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Microcontroller Based Automatic Power Factor Correction System

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Abstract

This project shows how to make an Automatic Power Factor Correction (APFC) device based on a microcontroller by using the Arduino. The goal is to raise the power factor in single phase inductive loads to more than 0.95 by using relay modules to instantly switch capacitor banks based on voltage and current readings taken in real time. The ZMPT101B voltage sensor and the ACS712 current sensor are used by the system to find the change in phase between the voltage and current waves. This information is sent to a program written in the Arduino IDE, which uses it to figure out the power factor and take appropriate action when it drops below a certain level. The results show that the system does a good job of increasing the power factor, which lowers energy waste and raises efficiency. This small, cheap, and expandable system is perfect for small scale commercial and home uses where correcting the power factor is important.

1. Introduction

These days, more and more people need electricity, so making power systems more efficient is becoming more and more important. Power factor is one of the most important things that affects how well and reliably electricity systems work. The power factor is the ratio of the useful power (real power) to the apparent power (as a whole, the power that is provided to the circuit). The best way to use electricity is to have a power factor of 1. On the other hand, many everyday electrical items, especially inductive loads like motors, transformers, and fluorescent lights, cause the current to be slower than the voltage. This is called a low power factor.

People don't want a low power factor because it means more losses in the power grid, more people using electricity, less system capability, and often extra fees from utility companies for wasteful energy use. This issue is especially clear in businesses, factories, and even homes with a lot of inductive products. Adding power factor correction methods is necessary to make the power system work better and lower its costs.

Power factor correction has usually been done with capacitor banks that are managed by hand. These methods are old and ineffective, though, because they need to be changed by a person all the time and can't adapt to changing load conditions. With the progress made in microprocessor technology, this process can now be done automatically. Microcontrollers can be set up to constantly check the electrical settings and manage capacitor banks automatically to keep the power factor in a good range which is above 0.95 .

This project is all about making an Arduino based microcontroller-based automatic power factor correction (APFC) device. For embedded applications, Arduino is picked because it is easy to use, cheap, and flexible. To make up for the reactive power, the system senses the voltage and current waveforms, figures out the power factor, and uses relays to connect or separate capacitors as needed. By automating the process, the suggested system not only raises the power factor, but it also makes the electrical system more efficient overall, which lowers energy bills. This makes it perfect for small-scale uses like schools, businesses, and homes.

2. Methodology

The microcontroller-based automatic power factor correction (APFC) system was made using an organized process that includes choosing the right parts, designing the circuit, programming it, and gathering data. The system is meant to keep an eye on the power factor of a single-phase AC load and fix it on its own if it drops below 0.95. The prototype was made and tried with fake inductive loads like fluorescent lights and table fans, which are known to have a negative power factor because they are reactive (Gupta, 2020).

An Arduino microcontroller, a ZMPT101B voltage sensor, and an ACS712 current sensor are the main tools used in this project. The voltage and current patterns are detected by these devices. Because they are accurate and work with microcontrollers. These sensors are widely used in low-cost energy tracking applications. Time difference measurements are used to figure out the phase angle between the current and voltage in the waves. This lets the power factor be found as the cosine of the phase angle. There is a relay module built in that instantly switches capacitors on and off, making up for the lagging power factor with reactive power. An LCD module shows the power factor and system state in real time, letting the user give feedback and keep an eye on things.

The first step of the project was to design the circuit and try the parts on a breadboard to make sure the sensor readings and switching worked correctly. To make sure the analog output was reliable and accurate, standard voltages and loads were used to calibrate the voltage and current sensors. The Arduino IDE was used to program the microcontroller, and a custom sketch was made to take waveform data, find the phase difference, and turn on the relay when needed. The code constantly checks the power factor and changes the switching of the capacitors to keep the power factor close to one (Singh et al., 2021).

Several types of inductive loads were used for testing to see how the system reacts to different power factor situations. For each test run, the load had to be turned on so that the Arduino could see the drop in power factor and watch as the automatic fix was made by switching capacitors. The original and corrected power factor values were shown on the LCD and saved using the Arduino serial monitor so that they could be studied further. The system's success was judged by how quickly and well it could adapt to changes in load, with the goal of getting a corrected power factor of at least 0.95.

By using this method, you can see how embedded systems can be used in energy management tasks, providing an easy and inexpensive way to make small spaces use electricity more efficiently.

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2.1 Circuit Diagram

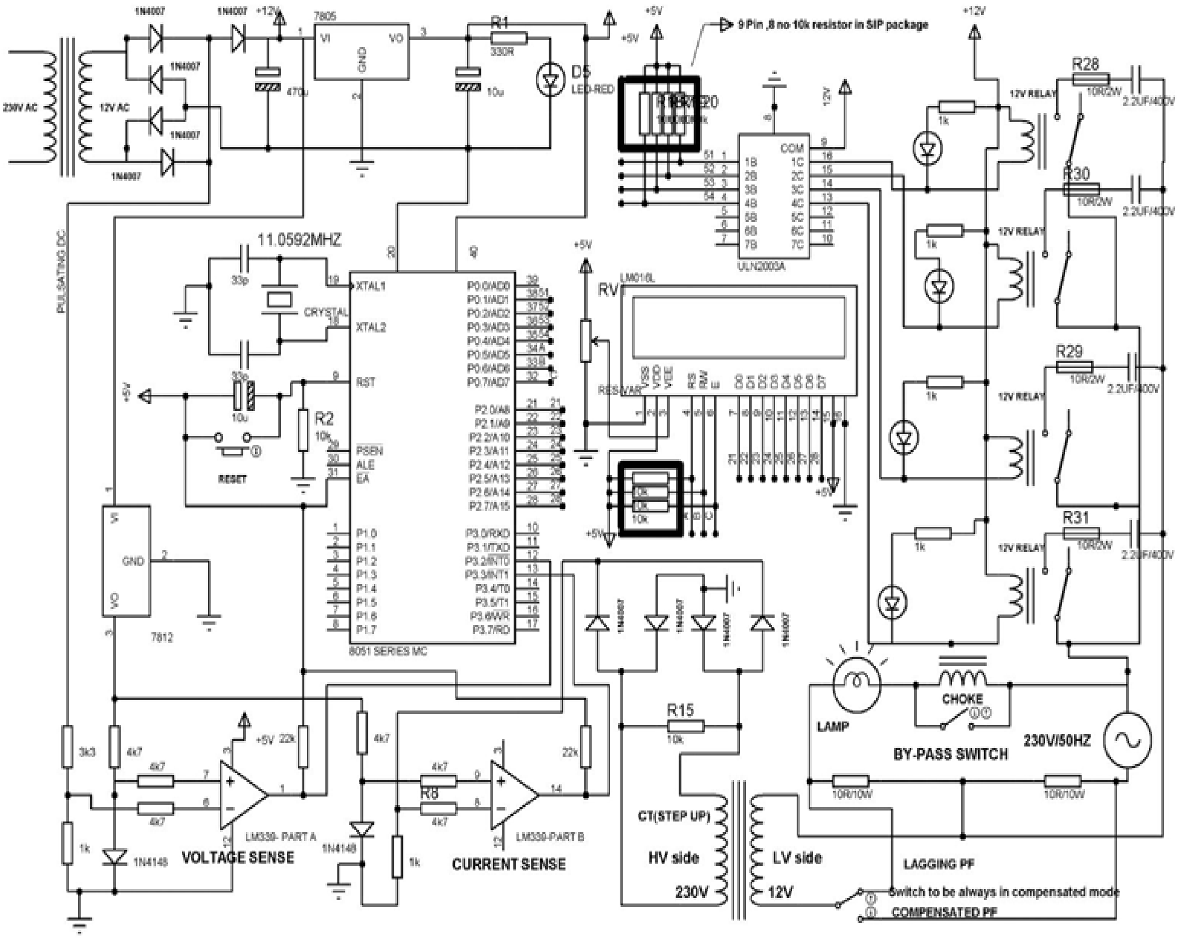

Figure 2.1 shows the circuit diagram for this project

2.2 Block Diagram

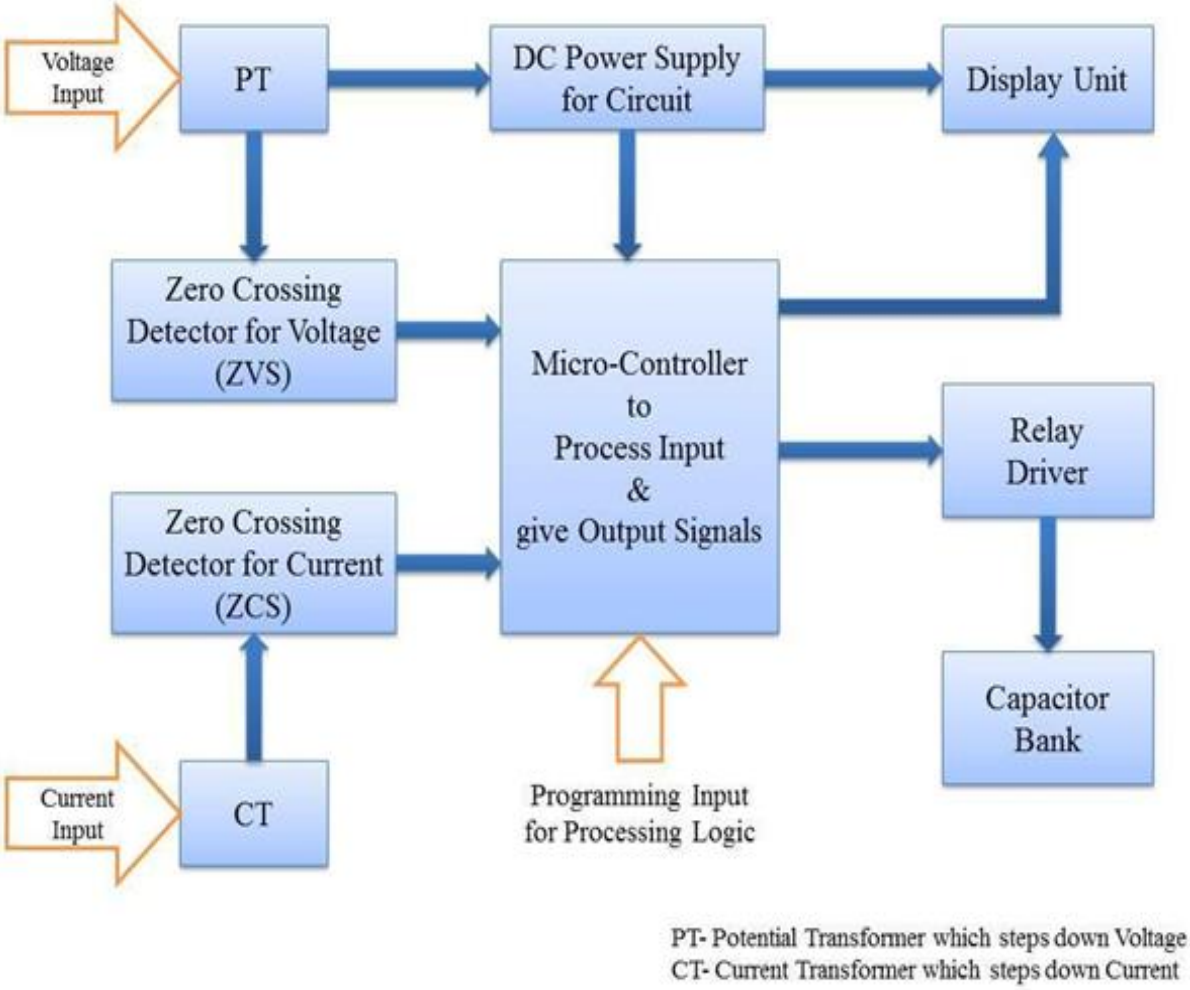

Figure 2.2 shows the block diagram of this project

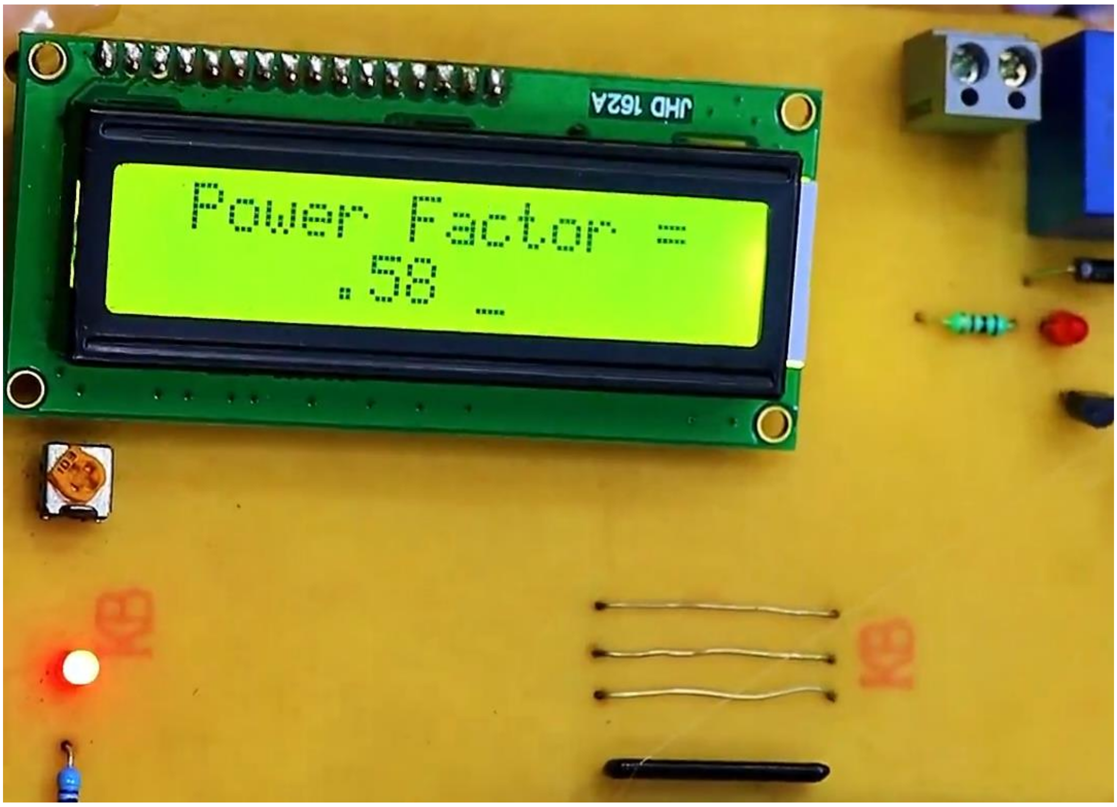

Figure 2.3 shows the power factor before the project on

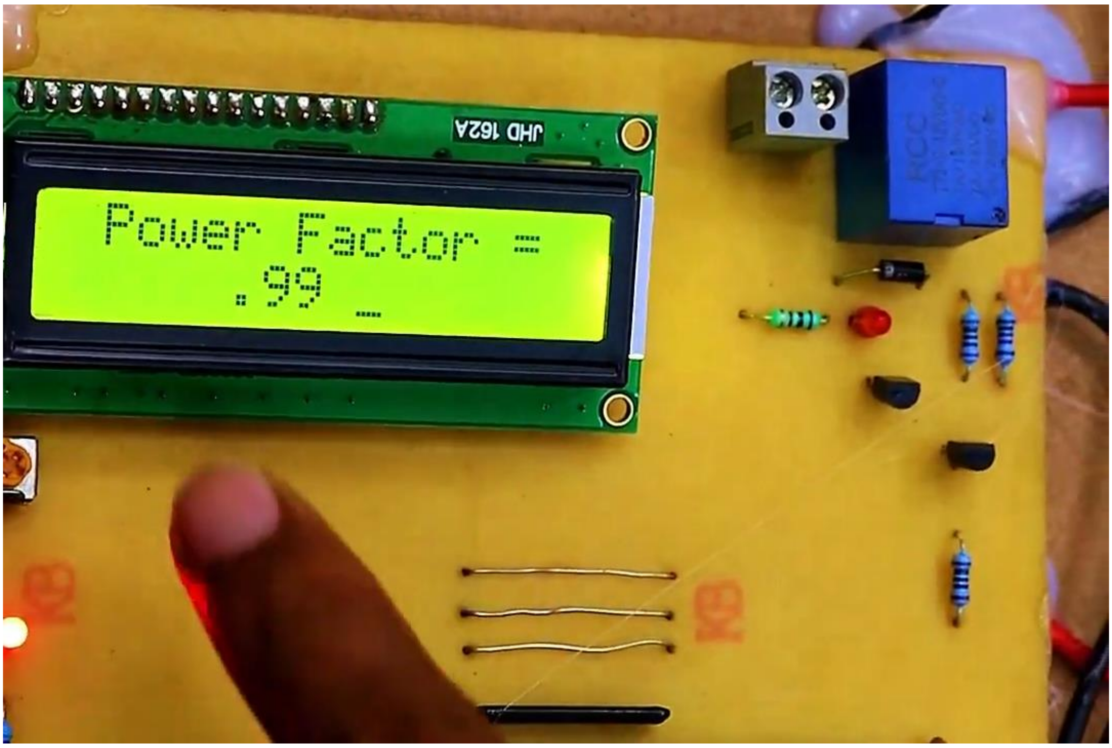

Figure 2.4 shows the power factor after the project on

3. Results and Discussion

The automatic power factor correction system was evaluated under various inductive load conditions to assess its effectiveness. Initial measurements indicated a low power factor due to lagging current, which is commonly observed in inductive electrical loads. Once the APFC system was activated, the Arduino controller accurately detected the phase displacement between voltage and current and responded by engaging the appropriate capacitor banks. As a result, the power factor showed a significant improvement, stabilizing at approximately 0.95, which falls within an acceptable and efficient operating range. Furthermore, the system demonstrated reliable and repeatable performance throughout multiple testing cycles. The capacitor switching sequence responded effectively to load changes without causing noticeable voltage disturbances or system instability. The achieved power factor of around 0.95 confirms that the system was able to reduce reactive power flow and improve overall electrical efficiency. These results indicate that the designed APFC system is suitable for practical applications where maintaining a near-unity power factor is required. The coding used for the project in Arduino IDE is listed at the appendix.

The improvement of the power factor to approximately 0.95 highlights the effectiveness of the automatic compensation strategy employed in this project. Maintaining the power factor within this range significantly reduces reactive power demand and improves the utilization of electrical energy. Compared to uncompensated operation, the system demonstrates better efficiency and contributes to reduced losses in conductors and distribution equipment. This level of correction is generally acceptable for most industrial and commercial installations. Despite the positive results, certain factors limit the system from achieving a perfect unity power factor. Measurement inaccuracies due to sensor resolution, signal noise, and timing delays in the microcontroller can affect precision. In addition, the discrete nature of capacitor bank switching restricts fine adjustment of compensation levels. Future improvements could include higher resolution sensors, digital filtering techniques, and solid-state switching to enhance accuracy and system lifespan.

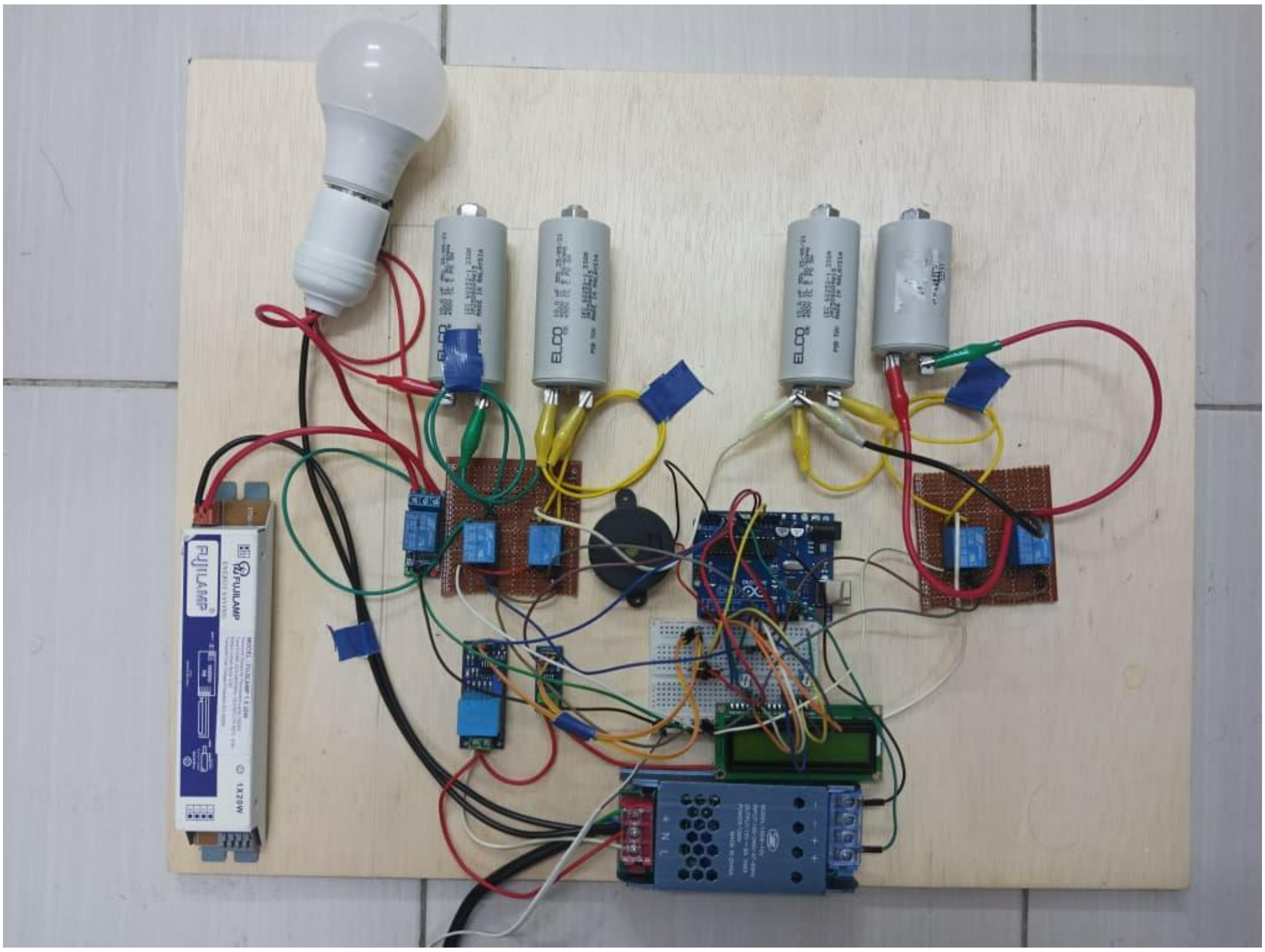

Figure 3.1 shows the complete project

4. Conclusion

This project successfully developed an Arduino based automatic power factor correction system capable of improving power factor under varying load conditions. The system effectively monitored phase differences and dynamically switched capacitor banks to compensate for inductive loads. Experimental results confirmed that the power factor was improved to approximately 0.95, demonstrating that the system meets its intended design objectives. In conclusion, the developed APFC system offers a practical, economical, and reliable solution for improving power quality in low to medium power electrical systems. The project provided valuable insights into power factor correction techniques, microcontroller control, and real-time system response. With further enhancements in sensing accuracy and switching methods, the system has strong potential for wider industrial application and performance optimization.

Acknowledgement

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