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Power System Stability Improvement By Using SSSC With Power System Controller

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***Abstract*—This paper presents the model of a Static Series Synchronous Compensator (SSSC) 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 has 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 SSSC, With SSSC but no externally controlled, SSSC with Power System Controller. Simulation result shows that without SSSC, the system parameters becomes unstable during faults. When SSSC is imposed in the network, then system parameters becomes stable. Again, when SSSC is controlled externally by PSC controllers, then system parameters(V,P,Q) becomes stable in faster way then without controller. It has been observed that the SSSC ratings are only 15 MVA with controllers and 100 MVA without controllers. So, SSSC with PSC controllers are more effective to enhance the voltage stability and increases power transmission capacity of a power system .The power system oscillations is also reduced with controllers in compared to that of without controllers. So with PSC controllers the system performance is greatly enhanced.**

Keywords—SSSC, Voltage Regulator, PSC, TID Tuning, Power Oscillation Damping, MATLAB Simulink.

I. INTRODUCTION

Stability improvements is very important for large scale power system. SSSC is one of the important members of FACTS family which can be installed in series in the transmission lines[1]. Traditionally, fixed or mechanically switched shunt and series capacitors, reactors and synchronous generators were being used to damped out oscillation[2]. However, there are some restrictions as to the use of these conventional devices. For many reasons desired performance was being unable to achieve effectively[3]. A SSSC is an electrical device for providing fast-acting reactive power compensation on high voltage transmission networks and it can contribute to improve the voltages profile in the transient state[5]. A SVC/SSSC can be controlled externally by designing Power System controller which can improve the dynamic & steady state performance of a large scale power system[6]. The dynamic nature of the SSSC lies in the use of thyristor devices (e.g. GTO, IGCT)[4].Therefore, this paper presents thyristor based SSSC controllers to improve the performance the multi-machine power system.

II. CONTROL CONCEPT OF SSSC

The SSSC does not use any active power source, the injected voltage must stay in quadrature with line current. By varying the magnitude V_q of the injected voltage in quadrature with current, the SSSC performs the function of a variable reactance compensator, either capacitive or inductive. The variation of injected voltage is performed by means of a Voltage-Sourced Converter (VSC) connected on the secondary side of a coupling transformer. The VSC uses forced-commutated power electronic devices (GTOs, IGBTs or IGCTs) to synthesize a voltage $V_{\_conv}$ from a DC voltage source that shown in fig.1[6].

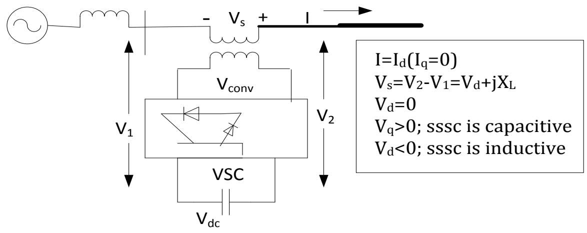

Fig.1 Connection diagram of SSSC with transmission Line

A capacitor connected on the DC side of the VSC acts as a DC voltage source. A small active power is drawn from the line to keep the capacitor charged and to provide transformer and VSC losses, so that the injected voltage Vs is practically 90 degrees out of phase with current I. In the control system block diagram V_{d_conv} and V_{q_conv} designate the components of converter voltage V_{q_conv} which are respectively in phase and in quadrature with current.

The control system consists of:-

A phase-locked loop (PLL) which synchronizes on the positive-sequence component of the current I. The output of the PLL (angle $T=\omega t$) is used to compute the direct-axis and quadrature-axis components of the AC three-phase voltages and currents (labeled as V_d, V_q or I_d, I_q on the diagram).Measurement systems measuring the q components of AC positive-sequence of voltages V_1 and V_2 (V_{1q} and V_{2q}) as well as the DC voltage V_{dc}. AC and DC voltage regulators which compute the two components of the converter voltage

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(V_{d_conv} and V_{q_conv}) required to obtain the desired DC voltage (V_{dcref}) and the injected voltage (V_{qref}). Fig.2 represents that control concept[6]. The V_q voltage regulator is assisted by a feed forward type regulator which predicts the $V_{\_conv}$ voltage from the I_d current measurement.

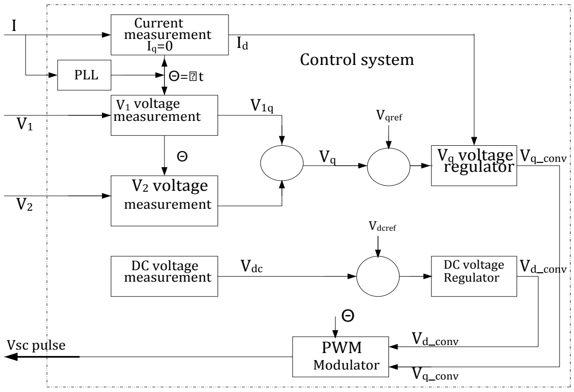

Fig.2 SSSC based control system

III. POWER SYSTEM MODEL WITH SSSC

This example described in this section illustrates modeling of a simple transmission system containing 2- hydraulic power plants [Fig.3]. The power grid consists of two power generation substations and one major load center at bus B3.Complete simulink model is shown in Fig.4.

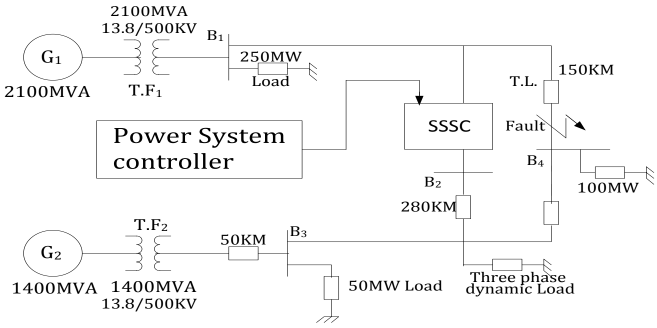

Fig.3Single line diagram of 2-machine power system with different types of SSSC controller

The first power generation substation (G_1) has a rating of 2100 MVA, representing 6 machines of 350 MVA and the other one (G_2) has a rating of 1400 MVA, representing 4 machines of 350 MVA. The load center of approximately 2200 MW is modeled using a dynamic load model. The generation substation G_1 is connected to this load by two transmission lines L_1 and L_2. L_1 is 280-km long and L_2 is split in two segments of 150 km in order to simulate a three-phase fault at the midpoint of the line.Complete Simulink model has shown in Fig.4& Fig.5.

The generation substation G_2 is also connected to the load by 50-km line (L_3). When the SSSC is bypass, the power flow towards this major load is as follows: 664 MW flow on L_1 (measured at bus B_2), 563 MW flow on L_2 (measured at B_4) and 990 MW flow on L_3 (measured at B_3). The SSSC, located at bus B1, is in series with line L1. If it has a rating of 100MVA then it is capable of injecting up to 10% of the nominal system voltage. This SSSC is a phasor model of a typical three-level PWM SSSC. Machine, POD &SSSC parameters value was taken from reference[7].

IV. SIMULATION RESULTS

Two types of faults: A. Single line to ground fault &B. Three-phase faults have been considered.

A. Single line to ground fault

During single line to ground fault occurred at 0.1s & circuit breaker is opened at 0.2s (3-phase 4-cycle fault),If no SSSC is used then system voltage & power becomes unstable[Fig.6(a,c)].But, If SSSC is applied then system voltage & power becomes stable within 1s & 1.5s[Fig.6(b,d)].

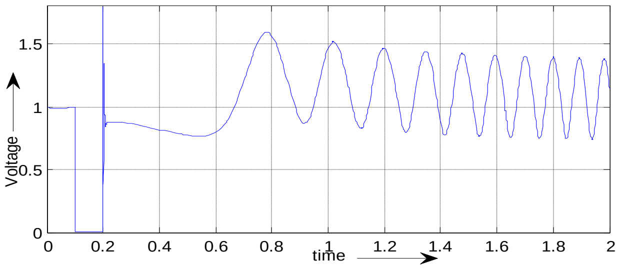

Fig.6(a) Bus voltage(B_1) in p.u.(without SSSC)

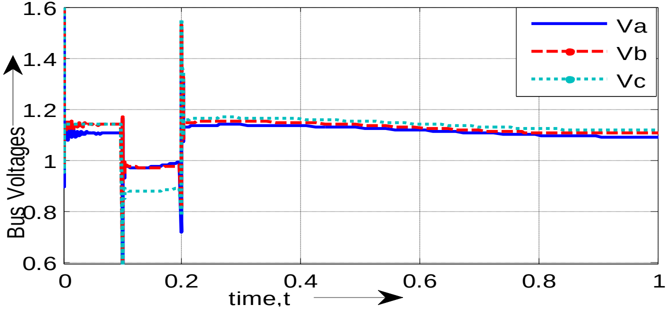

Fig.6(b) Bus voltage(B_1) in p.u for 1-phase fault (with SSSC)

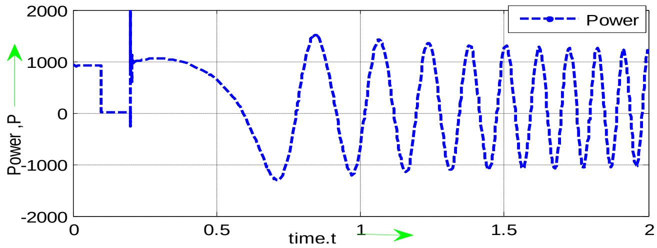

Fig.6(c) Bus power (without SSSC)

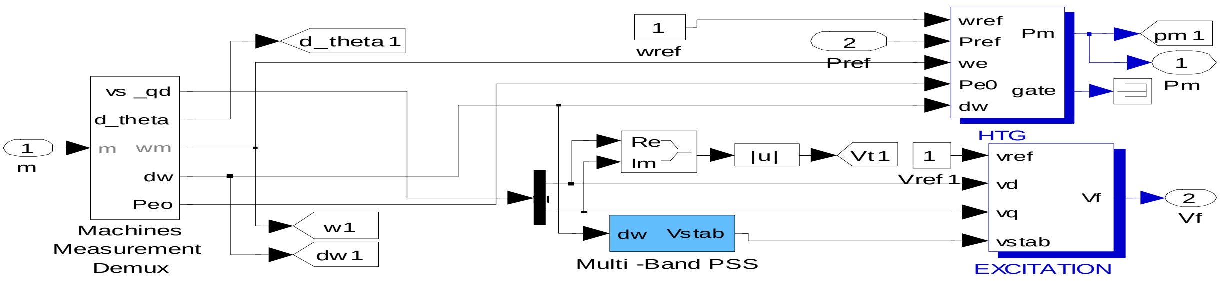

Fig.4 PSS, HTG and excitation system block diagram for machine 1.

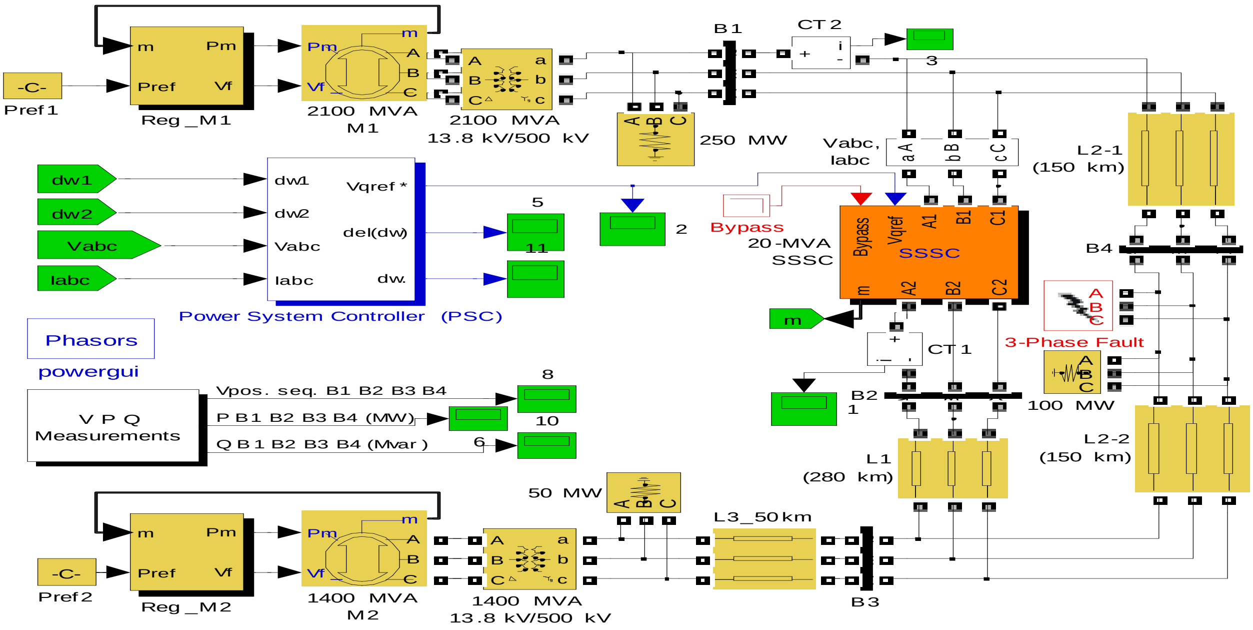

Fig.5 Complete simulink model of SSSC with PSC controller

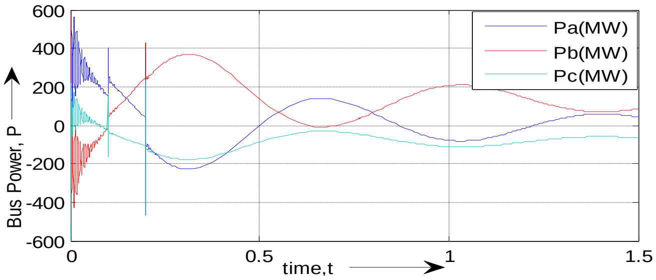

Fig.6(d) Bus power (with SSSC)

B. Three-phase faults

During 3-phase faults, If SSSC is applied then system voltage becomes stable at t=0.7s[Fig.6(e)] &Power becomes stable at t=1s[Fig.6(f)].

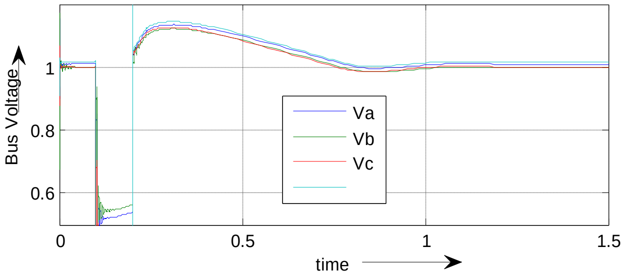

Fig.6(e) Bus voltages in p.u(with SSSC)

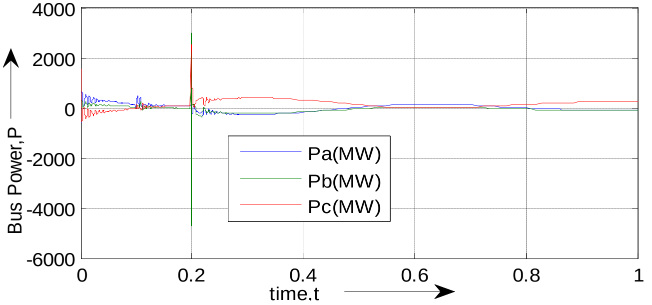

Fig.6(e) Bus power (with SSSC)

V. DESIGNE 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[6], 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},dω& 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,

$$u(t) = K_p e(t) + \frac{K_p}{T_i} \iiint e(t)dt + K_p T_d \frac{d^3 e(t)}{dt^3} \quad ....(1)$$

In Laplace Form,

$$\frac{U(s)}{E(s)} = K_p \left(1 + \frac{1}{T_i S^3} + T_d S^3 \right) \quad ....(2)$$

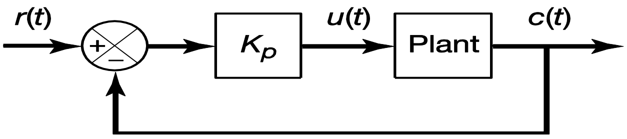

Fig.7 PID controller is in proportional action

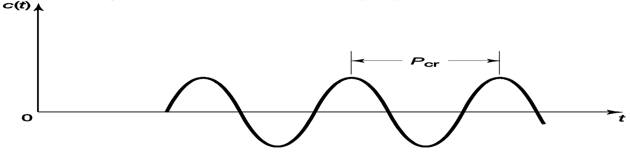

Fig.8 Determination of sustained oscillation (P_{cr})

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.7]only increase K_p from 0 to a critical value K_{cr}. At which the output first exhibits sustained oscillations[Fig.8]. 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 Zieglar-Nicles methods[4].

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

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

$$G_C(s)=\frac{3}{S}\left(\frac{0.2S^3+4}{0.2*S}\right)^2 \quad \ldots\ldots(3)$$

$$G_C(s)=0.6K_{cr}\left(1+\frac{1}{0.5P_{cr}S^3}+0.125P_{cr}S^3\right) \quad \ldots\ldots(4)$$

$$G_C(s)=0.075*K_{cr}P_{cr}S\left(\frac{P_{cr}S^3+4}{P_{cr}S^2}\right)^2 \quad \ldots\ldots(5)$$

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

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

$$G_C(s)=0.075K_{cr}P_{cr}S\left(S^2+2*\frac{4}{P_{cr}S^2}S+\left(\frac{4}{P_{cr}S^2}\right)^2\right) \quad \ldots(7)$$

$$G_C(s)=0.075*K_{cr}P_{cr}S\left(S+\frac{4}{P_{cr}S^2}\right)^2 \quad \ldots\ldots(8)$$

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

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

$$G_C(s)=K_p\left(1+\frac{1}{T_iS^3}+T_dS^3\right) \quad \ldots\ldots(11)$$

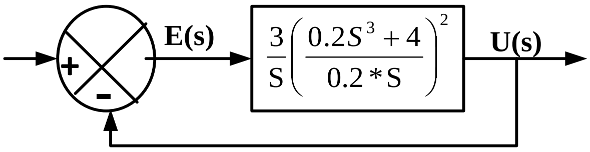

Fig.9 PID controller Tuning parameters

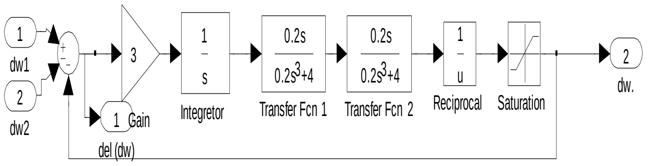

Fig.10 Internal Structure of PID controller with dω input

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 dampoutoscillation, it also gives an error signal & finally two error signal has been added & this is V_{qref}.

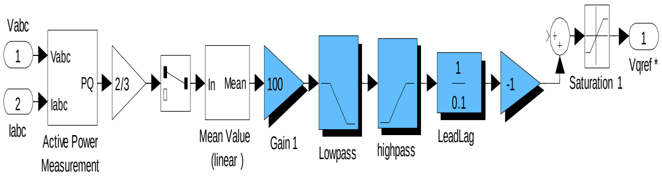

Fig.11 Internal Structure of POD controller

C. Power System Controller(PSC)

The proposed Power System Controller[6] consists of both two controllers(PID & POD)[Fig.12] which injects V_{qref} in SVC[Fig.13]& further improve the power system stability.

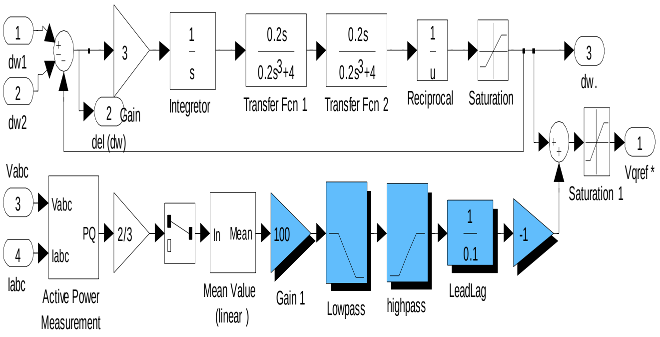

Fig.12 Internal Structure of Power System Controller(PSC)

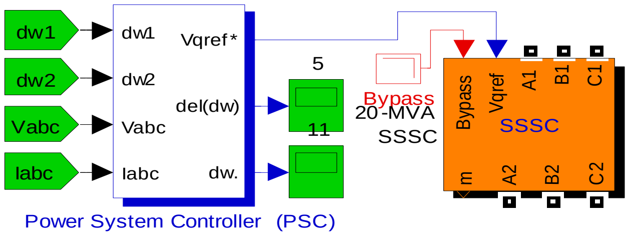

Fig.13 SVC with Power System Controller (PSC)

VII. SIMULATION RESULTS

The network remains same [Fig.5],just simple SSSC is replaced by power system controlled SSSC[Fig.13)]. During fault ,machines speed deviation(dω) & 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.11, it reduces damping of power system oscillation & helps SSSC 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 SSSC controller then, the system voltage becomes stable within 0.3s with 0% damping [Fig.14] & Power (P,Q) becomes stable within 0.6s& 0.4s [Fig.15,16].

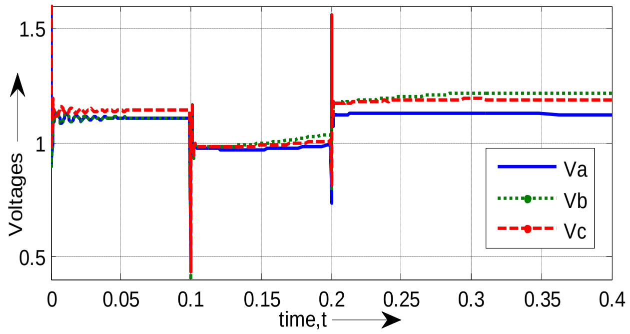

Fig.14 Bus voltage in p.u for 1-Ø fault (with PSC)

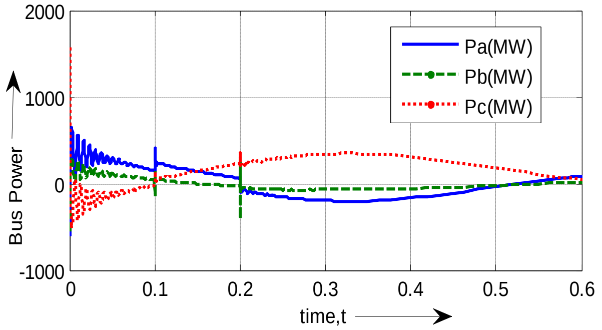

Fig.15 Bus power,P in MW for 1-Ø fault (with PSC)

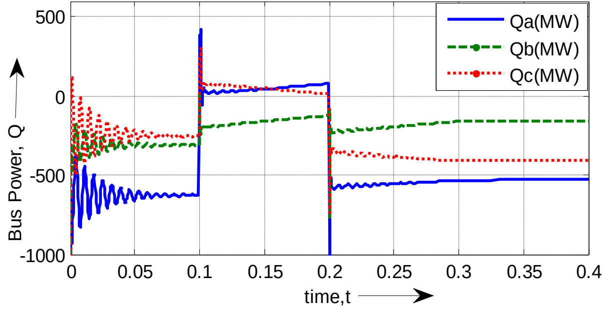

Fig.16 Bus Power,Q for 1-Ø fault in MW(with PSC)

B. Three phase fault

During 3-phase faults, If PSC is used as SSSC controller then, the system voltage becomes stable within 0.3s [Fig.17] & Both power (P,Q) becomes stable within 0.3s & 0.6s [Fig.18,19].

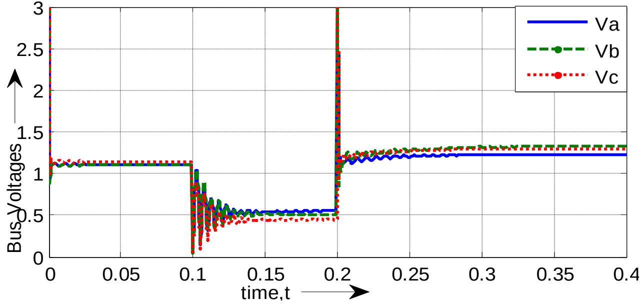

Fig.17 Bus voltages in p.u for 3-Ø fault (with PSC)

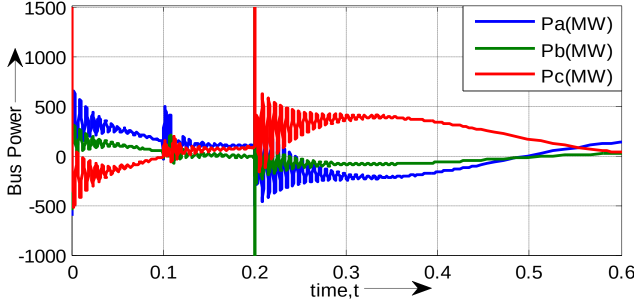

Fig.18 Bus power, P in MW for 3-Ø fault (with PSC)

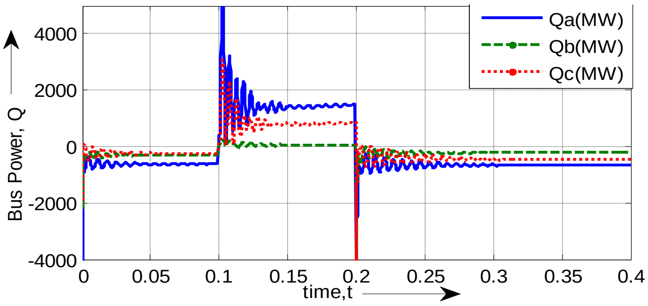

Fig.19 Bus power, Q in MVAR for 3-Ø fault (with PSC)

VIII. RESULTS & DISCUSSIONS

The performance of SSSC with Power System controller taking same 500KV transmission line are summarized below. In this table SSSC rating is represents in MVA, Syatem stability time is in Seconds.

Table-I
Performance ofproposed Power SystemController(PSC)

		Stability time			
		1-Ø fault		3-Ø fault	
Status	SSSC Rating	Volt	P,Q	Volt	P,Q
No SSSC	No	inf	inf	inf	inf
SSSC	100	1s	1.5s	0.7s	1s
SSSC+ PSC	15	0.3s	0.6s,0.4s	0.3s	0.3s,0.6s

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 SSSC without or with proposed Power System Controller for different types of faulted conditions. PSC is also a very efficient controller then others for SSSC 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 SSSC 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 SSSC 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 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. Fazzy logic, ANN, Genetic algorithm, FSO etc. for both transient and steady state stability improvement of a power system.

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