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Implementation of the Internet of Things in the Design and Development of a Three-Phase Power Monitoring System

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Abstract

This research aims to design an IoT-based three-phase electrical power monitoring system, evaluate its performance, and compare it with manual measurements. The system is developed by using microcontroller-based sensors to measure voltage, current, and power parameters in real-time. The methodology used is the 4D model, simplified into three stages: define, design, and development. In the define stage, issues related to the inefficiency of conventional monitoring were identified. The design stage involved creating a system diagram incorporating components such as the PZEM-004T sensor, ESP8266 microcontroller, LCD I2C 16x2 display, and the Blynk application for real-time data visualization. The development stage included system construction, testing, and validation by four media experts, yielding a validation score of 92%, indicating that the system is highly feasible for use. The results indicate that the IoT-based monitoring system effectively measures three-phase electrical parameters, with real-time data displayed on both an LCD screen and the Blynk application for remote access. Compared to conventional monitoring methods, the system offers greater efficiency and responsiveness. Overall, the research stated has successfully enhanced the accuracy and convenience of three-phase power monitoring.

Keywords: *Internet of Things, Monitoring System, Three-Phase Electric Power*

Abstrak

Penelitian ini bertujuan untuk merancang sistem pemantauan daya listrik tiga fasa berbasis IoT, mengevaluasi kinerjanya, dan membandingkannya dengan metode pengukuran manual. Sistem dikembangkan menggunakan sensor berbasis mikrokontroler untuk mengukur parameter tegangan, arus, dan daya secara waktu nyata. Metodologi yang digunakan adalah model 4D yang disederhanakan menjadi tiga tahap: define, design, dan development. Pada tahap define, diidentifikasi permasalahan terkait rendahnya efisiensi pemantauan konvensional. Tahap design melibatkan perancangan diagram sistem dengan komponen seperti sensor PZEM-004T, mikrokontroler ESP8266, layar LCD I2C 16x2, serta aplikasi Blynk untuk visualisasi data secara real-time. Tahap *development* mencakup pembangunan sistem, pengujian, dan validasi oleh empat ahli media, yang menghasilkan skor validasi sebesar 92%, menandakan bahwa sistem ini sangat layak untuk digunakan. Hasil penelitian menunjukkan bahwa sistem pemantauan berbasis IoT ini mampu mengukur parameter listrik tiga fasa secara efektif, dengan data ditampilkan secara waktu nyata melalui layar LCD dan aplikasi Blynk untuk pemantauan jarak jauh. Dibandingkan dengan metode pemantauan konvensional, sistem ini menawarkan efisiensi dan responsivitas yang lebih tinggi. Secara keseluruhan, penelitian ini telah berhasil meningkatkan akurasi dan kemudahan dalam pemantauan daya listrik tiga fasa.

Kata kunci: Internet of Things, Sistem Monitoring, Daya Listrik 3 fasa

Introduction

The three-phase electrical system is widely used in industries and commercial facilities due to its efficiency in transmitting large amounts of power, which must be maintained in real-time [1][2], [3]. This quality directly affects the performance and lifespan of electrical equipment, making it essential to carefully monitor three-phase electrical parameters such as voltage (V), current (A), power (W), power factor (cos φ), and energy consumption (kWh) to assess the quality of the power supply [4], [5]. The need for efficient power monitoring and management is becoming increasingly important, especially in environments utilizing three-phase power systems. The three-phase system was developed due to its advantages, including the ability to transmit more power compared to a single-phase system while using the same conductor size and current [6][7], [8]. Since the three-phase system can deliver greater electrical power, equipment such as electric motors can operate more powerfully when using this system [9], [8]. Manual monitoring using a multimeter has limitations, such as requiring on-site measurements and lacking real-time monitoring capabilities, making it less efficient. With advancements in technology and the growing demand for energy efficiency, real-time power monitoring has become crucial, particularly in three-phase electrical systems commonly used in industries and commercial facilities.

Technological advancements, particularly the Internet of Things (IoT), can provide solutions to these issues. IoT technology can receive and process measurement data from sensors, which is then transmitted over the internet and processed for display on a user-friendly website or smartphone interface. This makes it easier for users to monitor and access measurement results via a website or smartphone [6], [10], [11]. Currently, IoT development is expanding across various fields, especially in microcontroller applications for control and display purposes [12], [13], [14]. This technology enables devices to connect through the internet, creating an automated monitoring system capable of providing real-time data [15]. With this technology, electrical parameters can be monitored via a mobile application, eliminating the need for physical presence at the location. Energy consumption data recorded by sensors is wirelessly transmitted to the mobile application for real-time monitoring and analysis. Research findings indicate that an IoT-based power monitoring system can provide accurate and timely information on electricity consumption, helping users improve energy efficiency and reduce operational costs associated with power usage [16], [17], [18].

This research aims to design and evaluate the performance of an IoT-based three-phase power monitoring system and compare the measurement results of the IoT-based system with manual measurements. The goal is to determine whether the IoT-based system provides more accurate and efficient measurements, addressing the limitations of manual measurement methods.

Method

This research employs an experimental method using a 4D model approach that has been simplified into 3D, consisting of Define, Design, and Development [19]. The research stages can be seen in Figure 1.

Figure 1. Research Stages

In the Define stage, problem identification is carried out to determine the need for three-phase power monitoring and analyze the electrical parameters to be measured, such as voltage, current, active power, reactive power, power factor, and frequency. In the Design stage, the monitoring system is designed and integrated with the IoT platform Blynk. The electronic components used in this study include the PZEM-004T sensor, ESP8266 microcontroller, Blynk application for remote monitoring, and an I2C LCD for direct data display. The flow steps include the PZEM-004T Sensor for each phase (R, S, and T) connected to the NodeMCU ESP8266, with all Vcc pins connected to the 3.3V pin (Vin) and all Gnd terminals connected to the ESP8266 Gnd pin. Data communication is done through specific GPIO pins: R Phase uses D1 (RX) and D2 (TX), S Phase uses D3 (RX) and D4 (TX), and T Phase uses D5 (RX) and D6 (TX). The system diagram is designed using the Fritzing application. In the Development stage, a hardware and software prototype are built, followed by system testing and validation by media experts to assess the validity of the designed system.

The data collection instruments used in this research include a media expert validation sheet and measurement testing. The media expert validation sheet is assessed by experts to determine the feasibility of the IoT-based three-phase power monitoring system. Measurement testing is conducted to compare the measurement results obtained from the designed monitoring system with those obtained using a multimeter and power solar meter. The comparison results of both measurement methods are determined by calculating the error values for each method [19]. The error calculation for voltage and active power is obtained using the following equations:

$$V_{error} = \left| \frac{V_{sensor} - V_{reference}}{V_{reference}} \right| x\ 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$W_{error} = \left| \frac{W_{sensor} - W_{reference}}{W_{reference}} \right| x\ 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where: V sensor = Voltage measured by the PZEM-004T sensor

V reference= Voltage measured by the multimeter

W sensor = Active power measured by the PZEM-004T sensor

W reference= Active power measured the power meter

These formulas are used to determine the level of accuracy and reliability of the IoT-based monitoring system in comparison with standard measurement tools.

Result and Discussion

The results of the design of the IoT-based three-phase power monitoring system can be seen in Figure 2 below.

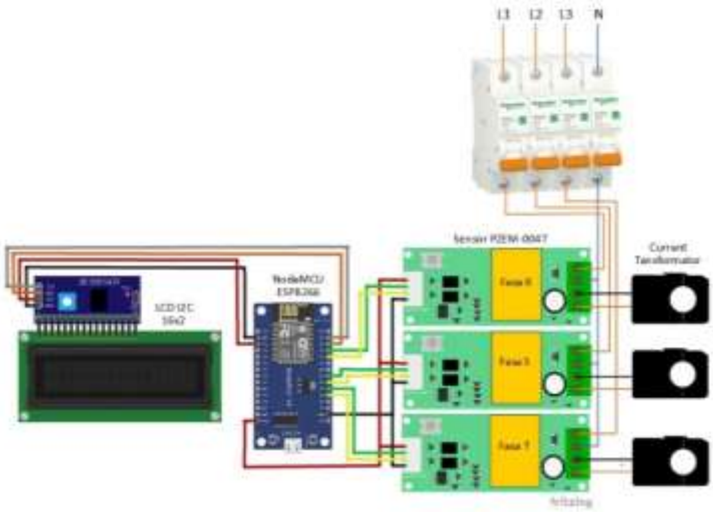

Figure 2. Overall System Design

Figure 2 illustrates the connection between the NodeMCU ESP8266 and the PZEM-004T sensor. The Vcc voltage of each PZEM-004T sensor for the three phases (R, S, and T) is connected to the Vin or 3.3V pin of the ESP8266, while the Gnd terminal of the PZEM-004T sensors for all three phases is connected to the Gnd pin of the ESP8266. Next, the RX pin of the PZEM-004T sensor for phase R is connected to the D1 pin of the ESP8266, and the TX pin is connected to the D2 pin of the ESP8266. For phase S, the RX pin is connected to the D3 pin of the ESP8266, and the TX pin to the D4 pin of the ESP8266. For phase T, the RX pin is connected to the D5 pin of the ESP8266, while the TX pin is connected to the D6 pin of the ESP8266.

(a) (b)

Figure 3. (a) Internal Circuit View, (b) External Circuit View

Figure 3 (a) shows the physical form of the circuit, while Figure 3 (b) illustrates the external design of the IoT-based three-phase power monitoring system. This circuit consists of an ESP8266 as the microcontroller, three PZEM-004T sensors for each phase, and a 16x2 I2C LCD module.

Figure 4. Measurement Results Using a Power Meter

Figure 4 above shows the measurement of three-phase voltage using a power meter, with a three-phase electric motor as the load. The power meter is used to compare the measurement results obtained from the sensor with those from the power meter in terms of accuracy and measurement efficiency. This study consists of two testing phases. The first phase involves measuring electrical power using the power meter, while the second phase involves measurements using the Blynk application, which is accessible via smartphone, as well as through an LCD display for direct observation. Testing was conducted with a three-phase motor load. The test results using the power meter show that the voltage in Phase R (L1) was 220.9 V, in Phase S (L2) was 112.3 V, and in Phase T (L3) was 112.2 V. The voltage value for Phase R provided by the power meter showed a slight difference when compared to the value shown in the Blynk application (219 V) showed in Figure 5 and on the LCD display (218 V) showed in Figure 6. However, there was no difference in the current and power values for Phase R across the different platforms.

Figure 5. Measurement Results Displayed on the Blynk Application

Figure 6. Measurement Results Displayed on a 16x2 LCD

Figures 5 and 6 display the measurement results on the Blynk application and LCD screen. Based on two Figures, no differences were found between the measurement results from both platforms, indicating that the IoT-based power monitoring system functions optimally and consistently. Data from the PZEM-004T sensor was successfully displayed on both the LCD and the Blynk application without significant discrepancies. This consistency demonstrates that communication between the microcontroller and the IoT application is reliable for real-time electrical parameter monitoring, enhancing efficiency in remote monitoring without compromising data quality or accuracy [1], [20]. The similarity in results further reinforces the system's reliability and validity in providing accurate information to users. The following are the measurement results obtained using the IoT-based power monitoring system compared to those from the power meter.

Table 1. Measurement Results of Voltage and Current on a 3-Phase Motor

Phase	Voltage (V)			Current (A)		
	Multi Meter	PZEM 004-T	V_{error} (%)	Multi Meter	PZEM 004-T	I_{error} (%)
R	239 V	239 V	0%	1,01 A	1,02 A	0.9%
S	234 V	233 V	0,4%	1,17 A	1,16 A	0,9%
T	234 V	234 V	0%	1,20 A	1,22 A	1,6%

Table 2. Measurement result of Power on a 3-phase Motor

Phase	Power (Watt)			Reactive Power (VAR)	Apparent Power (VA)	Power Factory (Cos φ)	Frequency (Hz)
	Power meter	PZEM 004-T	W_{error} (%)				
R	144	147	2,04%	196,1	245,1	0,60	50
S	71	70,70	0,42%	262.5	271,9	0,26	50
T	39,80	40,10	0,75%	283,6	286,4	0,14	50

Based on Tables 1 and 2, the active power values measured by the PZEM-004T show a small deviation compared to the power meter. The largest error occurs in phase R, with an error of 2.04%, while phases S and T have smaller errors of 0.42% and 0.75%, respectively. This indicates that the PZEM-004T sensor has good accuracy in measuring active power with a low error rate. Additionally, reactive power and apparent power values vary across each phase. In phase R, the reactive power reaches 196.1 VAR, while the apparent power is 245.1 VA, with a power factor of 0.60. Phase S has a reactive power of 262.5 VAR and an apparent power of 271.9 VA, with a lower power factor of 0.26, indicating a more inductive load. Meanwhile, phase T has a reactive power of 283.6 VAR and an apparent power of 286.4 VA, with the lowest power factor of 0.14, suggesting that its active power is significantly lower than its reactive power. The lower the power factor, the greater the difference between active and apparent power, reflecting inefficiency in electrical energy utilization. Among the three phases, phase R demonstrates better energy efficiency than phases S and T due to its higher power factor. The low power factor in phases S and T indicates the dominance of inductive loads, leading to higher reactive power consumption. Nevertheless, the frequency remains constant at 50 Hz across all phases, indicating that the system operates within normal limits without significant fluctuations. Based on these results, it can be concluded that the IoT-based power monitoring system using the PZEM-004T sensor is reliable for monitoring electrical power with minimal errors. However, the low power factor in certain phases should be addressed to improve energy efficiency.

Table 3. Media Expert Validation Test Results

No	indicator	Questionnaire item	Ex 1	Ex 2	Ex 3	Ex 4	Average
1	Monitoring system	• The system design was successfully developed with an attractive layout	5	5	4	5	4,75
		• The system can accurately monitor from a remote location	5	5	4	5	4,75
		• The system can detect changes in power consumption and provide real-time information	4	4	5	5	4,5
2	IoT	• IoT has been implemented in the system	5	5	5	5	5
		• Reliability in data transmission.	5	4	5	4	4,5
3	Electric Power	• The system measures and monitors power consumption across all three phases.	5	5	5	4	4,75
		• The generated data includes active power information and daily energy consumption	5	5	2	4	4
		Total	34	33	30	32	32,25
		percentage	92%				

Table 3 presents the validation results of the IoT-based three-phase power monitoring system, assessed based on several key aspects, including design, monitoring reliability, IoT implementation, and the system's ability to measure and display power consumption data. The validation results indicate a high level of validity, with a score of 92%. The implementation of IoT in three-phase power monitoring has proven to be more efficient in overcoming the limitations of manual measurement. However, the system's success heavily depends on the stability of the Wi-Fi network, which is one of the main challenges in field implementation.

Conclusion

The IoT-based three-phase power monitoring system has been successfully designed and implemented using the ESP8266 and PZEM-004T sensors. This system can measure and transmit data in real-time through the Blynk platform for remote monitoring while also displaying measurement results on an LCD for direct monitoring. However, the system can only operate when connected to a Wi-Fi network, making its dependence on internet connectivity one of its limitations. In practice, the system is capable of monitoring electrical parameters across all three phases via the LCD, whereas the Blynk application can only display current, voltage, and power due to feature limitations in the free version of the application. Compared to conventional measurement methods, the IoT-based monitoring system is more efficient, especially in terms of remote monitoring and automation of the measurement process. This system allows continuous monitoring without requiring intensive direct interaction from users, unlike conventional measurements, which require direct measurement and greater human involvement. This makes the IoT-based system more practical and efficient, particularly in applications that require periodic and real-time power monitoring.

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