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Hardware Circuit Implementation of Automatic Control of Static Var Compensator (SVC) using Micro Controller

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Abstract - The design, Fabrication of 1Kvar 1-phase fixed capacitor-thyristor controlled reactor (FC-TCR) type SVC based on microcontroller have been developed in the laboratory for SMSL(Single Machine Single Load) Test System. The test system is setup in the laboratory with a 3-phase Synchronous Machine of 5kva capacity and a 1-phase Induction Motor of 1HP Rating. Brake test have been performed on the Induction Motor by taking the supply from one of the phases of Synchronous Generator. The bus voltage is fall down from 230 V to 195 V on Full Load. Automatic control circuit Hardware of this SVC have been designed and fabricated based on Microcontroller LPC 2148 chip, the most modern industrial controller. The same test system also has been tested with SVC automatic control circuit and experimental results have been presented in this paper. The P-V Curves of the SMSL Test system with and without SVC Control have been plotted which shows the effectiveness of Automatic control of SVC on Voltage Stability enhancement.

Keywords - FC-TCR type SVC, SVC control, dynamic control of reactive power, FACTS Controllers, Microcontroller based control of Reactive power, Automatic control of SVC, closed loop control of SVC, TCR control, Single Machine Single Load System, Voltage Stability Enhancement and P-V Curves.

I. INTRODUCTION

A TCR is one of the most important building blocks of thyristor-based SVCs. Although it can be used alone, it is more often employed in conjunction with fixed or thyristor switched capacitors to provide rapid, continuous control of reactive power over the entire selected lagging-to-leading range. Traditionally TCR controllers are microcontroller based. Recently, with the development of microelectronics, LPC 2148Chip become more and more widely used in electric apparatus controllers to increase the accuracy and the computation rate of the control algorithms.

In this paper, the design and fabrication of 1Kvar 1-phase fixed capacitor-thyristor controlled reactor (FC-TCR) type SVC based on microcontroller have been developed in the laboratory for SMSL(Single Machine Single Load) Test System. The test system is setup in the laboratory with a 3-phase Synchronous Machine of 5kva capacity and a 1-phase Induction Motor of 1HP Rating. The Static Var Compensator (SVC) is an early generation of FACTS Controllers and a proven technology for voltage stability and power factor correction. The SVC is composed of a fixed capacitor (FC) and a thyristor controlled reactor TCR. A PI feedback closed voltage regulation scheme is presented

to adjust the equivalent Susuptance of a single phase SVC.

This paper deals with the Design, Fabrication and Testing of Microcontroller based 1KVAR SVC along with Automatic Control circuit Hardware. The laboratory setup of the SMSL test system with and without SVC Automatic control circuit have been Developed. SVC is comprised of a 1-Kvar thyristor controlled reactor in parallel with 1-Kvar capacitor. The test results to inject or absorb VARs into the system for maintaining constant voltage profile have been presented in this paper. This fine tuning is accomplished by varying the firing delay angle (α) of the reactor, thus modifying the TCR VARs absorbed. if $\alpha = 0$ is defined as the zero crossing of the applied voltage, then firing angles will be in the range of $(\pi / 2) \leq \alpha \leq \pi$ for each half-cycle. Experimentally the P-V Curves of the test system without and with SVC have been drawn. Ultimately results show the effectiveness of SVC on Voltage Stability Enhancement.

Fig. 1 SVC with control concept briefly illustrated.

Voltage regulation is provided by means of a closed-loop controller. SVC control circuit consists following blocks, such as step down/up transformer, rectifier bridge circuit, active power filter, voltage

regulator, PI controller, gate pulse generating unit (i.e. firing unit). *Figure.1* illustrates FC-TCR type SVC, including the operational concept. The control objective of the SVC is to maintain a desired bus voltage. In the steady-state, the SVC provides steady-state control of the bus voltage at a pre-defined level.

The control scheme implemented for FC-TCR topology works as follows:

- The amplitude of the bus voltage V_{bus} is measured and filtered.(sec.1.1,1.2,6.3)
- Then it is compared against the voltage reference V_{ref} .

The voltage difference between the two signals is processed by a PI controller which causes a corresponding change in the firing angle α . The value provided by the PI controller is used as the input to the TCR firing control unit.



Fig. 2 : TCR current observed in the lab

The gating or ‘turn on’ signal to each thyristor is delayed by α , the firing or conduction angle, from the zero crossing of the source voltage as illustrated in *Figure 2*. As current lags the voltage across the reactor by 90° , so a firing angle of ninety degrees results in maximum, that is, continuous reactor current. For a firing angle of 180° , the reactor current will be zero. As the thyristor firing angle is increased from 90° towards 180° , the current in the reactor is reduced. Therefore, the firing angle can be in the range of $90^\circ \leq \alpha \leq 180^\circ$ to vary the TCR current from zero to its maximum by phase angle control of the thyristors. The reactor is connected in series with two antiparallel thyristors. One of these thyristors conduct in each positive half cycle, while the other conducts in the subsequent negative half cycle.

Table1: TCR current Observations

S. No.	Input Voltage(V)	α	I_{TCR}	V_R
1	220	180	0	0
2	220	160	0.07	30
3	220	150	0.3	74
4	220	130	0.74	105
5	220	110	0.92	145
6	220	90	1	190

II. DESIGN REQUIREMENTS OF SVC

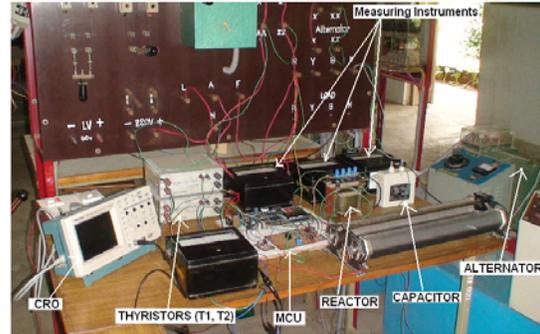


Fig. 3 : Power and Control circuit of SVC (FC-TCR)

III. OPERATION OF SVC

The SVC behaves like a shunt-connected variable reactance, which either generates or absorbs reactive power in order to regulate the PCC voltage magnitude. In its simplest form, the SVC consists of a TCR in parallel with a bank of capacitors

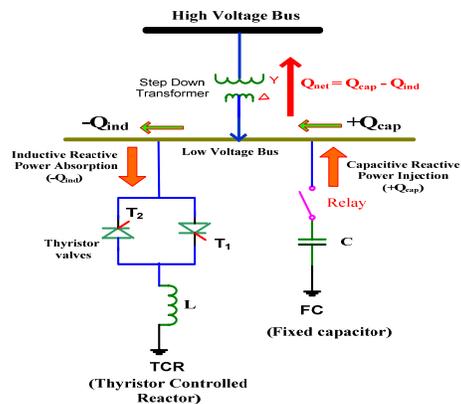


Fig. 4 : Block Diagram of FC-TCR SVC

The SVC regulates voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the SVC generates reactive power (SVC capacitive). When system voltage is high, it absorbs reactive power (SVC inductive).

SVC principle is supplying a varying amount of leading or lagging VAR to the lagging or leading system. By phase angle control of thyristor, the flow of current through the reactor is varied. Hence by varying the firing angle α from 90° to 180° , the conduction interval is reduced from maximum to zero.

In terms of susceptance, $I_{SVC} = j B_{SVC}V$

Where: $B_{SVC} = B_{TCR} + B_c$

$$B_{SVC} = B_L ((\pi - 2\alpha - \sin\alpha)/\pi) + B_c$$

$$\text{Where, } B_c = 1/X_c$$

$$B_L = 1/X_L$$

$$\text{In terms of reactance, } X_{SVC} = \frac{X_c X_{TCR}}{X_c + X_{TCR}}$$

$$\text{Where, } X_{TCR} = \frac{\pi X_L}{\sigma - \sin \sigma}$$

$$X_{SVC} = \frac{\pi X_c X_L}{(X_c (\sigma - \sin \sigma) - \pi X_L)}$$

$$\text{Where, } \sigma = 2(\pi - \alpha)$$

$$X_{SVC} = \frac{\pi X_c X_L}{X_c [2(\pi - \alpha) + \sin 2\alpha] - \pi X_L}$$

$$X_{SVC} = \frac{V_{Bus}^2}{Q_{SVC}}$$

$$Q_{SVC} = \frac{V_{Bus}^2 (X_c [2\pi - \alpha + \sin 2\alpha] - \pi X_L)}{(\pi X_c X_L)}$$

Generally, by changing the firing angle ‘ α ’ the fundamental reactance X_L of the reactor is changed.

$$X_L = \frac{V}{I_{FL1}}$$

3.1 Variable Shunt Compensation

Conventional thyristor controlled compensator, the SVC, presents variable reactive **impedance** to, and thus acts indirectly on, the transmission network. The SVC functions as a controlled shunt reactive admittance that produces the required reactive compensating **current**. Thus, the attainable reactive compensating current is a function of the prevailing line voltage.

It can be seen that the gating delay angle varies between 90^0 (full conduction) to 180^0 (no conduction). The effect of increasing the gating delay angle is to vary the amplitude of the current through the inductor. The current is not particularly sinusoidal over one cycle, except if the thyristors are fully conducting.

$$I = \frac{\sqrt{2}V}{X_L} (\cos \alpha - \cos \omega t)$$

$$\text{For } \alpha < t < \alpha + \sigma \text{ (conduction)}$$

$$I = 0 \text{ for } \alpha + \sigma < \omega t < \alpha + \pi \text{ (No conduction)}$$

IV. EXPERIMENTAL RESULTS

Table 2: Bus Voltage Variation without SVC

S. No	Terminal voltage V_L (V)	Load current I_o (Amps)	Output Power (Watts)
1.	230	3.4	320
2.	225	3.8	360
3.	220	4.2	480
4.	205	4.8	560
5.	195	5.2	630
6.	190	6.0	700

Table 3: Bus Voltage Variation with SVC

S. No	Terminal voltage V_L (V)	Load current I_o (Amps)	Output Power (Watts)
1.	235	3.0	280
2.	232	3.2	300
3.	230	3.6	440
4.	230	4.2	500
5.	230	4.8	580
6.	225	5.2	650

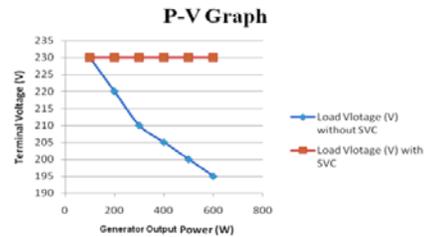


Fig. 5 : P- V curve for with and without compensation

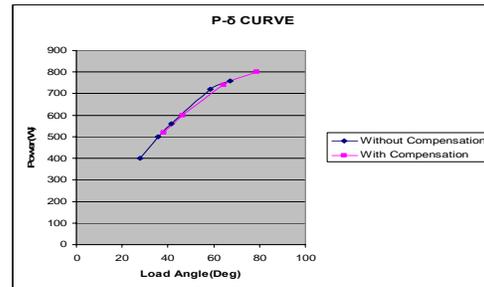


Fig. 6 : P- δ curve for with and without compensation

V. CONCLUSION

In this paper, a single phase 1kvar SVC is Fabricated and Tested experimentally by connected to a SMSB Test System. The hardware of this SVC control

system is developed based on Microcontroller LPC 2148 chip, the most modern industrial controller. Simulation analysis was done for the current with various firing angles and the results are presented. The harmonics increase with the increase in the firing angle.

The proposed model is experimentally verified and is found to give very fast and precise compensation characteristics. Detail is given for the experimental system implementation. Balanced voltage on the test system. Demonstrates the effectiveness of the open loop control for the compensator.

FUTURE SCOPE

The variable shunt compensation using SVC can be extended to the large rating machines and Large Interconnected Power Systems. The SVC can also be fabricated by using IGBT's and testing can also be performed using DSP. TSC-TCR based SVC can also be implemented for SMSL Test System.

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NOMENCLATURE

- α is the Firing Angle
TCR : Thyristor Controlled Reactor
 I_{TCR} is the Current Through TCR
 V_{TCR} is the voltage across TCR
PI : Proportional and Integral
SMSL: Single Machine and Single Load
FC: Fixed Capacitor
SVC: Static Var Compensator
P-V: Power – voltage
 B_{SVC} : Net susceptance of SVC
 X_{SVC} : Net reactance of SVC
 B_{TCR} : susceptance of TCR
 X_{TCR} : reactance of TCR
 B_c : Capacitive susceptance
 X_C : Capacitive reactance
 X_L : Inductive reactance
 Q_{SVC} : Reactive Power supplied or absorbed by SVC
 I_C : Current Through the Capacitor

