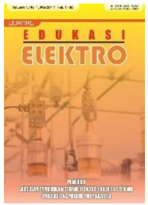
Volume 8, No. 2, November 2024, pages 172 - 186

JEE

Jurnal Edukasi Elektro

https://dx.doi.org/10.21831/jee.v8i2.78488



IoT-based Epever Tracer 1210 MPPT Monitoring System Using Modbus Communication Protocol

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Abstract— This research examines the integration of Maximum Power Point Tracking (MPPT) technology with Internet of Things (IoT) and Modbus communication protocols in solar energy systems, with the main objective of increasing efficiency and enabling real-time performance monitoring. The research method used is experimental. The Epever Tracer 1210 MPPT is used to optimize energy absorption from solar panels, while IoT devices are connected via ESP32 using Modbus protocol. Data such as current, voltage, power, and energy generated are collected and analyzed in real-time using the Blynk app. Tests were conducted at three time periods (morning, afternoon, evening) to measure the accuracy and consistency of the data, and the results show that the IoT-based monitoring system provides accurate data, with minimal difference between the data from the MPPT, measuring instruments, and Blynk application. In addition, the integration of Modbus RTU with the IoT platform improves communication efficiency and security. IoT-connected MPPT technology has proven effective in improving operational efficiency and power conversion in solar energy systems, enabling optimal energy absorption in various weather conditions, thereby maximizing energy production. IoT integration also strengthens the real-time remote monitoring system, which is essential for early detection of faults or performance degradation.

Keywords: solar energy, mppt, iot, modbus protocol, real-time monitoring.

Article submitted 2024-10-21. Resubmitted 2024-11-10. Final acceptance 2024-11-17. Final version published as submitted by the authors.

1 Introduction

The development of renewable energy technologies, particularly solar energy, is a key focus in global efforts to reduce reliance on fossil fuels. The uncontrolled consumption of fossil fuels leads to environmental degradation, and with rapid economic growth and population increase [1], energy demand continues to rise. As a result, renewable energy sources are increasingly installed to meet this demand. However, addressing variability and intermittency remains a major challenge in enhancing the reliability and efficiency of these systems. Currently, the world is actively seeking renewable energy sources such as water [2].

One of the most widely used forms of alternative energy utilization is solar energy, which is the largest source of energy the Earth has. Of all the sunlight emitted to Earth, only about 30% returns to space [3]. The rest can be utilized for various purposes, one of which is through solar panels, which convert solar energy into electrical energy. Along with the times, the need for electrical energy continues to increase, making it important to develop sustainable alternative energy sources, such as solar power plants [4]. Solar panels act as the main component in a solar power generation system, directly converting sunlight energy into electrical energy. Solar cells in solar panels are made of silicon, which has an excellent ability to absorb solar thermal energy. When the solar panel operates in sunlight, the solar thermal energy is converted into electrical energy [5].

However, the efficiency of this energy conversion is influenced by various factors. The efficiency of solar panels depends on the level of sunlight available. If you live in an area with little sunlight, solar panels may not provide optimal results. Although solar panels are capable of generating electricity from sunlight, weather factors such as thick clouds or adverse weather conditions can affect charging efficiency [6]. Therefore, sufficient sunlight plays a crucial role in the efficiency of using solar panels. To optimize the absorption of solar energy and increase its conversion efficiency, technology that can maximize the maximum power point (Maximum Power Point Tracking or MPPT) is needed.

MPPT is a method used to find the optimal operating point of an energy resource to produce maximum power in various load and weather conditions. The maximum output power of the solar panel is achieved at a certain current and voltage value. In order to get maximum solar energy, the solar panel must be directed directly at the sun [7]. The Epever Tracer 1210AN charger controller, is one of the MPPT controllers designed to optimize energy absorption from solar panels. The Tracer-AN series charge controller (10A~40A) uses MPPT technology that allows the device to track the maximum power point (MPP) of the solar panel array in all conditions, so that it can get the maximum solar energy quickly and precisely. Compared to PWM charge controllers, this device is capable of producing up to 30% more power. The series can accept a maximum voltage of 100V Voc and is compatible with solar panels designed for on-grid applications. Its multi-function LCD displays the system status clearly [8]. While these devices can work independently to improve energy conversion efficiency, real-time monitoring and control of their performance is essential to ensure optimal performance [9].

In today's digital era, the use of Internet of Things (IoT) technology can optimize various aspects of life. IoT is recognized as an innovation that can be integrated into daily life to meet needs and make work easier [10]. IoT enables the integration of various devices over the internet network, enabling real-time data collection and analysis for better decision-making [11].In this context, the Modbus communication protocol is an ideal solution for connecting MPPT devices with IoT systems. Modbus is a two-way serial communication protocol that links a Modbus master (controller) with Modbus slaves (controlled devices). Developed by Modicon (now Schneider Electric), Modbus RTU is an open serial protocol known for its ease of use and reliability, commonly used in Building Management Systems (BMS) and Industrial Automation Systems (IAS). It employs RS-232 or RS-485 serial interfaces for communication and is compatible with a wide range of SCADA devices, Human Machine Interfaces (HMI), and OPC Servers, facilitating the integration of Modbus devices into both new and existing monitoring and control systems. As the most widely used variant of Modbus, its application in automation technology enhances production speed, material efficiency, occupational safety, and accuracy while minimizing human labor involvement [12].

Modbus works with a request/reply pattern. The request is made by the device acting as the master, while the reply is given by the device acting as the slave. In general, a Modbus data package consists of a Protocol Data Unit (PDU) and an Application Data Unit (ADU). PDUs include function code and data, while ADUs consist of PDUs that are added with addresses and error checks. Modbus is a simple, reliable, and widely used communication protocol in industry to connect electronic devices with computers or other control systems [13]. For this research, we use Modbus RS485 which allows multipoint communication involving master and slave. The master can connect to up to 32 slaves simultaneously using only two wires without the same ground reference. RS485 has an advantage in dealing with electrical disturbances in the transmission line, as the induction is received by both cables. Because the receiver compares the voltage difference between the two transmission wires, the voltage induction does not affect the output [14].

The use of Modbus in IoT-based monitoring systems facilitates efficient and reliable communication between MPPT devices and monitoring platforms. This study aims to design and implement an IoT-based monitoring system for the MPPT Epever Tracer 1210 controller using the Modbus protocol, providing accurate, real-time information on MPPT performance. This allows users to monitor and adjust settings to optimize the solar energy system's efficiency, while also enhancing their understanding of MPPT operation and maintenance. The research began with a literature review on MPPT technology, Modbus communication, and IoT applications in solar energy systems, followed by the design, implementation, testing, and analysis of the developed monitoring system. The findings are expected to significantly contribute to improving the efficiency and effectiveness of solar energy utilization through the integration of MPPT technology and IoT.

2 Literature Review

A literature review including previous research has shown the effectiveness of the use of MPPT in solar energy systems. Several studies have also discussed the use of IoT in energy monitoring, showing that this technology can improve efficiency and data management. The Modbus communication protocol has been widely used in industrial applications because of its reliability, the following authors present the conclusions of several scientific articles that lead to the author's topic, so that the latest and more accurate research titles can be raised regarding the results.

2.1. Monitoring MPPT

MPPT (Maximum Power Point Tracking) is a technique used to improve power conversion efficiency in renewable energy systems, such as solar panels, by finding the maximum power point that can be generated. The working principle of MPPT involves adjusting the output voltage and current of the energy source to keep it at the maximum power point, despite changes in environmental conditions, such as light intensity and temperature. Some of the algorithms used in MPPT include Perturb and Observe (P&O), Incremental Conductance, Constant Voltage Tracking (CVT), as well as artificial intelligence-based methods such as Fuzzy Logic and Neural Networks, all of which aim to ensure that the power generated is always optimal [15].

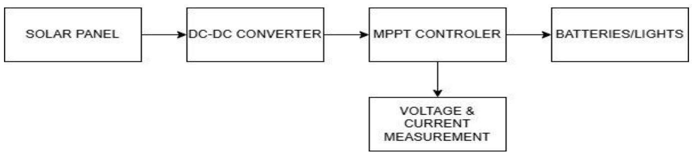

Fig. 1. Block diagram MPPT

In its application, MPPT is integrated with a DC-DC converter to regulate the output voltage of the energy source according to the needs of the load or energy storage. This converter uses PWM (Pulse Width Modulation) technique to adjust the duty cycle so that the maximum power point can be reached. The MPPT control continues to work dynamically by monitoring and adjusting the output voltage and current, so that the power entering the storage system or load is always in optimal condition. Nonetheless, the application of MPPT often faces challenges, such as reading errors under conditions of rapid radiation changes and limitations in remote monitoring. To improve system efficiency and flexibility, IoT technology can be applied in MPPT monitoring systems, enabling real-time monitoring and regulation remotely. By integrating IoT, data from sensors can be accessed through the internet network, which enables better monitoring and further automation to improve system performance and safety.

These results show that with IoT integration, the MPPT system can be more responsive to changes in environmental conditions, such as fluctuations in solar radiation intensity, so that the power delivered to the load or storage system remains optimized. The use of IoT enables real-time monitoring of system performance through the internet-based Blnyk application, which improves the limitations of traditional systems that rely on manual monitoring. In addition, it overcomes the problem of data reading errors that often occur in conventional MPPT systems due to the instability of solar radiation conditions. The IoT-integrated system allows for faster adjustments and repairs, minimizing errors in readings and improving overall system accuracy.

2.2. Modbus Protocol in The Industrial World

The Internet of Things (IoT) is a concept that connects physical devices to the internet network, allowing them to communicate and exchange data automatically. In industry, IoT is applied to improve efficiency and monitoring through the integration of interconnected sensors, actuators, and control systems. Each device can transmit data and receive commands to perform specific tasks, which enables process automation and smarter decision-making based on real-time data.

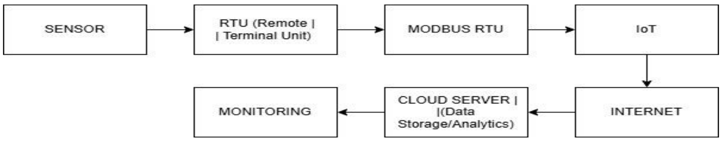

Fig. 2. Block diagram of control flow and bidirectional communication

To implement IoT in industrial control devices that use Modbus RTU, an IoT gateway is needed that can connect the Modbus RTU protocol with IoT communication protocols such as MQTT. An IoT gateway, such as a Raspberry Pi device, serves as a link between the Modbus RTU system that uses serial communication and the internet network, allowing data from industrial devices to be sent to the cloud to be analyzed and monitored remotely. This allows real-time monitoring and control of the system through web-based applications or mobile devices, increasing operational flexibility and efficiency [16].

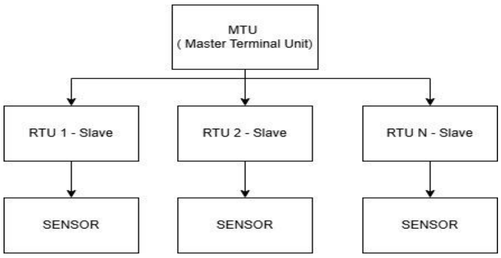

Fig. 3. Block diagram showing the flow of data

In MPPT (Maximum Power Point Tracking) systems, Modbus is used to collect data from sensors that measure voltage, current, and temperature from solar modules. The data is then sent through the IoT gateway and processed to optimize the performance of the DC-DC converter in maximizing the panel output power.

3 Method

This study uses an experimental approach with the following stages [17].

3.1. System Design

In the initial stage, the design of an IoT monitoring system based on Epever Tracer 1210 MPPT using Modbus communication protocol was developed. This design involves:

1. IoT infrastructure planning which includes hardware selection, such as the ESP32 IoT module as the link between the MPPT and the internet.

2. Data collection from the Epever Tracer 1210 MPPT, including parameters such as current, voltage, power, and energy generated. This data will be forwarded to the IoT device via Modbus protocol.
3. Configuration of Modbus communication between the MPPT and IoT devices, involving determination of device addresses, communication parameters, as well as setting up physical connections between devices.
4. Designing a user interface for real-time monitoring, which can be a dedicated application or dashboard to display historical data and MPPT.

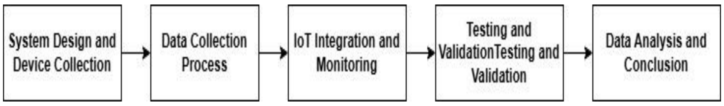

Fig. 4. Block diagram research steps

Some previous studies relevant to IoT-based solar power plant monitoring systems show useful results, but also have weaknesses. For example, research on solar PV monitoring systems using the Blynk application emphasizes the ease of remote monitoring and real-time data access. However, this system often suffers from network connection stability, which can disrupt data updates and reduce system reliability under poor internet connectivity conditions. In addition, studies on the use of MPPT for power optimization in solar power plants show that MPPT is very effective in keeping the output at the maximum power point, but they pay little attention to integration with remote monitoring technology, so users must be near the device to monitor data directly.

Another study comparing the measurement accuracy of solar power plant parameters using manual measuring instruments, integrated sensors, and IoT devices revealed that although IoT sensors can provide real-time data and easy access, their accuracy is sometimes lower than that of manual measuring instruments or more precise MPPT systems. The limited measurement resolution of IoT devices makes it difficult to accurately display detailed data in decimal numbers. These shortcomings point to the need for a system that integrates MPPT technology, IoT, and measuring instruments with a higher level of accuracy to ensure efficient monitoring and more consistent and reliable data.

Based on the flowchart in Figure 5, the incoming data will be processed by the MPPT Epever Tracer, where the data is processed into inputs and outputs on the PLTS (Solar Power Plant) system. Furthermore, this data will be transferred to the microcontroller through the Modbus communication protocol. Once the microcontroller receives the data, the information will be transmitted to the user's smartphone via the Blynk app, enabling real-time monitoring and control of the system.

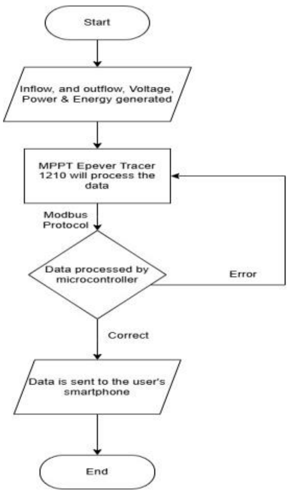

Fig. 5. Flowchart

3.2. Hardware Implementation

This stage involves:

1. Hardware installation, where the Epever Tracer 1210 MPPT is connected with the solar panel and battery. Data from the MPPT, such as current, voltage, power, and energy, is passed tothe ESP32 module.
2. The use of an RS485 module as a converter between Modbus and ESP32 protocols to bridge the communication between the MPPT and the IoT infrastructure.
3. Preparation of the physical circuit, which involves wiring and connections between the solar panel, MPPT, IoT module, as well as other hardware according to the circuit diagram.

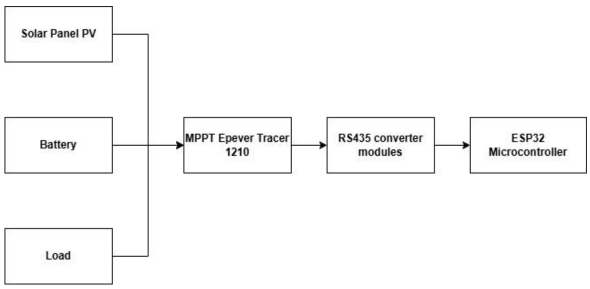

Fig. 6. Tool design diagram

The flowchart above shows the sequence of hardware that will be assembled into a single unit. Starting from the inputs, namely solar panels, batteries, and loads, which are then forwarded to the MPPT Epever Tracer for processing. After that, the data from the MPPT will be transferred to the ESP32 through the RS485 converter module, using the Modbus communication protocol. This whole circuit ensures the system runs according to its function in managing the energy from the solar panel.

Development of a more integrated and real-time solar power system by combining Epever Tracer MPPT technology, RS485 communication module, and ESP32 microcontroller for monitoring and control using Blynk application. This approach not only optimizes power management from solar panels but also makes it easier for users to monitor and control the system via smartphone. Optimization of power management is achieved through the combination of Epever Tracer MPPT and Modbus protocol via ESP32, thereby improving power absorption efficiency. Real-time monitoring via the Blynk app allows users to directly monitor system performance and detect problems quickly, while the integration of the Modbus protocol with the RS485 module ensures reliable data transfer between the hardware and the microcontroller. This makes up for the shortcomings of previous studies by addressing the oscillation problem that often occurs in traditional MPPT algorithms using a more stable Epever Tracer device. In addition, this study enhances data security in communication by using ESP32 which has encryption capabilities, addressing the concern of cyber-attacks on IoT-based systems.

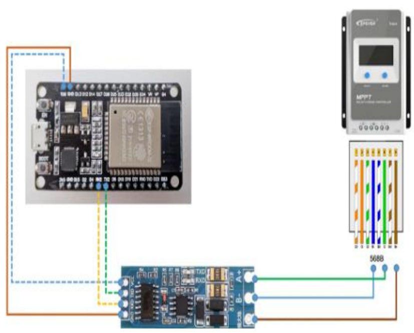

Fig. 7. Series of monitoring systems

The figure above shows the microcontroller circuit used to connect the MPPT Epever Tracer with the IoT-based Modbus communication system. This circuit consists of an ESP32 microcontroller and an RS485 converter module, which is connected to the MPPT Epever Tracer using a LAN cable. With this configuration, data from the MPPT can be monitored and managed.

3.3. Software Development

The software development phase aims to manage data collection and transmission from the MPPT through the Modbus protocol. The steps include.

1. Code development to handle communication with the MPPT and read sensor data.
2. Integration with an IoT platform, such as Blynk, which will store and display data in real-time via a cloud-based interface[18].
3. Database creation, structured to store the monitored data, allowing users to conduct further analysis of system performance.

4 Results and Discussion

The test results indicate that the system effectively monitors key parameters such as voltage, current, power, and temperature from the Maximum Power Point Tracking (MPPT) in real-time. The collected data is displayed on an IoT-based dashboard accessible via an internet connection, enabling practical and efficient remote monitoring. Data analysis shows that the system enhances solar energy monitoring efficiency and accelerates the early detection of potential issues, minimizing downtime and improving overall system reliability. Data was collected at three different times—morning, afternoon, and evening—using the MPPT Epever Tracer, conventional measuring instruments, and the Blynk platform, allowing for a comprehensive assessment of the solar energy system's performance under varying sunlight conditions.

The use of the MPPT Epever Tracer and conventional measuring instruments offers valuable insights into the differences between manual and automatic measurement techniques. Additionally, the integration of the Blynk platform enhances accessibility for users, allowing data to be monitored directly through mobile devices or computers. This flexibility enables users to supervise the solar energy system anytime and anywhere, thereby improving user engagement and responsiveness to system performance.

4.1. Testing and Validation

Testing and validation are conducted to evaluate the performance of the system. The testing process is carried out during three different periods of the day:

a. Morning (10:00-11:30)
b. Daytime (13:00-14:30)
c. Afternoon (15:30-17:00)

Measurements are taken every 10 minutes, focusing on the following parameters:

a. PV (Solar Panel) Voltage
b. PV Current
c. Load Voltage

The testing utilizes the Blynk application for real-time monitoring and instruments such as Avo meters and Clamp Ammeters to validate the measurement results.

Fig. 8. Feature apk blynk

Data collection through the Blynk application to monitor the measurement results on the Solar Power Plant (PLTS) which is placed in an open space aims to get optimal sunlight. The data taken includes voltage, current, solar panel. The Blynk application facilitates real-time monitoring, allowing us to easily record any changes to the measurement parameters. With this app, users can remotely monitor the performance of the solar farm, ensuring that the system is working efficiently under maximum sunlight conditions. The collected data is then analyzed to optimize the performance and maintenance of the solar panels in the future.

Fig. 9. Measurement using a measuring instrument

Data collection using Avo meter and amperage pliers aims to monitor the measurement results on the Solar Power Plant (PLTS), which is placed in an open space to receive optimal sunlight. Avo meters are used to measure voltage and current, while amperage pliers help monitor the electric current flowing without breaking the circuit. With these measuring instruments, we can accurately record any changes in parameters that occur, ensuring that the performance of the solar power plant remains optimal under maximum sunlight conditions. The data collected can be further analyzed to improve the performance and maintenance of solar panels in the future.

Fig. 10. Measurement via MPPT Epever Tracer screen monitoring

Data collection using MPPT Epever Tracer aims to monitor the measurement results on Solar Power Plants (PLTS) which are placed in open spaces to obtain optimal sunlight. MPPT (Maximum Power Point Tracking) Epever Tracer serves to optimize the absorption of power from solar panels by adjusting the voltage and current to match ideal conditions. It not only helps in maximizing battery charging efficiency, but also allows real-time monitoring of the voltage, current, and power generated. The data collected from the MPPT Epever Tracer is very useful to ensure the solar system is working optimally and can be further analyzed for future repairs or maintenance.

4.2. Testing in The Morning

Tests were conducted in the morning, from 10:00 to 11:30, including measurements using the Blynk application, manual measuring instruments, and MPPT Epever Tracer. The data taken includes PV voltage, PV current, and load voltage. The data obtained will then be graphed as in the figure below.

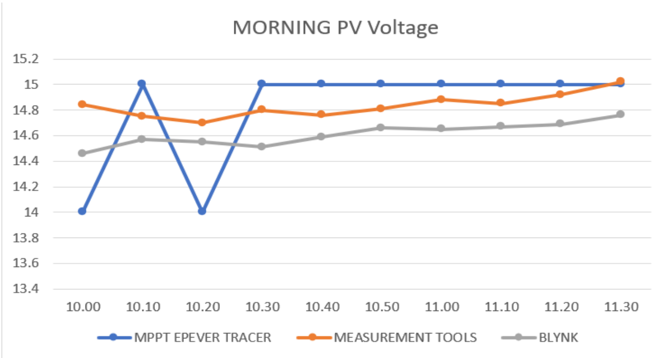

Fig. 11. Morning PV Voltage

From the graph above, the PV voltage of the three data is stable in the range of 14 to 15 volts. The data obtained through the Blynk application is also not much different from the measurement results using a manual measuring instrument, with the data results from up to the details on the decimal number. This shows that both the Blynk application and the manual measuring instrument provide consistent and accurate results, so they can be relied upon in monitoring the performance of the Solar Power Plant (PLTS). and the data on the Epever Tracer MPPT cannot show data in decimal so that the rounding of data at 14V and also 15V.

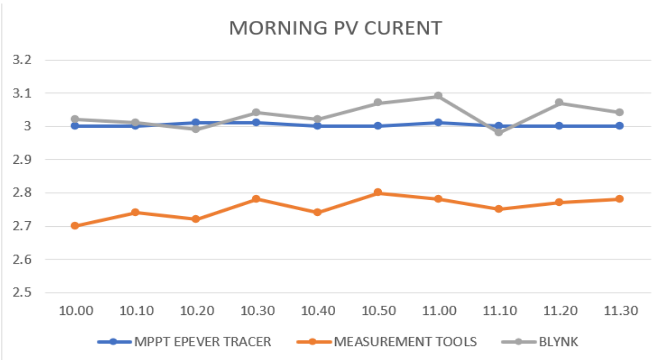

Fig. 12. Morning Curent PV

From the PV current graph above, the amount of PV current in the morning from all three data is in the range of 2.7 amperes to 3.1 amperes. The data obtained from the MPPT Epever Tracer and Blynk app are close to each other and dominate the graph, showing consistency in current measurement. Meanwhile, the data taken using the manual measuring instrument is slightly lower than the other two. This small difference is likely due to differences in the sensitivity of the manual measuring instrument or variations in the time of data collection. Nonetheless, the overall measurement results show that the solar system is operating well, and the current generated is within the normal range for morning tests, with only a small decimal point difference.

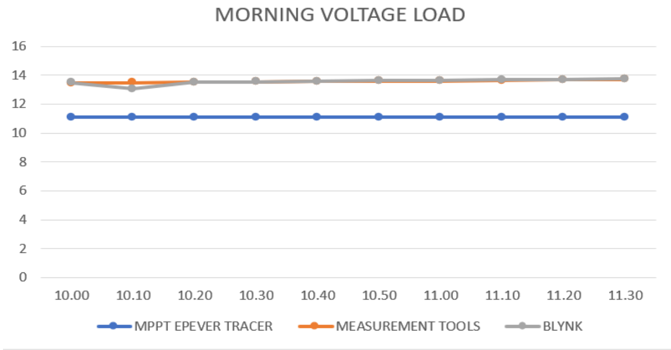

Fig. 13. Morning load voltage

From the load voltage graph above, the voltage generated in the morning is in the range of 11 volts to 14 volts. The data obtained from the Blynk application and manual measuring instruments show very precise results, with both dominating at 14 volts. However, the load voltage data taken from the MPPT Epever Tracer shows a straight graph and is at 11 volts. This difference may be due to the different settings or measurement characteristics of the MPPT Epever Tracer compared to the other tools. Nonetheless, these results provide a clear picture of the performance of the solar system in producing power for the load in the morning.

4.3. Testing During the Day

Tests were conducted in the morning, from 13:00 to 14:30, including measurements using the Blynk application, manual measuring instruments, and MPPT Epever Tracer. The data taken includes PV voltage, PV current, and load voltage. The data obtained will then be graphed as in the figure below.

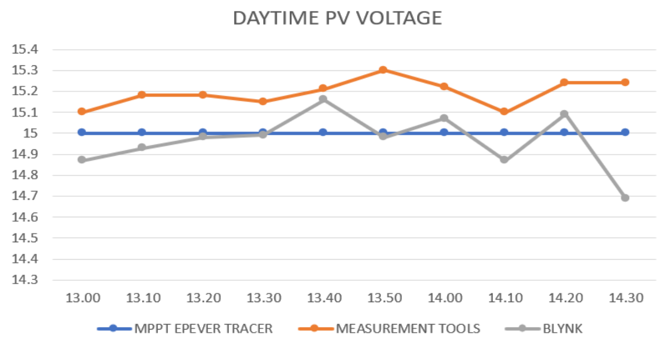

Fig. 14. Daytime PV Voltage

From the PV voltage graph above, the voltage generated by the solar panels during the day ranges from 14.7 volts to 15.3 volts. This data is not much different from the PV voltage measured in the morning. In addition, the data displayed on the Blynk application is more inclined to be the same as the data from the MPPT Epever Tracer at 13:20 to 13:30. Thus, the difference between the three data is not far adrift, only lies in decimal numbers. This shows the consistency of the solar system performance throughout the day.

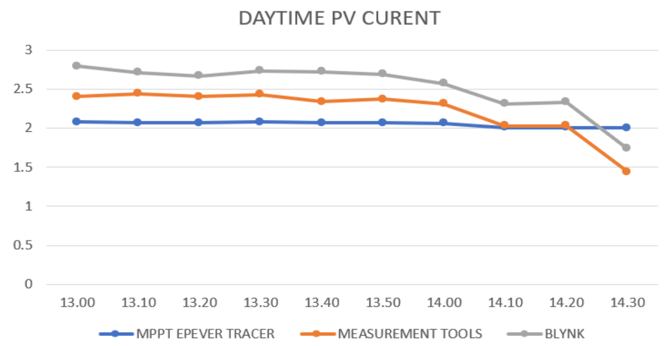

Fig. 15. Daytime PV current

From the PV current graph above, data collection during the day shows similar results to the previous data. The three data are still adrift with an insignificant difference, which is in decimal numbers. At 13:00, there is a very high increase in current because the position of the sun is right above the solar panel, resulting in an optimal value. Meanwhile, the data from the MPPT Epever Tracer showed consistent results at 2 amperes. Overall, the current data during the day ranged from 1.5 amperes to 2.9A. This reflects the efficient performance of the solar panels in absorbing solar energy at these times.

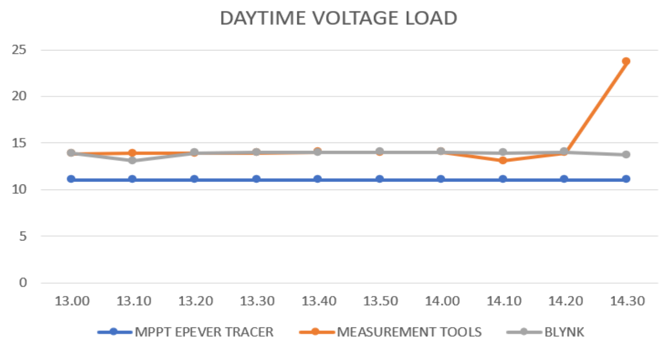

Fig. 16. Daytime load voltage

From the load voltage graph above, during the daytime data collection, the load voltage from the MPPT Epever Tracer averages at 10 volts. Meanwhile, the data from the Blynk app and the manual measuring instrument showed very consistent results, stabilizing at 15 volts from 13:00 to 14:20. Although there were slight differences within a few minutes, most of the data from both sources showed the same value.

4.4. Testing in the Afternoon

Tests were conducted in the morning, from 15:30 to 17:00, including measurements using the Blynk application, manual measuring instruments, and MPPT Epever Tracer. The data taken includes PV voltage, PV current, and load voltage. The data obtained will then be graphed as in the figure below.

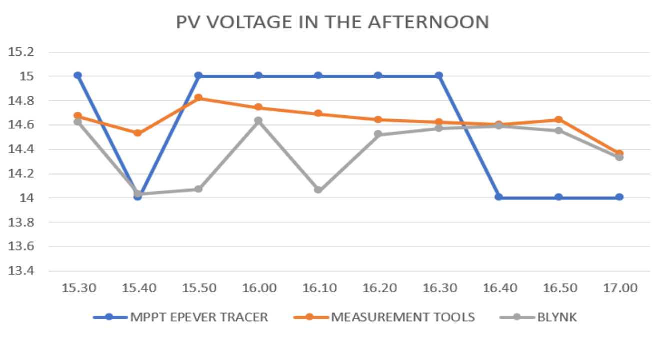

Fig. 17. PV Voltage in the afternoon

The PV voltage graph above shows data taken in the afternoon with a voltage range between 14 volts and 15 volts. Just like the previous data, the difference between the data is only around the decimal point, so the comparison of the three data is not too far away.

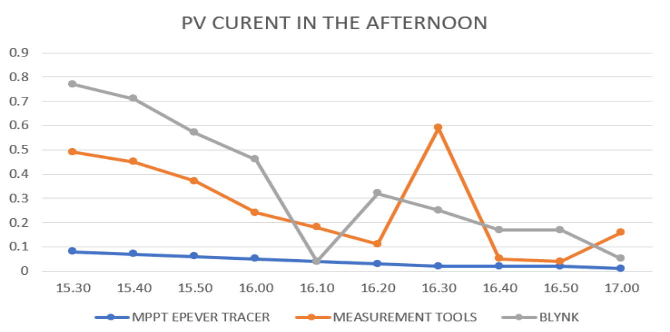

Fig. 18. PV current in the afternoon

The PV current graph above shows data collection in the afternoon. At that time, the PV gets less sunlight, so the current produced is very small, ranging from 0 ampere to 0.8 ampere. The data reading on the MPPT Epever Tracer cannot detect in detail, so it is focused at 0.1 ampere. In contrast to data from Blynk and measuring instruments that can record currents to decimal numbers, providing more detailed results**.**

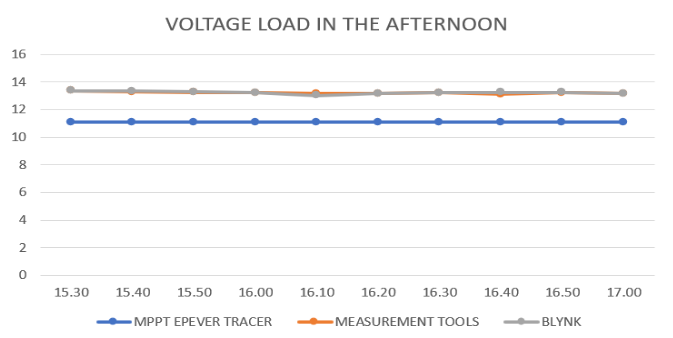

Fig. 19. Voltage load in the afternoon

The load voltage graph above shows data taken in the afternoon with a voltage range between 11 volts to 14 volts. The voltage from the MPPT Epever Tracer is stable at 11 volts, while the voltage on Blynk and the measuring instrument is on average 14 volts.

4.5. Discussion

This research makes up for some of the shortcomings in previous studies, especially in terms of measurement accuracy and detail. Many previous studies used manual methods or less sophisticated systems, resulting in less accurate or detailed data. Using the MPPT Epever Tracer and the Blynk app, this study can provide real-time data with high accuracy, including decimal numbers that can be captured by both the Blynk app and manual measuring instruments. This helps users get more complete and relevant information regarding their system performance.

In addition, this research presents a comparison of data from different sources-MPPT, manual measuring instruments, and the Blynk platform-that provides a comprehensive evaluation of the differences in measurement results and tool characteristics. This approach helped identify weaknesses in certain techniques, such as the MPPT's limitations in displaying decimal details, thus enabling future device upgrades and improvements. This multi-source comparison ensures that the data collected is completer and more accurate, supporting the optimization of system performance.

Utilize the efficiency of IoT technology to improve the monitoring capability of solar PV systems. Previous studies have shown that IoT technology for remote monitoring is often inefficient or limited. Using the user-friendly Blynk application, this research offers a reliable and easy-to-use monitoring solution, which can be more widely adopted in renewable energy systems.

5 Conclusion

Based on the data obtained from testing the solar power generation system (PLTS) using MPPT Epever Tracer, Blynk, and manual measuring instruments, it can be concluded that PV Voltage: The voltage data generated by the solar panels is quite stable throughout the day, with a voltage range from 14 volts to 15 volts. The difference in data from the three sources (MPPT Epever Tracer, Blynk, and manual measuring instrument) is only a small difference in decimal numbers, which shows the accuracy and consistency of the system in monitoring the voltage. PV Current: In the morning and afternoon, the current generated ranged from 2.7 amperes to 3.1 amperes in the morning and 1.5 amperes to 2.9 amperes in the afternoon. However, in the afternoon, the current dropped dramatically due to the reduced sunlight, with values ranging from 0 amperes to 0.8 amperes. The data from the MPPT Epever Tracer tends not to be as detailed as Blynk and manual measuring instruments in recording decimal values. Load Voltage (Load): The load voltage during the day and evening from Blynk and manual measuring instruments is around 14 volts, while the data from MPPT Epever Tracer tends to stabilize at 11 volts. This difference could be due to the different measurement characteristics of the MPPT.

Overall, the data taken from the three sources showed consistency in the measurement of important parameters such as voltage and current, although there were small differences in decimal details. The system demonstrates a good ability to monitor the performance of solar power plants in various time conditions, allowing users to monitor accurately and efficiently through the Blynk application as well as through MPPT, as the difference in values is not very far.

Suggestions for future work is to improvement of MPPT Data Accuracy: It is necessary to improve the MPPT software to increase the precision of decimal data recording, to make it comparable to Blynk and manual measuring instruments, so that the data is more detailed and accurate. Advanced Monitoring Function Development: Integration of additional features to the Blynk app, such as historical data analysis and automatic notifications if certain parameters are outside safe limits, will help users monitor and manage the system more proactively. Advanced IoT Integration Development: Adding a connection option to the cloud that can centrally store data and provide a web interface for remote monitoring could be a strategic step in improving system accessibility.

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