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PIC Microcontroller Based SVC for Reactive Power Compensation and Power Factor Correction

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Abstract— ***An active power factor corrector (active PFC) is a power electronic device that controls the amount of reactive power drawn by a load in order to obtain a power factor as close as possible to unity. In order to reduce the power losses and to improve the stability and transmission efficiency of transmission and distribution lines, power factor correction research has become a hot topic. Many control methods for passive and active PFC were proposed. This paper describes the design and development of a single phase TRIAC based Static VAR Compensator for reactive power compensation and power factor correctionusing PIC (Programmable Interface Circuit) micro-controlling chip. The PIC microcontroller determines the firing pulses for the TRIAC to compensate excessive reactive components, thus withdraw PF near to unity. The investigations were also carried out by using PFC at the output of a digital voltage corrector (DVC).***

Keywords— ***Power factor correction, DVC, reactive power, PIC microcontroller.***

I. INTRODUCTION

Power factor correction (PFC) circuits were introduced in power systems to sinusoidally shape the ac line current and to put it in phase with the ac line voltage. Electrical engineers involved with the generation, transmission, distribution and consumption of electrical power have an interest in the power factor of loads because of the dynamic behaviour of industrial loads such as rolling mills, arc furnaces, traction loads and large fluctuating single-phase loads draw wildly fluctuating amounts of reactive power from the supply systems. Power factors affect efficiencies and costs for both the electrical power industry and the consumers. In addition to the increased operating costs, reactive power can require the use of wiring, switches, circuit breakers, transformers and transmission lines with higher current capacities, this requires larger, more expensive power plant equipment, transmission lines, transformers, switches, etc. than would be necessary for only real power delivered. The presence of reactive power thus causes the real power to be less than the apparent power, and so, the electric load has a power factor of less than 1. Therefore, power companies require their customers, especially those with large loads, to maintain their power factors above a specified amount (usually 0.90 or higher) or be subject to pay additional charges. Electricity utilities thus measure reactive power used by high demand customers and charge higher rates accordingly. Some consumers install power factor correction schemes at their factories to cut down on these higher costs. Power factor correction attempts to adjust the power factor of an AC load or an AC power transmission system to unity (1.00) through various methods. Table 1 list a number of common loads appears in general industrial systems and their typical power factor.

Simple methods include switching in or out banks of capacitors. This method of improving the power factor using capacitor banks is also called as dynamic VAR compensator or dynamic power factor control because reactive power generation is carried out through switching in or out the capacitors to achieve a desired power factor at different load conditions. The switching action here is performed through the mechanical switches and relays, which are sluggish, unreliable, require frequent maintenance and introduce switching transients, It is also possible to implement power factor correction with an unloaded synchronous motor connected across the supply. The power factor of the motor is varied by adjusting the field excitation and can be made to behave like a capacitor when over excited. A capacitor bank provides power factor control in discrete steps where as synchronous motor provides a smooth control of power factor but they are not fast enough to compensate reactive power for rapid load changes due to large time constant of their field circuit and they have much higher losses. The simple correction techniques described above for power factor correction have some of the disadvantages such as dynamic VAR compensation, use of mechanical switches and relays, not fast enough for rapid load changes and higher losses, so more sophisticated technique must be used to correct for non-linear loads. In this paper an active power factor corrector is used for reactive power compensation. Some types of active PFC are: Boost, Buck and Buck-boost [1-9]. One of the new approaches for active power factor correction is TRIAC based active power factor corrector to regulate the reactive power, this method of active power factor correction is characterized by continuous and static VAR control, low losses, redundancy, flexibility and provides the smooth control of flow of reactive power.

An improved power factor is the main target of this paper. This paper describes the design, development and implementation of a reliable, efficient and cost effective "Active Power Factor Corrector" comprising microcontroller based hardware and compatible software which will be able to control the power factor of both linear and non linear load. The PFC has been connected at the output of a digital voltage corrector (DVC).

TABLE 1
TYPICAL POWER FACTORS OF END USE EQUIPMENT

Load	**Power Factor (cosφ)**
Transformer (no load conditions)	0.1 - 0.15
Motor	0.7 - 0.85
Metal Working Apparatus	
Arc Welding	0.35 - 0.6
Arc Welding	0.7 - 0.8
Resistance Welding	0.4 - 0.6
Arc Melting furnace	0.75 -0.9
Fluorescent Lamp	
Compensated	0.9
Uncompensated	0.4 - 0.8
AC –DC Converter	0.6 - 0.95
DC Drives	0.4 - 0.75
AC Drives	0.95 - 0.97
Resistive Load	1

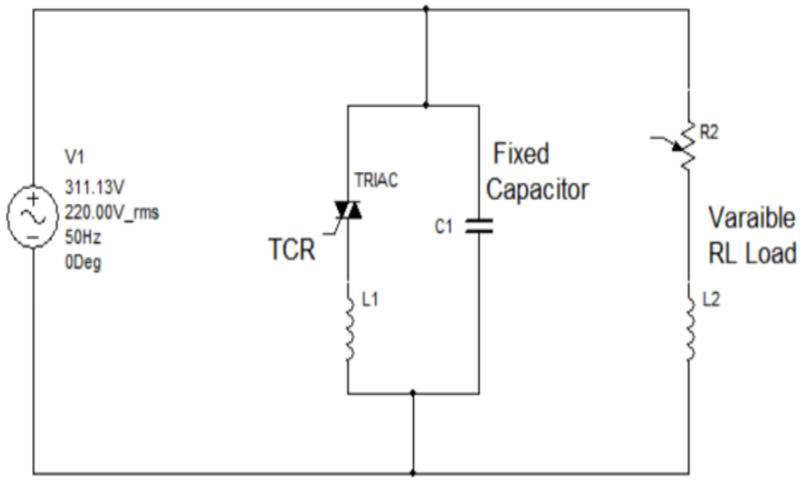

Fig. 1 Circuit diagram for the power factor controller using SVC

II. STATIC VARIABLE REACTIVE POWER

The Static VAR Compensator (SVC) is an early generation FACTS device and a proven technology for voltage stability and power factor correction. The SVC is a shunt-connected an automated impedance varying device consisting of two branches – the fixed capacitor and the TRIAC controlled branch, the fixed capacitor branch generates reactive power and the TCR (TRIAC Controlled Reactor) branch absorbs reactive power. If the power system's reactive load is capacitive (leading), the SVC will use reactors (usually in the form of TRIAC Controlled Reactors) to consume VARs from the system, lowering the system voltage. Under inductive (lagging) conditions, the SVC will generate VARs from the system, thus the coordination of the two branches works together to balance the reactive power absorbed or generated by the SVC, thus providing reactive power compensation. The Fig. 1 shows the circuit diagram of Static VAR Compensator. In this method the reactive power taken from the supply can be regulated continuously by appropriately controlling the firing angle of TCR from $\pi/2$ to π or in other words the source power factor gets improved from lagging to leading as the firing angle is progressively altered from $\pi/2$ to π. They also may be placed near high and rapidly varying loads, such as arc furnaces, where they can smooth flicker voltage and correct the power factor of load. The static VAR compensator (SVC) is characterized by continuous control, low losses, redundancy, and flexibility.

III. DESIGN OF STATIC VAR COMPENSATOR

The Fig. 2 shows the equivalent circuit of SVC. It consists of two branches a fixed capacitor and a TCR branch, the fixed capacitor branch generates reactive power and the TRIAC Controlled Reactor (TCR) branch absorbs reactive power thus the reactive power take from the supply can be regulated continuously by varying the firing angle of the TRIAC.

A. Relationship of Fixed capacitor branch with power factor

Capacitor is the main component that supplies capacitive reactance, which is negative reactive power. Since, the power factor is the ratio of real power and apparent power, where apparent power has the relation with reactive power and real power as shown in the power triangle in Fig. 3[10]. As majority power system has inductive loads thus normally only lagging power factor occurs hence capacitors are used to compensate by producing leading current to the load to reduce the lagging current, thereby shrink the phase angle distance between the real power and apparent power.

The function of shunt power capacitor is to provide leading (capacitive) kVARs to an electrical system when and where needed. The actual capacitor in farads of a capacitor can be calculated using the following equation:

$$C = \frac{Q}{2\pi f * V^2} \tag{1}$$

where, Q= capacitor unit rating in VAR
C = capacitor (farads)
f = frequency (cycles/second) in HZ
V_R = capacitor unit rating in volts

The SVC is sized with enough capacity to supply at least the reactive power absorbed by the nonlinear load (QSVC ≤ QL).

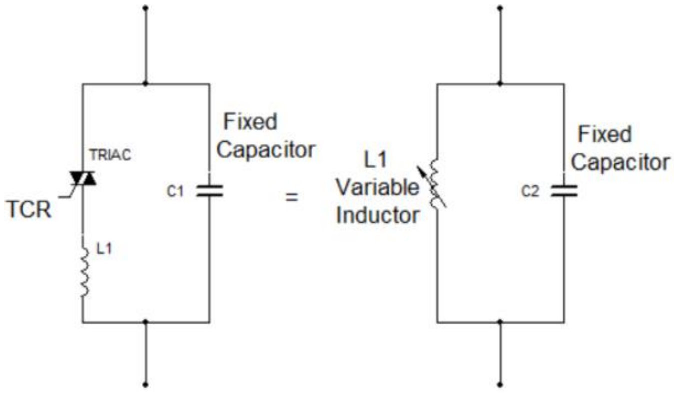

Fig. 2 Equivalent Circuit of SVC

$$Q = Q_{max} \text{ of Load} + 10\ \% \text{ of } Q_{max} \text{ of Load} \tag{2}$$

Here, $Q_{max.}$ Of Load = 90 VARs at 220 Volts

$$C = \frac{Q}{2\pi f * V^2} = 6.5\ \mu f$$

So, capacitor to absorb 98 VARs at 220 V = 6.5 µf

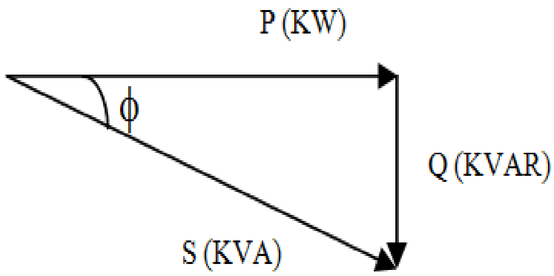

Fig. 3 Power angle triangle

B. TRIAC Controlled Reactor (Variable Inductance) Branch

This branch is a TRIAC controlled reactor i.e. variable inductance branch; the main concept behind controlling TCR is to control the firing instant of the TRIAC to control the current in the reactor, thus controlling the reactive power absorbed by the TCR. The current flowing through the reactor can be controlled by varying the firing angle of the TRIAC and is given by [2]:

$$I_L = \frac{V}{\omega L} \times \frac{2\pi - 2\alpha + \sin 2\alpha}{\pi} \tag{3}$$

where, α = firing angle of TRIAC

The reflected inductance can be varied and its value as a function of firing angle thus is given by:

$$L(\alpha) = L\frac{\pi}{2\pi - 2\alpha + \sin 2\alpha} \quad (4)$$

where the firing angle (α) is bounded as (π/2) < α < π

The reflected reactance thus can be given by equation (5) and its value as a function of firing angle can be varied as:

$$X_L(\alpha) = 2\pi fL\frac{\pi}{2\pi - 2\alpha + \sin 2\alpha} \quad (5)$$

It can be seen from the equation (5) that the reflected reactance of TCR branch is a function of firing angle (α)and the reflected reactance increases with increase in firing angle, the reflected reactance is ∞ for $\alpha = 180^0$.

C. Determination of Inductance of TCR reactance

At unity load power factor the SVC does not exchange any reactive power with the ac system, under this operating condition the net reactance of static VAR compensator should neither capacitive nor inductive i.e the reactance of fixed capacitor branch be equal to the reactance of the TCR controlled branch.

i.e $X_C = X_L(\alpha)$

For C=6.5 µf and $\alpha=130^0$;

The inductance of TCR = 0.34 H

D. Reactive Power Compensation

Reactive-power compensation is implemented with a VAR generator connected in parallel with the nonlinear load. The total reactive power of the Static VAR compensator is given by:

$$Q(\alpha) = V^2(B_c - B_L(\alpha)) \quad (6)$$

$$B_c = \omega_0 C \quad (7)$$

The susceptance of TCR as a function of firing angle is given by:

$$B_L(\alpha) = B_L\frac{2\pi - 2\alpha + \sin 2\alpha}{\pi} \quad (8)$$

$$B_L = \frac{1}{\omega_0 L} \quad (9)$$

Where the firing angle (α) is bounded as (π/2) < α < π

TABLE 2

VARIATION OF Q W.R.T α

α in degrees	**$B_L(\alpha)$ In Mho**	**$Q(\alpha)=V^2(B_c - B_L(\alpha))$**
90^0	0.00903	-334.0
100^0	0.00704	-238.0
110^0	0.00520	-149.0
120^0	0.00350	-50.00
130^0	0.00220	+05.00
140^0	0.00115	+43.50
150^0	0.00050	+74.50
160^0	0.00014	+91.70

The reactive power of the SVC is either positive or negative, as from equation (6) the sign of the reactive power depends on the firing angle of the TCR. If $B_c < B_L(\alpha)$, the sign of the reactive power is negative thus the SVC provides lagging reactive power i.e. the SVC acts as inductive reactance where as if $B_c > B_L(\alpha)$, the sign of the reactive power is positive thus the SVC provides leading reactive power i.e. the SVC acts as capacitive reactance. The Table 2 shows the variation of reactive power of SVC w.r.t firing angle (α).

IV. TCR CONTROL SCHEME

The design aims to monitor phase angle continuously and in the event of phase angle deviation, a correction action is initialized to compensate for this difference by continuous changing the firing angle of TCR via opto isolator TRIAC driver circuit. The overall system requires the PIC chip, TRIAC, TRIAC driver opto isolator circuit and a fixed capacitor. Fig. 4 show the hardware block diagram layout of the TCR control scheme to regulate the reactive power of SVC.

A. Sensors

The load voltage and current signals are both sensed and stepped down using potential transformer and current transformer respectively to their respective levels, the current is converted into an equivalent voltage representation.

B. Zero Crossing Detectors

The synchronizing unit will produce a pulse at each Zero-crossing of the supplied sine wave voltage. The output pulses obtained from the synchronizing unit will be applied to the input of microcontroller as a reference in order to achieve a required firing pulse to control the TRIAC firing angle. The output pulses obtained from the zero crossing detectors will also be used to measure the phase displacement between voltage and current. Fig. 5 shows the circuit diagram of Zero crossing detector.

C. Algorithm and Programming of Control Scheme

An algorithm is developed to make the PIC read the inputs and respond accordingly. There are two parts of programming one is related to counter, which is initialized through the timer 0 interrupt. Second is the main part of the program in which signal is taken by the PIC and gives the appropriate response to the controlling schemes.
Main program is divided into-
Initialization of External Interrupt (RB_0 / INT)
Initialization of TIMER1
Calculation of Power Factor
Initialization of ADC module
Calculation of Voltage and Current
Calculation of Reactive Power
Initialization of LCD
Calculating the desired firing angle
Generating the switching signal to trigger the TRIAC

D. TRIAC Firing Circuit and Static VAR Compensator

The Fig. 6 shows the circuit diagram of TRIAC firing and static VAR compensator. The output pulses obtained from the microcontroller are applied to the pin no. 3 of IC MOC3042, a triac driver opto coupler IC. The pulse signal from the MOC 3042 drives the gate of the TRIAC so as to control the reactor current. The displacement factor i.e. the phase displacement between voltage and current actually determines the number that is loaded into the programmable interval timer in order to change the firing angle of the TRIAC in the static compensator circuit.

V. RESULTS AND DISCUSSIONS

The fabricated active power factor corrector has been tested on variable resistor in series with fixed inductive coil. Investigations were carried out at five load conditions by varying the values of load resistance. The inductive reactance and resistance of the coil is fixed at 503 Ω and 136 Ω respectively. Table 3 shows the load impedance and the corresponding power factor with and without SVC. These results are also plotted in Fig. 7. It is clear from the figure that the system is able to adjust the power factor from its low initial value to an almost unity power factor. Analysis of the waveforms for different values of load power factors showed that the correction of the power factor did not take any observable time. It was also observed that the PIC microcontroller based switching did not introduce any distortions in the output waveform while correcting the power factor.

In conclusion, the proposed system is able to adjust the power factor to a desirable value of approximately 1 and hence the system may be very useful for power control application where the load power factor changes abruptly. The Fig. 7 shows the voltage and current waveform without and with SVC as can be observed from the waveforms there is no phase angle displacement between main input voltage and current with SVC. The validation has been carried out to check the overall performance of the power factor correction.

When the PFC was applied to the DVC, the results obtained are shown in Fig. 8. Investigations were carried out at eight load conditions by varying the values of inductance. The inductance is ranging from 1232mH to 269.1mH and keeping resistance (124Ω) and capacitance (50µF) are constant. As the values of the impedance is decreased i.e. variation in the value of inductance from Henry (H) to mH, the uncorrected power factor value rises giving minimum and maximum values of 0.358 and 0.987 respectively. The value of corrected power factor is almost near to unity. The system is able to adjust the power factor from its low initial value to an almost unity power factor. Analysis of the waveforms for different values of impedance power factors showed that the correction of the power factor did not take any observable time. It was also observed that the PIC microcontroller based switching did not introduce any distortions in the output waveform.

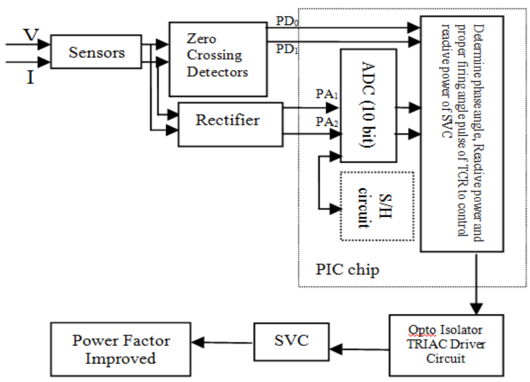

Fig. 4 Block diagram layout of the TCR control scheme

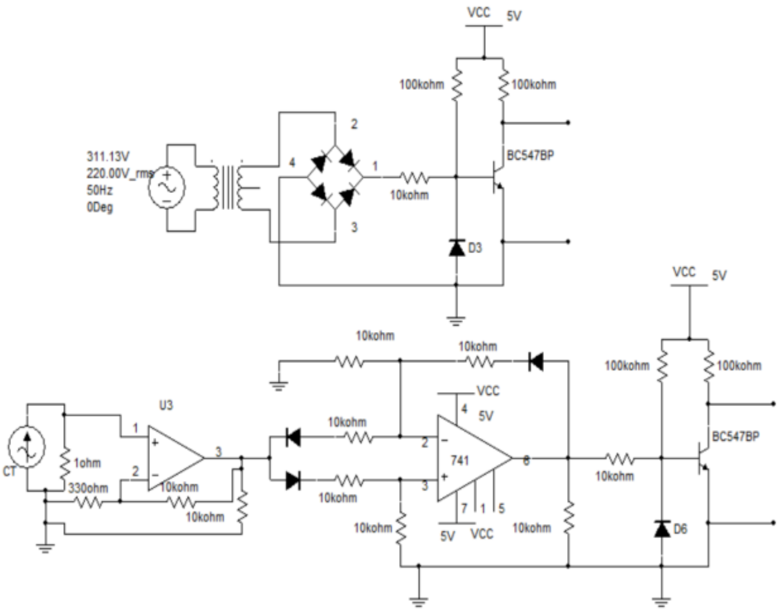

Fig. 5 Zero crossing detector

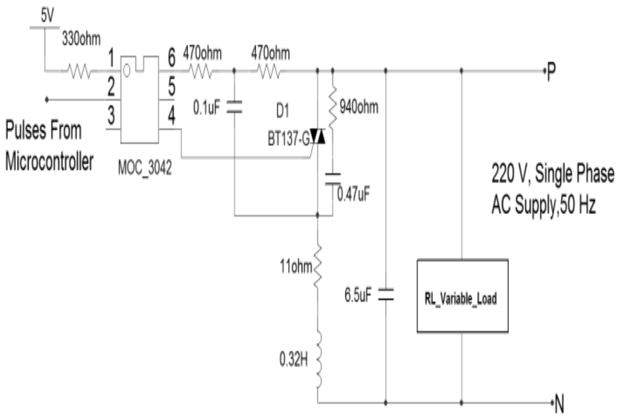

Fig. 6 TRIAC firing circuit and static VAR compensator scheme

TABLE 3
POWER FACTOR WITH AND WITHOUT SVC AT DIFFERENT LOAD CONDITIONS

Step No.	1	2	3	4	5
Load Resistance	0 Ω	132 Ω	258 Ω	390 Ω	550 Ω
Choke Resistance	136 Ω	136 Ω	136 Ω	136 Ω	136 Ω
Choke Reactance	503 Ω	503 Ω	503 Ω	503 Ω	503 Ω
Impedance Z=$\sqrt{R^2+X^2}$	520 Ω	570 Ω	638 Ω	727 Ω	850 Ω
Power factor without SVC	0.267	0.47	0.61	0.76	0.81
Φin degree without SVC	74.8^0	61.4^0	51.8^0	40.7^0	35.0^0
Φin degree with SVC	1^0	1.5^0	1^0	2^0	1.8^0
Power factor with SVC	0.999	0.999	0.999	0.999	0.999

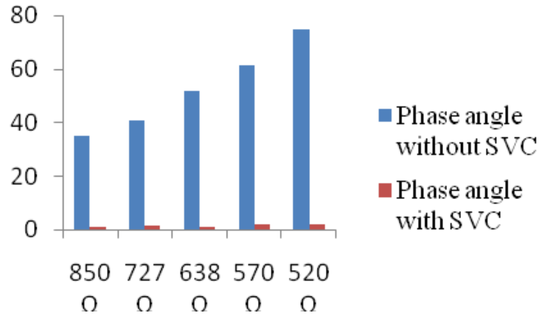

Fig. 7 Power factor angle (degree) with and without SVC

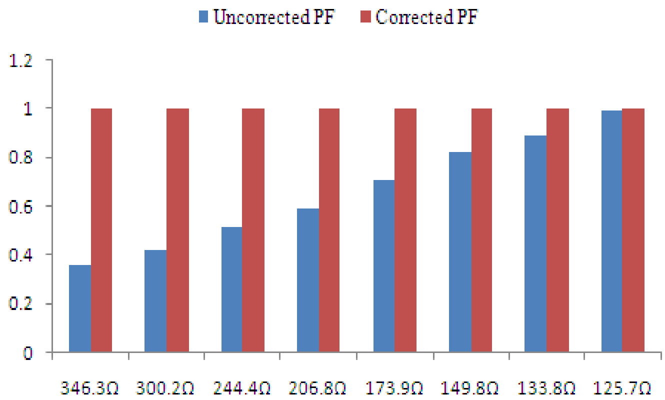

Fig. 8 Power factor with DVC

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