JURNAL ECOTIPE
Electronic, Control, Telecommunication, Information, and Power Engineering

Volume 11, Issue 1, April 2024, pp. 10-18
ISSN 2355-5068 ; e-ISSN 2622-4852
DOI: 10.33019/jurnalecotipe.v11i1.4361

Design of Automatic Power Factor Correction for Optimization of Electric Energy Consumption

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ARTICLE INFO

Article historys:

Received : 24/08/2023
Revised : 08/09/2023
Accepted : 01/04/2024

Keywords:

Power Factor; Capacitor; Optimization; Automatic

ABSTRACT

Electrical energy is a major human need which, when viewed from its main source, namely fossil energy, will be increasingly depleted. There needs to be an effort to utilize electrical energy more optimally. The problem discussed in this research is the decrease in power factor. The State Electricity Company (PLN) has a minimum power factor standard above 0.85 which is found in the SPLN 70-1 regulation and PERMEN ESDM No. 09 of 2011. If the power factor is below the minimum limit, it will result in losses, because consumers have to pay for excess Kilo Volt Ampere Reactive Hours (kVARh). Power factor drops are caused by the use of inductive loads. With automatic power factor correction, the poor power factor due to the use of inductive loads will be resolved and optimization of the use of electrical energy can be achieved. The author tests the tool with an experimental method. From the test results conducted using 3 cumulative loads, the worst power factor value before PF repair by the system is 0.38 and after PF repair by the best power factor system reaches 0.99 and the active power value and apparent power after PF repair is almost the same (comparable) and it can be said that there is an optimization of the use of electrical energy in this study.

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1. INTRODUCTION

Electrical energy is an energy that cannot be separated in human life in this modern era. The need for electrical energy will continue to increase over time, while the current fossil energy will decrease and even run out. Efforts are needed to be able to utilize electrical energy more efficiently [17].

Power quality is the parameter of an electric power system performing its duties reliably as seen from the constant voltage, current and frequency in accordance with its nominal value. Electrical power quality is a very important thing to consider in an effort to save electrical energy. Non-linear electrical loads become a factor that can affect power quality. Non-linear loads are loads whose output waveforms are not comparable in each half cycle so that the output voltage and current waves are not the same as the input wave or distorted. Problems that occur in electrical power quality are voltage drops, voltage swells, transients, harmonics, voltage distortion, flicker, voltage imbalance, frequency deviation, outages and power factor drops [14].

In an electric power system, Power factor (PF) can cause losses if the PF value decreases. The disadvantage for consumers if PF decreases is that the system voltage drops, the supply of electric power cannot be maximized. The State Electricity Company (PLN) has a minimum standard of power factor value that is above 0.85 which is found in SPLN 70-1 regulations and PERMEN ESDM No. 09 of 2011. If the power factor is less than 0.85, consumers will bear the payment of excess usage of Kilo Volt Ampere Reactive Hours (kVARh) with a cost per kVARh of Rp 1,444.70. Many household activities to

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large industries that use inductive loads in the form of electrical machinery, such as motors that can cause inductive reactive power which causes a low or poor power factor below the standards set by PLN. By improving the power factor to more than 0.85, the excess kVARh does not need to be paid and also the consumption of electric power by the load will be reduced or the consumption of electrical energy will be more optimal [5].

Inductive load is a load that has an element of wire winding in it. With the increase in inductive load, reactive power will also increase its use and can affect the quality of electrical power, especially power factor. One way to be able to reduce reactive power caused by the use of inductive loads is to compensate for reactive power. Capacitors are capacitive loads that can reduce reactive power on inductive loads. It is necessary to use capacitors so that the use of electric power to load needs is more appropriate [3].

Many jobs cannot be done effectively and efficiently if using manual methods in doing their work. Technology is needed in achieving maximum work results, including in an effort to optimize the use of electrical energy. The use of technology to be able to optimize the use of electrical energy is to make it easier for people to obtain load data when running and in this case make an automatic system on the power factor repair tool so that it no longer uses the manual method to add capacitors needed in power factor repair. Microcontroller is one of the tools that can be used as a system controller automatically. Based on the above problems, research was conducted to be able to help solve the problem with the title "Designing Automatic Power factor Correction Based on Microcontroller for Optimizing Electric Energy Consumption". By using this microcontroller capacitor bank as a power factor repair is expected to be able to work automatically to adjust the load used in achieving the desired power factor.

2. RESEARCH METHOD

System modeling begins with a design block diagram, power factor improvement process, schematic circuit of the tool and determination of the range of capacitor values for system improvement as follows:

2.1. Design Block Diagram

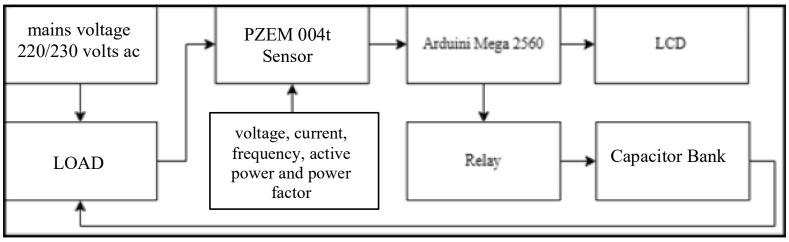

Figure 1. Design Block Diagram

The Design Block Diagram explains the location of the Input - Process - Output design. Starting from the input which is a 220/230 Volt AC voltage source and also the load that will be carried out to improve the power factor. Then in the process section is the arduino which is the core of the system that can run automatically or that regulates the work of the PZEM 004t sensor, relay and LCD, there is also a PZEM 004t sensor that detects current, voltage, active power, frequency, power factor on the load, relay as a component that can connect the capacitor bank to the system to improve the power factor. And at the output there is an LCD that displays the PZEM 004t sensor reading data before and after repairing the power factor, and there is also the load itself which experiences the impact of changes in power factor.

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2.2. Power Factor Improvement Process Flowchart

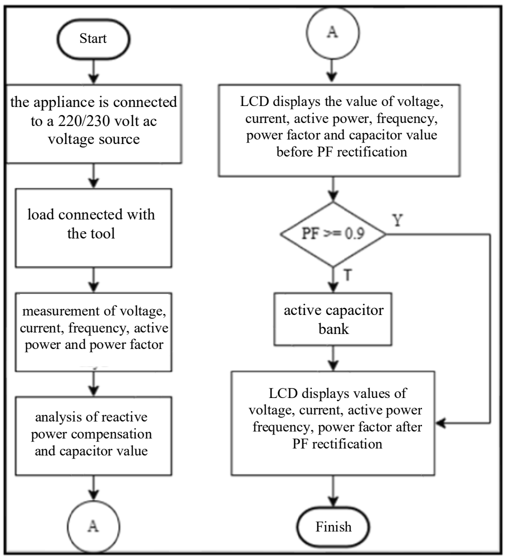

Figure 2. Power Factor Improvement Process Flowchart

The first stage is to connect the automatic power factor correction tool with an AC 220/230 Volt voltage source so that it can be activated, the second stage is to connect the load with the automatic power factor correction tool, the third stage is the system on the automatic power factor correction tool will take measurements of voltage, current, active power, frequency and power factor, the fourth stage is the system will analyze reactive power compensation and the value of capacitors used in power factor improvement, The fifth stage LCD 1 on the tool will display the value of voltage, current, active power, frequency, power factor and the value of capacitors needed for power factor correction with information before PF repair, The sixth stage if the power factor ≥ 0.9 then LCD 2 will immediately display the value of voltage, current, active power, frequency and power factor, but if the power factor < 0.9 then the capacitor bank will be activated, The seventh stage LCD 2 will display the value of voltage, current, active power, frequency and power factor that has been more than 0.9 after the capacitor bank is activated, Finish.

2.3. Schematic Circuit

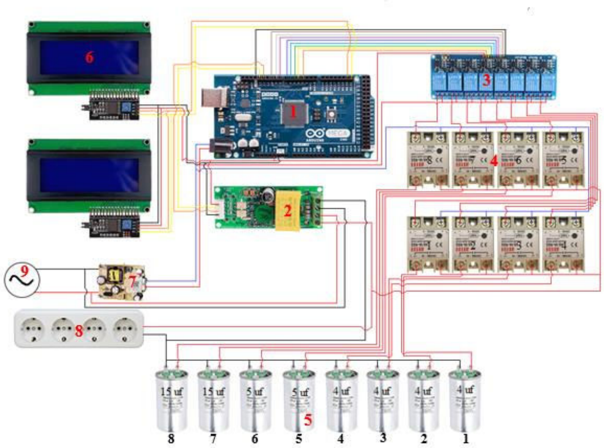

Figure 3. Schematic Circuit

Description: (1)Arduino Mega 2560, (2) PZEM 004T, (3) 8 Channel Electromagnetic Relay, (4) SSR Relay, (5) Capacitor, (6) LCD 20 x 4 with I2C, (7) Adapter, (8)Contact Stop, (9) Voltage Source 220/230 AC

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2.4. Range Nof repair capacitor values

Table 3. Range Nof repair capacitor values

Desired Capacitor Value	System Capacitor Value
3 – 3.99 μF	4 μF
4 – 4.99 μF	5 μF
5 – 5.99 μF	8 μF
6 – 7.99 μF	8 μF
8 – 9.99 μF	10 μF
10 – 11.99 μF	12 μF
12 – 13.99 μF	14 μF
14 – 15.99 μF	15 μF
16 – 17.99 μF	18 μF
18 – 19.99 μF	20 μF
20 – 21.99 μF	22 μF
22 – 23.99 μF	23 μF
24 – 25.99 μF	25 μF
26 – 27.99 μF	27 μF
28 – 30.99 μF	30 μF
31 – 33.99 μF	33 μF
34 – 36.99 μF	36 μF
37 – 39.99 μF	39 μF
40 – 42.99 μF	42 μF
43 – 46.99 μF	46 μF
47 – 50.99 μF	51 μF
51 – 56 μF	56 μF

Table 3 above is the range of repair capacitor values that work on the system given input to the microcontroller as the brain of the system. The system capacitor value is the summation value of the parallel capacitors available in the system.

3. RESULTS AND DISCUSSION

3.1. Tool Description

Designing Automatic Power Factor Correction Based on Microcontroller to Optimize Electric Energy Consumption is a method applied to the form of a tool used to improve the power factor or power factor on inductive loads with the aim of increasing the effectiveness of the use of electrical energy. This power factor improvement tool will be active when the plug connected to the component circuit on the panel box is connected to a 220/230 Volt AC power source, the adapter contained in the tool will convert AC voltage to DC to activate electronic components that use DC voltage. The main brain of the system is arduino mega 2560 and the main data reading sensor is pzem 004t. When the load is connected to the terminal on the device, the system will read the data then LCD 1 will display the value of voltage, current, active power, frequency, power factor and the value of the capacitor needed to improve the power factor. The system will activate the relay according to the known and required capacitor value. LCD 2 will display the value of voltage, current, active power, frequency and power factor that has been improved.

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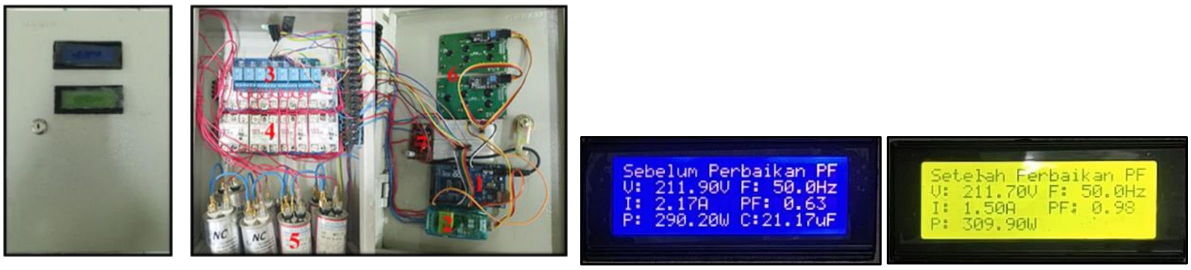
3.2. Overall Tool Display



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

Figure 4. Tool and LCD Display

Front view and (b) Inside view. On the inside view there are system components, namely (1) arduino mega 2560, (2) pzem004t sensor, (3) 8 channel electromagnetic relay, (4) solid state relay, (5) capacitor, (6) lcd 20 x 4 with I2C, (7) adapter.(c) LCD 1 reading results before power factor improvement (d) LCD 2 reading results after power factor improvement. On LCD 1 the range of power factor values that can be displayed is 0 - 0.9 while LCD 2 the range of power factor values that can be displayed is 0.9 - 1. On the LCD 1 display, the reading results before the power factor repair are displayed the value of voltage (V), current (I), active power (P), frequency (f), power factor (Pf) and the capacitor needed for repair (C). On the LCD display 2 the reading results after the power factor repair are displayed the value of voltage (V), current (I), active power (P), frequency (f), power factor (Pf). The automatic power factor correction tool can work well because LCD 1 and 2 can display the power factor value according to the range of power factor values and there is an improvement in the power factor displayed on LCD 2.

3.3. Data Collection

Table 4. System Test Results with Systematic Cumulative Load

No	Cumulative Load	Before PF Improvement					After PF Improvement					Capacitor	
		Power factor	Power (W)	Voltage (V)	Current (A)	Frequency (Hz)	*Power factor*	Power (W)	Voltage (V)	Current (A)	Frequency (Hz)	Measurable (µF)	Available (µF)
1	Electric Drill (550W) + Grinding (400W) + Ice Crusher (300W)	-	-	-	-	-	0.94	655.82	230.64	3	50	-	-
2	Grinding (400W) + Ice Crusher (300W) + Water Pump (200W)	0.86	620.7	230.6	3.13	50	0.94	630.22	230.43	2.91	50	14.5	15
3	Ice Crusher (300W) + Water Pump (200W) + Water Pump (125W)	0.66	528.7	230.7	3.45	50	0.96	538.04	231.15	2.42	50	29.32	30
4	Water Pump (200W) + Water Pump (125W) + Induction Motor (125W)	0.6	395.9	231.8	2.85	50	0.97	410.83	232.41	1.82	50	26.5	27
5	Water Pump (125W) + Induction Motor (125W) + Fan (55W)	0.67	311	230.2	2.01	50	0.98	310.39	230.33	1.37	50	16.81	18

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No	Cumulative Load	Before PF Improvement					After PF Improvement					Capacitor	
		Power factor	Power (W)	Voltage (V)	Current (A)	Frequency (Hz)	*Power factor*	Power (W)	Voltage (V)	Current (A)	Frequency (Hz)	Measurable (μF)	Available (μF)
6	Induction Motor (125W) + Fan (55W) + Fan (45W)	-	-	-	-	-	0.96	242.11	228.78	1.1	50	-	-
7	Fan (55W) + Fan (45W) + TL Lamp Ballast (36W)	0.82	142	238.1	0.73	50	0.98	141.14	237.9	0.6	50	3.94	4
8	Fan (55W) + Fan (45W) + TL Light Ballast (18W)	0.84	131.9	228.3	0.69	50	0.99	130.84	227.7	0.58	50	3.59	4
9	Ice Crusher (300W) + Water Pump (125W) + TL Lamp Ballast (36)	0.69	393.8	223.1	2.56	50	0.98	397.58	223.7	1.82	50	21.33	22
10	Ice Crusher (300W) + Water Pump (125W) + TL Lamp Ballast (18)	0.6	381.5	228.6	2.79	50	0.97	391.28	228.96	1.76	50	26.41	27
Average		0.72	363.18	230.17	2.28	50	0.97	384.83	230.2	1.74	50	-	-

In systematic cumulative load testing, the range of power factor values obtained before PF improvement is carried out by the system is 0.6 - 0.86, after PF improvement the range of power factor becomes 0.94 - 0.99. The range of active power values obtained before PF improvement is performed by the system is 142.7 - 620.7 Watt, after PF improvement the range of active power values becomes 141.14 - 630.22 Watt. The voltage value range obtained before PF rectification is performed by the system is 223.1 - 238.1 Volts, after PF rectification the voltage value range becomes 223.7 - 237.9 Volts. The range of current values obtained before PF repair is performed by the system is 0.69 - 3.45 Amperes, after PF repair the range of current values becomes 0.58 - 2.91 Amperes. The range of capacitor values measured by the system for PF repair is 3.59 - 29.32 μF. From the cumulative load testing it can be systematically concluded that the greater the power required by the load, the greater the current, but the power factor also greatly affects the power and current generated.

Table 5. Percentage Increase in Power factor Efficiency Value of Cumulative Load Testing Systematically

Cumulative Load	Before improvement Power factor	After improvement Power factor	Increase in Power factor Efficiency Value
Electric Drill (550W) + Grinding (400W) + Ice Crusher (300W)	-	0.94	0
Grinding (400W) + Ice Crusher (300W) + Water Pump (200W)	0.86	0.94	8.51 %
Ice Crusher (300W) + Water Pump (200W) + Water Pump (125W)	0.66	0.96	31.25 %
Water Pump (200W) + + Water Pump (125W) + Induction Motor (125W)	0.6	0.97	38.14 %
Water Pump (125W) + Induction Motor (125W) + Fan (55W)	0.67	0.98	31.63 %
Induction Motor (125W) + Fan (55W) + Fan (45W)	-	0.96	0
Fan (55W) + Fan (45W) + TL Lamp Ballast (36W)	0.82	0.98	16.32 %
Fan (55W) + Fan (45W) + TL Light Ballast (18W)	0.84	0.99	15.15 %
Ice Crusher (300W) + Water Pump (125W) + TL Lamp Ballast (36)	0.69	0.98	29.59 %
Ice Crusher (300W) + Water Pump (125W) + TL Lamp Ballast (18)	0.6	0.97	38.14 %

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Table 6. Percentage Decrease in Electric Current Value of Systematic Cumulative Load Testing

Cumulative Load	Before repair Current (Ampere)	After repair Current (Ampere)	Electrical Current Impairment
Electric Drill (550W) + Grinding (400W) + Ice Crusher (300W)	-	3	0
Grinding (400W) + Ice Crusher (300W) + Water Pump (200W)	3.13	2.91	7.03 %
Ice Crusher (300W) + Water Pump (200W) + Water Pump (125W)	3.45	2.42	29.85 %
Water Pump (200W) + + Water Pump (125W) + Induction Motor (125W)	2.85	1.82	36.14 %
Water Pump (125W) + Induction Motor (125W) + Fan (55W)	2.01	1.37	31.84 %
Induction Motor (125W) + Fan (55W) + Fan (45W)	-	1.1	0
Fan (55W) + Fan (45W) + TL Lamp Ballast (36W)	0.73	0.6	17.8 %
Fan (55W) + Fan (45W) + TL Light Ballast (18W)	0.69	0.58	15.94 %
Ice Crusher (300W) + Water Pump (125W) + TL Lamp Ballast (36)	2.56	1.82	28.9 %
Ice Crusher (300W) + Water Pump (125W) + TL Lamp Ballast (18)	2.79	1.76	36.91 %

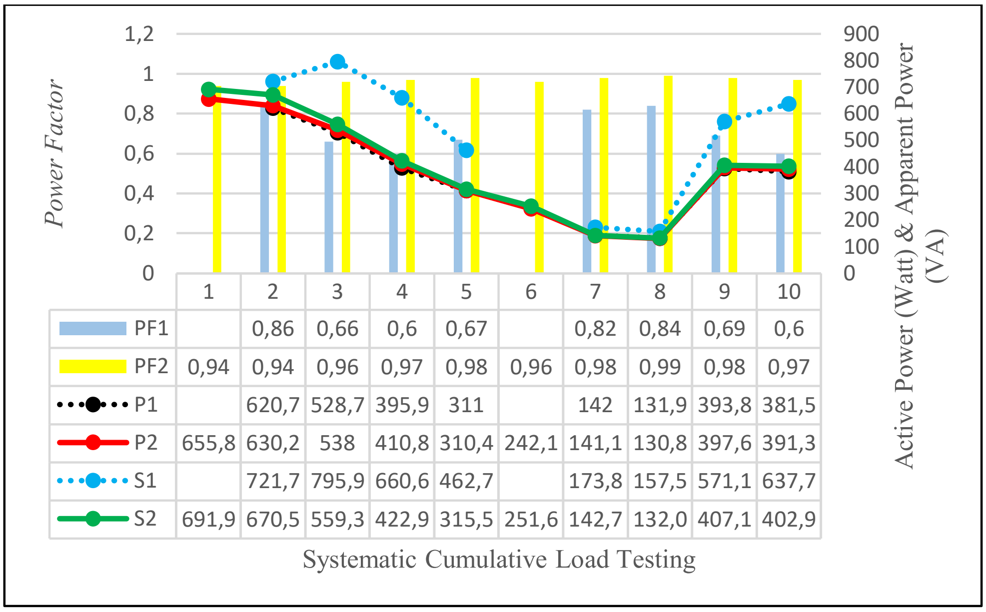

Figure 5. Comparison Chart of Power Factor, Active Power and Apparent Power Before and After Power Factor Improvement at Systematic Cumulative Load

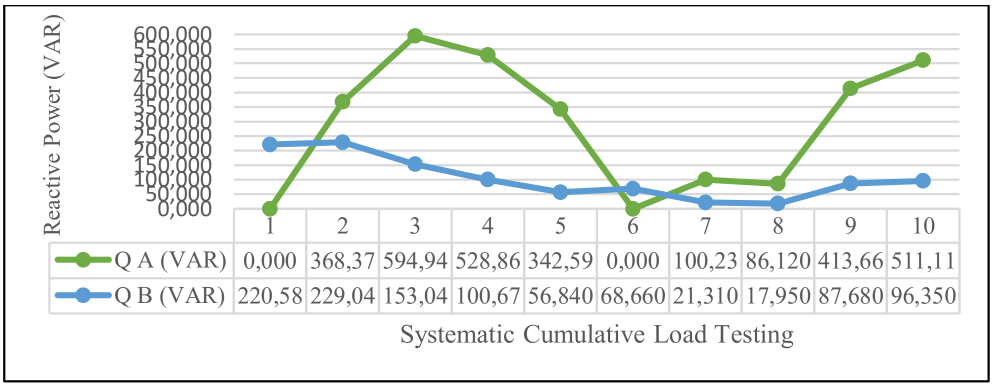

Figure 6. Comparison Chart of Reactive Power Before and After Systematic Cumulative Load Power Factor Improvement

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In Figure 5, the initialization (PF1, P1 and S1) respectively is the power factor, active power and apparent power before the power factor improvement in the system and the initialization (PF2, P2, and S2) respectively is the power factor, active power and apparent power after the power factor improvement in the system. Figure 5 is a comparison graph of power factor, active power and apparent power before and after power factor improvement in the system. It can be seen that after the power factor increases, the apparent power and active power are almost the same (comparable), meaning that the apparent power which is the power generated or the source power obtained from PLN can be used by inductive loads, namely the active power optimally. In Figure 5 there are also empty values (PF1, P1 and S1) because there is no improvement in power factor because the power factor is good or above the standard that has been determined in the system, namely 0.9. In Figure 6, the initialization (Q A) is reactive power before power factor improvement and (Q B) is reactive power after power factor improvement by the system. Figure 6 is a comparison graph between reactive power before and after power factor improvement. From the graph it can be concluded that capacitor compensation has occurred in each cumulative load test. With this, the capacitor helps the power source to produce reactive power used by loads.

4. CONCLUSION

Based on the results of research that has been carried out in optimizing electrical energy consumption using a microcontroller-based automatic power factor corection tool, the following conclusions are obtained:

1. The design of an automatic power factor correction tool has been carried out which can automatically repair the power factor with commands or coding given to the brain of the system, namely the microcontroller and the use of pzem004t sensors to read the value of active power, voltage, current, frequency and power factor and LCD which is used to display the results before and after the occurrence of power factor improvement by the system, the solid state relay used has the advantage of being able to distribute capacitors on the power grid without fear of current spikes in inductive loads when the system works and also uses a panel box as a container for each component used to be safe and neat.
2. In this study, the capacitor bank has a function as a reactive power producer used for compensation in order to improve the power factor which affects the optimization of electrical energy because the capacitor is able to reduce the dependence of the electricity source (PLN) in supplying reactive power to inductive loads. Evidenced by the percentage increase in the value of power factor efficiency after improving the power factor, namely 4.04% - 59. 57% and the percentage decrease in current that occurs in inductive loads after improving the power factor, namely 1.76% - 57.38% and also the value of active power (P) becomes almost the same (comparable) with apparent power (S).
3. In this study, a microcontroller has been used as the brain of the system so that it can work automatically in performing power factor improvement. The microcontroller provides input to the pzem004t sensor to read the required value as well as instructs the relay to activate according to the needs of the capacitor used in the repair of the power factor and instructs the LCD to display the value before and after repairing the power factor.

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