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# Integrated IoT System for Real-Time Electrical Load Monitoring

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**ABSTRACT**

The uncontrolled and excessive consumption of electrical energy, especially in households, often leads to significant energy waste. This issue adversely affects both consumers and electricity providers such as PLN. To address this problem, a system titled "Centralized Monitoring and Control Based on Load Characteristics Using the Internet of Things (IoT)" was developed. This system is designed to monitor and control household electrical loads in real time. The system consists of a PZEM-004T sensor for measuring voltage, current, power, energy usage, frequency, and power factor. An Arduino microcontroller processes the sensor data, while an ESP32 module transmits the data to an online database. A relay module is used to control electrical devices remotely. The data is stored in a database and visualized through a web-based interface, which also enables users to download monitoring reports in PDF or Excel formats. Testing results showed that the system operates with high accuracy. When compared to a standard power analyzer, the measurement error for parameters such as voltage, current, frequency, and power factor remained low, with a maximum error of only 1.9%. It demonstrates the system's potential for efficient energy monitoring and management in residential settings.

**Keywords: Integrated system, Internet of Things, Electrical Load, Monitoring, Energy**

**ABSTRAK**

Penggunaan energi listrik yang kurang terkontrol dan berlebihan khususnya konsumsi pada rumah tangga, dapat menyebabkan pemborosan energi listrik. Hal ini memberikan dampak kerugian bagi masyarakat sebagai konsumen maupun PLN sebagai pihak penyedia energi listrik. Maka dari itu dibuat "Monitoring Dan Kontrol Terpusat Berdasarkan Karakteristik Beban Berbasis Internet Of Things (IOT)" yang bertujuan untuk memonitoring dan mengontrol beban listrik yang digunakan. Perancangan sistem ini terdiri dari Sensor PZEM-004T yang berfungsi untuk mengukur nilai tegangan, arus, daya, penggunaan, frekuensi dan pf. kemudian Arduino berfungsi untuk mengolah data sensor PZEM-004T. Kemudian ESP32 berfungsi sebagai pengirim data hasil pengukuran ke database. kemudian Relay yang berfungsi sebagai saklar magnetik. Database digunakan sebagai penyimpan data. Website yang merupakan laman utama yang digunakan memonitoring dan mengendalikan sistem secara keseluruhan. Pada website juga terdapat opsi simpan data hasil monitoring yang dapat didownload berupa file PDF maupun file Excel. Setelah dilakukan pengujian yang dibandingkan dengan alat ukur power analyzer nilai error pada setiap hasil pengukuran seperti pada tegangan, arus, frekuensi & pf terbilang rendah. nilai error paling tinggi hanya 1,9%., hal ini menunjukkan potensi sistem untuk pemantauan dan pengelolaan energi yang efisien dalam pengaturan perumahan.

**Kata kunci: Sistem integrasi, Internet of Things, Beban listrik, Pemantauan, Energi**

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## 1. INTRODUCTION

The growing global demand for electrical energy, driven by rapid industrialization, urbanization, and the increasing number of smart devices, necessitates the development of efficient and intelligent energy management systems. Inadequate monitoring of energy consumption can lead to inefficiencies, excessive energy waste, and increased operational costs. Traditional energy monitoring systems often lack real-time data collection, centralized control, and smart analytical capabilities, making them insufficient for current and future energy challenges.

In recent years, the Internet of Things (*IoT*) has emerged as a promising solution for real-time electrical load monitoring. IoT enables interconnected devices to collect, transmit, and analyze energy data remotely, enhancing the visibility and control of power usage across residential, commercial, and industrial settings [1]. However, despite its growing adoption, many existing IoT-based monitoring systems operate in a decentralized manner, which can lead to fragmented data, lack of synchronization, and difficulties in analyzing overall energy patterns effectively [2].

Several studies have explored the use of IoT for electrical monitoring, such as using smart meters for real-time data collection [3], or applying machine learning techniques for energy consumption prediction [4]. While these efforts show significant progress, there remains a gap in the integration of centralized monitoring systems with intelligent load pattern recognition. Such integration would allow for more holistic data processing, anomaly detection, and optimized energy usage based on historical and real-time patterns.

To address these challenges, this research proposes a *Centralized Integrated System* for IoT-based electrical load monitoring that incorporates load pattern recognition. The system collects data from multiple smart nodes, transmits it to a centralized server, and uses pattern recognition algorithms to classify and predict load behavior. This centralized architecture improves data coherence, enhances analysis accuracy, and enables smarter decision-making in energy management.

The novelty of this study lies in its integration of centralized data handling and intelligent load pattern recognition within a unified IoT-based monitoring framework. Unlike conventional decentralized systems, the proposed architecture enables synchronized, real-time data acquisition from multiple nodes and centralized processing for enhanced accuracy and coherence. By applying pattern recognition algorithms, the system can identify usage trends, detect anomalies, and predict future load behavior, allowing for proactive and optimized energy management. This research contributes to the field by providing a scalable and adaptable solution that bridges the gap between real-time monitoring and intelligent analysis. It offers a practical approach for improving the efficiency, reliability, and responsiveness of energy management systems across residential, commercial, and industrial environments.

## 2. RESEARCH METHOD

The proposed research adopts an experimental and prototyping approach to develop an Integrated System for IoT-based Electrical Load Monitoring. The system is designed to monitor electrical loads from multiple endpoints, collect real-time consumption data, and centrally process this data to identify load patterns and detect anomalies. The overall architecture comprises three main components: IoT sensing nodes, a centralized server, and a data analysis module. The implementation utilizes IoT devices based on microcontrollers (e.g., ESP32 or Arduino), connected to a cloud platform such as AWS IoT or Google Cloud IoT. The user interface will be developed using a web-based framework for cross-platform accessibility.

The research workflow consists of several stages among others system design and planning, hardware development, data transmission, centralized server configuration, data analysis module development, user interface design, testing and evaluation, result analysis and optimization**.** By following this structured methodology, the research ensures a comprehensive approach to developing a scalable and intelligent electrical load monitoring system with centralized analysis and real-time control capabilities.

### 2.1. Arduino Uno

Arduino is an electronic board consisting of a main component: a microcontroller chip. A microcontroller is an integrated circuit (IC) that can be programmed via a computer. The purpose of the microcontroller is to read input, process it, and then produce an output.

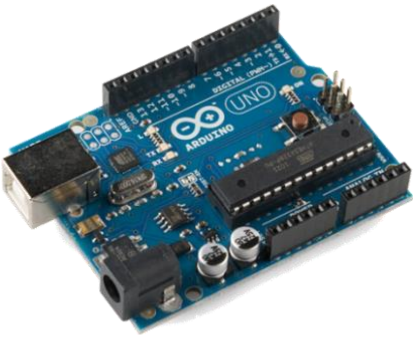

Figure 1. Arduino Uno

### 2.2. PZEM-004T Module

The PZEM-004T module is a multifunction sensor module used to measure power, voltage, current, and energy in an electrical circuit. It is equipped with an integrated voltage sensor and current transformer (CT). This module is intended for indoor use only, and the connected load must not exceed the specified power limit.


Figure 2. PZEM-OO4T Module

### 2.3. ESP32 Module

The ESP32 is a microcontroller introduced by Espressif Systems as the successor to the ESP8266 microcontroller. This microcontroller comes with an integrated Wi-Fi module, making it highly suitable for developing Internet of Things (IoT) applications.


Figure 3. ESP32 Module

### 2.4. Relay

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A relay is an electromagnetic switch circuit that operates when it receives power and a triggering signal. A relay has nominal voltage and current ratings that must be met by the output of the driver circuit. The construction of a relay consists of a wire coil wound around a soft iron core. When current flows through the coil, the soft iron core generates a magnetic field that attracts the contact switch. This switch then moves due to the magnetic force, either connecting to another terminal or disconnecting from its original contact point.

Based on its operation, relays can be categorized into:

- Normally Open (ON): the switch remains open until current flows through the coil.
- Normally Closed (OFF): the switch remains closed until current flows through the coil.
- Change Over (CO): this type of relay has a single switch that is normally connected to one terminal. When coil 1 is energized, the switch connects to terminal A. When coil 2 is energized, it connects to another terminal.


Figure 4. Relay

## 2.5. Web Server

A web server is a software application that functions as a receiver of requests sent through a browser and then responds by delivering web pages, typically in the form of HTML documents. The web server is used to transfer all aspects of file content in a web page, including text, videos, images, and more.

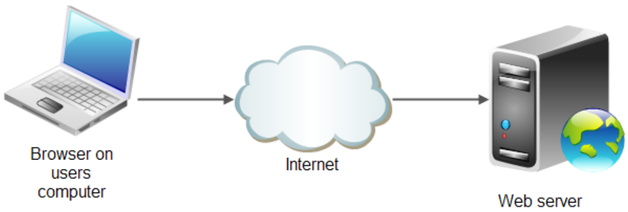


Figure 5. Web Server

## 2.5. Database

A database is a collection of interrelated data that is stored on computer hardware and manipulated using software applications (Jogiyanto, 2005). The term database can be interpreted as a central repository or warehouse—a place where data is gathered and stored. Data itself represents real-world facts and can describe objects such as people (employees, students, buyers, customers), goods, concepts, conditions, and so on. These facts are recorded in the form of numbers, letters, symbols, text, images, sounds, or a combination thereof.

igure 6. Database

## 3. RESULTS AND DISCUSSION

This system consists of several main components, namely the PZEM-004T sensor, Arduino Uno, ESP32, and a relay module. The process begins with data acquisition by the PZEM-004T sensor, which is responsible for measuring electrical parameters such as voltage, current, power, and energy consumption. The sensor is connected to the Arduino Uno via serial communication (TTL). The Arduino Uno processes the data received from the sensor and temporarily stores it.

The ESP32, which is connected to the internet via Wi-Fi, periodically sends requests to the Arduino Uno to retrieve the latest sensor data. Communication between the ESP32 and Arduino Uno is done using UART (serial communication). After receiving the data, the ESP32 sends it to a pre-configured server or database, making it accessible remotely.

To facilitate monitoring and control, the system includes a web-based interface. Through this website, users can view real-time sensor readings. In addition, the website provides features for manually controlling the relay. Commands from the website are sent to the ESP32, which then forwards them to the Arduino Uno to activate or deactivate the relay. The relay can be used to control an electrical load, such as turning a device on or off.

The physical circuit involving the Arduino Uno, PZEM-004T, ESP32, and relay module has been assembled and connected according to their respective functions, as illustrated in the following diagram.

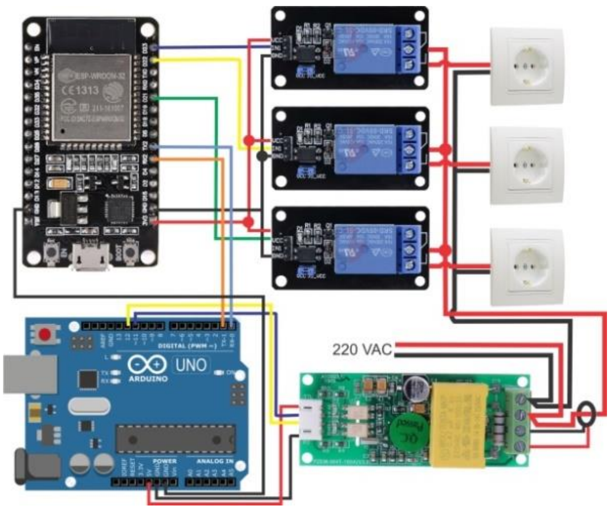


Figure 7. Equipment system diagram

The PLN/kWh Power Source supplies electricity, with PT and CT (transformers) providing voltage and current data to the PZEM-004T. The PZEM-004T sensor measures electrical parameters and sends the data to the Arduino Uno. The Arduino Uno processes the sensor data and communicates with the ESP32 via serial connection. The ESP32, connected to the internet, transmits the data to an online database. Data can be accessed and monitored in real time through a web interface.

From the web, users can also send control commands to the ESP32, which are passed to the Arduino to operate the relay module. The relay controls the power to connected electrical loads like lights, fans, or pumps.

### 3.1. Monitoring Results

The image shows an electrical monitoring dashboard designed for an admin user. The dashboard interface is minimalist, utilizing a combination of dark and light themes. The left sidebar provides navigation options, including links labeled "Dashboard" and "Data Monitoring."

In the central section of the dashboard, various electrical measurements are displayed in a neatly organized format. The parameters include Voltage (215 Volt), Current (1.87 A), Power (403.33 Watt), Energy Consumption (8.07 Wh), Frequency (50 Hz), and Power Factor (1.00). These values provide critical insights into the electrical system's performance, allowing the admin to monitor real-time conditions efficiently. The display is structured using labeled boxes for clear and quick data interpretation.

Below the data display, there are three control buttons labeled "Relay 1," "Relay 2," and "Relay 3." Each relay button is marked as "ON," indicating that the corresponding relays are active. These relays can be associated with controlling different electrical devices or circuits within the system, allowing for manual or automated control directly from the dashboard. The use of relay control adds a layer of flexibility to the electrical monitoring system.

Additionally, the dashboard includes export options, specifically for Excel and PDF formats, located just below the relay controls. These options facilitate data recording and reporting, allowing the admin to save the monitored data for analysis or documentation purposes. The combination of real-time data monitoring and export capabilities makes this dashboard practical for managing electrical systems in industrial or residential settings.

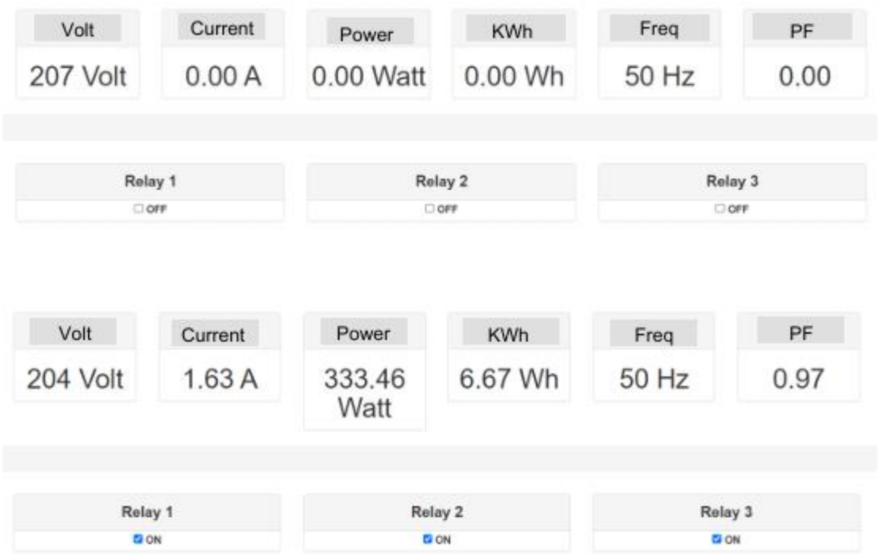


Figure 8. The dashboard for monitoring electrical parameters.


(a) (b)

Figure 9. The results for power quality analyzer with load condition (a) OFF and (b) ON.

The image presents a dashboard for monitoring electrical parameters, designed with a simple and clean interface. The dashboard is divided into two main sections, each displaying a set of electrical data and relay control states. The layout is structured to allow users to compare two different sets of measurements or operational conditions. The top section displays a set of electrical parameters with all values reading zero, except for the voltage, which is shown as 207 Volts, and the frequency, which remains stable at 50 Hz. This indicates that although the system is powered, there is no current flowing, leading to zero power consumption and a power factor of 0.00. Additionally, all three relays (Relay 1, Relay 2, and Relay 3) in this section are turned off.

The second section of the dashboard displays a distinct set of electrical parameters, with the voltage slightly lower at 204 Volts and the current increasing to 1.63 A. This results in a power output of 333.46 Watts. The recorded energy consumption is 6.67 Wh, while the frequency remains stable at 50 Hz. The power factor is displayed as 0.97, indicating efficient power usage with minimal reactive power. Notably, all three relays in this section are turned ON, suggesting active power distribution or control of connected electrical devices.

The contrast between the two dashboard sections likely reflects two different system states or operational conditions being monitored. The first section may represent an idle or standby state, characterized by lower current and power values, while the second indicates an active operational state with higher load consumption. The ON status of the relays in the second section supports this interpretation, implying that connected devices are being powered or controlled actively, whereas the OFF state of the relays in the first section corresponds to the absence of load activity.

This dual-display format enhances the dashboard’s usability by enabling direct comparison between different operational conditions. It supports real-time assessment of system dynamics, providing immediate insight into transitions between idle and active states. The clear visual indicators for relay status, combined with detailed parameter readings, make the dashboard suitable for real-time monitoring, diagnostic evaluation, and data logging applications in dynamic electrical environments.

Figure 9 further validates the system’s accuracy by comparing its readings with those from a power quality analyzer under two conditions: when the load is OFF (a) and ON (b). In the OFF state, current and power readings are nearly zero, confirming minimal consumption. In the ON state, there is a marked increase in current (1.64 A), active power (0.32 kW), and power factor (0.973), demonstrating active load presence and efficient energy use. This comparative data supports the reliability of the monitoring system.

While the current discussion provides a clear descriptive overview of the dashboard and relay control, incorporating deeper analysis—such as the implications of the load profile on energy efficiency or the system's responsiveness to load changes—would further strengthen the evaluation. Additionally, discussing potential applications in predictive maintenance or anomaly detection could provide added analytical value.

## 4. CONCLUSION

The developed system effectively monitors key electrical parameters—voltage, current, power, energy, frequency, and power factor—while also enabling remote control of three electrical loads (a computer, an iron, and a laptop charger) via a user-friendly web interface accessible from both PCs and smartphones with internet connectivity. Sensor data from the PZEM-004T is processed by the Arduino, transmitted to a central database by the ESP32, and displayed in real time on the website. Testing results demonstrate high measurement accuracy for voltage, current, frequency, and power factor, with a maximum error of only 1.9%, although power measurements showed a significantly higher error of up to 50%. Despite this limitation, the system offers a practical and flexible solution for real-time electrical load monitoring and control.

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