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Automated Power Factor Correction for Smart Home

Bilal Naji Alhasnawi
Electric Eng.
University of Basrah
Basra/ Iraq.
bilalnaji11@yahoo.com

Dr Basil H.Jasim
Electric Eng.
University of Basrah
Basra/ Iraq.
hanbas632@gmail.com

Abstract: *In the current scenario, power factor has become an important concern in all industries. Poor power factor gives rise to many problems which result in financial loss of industries and also for the commercial users. The main concern of this work is to improve the usage of real power with respect to reactive power hence improving the power factor. Here we have used the technique of relay switching method with a capacitor so that any drop in power factor can be sensed by the controller and switch the capacitor as required. This will not only help to improve power factor but also demand of electricity supply on utility side will be reduced. The Significance of this work is to build an APFC (Automatic Power Factor Correction) Unit. The APFC appliance calculates the reactive power (KVAR) expended by a system's load and compensates the lagging PF (power factor) utilizing capacitances from capacitor banks.*

Keyword: Potential Transformer, Amplifier (Op-Amp), Current Transformer, Two Microcontroller, Capacitors, Conductors, Relays, LCD 20x4 (Liquid Crystal Display).

I. INTRODUCTION

The PF is the ratio between the actual load power (KW) and the apparent load power (KVA) drawn via an electrical load [1]. It can be also stated as usage of real power to total power provided. Poor power factor gives rise to many problems such as large kVA rating of the equipment, larger conductor size, poor voltage regulation, increased copper loss, reduced power handling capacitor and much more. There are several methods for improving the power factor of the system such as a synchronous condenser, static compensator, static capacitor, etc. they are either highly priced methods or inefficient methods. To overcome these disadvantages, the new method depends on reactive power and this method is very efficient and also less expensive compared to other methods. A necessary capacitance is connected so that PF is adjusted as close to unity as possible. Theoretically, capacitors could provide 100% of the needed KVAR, however, practically, correcting PF much nearer to unity.

Automatic power factor controller project is planned to improve power factor automatically, whenever power factor falls below convinced level [2]. As we know that the requirement of electrical energy is increasing day by day, more and more inductive loads are increasing in industries as well as for household purpose [3]. Inductive loads are the main reason for low power factor in power system [4].

This paper will describe how the power factor will be improved by using reactive power technique.

II. ADVANTAGES OF POWER FACTOR IMPROVEMENT

The power factor derives the actual usage of real power by the equipment. The power triangle is shown in Fig.1. In this figure, real power is denoted by kW, reactive power denoted by KVAR and apparent power is denoted by kVA. The power factor from Fig.1 can be derived as cosine angle of apparent power and real power which is denoted by CosØ. If the PF of the system is “1‟, then it can be said that 100% power has been used and no reactive power is present. Similarly, if power factor is “0.5‟, then it can be stated that 50% real power is consumed and remaining 50% is reactive power. So power factor is a very important concept which has to be studied to specify the system power usage and also losses [5], [6], [7], [8]. The power factor can be denoted mathematically as shown in fig1

$$\cos\emptyset = \frac{Real\ power\ (KW)}{Apperant\ power\ (KVA)} \text{.........(1)}$$

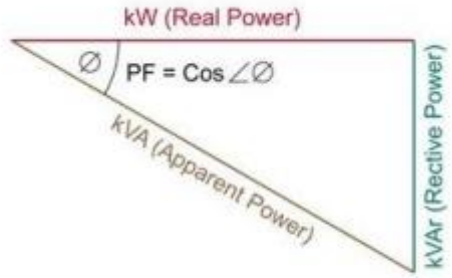

Fig.1 Power Triangle

From the equations below we can identify the disadvantages of poor power factor;

$$\text{Real power} = \text{I} * \text{V} * \cos\emptyset \text{....... (1Ø)} \qquad (2)$$

$$I = \frac{P}{V * \cos\emptyset} \text{.......} \qquad (3)$$

$$\text{Real power} = \sqrt{3} * \text{I} * \text{V} * \cos\emptyset \text{....... (3Ø)} \qquad (4)$$

$$I = \frac{P}{\sqrt{3} * V * \cos\emptyset} \text{........} \qquad (5)$$

1- Less Demand of kVA rating of Equipment

$$Apperant\ power(KVA) = \frac{Real\ power\ (KW)}{\cos\emptyset} \text{... (6)}$$

From above equation, we can clearly see that power factor is inversely proportional to the apparent power. So, if the power factor is low then the kVA demand of the equipment will be increased, and the utility will have to supply high demand.

2- Smaller conductor diameter

To deliver a fixed amount of power if power factor is low then the current drawn by the system will be large. To overcome this, conductor with a larger diameter will be required. This will cause an increase in the cost of the conductor.

3. Copper loss

As referred from above if the current drawn by the system is increased the copper loss of the system will also increase. This will cause an increase in total loss of system and hence the efficiency of the system will be decreased.

4- Voltage regulation

Due to large currents, a high voltage drop occurs in the alternator which reduces the voltage at the terminal of the alternator. As no load gives voltage regulation to full load voltage drop the regulation will be poor.

III. AUTOMATED POWER FACTOR CORRECTION SYSTEM DESCRIPTION

The proposed system makes use of a microcontroller to manage the process of switching the capacitors bank connected at the end of main power supply. It is APFC equipment connected at the end of the main supply close to the variable load. In general, APFC consist of 3 of the capacitor connected to the load terminal of the main supply, relays connected in series with capacitors and controller. In this work, three capacitors had utilised to form the APFC. The task of the controller is to read the system power factor, voltage and current. Then according to a known algorithm, the controller decides how many capacitors should be inserted to bring up the power factor to the required value, thereby the main supply is being compensated with shunt technique. The main equipment that composed the APFC model is reactive power elements (capacitors), switching elements (relays), contactors connected in series with the capacitor (in the case of high current rating for protection of the relay) interfacing circuits (voltage, current and power factor) and controller.

IV. SYSTEM DESCRIPTION

Our system takes 220v supply and steps down the voltage to 9V through a potential transformer, then converts this 9v AC into the less 5V input to the microcontroller. A signal of current is also obtained from the main power supply by a CT and processed by a current sensor circuit for microcontroller input. The microcontroller performs PF calculations and controls capacitors. The results displayed on a 4x20 liquid crystal display. The block diagram of the complete work shown in the following Fig.2.

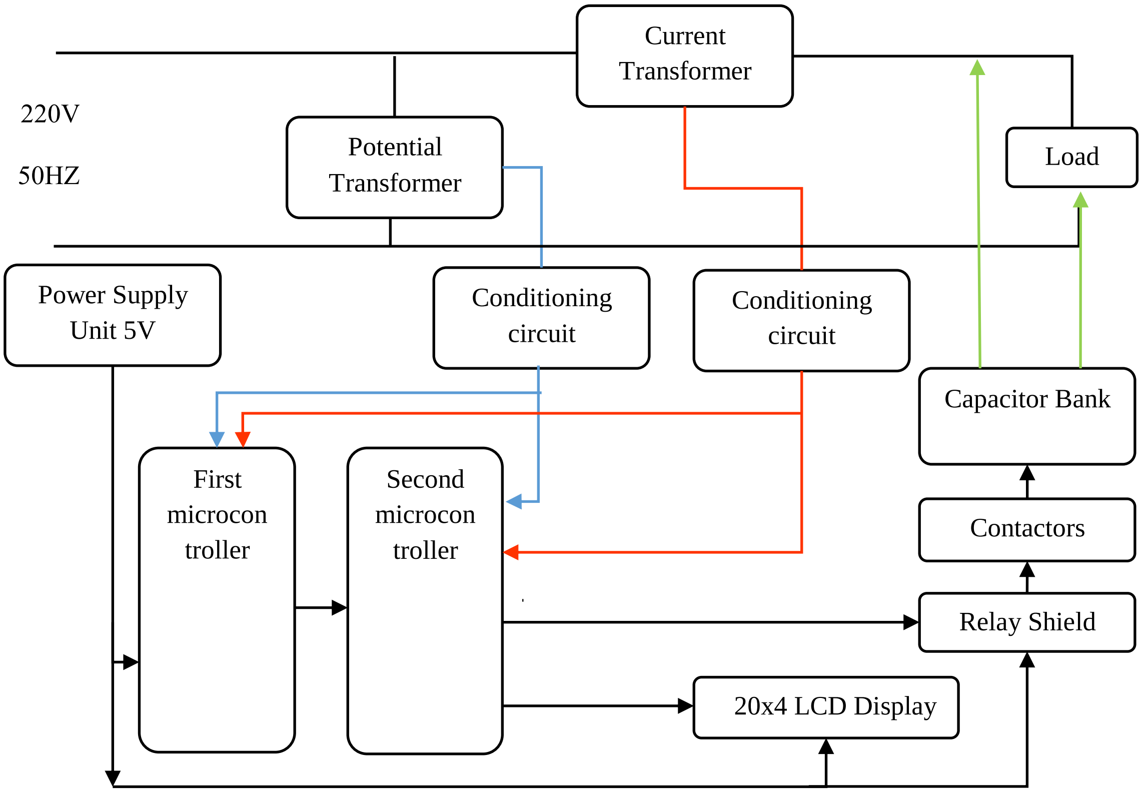

Fig. 2 Proposed System Diagram

V. DESIGN METHODOLOGY

The whole Automated Power Factor Correction unit involves of several modules these modules are: Capacitor Banks, 4x20 LCD monitor, two microcontrollers, main supply, Current sensor, Current sensor circuit, a Voltage sensor, Voltage sensor circuit, conductors, Relay driver and Inductive load network.

A. AT328 Microcontroller

It is a low power CMOS 8-bit MCU based on the AVR enhanced RISC architecture. The powerful execution of instructions in a single clock cycle leads to the achievement of 1 MIPS per MHz throughputs allowing the designer to optimise power consumption versus processing speed. The CPU is the brain of the MCU which controls the execution of the program. The microcontroller consists of 256/412/1K bytes EEPROM along with the 512/1K/2K bytes of SRAM, 4K/8K bytes of in system programmable flash with reading while writing capabilities. The AT328-MCU has many advantages as 23 general purposes I/O lines, three adjustable timer/counters with compare modes, 32 general purpose working registers, a byte oriented 2-wire serial interface, external, internal interrupts and a serial programmable USART, a 6-channel 10-bit ADC, an SPI serial port [14]. The AT328 and pins configuration is shown in Fig.3.

Fig.3 AT328 Microcontroller

C. network of Inductive load

The inductive load is a mixture of loads consuming huge electrical power and having inductive characteristics due to lagging power factor.

D. Potential transformer

The potential transformer in proposed system transfers 220V to 9V shown in Fig.4 .

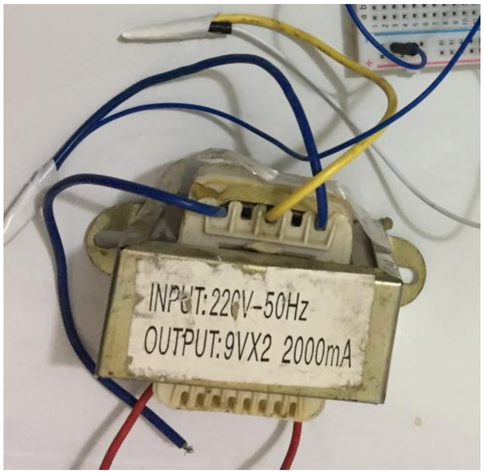

Fig.4 Potential Transformer

1. Voltage Measurement

To read the main power supply voltage, first the system voltage 9 V RMS must be stepped down to the level that the microcontroller is compatible. Microcontroller A/D converter deals with the signal in the range of 0 to 5 V, So the next step should be taken is converting the stepped down RMS voltage to signal voltage in the range of (0-5V).

2. Circuit for Sensing Voltage

An RMS voltage measurement is required to determine, PF, S and P. This measurement can be completed by utilising an AC to AC Potential transformer. The Potential transformer in the convertor provides separation from the high voltage. The aim for the signal conditioning electronics detailed under is to condition the output of the AC power convertor, so it meets the necessities of the microcontroller analog inputs: a positive voltage between 0V and the analog to digital converter (ADC) reference voltage (5V). The output signal from the AC Potential transformer is a sinusoidal signal. a 9V power converter the positive voltage peak be +12.727V, the negative peak -12.727V. The signal conditioning electronics need to convert the output of the converter to a waveform that has a positive peak that's less than 5.0V and a negative peak that is more than 0.0V. So we need to:

1. Scale down the sinusoidal waveform.
2. Add an offset, so there is no negative component.

The sinusoidal waveform can be scaled down using a voltage divider connected crossways the adapter's terminals, and the offset (bias) can be added using a source of voltage created by another voltage divider connected across the microcontroller's power supply.

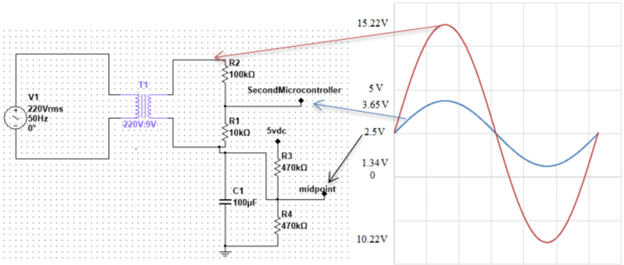

Fig. 5 Voltage sensing circuit diagram

Resistors R2 and R1 form a voltage divider that scales down the Potential transformer AC voltage. Resistors R4 and R3 deliver the voltage bias. C1 (Capacitor) provides a low impedance path to ground for the AC signal. The value of C1 is not critical, (10 µF – 100 µF) will be satisfactory. R2 and R1 need to be chosen to give a peak voltage output of ~1V. For an AC to AC converter with a 9V RMS output, a resistor combination of 100k for R2 and 10k for R1 would be suitable:

Peak output voltage

= R1 / (R2 + R1) x peak voltage input

= 10k / (10k + 100k) x 12.72V =

The voltage bias providing by R4 and R3 should be half of the second microcontroller supply voltage. As such, R4 and R3 need to be of equal resistance. In proposed system used 470k ohm resistors for R4 and R3. If the second microcontroller is running at 5V, the resultant sinusoidal waveform has a positive peak of 2.5V + 1.156V = 3.656V, and negative peak of 1.344V satisfies the microcontroller analog input voltage requirements.

E. Current Transformer

In proposed system, used Current Transformer YHDC used. This CT is made up of a ferrite material. The input current ranges are 0 to 100A which gives output current of 0 to 50mA. The input to the output ratio is about 20000:1. The input frequency ranges from about 50Hz to about 150 KHz. The device works at a temperature of about -25 o C to about 70 o C. Some other single input channeled, Hall-effect based, open-loop type current sensors for measuring AC/DC currents operating in the range of -40 o C to 150 o C whose measurement is as per radiometric voltage are very accurate [13].

Fig. 6 Current Transformer

Circuit of Current sensor

To join a Current Transformer sensor to the second microcontroller, the output signal from the Current Transformer needs to be conditioned, so it meets the input requirements of the microcontroller analog inputs.

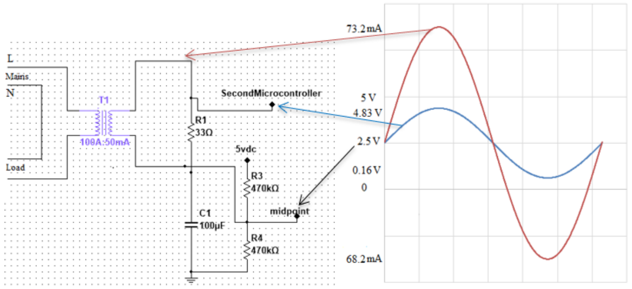

Fig.7 Current sensing circuit

Calculating a Resistor

If the Current Transformer is a "current output" type, the current signal needs to change to a voltage signal with a burden resistor. If it is a voltage output Current Transformer, then this step can be skipped and leave out the burden resistor, as the load resistor built into the Current Transformer.

1) The Current Transformer has a current range of (0A-100A). For this illustration, let's select 100 A as our maximum current.

2) Peak current

Primary peak current = √2 × RMS current

= 1.414 × 100 A =141.4A

3) Peak current in the secondary coil.

The Current Transformer has 2000 turns,

Secondary peak current

= Primary peak current / number of turns

= 141.4 A /2000= 0.0707A

4) To risk amount resolution, the voltage across the burden resistor at peak current should be equal to AREF/2 (one half of the microcontroller analog reference voltage).

Ideal burden resistance

= (AREF/2) / Secondary peak current

= 2.5 V / 0.0707 A = 35.36 Ω

Burden Resistor (ohms)

= (CT TURNS *AREF) / (2√2 *max primary current)

If connect one of the Current Transformer wires to ground and measure the voltage of the second wire, relative to ground, the voltage would vary from positive to negative concerning ground. However, the microcontroller analog inputs require a positive voltage. By connecting the Current Transformer lead we connected to ground, to a source of half the supply voltage instead, the Current Transformer output voltage will now swing above and below 2.5 V thus remaining positive. Resistors R2 & R1 in the diagram above are a voltage divider that delivers the 2.5 V. C1 (Capacitor) has a little reactance a few 100 ohms and provides a path for the AC to bypass the resistor. A value of 100 µF is suitable.

Choosing resistors R3 & R4

Higher resistance lowers quiescent energy consumption. Uses 470 kΩ resistors to save the power consumption to a smallest, as it is intended to run on batteries for many months.

H. Capacitor Bank

The capacitor bank is the collection of different values capacitors. Parallel and Series combination of various capacitors provide a range of capacitance required to compensate reduced power factor. The sizing of capacitors is determined based on the required reactive power (KVAR) demand by the load network. In our proposed system we used capacitors 5µF, 10µF and 20µF.

VI. AUTOMATED POWER FACTOR CALCULATION

To calculate that delay to find out system lead or lag, a first microcontroller is used to determine that delay. The first step that must do is converting the sinusoidal wave of the voltage and current into a square wave, to be logically read by the controller. Fig.8 and Fig.9 respectively show the implemented circuit of the sine wave to the square wave signal converter. So a second microcontroller has been used to calculate the PF. The value of PF then transferred from the first microcontroller to the second microcontroller via PIN communication. A specified circuit is required to send the data from the first microcontroller to the second microcontroller which explained in next section.

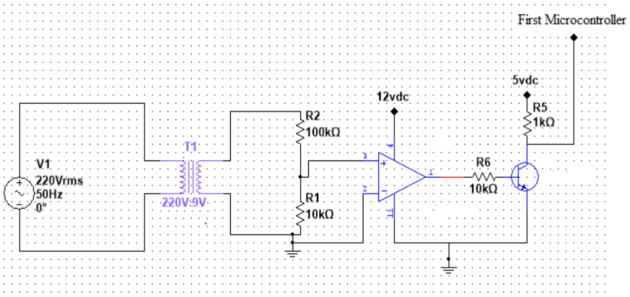

Fig.8 Sinusoidal, square wave converter of voltage

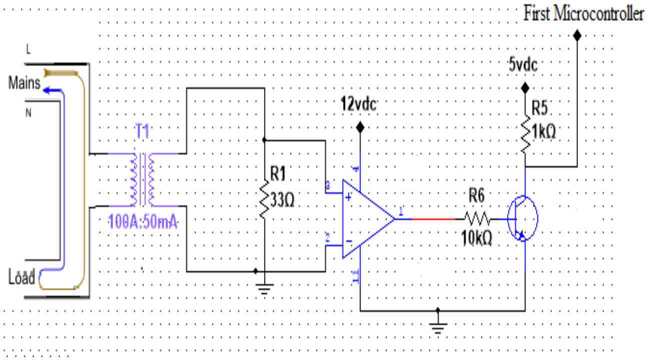

Fig.9 Sinusoidal square wave converter of current

In addition to the power factor value, the first microcontroller also sends an indication as a logic signal to inform the second microcontroller the nature of the power factor (lead or lag). The software of calculating the state of power factor summarised in the flowchart shown in Fig. 10.

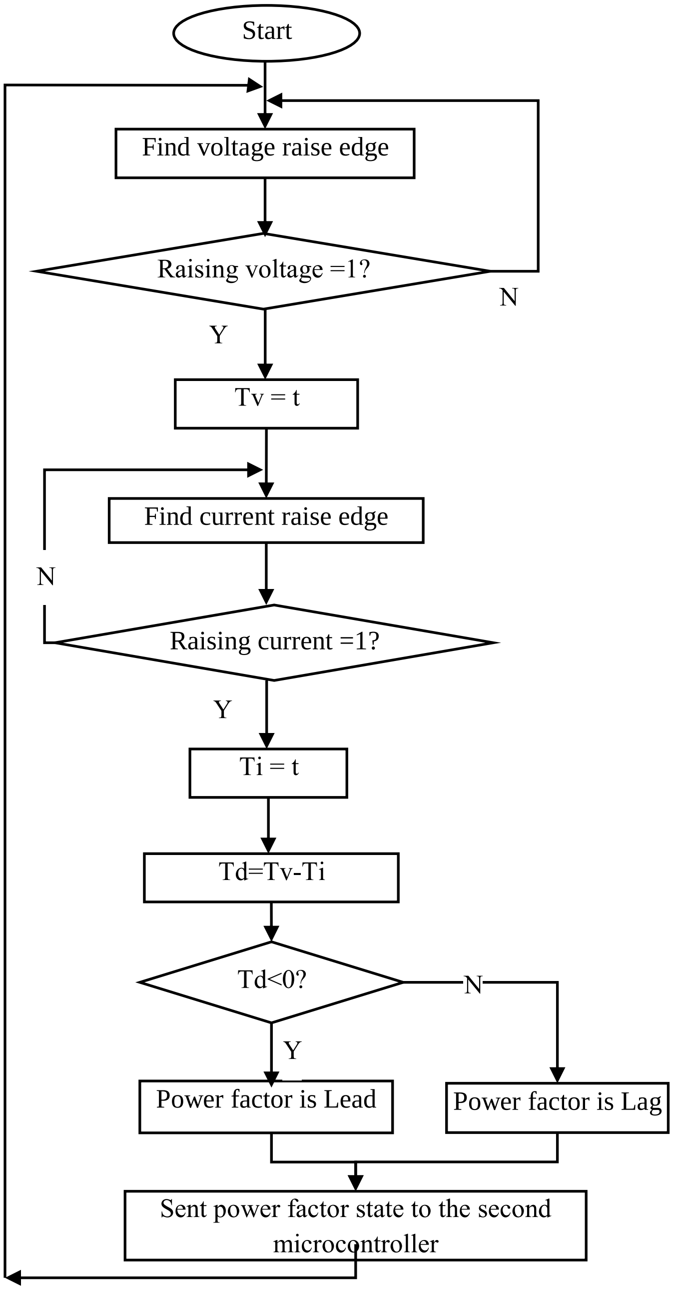

Fig.10 Flowchart of state power factor (lag or lead) in the first microcontroller

VII. DESIGN OF TECHNICAL

Reactive power = $\sqrt{(Apperant\ power)^2 - (Real\ power)^2}$

Capacitance in Farad, C = ((Reactive power) ^{2} /2πf V^2)

Reactive power = V^{2}x2πfC

Where V is the voltage and f are the frequency of the power system.

Reactive power for 5µF capacitor = $(220)^2$x2x3.14x50x5x10^{-6} =76 VAR
Reactive power for 10µF capacitor = $(220)^2$x2x3.14x50x10x10^{-6} =152 VAR
Reactive power for 20µF capacitor = $(220)^2$x2x3.14x50x20x10^{-6} =304 VAR

VIII. SOFTWARE DEVELOPMENTS

This paragraph presents the algorithm of APFC based microcontroller. The process needs to sense the power factor, current and voltage at the end of the main supply of house. The algorithm summarised in the flowchart illustrated in Fig.11. Where, Real power= P (KW), Apparent power=S (KVA), reactive Power=Q (KVAR), current=Irms (A), voltage= Vrms (V).

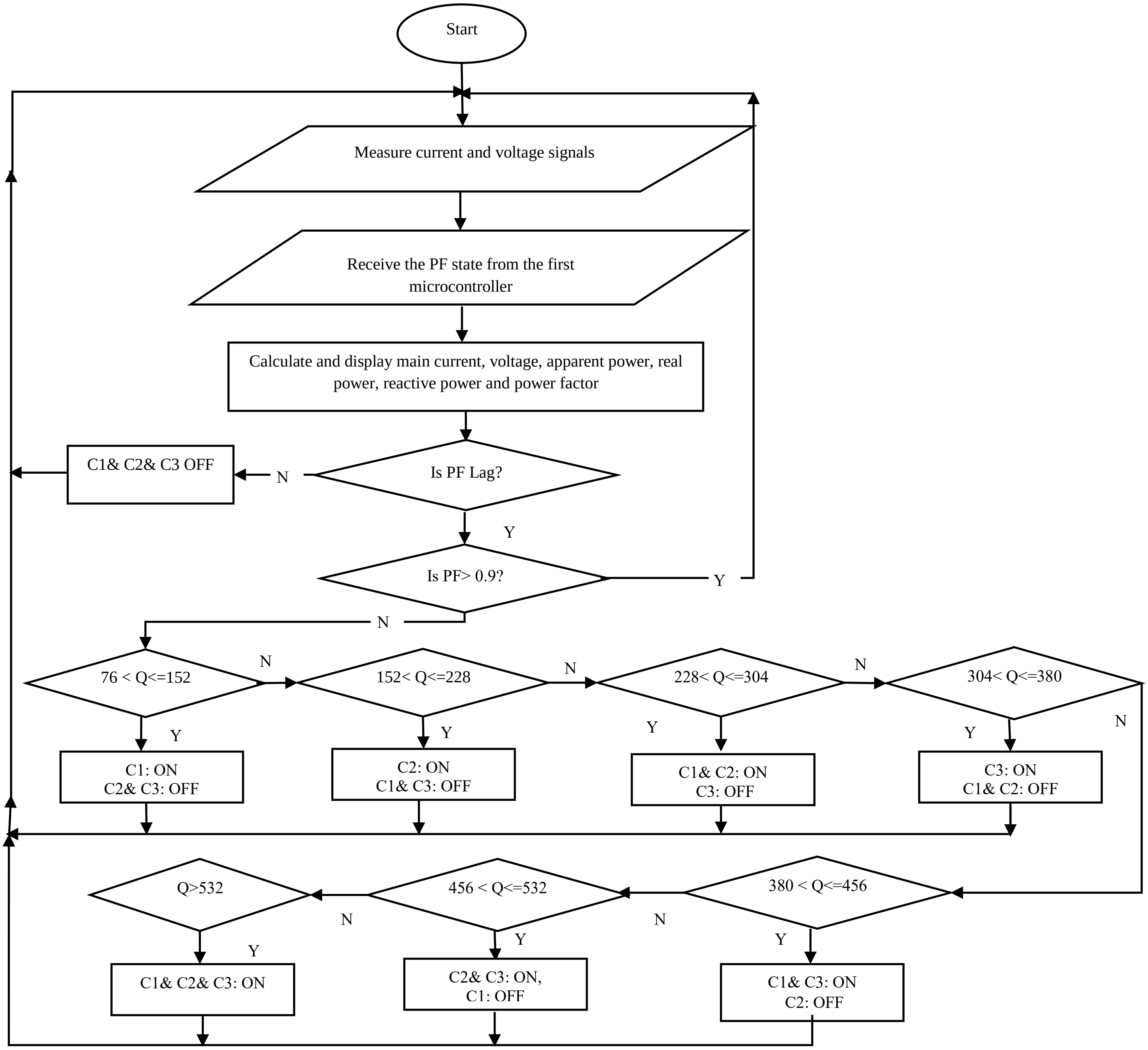

Fig.11 Flowchart of proposed system (second microcontroller)

IX. EXPERIMENTAL SET UP OF SYSTEM UNDER CONSIDERATION

The basic components that have been used to complete this work are main home supply, variable inductive load, capacitors bank, interfacing circuits, switching circuits, tow microcontrollers. Fig.12 shows the complete construction of automatic power factor correction installed on the home power supply.

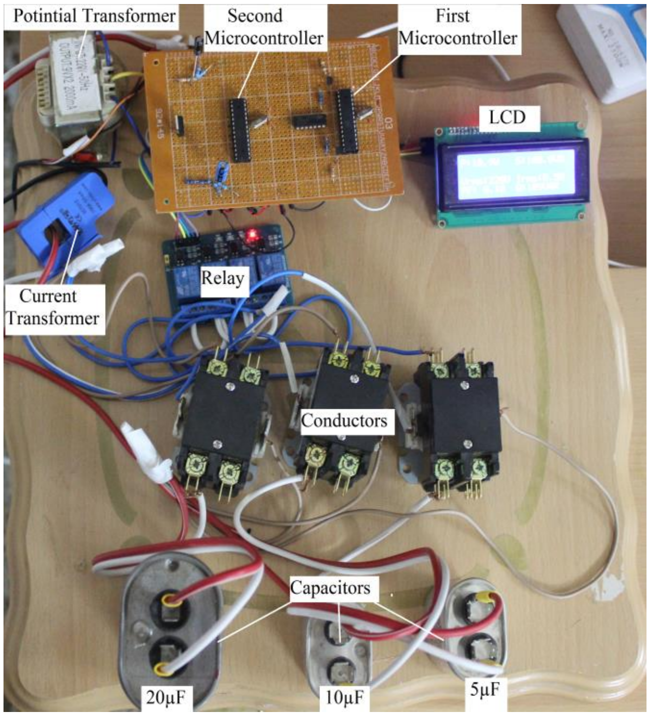

Fig. 12 Complete APFC and Energy Monitoring System

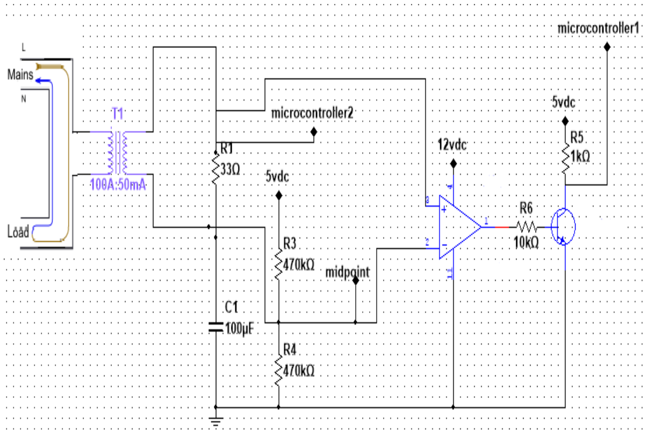

Fig. 13 Current Circuit

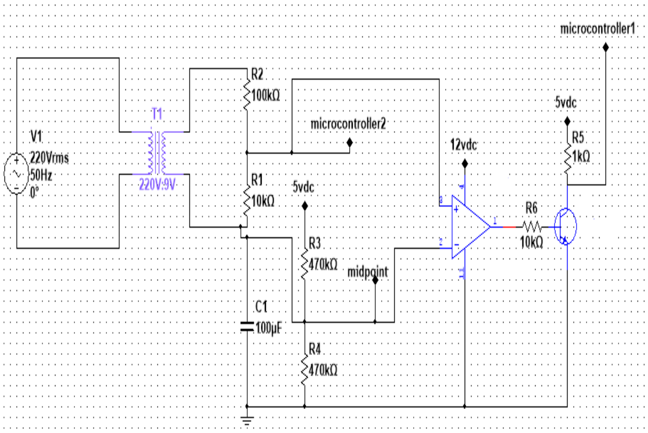

Fig. 14 Voltage Circuit

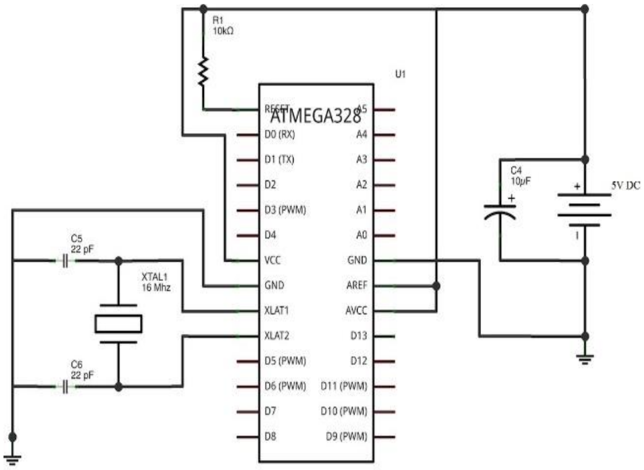

Fig. 15 Microcontroller Circuit

X. RESULTS AND ANALYSIS IN REAL SMART HOME

Table1 provides the data recorded from the smart home system.

Load used in APFC for the smart home system:

1) Fluorescent Light (FL),
2) Ceiling Fans in house (fan)
3) Refrigerator
4) Water Pump motor
5) Television (TV).

Table I

The experimental results of APFC on real home

Appliances	P (W)	S (VA)	V (V)	I (A)	PF	Q(VAR)	CμF	State
2 FL +1fan	196	229.2	214	1.1	0.86	120	NO	Before Correction
	196	202	215	0.9	0.97	40	5	After Correction
3 FL +2fan	368.7	431	227	1.9	0.86	224	NO	Before Correction
	352.8	364.3	225	1.6	0.97	90.8	10	After Correction
4 FL+ 1fan	291.9	384.1	217	1.8	0.79	250	NO	Before Correction
	281.9	290.1	218	1.3	0.97	64	15	After Correction
6 FL +1fan	369.8	528	218	2.4	0.7	378	NO	Before Correction
	349.3	362.5	217	1.7	0.96	97	20	After Correction
5 FL +2fan	452	584.8	223	2.6	0.77	369	NO	Before Correction
	448.2	460.9	224	2.0	0.97	111	20	After Correction
6 FL +1fan+water pump	696.8	813.7	217	3.7	0.86	418	NO	Before Correction
	687	688.8	215	3.2	0.99	38	25	After Correction
8 FL +3fan +water pump	820	975.6	214	4.5	0.84	523	NO	Before Correction
	760.5	773.5	216	3.6	0.98	114	30	After Correction
8 FL +3fan	585.5	769	214	3.6	0.76	496	NO	Before Correction
	564.5	568.5	213	2.7	0.99	62	30	After Correction
5 FL+ 2refregrator +2fan	832.5	1108.6	218	5.1	0.75	742	NO	Before Correction
	837.5	860.2	218	3.9	0.97	204	35	After Correction
6 FL+ 3refregrator +2fan	957.9	1293.5	218	5.9	0.74	874	NO	Before Correction
	967.3	1010.7	218	4.6	0.96	302	35	After Correction
12 FL+6fan+ 3refregrator+ TV	1664.9	2055.6	218	9.4	0.81	1196	NO	Before Correction
	1652	1755.7	218	8	0.94	623	35	After Correction
10 FL+7fan+ 3refregrator+ 2TV	2401.2	2703.1	216	12.5	0.89	1242	NO	Before Correction
	2414.9	2527.3	218	11.6	0.96	716	35	After Correction

As shown in Table I, we note that the value of the power factor before the addition of the capacitance was low, i.e. less than 0.9, while at the addition of the capacitance we note that the power factor value is close to 1.

Besides automatically correcting PF of an electrical load, the designed system also performs power observing. The 4x20 LCD shows the power consumption. It shows the user the immediate P (real power), S (apparent power), voltage (Vrms), current flow (Irms), PF (power factor) and Q (reactive power) consumption.

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P:957.9W  S:1293.5VA

Vrms:218V Irms:5.9A
PF: 0.74  Q:874VAR
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Fig.16. Condition of Load before APFC

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P:967.3W  S:1010.7VA

Vrms:218V Irms:4.6A
PF: 0.96  Q:302VAR
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Fig.17: Condition of Load after APFC

XI. CONCLUSION

The automatic power factor correction thus gives us an efficient technique of capacitor switching technique which utilised in improving the power factor of the system to maintain it near unity as much as possible which will give various advantages to industrial consumers and also the commercial consumers. So by using automatic power factor correction, the system calibrates the power factor in real time and according to the condition of power factor signal of switching is given to the capacitor banks connected.

XII. REFERENCES

[1] Y. Kabir, Y. M. Mohsin, and M. M. Khan, “Automated Power Factor Correction and Energy Monitoring System”, IEEE, Energy and Technology, 3rd International Conference, pp. 1-5, 2017.

[2] J. G. Cho, J. W. Baek, D. W. Yoo, H. S. Lee, “Reduced Conduction Loss Zero Voltage Transition Power Factor Correction Converter With Low Cost ”, IEEE, Transactions on Consumer Electronics, Vol. 45, Issue 3, pp. 395- 400, Jun 1998.

[3] L. D. Jones, D. Blackwell, “Energy Saver Power Factor Controller for Synchronous Motors”, IEEE, Transactions on Power Apparatus and Systems, Vol. 102, Issue 5, pp. 1391 -1394, May1983.

[4] Y. Jiang, F. C. Lee, G. Hua, W. Tang,” A Novel Single phase Power Factor Correction Scheme, Applied Power electronics” IEEE, Applied Power Electronics Conference and Exposition, Conference Proceedings, Eighth Annual. 1993.

[5] M. A. EL-Sharkawi, M. Chen, S. V. Vadari, G. W. Fissel and S. S. Venkata,, “ Development and Field Tasting of A Closed Loop Adaptive Power Factor Controller”, IEEE, Transactions on Consumer Electronics, Vol.3, No. 2, pp. 235-240, June 1988.

[6] M. Nalbant, “Power Factor Calculations and Measurement”, IEEE, Transactions on Consumer Electronics, Vol.5, No. 10, pp. 543-552, 1990.

[7] A. Kumar Tiwari, D. Sharma, V. Kumar, “Automatic Power Factor Correction Using Capacitive Bank” International. Journal of Engineering Research and Applications, Vol. 4, Issue 2 (Version 1), pp.393-395, Feb, 2014.

[8] S. B. Jamge and P. Devanpalli, “Automatic Power Factor Controller using PSoC3”, International Journal of Engineering Research & Technology (IJERT), Vol. 3 Issue 5, pp. 1056-1058, May, 2014.

[9] S. Luitel, “Design and Implementation of a Smart Home System”, M. Sc Thesis, Helsinki Metropolia University of Applied Sciences, Finland, 29 August 2013.