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Automatic Power Factor Correction By Using Synchronous Condenser With Continuous Monitoring

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ABSTRACT

The thirst for energy sources is unquenchable, butwe hardly realize that we are wasting a part of energy every day due to lagging power factor of the inductive load we use. Now-a-days it is a great concern of power Engineers to compensate this loss by the improvement of power factor. There are many methods of power factor correction have been proposed but with the growth of technological revolution automation of every system is desired. Whenever we think about automatic systems, programmable devices come to our fore front. This manuscript describes the design and development of power factor correction with AVR microcontroller. Here correction method is described by synchronous condenser instead of capacitor bank because of long life and low maintenance cost. It also suppresses harmonics which can't be possible by using capacitor bank. This method involves continuous measurement and monitoring the power factor of an inductive load and generation of required control signal from microcontroller for controlling the DC excitation of synchronous condenser so as to improve the power factor. Here power factor calculation scheme has been done practically but correction scheme has been showed by simulation.

Keywords—power factor, zero crossing detector, thyristor chopper, correction unit.

INTRODUCTION

The power factor of an AC electrical system is defined as the ratio of the real power flowing to the load, to the apparent power in the circuit and is a dimensionless number between -1 and 1.Real power is the capacity of the circuit for performing work in a particular time. Apparent power is the product of the RMS values of current and voltage of the circuit [15]. Due to energy stored in the load and returned to the source, or due to a non-linear load that distorts the wave shape of the current drawn from the source, the apparent power will be greater than the real power. A negative power factor occurs when the device which is normally the load generates power which then flows back towards the device which is normally considered the generator. It is a measure of how effectively the current is being converted into useful work output and more particularly is a good indicator of the effect of the load current on the efficiency of the supply system

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When an electric load has a power factor lower than 1, the apparent power delivered to the load is greater than the real power that the load consumes voltage. All currents will cause losses in the supply and distribution system. A load with a power factor of 1.0 provides most efficient loading of the supply and a load with a power factor of 0.5 will result in much higher losses in the supply system. A poor power factor can be the result of a significant phase difference between the voltage and current at the load terminals. Poor load current phase angle is generally the result of an inductive load such as an induction motor, power transformer, lighting ballasts, welder or induction furnace. An improved power factor AC output is the main target of this paper. This paper focuses on the design and implementation of power factor monitoring and correction using ATmega32 Microcontroller chip and synchronous condenser. In an electric power system, a load with a low power factor draws more current than a load with a high power factor for the same amount of useful power transferred. The high currents increase the energy lost in the distribution system, and require larger wires and other equipment. Because of the costs of larger equipment and wasted energy, electrical utilities will usually charge a higher cost to industrial or commercial customers where there is a low power factor. Linear loads with low power factor (such as induction motors) can be corrected with a passive network of capacitors or inductors. Non-linear loads, such as rectifiers, distort the current drawn from the system. In such cases, active or passive power factor correction may be used to counteract the distortion and raise the power factor. The device for correction of the power factor may be at a central substation, spread out over a distribution system, or built into power -consuming equipment.

The main objective of the proposed system is to monitor the power factor of an electrical system and maintain it to unity by controlling the DC excitation of synchronous condenser through using ATmega32 microcontroller chip.

METHODOLOGY

The design aims at measuring the phase angle between voltages and current continuously, calculating the power factor of the circuit from the phase angle and a correction action is initialized to compensate this phase difference by synchronous condenser using the proposed control scheme.

The principle of operation

- Current Transformer (CT) and Potential Transformer (PT) step down the voltage and current level.
- The output of CT and PT are given as input for ZCD.
- ZCD converts sinusoidal voltage and current wave from CT and PT into square wave.
- Two square waves corresponding to voltage and current are given to the input of XOR gate.
- If there is a phase difference between two inputs of XOR gate, the output of the XOR gate remains high for a period equal to that phase difference.
- The output of XOR is given as the input of microcontroller.

- Microcontroller calculates the phase difference between them as well as power factor.
- According to the difference between measured power factor and desired power factor, microcontroller generates control signal and controls the excitation current of synchronous condenser.
- LCD module is connected to the PORT A of AVR microcontroller.
- The system power factor can be monitored by LCD.

Fig. 1 shows DC power supply unit. Here the input 230v AC supply is converted into 5v DV supply with the help of bridge rectifier and it is filtered through a capacitor to get pure DC supply, and a voltage regulator 7805 is placed in order to give a constant 5 volt DC, hence microcontroller works with 5v DC supply. A LED is placed in parallel across the constant 5v DC voltage.

Sampling of Voltage and Current

Since in power system it has to deal with very high voltage and current so, it is advantageous to take the sample of voltage and current for measuring the phase angle between them. Instrument transformers are used for this purpose [6]. Instrument transformer [14] is classified

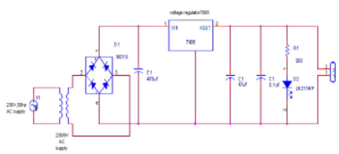

Fig 1. Example of a DC Power supply unit for microcontroller

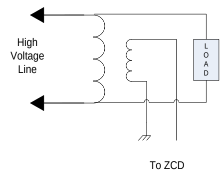

Fig 2. Potential transformer connection

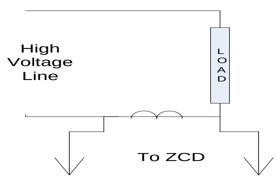

Fig 3. Current Transformer Connection

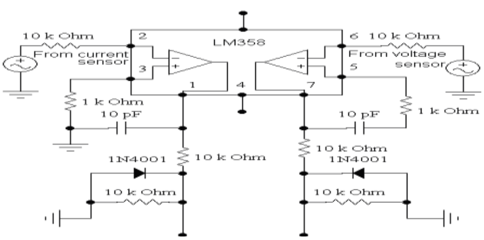

Fig 4. Zero Crossing Detector

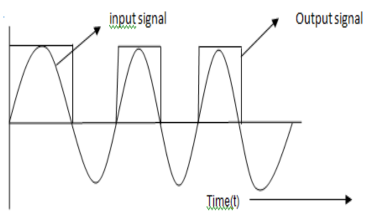

Fig 5. The input and output signal of LM358

as PT (Potential Transformer) and CT (Current Transformer).

A potential transformer is a step down transformer. As shown in Fig 2, it is connected in parallel with the supply voltage. It has very high turns ratio which converts a very high voltage connected to the primary into a low voltage at secondary.A current transformer differs from the potential transformer and power transformer in that it is series connected [14]. The current transformer is designed to produce alternating current or alternating voltage proportional to the current measured. In Fig 3 given above the primary is connected in series with the load. The secondary is grounded. Unlike the conventional transformer the load or volt-ampere is determined by the primary, since the impedance across the secondary remains constant. Thus although the number of turns is fixed, the flux varies with the current in load circuit.

Zero Crossing Detector

A zero crossing detector is a sine-to-square wave converter. The output signal is driven into negative saturation when input signal passes through zero in positive direction. Conversely, when input signal passes through zero in the negative direction the output saturates positively.The zero crossing detectors are nothing but a comparator where reference voltage is set to zero [11]. The zero crossing detectors used in this method is shown in Fig 4. As shown in Fig. 4 the output of CT and PT are connected to LM358 as input. When AC signal is applied to LM358, the output of LM358 is 1 as logically (5 volts) while signal is crossing from the zero point, otherwise output is zero. The input and output signal to LM358 is shown in Fig. 5.There are two inputs and outputs of LM358. One of them is used for current signal. The other one is used for voltage signal [4]. The current and voltage signals are adapted for LM358 by current and voltage sensor respectively. A resistive 10kohm is connected to the output of current and voltage sensor, thus current and voltage signals are adapted for LM358.The XOR logic gate [12] produces logic high at output when inputs are different, otherwise produces zero at output. The output signals from zero crossing detector are given as inputs to XOR gate. The input signals of XOR in case of inductive load and the corresponding output are shown in Fig 5.

The input to the Microcontroller Input Capture Pin (ICP) [8] is provided from the output of XOR gate. Microcontroller calculates the time through which the XOR gate output remains high. From this time period it calculates the phase difference between voltage and current waves as well as power factor. An Algorithm is developed to make ATmega32 read the input and respond accordingly in Fig 6. The timer/counter incorporates an Input Capture unit that can capture external events and give them a time-stamp indicating time of occurrence. The external signal indicating an event, or multiple events, can be applied via the ICP pin of microcontroller

Let, CLK CPU = 4MHz
Pre-scale=8
CLK timer = (4 MHz)/8 = 500 KHz
T timer = 1/(500 MHz)= 2us
So, 2us is needed to count pulse 1.
10us is needed to count pulse = (10us *1)/2us= 5000
S0, maximum pulse value=5000.
Microcontroller detects its falling or rising edge as declared in the program.

The timer value from one falling edge to next rising edge is taken first. Now this value is subtracted from the maximum pulse value [16]. This is the timer value of displacement between voltage and current.
Now, from the main signal we get,
10ms is equal to displacement = 3.1516 radian
1us is equal to displacement = (3.1516/10000) radian
= 0.00031516 radian
Now, pulse width, t= 2us*(5000-clock number)
Angle, theta = 0.00031516*2us*(5000-clock number) radian
= 0.000628*(5000-clock number) radian
Power factor = cos(theta). Here clock number is variable depending on the signal. Power factor can be easily calculated by this method.

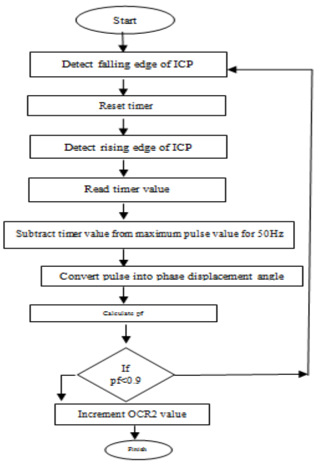

Fig 6. Algorithm for the control scheme

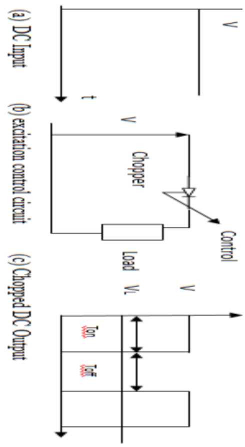

Fig 7. DC excitation control by thyristor chopper

Power factor correction unit

As discussed above in order to improve power factor, the reactive power has to be compensated. It can be done by various methods, but here we choose synchronous condenser for providing leading reactive power in order to improve power factor. This reactive power can be varied by varying its DC field excitation.In a synchronous machine a back e.m.fEb is set up in the armature(stator) by the rotor flux which opposes the applied voltage V. This back e.m.f depends on rotor excitation only. The net voltage ER in the armature is the vector difference between V and Eb. Armature current *Ia* is obtained dividing this vector difference of voltage by armature impedance. Back e.m.fEb can be varied by varying DC excitation of the rotor circuit which in terms varies rotor flux. DC supply is provided by means of DC generator.In this method voltage of DC generator is controlled by controlling its speed. Here we choose thyristor chopper for controlling speed [12]. Since thyristor can be switched on and off very rapidly, it is used to interrupt a DC supply at a regular frequency in order to produce lower (mean) DC supply voltage as shown in the Fig 7. The mean value of output voltage is given by equation (1) [12].

$$V_{dc} = V_L = V\times Ton/(T_{on}+T_{off}) \quad (1)$$

In this work, on period and off period of thyristor is controlled by PWM (Pulse Width Modulation) generated by microcontroller. The width of pulse can be varied according to the difference between calculated power factor and desired power factor. In this work, PWM is used to control the thyristor gate pulse in DC motor circuit which drives DC generator. So, the output of DC generator is controlled by PWM generated. The thyristor is turned on and off several times during a half cycle and the output voltage of DC generator is controlled by varying the pulse width [17]. The main advantage of PWM is that power loss in the switching devices is very low. When a switch is off there is practically no current, and when it is on, there is almost no voltage drop across the switch. Power loss, being the product of voltage and current, is thus in both cases close to zero. PWM also works well with digital controls, which, because of their on/off nature, can easily set the needed duty cycle.

EXPERIMAL RESULT

In this article, power factor has been calculated practically in laboratory and control signal is produced for correction through ATmega32 microcontroller. The experimental results can be divided into 5 sections. They are-

- Test the voltage and current level
- Detecting Zero crossing
- Finding time gap between voltage and current
- Power factor calculation and monitoring
- Generation of control signal for power factor correction

Test the voltage and current level

Voltage signal and current signal has been taken from 220 volt AC line through PT and CT. PT was parallel connected with the line and CT was series connected. CT's output is a voltage which is proportional to the current. The experimental setup for measuring voltage and current level is shown in Fig 8

Detecting zero crossing

Here LM358 is used as the zero crossing detectors which give a square output wave when input is sinusoidal. As the microcontroller does not take negative input so we used a diode at each input side to clipped the negative portion of the sine wave. Then we got the signal which is suitable for Exclusive-OR gate. The circuit connection for zero crossing detector is shown in Fig 9 .Fig 10 (a) shows the output signal of Zero Crossing Detector when the input is PT output signal and Fig 10 (b) shows the output signal of Zero Crossing Detector when the input is CT output signal.The two output signal of LM358 was passed through the two input pin of Exclusive-OR gate. The output of Exclusive-OR gate is the measurement of the time gap between voltage and current signal that is the phase difference. Fig 11 shows the output signal of XOR gate, when two outputs of Zero Crossing Detector is given as input signals.

Fig 8. Experimental setup for measuring level

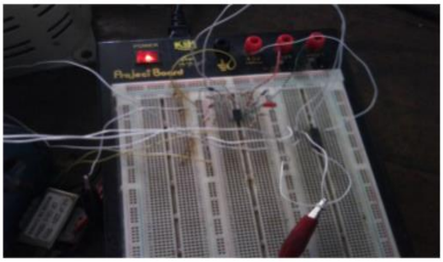

Fig 9. Circuit connection for zero crossing detector

Fig 10 (a). Voltage signal after passing through the zero crossing detector

Fig 10 (b). current signal after passing through the zero crossing detector

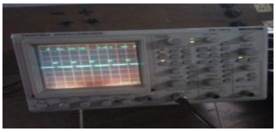

Fig 11. The output signal for Exclusive-OR gate

Table 1: Experimental Data

Serial No	**Voltage (V) Volt**	**Current (I) Amp**	**Power(P) Watt**	**Power factor(cosφ) P/(V*I)**	**PF by Atemega 32**
1	30	0.6	13	0.73	0.72
2	30	0.8	20	0.83	0.8

From Table. 1, error of power factor is calculated as follows:

1. Error = {(0.73-0.72)/0.73}*100% =1.4%
2. Error = {(0.83-0.8)/0.83}*100% = 3.6%

The control signal for power factor correction is the pulse width modulation (PWM) is generated by microcontroller, which controls the gate pulse of thyristor. The thyristor controls the dc excitation of the synchronous condenser to improve the power factor.

Power factor calculation and monitoring

The output signal of Exclusive-OR gate is now suitable to pass through the ICP pin of the microcontroller and the microcontroller calculates the power factor. LCD is interfaced with microcontroller and LCD displays the power factor as shown in Fig. 12.

Fig 12. LCD interfacing With Microcontroller

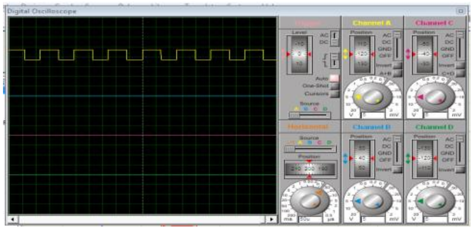

Fig 13. Proteus simulation of Pulse width modulation through Atmega32

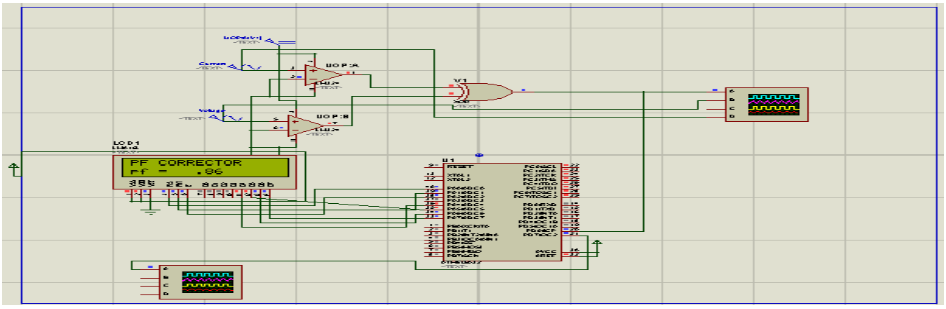

Fig 14. Proteus simulation of power factor calculation by Atmega32

Fig. 13 shows the Proteus simulation of PWM output from microcontroller. Fig. 14 shows the complete Proteus simulation circuit.

CONCLUSION

The research shows a well-organized technique for power factor calculation and correction. Here PF calculation has been done practically but correction technique has been given theoretically because of high cost of synchronous condenser. In high voltage systems it is necessary to use synchronous condenser instead of capacitor bank because of long life of condenser. Here power factor of the line is continuously monitored through the microcontroller. So it is a time saving technique and required controlled signal is produced automatically for correction. The technique is also very economical in comparison with capacitor bank. So a variable speed synchronous condenser can be used in any high voltage transmission line to improve power factor & the speed of synchronous condenser can be controlled by microcontroller through the thyristor.

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