge with the energy from the photovoltaic panel. With these values, it is possible to have patterns of battery behavior that could give information about the battery state operation.

Table 1 shows a descriptive statistic applied to data acquired from the monitoring system. In this table, solar irradiance has a maximum of 1100 W/m^2 with standard deviation of 414.19 W/m2 that represents solar irradiation of one day. Instead, module temperature has a maximum temperature of 56.75 ºC with a standard deviation of 11.59 ºC and a minimum of 5.88 ºC.

Table 2 shows a correlations analysis of measurement variables. In the table, Solar irradiance and PV temperature have a high correlation with PV power generation.

Compared to the method presented in [3] and [4] which use the ThingSpeak Platform, the data of the present work is stored in a cloud database for further analysis and visualization in different time frames. In this way, you can see how the measured variables behave over days, weeks or months.

Table 1. Descriptive Statistics of measured variables

	Voltage	Current	Solar Irradiance	Temperature	Power > 0
Mean	11.228	3.208	594.529	25.960	36.936
Standard Error	0.031	0.026	3.741	0.105	0.305
Mode	9.877	0.481	0.000	12.500	0.107
Median	11.402	2.270	658.540	24.000	26.262
First Quartile	10.037	0.744	154.086	15.937	8.385
Third Quartile	12.081	5.071	1024.525	34.687	58.189
Variance	11.591	8.127	171553.990	134.537	1140.081
Standard Deviation	3.405	2.851	414.191	11.599	33.765
Kurtosis	4.680	−0.508	−1.589	−0.839	−0.226
Skewness	0.080	0.833	−0.180	0.437	0.902
Range	23.056	11.399	1100.351	50.875	149.866
Minimum	0.123	0.005	−0.001	5.875	0.100
Maximum	23.179	11.404	1100.350	56.750	149.966
Sum	137598.389	39318.393	7285953.798	318143.546	452651.517
Count	12255.000	12255.000	12255.000	12255.000	12255.000

Table 2. Correlation analysis of measured variables

Correlations	Voltage	Current	Solar Irradiance	PV Temperature	Power
Voltage	1.0000				
Current	0.0941	1.0000			
Solar Irradiance	0.4486	0.8024	1.0000		
PV Temperature	0.4313	0.8250	0.9095	1.0000	
Power	0.1828	0.9876	0.8127	0.8431	1.0000

As mentioned in [2], the most widely used technology is WIFI, which shows good performance for distances of up to 100 m. Regarding security, the device with WIFI connection and Internet access is the Raspberry PI that has a Linux-based operating system installed that is less prone to security flaws, although updates to this operating system must be made regularly.

4 Conclusions

IoT technology is an effective and promising solution in the field of remote monitoring photovoltaic systems variables, the main advantage of these systems is the ability to present real values of the monitored variables and facilitates the visualization of the monitored system operating status.

The study demonstrated the feasibility of using IoT technology for real-time remote monitoring of photovoltaic systems variables. The results obtained allowed us to observe the variability of the characteristic variables of monitored systems by time series analysis techniques.

The adequate treatment of the data acquired through IoT technology, especially through time series analysis techniques, provides important information for decision-making based on data and the implementation of corrective actions in a timely manner in the case to detect any anomaly in the data obtained by the monitoring system.

The remote monitoring system based on IoT technology can be the initial point for the development of new advances in the field of remote monitoring. The system stores the results obtained in time series in a database, which makes it possible to identify behavior patterns and therefore the possibility of observing an anomaly that could be due to a fault at some point in the photovoltaic system.

References

1. Masson, G., Bosch, E., Kaizuka, I., Jäger-Waldau, A., Donoso, J.: Snapshot of global PV markets 2022 task 1 strategic PV analysis and outreach PVPS (2022)
2. Mellit, A., Kalogirou, S.: Artificial intelligence and internet of things to improve efficacy of diagnosis and remote sensing of solar photovoltaic systems: challenges, recommendations and future directions. Renew. Sustain. Energy Rev. **143**, 110889 (2021). https://doi.org/10.1016/j.rser.2021.110889
3. Priharti, W., Rosmawati, A.F.K., Wibawa, I.P.D.: IoT based photovoltaic monitoring system application. J. Phys. Conf. Ser. **1367**(1), 012069 (2019). https://doi.org/10.1088/1742-6596/1367/1/012069
4. Muthusamy, S.: Fault detection and monitoring of solar PV panels using internet of things. Int. J. Ind. Eng. **2**, 146–149 (2018)
5. Tellawar, M.P., Chamat, N.: An IOT based smart solar photovoltaic remote monitoring system. Int. J. Eng. Res. **8**(09) (2019)
6. Gopal, M., Prakash, T.C., Ramakrishna, N.V., Yadav, B.P.: IoT based solar power monitoring system. In: IOP Conference Series: Materials Science and Engineering, vol. 981, no. 3, p. 032037 (2020). https://doi.org/10.1088/1757-899X/981/3/032037
7. Rerhrhaye, F., et al.: IoT-based data logger for solar systems applications. In: ITM Web Conference, vol. 46, p. 01003 (2022). https://doi.org/10.1051/itmconf/20224601003
8. Vujović, I., Koprivica, M., Đurišić, Ž.: Monitoring and management solution for distributed PV systems based on cloud and IoT technologies. In: 2022 30th Telecommunications Forum (TELFOR), pp. 1–4 (2022). https://doi.org/10.1109/TELFOR56187.2022.9983768
9. Sasikala, G.: Arduino based smart solar photovoltaic remote monitoring system. Malays. J. Sci. 58–62 (2022). https://doi.org/10.22452/mjs.vol41no3.8
10. Aghenta, L.O., Iqbal, M.T.: Development of an IoT based open source SCADA system for PV system monitoring. In: 2019 IEEE Canadian Conference of Electrical and Computer Engineering (CCECE), pp. 1–4 (2019). https://doi.org/10.1109/CCECE.2019.8861827

11. Ahmad, S., Shakir, M., Ahmad, B., Aslam, Z., Qaiser, M., Aslam, S.: Development of an IoT based DAQ system for PV monitoring and management. In: 2022 International Conference on Engineering and Emerging Technologies (ICEET), pp. 1–6 (2022). https://doi.org/10.1109/ICEET56468.2022.10007393
12. Hojabri, M., Kellerhals, S., Upadhyay, G., Bowler, B.: IoT-based PV array fault detection and classification using embedded supervised learning methods. Energies **15**(6), Art. No. 6 (2022). https://doi.org/10.3390/en15062097
13. Mellit, A., Hamied, A., Lughi, V., Pavan, A.M.: A low-cost monitoring and fault detection system for stand-alone photovoltaic systems using IoT technique. In: Zamboni, W., Petrone, G. (eds.) ELECTRIMACS 2019. LNEE, vol. 615, pp. 349–358. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-37161-6_26
14. Hamied, A., Boubidi, A., Rouibah, N., Chine, W., Mellit, A.: IoT-based smart photovoltaic arrays for remote sensing and fault identification. In: Hatti, M. (ed.) Smart Energy Empowerment in Smart and Resilient Cities. LNNS, vol. 102, pp. 478–486. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-37207-1_51
15. Current Sensor ACS712 (AC or DC) 30A. Future Electronics Egypt. https://store.fut-electronics.com/products/current-sensor-acs712-ac-or-dc-30a. Accessed 19 Mar 2023
16. Módulo Sensor Medidor de Voltaje Breakout FZ0430. Carrod. https://www.carrod.mx/products/modulo-sensor-fz0430-medidor-de-voltaje-breakout. Accessed 19 Mar 2023
17. J. A. K. Electronics. DS18B20+PAR Maxim Integrated - Analog Output Temperature SensorsJAK Electronics. https://www.jakelectronics.com/productdetail/maximintegrated-ds18b20par-6131397 Accessed 19 Mar 2023
18. Intelligent Detection of Solar Radiation Energy. https://rainbowsensor.en.made-in-china.com/product/uwrtdLzYggRo/China-Intelligent-Detection-of-Solar-Radiation-Energy.html Accessed 19 Mar 2023