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Analysis of STATCOM based Power oscillation Damping Controller in Power System

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Abstract- The paper presents design and analysis of STATCOM based power oscillation damping controller. The Phillips- Heffron model of the Single Machine Infinite Bus power system installed with STATCOM has been derived and the systematic approach for designing STATCOM POD controller has been presented, the controller places the Eigen value at desired location depending upon mode of oscillation, so that the system has desired degree of stability. The performance of controller has been examined at different system conditions and line loadings .The effectiveness of proposed controller is verified through MATLAB simulations.

Keywords: FACTS, STATCOM, Phillips–Heffron model, Power Oscillation Damping (POD) controller, SMIB.

I. INTRODUCTION

Generally the power generation system does not installed near load centre, for the satisfying the growing power demands; utilities have an interest in better utilization of available power system capacities, generation and existing power transmission network, instead of building new transmission lines and expanding substations. On the other hand, power flows in some of the transmission lines are overloaded, which has as an overall effect of deteriorating voltage profiles and decreasing system stability and security. The Electric Power Research Institute (EPRI) introduced in the late 1980, called Flexible AC Transmission Systems (FACTS), it was answer to call for a more efficient use of already existing resources in present power systems while maintaining and even improving power system security and stability [1].

In the interconnected complex electric power systems there are spontaneous system oscillations at very low frequencies of order of 0.2-3.0 Hz. These oscillations causing system separation and stability related problem [3]. In order to damp these power system oscillations and to increase power system stability, the Power System Stabilizer (PSS) have been used for many years [4]. However, PSSs suffer a drawback of being liable to cause great variations in the voltage profile. Although, the power oscillation damping duty of FACTS controllers often is not their primary function, the capability of FACTS based stabilizers to increase power system oscillation damping characteristics has been recognized [5]. STATCOM can improve power oscillation damping effectively.H.F. Wang [6] presented a modified linearized Phillips-Heffron model of a power system installed with STATCOM and addressed basic issues pertaining to design of STATCOM based power oscillation damping controller.

II. POWER SYSTEM INSTALLED WITH STATCOM

Figure 1, shows a single machine infinite bus power system installed with STATCOM connected through a transformer. An STATCOM based on pulse width modulation (PWM) technique is being used, it consist of a coupling transformer, a VSC, and a dc energy storage device, the energy storage device is a relatively small dc capacitor.

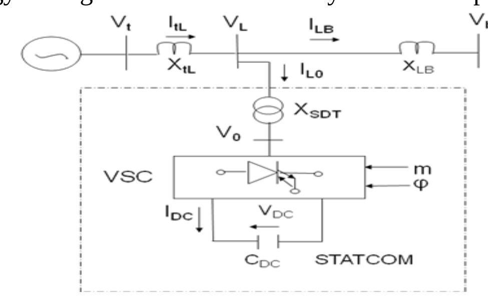

Fig. 1: STATCOM in SMIB power system.

In Fig. 1Single machine infinite bus power system with STATCOM

$$\overline{V_0} = c\ V_{DC}\ (Cos\ \ + J sin\ \ ) = c V_{DC} \angle$$

$$\frac{d v_{DC}}{dt} = \frac{I_{DC}}{c_{DC}} = \frac{c}{c_{DC}}\left(I_{Lod} Cos\ \ + J I_{Loq}\ sin\ \ \right) \qquad (4)$$

$$c = m k,$$

K is ratio between A C & D C Voltage & m = modulation index defined by the PWM. From fig.1

$$\overline{I_{LB}} = I_{tL}\ \ \overline{I_{Lo}}$$

where

$$I_{L0} = \frac{V_L\ \ V_0}{X_{SDT}}$$

$$I_{LB} = \overline{I_{tL}}\ \ \frac{\overline{V_L}\ \ \overline{V_O}}{J x_{SDT}} \qquad (1)$$

$$V_L = V_t\ \ JX_{tL} I_{tL}$$

we get

$$\overline{I_{LB}} = \overline{I_{tL}}\ \ \frac{\overline{V_t}\ \ JX_{tL} I_{tL}\ \ \overline{V_o}}{J x_{SDT}} \qquad (2)$$

$$\vec{V_t} = J x_{tL} I_{tL} + J X_{LB} I_{LB} + \overline{V_B} \qquad (3)$$

Substituting equation (2) into equation (3) which gives

$$\overline{V_t} = J X_{tL} I_{tL} + J X_{LB}\left\{\overline{I_{tL}} - \frac{\overline{V_t} - JX_{tL} T_{tL} - \overline{V}_0}{J x_{SDT}}\right\} + \overline{V_B}$$

$$= J X_{tL} I_{tL} + \frac{JX_{tL}.JX_{LB}.I_{tL}}{Jx_{SDT}} + J X_{LB} I_{tL} - JX_{LB}\left(\frac{\overline{V}_t - \overline{V_0}}{J x_{SDT}}\right) + V_B$$

$$V_t = J\left(x_{tL} + x_{tL}.\frac{X_{LB}}{x_{SDT}} + X_{LB}\right) I_{tL} - J x_{LB} \frac{V_t}{J x_{SDT}} + \frac{JX_{LB} V_0}{J x_{SDT}} + V_B$$

$$\left(1 + \frac{X_{LB}}{x_{SDT}}\right)\overline{V_t} - \frac{X_{LB}}{X_{SDT}} V_0 - \overline{V_B} = J \overline{I_{tL}}\left\{X_{tL} + X_{tL}.\frac{X_{LB}}{x_{SDT}} + X_{LB}\right\}$$

$$I_{tL} = I_{tLd} + jI_{tLq}$$

Following linearized state –space model of SMIB system installed with STATCOM is obtained as:

$$\dot{X} = AX + BU$$

$$\dot{X} = \begin{bmatrix} \Delta\dot{\delta} \\ \Delta\dot{\omega} \\ \Delta\dot{E}'_q \\ \Delta\dot{E}_{fd} \\ \Delta\dot{V}_{DC} \end{bmatrix}, \quad U = \begin{bmatrix} \Delta C \\ \Delta\varphi \end{bmatrix}$$

Where $\Delta C \, and \Delta\phi$ is the linearization's of the input control signals of the STATCOM

$$A = \begin{bmatrix} 0 & \omega_b & 0 & 0 & 0 \\ \frac{-k_1}{M} & -\frac{D}{M} & \frac{-k_2}{M} & 0 & \frac{-k_{PDC}}{M} \\ \frac{-k_4}{T'_{do}} & 0 & -\frac{k_2}{T'_{do}} & \frac{1}{T'_{do}} & -\frac{K_{qDC}}{T'_{do}} \\ -\frac{k_A k_5}{T_A} & 0 & -\frac{k_A k_6}{T_A} & -\frac{1}{T_A} & -\frac{k_A k_{VDC}}{T_A} \\ k_4 & 0 & k_8 & 0 & k_9 \end{bmatrix}$$

$$B = \begin{bmatrix} 0 & 0 \\ -\frac{k_{pc}}{M} & \frac{k_{p\varphi}}{M} \\ -\frac{k_{qc}}{T'_{do}} & -\frac{k_{q\varphi}}{T'_{do}} \\ -\frac{k_A k_{vc}}{T_A} & -\frac{k_A k_{v\varphi}}{T_A} \\ k_{dc} & k_{d\varphi} \end{bmatrix}$$

ΔC = Deviation in pulse width modulation index 'm' of the shunt inverter.

Δφ = Deviation in phase angle of the shunt converter voltage.

The linearized dynamic model of above state space is shown by following figure 2.

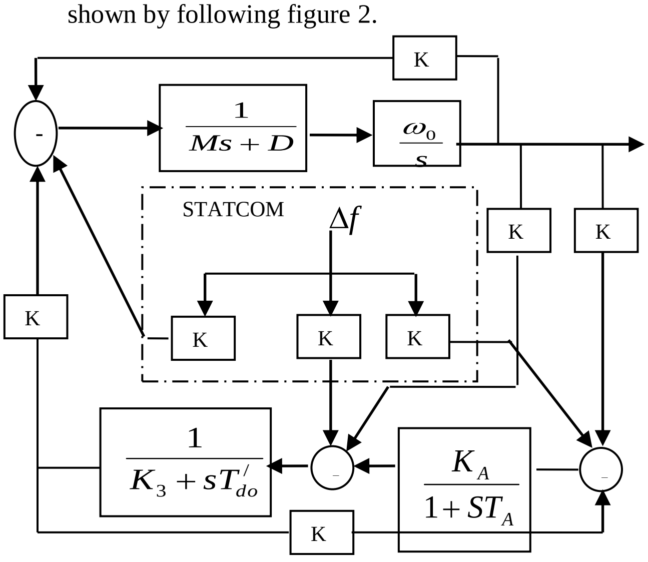

Fig2: Phillips-Heffron model of power system installed with STATCOM.

III. POD CONTROLLER

The dynamic characteristics of system can be influenced by location of eigenvalues, for a good system response in terms of overshoots /undershoot and settling time, a particular location for system eigenvalues is desired depending upon the operating conditions of the system. The damping power and the synchronizing power are related respectively, to real part and imaginary part of eigenvalue that correspond to incremental change in the deviation of the rotor speed and deviation of rotor angle[8], this Eigenvalue is known as electromechanical mode. This paper present controller such that the closed loop designed system will have a desired degree of stability [9], and [10].

Design of Pod Controller

The Linearized state – space model of SMIB power system is determine by phillips-heffron model as expressed by:

$$\dot{X} = AX + BU \qquad (12)$$

Where A and B are the matrices of the system and input respectively.. If we use state feedback, that is, if we set U= -KX where K is the chosen gain matrix, the equation:

$$\dot{X} = (A - BK)X \qquad (13)$$

And the problem is to allocate any set of eigenvalues to closed loop matrix (A-BK) by selecting the gain matrix K .Here in the gain matrix K is selected by MATLAB tool. The syntax is given below:

$$K = place(A, B, p) \qquad (14)$$

Where vector p of desired self-conjugate closed-loop pole locations, computes a gain matrix K such that the state feedback places the closed-loop poles at the locations p.

•Eigen- values analysis under weak power System and various line loadings

Load → / Controller ↓	Load decreased (0.8) p.u.	Normal load (1.0) p.u.	Load increased (1.2) p.u.
Without STATCOM	-98.6815 **0.0173 + 8.0820i** **0.0173 - 8.0820i** -1.7055	-98.6747 **0.0184 + 8.9851i** **0.0184 - 8.9851i** -1.7146	-98.6701 **0.0183 + 9.8053i** **0.0183 - 9.8053i** -1.7189
With STATCOM	-98.8545 **-0.0270+ 5.0788i** **-0.0270 - 5.0788i** **(0.00532)** -1.3744 -0.1135	-98.8533 **-0.0217+ 5.6963i** **-0.0217 - 5.6963i** **(0.00381)** -1.4118 -0.0879	-98.8525 **-0.0181+ 6.2519i** **-0.0181 - 6.2519i** **(0.0029)** -1.4360 -0.0718
With POD Controller	-98.8545 **-0.1352+ 5.0788i** **-0.1352 - 5.0788i** **(0.0266)** -0.1135 -1.3744	-98.8533 **-0.1086+ 5.6963i** **-0.1086 - 5.6963i** **(0.0191)** -0.0879 -1.4118	-98.8525 **-0.0905+ 6.2519i** **-0.0905 - 6.2519i** **(0.0145)** -0.0718 -1.4360

Table1: Eigen values with STATCOM POD controller for weak SMIB system.

- **Eigen- values analysis under strong power system and various line loadings.**

Load → Controller ↓	Load decreased (0.8) p.u.	Normal load (1.0) p.u.	Load increased (1.2) p.u.
Without STATCOM	-98.6815 **-0.3157 + 8.074i** **-0.3157 - .0744i** **(0.0391)** -1.7061	-98.6747 **-0.3146 + 8.978i** **-0.3146 -8.9783i** **(0.035)** -1.7152	-98.6701 **-0.3148 + 9.799i** **-0.3148 -9.7990i** **(0.0321)** -1.7194
With STATCOM	-98.8545 **-0.3633 + 5.069i** **-0.3633 - 5.0690i** **(0.0715)** -0.1139 -1.3681	-98.8533 **-0.3569 + 5.687i** **-0.3569 - 5.6875i** **(0.0626)** -0.0881 -1.4079	-98.8525 **-0.3527 + 6.243i** **-0.3527 - 6.2438i** **(0.0564)** -0.0719 -1.4333
With POD Controller	-98.8545 **-1.8166 + 5.069i** **-1.8166 - 5.0690i** **(0.337)** -1.3681 -0.1139	-98.8533 **-1.7847 + 5.687i** **-1.7847 - 5.6875i** **(0.299)** -1.4079 -0.0881	-98.8525 **-1.7637 + 6.243i** **-1.7637 - 6.2438i** **(0.272)** -1.4333 -0.0719

Table2: Eigen values with STATCOM POD controller for strong SMIB system .

The complex rows of this table represent the eigenvalue and its damping ratio. It can be observed from the table that STATCOM with proposed controller greatly improve the system stability.

- **Simulation results under different system and loading conditions**

From the results it is clear that the controller performance is better in terms of reduction of overshoot and settling time than system without STATCOM and with system with STATCOM only. Simulation results with variation in system- state, rotor angle (**φ**) of generator is only considered. The system responses are simulated using M-file program of MATLAB. Figures 3 to 6 show the combined system response without STATCOM, with STATCOM and with STATCOM POD controller at 1.0 pu, 0.8 pu and 1.2 pu line loading with 0.85 power factor of weaker (damping coefficient D=0) and stronger (damping coefficient D=4) SMIB power system. It can be observed from these figures that the STATCOM with POD controller can greatly improve stability under different line loading and system condition as mention above.

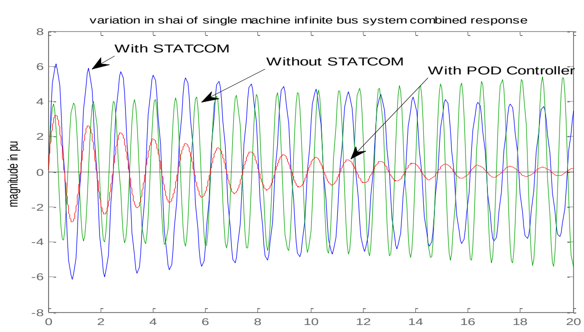

Fig.3 Response at D=0, Load=0.8 p.u.

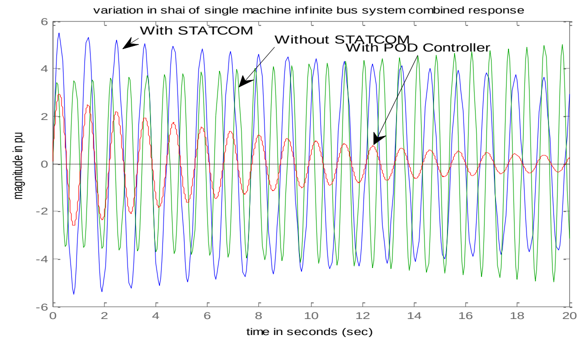

Fig 4 Response at D=0, Load=1 p.u.

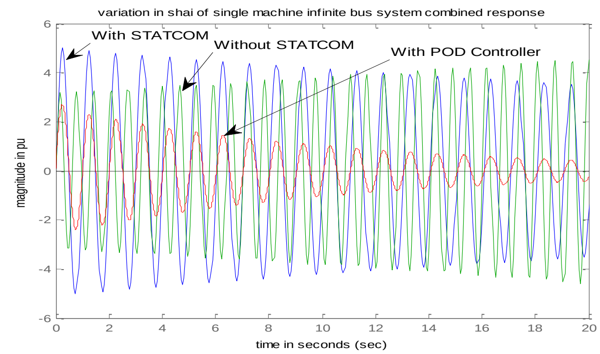

Fig 5 Response at D=0, Load=1.2 p.u.

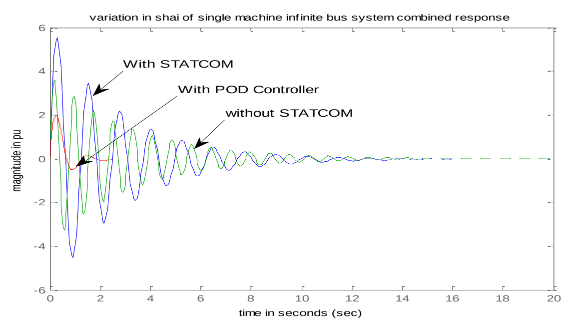

Fig .6 Response at D=4, Load=0.8 p.u.

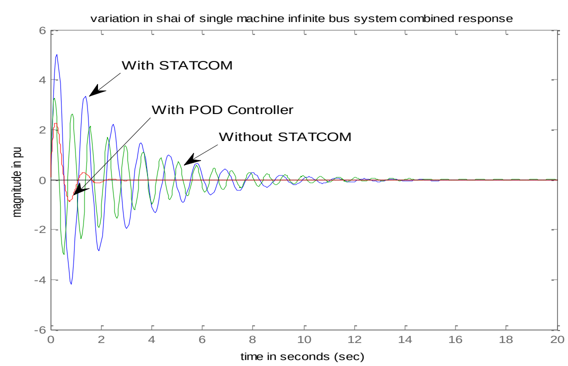

Fig .7 Response at D=4, Load=1.0 p.u.

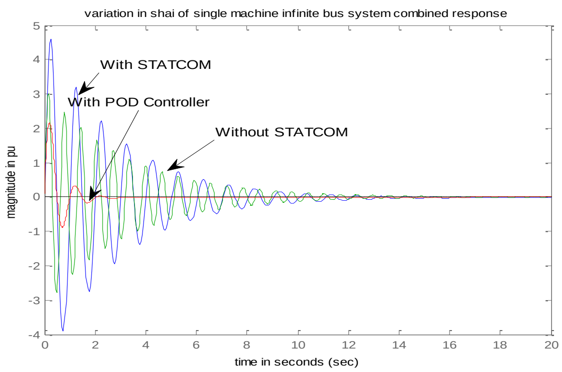

Fig .8 Response at D=4, Load=1.2 p.u.

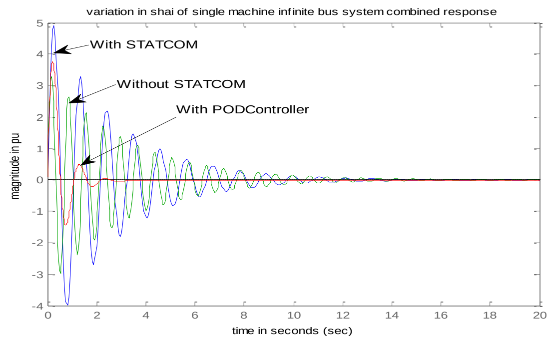

Fig .9: Response at 1 p.u. load and D=4, m=0.3

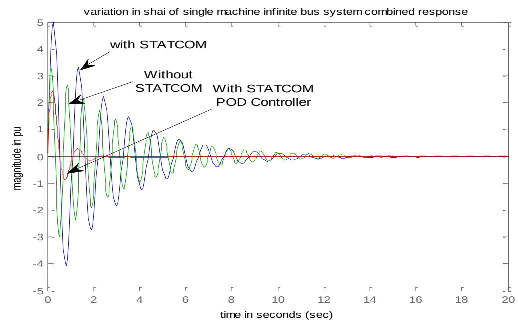

Fig .10: Response at 1 p.u. load and D=4, m=0.7

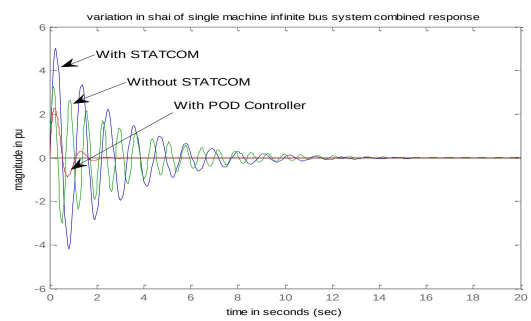

Fig 11 Response at 1 p.u. load and D=4, m=1

•Eigen- values and simulation results with variation in modulation index

modulation index → Controller ↓	m= 0.3 p.u.	m= 0.7 p.u.	m=1 p.u.
Without STATCOM	-98.6747 **-0.3146 + 8.9783i** **-0.3146 - 8.9783i** **(0.0345)** -1.7152	-98.6747 **-0.3146 + 8.9783i** **-0.3146 - 8.9783i** **(0.035)** -1.7152	-98.6747 **-0.3146 + 8.9783i** **-0.3146 - 8.9783i** **(0.035)** -1.7152
With STATCOM	-98.8539 **-0.3711 + 5.8259i** **-0.3711 - 5.8259i** **(0.0636)** -0.0073 -1.4597	-98.8535 **-0.3652 + 5.7481i** **-0.3652 - 5.7481i** **(0.0634)** -0.0414 -1.4378	-98.8533 **-0.3569 + 5.6875i** **-0.3569 - 5.6875i** **(0.0626)** -0.0881 -1.4079
With POD Controller	-98.8539 **-1.8557 + 5.8259i** **-1.8557 - 5.8259i** **(0.305)** -2.9194 -0.0146	-98.8535 **-1.8260 + 5.7481i** **-1.8260 - 5.7481i** **(0.303)** -0.0827 -2.8757	-98.8533 **-1.7847 + 5.6875i** **-1.7847 - 5.6875i** **(0.299)** -0.1762 -2.8158

Table 3: Variation in modulation index of VSC with different system conditions

The variation in modulation index shows in the table-3 in which the study of eigenvalues is done. From this study it is find that as the modulation index increases stability of the system decreases. and the simulation results as shown in fig. 7,8 and 9.

•Eigen- values and simulation results with variation in converter angle

The variation in converter angle of STATCOM is another equally important factor for the study of performance POD controller using eigenvalue analysis.Table-4 shows the combined study of eigenvalues of variations in converter angle of STATCOM. From this table it can be observe that at lower value of the variation in converter phase angle is more effective than higher value of angle, The comparative study from this table-3 and table-4 shows that variation in converter phase angle is more effective than variation in amplitude modulation index of converter; and the simulation results are shown in fig. 7 to 12. Hence performance of proposed controller is more effective.