Coordinated PSS and STATCOM Controller for Damping Low Frequency Oscillations in Power Systems

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Abstract: **The low frequency oscillations have become the main problem for power system small signal stability. They restrict the steady-state power transfer limits, which therefore affects operational system economics and security. In this work, using Parameters of the classic PSS and STATCOM internal AC and DC voltage controllers and AC damping stabilizer is designed in order to damp the Low Frequency Oscillations (LFO). The STATCOM is used for adjusting the voltage in line and the dynamic effect of STATCOM is proposed. The study is performed on the linearized power system model with presence of STATCOM and PSS. The designing results are performed using nonlinear simulation. The results show that the design according to simultaneous optimization is an effective procedure for power system stability improvement.**

Keywords: STATCOM, PSS, FACTS devices, Power System Stability.

I.INTRODUCTION

The low frequency oscillations have become the main problem for power system small signal stability. They restrict the steady-state power transfer limits, which therefore affects operational system economics and security. Using PSS create change in oscillation stability. To increase power system oscillation stability, the installation of supplementary excitation control, power system stabilizer (PSS), is a simple, effective and economical method [1].

These oscillations may sustain and grow to cause system separation if no adequate damping is available. Although PSSs provide supplementary feedback stabilizing signals, they suffer a drawback of being liable to cause great variations in the voltage profile and they may even result in leading power factor operation under severe disturbances.

The recent advances in power electronics have led to the development of the flexible alternating current transmission systems (FACTS) [2]. Generally, a potential motivation for the accelerated use of FACTS devices is the deregulation environment in contemporary utility business. Along with primary function of the FACTS devices, the real power flow can be regulated to mitigate the low frequency oscillations and enhance power system stability. This suggests that FACTS will find new applications as electric utilities merge and as the sale of bulk power between distant and ill interconnected partners become more wide spread.

Recently, several FACTS devices have been implemented and installed in practical power systems such as static VAR compensator (SVC), thyristor controlled series capacitor (TCSC), and thyristor controlled phase shifter (TCPS) [3].

The emergence of FACTS devices and in particular gate turnoff (GTO) thyristor-based STATCOM has enabled such technology to be proposed as serious competitive alternatives to conventional SVC. From the power system dynamic stability viewpoint, the STATCOM provides better damping characteristics than the SVC as it is able to transiently exchange active power with the system [4].

The method of phase compensation [5] and damping torque analysis method [6] are conventional methods for design and control of power system stabilizers [7]. Also multivariable design method has been performed on coordination between internal AC and DC voltage controllers [8]. The coordination between the AC and DC voltage PI controllers was taken into consideration. However, the structural complexity of the presented multivariable PI controllers with different channels reduces their applicability. Moreover, the utilization of damping capability of the STATCOM has not been addressed. The STATCOM damping characteristics have been addressed in [9]. However, the coordination among the STATCOM damping controllers and AC and DC voltage PI controllers has not been investigated. The coordination among different Controllers has been taken into consideration [10] where different damping channels of the STATCOM have been assessed in terms of their respective effectiveness on electromechanical modes controllability. In this study, to improve power system dynamic stability and voltage regulation, coordination among internal AC and DC voltage controller of STATCOM and AC-damping stabilizer and also PSS are performed. The studies are performed on a single machine infinite-bus power system. The linearized power system model is used for the studies [11].The parameters design is considered as an optimization problem and the genetic algorithm is used for searching optimized parameters [12].

II.POWER SYSTEM MODEL WITH STATCOM

Fig.1 shows a SMIB system equipped with a STATCOM. A single machine infinite bus (SMIB) system installed with STATCOM is considered for the analysis of stability.A simple STATCOM is incorporated which consists of a step down transformer (SDT) with a leakage reactance, three phase GTO based voltage source converters (VSC's), and a DC capacitor. The VSC generates a controllable AC-volt- age source behind the leakage reactance. The voltage difference between the STATCOM-bus AC voltage and produces active and reactive power exchange between the STATCOM and the power system, which can be controlled by adjusting the phase and the magnitude Vo.

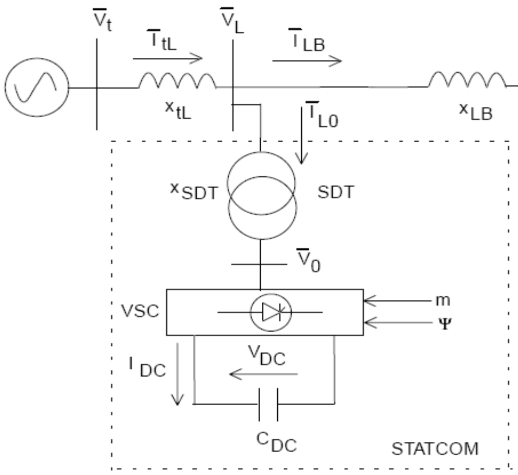

Fig.1. SMIB power system equipped with STATCOM

III. POWER SYSTEM NON-LINEAR DYNAMIC MODEL WITH STATCOM

During low-frequency oscillations, the current induced in a damper winding is negligibly small hence the damper windings are ignored in system modelling. The natural oscillating frequency of the d and q armature windings of a synchronous machine is extremely high; their Eigen modes will not affect the low frequency oscillations hence they can be described simply by algebraic equations. The field winding circuit of the machine must be described by a differential equation, not only because of its low Eigen mode frequency, but also because it is connected directly to the excitation system to which the supplementary excitation controller is applied. The torque differential equation of the synchronous machine also must be included in the model.

$$\dot{\omega} = (P_m - P_e - D\Delta\omega)/M$$

$$\dot{\delta} = \omega_o(\omega - 1)$$

The real power output of the generator is described as

$$P_e = V_{td} I_{td} + V_{tq} I_{tq}$$

$$E_q = E'_q + (X_d - X_d')I_{tld}$$

$$V_t = V_{td} + jV_{tq}$$

The real power output of the generator is described as

$$I_{tld} = \frac{E_q' - V_B \cos\delta - \frac{x_{LB}}{x_{sdt}} c v_{dc} \sin\psi}{x_{tL} + x_{LB} + x_{tL}\frac{x_{LB}}{x_{SDT}} + (1 + \frac{x_{LB}}{x_{sdt}})x_d'}$$

$$I_{tlq} = \frac{v_B \sin\delta + \frac{x_{LB}}{x_{sdt}} c v_{dc} \cos\psi}{xL + x_{LB} + x_{tL}\frac{x_{LB}}{x_{SDT}} + (1 + \frac{x_{LB}}{x_{SDT}})x_q}$$

Power System Linearized Dynamic Model

The non-linear dynamic equations are linearized around a given operating point to have the linear model as given below

$$\Delta P_e = K_1\Delta\delta + K_2\Delta E_q' + K_{pdc}\Delta V_{dc} + K_{pc}\Delta C + K_{p\psi}\Delta\psi + K_{pc}\Delta u_E + K_{pm}\Delta T_m$$

$$\Delta E_q' = K_4\Delta\delta + K_3\Delta E_q' + K_{qdc}\Delta V_{dc} + K_{qc}\Delta c + K_{q\psi}\Delta\psi + K_{qe}\Delta U_E + K_{qm}\Delta T_m$$

$$\Delta V_t = K_5\Delta\delta + K_6\Delta E_q' + K_{vdc}\Delta V_{dc} + K_{vc}\Delta c + K_{v\psi}\Delta\psi + K_{ve}\Delta U_E + K_{vm}\Delta T_m$$

$$\Delta \dot{V}_{dc} = K_7\Delta\delta + K_8\Delta E_q' - K_9\Delta V_{dc} + K_{DC}\Delta C + K_{D\psi}\Delta\psi + K_{ce}\Delta U_E + K_{cm}\Delta T_m$$

Where

K_1 to $K_9, K_{pDC}, K_{pc}, K_{p\psi}\ K_{qDC}\ K_{qc}\ K_{q\psi}\ K_{vDC}\ K_{vc}\ K_{v\psi}\ K_{dc}\ K_{d\psi}$

$$K_1 = \frac{E_q' V_b \cos\delta}{\sum X_E} + \frac{X_q - X_d'}{\sum X_E} I_{tld} V_b COS\delta + \frac{X_q - X_d'}{\sum X_d} I_{tlq} V_b \sin\delta$$

$$K_2 = I_{tlq} + \frac{(X_q - X_d')}{\sum X_d} I_{tlq}$$

$$K_3 = 1 + \frac{(X_d - X_d')}{\sum X_d}$$

$$K_4 = \frac{(X_d - X_d')}{\sum X_d} * V_b \sin\delta$$

$$K_5 = \frac{V_{td}}{V_t}\frac{X_q}{\sum X_E} * V_b * \cos\delta - \frac{V_{tq}}{V_t}\frac{X_d'}{\sum X_d} * V_b * \sin\delta$$

$$K_6 = \frac{V_{tq}}{V_t} - \frac{V_{tq}}{V_t}\frac{X_d'}{\sum X_d}$$

$$K_7 = \frac{V_b * C * \cos\psi * \sin\delta}{\sum X_d * C_{DC}} + \frac{V_b * C * \cos\delta * \sin\psi}{\sum X_E * C_{DC}}$$

$$K_8 = \frac{C * \cos\psi}{\sum X_d * C_{DC}}$$

$$K_9 = \frac{-C * \cos\psi}{\sum X_d * C_{DC}}\frac{X_{LB}}{X_{SDT}} * C * \sin\Psi + \frac{C * \sin\psi}{\sum X_E * C_{DC}}\frac{X_{LB}}{X_{SDT}} * C * \cos\Psi$$

$$K_{qDC} = \frac{-(X_d - X_d')}{\sum X_d} * \frac{X_{LB}}{X_{SDT}} C * \sin\Psi$$

$$K_{qc} = \frac{-(X_d - X_d')}{\sum X_d} * \frac{X_{LB}}{X_{SDT}} V_{DC} * \sin\Psi$$

$$K_{q\Psi} = \frac{-(X_d - X_d')}{\sum X_d} * CV_{DC} * \cos\Psi$$

$$K_{VDC} = \frac{V_{td}}{V_t}\frac{X_q}{\sum X_E}\frac{X_{LB}}{X_{SDT}} * C * \cos\Psi + \frac{V_{tq}}{V_t}\frac{X_d'}{\sum X_d}\frac{X_{LB}}{X_{SDT}} * C * \sin\psi$$

$$K_{VC} = \frac{V_{td}}{V_t}\frac{X_q}{\sum X_E}\frac{X_{LB}}{X_{SDT}} * V_{DC} * \cos\Psi + \frac{V_{tq}}{V_t}\frac{X_d'}{\sum X_d}\frac{X_{LB}}{X_{SDT}} * V_{DC} * \sin\psi$$

$$K_{dc} = \frac{-C * \cos\psi}{\sum X_d * C_{DC}}\frac{X_{LB}}{X_{SDT}} * V_{dc} * \sin\Psi + \frac{C * \sin\psi}{\sum X_E * C_{DC}}\frac{X_{LB}}{X_{SDT}} * C * \cos\Psi$$

$$K_{d\psi} = \frac{-C * \cos\psi}{\sum X_d * C_{DC}}\frac{X_{LB}}{X_{SDT}} * C * V_{dc} * \cos\Psi - \frac{C * \sin\psi}{\sum X_E * C_{DC}}\frac{X_{LB}}{X_{SDT}} * C * V_{dc} * \sin\Psi$$

Are linearization constants The 20 constants of the model depend on the system parameters and the operating condition. The expressions for the constants are derived and are as follows.

SMIB POWER SYSTEM STATE-SPACE MODEL WITH STATCOM

The SMIB power system state-space model is obtained from the linearized dynamic equations as

$$\Delta X = AX + BU$$

$$\Delta x = [\Delta\delta\ \Delta\omega\ \Delta E_q^{'}\ \Delta E_{fd}\ \Delta V_{DC}]$$

$$\Delta U = [U_E\ \Delta T_m\ \Delta C\ \Delta\psi]$$

$$A = \begin{bmatrix} 0 & \omega_b & 0 & 0 & 0 \\ -\frac{K_1}{M} & -\frac{D}{M} & -\frac{K_2}{M} & 0 & -\frac{k_{pDC}}{M} \\ -\frac{K_4}{T_{dpo}^{'}} & 0 & \frac{K_3}{T_{dpo}^{'}} & \frac{1}{T_{dpo}^{'}} & -\frac{K_{qDC}}{M} \\ -\frac{K_A K_5}{T_A} & 0 & -\frac{K_A K_6}{T_A} & -\frac{1}{T_A} & -\frac{K_A K_{vDC}}{T_A} \\ K_7 & 0 & K_8 & 0 & K_9 \end{bmatrix}$$

$$U = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & \frac{1}{M} & -\frac{K_{pc}}{M} & -\frac{k_{p\psi}}{M} \\ 0 & 0 & -\frac{K_{qc}}{T_{dpo}^{'}} & \frac{K_{q\psi}}{T_{dpo}^{'}} \\ \frac{K_A}{T_A} & 0 & -\frac{K_A K_{vc}}{T_A} & \frac{K_A K_{v\psi}}{T_A} \\ 0 & 0 & K_{dc} & K_{d\psi} \end{bmatrix}$$

IV. POWER SYSTEM STABILIZER

One problem that faces power systems nowadays is the low frequency oscillations arising from interconnected systems. Sometimes, these oscillations sustain for minutes and grow to cause system separation. The separation occurs if no adequate damping is available to compensate for the insufficiency of the damping torque in the synchronous generator unit . This insufficiency of damping is mainly due to the AVR exciter's high speed and gain and the system's loading. In order to overcome the problem, PSSs have been successfully tested and implemented to damp low frequency oscillations. The PSS provides supplementary feedback stabilizing signal in the excitation system. The basic function of PSS is to damp electromechanical oscillations. To achieve the damping, the CPSS proceeds by controlling the AVR excitation using auxiliary stabilizing signal. The CPSS's structure is illustrated in Fig 2 shows

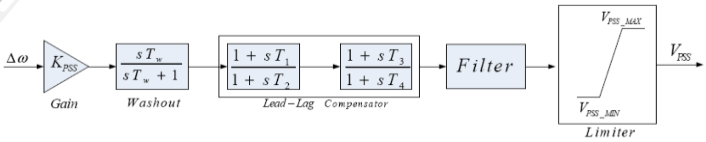

Fig.2 PSS structure

The block diagram of a linearized model of the SMIB power system with STATCOM is shown in fig 3

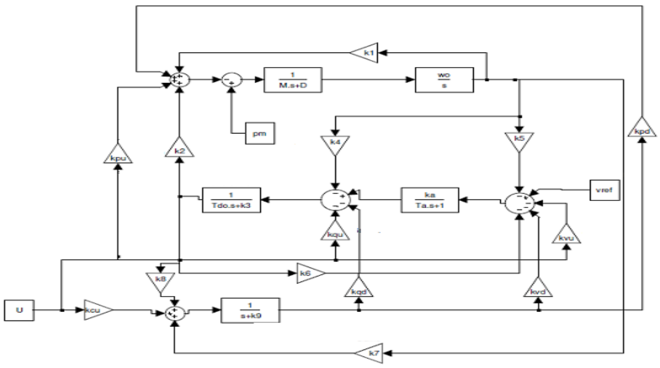

Fig.3 Modified Heffron-Phillips transfer function model

V.SIMULATION RESULTS

The disturbance is given as step input and the output response is taken from omega, delta, change in power and DC voltage. The system shows with STATCOM and PSS in a time span of 10 seconds for light, nominal and heavy condition. From the Fig.4 to Fig.11 we concluded that STATCOM and PSS are more effective than the STATCOM.

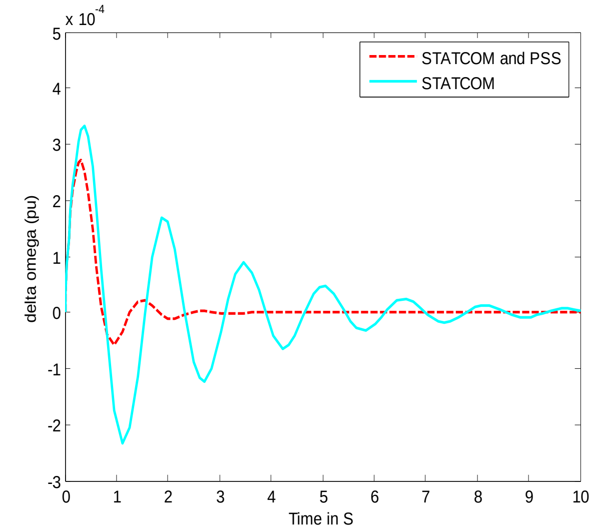

Fig.4 Time response of with $\Delta\omega$ STATCOM & STATCOM and PSS at light load

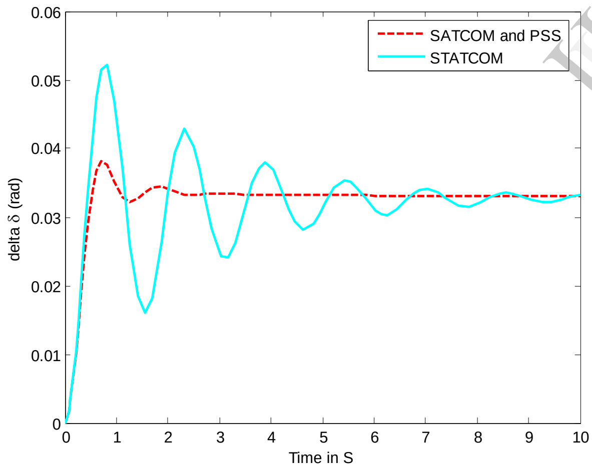

Fig.5 Time response of $\Delta\delta$ with STATCOM & STATCOM and PSS at light load.

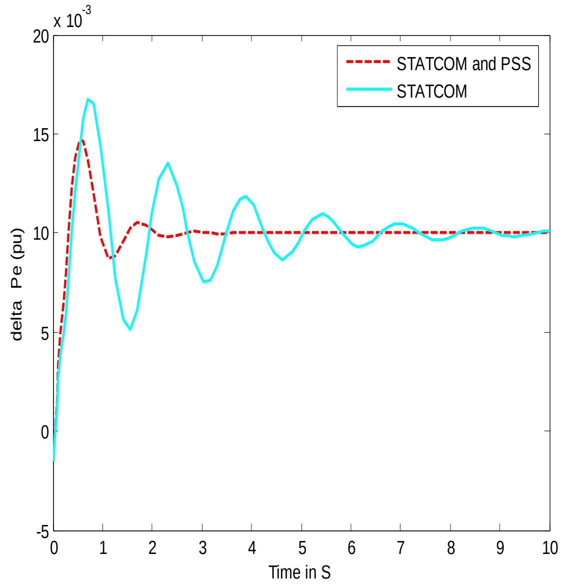

Fig.6Time response of ΔP_e with STATCOM & STATCOM and PSS at light load.

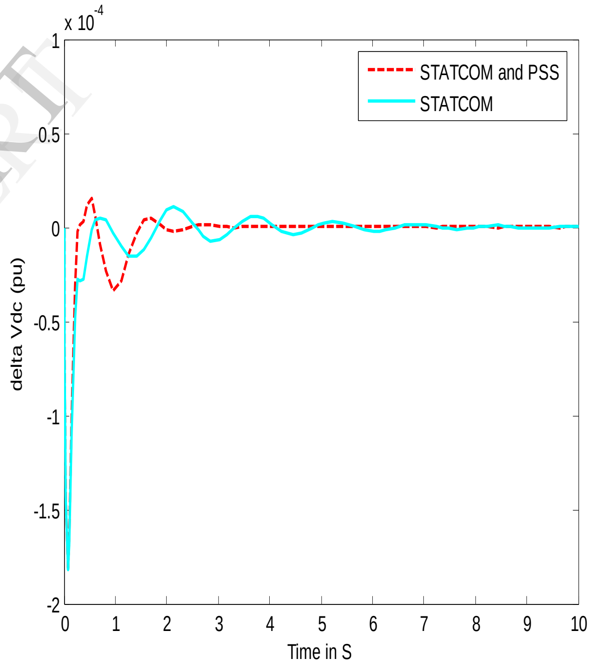

Fig.7 Time response of ΔV_{dc} with STATCOM & STATCOM and PSS at light load

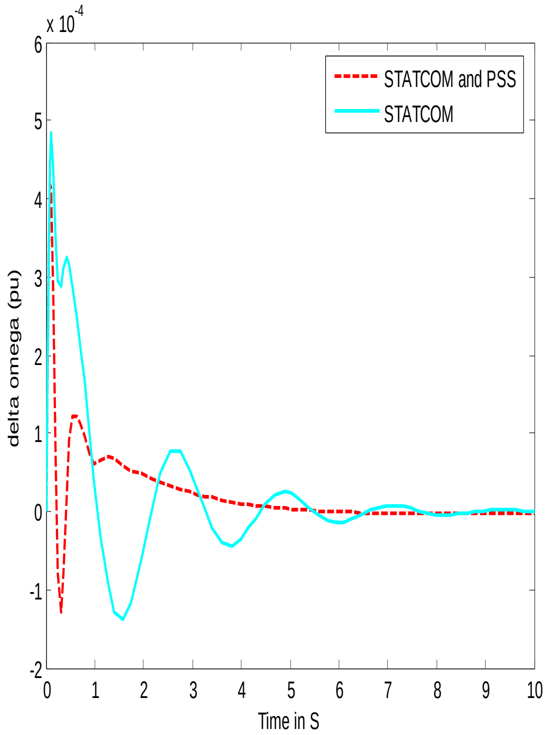

Fig.8 Time response of with $\Delta\omega$ STATCOM & STATCOM and PSS at high load.

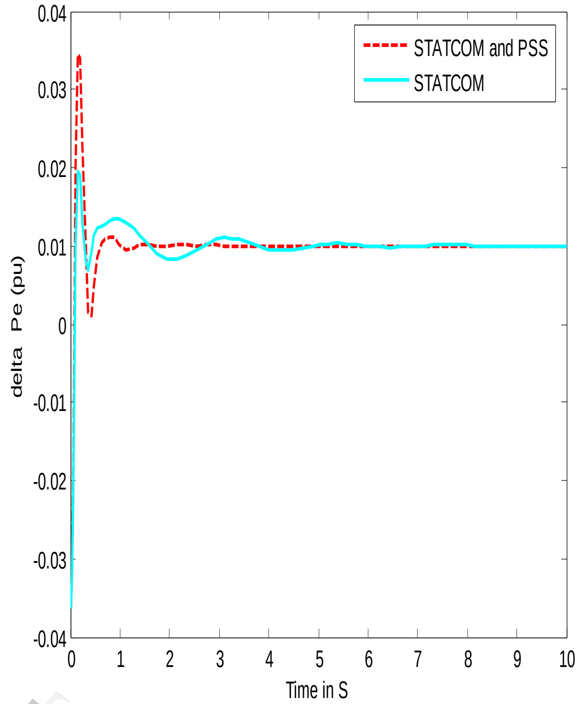

Fig.10Time response of with ΔP_e STATCOM & STATCOM and PSS at high load

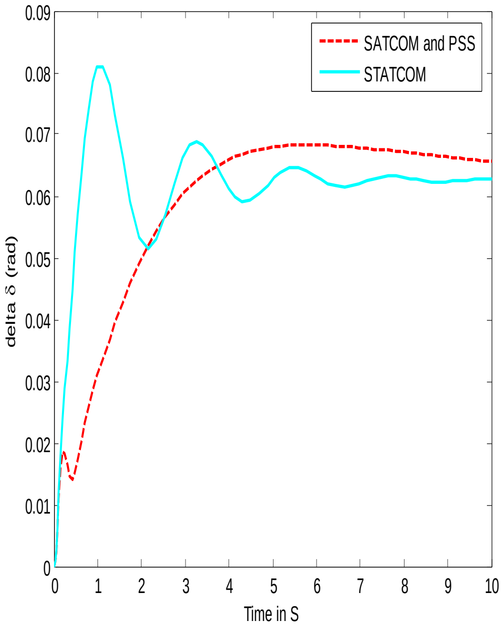

Fig.9 Time response of $\Delta\delta$ with STATCOM & STATCOM and PSS at high load.

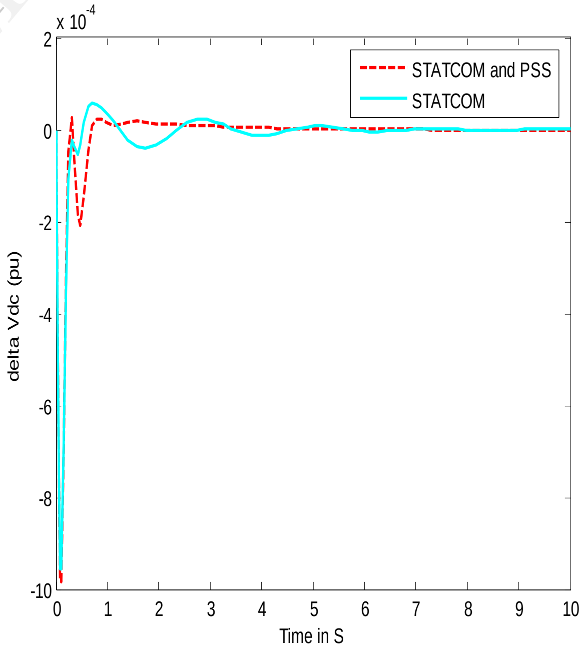

Fig.11 Time response of with ΔV_{dc} STATCOM & STATCOM and PSS at high load.

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VI.CONCLUSIONS

This work the coordination among PSS and STATCOM was presented and discussed for power system dynamic stability improvement. The design results are performed for three loading conditions and also the nonlinear simulations are performed loading conditions. A MATLAB/SIMULINK has been developed for a single machine infinite bus power system with STATCOM and PSS. The design results are confirmed with nonlinear simulations. The results of coordinated design show dynamic stability improvement. With nonlinear simulation in coordinated design case has been shown that the oscillations are damped properly.

Appendix

System data: M=8 MJ/MVA, D=0, T'_{do} =5.044s,

X_d =1pu, X_q =0.6pu, X'_d =0.3pu, K_A =10, T_A =0.05s,

$X_T = X_B = X_E$ =0.1pu, $X_{T1} = X_{T2}$ =1pu,

Operating conditions:

1)Nominal load	P=0.8	Q=0.15	V_t =1.032
2)	P=0.9	Q=0.17	V_t =1.032
3)	P=1.0	Q=0.20	V_t =1.032
4)	P=1.1	Q=0.28	V_t =1.032
5)Heavy load	P=1.125	Q=0.285	V_t =1.032
6)	P=0.7	Q=0.10	V_t =1.032
7)Very heavy load	P=1.15	Q=0.3	V_t =1.032

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