Coordinated tuning of POD and PSS controllers with STATCOM in increasing the oscillation stability of single and multimachine power system.

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Abstract—**Static synchronous compensator (STATCOM) is a shunt connected voltage source converter (VSC), which can affect rapid control of reactive flow in the transmission line by controlling the generated a.c. voltage. The main aim of the paper is to design a power system installed with a Static synchronous compensator (STATCOM) and demonstrates the application of the model in analyzing the damping effect of the STATCOM to improve power system oscillation stability. The proposed controllers are designed to coordinate two control inputs: Voltage of the injection bus and capacitor voltage of the STATCOM, to improve the transient stability of a SMIB system and multimachine system .The STATCOM controller namely conventional PI controller. The power oscillations damping (POD) control and power system stabilizer (PSS) and their coordinated action with proposed controllers are tested. The simulation results show that the proposed controller provides satisfactory performance in terms of improvements of transient stability of the system. The results indicate that the coordinated POD & PSS action further improves the dynamic performance of the system under various system conditions.**

Index Terms—damping oscillations, FACTS, STATCOM, Transient stability, Coordination.

I:INTRODUCTION

FIXED or mechanically switched capacitors and reactors have long been employed to increase the steady-state power transmission by controlling the voltage profile along the line. The FACTS devices are known to improve both the transient as well as dynamic performance of a power system. The static synchronous compensators (STATCOM) provide shunt compensation in a way similar to the static var compensation (SVC), but utilize a voltage source converter rather than shunt capacitors and reactors. STATCOM can control voltage magnitude and to a small extent, the phase angle in a very short time and therefore, has the ability to improve the system damping as well as voltage profile of the system. A schematic diagram of STATCOM connected to SMIB system and multimachine system is shown in figure (1) and figure (2) respectively.

Two basic controls are implemented in a STATCOM. The first is the a.c voltage regulation of the power system, which is realized by controlling the reactive power interchange between the STATCOM and the power system. The other is the control of the d.c voltage across the capacitor, through which the active power injection from the STATCOM to the power system is controlled. PI controllers have been found to provide stabilizing controls when the a.c and d.c regulators were designed independently. However, joint operations of the two have been reported to lead system instability because of interaction of the two controllers and can be stabilized by using damping signals. The designed controllers for STATCOM are tested for transient stability investigations of single machine connected to infinite bus system (SMIB) and multimachine system. This paper also presents the coordination of power oscillation damping control (POD) and power system stabilizer (PSS) with the proposed controllers for further improvements in the dynamic performance of the system.

II: SYSTEM MODEL

The system depicted in Figure (1) is used to validate the implementation of the proposed controllers for STATCOM. The detailed system data is given in Appendix.The multimachine system model is shown in figure (2). The synchronous generator is represented by a 6^{th} order machine model and the generator excitation system has a simple automatic voltage regulator (AVR) as shown in Figure (3). For the transient stability analysis mechanical power input is assumed to be constant. The transmission line distributed model is used for simulation. The POD control and PSS are described in section IV.For the SMIB system, the STATCOM is located at the sending end of the line, chosen as a typical case.

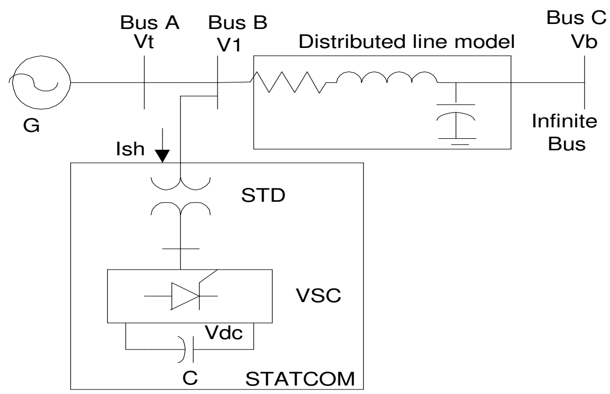

Figure (1): System with STATCOM at sending end of Line

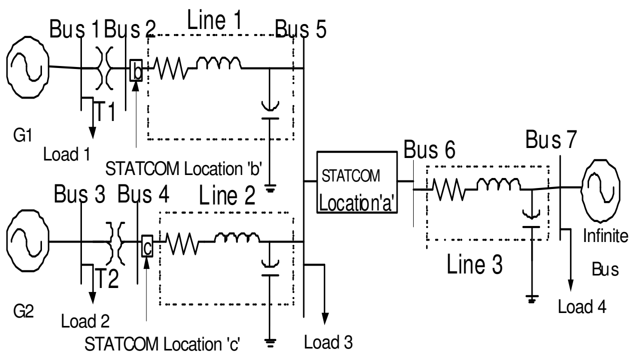

Figure (2): Multimachine system model

III. STATCOM MODEL

The main advantage of the power electronics based FACTS controller over mechanical controller is its fast operation. Therefore, the capability of STATCOM needs to be exploited not only for voltage control but also to improve damping of the system. STATCOM can be controlled by the voltage magnitude and the phase angle control.

A. Conventional PI Controller

The shunt current is controlled indirectly by varying the shunt converter voltage magnitude and phase angle. Thus, the shunt current is split into real $\dot{i}_P^{sh}$ and reactive current $\dot{i}_R^{sh}$ components [3,7].

$$\dot{i}_R^{sh} = \dot{i}_D^{sh}\cos(\phi^1) - \dot{i}_Q^{sh}\sin(\phi^1) \quad (1)$$

$$\dot{i}_P^{sh} = \dot{i}_D^{sh}\sin(\phi^1) + \dot{i}_Q^{sh}\cos(\phi^1) \quad (2)$$

Where $\phi^1 = \tan^{-1}(v1_D/v1_Q)$

The subscript 'D' and 'Q' denote the variable in D-Q frame. [$\dot{i}_{D,}^{sh}\dot{i}_Q^{sh}$]: are the D-Q components of shunt branch current. [$v1_D$,$v1_Q$]: are the components of bus B voltage. For control of shunt current, the differential equations are written as [3,7]:

$$\frac{d\,\dot{i}_R^{sh}}{dt} = (-rsh*wb/xsh)\,\dot{i}_R^{sh} - w*\dot{i}_P^{sh} + (wb/xsh)\,e_R^{sh} \quad (3)$$

$$\frac{d\,\dot{i}_P^{sh}}{dt} = (-rsh*wb/xsh)\,\dot{i}_p^{sh} + w*\dot{i}_R^{sh} + (wb/xsh)*(e_P^{sh} - v1) \quad (4)$$

Similar to equations (1) and (2) for voltages.

$$e_R^{sh} = e_D^{sh}\cos(\phi^1) - e_Q^{sh}\sin(\phi^1) \quad (5)$$

$$e_P^{sh} = e_D^{sh}\sin(\phi^1) + e_Q^{sh}\cos(\phi^1) \quad (6)$$

$$w = w_0 + \frac{d\,\phi^1}{dt} \quad (7)$$

If we vary the converter output voltages as follows,

$$e_R^{sh} = (w*xsh/wb)\,\dot{i}_P^{sh} + (xsh/wb)\,u_R \quad (8)$$

$$e_P^{sh} = -(w*xsh/wb)\,\dot{i}_R^{sh} + v1 + (xsh/wb)\,u_P \quad (9)$$

The DC side capacitor voltage V_{dc} is described by the dynamic equation:

$$\frac{dV_{dc}}{dt} = (-gc*wb/bc)*V_{dc} - \dot{i}_{dc}^{sh} \quad (10)$$

Where, gc and bc are the conductance and susceptance of the DC capacitor respectively,[rsh, xsh] are shunt transformer resistance and leakage reactance respectively., and [$e_{D,}^{sh}e_Q^{sh}$] are the converter output voltage components. It is established that components of the reactive current $\dot{i}_R^{sh}$ can be controlled by bus B voltage magnitude and real current $\dot{i}_P^{sh}$ component can be controlled by V_{dc} capacitor voltage [3, 7]. By using equations (1) to (10), the conventional STATCOM controller block diagram is developed as shown in Figure (4).

The control strategy considered for the STATCOM is designed by using locally available measurable components [3, 7] of the system. During system abnormal condition, the decrease in voltage at bus B can be arrested by controlling the quadrature current component $\dot{i}_R^{sh}$ which can control the shunt converter voltage component e_P^{sh} and hence the improvements in transient stability [7]. The gain of the feedback system Ks and Kd are tuned by using nonlinear control block set (NCD) [9]. By adjusting the gain of feedback system, damping ratio can be improved. The maximum and minimum voltage limits are chosen for the safe operation of STATCOM under abnormal system conditions.

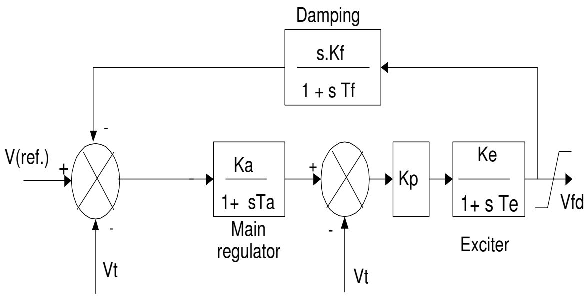

Figure (3): Excitation system

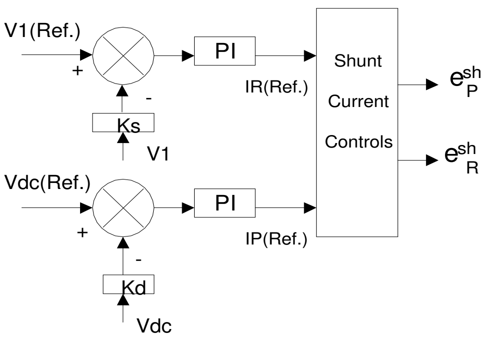

Figure (4): STATCOM current controller

IV. POWER SYSTEM OSCILLATION DAMPING CONTROLLER

A damping controller is provided to improve the damping of power system oscillations. The damping controller be considered as comprising two cascade connected blocks. The speed deviation signal is derived from the difference of measured power at STATCOM location and the set mechanical input power and the error signal is integrated and multiplied by 1/M, where M is inertia constant of the machine. The second block comprises a lead lag compensator. Figure (5) shows the block diagram of power oscillation damping controller (POD). The parameters of POD controller is tuned by using Ziegler Nichols method [9], so as to achieve the desired damping ratio of the electromechanical mode and compensate for the phase shift between the control signal and the resulting electrical power deviation. The output of the damping controller modulates the reference setting of voltage of bus B. In Figure (5), the ΔV deviation signal is replaced by ΔV+ U in order to include the POD for improvement of dynamic performance. The Figure (6) shows the block diagram of power system stabilizer (PSS).

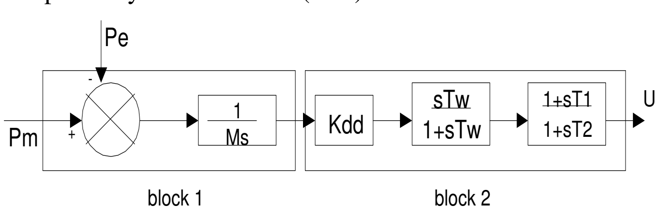

Figure (5): Transfer function block diagram of the POD

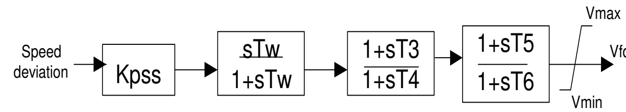

Figure (6): Transfer function block diagram of the PSS.

V. POWER DELTA CURVE AND STABILITY

The firing signals for VSC based STATCOM is controlled by controllers so as to achieve maximum sending end real power at bus B. The system transmission characteristics, sending end real power vs. transmission angle (δ) curve with conventional PI controller are shown in Figure (7). The results indicates that the sending end real power (Psen) is maximum (Psen = 3.6 p.u.) at (δ) =90^0 and power reaches to zero at delta (δ) =180^0 without STATCOM. In the case of conventional PI based STATCOM, sending end power reaches to maximum (Psen= 3.67 p.u.) at (δ) =90^0 and power reaches to zero at delta (δ) =180^0 .

VI. SIMULATION RESULTS

Digital simulation is carried out by the MATLAB software. For the simulation, different loading conditions with different fault locations in the SMIB and multimachine systems are considered.

The results of the proposed controllers with POD and PSS under heavily loaded condition (generator output Pg =1.01 p.u.) with three phase fault of 50 ms duration at sending end of the line are shown in Figure (8). The results demonstrate that the satisfactory performance of controllers under different loading conditions and fault locations The coordinated effect of POD and PSS further improves the dynamic performance of the system than conventional PI controller. The proposed PI controller performance is tested in multimachine system at three different locations ‘a’, ‘b’and ‘c’as shown in figure(2). The simulation results for the proposed PI controller for the fault duration of 50 ms are shown in figure(10). Results indicate that STATCOM at location ‘a’ is considered to be more favorable location.

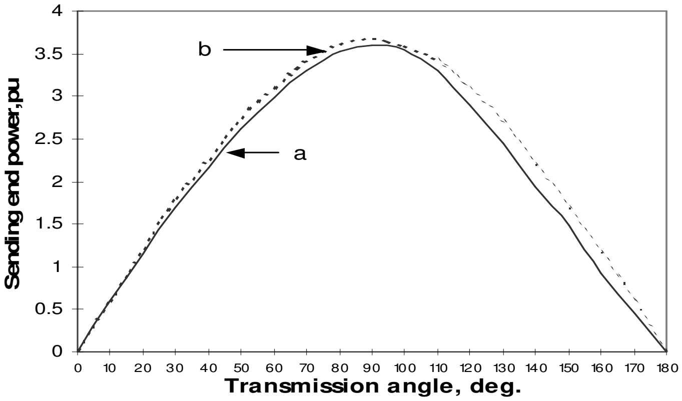

Figure (7): Power-Angle curve of the SMIB system

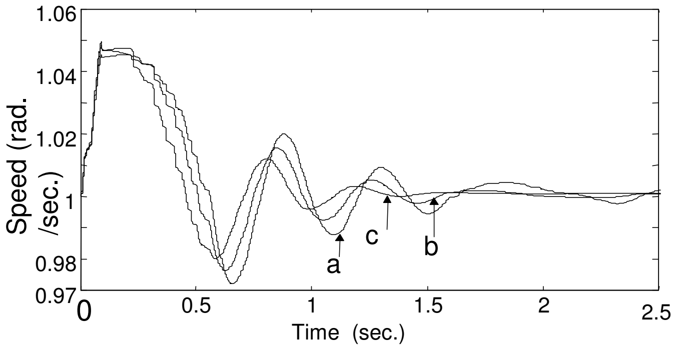

Figure (8): Response of the SMIB system with PI based STATCOM

a) System with PI controller and POD
b) System with PI controller and PSS
c) System with PI controller and POD and PSS

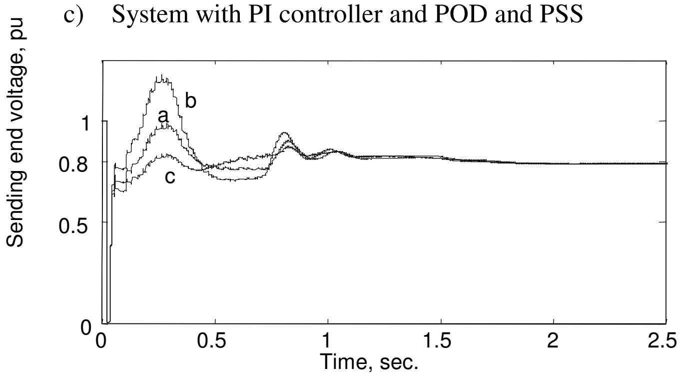

Figure (9): Three Phase fault at Sending end with 50ms duration.

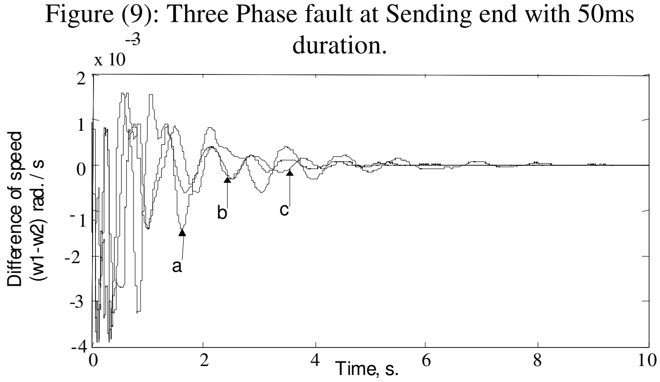

Figure (10): Response of the short scale multi-machine system with PI based STATCOM during three phase short circuit at bus 7 a. located at 'a' b. located at 'b' c. located at 'c'

VII. CONCLUSION

This paper presents a design of PI based STATCOM controller in a single machine infinite bus system and multimachine system for the transient stability improvements. The results indicate that the conventional power system stabilizer (PSS) performance is better than independent action of power oscillation damping (POD) control in the power system. The coordinated action of POD and PSS with proposed controller provides further improvement in dynamic performance under different loading conditions.

VIII: APPENDIX

SMIB system data(in p. u.):

G: 250 MVA, 13.8 KV, 60 c/s, Rs =0.00045, Ls = 0.14, Lmd =1.51, Lmq = 1.45, Rf = 0.000096, Lfd = 0.61168, H(s) =0.87882.

Exc.System: Ka = 2, Ta =0.001 s, Ke = 1.0, Te = 0.001 s, Kp = 1

T.Line: R1 = 0.01273 ohm/km, R0 = 0.3864 ohm/km, L1 =0.9337e-03 H/km,L0 = 4.1264e-03 H/km, C1 = 12.74e-09 F/km, C0 = 7.751e-09 F/km, length of line = 450 km

STATCOM: Vop = 345KV , Vpq (max) = 0.3Vop,Vpq (min) = -0.3Vop, Ks =0.9,Kd = 1.0

POD: Kdd = 144, Tw = 15, T1= 0.0518e-6 s,T2 = 0.0221e-6s

PSS:Kpss = 20, Tw = 15, T3= T5 =0.02e-6,T4= T6=0.035e-6 s.

Multi-machine system data

Base voltage :220kV, MVA (Base):100MVA, F=50Hz
G1:Simillar to SMIB system, G2: 300MVA,22kV , 60 c/s,Rs=0.00045p.u.,Ls=0.14p.u.Lmd=1.51p.u.,Lmq=1.45p.u., Rf=0.000096,Lfd=0.61168p.u.,H=2.87882s
Excitation system1 and Excitation system 2: Ka=1,Ta=0.001s,Ke=1.0,Te=0.001s,Kp1=1,Kp2=2.0
STATCOM:Vop=220kV,Vpq= 0.3Vop,Ks=0.5,Kd=0.5
POD:Kpod=0.5,Tw=10,T1=0.051e-6s,T2=0.022e-6s
PSS: Kpss=2,Tw=10,T3=T5=0.02e-6,T4=T6=0.035^{e}-6s
Load1 and Load
2 :0.15p.u.,Load3:0.40+j0.10p.u.,Load4:1.0+j0.05p.u.

IX: REFERENCES

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