

AUTOMATIC POWER FACTOR CONTROL USING ARDUINO UNO

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Abstract— This composition presents a straightforward and provident approach to designing an Automatic Power Factor Correction (APFC) system for domestic single-phase electrical loads. The core switching medium relies on TRIACs, which connect capacitor banks in resemblance with inductive loads to enhance the power factor. Compared to conventional electro-mechanical relays, TRIACs deliver briskly response times and lesser functional trustability. An Arduino microcontroller governs the switching sense, continuously testing signals from a current motor (CT), a implicit motor (PT), and zero-crossing sensors (ZCDs) to estimate cargo power factor in real time. When the measured power factor falls below the preset threshold of 0.9, the regulator selects and energizes applicable capacitor combinations until the target value is achieved. dimension results — both before and after correction — are presented on a liquid demitasse display (TV). A physical prototype was constructed and validated across resistive, inductive, and combined cargoscripts, attesting that the system delivers reliable correction performance suitable for practical domestic deployment.

Keywords: automatic power factor correction, single-phase supply, TRIAC switching, capacitor bank, Arduino microcontroller, domestic loads.

I. INTRODUCTION

Current electrical power distribution systems suffer from a low power factor, an issue that affects both end-users and electricity suppliers' ability to provide their products in a productive, effective and profitable manner. Power factor -- which indicates how effectively electrical energy is converted into productive work -- generally decreases as more inductive loads, such as motors, factories and fluorescent lights, are added to the overall load of the system. A drop in power factor results in increased demand for reactive power, increased line current, increased electrical transmission losses and greater voltage drop along the supply network.

Most electricity utility companies charge customers with a power factor below a certain level (typically around 0.9) a financial penalty. This causes increased monthly electric bills to residential and commercial customers, and it increases the risk that electrical devices connected to low power factor customers will incur damage due to over-current when they are running at a low power factor. While low power factor operation of the customer's electrical infrastructure has received little attention to date, the financial consequences of low power factor operation are viewed as a supply-side issue and not an issue of customer liability.

The use of fixed capacitor banks has become one form of remedy.

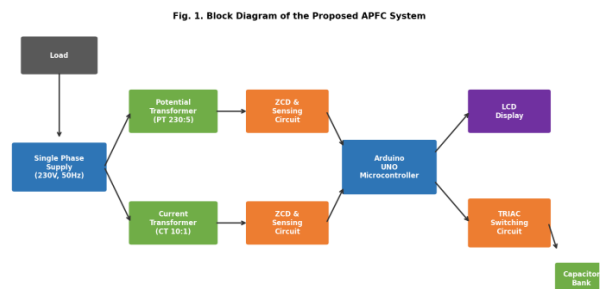


Fig. 1. Proposed APFC system block diagram.

II. BACKGROUND AND RELATED WORK

Previously, the use of relay-switched capacitor banks to provide automatic reactive power compensation was limited to using programmable logic controllers or discrete timer circuits to perform the switching. These systems produced adequate reactive power compensation when the loads were stable; however, they had slow response times and a large number of mechanical contacts that needed to be serviced. With the introduction of microcontrollers, more complex real-time algorithms were developed that could monitor variances in load and then switch capacitor banks within a fraction of a cycle.

The introduction of PIC-family microcontrollers provided a platform for developing control algorithms for capacitor banks, which allowed for power factor correction to be maintained above 0.95 under changing inductive loads. The research focused on developing algorithms for three-phase applications using DSP-based platforms; however, the associated costs and complexity of these systems precluded their use in residential applications. The low cost of 8-bit Arduino platforms has allowed many

experimenters and engineers access to microcontroller-based designs and develop prototypes of automatic power factor correction (APFC) solutions with limited resources .

Many of the automatic power factor correction (APFC) devices used semiconductor switching methods such as TRIACs. Research was completed comparing the use of TRIACs and mechanical relays as a means of switching capacitor banks for APFC applications. The results of the study demonstrated that the use of solid-state devices such as TRIACs resulted in less transient disturbances being produced during the insertion of the capacitors, which increases the life expectancy of the equipment being switched with these devices. The use of opto-couplers for isolation of low-voltage control circuits from mains-connected switching stages is essential to avoid damage to the microcontroller from voltage spikes at the switching devices. Despite these advances, published designs for domestic-scale single-phase applications remain scarce in open literature. Most contributions focus on industrial three-phase networks or academic demonstrations without hardware validation. The present work addresses this gap by providing a fully tested, component-level implementation specifically designed for residential single-phase supplies operating at 230 V, 50 Hz.

Fig. 2. Signal Processing and Measurement Flow Diagram

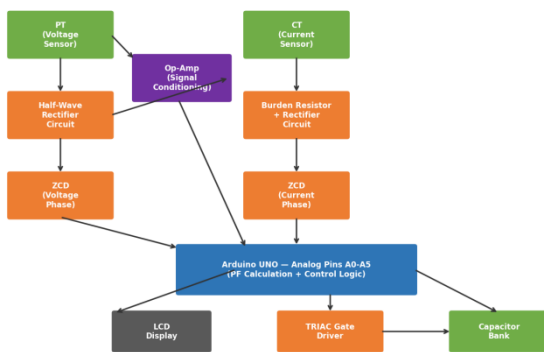


Fig. 2. Signal measurement and processing flow.

III. SYSTEM DESIGN AND CIRCUIT DESCRIPTION

The system diagram consists of two side to measure and to detect Mains Voltage and Mains Current respectively. Mains Voltage will be detected on the left hand side and Mains Current on the right hand side both of which will be used together to determine the actual RMS values of each Mains component so that they can be subsequently processed by the Arduino as part of a control algorithm to drive a pair of TRIACs.

Voltage and Current Measurement:

The measurement of mains voltage is achieved through the use of an instrumentation based voltage measuring device. The value of voltage to be controlled is stepped down from 230 volt mains supply voltage to 5volt (i.e. $230v \div 5V = 46$), it is then converted to DC voltage using either a half or full bridge rectifier and then connected to one of the Arduino's Analog Input Pins, which will use this

voltage to calculate the RMS value of the voltage to be controlled.

The method of measuring the mains current is similar to that of measuring mains voltage where the current coming from the current sensing side (right hand) of the CT will be converted to a voltage by means of connecting a burden resistor between the CT's secondary winding and the Analog Input Pins of the Arduino. The remaining secondary value would be its headvalue

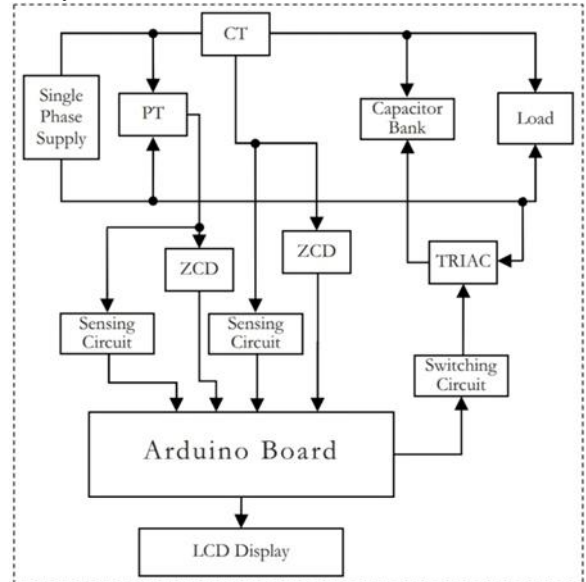


Fig. 3. Complete circuit schematic of the proposed APFC system.

IV. CONTROL ALGORITHM

The control algorithm is governed by the logic defined above in the flowchart control diagram for the closed-loop correction process. After power is applied, the microcontroller begins to sample the analog readings of the sensors. The analog readings will determine the amplitude and the amplitude of both voltage and current through rectified sensing circuits; the zero-crossing signal will be used to determine the phase angle through a pulse-width measurement method. The instantaneous power factor (calculated using the inverse cosine of the phase displacement), along with the apparent and actual power of the measured load, will be established using the information identified above. The voltage, current, active power, and power factor calculated above are then temporarily stored in the internal memory of the microcontroller while the system determines whether to perform a corrective adjustment or not. If the measured power factor is equal to or greater than the power factor reference value set to 0.9, then no switching method will be engaged.

The LCD will be updated with the current measurements while the system continues to monitor; this allows the prevention of the use of a capacitor when the load is either light or predominantly resistive, thereby preventing the potential of over-correction of compensation to load condition. If the power factor is less than 0.9, the loop will contain...

difference of 5sec time interval.

V. WORKING ALGORITHM

The detailed working algorithm of the proposed APFC system is shown in Fig. 3. The algorithm is self-explanatory that starts from the signals inputs from PT and CT and finishes at display of power factor after attaining desired correction. The Arduino is the core of the proposed APFC system for all operations such as measuring and calculating the voltage, load power, load current and power factor before and after correction, storing the initial values before correction, switching of capacitors for power factor correction, displaying the power factor values that are calculated before and after correction.

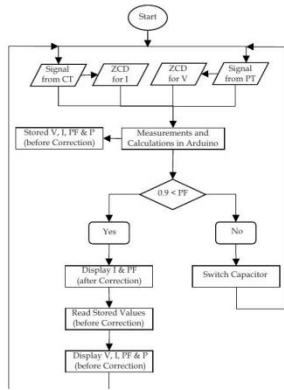


Fig. 4. Control algorithm flowchart.

V IMPLEMENTATION OF HARDWARE PROTOTYPE

The completed hardware prototype is shown in Figure 5. Each functional block consisting of the sensing network, Arduino board, TRIAC switching stage, and capacitor bank, has been constructed as a complete circuit on one prototype development board to promote ease of testing. During testing of the hardware configuration there were three different types of loads (‘incandescent’, ‘choke’, and ‘combined’) connected to the prototype: -(A) 200 Watts incandescent light; (B)36 Watts choke; (C)combined load 60 Watt incandescent light, 36 Watt choke, and 60 Watt fan motor.

The prototype operates from a single phase electrical source, with an internal transformer and rectifier combination supplying the appropriate regulated 5V DC power to the Arduino board and supporting circuitry. Switching events will be documented by an LCD display, thus providing an easy method to verify that the prototype is operating as intended without having to use additional measuring devices.

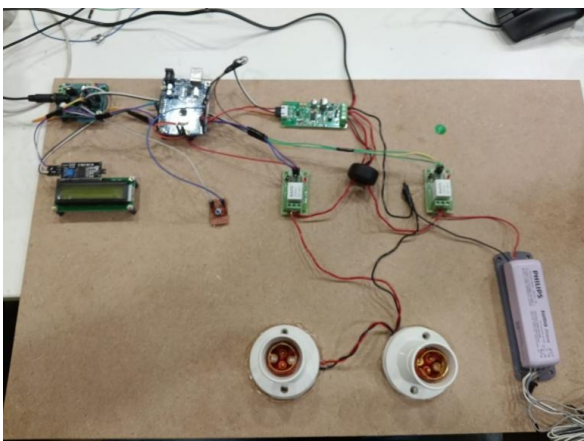


Fig.5 Assembled Hardware Prototype for the Adaptive Power Factor Correction (APFC) System

VI. RESULT AND DISCUSSION

To evaluate the performance of a system three loading scenarios were tested. All three of the scenarios recorded the LCD display before and after the correction cycle in order to show the power factor was raised to or above a .9 power factor.

A. Resistive Load (200 Watt Incandescent Lamp)

A typical 200 Watt incandescent lamp will draw nearly sinusoidal currents that are in phase with the supply voltage as illustrated in figure 5: The assembled hardware prototype for the Adaptive Power Factor Correction (APFC) system.

B. Inductive Load (36 Watt Choke)

The addition of the 36 Watt air-core choke provided a highly inductive load to the supply, with the power factor being measured at .49 with a line current of .32 Amps, both values are expected as this is a highly inductive device. Upon sensing the inductive power factor value the APFC system immediately started the switching sequence for the capacitors, resulting in an increase in the power factor to .93 and a decrease in line current to .17, which illustrates to a significant extent that reactive current flow in the supply conductors would have been greatly reduced and that in turn correlates to reducing distribution losses in an actual installation.

B. Case: Inductive Load

For the inductive load case, a choke of 36W is used to test the operation of APFC system. The LCD result of Fig. 7 shows the power factor of this load before correction when it is turned ON. The APFC system quickly inserts the capacitor(s) in parallel to this load in order to correct the power factor as its power factor value is less than the reference value. The corrected value of power factor is shown in the LCD display of Fig. 8.



Fig. 8. LCD output before correction — inductive load.



Fig. 7. LCD display result before correction: inductive load case.



Fig. 9. LCD output after correction — inductive load.

C. Mixed Load (60 W Lamp + 36 W Choke + 60 W Fan Motor)

At an initial combined load of 156W (resistive and inductive connections) and an initial power factor of 0.79 at 0.87A, the initial condition resembles a typical domestic application where a number of types of appliances are on simultaneously. After completing the correction cycle, the power factor improved to 0.97 and the supply current decreased to 0.71A; therefore, both results verify that there was effective compensation in all three cases. A summary of all three test cases is provided in Table I.

power factor before and after correction respectively for mixed load case. The mixed load comprises of a 60W incandescent lamp, a 36W choke and a 60W fan motor. Upon turning ON this load, the APFC system quickly measures and correct the power factor by inserting the capacitor(s) in parallel to this load.



Fig. 10. LCD output before correction — mixed load.

Fig. 9. LCD display result before correction: mixed load case.

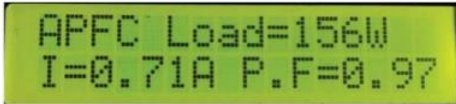


Fig. 10. LCD display result after correction: mixed load case.

Fig. 11. LCD output after correction — mixed load.

TABLE I. EXPERIMENTAL RESULTS SUMMARY

Load Type	Load Rating	PF Before	PF After	Current Before	Current After
Resistive	200 W	0.99	0.99*	0.9 A	0.9 A
Inductive	36 W	0.49	0.93	0.32 A	0.17 A
Mixed	156 W	0.79	0.97	0.87 A	0.71 A

* No correction needed — PF already above threshold.

In every scenario tested (whether inductive or mixed), the new system was able to lift the power factor above 0.9 with one or two additional capacitors without human input. By using variable-capacitance inductance/ capacitance (i.e. variable-capacitance inductive loads) as part of the incremental capacitor engagement strategy there were no overcompensating conditions created, nor was there ever a leading power factor condition observed throughout all of the tests conducted. Time between load connection and viewer knowing that load has been fixed was only a few seconds, providing adequate time for homeowners to adjust to their home's electrical demands over time rather than immediately.

VII. CONCLUSION

A low-cost, practical approach to automatic power factor correction (APFC) has been developed, prototyped, and experimentally verified for single-phase residential loads. This design utilizes an Arduino microcontroller to receive power factor data based on voltage transformer (PT), current transformer (CT), and zero crossing detector (ZCD) measurements; and will selectively switch TRIAC-controlled capacitor stages to restore a load's power factor to greater than 0.9. Using TRIACs rather than electromechanical relays increases the reliability of the switching mechanism and eliminates the mechanical wear associated with extended use. Opto-isolation of the control circuitry from the mains provides isolation between these two circuits.

Prototype results from testing the device under resistive, inductive, and mixed load conditions prove that the system is capable of identifying whether a power factor

correction is required and how much correction is required in each case. The results from testing also show that the TRS (total reactive power in KVAR) and VRG (voltage drop across the load due to supply current) both improve with respect to before using this automatic power factor correction method. This design uses the fewest number of components possible and makes use of readily available, low-cost materials, thus making the construction simple, and may be easily scaled up to larger stages of capacitor banks to support higher reactive power loads.

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