Congestion Management and Voltage Profile Improvement of a Transmission System using Static VAr Compensators

Pallavi Desai[1] and Yogini Bhosale[2]

[1]*Research Student, Rajarambapu Instiitute of Technology, Maharashtra, India*
[2]*Assistant Professor, Rajarambapu Instiitute of Technology, Maharashtra, India*

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Abstract - *Congestion management is an important technical problem in a deregulated power system and has to be effectively solved to increase the utilization of transmission line capability. Out of the two methods of congestion management viz. cost-free and non-cost-free methods, congestion management using FACTS device such as Static VAR Compensator (SVC), which comes under cost-free method, is proposed in this paper. Various modes of operation of SVC are studied using MATLAB/Simulink. By manually adding instances, congestion was generated. For these situations, the performance analysis was compared with and without SVC. The outcome demonstrates that the suggested method enhances the voltage profile of the power system network.*

Key Words: Congestion management, Static VAr Compensator, voltage profile, FACTS, MATLAB/Simulink

1.INTRODUCTION

Modern power systems are nonlinear interconnected networks that include of interconnected generator power plants, transformers, and transmission lines with varying loads. The connectivity of smaller subsystems reduces operational expenses (e.g., fuel expenditures, resource sharing), and variety of loads enhances system dependability [1]. However, technological problems such as low frequency electro-mechanical oscillation induced by electrical disturbances [2] arise. The capacity of a power system to recover to its previous operational condition after a disruption is known as stability [3]. Increased power is a requirement in contemporary power systems. Long transmission lines are overburdened as a consequence of increased demand which may lead to congestion. (above normal limits), aggravating the temporary issue stability, which has been a major stumbling block in electrical engineering is a branch of engineering that deals with electricity [4].

Deregulation of power markets, i.e., supplying electricity in a cost-effective and efficient manner, is the major limitation in congestion management. Congestion in the line, in addition to the excess congestion charges, raises the cost of the supply unit [5]. The primary goal of FACTS devices is to enhance the transmission line's transfer capacity. By executing voltage management, power system stability limits, and reactive power compensation, it also lowers congestion costs [6-9]. SVC is a member of the FACTS family and is linked to the system via a shunt. Despite the fact that the primary purpose of shunt FACTS devices is to support bus voltage by injecting (or absorbing) reactive power, they can also improve transient stability by increasing (decreasing) power transfer capability as the machine angle increases (decreases), which is accomplished by operating the shunt FACTS devices in capacitive (inductive) mode [10-12].

Previous research has shown that when shunt FACTS devices are installed in the middle of the transmission line, they provide the most advantage from their stable voltage support. The greatest improvement in power transmission capability is demonstrated using a simplified line model that ignores line resistance and capacitance. When considering the real model of a lengthy transmission line, however, the findings may differ substantially from those obtained using the simplified model [13-18].

The primary objective of this paper is to study the effect of SVC on a transmission line and to evaluate its performance. Then a manual congestion is created and performance of SVC is tested for the same. The organization of this paper is as follows: Section II discusses congestion management using FACTS devices; Section III presents mathematical model of SVC and explains its working along with its different modes of operation; Section IV presents the MATLAB/Simulink model of the test system while Section V discusses its results; and Section VI concludes the paper.

2. CONGESTION MANAGEMENT USING FACTS DEVICES

Congestion management is a very important and vital problem in the deregulated electricity power market. It can occur as a result of a sudden increase in load demand, a lack of coordination between generation and transmission utilities, or any contingency such as a transmission line or generator outage, or any failure of any equipment in the electric power system. Congestion in the electric power system can cause a variety of issues, including an increase in the cost of electricity, an increase in system losses, a cascading outage of transmission lines, and even system failure or collapse. As a result, when congestion occurs, ISO should take measures to protect the power system's stability while also considering the cost of fixing the problem. There are several solutions for resolving the congestion problem, including the construction of new generating units near load centers, the construction of new transmission lines at appropriate locations, generation rescheduling of real power production, and load shedding [2]. Installation of FACTS devices is a commonly used approach for congestion management, and because to the high cost of FACTS, an optimization methodology is utilized to identify the best size and placement for it.

2.1 Voltage Stability

Voltage stability (VS) has become a major issue in the planning and operation of electric power systems. The capacity of a power system to retain voltage values within permitted limits during normal operation and after a disturbance is concerned with voltage stability. Short-term and long-term voltage stability are two types of voltage stability. The research period for short-term VS is several seconds and incorporates fast-acting load components such as induction motors or electronically controlled loads. Long-term VS, on the other hand, uses slow-acting equipment such as tap changing transformers or generator current limiters, with a study duration of several minutes. If the voltage on one or more buses exceeds the allowed range, the system is unstable; voltage instability may or may not progress to voltage collapse, based to ISO's reaction, which utilizes the voltage stability index to determine how near the system is to voltage collapse [4].

2.2 Causes of Congestion

Increased participation of distributed energy generation in distributed systems may result in a high level of active distribution network management, resulting in native network congestion and voltage issues. Deregulation of the electricity system increases demand at the utility, resulting in transmission line overloading. Generation firms produce more electricity to meet demand, but transmission lines are the most common, and they get crowded as they transport more power than their capacity. Various congestion management methods, which play a key role in today's deregulated electricity market, are used to address these issues. As a result, power system restructuring is required to achieve a transition in which electricity has become an artefact and has regenerated into a deregulated one. FACTS devices are used to minimize congestion in transmission lines by managing power flow and reducing power system losses [7].

3. MATHEMATICAL MODELLING OF SVC

Static Var compensator (SVC) is a type of FACTS device, designed for shunt compensation to maintain bus voltage magnitude. SVC controls bus voltage to compensate constantly the change of reactive power loads. Figure 1 shows the most common design of this type of shunt-connected device, which consists of a fixed capacitor C and a thyristor-controlled reactor (TCR).

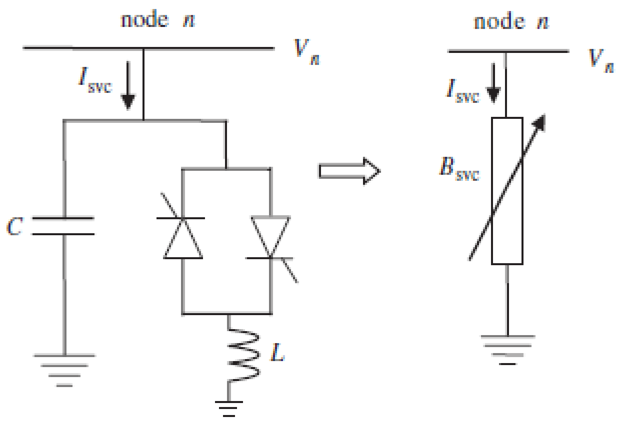

Fig -1. Advanced SVC module

The thyristor valves are fired symmetrically in an angle α, ranging from 90deg. to 180deg. The variable SVC equivalent susceptance Bsvc at fundamental frequency can be obtained as follows:

Let the source voltage (bus voltage) be expressed as Vn(t) = V sinωt, where V is the peak value of the applied voltage and ω is the angular frequency of the supply voltage. The TCR current is then given by the following differential equation:

$$L\frac{di}{dt} - V_n(t) = 0 \quad (1)$$

where L is the inductance of the TCR. Integrating Equation (1), we get

$$i(t) = \frac{1}{L}\int V_n(t)\,dt + C_n \quad (2)$$

where Cn is the constant.
Alternatively,

$$i(t) = -\frac{V}{\omega L}\cos\omega t + C_n \quad (3)$$

For the boundary condition i(ωt= α)=0,

$$i(t) = -\frac{V}{\omega L}(\cos\alpha - \cos\omega t) \quad (4)$$

where α is the firing angle measured from positive to zero crossing of the applied voltage. To derive the fundamental component of the TCR current I(α), Fourier analysis is used, which in general is given as

$$I_1(\alpha) = a_1\cos\omega t + b_1\sin\omega t \quad (5)$$

where b_1 =0 because of the odd-wave symmetry, that is, f(t)=f(-t). Also, even harmonics are not generated because of the half-wave symmetry, i.e., f(t+T/2) = -f(t). The coefficient a_1 is given by

$$a_1 = \frac{4}{T}\int_0^{T/2} f(t)\cos\left(\frac{2\Pi t}{T}\right)dt \quad (6)$$

Solving for I(α),

$$I_1(\alpha) = \frac{V}{\omega L}\left(1 - \frac{2\alpha}{\Pi} - \frac{1}{\Pi}\sin 2\alpha\right) \quad (7)$$

Expressing Equation (7) in terms of the conduction angle σ, the fundamental component of TCR current is given by

$$I_1(\alpha) = V\left(\frac{\sigma - \sin\sigma}{\Pi X_L}\right) \quad (8)$$

where conduction angle σ is related by the equation, $\alpha + \sigma/2 = \pi$, and X_L is the reactance of the inductor. Equation (8) can be written as

$$I_1(\alpha) = VB_{TCR}(\sigma) \qquad (9)$$

where $B_{TCR}(\sigma)$ is the adjustable fundamental frequency susceptance controlled by the conduction angle to the law

$$B_{TCR}(\sigma) = \frac{\sigma - \sin\sigma}{\pi X_L} \qquad (10)$$

The maximum value of $B_{TCR}(\sigma)$ is $1/X_L$, obtained with σ = π or 180deg., i.e., full conduction angle in the thyristor controller. The minimum value is zero, obtained with σ =0 (a=180deg).
From Equation (10), the TCR equivalent reactance X_{TCR} can be written as

$$X_{TCR} = \frac{\pi X_L}{\sigma - \sin\sigma_L} \qquad (11)$$

The total effective reactance of the SVC, including the TCR and capacitive reactance, is determined by the parallel combination of both components:

$$X_{SVC} = \frac{X_C X_{TCR}}{X_C + X_{TCR}} \qquad (12)$$

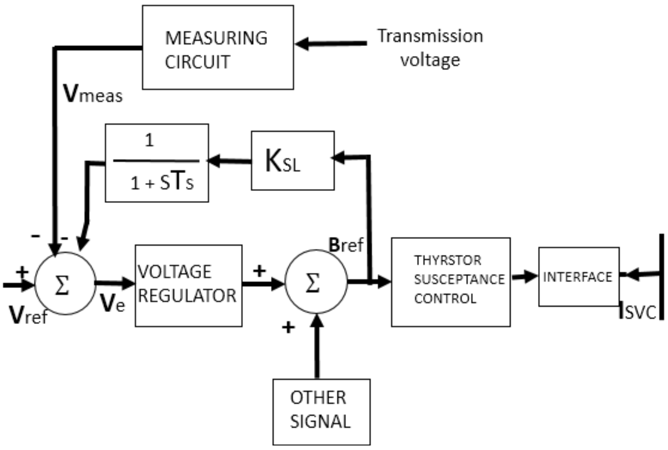

Fig -2: Control system of SVC

The control system of SVC consists of a measurement of system, voltage regulator and synchronizing system, as shown in Fig. 2. The measurement system measures the positive sequence voltage to be controlled. Fourier transformation is used for measurement system a voltage regulator that uses the voltage error. The SVC suspectance (B) is determined by the difference between measured voltage (Vm) and the reference voltage (Vref). The susceptance B is important to maintain constant system voltage. The TSC (and eventually the TCR) to be switched in and out is determined by distribution unit that computes the firing angle α of TCR. A synchronizing system consists of a phase-locked loop (PLL) and a pulse generator sends an appropriate pulse to the thyristor [Hague].

4. MATLAB/SIMULINK MODEL

A four machine six bus test system was created using the MATLAB/Simulink environment for evaluation of the performance of SVC in the system. The test system model is shown in Fig. 3.

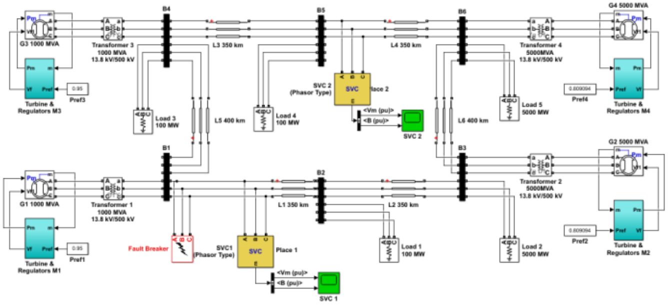

Fig -3: Modelling of 4 machine, 6 bus Test system using MATLAB/Simulink

Two SVC blocks from the MATLAB/Simulink library are connected between buses 1-2 and 5-6 to evaluate its performance for transient stability, voltage profile improvement and congestion management. The MATLAB model of SVC is shown in Fig. 4.

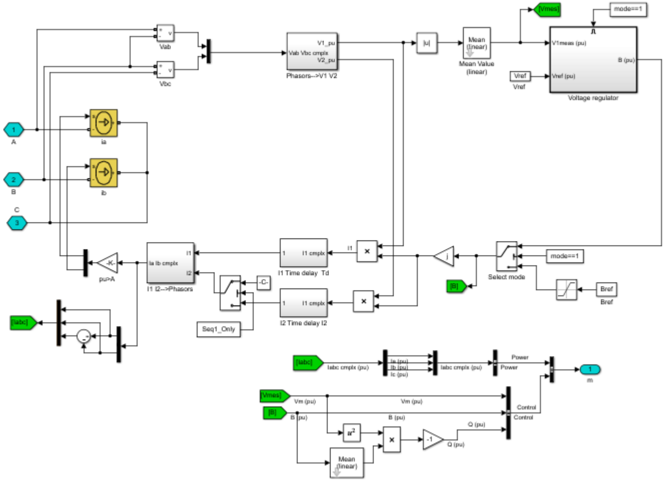

Fig -4: SVC Model in MATLAB/Simulink

The data considered for modelling of the test system is given below.

1. Transmission lines data
   Vbase = 500 KV
   Resistance per unit length (Ohms/km) = 0.01755
   Inductance per unit length (H/km) = 0.8737e-3
   Capacitance per unit length (F/km) = 13.33e-9
2. Loads data
   All loads are resistive load
   Bus 2 = 100 MW
   Bus 3 = 4900 MW
   Bus 4 = 100 MW
   Bus 5 = 100 MW
   Bus 6 = 4900 MW
3. SVC data
   Reactive power limits: [Qc (var>0) Ql(var<0)] = [200e6 -200e6]
   Average time delay Td =0.004

The generators' data used in th e test system is shown in Table 1.

Table -1: Generators' Data

Parameters	G1	G2	G3	G4
Gen types	Hydraulic	Hydraulic	Hydraulic	Hydraulic
Capacity (MVA)	1000	5000	1000	5000
Xd (pu)	1.305	1.305	1.305	1.305
X'd (pu)	0.296	0.296	0.296	0.296
X"d (pu)	0.252	0.252	0.252	0.252
Xq (pu)	0.474	0.474	0.474	0.474
X"q (pu)	0.243	0.243	0.243	0.243
X1 (pu)	0.18	0.18	0.18	0.18
H (s)	3.7	3.7	3.7	3.7
T'd (s)	1.01	1.01	1.01	1.01
T"d (s)	0.053	0.053	0.053	0.053
T"qo (s)	0.1	0.1	0.1	0.1
Rd (pu)	2.8544e-3	2.8544e-3	2.8544e-3	2.8544e-3

5. RESULTS AND DISCUSSIONS

First, the developed test model is run with a single-phase fault occurring at t=5sec and results of all the bus voltages and power along with generator parameters are observed as shown in Fig. 5 and 6. It can be seen that the generator lose synchronism and that the system needs to be stopped.

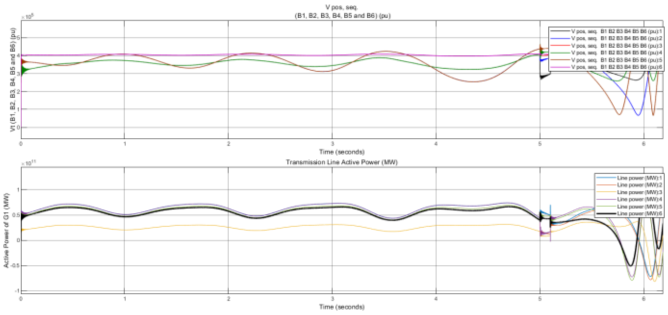

Fig -5: Test system terminal voltages and power without SVC

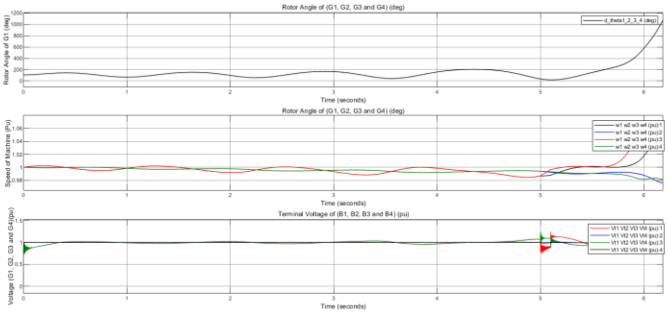

Fig -6: Test system generators' parameters without SVC – rotor angle, speed and terminal voltages

The application of SVC at buses 1 and 2 and 5 and 6, however, prevents the system from a collapse and voltages and power quickly recover and system continues to work stably proving the effectiveness of the SVC devices as shown in Figs. 7 and 8.

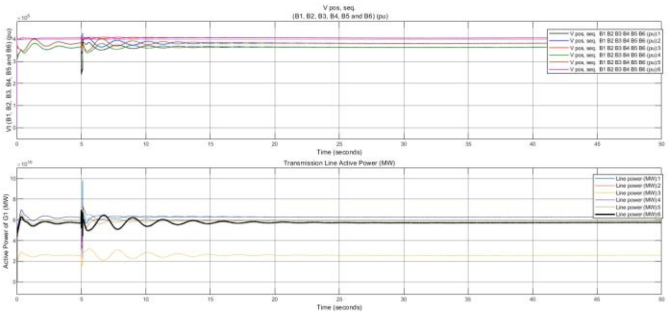

Fig -7: Test system terminal voltages and power without SVC

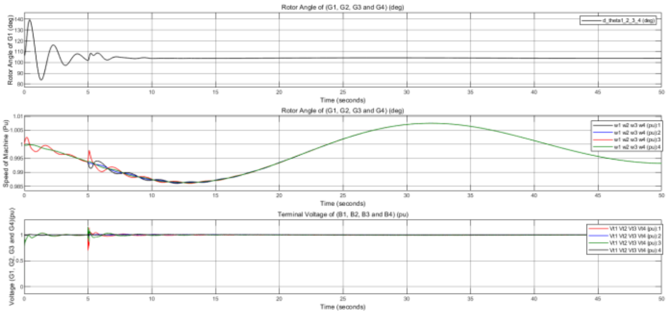

Fig -8: Test system generators' parameters with SVC – rotor angle, speed and terminal voltages

The voltages and susceptance values of SVC 1 and 2 are shown in Fig. 9 and 10. It can be seen that the voltage value of SVC 1 dips for short time at t=5s (during fault) as the fault bus is connected near it. However, it recovers quickly. SVC2 remains unaffected during the whole condition.

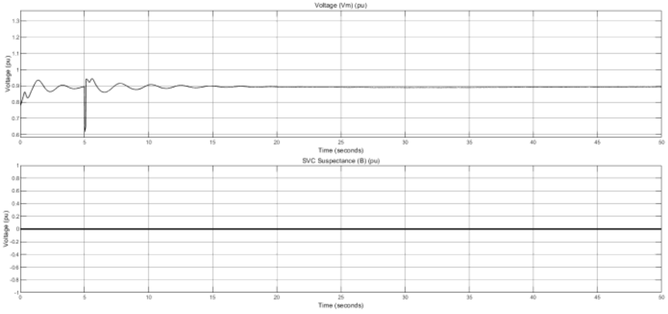

Fig -9: Voltage and susceptance of SVC 1

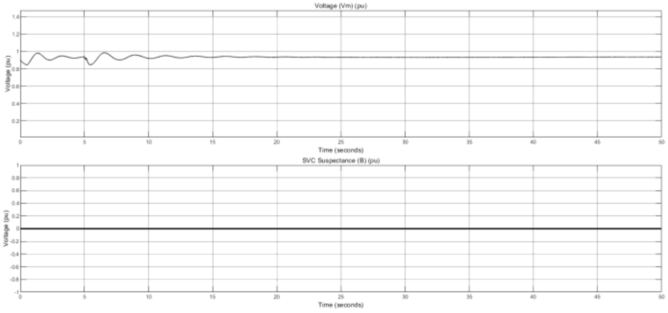

Fig -10: Voltage and susceptance of SVC 2

The initial reactive current injected is 0.12873p.u., which corresponds to the normal power flow. The voltage profile and real power flow in power system transmission with SVC are then raised in lines 2; 3; and 6, while the reactive power flow in all transmission lines is increased, causing congestion in the other line to diminish. Increased voltage buses and reactive power resulted in less congestion on buses 5 and 6. The power fluctuation on each bus demonstrates this. The total active power loss is reduced due to the transmission line's total power results.

Table 2 shows the real and reactive power flow in transmission lines of power system. Results of simulation for real and reactive power flow at buses of power system have been illustrated.

Table -2: Real and Reactive Power Flow Results

From Bus	To Bus	Line	Active power Flow (p.u.)		Reactive Power Flow (p.u.)	
			Without SVC	With SVC	Without SVC	With SVC
1	2	1	0.886	0.886	-0.0838	-0.074
1	4	2	0.002	-	-0.003	-
2	3	3	0.608	0.608	-0.180	-0.175
2	1	4	0.230	0.110	-0.056	-0.034
3	2	5	1.63	1.63	0.0665	0.0015
3	6	6	0.005	0.001	-	-
4	5	7	0.886	0.886	-0.0838	-0.074
5	6	8	0.716	0.715	0.270	0.248
5	4	9	-0.002	-	-	-
6	5	10	1.57	1.57	0.0775	0.002

Table 3 shows the magnitude voltage and phase voltage (or angle of voltage) at buses of power system. Magnitude of voltage at buses of power system for case study at buses 1, to 6 of power system have been illustrated.

Table -3: Magnitude and Angle Voltage at Buses of System

Bus No.	Mag. Of Voltage (p.u.)		Angles of Voltages (rad)	
	Without SVC	With SVC	Without SVC	With SVC
1	1.04	1.02	0	0
2	0.97	0.995	0.16	0.15
3	1.03	1.01	0.08	0.08
4	0.988	0.997	-0.03	-0.03
5	0.985	0.992	0.064	0.063
6	0.97	0.989	0.0343	0.0337

6. CONCLUSIONS

This paper has discussed and investigated the transient stability enhancement by using a static Var compensator. A multi-machine testing system consisting of four machines and six buses was developed in MATLAB Simulink. A single-phase fault was created at t=5s to test the performance of SVC for transient stability. The system collapses if SVC is not used, while it recovers in 1.5ms and continues to remain stable when SVC is connected. Secondly, the active powers and reactive powers were measured along with voltages and phase angles at all the buses. The observations suggest that the congestion in the lines has been reduced.

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