

# An Optimized and Cost Effective Power Management System for End-users of Electricity

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## Abstract

This paper presents a novel technique of Optimized and Cost Effective Power Management System (OCEPMS) for end users of electricity. The technique incorporates all the three important aspects of a power management system and gives a complete microcontroller based low cost solution. These aspects include: power factor improvement, voltage optimization and surge / spike suppression. For power factor improvement, an algorithm is devised which automatically switches capacitors based on real time calculated requirements. A soft switching mechanism is used for the purpose of bringing capacitors in or out of the circuit depending upon the overall inductive load. For voltage optimization purpose, a circuitry is included in the design which manages incoming voltage and regulates it to a level more suitable for home appliances. Furthermore, to protect the system from dangerous and harmful surges and spikes transmitted through supply line, a surge suppression circuitry is also incorporated in the design. The proposed design is physically developed and experimentally tested with various domestic loads like compact florescent lamps, chokes, pumps and a combination of induction motors. Experimental results validate proposed approach and show that, up to 15% reduction in domestic electricity bills can be achieved by using the developed power management system.

**Keywords:** Power management; power factor improvement; voltage optimization; surges and spikes circuitry; domestic users.

## 1. Introduction

The present energy crisis has required significant energy reduction in all areas. The demand of energy utilization in domestic areas has been increasing every year due to installation of new home appliances for daily life styles.

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In the last few years it has been observed that the “cost of power” is increasing due to escalation in cost of fuels for generation. Peoples want to save on electricity consumption, because electric rates have become unaffordable for them. Power can be saved only by minimizing the losses and it can be saved by improving the power factor of domestic inductive load and with voltage optimization [1, 2].

The conventional scheme for power factor improvement involves a zero crossing detector which is usually accomplished by converting sinusoidal current and voltage wave forms to square waves and then comparing them by means of a comparator [3, 4]. Although this approach is quite satisfactory for sinusoidal currents, the problem of higher harmonic components caused by nonlinear appliances present in the load remains unaddressed. This causes incorrect readings of power factor (PF) and ultimately leads to failure in the improvement of power factor.

A concise survey of literature reveals a number of techniques used for power factor improvement [5, 6], some of which are purpose specific e.g. AC to DC switch mode power supply or end-user appliances [7, 8], while some are without intelligent devices such as Microcontroller, Application Specific Integrated Circuit (ASIC) etc. These designs face difficulties in unknown load conditions because at nonlinear load, higher order harmonic components dominate the load which causes incorrect measurement of power factor (PF) value. Another major disadvantage of traditional approach is that the value of power factor fluctuates at variable noise conditions because only zero crossing (ZC) is sensed. A noise having small SNR (Signal to Noise Ratio) but sudden large value at zero crossing (ZC) can cause a major change in measured power factor (PF) value.

In the proposed Optimized and Cost Effective Power Management System (OCEPMS), square wave converter stage for zero cross detection of power factor improvement [1, 9] has been eliminated and instantaneous values of current and voltage signals are utilized.

Voltage optimization is another important aspect in proposed OCEPMS. Literature review reveals that there are number of voltage regulation techniques at consumer end such as coil rotation AC voltage regulator, electromechanical regulators, PWM static voltage regulator, constant voltage transformer regulator and microcontroller based voltage stabilizer [10]. These techniques manage the input voltage and limit it into the level suitable for the consumer’s appliances. In the proposed OCEPMS, microcontroller based voltage optimization scheme is utilized for energy saving, that gives multiple benefits to users such as reduction in the heat dissipation which enhances the life of appliances and reduce the  $I^2R$  losses etc.

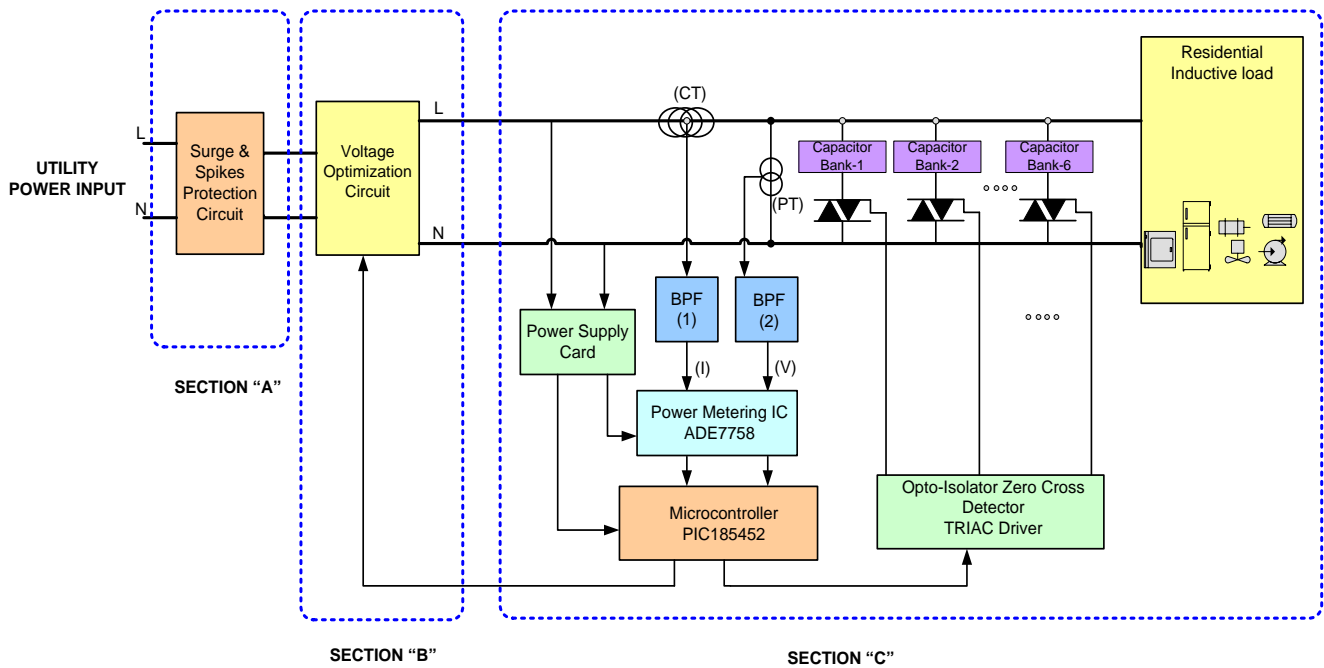
In the proposed OCEPMS, to protect the system from dangerous and harmful voltage surges and spikes, a surge and spike suppression circuitry consisting of MOVs (Metal Oxide Varistor) [11] is also incorporated in the pro design.

Over all structure of the research paper is divided into four sections. Section 1 of the research paper gives brief but concise literature review. The proposed OCEPMS is described through a block diagram in section 2. In sub-section 2.1 surges and spikes circuitry for proposed OCEPMS has been described. In sub-section 2.2 the voltage optimization through a flow diagram is illustrated. In sub-section 2.3 power factor improvement, the most

important part of proposed OCEPMS is explained. In section 3 the experimental results of hardware design are presented and discussed. Finally the conclusions and future recommendations are drawn at section 4.

## 2. Proposed OCEPMS and its Description

A block diagram of whole proposed OCEPMS is presented in Figure 1. Microcontroller is the central part of the Optimized and Cost Effective Power Management System (OCEPMS). In this proposed scheme principal ingredient is PIC18F452 microcontroller using crystal oscillator of 18 MHz [12].



**Figure 1:** Block diagram of proposed OCEPMS

The block diagram of developed OCEPMS is divided in three main sections:

- Section-A: Surges and Spikes Suppression.
- Section-B: Voltage Optimization.
- Section-C: Power Factor Improvement.

Section-A is used to remove the disturbances like surges and spikes form input voltage being fed from the utility. It is necessary to eliminate these in order to protect the home appliances and other electronics equipment. Detailed has been discussed in sub-section 2.1.

Section-B optimizes input voltage by using an autotransformer. The input voltage is first stepped down by a potential transformer (PT), then is filtered using Band Pass Filter (BPF) for elimination of noise. This voltage is then fed to the energy metering IC ADE7758 [13]. The Microcontroller is interfaced with the metering IC and reads the input voltage form the register of metering IC.

Microcontroller compares the input voltage with the set value. If it is greater, then the microcontroller sends a signal to the driver circuitry to BUCK the input voltage through the autotransformer. If the input voltage is less than the set value, the microcontroller sends a signal to driver circuitry to BOOST the input voltage. Algorithm of voltage optimization has been explained through flow diagram in sub-section 2.2.

Section-C is used for measuring and improvement of power factor. In this section voltages and currents which are taken by the current transformer and potential transformer respectively, are passed through BPF filter and fed to energy metering IC. Microcontroller reads all three powers i.e. active, reactive and apparent power from the register of the metering IC and displays these parameters on LCD. The microcontroller calculates the power factor by using the active power divided by the apparent power. The value of capacitance required to improve the power factor is calculated by using initial power factor, the required power factor and by mathematical formulas. A zero crossing interrupt is read from energy metering IC. Microcontroller switches in/out the capacitors in the circuit on the basis of calculated value of C (Capacitance) at point of zero crossing for soft switching. TRIACs are also used for soft switching of capacitors.

Microcontroller is responsible for deciding the values of the capacitors to be incorporated. The proposed designed scheme eliminates the frequent swapping of capacitors by discarding the trial and error technique. The prototype hardware of proposed OCEPMS is shown in Figure 2. The detail of power factor improvement has been discussed in section 2.3.



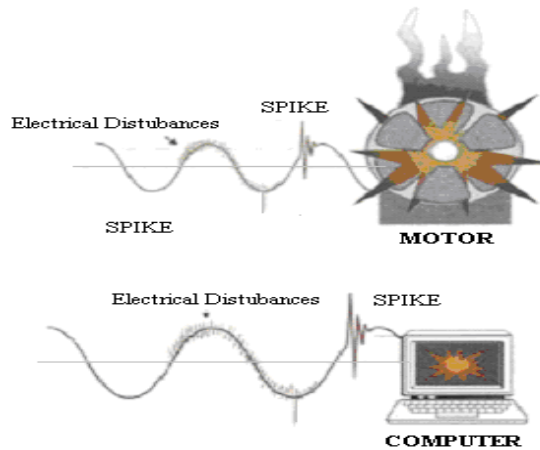
**Figure 2:** Hardware prototype of proposed OCEPMS

### ***2.1. Surges and Spikes Suppression***

When a power line observes a sudden high voltage which is more than line normal voltage then it is termed as power surge. Power surges voltage is normally less than voltage of power spikes (normally 10% to 35% more than normal ac voltage) but remains for much longer time, from 15 msec to few minutes. Power surges enter in house by several paths like external power surges caused by lightning, through TV cable of satellite dish, telephone lines and electrical utility service line.

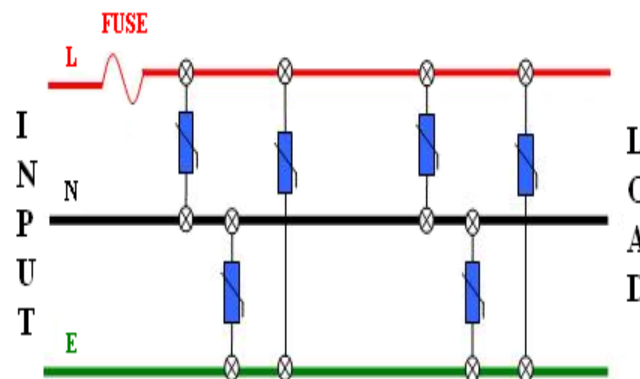
Spikes appearing on power lines are very small pulses of energy. Power spikes contain high voltages that normally die out after a few milliseconds. Their value varies from a few hundred volts to thousands of volts.

These spikes are harmful for the domestic appliances and other electronic items. When the input voltage increases excessively beyond the appliance's normal operating voltage, an arc is produced in domestic appliances as shown in Figure 3. The arc causes heat generation in the electronic circuit's boards and in other electrical components.



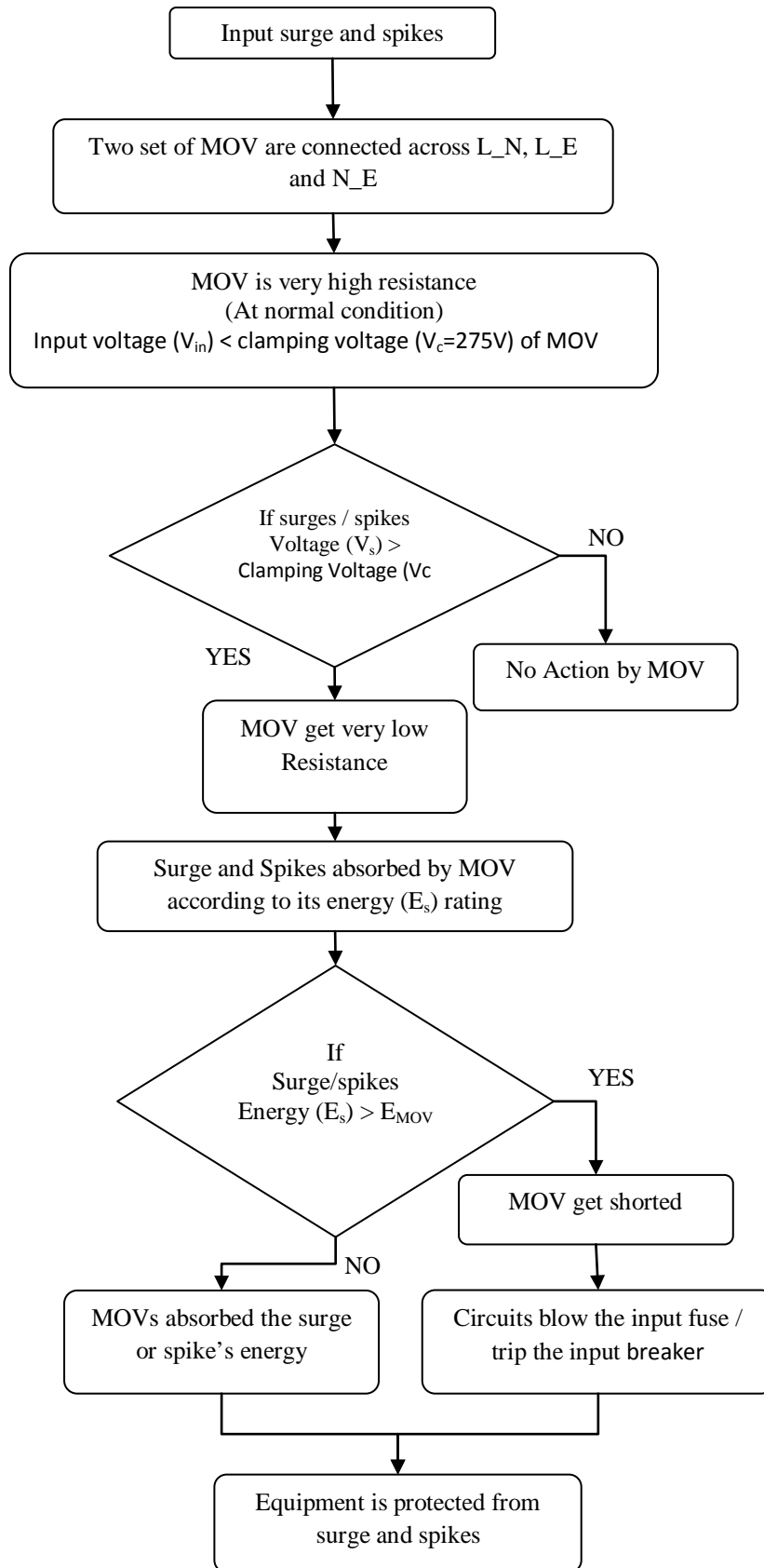
**Figure 3:** Spikes on ac power line

Surges and spikes can be filtered by using Metal Oxide Varistors (MOV), it includes two plates of metal separated by porcelain which offer a low resistance to excessive voltage that limits the surges and spikes energy. Circuit diagram for surges and spikes suppression shown in Figure 4 is utilized in proposed OCEPMS.



**Figure 4:** Circuit diagram of surges and spikes suppression for proposed OCEPMS

Above circuit diagram shows three MOVs, one across Live-Neutral, second across Neutral-Earth and third across Live-Earth are connected, each having clamping voltage of 275V. To increase the energy and level of protection, an additional set of MOVs is connected in parallel. Functional flow diagram of surges and spikes suppression circuit is shown in Figure 5.

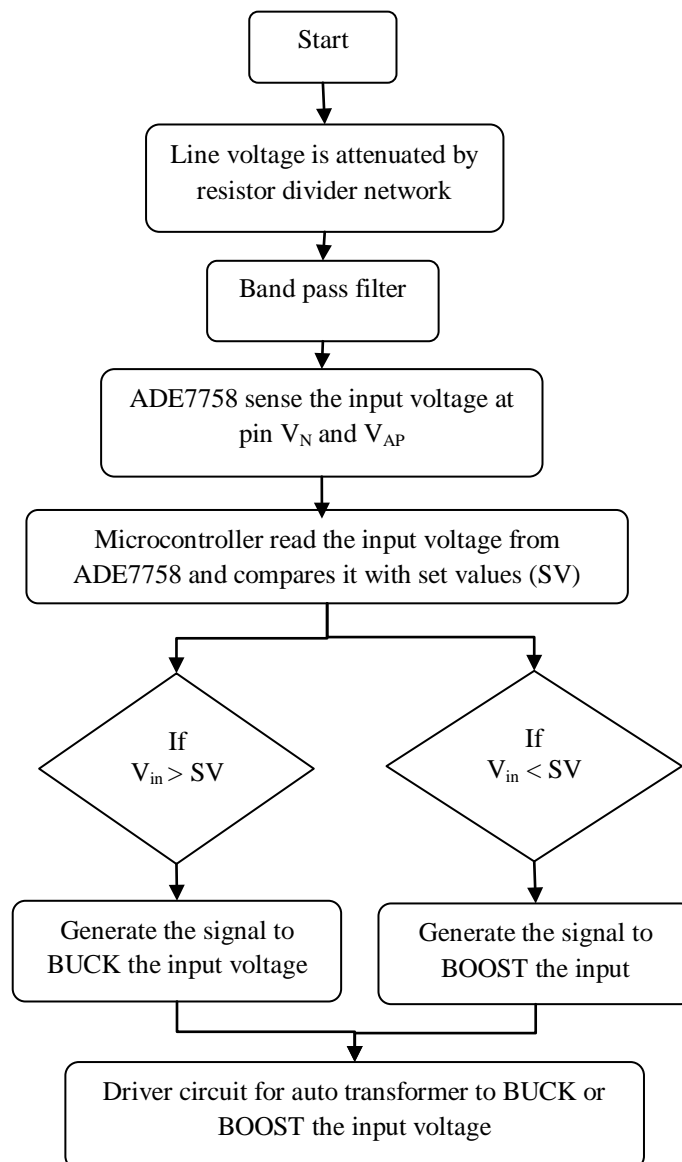


**Figure 5:** Functional flow diagram of MOVs based surges and spikes suppression

## 2.2. Voltage Optimization

Various domestic appliances are designed at rated voltage at which they can operate smoothly. The voltage optimizer circuit controls and stabilizes the input voltage to an optimum level.

In voltage optimization section, for sensing input voltage line voltage is attenuated using a simple resistor divider circuit. A Band Pass Filter (BPF) is used for filtering noise. Afterwards this signal is fed to the energy metering IC ADE7758 at pin labeled  $V_N$  and  $V_{AP}$  as shown in Figure 8. Energy metering IC read this signal and stores it into specified register. Microcontroller that interfaced with this IC reads the input voltage from its register. Afterward this value is compared with the set values in microcontroller. If input voltage is greater than the set value, the microcontroller sends a signal to driver circuitry to BUCK (decrease) the input voltage through autotransformer. If input voltage is less than the set value, microcontroller sends a signal to driver circuitry to BOOST (increase) the input voltage. The flow diagram of voltage optimization is shown in the Figure 6.



**Figure 6:** Flow diagram of developed program for voltage optimization using microcontroller

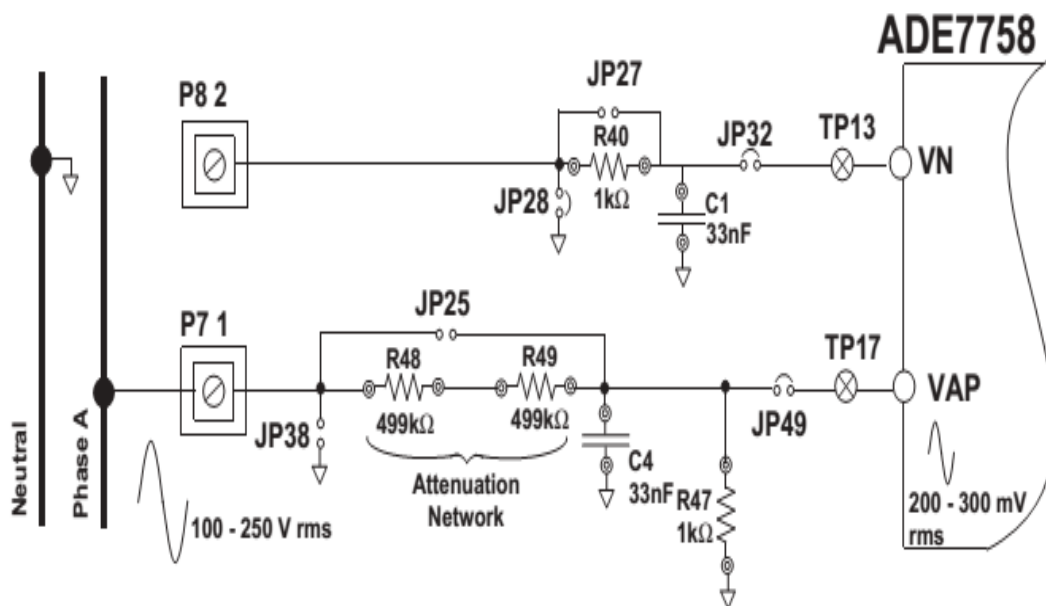
### 2.3. Power Factor Improvement

In the proposed scheme of power factor improvement, current signals taken by current transformer is fed to Band Pass Filter (BPF). The signal is transmitted to energy metering IC ADE7758 at pin labeled  $I_{AP}$  and  $I_{AN}$  for sensing current signal as shown in Figure 9. Similarly the line voltage is attenuated using a simple resistor divider network before it is fed to the ADE7758 at pin labeled  $V_N$  and  $V_{AP}$  for sensing voltage signal as shown in Figure 7. Microcontroller that interfaced with this IC reads the input voltage and current values from its register. Microcontroller calculates and displays three powers i.e. active, reactive and apparent power on LCD. The microcontroller also calculates the power factor in time domain by using the formula provided in the Eq.1

$$\text{Power Factor} = \frac{\text{Power}}{V_{\text{rms}} \times I_{\text{rms}}} \quad (1)$$

Where  $V_{\text{rms}}$  and  $I_{\text{rms}}$  are RMS values of current and Voltage. Due to efficient developed soft switching algorithm, the microcontroller decides the required capacitance which best improves the PF as a whole and then activates the corresponding capacitor banks at the same time. The developed design thus avoids the frequent switching of capacitors and ensures faster response to changing load conditions. In the proposed scheme soft switching technique is used i.e. capacitor banks are switched ON and OFF at zero crossing.

The developed code for proposed OCEPMS is programmed in the in the microcontroller. It emphasize on faster operation and the use of lower memory space. One of the major advantages of using a microcontroller is the use of ISP (In System Programming), which enables easier program upgrade. The overall algorithm of the proposed scheme is illustrated by a flow diagram in Figure 8.



**Figure 7:** Voltage attenuation using voltage divider at voltage channel of ADE7758



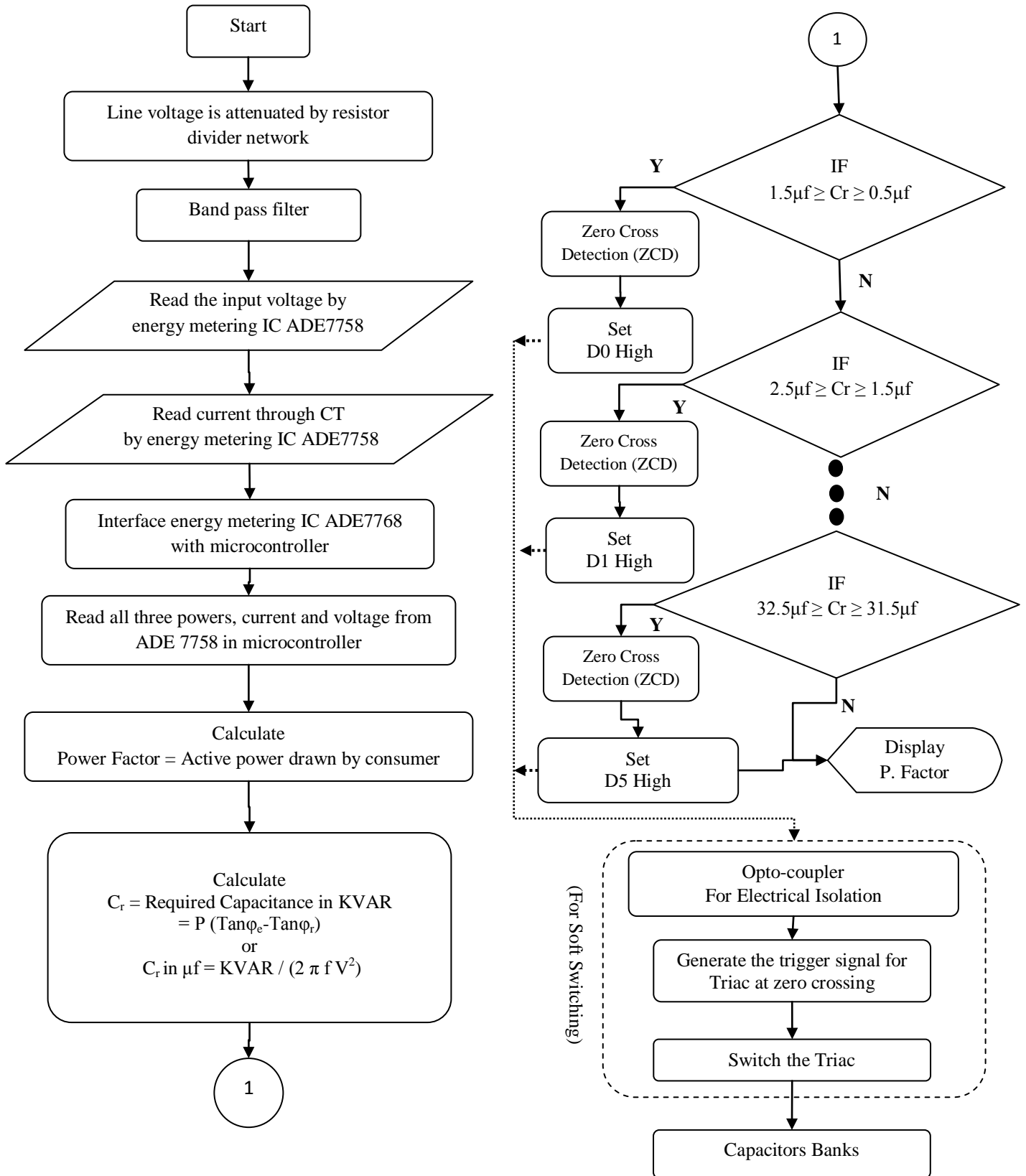


Figure 8: Flow chart of developed program for power factor improvement using microcontroller

The proposed Optimized and Cost Effective Power Management Systems (OCEPMS) improves the power factor using automatic soft switching of capacitor banks placed in parallel with load as per developed algorithm. The improved PF achievable by the proposed OCEPMS also reduces power losses in power lines/cables, prevents unnecessary I<sup>2</sup>R voltage drop at secondary winding of the transformer which is an essential component of AC power transmission [14, 15].

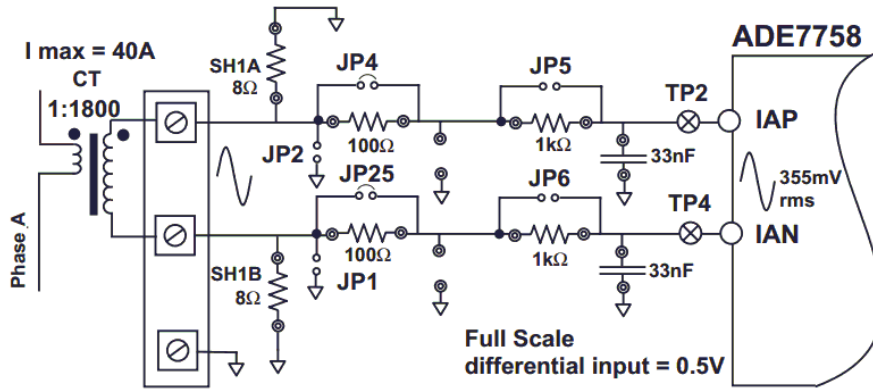


Figure 9: CT connection to current channel of ADE7758

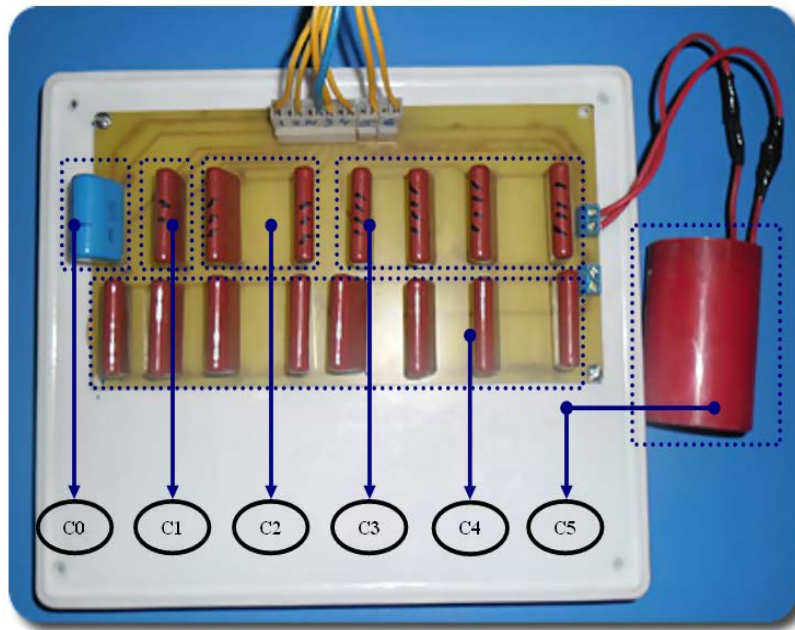
### 2.3.1. Proposed Design of Capacitor Banks

An array of six capacitor banks, C<sub>0</sub> through C<sub>5</sub> for proposed design of capacitor banks in OCEPMS is shown in Figure 10. The capacitance value of each next capacitor bank is twice than the previous one as expressed mathematically by Eq. 2 and is connected in parallel with the load. The detail of each capacitor bank which is connected at microcontroller outputs D<sub>0</sub>, D<sub>1</sub>... D<sub>5</sub> is shown in Table 1.

$$C_i = 2^i \times C_0 \quad \text{where } (i=1, 2, 3, 4, 5) \quad (2)$$

Where C<sub>i</sub> is the capacitance of i<sup>th</sup> capacitor bank. The proposed arithmetic variation in the values of the capacitor banks ensures the maximum range of shunt capacitance available. The maximum possible combinations of capacitor available for improvement of power factor along with microcontroller selected outputs are shown in Table 2. Each capacitor bank provides a way to increase the initial power factor [PF<sub>1</sub> = cosφ<sub>i</sub>] to the required improved power factor [PF<sub>2</sub> = cosφ<sub>r</sub>]. If the power system frequency is f, then eq. 3 describes the required PF.

$$\cos(\phi_r) = \cos \left[ \tan^{-1} \left( \tan \phi_i - \frac{2 \pi f \times C_i \times \phi_i \times V_{rms}^2}{P} \right) \right] \quad (3)$$



**Figure 10:** Capacitor banks arrangement in proposed designed of OCEPMS

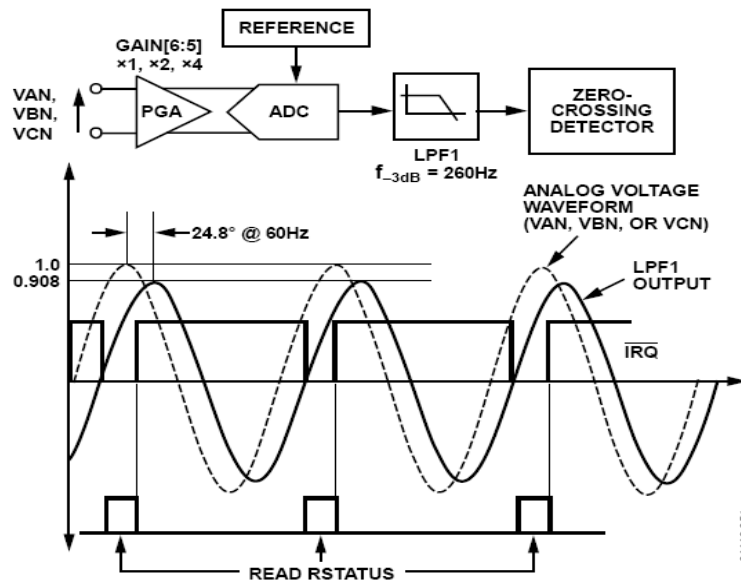
**Table 1:** Capacitor banks details

Banks Details	Bank's Capacitance	Connected at Microcontroller Output
1st Bank= C <sub>0</sub>	1 $\mu$ F	D0
2 <sup>nd</sup> Bank= C <sub>1</sub>	2 $\mu$ F	D1
3rd Bank= C <sub>2</sub>	4 $\mu$ F	D2
4th Bank= C <sub>3</sub>	8 $\mu$ F	D3
5th Bank= C <sub>4</sub>	16 $\mu$ F	D4
6th Bank= C <sub>5</sub>	32 $\mu$ F	D5

### 2.3.2. Soft Switching of Capacitor Banks

Energy metering IC ADE7758 has zero cross detection circuits for each of the voltage channels i.e. (VAN, VBN, and VCN). Figure 11 describes how zero-cross detection signal is generated at the output of ADC voltage channel.

The zero-cross interrupt is generated at the output of Low Pass Filter (LPF1), it is then read in microcontroller. In the Proposed OCEPMS, for soft switching mechanism this interrupt is utilized for the purpose of bringing the capacitors in or out of the circuit at zero crossing of voltage signal depending upon the inductive load.



**Figure 11:** Zero cross detection on voltage channel of ADE7758 for soft switching of capacitor banks

**Table 2:** Capacitor banks switching detail

S/No	Required Capacitance ( $\mu\text{F}$ )	Micro Controller Outputs					
		D0	D1	D2	D3	D4	D5
1	1 $\mu\text{F}$	1	0	0	0	0	0
2	2 $\mu\text{F}$	0	1	0	0	0	0
3	3 $\mu\text{F}$	1	1	0	0	0	0
4	4 $\mu\text{F}$	0	0	1	0	0	0
5	5 $\mu\text{F}$	1	0	1	0	0	0
6	6 $\mu\text{F}$	0	1	1	0	0	0
7	7 $\mu\text{F}$	1	1	1	0	0	0
8	8 $\mu\text{F}$	0	0	0	1	0	0
9	9 $\mu\text{F}$	1	0	0	1	0	0
10	10 $\mu\text{F}$	0	1	0	1	0	0
11	11 $\mu\text{F}$	1	1	0	1	0	0
12	12 $\mu\text{F}$	0	0	1	1	0	0
13	13 $\mu\text{F}$	1	0	1	1	0	0
14	14 $\mu\text{F}$	0	1	1	1	0	0
15	15 $\mu\text{F}$	1	1	1	1	0	0
16	16 $\mu\text{F}$	0	0	0	0	1	0

17	17 $\mu$ F	1	0	0	0	1	0
18	18 $\mu$ F	0	1	0	0	1	0
19	19 $\mu$ F	1	1	0	0	1	0
20	20 $\mu$ F	0	0	1	0	1	0
21	21 $\mu$ F	1	0	1	0	1	0
22	22 $\mu$ F	0	1	1	0	1	0
23	23 $\mu$ F	1	1	1	0	1	0
24	24 $\mu$ F	0	0	0	1	1	0
25	25 $\mu$ F	1	0	0	1	1	0
26	26 $\mu$ F	0	1	0	1	1	0
27	27 $\mu$ F	1	1	0	1	1	0
28	28 $\mu$ F	0	0	1	1	1	0
29	29 $\mu$ F	1	0	1	1	1	0
30	30 $\mu$ F	0	1	1	1	1	0
31	31 $\mu$ F	1	1	1	1	1	0
32	32 $\mu$ F	0	0	0	0	0	1

### 3. Experimental Results with Discussion of Developed Hardware Design for OCEPMS

A series of tests were performed with various loads to test the designed circuit of proposed OCEPMS. The experimental results of developed hardware for eight different cases by utilizing various combination of load, with and without use of OCEPMS are explained below. Results with proposed OCEPMS are also verified from power analyzer.

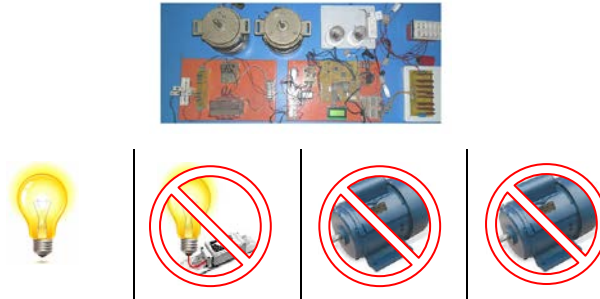
#### 3.1. Case 1: Resistive Load P=100 Watt (with/without OCEPMS)

When a pure resistive load of 100 Watt is brought into the circuit as shown in Figure 12, system's current and voltage are in phase and there is no phase shift between the two signals. Experimental results for both with and without OCEPMS system are shown in Table 3. Results show that OCEPMS has optimized the input voltage from 239V to 216V and no improvement is made in power factor because of resistive load. It is also observed that active power drawn by consumer has been reduced with the use of developed OCEPMS, which saved appreciable amount of power.

#### 3.2 Case 2: "Choke in Series with Bulb" P= 60 Watt (with/without OCEPMS)

When inductive load i.e. choke is connected in series with bulb of 60 Watt is brought into the circuit as shown in Figure 13, system's current and voltage are not in phase and there is a phase shift between two signals. Microcontroller calculates the power factor and according to power factor requirement, it inserts the desired

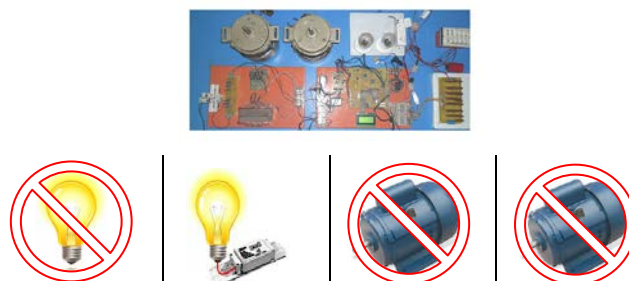
value of capacitors to improve the power factor of the system. Experimental results for both with and without OCEPMS system are shown in Table 4. Results show that OCEPMS has optimized the input voltage from 244V to 220V and improved the power factor from 0.80 to 0.88. It is also observed that active power drawn by consumer has been reduced with developed OCEPMS which means an energy saving.



**Figure 12:** Case 1 when pure resistive load is switched ON

**Table 3:** Case 1 Experimental Results

Description	Results	Results
	without OCEPMS	With OCEPMS
Voltage (V)	239.71	216.8
Current (A)	0.47	0.45
Active power (W)	114.36	97.49
Apparent Power (VA)	115.41	98.54
Reactive power (VAR)	15.52	14.33
Power Factor (Cosφ), Lagging	0.99	0.98



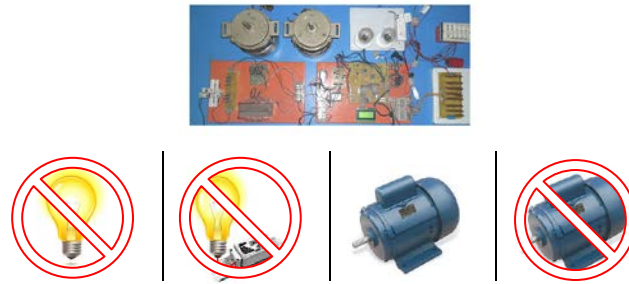
**Figure 13:** Case 2 when choke connected in series with bulb is switched ON

**Table 4:** Case 2 Experimental Results

Description	Results	Results
	without OCEPMS	with OCEPMS
Voltage (V)	244.69	220.8
Current (A)	0.35	0.29
Active power (W)	71.18	57.91
Apparent Power (VA)	87.93	65.36
Reactive power (VAR)	51.62	30.31
Power Factor (Cosφ), lagging	0.81	0.88

**3.3. Case 3: Inductive Load (Motor-1) P= 250 Watt (with/without OCEPMS)**

When inductive load, Motor-1 of 250 Watt is brought into the circuit as shown in Figure 14, system’s current and voltage are not in phase and there is a phase shift between two signals. Microcontroller calculates the power factor and according to power factor requirement, it inserts the desired value of capacitors to improve the power factor of the system. Experimental results for both with and without OCEPMS system are shown in Table 5. Results show that developed OCEPMS has optimized the input voltage from 238V to 219V and improved the power factor from 0.73 to 0.86. It is also observed that active power drawn by consumer has been reduced with developed OCEPMS, which saved appreciable amount of power.



**Figure 14:** Case 3 when Motor-1 is switched ON

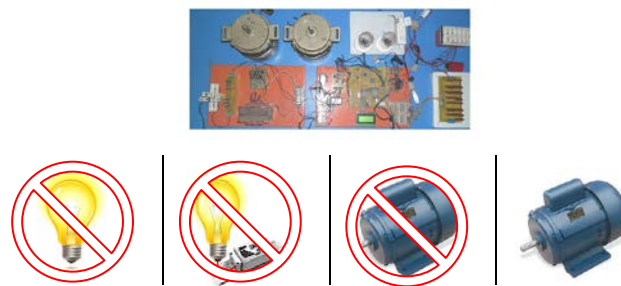
**Table 5:** Case 3 Experimental Results

Description	Results	Results
	without OCEPMS	with EPMS
Voltage (V)	238.01	219.58
Current (A)	1.40	1.01

Active power (W)	248.85	195.34
Apparent Power (VA)	339.92	224.37
Reactive power (VAR)	231.55	110.38
Power Factor (Cosφ), Lagging	0.73	0.86

**3.4. Case 4: Inductive Load (Motor-2) P= 250 Watt (with/without OCEPMS)**

When inductive load, Motor-2 of 250 Watts is brought into the circuit as shown in Figure 15, system’s current and voltage are not in phase and there is a phase shift between two signals. Microcontroller calculates the power factor and according to power factor requirement, it inserts the desired value of capacitors to improve the power factor of the system. Experimental results for both with and without OCEPMS system are shown in Table 6. Results show that OCEPMS has optimized the input voltage from 241V to 219V and improved the power factor from 0.62 to 0.90. It is also observed that active power drawn by consumer has been reduced with developed OCEPMS, which saved appreciable amount of power.



**Figure 15:** Case 4 When Motor-2 is switched ON

Table 6: Case 4 Experimental Results

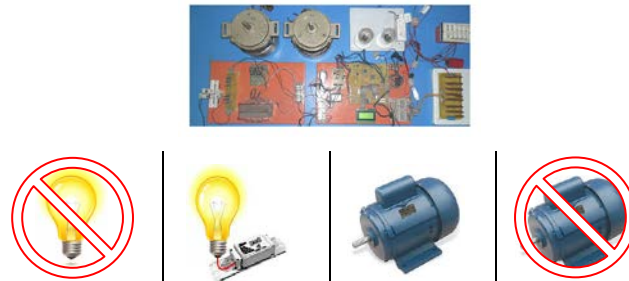
Description	Results	
	Without OCEPMS	With OCEPMS
Voltage (V)	241.38	219.21
Current (A)	1.45	1.01
Active power (W)	218.73	199.2
Apparent Power (VA)	350.82	221.40
Reactive power (VAR)	274.28	110.5
Power Factor (Cosφ), lagging	0.62	0.90

**3.5. Case 5: “Choke in Series with Bulb” and Motor-1 (with/without OCEPMS)**

When “choke in series with bulb” and Motor-1 are brought into the circuit as shown in Figure 16, system’s current and voltage are not in phase and there is a phase shift between two signals. Microcontroller calculates



the power factor and according to power factor requirement, it inserts the desired value of capacitors to improve the power factor of the system. Experimental results for both with and without OCEPMS system are shown in Table 7. Results show that OCEPMS has not optimized the input voltage because input voltage is within range but improved the power factor from 0.78 to 0.91. It is also observed that active power drawn by consumer has been reduced with developed OCEPMS, which saved appreciable amount of power.



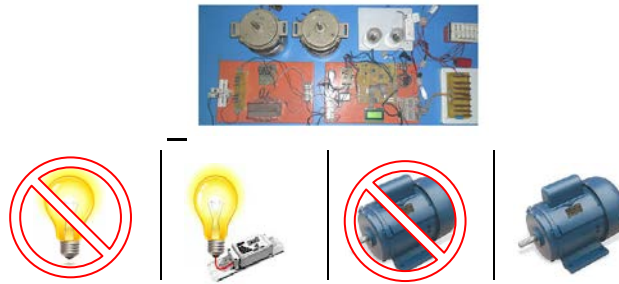
**Figure 16:** Case 5 When Motor-1 and “Choke in series with bulb” are switched ON

**Table 7:** Case 5 Experimental Results

Description	Results	
	Without OCEPMS	With OCEPMS
Voltage (V)	224.82	223.24
Current (A)	1.57	1.30
Active power (W)	280.96	267.72
Apparent Power (VA)	253.84	291.66
Reactive power (VAR)	215.09	115.72
Power Factor (Cosφ), lagging	0.78	0.91

**3.6. Case 6: “Choke in Series with Bulb” and Motor-2 (with/without OCEPMS)**

When “choke in series with bulb” and Motor-2 are brought into the circuit as shown in Figure 17, system’s current and voltage are not in phase and there is a phase shift between two signals. Microcontroller calculates the power factor and according to power factor requirement, it inserts the desired value of capacitors to improve the power factor of the system. Experimental results for both with and without OCEPMS system are shown in Table 8. Results show that OCEPMS has not optimized the input voltage because input voltage is within range but improved the power factor from 0.68 to 0.87. It is also observed that active power drawn by consumer has been reduced with OCEPMS, which saved appreciable amount of power.



**Figure 17:** Case 6 When Motor-2 and “Choke in series with bulb” are switched ON

**Table 8:** Case 6 Experimental Results

Description	Results	Results
	Without OCEPMS	With OCEPMS
Voltage (V)	225.6	223.9
Current (A)	1.56	1.17
Active power (W)	241.7	233.3
Apparent Power (VA)	353.59	266.47
Reactive power (VAR)	258.08	128.75
Power Factor (Cos $\phi$ ), lagging	0.68	0.87

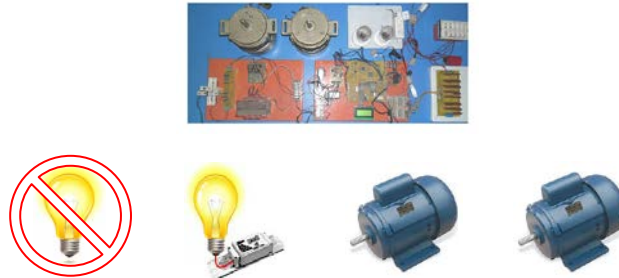
**3.7. Case 7: “Choke in Series with Bulb”, Motor-1 and Motor-2 (with/without OCEPMS)**

When “Choke in series with bulb”, Motor-1 and Motor-2 are brought into the circuit as shown in Figure 18, system’s current and voltage are not in phase and there is a phase shift between two signals. Microcontroller calculates the power factor and according to required power factor, it inserts the desired value of capacitors to improve the power factor of the system. Experimental results for both with and without OCEPMS system are shown in Table-9. Results show that OCEPMS has not optimized the input voltage because input voltage is within range but improved the power factor from 0.74 to 0.86. It is also observed that active power drawn by consumer has been reduced with developed OCEPMS, which saved appreciable amount of power.

**3.8. Case 8: “Choke in Series with Bulb”, Motor-1, Motor-2 and Resistive Load (with/without OCEPMS)**

When “choke in series with bulb”, Motor-1, Motor-2 and Resistive load are brought into the circuit as shown in Figure 19, system’s current and voltage are not in phase and there is a phase shift between two signals. Microcontroller calculates the power factor and according to power factor requirement, it inserts the desired

value of capacitors to improve the power factor of the system. Experimental results for both with and without OCEPMS system are shown in Table 10. Results show that OCEPMS has not optimized the input voltage because input voltage is within range but improved the power factor from 0.81 to 0.91. It is also observed that active power drawn by consumer has been reduced with OCEPMS which is good sign for saving energy.



**Figure 18:** Case 7 When Motor-1, Motor-2 and “Choke in series with bulb” are switched ON

**Table 9:** Case 7 Experimental Results

Description	Results	Results
	Without OCEPMS	With OCEPMS
Voltage (V)	224.89	222.53
Current (A)	2.76	2.26
Active power (W)	461.62	439.48
Apparent Power (VA)	621.87	248.5
Reactive power (VAR)	416.68	54.87
Power Factor (Cosφ), lagging	0.74	0.86



**Figure 19:** Case 8 when Resistive load, Motor-1, Motor-2 and “Choke in series with bulb” are switched ON

**Table 10:** Case 8 Experimental Results

Description	Results	Results
	Without OCEPMS	With OCEPMS
Voltage (V)	223.27	220.72
Current (A)	3.07	2.65
Active power (W)	558.6	538.87
Apparent Power (VA)	685.56	586.99
Reactive power (VAR)	397.43	232.75
Power Factor (Cosφ), lagging	0.81	0.91

Two different types of studies are performed to determine the resultant energy conservation as a result of domestic power factor improvement up to 0.95 along with voltage optimization by mean of auto transformer using microcontroller PIC18F452.

The developed prototype OCEPMS system is designed for single phase users of electricity which will be capable of optimized the input voltage  $220\pm 20\%$  to the normal voltage level  $220\pm 10\%$  and also improve the power factor up to 0.95 (lagging). The maximum power rating of proposed prototype system is 1000VA.

In this paper practical studies have been carried out and results with proposed OCEPMS and without OCEPMS have been compared. Same results of proposed OCEPMS were also cross verified by power analyzer meter. Proposed OCEPMS system not only helps in reduction of utility bill of domestic consumers up to 15 % but also provide the voltage optimization along with surges and spikes protection. Comparison of proposed OCEPMS for power factor improvement of load with selected reference research paper [1] is shown in a Table 7.9. It shows the developed OCEPMS works more efficiently and helps in reducing electricity bill.

**Table 11:** Comparison with selected reference paper [1]

Reference Research Paper [1]	Proposed OCEPMS Research
Power Factor calculation by a traditional approach a Zero Cross Detection circuits is used.	In the proposed OCEPMS scheme, square wave converter stage for zero cross detection has been effectively eliminated and instantaneous values of current and voltage signals are utilized for calculation of power factor by metering IC ADE7753 & microcontroller.
Switching of capacitor is one by one.	At a time required switching of capacitor banks eliminates trial-and-error technique of switching of capacitors and thus avoids the additional delays in

	power factor improvement.
Relay driver circuit is used for switching of capacitor.	Triac based circuits is developed for switching of capacitor banks.
No soft switching of capacitor banks techniques is used.	Techniques for soft switching of capacitor banks is used, Capacitor banks are switched on at zero crossing.
ARM® based 32-bit microcontroller is used.	Micro-chip microcontroller PIC18F452 is used.
The maximum power rating is 440 Watts max.	The maximum power rating of developed prototype is 1000 VA i.e (for more inductive load)
No surges & spikes suppression	Present (surge and spikes suppression).
No Voltage optimization	Yes Voltage optimization
4 x Capacitor banks are used	6 X Capacitor banks are used.
3.15 $\mu$ F, 3.15 $\mu$ F, 3.15 $\mu$ F, 3.15 $\mu$ F	1 $\mu$ F, 2 $\mu$ F, 4 $\mu$ F, 8 $\mu$ F, 16 $\mu$ F, 32 $\mu$ F
Capacitor banks resolution 3.15 $\mu$ F	Capacitor banks resolution 1 $\mu$ F
Display Power Factor	Display Power Factor, Frequency, Voltage, Current, Active, Reactive and Apparent power

#### 4. Conclusions & Future Recommendations

A model of an Optimized and Cost Effective Power Management System (OCEPMS) has been presented, which provides real time improvement of domestic consumer power factor and optimize voltage. In the proposed OCEPMS scheme, square wave converter stage for zero cross detection for calculation of power factor has been effectively eliminated and instantaneous values of current and voltage signals are utilized for calculation of power factor through metering IC ADE7758. The developed design eliminates trial-and-error technique of switching of capacitors and thus avoids the additional delays in power factor improvement calculation providing better accuracy and consistency. In developed OCEPMS, a soft switching algorithm is also developed. For soft switching mechanism the interrupt generated by metering IC ADE7758 is utilized for the purpose of bringing the capacitors in or out of the circuit at zero crossing of voltage signal to avoid harmonic/noise.

Since the proposed OCEPMS displays all the parameters such as voltage, current, frequency, active power, apparent power and reactive required for analyzing the power, hence the proposed study may be utilized for development of three phase power analyzer as well.

Metering IC ADE7758 is utilized in the developed OCEPMS. Inherently this IC is designed for three phase energy metering. However in the proposed research only single phase energy metering is utilized for calculation and power factor improvement for domestic users. In future, three phase power factor improvement system can also be developed for all kind of industries using proposed OCEPMS scheme and with metering IC ADE7758.

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