Chapter 90
Comparative Study of Prototype and Simulation of SVC for Transmission Congestion Management

Khatavkar Vrushali, Redekar Abhijeet and Dharme Anjali

Abstract In deregulated/restructured power system, congestion of electrical power is a major problem. The solution includes the management methodologies namely technical and pricing methods. The technical methods suggest the use of FACTS controllers to reduce the congestion without considering the economic matters. This work deals with designing a prototype of Static VAR Compensator (SVC). This SVC prototype comprises of 440 kV, 300 km modular transmission line model which operates on lab voltage i.e. 400 V, 50 Hz, and compensator consisting of three delta connected capacitors together with three delta connected air gap type linear inductors along with two anti-parallel thyristors. Modelling has been done considering two modes of thyristor i.e. when thyristor is ON and second when thyristor is OFF. Both modes are characterised by the time duration. With these two modes, two second order differential equations are derived and finally converted into second order state space model. This state space model will be helpful to predict the load voltage behaviour. SVC is modelled in MATLAB Simulink and simulation results are compared with the prototype results to validate the controller design parameters. The aim of this work is to enhance voltage stability and increase power transfer capability of the long transmission line using FC-TCR configuration of Static VAR Compensator.

Keywords Static VAR compensator (SVC) · Fixed capacitor thyristor controlled reactor (FC-TCR) · PID controller

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90.1 Introduction

For many years the electric power industry was characterized by a vertically integrated structure (Bundled Power System), consisting of power generation, transmission/distribution and trading [1]. The liberalization process has resulted in the unbundling of this organizational structure. Now generation and trading are organized as separate business entities, subject to competition, while the transmission/distribution business remains a natural monopoly. The electric transmission network has a fixed structure consisting of different voltage levels; the higher levels are for transmission purposes whereas the lower levels are used for the distribution tasks. Each network element has a finite power transmission capacity, limiting the amount of electricity to be transported or distributed. Open access electricity market activities and a growing demand for electricity have led to heavily stressed power systems. This requires operation of the networks closer to their stability limits. Therefore Power system operation is affected by stability related problems, leading to unpredictable system behaviour. Cost efficient solutions are preferred over network extensions. In many countries, permits to build new transmission lines are hard to get, which means the existing network has to be enforced to fulfil the changing requirements [2]. This increasingly unpredictable system behaviour requires innovative equipment to handle such situations successfully. Innovative operational equipment based on power electronics offer new and powerful solutions commonly described by the term ‘Flexible AC Transmission Systems’ or ‘FACTS devices’ [3]. FACTS-devices can be utilized to increase the transmission capacity, improve the stability and dynamic behaviour or ensure better power quality in modern power systems. Their main capabilities are,

1. Reactive power compensation
2. Voltage control
3. Enhancing active power flow

Transmission line parameters like R, L, and C, are taken as scaled down parameter per km basis. Paper [4] deals with microprocessor based static VAR compensator. This paper gives the details of closed loop control strategy and procedure of compensating power calculation of SVC and long transmission line which is suitable for laboratory experiments. Simple software strategy for PD/PID control is introduced. The output of hardware presented as receiving end voltage and three phase power transferred to load. The controller demonstrated with resistive load, which is for system compensation only [5]. Binary capacitor bank instead of using one capacitor bank, has made this type of compensation scheme deals with the performance evaluation of SVC through analytical studies and practical implementation on an existing system. The SVC consists of Thyristor Binary Compensation (TBC) and Thyristor Controlled Reactor (TCR). A fast acting error adaptive controller is developed using micro controller 89C51 with PI control strategy for contactor switched capacitors and Thyristor switched capacitors. The controller is kVAR based i.e. kVAR sensed at Point of Common Coupling (PCC) and fed back to the controller. In the result PCC voltage, voltage regulation, and load capacity are shown. Work presented in [6] compares SVC compensation with fixed capacitor compensation for active, reactive power and voltages at R.E. bus. It is possible to increase the power transfer capability of line with FC (Fixed Capacitor), but the voltage control is not satisfactory. The power deals with the simulation of SVC on PSCAD/EMTDC. For SVC the TSC-TCR (Thyristor Switched Capacitor–Thyristor Controlled Reactor) scheme is used with bus voltage as a sensing parameter.

90.2 Experimental Study

The individual performance of prototype and simulation circuit has been compared in the presented work.

This SVC prototype comprises of 440 kV, 300 km modular transmission line model which operates on lab voltage i.e. 400 V, 5 A, 50 Hz, and compensator consisting of three delta connected capacitors (2.4 kVAR) together with three delta connected air gap type linear inductors (2.6 kVAR) along with two anti-parallel thyristors. Figure 90.1 shows SLD of Transmission line with its parameters, as well as a capacitor bank and Thyristor Controlled Reactor (TCR) connected at receiving end bus (Load bus). Fixed capacitor Thyristor Controlled Reactor (FC-TCR) is one

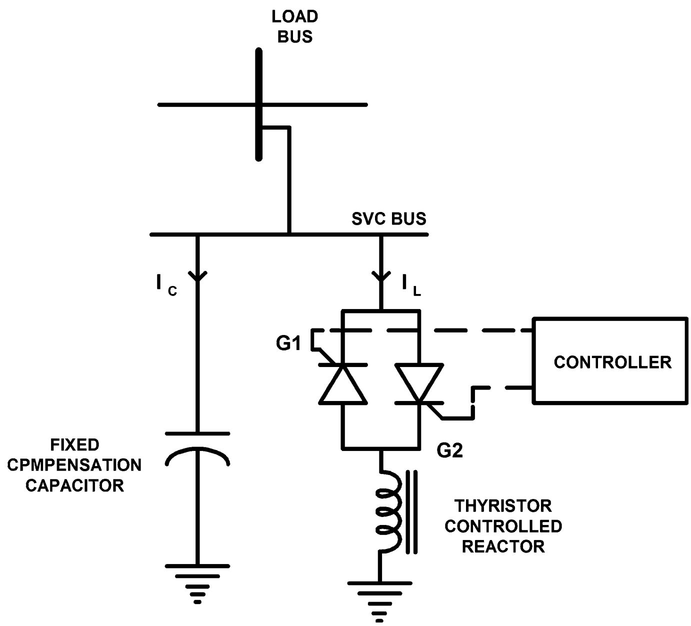

Fig. 90.1 Prototype study system

Table 90.1 Observations of simulations

Sr. no.	Load step	Before compensation			After compensation	
		Vs (V)	Vr (V)	Active power transferred Pr (W)	Vr (V)	Active power transferred Pr (W)
1	1	300	275	295	300	340
2	2	300	269	560	300	690
3	3	300	260	800	290	850

of the configurations of SVC. In the prototype, generator bus is connected to a.c. supply and static balanced R-L load is connected al load bus. From Table 90.1, it is clear that between the sending-end and the receiving-end voltages, a magnitude variation. The most significant part of the voltage drop in the line is due to the reactive component of the load current and the line parameters for each pi unit as given in Fig. 90.1. In the experimental set-up the sending end voltage is adjusted to specified value as shown in the observation table. Star connected variable R-L Load is connected to Load bus. Load is gradually increased in steps from step 1 to step 3 and observations are taken without compensation and with compensation.

90.3 State Space Model of SVC

When analysing the steady state operation of the SVC circuit of Fig. 90.2, two modes of operation can be noted. The time location of the two modes of operation is shown in Fig. 90.2.

Mode I: Characterized by a time duration for an interval, $\pi - \alpha < \omega t < \alpha, and$ $2\pi - \alpha < \omega t < \pi + \alpha$. Its dynamic equation is represented in second order differential equation as,

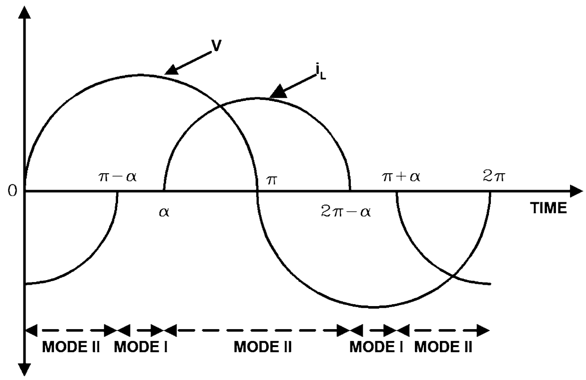

Fig. 90.2 Operation mode locations

$$V_s = L_t C \frac{d^2 v}{dt^2} + \frac{L_t}{R}\frac{dv}{dt} + v \tag{90.1}$$

where α represents the firing angle and ω is the angular velocity of the supply voltage (Vs). In such a mode, the two thyristors are not conducting and thus the SVC inductor can be omitted.

Mode II: Characterized by a time duration for an interval, $0 < \omega t < \pi - \alpha$, $\alpha < \omega t < 2\pi - \alpha$, and $2\pi - \alpha < \omega t < 2\pi$. Its dynamic equation is represented in second order differential equation as,

$$V_s = \frac{L_t}{L} + L_t C \frac{d^2 v}{dt^2} + \frac{L_t}{R}\frac{dv}{dt} + v \tag{90.2}$$

These are presented through a single equivalent dynamic representation, valid for both Modes as,

$$x = Ax + bu \tag{90.3}$$

$$\begin{bmatrix} \frac{dv}{dt} \\ \frac{di}{dt} \end{bmatrix} = \frac{1}{L_t C}\begin{bmatrix} 0 & L_t C \\ -(1 + m\frac{L_t}{L}) & \frac{-L_t}{R} \end{bmatrix}\begin{bmatrix} v \\ i \end{bmatrix} + \frac{1}{L_t C}\begin{bmatrix} 0 \\ 1 \end{bmatrix} V_s \tag{90.4}$$

90.4 Simulink Model of SVC

The SVC is modelled in Simulink using four main components viz: Source, Transmission line, Controller, and Static load. The main function of a SVC is to inject a controlled capacitive or inductive current so as to maintain or control mainly load bus voltage. A well-known configuration of SVC, the Fixed Capacitor (FC) with Thyristor Controlled reactor (TCR) is implemented. The SVC is typically modelled using a variable reactance with maximum inductance and capacitance, which directly correspond to the limits in the firing angles of the thyristors. In addition to the main function of the SVC controller to control the SVC bus voltage (Fig. 90.3).

In controller model the PID control block is selected but only K_p and K_i parameter are required. So here K_d factor is always set as zero to keep off the effect of derivative controller. Therefore only PI controller is used. As shown in Fig. 90.4 the addition of K_p, K_i, and K_d gain blocks are fed to the saturation function. The saturation function feeds signals to the PWM generator. This generates pulses to trigger anti parallel thyristors as shown in Fig. 90.4.

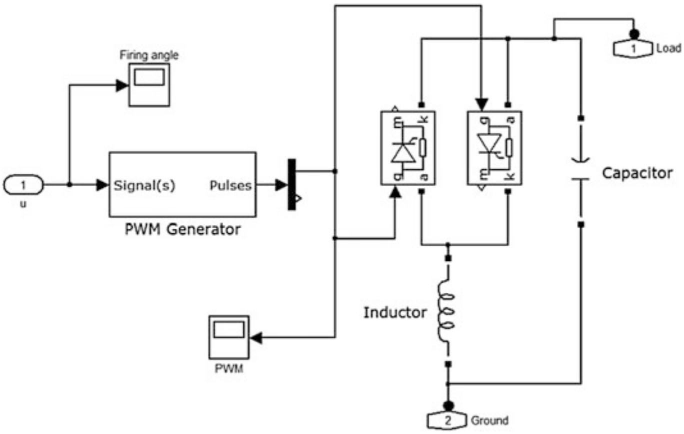

Fig. 90.3 FC-TCR Simulink model

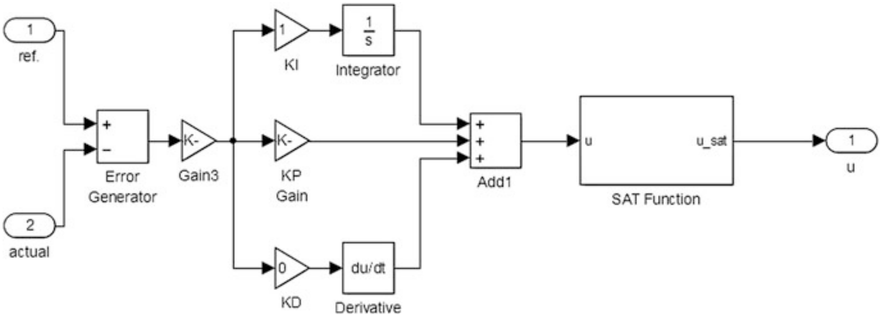

Fig. 90.4 Controller Simulink model

90.5 Performance of Prototype and Simulation

We are interested in load bus voltage and active power transferred at load side, so observations were taken with and without compensation from both systems. In prototype model RMS value of voltage and current are measured so for comparison purpose we have to connect RMS block in Simulink model. Each Figs. 90.5, 90.6, and 90.7 shows the simulation results of load bus voltage and active power transferred for three loading steps.

From prototype model we can get results from voltmeter and watt-meter which is connected at load bus. This is shown in Table 90.2.

The effect on the power transferred and load bus voltage to the load is also clearly understood from the Table 90.3. If the voltage at the receiving end is maintained high, larger power can be delivered to the load. Figure 90.8 shows percentage increase in power transferred and bus voltage at each loading condition.

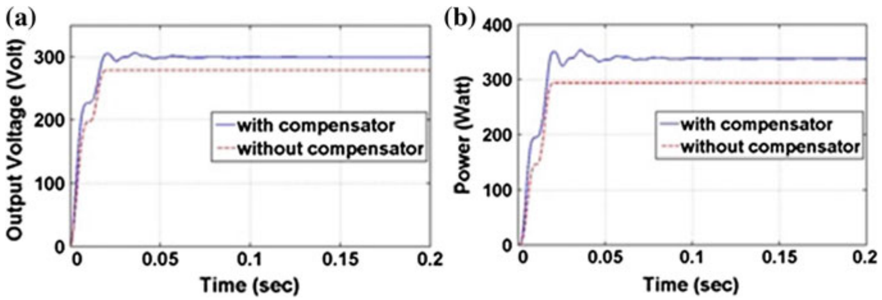

Fig. 90.5 **a** Simulation result for bus voltage at first loading condition. **b** Simulation result for active power transferred at first loading condition

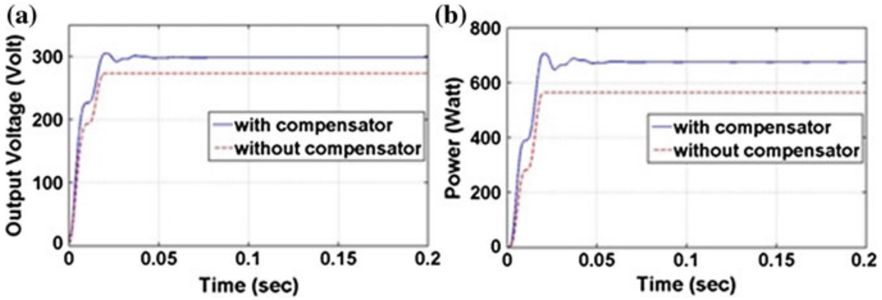

Fig. 90.6 **a** Simulation result for bus voltage at second loading condition. **b** Simulation result for active power transferred at second loading condition

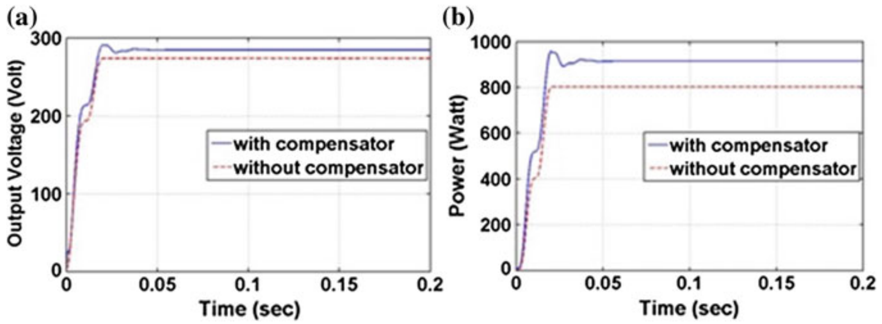

Fig. 90.7 **a** Simulation result for bus voltage at third loading condition. **b** Simulation result for active power transferred at third loading condition

Table 90.2 Observations of prototype

Sr. no.	Load step	Vs (V)	Before compensation			After compensation		
			Vr (V)	Active power transferred Pr (W)	Power factor (lag)	Vr (V)	Active power transferred Pr (W)	Power factor (lag)
1	1	300	270	281	0.8	300	328	0.99
2	2	300	260	537	0.75	300	674	0.99
3	3	300	255	787	0.7	290	838	0.98

Table 90.3 Percentage improvement of load bus voltage and power transferred

Sr. no.	Load step	By simulation		By prototype	
		R.E. bus voltage (%)	Power transferred (%)	R.E. bus voltage (%)	Power transferred (%)
1	1	9.1	15.25	11.11	16.72
2	2	11.52	23.21	15.38	25.51
3	3	11.53	6.25	13.72	6.48

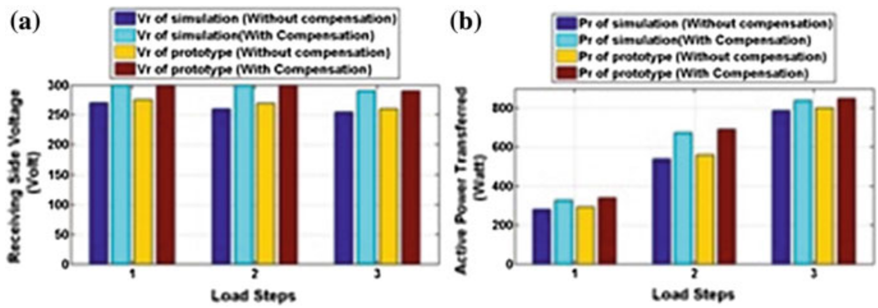

Fig. 90.8 Percentage improvement by simulation and prototype method. **a** Load bus voltage. **b** Power transferred

90.6 Comparison of Simulation and Experimental Results

Finally comparison of active power transferred by simulation and by experimentation is shown in Table 90.4. The percentage deviations between the two methods do not exceed 4 %. The dotted line in graph shows before compensation results and continuous line shows after compensation results (Fig. 90.9).

Table 90.4 Comparison of simulation and experimental results

Sr. no.	Load step	Power transferred (W)	Load bus voltage (V)	Percentage deviations between two methods
1	1	340	328	3.5
2	2	690	674	2.3
3	3	850	838	1.4

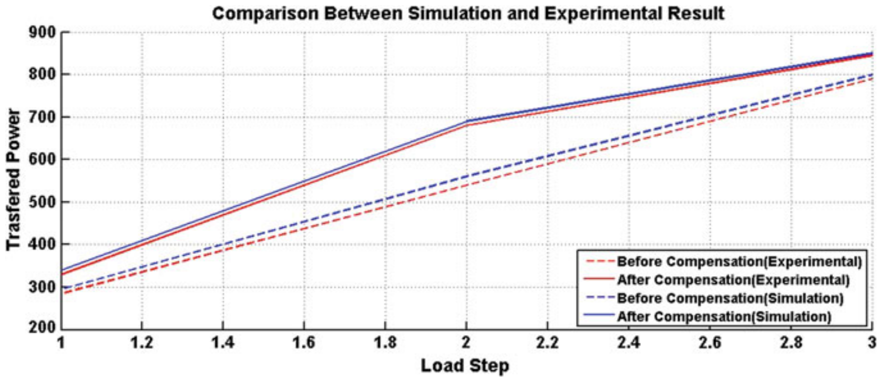

Fig. 90.9 Comparisons between simulation and experimental result

90.7 Conclusion

A laboratory model representing static VAR compensator using FC-TCR configuration was constructed. It was demonstrated that use of SVC could effectively control bus voltage and increases active power transfer capacity. The rise in active power transferred helps to relieve the congestion. The difference between the implemented SVC model in MATLAB-Simulink and the prototype is less than 3.5 %. Moreover, more accurate results are obtained by increasing the load; also the disturbance introduced by load resistance can be overcome within 1 s.

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Appendix

The value of each loading step is given as follows

- Load step1—(480 − j450) Ω,
- Load step2—(820 − j748) Ω, and
- Load step3—(1,044 − j876) Ω

PI Controller: Kp: 12.0, Ki: 1
T.F. of controller:

$$Gc = \frac{S + 12}{S}$$

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