Design of a Stabilizer for Overload Protection Integrated with an Internet of Things-Based Smart Home System

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Abstract

Electricity is the primary source of energy essential in daily life, used in various sectors from households to industries. However, the use of electrical energy is not without challenges, one of which is voltage instability that can cause damage to electronic devices and losses for consumers. To address this issue, a voltage stabilizer system integrated with IoT-based Smart Home technology has been developed. This system comprises an ESP 32, transformer slider, MCB, servo motor, PZEM004T sensor, ZMPT101B sensor, LCD, and a 5VDC relay. The design results show that the miniature design and panel box align with the initial design. The output voltage ranges from 218.4V to 222.4V, within PLN's standard tolerance (220V). The relay response time through the application varies between 4.1 to 14.1 seconds, depending on the WiFi network speed. The power measurement difference on the panel ranges from 0.01% to 17.9% compared to the reference measuring instrument. The system responds to overloads by turning off the relay within 7.1 to 67 seconds and sends email notifications when the voltage drops below 150V or the load exceeds 900W. Thus, this system is effective in maintaining voltage stability, mapping loads, and providing abnormal condition notifications, protecting electronic devices and reducing consumer losses.

Keywords— *Smart home, Voltage Stabilizer, Voltage instability.*

1. INTRODUCTION

Electricity is one of the most widely used forms of energy today. In 2022, electricity consumption in Indonesia reached 1,173 kWh per capita and is expected to continue rising in line with Indonesia's economic growth, which is projected to reach 5.3% in 2023. Currently, the electrification ratio in Indonesia has reached 99.6%, meaning that more than 99% of households have access to electricity. The goal is to achieve full electrification for all households in Indonesia by 2023 [1].Although electricity development in Indonesia is progressing rapidly, it is not without problems, one of which is voltage instability in various regions. A real-time monitoring program by the Institute for Essential Service Reform (IESR) found that homes in densely populated areas of Jakarta experience unstable voltage, unlike those in suburban areas. This instability can damage electronic equipment and increase power consumption [2]–[4].

Voltage instability occurs after or during numerous disturbances. It is also defined as the system's inability to maintain voltage profiles under normal conditions and after disturbances. A voltage drop can lead to system damage or malfunction, potentially causing partial or total power outages [5]. Voltage instability is detrimental to consumers, making it crucial to maintain stable voltage using a stabilizer. However, conventional stabilizers cannot map the load or provide notifications if the load exceeds capacity, which causes the MCB to cut off the load directly when the stabilizer exceeds its specifications. Therefore, this research aims to design a stabilizer to secure overloads, integrated with an Internet of Things-based smart home system that can map loads and provide notifications when an overload occurs.

A Literature Review is conducted by comparing similar studies with the same literature used as a reference. This comparison can serve as a basis for consideration and is expected to assist in the development of a new system include:

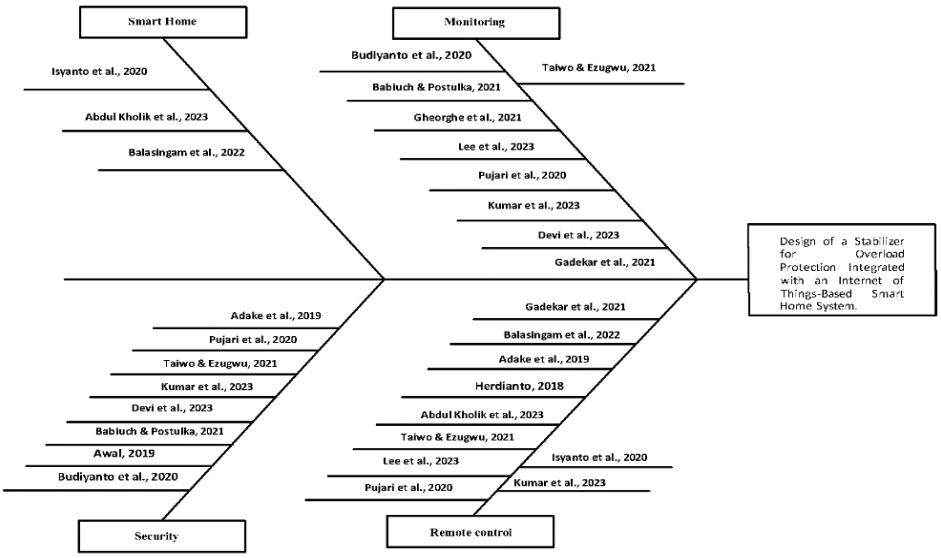


Figure 1. Fishbone diagram mapping research topics

1. Based on the literature from [6] [7] [8] research has been conducted on the design of smart homes using microcontrollers such as the ESP8266 and ESP32, as well as IoT applications like Blynk and Google Assistant. The focus of these studies is on remote load control, which is a key function of smart homes.
2. Based on the literature from [9] [10] [11] [12] [13] [14] [15] [16] [17] focus on the design of monitoring systems, such as energy monitoring and home security, utilizing the Internet of Things (IoT) concept. Various microcontrollers like ESP32, ESP8266, and Arduino were used in these studies. The primary focus of these designs is remote monitoring.
3. Based on the literature [18] [13] [17] [16] [14] [10] [19] [9] research has been conducted on designing security systems, including home security, protection against electricity theft, gas leaks, and fire hazards, using IoT concepts. The microcontrollers used in these designs include ESP32, ESP8266, and Arduino. The focus of these designs is to create security systems tailored for specific needs.
4. Based on the literature [15] [18] [7] [8] [20] [17] centers on the design of remote control systems using the IoT concept. The microcontrollers used in these studies include ESP32, ESP8266, and Arduino. The primary goal of these designs is to develop systems for remote control.

To facilitate the mapping of the literature, a fishbone diagram is presented in accordance with the research topics in Figure 1. This diagram visually organizes the various studies and key focus areas related to the research, making it easier to identify connections and gaps within the literature.

From the fourteen sources of literature, various applications of the Internet of Things (IoT) have been explored three studies focus on smart homes [21]–[23], eight on security systems, ten on monitoring systems, and ten on remote control systems [24]–[26]. However, none of these studies have designed a system that combines a voltage stabilizer, which protects against voltage drops and instability, with a smart home system that enables remote load control and electrical security management. This indicates a gap in the existing literature, highlighting the need for a new design that integrates these functionalities.

2. RESEARCH METHODS

The method used in this research is adapted from one of the Six Sigma methods, namely DMADV (Define, Measure, Analyze, Design, Verify), which has been modified to develop the DDIMAVC method (Define, Design, Implementation, Measure, Analyze, Verify, Conclusion) as shown in Figure 2.

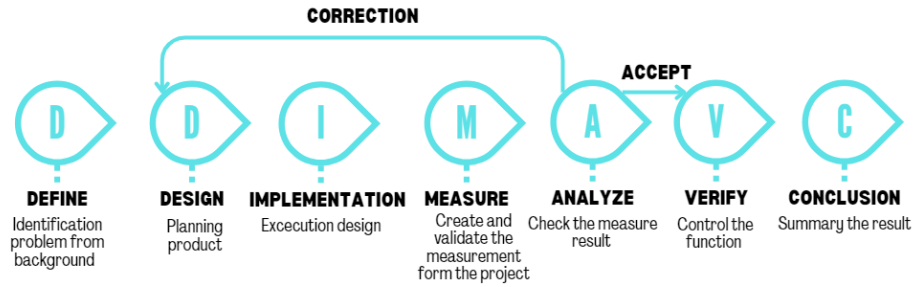


Figure 2. DDIMAVC

In the Define step, the existing problems are identified according to the background. This is followed by the Design step, where a device is designed as a solution to the identified problems. Next, in the Implementation step, the planned design is executed. The Measure step involves measuring and testing the outcomes of the designed device. The subsequent step is Analyze, where the test results are examined and analyzed for further stages. If corrections are needed, the process returns to the Design phase to fix any errors. However, if the results are satisfactory, the process moves on to the Verify step, where the device's capabilities are validated to ensure it functions correctly. The final step is Conclusion, where the findings about the device are summarized.

2.1. Diagram Block

Block diagram that has been designed, as shown in Figure 3. A block diagram is designed to simplify the process of creating the device, allowing for a clear understanding of its input and output. The block diagram is divided into three sections: input, process, and output, each with specific functions and purposes.

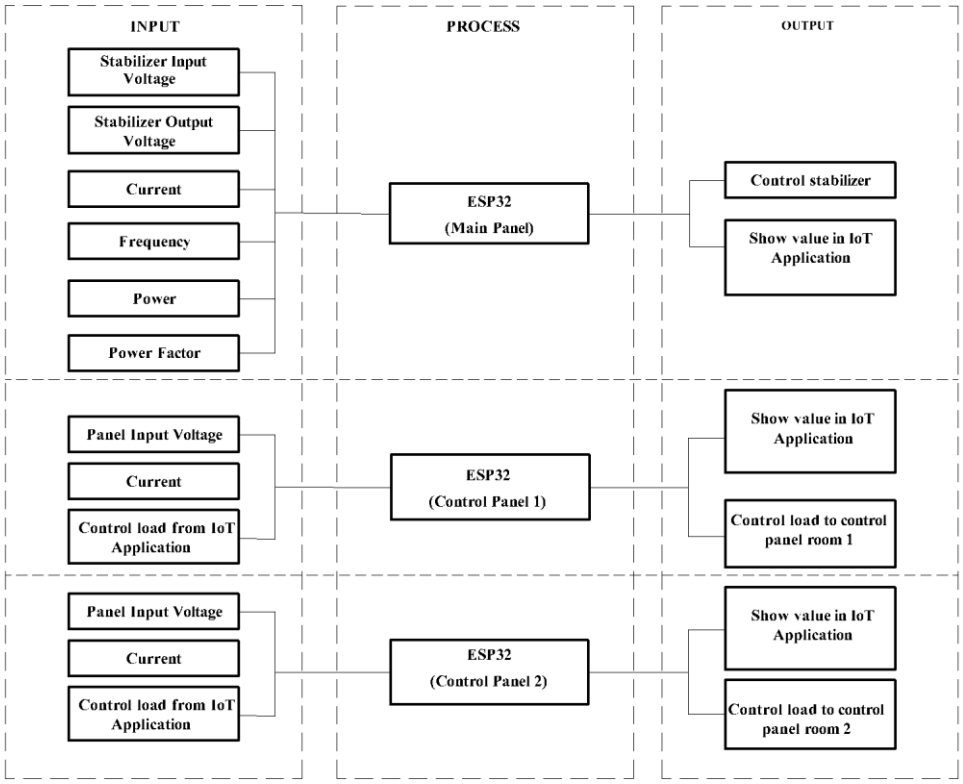


Figure 3. Block diagram system

The following are the components of the block diagram:

1. Input
   The input section consists of several components that serve as inputs to the microcontroller from the sensors used. It also includes load control commands, each serving as an input for ESP32 panel 1 and ESP32 panel 2.
2. Process
   In the process stage, the input data received is processed through the ESP32. This program is also connected to the IoT, allowing the received data to be accessed from anywhere as long as the device remains connected to the internet.
3. Output
   In the output stage, the processed data will result in either a graphical display or control commands. The control commands come from the IoT platform or the program used to manage the load, enabling remote or automated load control according to the established criteria.

2.2. Flowchart

A flowchart is a graphical representation of a process or workflow. Below is the flowchart used in this study, as shown in Figure 4. Figure 4 illustrates the planned system flow. When the device is activated, all sensors will start functioning and send data to the ESP32. This data will then be forwarded to the IoT application for monitoring purposes. Additionally, the IoT application is used to control the loads on Control Panel 1 and Control Panel 2. If a load is turned on or off via the IoT application, the ESP32 will receive the command and subsequently output the appropriate signal to the relay according to the received instructions.

2.3. Device Design

Figure 5 shows the relationship between the three controllers on each panel, all connected to a single IoT platform. This setup simplifies monitoring power usage and controlling loads. The main panel includes a transformer slider that regulates voltage stability, and the output voltage is distributed to areas based on the mapped controllers. All controllers are connected to the same Wi-Fi network and IoT application, allowing for real-time monitoring of power usage in each area. Additionally, the relay for each area can be controlled via the IoT application, enabling remote activation and deactivation of loads. There are two room panels placed in separate rooms, each connected to the same IoT platform, ensuring cohesive control and monitoring across the system.

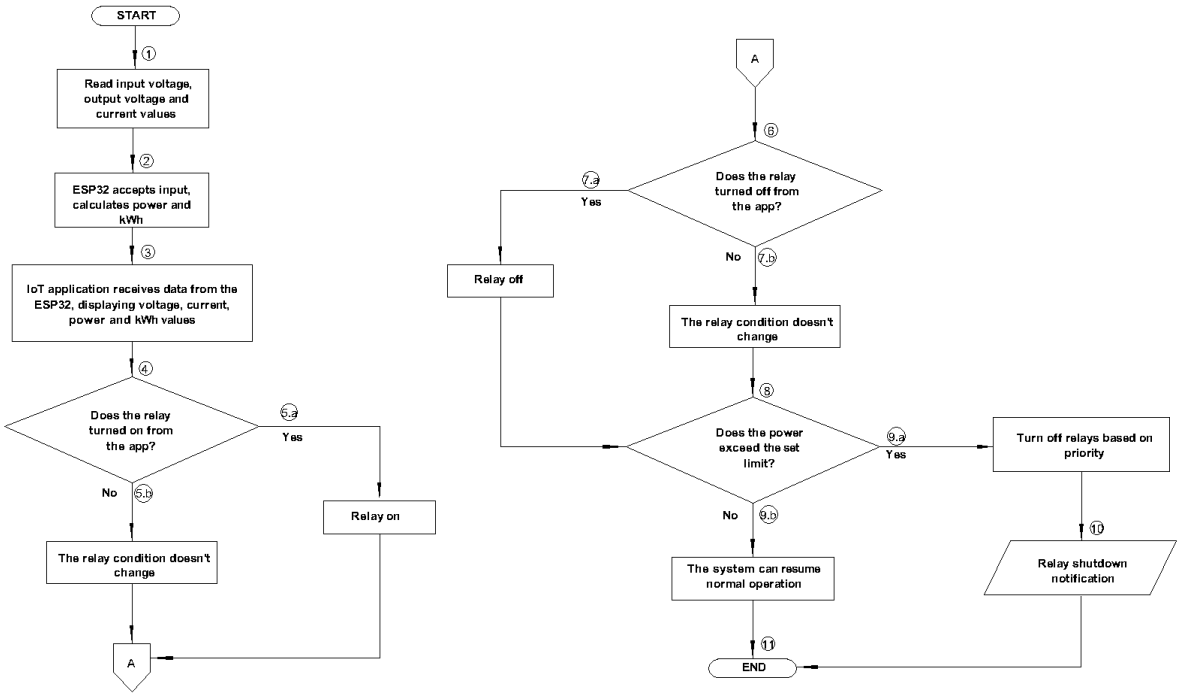


Figure 4. Block diagram system

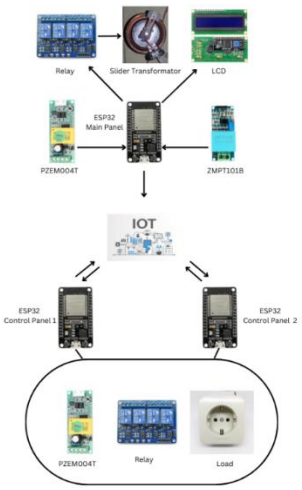


Figure 5. Device Design

3. RESULTS AND DISCUSSION

3.1. Results of the Miniature Design

The miniature design results in a model house made using 2 mm thick acrylic. Figure 6 (A) shows the design of the miniature, while Figure 6 (B) shows the implementation of the design from Figure 6 (A).

Shown in Figure 6 (B) is the result of the miniature house design, which includes Room 1, the living room, the kitchen, Room 2, and the bathroom. Each room has different loads: Room 1 contains a light, an outlet for Room 1, and a Wi-Fi outlet. The living room only has a light, and similarly, the bathroom also only has a light. The kitchen is equipped with a light, an outlet for the refrigerator, and an outlet for the kitchen. Room 2 has a light, an outlet for Room 1, an air conditioning outlet, and a TV outlet.

3.2. Results of the Aplication and Notification

The IoT application used in this design is a custom-built app created using Kodular. Figure 7 shows the results of the app design developed through Kodular.Figure 7 (A) displays the initial interface of the app, which consists of two buttons. The first button labeled “Turn On/Off Load” leads to a load control settings page, as shown in Figure 7 (B). The second button on the main page, labeled “Electrical Parameters” as shown at Figure 7 (C) takes the user to a page displaying electrical parameters. This page provides information measured by sensors, such as voltage, current, frequency, power usage, kWh consumption, power factor, and estimated cost. Figure 7 (D) shows the notification display for low voltage and overload conditions.

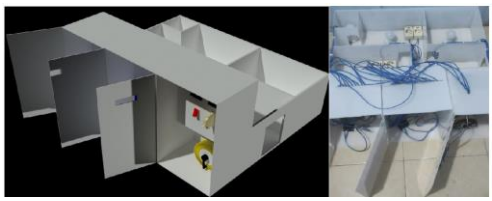
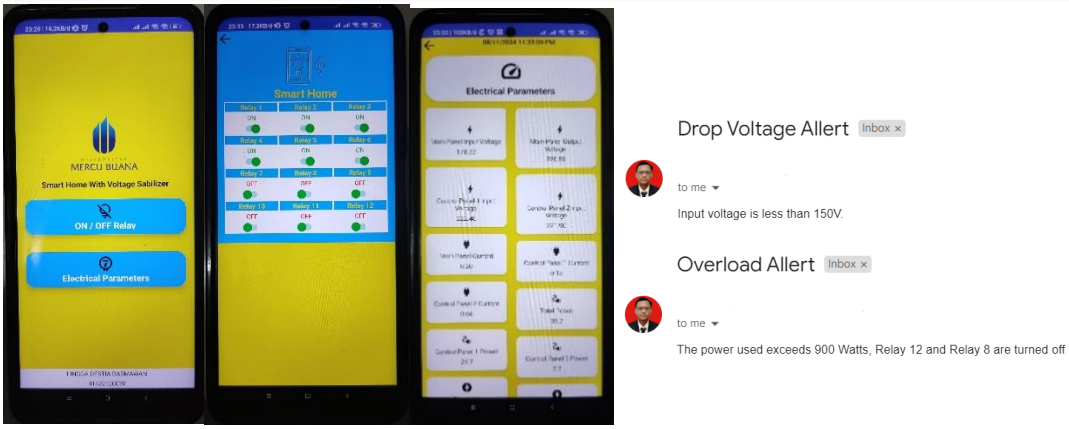


Figure 6. Implementation result of miniature and panel (A) Design drawing ; (B) Design result

3.3. Result of Voltage Testing

Voltage testing is conducted to determine the magnitude of the voltage entering the panel and the voltage that has been stabilized by the transformer slider. Based on the literature [27] [28] [29] the results can be analyzed to obtain the percentage difference using Equation 4.1 as follows:

$$Difference\ (\%) = \left| \frac{LCD\ voltage - Voltmeter\ Read}{Voltmeter\ Read} \right| \times 100 \quad (1)$$



A B C D

Figure 7 Application design results: (A) Main page display; (B) Load settings page display; (C) Electrical parameters display; (D) Notification display.

Table 1 described the result of voltage testing. In the difference of input voltage readings, the average difference is about 0.38%, while the average difference in output voltage readings is about 0.23%. These average differences indicate that the sensor has been calibrated, resulting in a reading discrepancy of less than 1%. The average reading from the PZEM004T sensor for the stabilizer's output voltage is 220.65 V, whereas the average voltage reading from the voltmeter is 220.63 V. These readings show that the device effectively stabilizes varying input voltages to approach the standard low voltage value of 220V set by PLN.

$$(1)$$

Table 1 Result of Voltage Testing

Date	Time	Input Voltage (Volt)		Difference (%)	Output Voltage (Volt)		Difference (%)
		LCD	Voltmeter		LCD	Voltmeter	
04/07/2024	19:00	185,1	186,1	0,53	218,4	218,5	0,045
	20:00	181,6	181,3	0,16	222,5	222,1	0,18
	21:00	187,9	187,2	0,37	220,3	220,7	0,18
05/07/2024	19:00	189,9	190,1	0,1	219	219,8	0,36
	20:00	185,6	185,2	0,21	220,4	219,2	0,54
	21:00	189,2	189,3	0,052	219,9	219,6	0,13
06/07/2024	19:00	199,5	198,2	0,65	220,9	221,6	0,31
	20:00	197,6	196,7	0,45	221,2	221,6	0,18
	21:00	195,5	194,0	0,78	220,2	219,6	0,27
07/07/2024	19:00	186	186	0	218,7	218,3	0,18
	20:00	177,6	176,7	0,50	222,3	221,5	0,36
	21:00	169,4	168,1	0,77	221,6	221,9	0,13
08/07/2024	19:00	182,4	183,3	0,49	221,8	221,6	0,09
	20:00	184,1	183,7	0,21	219,4	219,1	0,13
	21:00	187,9	187,3	0,32	219,6	220	0,181
09/07/2024	19:00	190	189,4	0,31	221,6	222,1	0,22
	20:00	178,2	178,9	0,39	219,8	218,8	0,45
	21:00	176,4	177,9	0,84	222,4	221,8	0,27
10/07/2024	19:00	182,1	181,4	0,38	220,4	221,2	0,36
	20:00	186,7	186,8	0,053	221,8	222,4	0,26
	21:00	185,2	184,4	0,433	221,6	221,9	0,13

3.4. Results of Testing Load On and Off

The purpose of testing the relay's function and response when activated and deactivated is to determine whether the relay can be controlled through the application when turned on and off. Based on table 2, the response time for the relay when active is approximately 11.3s, while the response time for the relay when inactive is approximately 7.6s. The results of the relay testing

show that this device can perform one of the functions of a smart home: remote load control through an application connected to the internet.

Table 2 Result of test load on and off

No	Relay	Condition	Description	Response Time (Second)	Relay	Condition	Description	Response Time (Second)
1	Relay 1	Turn On	Relay On	12,8	Relay 1	Turn Off	Relay Off	4,1
2	Relay 2	Turn On	Relay On	13,5	Relay 2	Turn Off	Relay Off	5,8
3	Relay 3	Turn On	Relay On	13,3	Relay 3	Turn Off	Relay Off	12,8
4	Relay 4	Turn On	Relay On	13,2	Relay 4	Turn Off	Relay Off	4,3
5	Relay 5	Turn On	Relay On	8,3	Relay 5	Turn Off	Relay Off	4,8
6	Relay 6	Turn On	Relay On	6	Relay 6	Turn Off	Relay Off	6,1
7	Relay 7	Turn On	Relay On	8,9	Relay 7	Turn Off	Relay Off	14,1
8	Relay 8	Turn On	Relay On	12,9	Relay 8	Turn Off	Relay Off	5,1
9	Relay 9	Turn On	Relay On	12,3	Relay 9	Turn Off	Relay Off	10,6
10	Relay 10	Turn On	Relay On	13,1	Relay 10	Turn Off	Relay Off	9,7
11	Relay 11	Turn On	Relay On	13,9	Relay 11	Turn Off	Relay Off	9,4
12	Relay 12	Turn On	Relay On	7,9	Relay 12	Turn Off	Relay Off	5,5

4. CONCLUSION

The results from design, testing, and analysis can be summarized into the following points:

1. The output voltage of the main power panel ranges from 218.4 volts to 222.4 volts, with an average output voltage of 220.6V. This voltage is close to the standard PLN voltage of 220V.
2. Load mapping is separated based on the load locations. The loads in Room 1, the living room, the kitchen, and the bathroom are mapped to one panel, namely Control Panel 1, while the loads in Room 2 are controlled by Control Panel 2.
3. All relays can be controlled through the IoT application. The average response time for activating a relay is 7.6 seconds, and the response time for deactivating a relay is 11.3s.
4. The test results for both input and output voltages show a small average difference. The average difference in input voltage at the main panel is 0.38%, while the average difference in output voltage at the main panel is 0.23%.

5. SUGGESTED

Based on the results and the conclusions, several recommendations for future research are:

1. The use of IoT devices requires a fast and stable internet connection. When the connection is unstable or slow, it delays the relay response and updates from the measured parameters.
2. The measurement of delay time is currently done using a phone stopwatch. It would be more accurate to use the serial monitor for this measurement.

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