

Automatic Power Factor Correction Using Fuzzy Inference System And Internet Of Things

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Abstract --There are 3 types of electrical loads: inductive, capacitive and resistive. Most of what happens in the use of electricity is inductive load. This inductive load arises because many electricity consumers utilize loads that use coils. The excessive inductive load will cause the appearance of a low power factor value. A good power factor value is 0.85-1. This research aims to improve the low power factor value, the use of capacitors installed parallel to the load can compensate for reactive power and increase the power factor value. How much capacitor value should be installed to obtain a good power factor. There are 2 kinds of calculations carried out, namely without using a Fuzzy Inference System and using a Fuzzy Inference System. The calculation results are compared with the measurement values. Then, the Mean Absolute Error value obtained if without using the Fuzzy Inference System is 8.500% and if using the Fuzzy Inference System has a Mean Absolute Error value of 4.060%. Therefore, the capacitor value calculation system using the Fuzzy Inference System can be proposed to be applied to the use of an automatic system to increase the power factor value.

Keywords:
Capacitor; Power Factor; Internet of Things

Article History:
Received: 21 April 2025
Revised: 20 May 2025
Accepted: 30 May 2025
Published: 31 May 2025

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DOI: 10.46962/forteijeeri.v6i1.28

I. INTRODUCTION

The use of electrical energy is an important requirement in everyday life, for example for washing clothes, cooking rice, or lighting at night as well as the use of electricity in the industrial and business world [1]. With the development of technology, there is an increase in the quality of service that is getting better. The use of artificial intelligence in the operation of electric power is also increasing [2][3]. The growth in the use of electrical energy will continue to increase along with the increase in population. Likewise, the increase in electricity demand in the industrial and business world [4].

State companies that operate electricity in a country will apply electricity tariffs. This tariff is calculated using units of kilo Watt hours (kWh) [5]. On the other hand, industrial loads or business loads using large electric power in addition to calculations with kWh also use kilo Volt Ampere Reactive (kVAR) [6]. This kVAR calculation is also part of the cost to be paid [7].

The operation of electric power is also related to economic issues [8][9]. The electrical energy generation system requires energy sources from other forms of energy, such as coal, natural gas, water, etc. [10]. At the time of loading, there are 3 kinds of loads: inductive, capacitive, and resistive. These three types of loads are always found in distribution systems and transmission systems [11]. In low voltage loads, there are also several types of loads in households that have inductive loads [12]. This inductive load changes energy from electrical energy to magnetic energy (coils) and electrical energy [13]. This inductive load causes a cost effect. For this inductive load to be reduced, it must be reduced using a capacitive load [7].

Inductive loads contain inductors in the form of wire coils, in this case the inductor can absorb electrical power to produce a magnetic field [14]. The use of inductive electrical loads causes reactive power to

increase so that a large supply of electrical energy is needed [15]. Reactive power is the electrical power used in the formation of magnetic fields in inductive loads in coils. The unit of reactive power is Volt-Ampere Reactive (VAR) [16]. Examples of reactive loads are electrical equipment containing coils in them such as electric motors and transformers [17]. Capacitive load regulation to reduce this reactive load needs to be done to reduce electricity usage costs as well as from the engineering side will improve the quality of the network [16][18]. If the value of this induction reactance is too high, it will impact the decrease in $\cos \phi$ and result in a voltage drop [18].

This research was conducted to analyze the calculation of the desired capacitor value to overcome the reactive load problems arising from inductive loads. This calculation analysis is carried out automatically, the results of which will be used to create an automatic system for providing capacitors to improve the power factor. The calculation will determine how many capacitors are needed to improve the $\cos \phi$ value [16]. This $\cos \phi$ value improvement is done in 2 ways, namely without using the Fuzzy Inference System (FIS) algorithm and using (FIS) [1][19]. To determine which system has a good error rate, the system will be simulated using the (FIS) algorithm. Thus, the best system can be determined. What is the value of the capacitor that must be installed when the system experiences a decrease in $\cos \phi$ value? After the system runs well, the next step is to send data [20]. Data transmission in this study is using the Internet of Things (IoT). By using this IOT, the data obtained in the process can be sent to another place using internet facilities. The Blynk device data connected to Android or other systems can be used [21].

This IoT facility is installed to overcome the problem of remote control [22][23]. This remote control is used by the maintenance team and system owner. The maintenance team and system owner will be able to know whether the power supply repair system is working or not. On the other hand, the maintenance team and the owner will know how big the inductive load is and how much it saves with the capacitor to improve this power factor.

This research uses several components, such as the ESP32 microcontroller which is equipped with a wifi module to connect to the internet network [24]. The pzem 004-T sensor is also used to detect the amount of electricity in the system, a 20x4 LCD to display sensor reading data in the form of voltage, current, power, frequency, and power factor, as well as a relay module to activate the capacitor automatically and also a tool for transmitting data [25][26]. After the above equipment was assembled, the system was tested. Testing is done independently on the system and remotely.

II. METHOD

This research analyzes the use of apparent power, real power, and reactive power [7][27]. These three powers can be seen more clearly in the power triangle in Figure 1.

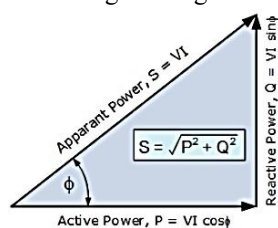


Figure 1. Power triangle

The power triangle above has 3 parts where S is apparent power, P is active power or real power, and Q is reactive power. Apparent power has a value as large as the current and voltage entering the system [28]. While real power is the result of multiplying the apparent power multiplied again by $\cos \phi$ [29]. $\cos \phi$ is the ratio between real power and apparent power [30]. $\cos \phi$ is often referred to as the power factor [31]. Therefore, if the $\cos \phi$ value is getting smaller, the value of real power and apparent power will be more equal or the ratio has a value of 1 [32].

The apparent power value will be obtained by knowing the voltage and current value. The measuring instrument can know the magnitude of $\cos \phi$. Thus, with data on current, voltage and $\cos \phi$, the real power value will be obtained using the equation [33]:

$$P1 = I1 \cdot V1 \cdot \cos \phi \quad (1)$$

If the $\cos \phi$ measurement is known to be bad (below 0.8) then we can raise it by adding a capacitor by entering equation (1) and then entering it in the equation below:

$$P_2 = I_2 \cdot V_2 \cdot \cos \phi_2 \quad (2)$$

With the value of $P_2 = P_1$; $V_2 = V_1$ and the desired $\cos \phi$ value of 0.8, the equation is obtained:

$$I_2 = \frac{P_2}{V_2 \cdot \cos \phi_2} \quad (3)$$

Thus, the value of I_2 is obtained. After obtaining the I_2 value, a comparison is made between I_1 and I_2 using the equation:

$$I_1 - I_2 = I_3 \quad (4)$$

$$I_3 / I_1 = X\% \quad (5)$$

With equation number 4, the percentage value of the passing current change is obtained. The percentage value shows the amount of current savings that pass with the improvement of the power factor or $\cos \phi$ value. Of course this will result in a decrease in electricity usage costs.

The next step is to determine the value of the capacitor to be installed. By using the following equation:

$$\cos \phi_1 = \cos^{-1} \times \cos \phi_1 \quad (6)$$

$$\cos \phi_2 = \cos^{-1} \times \cos \phi_2 \quad (7)$$

By knowing the real power; apparent power (at $\cos \phi$ and desired current), the reactive power will be obtained using the following equation:

$$Q_1 = S \sin \phi_1 \quad (8)$$

For the condition of changing the current with the corrected $\cos \phi$ entered in equation (8), the result of Q_2 will be obtained. So that with Q_1 and Q_2 , entered in the following equation:

$$\Delta Q = Q_2 - Q_1 \quad (9)$$

With the difference between Q_2 and Q_1 known, the difference is entered in the following equation:

$$C = \Delta Q / - V_2 \cdot \omega \quad (10)$$

The value of the capacitor that must be installed to increase $\cos \phi$ will be obtained. The global process of determining the value of capacitors to increase the power factor can be seen in Figure 2. In the flow chart of Figure 2, the algorithm is not used

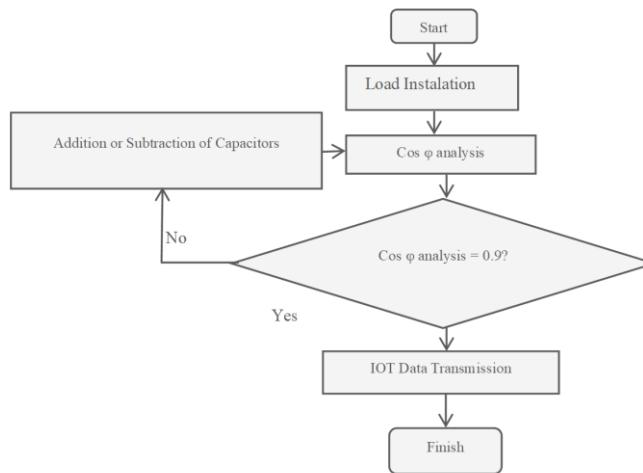


Figure 2. Flow Chart of Power Factor Improvement

In Figure 2, the process starts with the installation of the load. After that, the voltage, current, and $\cos \phi$ values are measured. Then, the system will ask if the $\cos \phi$ value has reached 0.9. If not, the addition or reduction of capacitors will be carried out. Then, the repeated process enters the loop again. And it is checked to know whether $\cos \phi$ is 0.9 until it is fulfilled. Capacitors with a certain capacity have been installed and will be switched according to the desired $\cos \phi$ requirement. If $\cos \phi$ is met, data will be sent to the intended device using IoT.

After calculations and measurements are performed, an error calculation is carried out as a comparison between the calculation value and the measurement value. This error calculation is called Mean Absolute Error (MAE) [34]. This calculation is done using the equation:

$$MAE = 1/n * \sum_{i=1 \text{ to } n} |y_i - \hat{y}_i| \quad (11)$$

The next step is to compare the calculation and measurement results of the paired capacitor value. The second process uses the Fuzzy inference System (FIS) algorithm. The use of this FIS algorithm is with 2 inputs and 1 output. Two input variables are real current and desired current with $\cos \phi$ of 0.9. In contrast, one output variable is the value of the capacitor installed. The flow chart is shown in Figure 3.

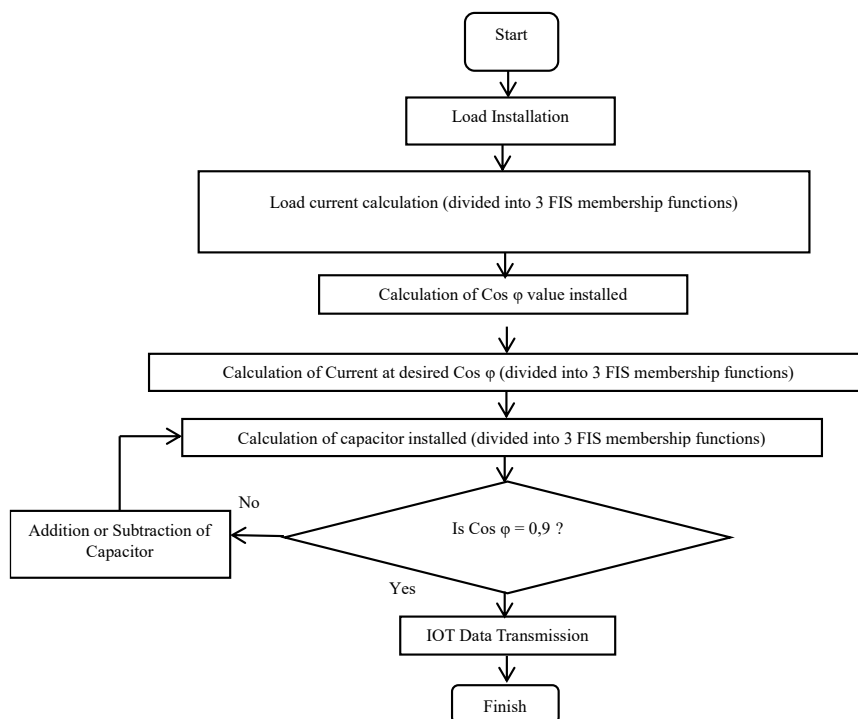


Figure 3. Flow chart of power factor improvement using Fuzzy inference system

Figure 3 shows that the process of implementing the capacitor calculation is the same as the flow chart that does not use FIS. However, in this section, the implementation of the analysis uses FIS. The use of FIS is by using 2 input variables and 1 output variable. The first input variable is: load current, the second is the current at $\cos \phi$ which is the initial $\cos \phi$ with an output variable of 1, namely the value of the capacitor installed/required.

For the first input variable is the load current. The load current is divided into 7 Fuzzy sets (Figure 4), namely: (umf1) is very low current, (umf2) is low current, (umf3) is medium-low current, (umf4) is medium current, (umf5) is high intermediate current, (umf6) is high current, and (umf7) is very high current.

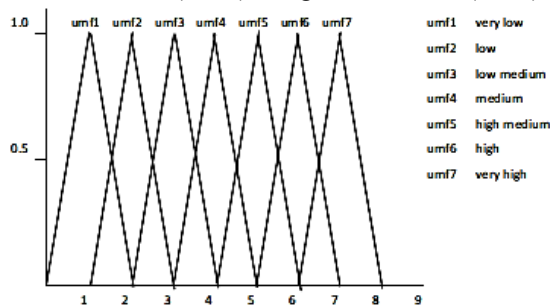


Figure 4. Load flow current

The second input variable is the initial $\cos \phi$. The initial $\cos \phi$ consists of 7 Fuzzy sets (Figure 5), namely: (smf1) is very low $\cos \phi$, (smf2) is low $\cos \phi$, (smf3) is medium-low $\cos \phi$, (smf4) is medium $\cos \phi$, (smf5) is $\cos \phi$ medium-high, (smf6) is high $\cos \phi$, and (smf7) is very high $\cos \phi$.

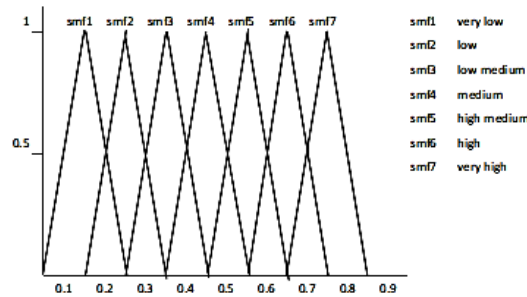


Figure 5. Initial $\cos \phi$ value

The output variable is the capacitor installed. This installed capacitor is divided into 7 Fuzzy sets (Figure 6), namely: (pmf1) is very small capacitor capacity, (pmf2) is small capacitor capacity, (pmf3) is small medium capacitor capacity, (pmf4) is medium capacitor capacity, (pmf5) is large capacitor capacity medium, (pmf6) is large capacitor capacity, and (pmf7) is very large capacitor capacity

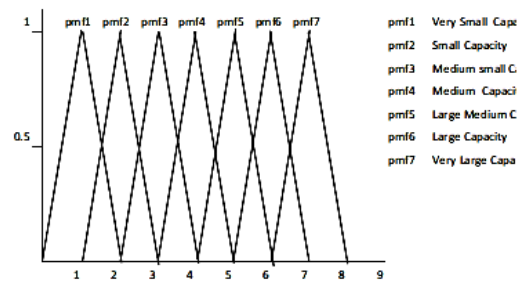


Figure 6. Calculated installed capacitor capacity

The sequence of steps performed is (i) performing Fuzzification process, (ii) performing Fuzzy inference system process, and (iii) 3. performing the defuzzification process [35][36], as shown in Figure 7:

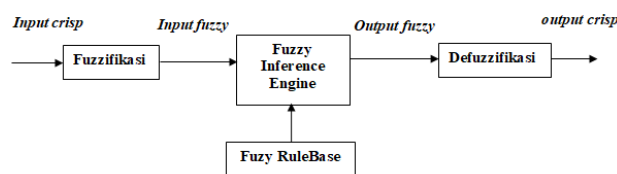


Figure 7. Type-1 Fuzzy logic system structure

In the Fuzzy inference system process, it is known that all variables used in FIS, namely load current, initial $\cos \phi$ and capacitor to be installed, are carried out in the fuzzification process[37][38]. This process converts real numbers into fuzzy numbers with their membership degrees. All variables are done similarly[39]. After all the variables are converted into fuzzy form with their membership degrees, an analysis is carried out using FIS[40]. The analysis results using FIS are still in the form of numbers in fuzzy form with their membership degrees. To become a real value, the defuzzification process is carried out[41]. Therefore, the defuzzification process is the process of converting from fuzzy value to real value [42].

The results of calculations carried out using FIS and not using FIS will be compared with the measurement results. It is followed by measuring the error rate. The next step is to make the hardware. After the hardware is assembled, the programming process and software design are carried out to display the results of monitoring electrical energy on the system via a smartphone, then integration between

hardware and software is carried out. A description of the system is shown in Figure 8:

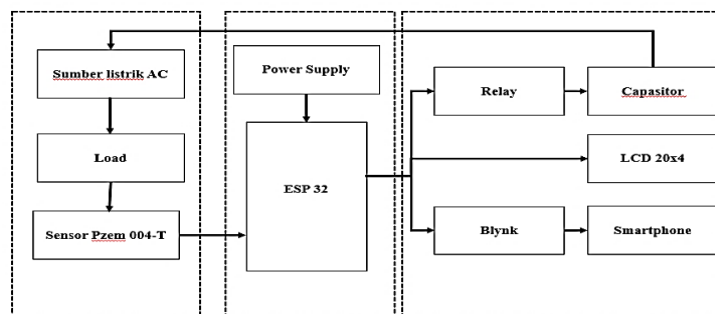


Figure 8. Process block diagram

Figure 7 shows that the pzem 004-T sensor functions to detect electricity flow in this sensor circuit and will calculate the voltage, current, power, power factor, and frequency values in the system's electrical circuit. The results of the sensor readings are processed by the ESP32 microcontroller and the results of data processing on the ESP32 microcontroller are displayed on the 20x4 LCD board. In addition, the data is also sent to the online blynk web server to be displayed on a smartphone. Suppose the power factor reading is less than 0.85. In that case, the microcontroller will activate the relay to supply electric current to the capacitor so that the power factor value can be changed for the better

III. RESULTS AND DISCUSSION

The calculation process is carried out using the existing equations in the methodology. The first step is to know the amount of power, voltage and power factor. The data is $P = 20 \text{ W}$, $V = 220\text{V}$, and $\text{Pf} (\text{Cos}\phi) = 0.35$. After that, by using equation (1), the current value and the results will be obtained $I_1 = 0.26 \text{ A}$. The current value listed is at pf 0.35. While the normal system is to have a value of pf = 0.85. At pf = 0.85, then by using equation (3), the value will be obtained $I_2 = 0.11 \text{ A}$. At the value of I_1 and the value is entered into equation (6), the value is obtained $\phi_1 = 69.550$. At the value of I_2 and the value is entered into equation (7), the value is obtained $\phi_1 = 31.800$. From the known current and Θ values, the value is entered into equation (8), therefore the apparent power value will be obtained $S_1 = 57.14 \text{ VA}$ and $S_2 = 23.25 \text{ VA}$. With the known apparent power above, the reactive power will be obtained using equation (8). And the following values are obtained $Q_1 = 53.53 \text{ VAR}$ and $Q_2 = 12.39 \text{ VAR}$. After that, the difference between $Q_2 - Q_1$ will be found (equation no. 9) with the result $\Delta Q = -41.13 \text{ VAR}$.

The desired capacitor value will be obtained with the reactive power difference value. This capacitor value will be obtained using equation (10), then $C = 2.71 \mu\text{F}$. Thus, with the calculation method as above, the results are obtained with the variable power that changes up every 5 W and they are shown in Table 1 and Table 2. Table 2 shows the value of the capacitor that must be installed when there is a decrease in pf value. In Table 3, the value of the capacitor installed in the calculation is compared with the value of the capacitor measured on the test equipment.

Table 1. Calculation results of capacitors required to increase pf value with fixed initial cos ϕ

| No | Power (W) | V | cos Θ_1 | cos Θ_2 | I_1 (A) | I_2 (A) | Θ_1 | Θ_2 |
|----|-----------|-----|----------------|----------------|-----------|-----------|------------|------------|
| 1 | 20 | 220 | 0.35 | 0.85 | 0.260 | 0.107 | 69.55 | 31.80 |
| 2 | 25 | 220 | 0.35 | 0.85 | 0.325 | 0.134 | 69.55 | 31.80 |
| 3 | 30 | 220 | 0.35 | 0.85 | 0.390 | 0.160 | 69.55 | 31.80 |

| | | | | | | | | |
|---|----|-----|------|------|-------|-------|-------|-------|
| 4 | 35 | 220 | 0.35 | 0.85 | 0.455 | 0.187 | 69.55 | 31.80 |
| 5 | 40 | 220 | 0.35 | 0.85 | 0.519 | 0.214 | 69.55 | 31.80 |
| 6 | 45 | 220 | 0.35 | 0.85 | 0.584 | 0.241 | 69.55 | 31.80 |
| 7 | 50 | 220 | 0.35 | 0.85 | 0.649 | 0.267 | 69.55 | 31.80 |
| 8 | 55 | 220 | 0.35 | 0.85 | 0.714 | 0.294 | 69.55 | 31.80 |
| 9 | 60 | 220 | 0.35 | 0.85 | 0.779 | 0.321 | 69.55 | 31.80 |

Table 2. Calculation results capacitor required to raise pf value

| No | Power (W) | S1 (VA) | Q1 (VAR) | S2 (VA) | Q2 (VAR) | $XQ=Q2-Q1$ (VAR) | C (μ F) |
|----|--------------|---------|-------------|---------|----------|---------------------|--------------|
| 1 | 20 | 57.14 | 53.53 | 23.53 | 12.39 | - | 41.13 |
| 2 | 25 | 71.43 | 66.91 | 29.41 | 15.49 | - | 51.42 |
| 3 | 30 | 85.71 | 80.29 | 35.29 | 18.59 | - | 61.70 |
| 4 | 35 | 100.00 | 93.67 | 41.18 | 21.69 | - | 71.98 |
| 5 | 40 | 114.29 | 107.06 | 47.06 | 24.79 | - | 82.27 |
| 6 | 45 | 128.57 | 120.44 | 52.94 | 27.89 | - | 92.55 |
| 7 | 50 | 142.86 | 133.82 | 58.82 | 30.99 | - | 102.83 |
| 8 | 55 | 157.14 | 147.20 | 64.71 | 34.09 | - | 113.12 |
| 9 | 60 | 171.43 | 160.59 | 70.59 | 37.18 | - | 123.40 |

Table 2 shows the C (Capacitor) column that must be installed in the system. As for comparing the increase in power with the value of the installed capacitor, measurements are made on the real load. Table 2 shows that the power value is increased per 5 watts with the same $\cos \phi$ of 0.35. With these conditions, the results of the capacitor that must be installed to get $\cos \phi$ of 0.85 have a value that increases linearly as well. This can be shown in Figure 9 which shows the change in power against the value of the installed capacitor.

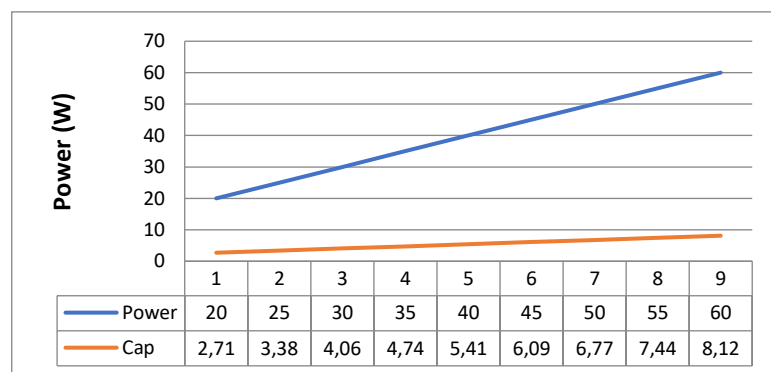


Figure 9. Comparison of power and installed capacitor

The next analysis is to provide a fixed power value with a changed Cos ϕ value. Tables 3 and 4 show the value of changes in capacitors that must be installed. Meanwhile, the graph of the calculation results with a fixed power and cos ϕ value changes is shown in Figure 9.

Table 3. Calculation Results of Capacitors Needed to Raise the Value of Power Factor (cos ϕ) with Fixed Power Value and Initial Cos ϕ Changed

| No | Power (W) | V | cos ϕ_1 | cos ϕ_2 | I1 (A) | I2 (A) | ϕ_1 | ϕ_2 |
|----|-----------|-----|--------------|--------------|--------|--------|----------|----------|
| 1 | 20 | 220 | 0.35 | 0.85 | 0.260 | 0.107 | 69.55 | 31.80 |
| 2 | 20 | 220 | 0.40 | 0.85 | 0.227 | 0.107 | 66.46 | 31.80 |
| 3 | 20 | 220 | 0.45 | 0.85 | 0.202 | 0.107 | 63.29 | 31.80 |
| 4 | 20 | 220 | 0.50 | 0.85 | 0.182 | 0.107 | 60.03 | 31.80 |
| 5 | 20 | 220 | 0.55 | 0.85 | 0.165 | 0.107 | 56.66 | 31.80 |
| 6 | 20 | 220 | 0.60 | 0.85 | 0.152 | 0.107 | 53.16 | 31.80 |
| 7 | 20 | 220 | 0.65 | 0.85 | 0.140 | 0.107 | 49.48 | 31.80 |
| 8 | 20 | 220 | 0.70 | 0.85 | 0.130 | 0.107 | 45.60 | 31.80 |
| 9 | 20 | 220 | 0.75 | 0.85 | 0.121 | 0.107 | 41.43 | 31.80 |

Table 4. Calculation results capacitor required to raise pf value

| No | Power (W) | S1 (VA) | Q1 (VAR) | S2 (VA) | Q2 (VAR) | $\Delta Q=Q2-Q1$ (VAR) | C (μ F) |
|----|-----------|---------|----------|---------|----------|------------------------|--------------|
| 1 | 20 | 57.14 | 53.53 | 23.53 | 12.39 | - | 41.13 2.71 |
| 2 | 20 | 50.00 | 45.83 | 23.53 | 12.39 | - | 33.43 2.20 |
| 3 | 20 | 44.44 | 39.69 | 23.53 | 12.39 | - | 27.30 1.80 |
| 4 | 20 | 40.00 | 34.64 | 23.53 | 12.39 | - | 22.25 1.46 |
| 5 | 20 | 36.36 | 30.37 | 23.53 | 12.39 | - | 17.97 1.18 |
| 6 | 20 | 33.33 | 26.67 | 23.53 | 12.39 | - | 14.27 0.94 |
| 7 | 20 | 30.77 | 23.38 | 23.53 | 12.39 | - | 10.99 0.72 |
| 8 | 20 | 28.57 | 20.40 | 23.53 | 12.39 | - | 8.01 0.53 |
| 9 | 20 | 26.67 | 17.64 | 23.53 | 12.39 | - | 5.24 0.35 |

In Figure 10, the power value is fixed while the cos ϕ value changes, resulting in the value of the installed capacitor. If the cos ϕ value installed continues increasing, the value of the capacitor installed will decrease.

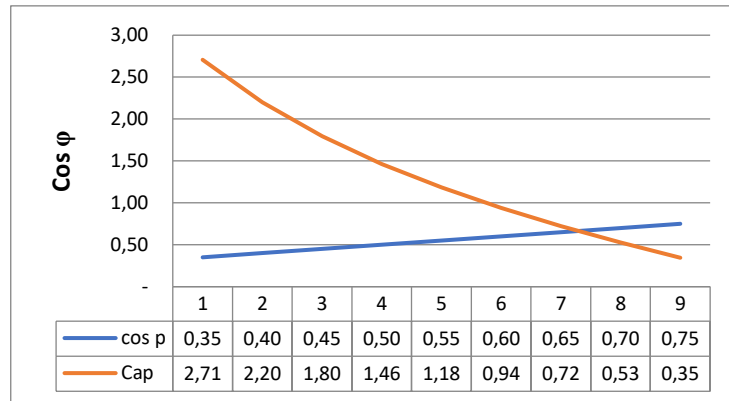


Figure 10. Comparison of $\cos \phi$ with fixed power and installed capacitors

The next step is to analyze with the actual load. Eight types of loads will be analyzed: fan, solder, waterpump, iron, mixer, blender, freezer, and grinder. The analysis process calculates the capacitor value needed to improve the power factor. After that, measurements are made to know how many capacitors are installed using measuring instruments for the desired power factor improvement at 0.85. The next step is to use the calculation using FIS. The calculation results of the required capacitor value without FIS and the calculation with FIS are compared with the measurement results. Table 5 shows the calculation results of the capacitor value installed without using FIS.

Table 5. Table of calculation results of capacitors needed to raise the power factor value ($\cos \phi$) without using FIS

| No | Load | Power (W) | V | Curret | $\cos \phi 1$ | $\cos \phi 2$ | I1 (A) | I2 (A) | $\phi 1$ | $\phi 2$ |
|----|------------|-----------|-------|--------|---------------|---------------|--------|--------|----------|----------|
| 1 | Fan | 25.86 | 235.1 | 0.20 | 0.55 | 0.85 | 0.200 | 0.129 | 56.66 | 31.80 |
| 2 | Solder | 26.33 | 235.1 | 0.14 | 0.80 | 0.85 | 0.140 | 0.132 | 36.89 | 31.80 |
| 3 | Water pump | 226.22 | 233.7 | 1.21 | 0.80 | 0.85 | 1.210 | 1.139 | 36.89 | 31.80 |
| 4 | Iron | 340.27 | 233.7 | 1.82 | 0.80 | 0.85 | 1.820 | 1.713 | 36.89 | 31.80 |
| 5 | Mixer | 542.18 | 233.7 | 2.90 | 0.80 | 0.85 | 2.900 | 2.729 | 36.89 | 31.80 |
| 6 | Blender | 280.82 | 234.6 | 1.71 | 0.70 | 0.85 | 1.710 | 1.408 | 45.60 | 31.80 |
| 7 | Freezer | 543.59 | 233.8 | 3.10 | 0.75 | 0.85 | 3.100 | 2.735 | 41.43 | 31.80 |
| 8 | Grinder | 445.37 | 234.9 | 2.40 | 0.79 | 0.85 | 2.400 | 2.231 | 37.83 | 31.80 |

Table 6. Calculation results capacitor required to raise pf value

| No | Load | S1 (VA) | Q1 (VAR) | S2 (VA) | Q2 (VAR) | $\Delta Q = Q2 - Q1$ (VAR) | C (μF) |
|----|------|---------|----------|---------|----------|----------------------------|---------------|
| 1 | Fan | 47.02 | 39.27 | 30.42 | 16.03 | - | 23.24 |

| | | | | | | | | |
|---|------------|--------|--------|--------|--------|---|--------|------|
| 2 | Solder | 32.91 | 19.75 | 30.98 | 16.32 | - | 3.43 | 0.20 |
| 3 | Water pump | 282.78 | 169.67 | 266.14 | 140.20 | - | 29.47 | 1.72 |
| 4 | Iron | 425.33 | 255.20 | 400.31 | 210.88 | - | 44.32 | 2.58 |
| 5 | Mixer | 677.73 | 406.64 | 637.86 | 336.02 | - | 70.62 | 4.12 |
| 6 | Blender | 401.17 | 286.49 | 330.37 | 174.03 | - | 112.46 | 6.51 |
| 7 | Freezer | 724.78 | 479.40 | 639.51 | 336.88 | - | 142.51 | 8.30 |
| 8 | Grinder | 563.76 | 345.65 | 523.97 | 276.02 | - | 69.63 | 4.02 |

Table 5 and Table 6 show the calculation results of the real loads studied. Various types of loads have different power values and power factor values. From the above calculations, the next step is to measure the real installed capacitor to get the desired $\cos \phi$ value of 0.85. The results of this real load measurement are shown in Table 7. After the measurement, the measurement results are compared with the calculation results to get the Mean Absolute Error (MAE) value. By using equation (11), the MAE value is obtained, as shown in Table 7.

Table 7. Calculation and measurement results of capacitor required

| No | Equipment | Power (W) | V | C (μ F) Calc | C (μ F) Measur | error measur (%) |
|---------|------------|-----------|--------|-------------------|---------------------|------------------|
| 1 | Fan | 25.86 | 235.10 | 1.339 | 1.430 | 6.350 |
| 2 | Solder | 26.33 | 235.10 | 0.198 | 0.212 | 6.783 |
| 3 | Water pump | 226.22 | 233.70 | 1.718 | 1.810 | 5.070 |
| 4 | Iron | 340.27 | 233.70 | 2.584 | 2.780 | 7.034 |
| 5 | Mixer | 542.18 | 233.70 | 4.118 | 4.320 | 4.674 |
| 6 | Blender | 280.82 | 234.60 | 6.507 | 7.130 | 8.735 |
| 7 | Freezer | 543.59 | 233.80 | 8.303 | 8.920 | 6.917 |
| 8 | Grinder | 445.37 | 234.90 | 4.019 | 4.250 | 5.440 |
| Sum | | | | | | 51.002 |
| Average | | | | | | 8.500 |

In Table 7, there appears to be a difference in the value of the installed capacitor by calculation and measurement. From both values, it is known that there is a difference. The difference value can be obtained by calculating the MAE value. The MAE value above is 8.5%. When viewed in the table and Figure 11, the difference between the calculation value and the measurement value is not too far. But it can be seen that at a rather high power, namely the freezer load and the initial $\cos \phi$ value is low, the value of the capacitor that must be installed is 8,920 μ F.

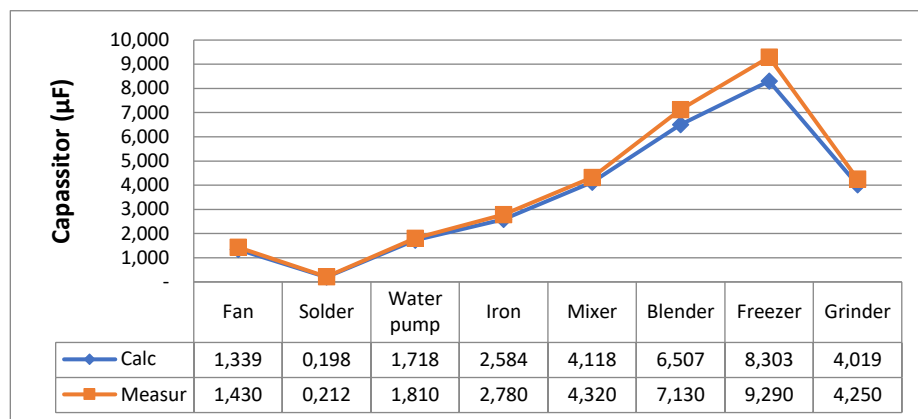


Figure 11. Comparison of $\cos \phi$ calculation and measurement results

The next analysis is using FIS by entering the initial power and $\cos \phi$ measurement numbers in the FIS variable. By entering the initial power measurement numbers and initial $\cos \phi$, the fuzzification process has been carried out. With the initial power and $\cos \phi$ numbers in the FIS Membership Function (MF), results of calculating the value of the capacitor that must be installed will be obtained. The calculation value obtained from this FIS will be compared with the measurement value using the MAE method. Results calculations using FIS and its MAE value can be seen in table 8.

Table 8. Results of calculation and measurement of capacitors needed using FIS

| No | Equipment | Power (W) | V | C (µF) Measurement | C (µF) FIS Calculation | FIS error Measurement (%) |
|---------|------------|-----------|--------|--------------------|------------------------|---------------------------|
| 1 | Fan | 25.86 | 235.10 | 1.430 | 1.390 | 2.878 |
| 2 | Solder | 26.33 | 235.10 | 0.212 | 0.208 | 4.072 |
| 3 | Water pump | 226.22 | 233.70 | 1.810 | 1.770 | 2.260 |
| 4 | Iron | 340.27 | 233.70 | 2.780 | 2.710 | 2.583 |
| 5 | Mixer | 542.18 | 233.70 | 4.320 | 4.177 | 3.424 |
| 6 | Blender | 280.82 | 234.60 | 7.130 | 6.890 | 3.483 |
| 7 | Freezer | 543.59 | 233.80 | 8.920 | 9.290 | 3.983 |
| 8 | Grinder | 445.37 | 234.90 | 4.250 | 4.180 | 1.675 |
| Sum | | | | | | 24.357 |
| Average | | | | | | 4.060 |

Table 8 shows that the value of the FIS calculation results with the measurement results has a slight difference. Therefore, each type of load has a different error value. In total, the 8 types of loads have an MAE value of 4.060%. This value is better when compared to the MAE value without using FIS. The comparison of MAE values between calculations using non-FIS and FIS against measurement results is shown in Figure 12. As for the comparison of the installed capacitor value of non FIS calculation results, FIS and measurement results can be seen in Figure 13.

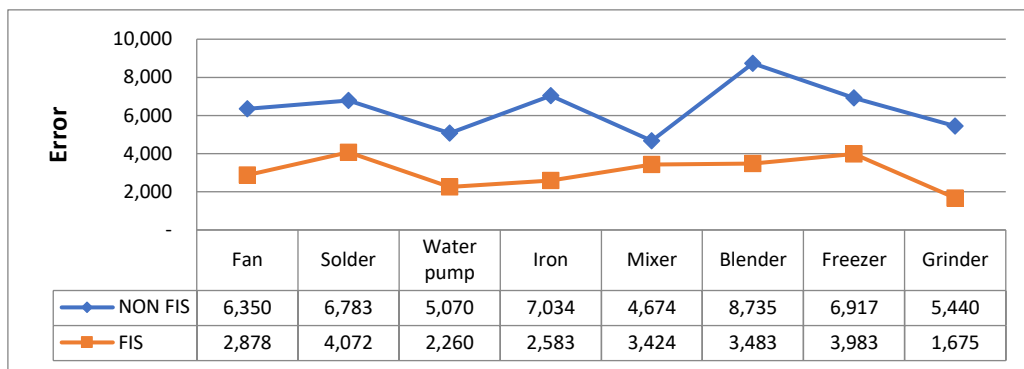


Figure 12. Comparison of MAE values between calculations using non FIS and FIS

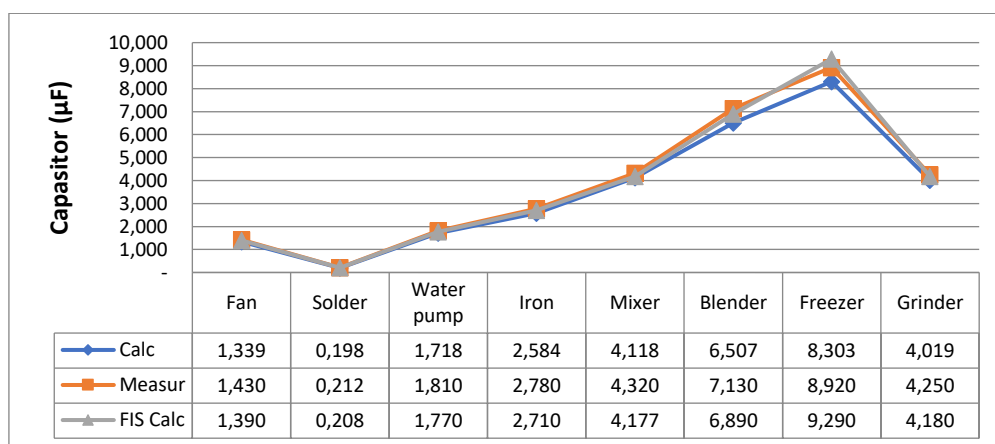


Figure 13. Comparison of calculated value of non-FIS installed capacitors, FIS, and measurement results

In Figure 13, there appears to be an up-and-down movement of the calculation value and the measurement value of the installed capacitor. This is caused by the amount of power passing through and the amount of initial $\cos \phi$. If the load requires a large amount of power to operate, the capacitor required is higher. Likewise, if the load value has a low ϕ value, the capacitor installed is also higher. The next thing to do is to send data remotely. This remote data transmission is done using the IoT. Using the IoT, the measurement value on the load will be broadcast by Blynk and received by an Android cell phone or any form of server. The measurement results appear on the Android cell phone as seen in Figure 14.

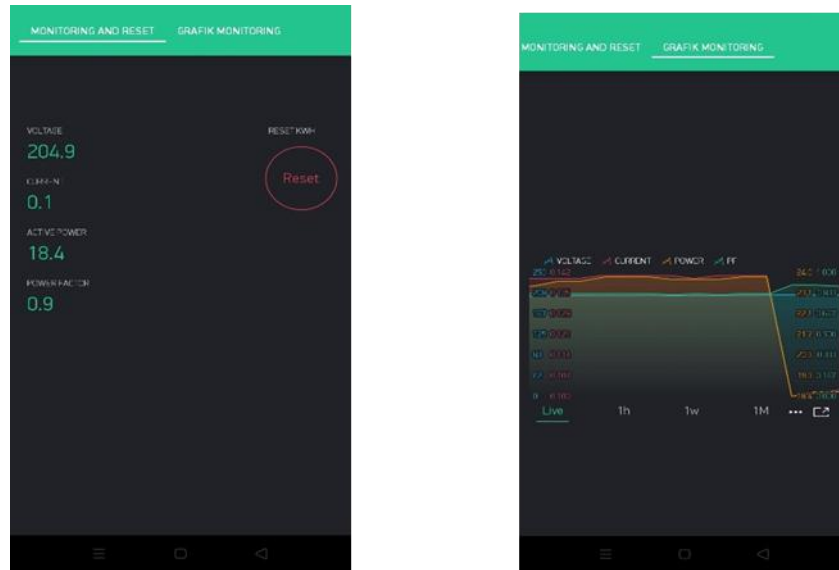


Figure 14. Display of calculation results on android

This display of remote measurement results from using the IoT on the system. The IoT will send a signal to an Android phone or server or whatever. The variables sent consist of voltage, current, active power, and power factor. The purpose of using the IoT is to provide information to interested parties to get information on how much the power factor is in the system, so that if there is an abnormality, action can be taken immediately.

In software testing, data transmission testing is carried out to determine the effectiveness of mobile phones to send data carried out by devices attached to the system. Several brands of mobile phones have been tried to receive information from data sending devices. The data obtained is as in Table 9. In table 9, it is concluded that several brands of mobile phones have been able to receive data transmission from the sending device. All brands of cell phones can be connected properly.

Table 9. Data transmission distance test result

| No. Test | Smartphone | Distance | Connectivity |
|----------|-------------|----------|--------------|
| 1 | Inflix x692 | 2.5 km | connected |
| 2 | Realme 3 | 7.1 km | connected |
| 3 | OPPO F5 | 53 km | connected |

IV. CONCLUSION

Several conclusions are drawn based on the test and measurement results as carried out above. If the calculation analysis is carried out with fixed power while the initial $\cos \phi$ value changes, the calculation results will show that the better the initial $\cos \phi$, the value of the capacitor to be installed will decrease. For the results of measurements taken to obtain the value of capacitors that must be installed to improve the $\cos \phi$ value with the results of calculations without using FIS is not much different. In this section, the Mean Absolute Error value is 8.500%.

Meanwhile, the measurement results and the calculation of the capacitor that must be installed to improve $\cos \phi$ by using FIS has a Mean Absolute Error value of 4.060%. From these data, the calculation of the installed capacitor value using FIS and not using FIS can be concluded. The former has a smaller Mean Absolute Error value. This means that using FIS calculations is good enough to be applied to automatic power factor ($\cos \phi$) improvement tools.

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