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## A Conceptual Design of Microcontroller-Based Power Factor Corrector Circuit

B.C. Kok, C. Uttraphan, and H.H. Goh

**Abstract**— One of the concerns to put on the energy efficiency is in relation to the system power factor. From the view of industrial practices, low power factor might cause equipment failure and higher operation costs. This paper proposes a conceptual design of microcontroller-based self-adaptive power factor corrector (PFC) circuit with the intention to be used in the poor power factor (either linear or nonlinear) loads applications. The design of this auto-adjustable power factor corrector is to ensure the entire power system always preserving almost unity power factor and thus optimizing the current consumption. Power factor value is initially measured via microcontroller and it is then compared with a pre-determined reference value. The poor power factor of the entire system will then be adjusted by the aid of the microcontroller to as close as the pre-determined value as possible. The proposed power factor corrector has an adjustable sensitivity of 50 microseconds or 0.9 degree interval step setting. The conceptual design of the power factor corrector circuit has gone through a set of simulation tests using Computer Aided Engineering (CAE) tool. The results obtained are verified that the proposed PFC circuit is capable to produce a reliable output and can be further implemented in practical applications.

**Keywords:** Energy saving, Microcontroller, Power factor corrector.

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### I. INTRODUCTION

LOW power factor in the power distribution system causes the energy crisis in the supply of energy resources. Most of industrial electric loads have a low power factor not exceeding 0.8 and thus contributes to the distribution system losses [1-4]. There are different methods of power factor correction implemented with large lagging or leading nonlinear loads [1]. One of the new approaches is to use a variable inductor in parallel with a fixed capacitor as a reactive power compensating circuit [5-6]. The inductor current is controlled by adjusting the firing angle of two anti-parallel connected thyristors or using TRIAC [4].

The adjustment of the thyristors' firing angle is made in accordance to the result of a comparison between the measured value of a certain system parameter with its reference value [7-10]. This approach is more reliable because it involves the counts of the leading and lagging current in the power factor with a very accurate and precise step setting, in terms of calculating the phase angle, in the power factor corrector. In spite of giving pre-calculated relations between the system power factor and the static VAR compensator firing angle, the suggested power-factor correction scheme do not give a real-time solution to the problem of low power factor in nonlinear loads.

This paper proposes a real-time microcontroller-based power factor correction scheme for low power factor loads. The software and hardware required to implement the suggested adaptive power factor correction scheme are explained, and its operation is described.

### II. BLOCK DIAGRAMS AND DESCRIPTIONS

The block diagram of the microcontroller based power factor corrector is shown in Figure 1.

A microcontroller of PIC16F84A with a crystal of 4 MHz has been utilised in the proposed scheme. The static compensator employed in the system is a parallel combination of a fixed capacitor  $C$  and a TRIAC controlled reactor (inductor  $L$ ). A small inductance  $L_f$  is connected in series with  $C$  to prevent parallel resonance.

Two back-to-back thyristors are used to control the current flow through the reactor. The supplied voltage and current signals, taken through a potential transformer and a current transformer, respectively, are applied to band pass filters (BPF 1 and BPF 2). The detail of the filter design is depicted in Figure 2. The outputs of these two filters are the fundamental complex waveforms of the supplied voltage

and current, respectively. Subsequently, the two sinusoidal waveforms are being changed to square waves through two zero-crossing detectors (ZCD 1 and ZCD 2) as the microcontroller can only detect the digital signal input, or known as ‘pulse’. Figure 3 shows the particular system voltage and current waveforms.

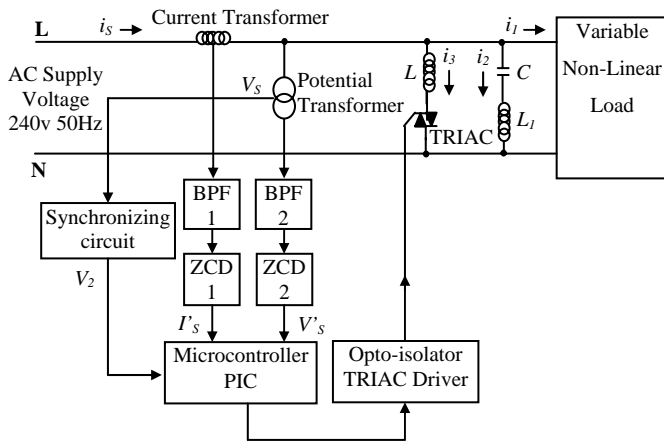
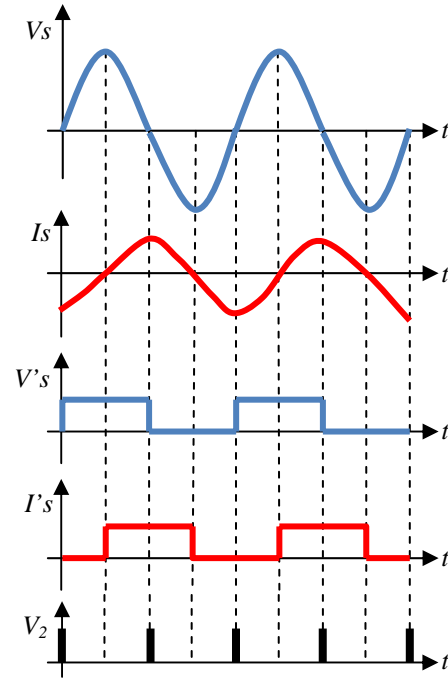


Figure 1: Overview of the block diagram for the microcontroller-based power factor corrector.



b) Lagging power factor

Figure 3: System current and voltage waveforms for (a) leading power factor, and (b) lagging power factor.

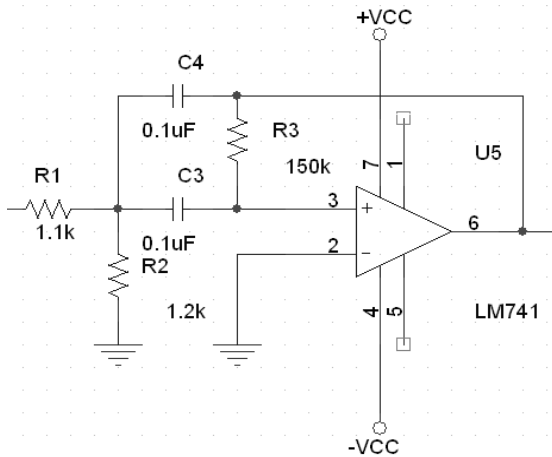
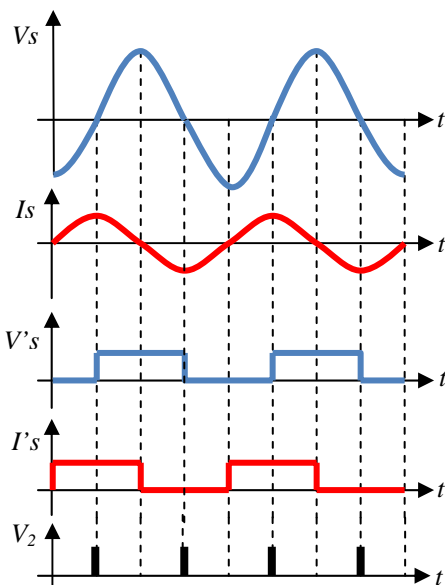


Figure 2: Bandpass filter.



a) Leading power factor

The synchronizing circuit shown in Figure 4 produces a pulse at each zero-crossing of the supplied sine wave voltage. The rising edge of the synchronizing circuit output pulse is synchronized with the zero-crossing of the input sine wave voltage. The output pulses obtained from the synchronizing circuit are then applied to the input of microcontroller as a reference in order to trigger the TRIAC firing angle which is to make sure the pulse is synchronised to the input sine wave voltage.

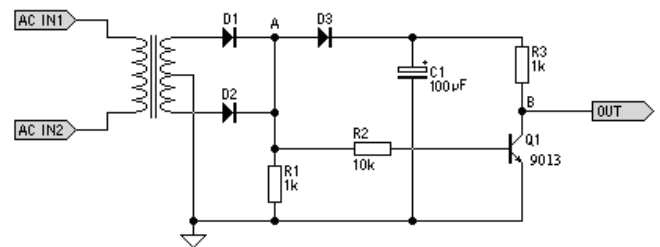


Figure 4: Synchronizing circuit.

Afterwards, the pulse signal from the microcontroller drives the gates of the two back-to-back thyristors or TRIAC so as to control the reactor current. The phase angle,  $\phi_m$  between the fundamental components of the supplied voltage and current ( $V$  and  $I$  respectively) is measured by the microcontroller. The details of the source code developed to achieve the above task are explained in the next section. The measured phase angle  $\phi_m$  is then compared with a reference value,  $\phi_r$  that gives the required power factor (displacement factor). The resultant error signal is used to adjust the number that is loaded into the programmable interval timer in order to change the firing angle,  $\alpha$  of the thyristors in the

static compensator circuit. These changes should be in the direction that reduces the difference between  $\phi_m$  and  $\phi_r$  to a certain acceptable tolerance value. Figure 5 shows the phasor diagrams of the system currents shown in Figure 1. These phasor diagrams may help to explain the operation principle of the proposed adaptive power factor corrector and to distinguish between the following three cases, assuming  $\phi_r$  is always lagging:

- (1)  $\phi_r$  and  $\phi_m$  have different signs.
- (2)  $\phi_r$  and  $\phi_m$  have the same sign and  $|\phi_r| > |\phi_m|$ .
- (3)  $\phi_r$  and  $\phi_m$  have the same sign and  $|\phi_r| < |\phi_m|$ .

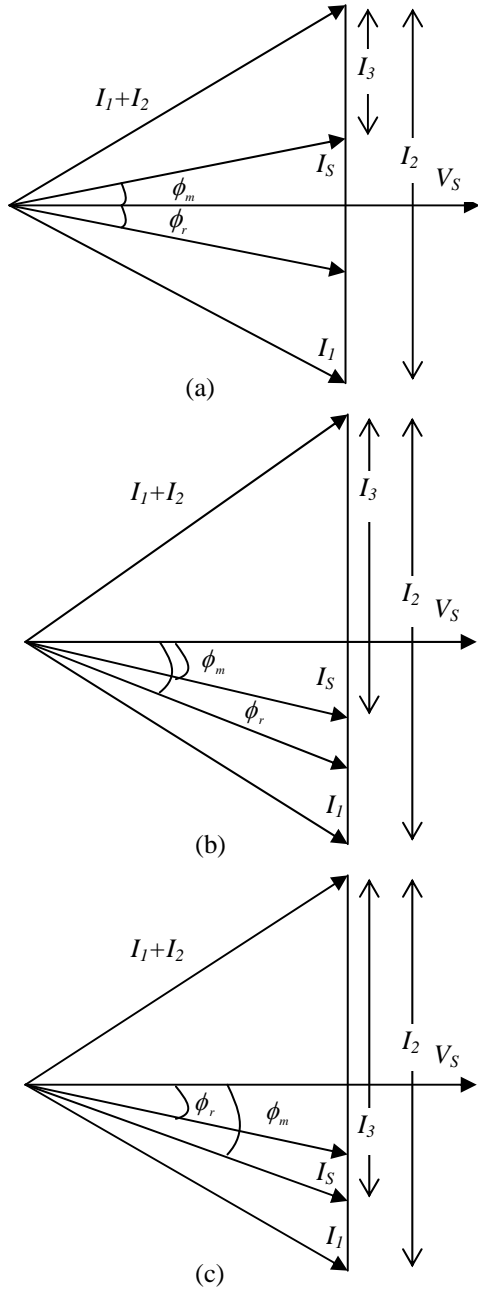


Figure 5: Phasor diagram of the system currents: (a)  $\phi_r$  and  $\phi_m$  have different signs; (b)  $\phi_r$  and  $\phi_m$  have the same sign and  $|\phi_r| > |\phi_m|$ ; (c)  $\phi_r$  and  $\phi_m$  have the same sign and  $|\phi_r| < |\phi_m|$ .

In cases (1) and (2), the reactor (inductor  $L$ ) current must be increased, and consequently,  $\alpha$  must be decreased to get the required power factor ( $\phi_m = \phi_r$ ). In case (3), the reactor current must be decreased, and consequently,  $\alpha$  must be increased to have  $\phi_m = \phi_r$ . The above mentioned cases are taken into consideration in the main control program. In the proposed scheme, the system power factor is improved by adjusting the displacement factor only. The distortion factor may be improved by using filters adjusted to remove the dominating harmonics.

### III. MICROCONTROLLER ROUTINES

The microcontroller PIC16F84A has two I/O ports, namely PORTA and PORTB. PORTB has eight pins. RB0, RB1 and RB2 are programmed to operate as input pins, in which the RB1 representing voltage, RB2 representing current and RB0 representing synchronizing pulse. Meanwhile, the pin RB3 operates as output pin.

In the first stage, the system is initialized, and the TRIAC triggering angle,  $\alpha$  is set to the chosen initial value,  $\alpha_{initial}$ . The value of  $\alpha$  is loaded into one general purpose file register in the microcontroller, named as  $rALPHA$ . The initial triggering signals (60 degree or 3.33mS) are shown in Figure 6. The flow chart of the program has been developed and is given in Figure 7.

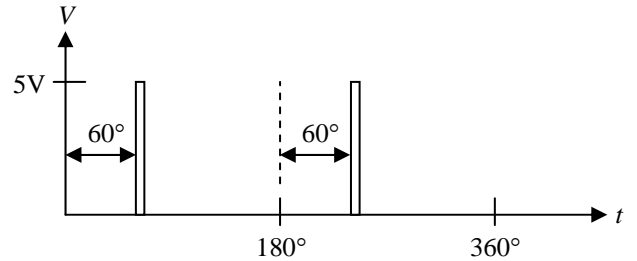


Figure 6: The initial triggering signals from PIC.

The Counter register function is to count the number of the steps which is lagging or leading of the current (RB2) for determining the phase angle  $\phi_m$ . A low input test followed by a high input one is first performed on input RB1, which represents the main value of the complex supplied voltage waveform. This is to ensure that  $\phi_m$ , is measured accurately irrespective of instant switching of the system.

When input RB1 goes low at the end of the high input test, the microcontroller starts reading and testing input RB2. If the input is high, this denotes that the main supplied current lags the main supplied voltage and that can be referred to the case of  $|\phi_r| > |\phi_m|$  or the  $|\phi_r| < |\phi_m|$  where  $\phi_r$  is the reference value. As long as input RB2 is high, the microcontroller keeps looping and testing the input.

The Counter is incremented after each test. The loop time,  $D$  ( $\mu$ s) may be adjusted to any suitable value by adding the required delay time, since there is a delay time in looping period. When the input RB2 goes low, the contents of Counter are tested. If the content of Counter is not equal to 0, the main supplied current is lagging the main supplied

voltage by an angle,  $\phi_m$  which equals to the multiplication of Counter's content to the loop time,  $D$  ( $\mu$ s).

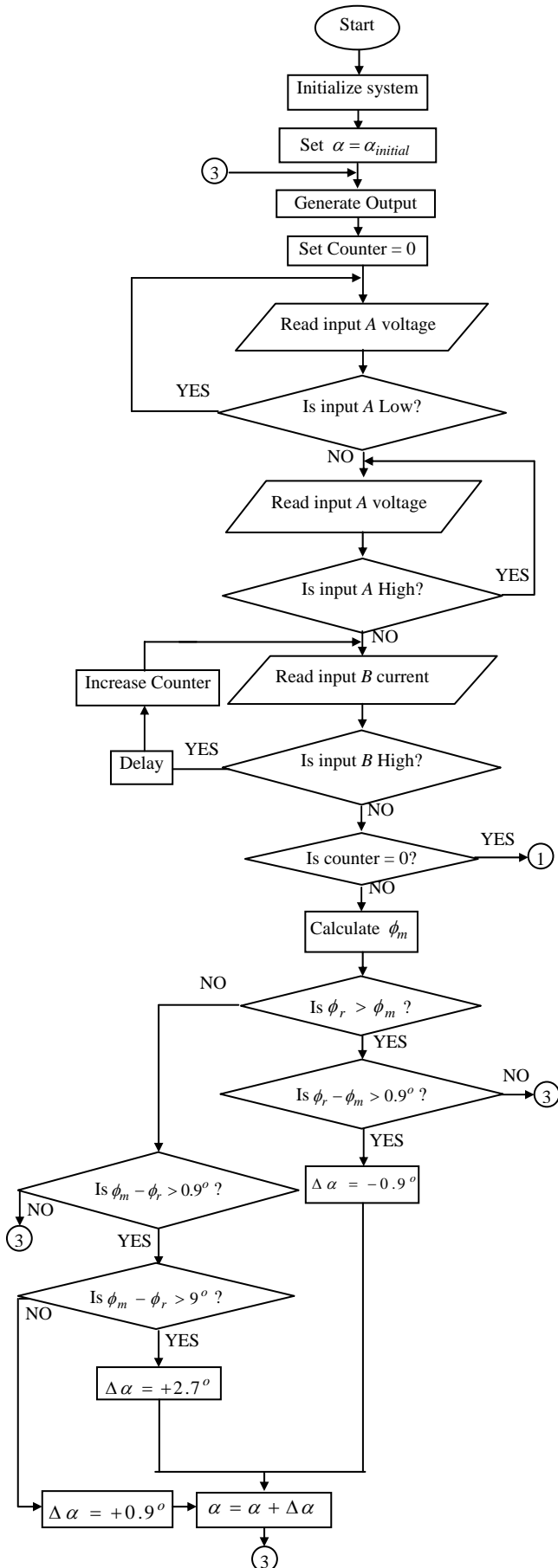
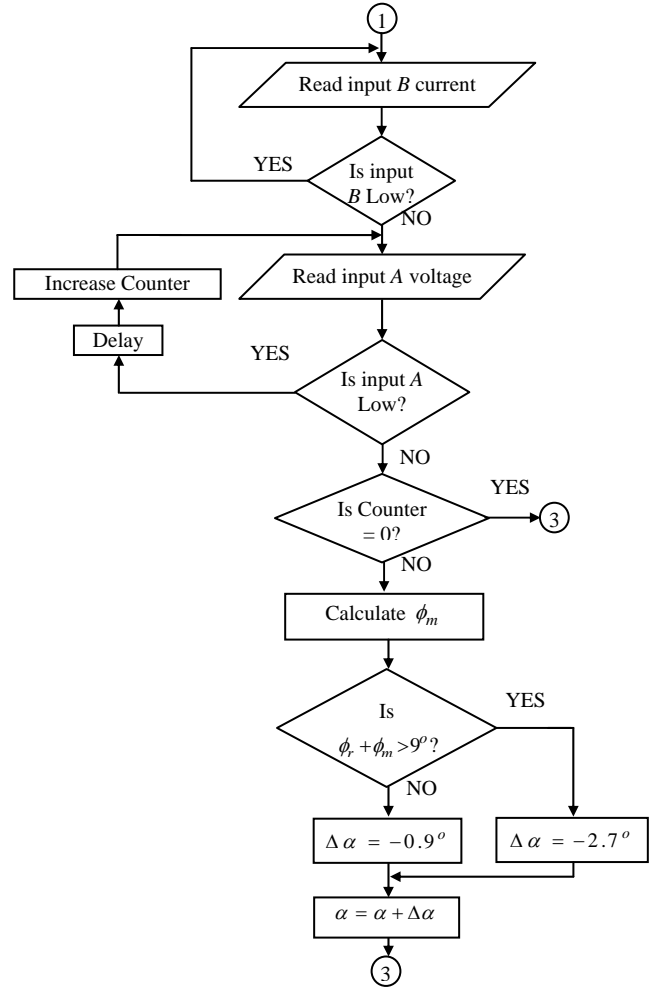


Figure 7: Flow Chart of the proposed PFC circuit (Cont.)



(Cont.) Figure 7: Flow Chart of the proposed PFC circuit.

The microcontroller will then distinguish whether it is the case of  $|\phi_r| > |\phi_m|$  or the case of  $|\phi_r| < |\phi_m|$  and thus compares the measured phase angle  $\phi_m$  with the required or reference value  $\phi_r$ , and chooses the change,  $\Delta\alpha$  in the TRIAC firing angle,  $\alpha$  accordingly, as shown in Figure 7.

After that, the microcontroller jumps back to reload the  $rALPHA$  with the new value of  $\alpha$  and then tests RB1 after clearing the Counter, and the above sequence is repeated. If the contents of Counter are found to be zero, this means that input RB1 is low throughout the test, which in turn means that it is in case 1 in which the fundamental supplied current is leading the fundamental supplied voltage (see Figure 3). In such a case, the microcontroller branches (Figure 6) read and test the input RB2.

As long as the RB2 is low, the microcontroller continues looping and testing that pin. When RB2 goes high, pin RB1 is read and tested. As long as RB1 remains low, the microcontroller will continue looping and testing RB1. Register Counter is incremented after each test. If the contents of Counter are found to be zero, this means that  $\phi_m$  equals to 0, which in turn means that the fundamental supplied voltage and current are in phase. In such a case, the value of  $\alpha$  is kept constant, and the microcontroller jumps back to reload the  $rALPHA$  with  $\alpha$ , and a new cycle of the testing procedure is started.

If the contents of Counter are not zero, the program starts calculating  $\phi_m$ . In this case,  $\phi_r$  and  $\phi_m$  have different signs (since  $\phi_r$  is always lagging), and hence, the value  $\phi_r + \phi_m$  is tested to find the actual deviation of  $\phi_m$  from  $\phi_r$ . A large deviation needs a large step change  $\Delta\alpha$  in the thyristor firing angle  $\alpha$ , whereas a small deviation needs a smaller  $\Delta\alpha$ . After the *rALPHA* is reloaded with the new value of  $\alpha$ , the microcontroller jumps back to read and test pin RB1 after clearing the Counter, and the above sequence is repeated.

Referring to the calculated values, all actual measurements and comparison of  $\phi_m$  and  $\phi_r$  are made in microseconds rather than in degrees. The loop time,  $D$  is adjusted to be 50  $\mu\text{s}$ , which corresponds to an angle of  $0.9^\circ$  at a supplied frequency of 50Hz. Since the LSB in Counter represents a delay angle of  $0.9^\circ$ , a change ( $\Delta\alpha$ ) of  $0.9^\circ$  corresponds to a change of a decimal number of 1, whereas a change of  $\Delta\alpha$  equals to  $2.7^\circ$  corresponds to a decimal number of 3. When the differences between  $\phi_m$  and  $\phi_r$  is decreased to a value less than or equal to  $0.9^\circ$ ,  $\phi_m$  is considered to be equal to  $\phi_r$  and thus  $\alpha$  is no longer changed. However, one may change this difference to any other value that achieves the required accuracy.

#### IV. SIMULATION RESULTS

The proposed power factor corrector circuit is tested using Proteus Design Suite in which the simulations have been divided into 5 study cases depending on the loading conditions, i.e.: (1) purely resistive load, (2) large inductive load (with  $\phi_m - \phi_r > 9^\circ$ ), (3) small inductive load (with  $\phi_m - \phi_r < 9^\circ$ ), (4) inductive load with over corrected condition (with  $\phi_r > \phi_m$  and  $\phi_r - \phi_m > 0.9^\circ$ ), and (5) capacitive load (with  $\phi_r + \phi_m > 9^\circ$ ). For all study cases, the reference phase angle,  $\phi_r$  is set to 6 steps ( $5.4^\circ$ ) or the system's power factor will be corrected to 0.9956.

##### Study Case (1)

In this case, the system voltage and current waveforms are always in-phase. The microcontroller does not correct the TRIAC firing angle ( $\phi_m < \phi_r$ ) as depicted in Figure 8.

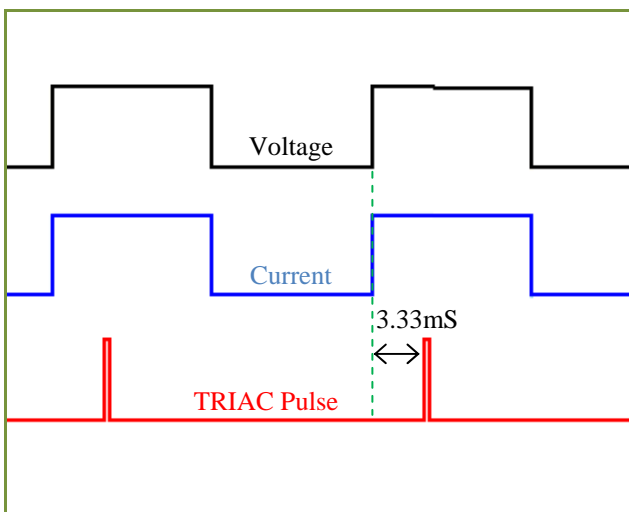


Figure 8: Waveforms for study case (1).

The TRIAC firing angle is initially set to  $60^\circ$  or equals to 3.33mS. Since the voltage and current waveforms are operating at the same phase all the time, the firing angle is consequently remains at its initial setting angle for each cycle (1 cycle = 20mS for 50Hz supply).

##### Study Case (2)

The power system is connected to large inductive load so as the system current lags the voltage by 1mS ( $18^\circ$ ). In this case, the calculated  $\phi_m$  is 20 steps. Since  $\phi_m - \phi_r > 9^\circ$ , the firing angle must be increase  $+2.7^\circ$  (150 $\mu\text{s}$ ) in the next cycles so as to decrease the reactor current.

Obviously, the firing angle before the correction is  $60^\circ$  (3.33mS) and the firing angle after the correction is  $62.7^\circ$  (3.48mS) as shown in Figure 9.

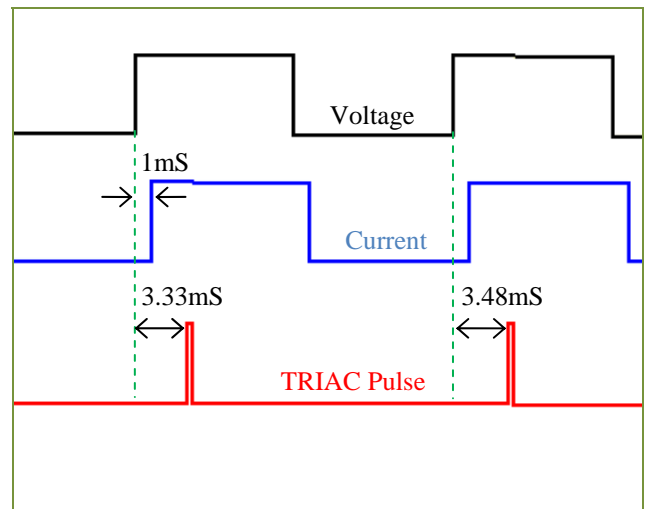


Figure 9: Waveforms for study case (2).

##### Study Case (3)

The power system is connected to small inductive load with the system current lags the voltage by 500 $\mu\text{s}$  ( $9^\circ$ ) and thus  $\phi_m$  is calculated as 10 steps. Since  $\phi_m - \phi_r < 9^\circ$ , the firing angle must be increase  $+0.9^\circ$  (50 $\mu\text{s}$ ) in the next cycles until  $\phi_m = \phi_r$ .

This scenario is depicted in Figure 10. The firing angle before the correction is 3.33mS and after the correction, it is adjusted to 3.38mS ( $60.9^\circ$ ).

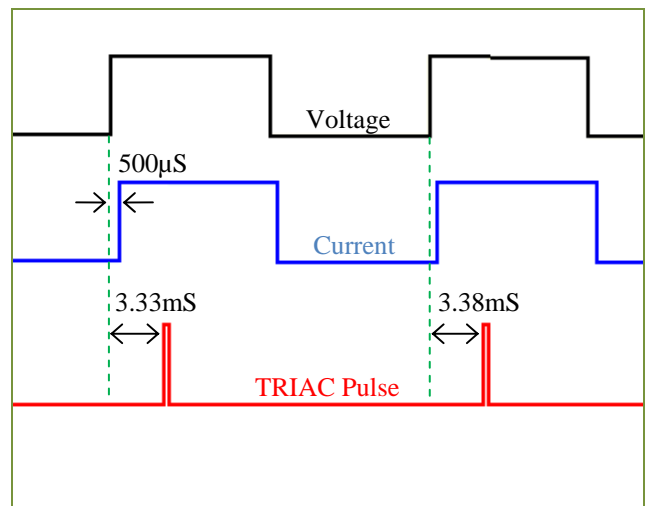


Figure 10: Waveforms for study case (3).

#### Study Case (4)

This study case representing the scenario of the over corrected as in case (2) and case (3). As shown in Figure 11, the firing angle is now over corrected to the condition that  $\phi_r > \phi_m$  and  $\phi_r - \phi_m > 0.9^\circ$ . The system current at this moment is still lagging the voltage by  $100\mu\text{s}$ . Thus, the firing angle now has to be decreased by  $-0.9^\circ$  to  $3.28\text{mS}$  ( $59.1^\circ$ ).

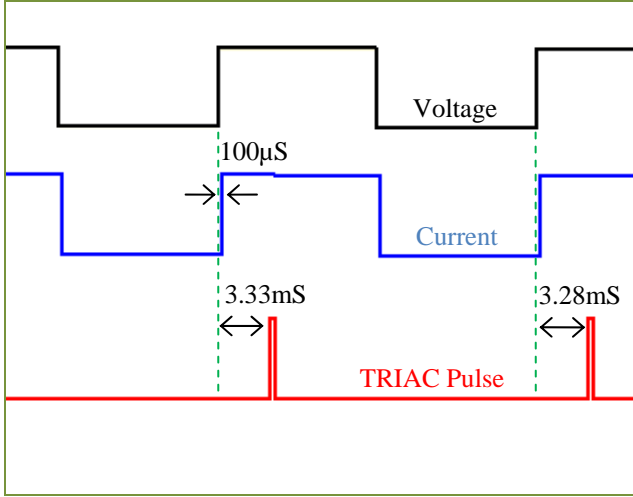


Figure 11: Waveforms for study case (4).

#### Study Case (5)

The power system is connected to capacitive load and the system current leads the voltage by  $2\text{mS}$  or  $36^\circ$ . In this case, the phase angle ( $\phi_m$ ) is calculated as 40 steps. According to the phasor diagram in Figure 5(a) and the flow chart in Figure 7, if  $\phi_r + \phi_m > 9^\circ$ , the firing angle must be decreased by the steps of  $-2.7^\circ$  ( $-150\mu\text{s}$ ). This event can be observed in Figure 12, in which the corrected firing angle is  $3.18\text{mS}$  (or  $57.3^\circ$ ).

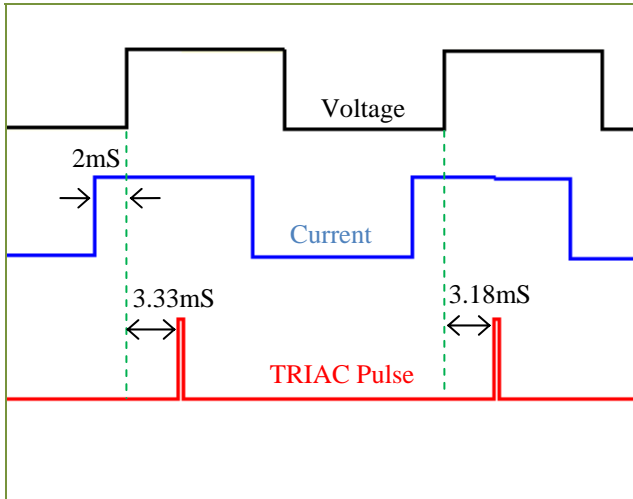


Figure 12: Waveforms for study case (5).

## V. CONCLUSION

A microcontroller-based power factor corrector for single-phase low power factor loads has been presented in terms of the software algorithm development. The system can adjust the supplied system power factor to almost any required reference value. The proposed power factor correction scheme is designed to operate with most of the possible lagging or leading values of the load power factor. This shows the adaptability of this power factor corrector. The system design allows more accurate in the measuring and compensating power factors than the passive power factor designs. This is because its operation principles' is based on the measurement of the displacement angle between the fundamental components of the supplied voltage and current, rather than measuring the system voltage signal. The principle of operation adopted in this paper may be applied further in designing the power factor correction schemes for loads driven by 3-phase voltage supplies.

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## REFERENCES

- [1] Alexander, C.K. and Sadiku, M.N.O. (2000). "Fundamentals of Electric Circuit" United States of America: McGraw-Hill Companies, Inc.
- [2] Stephen, J. C. (1999). "Electric Machinery and Power System Fundamentals." 3<sup>rd</sup>.ed. United State of America: McGraw-Hill Companies, Inc.
- [3] John J. Grainger, William D. Stevenson (1994). "Power System Analysis." New York: McGraw-Hill.
- [4] Jos Arrillaga, Neville R. Watson (2003). "Power System Harmonics" 2<sup>nd</sup>.ed. Chichester: John Wiley.
- [5] J. E. Miller (1982). "Reactive Power Control in Electric System." New York: Wiley
- [6] Roger C. Dugan, Mark F. McGranaghan, H. Wayne Beaty (1996). "Electrical Power Systems Quality" 1<sup>st</sup>.ed. New York: McGraw Hill.
- [7] Paul Gill (1998). "Electrical Power Equipment Maintenance and Testing." Boca Raton, FL: CRC Press.
- [8] Keith Harker (1998). "Power System Commissioning and Maintenance practice." London: Institution of Electrical Engineers.
- [9] Ramasamy Natarajan (2005). "Power System Capacitors." Boca Raton, FL: Taylor & Francis.
- [10] H.M. El-Bolok, M.E. Masoud, And M.M. Mahmoud (1990). "A Microprocessor -Based Adaptive Power Factor Corrector for Nonlinear Loads" Faculty of Engineering and Technology, University of Helwan, Cairo, Egypt.