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Impact of Pa & MB-PSS on Transient Stability of Power System along with SVC Operating in VAR Control Mode for a Weakly Damped Power System Operating near Stability Limit

Manish Chavan[1], Prasad Kulkarni[2]

M.Tech Student (EPS), Department of Electrical Engineering, KCES's COE & IT, Jalgaon, MH, India [1]

Assistant Professor, Department of Electrical Engineering, KCES's COE & IT, Jalgaon, MH, India[2]

ABSTRACT: This paper present the coordinated control for Static Var Compensator and generic (Pa)/multi-band(MB)PSS for power transient damping for the multimachine weakly damped power system. The basics and the mathematical models of the Pa PSS, the MB PSS and the SVC are presented. The Voltage-Current characteristics along with dynamic characteristics of the static var compensator (SVC) are discussed. The two-machine power system is simulated using MATLAB and the Impact of PSS and SVC on dynamic response of the system under single and three-phase fault are simulated. The simulation results reveal that the coordinated control of the SVC and the generic (Pa)/multi-band(MB)PSS is an effective technique to damp low frequency oscillation for multimachine power system and increase stability of the large inter-connected power system.

KEYWORDS: FACTS, Static Var Compensator (SVC), Power System Stabilizer (PSS), Pa PSS, MB PSS, phasor simulation method, Transient stability, Reactive shunt power Compensation.

I. INTRODUCTION

As the world is continuously growing so the generation, distribution and transmission of power are simultaneously required to increase in same manner to fulfill the requirement. Power system stability may be broadly defined as that property of a power system that enables it to remain in a state of operating equilibrium under normal operating condition and to regain an acceptable state of equilibrium after being subjected to a disturbance [2,3].
Stability of this system needs to be maintained even when subjected to large low-probability disturbances so that the electricity can be supplied to consumers with high reliability. Certain system disturbances may cause loss of synchronism between a generator and the rest of the utility system, or between interconnected power systems of neighboring utilities. Various control methods and controllers have been developed over time that has been used for this purpose [1].

Recently, there has been a surge of interest in the development and use of FACTS controllers in power transmission systems. These controllers utilize power electronics devices to provide more flexibility to AC power systems. The most popular type of FACTS devices in terms of application is the SVC [5]. This device is well known to improve power system properties such as steady state stability limits, voltage regulation, and damp power system oscillations.
The SVC is an electronic generator that dynamically controls the flow of power through a variable reactive admittance to the transmission network. In systems work with PSS we must study the concepts of power system stability, excitation system of a single generator, Automatic Voltage Regulator (AVR) and Power System Stabilizer (PSS)
In this paper and depending on the above information, we will describe and illustrate modeling of transmission system containing two power plants in addition to using Static Var Compensator (SVC) and Power System Stabilizers (PSS) to improve and damp oscillation of power and frequency.

This paper presents the coordinated control for SVC and PSS for power swing damping for the multimachine power system by using MATLAB/SIMULINK. Firstly, the background of the PSS and SVC is introduced, and the mathematical models of these controllers are also presented. The generic PSS and the multi-band PSS are introduced and compared. The static var compensator (SVC) is discussed, the V-I characteristics as well as the dynamic properties are presented. The multi-machine power system is simulated using MATLAB and the effect of PSS and SVC on dynamic response of the system under single-phase fault and three phase fault are simulated.

II. POWER SYSTEM UNDER STUDY

A. Description of the large two area power system

The power system under study is having two power stations with capacity of 1000 MVA and 5000 MVA. The generation voltage is 500kV. The load demand side is near to the 5000 MVA generator. The 700km transmission line is used to transfer the power from 1000 MVA to the load as shown in fig.1.

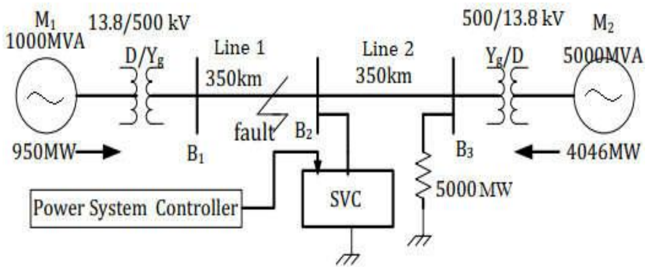

Fig. 1. power system under study

The load is modeled by a 5000 MW resistive load through the transmission line. Initially a load flow has been performed on the power system under study and generation of both plants and line current are noted. The line current is found nearer to its its surge impedance loading (SIL). A 3 phase fault is created in the system near to bus B1. To maintain system stability after faults, the transmission line is shunt compensated at Bus B2 by a 200 Mvar static var compensator (SVC).

B. Modeling of the hydro-electric power plants

The two power generation plants having a hydraulic turbine and governor (HTG), excitation system, and power system stabilizer (PSS). The hydraulic turbine and governor and the excitation system are also implemented inside subsystems. Two types of stabilizers type) model using the acceleration power (Pa=Pm-Pe) and a Multiband stabilizer (MB type) using the speed deviation (dw). These two stabilizers are standard models of the Fundamental Blocks/Machines library. Manual Switch blocks are used to select the type of stabilizer used for both machines.

C. Modeling of the Generic Power System Stabilizer

The generic power system stabilizer (PSS) block can be used to add damping to the rotor oscillations of the synchronous machine by controlling its excitation. The disturbances occurring in a power system induce electromechanical oscillations of the electrical generators. These oscillations, also called power swings, must be effectively damped to maintain the system stability [1, 3, 4].

The output signal of the PSS is used as an additional input (*vstab*) to the Excitation System block. The PSS input signal can be either the machine speed deviation, *dw*, or its acceleration power, *Pa=Pm-Peo* (difference between the mechanical power and the electrical power) [1, 5-8].

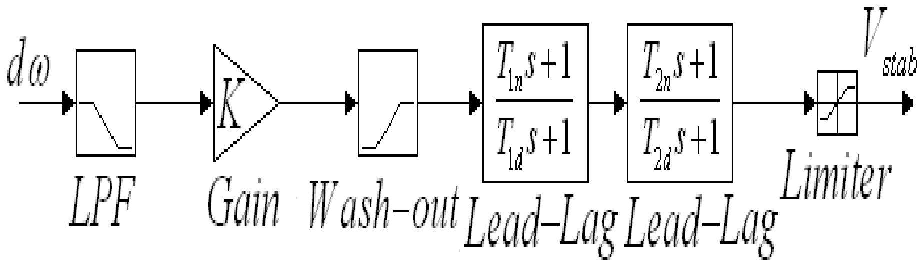

Fig. 2. Block Diagram of the Generic Power System Stabilizer

Fig 2. shows the block diagram of the generic power system stabilizer (PSS), which can be modeled by using the following transfer function [1]:

$$G(s) = K \cdot \frac{T_{1n}s+1}{T_{1d}s+1} \cdot \frac{T_{2n}s+1}{T_{2d}s+1}$$

To ensure a robust damping, the PSS should provide a moderate phase advance at frequencies of interest in order to compensate for the inherent lag between the field excitation and the electrical torque induced by the PSS action. The

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model consists of a low-pass filter, a general gain, a washout high-pass filter, a phase-compensation system, and an output limiter. The general gain *K* determines the amount of damping produced by the stabilizer [1, 3, 4].
The washout high-pass filter eliminates low frequencies that are present in the *dw* signal and allows the PSS to respond only to speed changes. The phase-compensation system is represented by a cascade of two first-order lead-lag transfer functions used to compensate the phase lag between the excitation voltage and the electrical torque of the synchronous machine.

D. Modelling of the Multi-band Power System Stabilizer

The disturbances occurring in a power system induce electromechanical oscillations of the electrical generators.
These oscillations, also called power swings, must be effectively damped to maintain the system's stability. Electromechanical oscillations can be classified in four main categories [1, 3, 4]:
(1) Local oscillations: between a unit and the rest of the generating station and between the latter and the rest of the power system. Their frequencies typically range from 0.8 to 4.0Hz.
(2) Interplant oscillations: between two electrically close generation plants. Frequencies can vary from 1 to 2Hz.
(3) Inter-area oscillations: between two major groups of generation plants.Frequency are typically a range of 0.2-0.8Hz.
(4) Global oscillation: characterized by a common in-phase oscillation of all generators as found on an isolated system. The frequency of such a global mode is typically under 0.2Hz. The need for effective damping of such a wide range, almost two decades, of electromechanical oscillations motivated the concept of the multiband power system stabilizer (MBPSS), as shown in Figure 3. Just as its name reveals, the MB-PSS structure is based on multiple working bands. Three separate bands are dedicated to the low-, intermediate-, and high-frequency modes of oscillations: the low band is typically associated with the power system global mode, the intermediate with the interarea modes, and the high with the local modes.

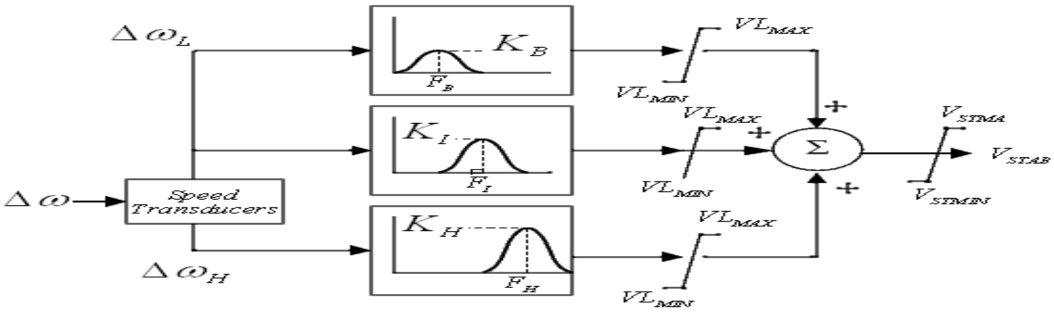

Fig. 3. Block Diagram of Multi-band Power System Stabilizer (MB-PSS)

E. Modelling of the Transmission System and SVC

The SVC and power system stabilizers (PSS) are used to improve the transient stability and power oscillation damping of the system. The SVC regulates voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. The variation of reactive power is performed by switching three phase capacitor banks and inductor banks connected on the secondary side of a coupling transformer. The SVC is the phasor model from the FACTS library. It does not have apower oscillation damping (POD) unit. The SVC rating is +/- 200 Mvar. The SVC can be operated in Voltage regulation or Var control (Fixed susceptance Bref) mode by selecting in the Control parameters. Initially the SVC is set in Var control mode with a susceptance Bref=0, which is equivalent to having the SVC out of service.
Figure 4 shows the single-line diagram of a static var compensator and its control system. The variation of reactive power is performed by switching three-phase capacitor banks and inductor banks connected on the secondary side of a coupling transformer. Each capacitor bank is switched on and off by three thyristor switches (Thyristor Switched Capacitor or TSC). Reactors are either switched on-off (Thyristor Switched Reactor or TSR) or phase-controlled (Thyristor Controlled Reactor or TCR) [1, 2].
The control system consists of the following issues:
1) A measurement system measuring the positivesequence voltage is to be controlled.
2) A Fourier-based measurement system using a one-cycle running average is used.
3) A voltage regulator that uses the voltage error (difference between the measured voltage Vm and the reference voltage Vref) to determine the SVC susceptance B needed to keep the system voltage constant.
4) A distribution unit that determines the TSCs (and eventually TSRs) must be switched in and out, and computes the firing angle of TCRs.

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5) A synchronizing system using a phase-locked loop (PLL) synchronized on the secondary voltages and a pulse generator that send appropriate pulses to the thyristors.

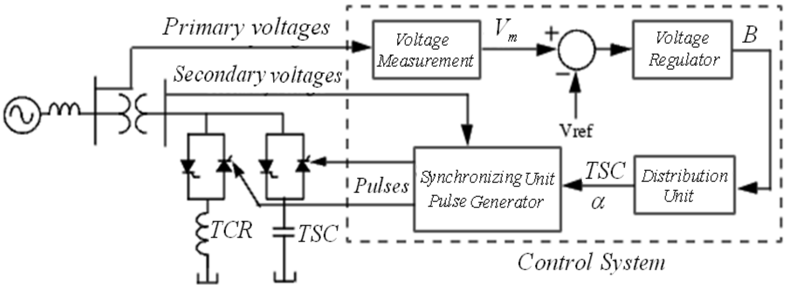

Fig. 4. Single-Line Diagram of a SVC with its Control System

E.1 SVC V-I Characteristic

The SVC can be operated in two different modes: In voltage regulation mode (the voltage is regulated within limits as explained below). In var control mode (the SVC susceptance is kept constant). When the SVC is operated in voltage regulation mode, it implements the following V-I characteristic (Figure 4) [1].

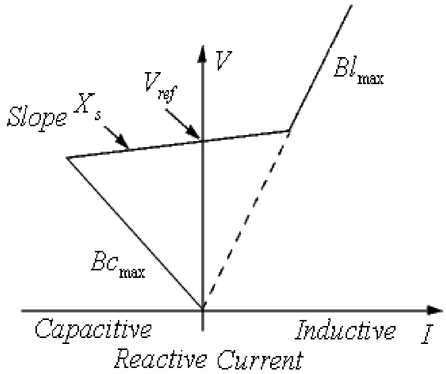

Figure 5. The V-I Characteristics of the SVC

As long as the SVC susceptance (*B*) stays within the maximum and minimum susceptance values imposed by the total reactive power of capacitor banks (*Bcmax*) and reactor banks (*Blmax*), the voltage is regulated at the reference voltage *Vref*. However, a voltage droop is normally used (usually between 1% and 4% at maximum reactive power output), and the *V-I* characteristic has the slope indicated in the Figure. The *V-I*
characteristic is described by the following three equations [1, 3, 4]:
$V = Vref + Xs \cdot I$, SVC is in regulation range ($-Bcmax<B<Blmax$) (2)

$V = - I/ Bc\text{max}$, SVC is fully capacitive ($B=Bcmax$) (3)

$V = I/ Bl\text{ max}$, SVC is fully inductive ($B=Blmax$) (4)

where '*V'* denotes the positive sequence voltage (p.u.); '*I'* denotes the reactive current (p.u./Pbase) ('*I'*>0 indicates an inductive current); '*X s'* denotes the slope or droop reactance (p.u./Pbase); '*Bc max'* denotes the maximum capacitive susceptance (p.u./Pbase) with all TSCs in service, no TSR or TCR; '*Bl max'* denotes the maximum inductive susceptance (p.u./Pbase) with all TSRs in service, or TCRs at full conduction, no TSC.

E.2 SVC Dynamic Response

When the SVC is operating in voltage regulation mode, its response speed to a change of system voltage depends on the voltage regulator gains (proportional gain *Kp* and integral gain *Ki*), the droop reactance *Xs*, and the system strength (short-circuit level). For an integral-type voltage regulator (*Kp*= 0), if the voltage measurement time constant Tm and the average time delay *Td* due to valve firing are neglected, the closed-loop system consisting of the SVC and the power system can be approximated by a first-order system having the following closed-loop time constant [1, 3, 4, 7]:

$T_c = 1/ K_i (X_s + X_n)$ (5)

where *'T c'* represents the closed-loop time constant; *'K i'* represents the proportional gain of the voltage regulator (p.u._B/p.u._V/s); *'X s'* represents the slope reactance p.u./Pbase; *'X n'* represents the equivalent power system reactance (p.u./Pbase). This equation demonstrates that we obtain a faster response speed when the regulator gain is increased or when the system short-circuit level decreases (higher *Xn* values). If we take into account the time delays due to voltage measurement system and valve firing, we obtain an oscillatory response and, eventually, instability with too weak a system or too large a regulator gain.

F. Complete Simulink Model of the Large Area Power System

The Complete Simulink Model of the Large Area Power System is shown in Fig.5. A Fault Breaker block is connected at bus B1. It can be programed for different types of faults on the 500 kV system and the impact of the PSS and SVC on system stability can be observed.

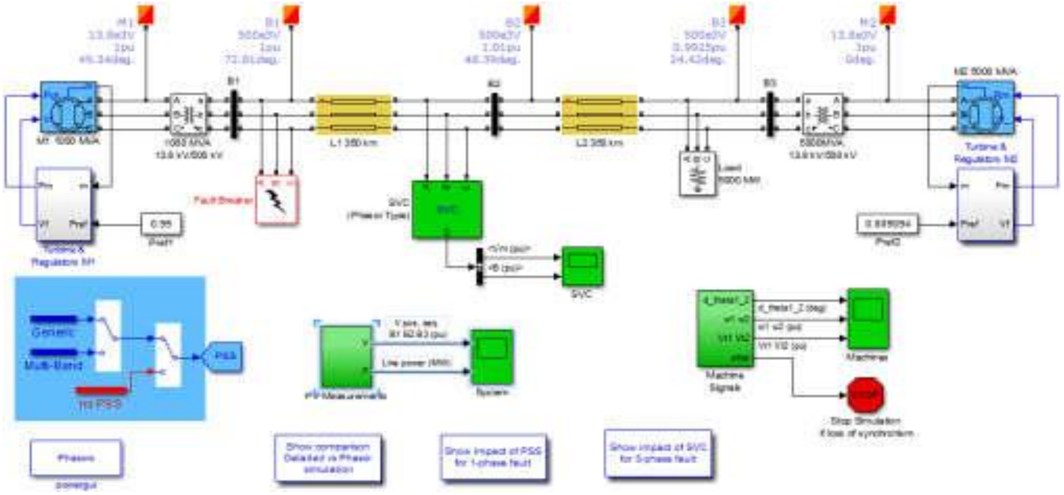

Fig. 5. Simulink model of system under study

System description:

Tab. 1. System Parameters description

System Parameter	description
Two synchronous generators	1000 &5000 MVA
Two power transformers	13.8 kV /500 kV
700 km Transmission line	500 kV
Two PSS and two AVR	Pa / MB
SVC	200 Mvar
resistive load	5000 MW

A Static Var Compensator (SVC) and Power System Stabilizers (PSS), are used to improve transient stability and power oscillation damping of the system. In order to show the performances and observe the impact of PSS and SVC on the power system stability a single-phaseto ground fault and a three-phase fault have been applied on the first section of the line (L1).

III. SIMULATION FOR TRANSIENT STABILITYANALYSIS

A. Simulation Initiation and Load Flow Analysis

In steady-state, the machines and the regulators have been previously initialized by means of the Machine Initialization utility of the Powergui block. The 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.

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B. Inter-area oscillation damping with PSS — No SVC Under Single-Phase Fault condition

Initially the accelerating power type PSSs (Generic Pa type) are in service and a 6-cycle single-phase fault is programmed in the Fault Breaker block by checking Phase

A. Now the simulation is started and signals on the Machines scope is observed. For this type of fault the system is stable without SVC. After fault clearing, the 0.6 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 which is shown in fig.6. Power transfer is maximum when this angle reaches 90 degrees. Second trace on the Machines scope shows the speeds of the two machines.

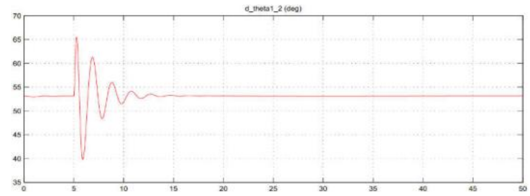

Fig. 6. Rotor angle difference d_theta1_2 between the two machines with accelerating power type PSSs

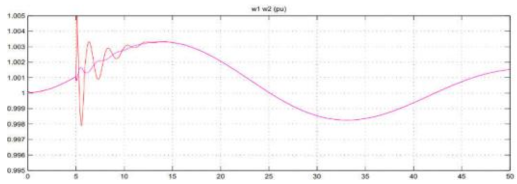

Fig. 7. speeds of the two machines with accelerating power type PSSs

It is noticed that machine 1 speed increases duringthe fault because during that period its electrical power islower than its mechanical power. By simulating over a longperiod of time (50 seconds) it is noticed that the machinespeeds oscillate together at a low frequency (0.025 Hz) afterfault clearing. The two PSSs (Pa type) succeed to damp the0.6 Hz mode but they are *not efficient for damping the 0.025Hz mode* which is shown in fig.7. This oscillation mode istypical of low frequency inter-area oscillations in a largepower system.

Secondly the multiband type PSSs (speed variationtype) are kept in service and a 6-cycle single-phase fault isprogrammed in the Fault Breaker block. Now the simulationis started and signals on the Machines scope is observed. Itis noticed that speed variation type stabilizer succeeds todamp both the 0.6 Hz mode and the 0.025 Hz mode whichare shown in fig.8 and fig.9. The analysis of the SVC and PSS interestingly shows that how the SVC helps to improve the stability when PSS is fail to maintain the stability.

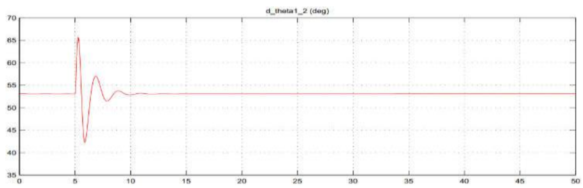

Fig. 8. Rotor angle difference d_theta1_2 between the two machines with multiband type PSSs

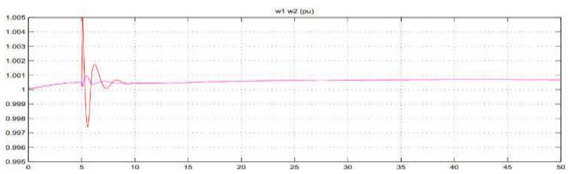

Fig. 9. speeds of the two machines with multiband type PSSs

Thirdly both the Pa type and speed variation type PSSs are out of service. Now the simulation is started and signals on the Machines scope is observed which are shown in fig.10 and fig.11. It is noticed that the system is unstable without PSS.

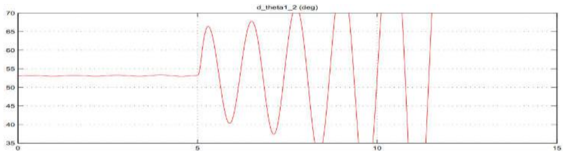

Fig. 10. Rotor angle difference d_theta1_2 between the two machines with multiband type PSSs

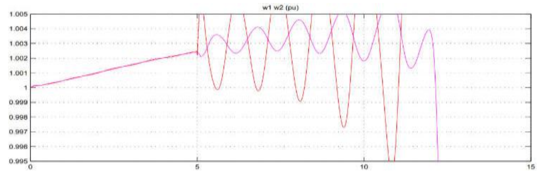

Fig. 11. speeds of the two machines with multiband type PSSs

C. Single-Phase Fault — Impact of PSS — No SVC

The accelerating power type and multiband type PSSs (Generic Pa type) are alternately kept in service. A 6- cycle single-phase fault is programmed in the Fault Breaker block by checking Phase A, and fault is applied at t=0.1 s and cleared at t=0.2 s). now the simulation is started and signals on the Machines scope is observed which are shown in fig.12.

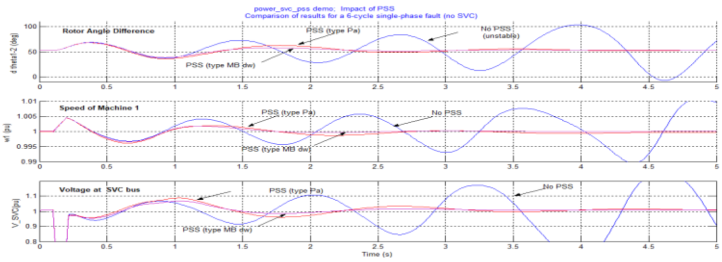

Fig. 12. Impact of PSS for 1-phase fault (without SVC).

For this type of fault the system is stable withoutSVC. After fault clearing, the 0.6 Hz oscillation is quicklydamped. The results with and without PSS are compared asshown in fig.12.

D. Three-Phase Fault — Impact of SVC — PSS in Service

A 3-phase fault is applied and the impact of the SVC is observed for stabilizing the network during a severe contingency. The two PSS (Generic Pa type) are put in-service. The Fault Breaker block is Reprogrammed to apply a3-phase-to-ground fault. This part contains two tests the first one the SVC is set to operate in fixed susceptance mode with (Bref=0) thisis equivalent to putting the SVC out of order. The second one the SVC is set to operate in voltage regulator mode however the two PSS has been maintained in service by fixing value=1 in the PSS constant block. Also a three-phase to ground fault have been applied at t=0.1 s and removed at t=0.2 s.

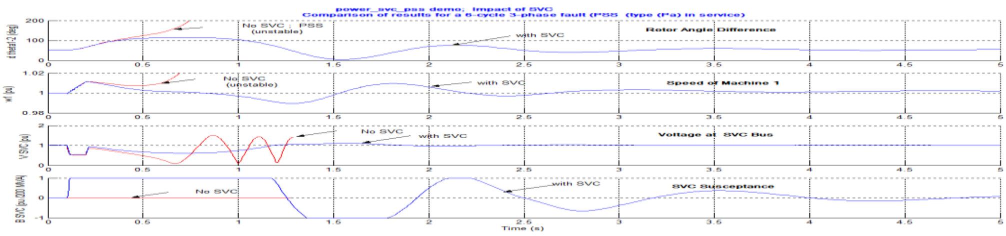

Fig. 13. Impact of the SVC for 3-phase fault

When SVC is set to operate in fixed susceptance mode, 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*360 degrees.

Now SVC is set to operate in the Voltage regulation mode. Now the SVC tries to support the voltage by injecting reactive power on the line when the voltage is lower than the reference voltage (1.009 pu), which corresponds to the bus voltage with the SVC out of service. In steady state the SVC will therefore be floating and waiting for voltage compensation when voltage departs from its reference set point. It is observed that the system is now stable with a 3-

phase fault. The results of these studies show that the SVC has an excellent capability in damping power system oscillations and enhances greatly the transient stability of the power system. It is also observed that the stabilization time is minimal.

IV. CONCLUSION

The work described in this paper illustrates modeling of a simple transmission system containing two hydraulic power plants. A static Var compensator (SVC)and power system stabilizers (PSS - generic & multiband types) are used to improve transient stability and power oscillation damping of the system. The results depict that a system has been developed successfully for the stability of transients in a bi-machine transmission system with PSS and SVC. The basic structure of (PSS) is operating under typical control generator while the basic structure of (SVC) is operating under typical bus voltage control. The proposed controller is used (PSS) & (SVC) under abnormal system conditions. The analysis of the SVC and PSS interestingly shows that how the SVC helps to improve the stability when PSS is failing to maintain the stability. From simulation results of the proposed model it is conclude that:

1. The proposed model is oscillatory and instable with absence effects of (PSS) and (SVC).
2.The selective of (PSS) are capable of proving sufficient damping to the steady state oscillation and transient stability voltages performance over a wide range of operating conditions and various types of disturbances of the system used in proposed model.
3. If there is Single line to ground fault than the PSS able to sustain the stability, but using SVC the angle deviation is reduced.
4. If there is three phase transient fault, then Without SVC both PSS are not able to maintain the stability.
5. The multiband type PSS quickly damp out oscillations than the Pa type PSS when compared working of two types of (PSS).
6. The coordinated control of the SVC and the generic/multi-band PSS is an effective solution to damp low frequency oscillation for multi-machine power system and enhance global stability of the large inter-connected power system.

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