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Design of IoT-Based Battery Monitoring for DC Backup

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ABSTRACT: The battery monitoring process for the DC backup power supply at the Banda Aceh Main Substation was previously performed manually using a multimeter, leading to inefficiencies. This study aimed to develop an automated battery monitoring system based on the Internet of Things (IoT) to enhance operational efficiency. The proposed system integrated a DC voltage sensor (voltage divider) connected to the battery and an INA219 sensor to measure current flow during battery usage. A NodeMCU ESP8266 microcontroller, programmed with the Arduino IDE, served as the main data processor and internet interface. Monitoring data was transmitted to officers via an IoT-based cloud server on the Blynk platform. The system was tested using eight NiCd 1.2 V battery cells arranged to simulate the substation setup. The resulting prototype automated daily battery monitoring, significantly improving the efficiency and effectiveness of the monitoring process.

KEYWORD: Battery; monitoring; voltage; nicd.

1. Introduction

Substation Banda Aceh's parent company has two sources of power in its operations, namely Alternating Current (AC) and Direct Current (DC). The DC power source in the parent substation (GI) played a vital role in supplying the electricity needed for consumers. This DC system powered equipment control, such as protection relays, motors (PMT and PMS), telecommunications systems, and other devices [1]. A battery is a device capable of storing and releasing energy for use in electronics and other equipment [2]. Batteries in the parent substation were used to store DC power sourced from the rectifier that converted AC power [3]. The battery capacity in the parent substation was 110V, achieved by combining 92 battery cells, each with a capacity of 1.2V, arranged in series [4]. These batteries served as a backup power source in case of a blackout in the main AC system, ensuring uninterrupted operation of control equipment and other essential systems [5].

Damage to a single battery cell during operation could result in system-wide failure. For instance, at the GIS (Gas Insulated Switchgear) Mangga Besar substation, a PMT failure caused a trip at the Kemayoran GI due to a DC system failure stemming from a battery drop [6]. This case highlighted the significant losses that could arise from DC supply failures [7].

To monitor the battery's condition, a monitoring process was needed. The existing process was manual, requiring officers to use a multitester and subsequently record the data on a computer [8]. This approach was neither efficient nor effective. Consequently, a smart monitoring system based on automation was necessary to enable real-time monitoring of battery cell parameters and send data directly to officers via the internet. Automating the monitoring system would enhance efficiency by promptly identifying abnormalities, leading to more effective maintenance [9]. Previous research proposed solutions, such as total battery voltage and current measurement with data displayed on an LCD or sent via SMS gateways [10], Wi-Fi routers [11], or Zigbee wireless communication with GPS assistance [12]. However, most of these studies focused only on overall battery voltage monitoring.

This research aimed to design a prototype capable of monitoring individual battery cell voltages. Monitoring was conducted on eight NiCd 1.2V batteries (1000mAh) arranged in series. Parameters such as voltage and current were monitored to assess battery conditions during standby, discharging, and charging phases. These parameters were obtained using a DC voltage sensor (voltage divider) and an INA219 current sensor, with the system simulating PLN's setup using AC voltage sensors and relays. The prototype utilized an ESP8266 microcontroller equipped with built-in Wi-Fi. The Internet of Things (IoT) enabled continuous monitoring and remote access via stable internet connectivity. Monitoring data was sent to officers through the Blynk platform, leveraging the Blynk Cloud Server [14]. This system facilitated quick and easy data visualization on a computer or smartphone. The results of this research are expected to enhance energy efficiency by minimizing power waste and extending battery life through real-time tracking and predictive maintenance enabled by IoT integration. This approach indirectly reduces the need for new batteries by optimizing their usage, thus lowering the carbon footprint. By promoting smarter energy use, reducing resource waste, and fostering sustainable power management practices, this IoT-based monitoring system aligns with green technology principles [15].

2. Materials and Methods

The research process began with problem identification, followed by a literature study, hardware design, software design, and testing. The performance of the designed system was evaluated using data obtained from detecting battery voltage, current, and AC voltage from a battery monitoring prototype integrated with IoT technology during the study [16]. Battery voltage monitoring was conducted using a series voltage divider method, which divided the output voltage across two resistors in series. The resulting voltage depended on the resistor values used [17]. Figure 1 illustrates the system's working diagram. It starts with battery charging from the main DC power source, rectified from an AC power source. The charging and discharging of each battery cell were monitored using a DC voltage sensor and an INA219 current sensor. An AC voltage sensor (Zmpt101b) detected AC voltage and directed the relay, via the ESP8266, to switch between the main power source and the backup power source. The ESP8266 microcontroller processed all data and sent the results via the internet for monitoring by officers.

The software design begins with connecting the system to the internet via Wi-Fi, which is handled by the microcontroller. The system then collects data from each sensor according to the required parameters, namely voltage and current. This data, initially generated in analog form by the sensors, is processed by the microcontroller and converted into digital form for transmission over the internet [18]. The processed data is sent to the Blynk platform via the internet, utilizing the Blynk Cloud Server feature. Once transmitted, the data is received and displayed on the Blynk dashboard, accessible through either a computer web interface or the officer's mobile phone. The entire system's operation relies on the ESP8266 microcontroller and the Blynk platform. The software for the ESP8266 is designed using the Arduino IDE, employing the C programming language. The program code enables the ESP8266 to act as the main controller, managing each sensor to provide accurate readings and transmitting data to the Blynk platform for real-time monitoring via the internet.

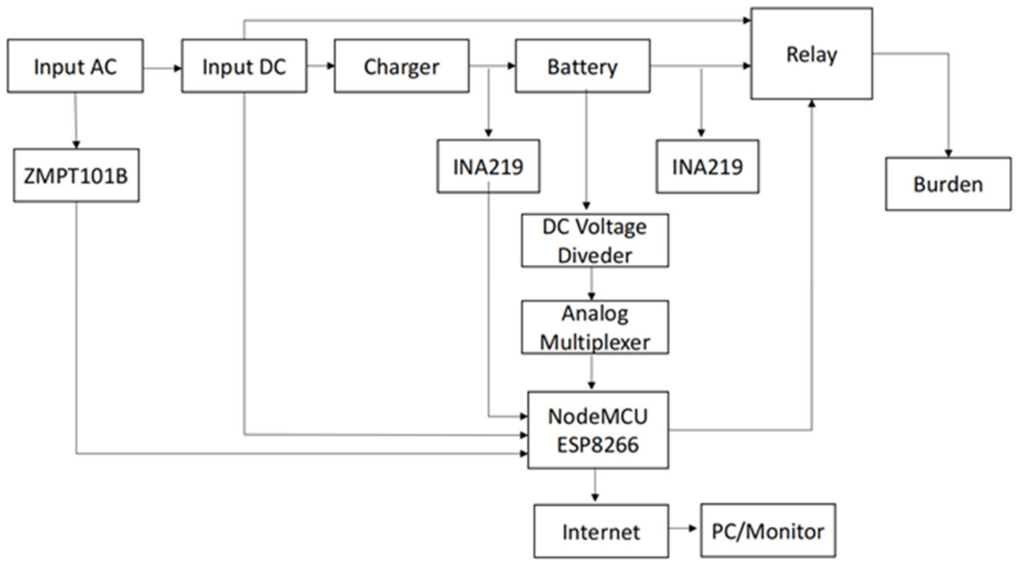


Figure 1. Working diagram system on the device hard.

The hardware design consists of various interconnected components that monitor the battery, as illustrated in Figure 2. In the circuit, there are a number of components, namely 8 (eight) Ni-Cd 1.2 V 1000 mAh batteries as the main research object; the microcontroller used is NodeMCU ESP8266 with a wifi module in it, Analog Multiplexer as a connecting module between the DC voltage sensor and the microcontroller as well as the analog pin adder on the Eps8266, DC voltage sensor with a voltage divider method that will read the voltage parameters of each battery cell so that it can be received and read by the Esp8266, Current sensor (INA219) as a reader of current parameters in the battery charging process from the charger or discharging the battery to the load in the form of a bulb namely 8 (eight) Ni-Cd 1.2 V 1000 mAh batteries [19].

In the circuit, there is also a single-channel relay module that functions as a switch to disconnect and connect the battery to the load as a backup power source. If there is no main power source or DC main power source with a load, the sensor detects the presence of an AC main power source. The circuit is also equipped with an AC voltage sensor (ZMPT101B) as a detector of the main AC power source to determine the working function of the relay module [20]. All components get voltage from the breadboard power supply, which supplies a voltage of 5 V.

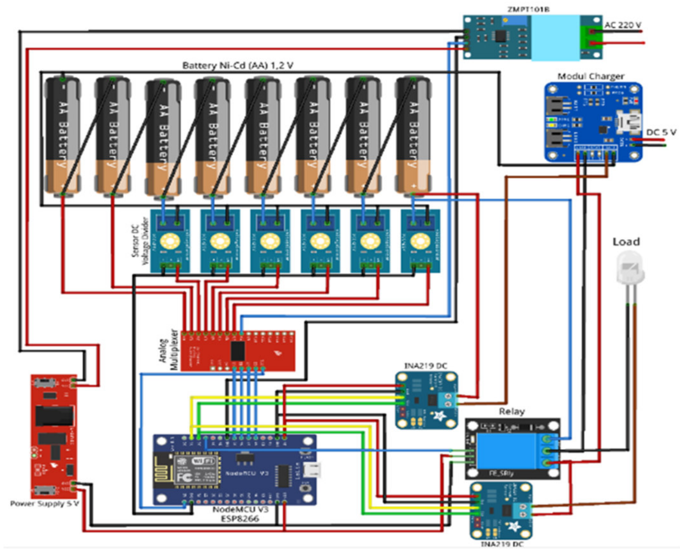


Figure 2. Circuit system battery monitoring.

The interface for displaying battery monitoring results was designed using the Blynk platform, featuring a simple layout to facilitate an efficient monitoring process. The web-based display, as shown in Figure 3, includes several widget boxes, such as gauges, which present the parameter values recorded by the system. Adjacent to the gauges, a chart table illustrates the relationship between the recorded values and time, providing a clear visual representation of the data trends.

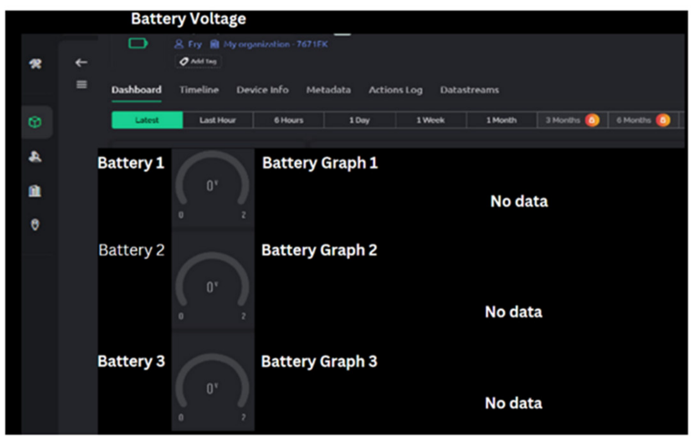


Figure 3. Blynk website display design.

3. Results and Discussion

3.1. Devices hard.

The result of the hardware design in this research is an IoT-based battery monitoring system prototype, as shown in Figure 4. The figure illustrates the integration of various components, including the ESP8266 microcontroller, analog multiplexer, DC voltage sensors (voltage divider), INA219 current sensor, ZMPT101B AC voltage sensor, relay module, incandescent lamp, breadboard power supply, and eight Ni-Cd 1.2V batteries. These components are interconnected using jumper cables to form the complete monitoring system.

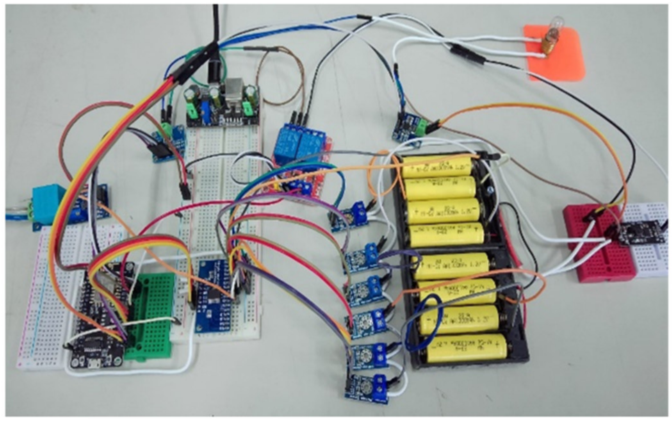


Figure 4. prototype battery monitoring tool.

3.2. Software.

The results of the software design were implemented using the Blynk Cloud application on the website and the Blynk Mobile application for Android. When the device and both applications were connected to the internet, an online status was indicated on both platforms. In the website-based Blynk application, several menus were available, including Dashboard, Timeline, Device Info, Metadata, Action Log, and Datastream. The main monitoring system interface was located in the Dashboard menu, which displayed two widgets: a Gauge for showing sensor readings and a Graphical Box for tracking changes in sensor data over time. The graphical box presented a line graph illustrating the relationship between voltage readings and time, as shown in Figure 5.. The display Android-based Blynk application produces a gauge to display the sensor reading results. There are three small menus, namely a button or wrench that functions to edit the display as desired, a bell menu to view notification information, and a circle menu of the letter "i," which functions to view information from the Blynk application that has been designed.

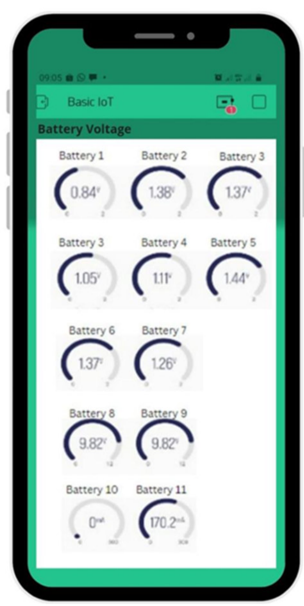
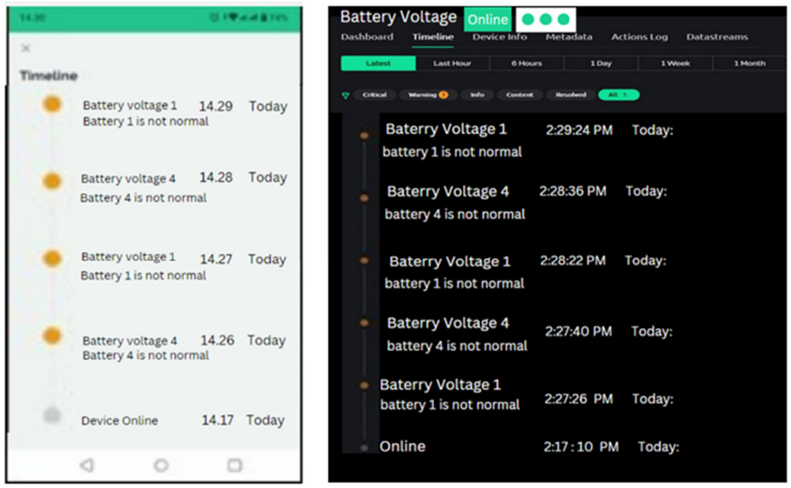


Figure 5. Display results on the android-based Blynk application.

In Figure 6.a, the Blynk website notification results are displayed, serving as a reference for monitoring the battery's condition in case of abnormalities. Figure 6.b presents notifications from the timeline menu, as generated by the Blynk website and Android applications. Both devices emit notifications under specific conditions: when the system goes online or offline, or when the battery voltage drops below the defined threshold. In such cases, the notification includes the description "Battery n is not normal", where "n" specifies the problematic battery, ensuring precise identification of the issue.



(a) **(b)**

Figure 6. (a) Display results on the Android -based Blynk application, (b) Display results Blynk website notification.

3.3. System testing.

o verify whether the designed system operates as intended, tests were conducted on the ZMPT101B sensor, battery voltage readings, and INA219 sensor.

3.3.1. Zmpt101b sensor testing.

The ests involved comparing two sets of measurements for AC voltage: the output displayed on the Blynk application and the readings obtained using a multimeter [21]. The measurements were performed by connecting both the sensor and the multimeter to an AC voltage source.

Table 1. Comparison results measure the Zmpt101b sensor with multimeter.

Condition	Results measuring multimeter (v)	Results sensor reading (v)	Difference (v)	Error (%)	Relay
moment AC detected	223.2	221.8	1.4	0.6	active

Based on the table, the results demonstrate the reliable performance of the ZMPT101B sensor in monitoring battery values. During testing, the operation of the ZMPT101B sensor was shown to influence the functioning of the relay. The results indicate that the relay operates as programmed: it becomes active when AC voltage is detected and remains inactive when no AC voltage is detected [22]. When the relay is active, the load voltage is supplied from the main power source. Conversely, when the relay is inactive, the load voltage is supplied from the backup power source, which is the battery.

3.3.2. INA219 sensor testing.

The INA219 sensor testing was carried out to measure the current flow through the sensors, which were also connected to a multimeter for comparison [23]. The testing was conducted under two conditions: charging current and discharging current.

Table 2. Comparison of Ina219 sensor reading results with a multimeter.

No.	Results tool measure (ma)	Results sensor reading (ma)	Difference (ma)	Error (%)
1.	73.5	74.77	1.27	1.73%
2.	71.4	72.3	0.9	1.26%
3.	61.4	62.3	0.9	1.47%

Based on the tests, which were conducted three times, the results show that the INA219 sensor provides accurate readings. This is further confirmed by the small or low percentage of errors in the measurements. The graph generated from the INA219 sensor reading data is shown in **Figure 7**. It illustrates that as the battery is used over time, the current flow decreases. This decrease in current corresponds to the reduction in the battery's power

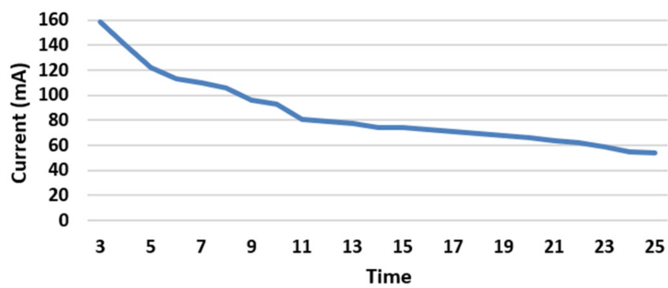


Figure 7. Graph Ina219 sensor output on current burden moment use power backup.

3.3.3. Voltage value reading test.

This test was conducted to compare the results of battery measurements using a DC voltage sensor with measurements obtained from a multimeter [24]. The testing was performed on the batteries under three conditions: normal (standby), discharging, and charging. A battery is considered normal when it is fully charged and ready for use but has not yet been used. It is in a discharging condition when connected to a load as a backup power source during a power outage. The battery is in a charging condition when it is being recharged after being discharged or used.

Table 3. Comparison of voltage sensor reading results with a multimeter under normal conditions.

Battery	Results measuring multimeter (v)	Results sensor reading (v)	Difference (v)	Error (%)
Battery 1	1.3	1.39	0.09	6.92%
Battery 2	1.29	1.4	0.11	8.53%
Battery 3	1.3	1.37	0.07	5.38%
Battery 4	1.29	1.34	0.05	3.88%
Battery 5	1.25	1.35	0.1	8.00%
Battery 6	1.32	1.35	0.03	2.27%
Battery 7	1.31	1.4	0.09	6.87%
Battery 8	1.35	1.4	0.05	3.70%
Total battery	10.41	11	0.59	5.67%

Table 4. Comparison of voltage sensor reading results with a multimeter in discharge conditions.

Battery	Results measuring multimeter (v)	Results sensor reading (v)	Difference (v)	Error (%)

Battery 1	1.17	1.09	0.08	6.84%
Battery 2	1.18	1.3	0.12	10.17%
Battery 3	1.39	1.29	0.1	7.19%
Battery 4	1.13	1.1	0.03	2.65%
Battery 5	0.17	0.13	0.04	23.53%
Battery 6	0.9	1.02	0.12	13.33%
Battery 7	1.03	1.06	0.03	2.91%
Battery 8	1.24	1.27	0.03	2.42%
Total battery	8.21	8.26	0.05	0.61%

Table 5. Comparison of voltage sensor reading results with a multimeter under charging conditions.

Battery	Results measuring multimeter (v)	Results sensor reading (v)	Difference (v)	Error (%)
Battery 1	1,411	1,461	0.05	3.54%
Battery 2	1,380	1,450	0.07	5.07%
Battery 3	1,284	1,434	0.15	11.68%
Battery 4	1,306	1,406	0.1	7.66%
Battery 5	1,302	1,412	0.12	8.45%
Battery 6	1,283	1,373	0.09	7.02%
Battery 7	1,428	1,458	0.03	2.10%
Battery 8	1,284	1,394	0.11	8.57%
Total battery	11,297	11,387	0.09	0.80%

The results from Table 3 to Table 5 are illustrated in the graph shown in Figure 9. This graph represents the load data under three conditions: Normal, Discharging, and Battery Charging. Under normal conditions, the battery voltage ranges from 1.2V to 1.4V, producing a stable, straight-line graph. In the discharging condition, the battery voltage gradually decreases over time, though some batteries experience a faster drop than others. During the charging condition, the battery capacity increases rapidly as it undergoes quick recharging (boost charging) after excessive discharge. For batteries that experience faster capacity discharge compared to others, it can be concluded that their condition is no longer suitable for long-term use, and they should be replaced. The results of this study show that the IoT-based battery monitoring process significantly enhances the monitoring system, allowing for continuous tracking of the battery's condition. This helps make the monitoring process more effective and efficient, enabling immediate action if abnormal battery voltage or capacity is detected.

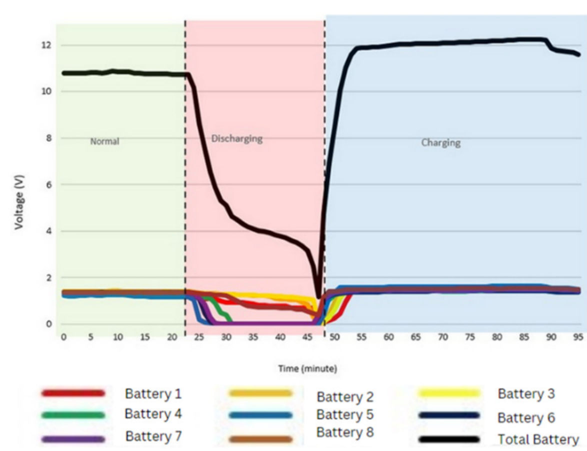


Figure 8. Graph overall results research on reading tension battery.

4. Conclusion

In this study, our work contributes to the advancement of battery monitoring systems by focusing on the condition of individual battery cells, specifically monitoring voltage and current parameters during normal operation, discharging, and charging states. This target measurement allows for the identification of specific cells exhibiting abnormalities. As a result, only the affected cells need to be replaced, eliminating the need to replace the entire battery pack, which enhances efficiency and reduces costs. The ZMPT101B sensor in this study successfully enabled the relay to switch smoothly between the primary and backup power sources, ensuring reliable power transfer. Additionally, the system provided accurate real-time data on battery current and voltage levels, with results within a tolerance of 0.6. The IoT-based monitoring system, integrated with the Blynk application, offers efficient and timely data monitoring and notifications, making the battery monitoring process effective in minimizing potential abnormalities and maintaining optimal performance.

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Competing Interest

We declared that the research without financial interest.

Author Contribution

Main Author: Yunidar, who was involved in data collection Fathurahman and Melinda, Analysis was carried out by Ery Azra, Malahayati and Elizar.

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