Implementation of Android-Based Electrical Energy Monitoring and Power Factor Improvement Using MIT App Inventor and Firebase

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Abstract— **As inductive loads like washing machines and water pumps become more common, they utilize more reactive energy and lower the power factor. If the power factor is less than 0,85 PLN, electrical protection devices like MCBs and ELCBs could stop working. To utilize less power, things need to change. Adding a capacitor bank to add reactive power can make the power factor value better. Using the MIT App Inventor and Firebase platforms, this study built an app that lets you keep track of and improve your power factor. The app had an average data latency of 11,20 seconds. After 11 load changes, the average power factor went up from 0,64 (before improvement) to 0,88 (after). So, this method for optimizing power factor helps to get a low power factor up to the right level.**

Keywords: Capacitor Bank, Energy Efficiency, Inductive Load, IoT, MIT App Inventor.

I. INTRODUCTION

Life depends on electrical energy. Most people today rely heavily on electrical energy; therefore, it becomes difficult to perform everyday tasks if the power goes out, even for a short time [1]. Almost everything we do every day needs electricity, so using it wisely not only saves money but also helps make the world a better, more sustainable place [2]. As more electricity is utilized in homes, so are inductive loads like fans, water pumps, washing machines, refrigerators, and more. More inductive loads could mean that more reactive energy is needed, which would mean that more energy has to be available [3]. It is very important for reactive power to maintain the quality of stable electricity. If the reactive power in a network isn't balanced right, the voltage can drop, which can broke electrical devices. Voltage drops and power losses get worse when more current flows through the lines. Keeping a suitable power factor helps make sure that energy is sent safely and efficiently [4]. A rise in reactive power widens the phase difference between apparent and active power, resulting in a reduced power factor. In accordance with the PLN regulation SPLN 70-1, the power factor value should exceed 0,85 to comply with operational standards [5]. Within an electrical system, maintaining a power factor of at least 0,85 is essential to prevent additional costs associated with reactive power for industrial consumers. In contrast, residential users are generally not subject to such penalties, even when their power factor operates below the 0,85 threshold [6]. Hartono et al research shows that when a household's power factor is low, protection devices like micro circuit breakers (MCBs) and earth leakage circuit breakers (ELCBs) can trip while they are working with volt-amperes of apparent power. This happens when electrical devices use more power than they can handle. This is often true for inductive loads in homes. This means that the phase of the current is behind the phase of the voltage [7]. Zakaria et al propose the development of a self-regulating power factor system integrated with a smartphone platform to monitor electricity use. The steps were to make the hardware and software, test the PZEM-004T sensor, change the power factor, and submit the results. This can utilized an LCD module and the Blynk app to keep an eye on the system. The investigations' power factor changed from 0,53 to 0,88 [8]. Fartino et al aimed to design and test a power factor improvement system. This research method includes software simulation, system design using an ATMEGA 328P microcontroller integrated in an Arduino Mega development board, and relay testing as a capacitor bank selector. The results of this study using a smart power meter prototype integrated with a power factor improvement circuit on a single-phase network with a reactive power range of 1-1000 VAR [4]. The main goal of making the power factor better is to make the system work better while using the least amount of energy. You can improve things in a number of ways, like adding electrical parts with a higher power factor or fine-tuning the system. A capacitor bank that is connected in parallel with the power grid is one of the best ways to send reactive power. This method lowers the phase angle between real and apparent power, which improves the power factor of the system [9]. Based on the issues discussed before, a series of measurement studies were conducted on different household electrical appliances. The surveys were done in several homes in Jambi province, such as those in Kota Baru District, Jambi Selatan District, Mendalo Darat Village, and Sumber Agung Village. The results indicated that some types of household appliances had an average power factor less than 0,85. for example, ceiling fans had a power factor of 0,53, refrigerators had a power factor of 0,61, coconut graters had a power factor of 0,44. These results indicate that there is a need for programs that will help improve the quality of the power factor in homes electrical system. The main goals of improving the power factor are to make the system more powerful and use the power it does use more efficiently. You can fix this problem in a number of ways, such as by using electrical parts with higher power factor values or by making the shole system work better. One of the best ways to do this is to install capacitor banks, which are usually connected in parallel to the electrical network to give it the reactive power it needs. This process lowers the phase angle between real and apparent power, which makes the power factor of the system better overall.

The objective of this research is to develop a system that is capable of improving the performance of low power factor in domestic electrical networks by taking into consideration the history of the problem as well as the problems that have been recognized. Through the utilization of variable capacitors and the monitoring of electrical characteristics in real time, this research develops an automatic device that enhances the power factor. A few examples of these characteristics are voltage (V), frequency (Hz), current (A), active power (W), apparent power (VA), reactive power (VAR), electrical energy (kWh), phase angle (°), phase type, power factor (cos φ), PLN cost estimation, and the required capacitor value. All of these parameters will be discussed more in the following test. Voltage, frequency, current, active power, electrical energy, and power factor are some of the things that may be measured with the PZEM-016 sensor. It is designed to measure things in a quick and accurate manner, and it comes equipped with current transformer (CT). A 20x4 LCD with an I2C interface displays the data that was gathered.it is also possible to access it by means of an Android application that was developed using MIT App Inventor. This is framework that simplifies the process of developing applications without requiring a significant amount of knowledge regarding programming. Additionally, the device is able to automatically log data and save the results of measurements in Google Spreadsheets, which makes it both simple and straightforward to monitor and evaluate the data. It is anticipated that this study will improve the management of electrical energy in houses in a way that is both efficient and sustainable. This will make it simpler to initiate initiatives that wish to improve energy consumption as well the overall quality of power.

II. METHOD

In this research, careful to proceed with the Research and Development (R&D) process [10] as per the ADDIE model with five phases: Analysis, Design, Development, Implementation, and Evaluation [11]. This systematic approach guarantees that every phase of the study is well planned and systemically linked, which makes our process reliable.

The research process entailed literature review and observations, development of software and hardware, device designing, field testing, and cross-validation by testing to measure the system performance [12].

A. Software Design

The software design focuses on creating an electrical energy monitoring system based on Android that can show sensor measurement parameters in real time. The Android application was created using MIT App Inventor, which is an open-source Android application development platform that facilitates interface designing through visual block programming without the necessity of advanced programming knowledge [13].

The Android app is connected to the firebase real time database, which is a cloud-hosted database storing, modifying, and displaying data directly from the microcontroller. The data that is sent is voltage (V), current (A), frequency (Hz), active power (W), apparent power (VA), reactive power (VAR), electrical energy (kWh), power factor (cos φ), phase type, price of electricity in PLN, and value of capacitor that needs to be installed for power factor correction [14]. Figure 1 is flowchart system.

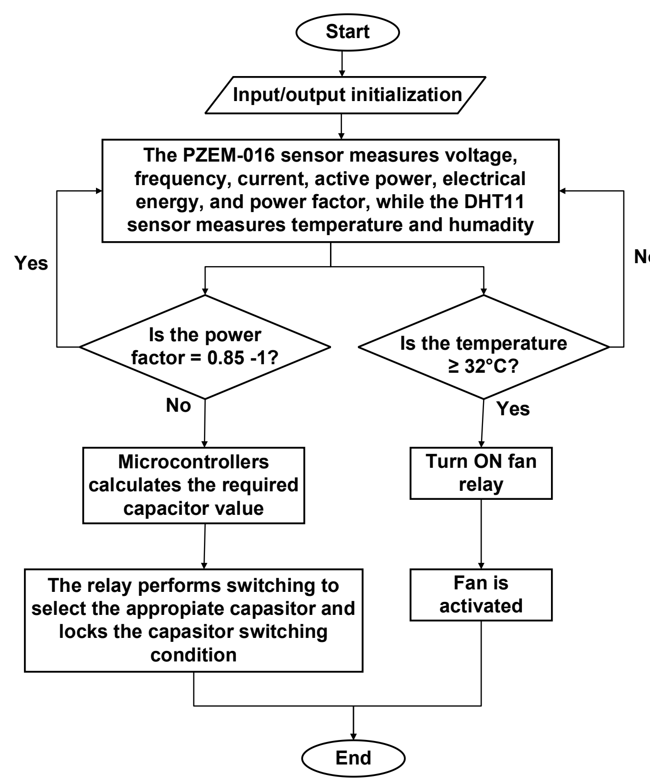

Figure 1. Flowchart Illustrating of System Designing

The flowchart work system in Figure 1 illustrates the input/output initiation process for the PZEM-016 sensor that measures various electrical parameters such as voltage, frequency, current, active power, electrical energy, and power factor, as well as the DHT11 sensor to measure temperature and humidity in the tool box. If the power factor is not in the range of 0,85 to 1, the microcontroller will calculate the required capacitor value, then the relay will switch to select the capacitor, then the relay will lock the capacitor switching condition and the process is complete. Meanwhile, if the power factor is in the range of 0,85 to 1, the tool will read the parameters again. Furthermore, in the process selection, if the temperature is above or equal to 32, then the fan relay will turn on, then the fan turns on, and the process is complete. Meanwhile, if the temperature is below 32 then the DHT11 will read the temperature again.

B. Hardware Design

Mechanical design establishes the power factor correction unit's physical layout, both the component placement and the enclosure layout [15]. Design was done using SketchUp because it has very good 3D visualization and also because it is easy to use, permitting a good modeling of the physical layout of the device [16].

The design revolves around safety, simplicity in maintenance, and compactness. All the key components, including the PZEM-016 sensor in the center, ESP32 module, LCD display, capacitor bank, and relay driver, are housed in a compact, insulated enclosure. The design facilitates convenient access, shields against interference from the external environment, and also enhances performance as a whole [17]. Figure 2 illustrates the complete mechanical design of the power factor correction device.

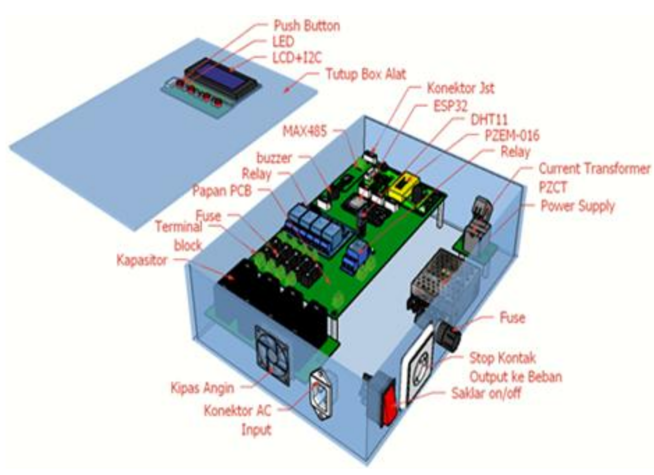

Figure 2. Illustration of Mechanical Design of The Power Factor Correction Device

C. Implementation and Testing Phase

After the design of the hardware and software was complete, implementation began. Integration of all the main elements, each of which was carrying out its assigned function, was part of this phase. Electrical characteristics were measured by the PZEM-016 sensor, data was processed by the ESP32 microprocessor, and reactive power adjustment was accomplished by the capacitor bank [17]. To make the system effective in power factor correction, each of these components was carefully selected and incorporated.

All components were interfaced and programmed to run in an integrated manner. The system was designed to measure voltage, current, active power, apparent power, reactive power, electrical energy, and power factor in real time and transmit the obtained data to the Android application via a wireless IoT-based connection [18], [19]. The testing phase was performed with maximum caution to quantify the accuracy and performance of the system in enhancing power factor at various loads. We employed four diverse types of inductive loads and tested combinations of them to gather a diverse set of data to make the system dependable over a wide range of situations. During the testing, voltage, current, active power, apparent power, reactive power, and power factor before and after correction were measured by the system. Also, data transmission delay from the device to Android app was measured in order to evaluate the performance of Firebase Realtime Database-based communication system [19].

D. System Evaluation

The purpose of the testing procedure was to confirm that the Android application accurately displayed measurement values and that the system was effective in correcting for power factor. The effectiveness of power factor correction and the dependability of the monitoring system were the two main areas of testing [19], [20].

Power factor values before and after compensation were compared to establish the degree of efficiency attained. The method of assessment aligns with prior research, complementing the utility and applicability of our research to the area of power factor correction. Apart from cross-checking the measurement data, the testing also involved testing the stability of data transmission and the responsiveness of the Android application. The Firebase Cloud Database was utilized in testing the performance of synchronizing data among devices as it was suggested in earlier work on IoT-based Android application development [19].

The outcome of the evaluation phase directed the computation of the system success rate and established a foundation for future enhancement in hardware as well as software. Simply put, the implementation and evaluation phases were aimed at making the resulting power factor correction system meet the efficiency and reliability requirements documented in literature [17]–[21].

III. RESULT AND DISCUSSION

This stage discusses the result of implementing an android-based electrical energy monitoring and power factor improvement system developed using MIT App Inventor and Firebase.

A. System Implementation

The system implementation was conducted following the research flowchart and methodological design. The integration of components, sensors, and the overall testing of the Android-based power factor monitoring and correction system were successfully completed. The results of implementation are show at figure 3.

Figure 3. The Result of Implementation

B. Load Testing

The power factor improvement device was tested using four different types of electrical loads. The loads consist of a fan (25 W), a refrigerator (75 W), a coconut grater (180 W), and a water pump (200 W). The arrangement of these loads is illustrated in Figure 4.

Figure 4. The Load use

Table I presents the test results of the power factor correction device using 11 different load variations.

TABLE I
TESTING WITH 11 LOAD VARIATIONS

No.	Load	Initial Power Factor	Final Power Factor
1.	Fan (25 Watt)	0,53	0,89
2.	Refrigerator (75 Watt)	0,67	0,92
3.	Coconut Grater (180 Watt)	0,81	0,89
4.	Water Pump (200 Watt)	0,49	0,85
5.	Fan and Refrigerator (100 Watt)	0,65	0,87
6.	Fan and Coconut Grater (205 Watt)	0,76	0,87
7.	Fan and Water Pump (225 Watt)	0,52	0,89
8.	Refrigerator and Coconut Grater (255 Watt)	0,72	0,88
9.	Refrigerator Water Pump (275 Watt)	0,57	0,85
10.	Coconut Grater and Water Pump (380 Watt)	0,63	0,88
11.	All of the loads (480 Watt)	0,65	0,88
	Average	0,64	0,88

An improvement in power factor can be observed across all variations. The average power factor before correction was 0,64 and after the correction process, it increased to an average value of 0,88. The graphical representation of the best results for the 11 load variations is shown in Figure 5.

Figure 5 describe, the first power factor graph shows a big increase in value, which is typical for how people use electrical energy in their homes. The type of equipment greatly influences the power factor value. You can see that some machines have a low power factor at first. For instance, the Water Pump (200 Watt) is valued at about 0,5, which means it has a very inductive load and needs a lot of reactive power, which makes it less efficient. Then, a few other pieces of equipment, like the Coconut Grater (180 Watt), have a fairly good initial value (about 0,82), while the Fan (25 Watt) has a fairly low value (about 0,52).

The last power factor line shows how well the system changes worked. The most important thing to note is that the orange line is always higher than the blue line in all eleven test cases. This graph shows that the corrective system worked under all test situations to enhance the power factor. The orange line is very stable, while the blue line has many ups and downs. The system may raise the starting value to a much more efficient level, no matter how low it was. For example, a water pump with an initial power factor of 0,5. Most of the final power factor values were in the near-optimal range, which is between 0,85 and 0,9 (for example, the refrigerator got 0,92 and the fan and coconut grater combination got 0,87).

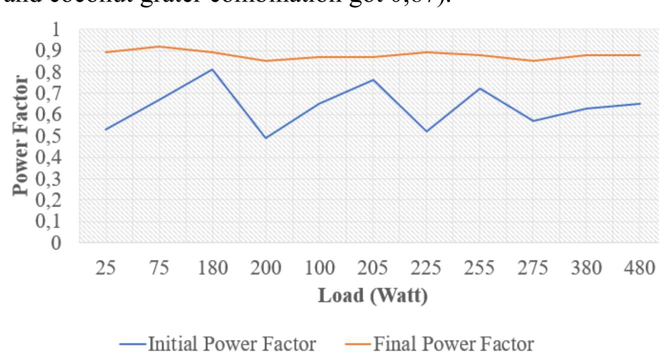

Figure 5. Graphical Results 11 Load Testing

C. Monitoring Testing

The monitoring test was conducted to ensure that parameter data measured by PZEM-016 module and displayed on the LCD could also be accurately shown in the Android application. The monitoring results from both the LCD display and the Android interface are presented in Figure 6 and 7.

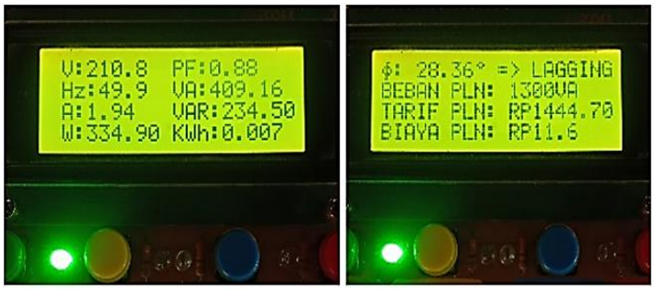

Figure 6. The LCD Monitoring Results

According at figure 6, the information provided, the system is operating at a frequency of 49.9 Hz and a voltage of 210,8 V throughout its operation. On account of the fact that it draws 1,94 A of current, the connected load consumes 334,90 W of active power, also known as apparent power. The power factor value of 0,88 and the reactive power (VAR) of 234,50 demonstrate that there is a disparity between the active power (W) and the perceived power (VA). There is also a difference between the two. Figure 6 validates the preceding screen's findings. A power factor of 0,88 and the condition "LAGGING" indicate that the associated load is inductive. The system is set up with a 1300 VA power capacity and a tarif of Rp 1444,70 per unit of energy. The total cost at the time reading, based on 0,0007 kWh of energy consumption is Rp 11,60.

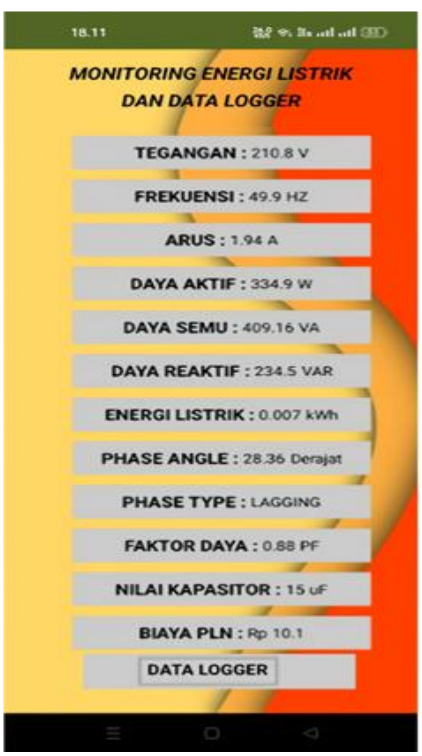

Figure 7. Android Application Monitoring

As shown in Figures 6 and 7, the parameters measured by the PZEM-016 sensor appear correctly on both the LCD display and the Android application. During the data transfer process to the Android app, a small delay can be observed, which is summarized in Table II.

TABLE II
DATA TRANSMISSION DELAY TO THE ANDROID APPLICATION

No	Load (Watt)	Data transmission delay to the application (s)	Successfully send	Failed to send
1	Fan (25 Watt)	14,33	✓	-
2	Refrigerator (75 Watt)	9,67	✓	-
3	Coconut Grater (180 Watt)	11,33	✓	-
4	Water Pump (200 Watt)	11	✓	-
5	Fan and Refrigerator (100 Watt)	11,33	✓	-
6	Fan and Coconut Grater (205 Watt)	13	✓	-
7	Fan and Water Pump (225 Watt)	10	✓	-
8	Refrigerator and Coconut Grater (255 Watt)	11,22	✓	-
9	Refrigerator and Water Pump (275 Watt)	10,67	✓	-
10	Coconut Grater and Water Pump (380 Watt)	8,67	✓	-
11	All of the loads (480 Watt)	12	✓	-
Average Delay		11,20		

Table II presents the delay that occurs during data transmission to the Android application. From the test results, the average delay recorded was around 11,20 seconds. This delay may vary depending on the quality of the internet connection used. A faster and more stable connection generally results in shorter delay time.

IV. CONCLUSION

Based on the research results, the power correction device was successfully designed and developed. All components and sensors worked properly and were able to read the required parameters as expected. The electrical energy monitoring and power factor correction application was created using the MIT App Inventor platform with Firebase as the database. During data transmission to the Android application, an average delay of around 11,20 seconds was observed, which varied depending on the internet connection used faster connections produced shorter delays. Based on testing with 11 different load variations, the average power factor before correction was 0,64, and after correction it increased to 0,88. These results show that the developed device can effectively improve low power factor values below 0,85.

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