Design and Development of a Micro Inverter Power Monitoring System to Enhance Photovoltaic System Performance by Integrating LoRaWAN and IoT

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Abstract. This research examines the significance of utilizing Photovoltaic Solar Power Systems (PVSPS) with Micro Inverters and Internet of Things (IoT) technology, particularly LoRaWAN, in addressing challenges related to efficiency and power management. PVSPS has emerged as a leading solution to tackle the increasing global energy consumption and the adverse effects of greenhouse gas emissions. The rapid growth of the PVSPS industry underscores its relevance. This study explores the impact of shading on solar panels connected in series and parallel configurations, emphasizing the importance of proper placement. The results indicate that shading significantly reduces energy production, especially in panels connected in series. Micro Inverters play a crucial role in maintaining stable output voltage, even under shading conditions. However, attention must be paid to their influence on output current. Efficient monitoring and management of PVSPS through IoT technology such as LoRaWAN are key in supporting the transition to sustainable energy. This data underscores the importance of continuous monitoring to identify issues and optimize PVSPS performance, in the face of environmental challenges and climate change.

1 Introduction

In the present era, global energy consumption continues to rise rapidly. This phenomenon is driven by the diminishing reserves of finite fossil fuel resources and the escalating issue of greenhouse gas emissions. These circumstances have spurred global interest in developing alternative, more sustainable energy systems [1] [2]. One solution that has garnered worldwide attention is the utilization of Photovoltaic Solar Power Systems (PVSPS) as a replacement for fossil-fueled power generation.

The development of PVSPS has gained significant attention from academics, researchers, and practitioners worldwide. The PVSPS industry has seen impressive growth, with annual growth rates reaching up to 45% [3]. PVSPS relies on inverter technology, and among the various types of inverters available, Micro Inverter shave become an exceptionally appealing choice. Micro Inverters not only enhance the performance and reliability of each

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solar panel in a PVSPS but also offer safety advantages due to their operation at low DC voltage levels [4].

However, the efficiency of PVSPS depends not only on the type of inverter used but also on proper power management. PVSPS systems often face challenges when multiple solar panels are connected in series, leading to differences in panel orientation and shading effects that reduce power production across the entire PV array. To address this mismatch issue, researchers have considered the use of Micro Inverters as one solution [5].

Furthermore, monitoring and control of PVSPS systems have also become a crucial component in maintaining their performance and efficiency. In this regard, Internet of Things (IoT) technology has brought about significant breakthroughs. Various studies have developed power monitoring systems for PVSPS using IoT [6][7]. LoRaWAN technology, as one of the long-range telemetry communication networks, offers advantages in terms of cost, extensive coverage, and low power consumption [8][9][10]. LoRaWAN enables efficient measurement and monitoring of PVSPS, even in remote environmental conditions [11]. Hence, the use of LoRaWAN in monitoring and controlling PVSPS systems has become increasingly appealing and relevant [12][13].

In the context of advancing technology and mounting environmental challenges, efficient monitoring and management of PVSPS using Micro Inverters and IoT technology such as LoRaWAN represent a crucial step toward supporting the transition to more sustainable energy sources. Through this development, it is anticipated that PVSPS efficiency can be enhanced, which, in turn, will support global efforts to address climate change and the growing energy demands.

2. Technical Approach

2.1 System Design

In this research, several stages will be undertaken. Beginning with a crucial literature review, its role is pivotal in building the argument for problem formulation and the determination of the research title to be pursued. Next is to conduct an analysis of the requirements for the system to be developed, thereby elucidating how the system's design will function.

Equally important, once the design of the system's operation has been outlined, the subsequent step is to establish a clear plan for how the system will be constructed and researched. Subsequently, the selection and specification of the components to be used in the design and creation of the system will be made, facilitating the determination of how to create the Hardware Design.

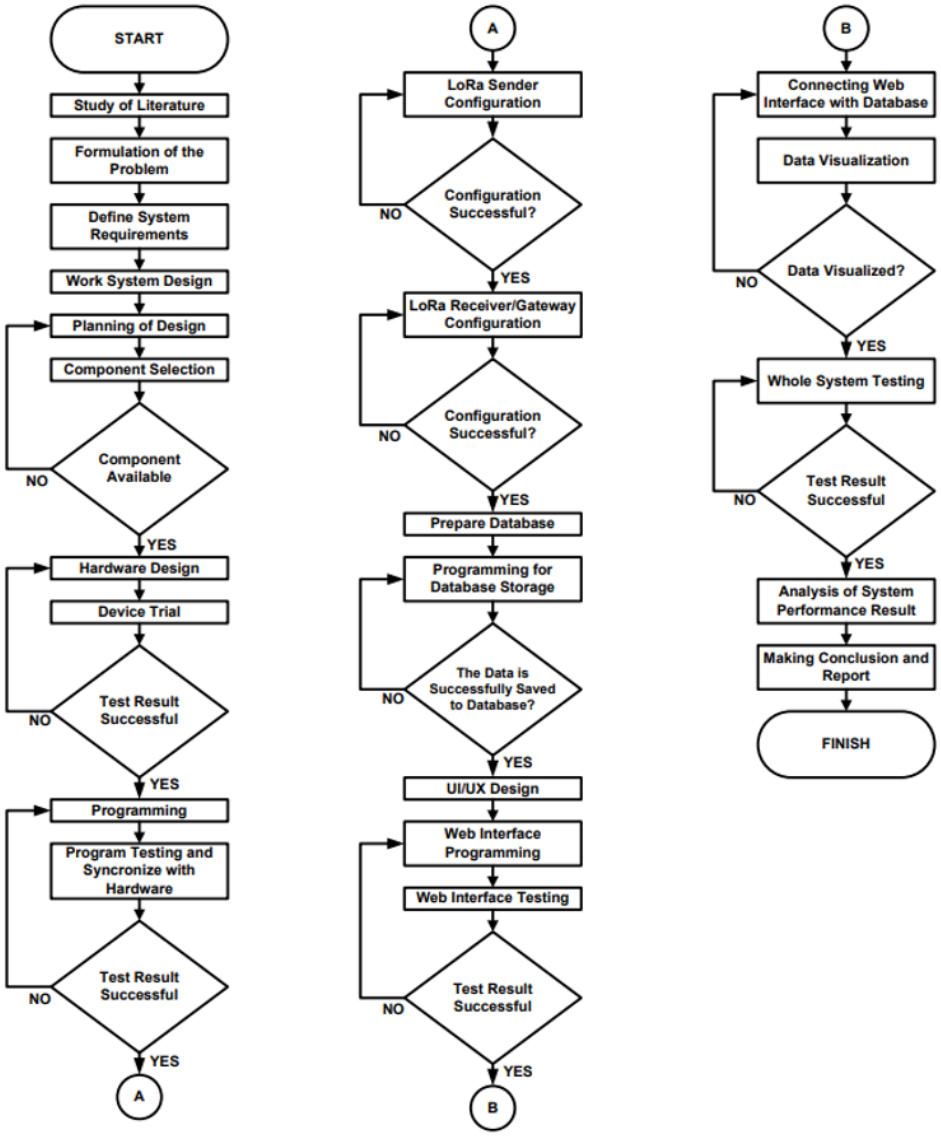

Fig. 1. Research Flowchart.

In the Hardware Design process, this includes the creation of Schematics Diagrams and PCB Layouts for IoT Node 1 and IoT Node 2. Of course, the PCBs are printed and then soldered to proceed to the next stage, which is Device Trial. This is done to determine whether the hardware is functioning correctly. Subsequently, programming is performed using the Arduino IDE. The program is then uploaded to the microcontroller on the hardware to ensure that the hardware and program are in accordance with the desired operational principles.

The next stage involves configuring the LoRa Sender and LoRa Receiver/Gateway. This is followed by testing to verify whether the circuits can operate accurately. The next step is preparing and programming to perform the data storage process and data input into the database using the HTTP protocol. After the data successfully enters MySQL, the next step is UI/UX Design and programming to create and implement the Web Interface that was

designed during the UI/UX Design process. The next step is testing the Web Interface system, which involves functional testing to ensure that the system's functionality operates as expected.

Next is establishing the connection between the database and the system on the web interface. This is done to display the data stored in the database on the web interface. Then, a comprehensive system test is conducted. All components are placed according to the plan, and the entire system is analyzed, with particular emphasis on the data transmission system using the LoRaWAN telemetry data method. The final step is drawing conclusions and writing the research report.

In this research, the equipment circuitry is divided into two parts, namely IoT Node 1 and IoT Node 2. IoT Node 1 consists of solar panels, Micro Inverters, microcontrollers, LoRa RFM96, SD Card Module, current sensors, and voltage sensors. The current and voltage sensors are installed between the Micro Inverter and the load, and their data is processed and transmitted via the LoRaWAN network to IoT Node 2. Subsequently, IoT Node 2 is responsible for sending the received data to the database through the HTTP protocol online with the assistance of the internet. The Block Diagram of the system is depicted in Figure 2.

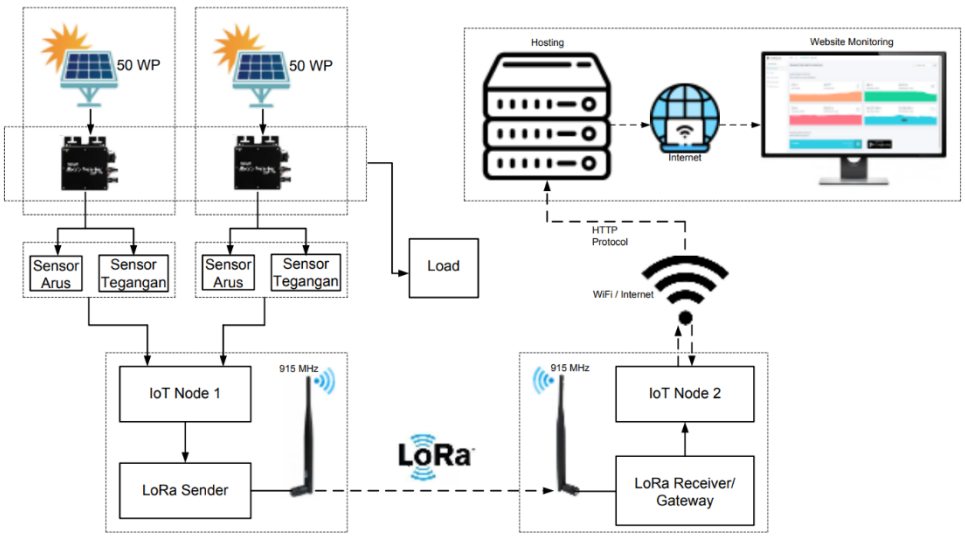

Fig. 2. The Block Diagram of the System.

2.2 Hardware System Testing

The first step is to measure the output voltage of the PV panels arranged in series as shown in the following diagram in Figure 3.

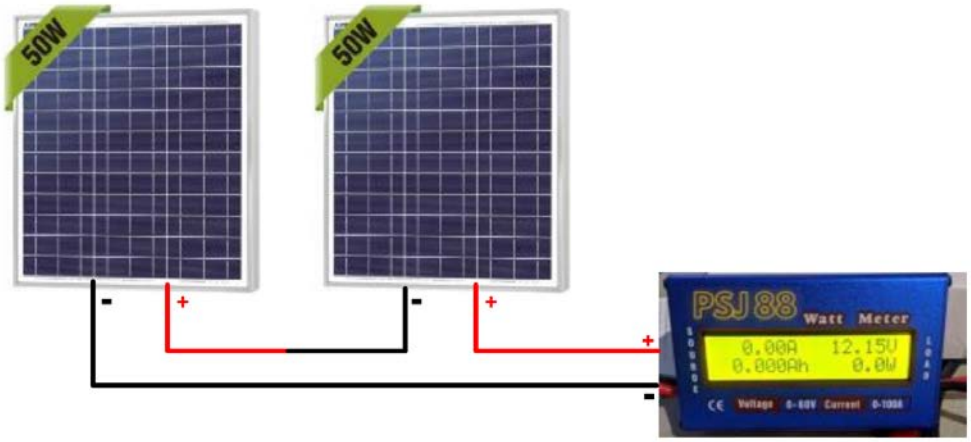

Fig. 3. Serial PV Testing.

The second step involves measuring the output voltage of the PV panels arranged in series with shadows, as illustrated in the following diagram in Figure 4.

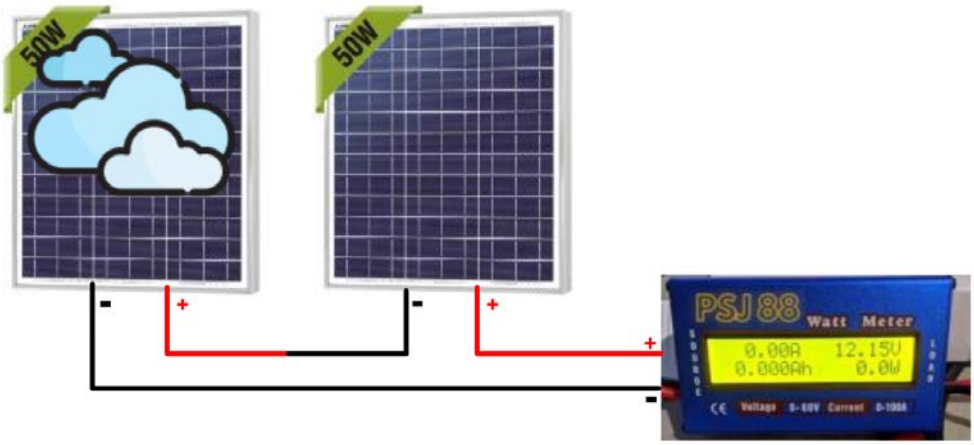

Fig. 4. Serial PV Testing with Shadows.

The measurement results are recorded, and an analysis is conducted to compare the two experiments.
The first step is to measure the output voltage of the PV panels arranged in parallel, as shown in the following diagram in Figure 5.

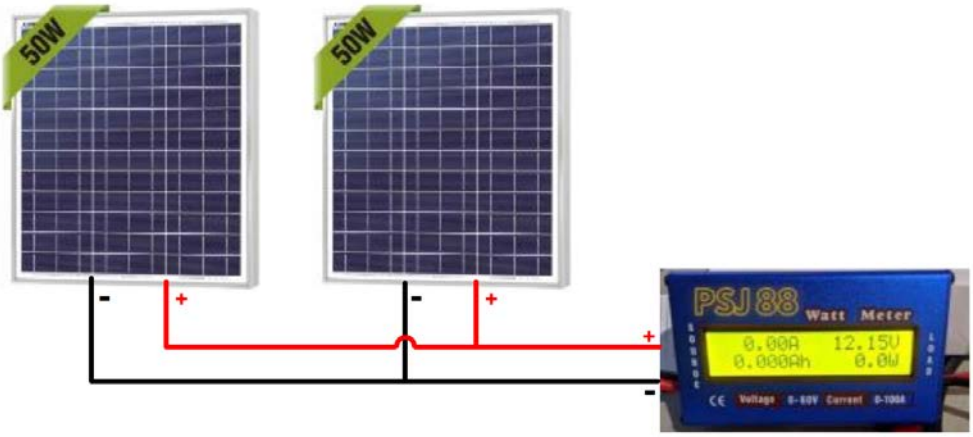

Fig. 5. Parallel PV Testing.

The second step involves measuring the output voltage of the PV panels arranged in parallel with shadows, as illustrated in the following diagram in Figure 6.

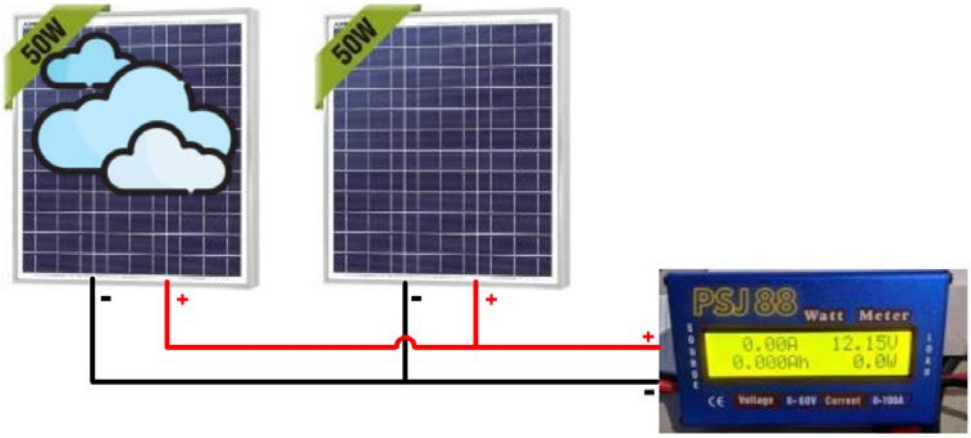

Fig. 6. Parallel PV Testing with Shadows.

Measurement results are recorded, and an analysis is conducted to compare the two experiments.

This testing is conducted to demonstrate that the use of Micro Inverters helps maintain the performance of the PV system in the presence of shadows or performance reductions in one of the installed PV panels. The first step is to measure the output voltage of the Micro Inverter, as shown in the diagram below.

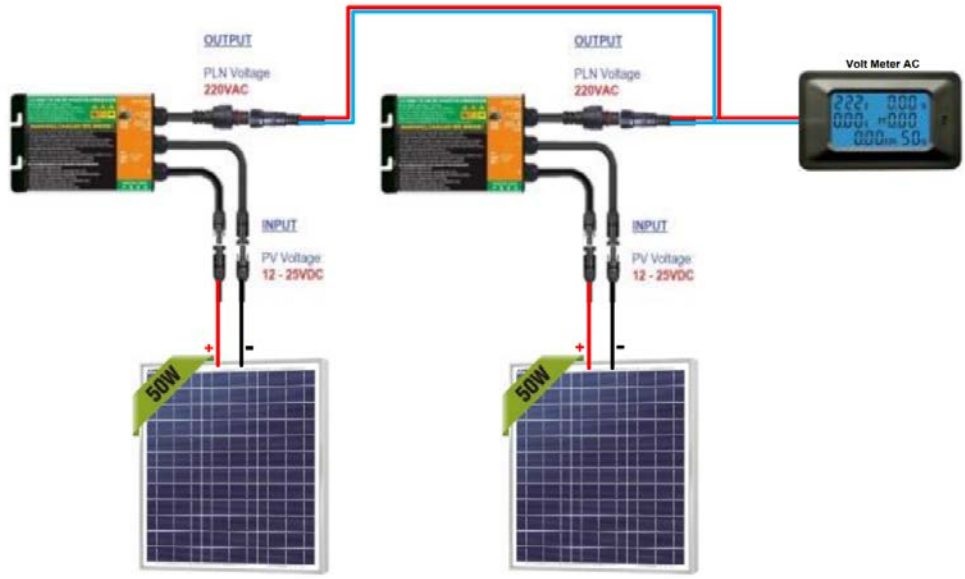

Fig. 7. Micro Inverter Testing Circuit.

The second step involves measuring the output voltage of the Micro Inverter with shadows, as shown in the following diagram in Figure 8.

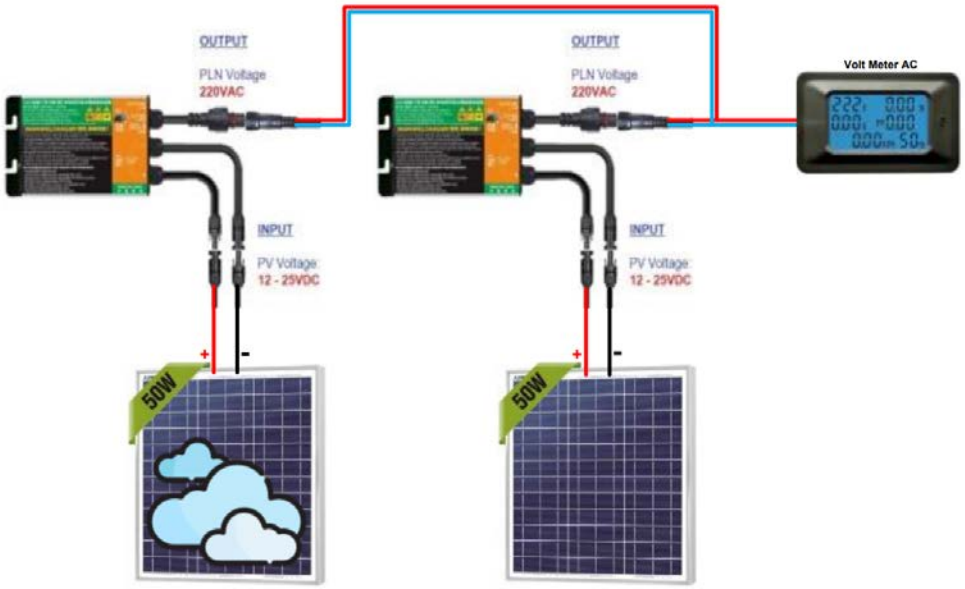

Fig. 8. Micro Inverter Testing Circuit with Shadows.

Measurement results are recorded, and an analysis is conducted to compare the two experiments.

2.3 LoRaWAN Data Transmission Testing

The method for testing the Micro Inverter power monitoring system involves comparing the accuracy of data stored on the SD Card in IoT Node 1 with the data received by IoT Node 2, which is stored in the database. Therefore, the functional testing of the system in this research focuses on telemetry using LoRaWAN to determine whether the system operates as designed, both in terms of software and hardware capabilities. The testing does not delve into detailed program code and logic. This testing aligns with the functional requirements, verifying that the system's features operate in accordance with the previously established design.

3. Result and discussion

The researcher conducted various tests, including Hardware System testing and LoRaWAN data transmission testing, as described below.

3.1 Results and Analysis Hardware System Testing

In the testing of PV panels arranged in series, the results showed that without any shadow, the output voltage was 44.32 Volts. However, when there was a shadow covering one of the PV panels, the output voltage dropped to 21.80 Volts.

The significant drop in output voltage from 44.32 Volts (no shadow) to 21.80 Volts (with shadow) indicates that shading on solar panels substantially reduces energy production. Shadows on solar panels can result from various factors such as buildings, trees, or other objects obstructing sunlight from reaching the panels. This underscores the importance of positioning solar panels in locations that receive sunlight throughout the day to maximize energy production.

Next, in the testing of PV panels arranged in parallel, the results revealed that without any shadow, the output voltage was 21.85 Volts. However, when there was a shadow covering one of the PV panels, the output voltage decreased to 21.05 Volts.

From these test results, the comparison between the two conditions showed a relatively small difference in output voltage between no shadow and with shadow. Although there was a decrease in output voltage from 21.85 Volts (no shadow) to 21.05 Volts (with shadow), this difference was relatively small. This suggests that the impact of shading on parallel- arranged solar panels may not be as significant as on series-arranged panels. Nevertheless, it is still essential to optimize the performance of solar panels. In the testing results, two conditions were compared: no shadow and with shadow, where the output voltage and current from the Micro Inverter were measured. Without shadow, the measured output voltage was 217 Volts, with an output current of 0.15 A. With shadow, the measured output voltage remained at 217 Volts, but the output current increased to 0.7 A.

The testing results revealed a significant difference between the two conditions, especially in the output current of the Micro Inverter. The output voltage of the Micro Inverter remained stable at 217 Volts, whether there was shadow or not, indicating that the Micro Inverter successfully maintained consistent output voltage. The decrease in output current from 0.15 A to 0.7 A in the presence of shadow demonstrates a significant impact on output current performance. This could be attributed to the shadow on one of the solar panels, reducing the current-generation capacity. These findings suggest that the Micro Inverter aids in maintaining a stable output voltage even in the event of reduced performance in one of the installed PV panels. This can be advantageous as the PV system can still provide a consistent voltage to the overall system.

3.2 Results and Analysis of LoRaWAN Data Transmission Testing

The researcher conducted testing for a period of 5 days, from September 26, 2023, to September 30, 2023. The following are the results of the testing.

Table 1. Percentage of Stored Data.

Percentage of Stored Data		
Date	SD Card	Database
26/09/2023	100 %	100 %
27/09/2023	98.25 %	98.25 %
28/09/2023	99.85 %	99.85 %
29/09/2023	100 %	100 %
30/09/2023	99.60 %	99.60 %

The test results indicate that the percentage of data stored on the SD Card in IoT Node 1 and in the database of IoT Node 2 is very high and approaches 100% on most of the testing dates. This indicates that the power monitoring system using LoRaWAN telemetry method functions well and consistently stores data.
On September 27, 2023, there was a slight decrease in the percentage of stored data, both on the SD Card and in the database, to around 98.25%. This decrease might be attributed to factors such as LoRaWAN signal interference or errors in data transmission between the two IoT Nodes. However, the high percentage suggests that the system maintains a good level of reliability.
On September 30, 2023, there was another slight decrease in the percentage of data stored in both locations, approximately 99.60%. Despite the decrease, the system's reliability remains quite high. Overall, the test results indicate that the power monitoring system using LoRaWAN telemetry has a high level of data storage reliability. Although there is some variation in the percentage of stored data on certain dates, these results are generally acceptable and demonstrate that the system functions as expected. For further development, it may be worthwhile to consider improvements to address factors that could lead to minor fluctuations in the percentage of stored data.

4. Conclusions

The test results indicate that shading on solar panels significantly reduces energy production. When shading covers one of the panels, the output voltage from that panel experiences a significant decrease. Therefore, the placement of solar panels in locations that receive sunlight throughout the day is crucial for maximizing solar energy production.
In this study, there was a difference in the impact of shading between solar panels connected in series and in parallel. Solar panels connected in series are more sensitive to shading, while those connected in parallel have a smaller impact. This needs to be taken into account in the design and configuration of PV systems.
Micro Inverters have proven successful in maintaining stable output voltage in both conditions, both without shading and with shading. Although there is a decrease in output current when shading is present, the output voltage remains consistent. This demonstrates the significant role of Micro Inverters in maintaining the overall performance of PV systems in situations that may experience partial shading.
Data like this emphasizes the importance of proper monitoring and management of PV systems. By using IoT technology and advanced monitoring systems, you can optimize the performance of your PV system, even in shading conditions. While these results show a relatively minor impact of shading, continuous monitoring remains essential. With proper

monitoring, you can identify potential issues that may arise and take corrective actions as needed. The test results show that Micro Inverters can help maintain stable output voltage in shading conditions or during a decrease in the performance of solar panels. However, the impact on output current needs to be addressed to maximize energy production from PV systems.

The test results illustrate that the power monitoring system using LoRaWAN telemetry exhibits a high level of reliability in data collection and storage. Most of the time, the percentage of stored data approaches 100%, indicating good consistency in system operation. Although there is a slight decrease in the percentage of data on specific dates, such as September 27, 2023, and September 30, 2023, this is likely due to signal interference or other factors that can be addressed in further development. Overall, the results support that the system functions as expected and is reliable for power monitoring using the LoRaWAN telemetry method.

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