Data Collection Methodology in the 3.4 kWp Photovoltaic Power Plant at the Faculty of Engineering and Applied Sciences of the Technical University of Manabí

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Abstract
Real-time monitoring has a wide variety of applications across diverse sectors, as it allows for the immediate acquisition, processing, and analysis of data for timely decision-making. In the energy sector, it facilitates the efficient management of electrical and photovoltaic systems through the continuous observation of consumption and generation. The proposed methodology is based on experimental research that includes electrical design and the strategic placement of sensors; simulation of the monitoring system using specialized software; construction of a prototype with electrical and environmental sensors integrated into an Arduino ESP32 microcontroller; and testing of the system with backup power to ensure continuous data collection. The objective was the continuous monitoring of photovoltaic generation through the remote capture of electrical parameters (voltage, current, power, power factor, and frequency) and environmental parameters (irradiance, temperature, and humidity), sending the information to an institutional server for visualization on an interactive geoportal. The Internet of Things (IoT) was applied as the methodology. The results validate the system's accuracy and stability, facilitating dynamic analysis of plant performance and promoting applied research, predictive maintenance, and academic training in renewable energy. The implementation helps overcome previous limitations in data management and storage and positions the university as a leader in sustainable solar technologies in Manabí.

Keywords: Solar photovoltaic energy, monitoring system, data collection, smart sensors, geoportal, IoT.

Introduction

In recent decades, the transition to renewable energy sources has become a strategic priority globally, due to increased energy demand and the urgent need to mitigate the effects of climate change. Among the most promising alternatives, photovoltaic solar energy stands out for its inexhaustible nature, low environmental impact, and ability to generate electricity from solar radiation through the photoelectric effect (Carmona & Díaz, 2018), (Ayman, et al. 2025).

Technological advances in semiconductor materials, the reduction of production costs, and the fact that photovoltaic energy is a clean energy source has experienced sustained growth in recent years, currently being one of the main sources of clean generation in the world (National Geographic Editorial Staff, 2022) (Utpal, et al., 2018).

The efficiency and reliability of photovoltaic systems depend not only on the quality of the solar cells, but also on the accuracy of the monitoring and data collection processes, which allow the analysis of the electrical and environmental behavior of the installation (Ormachea & Serna, 2009), (Moaz & Imran, 2025).

Data collection systems are an essential tool for diagnosing the performance of solar modules, detecting faults early, and planning predictive maintenance. The continuous recording of variables such as current, voltage, irradiance, and temperature enables a comprehensive evaluation of the plant's energy performance (Solano, 2022), (Sameera & Mohd, 2024).

In Ecuador, the development of photovoltaic energy has gained prominence in recent years, driven by policies aimed at diversifying the energy mix and reducing dependence on fossil fuels. This has resulted in significant growth in the installation of solar power plants (Plaza, 2018), supported by public-private partnerships seeking to strengthen the use of clean technologies. Furthermore, national research has demonstrated the country's potential for solar power generation, highlighting the importance of data mining and predictive analytics as tools for optimizing energy production (Fabara, Maldonado, Soria & Tovar, 2019). Research has also focused on smart grids as a necessary element to address the increasing energy demand (Checa, Cabrera, Sampietro, Valencia, & Ulloa, 2024).

The Technical University of Manabí (UTM), committed to applied research and environmental sustainability, has implemented a 3.4 kWp photovoltaic power plant located on the rooftop of the Faculty of Engineering and Applied Sciences (Cajape, Cedeño, Cedeño, Molina, & Zambrano, 2023). However, the system presents several limitations in the management and storage of plant information, including power outages, deficiencies in data transmission, lack of storage capacity, and irregular data collection. These problems generate inconsistencies in the records and hinder an accurate evaluation of the system's performance, affecting the reliability of technical and academic analyses.

Faced with this problem, the need arose to develop a data collection methodology that guarantees the accuracy, continuity and availability of the information generated by the photovoltaic plant.

The integration of digital technologies, such as smart sensors, microcontrollers, cloud storage systems and remote monitoring platforms, constitutes a viable alternative to improve data management and optimize system efficiency (Haonan, et al., 2023), (Quiguango, 2024).

The use of data science and machine learning tools can contribute to advanced information analysis, facilitating pattern detection, failure prediction, and informed decision making (Yajure, 2023).

Internationally, leading solar energy producers such as Germany, Japan, China, and the United States have developed management models based on the automation and digitalization of monitoring systems (Shuo & Gerd, 2024; Kangas, Ollikka, Ahola, & Kim, 2021). In Latin America, countries like Brazil, Chile, and Mexico stand out for their policies promoting photovoltaic energy, achieving significant progress in installed capacity and technological competitiveness (Enciso, 2019; Ángulo, 2018). In this context, Ecuador seeks to position itself as a regional leader in the research and development of sustainable renewable technologies.

Materials and methods

The methodology employed was of an experimental type approach, since a monitoring system for the 3.4 kWp photovoltaic plant located on the terrace of building 1 of the Faculty of Engineering and Applied Sciences (FICA) of the UTM was developed, implemented and evaluated, using a bibliographic review, the inductive-deductive method and qualitative and quantitative research in order to analyze its operation under real operating conditions.

Analysis and discussion of the results

Continuous monitoring of photovoltaic generation through remote parameter capture has become an essential tool for optimizing the efficiency and reliability of solar systems. Critical variables such as irradiance, module temperature, current, and voltage are recorded via sensors and IoT devices and sent to cloud platforms for real-time analysis. This constant monitoring facilitates early fault detection, predictive maintenance, and maximization of energy performance (Chouder & Silvestre, 2010). Furthermore, recent research demonstrates that implementing wireless sensor networks and intelligent algorithms significantly improves maximum power point tracking efficiency, achieving values exceeding 99% even under varying irradiance conditions (Wang et al., 2021; Benítez-López et al., 2022).

In this regard, remote data acquisition is an essential strategy for ensuring the sustainability and intelligent control of modern photovoltaic plants. Figure 1 illustrates the proposed methodology for the data collection design phases in the 3.4 kWp photovoltaic plant.

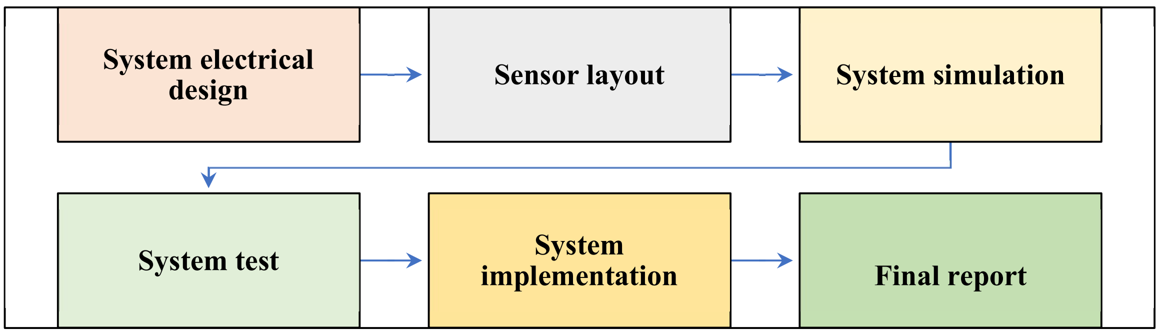

Figure 1. Proposed methodology for the phases of methodological design

Electrical system design

The initial phase comprises the electrical design of the photovoltaic plant's monitoring system, analyzing the appropriate alternatives for the plant. It should be remembered that solar panels transform solar radiation into electrical energy, so it is necessary to monitor in a photovoltaic generation system the electrical generation, voltage, current, energy, power factor, active power, and the meteorological parameters, solar radiation, relative humidity, ambient temperature.

The search for measuring elements for electrical and meteorological parameters laid the foundations of the system. Using the Fritzing electrical design software, the use of modules for measuring these parameters was established, linked to a microcontroller. The latter will send the information via a wireless network to the UTM database.

The planning allowed for the definition of an optimal distribution of the components, guaranteeing accuracy in the measurements and ease in the maintenance of the system. Below, in figure 2, the design of the electrical connection between the measurement modules and the microcontroller in the Fritzing software can be observed.

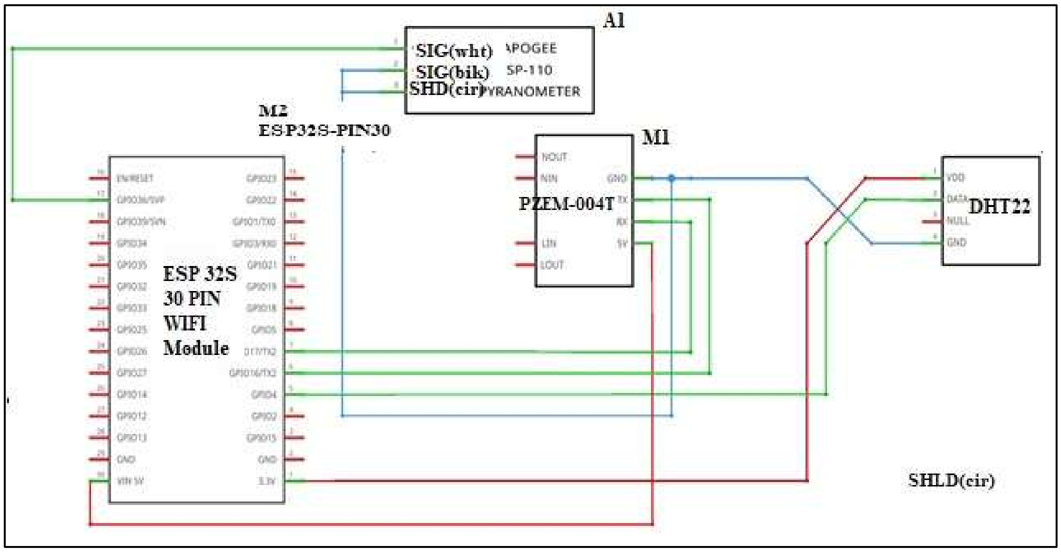

Figure 2. System design in Fritzing software

Simulation of the monitoring system

The simulation of the proposed monitoring system was developed, where the functional architecture of the system was established, defining the measurement modules for recording the electrical generation parameters of the pv system and the atmospheric variables.

The simulation is done in the same design software; this allowed verification of the correct interaction between the sensors and the main controller, anticipating possible failures in communication or data processing. Figure 3 shows the simulation of the sensors for measuring electrical and atmospheric parameters using a microcontroller in the Fritzing software.

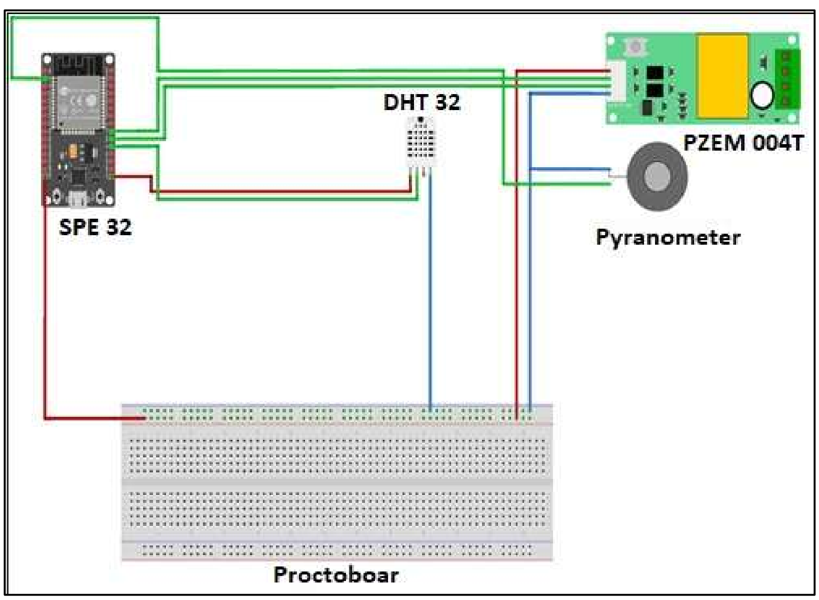

Figure 3. *System simulation in Fritzing software*

Figure 3 shows a data acquisition system based on an ESP 32, connected to a DHT22 sensor, a pyranometer, and a PZEM-004T module, all interconnected via a breadboard that distributes power and ground. The Arduino supplies 5V and GND to the sensors and uses a digital pin (pin 2 to be more precise) to receive the data signal from the DHT22, which provides temperature and humidity. The pyranometer is connected via an analog output to pin A1 of the Arduino to measure solar radiation. The PZEM-004T module, used to measure AC electrical parameters such as voltage, current, power, and energy, communicates with the Arduino via digital pins 11 and 12 and also includes a current transformer (CT) shown in the figure. All system grounds are unified to ensure a common reference, while the breadboard facilitates the order and distribution of connections, allowing the Arduino to simultaneously integrate environmental variables (temperature, humidity and solar radiation) along with electrical variables from the PZEM-004T, forming a complete monitoring system.

System test

The module for measuring electrical generation is the PZEM_004T energy and power measurement module. This module allows the measurement of electrical parameters such as voltage, current, frequency, power factor, energy, and power. Figure 4 below shows the location of the monitoring system components in the inverter cabinet.

Figure 4. *Location of the monitoring system components in the inverter cabinet*

For recording atmospheric variables, ambient temperature, solar radiation, and relative humidity sensors were used, all integrated and controlled by an Arduino ESP32 module. This module establishes wireless communication via Wi-Fi with a router that transmits the data to the UTM web server. Throughout this testing phase, the region experienced scheduled power outages, which led to problems with the monitoring system. For this reason, a backup power supply (UPS) was installed for the monitoring system.

Importance of implementing a backup power supply (UPS) in metering systems

Implementing a backup power source, such as an Uninterruptible Power Supply (UPS), is essential to ensure the continuity and reliability of measurement systems, especially in environments where data accuracy and availability are critical. A UPS protects equipment from power failures, voltage fluctuations, or outages, preventing data loss and damage to sensors or recording devices. It ensures that monitoring and control processes remain operational during interruptions, contributing to the stability of electrical networks and enabling real-time, data-driven decision-making (Ardila, Sanabria, & Hernández, 2015).

The integration of UPS systems into critical infrastructures allows for the traceability and continuity of measurements (Hernández et al. (2022)), strengthening the resilience of facilities against unplanned events. Thus, power backup becomes an indispensable component within modern energy management and industrial instrumentation (Köhler et al., 2020; Katarzyński & Olesz, 2020), as shown in Figure 5.

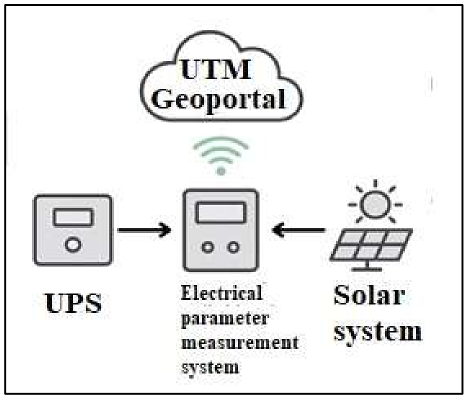

Figure 5. *System flowchart*

The measurement system is complemented by a backup power supply (UPS), ensuring operational continuity in the event of power outages.

Implementation of the data collection system

The final stage consisted of the experimental verification of the monitoring and data collection system. The components were installed in the field, and comparative tests were performed between the measurements obtained by the system and those recorded by reference instruments, such as digital multimeters for electrical parameters and a thermal imaging camera for temperature measurement.

The implementation of the monitoring system for the 3.4 kWp photovoltaic plant belonging to the Faculty of Engineering and Applied Sciences at the Technical University of Manabí, and its integration into the institutional geoportal, yielded highly satisfactory results. The system allowed for the continuous visualization of electrical and atmospheric parameters, with automatic hourly updates, ensuring dynamic monitoring of the photovoltaic array's performance, as shown in Figure 6.

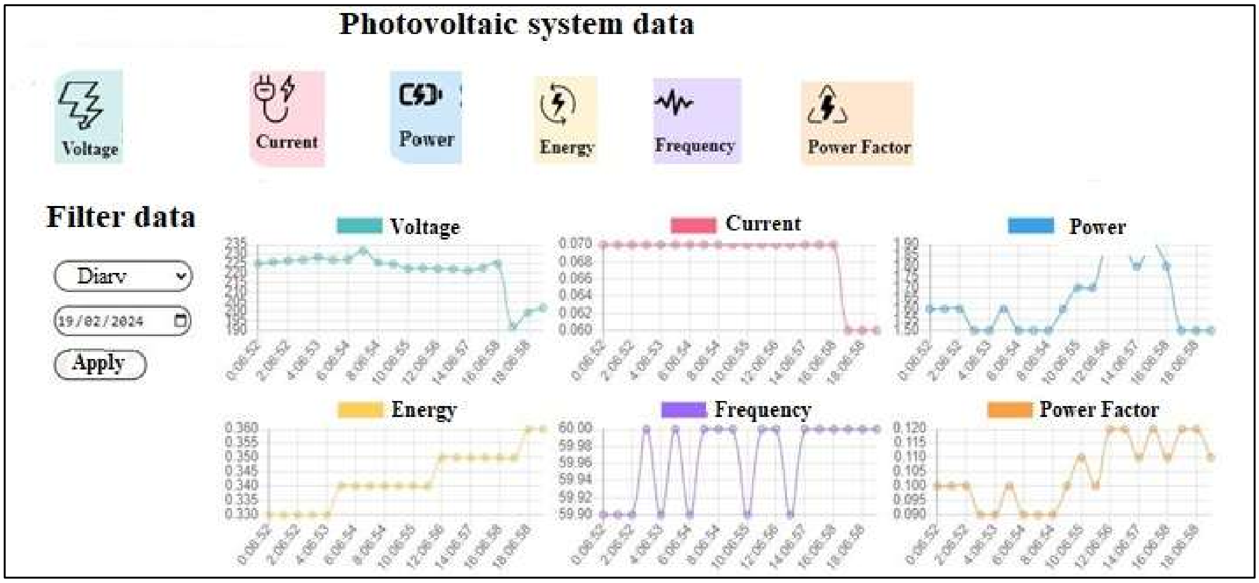

Figure 6. Information observed in the geoportal.

The institutional Geoportal displays real-time information about the 3.4 kWp photovoltaic plant. The collected data is presented through interactive graphs that facilitate the visual interpretation of monitored variables, such as generated power, stored energy, solar radiation, temperature, and relative humidity. The system allows for the collection of daily, monthly, and annual data, which can then be downloaded and used for various types of analysis.

This graphical representation allows for easy identification of daily and seasonal trends, as well as variations associated with local weather conditions. These results have demonstrated reliable system performance, with adequate correspondence between measured values and reference instruments.

The correlation between the system measurements and the reference values of calibration instruments showed a reduced margin of error, which validates the accuracy of the implemented sensors. In addition, stability in data transmission was demonstrated through the Wi-Fi connection and the institutional server, without significant loss of information.

The monitoring system is becoming established as a fundamental tool for applied research and academic development at the photovoltaic plant. The recorded data not only allows for the evaluation of the solar modules' energy performance but also serves as a basis for conducting economic analyses, developing preventive and corrective maintenance strategies, conducting thermal studies related to conversion efficiency and temperature losses, and predicting future performance.

The availability of this information on an institutional access platform encourages the participation of the university community in the analysis of photovoltaic systems, promoting the practical training of students and interdisciplinary research in areas such as electrical, electronic, environmental and other disciplines.

Conclusions

The designed monitoring system showed a high correlation with the reference instruments, demonstrating the accuracy in the measurement of electrical and atmospheric variables, proving the reliability of the sensors and the proposed data collection method.

The availability of real-time information, through the institutional geoportal, facilitates the interpretation of trends and the analysis of the behavior of the photovoltaic system under various environmental conditions.

The integration of technologies such as microcontrollers, smart sensors, and IoT demonstrates the potential of different low-cost solutions to modernize the monitoring of photovoltaic systems, helping various projects that can be carried out at the plant.

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