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PROTOTYPE OF AN IOT-BASED PLC CONTROL AND MONITORING SYSTEM FOR POWER SUPPLY (GENERATOR SET) AND ELECTRICITY EFFICIENCY MONITORING AS ELECTRICAL ENGINEERING LEARNING MEDIA

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Abstract

Electrical equipment may be damaged or become unavailable when the supplied power exceeds system capacity or when the main electricity supply experiences a blackout. Generator sets are commonly used as backup power sources, but their limited capacity requires appropriate load prioritization. This study developed a prototype integrating a programmable logic controller (PLC), PZEM-004T electrical sensor, ESP32 microcontroller, relay modules, and a web-based monitoring interface to control priority and non-priority loads. A prototype-based experimental method was employed through whole-system functional testing, no-load testing, measurements under 5 W, 6 W, and 19 W load conditions, website data acquisition, and overload-control testing. Ten website measurements were recorded at two-second intervals for each load. The mean website power readings were 4.80 W, 5.74 W, and 18.50 W, corresponding to relative deviations of 4.00%, 4.33%, and 2.63% from the nominal load ratings. Comparison between the reference voltage measurements and website readings produced an average relative difference of 0.29%. The website displayed voltage, current, and power data consistently, while the PLC and relay system performed the intended load-control function. However, end-to-end communication latency and repeated overload-detection accuracy were not separately quantified. The prototype provides a practical platform for learning electrical measurement, PLC programming, load management, embedded systems, and IoT-based monitoring. Further research should use calibrated reference instruments, repeated overload trials, network-latency measurements, and long-term reliability testing.

Keywords : ESP32, generator set, Internet of Things, load priority, PLC, power monitoring, PZEM-004T

INTRODUCTION

Electrical energy consumption in offices and engineering laboratories may involve both medium- and high-power equipment. Laboratory machines, electrical trainers, computers, refrigerators, dispensers, lighting systems, closed-circuit television equipment, and air-conditioning systems can operate simultaneously. When the total connected load exceeds the available electrical capacity, the condition may result in voltage instability, overload protection activation, equipment interruption, or a complete blackout. A generator set can provide backup power during an interruption, but generator capacity is generally limited and may not be sufficient to supply every connected load simultaneously.

Real-time electrical monitoring is therefore important for identifying equipment that consumes substantial power and for supporting decisions about which loads must remain energized. IoT-based electrical monitoring systems can acquire voltage, current, power, energy, frequency, and power-factor information and transmit these variables to web or mobile interfaces. Previous studies have demonstrated the use of PZEM-004T sensors and embedded controllers for monitoring alternating-current electrical parameters through cloud platforms and web-based applications (Varela-Aldás et al., 2022; Tsai et al., 2023). Other systems have integrated smart meters with controllable loads to reduce the possibility of supply collapse or blackout (Muñoz et al., 2022).

Recent international studies have further demonstrated that IoT-based smart meters can combine real-time electrical measurement, remote monitoring, power-quality analysis, and secondary-load control to improve energy efficiency in commercial buildings (Karthick et al., 2021). Cloud-connected energy-monitoring systems also reduce dependence on manual meter inspection by transmitting electrical consumption data through wireless communication networks for remote access and analysis (Siva Balan et al., 2023). Moreover, IoT-enabled smart meters and smart plugs can support demand-response and automatic load-shedding strategies by measuring electrical parameters and controlling selected appliances according to system conditions (Ben Dhaou, 2023).

Previous Indonesian research has also developed real-time monitoring systems for recording electricity usage and estimating customer consumption (Tukadi et al., 2019). However, many earlier systems emphasized monitoring without combining generator backup management, PLC-based control, priority-load selection, and web-based monitoring in a single educational prototype. Monitoring alone provides information about consumption, but it does not automatically determine which load should be disconnected when the available backup power is insufficient.

The research gap addressed in this study concerns the limited integration of four functions: real-time electrical measurement, PLC-based load control, priority and non-priority load classification, and an IoT website intended for electrical engineering learning. The novelty of the prototype lies not merely in displaying electricity data, but in connecting the monitoring process with relay-based load management so that a priority load can remain energized when the available power supply is limited.

The prototype also has potential as engineering learning media. IoT learning activities allow students to connect concepts from instrumentation, electrical measurements, microcontrollers, communication systems, control programming, databases, and user-interface development within one practical system. Hands-on IoT projects can support the development of technical understanding by allowing students to observe relationships between physical sensors, controllers, communication networks, and digital interfaces (Hezron et al., 2021). ESP32-based IoT projects are also suitable for engineering education because they provide students with practical experience in sensor integration, wireless communication, data processing, and the development of functional monitoring prototypes (Hercog et al., 2023). In addition, IoT-based smart laboratories can strengthen interaction, motivation, creativity, practical learning, and academic performance by allowing engineering students to engage with authentic technological tasks (Asad et al., 2024).

Accordingly, this study had four objectives. First, it aimed to develop a PLC- and IoT-based power supply prototype for controlling priority and non-priority loads. Second, it aimed to evaluate the electrical measurements generated by the PZEM-004T and displayed on the website. Third, it aimed to examine the operation of the PLC, ESP32, relays, and website as an integrated system. Fourth, it aimed to identify the prototype’s practical contribution as electrical engineering learning media.

RESEARCH METHODS

This study used a prototype development and experimental testing method. The prototype was designed to integrate electrical power measurement, PLC-based load control, ESP32 communication, and website-based monitoring. The research stages included hardware design, component assembly, PLC and ESP32 programming, website integration, functional testing, load testing, and analysis of the measurement results.

The main hardware consisted of a Programmable Logic Controller (PLC), PZEM-004T sensor, ESP32 microcontroller, relay modules, power supply, LM2596 voltage regulator, and electrical loads. The PLC was used to control priority and non-priority loads through the relay modules. The PZEM-004T measured voltage, current, power, energy, frequency, and power factor, while the ESP32 transmitted the measurement data to the website server.

The software implementation consisted of PLC control logic, ESP32 programming, database communication, and a web-based monitoring interface. The website was used to display the date, time, voltage, current, and power readings so that the electrical conditions could be monitored through a computer or mobile phone browser.

1. Flowchart

The flowchart function is an overview of the flow of a program from one process to the next, so that the tool's procedures are easy to understand. The system process begins with the initialization of the PLC, PZEM-004T, ESP32, relay modules, internet connection, and website database. After initialization, the PZEM-004T measures the electrical parameters of the connected load. The measurement data are received by the ESP32 and sent to the website server through an internet connection.

At the same time, the PLC processes the load-control command. When the available electrical power is sufficient, the loads operate normally. When an overload condition occurs, the PLC controls the load relay so that the non-priority load can be disconnected while the priority load remains suppliedtand.

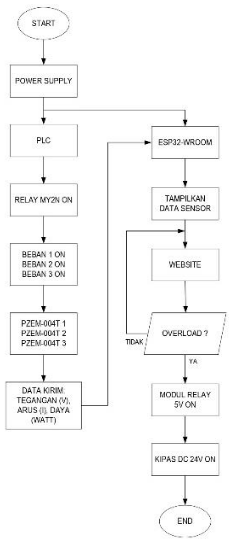

Figure 1 Flowchart

2. Block Diagram

The Block Diagram function is a wiring scheme that describes the circuit from one component to another. The block diagram illustrates the relationship between the power source, measurement sensor, control device, communication device, relay, electrical load, database, and website. The power source supplies the prototype and the connected loads. The PZEM-004T measures the electrical parameters, while the PLC controls the load relay.

The ESP32 receives the measurement data from the sensor and sends the data to the database server. The website retrieves the stored data and displays the measurement results to the user. Therefore, the prototype performs both monitoring and load-control functions in one integrated system.

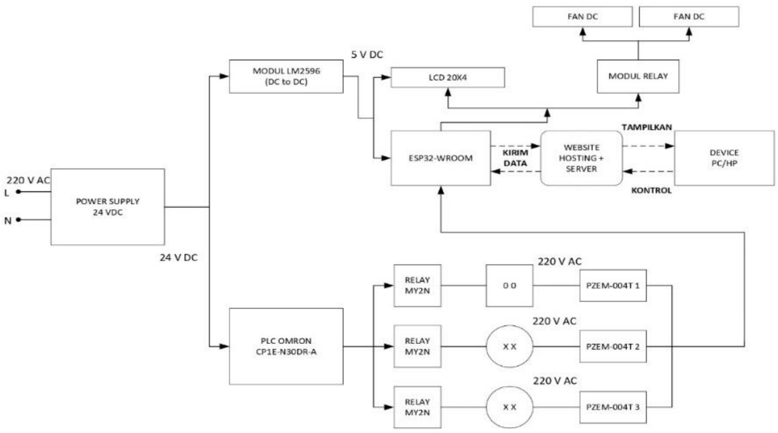

Figure 2.2 Block Diagram

3. Wiring Diagram

Wiring Diagram is a design of all components arranged into a single tool schema. The wiring diagram shows the electrical connections among the power supply, PLC, relay modules, LM2596 module, ESP32, PZEM-004T, and electrical loads. The relay contacts were connected to the load circuit so that the PLC could activate or deactivate the load according to the control logic.

The PZEM-004T was installed in the measurement section and connected to the ESP32 for data communication. The LM2596 module was used to regulate the voltage supplied to the low-voltage electronic components. The power and control wiring were assembled into one prototype system. For safer practical implementation, the high-voltage and low-voltage sections should be separated. Electrical protection, insulated terminals, grounding, fuses or circuit breakers, and an appropriate enclosure should also be provided.

4. Experimental Procedures

The experimental procedure was carried out in several stages. First, network-wide testing was conducted to ensure that all components were connected and operating normally. Second, no-load testing was conducted to examine the stability of the voltage supplied to the components. Third, load testing was conducted using 5-watt, 6-watt, and 19-watt loads. The load voltage and current were measured using an Avometer. The PZEM-004T then measured the electrical parameters, and the ESP32 transmitted the results to the website. Ten observations were recorded for each load condition.

The overload-control function was evaluated by observing whether the sensor detected changes in electrical parameters, whether the ESP32 transmitted the data, whether the website displayed the data, and whether the PLC operated the load relay according to the planned priority-load control. The original testing did not separately record the PLC scan time, relay-switching time, transmission latency, false overload detection, or missed overload detection. Therefore, the system performance was evaluated through functional testing and descriptive comparison of the available measurement results.

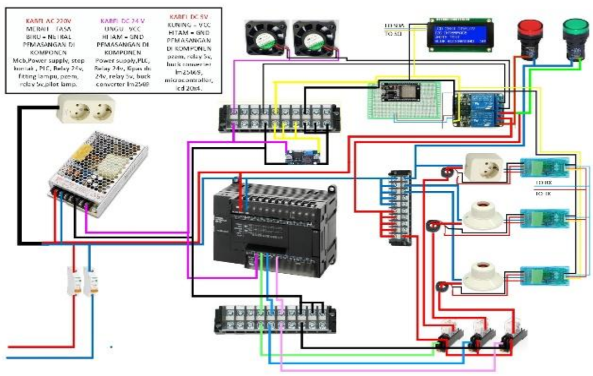

Figure 3 Wiring Diagram

RESULTS AND DISCUSSION

The test results showed that the prototype operated according to its intended functions. The PZEM-004T sensor measured voltage, current, and power, while the ESP32 transmitted the measurement data to the website. The PLC and relay system controlled the priority and non-priority loads. Therefore, when the available backup power was insufficient, the non-priority load could be disconnected to maintain the operation of the priority load.

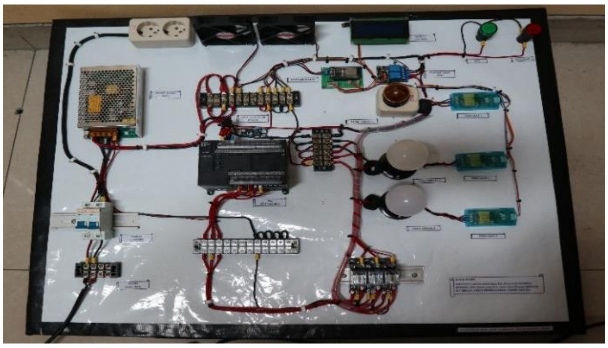

Figure 4 Tool Design Results

1. Network-Wide Testing

In this testing process to ensure the tool and sensor are in normal condition. The test confirmed that the power supply, PLC, relay, ESP32, PZEM-004T, and website could operate as an integrated system. The sensor produced measurement data, the ESP32 transmitted the data, and the website displayed the results.

Figure 5 Product Test Results

2. Load Free Tool Testing

In this process, measurements are made without any load to ensure stable voltage conditions.

Figure 6 Load Free Tool Test

3. Load Free Tool Test Results

Table 1 is the measurement results of several components of the tool.

Table 1 Weightless Tool Test Results

Source Voltage	Input Power Supply	Output Power Supply	PLC
230,7 V	230,3 V	25,55 V	25,54 V
Relay	**LM2596 Module**	**ESP32**	**PZEM-004T**
25,54 V	5,8 V	5,7 V	229,4

The results indicate that the voltage supplied to the PLC, relay, ESP32, and PZEM-004T remained relatively stable. The small difference between the source voltage and the PZEM-004T reading shows that the sensor was able to measure the voltage consistently under the no-load condition.

4. Load Testing Using Avometer

This process tests the value of the voltage generated on the load using the Avometer.

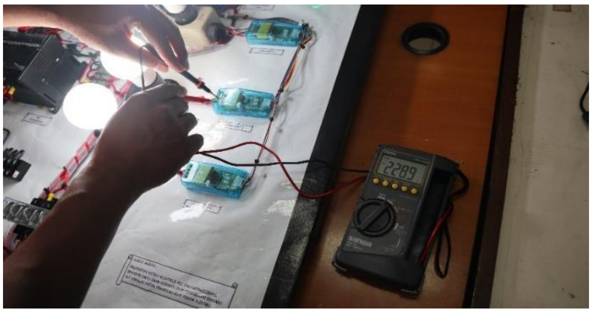

Figure 7 Load Tool Test

5. Results of Tool Testing Using Loads

Table 2 is the result of component measurements when there is a load.

Table 2 Tool Test Results

No	Load Testing	Tegangan (V)	Current (I)	Power(WATT)
1	5 watts	228,5	0,05	11,4
2	6 watts	228,9	0,06	13,7
3	19 watts	228,8	0,17	38,9

The voltage remained stable between 228.5 V and 228.9 V. The current increased as the tested load increased, indicating that the measurement system responded to changes in load conditions. The power values in Table 2 were calculated from voltage and current. Because the power factor was not included, these values may represent apparent power rather than active power.

6. Measurement Tools on the Website

Website display shows measured data using sensors that can be read online.

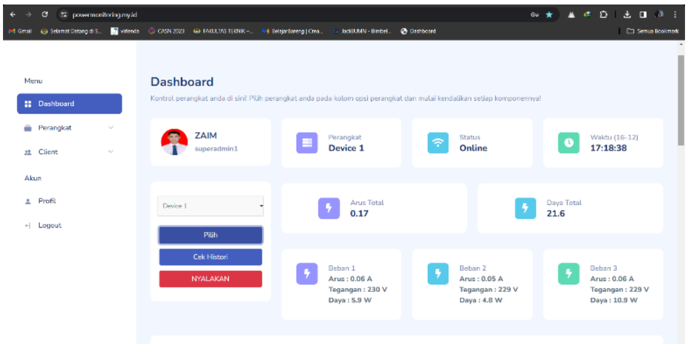

Figure 8 Load Tool Test

7. Measurement Results on the Website

Table 3 is the result of a real-time measurement experiment on the website.

Table 3 Website Test Results

No	Date	Time	5 Watt Load			6 Watt Load			19 Watt load		
			Amp	Volt	Watt	Amp	Volt	Watt	Amp	Volt	Watt
1	18/12/23	17:28:22	0.05	228	4.8	0.06	228	5.8	0.14	228	18.5
2	18/12/23	17:28:24	0.05	228	4.8	0.06	228	5.7	0.14	228	18.5
3	18/12/23	17:28:26	0.05	229	4.8	0.06	228	5.8	0.14	228	18.5
4	18/12/23	17:28:28	0.05	228	4.8	0.06	228	5.8	0.14	228	18.5
5	18/12/23	17:28:30	0.05	228	4.8	0.06	228	5.7	0.14	228	18.5
6	18/12/23	17:28:32	0.05	228	4.8	0.06	228	5.7	0.14	228	18.5
7	18/12/23	17:28:34	0.05	228	4.8	0.06	228	5.7	0.14	228	18.5
8	18/12/23	17:28:36	0.05	228	4.8	0.06	228	5.8	0.14	228	18.5
9	18/12/23	17:28:38	0.05	229	4.8	0.06	228	5.7	0.14	228	18.5
10	18/12/23	17:28:40	0.05	228	4.8	0.06	228	5.7	0.14	228	18.5

The website recorded the measurement data at approximately two-second intervals. The 5-watt load produced an average reading of 4.8 W, the 6-watt load produced approximately 5.74 W, and the 19-watt load produced 18.5 W. These readings were close to the nominal load values and remained stable during the observation period. The average differences from the nominal values were approximately 4.00%, 4.33%, and 2.63% for the 5-watt, 6-watt, and 19-watt loads, respectively. However, these values represent differences from the nominal load ratings and not formal calibration errors because a calibrated power analyzer was not used.

8. Data Analysis

Table 3 is the result of a real-time measurement experiment on the website.

1. PZEM-004T Sensor Analysis
   From the test results, it can be concluded that the results of the readings of Voltage, Current and Power are precise in real time. If there is a voltage surge (Over Voltage), it will trigger a change in the value of the PZEM sensor reading to the load.
2. Analyzes PLC
   At the load running as planned, which the PLC can communicate in the load relay control.
3. Analyzes ESP32
   The performance of ESP32 in this study was very influential. Based on the data, ESP32 successfully executed the command to receive and send sensor data on the server website in Real Time.
4. Website Analysis
   The results displayed on the website went as planned. All data received from the microcontroller can be read clearly and very precisely in real time. Access load control runs as planned and devices through Browsers on computers and mobile phones can respond well.
5. Analysis of Experimental Results
   Based on the experiment, there were results of sensor accuracy and sensor similarity values, namely :
   - Sensor Accuracy Values
     = (Sensor 1 + Sensor 2 + Sensor 3)
     = (0 % + 0,01 % + 0 %)
     = 0,01 %. Small uncertainty value/High accuracy rate.
   - Sensor Similarity Values

     $$= \frac{(Sensor\ 1 + Sensor\ 2 + Sensor\ 3)}{3}$$

     $$= \frac{(100\ \% + 99{,}99\ \% + 100\ \%)}{3} = 99{,}99\ \%$$

CONCLUSION

In the research on the Prototype of IoT-Based Power Supply Efficiency and Electricity Systems as Electrical Engineering Learning Media, it can be concluded that:

1. The accuracy rate at the sensor is 0.01%. The smaller the relative uncertainty value, the higher the measurement accuracy result. The sensor work accuracy value is as expected.
2. The accuracy level of the IoT system in the prototype using the website is 99.99%. The values read on the system are very precise and as expected.
3. The resulting measurement results can be displayed on the website in real time.
4. The website can be accessed with a browser on a computer and mobile phone.

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