Modeling and Simulation of SVC for Reactive Power Compensation and Harmonic Analysis

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Abstract: This paper will discuss and demonstrate Static Var Compensator (SVC) for reactive power compensation. SVC is basically a shunt connected static Var generator whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific power variable. In this paper, simple circuit model of Thyristor Controlled Reactor is modeled and simulated using MATLAB. Hardware implementation of TCR is done by using MATLAB-dSPACE interfacing. The current drawn by the TCR varies with the variation in the firing angle and as the current varies ultimately reactive power compensation can be achieved. Also the harmonic analysis is done. The simulation results are compared with the experimental results.

Index terms- Thyristor controlled reactor (TCR), Static VAr compensator (SVC), Total harmonic Distortion (THD)

I. INTRODUCTION

SVC is rising technology to gain total control on power system. SVC is self-controlled technology which can control different parameters of power system like Active power, Reactive power, Harmonics, Power factor, Regulation etc.

Reactive power is very much essential to maintain active power flow through power system. When there is heavy load at receiving end system voltage sags down and hence absorbed reactive power is more than generated. On the other hand when there is light load or no load at receiving end generated reactive power is more than absorbed so voltage swell occurs. Due to this unbalanced conditions in power system power quality falls down. So there is need to compensate the reactive power to avoid the problem occurred in power system. Reactive power generated by the AC source is stored in capacitor or reactor during a first quarter of a cycle and in next quarter of a cycle it is sent back to the ac power source. Therefore decrease in reactive power causing voltage to fall while increase in reactive power causes voltage to rise. Reactive power oscillates between the ac source and load to two times of the rated frequency of the system. So to avoid circulation of reactive power between load and source it needs to be compensated. Also to regulate the power factor of the system and maintain the voltage stability we need to compensate the reactive power. One of the major reasons for installing a SVC is to improve dynamic voltage control and thus increase system load ability. [5] There are different reactive power compensation techniques Such as by using synchronous condenser, Static VAR Compensators, capacitor banks, Reactor banks etc. But most of them have disadvantages like Synchronous condenser are not handy, they are too bulky in nature, they require special starting and protective equipment, they require strong foundation, and they have poor transient response. Also, these compensators are expensive. So it is preferable to use SVC technology. There are different types of SVC devices like TCR, FC-TCR, TSC-TCR, TBSC-TCR etc. This paper deals with the design and analysis of TCR.

II. THYRISTOR CONTROLLED REACTOR

2.1 Principle of TCR

A thyristor controlled reactor (TCR) structure is an inductor connected in series with an antiparallel thyristor valve. The bidirectional thyristor switch is phase-controlled device, which adjusts the value of delivered reactive power to meet changing system conditions. The current in the TCR is varied from maximum to nearly zero by varying the firing delay angle α from 90° to 180°. α is defined as the delay angle from the point at which the voltage becomes positive to the point at which the thyristor valve is turned on and current starts to flow. For positive half cycle one thyristor forward biased and for negative half cycle another will so that we can control full cycle. TCR is able to mitigate the voltage swell by absorbing the excessive reactive power. [4]

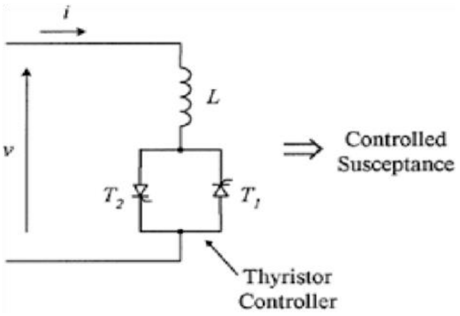

Fig-1: Basic TCR module

Fig-1 shows typical TCR module In TCR current can be continuously varied from maximum to minimum by varying firing angle
from to 90° -180°. The instantaneous current over half cycle is given by,

$$i_{TCR} = \frac{\sqrt{2V}}{XL}(cos \propto -coswt) \qquad \alpha < wt < (\alpha + \sigma)$$

$$= 0 \qquad (\alpha + \sigma) < wt < (\alpha + \pi) \qquad (1)$$

Where V is the RMS Voltage applied, XL is the reactance at the fundamental frequency. And the conduction angle σ is related to $\propto$ by,

$$\sigma = 2(\pi - \alpha) \tag{2}$$

Amplitude of fundamental current $I(\alpha)$ is given by,

$$I_l(\alpha) = \frac{V}{Xl}(1 - \frac{2}{\pi}\alpha - \frac{1}{\pi}sin2\alpha) \tag{3}$$

TCR can control the fundamental current continuously from zero (SCR open) to a maximum (SCR closed) as if it was a variable reactive admittance.

$$BL(\alpha) = \frac{1}{wL}(1 - \frac{2}{\pi}\alpha - \frac{1}{\pi}sin2\alpha) \tag{4}$$

TCR can control the fundamental current from zero (valve closed) to a maximum (valve opened) amounting to continuously variable reactive admittance. Thus the admittance varies with the same manner as the fundamental current $I(\alpha)$ varies. [1]

III. OPEN LOOP TCR SCHEME

The scheme presented in the paper is for single phase system. In the TCR the specifications are as follows: Source Voltage: V=230 Volts, R=0.2047 Ω, L=0.2e-3, Inductor Specification: 310mH, R=10Ω.

In thyristor controlled reactor the current varies from 90° to 180°, below 90° the current is maximum. The main objective of TCR is to absorb the capacitive reactive power. The maximum reactive power compensation from 310mH inductor is 237 Var at 90° and according to the requirement one can obtain required reactive power.

From simulation results one can see that in fig-2 the current is maximum and continuous at 90° so reactive power obtained is also maximum as shown in fig-3. Fig-4 shows current at 150° so it can prove that as firing angle increase current decreases and also the reactive power. Reactive power at 150° is as shown in fig-5.

3.1 Simulation Results

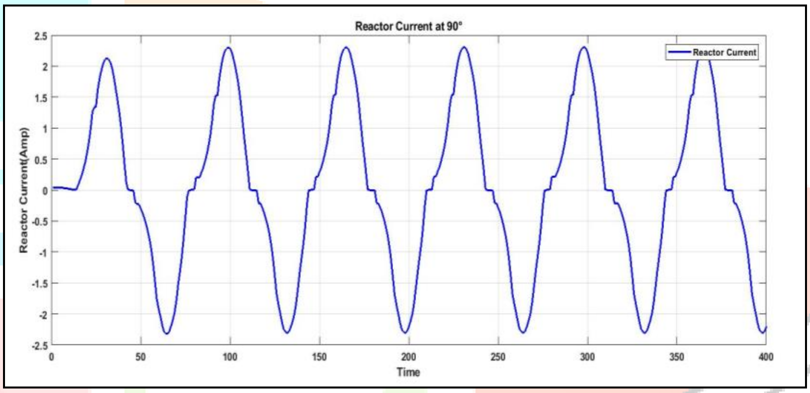

Fig-2: Reactor Current at 90°

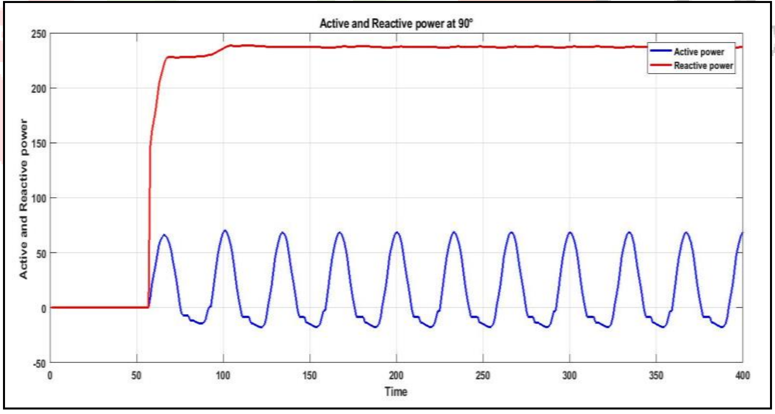

Fig-3: Active and Reactive Power at 90°

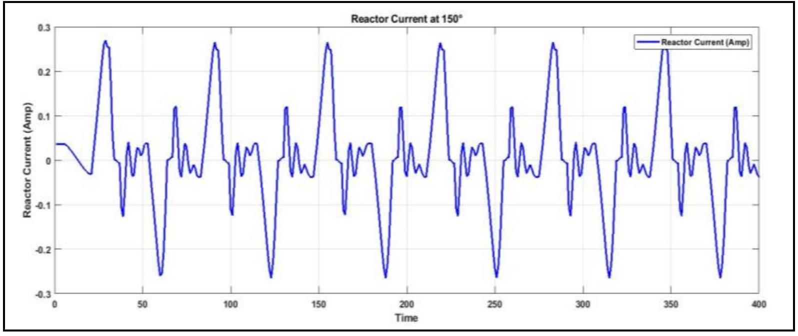

Fig-4: Reactor Current at 150°

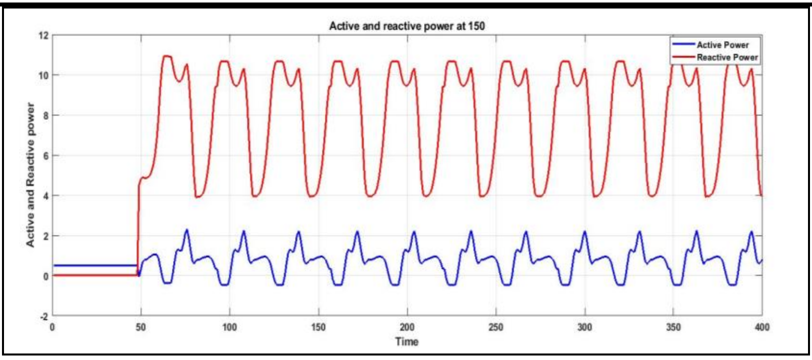

Fig-5: Reactor current and THD at 150°

From above figure we can say that at 90° maximum current flows through inductor and harmonics induced are negligible. And as the firing angle increases current becomes discontinues and more harmonics are try to inject in the system. [3]
The harmonic analysis from the simulation results is as follows,

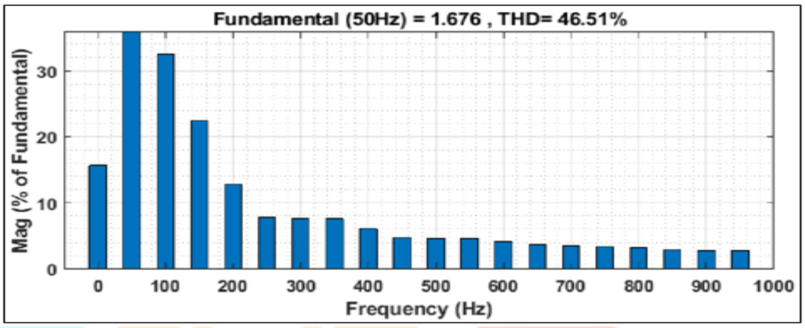

Fig-6: THD at 90°

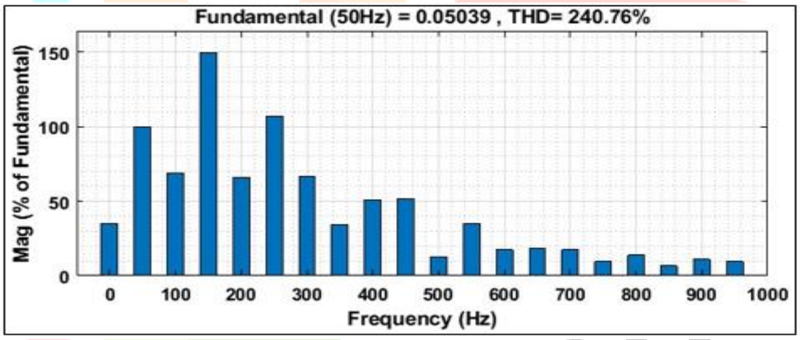

Fig-7: THD at 150°

THD at 90° is shown in fig-6 and THD at 150° is shown in fig-7 from this we can say that as firing angle increases more harmonics are try to inject in the system. A TCR is a source of harmonics the same as the rest of power semiconductor devices. It actually generates harmonics which are traced back to the supply and destroy the supply waveform and reduce power quality. These harmonics are related to the triggering angle. As the triggering angle increased the conduction angle decreased resulting in blocking the circuit current which in the other hand will make the current waveform less sinusoidal. The most effective harmonics are the odd harmonics, which are the triple of the fundamental frequency. The odd harmonics are given by the following:

$$In = \frac{4V}{\pi X}\left[\frac{\sin(n+1)\alpha}{2*(n+1)} + \frac{\sin(n-1)\alpha}{2*(n-1)} - cos\alpha * \frac{sin\alpha}{n}\right] \qquad (5)$$

THD readings are taken for 90°-180°. From these readings we can say that firing angle range between 90°-130° gives very satisfactory performance with regards to harmonics, active and reactive power. THD results are verified with hardware in next section.

3.2 Closed Loop TCR Scheme

A block diagram of reactive power compensation using TCR is shown in fig-8. Reference reactive power Qref is compared with the actual reactive power and error signal is converted into TCR firing angle.
For the same specification which are for the open loop closed loop scheme is developed. This scheme acts as a variable reactive power source. As we have seen in the open loop reactive power varies from 237 Var at 90° to 4 Var at 180° close loop system is able to give reactive power between the same ranges as the reference varies.

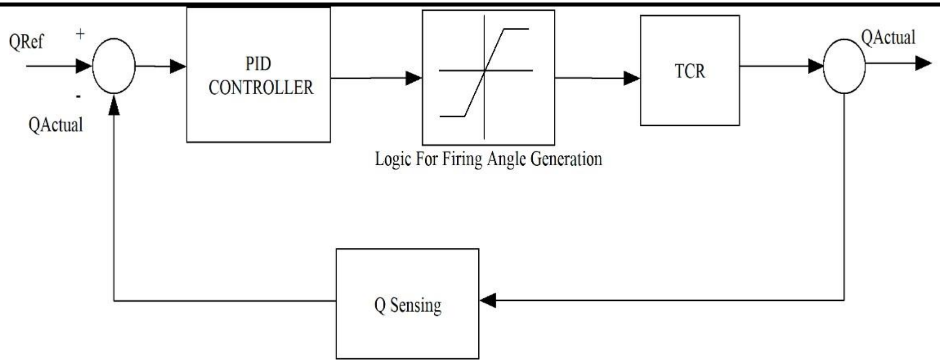

Fig-8: Closed loop TCR system

Above figure shows the closed loop reactive power system. The required reactive power compensation can be achieve from close loop system. It can continuously control the reactive power from 4 VAr to 237 VAr according to reference firing angle changes and gives required reactive power compensation.

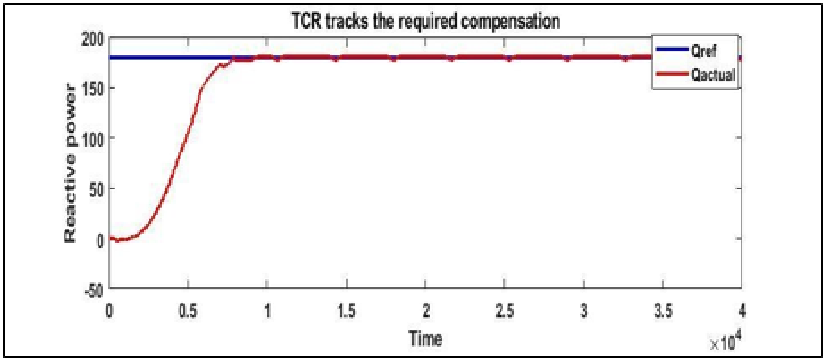

Fig-9: Required Reactive Power by TCR at 180VAr

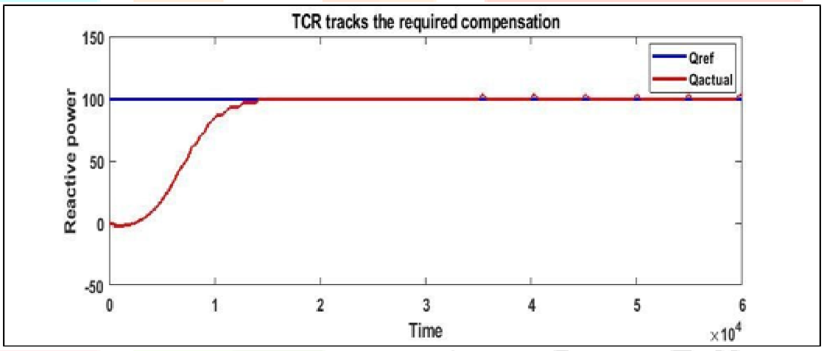

Fig-10: Required Reactive Power by TCR at 100VAr

IV. HARDWARE IMPLEMENTATION

The hardware results are taken on MATLAB-dSPACE platform. The hardware set-up consist of mainly SSR which is assembly of antiparallel thyristor and gate driver circuit and inductor which is the source of reactive power. The firing angle pulses has been given from MATLAB-dSPACE environment. According to requirement we can change the firing angle and get required results.
For hardware implementation of TCR we require SSR as antiparallel thyristors and 310mH inductor. Random turn on SSR which has inbuilt gate driver circuit is suitable for implementation. The inductor design is explained as follows

4.1. Air Cored Reactor Design

Air cored coils are preferred as the inductance remains same over the entire range of operation. This is most suitable for static Var applications. Air cored reactor design is as given below for multilayer inductor coil,

$$L = \frac{0.8 * a^2 * n^2}{6a+9b+10c}\ \mu H \qquad (6)$$

Here n = no. of turns; b= length of the coil; c = thickness of the winding. All dimensions are in inches.
17 SWG super enameled wire is used for the reactor. The dimensions obtained as per the above mentioned formula are as follows:
a = 4.5 inches; b = 6 inches; c = 2.5 inches; n = 1500 turns, number of layers = 14, Turns per layer = 107/108;
Inner Diameter = 6.5 inches; Outer Diameter = 11.5 inches; Mean Diameter = 9 inches; Weight of copper 15.25 kg per coil; Dimensions of super enameled wire employed are 17 SWG, 1.42 mm diameter, 14.13 Kg. weight per Km length. Total length of wire used is approximately 1.07 km for coil. There are thirteen gaps between layers each approximately 4 mm thick, separated by strips for insulation purpose. The air core inductor used for this application because it is very suitable for low frequency. [1]

4.2 dSPACE interfacing

Hardware implementation is done with the help of dSPACE. The firing pulses are generated in such way that the must be in synchronization with supply voltage. The firing pulses generated in simulation are given to SSR using dSPACE interface. For positive half cycle one thyristor is forward bias and for negative half cycle second one will forward bias and we can achieve full conduction.

V. HARDWARE RESULTS AND DISCUSSION

5.1 Harmonic Analysis

From hardware Harmonic analysis is as follows

Table-1

Sr. No	Firing Angle	Current (Amp)	THD H1%	THD H3%	THD H5%	THD H7%	THD H9%	THD H11%	THD H13%
1	90°	2.2	12.5	10.8	7.1	5.7	4.8	1.2	0.9
2	99°	1.5	28.1	25.9	24	23.9	20.2	19.5	2.3
3	108°	1.4	30.1	28.2	26.1	25.03	24.2	18.4	10
4	117°	1	93	38.5	8.5	6.6	3.6	2.4	1.5
5	126°	0.9	94.8	47	1.5	7.6	3.2	2.9	0.6
6	135°	0.5	83	58	31	12.6	6.6	4.2	1.8
7	144°	0.3	84	57	35.8	15.7	6.8	2.3	0.9

Table-1 shows the total harmonic distortion at different firing angles from hardware results. Harmonic content in the system is increasing as the firing angle increases. As harmonic content increases the system does not give satisfactory operation. From the above readings we can conclude that firing angle range between 90° to 130° gives satisfactory performance in regards to active power, reactive power.

5.2 Reactor Current and Reactive Power

For various firing angle reactor current is measured and total harmonic distortion is noted down. As firing angle goes on increasing reactor current decreases and more harmonics are try to inject in the system.

The prototype model gives 4 VAR to 237 VAR reactive power depends on inductor capacity. So as the set point changes TCR tracks respective set point. Above figure shows one of the set point tracking by TCR. In between 4 VAR to 237 VAR it can track the set point but out of it system is unstable.

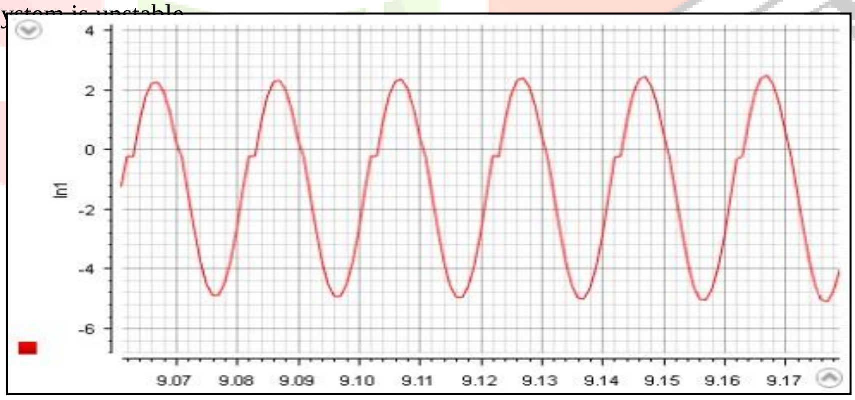

Fig-11: Reactor Current at 90°

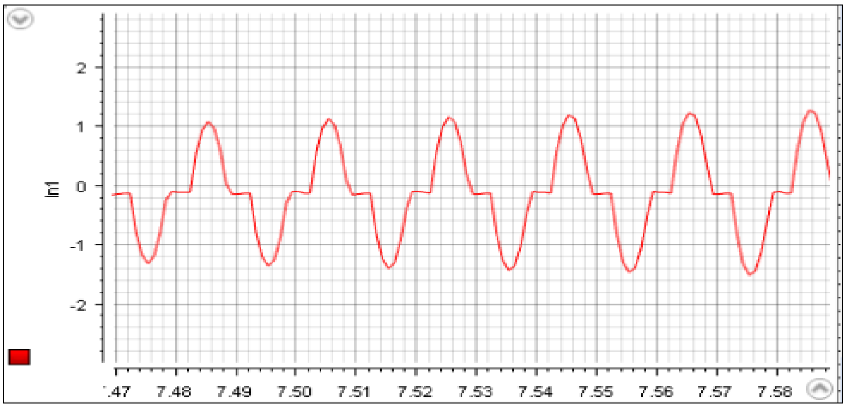

Fig-12: Reactor Current at 117°

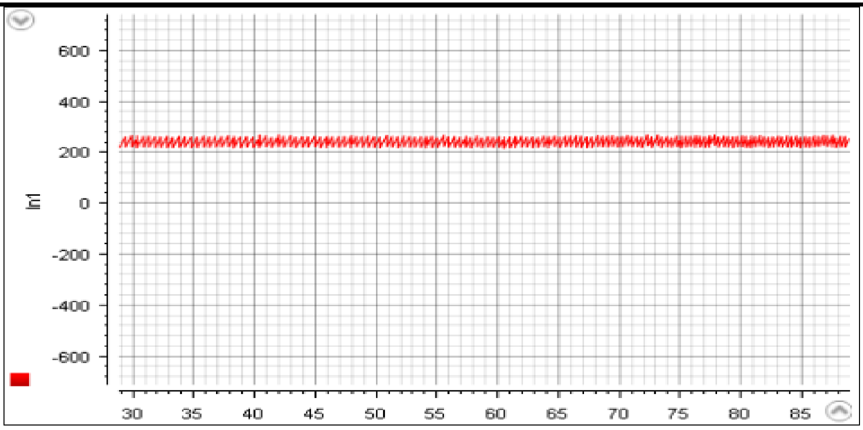

Fig-13: Required Reactive power by TCR at 237 VAr

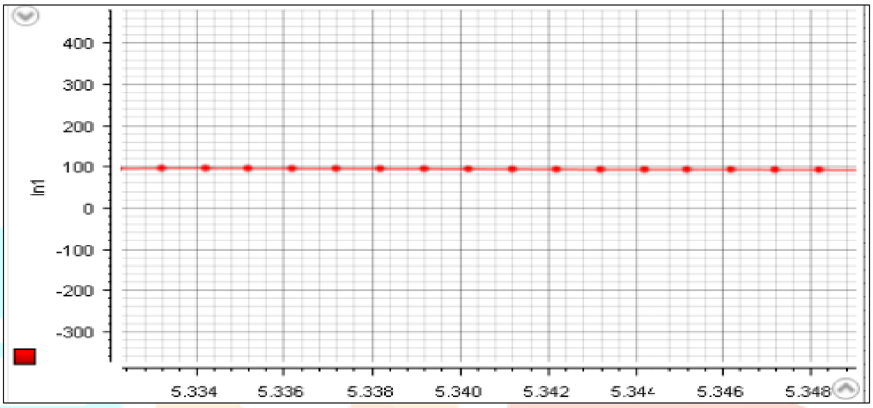

Fig-14: Required reactive power by TCR for 100 VAr

From above fig-10 to 14 one can say that the closed loop control system of TCR is able to provide required reactive power. According to reference reactive power TCR closed loop control try to track the system. By using dSPACE as a interfacing device one can verify and cross check the simulation results with hardware results.

6. CONCLUSION

From the results we can conclude that if capacitor value is constant and vary the value of inductor then reactive power is increasing and we can also conclude that if we increase firing angle current through TCR decreases with increase of firing angle thereby increasing the Reactive Power output. The compensated reactive power can be selectively controlled by appropriately changing the firing angle of the TCR circuit in lagging power factor range. This shows that reactive power is compensated and that improve power system stability. PID controllers are simple, widely used control method. Hence from above analysis we can say that TCR is capable to compensate the reactive power and so that mitigate the voltage swell in the system.

ACKNOWLEDGMENT

I wish to acknowledge, Walchand college of Engineering. Sangli, Maharashtra for their support and provision of required Lab accessories. For my pleasure I am presenting deepest gratitude especially towards Dr. D.R.Patil Sir and all those who have contributed their valuable effort in completing my project work as curricular activity for their guidance and support.

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