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Automatic Power Factor Correction for Residential Consumers

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Abstract*: This paper presents an automatic power factor correction unit which reduces system power loss and improves system performance by increasing the efficiency. Power wastage, now a days, is a global issue and hence proposed unit provides cost and energy effective solution. The increased use of inductive loads results in poor power factor in various residential locations. Therefore, a need to enhance the power factor of system increases in a present scenario and power factor can easily be improved by employing suitable techniques of power factor correction. The proposed technique improves the power factor and restores its value close to unity for efficient operation. The increased power factor reduces the system losses which in turn improves the voltage at load end. The corrected power factor also enhances the load carrying capability of an entire network. The proposed technique to improve the power factor, monitors the energy consumption continuously and automatically improves the power factor. The proposed technique discussed in this paper is possible with the help of 8051 microcontroller. The 8051 microcontroller senses time-variant values i.e. line voltage and line current from the system and these time variant values are further utilized to obtain phase angle and corresponding power factor. These two time variant values are calibrated properly to obtain the desired power factor. It also determines the range of power factor and depending on the power factor, it incorporates the capacitor in shunt across the load which in turn improves the power factor. The power factor correction device is designed and tested under load conditions and it is found that the power factor value is increased from 0.71 to 0.96. The average savings in energy consumption is also found to be 1.5% for load used for this proposed technique. There is significant saving in energy cost due to compensation of reactive power.

***Keywords* : Shunt Capacitor, Power factor Correction Unit, Power factor, Apparent power, Reactive power, Active power.**

I. INTRODUCTION

The ratio of active power consumed in a load to the apparent power flowing in an electrical power system is known as power factor of the entire system. The range of power factor is from 0 to 1. The power factor doesn't have any S.I. unit associated with it. It is a dimensionless value which ranges from 0 to 1.

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Active power is the actual or real power consumed by the load and it is useful in performing any work for a particular time period. This active power is either consumed or dissipated from the circuit. It can also be termed as the product of two time variant values i.e. sine voltage and current value. Reactive power is one more component of apparent power. This power is visible only in AC circuits. Reactive power flows in an AC circuit due to the presence of inductor and capacitor in a circuit. The S.I. unit used for reactive power is KVAR. The phasor summation of active and reactive power is termed as apparent power. It has two main components i.e. active power and reactive power. It is also the product of two time variant values i.e. system voltage and line current. The S.I. unit associated with apparent power is VA or KVA or MVA depending upon the size and power rating of electrical power system.

Apparent power is having higher value as compared to active and reactive power. The reactive power is generally stored in an AC components i.e. inductor and capacitor. Due to this reason, the reactive power is negative. As reactive flows in an AC circuit, the line current lags the system voltage by a certain phase angle. The reactive power is never consumed by the load and therefore it travels back to an electrical power source. A purely resistive load is a load with a power factor value equals to unity. The two time variant values i.e. system voltage and line current are in same phase and due to which the phase angle is zero. There is no phase difference two time variant values which makes phase angle equals to zero [2]. A lagging power factor arises due to significant phase difference between applied voltage and current flowing into load terminals. A poor factor also obtained due to harmonic content present in line current. The presence of harmonics or discontinuity in line current distorts the real nature of line current. This discontinuity or harmonics is the reason behind poor factor of the system. Now a days, 80% of the industrial loads are induction motors which can also contribute for lagging power factor. The power factor associated with three phase inductor motor ranges from 0.85 to 0.89. The power transformers and ballasts are also a major contribution in poor power factor. A distortion in current waveform occurs due to usage of power electronics devices in an electrical power system. A distortion results due to various devices like bridge rectifier, SMPS power supplies, variable speed drives and various power electronics equipment's. The poor power factor of an electrical power system increases the system losses which in turn increases the cost of electricity bill. The poor power factor has an influence on power supplies and distribution system. It increases the losses over the entire network of the system. The purely resistive loads like filament lamps and cooking stoves have a power factor equals to unity whereas inductive and capacitive elements like electronic ballasts and three phase induction motors have a power factor less than unity.

The compensation of reactive power in various power system network is growing in today's world. The energy supplier charges a customer for increased reactive power and in order to avoid such problems, the reactive power compensation is the need of the hour. There are many ways by which the burden on individual consumers is reduced. An increased demand on an electrical power system also increases the reactive power which might increases the final cost of electricity. To alleviate this problem, the reactive power compensation using various methods proved to be very cost effective. The first method of reactive power compensation is use of shunt capacitors near to electrical load network. This method is very important and cost effective. The shunt capacitors used for power factor improvement are cheaper as compared to active filters. The active filters are second method of reactive power compensation and generally used for harmonics present in the loads network [4].

The power quality is an important problem in any organisation whether it is governmental or non-governmental organisation. The problem of power quality occurs due to power loss in transmission and unequal distribution of power. This unequal distribution of power is predominant in industries. The significant phase difference occurs due to unequal power distribution and due to finite power factor angle between system voltage and load current, the problem of poor or lagging power factor occurs in industries. The poor power factor in turn increases the cost of electricity bills on consumer side. The occurrence of lagging power factor is main factor behind steep increase in electricity bill of individual consumers.

The power factor correction technique mitigates the reactive power flowing in the system and in turn increases the flow of real power into the load terminals. The power factor correction techniques enhances the real power transmission from source to load. If an inductive load is connected by consumer in residential area and if the power factor decreased below the 0.97(lag), then the electrical supply company charges penalty on consumers due to increase in reactive power. Therefore, it is advisable to keep the power factor of residential systems within certain limits. The power factor correction unit analyses the power factor value obtained from line voltage and current and then it evaluates the requirement of shunt compensation. The requirement of shunt compensation decides the amount of leading reactive power to be injected into the network for compensation of lagging reactive power. In order to inject the leading reactive power into the system, the power factor correction unit switches on various capacitor banks [5].

The inductive load network makes the current to lag behind the system voltage whereas reverse action happens for capacitive load. The line current leads the system voltage when a capacitance is present in load network. The majority of load present in industries are inductive and therefore these load draws lagging current from the power system. This lagging current increases the line losses of the system and this lagging reactive power is not utilized to perform any work. The shunt capacitors connected near to the load terminals eliminates the lagging reactive power from the system as shunt capacitors injects leading current into the system. This leading current is opposite in nature with respect to lagging current and because of the opposite nature, it wipes out all the lagging current from the system. A decline in power factor provides a major concern from the viewpoint of supply authorities. Therefore, supply authorities always encourages the consumers to increase the power factor of load otherwise the penalty is imposed on customers. The power factor can be improved by reducing the phase difference angle between line voltage and line current. The power factor correction method reduces the difference in phase angle and makes the power factor of the system close to unity by injecting the leading reactive power. This leading reactive power is normally supplied by capacitors and this leading reactive is of opposite polarity with respect to lagging reactive power. The inductive effect of the load is easily cancelled by connecting the shunt capacitors near to load terminals [6].

The power factor correction unit cancels the effect of lagging reactive power by leading reactive power which is supplied from shunt capacitances. The shunt capacitances draws capacitive current from the system which leads the system voltage and hence it produces leading reactive power which makes power factor of the entire system close to unity. A bank of capacitors are connected which adjusts the power factor of system close to unity. A single capacitor can supply 100% of leading reactive power but the operation of capacitors to make power factor unit can distort the line current. The power factor correction technique reduces the amount of magnetising current which helps to reduce losses in power supply side and distribution side. The power factor correction methods provides benefits to commercial consumers by reducing their electricity bills. The energy efficiency of the system is also improved by employing power factor correction technique [7].

This paper discusses the proposed power factor correction unit, the number of shunt capacitor banks required in APFC unit, the system flowchart, result and analysis of proposed unit.

II. BLOCK DIAGRAM OF PROPOSED SYSTEM

A. Block Diagram of Automatic Power Factor Correction Unit

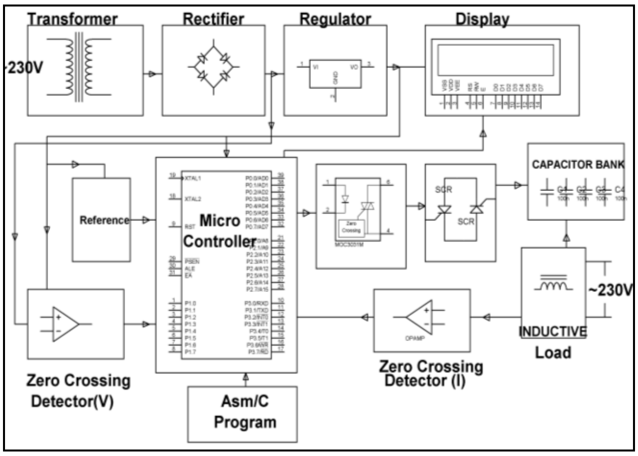

Fig. 1. Proposed block diagram of power factor correction unit

The functional block diagram of the proposed power factor correction unit is shown in Fig.1. The power supply unit comprises of step down transformer, rectifier and regulator. The power source provides 230V, 50Hz mains supply and it is stepped down to a voltage level of 12V using a step down transformer. The main function of this step down transformer is to step down the input voltage which is 230V AC supply. The rectifier unit converts AC power into unregulated DC power with the help of bridge rectifier and voltage regulator in turn provides +5V regulated power supply. The voltage regulator converts variable DC voltage into a constant DC voltage. The IC which performs the function of voltage regulation is LM317 which is a voltage regulator IC. It provides constant DC supply to 8051 microcontroller and LCD display. The constant DC supply is required for the working of 8051 microcontroller and LCD display. A part of voltage signal is extracted from 12V AC signal and this sample voltage signal is processed through voltage sensor circuit and this processed voltage signal is further applied to input of 8051 microcontroller. The current transformer is used for steeping down the current value to a measurable one. The current transformer senses the load current value from the system. The transformation ratio of current transformer is utilized for transforming the current. The current transformer then supplies signal to input of 8051 microcontroller [8-10]. A part of current signal is extracted from the input supply using a current transformer and this sampled current signal is processed through current sensor circuit which acts as one more input of microcontroller. The 8051 microcontroller in turn performs the calculations to obtain the desired power factor which helps in switching on of the capacitor from the bank of shunt capacitors. The result of desired power factor for a particular load is displayed on LCD.

B. Circuit Diagram of Connection of SCR with MOC triggering circuit

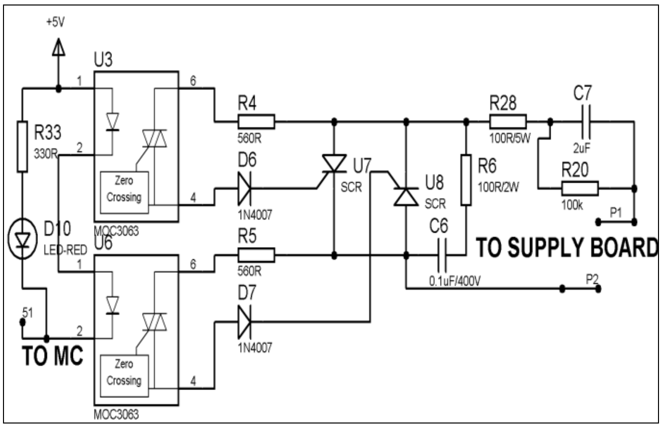

Fig. 2. Circuit Diagram of Connection of SCR with MOC triggering Circuit

The circuit diagram of connection of SCR with MOC triggering circuit is shown in Fig.2. The power supply of 5V is 40th pin of microcontroller and ground is connected to 20th pin of microcontroller. The pins 4, 5 and 6 of LCD are connected from P0.5 to P0.7 of the microcontroller. The data pins of LCD are connected from P2.0 to P2.7 of the microcontroller. The output of op-amp (A) which is LM339 IC is connected to port P3.2 of microcontroller. Similarly, the output of op-amp (B) is connected to port P3.3 of microcontroller. The zero crossing detector is an important component of automatic power factor correction unit. The zero crossing voltage pulses are generated by zero crossing detector. The supply voltage is stepped down to 12V in order to produce zero crossing voltage pulses. The stepped voltage is converted into pulsating DC with the help of rectifier. The amplitude of pulsating DC is scaled down to 3V using potential divider. The reduced voltage of 3V is given to comparator. The comparator then compares the pulsating DC voltage with 0.6V constant DC value. The constant DC of 0.6V is obtained from the diode. The comparison of pulsating dc and constant dc is shown in Fig.3. The obtained zero crossing pulses are also shown in same figure.

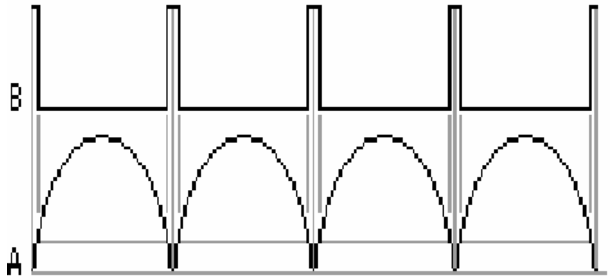

Fig. 4. Waveform of ZVS

The similar procedure is followed for zero crossing current pulses (ZVC). ZVC pulses are generated with the help of voltage drop. The proportional voltage drop is obtained by making the current flows through a particular resistor.

C. Load Network

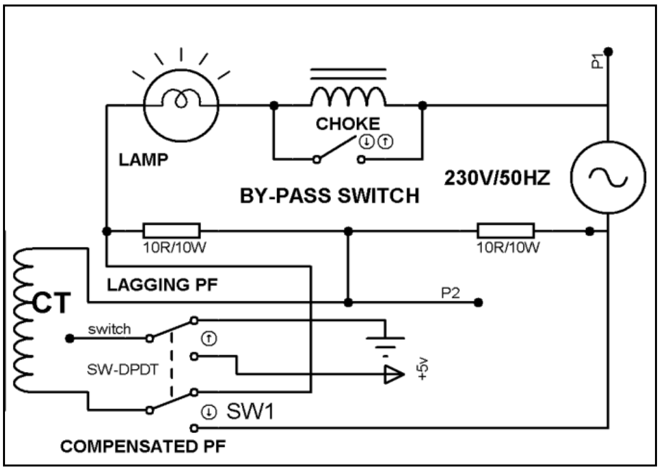

Fig. 3. Load circuit

The circuit shown in Fig.4 comprises of power supply, ZCD, 8051 microcontroller, LCD, opt-isolators, back to back connected SCRs and shunt capacitors. The DC power supply is used to provide the power supply to 8051 microcontroller and various other peripherals. The digital voltage and current signals are required for the estimation of targeted power factor. The voltage signal from the power supply of 230V AC is converted into pulsating DC using bridge rectifier. This pulsating DC is further given to comparator which produces digital signal.

The current signal is converted to voltage drop signal and this voltage drop signal proportional to current is obtained by making the line current to flow through a resistance of 10ohms. This AC signal is processed in the same way as the voltage signal to obtain digital signal. Then, these digital signals are applied to two inputs of 8051 microcontroller. The microcontroller then calculates the time difference depending on zero crossing points of system voltage and line current. Now, this time difference obtained after calculation is proportional to power factor and it provides the range in which the calculated power factor lies. The microcontroller then sends the time difference value and power factor to LCD for display. The opt-isolators then provides the signal to back to back connected SCRs depending on the range of power factor. The back to back connected SCRs incorporates shunt capacitors into the system for improving the power factor value. Hence, the shunt capacitors are connected into the system depending on the required KVAR demand. Thus, the power factor of the system is improved.

III. CALCULATION OF REQUIRED KVAR FOR NETWORK

The decision of required KVAR for improving the power factor of the system is taken by 8051 microcontroller. The program written in 8051 microcontroller takes the decision of required KVAR demand. The microcontroller in turn switches on the capacitors depending on the demand of desired KVAR. The signal from the microcontroller is given to bank of shunt capacitors which automatically switches on the capacitors. The relays used in multiple channels are used to perform the operation of switching of capacitors depending on KVAR demand. The desired KVAR demand is calculated by required power system parameters. If the current power factor is $\cos\Phi_1$ and targeted power factor is $\cos\Phi_2$, then

Desired reactive power, $Q = P(\tan\Phi_1 - \tan\Phi_2)$ (1)

Capacitance in farad, $C = (VAR/ 2\Pi f V^2)$ (2)

Where, P=active power in kW, f is the frequency and V is the system voltage of the power system.

IV. SYSTEM FLOWCHART

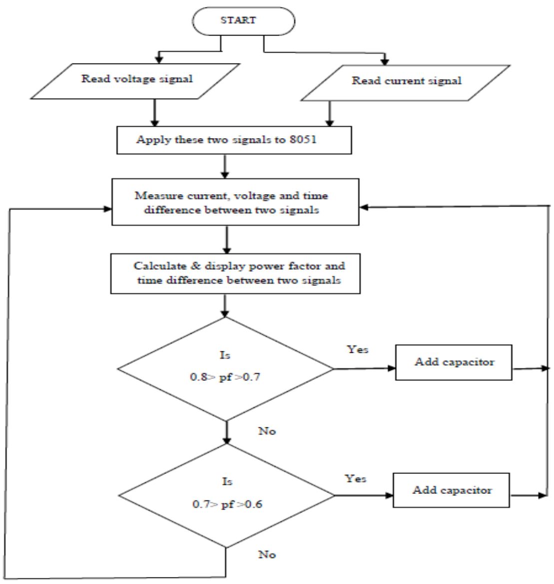

Fig. 5. Flowchart of proposed APFC unit

The flowchart of proposed power factor correction unit is shown in fig.5. The time variant values i.e. system voltage and line current are extracted and processed using corresponding sensors. These processed signals are further given to 8051µC. The zero crossing points of current and voltage signals are obtained with the help of zero crossing detector. The 8051 microcontroller evaluates the exact time difference of two zero crossing points. The time difference is measured from the zero crossing of voltage to zero crossing of current. The evaluated time difference is directly proportional to power factor. The microcontroller then provides the information of time difference and corresponding power factor to LCD.The calculated power factor is then tested for two power factor range. If the calculated power factor falls within two ranges listed in flowchart, then shunt capacitance is incorporated across load to improve the power factor. The shunt capacitance added across the load improves the power factor by decreasing the current from supply and by compensating the reactive power. The monitoring of voltage and current signals are carried out continuously in order to reduce the electricity bills of residential consumers.

V. RESULT ANALYSIS

The operation of automatic power factor correction unit is tested with inductive load. A very high inductive load is created to form load network for testing of proposed technique used to improve the power factor of the system. The load network is taken as the combination of resistor and inductor. The load network comprises of high value of inductance as compared to resistance. The high value of inductance is in series with the low value of resistors. Due to high value of inductance in the load, the power factor of the system falls down. The proposed automatic power factor correction unit first detects and measures power factor of load network. Then, 8051 microcontroller checks whether the measured power factor is within permissible limits and if the power factor falls apart from the permissible limits, then it switches on shunt capacitor to enhance the power factor of the system. The pre-programmed microcontroller incorporates shunt capacitors into electrical power system to improve the power factor. The pre-programmed microcontroller raises the power factor of the system to 0.96 after addition of shunt capacitances near to load network. The following figure shown below is a hardware prototype of proposed power factor correction unit for increasing the power factor of the system if it falls below a certain value.

Fig. 6. Complete power factor correction unit

The following table provides the information of the load network with and without shunt capacitors.

Table- I: Load Network with and without shunt capacitors

Load Network without shunt capacitor		Load Network with shunt capacitor	
Power factor	Line current (A)	Power factor	Line current (A)
0.85	0.77	0.96	0.70
0.70	1.02	0.96	0.79
0.60	1.22	0.96	0.80
0.50	1.35	0.95	0.76

The microcontroller displays the real time power on display. The microcontroller also displays the system voltage, line current drawn from system, active and reactive power requirements of the load network. These parameters of an electrical power systems are accessed from the serial ports of 8051 microcontroller. So, these values can be retrieved from these serial ports.

VI. CONCLUSION

The proposed power factor correction unit is designed and tested for different load conditions. The shunt capacitors are selected to nullify the effect of lagging reactive power and in turn used for improving the power factor. The shunt capacitors are selected to monitor the nature of different electrical load. The power factor correction unit which is designed for improving the power factor improves the power factor of the system to 0.96 under different test load conditions. There is a significant energy savings and it is found to be around 1.5% after the incorporation of power factor correction unit. There is also reduction in current drawn from the power supply for the proper compensation of reactive power. Due to improvement in power factor of the system, there is a significant amount of savings in energy cost.

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