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Design and Construction of IoT-Based Overvoltage and Undervoltage Detection Devices

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ABSTRACT

In this research, designed an overvoltage and undervoltage fault detector based on the Internet of Things (IoT), which aims to monitor the quality of electrical voltage in detecting overvoltage / undervoltage faults that change instantly with real-time monitoring. This system detects voltage disturbances using the PZEM-004t sensor by considering PLN standards. The overvoltage is above +5% normal voltage and for undervoltage below -10% normal voltage. Voltage disturbances are injected through the transformer configuration to generate overvoltage / undervoltage instantly. Furthermore, the voltage that has been read by the sensor is sent to the Blynk platform as a monitoring system. The transformer configuration is simulated first, with an overvoltage result is 251.8 V and an undervoltage is 110.6 V. In the results of the hardware transformer configuration test, the overvoltage injection is 253 V and the undervoltage is 117.3 V. The data displayed by the monitoring system is compared with the Fluke 43B measuring instrument to be calibrated, with an average error of 1.2%. Monitoring data can be accessed via gadgets. So that preventive actions and analysis can be carried out to reduce the risk of losses due to voltage disturbances.

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1. INTRODUCTION

Currently, Indonesia's electricity needs come from supplies from PT Perusahaan Listrik Negara (PLN) Persero, which is the sole State-Owned Enterprise (BUMN) that regulates electricity in Indonesia [1]. PLN is required to pay great attention to the reliability and quality of its services to customers, but sometimes power quality disruptions can still occur [2]. Examples of power quality disturbances that sometimes occur are overvoltage and undervoltage disturbances. Overvoltage and undervoltage are problems in the electrical distribution system that occur when there is a surge or drop in electrical voltage [3]. In the electricity distribution regulations according to SPLN 1:1995, it is explained that for low voltage it is said to be undervoltage if the voltage is below -10% of the normal voltage (Vn), while for overvoltage it is above +5% of Vn [4], [5]. Although these disruptions are often short-lived, their impact can be harmful. Therefore, a system is needed that is able to detect and respond to these disruptions quickly and accurately.

With the development of Internet of Things (IoT) technology, new opportunities have emerged to develop more effective electricity quality monitoring and control systems. IoT enables the integration of sensors and communication devices to collect, transmit, and analyze data in real time. The utilization of IoT technology is diverse, research [6], researchers conducted IoT-based monitoring to monitor renewable energy generators and PLN. The design of the tool has an average accuracy of 97% for voltage readings and an average current of 98%. However, researchers in collecting data on the application used the number of samples (data n), not real-time. In the study [7], conducted a design of a 1-phase kWh meter breaker system for customers who are late in paying with android features. The use of IoT technology provides notifications to officers via android when customers have not made payments, and displays sensor reading data on the application. However, this study does not display data graphs carried out on the IoT application used. Another study [8] used an IoT information system with operators to monitor and detect fires. IoT was used only to send fire notifications, not to monitor the parameters. The use of IoT for transformer monitoring was carried out in the study [9], Researchers monitor transformers using ZMPT1101b sensors for voltage sensors and data transmission using the NRF24L01 module. This study focuses on the load side that is changed, not on the source side that is subjected to voltage variations (voltage disturbances). The research on monitoring overvoltage and undervoltage voltage disturbances [10] Researchers use relays to break the circuit when a disturbance occurs and ZMPT sensors for voltage sensors, in addition to utilizing the Wi-Fi network to be sent to the internet (database) to be monitored for 24 hours. However, this study in injecting voltage disturbances uses a variable transformer, not an instant change. While the conditions in the field, voltage changes occur instantly. So it is necessary to inject voltage disturbances with instant changes, as well as a system that can send real-time data quickly through the IoT platform to be monitored via gadgets.

In this study, an IoT-based overvoltage and undervoltage disturbance detector was designed which aims to monitor the quality of electrical voltage in detecting overvoltage / undervoltage disturbances that sudden occur with real-time monitoring. This system detects voltage disturbances using the PZEM-004t sensor by considering PLN standards. The overvoltage reading voltage is above 231 V (+ 5% Vn) and for undervoltage below 198 V (-10% Vn). Voltage disturbances are injected through the transformer configuration to generate overvoltage / undervoltage instantly. The transformer configuration is first simulated in the PSIM software as an initial step in the injection system whether it can be made or not. Furthermore, the transformer configuration is built in hardware. The sensor measurement data that has been taken is sent to an IoT platform, namely Blynk. The data displayed from this monitoring system is compared with the Fluke 43B measuring instrument so that it is calibrated. Data can be accessed via gadgets via the Blynk platform. So that preventive actions and analysis can be taken to reduce the risk of losses due to voltage disturbances.

2. METHOD

In the early stages of this research, overvoltage and undervoltage disturbance injection was designed to cause disturbances to the load before being read by the sensor. Overvoltage and undervoltage disturbance injection is carried out through the transformer installation configuration. Transformers, if installed in series with the supply source (PLN), can produce a summed output voltage. The summation of the voltage can be selected from the transformer secondary voltage tap. The magnitude of the output voltage is the sum of the voltages produced by the transformer installed in series with the supply source. While if the transformer is installed as usual, it will produce its transformation voltage. Thus, it can regulate the transformer output voltage. This can be seen in the equation (1) [11], [12].

$$\frac{V_p}{V_s} = \frac{N_p}{N_s} = a \qquad (1)$$

Where V_p is the primary side voltage. V_s is the secondary side voltage. N_p is the number of primary side turns. N_s is the number of secondary side turns. Variable a is the transformation number.

This study refers to electrical circuit and the system block diagram as shown in Figure 1 and Figure 2 respectively. The supply source comes from PLN 220 V. So the voltage is undervoltage if the voltage is below 198 V and overvoltage when above 231 V. In this study, the undervoltage is set at 110 V and the overvoltage is set at 252 V. This is because it adjusts the existing transformer tap, which is 110 V and 32 V.

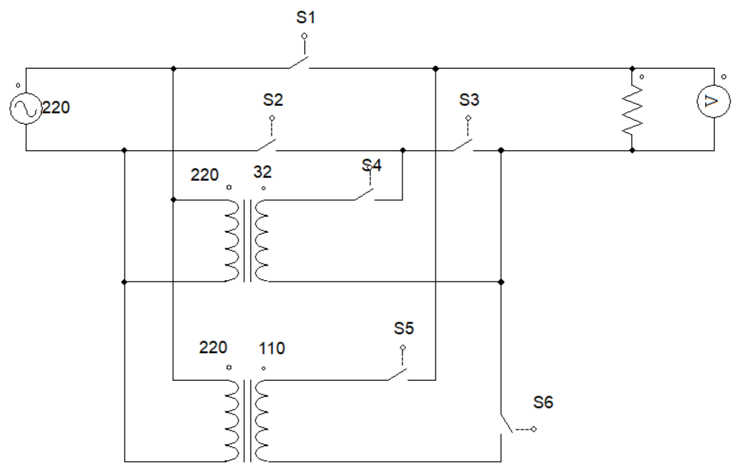


Figure 1. Electrical circuit

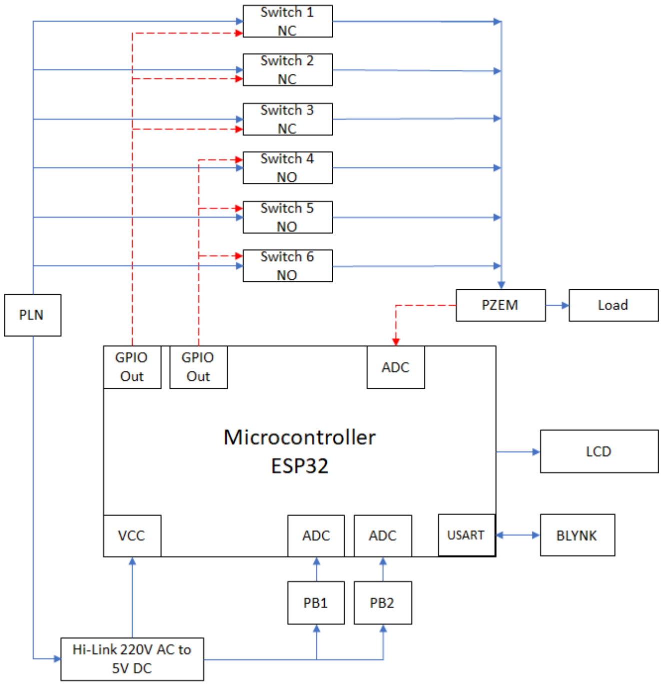


Figure 2. System block diagram

Based on the electrical circuit and block diagram, this study uses PLN grids, transformers to transform voltage, relay switches, PZEM-004t power sensors, ESP32 microcontrollers and lamp loads. PLN grids are used as the main source. The 1st transformer installed in series with the load is used as an overvoltage injection to the load, because the voltage on the load side will later increase according to the tap transformer used, which is 32 V. So that the voltage from the PLN grid (220 V) will increase to 252 V, where overvoltage occurs. While the 2nd transformer voltage from the PLN grid will be reduced to 110 V, so that undervoltage occurs. The use of relay switches is used to change the circuit. From the circuit to normal conditions, to overvoltage conditions, or to undervoltage conditions. The PZEM-004t power sensor is used to measure the electrical quantities of power factor, voltage, frequency, current, power and energy [13]. Furthermore, the data is sent to the ESP32 microcontroller. The ESP32 is compatible with mobile devices and IoT applications [14]. ESP32 will send to the IoT platform, Blynk. So if there is a change in voltage (up or down) it will be detected and monitored. ESP32 also displays data on the LCD and to see direct measurement monitoring [15]. The way the system works is based on the flowchart. This flowchart is embedded into the microcontroller to run the system. The flowchart is shown in Figure 3.

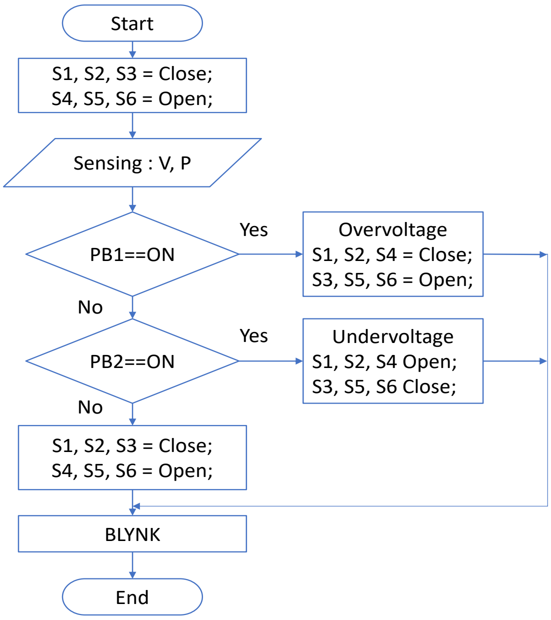
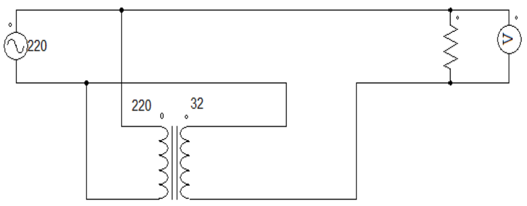
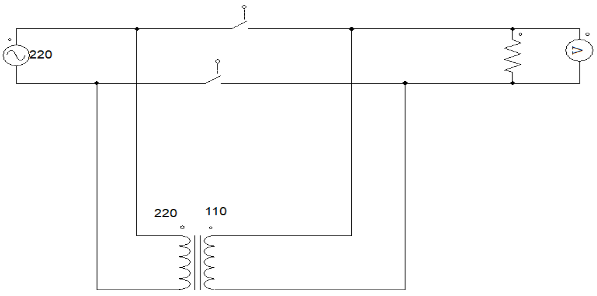


Figure 3. System flowchart

From Figure 3 it can be explained that at the initial condition, the system is in normal condition. That is, PLN will supply to the load with switch 1 Normally Close (NC), switch 2 NC and switch 3 NC in closed condition. While switch 4 Normally Open (NO), switch 5 NO and switch 6 NO in open condition. This will condition the lamp load to turn on in normal condition. For the next step if Push Button 1 (PB1) is pressed, the condition that occurs is overvoltage. Where the condition of switch 1 NC, switch 2 NC and switch 4 NO in closed condition, while switch NC 3, switch NO 5 and switch NO 6 in open condition. This will cause overvoltage injection. The circuit when overvoltage is shown in Figure 4a. After the overvoltage disturbance occurs, the PZEM sensor will send a Root Mean Square (RMS) signal to the microcontroller to monitor the voltage and current produced. The lamp load condition will light up very brightly because it gets a voltage supply of 252 V. For the next condition, if you want to inject undervoltage, Push Button 2 (PB2) is pressed. The switch condition during undervoltage is switch 1 NC, switch 2 NC and switch 4 NO in open condition, while switch NC 3, switch NO 5 and switch NO 6 in closed condition. Which will change the circuit to undervoltage condition with the condition of the lamp load dimly lit because the supply voltage is only 110 V. The circuit during undervoltage is shown in Figure 4b.



(a)



(b)

Figure 4. System circuit when: (a) overvoltage and (b) undervoltage

3. RESULT AND DISCUSSION

The results and analysis in this study were carried out both by simulation and hardware. The system was tested first by simulation using PSIM software to determine whether the circuit planning was appropriate or there were planning errors. The simulation results were then analyzed. Then the next step, implemented in hardware form and tested with proven measuring instruments to obtain data analysis.

3.1. System Testing by Simulation

The system is first tested by simulation using PSIM software. This is to determine whether the circuit planning is appropriate or there is an error in the planning. The system circuit in PSIM is shown in Figure 5. The simulation results are shown in Figure 6. Where Tover is the trigger for the duration of overvoltage injection, in this case at 5-10 seconds. While Tunder is the trigger for the duration of undervoltage injection, in this case at 14-19 seconds. The Vo variable is the voltage measured at the load.

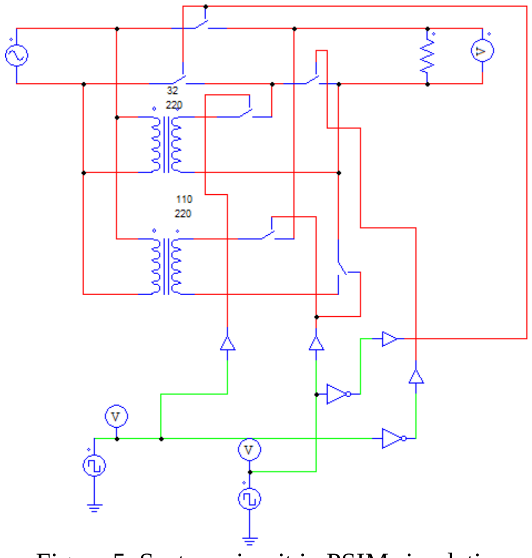


Figure 5. System circuit in PSIM simulation

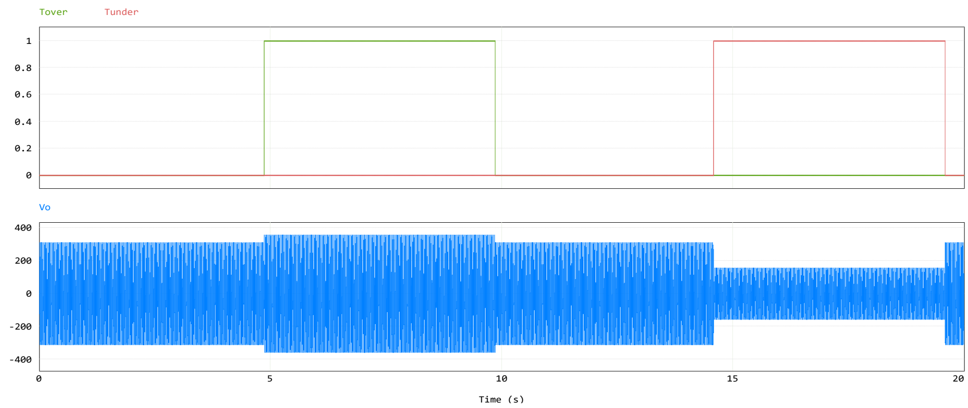
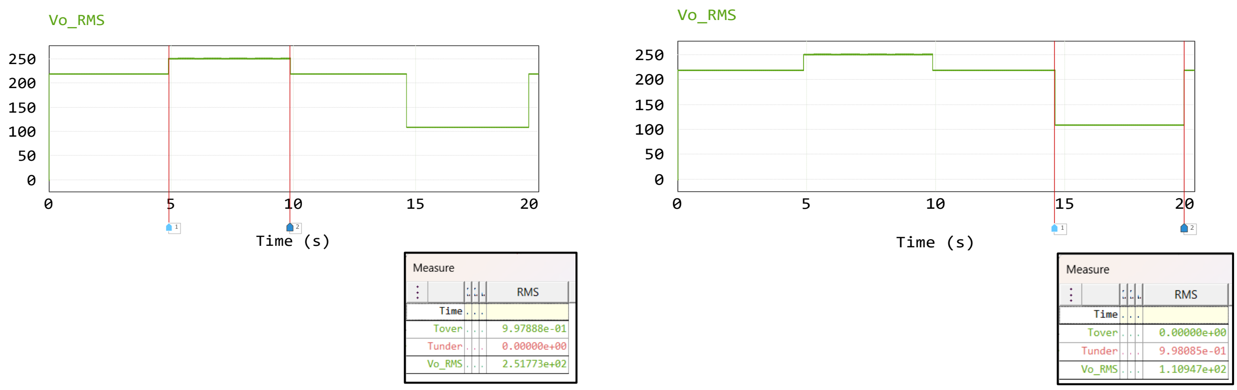


Figure 6. System simulation results in PSIM

Based on the results of the system simulation, it shows that the circuit successfully causes overvoltage and undervoltage. The switch is used to change the circuit from normal conditions with 220 V PLN voltage, to a circuit with overvoltage or undervoltage conditions. The switch gets a trigger from Tover and Tunder to change the circuit. When the condition becomes overvoltage, the RMS voltage (Vo RMS) is 251.87 V for seconds 5-10. While the Vo RMS when undervoltage is 110.61 V for seconds 14-19. Figure 7a and Figure 7b show the results of the Vo RMS values when overvoltage and undervoltage.



(a) (b)

Figure 7. Vo RMS values during (a) system overvoltage and (b) undervoltage on PSIM simulation

3.2. Pengujian Sistem secara *Hardware*

Next is implemented in hardware, and tested with proven measuring instruments to obtain data analysis. The hardware implementation is shown in Figure 8. System hardware based on block diagram and system electrical circuit.

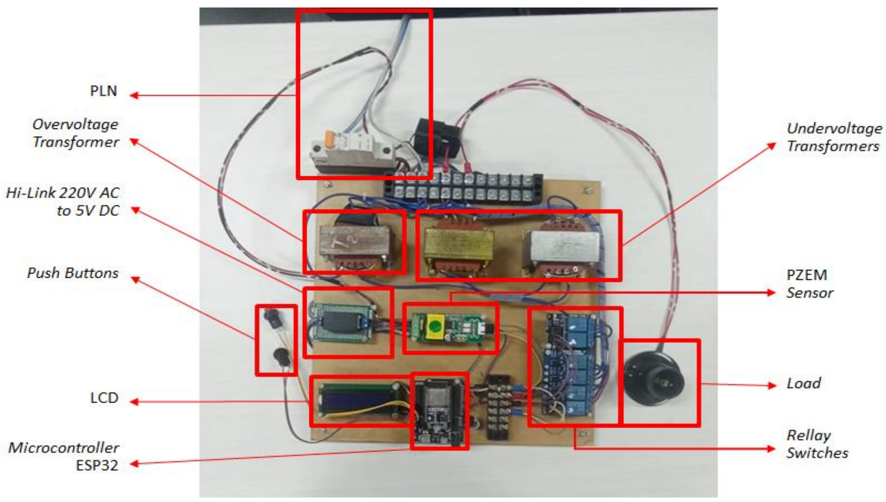


Figure 8. The hardware implementation

The hardware implementation of the system uses two transformers to produce undervoltage. This is to get a step-down voltage to 110 V. The first transformer changes 220 V to 24 V, then the second transformer changes 24 V to 110 V. So that a voltage of 110 V is obtained. Furthermore, the system is partially tested to ensure that the system can change configuration and can inject undervoltage and overvoltage disturbances. The system is measured using a multimeter to measure the voltage at the load. Figure 9 shows the system testing and measurement process. The measurement results are shown in the data in Table 1 where the values in bold are when overvoltage and undervoltage occur. Furthermore, it is presented in the graph in Figure 10.

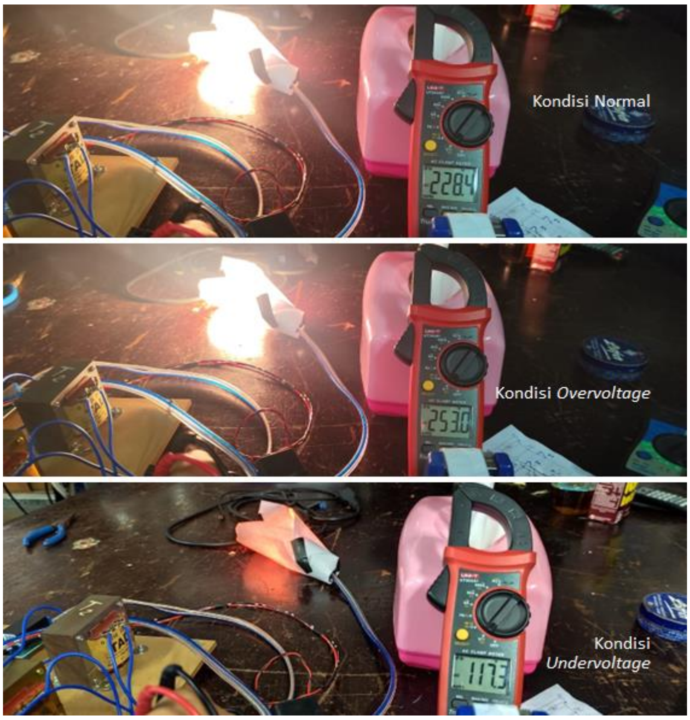


Figure 9. Partial testing process of transformer configuration changes

Table 1. Results of partial testing of transformer configuration changes

Tegangan dari kondisi normal ke kondisi overvoltage		Tegangan dari kondisi normal ke kondisi underrvoltage		Tegangan Kembali ke kondisi normal	
Waktu	V (V)	Waktu	V (V)	Waktu	V (V)
12:46:44 PM	185.2	12:46:56 PM	228.4	12:47:06 PM	222.9
12:46:45 PM	185.2	12:46:56 PM	228.4	12:47:07 PM	222.9
12:46:45 PM	228.4	12:46:57 PM	228.4	12:47:08 PM	222.9
12:46:46 PM	228.4	12:46:57 PM	228.4	12:47:08 PM	222.9
12:46:47 PM	228.4	12:46:58 PM	228.4	12:47:09 PM	222.9
12:46:48 PM	**232.8**	12:46:59 PM	228.4	12:47:10 PM	222.9
12:46:49 PM	**232.8**	**12:46:59 PM**	**125.9**	12:47:10 PM	222.9
12:46:49 PM	**253**	**12:47:00 PM**	**125.9**	12:47:11 PM	222.8
12:46:50 PM	**253**	**12:47:01 PM**	**117.3**	12:47:12 PM	222.8
12:46:51 PM	**253**	**12:47:01 PM**	**117.3**	12:47:12 PM	222.9
12:46:51 PM	**253**	**12:47:02 PM**	**117.3**	12:47:13 PM	222.9
12:46:52 PM	**253**	**12:47:03 PM**	**117.3**	12:47:14 PM	222.9
12:46:53 PM	**253**	**12:47:04 PM**	**117.3**	12:47:14 PM	222.9
12:46:53 PM	**253**	**12:47:04 PM**	**146.7**	12:47:15 PM	222.9
12:46:54 PM	**241.1**	**12:47:05 PM**	**146.7**	12:47:16 PM	223
12:46:55 PM	**241.1**	12:47:06 PM	222.9	12:47:16 PM	223

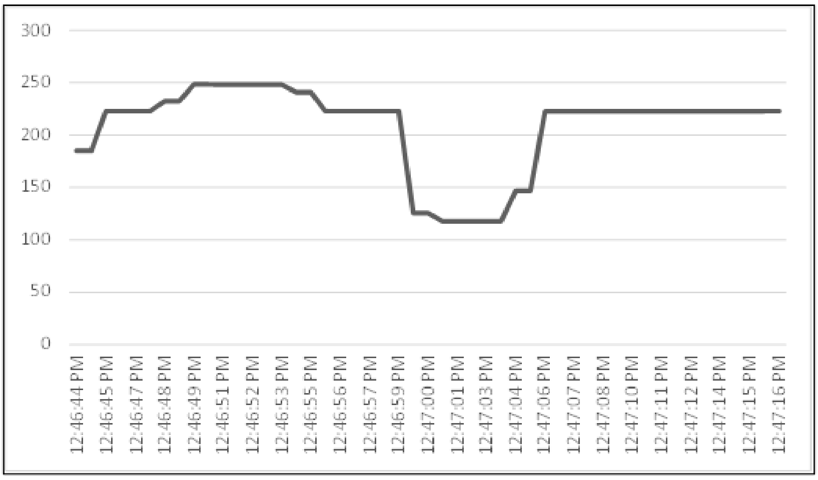


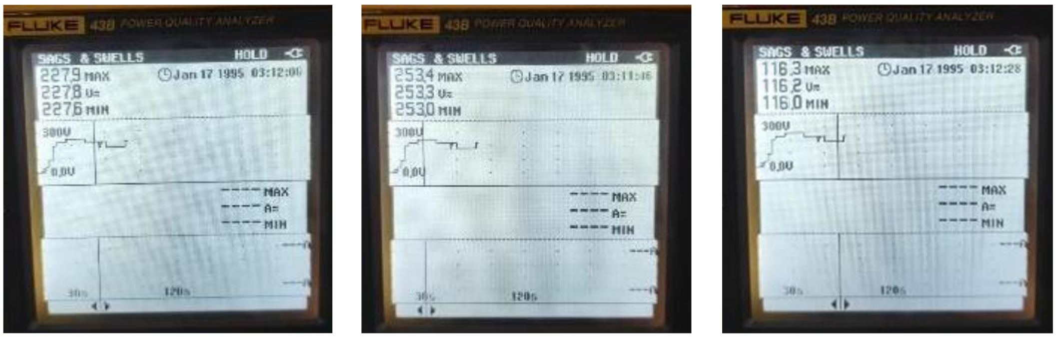
Figure 10. Partial test graph of transformer configuration changes

The partial test results show that the transformer configuration has successfully caused an increase and decrease in voltage at the load. Where when the circuit is in normal condition, the voltage at PLN directly supplies the load, namely the voltage read is 228.4 V. When the circuit is changed (via switch configuration), the circuit becomes an overvoltage condition. Namely, the active transformer is the one installed in series, causing an increase in the voltage value to 253 V. This is because the transformer tap used is 32 V. So that the normal PLN voltage of 220 V is added to the transformer series voltage of 32 V. The next circuit configuration is returned to normal conditions with the voltage read is 228.4 V again. When the circuit changes to an undervoltage condition, the transformer produces an output voltage that is read as 117.3 V. The transformer performs a voltage step-down from 220 V to 110 V.

Next, the hardware is tested as a whole (integration). This integration test is carried out by testing the microcontroller interface with IoT Blynk, where the ESP32 output will be connected to a switch to be able to change the circuit configuration. Measurements are made using the Fluke 43B Power Meter, as shown in Figure 11. The results of the Fluke 43B display measurements are shown in Figure 12 and the system measurements that have been monitored via the Blynk platform are shown in Figure 13.

The monitoring system on the Blynk platform on the device shows that the system is able to send PZEM sensor measurement data to the Blynk platform. So that changes in overvoltage and undervoltage can be detected. When a voltage change occurs, it will be recorded through a graph that appears on the device. The voltage data is compared between the Fluke 43B and that read on Blynk. The data is shown in Table 2 and presented in the graph in Figure 14.

Figure 11. Integration testing process with Fluke 43B measurements



(a) (b) (c)

Figure 12. System integration measurements with Fluke 43B: (a) under normal conditions, (b) under overvoltage conditions, (c) under undervoltage conditions.

(a) (b) (c)

Figure 14. View of the monitoring system on the Blynk platform on the device: (a) under normal conditions, (b) under overvoltage conditions, (c) under undervoltage conditions

Table 2. System integration test results compared to the Fluke 43B

WAKTU (S)	TEGANGAN (V) FLUKE 43B	TEGANGAN (V) SISTEM HARDWARE	ERROR (%)
1	227.8	220.4	0.35
2	227.8	220.4	0.35
2.02	253.3	221	9.98
3	253.3	255	0.67
4	227.8	220.4	0.35
4.05	227.8	220.4	0.35
5	116.2	116.5	0.25
5.02	116.2	116.5	0.25
6	227.8	220.4	0.35
7	227.8	220.4	0.35

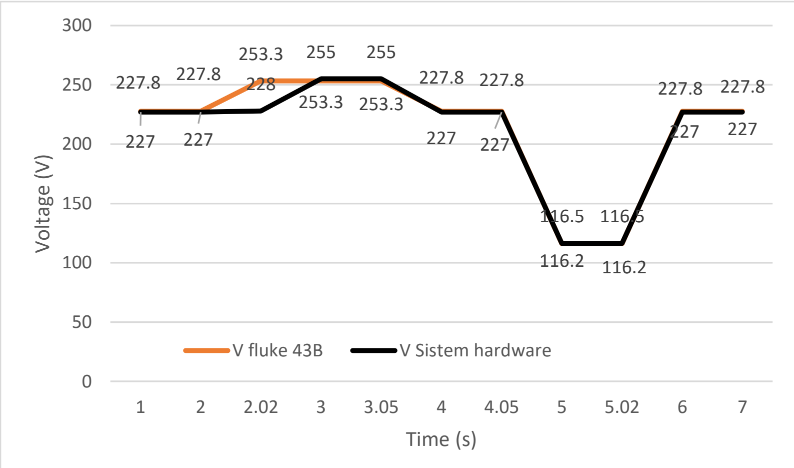


Figure 14. System integration test graph compared to the Fluke 43B

There is a difference in the data results received by the device and the Fluke 43B measuring instrument. This is caused by the level of sensitivity and precision of the sensor with the measuring instrument, where the level of sensitivity and precision is higher for the Fluke 43B measuring instrument. The average difference between the Fluke 43B measurement and the display on the device is 1.2%.

4. CONCLUSION

This study designs an IoT-based overvoltage and undervoltage fault detector that aims to provide a reliable solution in monitoring the quality of electrical voltage. The system is first simulated in PSIM software. The simulation results, the switch is used to change the circuit from normal conditions with 220 V PLN voltage, to a circuit in overvoltage or undervoltage conditions through a transformer configuration. When the condition becomes overvoltage, the voltage is 251.87 V. While when undervoltage is 110.61 V. Furthermore, the system is implemented in hardware form and partially tested to ensure that the transformer configuration can produce undervoltage and overvoltage disturbances. The result is when the circuit is in overvoltage conditions, the voltage value becomes 253 V. When the circuit changes to undervoltage conditions, the output voltage reads 117.3 V. Furthermore, the system is tested for integration. The test results show differences in the data results received by the device and the Fluke 43B measuring instrument. The average difference in the Fluke 43B measurement and the display on the device is relatively small, namely 1.2%. In detecting overvoltage/undervoltage disturbances, it is expected that the hardware of this tool will provide remote monitoring, so that preventive actions and analysis can be carried out to reduce the risk of losses due to voltage disturbances.

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