The Journal of CPRI,
Vol. 13, No. 3, September 2017 pp. 405-414

Design of coordinated control of series vectorial compensator and power system stabilizers with desired eigenvalues in the sliding mode

Himaja K*, Surendra T S** and Tara Kalyani S***

This study suggests a systematic approach for the design of Coordinated-Control (COC) of Series Vectorial Compensator (SVEC) and Power System Stabilizers (PSSs), with desired eigen-values in the sliding mode. The Optimal Sliding Mode Control (OSMC) is developed to damp Low Frequency Oscillations (LFO) under the nominal load condition. Despite the fact that SVEC and PSS have been incorporated individually in multi machine networks, OSMC based on feedback control for coordination of SVEC and PSS has not been developed. So, the OSMC control for SVEC and PSS in the COC manner has been developed in this paper. The performance of the proposed controller is checked through eigen-value analysis and non-linear simulations under nominal load operation. The multi machine network is used for comparison purpose. The net results show that OSMC for COC of SVEC and PSS can offer better damping characteristics than without control.

Keywords: *Multi machine networks, oscillation damping, SVEC and PSS, sliding mode control, coordinated - control*

1.0 INTRODUCTION

The present Electrical Power Systems (EPS) have become complex due to various factors like rapid increase of power demand, placing of large synchronous machines, economy and environment etc. As a result, some areas of EPS become additional heavily loaded and are interconnected by weak tie lines. So these weak tie lines have impact on the EPS stability, and damping of LFO tends to decline, which further limits the capacity to transmit power. If damping signal failed to offer, size of those oscillations might keep rising till network is unstable.

The most efficient and economic method to suppress oscillations is placing of PSS in order that provision for control action through exciter of generators [1, 2]. In case of large faults, it is difficult for the PSS to supress LFO in a large scale network by itself. Latest developments in power electronics introduce the use of FACTS technology in EPS and become more economical as compared to a extension of transmission system [3]. Many authors designed the COC of FACTS and PSS based damping controllers for damping LFO which is discussed in the publications [4-6]. SVEC is a innovative series FACTS device presented to control reactance of line and represented as a PWM controlled capacitor [7-10]. SVEC with a simple circuit arrangement regulates the scale of series capacitive impedance through duty cycle of switching device [7]. Comparison of SVEC with TCSC in small system is presented in [8], where it shows that SVEC is smoother control alternative than the TCSC. Stability enhancement of SVEC with different controllers is demonstrated for different case studies [9]. In [10], the authors

*Department of Technical Education, Government of Andhra Pradesh,521108,himajak2000@yahoo.co.in, Mob: +91 9966761321
**Department of Energy Systems, Visionary Lighting and Energy, Hyderabad, 500085, surendra.ts@gmail.com
***Department .of Electrical Engineering, JNTU, Hyderabad, 500085, tarakalyani@gmail.com

discussed the systematic comparison of SVEC with SSSC depending on switching function and comparative estimation cost of two devices are also presented. Because, SVEC till now has practically not been designed in the market and placed in a EPS. The operation of SVEC with PID to supress LFO in a simple system explained in [11]. Application of SVEC with SSSC and damping of LFO presented in [12]. The authors presented the COC of PWMSC and PSS for damping LFO in multimachine networks using dynamic index is presented in [13].

The EPS model is highly nonlinear and its response is highly unpredictable and uncertain, for this type of nonlinear system with chaos OSMC is recommended by utkin [14] is very effective. This control strategy proposes OSMC for COC of SVEC and PSS and a systematic approach to damp LFO is introduced.

This paper is classified as follows. Section- II presents the EPS model. Section III presents the mathematical model of SVEC in a multi machine networks. Section-IV represents the design procedure of the COC of SVEC and PSSs applied to test system. Section-V presents the Optimal sliding mode controller. Section –VI represents the simulation results and discussions using eigen-value and time response plots for the Western System Coordinating Council (W.S.C.C) for 3- machine, 9- bus system. Conclusions are summarized in Section- VII.

2.0 POWER SYSTEM MODEL

The differential algebraic equations of EPS with a two- axis, IEEE- type-1 exciter as follows [15

$$\dot{X} = Ax + Bu \quad \text{...(1)}$$

$$0 = g(x, y) \quad \text{...(2)}$$

Where "x" is a state vector of each machine, "y" is the set of algebric variables means voltage and current at all buses, "u" is a set of input vector for each machine, and "g" is the stator algebric and network equations. Eq. (1) is the dimension of 7m and Eq. (2) is the dimension of 2(m+n) although, EPS is non - linear and linearized at a certain operating point. It can be defined in state-space as [15].

$$\begin{bmatrix} \Delta\dot{X} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} A' & B_1' & B_2' \\ C_1' & D_{11}' & D_{12}' \\ C_2' & D_{21}' & D_{22}' \end{bmatrix} \begin{bmatrix} \Delta X \\ \Delta Y_C \\ \Delta Y_B \end{bmatrix} + \begin{bmatrix} E_1 \\ 0 \\ 0 \end{bmatrix} \Delta u \quad \text{...(3)}$$

In Eq. (3), D22 is the load-flow jacobian J_{LF} and JAE is the network algebraic jacobian. The systemmatrix A_{sys} from Eq. (3) is obtained as

$$\Delta\dot{X} = A_{sys}\Delta X + E.\Delta U \quad \text{...(4)}$$

$$\text{Where } [A_{sys}]_{7m\times 7m} = [A'] - [B_1'.B_2'][J_{AE}']^{-1}\begin{bmatrix} C_1' \\ C_2' \end{bmatrix} \quad \text{..(5)}$$

When a PSS and SVEC damping controllers are placed to the system, the extra state variable corresponding to these controllers will be added to the system matrix.

3.0 SVEC

The SVEC, as novel series FACTS device is represented for damping of low frequency oscillations. The SVEC exploits the variable reactance compensation in power networks. The schematic diagram of SVEC device inserted in series with a transmission line is represented in Figure 1. SVEC mainly consist of (i) Primarily based identical switches S_{1R}, S_{1Y}, S_{1Z}, S_{2R}, S_{2Y} and S_{2Z} and (ii) the compensation capacitors C_R, C_Y, and C_Z. The control and performance of SVEC and switching operation is presented in ref [12, 16]. Figure 2 shows the SVEC single line diagram of Figure 1 and the proposed SVEC is placed between bus 1 and 2 as displayed in Figure 2. Assume a line 1, having reactance X_{12} , connected between buses 1 and 2 in Figure 2. If the reactance of the injected SVEC inserted in the line 1 is X_{SVEC}. In the secondary side, there is the SVEC converter and a bank of capacitors with reactance X_C. The equivalent reactance in the network 1 and 2 from Figure 2 can be calculated as following [11]

$$X_{Total} = X_{12} + X_{SVeC} \quad \text{...(6)}$$

The relation between the reactance of the network and duty cycle can be defined as [9]

$$X_{SVeC} = -K^2(1 - D_S)^2 X_C \quad ...(7)$$

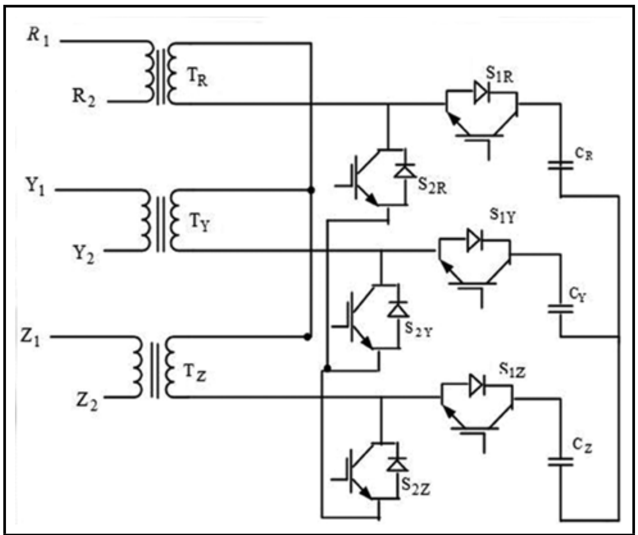


FIG 1. PWM SVcC INSERTED IN ATRANSMISSION LINE

Where X_C the capacitor reactance, transformer turns ratio is K and D_S is the term duty ratio is defined as the ratio of the on-state to the total switching period. Eq. (7) shows that changing duty cycle D_S is adjusted to provide equivalent reactance X_{SVEC}.

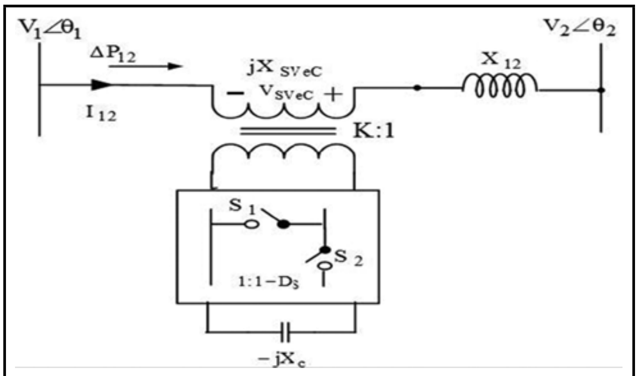


FIG 2. SINGLE LINE DIAGRAM OF WITH SVEC

Limits imposed by SVEC is D_S. Thus $X_{SVECmin} \leq X_{SVEC} \leq X_{SVECmax}$, The active power flow in the network 1 and 2 can be describe as

$$P_{12} = \frac{V_1.V_2}{X_{Total} - k^2(1 - D_S)^2.X_C}\sin(\theta) \quad ...(8)$$

The main disadvanges in TCSC are, harmonics are that present when the switches are gated at line frequency and open-circuit operating conditions and need several milliseconds to vary the firing angle of thyristors, and these drawbacks can be overcome by retrieving with ac controllers. On the other hand a synchronous type PWM is required in SSC; this leads to many complexities in control infrastructure.

4.0 PSS AND SERIES VECTORIAL COMPENSATOR DAMPING CONTROLLER

4.1 PSS

The PSS accomplishment through the exciter to give a factor of added damping force combine with speed deviation. It contains a transfer function having a gain block; wash out block and lead-l lag compensator. Phase compensator province is to control the phase lag between exciter and generator electrical torque [17]. Gain block serves the level of damping to the input. The wash-out block is omitted in this paper. Figure 3 shows the general block diagram of PSS damping controller. The transfer function of PSS structure is given by

$$\frac{V_S}{\Delta\omega_m} = K_{PSS}\ \frac{sT_w}{1+sT_w}\ \frac{1+sT_1}{1+sT_2} \quad ...(9)$$

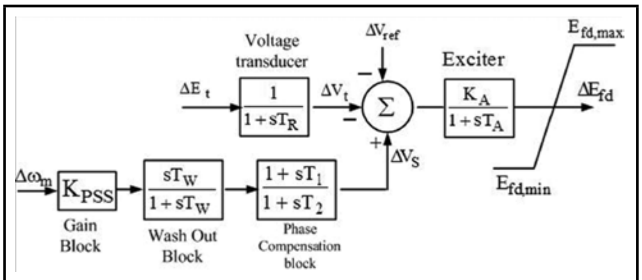


FIG 3. SIMPLIFIED BLOCK DIAGRAM FOR PROPOSED PSS

Where T_2 the lead is time constant and T_1 is the lag time constant. The input signal to the PSS is $\Delta\omega_m$ i.e. deviation in speed from synchronous speed and the output of PSS is the supplementary signal V_S. V_S is added to V_{Sref} and V_t to the exciter, so as to damp the LFO in a network. Therefore the system matrix A_PSS for a study network is $A\_PSS_{7m+1 \times 7m+1}$. So, test system eigen-values will be increased by one [18].

4.2 SVEC damping controller

The block diagram of SVEC based stabilizer is shown in Fig 4. It is similar to the PSS controller. The deviation in the duty ratio i.e. ΔD_S is taken into account as the output of damping controller. By vary the Damping Ratio (DR) the desired value of series compensation is obtained and it is added to the D_{Sref}. The value of reactance X_{SVEC} is automatically adjusted by vary the DR of IGBT switches.

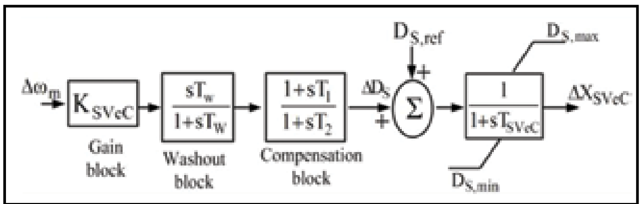


FIG 4. BLOCK DIAGRAM OF SVcC DANPING CONTROLLER

In COC of SVEC and PSSs results the extra state variables ΔV_{SI}, ΔDSi, ΔX_{SVECi} will be added to the A_{SYS}. The state variable ΔV_{Si} corresponding to PSS and ΔD_{si} and ΔX_{SVECi} are the state variables of the SVEC controller. The System matrix for COC of SVEC and PSS for multi machine network is $[(A\_COC)_{(8m+2)\times(8m+2)}]$. So, the test system eigen-values will be increased by three.

5.0 SLIDING MODE CONTROL

The optimal controller based on sliding mode theory is designed by the state feedback control law [14]. This state feedback control law is developed based on the design of sliding surface which is developed using optimal control parameters of the system. In robust control system the task of OSMC is primarily to transform system state on to switching hyper plane and then keep the plant parameters on the chosen surface of the hyper plane [19].

$$\dot{X} = Ax + Bu \qquad ...(10)$$

Define a similarity transformation as

$$Q = Hx \qquad ...(11)$$

Where the transformation matrix H is chosen so that

$$H = [N\ B]^T \qquad ...(12)$$

And the columns of the $n\times(n-m)$ matrix N are composed of basis vectors of the null space of B^T Substituting $x = H^{-1}Q$ from equ.11 into equ.10 we obtain

$$\dot{Q} = H\,A\,H^{-1}Q + HBu$$
$$= AQ + B\,u \qquad ...(13)$$

Where $A = HAH^{-1}$ and $B = HB$ Because of the special structure of the matrix H, the first (n-m) rows of B turn out to be zeros. Hence, the vector Q is decomposed as follows

$$Q = \begin{bmatrix} Q_1 \\ Q_2 \end{bmatrix} \qquad ...(14)$$

Where Q_1 and Q_2 are (n-m) and m-dimensional vectors, respectively. By partitioning equ.13 reduces to

$$\begin{bmatrix} Q_1 \\ Q_2 \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} Q_1 \\ Q_2 \end{bmatrix} + \begin{bmatrix} 0 \\ B_r \end{bmatrix} u \qquad ...(15)$$

A_{11}, A_{12}, A_{21} and A_{22} are the block matrices making up the HAH^{-1} matrix with appropriate dimensions. From equ.15

$$Q_1 = A_{11}Q_1 + A_{12}Q_2 \qquad ...(16)$$

$$Q_2 = A_{21}Q_1 + A_{21}Q_1 + B_r u \qquad ...(17)$$

Equ.16 may be viewed as the dynamics of open-loop network with state vector Q_1 and control signal Q_2. Since the pair A,B is assumed to be controllable, the pair A_{11}, A_{12} is also controllable. For m inputs, m hyper planes in the state space are defined as

$$S_i\ t\ = g_i^T X(t) \quad ; i = 1, 2 \ldots.m.$$

The change in the structure of the controller takes place on the hyperplane

$$S = G^T x = 0 \qquad ...(18)$$

Sub $x = H_{-1}Q$ in equ.18, the equ of the switching Hyperplane reduces to

$$S = G^T H^{-1} Q = 0 \qquad ...(19)$$

Writing $G^T H^{-1} = G1^T \; G_2$ where $G1$ is a (n-1) column vector and G_2 a scalar, equ. 19 can be written as

$$G_1{}^T Q_1 + G_2 Q_2 = 0 \qquad ...(20)$$

Without loss of generality, we can assume that $G_2=1$, and the control signal Q_2 can be expressed as

$$Q_2 = -G_1^T Q_1 \qquad ...(21)$$

Using eqns. 16 and 21 we obtain the equations of the OSMC in the closed loop form as

$$Q_1 = \; A_{11} - A_{12} G_1^T \; Q_1 = A_C Q_1 \qquad ...(22)$$

The eigen-values of the matrix A_C may be placed arbitrarily in the complex plane, since the pair (A_{11}, A_{12}) is controllable. By a suitable choice of the vector G_1

The algorithm for the realization of the switching vector and hence the switching hyperpalne can be summarised as follows

1. Select the transformation matrix H (equ.11)
2. Compute the vector G1 such that eigen-values of the matrix A_C characterising the dynamics in the OSMC have desirable placement.
3. Choose the equation of the hyper plane to be of the form

$$S = \; G_1^T \; 1 \; Hx = 0 \qquad ...(23)$$

The following are the limitations in the OSMC theory as

a. More complexity in programming when applying this methodology to multi input and multi output higher order nonlinear systems.

b. Adjustment of optimal parameters is more difficult to obtain desired sliding surface to attain good dynamic response.

6.0 SIMULATION RESULTS AND DISCUSSIONS

The OSMC control for COC of SVEC and PSSs is modeled and simulated by using MATLAB /SIMULINK™. The performance of test system is checked by means of eigen-value analysis and non- linear time - domain simulation results under nominal load conditions are discussed in the following sections.

The system W.S.C.C 3 machine, 9 bus is used for test system. Figure 6. shows the COC of SVEC and PSS connected to the network. Full particulars of the test system are given in [15]. Outcome results were accomplished with the help of MATLAB. IEEE Type-I exciter is consider for all 3 generators.

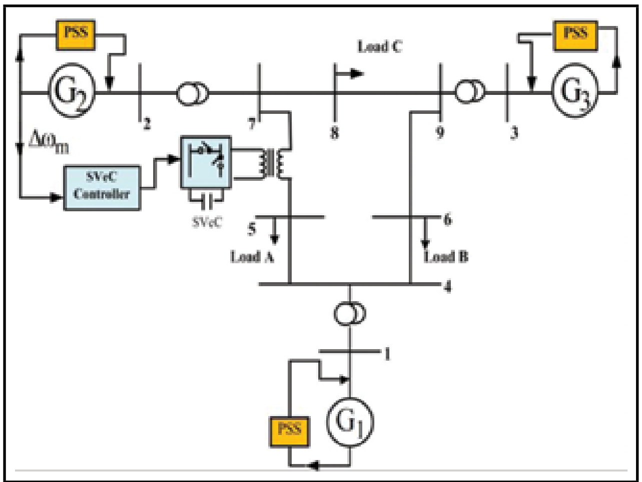


FIG 5. COC OF STUDY SYSTEM

6.1. Eigen-value analysis

A MATLAB/ Simulink program for the test system without control and OSMC control for COC of SVEC and PSS at nominal load condition has been carried out.

Table-1. lists the eigen-values of test system without control, total 21 eigen-values are present at nominal operating condition. In the total 21 eigen- values, two has zero magnitude, three are real and the remain 16 are complex conjugate. The eigen- values for W.S.C.C system without damping controller is most similar to with those described in [15]. In Table-1, without damping controller, the important dominant mode is (-0.1906 ± j 8.3666) and has the DR of 0.022 and therefore this mode has been referred to as critical swing mode. This DR can be improved by adding OSMC control for COC of SVEC and PSS to the network. So, the critical swing mode shifted to a most desirable position in the s plane.

The second column of Table.2 lists the eigen-values of test system for COC of SVEC and PSS with OSMC.

TABLE 1

EIGEN-VALUES OF TEST SYSTEM WITHOUT CONTROL.

Mode	Without Control	Damping Ratio (ζ)	Frequency (rad/sec)
Λ1	-0.7195 ± j12.745	0.056	12.8
Λ2	-0.1906±j 8.3666	0.022	8.37
Λ3	-5.6804 ±j 7.9656	0.581	9.78
Λ4	-5.3625 ±j7.9308	0.56	9.57
Λ5	-5.2280 ± j 7.8259	0.555	9.41
Λ6	-5.1777,-3.3983	1,1	5.18, 3.399
Λ7	-0.4511 ±j 1.2003	0.352	1.28
Λ8	-0.4478 ±j 0.7295	0.523	0.856
Λ9	-0.4362 ± j 0.4871	0.667	0.654
Λ10	0.0000,0.0000	1,1	0,0
Λ11	-3.1250	1	3.125

The SVEC has been located in the transmission line 5-7 and for each generator, PSS is installed in each machine separately a speed-input PSS has been equipped mandatorily to each machine is shown in Figure 6. Damping i.e 0.01 assumed for all the 3 machines, respectively and series compensation level is chosen as 0.5. The SVEC parameters are assumed as K_S=20, K_n =1, T_n =0.1s and X_C=0.5 p.u. The gain parameters for the both PSS and SVEC are kept identical for each step. In the COC of SVEC and PSS results 26 eigen-values are present. It has been observed that the critical swing mode Λ2 has been moved to (-1.2513 ± i 8.207) on the imaginary axis of the complex s plane and has the DR of 0.1510 respectively. Additional improvement of damping in the COC of SVEC and PSS with OSMC is 0.129.

TABLE 2

EIGEN- VALUES OF TEST SYSTEM FOR COC OF SVEC AND PSS WITH OSMC

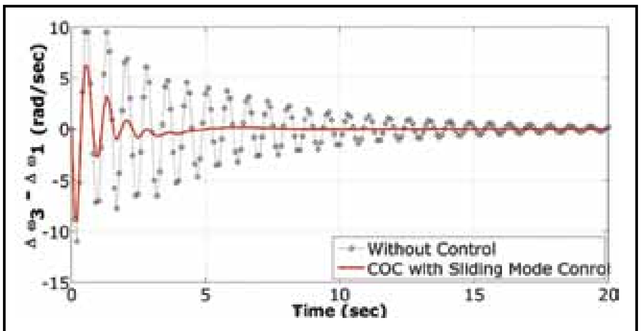
Mode	OSMC control	Damping Ratio (ζ)	Frequency (rad/sec)
Λ1	-0.8654 ± i12.893	0.0670	12.9000
Λ2	-1.2513 ± i 8.207	0.1510	8.3000
Λ3	-5.4573± i 8.2137	0.5530	9.8600
Λ4	-5.4564 ± i 7.418	0.5930	9.2100
Λ5	-5.1975 ±i 7.8503	0.5520	9.4100
Λ6	-7.4191, -9.0321	1.0, 1.0	7.42,9.03
Λ7	-0.4818 ± i 1.206	0.3710	1.3000
Λ8	-0.4750 ± i 0.721	0.5500	0.8640
Λ9	-0.2945 ± i0.6219	0.4280	0.6880
Λ10	-1.0000, -9.0909	1.0,1.0	1.0,9.09
Λ11	-9.1769, -9.1037	1.0,1.0	9.17,9.10
Λ12	-5.1490, -3.3793	1.0, 1.0	5.1590, 3.3793
Λ13	-1.2529,- 3.1250	1.0, 1.0	1.25, 3.125

It is observed that the COC of SVEC and PSS with OSMC can simultaneously improving the damping of the test system compared to the no control and influences the EPS stability.

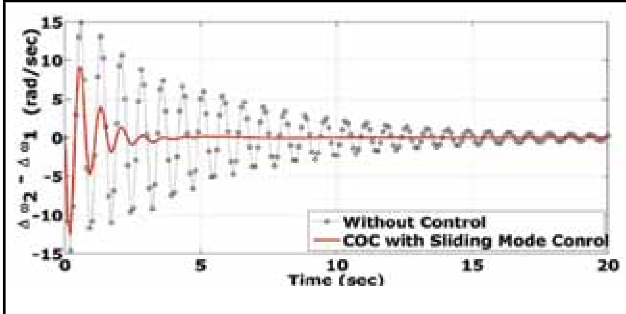
6.2 Time-response analysis

The time response analysis is simulated in MATALB. The non-linear time-response result has been checked by with the COC of SVEC and PSS with OSMC and without damping controller. The rotor angle and angular speed response has been plotted in Figure 7. Whereas ω_1, ω_2 and ω_3 are the rotor speed of machine 1, 2 and 3, respectively. Similarly δ1, δ_2 and δ_3 are the rotor angle of machine 1, 2 and 3 respectively. These Figure 7. (a) to (d) indicate the capability of the proposed COC of SVEC and PSS with OSMC control in reducing the settling time, peak overshoot and damping LFO.

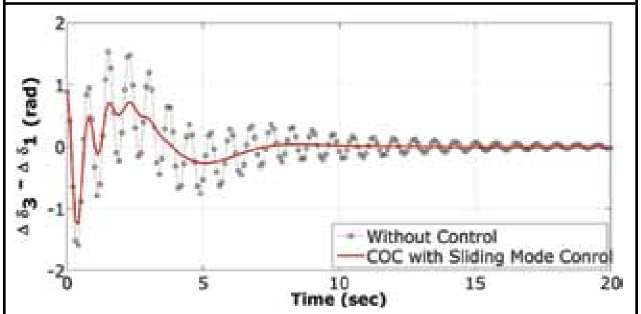
The performance of any network can be checked with settling time and peak overshoot. For better results the peak overshoot should be minimized with settling time. From the Table-3 observed that the COC of SVEC and PSS with OSMC provides better results interms of settling time, peak over shoot to damp rotor angle oscillations compared to without controller. Figs 7(a) to 7(b), shows the responses of the angular velocity deviation and, respectively. Moreover, the settling time of these oscillations for is = 19.75 s and 4.5318 s, respectively and is = 19.78 s and 3.4128 s, respectively for without control, and with COC of SVEC and PSS with OSMC. Also, the overshoot for is 2.67 %, and 1.648 %, respectively and is 3.95 %, and 2.4202 % respectively for without control, and with COC of SVEC and PSS with OSMC. Figs 7(c) to 7(d), shows the responses of the rotor angle deviation and, respectively. The results show that the proposed COC of SVEC and PSS with OSMC have an excellent capability in damping LFO. Moreover, the settling time of these oscillations for is = 18.82 s, and 9.5106, respectively and is = 18.81 s and 8.0237 s, respectively for without control, and with COC of SVEC and PSS with OSMC. Also, the peak



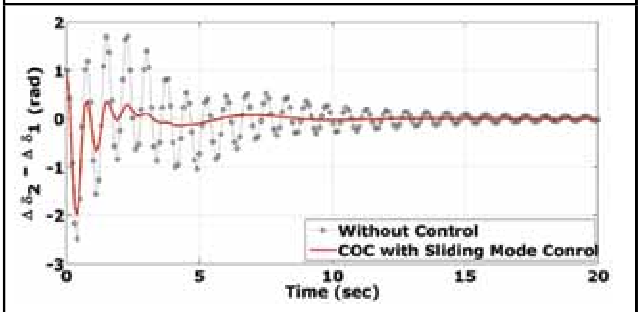
(A). DEVIATION IN ANGULAR VELOCITY Δω31



(B). DEVIATION IN ANGULAR VELOCITY Δω21 .



(C). DEVIATION IN GENERATOR ROTOR ANGLE Δδ31.



(D). DEVIATION IN GENERATOR ROTOR ANGLE Δδ21.

FIG 6. ROTOR ANGLE AND ANGULAR VELOCITY RESPONSES OF THE SYSTEM WITHOUT CONTROLLER AND COC OF SVEC AND PSS WITH OSMC

overshoot for δ31 is 0.84 %, and 0.6 %, respectively and δ_{21} is 0.95 %, and 0.52 %, respectively for without control, and with COC of SVEC and PSS with OSMC. From the results, the COC of SVEC and PSS with OSMC is more effective controller than without control to damp LFO

TABLE 3				
SETTLING TIME AND % OF PEAK OVERSHOOT OF TEST SYSTEM				
Name of the controller	**Settling time (Seconds)**			
	$\omega 3 - \omega 1$	**$\omega 2 - \omega 1$**	**$\delta 3 - \delta 1$**	**$\delta 2 - \delta 1$**
Without controller	19.7574	19.7856	18.8268	18.8143
With COC of SVEC and PSS with OSMC	4.5318	3.4128	9.5106	8.0237
% of peak overshoot				
Without controller	2.67 %	3.9538 %	0.84 %	0.95 %
With COC of SVEC and PSS with OSMC	1.648 %	2.4202 %	0.6 %	0.52 %

7.0 CONCLUSION

In this paper an approach for COC of SVEC and PSS with OSMC for power oscillation damping has been proposed. The approach is verified by means of eigen-value analysis and time-response results. At nominal load the eigen-values has been examined. The time-response results at without control and COC of SVEC and PSS with OSMC are compared. The results obtained for a W.S.C.C test system demonstrate the applicability of the controller and its ability to damp LFO at nominal loading condition. It can be concluded that the proposed COC of SVEC and PSS with OSMC has better in damping LFO in keeping small signal stability. Our future research would be developing COC of SVEC and PSS with OSMC to damp the LFO at different loading conditions.

REFERENCES

[1] P Kundur, M Klein, G.J.Rogers and M.S.Zywno, Application of power system stabilizers for enhancement of overall system stability, IEEE Transactions on Power Systems, Vol. 4, No.2 , pp.614-626, May 1989.

[2] A Ahmed , BA - Muqabel, and Mohammad A. Abido, Review of conventional power system stabilizer design methods, Proceedings of IEEE conference, pp.1-7, March 2006.

[3] N H Hingorani, L Gyugyi, Understanding FACTS: Concepts and Technology of Flexible AC Transmission System. Wiley-IEEE press, 2000.

[4] Xianzhang Lei, E N Lerch, and D Povh, Optimization and coordination of damping controls for improving system dynamic performance, IEEE Transactions Power Systems, Vol.16, No.3, pp.473-480, Aug 2001.

[5] P Pourbeik and M J Gibbard, Simultaneous coordination of power-system stabilizers and FACTS device stabilizers in a multimachine power system for enhancing dynamic performance, IEEE Transactions Power Systems Vol.13 , No.2, pp.473-479, May 1998.

[6] Jaun M Ramirez, and Isidro Castillo, I, PSS and FDS simultaneous tuning, Electric Power Systems research, Vol.68, No.1, pp.33-40, January 2004.

[7] L A C Lopes and G Joos, Pulse width modulated capacitor for series compensation, IEEE Transactions Power electronics, Vol. 16, No.2, pp.167-174, March 2001.

[8] G Venkataramanan and B K Johnson, Pulse width modulated series compensator, IEEE Proceedings of Generation, Transmission and Distribution,. Vol.149, No., 1, pp.71-75 August 2002.

[9] J M Gonzalez, C A Canizares and J M Ramirez, Stability modeling and comparative study of series vectorial compensators, IEEE Transactions Power Delivery, Vol. 25 , No.2, pp.1093-1103,April 2010.

[10] F.Mancilla-David, S Bhattacharya, and G Venkataramanan, A comparative evaluation of series power – flow controllers using DC and AC-link converters, IEEE Transactions

Power Delivery, Vol. 23, No.2, pp.985-996, March 2008.

[11] L Wang and D-N Truong, Dynamic stability enhancement of a single-machine infinite bus system using a series vectorial compensator, Proceedings of IEEE conference, pp.1-6, May 2013

[12] L Wang , D-N Truong, Application of a SVEC and a SSSC on damping improvement of a SG- based power system with a PMSG-based offshore wind farm, Proceedings of IEEE conference, pp.1-7, July 2012 .

[13] A Safari, H Shayeghi, and H Ali Shayanfar, Coordinated control of pulse width modulation based AC link series compensator and power system stabilizers, Electrical Power and Energy systems, Vol.83, pp.117-123, Dec .2016.

[14] Vadim Utkin, Sliding Modes in Control and Optimization, Springer –Verlag,1992.

[15] P W Sauer, and M A Pai, Power System Dynamics and Stability, New Jersey, 1st ed, Prentice–Hall publisher, 1998.

[16] K Himaja,T S Surendra and S Tara Kalyani, Coordinated design of PSS and Series vectorial compensator controllers for damping power system oscillations, Journal of Electrical Engineering, Vol 16, No 4, pp.507-512, Dec 2016.

[17] P Kundur, N J Balu, and M G Lauby, Power system stability and control. Vol.7 , McGraw- hill, New york,1994.

[18] Debasish Mondal, Abhijit Chakrabarti and Aparajita Sengupta ,Power System Small Signal Stability and Control: Academic Press, Elsevier.2014.

[19] Duy-Kynguyen, Sliding-mode control: Advanced Design Techniques, 1998.

[20] Stanislaw H Zak,Systems and Control, Oxford University Press, 2003,