SITEKIN: Jurnal Sains, Teknologi dan Industri, Vol. 22, No. 1, December 2024, pp.190 - 197
ISSN 2407-0939 print/ISSN 2721-2041 online

Design and Development of an Off-Grid Solar Power Monitoring System on A 160 Wp PV System at SMPN 04 Tempurejo, Jember Regency

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ABSTRACT

Solar energy can be converted into electrical power through photovoltaic (PV) technology, commonly referred to as solar panels. As a result, the implementation of a monitoring system is crucial to mitigate battery degradation caused by excessive discharging. This study employs a research and development (R&D) approach. The off-grid solar power monitoring system installed at SMPN 04 Tempurejo is designed to facilitate maintenance and enhance system reliability. By integrating Internet of Things (IoT) technology, the monitoring system allows for real-time tracking of voltage, current, and power output from the PV system via smartphone access, irrespective of location. Consequently, the IoT-based monitoring system significantly improves the management and oversight of the off-grid solar power system at SMPN 04 Tempurejo.

Keywords: *Solar Power, Monitoring System, Off-Grid, IOT*

Introduction

The utilization of renewable energy sources is increasingly being adopted to meet the growing demand for electricity. Indonesia possesses significant renewable energy potential, yet its utilization remains suboptimal [1]. With advancements in technology and the gradual depletion of fossil fuels used for electricity generation, researchers are exploring ways to harness the natural resources available to us, focusing on renewable energy sources [2]. One of the key applications of renewable energy is the conversion of solar energy into electricity, which is currently being actively developed by the Indonesian government [3,19,20]

The availability of Indonesia as a tropical country serves as an asset for electricity generation using photovoltaics [13]. Photovoltaic (PV) technology is a method for generating direct current electricity using semiconductor-based solar panels that produce energy when exposed to photon light [14]. Solar energy can be converted into electrical power through photovoltaic (PV) technology, commonly referred to as solar panels. Indonesia's solar energy potential is estimated at 200,000 MW (ESDM, 2021). Solar panels are devices that utilize the photovoltaic effect to convert sunlight into electrical energy [4,21,22]. The advancement of photovoltaic technology and improvements in energy efficiency are essential for fostering innovation in the renewable energy sector [5]

Previously, researchers installed a 150 Wp solar panel at SMPN 04 Tempurejo, located in Curahnongko Village, Tempurejo District, Jember Regency, to support teaching and learning activities. Curahnongko Village is situated in a lowland area surrounded by hills and has a solar irradiation potential of 990 W/m² per day. However, the output power of the installed solar panel fluctuates [17]. This fluctuation is caused by environmental factors such as solar irradiation, temperature, dust, and unpredictable weather conditions, which affect the panel's output power [6]. Due to the instability of energy produced by photovoltaic (PV) systems, off-grid solar power systems require a battery as an energy storage solution [23]. The primary function of the battery in an off-grid system is to store the energy generated by the PV panels [24]. The off-grid solar power system installed at SMPN 04 Tempurejo, Jember, utilizes a battery with a capacity of 100 Ah at 24 volts.

The installed off-grid solar power system (PLTS) has been in operation for 12 months. Due to the limited storage capacity of the system, efficient load usage is necessary. Solar power systems require monitoring to optimize performance and ensure the functionality of their components [7]. Therefore, a monitoring system is needed to reduce battery lifespan degradation caused by excessive discharging [18]. This monitoring system allows users to track the condition of the battery and other electrical components. It is expected that the implementation of this monitoring system will assist both our partners and us in overseeing the solar power system, while also enhancing the safety of the installed system.

The problem identification process involves investigating the issues present at SMPN 04 Tempurejo, specifically related to the off-grid PV system. During this process, the researchers conducted an observation of the solar power system at SMPN 04 Tempurejo and found that the system lacked equipment to monitor the power output generated by the PV. As a result, the power produced by the PV could not be optimally utilized, leading to a reduction in battery lifespan.

Based on the problem identification above, the purpose of the paper is to present the design, development, and implementation of an IoT-based monitoring system for the off-grid solar power system at SMPN 04 Tempurejo. The system aims to enhance the supervision and management of the solar power setup by providing real-time data through calibrated sensors and internet connectivity. This facilitates efficient monitoring and ensures the reliability of the solar power system.

Research Methods

The method employed in this research is research and development (R&D). According to Borg & Gall (1983: 772), educational research and development (R&D) is a process used to develop and validate educational products. The objective of this study focuses on the design and development of an off-grid solar power system (PLTS) monitoring system at SMPN 04 Tempurejo, Jember. The monitoring system designed in this research is limited to testing the voltage, current, and power monitoring at the input and output of the inverter, using a smartphone.

Component Data Collection

The primary components used in the off-grid photovoltaic monitoring system at SMPN 4 Tempurejo are as follows:

1. Microcontroller ESP 32

The ESP32 is an integrated SoC (System on Chip) microcontroller equipped with WiFi 802.11 b/g/n, Bluetooth version 4.2, and various peripherals. This chip uses a 32-bit Xtensa LX6 dual-core microprocessor. It features 18 ADC pins (12-bit), four SPI, and two I2C interfaces. The main advantages of this microcontroller include its relatively low cost, ease of programming, an adequate number of I/O pins, and an internal WiFi adapter for internet connectivity [8].

Figure 1. Microcontroller ESP 32

2. PZEM-004T

The PZEM-004T is an electronic sensor module used to measure AC voltage, current, power, power factor, and electrical energy. The PZEM-004T can provide information related to the performance and characteristics of the electrical power system [15]. This module can be interfaced with a microcontroller using the Arduino IDE or other open-source platforms. Communication with the microcontroller is done via TTL serial communication through the RX and TX pins. The sensor module is capable of measuring voltage within the range of 80 to 260 VAC and a maximum current of 100A. It can also measure power up to 23 kW and electrical energy up to 9999 kWh [9].

Figure 2. PZEM-004T

3. PZEM-017T

The PZEM-017T is a sensor module used for measuring DC voltage and current. This module can be interfaced with a microcontroller using RS485 communication. The sensor is capable of measuring voltage in the range of 0.05 to 300 VDC and a maximum current of 300A. Additionally, it can measure power up to 90 kW and electrical energy up to 9999 kWh [10].

Figure 3. PZEM-017T

4. USB TTL to RS485

The UART TTL to RS485 Converter module is used as an interface for RS485 communication via serial (UART TTL) communication. This module is employed in microcontrollers to communicate with devices that use RS485 protocol. It supports data transfer speeds of up to Mbps and can communicate with multiple slave devices, accommodating up to 32 devices [11].

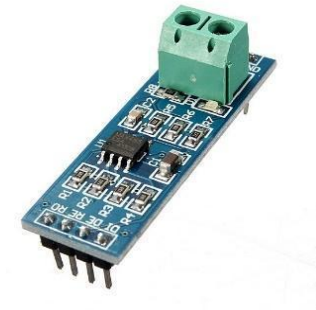

Figure 4. USB TTL to RS 485

5. TFT OLED 1,8'

TFT OLED is a display screen used to showcase a variety of colors with a resolution of 128x160 pixels. The TFT screen type offers better quality, including higher image quality and resolution, compared to LCD screens. This display can communicate with all types of microcontrollers using the SPI protocol, requiring only four I/O pins.

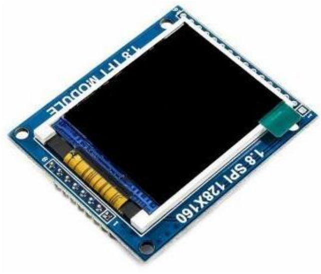

Figure 5. TFT OLED 1,8"

Design and Working Principle of the Device

The working principle of the off-grid solar power monitoring system utilizes the ESP32 as a microcontroller. The PZEM-004T is used to monitor the voltage, current, and power output of the inverter, while the PZEM-017T monitors the voltage, current, and power output of the solar panel. These measurements can be monitored in real-time via an LCD display or through a smartphone via the internet, using the WiFi capabilities of the ESP32.

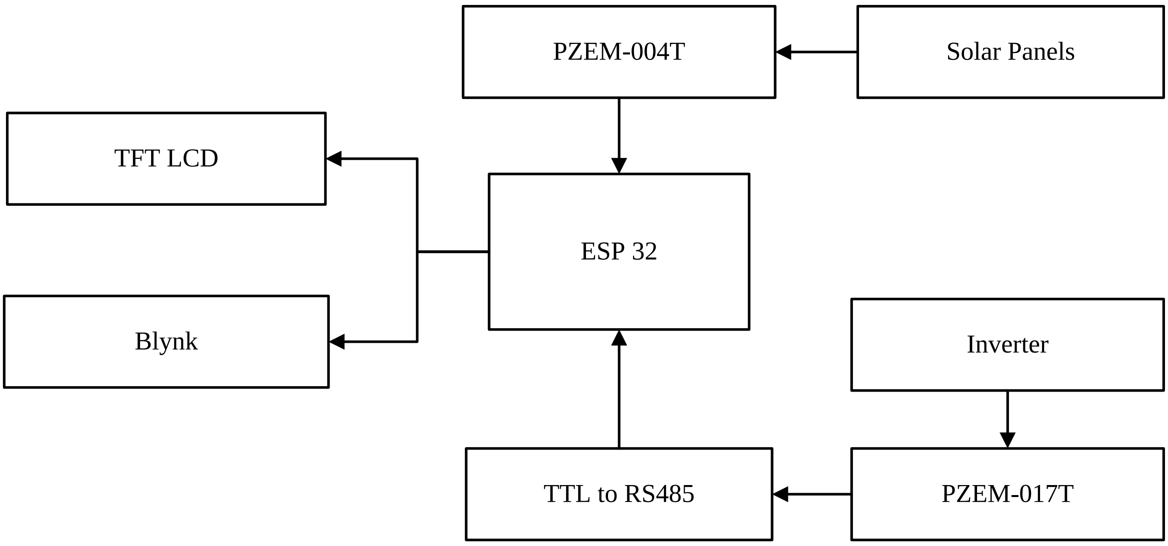

Figure 6. Working Principle of The Tool

Results and Discussion

The installation process includes the mounting of the PZEM-017 and PZEM-004T sensor modules, followed by the installation of the microcontroller module. Tools used during the installation include a screwdriver, double-sided tape, and scissors. This monitoring system can be viewed through an LCD display located on the control box and also via the Blynk app. Several parameters can be monitored, including voltage, current, power, energy, frequency, power factor, reactive power, and apparent power. Additionally, there is a graph available to facilitate easier monitoring of the solar power system.

The off-grid solar power monitoring system at SMPN 04 Tempurejo serves to facilitate maintenance and improve the reliability of the solar power system at SMPN 4 Tempurejo. Typically, solar power system parameters are limited to the Solar Charge Controller (SCC). With the IoT-based monitoring system, measurements can be taken in real-time and accessed via the internet. The schematic of the monitoring system's operation can be seen in figure 7.

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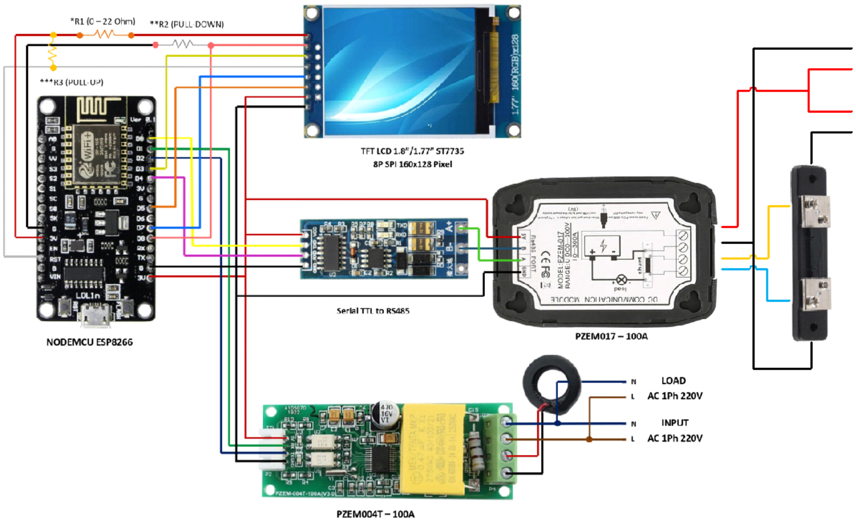

Figure 7. Monitoring System Wiring Diagram

This monitoring system can be accessed at any time as long as the smartphone is connected to the internet, making it easier to maintain the solar power system. Similar to [12] the development of a monitoring system using photovoltaic as a power source and the implementation of Internet of Things (IoT) technology allows for real-time environmental monitoring.

In this study, the data obtained from the current and voltage measurements conducted by the sensors are automatically stored in a Blynk application database. Consequently, the monitoring system for the off-grid solar power system at SMPN 04 Tempurejo heavily relies on a stable internet connection. However, this study is still limited by the stability of the internet connection and the lack of an internal feature for offline data storage. Due to the absence of internal data storage, some current and voltage measurements may not be recorded. Therefore, this system requires further development by incorporating a feature to record current and voltage data during periods of unstable internet connectivity. Additionally, the system should update the Blynk database once the internet connection is restored.

The solar power monitoring system data is stored in a database that can be integrated and displayed via the Blynk application. The Blynk application is an application for iOS and Android used for remote control via the internet [16]. Figure 8 shows the interface of the solar power monitoring system application at SMPN 4 Tempurejo, as viewed on a smartphone.

The sensors used in the monitoring system have been calibrated using measurement tools that meet standard measurement criteria. The calibration process was carried out by comparing the measurement results obtained using an SNI-certified multimeter with those obtained from the current and voltage sensors. Furthermore, to determine the percentage error of the sensor's detection, the following equation (1).

$$Error\ (\%) = \frac{multimeter - sensor}{sensor} \times 100\% \quad (1)$$

Presented below are the measurement results obtained from the monitoring system, comparing the data from a multimeter with the readings from the current and voltage sensors that are shown in Table 1. and Table 2.

Table 1. Measurement Voltage Results

Monitoring Voltage					
DC		Error %	AC		Error %
Multimeter	Sensor		Multimeter	Sensor	
19,5	19,56	0,31	242	242	0,00
19,1	19,21	0,57	235	236	0,42
17,5	17,63	0,74	233	233	0,00
18,5	18,49	0,05	234	235	0,43
Average		**0,42**	Average		**0,21**

Table 2. Measurement Current results

Monitoring Voltage					
DC		Error %	AC		Error %
Multimeter	Sensor		Multimeter	Sensor	
2,48	2,49	0,40	0,24	0,24	0
2,31	2,33	0,86	0,23	0,23	0
2,18	2,19	0,46	0,2	0,2	0
2,22	2,24	0,89	0,22	0,22	0
Average		**0,65**	Average		**0**

Figure 8. Monitoring System Interface

The measurement results indicate that the average percentage error for the current sensor is 0.35%, and for the voltage sensor is 0.32%. These average percentage errors are within the acceptable tolerance of 1% for current and voltage sensors [25]. The monitoring system results show that the measurements are within the standard measurement limits, ensuring that the monitoring system is suitable for use.

Conclusion

Based on the research and development of the Internet of Things (IoT)-based off-grid solar power monitoring system at SMPN 04 Tempurejo, the following conclusions can be drawn:

1. The primary function of the monitoring system is to provide real-time supervision and control of the off-grid solar power system, enhancing its operational reliability and management.
2. The system incorporates key components, including the ESP32 microcontroller, PZEM-004T and PZEM-017 measurement modules, TFT LCD for data display, and an RS485 communication module, ensuring efficient data acquisition and processing.
3. All sensors integrated into the system have been calibrated in accordance with established measurement standards, ensuring accuracy and consistency in data reporting.

4. The system is designed with internet connectivity, enabling seamless remote access and control, thereby improving user convenience.
5. The implementation of this IoT-based monitoring system significantly simplifies the supervision process for the off-grid solar power system at SMPN 04 Tempurejo, offering a practical and scalable solution for similar applications.

The limitation of this study in monitoring the system does not cover all relevant metrics. Further research is needed to include metrics that affect the performance and efficiency of the solar power system.

Acknowledge

Thank you for SMPN 04 Tempurejo, Jember Regency as a place for research.

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