Closed Loop Control and Harmonic Analysis of SVS for Maintaining Voltage Profile of Power System

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Abstract:- *In power system the voltage at different buses vary with the change in load. The voltage is normally high at light load condition and low at heavy load condition. The voltage level at the consumer terminal must be maintained within permissible limits irrespective of the type & magnitude of the load. To keep bus voltages within permissible limits, it is necessary to maintain the balance of reactive power in the system. That means reactive power generation must be equal to reactive power absorbed. Any mismatch in the reactive power balance affects the bus voltage magnitude. SVS provides a fast, smooth and step less variation of compensation of reactive power injected into the line. Thus it assures an accurate voltage control of buses over a wide range of loads. This paper deals with reactive power compensation by using SVS (combined TSC and TCR). Reactive power compensation is provided to minimize power transmission losses, to maintain power transmission capability and to maintain the supply voltage at load side. Also Harmonic Analysis for closed loop TSC and TCR system is done. Due to Harmonics, innocent customers suffer from poor power quality. This is due to nearby large nonlinear load. The SVC (combined TCR and TSC) provides the lagging and leading reactive power rapidly and independently with voltage constraints. The number of TSC and TCR to be used is decided according to the reactive power requirement of system.*

Keywords:- *FACTS, Static VAR Compensator (SVS/SVC), TSC, TCR, Real and Reactive Power.*

I. INTRODUCTION

Modern power system is complex and it is essential to fulfil the demand with better power quality. Advanced technologies are nowadays being used for improving power system reliability, security and profitability and due to this power quality is improved. Voltage stability, voltage security and power profile improvement are essential for power quality improvement. To achieve optimum performance of power system it is required to control reactive power flow in the network [1].

In conventional power system, generally capacitor banks are used for reactive power compensation. For this circuit breaker is used for turning on and off of capacitor banks. But there are some disadvantages they are, the operation of turning on/off of CB is about 2-3 cycles and by switching CB on/off it will generate transient in the system. By implementing FACTS devices particularly shunt compensation device we can compensate these disadvantages. SVC will compensate reactive power of the inductive load by improving the power factor of the load and will maintain the voltage level within the permissible limits. The power electronics based switches in the functional blocks of FACTS can usually be operated repeatedly and the switching time is a portion of a periodic cycle, which is much shorter than the conventional mechanical switches.

Amongst the type of FACTS devices Shunt Compensator (Static VAR compensators) combine capacitors and inductors with fast switching (sub cycle, such as <1/60 sec) time frame capability are used. Static Var compensator is a shunt-connected static Var generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system (typically bus voltage) [2]. In this voltage is regulated according to a slope of characteristic of SVC. SVC is based on Thyristors without gate turn-off capability. The objective of static compensation is that, unlike the synchronous compensator, it has no moving primary part. Similar to capacitors, the reactive output of an SVC varies according to the square of the connected bus voltage.

II. STATIC VAR COMPENSATOR

An SVC is "A shunt-connected static Var generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system". Basically an SVC consists of a combination of fixed capacitors or reactors, Thyristor Switched Capacitors (TSC) and Thyristors Controlled Reactors (TCR) connected in parallel with the electrical system as shown in Fig. 1. The basic structures and idea of the TSC is to split up a capacitor bank into sufficiently small capacitor steps and switch them on and off individually, using anti-parallel connected Thyristors as switching elements.

A. SVC Structure and Characteristic

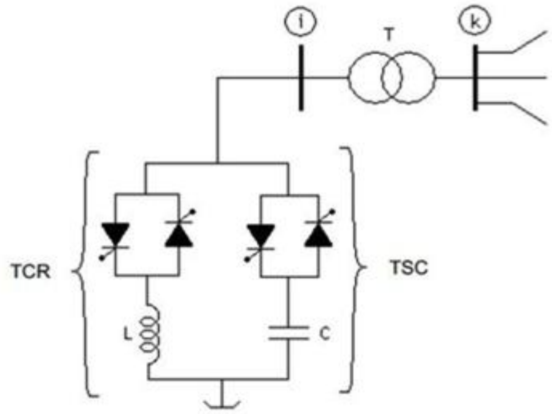

Fig.1: One Line Diagram of SVC Device

The SVC (combined TCR and TSC) provides the lagging and leading reactive power rapidly and independently with voltage in the acceptable range around the reference voltage V_0. The typical steady-state control law of a SVC used here is depicted in Fig. 2, and may be represented by the following voltage-current characteristic: where V_k and I_{svc} stand for controlled bus voltage and SVC device current. Typical values for the slope X_{sl} are in the range of 0.02 to 0.05 pu, depending on the SVC device rated parameters.

The slope of the SVC voltage control characteristics can be represented as X_{sl}, the equivalent slope reactance in p.u. The limiting values of the SVC inductive and capacitive reactance are given by X_l and X_c, respectively. V_k and V_{ref} are the controlled bus and reference voltage magnitudes, respectively. Modelling of the SVC as a variable VAR source, we can set the maximum and minimum limits on the reactive power output Q_{svc} according to its available inductive and capacitive susceptance B_{ind} and B_{cap}, respectively. These limits can be given as,

$$Q_{max} = B_{ind} * V^2_{ref} \quad (1)$$

$$Q_{min} = B_{cap} * V^2_{ref} \quad (2)$$

Where $B_{ind} = 1/X_L$ and $B_{cap} = 1/X_C$.

$$V_k = V_0 + X_{SL} * I_{SVC} \quad (3)$$

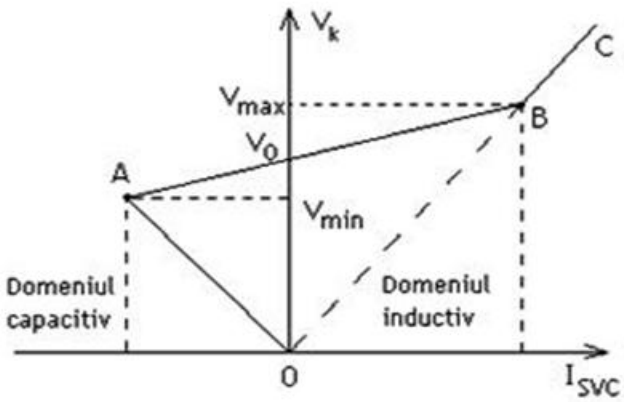

Fig.2: SVC V-I Characteristic

The control law corresponding to the SVC characteristic is as follows:

- If the monitored voltage is larger than the reference voltage, $V_k > V_0$, then the SVC device is absorbing reactive power
- If the monitored voltage is smaller than the reference voltage, $V_k < V_0$, then reactive power injection into bus k is required**.**

B. Types of Static VAR Compensator

SVC can be of one of the following types [2].

1) Thyristors Controlled Reactor (TCR)

TCR is a "shunt connected, thyristor controlled inductor whose effective reactance is varied in a continuous manner by partial conduction control of the thyristor valve." TCR is a subset of SVC, in which conduction time and hence, current in a shunt reactor is controlled by a thyristor based A.C. switch with firing angle control.

2) Thyristors Switched Capacitor (TSC)

TSC is a "shunt-connected, thyristor switched capacitor whose effective reactance is varied in a stepwise manner by full or zero-conduction operation of the Thyristors valve. TSC allows a step-by-step control of the reactive power delivered by groups of capacitors, whereas with TCR a continuous control of the reactive power drawn by the inductors is possible.

3) Thyristors Switched Capacitor & Thyristors Controlled Reactor (TSC-TCR)

By coupling a TSC with a TCR it is possible to obtain a continuous modulated regulation of the delivered/drawn reactive power.

III. REACTIVE POWER COMPENSATION OF LARGE INDUSTRIAL LOAD BY SVC

A. Calculation of capacitor value by assuming transmission line having following parameters:

Total input, P = 85000 KW

Original p.f. = COS (Θ_1) = 0.85 lag;

Desired p.f. = COS (Θ_2) = 0.98 lag;

Length of Transmission Line = 350 km

Current = 85000/ (1.73*220*0.9) = 247.85 A

Resistance per km = 0.137 ohm

Inductance (henry km) = $2e^{-7}$*ln(Dm/Ds)*(length of transmission line)

Inductance per km = 0.933mH

Capacitance = 1/ (18e9*ln(Dm/R))

Capacitance = 2.72e-9 F

Assuming 100 % efficiency,

Leading KVAR taken by condenser bank = P (tan Θ_1-tan Θ_2) =85000(0.6197-0.20300)

=35419.5 KVAR

Rating of each capacitor connected in phase = 35419.5/3

= 11806.5 KVAR

Phase current of each capacitor is Icp = (V_{ph}/X_c)

= 2*pi*50*C*(220000/1.73)

=126015698.35C KVAR/Phase = V_{ph}* I_{pc}/1000

= 160896836538C

Now to find capacitor value, compare KVAR/phase.

So we get, 1608968365328 C = 11806.5 KVAR.

The value of capacitor connected in each phase is 2.329uF.

B. Closed Loop Control of TSC-TCR

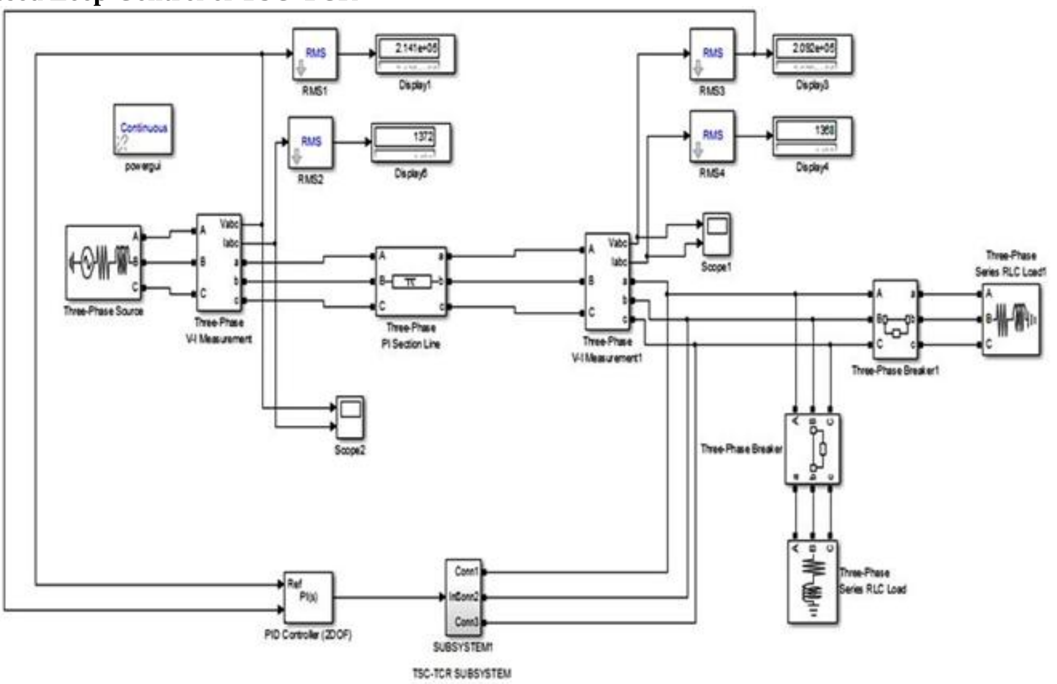

Fig.3: Closed Loop Control of TSC-TCR

The circuit in figure 3 consists of two RL loads of 0.85 pf and 0.9 pf. Circuit breaker 1 is open for 0.2 seconds. As a result 0.85pf is for 0.2 seconds 0.85 is high load. So the receiving end voltage is less than sending end voltage. In that case TSC works. Circuit Breaker 2 works after 0.2 seconds. As a result, 0.9 pf is for 0.2 second 0.9 is low load. So the receiving end voltage is higher than sending end voltage. In that case TCR works.

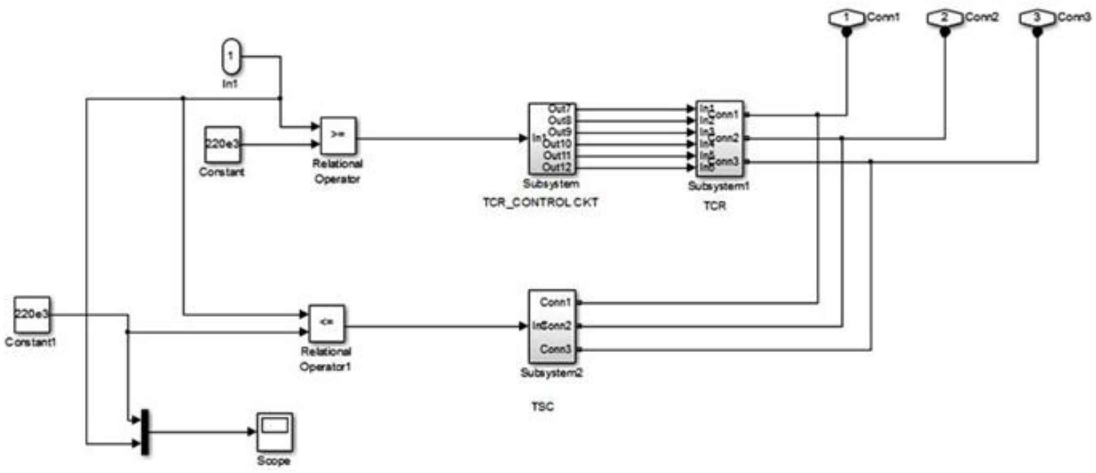

Fig.4: Subsystem of control loop of TSC and TCR Closed Loop System

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In the logic circuit shown in figure 4 whenever the receiving end voltage is less than 127 kV, the relational operator 1 will compare the result and enable the TSC circuit. As a result receiving end voltage increases. Whenever the receiving end voltage is greater than 127 kV, the relational operator 2 will compare the result and enable the TCR circuit. As a result receiving end voltage decreases.

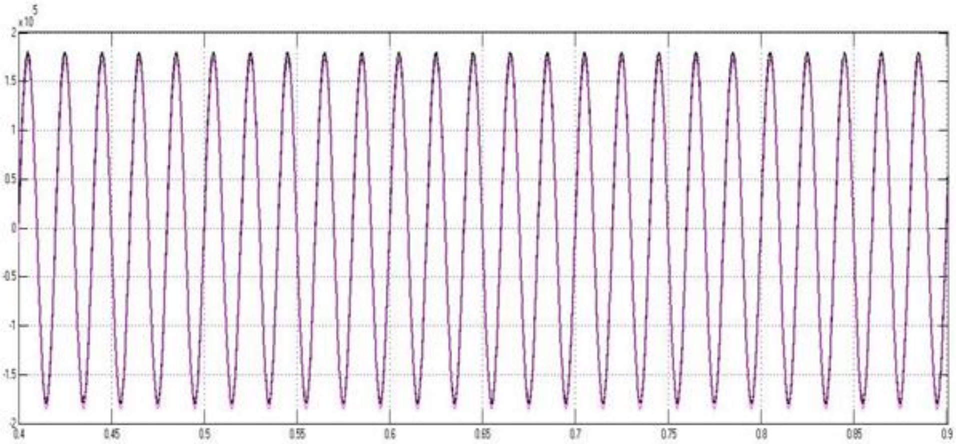

Fig.5: Comparison of sending end voltage and receiving end voltage for closed loop control of TCR and TSC

Fig. 5 represents waveform for sending end and receiving end voltage. From high load circuit sending end voltage is higher than receiving end voltage, So TSC works and as a result there will be an increase in receiving end voltage. For low load, receiving end voltage is higher than sending end, so TCR works and as a result there will be decrease in receiving end voltage to an appropriate value. Table 1 shows the comparison of sending end and receiving end voltage at different firing angle.

Table I: Comparison of sending end voltage and receiving end voltage for TCR-TSC at different firing angle

Firing Angle (α)	**Sending end Voltage (kV)**	**Receiving end Voltage (kV)**
0	126.8	100.9
30	126.8	114.2
60	126.8	116.2
90	126.8	117.8
120	126.8	121.8

IV. HARMONIC ANALYSIS (%THD CALCULATION) OF CLOSS LOOP TSC-TCR

A periodic composite waveform which consists of odd multiple of fundamental frequency is called harmonics. Harmonics gives distortion in power quality. Due to Harmonics, Innocent customers suffer from poor power quality which is nearby large nonlinear load. Due to the intensive use of power converters and other non-linear loads in industry and by user in residential area, it is observed that an increasing deterioration of the power systems voltage and current waveforms. [13] Fig. 6 presents a power system with sinusoidal source voltage (vs) operating with a linear and a non-linear load.

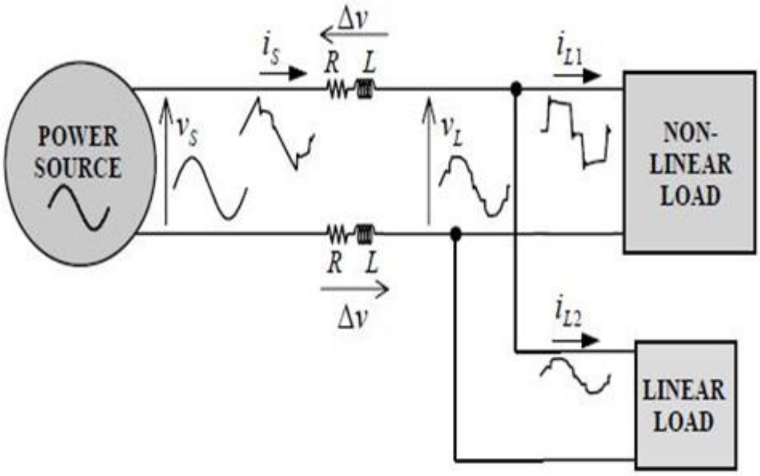

Fig.6: Harmonic Current Generation

The harmonics in power lines causes a greater power losses in the distribution system, interference problems in communication systems and, sometimes, in operation failures of electronic equipment, which are more and more sensitive since they include microelectronic control systems, which work with very low energy levels.

A. **Software Simulation Results for Harmonic Analysis**

The simulation is performs using Matlab Simulink software and the results are presented. Voltage waveform for three phase Closed Loop TSC-TCR circuit is shown in Fig. 3. Sending end and Receiving end

Voltage waveform with α = 30 is shown in Fig. 5. The Voltage through phase Close Loop TSC-TCR with α =

30 is shown in Fig. 3. The frequency spectrum for the Close Loop TSC-TCR system is shown in Fig 6 with the THD value is 3.49 %. Voltage wave form through Load with alpha = 30deg is shown in Fig. 6. In the case of the Closed Loop TSC-TCR system there is always an interaction between the odd harmonics. For accurate modelling of the Closed Loop TSC-TCR in a power system these interactions need to be taken in to account. One way is to use the Fourier matrix equations. This method works well in many situations including investigating the effects of ambient harmonics. The accuracy of this method decreases near resonance points. Harmonic analysis was done for the voltage with various firing angles and the results are presented.

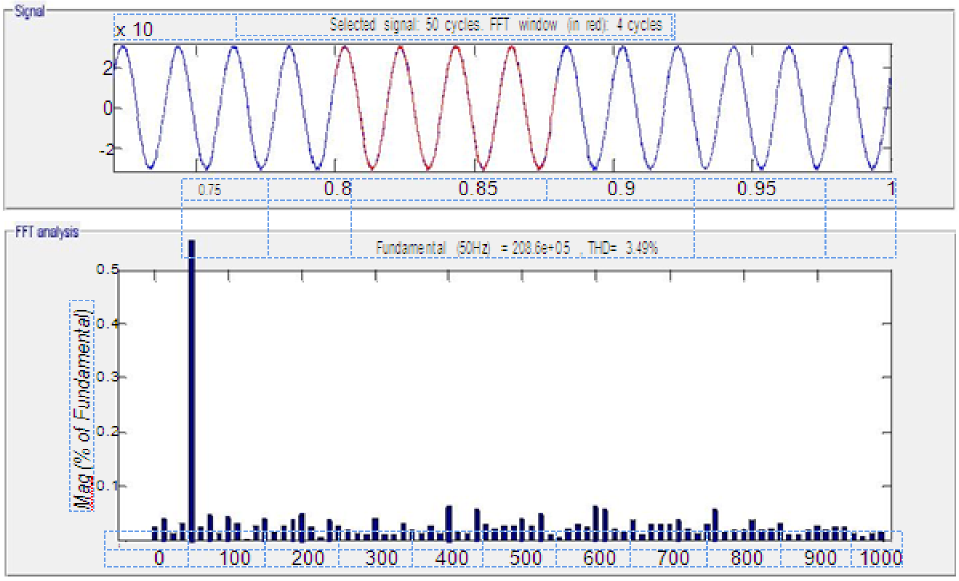

Fig.7: Harmonic Spectrum of Close Loop TSC-TCR system with alpha=30 degree

As shown in figure 7 the calculation is done for fundamental frequency 50 Hz. The Harmonic analysis of Closed Loop TSC-TCR system is done for output voltage waveform.

V. CONCLUSIONS

The main objective is to maintain the voltage profile at the load side of the power system. To maintain the voltage level, it is desirable to maintain the balance of reactive power in the system i.e. reactive power generation must be equal to reactive power absorbed. Any mismatch in the reactive power balance affects the bus voltage magnitude. From the simulation results of shunt compensation for FACTS Controller (TSC-TCR), it is proved that shunt compensation help in increasing the power transfer and also maintaining the voltage stability by improving the load angle. It does so by reducing the overall reactance of the transmission line. The closed loop TSC and TCR model developed here gives variable compensation depending on the firing angle which can be varied from 0 to 180 with respect to voltage. From the simulation of results of shunt compensation, it can be concluded that shunt compensation proves to be very rapid acting system to maintain the voltage profile. Also it helps in power factor improvement of the power system. Harmonic Analysis is made through FFT Matlab tool and got the % THD value. The value of % THD in any system should be maintained within +/-5% as per the IEEE standard 1100-1992. As per harmonic spectrum of closed loop TSC-TCR system, the THD is 3.49 %, which is within the permissible limits as per IEEE standards.

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