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Design and Implementation of a Microcontroller-based Automatic Power Factor Controller with Performance Analysis

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Abstract: *Efficient utilization of electrical energy is an important concern in modern power systems, where poor power factor leads to increased transmission losses, larger equipment ratings, and reduced system efficiency. This research presents a microcontroller-based automatic power factor controller designed to improve the power factor of AC loads by providing automatic reactive power compensation. The system measures voltage and current waveforms using sensing transformers and determines their phase difference through zero-crossing detection circuitry. Based on the calculated phase angle, the embedded microcontroller computes the power factor and activates suitable capacitor banks through relay switching mechanisms to achieve compensation. The controller operates dynamically, responding to load variations in real time and maintaining the power factor within a desired range. The hardware prototype developed for this study demonstrates stable and accurate performance under different inductive load conditions. Results indicate that the proposed system effectively improves the power factor, minimizes reactive power demand, and contributes to enhanced energy efficiency and reduced electricity costs. The system is suitable for industrial, commercial, and institutional power management applications..*

Keywords: *Efficient utilization*

I. INTRODUCTION

In modern electrical power systems, efficient utilization of electrical energy is essential for reducing operational costs and improving system performance. One of the major factors affecting electrical efficiency is power factor, which represents the phase relationship between voltage and current in an AC circuit. Ideally, the power factor should be close to unity; however, in practical systems, inductive loads such as induction motors, transformers, fluorescent lamps, and industrial machinery cause the current to lag behind the voltage, resulting in a low power factor. Low power factor leads to several disadvantages, including increased line current, higher copper losses, poor voltage regulation, reduced system efficiency, and larger kVA ratings of electrical equipment. Additionally, utility companies often impose penalty charges on industrial consumers operating with poor power factor due to the increased burden on the power distribution network. Traditional methods of power factor correction involve manually switching capacitor banks based on load conditions. These methods are inefficient, time-consuming, and unsuitable for systems where load varies dynamically. To overcome these limitations, automatic power factor correction systems have been developed that can continuously monitor system power factor and provide real-time compensation. This research focuses on the design and implementation of a microcontroller-based automatic power factor controller (APFC) that automatically measures the phase difference between voltage and current, calculates the corresponding power factor, and switches capacitor banks accordingly to maintain the power factor near unity. The use of a microcontroller enables precise measurement, intelligent control, and rapid response to changing load conditions. The proposed system improves energy efficiency,

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reduces reactive power demand, minimizes transmission losses, and enhances the overall reliability of the electrical network. The developed APFC system offers a low-cost, scalable, and efficient solution suitable for industrial, commercial, and institutional applications where inductive loads are predominant.

II. LITERATURE SURVEY

The data is survey to receive basic ideas and knowledge of the project topic, Automatic Power Factor Controller Panel (APFC Panel). Standard Publication International Journal of Innovations in Engineering Research and Technology [IJIERT] ISSN: 2394-3696 Volume 2, Issue 5, May 2015, the topic of Automatic Power Factor Correction published by Gopal Reddy K. This paper presents the control to correct the power factor automatically without any human presence. It automatically increases and decreases in power factor. It also helps the industries to continue even during peak hours. Different parts of the power factor contain the ripple current. Chetan Kidile, Payal Kadu Dinesh Thakare, Rushank Haral , Tejal Kadukar: From the literature survey, we've got determined that because of contemporary-day-day improvement withinside the commercial quarter the call for the strength has been multiplied extremely. There is a greater strength call for arises because of the masses in industries. An electric load may be categorized into 3 sorts and they're resistive load like filament lamp, capacitive load like motor starter.Keith Harker (1998): Power machine reliability and protection are enormously dependent on the practices hired in each commissioning and preservation process. Both ought to be to an excessive fashionable to make sure that the system does now no longer input carrier with latent deficiencies. This needs engineers who recognize the vital control worried in addition to the technical processes.

III. PROPOSED SYSTEM

The proposed system is a microcontroller-based automatic power factor controller designed to improve the power factor of AC electrical loads by providing real-time reactive power compensation. The system continuously monitors the phase difference between supply voltage and load current and automatically switches capacitor banks to maintain the power factor near unity.The system consists of voltage sensing and current sensing circuits connected to the AC supply and load. These sensing units provide scaled-down analog representations of voltage and current waveforms. The sensed signals are fed to zero-crossing detector circuits, which convert them into digital pulses corresponding to their zero-crossing instants.A microcontroller receives these pulses and calculates the time delay between voltage and current zero crossings to determine the phase angle. Based on this phase angle, the power factor is computed. If the measured power factor falls below the predefined threshold, the microcontroller activates relay-controlled capacitor banks to inject the required reactive power into the system. The capacitor banks are connected in binary or stepped combinations to provide flexible compensation levels. Relay driver circuits are used to interface the low-power microcontroller outputs with the relays controlling the capacitor banks. An LCD display may be incorporated to show real-time power factor values and capacitor bank switching status.The proposed system operates continuously and dynamically, allowing it to respond instantly to load variations. This automatic compensation mechanism reduces transmission losses, improves voltage regulation, enhances equipment efficiency, and minimizes electricity penalties due to poor power factor.

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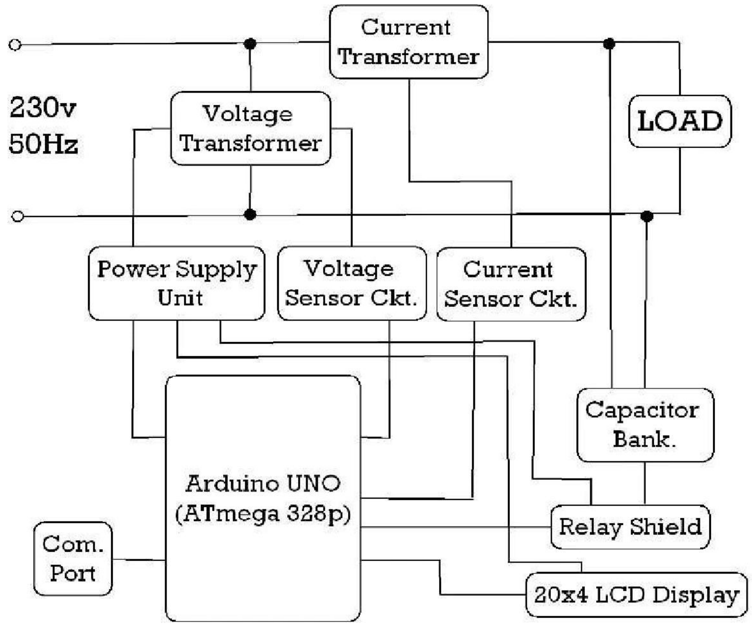

Fig3.1: Block diagram of microcontroller based automatic power factor controller

IV. HARDWARE DESCRIPTION

The hardware implementation of the proposed automatic power factor controller consists of sensing circuits, processing units, switching elements, and compensation components integrated to achieve real-time power factor correction. Each hardware component plays a crucial role in the operation of the system.

a) Arduino Uno R3: The Arduino Uno R3, based on the ATmega328P microcontroller, acts as the central controller of the system. It receives voltage and current zero-crossing signals, calculates the phase difference,determines the power factor, and controls the switching of capacitor banks.

Fig4.1: Arduino Uno R3

b) Rectifier: A rectifier is used in the power supply section of the proposed system to convert alternating current (AC) from the step-down transformer into direct current (DC) required by the electronic control circuitry. In this project, a bridge rectifier is employed to provide full-wave rectification, ensuring efficient conversion of both positive and negative half cycles of the AC input into pulsating DC output.

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Fig4.2: Rectifier

c) Relay: The relay acts as an electromechanical switching device in the APFC system. It is controlled by the Arduino microcontroller to connect or disconnect capacitor banks depending on the measured power factor. The relay provides electrical isolation between the low-voltage control circuit and the high-voltage capacitor switching circuit, ensuring safe and reliable operation of the automatic power factor correction system.

Fig4.3: Relay

d) LCD: A 16×2 LCD display is used to provide real-time visualization of system parameters such as measured power factor and capacitor bank status. It enables convenient monitoring of the APFC system during operation.

Fig4.4: LCD

e) Resistor: Resistors are used in the circuit for current limiting, voltage division, signal conditioning, and biasing of electronic components to ensure proper operation of sensing and control circuits.

Fig4.5: Resistor

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f) Capacitor Bank: The capacitor bank is used to provide reactive power compensation in the APFC system by supplying leading reactive power to the load, thereby improving the overall power factor of the electrical system.

Fig4.6: Capacitor Bank

g) Current Sensor: The current sensor is used to continuously measure the load current in the electrical circuit and generate a proportional output signal for the control system. This signal is utilized by the micro controller to determine the phase difference between voltage and current, enabling accurate calculation of power factor and appropriate capacitor bank switching.

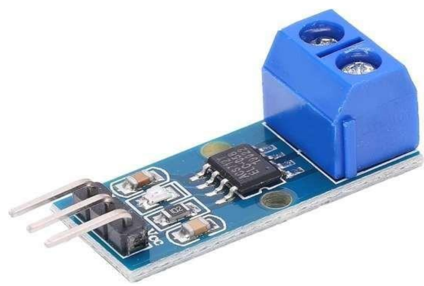

Fig4.7: Current Sensor

h) Transformer: The transformer is used to step down the AC mains voltage to a lower and safer level suitable for sensing, rectification, and powering the control circuitry. It also provides electrical isolation between the high-voltage supply and low-voltage electronic components of the APFC system.

Fig4.8: Transformer

V. ADVANTAGES

- Reduced Reactive Power Consumption – Minimizes unnecessary reactive power drawn from the supply.
- Lower Transmission Losses – Reduces line current and associated copper losses.
- Improved Voltage Regulation – Helps maintain stable voltage across the load.

- Reduced Electricity Penalties – Avoids utility charges associated with low power factor.
- Enhanced System Efficiency – Improves overall electrical system performance.
- Real-Time Compensation – Responds dynamically to varying load conditions.
- Low Maintenance – Requires minimal operator supervision after installation.
- Cost Effective – Provides economical reactive power compensation solution.
- Scalable Design – Can be adapted for larger industrial applications

VI. RESULT

The developed microcontroller-based automatic power factor controller was tested under varying inductive load conditions to evaluate its performance. Experimental observations showed that the system successfully measured the phase difference between voltage and current and automatically switched the required capacitor banks for compensation.The power factor of the test load improved significantly after compensation, demonstrating the effectiveness of the proposed APFC system in reducing reactive power demand. The system responded dynamically to load variations and maintained stable operation during continuous monitoring. The relay switching and capacitor bank control operated accurately according to the calculated power factor values.Overall, the experimental results confirm that the proposed system effectively improves power factor, reduces line current, enhances system efficiency, and provides reliable automatic compensation for inductive loads.

VII. CONCLUSION

The proposed microcontroller-based automatic power factor controller effectively improves power factor by automatically switching capacitor banks according to load conditions. It enhances system efficiency, reduces reactive power losses, and provides a reliable and cost-effective solution for power factor correction.

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