Power System Stability Enhancement with STATCOM Power Oscillation Damping Controller

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***Abstract-* The paper presents design and analysis of STATCOM 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 power oscillation damping controller has been presented, the controller places the Eigen value corresponding to mode of oscillation at desired location so that the system has desired degree of stability. The performance of controller has been examined at different system conditions, under different line loadings and the effectiveness of proposed controller is verified through MATLAB simulation.**

Keywords: FACTS, STATCOM, Phillips–Heffron model, Power Oscillation Damping controller.

I. INTRODUCTION

Today's Power system is a complex network, consist of thousands of buses and hundreds of generators. The available power generation usually does not situated near load center, in order to meet the growing power demands; utilities have an interest in better utilization of available power system capacities, existing 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. In addition, existing traditional transmission facilities, in most cases, are not designed to handle the control requirements of complex and highly interconnected power systems. This overall situation requires the review of traditional transmission methods and practices, and the creation of new concepts, which would allow the use of existing generation and transmission lines up to their full capabilities without reduction in system stability and security. In the past, power systems could not be controlled fast enough to handle dynamic system condition. This problem was solved by over-design; transmission systems were designed with generous stability margins to recover from anticipated operating contingencies caused by faults, line and generator outages, and equipment failures. Series capacitor, shunt capacitor, phase shifter are different approaches to increase the power system transmission lines load ability. In past days, all these devices are controlled and switched mechanically and were, therefore, relatively slow. They are very useful in a steady state operation of power systems but from a dynamical point of view, their time response is too slow to effectively damp transient oscillations. If mechanically controlled systems were made to respond faster, power system security would be significantly improved, allowing the full utilization of system capability while maintaining adequate levels of stability. This concept and advances in the field of power electronics led to a new approach introduced by the Electric Power Research Institute (EPRI) 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].

The development of interconnection of large electric power systems led to presence of spontaneous system oscillations at very low frequencies of order of 0.2-3.0 Hz. Once started, the oscillation would continue for a while and then disappear, or continue to grow, 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, to date; a number of major electric power system plants in many countries are equipped with PSS [4]. However, PSSs suffer a drawback of being liable to cause great variations in the voltage profile and they may even result in leading power factor operation and losing system stability under severe disturbances. In addition, in a deregulated environment, placement may be problematical due to generator ownership recently appeared FACTS-based stabilizer offer an alternative way in damping power system oscillation. 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, the power oscillation damping capability of STATCOM is required to be investigated thoroughly for proper on line applications in changing operating conditions. Different approaches based on modern control theory have been applied to STATCOM based POD controller design. 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. The single-machine infinite-bus (SMIB) system used in this study is for better understanding of power oscillation damping and hence enhancement of system stability. An STATCOM based on pulse width modulation (PWM) technique is being considered, it consist of a coupling transformer, a VSC, and a dc energy storage device, the energy storage device is a relatively small dc capacitor, hence the STATCOM is capable of only reactive power exchange with the transmission system. If a dc storage battery or other dc voltage source were used to replace the dc capacitor, the controller can exchange real and reactive power with the transmission system. The STATCOM's output voltage magnitude and phase angle can be varied by changing the modulation index m and the phase angle φ of the operation of the converter switches, thus controlling the magnitude of the fundamental component of the converter ac output voltage.

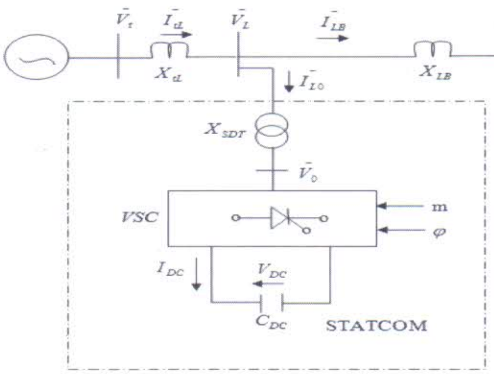

Fig. 1 STATCOM in SMIB power system.

The STATCOM is modeled as a voltage-sourced converter behind a Transformer as shown in Fig. 1 the STATCOM generates a controllable AC-voltage behind the leakage reactance.

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

$$\frac{dv_{DC}}{dt} = \frac{I_{DC}}{c_{DC}} = \frac{c}{c_{DC}}\left(I_{Lod}Cos\ \ +JI_{Loq}\sin\ \ \right) \quad (1)$$

$$c = mk,$$

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

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

$$I_{LB} = \overline{I_{tL}}\ \ \frac{\overline{V_L}\ \ \overline{V_O}}{J\,x_{SDT}} \quad (2)$$

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

weget

$$\overline{I_{LB}} = \overline{I_{tL}}\ \ \frac{\overline{V_t}\ \ JX_{tL}I_{tL}\ \ \overline{V_o}}{J\,x_{SDT}} \quad (3)$$

$$\vec{V_t} = J\,x_{tL}\,I_{tL} + J\,X_{LB}\,I_{LB} + \overline{V_B} \quad (4)$$

Substituting equation (3) into equation (4) 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 single machine infinite bus system installed with STATCOM is obtained as:

$$\dot{X} = A\,X + B\,U$$

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

Where, $\Delta C\ and\Delta\varphi$ are the linearizations 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 impulse width modulation index 'm' of the shunt inverter. By controlling m, the output voltage of the shunt converter is controlled.

$\Delta\varphi$ = Deviation in phase angle of the shunt converter voltage

The linearized dynamic model of above state model is shown by Fig. 2, where Δu being ΔC and $\Delta\varphi$.

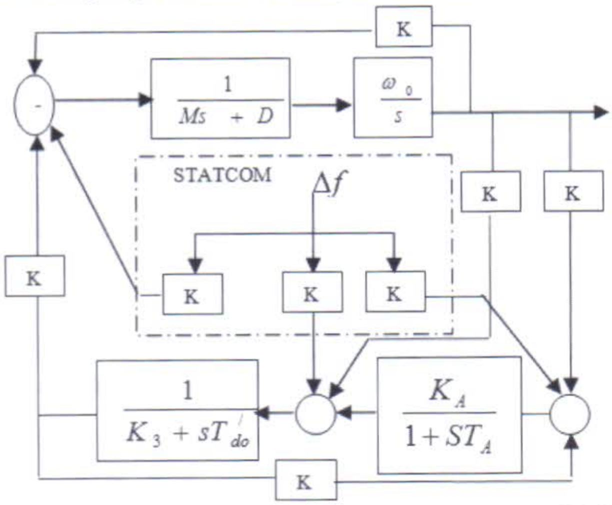

Fig.2 Phillips-Heffron model of power system installed with STATCOM

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. Power oscillation damping can be improved if real part of eigenvalue associated with mode of oscillation can be shifted to left-side in complex s-plane as desired. This thesis present controller such that the closed loop designed system will have a desired degree of stability [9], and [10]. For the power system representation in state – space form, a closed loop gain matrix A-BK obtained by choosing the gain matrix K through state feedback control law $U = -KX$ will have all its eigenvalue lies in left side of complexes-plane. It is an easy task to design power oscillation damping controller. Making use of proposed controller design approach, STATCOM based power oscillation damping controller is designed to damping of low frequency power oscillations. This has been attempted on a sample system. The expectation from STATCOM based POD controller is to provide instantaneous solution to power oscillation damping, the settling time as obtained from response of system is expected to be as small as possible. For minimizing settling time real part of eigenvalue corresponding to mode of oscillation are required to be shifted more and more on LHS of complex plane, this will require control effort. There is a hardware limit of any designed controller, for the case of STATCOM, in view of this, the control input parameters m and φ should be within their limit and the voltage of the DC link capacitor V_{dc} should be kept constant.

IV. DESIGN OF POD CONTROLLER

The Linearized state – space model of SMIB power system is obtained 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. X is the system state vector, and U is the input state-vector. The matrices A and B are constant under the assumption of system linearity. If we use state feedback, that is, if we set U= -KX where *K* is the chosen gain matrix, the equation becomes:

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

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

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

Where vector p of desired self-conjugate closed-loop pole locations, place computes a gain matrix K such that the state feedback places the closed-loop poles at the locations p. In other words, the eigenvalues of (A-BK) match the entries of p (up to the ordering).K=place(A,B,p)computes a feedback gain matrix *K* that achieves the desired closed-loop pole locations p, assuming all the inputs of the plant are control inputs.

V. ANALYSIS OF CONTROLLER AND SIMULATION RESULTS

The effectiveness of proposed STATCOM POD controller for damping local mode oscillations has been demonstrated with SMIB system. The linearized state space model for SMIB installed with STATCOM is given above. Using pole-placement controller design technique STATCOM POD controller for SMIB has been designed. Also, to have improved damping and hence the small settling time of response, it is desired to shift the real part of eigenvalue corresponding to mode of oscillation to LHS in complex s-plane. To achieve this, it is desired to place eigenvalue corresponding to mode of oscillation at location on LHS of complex plane. The change in operating conditions of power system is common phenomenon, e.g., line loading varies over