

Power System Stability Improvement By Using SVC With Power System Controller

Habibur Rahman¹, Ilius Hasan Pathan², Harun-Or-Rashid³

Abstract—This paper presents the model of a static VAR compensator (SVC) which is controlled externally by a newly designed Power System Controller (PSC) for the improvements of power system stability and damping effect of an on line power system. The proposed PSC consists of two controllers (PID & POD). PID parameters have been optimized by Triple Integral Differential (TID) close loop tuning method. Both single phase and three phase (L-L) faults have been considered in the research. In this paper, a power system network is considered which is simulated in the phasor simulation method & the network is simulated in three steps; without SVC, With SVC but no externally controlled, SVC with Power System Controller. Simulation result shows that without SVC, the system parameters become unstable during faults. When SVC is imposed in the network, then system parameters become stable. Again, when SVC is controlled externally by PSC controllers, then system parameters ($V, P, Q, d\omega, V_t$) become stable in faster way than without controller. It has been observed that the SVC ratings are only 20 MVA with controllers and 200 MVA without controllers. So, SVC with PSC controllers are more effective to enhance the voltage stability and increase power transmission capacity of a power system. The power system oscillations are also reduced with controllers in comparison to that of without controllers. So with PSC controllers the system performance is greatly enhanced.

Keywords—SVC, Voltage Regulator, Power System Controller, TID Tuning, Power Oscillation Damping, MATLAB Simulink..

I. INTRODUCTION

Power system stability improvements are very important for large scale systems. The AC power transmission system has diverse limits, classified as static limits and dynamic limits^[1-2]. Traditionally, fixed or mechanically switched shunt and series capacitors, reactors and synchronous generators were being used to enhance same types of stability augmentation^[3]. For many reasons, desired performance was being unable to achieve effectively. A static VAR compensator (SVC) is an electrical device for providing fast-acting reactive power compensation on high voltage transmission networks and it can contribute to improve the

voltage profiles in the transient state and therefore, it can improve the qualities and performances of the electric services^[3]. An SVC can be controlled externally by using properly designed different types of controllers which can improve voltage stability of a large scale power system. In previous study, authors have designed a PID controller which has been tuned by Triple Integral Differential (TID) tuning method^[4]. However, in this study, with a view to get better performance, a new power system controller (PSC) has been designed & proposed for SVC to inject V_{ref} externally for the improvement of power system stability. The dynamic nature of the SVC lies in the use of thyristor devices (e.g. GTO, IGCT)^[3]. Therefore, thyristor based SVC with PID controllers has been used to improve the performance of 2-machine power system.

II. CONTROL CONCEPT OF SVC

An SVC is a controlled shunt susceptance (B) which injects reactive power (Q_{net}) into thereby increasing the bus voltage back to its net desired voltage level. 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 [Fig.1]. Here, $+Q_{cap}$ is a fixed capacitance value, therefore the magnitude of reactive power injected into the system, Q_{net} , is controlled by the magnitude of $-Q_{ind}$ reactive power absorbed by the TCR. The basis of the thyristor-controlled reactor (TCR) which conducts on alternate half-cycles of the supply frequency. If the thyristors are gated into conduction precisely at the peaks of the supply voltage, full conduction results in the reactor, and the current is the same as though the thyristor controller were short circuited. SVC based control system is shown in Fig.1^[3].

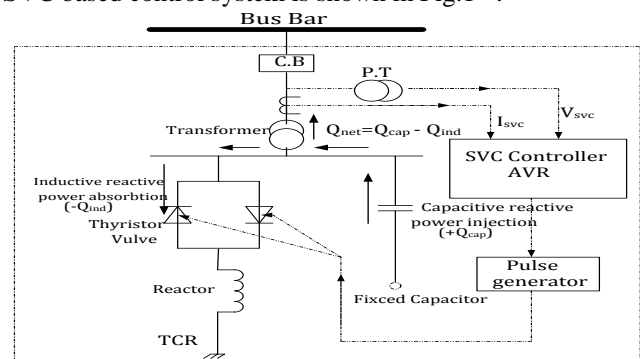


Fig.1 SVC based control system

III. SVC V-I CHARACTERISTICS

The SVC can be operated in two different modes:

a). In voltage regulation mode (the voltage is regulated within limits as explained below).

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b). In VAR control mode (the SVC susceptance is kept constant).

From V-I curve of SVC, From Fig.2^[3],
 $V = V_{ref} + X_s I_s$: 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 ($B = B_{lmax}$)

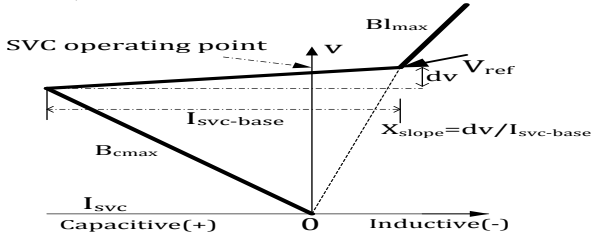


Fig.2 Steady state(V-I) characteristic of a SVC

IV. POWER SYSTEM MODEL

This example described in this section illustrates modelling of a simple transmission system containing 2- hydraulic power plants[Fig.3]. SVC has been used to improve transient stability and power system oscillations damping. The phasor simulation method can be used. A single line diagram represents a simple 500 kV transmission system is shown in Fig.3^[5].

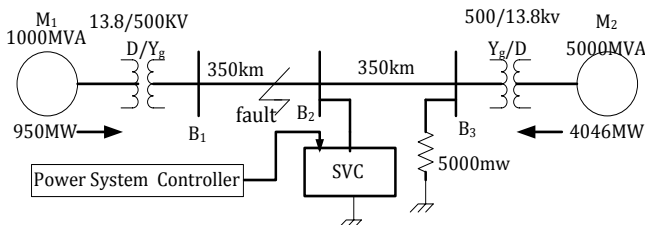


Fig.3 Single line diagram of 2-machine power system

A 1000 MW hydraulic generation plant (M1) is connected to a load centre through a long 500 kV, total 700km transmission line. A 5000 MW of resistive load is modelled as the load centre. The remote 1000 MVA plant and a local generation of 5000 MVA (plant M2) feed the load. 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 centre by a 200MVAR Static VAR Compensator (SVC).

The SVC does not have any controller unit. Machine & SVC parameters have been taken from reference[5]. The complete simlink model of SVC with power system controller is shown in Fig.4. To maintain system stability after faults, the transmission line is shunt compensated at its centre by a 200MVAR Static VAR Compensator (SVC) with power system controller. The two machines are equipped with a hydraulic turbine and governor (HTG) [Fig.6], excitation system, and power system stabilizer (PSS). Another machine is a swing generator. PSS is used in the model to add damping to the rotor oscillations of the synchronous machine by controlling its excitation current^[2]. Any disturbances that occur in power systems due to fault, can result in inducing electromechanical oscillations of the electrical generators. Such oscillating swings must be effectively damped to maintain the system stability and reduce the risk of stepping out of synchronism.

V. SIMULATION RESULTS

The load flow solution of the above system is calculated and the simulation results are shown below. Two types of faults: A. single line to ground fault & B. Three phase fault have been considered.

A. single line to ground fault

Consider a 1-phase fault occurred at 0.1s & circuit breaker is opened at 0.2s (4-cycle fault). Without SVC, the system voltage, power & machines oscillate and go unstable [Fig.(5,8,10)]. But if SVC (without controller) is applied then voltage becomes stable within 3s [Fig.7], power becomes stable within 3s [Fig.9] & machines oscillation becomes stable within 4.5s [Fig.11]. All results have been summarized in table-I.

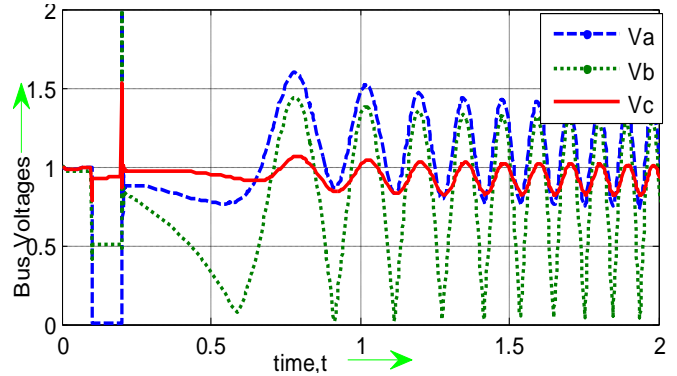


Fig.5 Bus voltages in pu for 1-phase fault (without SVC)

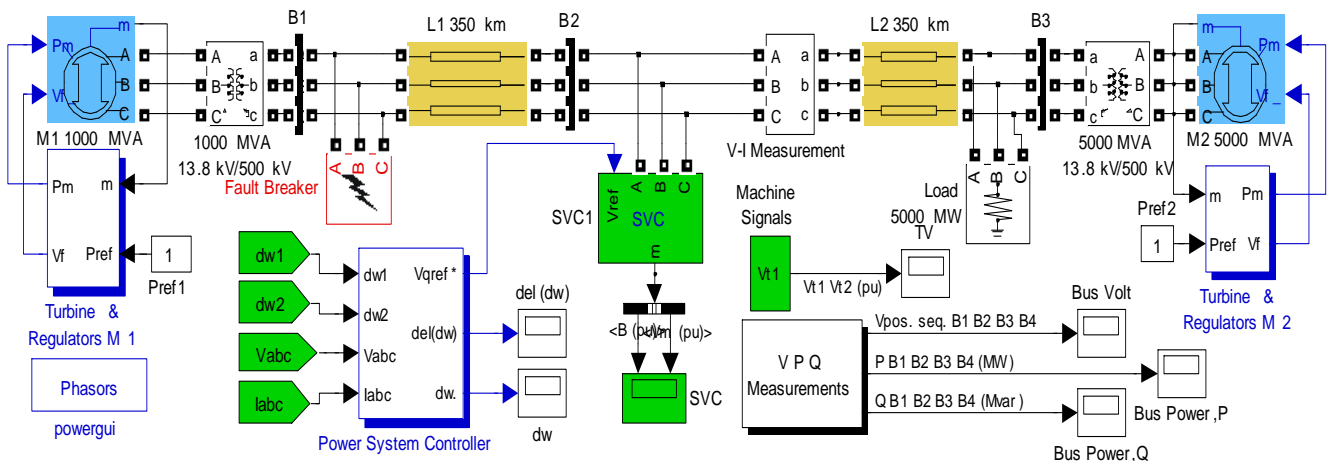


Fig.4 Complete simulink model of 2-machine power system

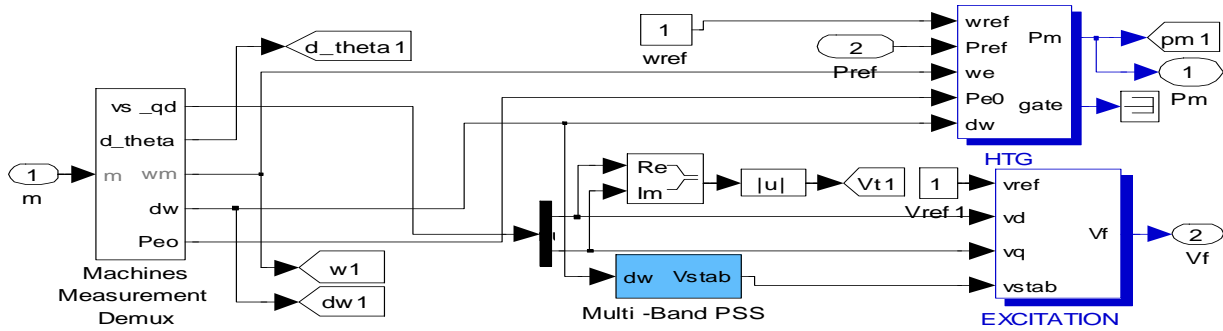


Fig.6 PSS, HTG and excitation system block diagram for machine 1.

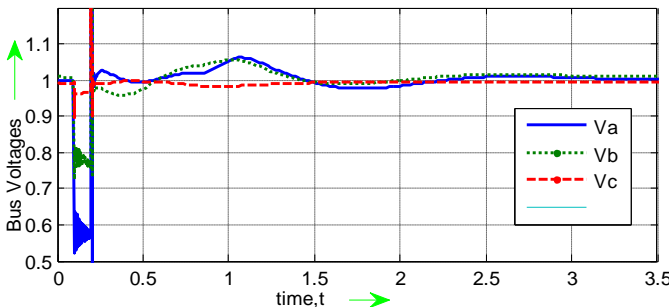


Fig.7 Bus Voltages in p.u for 1-phase fault (with SVC)

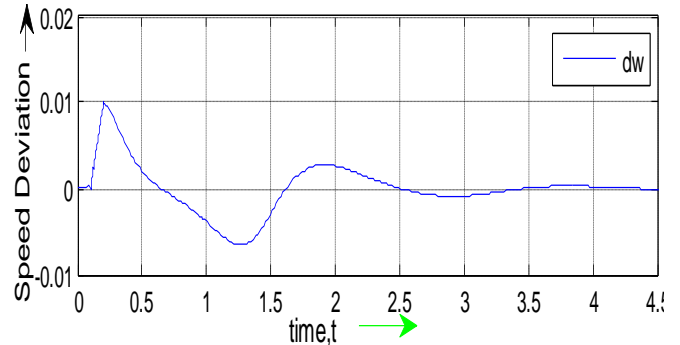


Fig.11 Speed oscillations for 1- phase fault(with SVC)

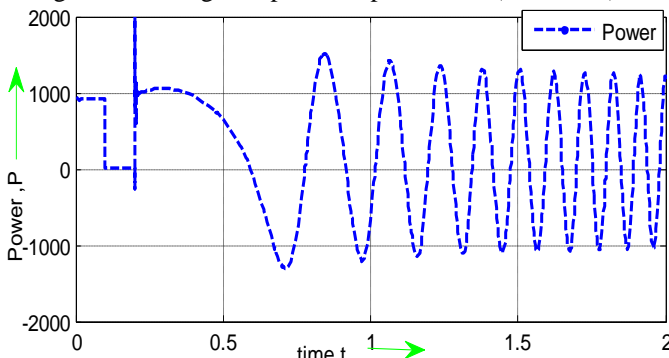


Fig.8 Bus power,P in MW during fault (Without SVC)

B. Three phase fault

During 3-phase faults, If no SVC is applied then system voltage & machines speed deviations becomes unstable But when SVC(without controller) is applied then the system voltage becomes stable within 5s [Fig.12] & machines speed deviation becomes stable within 5s [Fig.13].

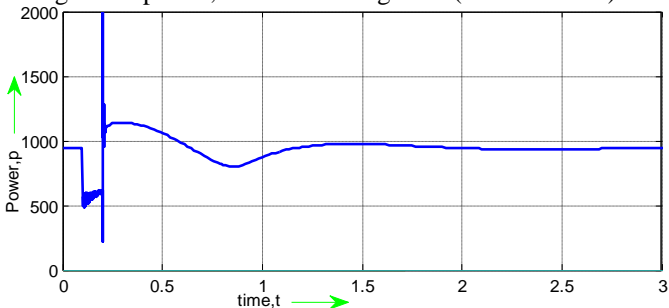


Fig.9 Bus Power(P)in MW for 1-Ø faults(with SVC)

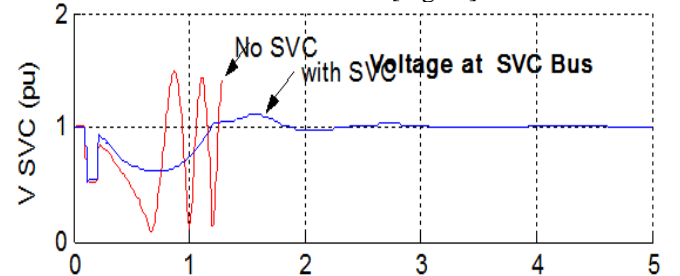


Fig.12 Bus Voltage(Va) in p.u for L-L phase fault

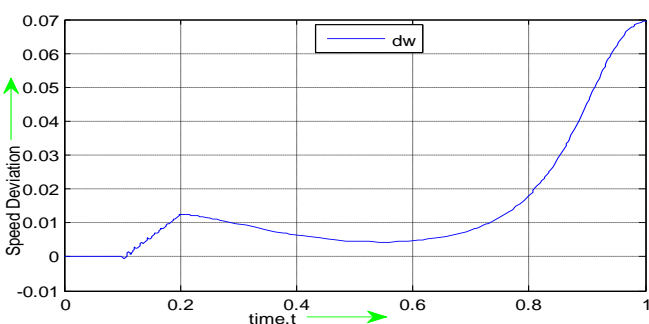


Fig.10 Speed deviation for 1- phase fault(without SVC)

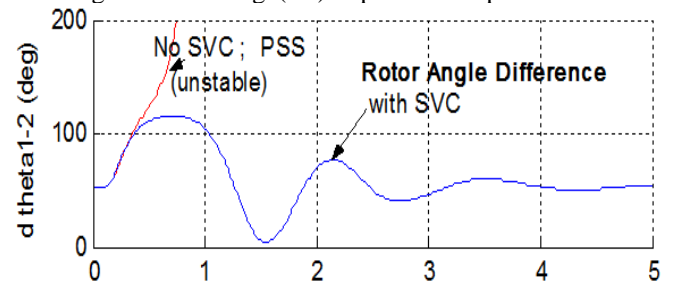


Fig.13 Machines speed deviation for L-L fault

VI. DESIGN OF POWER SYSTEM CONTROLLER(PSC)

The proposed Power system controller consists of two parts, A. Proportional Integral Derivative(PID) controller which is tuned by Triple Integral Differential(TID) method^[4], B. Power Oscillation Damping(POD) controller. PID controller takes input as machines angular speed deviation & get an

error signal & POD controller takes input as line voltage & line current & after damp out the oscillation it also gives as error signal. Finally, the proposed power system controller takes input as all parameters of power system network i.e. V_{abc}, I_{abc}, ω & it gives an error signal (V_{qref}) which injects SVC for improvement of power system stability.

A. Designed of PID Controller

PID controller is tuned by the proposed Triple Integral Differential(TID) tuning methods. The PID controller has three term control signal,

$$u(t) = K_p e(t) + \frac{K_p}{T_i} \iint e(t) dt + K_p T_d \frac{d^3 e(t)}{dt^3}$$

In Laplace Form,

$$\frac{U(s)}{E(s)} = K_p \left(1 + \frac{1}{T_i S} + T_d S^3 \right)$$

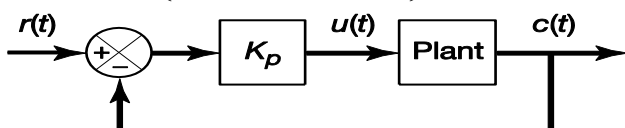


Fig.14 PID controller is in proportional action

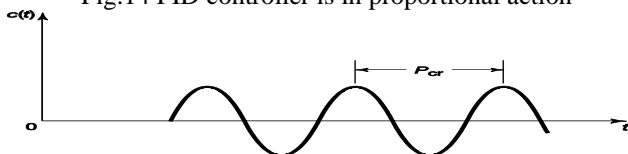


Fig.15 Determination of sustained oscillation (P_{cr})

For selecting the proper controller parameters, TID Tuning Method is described below.

In this method, the parameter is selected as $T_i = \infty, T_d = 0$. Using the proportional controller action [Fig.14] only increase K_p from 0 to a critical value K_{cr} . At which the output first exhibits sustained oscillations [Fig.15]. Thus the critical gain K_{cr} & the corresponding period P_{cr} are experimentally determined. It is suggested that the values of the parameters K_p, T_i, T_d should set according to the following formula same as Ziegler-Nicles methods [4].

$$K_p = 0.6 K_{cr}, T_i = 0.5 P_{cr}, T_d = 0.125 P_{cr}$$

Notice that the PID controller tuned by proposed TID tuning methods rules as follows, From Eq.2,

$$G_c(s) = K_p \left(1 + \frac{1}{T_i S} + T_d S^3 \right)$$

$$G_c(s) = (0.6 K_{cr}) \left(1 + \frac{1}{0.5 P_{cr} S} + 0.125 P_{cr} S^3 \right)$$

$$G_c(s) = 0.075 * (0.6 K_{cr}) P_{cr} S \left(\frac{P_{cr} S^3 + 4}{P_{cr} S^2} \right)^2$$

It's found that, $P_{cr} = 0.2s$ & $K_{cr} = 200$ [Fig.5]. So,

$$G_c(s) = \frac{0.075 * 200 * 0.2}{S} \left(\frac{0.2 S^3 + 4}{0.2 * S} \right)^2 \dots \dots \dots (6)$$

$$G_c(s) = 0.075 K_{cr} P_{cr} S \left(S^2 + 2 * \frac{4}{P_{cr} S^2} S + \left(\frac{4}{P_{cr} S^2} \right)^2 \right)$$

$$G_c(s) = 0.075 * K_{cr} P_{cr} S \left(S + \frac{4}{P_{cr} S^2} \right)^2$$

$$G_c(s) = 0.075 * K_{cr} P_{cr} S \left(S^2 + \frac{16}{P_{cr} S^4} + \frac{8}{P_{cr} S} \right) \dots \dots \dots (9)$$

$$G_c(s) = \frac{0.075 * K_{cr} P_{cr}}{S} \left(\frac{P_{cr} S^3 + 4}{P_{cr} S} \right)^2 \dots \dots \dots (10)$$

$$G_c(s) = \frac{3}{S} \left(\frac{0.2 S^3 + 4}{0.2 * S} \right)^2 \dots \dots \dots (11)$$

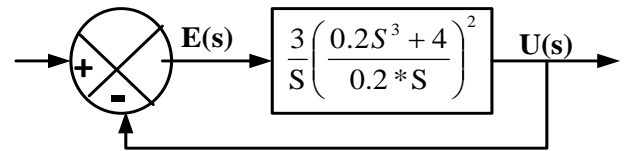


Fig.16 PID controller Tuning parameters

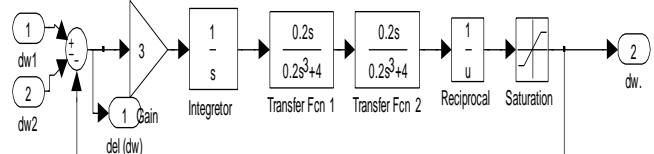


Fig.17 Internal Structure of PID controller with ω input

B. Designed of POD Controller

The Power Oscillation Damping Controller takes input as V_{abc}, I_{abc} & it convert it as power. If no faults has occurred then switch remains open. But when fault occurred then switch becomes closed & after filtering or dampout oscillation, it also gives an error signal & finally two error signal has been added & this is V_{qref} .

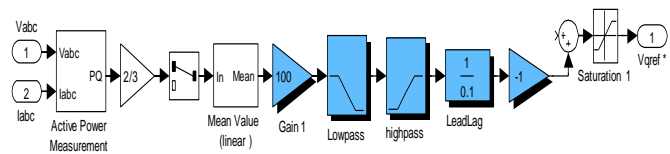


Fig.18 Internal Structure of POD controller

C. Power System Controller(PSC)

The proposed Power System Controller consists of both two controllers (PID & POD) [Fig.19] which injects V_{qref} in SVC [Fig.20] & further improve the power system stability.

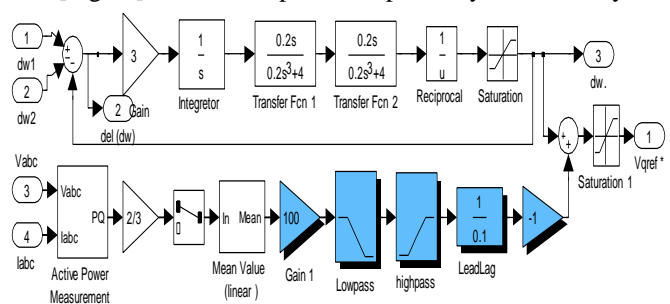


Fig.19 Internal Structure of Power System Controller(PSC)

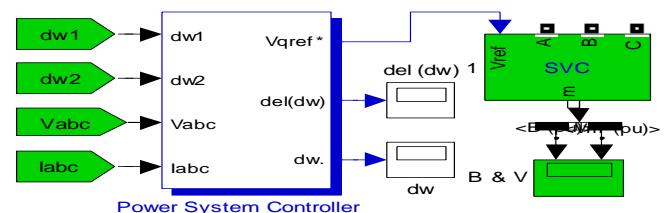


Fig.20 SVC with Power System Controller (PSC)

VII. SIMULATION RESULTS

The network remains same [Fig.4],just simple SVC is replaced by power system controlled SVC[Fig.20]. During fault ,machines speed deviation($d\omega$)& Line voltage(V_{abc}), Line current(I_{abc}) are always monitored by power system controller & taking input of those oscillation, after processing as shown in Fig.19, it reduces damping of power system oscillation& helps SVC to improve stability. Two types of faults has been considered: A. Single line to ground fault and B. Three phase L-L fault.

A. Single line to ground fault

During 1-phase faults, if PSC is used as SVC controller then, the system voltage becomes stable within 0.65s with 0% damping [Fig.21] &Power (P,Q) becomes stable within 0.6s [Fig.22,23] &Machines terminal voltage(V_t) becomes stable within 0.45s [Fig.24]& $d\omega$ becomes stable at 0.99s[Fig.25].

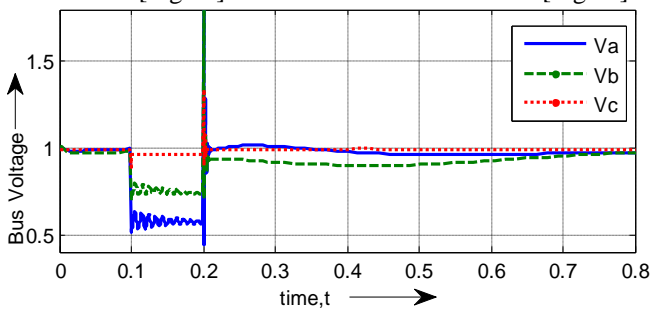


Fig.21 Bus voltage in p.u for 1-Ø fault (with PSC)

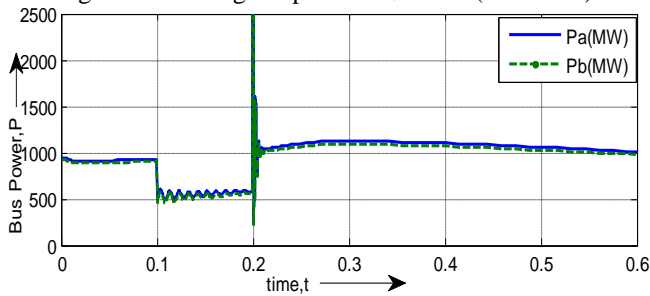


Fig.22 Bus power, P in MW for 1-Ø fault (with PSC)

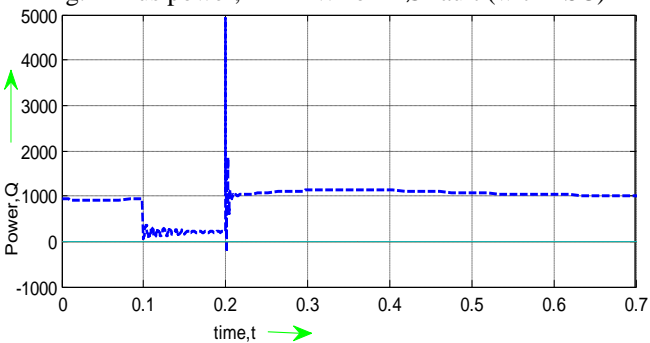


Fig.23 Bus Power, Q for 1-Ø fault in MW (with PSC)

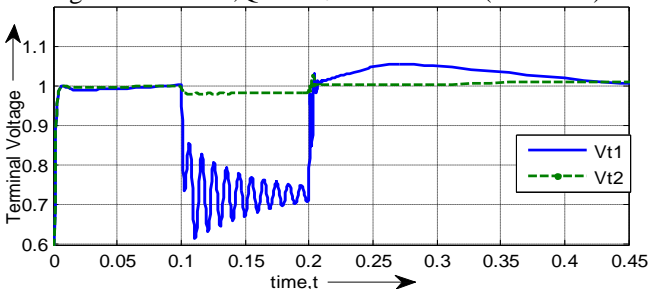


Fig.24 Machines terminal voltage for 1-Ø fault (with PSC)

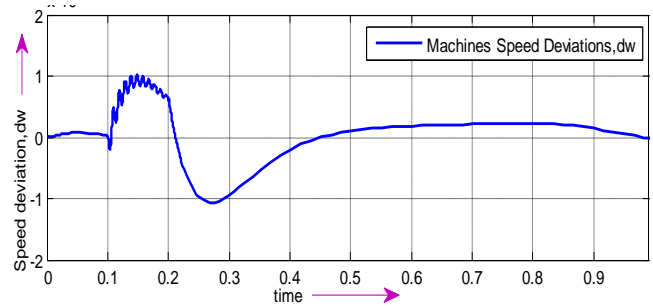


Fig.25 Machines speed deviation for 1-Ø fault (with PID)

B. Three phase fault

During 3-phase faults, If PSC is used as SVC controller then, the system voltage becomes stable within 1.3s [Fig.26] & Both power (P,Q) becomes stable within 0.5s & 0.7s [Fig.27,28]. Machines terminal voltage(V_t) becomes stable within 0.3s [Fig.29]& $d\omega$ becomes stable at 0.99s[Fig.30].

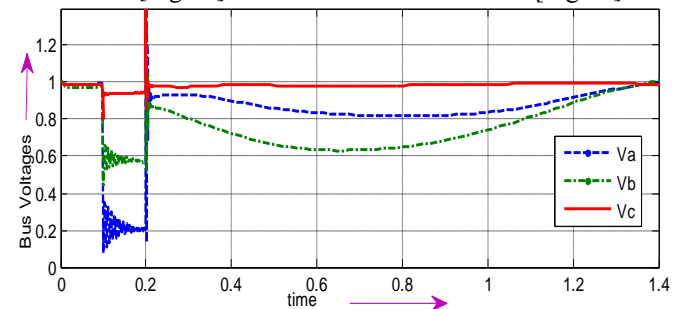


Fig.26 Bus voltages in p.u for L-L fault (with PSC)

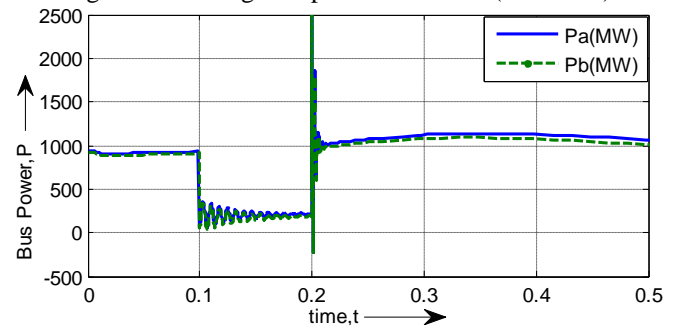


Fig.27 Bus power, P in MW for L-L fault (with PSC)

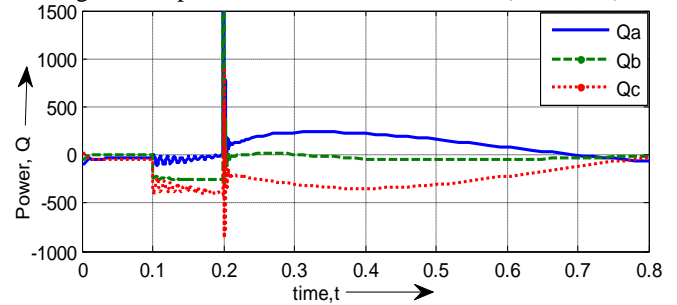


Fig.28 Bus power, Q in MVAR for L-L fault (with PSC)

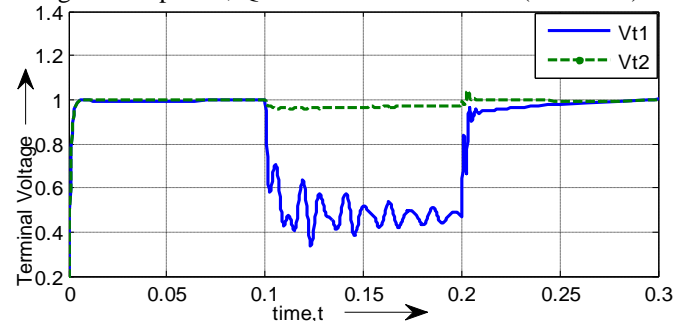


Fig.29 Machine terminal voltage for L-L fault (with PSC)

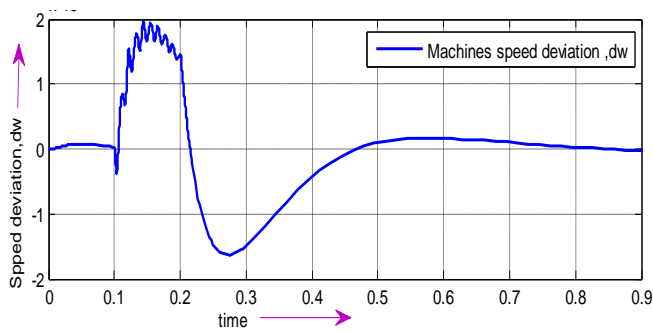


Fig.30 Machines speed deviation for L-L fault(with PID)

VIII. RESULTS & DISCUSSIONS

The performance of the proposed Power System Controller with SVC has been summarized in the table-I. In table-I, α (infinite time) means the system is unstable, SVC rating in MVA. The network is simulated in three steps; without SVC, With SVC, SVC with proposed Power System Controller(PSC).

Table-I

Performance of proposed Power System Controller(PSC)

Controller	SVC Rating	1- ϕ fault (Stability time)			L-L fault (Stability time)		
		Volt	P,Q	$d\omega$ & V_t	volt	P,Q	$d\omega$ & V_t
No SVC	200 MVA	α	α	α	α	α	α
SVC	200	3s	3s	4.5s	5s	5s	5s
SVC+ PSC	20 MVA	0.9s	0.6s	0.99s & 0.45s	1.3s	0.5s & 0.7s	0.8s & 0.3s

IX. CONCLUSION

This paper presents the power system stability improvement i.e. voltage level, machine oscillation damping, real & reactive power in a power system model of SVC without or with proposed Power System Controller for different types of faulted conditions. PSC is also a very efficient controller than others for SVC to enhance the power system stability. From above results, this proposed Triple Integral Differential(TID) close loop tuning method for selecting PID controller parameters & POD, In combine, Power System Controller may be highly suitable as a SVC controller because of shorter stability time, simple designed, low cost & highly efficient controller. Rather that, If PSC controller is used then only small rating of SVC becomes enough for stabilization of robust power system within very shortest possible time for both steady state & dynamic conditions. These proposed Power System Controller can be applied for any interconnected multi-machine power system network for stability improvement.

These controller can be applied to another FACTS devices namely SSSC, STATCOM, UPFC whose controllers may be controlled externally by designing different types of controllers which also may be tuned by using different algorithm i.e. Fuzzy logic, ANN, Genetic algorithm, FSO etc. for both transient and steady state stability improvement of a power system.

ACKNOWLEDGMENT

Author's would like to thanks specially to Dr. Md. Rafiqul Islam Sheikh, Professor & Head, Dept. of EEE, RUET for providing his innovative ideas, encouragement & observation for completing this research.

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