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ENERGY CONSERVATION USING AUTOMATIC POWER FACTOR MANAGEMENT WITH ARDUINO NANO FOR HOMES

Dr. Nagaraj Harthikote[1] and Ms. Al zahra Al Mukhaini[2], Ms. Reema Al Farsi[3], Ms. Zeyana Al Sabti[4] , Mr. Mohammed Al Zadjali[5]
[1] Senior Lecturer, Electrical and Electronics Engineering Section,
[2-5] B. Tech Students of Electrical and Electronics Engineering Section,
Department of Engineering,
University of Applied Science and Technology, Muscat, Sultanate of Oman.

ABSTRACT

Automated Power Factor Correction (APFC) technology is an integral part of modern electrical systems, and this paper focuses on designing a system tailored for domestic use. The primary objectives are to enhance power factor efficiency, minimize energy waste, and optimize the performance of household electrical networks. This APFC system is designed to monitor power factor in real time using Arduino nano and automatically switch capacitors to maintain optimal levels. It seamlessly integrates with existing domestic electrical setups and features a user-friendly interface for easy configuration and control. By implementing this technology, households can reduce energy costs, avoid penalties for low power factor compliance, and contribute to a more sustainable energy ecosystem. APFC systems improve energy efficiency by maintaining a power factor close to unity, significantly reducing energy losses during distribution and transmission, which directly translates into cost savings. Furthermore, APFC devices stabilize voltage and current waveforms, reducing distortions and harmonics. This not only ensures the effective utilization of the system's capacity but also promotes the reliable operation of electrical equipment. Maintaining an ideal power factor also reduces heat stress on machinery, enhancing its performance and extending its lifespan.

KEYWORDS: *Automated Power Factor Correction (APFC), Energy waste, Household electrical networks, Arduino nano, Real-time monitoring, User-friendly interface, Energy costs, Sustainable energy ecosystem, Reliable operation.*

1. INTRODUCTION

The power factor, defined as the ratio of real power (kW) to apparent power (kVA) consumed by a load, is a crucial concept in electrical systems. While apparent power (kVA) includes both real power and reactive power, the latter does not perform useful work but still influences the total power drawn from the supply. Real power (kW), on the other hand, is the actual power that performs beneficial work. Automatic Power factor correction (APFC) and harmonic filtering have become essential strategies in response to the increasing demand for electricity and a growing awareness of energy efficiency. Power quality, which directly impacts system reliability and cost savings, is increasingly a focal point. APFC plays a vital role in optimizing power flow and voltage stability, particularly in medium and low-voltage power distribution networks. It is critical for managing power distribution efficiently, as it generates reactive power that enhances the voltage profile and overall system reliability.

Improving power quality through APFC can lead to significant cost savings by reducing energy losses and ensuring more effective use of electricity. The savings achieved through reduced energy waste and enhanced system efficiency can quickly offset the initial investment, providing a fast return on investment (ROI). Additionally, harmonic filtering, often used alongside APFC, helps mitigate the effects of harmonic distortions caused by non-linear loads, thereby improving system stability and performance. The APFC system consists of simple components such as inductors, power switches, diodes, and capacitors. However, there are various other components that can improve power efficiency for specific applications, and the market for these components is competitive. The choice of inductor materials and proper winding size for a given application can influence the performance of the APFC.

1.1 Uses of capacitors in APFC

Automatic Power Factor Correction (APFC) systems employ a series of capacitors activated through contactors, which are controlled by a regulator that continuously monitors the power factor of the electrical network or individual loads. This system ensures that only the required capacitors are engaged based on the network's load and power factor, maintaining the power factor above a predetermined threshold.

Fixed capacitors are commonly used in such applications due to their simplicity and cost-effectiveness. Furthermore, capacitive load banks similar in rating and functionality to reactive load banks produce leading power factor loads. These loads emulate the characteristics of electronic or non-linear equipment typically found in industries such as telecommunications, computing, and uninterruptible power supply (UPS) systems.

To manage multiple loads effectively, automatic capacitor systems are essential for ensuring appropriate power factor correction. In such systems, microcontrollers play a pivotal role by automating the compensation process and maintaining optimal power factor levels.

2. FUNCTIONS OF MAJOR COMPONENTS.

a) **Arduino Nano**: The Arduino Nano, also referred to as Arduino Nano 3.x, is a small, feature-packed board that is compatible with breadboards. While it comes in a different form factor, it offers the same functionality as the Arduino. It uses a Mini-B USB cable instead of a standard USB and does not include a DC power jack.
b) **Current Transformer (CT)**: A current transformer is an instrument transformer designed to measure alternating current (AC). In this project, current transformers are used to detect the current flowing through the electrical system, which is essential for calculating the power factor.
c) **Voltage Transducer (VT)**: A voltage transducer is a device that converts electrical voltage into an equivalent electrical signal, making it useful for various applications.
d) **IC**: An integrated circuit (IC), commonly known as a microchip, computer chip, or simply a chip, is a compact electrical component consisting of multiple interconnected electronic elements such as resistors, capacitors, and transistors.
e) **LCD**: A liquid crystal display (LCD) is a flat-panel display or optoelectronic device that displays data by combining polarizers with the light-modulating properties of liquid crystals.

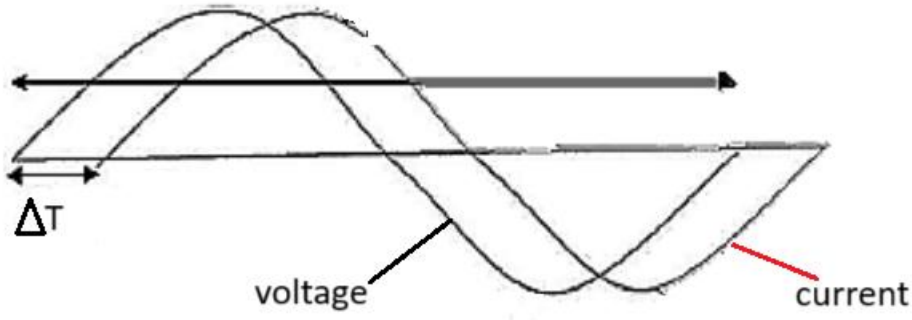


Fig.1: Voltage and Current wave with time difference.

3. DESIGN AND WORKING

The selection of capacitors is determined by the time delay between voltage and current, with the objective of achieving a power factor close to unity. The specific capacitor requirements vary depending on the load connected to the system. These factors must be carefully considered when selecting capacitors for commercial power factor correction applications.

Capacitors are selected as required.
Required VAR = P ($\tan \phi_1 - \tan \phi_2$)
We know that.
$I_c = V / X_c$
Whereas $X_c = 1 / (2 \times \Pi \times C)$

By calculating the kVAR, required capacitors in farads/micro farads can be calculated as:

$C = kVAR / (2 \times \Pi \times f \times V)$

The Arduino Nano is a microcontroller built on the ATmega328 platform. It features input/output pins, a USB connector, a power jack, and a reset button. The Nano can be powered either through a USB connection or an external power source.

3.1 Block diagram

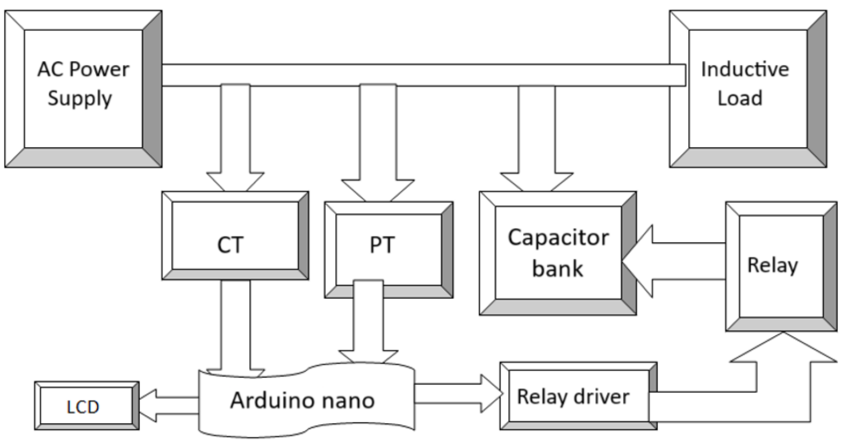


Fig.2: ***Block diagram- Energy Conservation using Automatic Power Factor Management with Arduino nano for Homes.***

Using a potential transformer (PT) and a current transformer (CT), the voltage and current signals from a single-phase wire are scaled down to a level suitable for Arduino processing. These signals are fed into the Arduino through sensor circuits and zero-cross detectors (ZCDs), which detect the current, voltage, and phase difference required to calculate the power factor and active power of the connected load. The Arduino board, designed to measure and adjust the power factor of the connected load, acts as the system's central control unit. In the case of a lagging power factor, the Arduino sends a control signal to the circuit, which activates the capacitor bank in parallel with the load to switch it on. This process is repeated until the desired power factor adjustment is achieved. The power factor values before and after the correction are displayed on the LCD for the connected load.

3.2 Circuit diagram

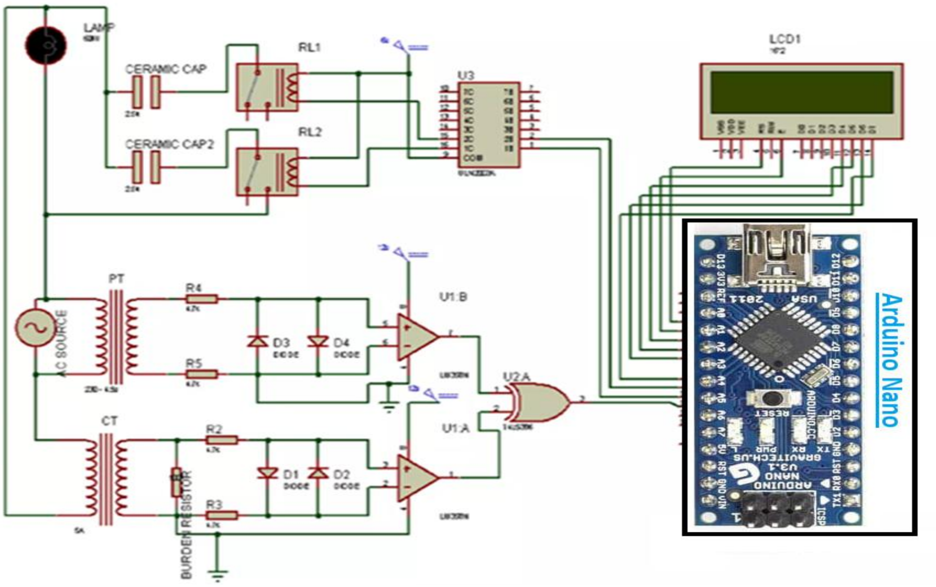


Fig.3: Functional diagram using Arduino nano.

The proposed Automatic Power Factor Correction (APFC) system features a circuit design comprising several key components. The voltage, current, power factor, and power of the connected load are measured by feeding the respective signals into the analog pins of the Arduino board through sensor circuits and zero-cross detectors (ZCDs). The signal from the potential transformer (PT) is routed to the Arduino board through a half-wave rectifier circuit for voltage monitoring. A 5V DC power source supplies the necessary power to the Arduino board and other peripherals in the APFC system. The system utilizes the PT and current transformer (CT) to capture voltage and current signals from the connected load. These signals trigger an optocoupler, activating a transistor. By providing the gate current, the output controls a relay, which connects the capacitor bank in parallel with the load.

The Arduino evaluates the improved power factor by processing the signals from the PT and CT after energizing the static capacitor. If the corrected power factor is lower than the set point, the microcontroller compares it to the reference value and repeats the correction process. This cycle continues until the desired power factor is achieved. Once the required power factor is reached, the microcontroller displays the power factor values before and after adjustment on the LCD, with a 3-second interval between the readings.

3.3 Working Model

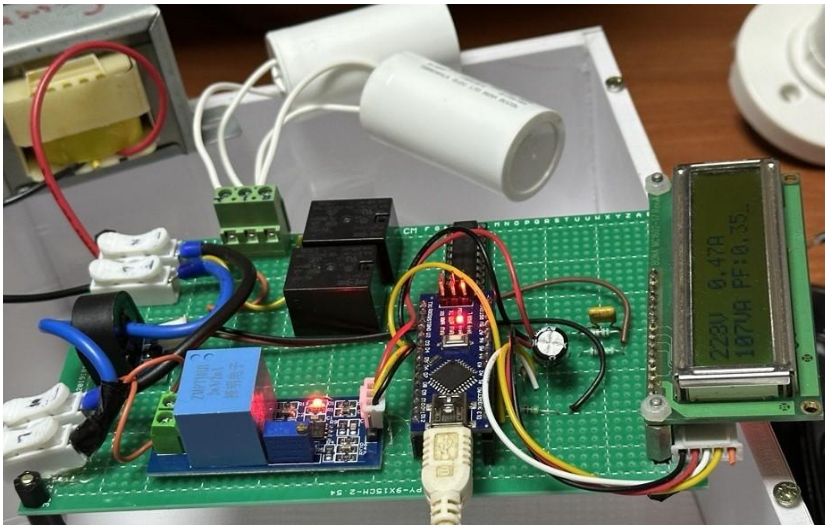


Fig.4: Testing of circuit.

The figure above illustrates the complete hardware setup of the proposed APFC system. The system includes both an inductive load (such as a fan and choke) and a resistive load (like an incandescent light), each with varying phase ratings, to test their respective operating processes.

When the load is activated, the LCD displays the power factor of the load before any correction. Since the power factor is lower than the reference value, the APFC system automatically connects the capacitor(s) in parallel with the load to correct the power factor. The LCD then shows the corrected power factor value.

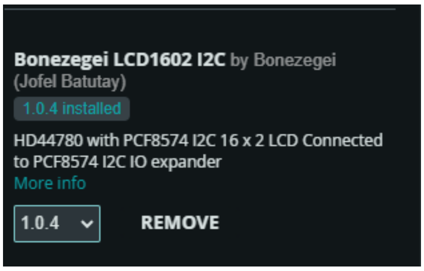
Data regarding the power factor before and after correction for the mixed load (consisting of an incandescent light and a fan motor) is displayed on the LCD, as shown in Figure [X]. Upon activating this load, the APFC system quickly detects the power factor and corrects it by connecting the capacitor(s) in parallel.

3.4 Code:

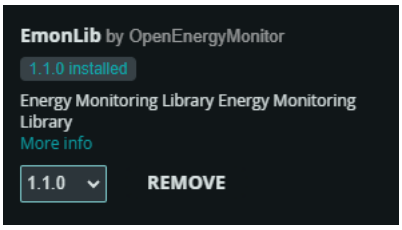
```
/*Implementation using Emonlib library from openenergymonitor.org, Licence GNU GPLV3 - Measure power factor and switch capacitor bank using relay to make PF approximately equal to 1*/
#include <Bonezegei_LCD1602_I2C.h>
#include "EmonLib.h"  // Include Emon Library
EnergyMonitor emon1;  // Create an instance
Bonezegei_LCD1602_I2C lcd(0x27);
String LCD_Msg;
const int Relay1 = 5;   // Relay 1 on pin 5
const int Relay2 = 6; // Relay 2 on pin 6

void setup() {
Serial.begin(115200);   // serial monitor to see what is happening
lcd.begin();          // Start LCD display
lcd.print("PF Correction");   // Print a message on LCD
lcd.setPosition(0, 1);  //param1 = X   param2 = Y
lcd.print("Capacitor Switch");
```

```
emon1.voltage(0, 172, 1.7);  // Voltage: input pin, calibration, phase_shift
emon1.current(1, 10.2);     // Current: input pin, calibration.

pinMode(Relay1, OUTPUT);     // Relay 1 pin as output
pinMode(Relay2, OUTPUT);   // Relay 2 pin as Output
digitalWrite(Relay1, HIGH);   // Turn ON relay1 by making pin High
digitalWrite(Relay2, HIGH);   // Turn ON relay2 by making pin High
delay(3000);              // some delay - just to know both relay work on program start
digitalWrite(Relay1, LOW);     // Turn OFF relay 1
Serial.println("Relay1 OFF.");
delay(2000);
digitalWrite(Relay2, LOW);     // Turn off Relay 2 after 2 second gap
Serial.println("Relay2 OFF.");
}

void loop() {
emon1.calcVI(20, 2000);  // Calculate all. No.of half wavelengths (crossings), time-out
emon1.serialprint();     // Print out all variables (realpower, apparent power, Vrms, Irms, power factor)
float realPower = emon1.realPower;        //extract Real Power into variable
float apparentPower = emon1.apparentPower;  //extract Apparent Power into variable
float powerFActor = emon1.powerFactor;     //extract Power Factor into Variable
float supplyVoltage = emon1.Vrms;         //extract Vrms into Variable
float Irms = emon1.Irms;               //extract Irms into Variable
lcd.clear();                         // clear LCD screen
lcd.setPosition(0, 0);                 // position LCD cursor top left (0, 0) position
LCD_Msg = String(supplyVoltage, 0);       // Print Voltage
LCD_Msg += "V  ";
LCD_Msg += String(Irms);               // Next to voltage current on same line
LCD_Msg += "A  ";
lcd.print(LCD_Msg.c_str());

/** Code for capacitor bank switching based on power factor obtained */
if(powerFActor < 0.8) { // if lagging power factor, connect capacitor
if(digitalRead(Relay1) == LOW) digitalWrite(Relay1, HIGH);       // 1st turn ON relay 1 so capacitor 1 is connected
else if(digitalRead(Relay2) == LOW) digitalWrite(Relay1, HIGH);   // else if relay 1 already ON turn ON realy 2
}
else if(powerFActor < 0) {  // else if leading power factor disconnect capacitor
if(digitalRead(Relay1) == HIGH) digitalWrite(Relay1, LOW);       // 1st turn OFF relay 1 so capacitor 1 is disconnected
else if(digitalRead(Relay2) == HIGH) digitalWrite(Relay1, LOW);    // else if relay 1 already OFF turn OFF realy 2
}
lcd.setPosition(0, 1);               // next line
LCD_Msg = String(apparentPower, 0);      // print power VA
LCD_Msg += "VA PF:";
LCD_Msg += String(powerFActor);         // Then Power factor
lcd.print(LCD_Msg.c_str());
delay(3000);                      // give delay of 3 seconds between each sample
}
```

Connect the project to the PC using an USB cable
Select Board Arduino Nano from tools menu
Select the COM port
Install Bonezegei LCD1602 i2c – required library for 16 character x 2 line LCD display



Test LCD working by downloading hello example
Install Emonlib library – you may study the library CPP file on how it gets the energy parameters



4. Test Results.

Table 1.

Type of the load	Power factor (before Cap connection)	Power factor (after Cap connection)	Voltage (V)	Current (A)
No load	0	0	1	0.23
Inductive load	0.16	0.35	227	0.48
Resistive load	0.83	0.83	240	0.78

4.1 Discussions.

A comparative observation of the power factor of the loads before and after the insertion of the APFC circuit reveals the following results. Before the APFC circuit is inserted, the power factor, measured with the load connected, is observed to be 0.16. After the APFC circuit is inserted, the power factor improves to 0.35. There is no change in power factor with and without APFC for resistive load. Therefor the power factor improves after the insertion of the APFC circuit, with a 2.5 µF capacitor providing the necessary correction.

5. CONCLUSIONS.

This project focuses on automatically correcting the power factor (PF) of a system. The Arduino Nano is used to sense the power factor by monitoring the load. Based on the lagging behavior of the PF due to the type of load, the system performs control actions by switching the capacitor bank through different relays, thus improving the power factor. The power factor correction techniques can be applied both in domestic and industrial settings to ensure system stability. Since capacitor switching is done automatically, the system provides more accurate results. The power factor correction enhances system stability, improves efficiency, and reduces costs. Moreover, by using the Arduino Nano, multiple parameters are controlled efficiently, reducing the need for additional hardware components such as timers, RAM, ROM, and I/O ports, further lowering overall costs. The automatic power factor correction system not only helps in reducing costs but also shortens development time, operates with low power supply requirements.

5.1 Future enhancements

The automotive power factor correction using capacitive load banks is very efficient as it reduces the cost by decreasing the power drawn from the supply.

As it operates automatically, manpower interference not required and this Automated Power factor Correction using capacitive load banks can be used for the industries purpose in the future. In future such techniques can be employed. Automatic power factor correction shall also be implemented in major industrial loads for efficient performance. In future, work can be extended for harmonics reduction.

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