ISSN 1 746-7233, England, UK
World Journal of Modelling and Simulation
Vol. 13 (2017) No. 4, pp. 314-321

Prototype design of power factor correction circuit for transmission lines using Thyristor switched capacitor scheme

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(*Received May 11 2016, Accepted September 07 2017*)

Abstract. Shunt capacitive compensation method is used to improve the power factor. Whenever an inductive load (capacitor) is connected is connected which draws current leading the source voltage, the net result is improvement in power factor. This paper deals with improvement in power factor using thyristor switched capacitors (TSC). Static VAR compensation (SVC) is used as a solution for reactive power compensation. To compensate power factor, in this paper shunt compensation duly controlled from a programmed microcontroller is used. The time lag between the zero voltage pulse and zero current pulse duly generated by suitable operational amplifier circuits in comparator mode are fed microcontroller where the program takes over to actuate appropriate number of opto-isolators interfaced to back to back SCR at its output for bringing shunt capacitors into the load circuit to get the power factor nearly unity. The supply circuit consists of a step down transformer 230/12V, which steps down the voltage to 12V AC. This is converted to DC using a bridge rectifier. The ripples are removed using a capacitive filter and it is then regulated to +5V using a voltage regulator 7805 which is required for the operation of the microcontroller and other components. Circuit is simulated in proteus software environment and results are verified with prototype design. The details of design and fabrication of TSC for reliable power factor improvement is the basic aim of this paper.

Keywords: flexible ac transmission, power factor correction, proteus, static var compensation, thyristor switched capacitor

1 Introduction

In DC circuit, resistance opposes flow of current, whereas in AC circuit, there are other circuit parameters like inductance and capacitance determines the current flow. Most of the loads in industries are inductive in nature which unnecessarily loads the system drawing lagging current. Capacitive current leads the voltage & supplies the reactive power. The loads connected to AC circuit consume both active and reactive power. The reactive power returns to the source in each cycle and it controls the voltage level for the active power to do the useful work. When there is increase in reactive power consumption, losses in the system will increase and hence efficiency reduces. Maintaining the stable voltage profile and designing lossless power system is the need of an electric network. Use of capacitor bank is the conventional method to compensate the reactive power.

Power factor is unity for circuit containing only resistive load, but, it is less than one for inductive or capacitive load. When power-factor is less than unity, the generation and transmission cost increases due to increased power at utility grid end. Continuous change in reactive power is required in real-time as the load varies continuously. In such cases, fixed capacitor can cause over-compensation resulting overvoltage at the load end. Recent advancement in power electronics technologies has made the application of flexible alternating current transmission system (FACTS) devices[9], very popular in power system. Though there are various methods can be implemented for power-factor correction, but FACTS are advantageous in all respects,

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like less harmonics, easy implementation, compactness and easy control[2, 12, 17]. Continuous adjustment of reactive power using FACTS devices in which static VAR compensator is simple proven technology for power-factor correction and reactive power compensation.

SVC[14] has been evolved in 1987 and used as a shunt connected device to control the reactive power. Using appropriate switching schemes, reactive power can be controlled continuously from capacitive to inductive output at a set value of voltage. The different types of SVCs are: Thyristor Controlled Reactor (TCR), Fixed Capacitor Thyristor Controlled Reactor (FC-TCR), Thyristor Switched Capacitor (TSC) and the combination of TCR & TSC (TCR-TSC)[3, 15]. These compensators regulate voltage, improve the stability and control overvoltage. This paper deals mainly with the TSC type SVC. The shunt capacitor bank in TSC is divided into an appropriate number of branches. Each branch is switched ON or OFF individually using anti-parallel connected thyristor switches. Furthermore, a series inductance is generally connected to limit the over-current due to mis-firing. The main characteristics of a TSC[6] are smooth control, flexible operation, no harmonics and less loss.

This paper proposes design and implementation of a low cost reactive power factor controller, capable of power factor correction in transmission lines. The main concept behind controlling TSC is the control of firing angle of the thyristor to control the reactive power. Microcontroller-based firing pulse control is simple, robust and economical. Enhancement of voltage profile and power factor improvement is achieved by developing a microcontroller based TSC in laboratory as a small scale prototype model intended for industrial manufacturers and all consumers.

This paper is organized as follows: Section 2 introduces some basic concepts in Flexible Alternating Current Transmission System. The block diagram of SVC is discussed in Section 3. The design of the proposed circuit modeling in proteus is presented in Section 4. Section 5 presents the prototype design of microcontroller based TSC circuit. Finally in Section 6 the main contributions of this paper are summarized.

2 FACTS (flexible alternating current transmission system)

Flexible alternating current transmission system refers to a family of power electronics-based devices able to enhance AC system controllability, reliability, stability and power transfer capability[4, 11, 19]. The implementation of different schemes and configurations of FACTS device can be achieved by combination of traditional power system components (such as transformers, reactors, switches, and capacitors) with power electronics elements (such as various types of transistors and thyristors)[8].

The transmission capacity enhancement of up to 40-50% may be achieved by installing a FACTS element depending on the type of device and on the specific voltage rating[1]. In comparison to traditional synchronous reactor and condensers, FACTS devices require a lower maintenance and provide rapid control of voltage. The main barrier in integrating these technologies to the existing power system is cost, reliability and stability issues [10].

A static VAR compensator is a set of electrical devices for providing reactive power compensation on high-voltage electricity transmission networks[16]. SVCs are part of the flexible AC transmission system device family which regulates voltage, compensate power factor, reduces harmonics and stabilizes the system. Unlike a synchronous condenser which is a rotating electrical machine, a static VAR compensator has no significant moving parts other than internal switchgear. Prior to the invention of the SVC, synchronous condensers or switched capacitor banks are used to achieve power factor compensation. The SVC is an automated impedance matching device, designed to operate the system with nearly unity power factor. SVCs are used in two main situations:

- Connected to the power system, to regulate the transmission voltage (“Transmission SVC”)
- Connected near large industrial loads, to improve power quality (“Industrial SVC”)

In transmission applications, the SVC is used to regulate the grid voltage[13]. If the load is capacitive (leading), the SVC will use thyristor controlled reactors to consume VARs from the system, lowering the system voltage. Under inductive (lagging) load conditions, the capacitor banks are automatically switched in, thus providing a higher system voltage. By connecting the thyristor-controlled reactor, which is continuously

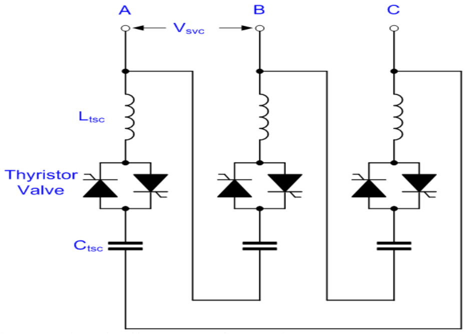


Fig. 1: Circuit diagram of a static VAR compensator

variable along with a capacitor bank; the net result is continuously variable leading or lagging power. Unlike the TCR, the TSC is only ever operated fully on or fully off provides rapid voltage regulation at the load bus. When TSC is operated in phase control, it will result in generation of very large amplitude resonant currents, leading to overheating of the capacitor bank & thyristor valve and harmonic distortion in the AC system to which the SVC is connected. When the TSC is on or deblocked, the current leads the voltage by 90° (as with any capacitor). The rms current is given by: $I_{tsc} = V_{svc}/X_{tsc}$ Where$X_{tsc} = (1/2\pi f C_{tsc}) - 2\pi f L_{tsc}$

V_{svc} is the rms value of the line-to-line bus bar voltage to which the SVC is connected.

C_{tsc} is the total TSC capacitance per phase.

L_{tsc} is the total TSC inductance per phase.

f is the frequency of the AC system.

The TSC forms an inductor-capacitor (LC) resonant circuit with a characteristic frequency of $f_{tsc} = 1/2\pi f C_{tsc} L_{tsc}$. The tuned frequency is usually chosen to be in the range 150-250Hz. The size of the TSC reactor is chosen carefully which increases with decreasing frequency. It also protects the thyristor valve from misfiring i.e. excessive oscillatory currents when the TSC is turned on at an incorrect point of wave. To avoid the risk of overloading due to flow of harmonic current, the TSC is usually tuned to a non-integer harmonic of the mains frequency.

The thyristor valve typically consists of 10-30 cascaded connected thyristors needed because all available thyristors can conduct current only in one direction. The series connection is needed because the maximum voltage rating of commercially available thyristors (up to approximately 8.5kV) is insufficient for the voltage at which the TSC is connected. For some low-voltage applications, it may be possible to avoid the series-connection of thyristors; in such cases inverse-parallel connection of two thyristors in thyristor valve is preferred. The thyristor valve is usually installed in a purpose-built, ventilated building, or a modified shipping container[5].

In each inverse-parallel pair of thyristors has an R-C (snubber circuit) connected across it, to force the voltage across the valve to divide uniformly amongst the thyristors and to reduce the commutation overshoot which occurs when the valve turns off. The thyristor valve for a TSC is very similar to that of a TCR. A number of thyristors are connected in series to withstand both the AC voltage and the capacitor voltage after blocking. Cooling for the thyristors and snubber resistors is usually provided by deionized water.

3 Block diagram of proposed scheme

Block diagram of SVC technique employing TSC is shown in fig. 2. In the circuit shown, the output of power supply i.e. 5V is connected to the 40th pin of microcontroller and gnd to the pin 20 of microcontroller. P0.1 and P0.2 of microcontroller is connected to opto-isolators U6 and U10 respectively. P0.5 to P0.7 of microcontroller is connected to Pin 4, 5 and 6 of LCD display. P2.0 to P2.7 of microcontroller is connected with Pin 7 to 14 of data pins of LCD display. P3.2 and P3.3 of microcontroller are connected to output of the OP-Amp (A) and OP-Amp (B) LM339 respectively.

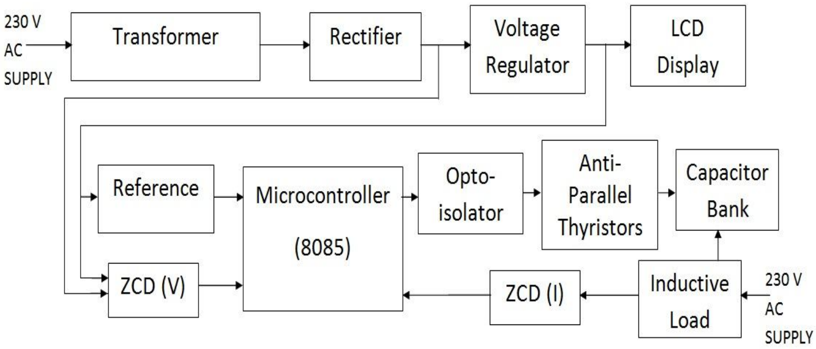


Fig. 2: Block diagram of SVC technique employing TSC

A comparator circuit compares two voltage signals and determines the signal with higher amplitude. In a current comparator, the current input is converted into its equivalent voltage and then it is fed to the op-amp. Potential dividers are connected to the inverting and non inverting inputs of the op-amp which give some voltage at these terminals. Supply voltage is given to $+Vss$ and $-Vss$ is connected to ground. The output of this comparator will be logic high (i.e., supply voltage) if the non-inverting terminal input is greater than the inverting terminal input of the comparator. If the inverting terminal input is greater than the non-inverting terminal input, then the output of the comparator will be logic low (i.e., gnd).

3.1 Zero crossing pulse generation

In order to generate zero crossing voltage pulses, the supply voltage is stepped down to 12V and then it is converted into pulsating D.C. A 3V input though the potential divider is given to a comparator. The comparator generates the zero crossing pulses by comparing this pulsating D.C with a constant D.C voltage of 0.6V which is taken across a diode. Similarly for zero crossing current pulses, the voltage drop proportional to the load current across a resistor is taken and is stepped up to generate pulses same as above. The zero crossing pulses from a pulsating D.C are shown in the Fig. 3. The voltage and current time lag is calculated by observing the zero crossing of the signals which in turn calculates the power factor of signal. As we know frequency of supply voltage is 50 Hz, so time period $T = 1/50 = 20msec = 360°$. Hence the time lag can be calculated by converting it into the equivalent angle and thus the power factor can be obtained as the cosine of that angle.

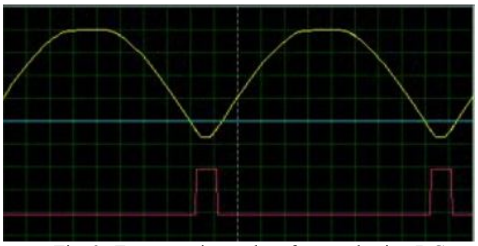


Fig. 3: Zero crossing pulses from pulsating DC

4 Power factor test layout using proteus

An arrangement with supply source 230V, one lamp, two low value resistors of 10R/10W for measuring current, a choke are all connected in series. Capacitors are connected in parallel through SCR switches to improve power factor. When the by-pass switch is off, same current will flow in both the 10R/10W resistors.

The primary side of CT as shown in Fig. 4 is connected to the common point of the resistors through sensors. The secondary of CT connects to one of the common point of a DPDT S1 switch. While the DPDT switch is moved to right, then the CT connects across left 10R/10W resistor and the voltage drop proportional to the current is sensed by it to develop increased voltage at its primary. This voltage is given to the current sensing circuit. When the DPDT switch is moved to left then the CT connect across right 10R/10W and the voltage drop proportional to the current is sensed by it to develop increased voltage at its primary. When no capacitors are switched, the voltage drops across both 10R/10W resistors are same. This voltage drop is proportional to lagging current. Thus the primary voltage from the CT provides lagging current reference to the current sensing circuit.

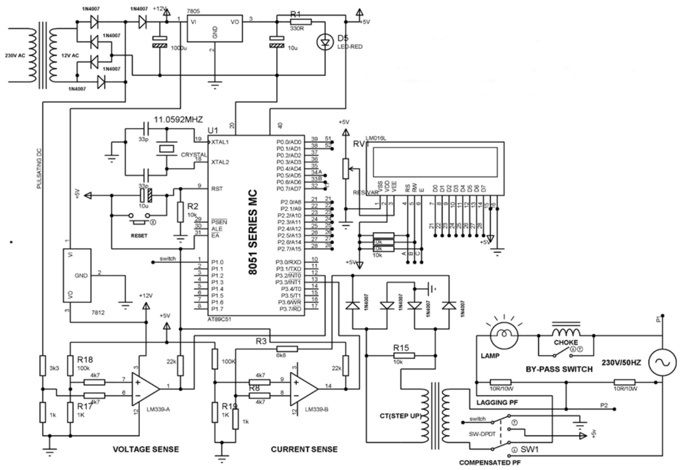


Fig. 4: Power factor correction circuit using microcontroller

The microcontroller based control[7, 18] circuit thus receives zero current reference and compares with the zero voltage reference for calculating the power factor based on their time difference. Microcontroller output develops logic high for appropriate number of port pins to feed to opto-couplers to help switching capacitors through SCR. Capacitor connects in parallel to the choke. So depending on the time difference, required number of SCR switches are switched on; there by switching additional capacitors till the power factor reaches unity. Once the capacitors are switched on, the right 10R/10W resistor current becomes compensated while current flowing through left 10R/10W remains unchanged which is the lagging current.

Thus depending on the switch S1 position, the lagging or the compensated current is sensed and the display provides accordingly the time delay between voltages, current. In case a linear load is required, switch by-pass is closed so that it by-passes the choke L2 and the CT reads unity power factor. The other common point of the DPDT switch goes to the microcontroller (MC) while it's switching points are connected to $+ve$ and ground so that appropriate logic is placed on the MC for right kind of display.

4.1 SCR in anti parallel

During the positive half cycle of main current, the current flows from supply to the load through SCR. During negative half cycle, it flows from load side to the supply. One SCR conducts in positive half cycle and another SCR conducts in the negative half cycle.

Two SCR's U7 & U8 are connected back to back through opto-isolators as shown in Fig. 5 and Fig. 6. MOC3063 opto-isolator is a LED-TRIAC combination. Two opto-isolator inputs are connected in series with the supply while their outputs are connected to SCRs. A 2uF capacitor C7 is connected in series with resistor R28. In switch off condition, capacitor C7 discharges through a 100K resistor R20 connected across it. R6 and C6 forms a snubber circuit connected for protection of the SCRs. The results obtained from proteus design are shown in Fig. 7 and Fig. 8. Result shows an improvement in power factor to unity after compensation which was 0.8 before compensation.

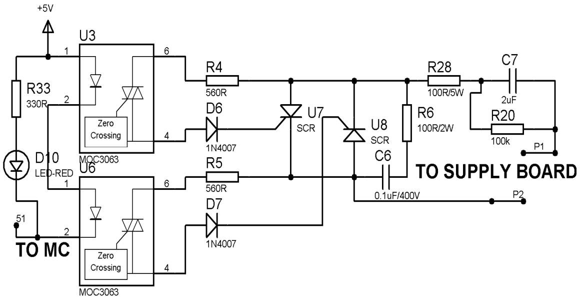


Fig. 5: SSupply circuit for experimental setup

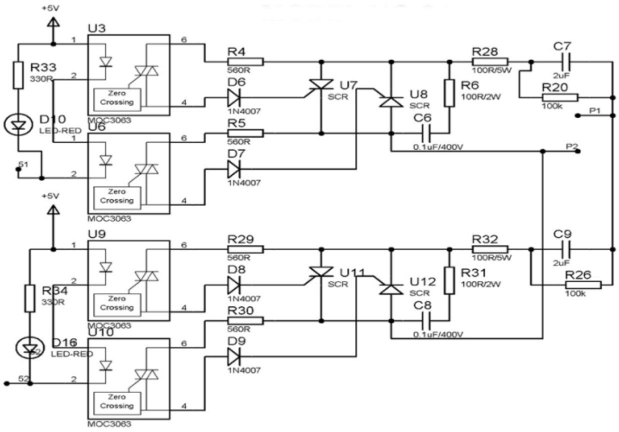
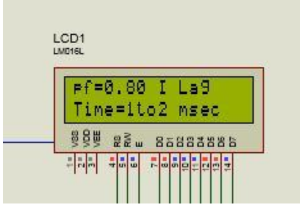
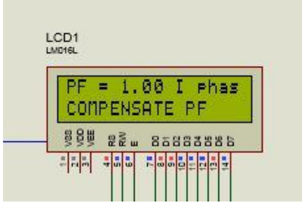


Fig. 6: Supply circuit for the main power factor correction circuit



```
pf=0.80 I Lag
Time=1to2 msec
```

Fig. 7: Before compensation: Result obtained from the proteus simulation



```
PF = 1.00 I phas
COMPENSATE PF
```

Fig. 8: After compensation: Result obtained from the proteus simulation

5 Hardware implementation

The circuit shown in Fig. 9 consists of DC power supply unit, zero voltage crossing detectors, microcontroller, LCD display, opto-isolator, SCR and capacitors. Microcontroller gets input from the DC source. For the calculation of the power factor by the microcontroller, digitized voltage and current signals are needed. The voltage signal from the mains is converted into pulsating DC by bridge rectifier and is given to a comparator which generates the digital voltage signal. Similarly the current signal is converted into the voltage signal by taking the voltage drop of the load current across a 10 ohm resistor. This is again converted into the digital signal as done for the voltage signal. Then these digitized voltage and current signals are sent to the microcontroller. The microcontroller calculates the time difference between the zero crossing points of current and voltage, which is directly proportional to the power factor. Thus it determines the range of power factor. Microcontroller sends information regarding time difference between current, voltage and power factor to the LCD display to display them. Depending on the range microcontroller sends the signals to the opto-isolators that in turn switch ON back to back connected SCRs (power switches). Thus, the required numbers of capacitors are connected in parallel to the load thereby improves the power factor. A result obtained from the design setup is shown in fig. 10. The output waveforms before and after compensation are also presented in Fig. 11, Fig. 12 and Fig. 13.

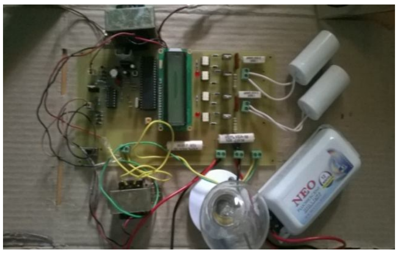


Fig. 9: Experimental setup

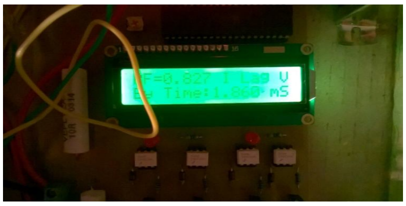


Fig. 10: Result obtained from the experimental setup

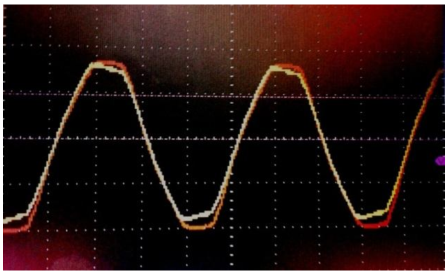


Fig. 11: Output waveforms with resistive load

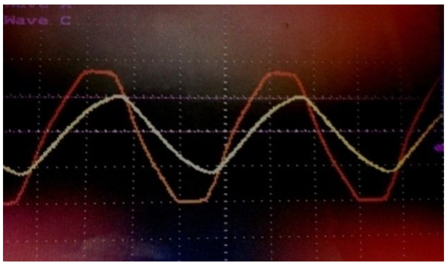


Fig. 12: Output waveforms with lagging PF

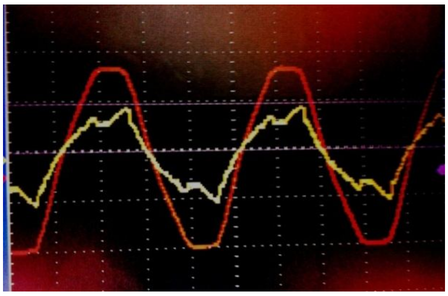


Fig. 13: Output waveforms after compensation

6 Conclusion

This paper proposes thyristor switched capacitor scheme based on fast acting thyristors for reactive power compensation. Reactive power compensation in turn improves the power factor by drawing leading current. The microcontroller based designed circuit shows the overall effect of the whole system using locally installed FACTS devices. Moreover by the use of microcontroller the on time and off time control of the shunt capacitance is easily done. Also the hardware design results are compared with software model implemented in proteus is justified. The model presented in this paper without use of harmonic filters has good compensation performance and has huge application in the transmission lines. A comparison of results with and without TSC which shows better improvement in power factor is represented in Fig. 14.

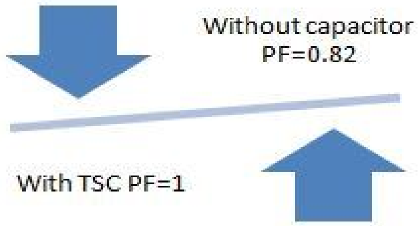


Fig. 14: Comparison of power factor with and without TSC

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