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A Simple and Cost-effective Design and Implementation of Power Factor Correction System

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ABSTRACT

This paper presents the simple and low-cost design of an automatic power factor correction (APFC) system for single phase domestic loads. The proposed design uses TRIACs to switch the capacitor banks to correct the power factor of inductive loads. TRIACs are more effective than electro-mechanical relays and hit the high-performance benchmarks. The switching of TRIACs is controlled by an Arduino board. The Arduino is programmed to non-stop monitor and calculate the power factor of the connecting load by sensing the signal from optocouplers and Zero Cross Detectors (ZCDs), and keep the power factor of the load above the reference value by appropriately energizing the capacitors in parallel to the connecting load through TRIAC switching. The values of power factor along with the current before and after improvement is displayed on LCD. The hardware prototype of the proposed APFC design is also developed to validate its operation. The satisfactory and acceptable results of the APFC system testing have confirmed that the suggested design yields a reliable output and can be further used in any single-phase practical application to ensure the power factor close to unity.

Keywords: Arduino, power factor, TRAIC, optocouplers, zero-cross detectors.

1. INTRODUCTION

In the present scenario of technological revolution, from the whole over observation it can be said that the power is very precious and becoming more and more complex with passing days. The increase in usage of inductive loads in industry will give impact to the power factor value of the system and thus due to that the efficiency of the power system decreases. Nonlinear loads will lead to a poor power factor which can disrupts the AC voltage and give poor performance to other equipment connected to the same source. The main objective of this project is an improvement of the existing AC power factor output by adding capacitance. The ideal power factor controller should produce unity power factor output. This project mainly aims the attention on the arrangement and development of power factor correction using Arduino Uno in which ATmega328 as microcontroller [1]. The power factor controller method and device are useful in improvement of the efficient transmission of active power. This PFC are popular because of their advantages such as high-power factor, fast dynamic response, and low cost. Digital PFC converters are more desirable because digital controllers have many advantages over the analog controllers due to their programmability, flexibility, no temperature and aging effect, and more resistance to the input voltage distortion. Power factor correction using capacitor banks reduces reactive power consumption which will lead to minimization of losses and at the same time increases the electrical system's efficiency [2]. Power saving issues and reactive power management has led to the development of single-phase capacitor banks for domestic and industrial applications.

1.1. POWER FACTOR IMPROVEMENT

Need for improvement Power factor correction is desirable because the source of electrical energy must be capable of supplying real power as well as any reactive power demanded by the load [2]. This can require large, more expensive power plant equipment, transmission lines, transformers, switches, etc. than would be necessary for only real power delivered. Also, resistive losses in the transmission lines mean that some of the generated power is wasted because the extra current needed to supply reactive power only serves to heat up the power lines. The electric utilities therefore put a limit on the power factor of the loads that they will supply. The ideal figure for load power factor is unity (1), that is a pure resistive load, because it requires the smallest current to transmit a given amount of real power. Real loads deviate from this ideal condition. Electric motor loads are phase lagging (inductive), therefore requiring capacitor banks to counter their inductance. Sometimes, when the power factor is leading due to capacitive loading, inductors are used to correct the power factor. In the electric industry, inductors are said to consume reactive power and capacitors are said to supply it, even though the reactive power is just moving back and forth between each AC cycle.

2. PROPOSED MODEL

This project provides continuous power factor correction without manual capacitive bank loading. The APFC controller provides power factor correction and peak current limiting for a switch-mode power converter of any topology (buck, boost, or buck-boost), without having to directly sense inductor current. The APFC control technique involves using a piecewise-polynomial analog computer to compute power transistor on-times in accordance with separate polynomial transfer functions for power-factor control and peak-current-linking using as inputs current representations of line input voltage, load output voltage, and long-term current demand. A conduction cycle is initiated by sensing when the rate of change in the inductor current reaches zero using an auxiliary winding on the current storage inductor, and terminated after the computed on-time to implement either power-factor control or peak-current-limiting.

The Reactive Power charge on your electricity bill is directly targeted against those companies who do not demonstrate clear energy efficiency use. You will find this charge itemized on electricity bill. Reactive power charges can be made significantly smaller by the introduction of Power Factor Correction Capacitors which is a widely recognized method of reducing an electrical load and minimizing wasted energy, improving the efficiency of a plant, and reducing the electricity bill. It is not always necessary to reach a power factor of 1.

A cost-effective solution can be achieved by increasing your power factor to greater than 0.95. This project uses regulated 5V, 750mA power supply. 7805 three terminal voltage regulatorsare used for voltage regulation. Bridge type full wave rectifier is used to rectify the ac output of secondary of 230/12V step down transformer.

3.1. Design

Power factor can be improved by installing especially designed PFC capacitors or reactive power generators into the electrical distribution system. These devices supplement the demand of reactive power for the operation of all inductive loads and reduce the amount of KVA drawn from the main transformer, registered on the meter as "peak demand". The capacitor draws a leading current and partly or completely neutralizes the lagging reactive component of load current. This raises the power factor of the load connected.

A high power factor output is the main goal of this paper which focuses on the design and implementation of power factor correction using Arduino Uno microcontroller, measures the power factor of loaded power system, performs proper action to feed sufficient capacitance to recover appropriate power loss using program and finally simulates the design with Arduino Uno controller chip. Program code has been written in C language.

3.2. Relationship of Capacitor with Power Factor

Capacitor is the main component that supplies capacitive reactance, which is negative reactive power. Since, the power factor is the ratio of real power and apparent power, where apparent power has the relation with reactive power and real power. As majority power system has inductive loads thus normally only lagging power factor occurs hence capacitors are used to compensate by producing leading current to the load to reduce the lagging current, thereby shrink the phase angle distance between the real power and apparent power.

In general, power capacitors shall be Y-connected on the three-phase distribution feeder. Grounding the neutral is essential for the fuses to operate in case of any event of capacitor fault. For a small ungrounded Y-connected capacitor bank, faulty capacitor would not blow the fuse to isolate faulty capacitor. Any event of this could lead to an explosion to the capacitor bank. However, isolating the neutral of the Y-connected of a capacitor bank has the advantage of reducing harmonics. The method can only be an alternative when grounding the neutral would cause operating difficulty for a

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installation. In case of insulation failure inside the unit, phase-to-ground fault can still occur to an ungrounded Y-connected capacitor bank even with its enclosure properly grounded.

The most effective solution is to insert reactors in series with each capacitor group connected between the phase wire and the neutral of a 3-phase bank. Frequency is standardized at constant 50 Hz, or 60 Hz; power factor correction is valid as a solution to such fixed network frequency, the only key solution is by addition of capacitor in shunt to the load. Capacitors are commonly used within a lot of power system, especially electronic constructed circuitry. Though common it is consequently least understood by majority as one most beneficial component for power system.

- Release of system capacity.
- Reduction of KVAR generation requirements.
- Reduction of system loss.
- Regulation or improvement in voltage.

Connects capacitor in parallel (shunt) rather connecting in series. The function of shunt power capacitor is to provide leading (capacitive) KVARs to an electrical system when and where needed. Lagging (inductive) KVARs appear when there are inductors (coils) exist within electrical (e.g. motor) or electronic (personal computer) equipment, as the amount grows, the increment of inductive KVARs will increase as well, thus the demand of capacitive KVARs to compensate is pretty much required in order to reduce unnecessary lost. The actual capacitor in farads of a capacitor bank can be calculated using the following equation,

$$C = \frac{VAR}{2\pi f \times V_R^2} \quad (1)$$

Where VAR = capacitor unit VAR rating.

C = capacitor (farads).

f = frequency (cycles/second).

V_R = capacitor unit rated voltage.

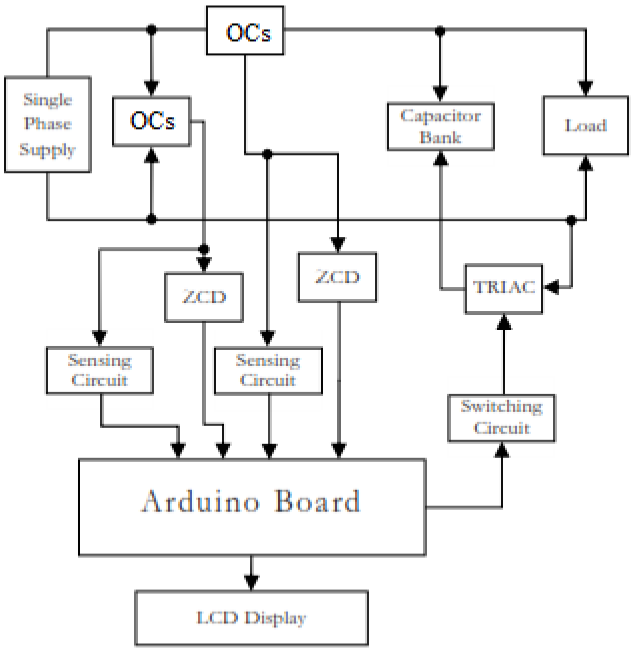

Figure 1. Proposed APFC block diagram.

3.3. Computation

Capacitors are connected in parallel. The function of shunt power capacitor is to provide leading (capacitive) KVARs to the electrical system. Lagging (inductive) KVARs appear when there are

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inductors (coils) within electrical (e.g. motor) or electronic equipment. As the amount grows, the increment of inductive KVARs will increase as well, consequently there is a need of capacitive KVARs to compensate it to reduce unnecessary power loss. The actual capacitor in farads of the capacitor bank is calculated using equation 1. Capacitors of standard ratings like 240uF, 300uF and so are available that are sufficient to provide enough KVARs for the desired power factor improvement on the load side. They are connected in parallel with the equipment in the form of a capacitor bank. Their demand is ensured by first determining the value of power factor from the code.

This project provides us with the learning's on the following aspects:

1. Embedded C programming.
2. PCB Design concepts.
3. Zero-crossing detector interfacing with Microcontroller.
4. Current transformer interfacing.
5. Potential transformer interfacing.

The major building blocks of this project are:

1. Regulated Power Supply.
2. Microcontroller.
3. Resistive load.
4. Inductive load.
5. Relay bank unit.
6. Optocouplers.
7. Zero-crossing detector.
8. LCD display.

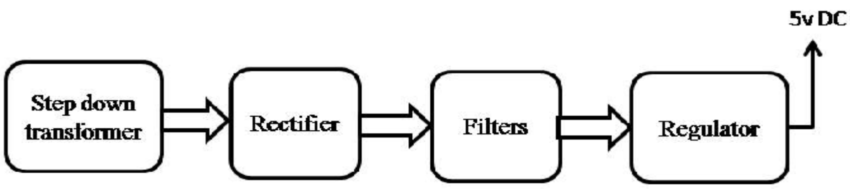

Figure 2. Regulated power supply.

3.4. Arduino Uno and IDE

The Arduino Uno is based on the popular Atmel ATmega 328P. Older Arduino Uno Boards utilized the ATmega8 or ATmega168, however, boards featuring those microcontrollers are no longer available. The ATmega 328P is a low power 8-bit AVR RISC-based microcontroller. The ATmega supports operating frequencies up to 20 MHz, however it is clocked at 16 MHz on Arduino Uno boards. The 328P features a variety of useful peripherals to interact with its environment. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

Another important feature of the ATmega 328P is its three hardware timers (0,1 and 2). Timer 0 and 2 are 8-bit timers, while Timer 1 is a 16-bit timer. The timers can be used to generate the PWM signal required to control the power converter. At 100 kHz, the PWM resolution is approximately 7.3 bits. In the standard Arduino programming environment, the PWM frequency is set to 490 Hz, which is far too low to be useful in any power electronics application. Methods to access the fast PWM will be

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elaborated on in later sections. The timer can also be useful to generate timed interrupts. All Arduino Uno boards are supported by the Arduino Integrated development environment (IDE). The Arduino IDE can be used to both program and communicate with the Arduino boards. The Arduino IDE utilizes its own programming language, which is based on C. The main advantage of the Arduino programming language is its ease of use. A variety of functions used to interact with the peripherals are predefined in the IDE. Some of these peripherals include: External Interrupts, Timer with PWM, ADC, and Serial Communication.

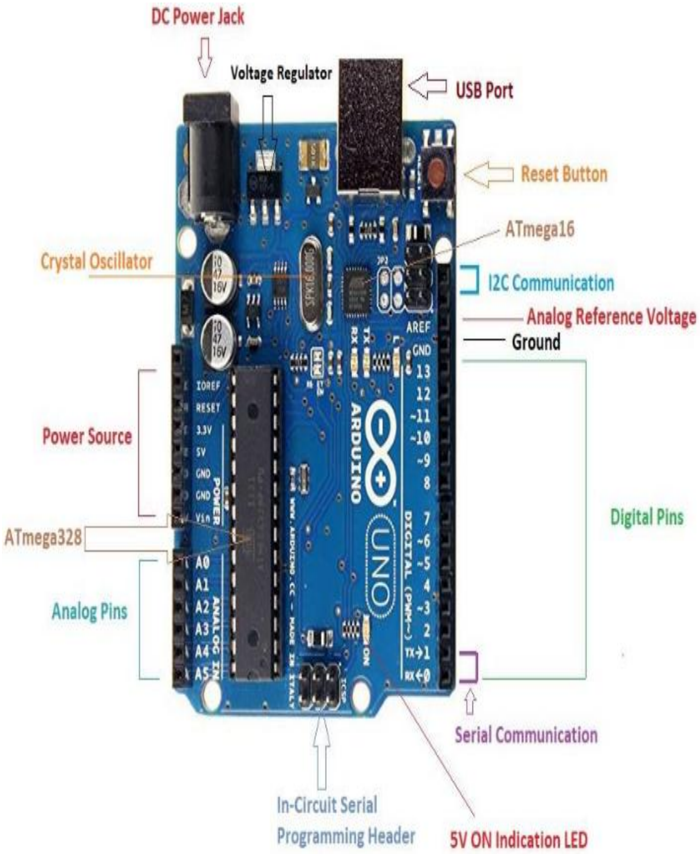

Figure 3. Arduino UNO microcontroller.

LCD

LCD is liquid crystal display technology works by blocking light. Specifically, it is made of two pieces of polarized glass that contain a liquid crystal material between them. A backlight creates light that passes through the first substrate. It is used for display purpose.

3. EXPERIMENTAL RESULTS

The microcontroller is programmed using Arduino IDE which is the official software based on C programmingsupplied from vendor and is used to program Arduino Uno. Figure 3 demonstrate the hardware setup of proposed APFC system.

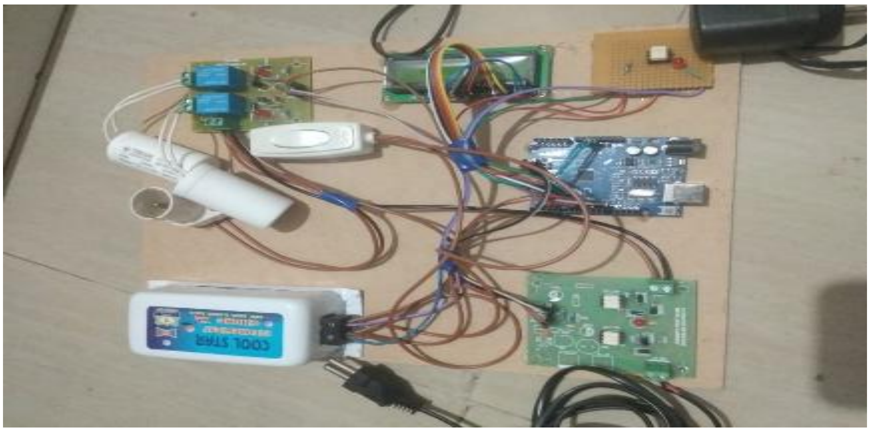

Figure 3. Hardware setup of proposed APFC system.

4. CONCLUSIONS

This article presented the APFC which is an efficient technique to improve the power factor of a power system by an economical way. By using the proposed module, we can raise power factor is a proven way of increasing the efficient use of electricity by utilities and end users. Economic benefits for end users may include reduced energy bills, lower cable, transformer losses and improved voltage conditions, while utilities benefit from released system capacity.

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