Research Journal of Applied Sciences, Engineering and Technology 3(7): 668-676, 2011
ISSN: 2040-7467

Received: May 13, 2011 Accepted: June 15, 2011 Published: July 25, 2011

Voltage Stability Analysis with Static Var Compensator (SVC) for Various Faults in Power System with and Without Power System Stabilizers (PSS)

Mohammad Mohammadi
Department of Engineering, Borujerd Branch, Islamic Azad University, Borujerd, Iran

Abstract: However, in previous study the effect of SVC and PSS on voltage transient in power system with suitable model of these component for various faults such as Single Line to Ground faults (SLG) and Line to line and Line to Line to Ground (LL and LLG) and three phase faults have not been considered and analyzed and investigated. Shunt Flexible AC Transmission System (FACTS) devices, when placed at the mid-point of along transmission line, play an important role in controlling the reactive power flow to the power network and hence both the system voltage fluctuions and transient stability. This study deals with the location of a shunt FACTS device to improve transient stability in along transmission line with pre defined direction of real power flow. The validity of the mid-point location of shunt FACTS devices is verified, with various shunt FACTS devices, namely Static Var Compensator (SVC) in a long transmission line using the actual line model. It has been observed that the FACTS devices, when placed slightly off-centre towards sending-end, give better performance in improving transient stability and the location depends on the amount of local/through load. This study investigates the effects of Static Var Compensator (SVC) on voltage stability of a power system. The functional structure for SVC built with a Thyristor Controlled Reactor (TCR) and its model are described. The model is based on representing the controller as variable impedance that changes with the firing angle of the TCR. A Power System Computer Aided Design /Electromagnetic Transients including DC (PSCAD/EMTDC) is used to carry out simulations of the system under study and detailed results are shown to access the performance of SVC on the voltage stability of the system.

Key words: FACTS, PSS, SVC, transient stability, Single Line to Ground fault (SLG), Line to Line fault (LL and LLG)

INTRODUCTION

Today's changing electric power systems create a growing need for flexibility, reliability, fast response and accuracy in the fields of electric power generation, transmission, distribution and consumption. Flexible Alternating Current Transmission Systems (FACTS) are new devices emanating from recent innovative technologies that are capable of altering voltage, phase angle and/or impedance at particular points in power systems (Acha *et al*., 2002; Acha *et al*., 2000).Their fast response offers a high potential for power system stability enhancement apart from steady-state flow control.

Among the FACTS controllers, Static Var Compensator (SVC) provides fast acting dynamic reactive compensation for voltage support during contingency events which would otherwise depress the voltage for a significant length of time (Cai, 2004; Muwaffaq, 2003).

SVC also dampens power swings and reduces system losses by optimized reactive power control. In previous works the effective methods of control have been implemented to control of SVC in order to damp power swings (Kazerani *et al*., 1997; Gyugyi *et al*., 1999; Teerathana *et al*., 2005). MATLAB/SIMULINK has been used in this study to conduct simulations on voltage regulation at the point of connection of SVC to the system. However, the aim of this paper is to enhance voltage stability using Static Var Compensator at the event of occurrence of fault in the system.

However, in previous work the effect of SVC and PSS on voltage transient in power system with suitable model of these component for various faults such as Single Line to Ground faults (SLG) and Line to Line and Line to Line to Ground (LL and LLG) and three phase faults have not been considered and analyzed and investigated.

SYSTEM MODEL

Studies have been performed on a single machine connected to a constant voltage bus through two transformers Z1 and Z4 and a Π transmission line divided equally into two sections Z2 and Z3 as shown in Fig. 1. An SVC device is connected at the middle bus. The SVC is a combination of reactors and capacitors. It can be controlled quickly by thyristor switching. The SVC acts as a variable susceptance. The SVC is shown in Fig. 2. The main inputs to the SVC controller are the reference

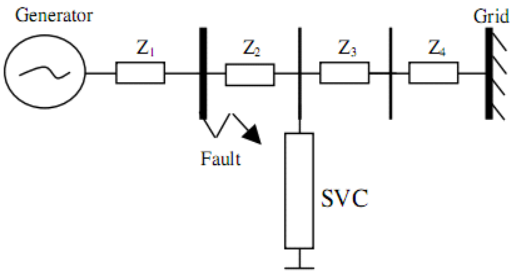

Fig. 1: Test power system to analyzing SVC for transient stability

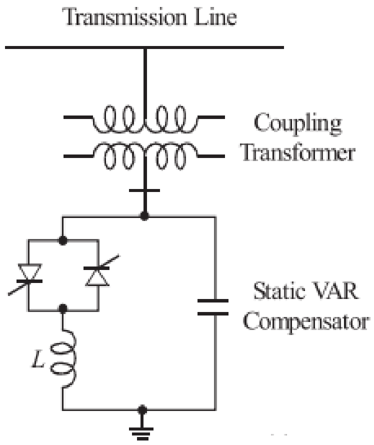

Fig. 2: SVC connected to a transmission line

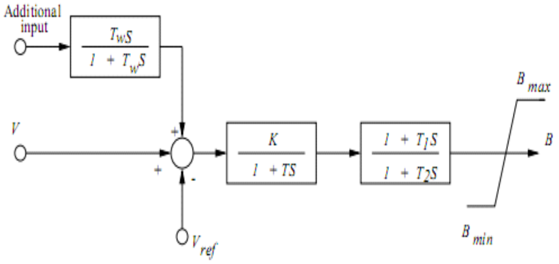

Fig. 3: Structure of SVC controller with oscillation damping, where B is the equivalent shunts susceptance of the controller

voltage (Vref) and the terminal bus voltage (Vt). The SVC has a firing control system and for simplicity, it is represented by a first order model characterized by a gain Ka and a time constant Ta. An auxiliary signal is used as the input to the adaptive fuzzy controller for system oscillations damping. The adaptive fuzzy logic controller consists of a recursive least squares with a variable forgetting factor (RLS) identifier that tracks the plant dynamic behavior by identifying the relation between the generator speed deviation signal and the incremental susceptance (B) and a fuzzy logic controller. The fuzzy logic controller is adapted using the identified model.

Static Var Compensator (SVC) Description and Modeling: The SVC uses conventional thyristors to achieve fast control of shunt-connected capacitors and reactors. The configuration of the SVC is shown in Fig. 2, which basically consists of a constant capacitor(C) and a thyris-tor controlled reactor (L).The delay angle control of the thyristor banks determines the equivalent shunt admittance presented to the power system (Zhang, 2003a, b),

New version of SVC is basically a shunt connected static var generator/load whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific power system variables; typically, the controlled variable is the SVC bus voltage (Stagg and El-Abiad, 2002; Saadat, 2002) .One of the major reasons for installing a SVC is to improve Dynamic voltage control and thus increase system load ability. An additional stabilizing signal,and supplementary control, super imposed on the voltage control loop of a SVC can provide damping of system oscillation as discussed .In this paper, the SVC is basically represented by a variable reactance with maximum inductive and capacitive limits to control the SVC bus voltage ,with an additional control block and signals to damp oscillations, as shown in Fig. 3.

The model considers SVC as shunt-connected variable susceptance, B_{SVC} which is adapted automatically to achieve the voltage control. The equivalent susceptance, B_{eq} is determined by the firing angle α of the thyristors that is defined as the delay angle measured from the peak of the capacitor voltage to the firing instant. The fundamental frequency equivalent neglecting harmonics of the current results (Gyugyi, 1988; Carsten, 2002):

$$B_{eq} = B_L(\alpha) + B_C$$

$$B_L(\alpha) = -\frac{1}{\omega L}\left(1 - \frac{2\alpha}{\pi} - \frac{\sin(2\alpha)}{\pi}\right),\ B_c = \omega C \ and \ 0^0 \le \alpha \le 90^0$$

If the real power consumed by the SVC is assumed to be zero, then:

$$P_{SVC} = 0$$
$$Q_{SVC} = -B_{SVC} * V^2$$

That, “V” is the bus voltage magnitude

As the reactive power demand at the bus varies, the susceptance is varied subject to the limits. However, the reactive power is a function of the square of the bus voltage. Hence the reactive power generated decreases as the voltage decreases.

Power system stabilizers: A PSS can be viewed as an additional block of a generator excitation controller AVR, added to improve the overall power system dynamic

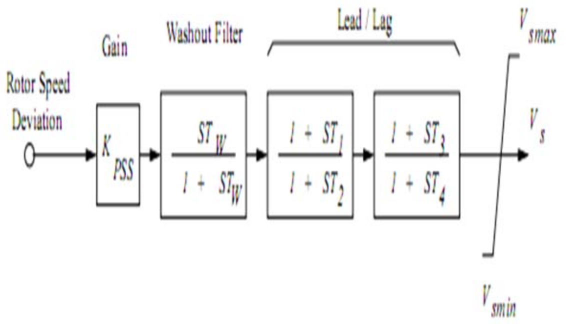

Fig. 4: PSS model used for simulations, that "Vs" is an additional input Signal for the AVR

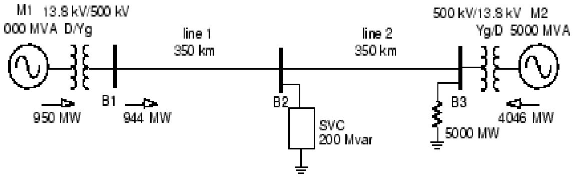

Fig. 5: Test power system

performance, especially for the control of electro mechanical oscillations. Thus, the PSS uses auxiliary stabilizing signals such as shafts peed, terminal frequency and/or power to change the input signal to the AVR (Hingorani and Gyugyi, 2000; Jun and Akihiko, 2006). This is a very effective method of enhancing small-signal stability performance on a power system network. The block diagram of the PSS used in the paper is depicted in Fig. 4.

In large power systems, participation factors corresponding to the speed deviation of generating units can be used for initial screening of generators on which toad PSS (Fuerte-Esquivel *et al*., 2000; Noroozian *et al*., 1997). However, a high participation factor is a necessary but not sufficient condition For a PSS at the given generator to effectively damp oscillation. Following the initial screening a more rigorous valuation using residues and frequency response should be carried out to determine the most suitable locations for the stabilizers.

Simulation: The single line diagram shown in Fig. 5 that addressed by (Xiao *et al*., 2002) represents a simple 500 kV transmission system.

A 1000 MW hydraulic generation plant (M1) is connected to a load center through a long 500 kV, 700 km transmission line. The load center is modeled by a 5000 MW resistive load. The load is fed by the remote 1000 MVA plant and a local generation of 5000 MVA (plant M2).A load flow has been performed on this system with plant M1 generating 950 MW so that plant M2 produces 4046 MW. The line carries 944 MW which is close to its surge impedance loading (SIL = 977 MW). To maintain system stability after faults, the transmission line is shunt compensated at its center by a 200 Mvar Static Var Compensator (SVC). The SVC does not have a Power Oscillation Damping (POD) unit. The two machines are equipped with a Hydraulic Turbine and Governor (HTG), excitation system, and Power System Stabilizer (PSS). This model is shown in Fig. 6-8.

RESULTS AND DISCUSSION

In this section illustrates modeling of a simple transmission system containing two hydraulic power plants. A Static Var Compensator (SVC) and Power System Stabilizers (PSS) are used to improve transient stability and power oscillation damping of the system.

Three-Phase Fault - Impact of SVC - PSS in Service: In another simulation a 3-phase fault is applied and the impact of the SVC for stabilizing the network during a severe contingency is investigated. In first the two PSS (Generic Pa type) are in service. By looking at the d_theta1_2 signal, it is observed that the two machines quickly fall out of synchronism after fault clearing. In order not to pursue unnecessary simulation, the Simulink Stop block is used to stop the simulation when the angle difference reaches 3*360º.

A Fault Breaker block is connected at bus B1. In this paper different types of faults on the 500 kV systems have been done and the impact of the PSS and SVC on system stability is investigated. To start the simulation in steady-state, the machines and the regulators have been previously initialized by means of the Load Flow and Machine Initialization utility of the Powerful block. Load flow has been performed with machine M1 defined as a PV generation bus (V = 13800 V, P = 950 MW) and machine M2 defined as a swing bus (V = 13800 V, 0 degrees). After the load flow has been solved, the reference mechanical powers and reference voltages for the two machines have been automatically updated in the two constant blocks connected at the HTG and excitation system inputs: Pref1 = 0.95 pu (950 MW), Vref1 = 1.0 pu; Pref2 = 0.8091 pu (4046 MW), Vref2 = 1.0 pu.

Because of SVC is near to line 2 respects to generator, the oscillation of transient current is damping faster than oscillation of current in line 2.

Figure 9-18 show the various parameters obtained from simulation for this section (Three phase fault with SVC and PSS).

Single-phase fault-impact of PSS-SVC in services: In this section the simulation is carried out with single-phase to ground fault in presence of PSS and SVC.

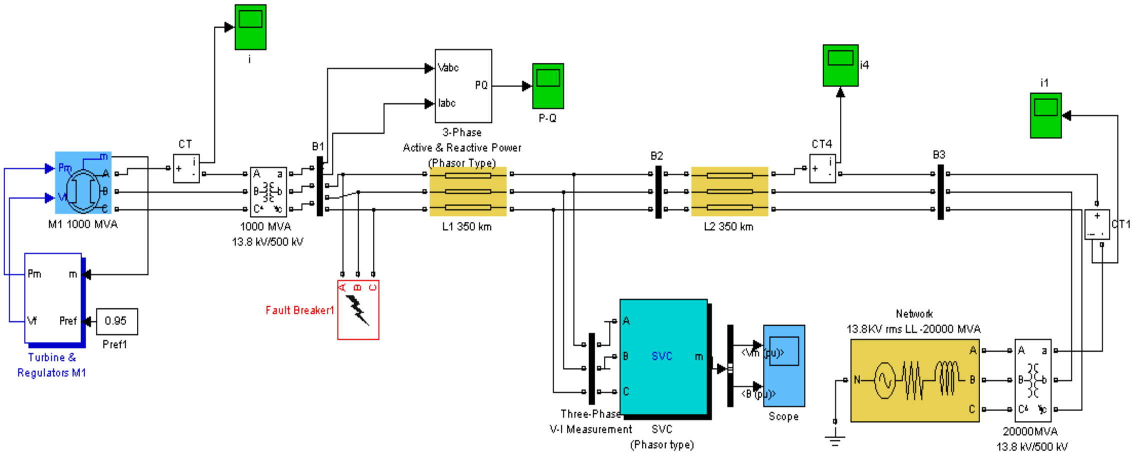

Fig. 6: SIMULINK test power system

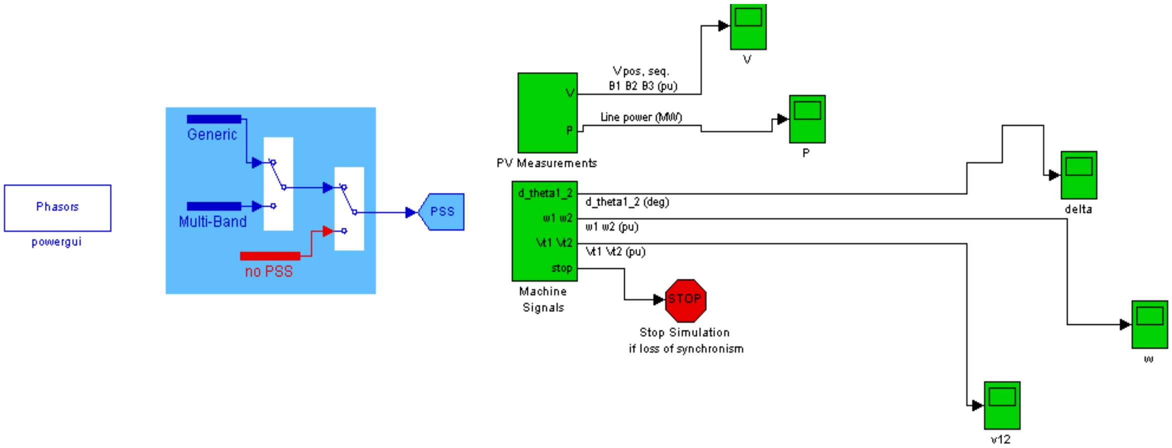

Fig.7: SIMULINK model of PSS for test power system

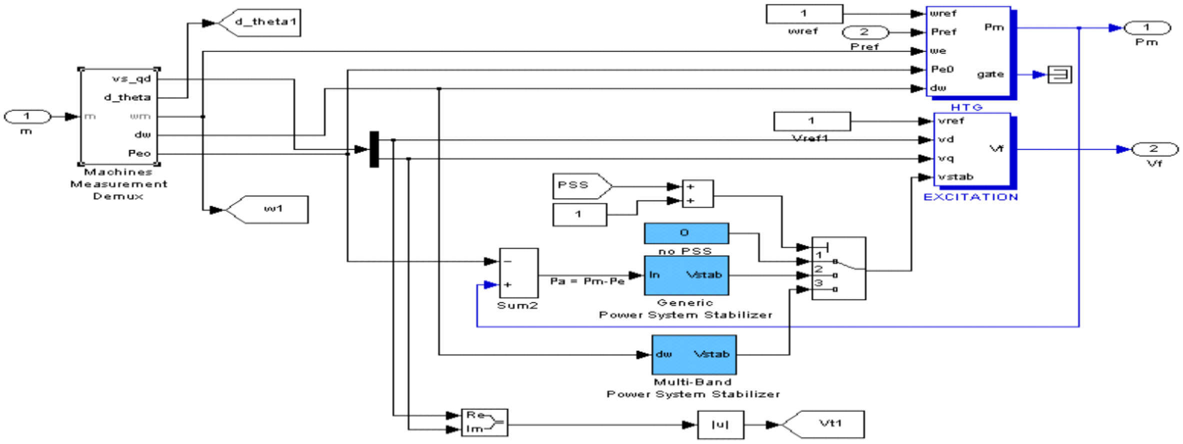

Fig. 8: Generator control system for test power system

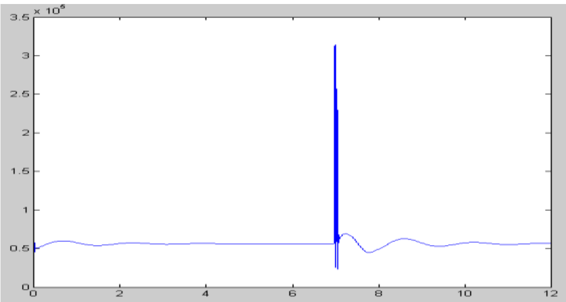

Fig. 9: Generator current oscillation

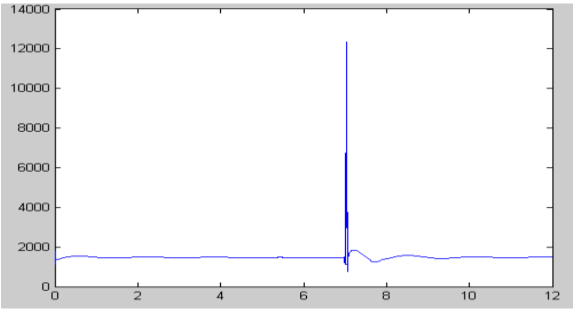

Fig. 10: Line 2 current oscillation

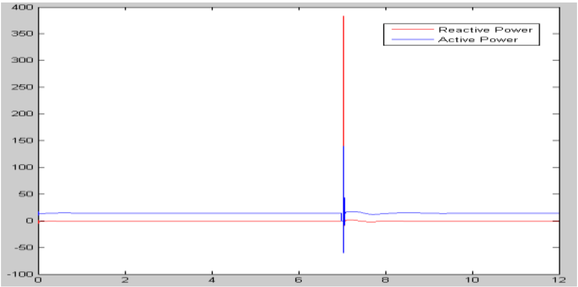

Fig. 11: Rael and reactive power flow in the line 1

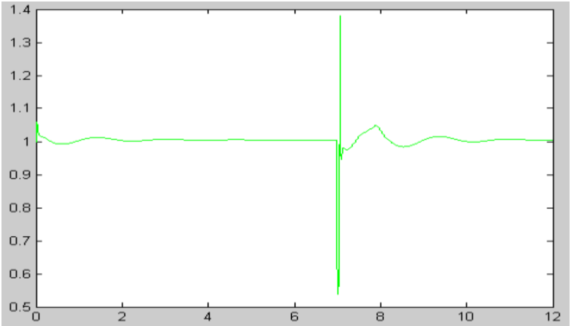

Fig. 12: Positive sequence voltage at SVC Bus

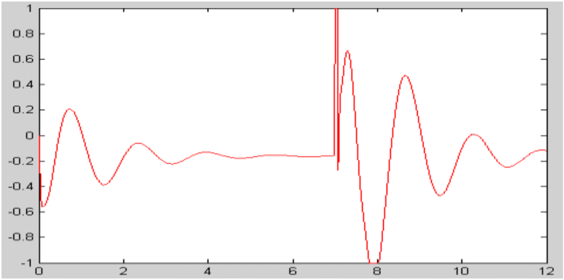

Fig. 13: Susceptance variation of SVC

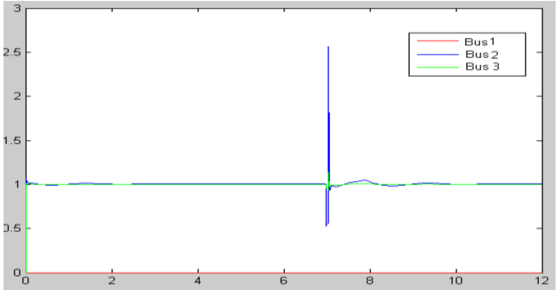

Fig. 14: Magnitude voltage in Bus 1,2,3

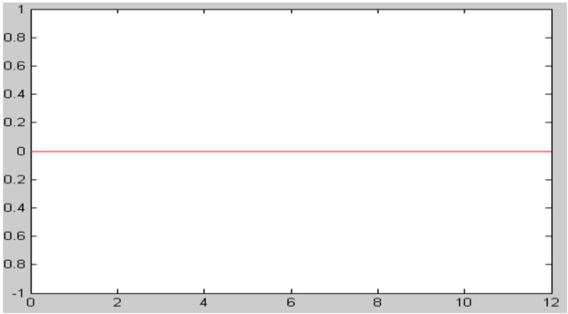

Fig. 15: Real power flow in line

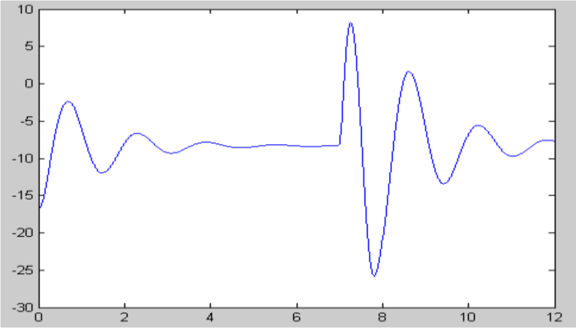

Fig. 16: Rotor angle differences between the two machines

It Verify that the PSSs (Generic Pa type) are in service and that a 6-cycle single-phase fault is programmed in the Fault Breaker block (Phase A checked, fault applied at t = 0.1 s and cleared at t = 0.2 s). For this type of fault the system is stable without SVC. After fault clearing, the 0.6

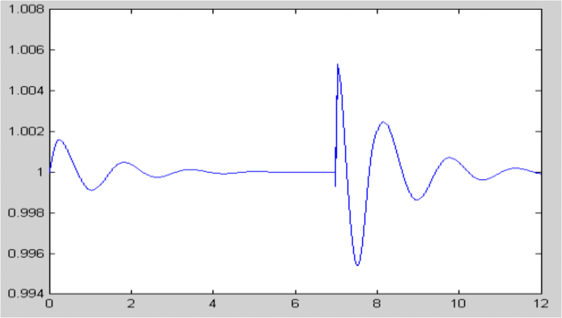

Fig. 17: Speed oscillation of machine1

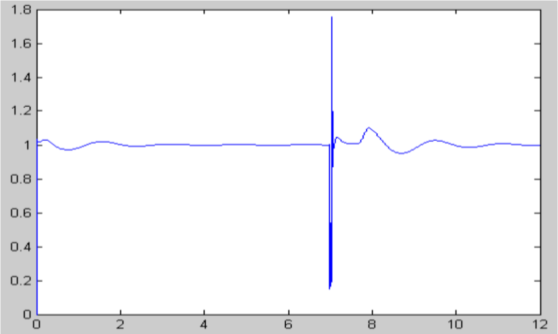

Fig. 18: Machine voltage oscillation

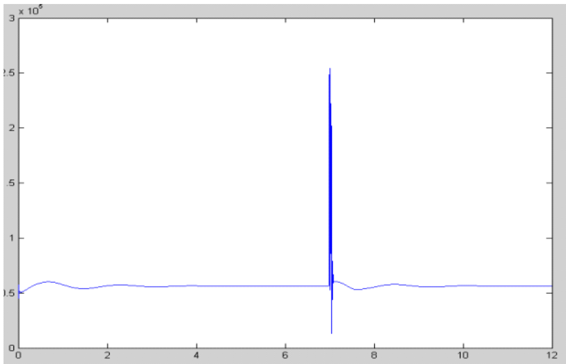

Fig. 19: Line 2 current oscillation following single line to ground fault

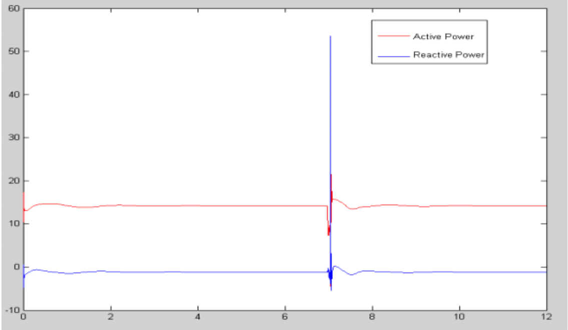

Fig. 20: Rael and reactive power flow in the line 1 following single line fault to ground

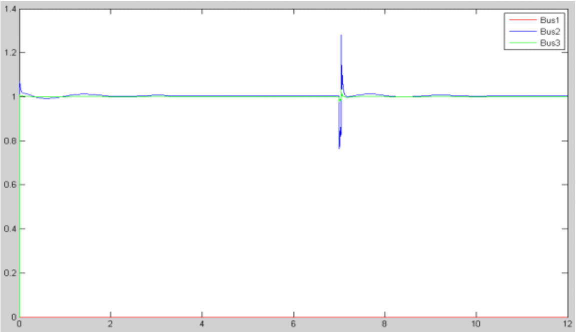

Fig. 21: Magnitude voltage in Bus 1,2,3 following single line to ground fault

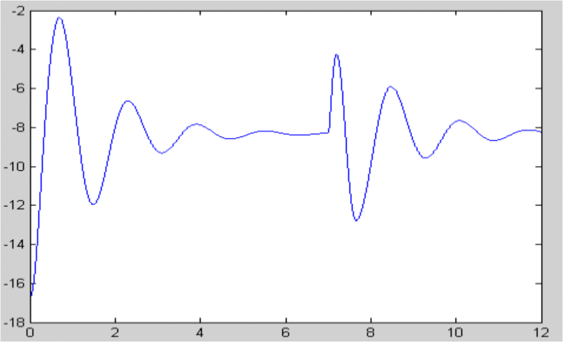

Fig. 22: Rotor angle differences between the two machines for single line to ground fault

Hz oscillation is quickly damped. This oscillation mode is typical of inter area oscillations in a large power system.

First trace on the Machines scope shows the rotor angle difference d_theta1_2 between the two machines. Power transfer is maximum when this angle reaches 90º. This signal is a good indication of system stability. If d_theta1_2 exceeds 90º for too long a period of time, the machines will lose synchronism and the system goes unstable.

Second trace shows the machine speeds. Notice that machine 1 speed increases during the fault because during that period its electrical power is lower than its mechanical power. By simulating over a long period of time (50 sec) it will also notice that the machine speeds oscillate together at a low frequency (0.025 Hz) after fault clearing. The two PSSs (Pa type) succeed to damp the 0.6 Hz mode but they are not efficient for damping the 0.025 Hz mode.

Figure 19-24 show the result of simulation for single phase to ground fault names as SLG.

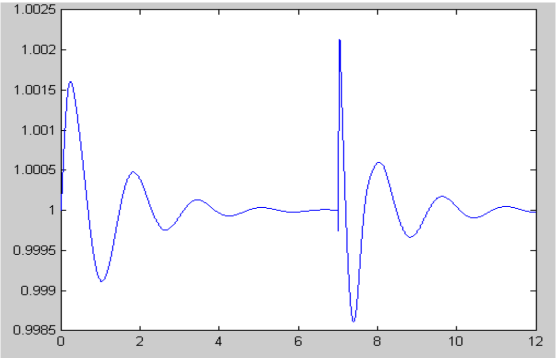

Fig. 23: Speed oscillation of machine1for single line to ground fault

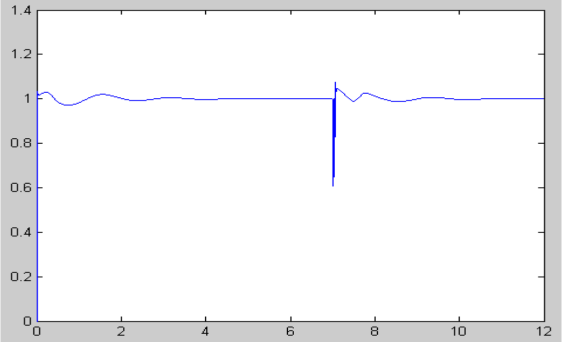

Fig. 24: Machine voltage oscillation for single line to ground fault

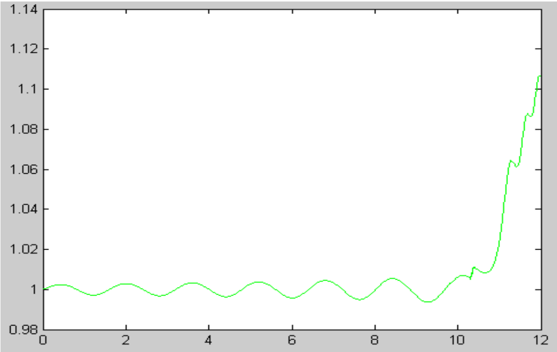

Fig. 25: Rotor angle differences between the two machines without PSS

Single phase to ground fault - impact of SVC -PSS out of service: In this section simulation is carried out with SVC but it assumed that PSS is out of service. The Fig. 25-29 show the results of simulation for this section.

Analysis id various kinds of faults with and without PSS: To understand the best concept of effect of type of faults on operation of SVC in order to stable power system, various fault such as Single Phase to Ground (SLG), Line to Line (LL) and Line to Line to Ground (LLG) are investigated. Figure 30-31 shows the results of simulation for this section.

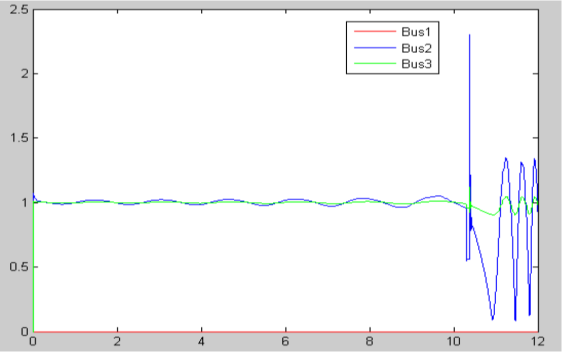

Fig. 26: Magnitude voltage in Bus 1,2,3 without PSS

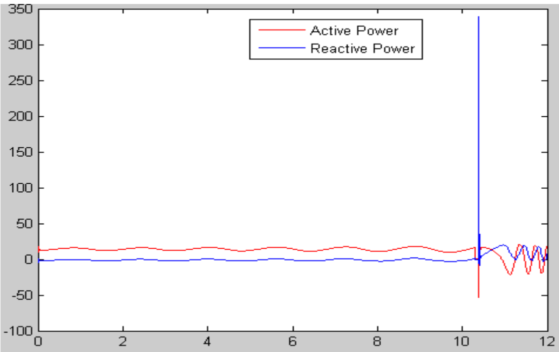

Fig. 27: Rael and reactive power flow in the line 1 without PSS

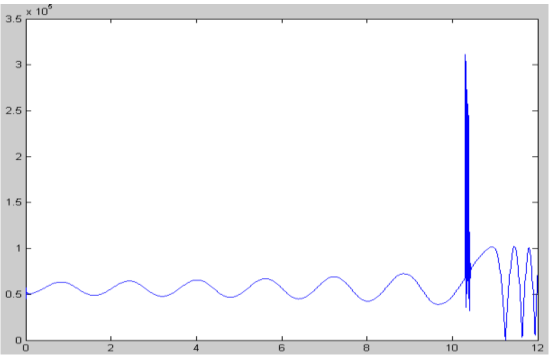

Fig. 28: Generator current oscillation without PSS

CONCLUSION

In this paper, the basic structure of an SVC operating under typical bus voltage control and its model are described. The model is based on representing the controller as variable impedance that changes with the

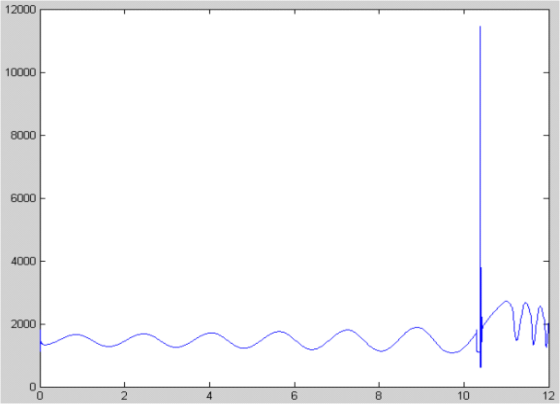

Fig. 29: Line 2 current oscillation without PSS

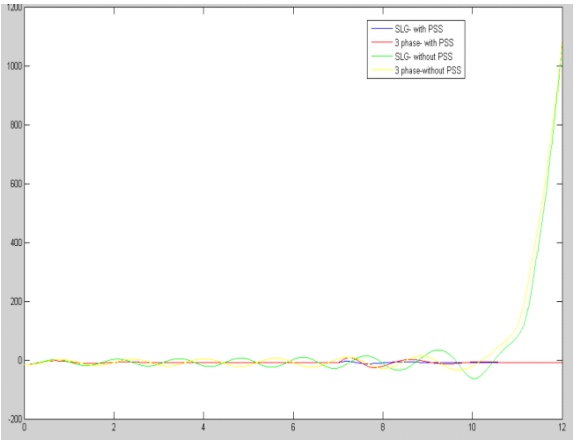

Fig. 30: Comparision of rotor angle differences oscillations for SLG and 3 phase faults with and without PSS

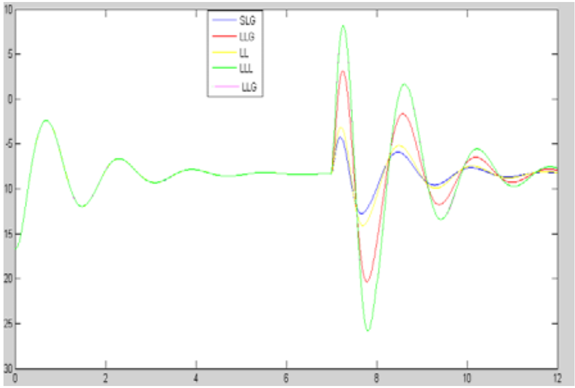

Fig. 31: Comparison of rotor angle differences oscillations for SLG-LL-LLG-3 phase and 3 phase to ground fault

firing angle of the Thyristor Controlled Reactor (TCR), which is used to control voltage in the system. Simulations carried out confirmed that Static Var Compensator could provide the fast acting voltage support necessary to prevent the possibility of voltage reduction and voltage collapse at the bus to which it is connected.

In this study, the effectiveness of shunt FACTS devices such as SVC has been studied in improving the transient stability of a sample two-area power system with various and different studies such as investigation the response of SVC to transient phenomena due to various faults such as single line to ground- line to line fault, line to line to ground fault and finally the three phase to ground fault are investigated.

In above studies the effect of PSS is considered to and simulation was carried out again without PSS. And finally the comparison between results are done .It also shows that when there is a pre-defined direction of real power flow, the shunt FACTS devices need to be placed slightly centre towards the sending end for maximum benefit from the stability point of view. The optimal location of these Devices also depends on the amount of local load and through load and it is seen that as the amount of local load increases the optimal location, from the transient stability point of view, moves towards the sending-end.

REFERENCES

Acha, E., V.G. Agelidis, O. Anaya-Lara and T.J.E. Miller, 2002. Power Electronic Control in Electrical Systems, Newnes Power. Engineering Series.

Acha, E., H. Ambriz-Perez and Fuerte-Esquivel, 2000. Advanced SVC models for newton-raphson load flow and newton optimal power flow studies. IEEE Trans. Power Sys., 15(1): 129-136.

Cai, L., 2004. Robust co-ordinated control of FACTS devices in large power systems. Ph.D. Thesis, University of Duisburg, Germany, Published by Logos Verlag Berlin.

Fuerte-Esquivel, C.R., E. Acha and H. Ambriz-Perez, 2000. A comprehensive Newton-Raphson UPFC model for the quadratic power flow solution of practical power networks. IEEE Trans. Power Syst., 15(1): 102-109.

Carsten, L., 2002. Security constrained optimal power flow for an economical operation of FACTS-devices in liberalized energy markets. IEEE Trans. Power Delivery, 17: 603-608.

Gyugyi, L., 1988. Power electronics in electric utilities: Static var compensators. Proc. IEEE, 76(4): 483-494.

Stagg, G.W. and A.H. El-Abiad, 2002. Computer methods in power system analysis. 1st Edn., Mc Graw-Hill.

Saadat, H., 2002. Power System Analysis. Tata McGraw-Hill.

Hingorani, N.G. and L. Gyugyi, 2000. Understanding, FACTS concepts and Technology of flexible AC transmission systems. IEEE Press, New York.

Jun, Z. and Y. Akihiko, 2006. Optimal power flow for congestion management by static var compensator (SVC). IEEE, International Conference on Power System Technology, Chongqing, China.

Kazerani, M., R. Marceau and Z. Wolanski, 1997. Mid-point sitting of FACTS devices in transmission lines. IEEE Trans. Power Delv., 12(4): 1717-1722.

Gyugyi, L., K.K. Sen and C.D. Schauder, 1999. The stativ var compensator concept a new approach to power flow management in Electronics Engineering 4:7 2010 95 transmission systems. IEEE Trans. Power Del., 14(3): 1115-1123.

Noroozian, M., L. Ängquist, M. Ghandhari and G. Andersson, 1997. Use of UPFC for optimal power flow control. IEEE Trans. Power Del., 12(4): 1629-1634.

Muwaffaq, I.A., 2003. Derivation of SVC load flow model with examples of its use in restructured power systems. IEEE Trans. Power Sys., 18: 1173-1180.

Teerathana, S., A. Yokoyama, Y. Nakachi and M. Yasumatsu, 2005. An optimal power flow control method of power system by Static Var Compensator (SVC). Proceeding 7th Int. Power Engineering Conference, Singapore, pp: 1-6.

Zhang, X.P., 2003a. Advanced modeling of the multicontrol functional Static Synchronous Series Compensator (SSSC) in Newton power flow. IEEE Trans. Power Syst., 18(4): 1410-1416.

Zhang, X.P., 2003b. Modeling of the interline power flow controller and the generalized unified power flow controller in Newton power flow. Proc. Inst. Elect. Eng. Gen. Transm. Distrib., 150(3): 268-274.

Xiao, Y., Y.H. Song and Y.Z. Sun, 2002. Power flow control approach to power systems with embedded FACTS devices. IEEE Trans. Power Syst., 17(4): 943-950.