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Research Article

Design of Power Factor Monitoring System Based on Android Application

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A B S T R A C T

Electrical energy is an essential resource for human needs. The prolific utilization of electrical devices accounts for high energy consumption patterns. Resistive and inductive loads characterize conventional electrical equipment. In practice, the properties of electrical loads impact energy demand and system efficiency. Thus, power factor correction presents a viable strategy to improve electrical energy efficiency. This research aims to develop an Internet of Things-integrated power factor monitoring system. When connected to Wi-Fi, the system employs a PZEM-004T sensor to monitor current, voltage, power, and power factor measurements from the load in the absence of active monitoring. The ESP32 microcontroller processes the sensor data. Then, control programs running on the microcontroller instruct a relay to engage capacitive banks accordingly. The system displays output metrics on a Liquid Crystal Display and Android application. Experimental results indicate that a single-phase electric motor operates at a baseline power factor of 0.31. However, integration of the factor correction tool detailed herein improves the power factor to 0.98 for the given load.

INTRODUCTION

A variety of tools have been developed to fulfill human needs and improve quality of life [1]. Many household appliances, including washing machines, refrigerators, air conditioners, and water pumps have been invented to assist with domestic chores [2]. Likewise, food production equipment such as rice cookers, microwaves, ovens, air fryers, food processors, blenders, and electric cooktops exemplify how technology has semi-automated culinary processes in the industrial sector [3]. The proliferation of such electronic devices has facilitated the satisfaction of human requirements [4].

In terms of electricity, electronic appliances represent a load that draws power. More specifically, this electrical load consumes energy from the power source to operate [5]. Loads are categorized as either active or reactive [6]. Dynamic loads consist of devices that utilize active power (watts) and accrue electric usage per hour (kilowatt-hours). Heat-generating, lighting, or motion-enabling equipment comprise these dynamic loads [7], [8]. On the other hand, reactive loads refer to components of active loads that produce reactive power. The reactive elements store energy briefly in electric and magnetic fields but do not directly power lighting, motion, or heating [9], [10]. However, the presence of reactive power can lead to reduced efficiency, voltage drops, and excessive working currents that disturb electrical performance [11]. Mitigating these issues requires power factor correction to enhance electrical energy efficiency [12], [13].

Several studies have examined the design of power factor improvement tools. For instance, research conducted by [14] developed an Internet of Things (IoT)-based energy monitoring system using a PZEM-004T sensor to concurrently measure voltage, current, and power metrics for microcontroller integration via an ESP 8266 module. Experimental validation involved resistive loads up to 45W, with a maximum observed voltage measurement error of 0.62%. Testing with a 5W lamp produced a current measurement error up to 50% and a power measurement error up to 5.1%.

Additional work conducted by [15] produced an IoT-enabled voltage, current, power, and power factor monitoring device with remote monitoring capacity via a Blynk Android application. Other research by [16] similarly leveraged IoT for home electrical monitoring using a NodeMCU microcontroller, ACS712 current sensor, and virtual private server (VPS) for data hosting. The electrical monitoring system demonstrated 92.87% accuracy for power measurements.

Likewise, research by [17] generated a real-time electrical monitoring and protection prototype that measured current and voltage parameters. The system incorporated load thresholds that automatically disengaged power outlets in the event of

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overcurrent conditions surpassing 2A (440W). Other research by [18] explored power factor correction in household appliances via the direct installation of optimized capacitor banks on loads including water pumps and refrigerators.

As the literature highlights, load properties intrinsically impact power factor, which theoretically ranges from 0 to 1. Values approaching unity indicate efficiently utilized active power, whereas figures nearing zero represent wasted reactive power. Lagging power factors prove particularly problematic. The integration of reactive power compensators such as capacitor banks serves to correct poor power factor. Controlled configurations of multiple capacitors connected in parallel or series allows for obtaining targeted capacitance levels.

Building from prior investigations, this work develops an IoT-integrated power factor monitoring platform with capacitance modulation capacity to optimize power delivery. The system displays voltage, current, power, and required capacitance levels on a 20x4 LCD. A 18 µF parallel capacitor bank provides reactive power control.

METHOD

The design of this Android application-based power factor monitoring design uses several research methods shown in Figure 1.

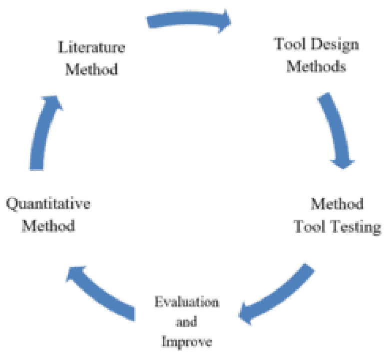

Figure 1. Power factor monitoring design method

Literature Method

Prior to developing the power factor monitoring tool, existing literature on the design and implementation of related systems and power factor correction techniques was consulted [19]. Reviewing prior art provides critical insight into prevailing research methodologies and findings to inform upgrades in the current work.

Tool Design Methods

After reading the previous research on the design of a power factor monitoring system, what is done next is to design the tool according to the expected way of working and upgrade the previous research. The design of this tool includes designing hardware, namely assembling electrical lines, placing each component, and making tool designs. Then, create software as a monitoring application that displays voltage, current, power, and power factor data

Tool Testing Method

After the tool has been designed, the next step is to test the hardware and software device. It aims to determine the performance of the instrument. Hardware tests carried out include testing the version of the Pzem-004T sensor by comparing the values of voltage, current, power, and power factor read on the LCD with a measuring instrument, testing the magnetic contactor whether it works according to the program made, measuring the capacitor charge whether the capacitance value according to the specifications or has decreased, trying the ESP-32 microcontroller whether the program created can work according to the purpose of making a power factor monitoring system based on an Android application, testing the LCD whether it succeeds in displaying data in the form of voltage, current, power, power factor values, and needs capacitors to improve the power factor.

Quantitative Method

This quantitative method is carried out to process data from the result of performance testing of the power factor monitoring tool that has been successfully created. The quantitative way in question is to compare data on the value of the power factor requirement on the instrument by calculation [20]. To find out if there is an error in calculating the value of the capacitor requirement.

Block Diagrams

The following is a block diagram for the Design of a Power Factor Monitoring System Based on an Android Application.

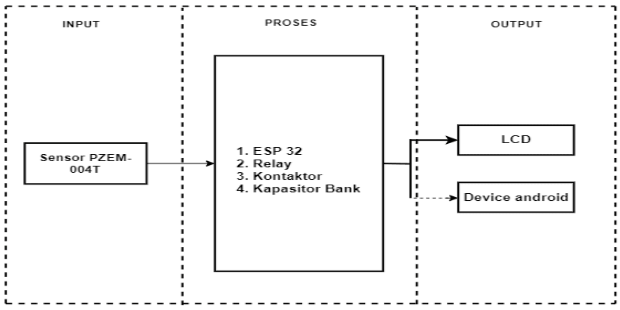

Figure 2. Block diagrams

The block diagram of the power factor monitoring system consists of several components with the component functions in the block diagram above, including,

1. The PZEM-004T sensor is used to send input from measurements of voltage, current, power, frequency, and power factor values to ESP 32.
2. ESP 32 functions to control PZEM-004T to detect current, voltage, power, frequency, and power factor. It is also responsible for sending data to the LCD for display. ESP 32 is also used to capture the Wi-Fi signal emitted by the access point, and then the data is sent to the Mitt App.
3. Relay as an electronic switch is needed to control high currents and voltages.
4. Contactor as a means of control to activate the capacitor.
5. Capacitor as a component to correct low power factor values.
6. The LCD will display the results or output that the system has calculated.

7. Android devices display output results when they are connected to a Wi-Fi network.

Flow chart

The workings of this Android application-based power factor monitoring system are broadly explained through the flowchart in Figure 3.

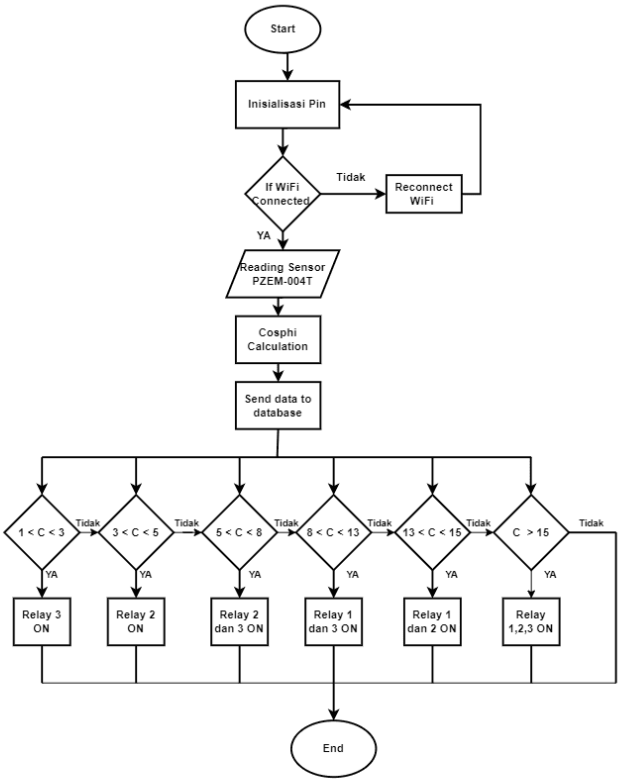

Figure 3. Flowchart

Wi-Fi connectivity is first verified and, if unavailable, pin initialization procedures are reiterated cyclically until network access is secured. Subsequently, the PZEM-004T sensor acquires measurement data which is then utilized to compute the necessary power factor angle. These calculations are stored in the database. The system determines required capacitance for power factor correction based on conditional rules governing individual relay actuation. Specifically, the activation of relay 3 is triggered if the capacitance requirement resides between 1 and 3 units. For demands ranging from 3 to 5 units, relay 2 engages alongside relay 3. The threshold spanning 5 to 8 units initiates relays 2 and 3 concurrently. If demand persists from 8 to 13 units, relays 1 and 3 are activated collaboratively. The zone of 13 to 15 units prompts the operation of relays 1 and 2. High demands from 15 to 18 units prompt the collective response of relays 1, 2, and 3. Finally, in excess of 18 units, all relays are activated simultaneously. The relays behaviorally adjust these capacitive loads in accordance with demand levels to optimize the system's power factor, concluding automated correction procedures.

Calculation of Determination of Capacitor Needs

In improving the power factor, each load has a different initial power factor, this is because each load has a different power. So, the need for the value of the capacitor to improve the power factor at each load is different. To determine the suitability of the required capacitor value shown in equation (1).

$$C = \frac{1}{\left(2 \times \pi \times F \times Z\right)} \tag{1}$$

Where C is the required value of the capacitor, the impedance value is obtained from equation (2).

$$Z = \frac{V^2}{Q_2} \tag{2}$$

Where Z is the total impedance value. Meanwhile, the initial reactive power value is obtained from equation (3).

$$Q_1 = V \times I \times \sin\varphi \tag{3}$$

To determine the desired power factor value, it is necessary to find the reactive power after the improvement shown in equation (4).

$$Q_2 = Q_1 - \left(P \times \tan 11.48^\circ\right) \tag{4}$$

When the Reactive Power after repair is obtained, the calculation of determining the required value of the capacitor at each load can be calculated according to the equation above.

RESULTS AND DISCUSSION

This power factor monitoring tool aims to determine how good the power factor is and what effect it has on efficiency in using electrical energy. This tool has a monitoring feature displayed via the LCD and an Android application to make it easier to read the values of voltage, power, current, power factor, and frequency. Hardware components required include ESP-32 Microcontroller, 12 V Power Supply, PZEM-004T-100A Sensor, four-channel 10 A Relay, Contactor, Bank Capacitor, 5V Step – Down Module, Switch, 20 X 4 LCD, Terminal Blocks and Sockets in designing software to create monitoring applications on Android using the MIT App Inventor software and Firebase, which is used to store data.

The power factor monitoring system design is divided into two parts, namely hardware design and monitoring application design on Android. The working steps of this power factor monitoring system, namely the ESP-32 microcontroller, will process data on the voltage, current, power, and power factor generated by the Pzem-004T sensor. Furthermore, the data received by ESP-32 is transferred to MIT App Inventor via TCP/IP or UDP protocol. The hardware communication flow with the MIT App Inventor is shown in Figure 4.

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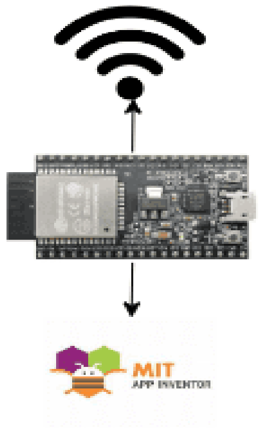


Figure 4. Hardware communication flow with the MIT app

Hardware Design Results

The hardware design of a power factor monitoring system based on this Android application includes the creation of electrical circuits. Each component is connected to produce an alt that monitors the power factor. There are components in this monitoring system, namely frequency and the energy that works on the device, the Terminal Block, which serves as a place to connect the input voltage to the electrical circuit and as an output connection to the socket. The socket acts as a source of electricity for the load, which will later be connected to this power factor monitoring tool. The overall electrical circuit for the device is shown in Figure 5.

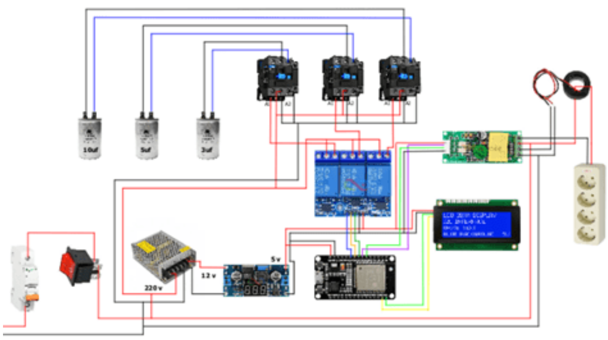


Figure 5. Electric circuit for the device

The design of this power factor monitoring system based on the Android application is in the form of an Acrylic box measuring 37 X 20 X 13 cm as a means of placing the components that make up this power factor monitoring system. The hardware design of this power factor monitoring system is shown in Figure 9.

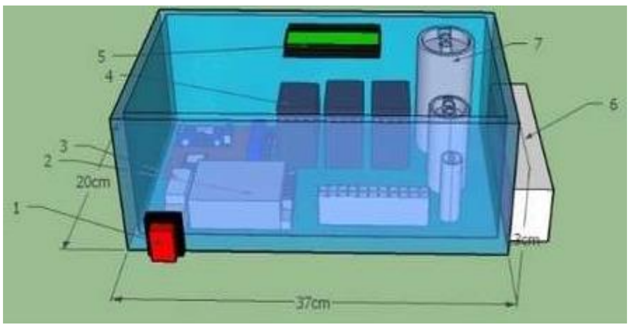


Figure 6. Hardware design

Several modules are contained in this hardware, including:

1. On/Off switch
2. *Power Supply*
3. MCB 4A
4. *Magnetic Contactors*
5. LCD 20X4
6. Electric socket
7. Bank capacitor

Results of Android Application Design

The android application in this study displays data obtained from sensors. The Android application created can only be installed on one Android device. The application will display power factor monitoring data. The use case diagram for the MIT App Inventor application is shown in Figure 7.

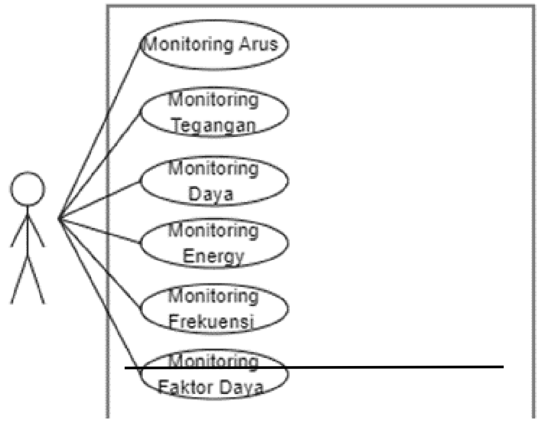


Figure7. Use case diagrams

By knowing the Use Case Diagram, in making monitoring applications using the help of the MIT App Inventor software. In the MIT App Inventor software, a logic block will be made to produce a monitoring application by displaying data according to the Use Case Diagram. The MIT App Inventor software logic block is shown in Figure 8.

Figure 8. Logic block MIT app inventor software

The features of the Android application consist of monitoring features for current, voltage, power, power factor, frequency, and energy as shown in Figure 9.

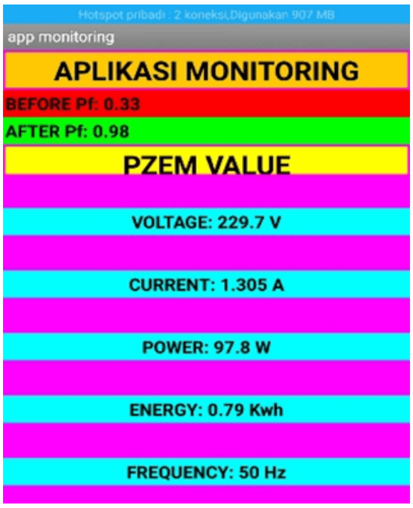


Figure 9. Display of power factor monitoring before – after, voltage, current, power, energy, and frequency

System Testing Results

Testing this system includes hardware and monitoring display testing on Android applications that have been successfully made. In hardware testing, a test was carried out on the results of the Pzem-004T sensor readings. Hardware testing is carried out by connecting the load to the socket on the power factor monitoring device. This hardware test will be carried out by clicking several electrical loads. The results of hardware testing using a 0.5 HP 1-phase electric motor load showed that the maximum power used was 97.80 W, the working current was 1.30 A, and the initial power factor was 0.33 with the need for a capacitor to improve the power factor of 15.99 uF.

Meanwhile, in manual calculations, the value of the capacitor requirement is 15.79 uF. Based on this, the error value obtained from reading the capacitor requirement is 1.2%. The LCD, when using an electric motor load, is shown in Figure 10.

(a) (b) (c) (d)

Figure 10. LCD display on 1-phase electric motor load: (a) display of V, I, F, P, and E; (b) display of capacitor requirements; (c) view of Pf before; and (d) after

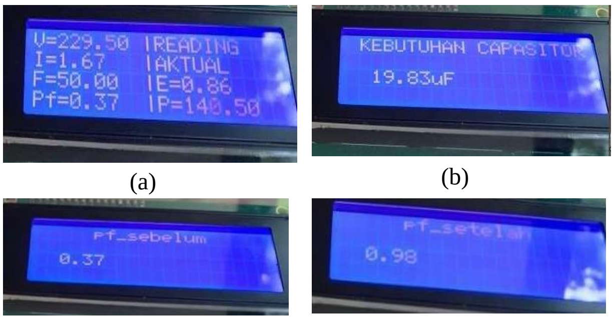
The second test, using a drill load, obtained a maximum power value of 104.6 W, a working current of 0.69 A, and an initial power factor of 0.65 with a value of the capacitor requirement to improve the power factor of 6.28 uF. Meanwhile, with manual calculations, the value of the capacitor needed to improve the power factor is 6,015 uF.

Based on this, the error value obtained from reading the capacitor requirement is 4%. The LCD, when using the drill load, is shown in Figure 11.

(a) (b) (c) (d)

Figure 11. LCD display on drill load: (a) display of V, I, F, P, and E; (b) display of capacitor requirements; (c) view of Pf before; and (d) after

The third test using a 1-phase electric motor load and a drill obtained a maximum power value used of 141.5 W, with a working current of 1.68 A and an initial power factor of 0.37 with the need for a capacitor value to improve the initial power factor of 19.83 uF. Meanwhile, by manual calculation, it is found that the value of the capacitor needed to improve the power factor is 19.8 uF. Based on this, the error value obtained from reading the capacitor requirement is 0.15%. The LCD when using an electric motor load and a drill is shown in Figure 12.



(a) (b) (c) (d)

Figure 12. LCD display on 1-phase electric motor and drill load: (a) display of V, I, F, P, and E; (b) display of capacitor requirements; (c) view of Pf before; and (d) after

The fourth test used a 1-phase electric motor load and Hair Dryes to obtain a maximum power value used of 436.5 W, with a working current of 2.26 A, and an initial power factor of 0.85 with the need for a capacitor value to improve the initial power factor of 11.24 uF. Meanwhile, with manual calculations, the value of the capacitor needed to improve the power factor is 11.21 uF. Based on this, the error value obtained from reading the capacitor requirement is 0.8%. The LCD when using an electric motor load and a hair dryer is shown in Figure 13.

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(a) (b)

(c) (d)

Figure 13. LCD display on 1-phase electric motor and a hair dryer: (a) display of V, I, F, P, and E; (b) display of capacitor requirements; (c) view of Pf before; and (d) after

CONCLUSIONS

After successfully making a power factor monitoring tool using IoT, it can be concluded that based on the experimental results on a single-phase electric motor load with a power factor value before repair of 0.33uf, after restoration, it becomes 0.98. The drill load before the repair was carried out was 0.65. After the repair was carried out, it was 0.98. At the burden of the electric motor and drill, the power factor value before the repair is 0.37. After the repair is made, it becomes 0.98. The load of single-phase electric motors and hair dryers before repairs was 0.85. After repairs were made, it was 0.98. Based on the test results, the need for the most significant capacitor value, 19.83, is found in the load of a single-phase electric motor with a drill. While the lowest capacitor value is 6.28 at the drill load. In the application, the display can monitor current, power, voltage,

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