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IoT based monitoring system of power supplies using solar panel and PLN

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ABSTRACT

The advancement of Internet of Things (IoT) technology has opened new opportunities in energy management, especially for power supply monitoring systems that combine solar panels and the PLN grid. This study designs and implements an IoT-based monitoring system to observe voltage levels of 5VDC, 12VDC, and 24VDC in real-time using INA219 sensors, a 20A PWM Solar Charge Controller, a 12V 5Ah battery, and a NodeMCU ESP32 connected to the Blynk application. The system features automatic switching from solar to PLN when abnormal conditions such as overcurrent (>100mA) or voltage drops occur. Testing under normal and fault conditions shows that the system effectively maintains stability, switches power sources automatically, and provides real-time notifications, demonstrating its efficiency and suitability as a reliable, environmentally friendly energy management solution.

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1. INTRODUCTION

The demand for stable and efficient power supply in electronic systems and light industry continues to rise alongside technological advancements and increasingly complex operational needs. Conventional electrical systems often exhibit limitations in terms of flexibility and responsiveness, particularly when facing voltage fluctuations or power outages that can disrupt industrial processes and electronic device operations. This condition drives the need for innovation in power monitoring technology capable of providing real-time supervision and adaptive control. The Internet of Things (IoT) technology has emerged as a potential solution to enhance power management systems. IoT enables remote monitoring of electrical parameters such as voltage, current, and power with accurate and real-time data, thereby facilitating decision-making and automatic system control [1]. Various previous studies have examined the application of IoT in energy monitoring and control systems. For example, the development of IoT-based energy monitoring systems for smart homes [2], as well as the application of INA219 sensors in voltage monitoring for electric vehicles [3]. Additionally, hybrid systems combining solar panels and primary power sources have been developed to improve energy supply reliability, especially in remote areas [4]. Another approach applied is the use of automatic switching algorithms in IoT-based renewable energy systems to ensure continuous energy supply [5]. Integration of monitoring systems with mobile applications has also become a key focus to facilitate remote supervision and control [6],[7]. The application of IoT in smart grids [8] and optimization of energy usage in the industrial sector [9] further strengthen the role of this technology in the transformation of modern electrical systems. Furthermore, real-time load monitoring has been shown to improve energy efficiency and savings [10].

Despite numerous studies related to IoT in energy management, research specifically emphasizing voltage monitoring systems at low voltage levels such as 5VDC, 12VDC, and 24VDC, which are commonly used in small industrial systems and embedded devices, remains relatively limited. Therefore, this study proposes the design and implementation of an IoT-based monitoring system that integrates energy sources from solar panels and the PLN electrical grid. The system employs INA219 sensors and an ESP32 microcontroller connected to the Blynk application to monitor and control voltage conditions in real-time. An automatic switching feature is also implemented to respond to abnormal conditions such as overcurrent or voltage drops by automatically switching the energy source. The primary objective of this study is to develop a reliable and efficient power supply monitoring system capable of operating at various voltage levels and performing automatic source switching during anomalies. This approach is expected to enhance energy utilization efficiency, strengthen electrical system resilience, and support more environmentally friendly energy solutions.

2. METHOD

This study employs an experimental approach involving the design, implementation, and testing of a voltage and current monitoring system based on the Internet of Things (IoT) for a hybrid power source comprising solar panels and the PLN (State Electricity Company) grid. The system is designed to monitor voltage at three commonly used DC levels 5V, 12V, and 24V and to perform automatic load control based on the measured voltage and current conditions. To facilitate the device design process and to support system analysis, a block diagram is used as a reference for system operation, as shown in Figure 1.

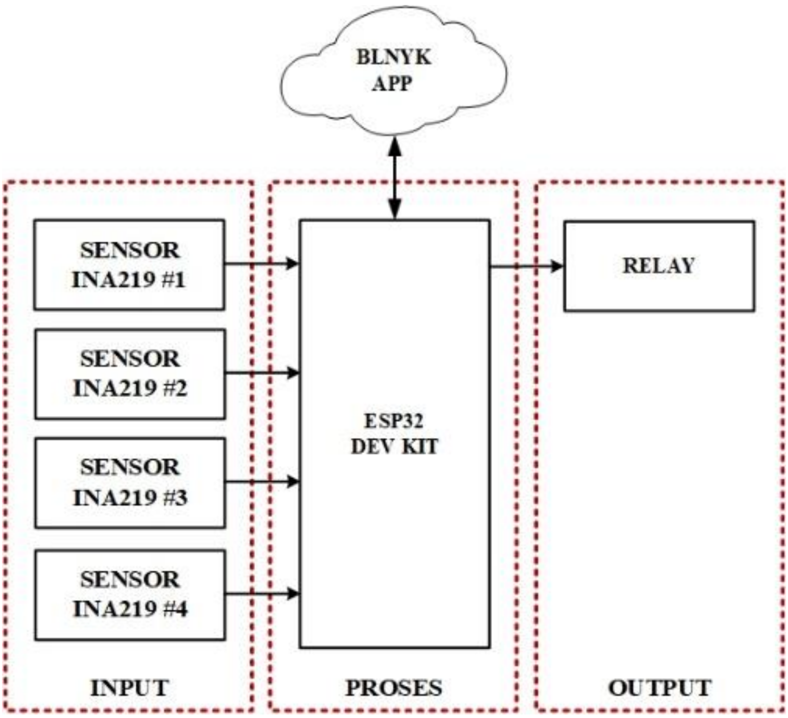


Figure 1. Block diagram system

The monitoring and automatic control system consists of three main components input, process, and output which are integrated to efficiently monitor and manage power distribution. Four INA219 sensors are employed to accurately measure current up to ±3.2 A and voltage up to 26 V, connected to the ESP32 microcontroller via I2C communication [11]. The ESP32 serves as the processing unit, supporting Wi-Fi, Bluetooth, as well as I2C and SPI protocols, and is capable of controlling relays automatically upon detection of abnormal conditions such as overcurrent [12],[13]. For remote monitoring, the Blynk platform is utilized, supporting MQTT communication and HTTP API protocols [14]. The system uses a 12V solar panel as the primary power source, equipped with a PWM solar charge controller for battery charging. A 12V battery serves as an energy backup, delivering power to the load via a step-up/down DC-DC converter to generate 5V, 12V, and 24V outputs [15]. The PLN (utility grid) power supply is also prepared as a backup source, with automatic switching controlled by the ESP32 to ensure seamless transitions between sources. With this architecture, the system enhances efficiency, enables early fault detection, and supports real-time monitoring through the IoT application. To systematically illustrate the system workflow, a flowchart is provided in Figure 2.

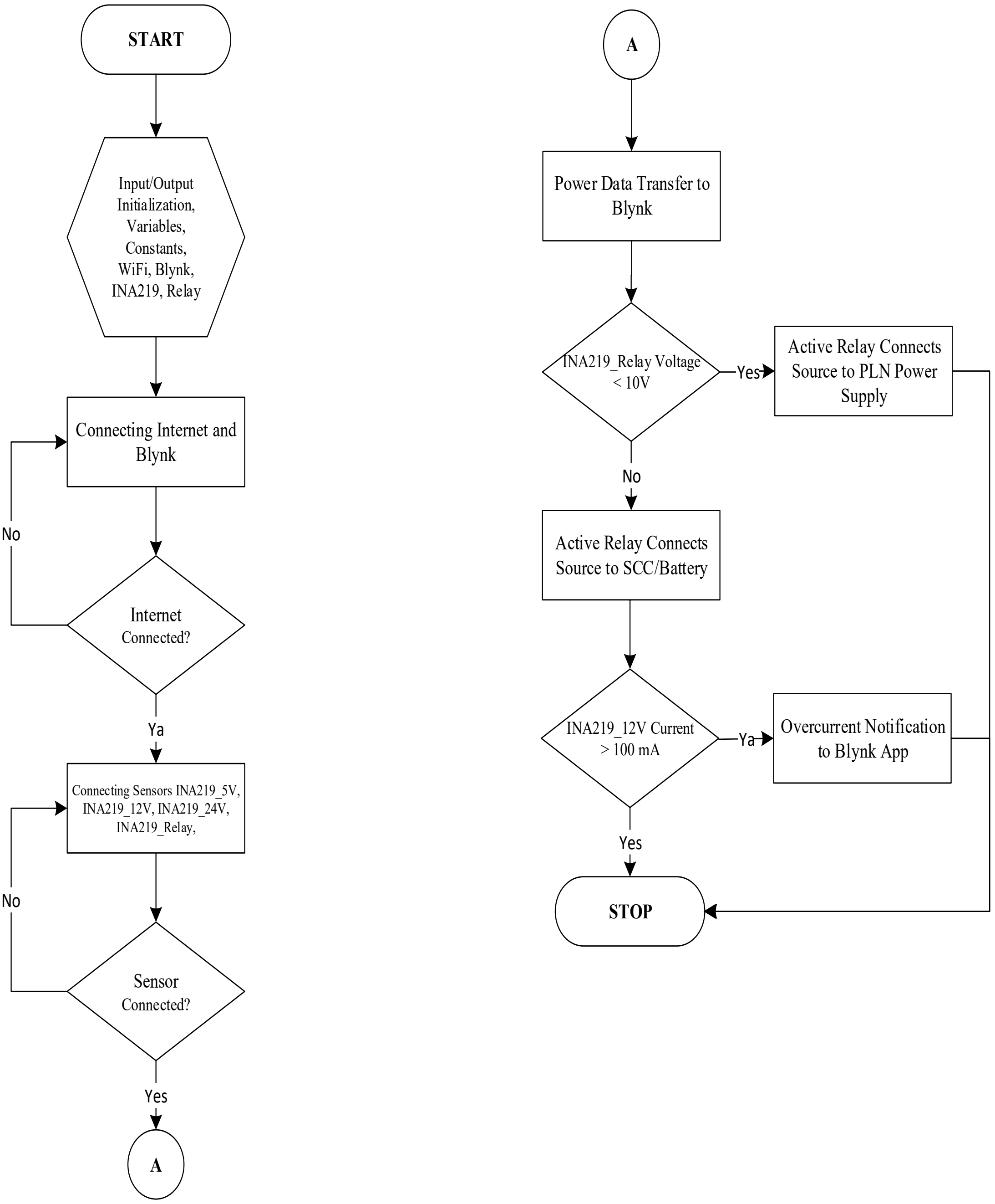


Figure 2. Flowchart system

Based on Figure 2, the process begins with system initialization, which includes configuring the microcontroller, establishing Wi-Fi and Blynk connections, initializing the INA219 sensors, and setting up the relays to ensure that all components are ready for operation. Once a successful connection to the internet and Blynk is established, the ESP32 initializes the INA219 sensors on the 5V, 12V, and 24V lines, as well as the relays. If any connection or initialization fails, the system will either wait or halt the process to prevent errors. ESP32 reads the voltage on the relay line. If the voltage drops below 10V, the system automatically switches the power source from the battery to the PLN grid. The system also monitors the current on the 12V line and sends an overcurrent notification if it exceeds 100 mA. This process runs continuously in a loop, enabling automated, real-time, and responsive monitoring and control of the power source in accordance with the IoT-based smart energy monitoring concept. The circuit schematic for the implementation of IoT-based monitoring of 5VDC, 12VDC, and 24VDC power supplies using a combination of solar panels and PLN grid power is shown in Figure 3 below.

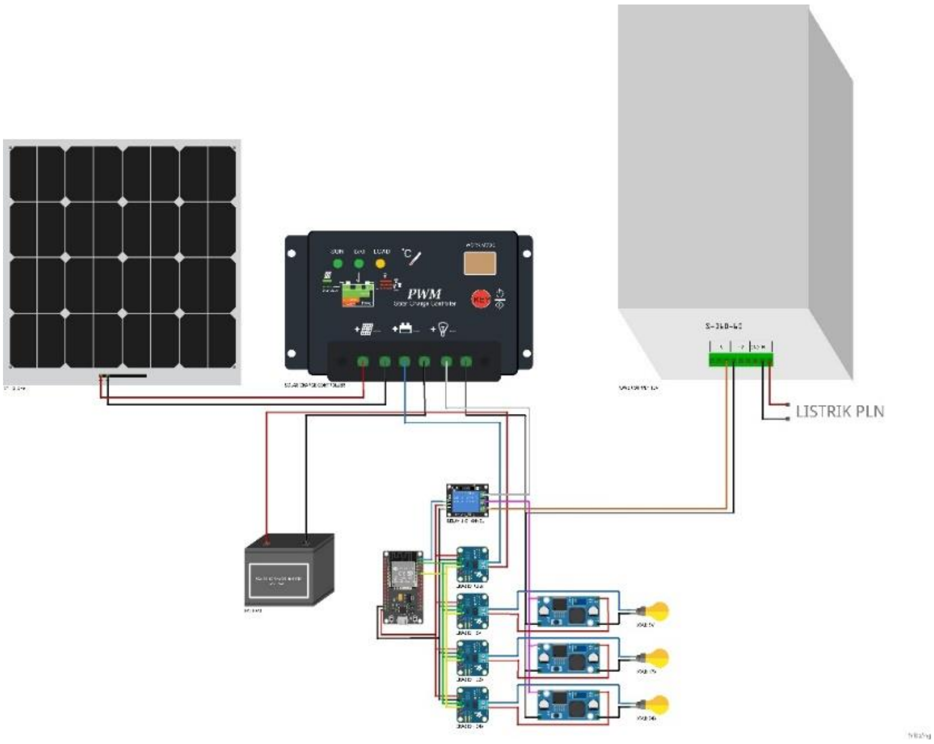
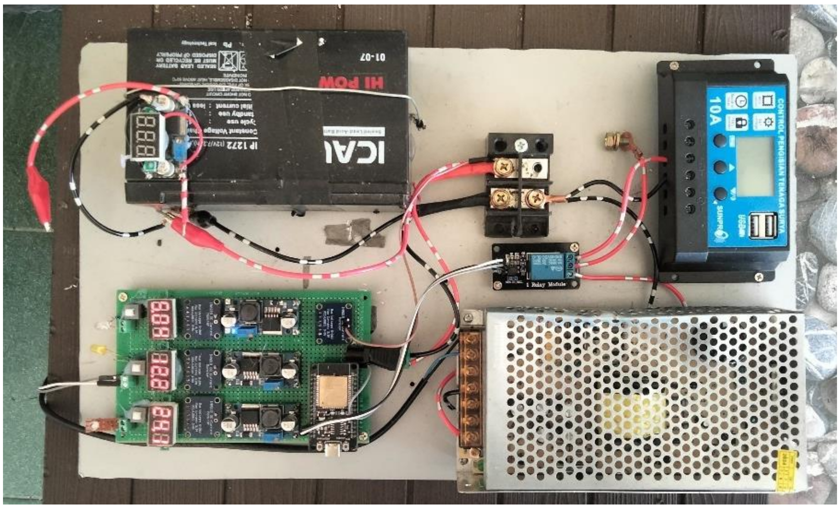


Figure 3. Mechanical device design

3. RESULTS AND DISCUSSION

In this study, testing was conducted under two conditions: normal operation and fault condition. The fault condition was simulated by adding a load in the form of a 12V DC motor, which caused a voltage drop due to the current exceeding the system’s safe threshold of 100 mA. The test circuit configuration for the system can be seen in Figure 4.



Figrure 4. Testing configuration of the device

Under normal operating conditions, the system automatically directs the battery charging process through the Solar Charge Controller (SCC), which is connected to the solar panel as the primary energy source. The SCC functions to regulate and control the power flow from the solar panel to the battery, ensuring efficient charging while preventing the risk of overcharging [1]. The results of the testing and monitoring under this condition are shown in Figure 5.

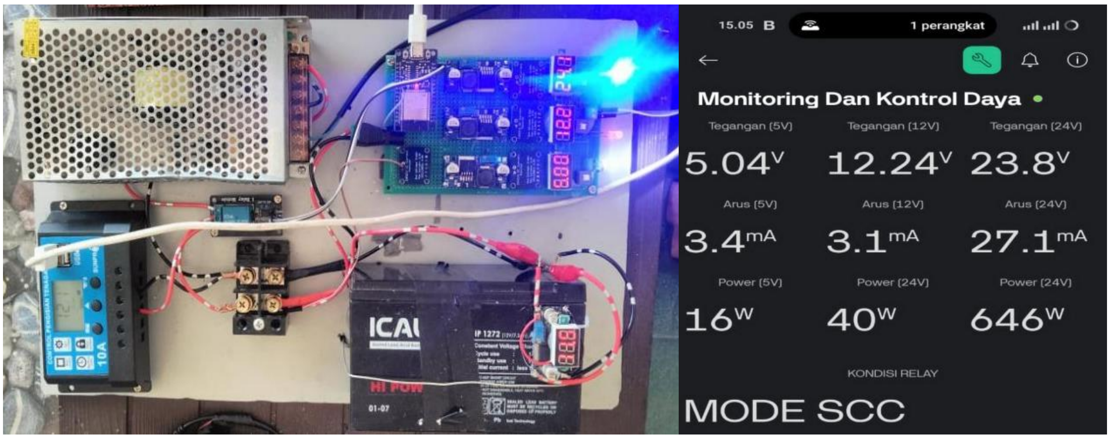


Figure 5. Normal operating conditions

Based on Figure 5, it is analyzed that the Internet of Things (IoT)-based monitoring system utilizes INA219 sensors to detect voltage and current parameters in real-time on each of the 5VDC, 12VDC, and 24VDC supply lines. When the power supply from the solar panel is sufficient and the load current remains within the normal threshold (≤100 mA), the system prioritizes the use of renewable energy and activates the battery charging process without engaging the PLN grid supply. The observed stable voltage values are 5.04V, 12.24V, and 23.8V, with current readings of 3.4 mA, 3.1 mA, and 27.1 mA respectively. The highest power was detected on the 24V line at 646 W, indicating that this line is used for the main load. All electrical parameters are visualized in real-time through the Blynk application interface, which also displays the active status of the SCC as the system's primary power source. Subsequent testing was carried out under abnormal conditions by adding a DC motor load to simulate an overcurrent scenario. This additional load caused a significant surge in current, resulting in a drastic drop in supply voltage. The system automatically detected this condition and switched the power source from the SCC/battery to the PLN grid supply by activating the relay module. This reflects the implementation of power redundancy principles in a renewable energy-based electrical system [2]. The testing and monitoring results under abnormal conditions are shown in Figure 6 below.

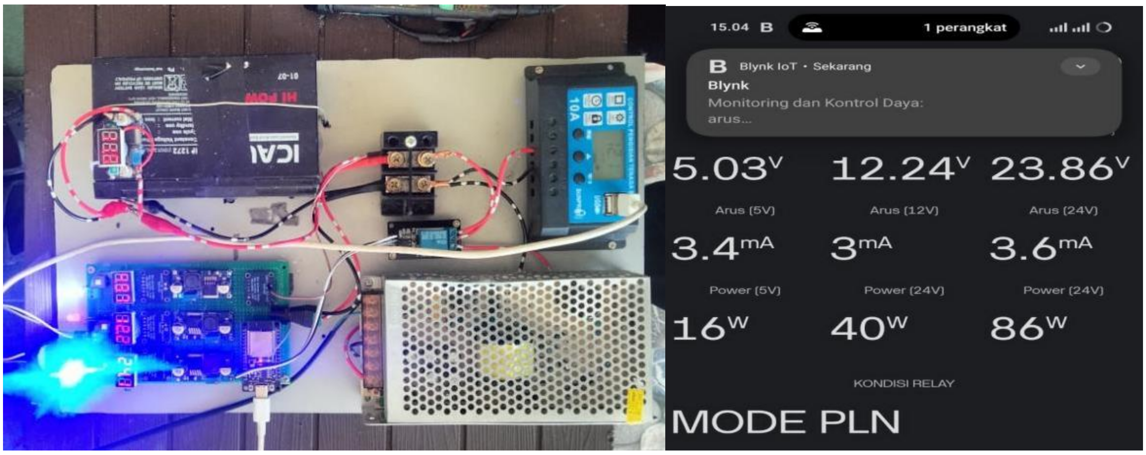


Figure 6. Abnormal operating conditions

Figure 6 shows that under this condition, the voltage on the 12V and 24V lines remained stable at 12.24V and 23.86V, respectively. However, the current readings exhibited changes, registering at 3.0 mA and 3.6 mA. These low current values may be attributed to the activation of an automatic current limiter or sensor readings outside the accuracy range due to transient disturbances. The power on the 24V line increased to 86 W, and the system simultaneously sent a notification via the Blynk application indicating a change in the operating mode from SCC to PLN, as shown in Figure 7.

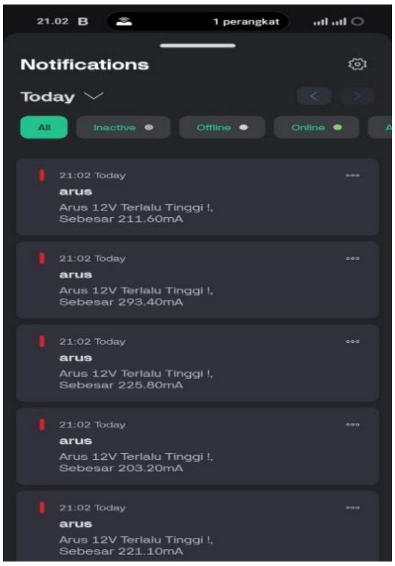


Figure 7. Notification System

Overall, the test results demonstrate that the system is capable of reliably detecting abnormal conditions and automatically switching power sources to protect the system from damage due to overcurrent. The real-time notification feature via the IoT platform enhances user responsiveness to disturbances, while also supporting the overall safety and efficiency of the system. The integration of sensors, relays, SCC, and the ESP32 microcontroller within this system architecture showcases intelligent and adaptive control capabilities in line with the principles of IoT-based energy monitoring systems.

4. CONCLUSION

This study successfully designed and implemented an Internet of Things (IoT)-based power supply voltage monitoring system effective for three primary voltage levels: 5VDC, 12VDC, and 24VDC. The system integrates solar panel and PLN grid energy sources with a Solar Charge Controller (SCC) and automatic relays controlled by an ESP32 microcontroller, utilizing the Blynk platform as a real-time monitoring interface. The test results indicate that the system is capable of accurately monitoring voltage and current, and effectively detecting overcurrent conditions. It automatically switches the power source from the solar panel to the PLN grid in response to anomalies such as voltage drops or current overloads, thereby maintaining continuity and stability of the power supply. Furthermore, the use of IoT enables responsive remote monitoring, enhancing system reliability and safety. These findings underscore the potential of IoT-based monitoring systems in optimizing renewable energy management and backup power systems for small-scale industrial applications.

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