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SVC Application for Damping Power System Oscillations

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ABSTRACT:Transmission networks of modern power systems are becoming increasingly stressed because of growing demand and restrictions on building new lines. One of the consequences of such a stressed system is the threat of losing stability following a disturbance. Flexible ac transmission system (FACTS) devices are found to be every effective in stressing a transmission network for better utilization of its existing facilities without sacrificing the desired stability margin. Flexible AC Transmission System (FACTS) controllers, such as Static Synchronous Compensator (STATCOM) and Static VAr Compensator (SVC), employ the latest technology of power electronic switching devices in electric power transmission systems to control voltage and power flow, and play an important role as a stability aid for and transient disturbances in an interconnected power systems. This report presents the improvement of transient stability of a multi-machine power system with a Static VAr Compensator (SVC). Static VAr Compensator has the capability of improving stability and damping by dynamically controlling its reactive power output. To illustrate the performance of the FACTS controller (SVC), a three machine, nine bus Western System Coordinating Council (WSCC) Multi-Machine Power System has been considered.

KEYWORDS:FACTS, MATLAB/SIMULINK, SVC, Transient Stability, Multi Machine Power System.

I.INTRODUCTION

Power system stability has been recognized as a vital and important issue for a reliable and secure interconnected power system operation as far back as the 1920s [1,2].The importance of stability problem associated with power system operation arises from increasing power exchange between the constituent parts of a large interconnected power system. In a free deregulated market, utilities are allowed to participate in the market without mandatory upper or lower limits. Thus, a number of highly publicized blackouts happened in the early years. The blackouts illustrate the necessity of assessing the stability of large power systems and maintaining an adequate level of system security to minimize the risk of major blackouts resulting from cascading outages emanating from a single disturbance. The main requirement of system stability is to keep the synchronous operation of power system with adequate capacity and fast reaction to meet the fluctuations in electric demand and changes in system topology. Successful operation of a power system depends largely on the engineer's ability to provide reliable and uninterrupted service to all loads and supply the required amount of loads by the available facilities [2]. If the oscillatory response of a power system during the transient period following a disturbance is damped within acceptable time and the system can settle in a finite time to a new steady-state, it is considered stable [3].

Now a days it is becoming very difficult to fully utilize the existing transmission system assets due to various reasons, such as environmental legislation, capital investment, rights of ways issues, construction cost of new lines, deregulation policies, etc. Electric utilities are now forced to operate their system in such a way that makes better utilization of existing transmission facilities.Flexible AC Transmission System (FACTS) controllers, based on the rapid development of power electronics technology, have been proposed in recent years for better utilization of existing transmission facilities. With the development of FACTS technique,it becomes possible to increase the power flow controllability and enhance power system's stability. Recently, Flexible Alternative Current Transmission System (FACTS) controllers have been proposed to enhance the transient or dynamic stability of power systems [4].Application of FACTS devices in power systems, leads to better performance of system in many aspects. Voltage stability, voltage regulation and power system stability, damping can be improved by using these devices and their proper control [4].There are various forms of FACTS devices, some of which are connected in series with a line and the others are connected in shunt or a combination of series and shunt.Among all FACTS devices, Static VAr Compensator (SVC) which is connected in shunt with power system plays much more important role in reactive power compensation and voltage support because of its

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attractive steady state performance and operating characteristics. The SVC can also increase transmission capacity, damping low frequency oscillation, and improving transient stability. Mathematical modeling and analysis of Static VAr Compensator (SVC) is presented in this paper.

The Static VAr Compensator (SVC) is one type of FACTS devices which resembles in many respects a thyristor controlled reactor and fixed capacitor used for voltage control and reactive power compensation. The SVC can increase transmission capacity, damping low frequency oscillation, and improving transient stability. This paper [14] presents a control block diagram of SVC for the transient stability improvement. The SIMULINK/MATLAB software package is used for simulation of test system. In this paper the SVC is connected to the 400 KV line for a typical two machine transmission system. The main reasons for occurring stability problem in the system is due to the fault occurs in the system.

In this paper [15] the effect of SVC on voltage stability is investigates using cascade Proportional Integral Differential controller. SVC is a shunt type FACTS device which is used in power system primarily for the purpose of voltage and reactive power control. The cascade PID controller parameters has been selected by using Tyreus-Luyben settings method for primary loop controller and modified Ziegler-Nichols method for secondary loop controller. In large power systems, low frequency electro-mechanical oscillations often follow the electrical disturbances. Generally, power system stabilizers (PSS) are used in conjunction with Automatic Voltage Regulators (AVR) to damp out the oscillations. However, during some operating conditions this device may not produce adequate damping and other effective alterations are needed in addition to PSS. That can be achieved with shunt FACTS device designed with auxiliary controllers. Static VAr Compensator (SVC) is a shunt type FACTS device which is used in power system primarily for the purpose of voltage and reactive power control it has also the capability of damping oscillations with suitable controllers.

A new Hybrid PID with fuzzy logic controller is designed and studied the performance. The results are obtained using nonlinear simulation in MATLAB. The results showed that Hybrid PID with fuzzy (HPF) controller is more effective in damping power system oscillations [16]. Transient stability is one of the most important stability of the power system. The loss of Transient stability is due to overloading of some of the lines (or due to sever line fault) as a consequence of tripping off of the other lines after fault or heavy loss of loads. The main aim of the work [17] is to design the model of SVC in Simulink as an alternate to the physical model which is not feasible due to enormous cost. The proposed work includes (WSCC) 3-machine 9-bus system incorporated with SVC controller using Matlab. The simulated SVC shows how the oscillations are damped out with SVC controller. The optimum location of the SVC in the system is also studied.

Transient stability is important from the view point of maintaining system security that is the incidence of a fault should not lead to tripping of generating unit due to loss of synchronism and the possibility of a cascaded outage leading to system black out. This paper [18] proposes the coordinated operation of optimal reclosing of circuit breakers and Static VAr Compensator (SVC) for enhancing the transient stability of a multi-machine power system. The transient stability performance of the combined operation of optimal reclosing of circuit breakers and SVC is compared with that of the combined operation of conventional reclosing of circuit breakers and SVC. The total kinetic energy (TKE) of the generators in the system is used to determine the transient stability enhance-ment index. Simulations are performed through Matlab/Simulink software. Simulation results for both the three-line-to-ground (3LG) and single-line-to-ground (1LG) permanent faults at different points of the power system indicate that the proposed combination of optimal reclosing of circuit breakers and SVC can enhance the transient stability of the system well. Also, the performance of the proposed method is better than that of the combined operation of conventional reclosing of circuit breakers and SVC.

II.CONTROL CONCEPT OF SVC

According to definition of IEEE PES Task Force of FACTS Working Group [4]:
Static VAr Compensator (SVC): *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).*

The term, “SVC” has been used for shunt connected compensators, which are based on thyristors without gate turn-off capability. It includes separate equipment for leading and lagging vars; the thyristor – controlled or thyristor – switched reactor for absorbing reactive power and thyristor – switched capacitor for supplying the reactive power[4],[6].

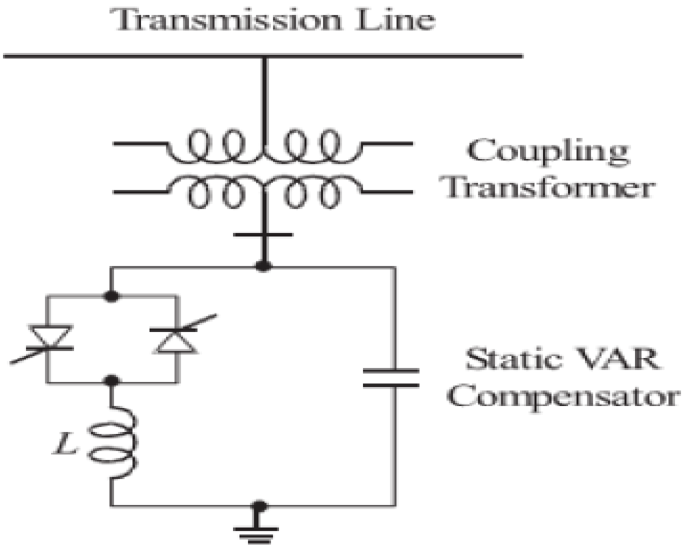

Fig. 1 Configuration of SVC

Static VAr systems are applied by utilities in transmission applications for several purposes. The primary purpose is usually for rapid control of voltage at weak points in a network. Installations may be at the midpoint of transmission interconnections or at the line ends. SVC are shunt connected static generators / absorbers whose outputs are varied so as to control voltage of the electric power systems. In its simple form, SVC is connected as Fixed Capacitor-Thyristor Controlled Reactor (FC-TCR) configuration as shown in Fig.1 The SVC is connected to a coupling transformer that is connected directly to the ac bus whose voltage is to be regulated. The effective reactance of the FC-TCR is varied by firing angle control of the antiparallel thyristors. The firing angle can be controlled through a PI controller in such a way that the voltage of the bus, where the SVC is connected, is maintained at the reference value. An SVC is a controlled shunt susceptance (B) which inject reactive power (Qnet) into there by increasing the bus voltage back to its net desired voltage level [15]. If bus voltage increases, the SVC will inject less (or TCR will absorb more) reactive power, and the result will be to achieve the desired bus voltage.

The SVC can be operated in two different modes

i. *In voltage regulation mode (the voltage is regulated within limits).*
ii. *In VAR control mode (the SVC susceptance is kept constant).*

From V-I curve of SVC, From Fig. 2

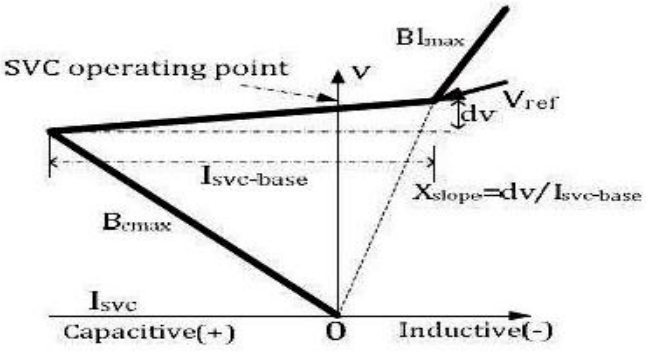

Fig. 2 Steady state (V-I) characteristic of a SVC

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V = V_{ref}+ X_S.I : In regulation range (-B_{Cmax}<B<B_{Cmax})
V = I/B_{Cmax}, : SVC is fully Capacitive (B=B_{Cmax})
V = 1/B_{lmax}, : SVC is fully inductive (B=B_{lmax})

The Static VAr Compensator is basically a shunt connected variable VAr generator whose output is adjusted to exchange capacitive or inductive current to the system [16].

The magnitude of the SVC in inductive admittance $BL(\alpha)$ is a function of the firing angle α and is given by

$$B_L(\alpha) = \frac{2\pi - 2\alpha + \sin 2\alpha}{\pi X_s} \qquad (1)$$

$$\text{For} \quad \frac{\pi}{2} \le \alpha \le \pi \qquad (2)$$

Where $X_s = \frac{V_s^2}{Q_L}$ (3)

α = Firing angle of thyristor
Vs= SVC bus bar voltage
Q_L= MVA rating of reactor

As the SVC uses a fixed capacitor and variable reactor combination (TCR- FC), the effective shunt admittance is

$$B_S = \frac{1}{X_c} - B_L(\alpha) \quad (4)$$

Where X_C=Capacitive reactance.

An SVC with firing control system can be represented, for the sake of simplicity by a first order model characterized by a gain K_{SVC} and time constants T_1 and T_2 as shown in fig.3. The controller send firing control signals to the thyristor switching unit to modify the equivalent capacitance of the SVC.

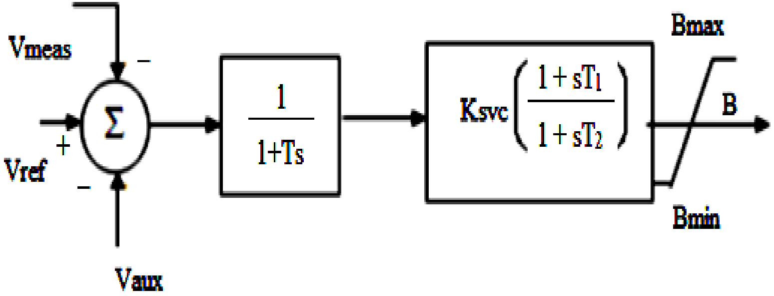

Fig.3 Block Representation of SVC Control

The auxiliary control loop of the SVC uses stabilizing signals, such as speed, frequency, phase angle difference etc. to improve the dynamic performance of the system.

III.POWER SYSTEM MODELING

For the proposed work I have considered the three- machine, nine- bus WSCC (Western System Coordinating Counsel) system as shown in Figure 4. The complete 3-generator system, given in Fig. 4, has been simulated as a single integral model in Simulink. The classical model, [1],[3] for the machines is used for transient stability studies is given below.

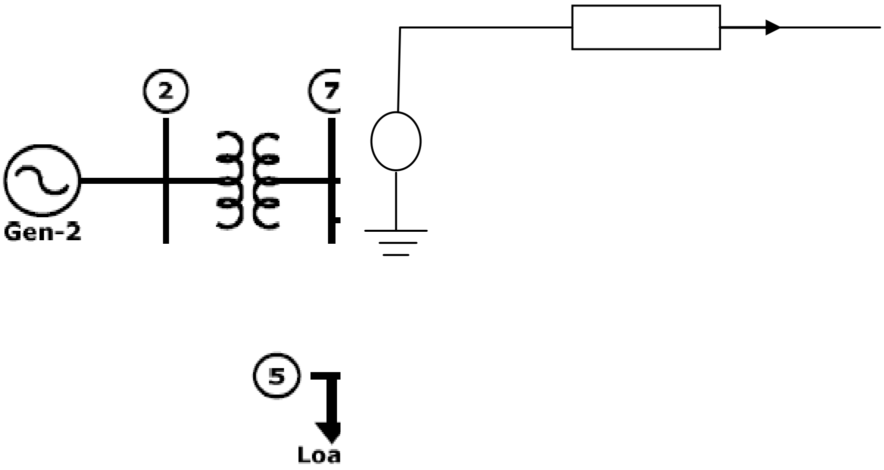

Fig. 4 WSCC, Three-Machine, nine-bus system

The classical model can be described by the following set of differential and algebraic equations:

Differential:

$$\frac{2H}{\omega_s}\frac{d\omega}{dt} = P_m - P_e \qquad (5)$$

$$\frac{d\delta}{dt} = \omega - \omega_s \qquad (6)$$

$$\dot{E_q} = \frac{1}{T'}\left(-\dot{E_q} + E_{fd}\right)(7)$$

Where
P_m = Input mechanical power
P_e= Electrical output power
H = Inertia constant of machine.
ω_s = Synchronous speed of machine in electrical rad/sec
ω = Speed of Synchronous machine in electrical rad/sec
δ = Angular displacement of rotor from the synchronously rotated reference axis
Eq = Voltage back of quadrature axis synchronous reactance
E'q =Voltage proportional to the field flux linkage resulting from the combined effect of the field and armature currents
E_{fd}= The field voltage acting along the quadrature-axis of the machine

Algebric:

$$E' = E_t + r_a I_t + jX'_d I_t \qquad (8)$$

$r_a + jx_d'$

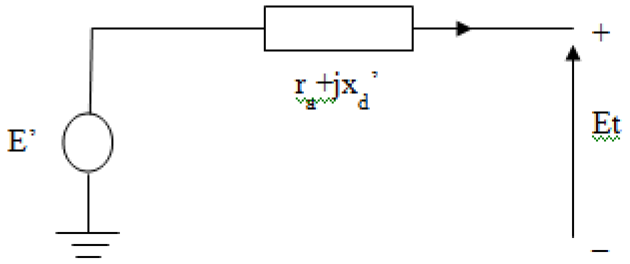

Fig. 5 Generator Classical Model

Where :
E'= Voltage back of transient reactance
E_t= Terminal voltage at the bus
I_t= Machine terminal current
r_a= Armature resistance
x_d'= Direct axis transient reactance

Exciter Modeling: Excitation system provides the current required for the field winding of a synchronous generator to produce the rated terminal voltage at the generator terminals. The basic blocks that are involved in the excitation system [21] are shown in Fig. 6.

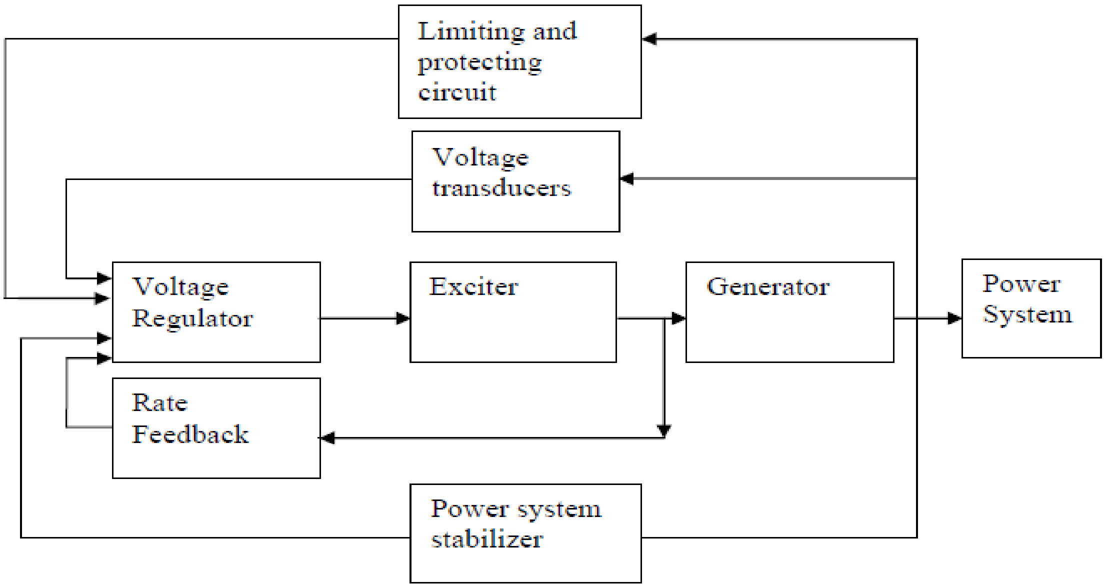

Fig. 6 Excitation system block diagram

In this paper IEEE Type AC1A model exciter is considered in simulation study.

IV.SEMULATION MODEL

This paper considered the popular Western System Coordinated Council (WSCC) 3-machine, 9-bus system shown in Fig. 7. The base MVA is 100, andsystem frequency is 60 Hz. The systemhas been simulated with a classical model for the generators. The complete system has been represented in terms of Simulink model. Oneof the most important features of a model in Simulink is its tremendous interactivecapacity. It makes the display of a signal at any point readily available, all one hasto do is to add a Scope block or, alternatively, an output port. SVC hasbeen used to improve transient stability and powersystem oscillations damping. The phasor simulationmethod can be used.

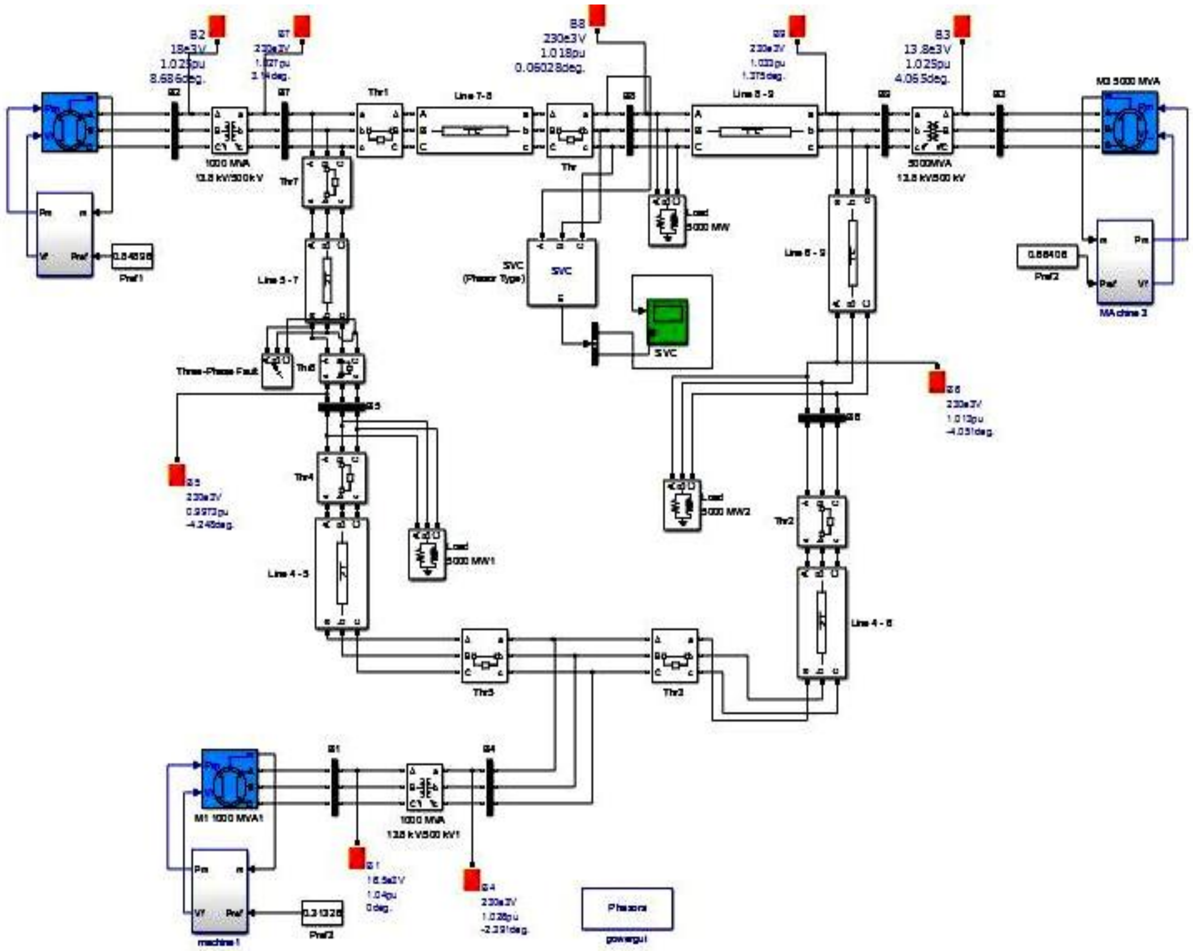

Fig. 7: Complete Simulink Model of 3-Machine 9 Bus System With SVC Connected at 8th Bus

V.SIMULATION RESULT

A three-phase fault is simulated in one of the lines of the 3 machine 9-bus system (WSCC) i.e. three phase to earth fault after 1 sec. The simulation is done in three phases. To start with, the pre-fault system is run for a small time. Then a symmetrical fault is applied at one end of a line (Fig. 7). Simulation of the faulted condition continues until the line is disconnected from the buses at both of the ends of the faulted line after a fault clearing time tc sec. Then the post-fault system is simulated for a longer time (say,30 sec.) to observe the nature of the transients.

A. Without SVC

1) Case I: fault on the line 5-7

Plot of relative machine angles δ_{21} , δ_{31} and δ_{23} are shown in Fig. 8 with fault clearing time tc = 0.1 (sec.) and fault on line 5-7 near to 5th bus.

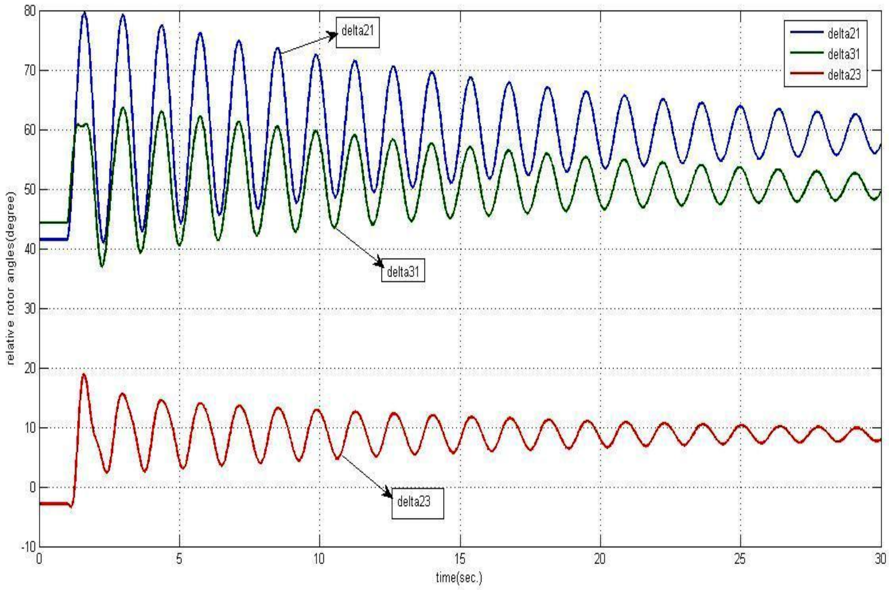

Fig. 8 Relative angles plot without SVC for fault on line 5-7 near to 5th bus

From the above plot before 1 (sec.) system was stable, fault occur at 1 (sec.) and cleared at 1.1 (sec.) by disconnecting the fault line. The rotor angle starts oscillating after occurrence of disturbance (3 phase fault).

Plot of relative machine speed ω_{21}, ω_{31} and ω_{23} are shown in Fig. 9 with fault clearing time tc = 0.1 (sec.) and fault on line 5-7 near to 5th bus.

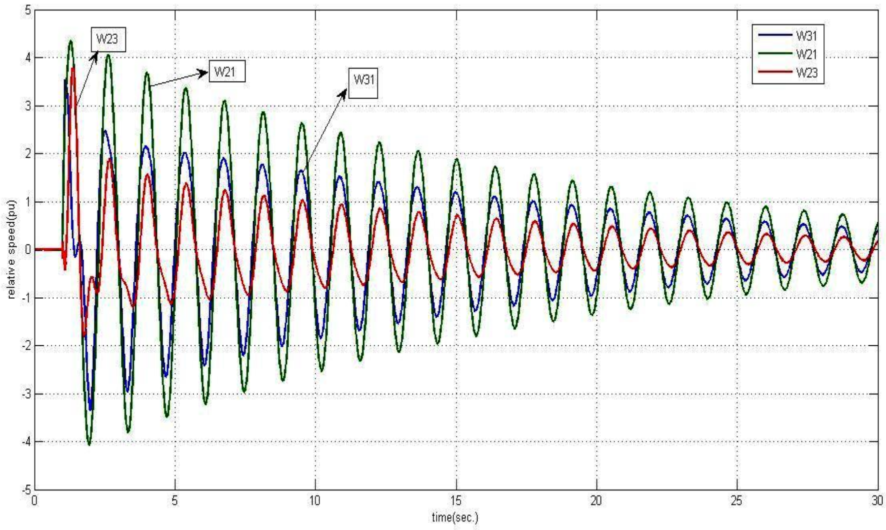

Fig. 9 Relative speed plot without SVC for fault on line 5-7 near to 5th bus

From the above plot before 1 (sec.) system was stable, fault occur at 1 (sec.) and cleared at 1.1 (sec.) by disconnecting the fault line. The speed of the machine deviates from its steady state position and starts oscillating after occurrence of disturbance (3 phase fault).

2) Case II: fault on the line 4-6

Plot of relative machine angles δ_{21} , δ_{31} *and* δ_{23} are shown in Fig. 10 with fault clearing time tc = 0.1 (sec.) and fault on line 4-6 near to 6th bus.

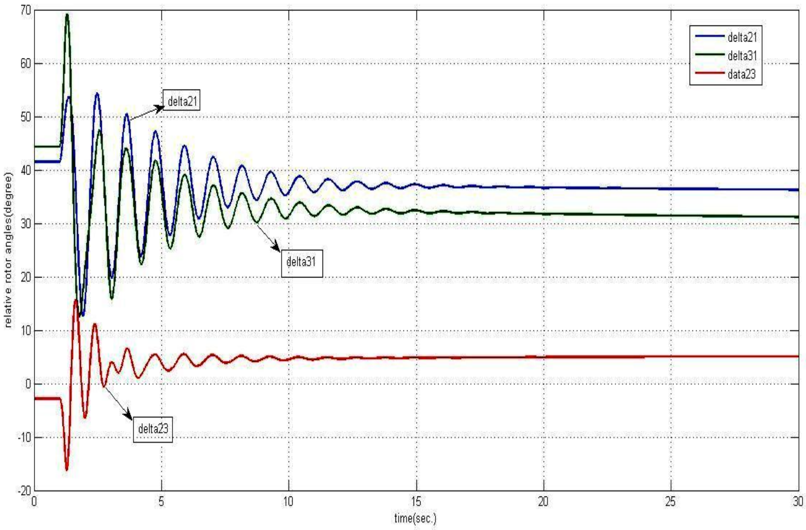

Fig. 10 Relative angles plot without SVC for fault on line 4-6 near to 6th bus

The above plot depicts the effect of 3 phase fault occur on the line 4-6 on relative rotor angles of the generators.
Plot of relative machine speed ω_{21}, ω_{31} and ω_{23} are shown in Fig. 11 with fault clearing time tc = 0.1 (sec.) and fault on line 4-6 near to 6th bus.

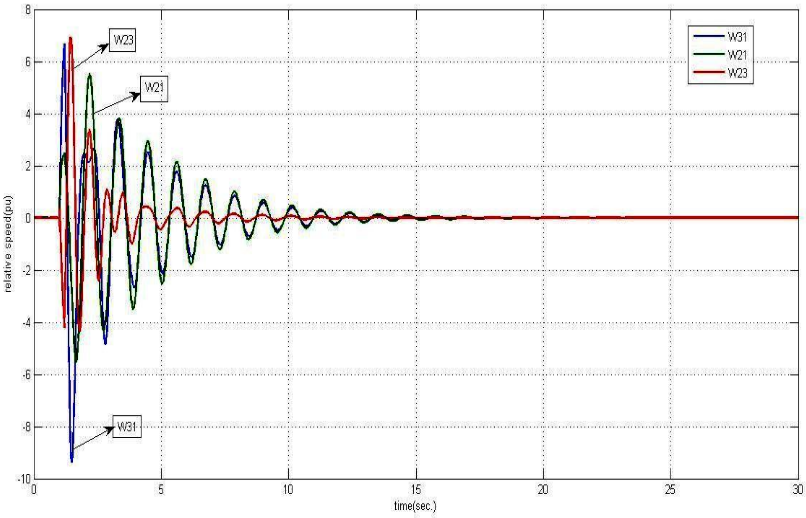

Fig. 11 Relative speed plot without SVC for fault on line 4-6 near to 6th bus

The above plot shows the effect of disturbance on machines speed. After occurrence of disturbance speed of machine deviates from its steady state position.

B. With SVC

Now SVC is connected to 8th bus in the test system which is shown in fig. 7. In this case study PI controller is used to control the susceptance of SVC. The below figures is showing the transient response of 9 bus system and how SVC improves these transient response of the system.

1) Case I:fault on the line 5-7

Plot of relative machine angles δ_{21} , δ_{31} *and* δ_{23} are shown in Fig. 12 with fault clearing time tc = 0.1 (sec.) and fault on line 5-7 near to 5th bus and SVC is connected at 8th bus.

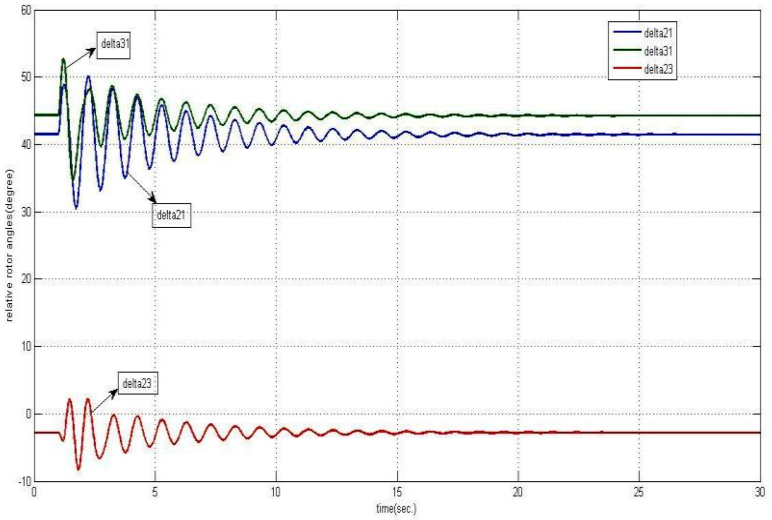

Fig. 12 Relative angles plot with SVC at 8th bus and fault on line 5-7 near to 5th bus

From the above plot it is clear that after introducing SVC with PI controller oscillations has been damped within 25 (sec.) and also peak of oscillation is reduced.

Plot of relative machine speed ω_{21}, ω_{31} and ω_{23} are shown in Fig. 13 with fault clearing time tc = 0.1 (sec.) and fault on line 5-7 near to 5th bus and SVC is connected at 8th bus.

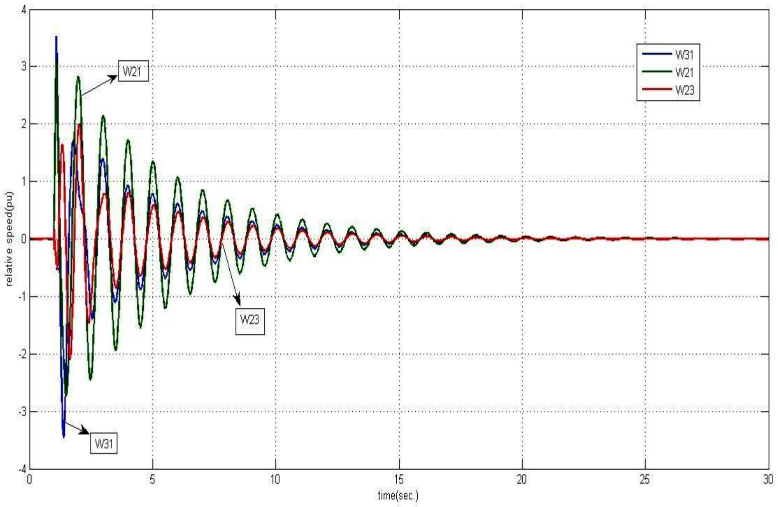

Fig. 13 Relative speed plot with SVC at 8th bus and fault on line 5-7 near to 5th bus

This plot depicts after introducing SVC at 8th bus relative speed of the machines comes to steady state operating condition within 25(sec.) which improves the transient stability of the system.

2) Case II: fault on the line 4-6

Plot of relative machine angles δ_{21} , δ_{31} *and* δ_{23} are shown in Fig. 14 with fault clearing time tc = 0.1 (sec.) and fault on line 4-6 near to 6th bus and SVC is connected at 8th bus.

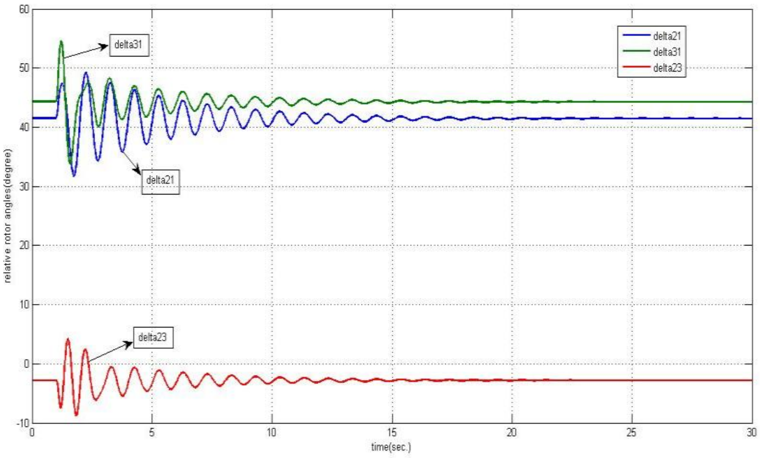

Fig. 14 Relative angles plot with SVC at 8th bus and fault on line 4-6 near to 6th bus

From the above plot it is clear that after introducing SVC oscillations of rotor angle of machine is damped within 20(sec.) when the fault occur on the line 4-6.

Plot of relative machine speed ω_{21}, ω_{31} and ω_{23} are shown in Fig. 15 with fault clearing time tc = 0.1 (sec.) and fault on line 4-6 near to 6th bus and SVC is connected at 8th bus.

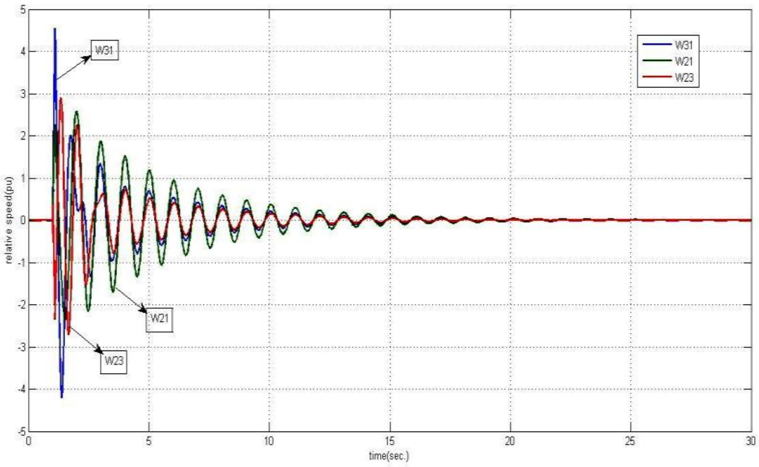

Fig. 15 Relative speed plot with SVC at 8th bus and fault on line 4-6 near to 6th bus

The above plot is showing that speed deviation of machines comes to steady state operating condition within 20(sec.) which improves transient stability of the system.

VI.CONCLUSION

In this paper, the effect of Static VAr Compensator for improving transient stability of the multi machine power system is investigated. The SVC is used to control power flow of power system by injecting appropriate reactive power during dynamic state. Computer simulation results shows that SVC not only considerably improves transient stability but also compensates the reactive power in steady state. Therefore SVC can increase reliability and capability of AC transmission system. It is quite clear that before compensating a power system with FACTS device to improve transient stability, we need to assess the system stability conditions for different locations of the fault and the compensator and also with different amounts of compensation. The transientstability improvement of the multi-machine power system for 3 phase fault condition is investigated in this work. To control the susceptance of SVC PI controller is employed in this work. Further, a fuzzy controlled SVC can be implemented on WSCC 9 bus system to improve the stability of system.

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APPENDIX

Table: Generator Data

Generator No.	1	2	3
Rated MVA	247.5	192	128
H(s)	23.64	6.4	3.01
Power Factor	1.0	0.85	0.85
Type	Hydro	Steam	Steam
x_d	0.1460	0.8958	1.3125
x'_d	0.0608	0.1198	0.1813
x_q	0.0969	0.8645	1.2578
x'_q	0.0969	0.1969	0.2500
x_l (leakage)	0.0336	0.0521	0.0742
T_{d0}	8.96	6.00	5.89
T'_{q0}	0	0.535	0.600
Stored energy at rated	2364MWs	640MWs	301MWs
Speed			

Reactance values are in pu on a 100MVA and 100KV base.

Table: Transmission Network Data

Bus NO.		Half line charging Admittance (p.u.)	Reactance (p.u.)	Resistance (p.u.)
From Bus	To Bus			
1	4	0.0000	0.0576	0.0000
4	6	0.0790	0.0920	0.0170
3	9	0.0000	0.0586	0.0000
6	9	0.1790	0.1700	0.0390
5	7	0.1530	0.1610	0.0320
7	8	0.0745	0.0720	0.0085
2	7	0.0000	0.0625	0.0000
8	9	0.1045	0.1008	0.0119

Table: Bus data (p.u.)

Bus No.	P_{gen}	Q_{gen}	P_{load}	Q_{load}	V_{spec}
1	0.00	0.0	0.00	0.00	1.040
2	1.63	0.0	0.00	0.00	1.025
3	0.85	0.0	0.00	0.00	1.025
4	0.00	0.0	0.00	0.00	1.000
5	0.00	0.0	1.25	0.50	1.000
6	0.00	0.0	0.90	0.30	1.000
7	0.00	0.0	0.00	0.00	1.000
8	0.00	0.0	1.00	0.35	1.000
9	0.00	0.0	0.00	0.00	1.00