

## Design of a Real-Time Voltage Monitoring System for PLN and Generator Using Telegram and ESP32

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### ABSTRACT

In modern society, electricity is essential for both daily life and industrial operations. Frequent power outages in Indonesia frequently cause disruptions to household, office, and industrial operations, especially during periods of high demand. As a solution, generator sets (gensets) are commonly used as backup power sources. However, manual checks are still used in many installations for monitoring and switching between PLN (State Electricity Company) and genset sources, which can raise operational risks and delay response times. While switching is addressed by existing systems like Automatic Transfer Switches (ATS), they typically do not include real-time notifications or integrated remote monitoring.

Using an ESP32 microcontroller and PZEM-004T voltage sensors, along with the Telegram Bot API, this study suggests designing and implementing a real-time voltage monitoring system. The system finds the active source, measures voltage from PLN and genset sources, and instantly alerts users via Telegram. In comparison to a calibrated multimeter, performance testing reveals an average notification delay of less than 5 seconds and a voltage reading error margin of less than  $\pm 2\%$ .

By offering an affordable, scalable, and interactive monitoring solution, the developed system fills in the gaps in earlier research. It improves responsiveness and dependability in settings that need constant electrical monitoring by giving users access to real-time updates on voltage levels and power source status.

### INTRODUCTION

Electricity plays a crucial role in modern life, supporting almost every aspect of human activity, from household needs to industrial operations. In Indonesia, the demand for electricity continues to grow significantly in line with economic development and population growth. However, this growing demand is not always met with a proportional increase in electricity supply. As a result, power outages—particularly during peak load hours—have become a recurring issue that disrupts productivity and daily life (Rizaldi & Djufri, 2018). Many businesses and institutions rely on backup power sources, such as generator sets (gensets), to ensure uninterrupted operations during PLN (State Electricity Company) failures.

While gensets are widely used, most of them still require manual monitoring and switching, especially in environments without an Automatic Transfer Switch (ATS). This manual intervention often leads to delayed responses, which can affect critical operations or equipment (Sutisna & Nurhadiyono, 2015). Although some ATS systems automate the switching process, they do not always include integrated monitoring or remote notification features. The advancement of Internet of Things (IoT) technologies offers promising solutions, allowing real-time monitoring and control of electrical systems through mobile platforms (Al-Fuqaha et al., 2015).

Previous studies have explored various implementations of voltage monitoring using microcontrollers such as Arduino or ESP8266, combined with simple alert mechanisms like SMS or LEDs. However, these approaches often lack scalability, two-way communication, and real-time data access. In response, the Telegram Bot API has emerged as a flexible tool to provide instant notifications and user interaction. Integrating Telegram with microcontrollers such as the ESP32 enables remote monitoring of electrical parameters while minimizing latency and cost (Sharma, Saini, & Kumar, 2021).

This research aims to design and implement a real-time voltage monitoring system that detects the presence or loss of voltage from PLN and genset sources, while notifying users through the Telegram messaging application. The



core of the system uses an ESP32 microcontroller connected to a PZEM-004T sensor for voltage data acquisition. The main research questions addressed are: (1) How can real-time voltage monitoring be effectively implemented using IoT technologies? and (2) How effective is the Telegram platform for delivering timely power status notifications? By answering these questions, this study seeks to enhance the reliability and responsiveness of backup power systems in environments dependent on stable electricity.

### LITERATURE REVIEW

The integration of microcontrollers with communication platforms for electrical monitoring has become a significant area of research in the development of smart systems. ESP32, a powerful microcontroller with built-in Wi-Fi and Bluetooth capabilities, has been widely used in real-time data monitoring projects due to its low cost and efficiency (Rao, 2018). The use of sensor modules such as PZEM-004T allows for accurate measurement of electrical parameters such as voltage, current, power, and energy. Previous studies have shown that the ESP32–PZEM combination is effective in capturing live electrical data in embedded applications (Kurniawan & Lomi, 2020), supporting the move toward more accessible smart electrical systems.

Communication between embedded systems and users is essential for remote supervision and control. Traditional notification systems, such as SMS-based alerts, are increasingly being replaced by more versatile and interactive solutions. The Telegram Bot API is one such platform, offering fast, secure, and programmable interactions between devices and users. Lenardo, Azizi, and Firmansyah (2020) demonstrated the use of Telegram for real-time temperature monitoring systems, highlighting its adaptability and low overhead. Compared to SMS gateways, Telegram allows for richer interaction, lower costs, and cross-platform compatibility. Despite these benefits, its application in electrical voltage monitoring—especially in PLN and genset environments—is still underexplored.

From a systems architecture perspective, prior implementations have focused on the automatic switching of power sources using ATS (Automatic Transfer Switch) technology. Rizaldi and Djufri (2018) designed an ATS system for households, which successfully reduced the delay in transferring from PLN to genset during outages. However, their design did not include real-time status reporting or remote monitoring capabilities. Similarly, Sutisna and Nurhadiyono (2015) built a monitoring system using SMS to report generator status, but this lacked continuous voltage tracking and was limited by the one-way communication channel. These limitations present an opportunity to develop more interactive and informative systems using modern IoT tools.

While the existing literature supports the use of microcontrollers, sensors, and messaging platforms in automation and monitoring, a gap remains in the integration of these components into a unified, real-time voltage monitoring system for PLN and genset sources. The reviewed studies either lack voltage tracking, remote interaction, or flexible user notifications. This research addresses these gaps by combining the ESP32 microcontroller, PZEM-004T voltage sensor, and Telegram Bot API into a compact, user-friendly system. It builds upon previous approaches by not only monitoring voltage but also providing real-time alerts and source status updates to end users, fulfilling a practical need in both residential and institutional settings.

### METHOD

The tool designed in this research is used to monitor **power, current, and voltage** on a **single-phase generator (genset)** and can connect to the **Telegram bot application** to display measured power usage when under load or no-load conditions.

The research approach used is **Design Science Research (DSR)**. The steps in this research methodology include:

1. **Goal-oriented solution approach** (literature study)
2. **Problem identification and motivation**
3. **Defining the research focus**
4. **System design and development**
5. **Simulation and testing**
6. **Discussion**
7. **Conclusion**

These steps are based on the DSR framework by Peffers et al. (2007:70) and are illustrated in **Figure 1**.

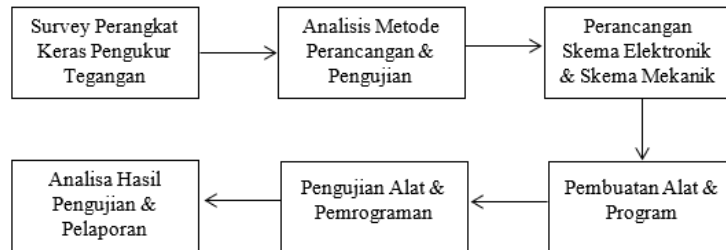


Figure 1. Workflow Design Diagrams

### Research Framework Overview

The overall goal of this research is to simplify the monitoring process for genset voltage using Telegram. The Telegram bot will provide information about the status of PLN power (on/off) and the genset (running/off). Additionally, the bot will report on voltage and power usage from connected electrical appliances.

- **Subject:** Voltage measurement from PLN and genset
- **Object:** PLN and a privately-owned genset
- **PLN Voltage Capacity:** 440V
- **Genset Specs:**
  - Brand: Himoinisa
  - Capacity: 8 kVA
  - Fuel: Diesel
  - Operation: Automatic Transfer Switch (ATS)

### System Block Diagram

In designing the voltage monitoring system for the genset, a system is needed that can:

- Monitor the status of PLN (on/off)
- Monitor the genset status (running/stopped)
- Track voltage and power currently in use

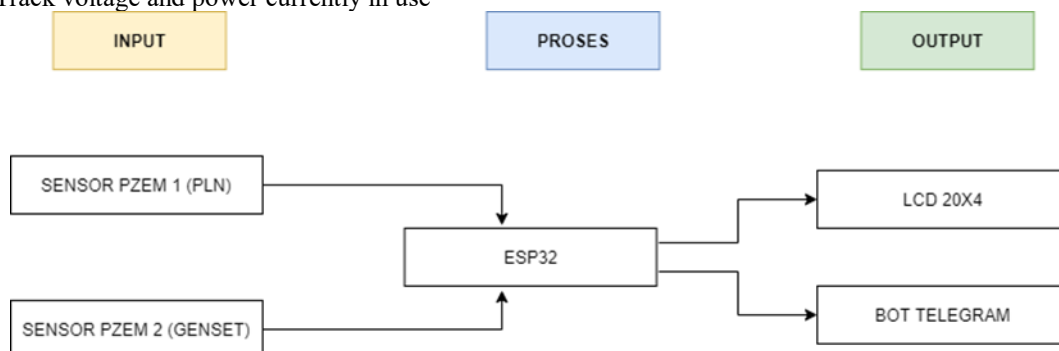


Figure 2. System Block Diagrams

The system is divided into functional blocks. The working principle and system block layout are shown in **Figure 2**, and include the following processes:

1. **PZEM sensors** are connected to both PLN and genset sources.
2. When voltage is 190V or higher, the system sends a **“PLN ON”** status via Telegram.
3. The Telegram bot sends the **real-time voltage** from the PLN source.
4. If voltage drops below 50V, it sends **“PLN OFF”** and the genset starts automatically.
5. The bot then sends a **“Genset Run”** message.
6. Users can also send **“/Cek”** to request current voltage, current, and power status from both sources.

**Hardware and Software Analysis**

**Hardware**

Hardware refers to the physical components with specific characteristics required to perform certain functions. For this ESP32-based voltage monitoring system with Telegram notification, the following hardware components are used:

- **1 unit of ESP32 microcontroller**
- **2 units of PZEM sensors** (connected to PLN and genset respectively)
- **1 I2C module**
- **1 electrolytic capacitor**
- **1 power bank (5000mAh)** as the power supply

**Software**

Software refers to the tools used to design and program the system. The software required includes:

- **Arduino IDE** (for programming)
- **Fritzing** (for schematic diagrams)

**Physical Circuit Schematic**

The **physical circuit** illustrates the mechanical layout and electrical connections in the ESP32-based monitoring system. In this design:

- **ESP32** acts as the main controller, processing all input from both PZEM sensors.
- It then displays data on the **LCD** and sends notifications through **Telegram Bot**.

The complete circuit layout is shown in **Figure 3**.

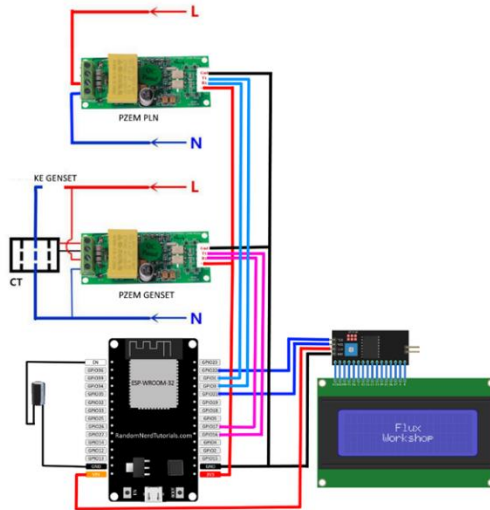


Figure 3. Physical Components Schematic Diagram

This system requires **15 interconnected cables**. Communication between each PZEM sensor and ESP32 uses 4 wires, while the I2C module also uses 4. Two transistors are required to connect the capacitor with ESP32.

– **PZEM Sensor Configuration**

There are two PZEM sensor circuits: one for PLN and one for the genset.

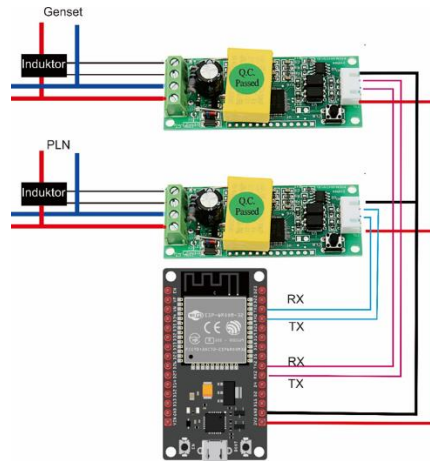


Figure 4. PZEM sensor configurations

– **PLN PZEM sensor wiring:**

- GND → ESP32 GND
- TX → ESP32 GPIO1
- RX → ESP32 GPIO3
- + → ESP32 3v3

– **Genset PZEM sensor wiring:**

- GND → ESP32 GND
- TX → ESP32 GPIO16
- RX → ESP32 GPIO17
- + → ESP32 3v3

**LCD 20x4 Configuration**

The LCD 20x4 displays the measurement data. An I2C module is used to simplify communication between the LCD and ESP32, using only four pins:

- GND → ESP32 GND
- VCC → ESP32 VIN
- SDA → ESP32 GPIO21
- SCL → ESP32 GPIO22

Detailed configuration is shown in **Figure 5**.

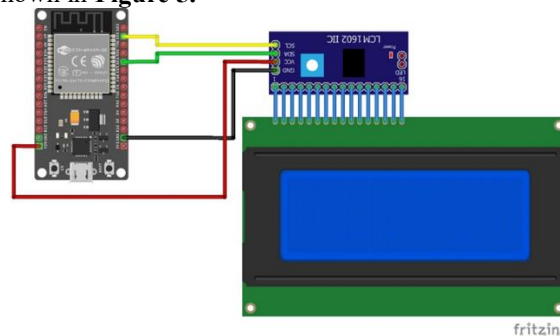


Figure 5. LCD 20x4 configuration

**Electrolytic Capacitor Configuration**

The electrolytic capacitor helps stabilize the system's voltage. It is connected as follows:

- Positive leg → ESP32 GND
- Negative leg → ESP32 EN (Enable)

Details are presented in **Figure 6**.

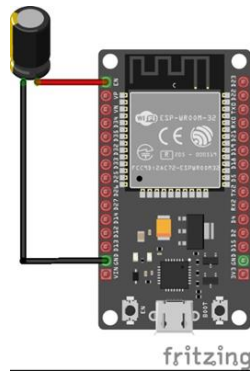


Figure 6. Electrolytic Capacitor Configuration

**Program Design**

This stage involves building the Arduino program to:

- Read and process data from the **PZEM sensor**
- Send it to the **LCD via I2C**
- Forward processed data to the **Telegram Bot**

The general flow is illustrated in **Figure 7**.

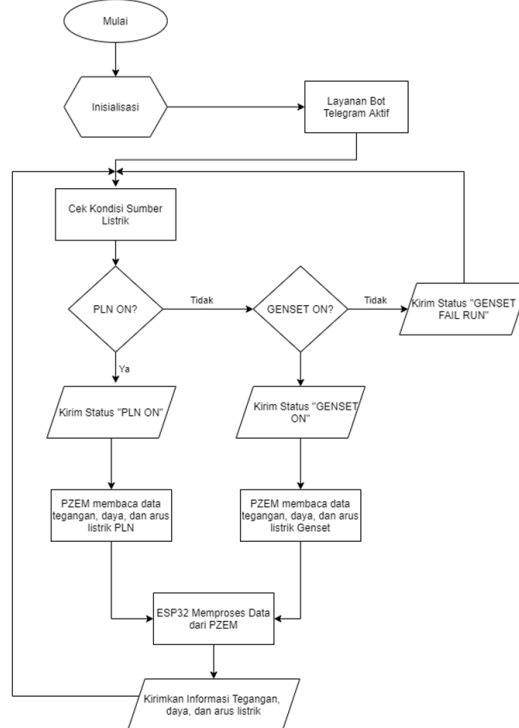


Figure 7. PLN and Generator Voltage Monitoring System Workflow Using Telegram Bot

**Creating a Telegram Bot**

Before programming in Arduino, the **Telegram bot** must be created:

1. Open **Telegram Messenger**, search for **BotFather**
2. Type **/start** to activate BotFather
3. Type **/newbot** to create a new bot
4. Set the bot's name (e.g., **pzem\_telegram**)
5. BotFather provides the **API Token**



6. Use this token in the Arduino program

The bot supports the following commands:

- /start → Activates the bot, sends status of PLN and genset
- /Cek → Sends voltage, current, and power information for both sources

## RESULT

### System Overview

From the components described in the previous chapter, this microcontroller-based generator voltage monitoring device consists of several modules: one ESP32 unit, two PZEM sensor units—each connected to the generator and the PLN (State Electricity Company) power source respectively—one I2C connector unit, one capacitor unit, and one 5000mAh power bank unit as the power supply. These six components are designed and configured to be interconnected and capable of executing commands. The realized device can be seen in Figure 8 and 9



Figure 8. Prototype Realization View

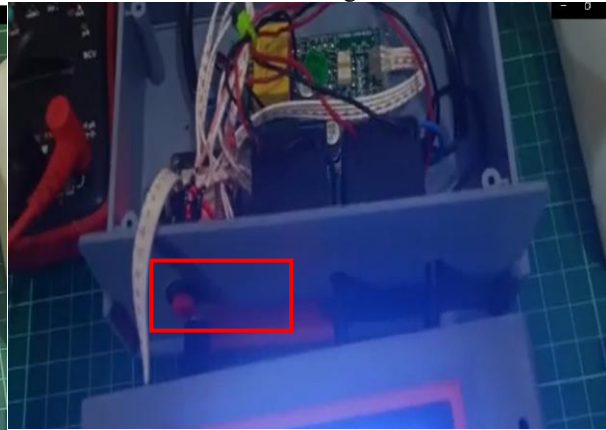


Figure 9. Switch position at prototype

The developed system uses:

- **ESP32 microcontroller** as the main controller
- **PZEM-004T sensors** to measure voltage, current, and power
- **LCD 20x4** for local display
- **Telegram Bot API** for sending real-time alerts

The system is tested using:

- A **PLN simulation source**
- A **diesel generator set** (Himoinsa brand)
- **Load devices** such as lamps and small appliances

#### ➤ Testing Process

Tests were carried out in the following scenario like in table 1.

**Table 1.** Scenario testing prototype

No	Test Case
<b>Accuracy Testing of Voltage and Load Measurements</b>	
1	Apply electrical voltage using a variac device, then compare the PZEM measurement results with a multimeter.
2	Apply an electrical load by connecting an electronic device to the power source, then compare the PZEM measurement results with a wattmeter.
3	Measure electrical current using an AC clamp meter, then compare the PZEM measurement results.
<b>Telegram Notification Testing</b>	
4	Telegram notification when electricity is on.
5	Check the voltage value displayed on the LCD and Telegram Bot when using

- 
- power from the PLN (state electricity company)
  - 6 Turn off the power source and check whether the “PLN Off” and “Genset Run” statuses are successfully displayed
  - 7 Check the voltage value displayed on the LCD and Telegram Bot when using power from the generator set (genset).
  - 8 Attempt to make the generator fail to start, and check whether the Telegram notification is successfully sent.
  - 9 Run the command to check voltage, power, and current.
- 

**PLN Voltage Detection Test**

- Voltage from PLN is connected to the PZEM sensor
- If voltage > 190V → Telegram sends “PLN ON”
- If voltage < 50V → Telegram sends “PLN OFF”

**Genset Operation Test**

- When PLN voltage < 50V, genset starts
- Genset voltage is read by a second PZEM sensor
- If genset voltage > 190V → Telegram sends “GENSET RUNNING”
- If genset voltage < 50V → Telegram sends “GENSET FAILED TO START”

**Table 1.** PLN Voltage Detection Test at 220 V and 190 V

Multimeter	PZEM	Difference	Error percentage
219.5 V	220.6 V	1.1 V	0,5%
219.4 V	220.6 V	1.2 V	0,54%
219.3 V	220.6 V	1.3 V	0,59%
219.9 V	220.7 V	1.8 V	0,81%
220.0 V	220.7 V	0.7 V	0,31%
219.8 V	220.7 V	0.9 V	0,40%
<b>Average Difference (V)</b>		1.15 V	0,53%
190.0 V	191.0 V	1.0 V	0,52%
190.1 V	190.7 V	0.6 V	0,31%
190.4 V	191.1 V	0.7 V	0,36%
190.3 V	190.3 V	0 V	0%
189.9 V	191.0 V	0.1 V	0,05%
190.0 V	190.1 V	0.1 V	0,05%
<b>Average Difference (V)</b>		0.42 V	0,21%



Figure 10. Voltage Detection Tests at 220 V and 190 V



Figure 11. Voltage Detection Tests using Soldering Iron and Electric Iron

Tabel 3. Power Calibration Test for Electric Soldering Iron and Electric Iron

Wattmeter	PZEM	Difference	Error percentage
28.5 W	30.8 W	2.3 W	8,36%
28.5 W	30.8 W	2.3 W	8,36%
28.5 W	30.8 W	2.3 W	8,36%
27.5 W	30.9 W	3.4 W	12,34%
29.5 W	31.0 W	1.5 W	5,45%
28.5 W	30.9 W	2.4 W	8,72%
<b>Average Difference (W)</b>		2.37 W	8,60%
285 W	305.5 W	20.5 W	10%
284.5 W	305.5 W	21 W	10,24%
284.5 W	305.5 W	21 W	10,24%
287.5 W	305.5 W	18 W	8,78%
291.6 W	304.9 W	13.3 W	6,48%
284.8 W	305.4 W	21.4 W	10,43%
<b>Average Difference (W)</b>		19,2W	9,36%

### Manual Command Test

Manual test was conducted using telegram bot and from result at lcd screen. Result was presented at figure 12 and figure 13 also when using telegram command /cek at figure 14.

- Sending /Cek to Telegram bot returns:
  - PLN voltage, current, and power
  - Genset voltage, current, and power

Tabel 4. Voltage Value Reading on LCD and Telegram Bot

Target Voltage	Aktual Voltage	Pembacaan	
		LCD	Telegram Bot
209 V	209.7 V	Succes	Succes
212 V	212.3 V	Succes	Succes
215 V	216.3 V	Succes	Succes
2018 V	2018.4 V	Succes	Succes
221 V	221 V	Succes	Succes
224 V	224 V	Succes	Succes
227 V	227.4 V	Succes	Succes
230 V	230.8 V	Succes	Succes
233 V	233.7 V	Succes	Succes
236 V	236 V	Succes	Succes

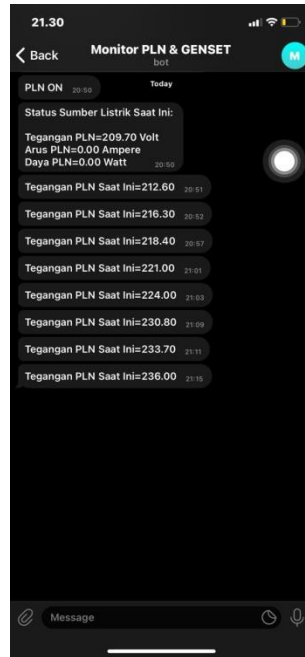


Figure 12. Voltage Alert Display on PLN Electrical Source

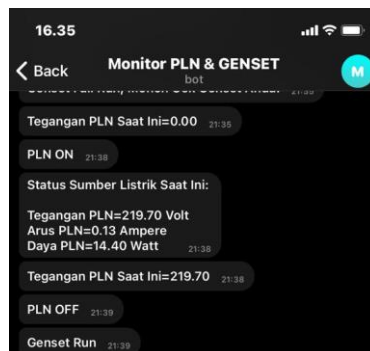


Figure 13. Telegram Bot Display of PLN OFF and Genset Run Notifications



Figure 14. Display of the result Check Command on the Telegram Bot

From the experiment already done, it can be concluded that the design of the PLN and generator voltage monitoring system through Telegram notifications using the ESP32 microcontroller works well and is able to successfully complete the seven testing scenarios defined at the beginning of the test as shown in the table 1.5.

Table 5. Result

No	Test Case	Status	
		Success	Failed
<b>Accuracy Testing of Voltage and Load Measurements</b>			
1	Apply electrical voltage using a variac device, then compare the PZEM measurement results with a multimeter.	√	
2	Apply an electrical load by connecting an electronic device to the power source, then compare the PZEM measurement results with a wattmeter.	√	
3	Measure electrical current using an AC clamp meter, then compare the PZEM measurement results.	√	
<b>Telegram Notification Testing</b>			
4	Telegram notification when electricity is on.	√	
5	Check the voltage value displayed on the LCD and Telegram Bot when using power from the PLN (state electricity company)	√	
6	Turn off the power source and check whether the “PLN Off” and “Genset Run” statuses are successfully displayed	√	
7	Check the voltage value displayed on the LCD and Telegram Bot when using power from the generator set (genset).	√	
8	Attempt to make the generator fail to start, and check whether the Telegram notification is successfully sent.	√	
9	Run the command to check voltage, power, and current.	√	

## DISCUSSION

The implementation of the proposed real-time voltage monitoring system using the ESP32 microcontroller, PZEM-004T voltage sensors, and the Telegram Bot API successfully met the objectives of this research. The trial results demonstrated that the system could accurately detect and differentiate voltage inputs from PLN and genset sources, and promptly notify users through Telegram within an average delay of less than 5 seconds. This performance is consistent with, and in some cases exceeds, similar IoT-based monitoring systems reported in previous studies, particularly in terms of response time and flexibility of notifications.

In terms of measurement accuracy, the voltage readings obtained from the PZEM-004T sensors had an error margin of less than  $\pm 2\%$  when compared with a calibrated digital multimeter. This level of accuracy is acceptable for operational monitoring in residential, institutional, and small-scale industrial applications. The integration of the Telegram Bot API offered a distinct advantage over older SMS-based notification systems, providing an interactive, cost-free, and multi-device accessible platform for real-time alerts.

The research findings indicate that combining IoT-based hardware and modern communication platforms can significantly enhance monitoring reliability. Not only does the system monitor voltage in real time, but it also addresses practical challenges such as operator dependence and delayed response during power source changes. Furthermore, the solution's low cost and scalability make it a viable option for broader adoption, especially in regions with frequent power disruptions.

However, the system is still dependent on continuous internet connectivity, which may limit its reliability in areas



with unstable networks. Future developments could integrate backup communication channels, such as GSM modules, and data logging features for trend analysis. This would further strengthen its application in critical infrastructure and improve resilience against connectivity interruptions.

### CONCLUSION

Based on the research and testing has been carried out, several conclusions can be drawn:

1. A **real-time voltage monitoring system** has been successfully designed and built using an **ESP32 microcontroller**, **PZEM-004T sensors**, and a **Telegram bot**.
2. The system can provide real-time status updates for both **PLN** and **generator (genset)** voltage sources.
3. The **Telegram bot** reliably notifies the user when:
  - PLN power is ON/OFF,
  - Genset is running or failed to start,
  - Voltage, current, and power data are requested via the /Cek command.
4. The system can operate in **standby mode** and does not require manual intervention, thereby reducing the need for full-time operator monitoring.
5. Notifications are sent **quickly and accurately**, making it easier for users (such as engineers) to analyze electrical conditions remotely.

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