International Journal of Smart Electrical Engineering, Vol.10, No.4, Fall 2021
ISSN: 2251-9246
EISSN: 2345-6221
pp. 197:202

Improvement Damping Power System Oscillations by Using Static Synchronous Series Compensator

Majid Dehghani*[1,3], Mehdi Mahdavian[2], AliAsghar Amini[1,3]

[1] Department of Electrical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran
[2] Department of Electrical Engineering, Naein Branch, Islamic Azad University, Naein, Isfahan, Iran
[3] Smart Microgrid Research Center, Najafabad Branch, Islamic Azad University, Najafabad, Iran

---

Abstract

From a steady state point of view, FACTS devices operate by increasing or decreasing voltage, supplying or absorbing reactive power, and controlling the impedance of a series of transmission lines or phase angles. There are two types of power fluctuation damping controllers in power systems: power system stabilization (PSS) and FACTS POD controllers. The planning and operation condition of electrical power systems are changing due to a variety of causes. Flexible ac transmission system (FACTS) controller helps in raising dynamic stability limit and provide better power flow control. Static synchronous series compensator (SSSC) is one of the important members of series FACTS controller, which consists of a solid-state voltage source inverter coupled with a transformer that is connected in series with a transmission line. In this paper is presented the effect of SSSC for damping power system oscillation. The complete digital simulation is performed in the Matlab Simulink environment.

Keywords: FACTS Controller, Static Synchronous Series Compensator, Damping, Oscillation
Article history: Received 16-Jun-2021; Revised 15-Aug-2021; Accepted 15-Oct-2021.

---

1. Introduction

From the steady-state point of view, FACTS devices operate by increasing or reducing voltage, supplying or absorbing reactive power and controlling the series impedance of transmission lines or phase angle [1,2]. FACTS controller can be classified in four main categories [3,4]: shunt controller, series controller, series-series controller and series-shunt controller [5,6]. A systematic classification of the FACTS devices is presented in Fig. 1 [7].

In recent years, flexible ac transmission system (FACTS) devices equipped with a power oscillation damper (POD) have been also efficiently used for damping oscillations of power system [8,9]. Generally, there are two kinds of power oscillation damping controllers in power systems: power system stabilizer (PSS) [10,11] and FACTS POD controllers [12,13].

A method for designing of PSS based on sliding mode control technique is presented in [14], which the control objective is to enhance stability and improve the dynamic response of the multi-machine power system and, also, the main approach is to focus on the control performance which later is proven to have the degree of shorter reaching time and lower spike.

Interaction analysis also provides a practical tool for quantifying and simultaneously evaluating the relative effect of both PSS and FDS on damping of rotor oscillation modes, which examines the interactions between stabilizers in multi-machine power systems in [15] has been. Interactions may increase or decrease the damping of some rotor oscillation modes.

An investigation of low-frequency oscillation and damping of stochastic solar power integrated power system by a UPFC-based dual optimal controller is presented in [16], which gains are optimised by a novel hybrid PSO and improved grey wolf optimiser.

Simultaneous design method of STATCOM controller parameters and PSS in multi-machine power system has been developed in [17], in which the bee colony colony algorithm has been used to search for optimal controller parameters.

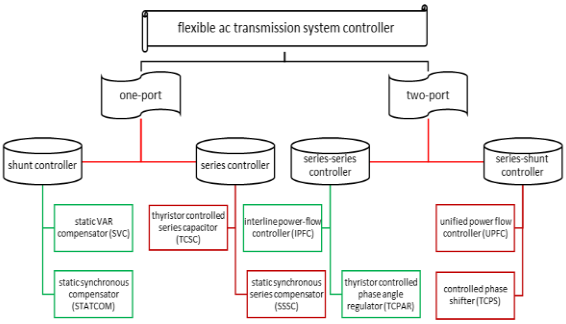

Fig. 1. Classification of the FACTS controller

The implement coordination of multi-type FACTS such as UPFC, SSSC and thyristor controlled series compensator (TCSC) for available transfer capability enhancement are study in [18], which a hybrid real power flow performance index and particle swarm optimisation (PSO) are used.

To adjust the parameters of FACTS devices, genetic algorithm and particle swarm optimization algorithm using fuzzy logic techniques have been used in [19], which are two types of FACTS devices. TCSC and Static Compensator (SVC) are used to optimize reactive power consumption and reduce line congestion.

The distributed SSC capability is used to reduce simultaneous resonance in [20], in which two conventional damping control controllers are designed and implemented in the traditional SSC distribution controller to provide effective damping.

An important member of the FACTS family is the static synchronous compensator (SSSC) [21,22], which has the ability to provide reactive power compensation in the power system. There are various uses for this compensator, such as power fluctuation damping [23,24] and improved stability in the power system [25].

The linear quadratic Gaussian (LQG) method has been used to design a powerful TCSC controller to increase the damping of power system fluctuations in [26], which the problems of using ring transfer recovery method to store LQG damping control resistor are investigated.

An implementation related to a new damping control algorithm for a STATCOM in a series offset wind farm to reduce SSR and damping power system fluctuations is mentioned in [27], that based on a nonlinear optimization design method, the auxiliary sub-synchronous damping control loop is intended for STATCOM to respond to damping torque in the critical torsional frequency range.

A control scheme for reducing low frequency fluctuations and voltage deviations of a multi-machine power system has been developed using a static synchronous compensator based on ant colony optimization [28], in which the control scheme consists of two different proportional integral controllers. To control the gate signal in the SSC as well as the time domain results of the rotor dynamics and the deviation in the generator voltage for different test cases, the proposed controller potential shows a general reduction in power system fluctuations.

The results of improving the stability and current control of a DFIG-based offshore wind farm shown using the SSSC in [29], in which the oscillation damping controller is designed using modal control theory.

An adaptive fuzzy neural inference system based on the POD controller is proposed for low frequency oscillations induced by induction motors in ac/dc composite microgrids in [30], which the complementary POD controller is built into the energy storage system controller, which provides additional damping power commensurate with frequency deviation.

The stability issues of a wind farm based on a variable wind speed induction generator with variable wind speed in a strong and weak power system have been investigated in [31] in which the effect of PSS and SSSC on the stability of wind energy system, considering IEEE 14 bus test system is analysed.

The SSSC is an important device to control transmission line impedance, and so to power flow control independent of the line current. In this paper, the application of SSSC in damping power system oscillation is investigated. Matlab Simulink software package is used for the simulations.

2. Static synchronous series compensator

SSSC is a series connected FACTS devices which can be installed in series in the transmission lines. It is very effective in controlling power flow in a transmission line with the capability to change its reactance characteristic from capacitive to inductive [32].

When the SSSC operates in induction mode, the injected voltage directs the line current and thus the reactive power is absorbed. In the capacitive state, the injected voltage lags behind the line current and therefore reactive power is injected into the transmission line. As shown in Fig. 2, the SSSC injects an AC voltage into the transmission line via a transformer.

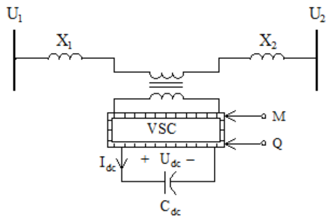

Fig. 2. SSSC in power system

U1 and U2 are the bus voltages and Udc is the dc voltage source. X1 represents the equivalent reactance between the bus 1 and the SSSC, and X2 represents the equivalent reactance between SSSC and the bus 2. The converter voltage is varied by changing the M is the amplitude modulation ratio and ϕ is the phase angle modulation ratio. A capacitor connected on the dc side of the VSC acts as a dc voltage source. The SSSC output voltage is defined by the following equation [33]:

$$U_S = M U_{dc}(\cos\phi + j\sin\phi) \tag{1}$$

The differential equation of the dc voltage is given below:

$$\frac{dU_{dc}}{dt} = \frac{M}{C_{dc}}(i_q cos\varphi + i_d sin\varphi) \tag{2}$$

where id and iq are the d and q axes currents of transmission line. The structure of SSSC-based controller is shown in Fig. 3. The input signal of the proposed controller is the rotor angle deviation (Δδ) and the output signal is the injected voltage Vs. The structure consists of a gain block with gain KP, a signal washout block with the time constant TW and two-stage phase compensation blocks.

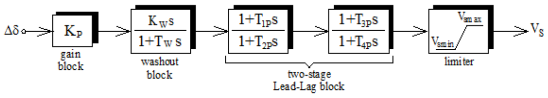

Fig. 3. Structure of SSSC-based controller

3. System under study

The simulation bock diagram of the power system with a SSSC in Matlab/Simulink environment is shown in Fig. 4. The parameter of the power system is listed in table 1.

The power grid consists of two power substations and a major load center on the B3 bus. To model the load center, a dynamic load model is used in which the active and reactive power absorbed by the load is a function of the system voltage. The L2 line is divided into two parts to simulate a three-phase fault at the midpoint of the line.

Table.1.
System Parameters

Components	***Value***
SSSC	S_n=100 MVA, U_{dc}=40 KV Cdc=375 μF, X_{eq}=0.16 pu
power generation substation (M1)	6×350 MW
power generation substation (M2)	4×350 MW
load center	2200 MW
line L_1	280 Km
line L_2	300 Km
line L_3	50 Km
POD	K_P=0.08, T_W=1 s, K_W=1, T_{P1}=1 s, T_{P2}=0.1 s, V_{smin}=-0.1, V_{smax}=0.1

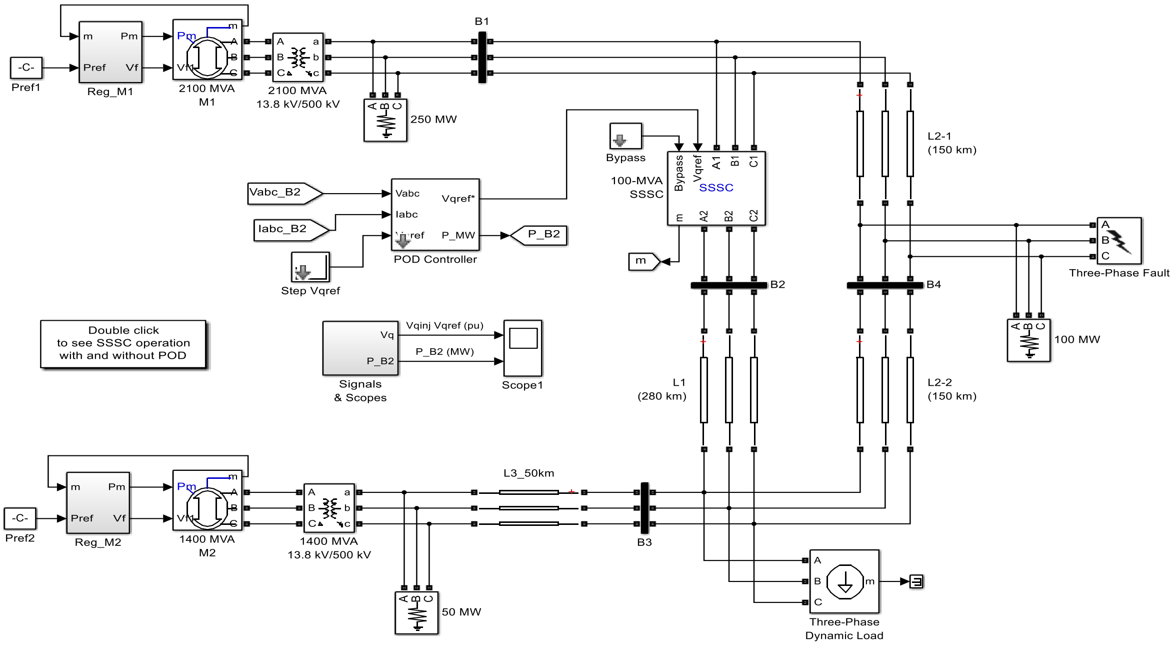

Fig. 4. Simulation block diagram of the power system with a SSSC in Matlab/Simulink

Figures 5 and 6 show the active power and reactive power measured in the bus. As can be seen, when the SSSC is bypassed, the current flows to the main load: 664 MW on L1, 563 MW on L2 and 990 MW on L3.

There are measured at bus B2, B4 and B3, respectively. The SSSC, located at bus B1, is in series with line L1. It has the ability to inject up to 10% of the system nominal voltage. A POD controller whose output is connected to the SSSC Uq input normally regulates the SSSC injected voltage reference. The POD controller inputs are the bus voltage at B2 and the current at L1.

4. Simulation Results

The input of the POD controller (reference voltage Uq) is zero. At t = 2 s, Uq is equal to 0.08 pu (inductive SSSC) and at t = 6 s, Uq is equal to 0.08 pu (capacitive SSSC).

Active current in line L1, measured in bus B2, is shown in fig. 7. Depending on the voltage injected, the current in the line varies from 575 to 750 MW. A comparison of SSSC performance with and without POD control is shown in fig. 8.

Previously, SSSC with POD controller was a very effective tool to reduce power fluctuations. The active output power of machine M1 for the two items is shown in the figs. 9 and 10. Also the rotation speed is shown in the fig. 11 and 12, and the excitation sound is shown in the figs. 13 and 14 for two M1 devices.

5. Conclusion

With the expansion of the modern power system, damping oscillations play an important role in the power system. This paper presents the effect of SSSC for power system oscillation damping. This study was performed in Matlab using Simulink and PSB toolboxes. The simulation results show that the SSSC controller is very efficient in damping power fluctuations.

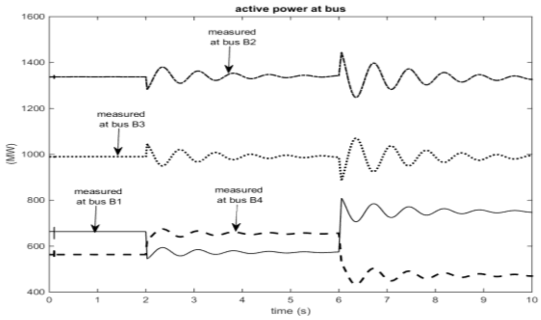

Fig. 5. Active power is measured on buses

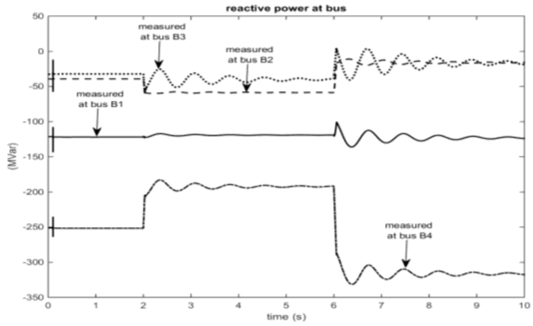

Fig. 6. Reactive power is measured on buses

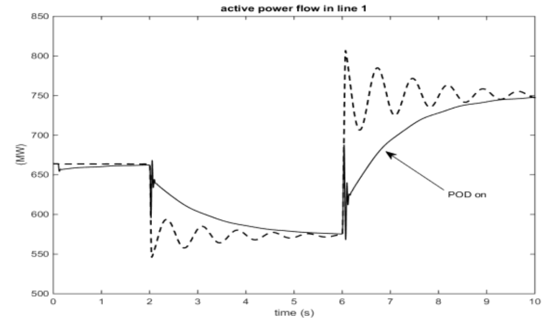

Fig. 7. Active power flow in line 1 where SSSC operates with and without POD

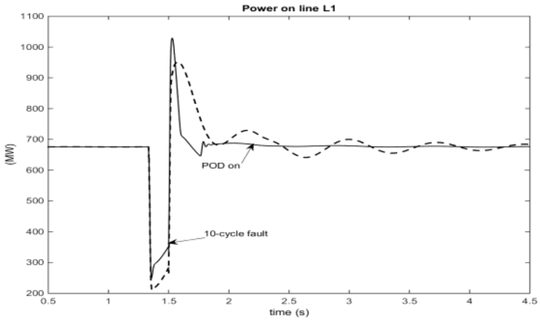

Fig. 8. Power flow in line 1 where SSSC without POD

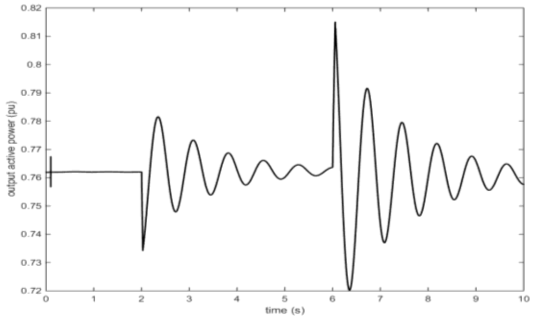

Fig. 9. Output active power without POD

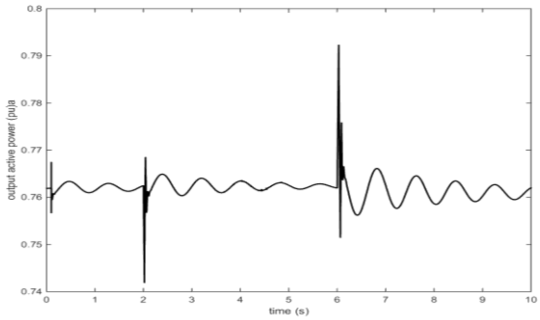

Fig. 10. Output active power without POD

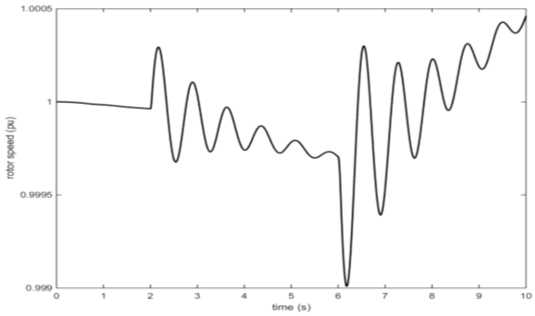

Fig. 11. Rotor speed without POD

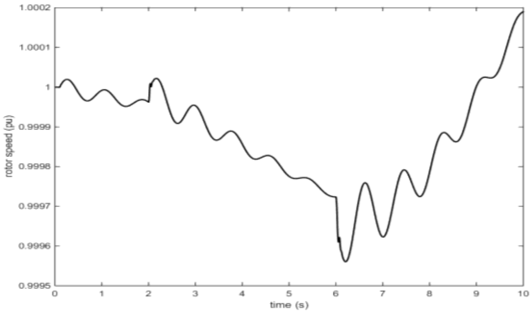

Fig. 12. Rotor speed without POD

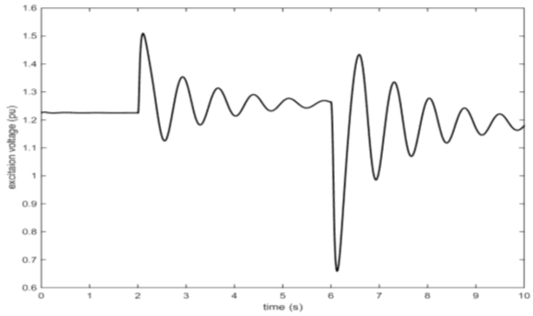

Fig. 13. Excitaion voltage without POD

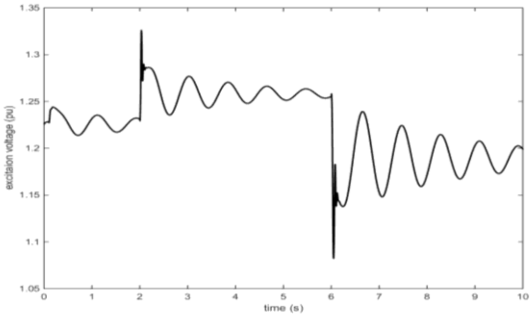

Fig. 14. Excitation voltage with POD

References

[1] A. Bakhtiari, S. Javadi, “UPFC siting and sizing in power network using two different evolutionary algorithm”, International Journal of Smart Electrical Engineering, vol. 05, no. 03, pp. 161-167, 2016.

[2] G. Shahgholian, E. Haghjoo, A. Seifi, I. Hassanzadeh, "The improvement DSTATCOM to enhance the quality of power using fuzzy-neural controller", Journal of Intelligent Procedures in Electrical Technology, Vol. 2, No. 6, pp. 3-16, Summer 2011.

[3] G. Shahgholian, J. Faiz, "Coordinated control of power system stabilizer and FACTS devices for dynamic performance enhancement- State of art", Proceeding of the IEEE/IEPS, pp. 1-6, Kyiv, Ukraine, June 2016.

[4] P. Bhatt, S.P. Ghoshal, R. Roy, "Load frequency stabilization by coordinated control of thyristor-controlled phase shifters and superconducting magnetic energy storage for three types of interconnected two-area power systems", International Journal of Electrical Power and Energy Systems, vol. 32, pp. 1111–1124, 2010.

[5] G. Shahgholian, B. Bayat, "A new control technique for improving the oscillations and decreasing the harmonic components of voltage in STATCOM", International Review of Electrical Engineering, Vol. 6, No. 6, pp. 3163-3174, 2011.

[6] A. Motaghi, M. AaLIzadeh, M. Abbasian, “Reactive power compensation and reducing network transmission losses by optimal placement of parallel and series FACTS devices with fuzzy-evolutionary method”, Journal of Intelligent Procedures in Electrical Technology, vol. 9, no. 35, pp. 27-38, Autumn 2019.

[7] G. Shahgholian, "Development of state space model and control of the STATCOM for improvement of damping in a single-machine infinite-bus", International Review of Electrical Engineering, Vol.4, No.6, pp.1367-1375, Nov./Dec. 2009.

[8] F. H. Gandoman, A. Ahmadi, A. M. Sharaf, P. Siano, J. Pou, B. Hredzak, V. G. Agelidis, "Review of FACTS technologies and applications for power quality in smart grids with renewable energy systems", Renewable and Sustainable Energy Reviews, Vol. 82, pp. 502-514, Feb. 2018.

[9] O. Ziaee, F.F. Choobineh, "Optimal location-allocation of TCSC devices on a transmission network", IEEE Trans. on Power Systems, Vol. 32, No. 1, pp. 94-102, Jan. 2017.

[10] O. Kahouli, M. Jebali, B. Alshammari, H.H. Abdallah, "PSS design for damping low-frequency oscillations in a multi-machine power system with penetration of renewable power generations", IET Renewable Power Generation, Vol. 13,No. 1, pp. 116-127, Jan. 2019.

[11] M. Zamani, G. Shahgholian, "Coordinated design of power system stabilizer and variable impedance devices to increase damping of inter-area modes using genetic algorithm", Iranian Journal of Electrical and Computer Engineering, Vol. 17, No. 4, pp. 271-278,Winter 2020.

[12] A. Kazemi-Zahrani, M. Parastegari, “Designing PSS and SVC Parameters simultaneously through the improved quantum algorithm in the multi-machine power system”, Journal of

Intelligent Procedures in Electrical Technology, vol. 8, no. 31, pp. 68-75, Autumn 2017.

[13] D. Rai, S. O. Faried, G. Ramakrishna, A. Edris, "Damping inter-area oscillations using phase imbalanced series compensation schemes", IEEE Trans. on Power Systems, vol. 26, no. 3, pp. 1753-1761, Aug. 2011.

[14] G. Shahgholian, A. Rajabi, B. Karimi, M. Yousefi, "Design of power system stabilizer based on sliding mode control theory for multi- machine power system", Journal of Intelligent Procedures in Electrical Technology, vol. 1, no. 1, pp. 13-22, Winter 2010.

[15] M. J. Gibbard, D. J. Vowles, P. Pourbeik, "Interactions between, and effectiveness of, power system stabilizers and FACTS device stabilizers in multimachine systems", IEEE Trans. on Power Systems, vol. 15, no. 2, pp. 748-755, May 2000.

[16] N. Nahak, R. K. Mallick, "Investigation and damping of low-frequency oscillations of stochastic solar penetrated power system by optimal dual UPFC", IET Renewable Power Generation, vol. 13, no. 3, pp. 376-388, Feb. 2019.

[17] S. Fazeli-Nejad, G. Shahgholian, M. Moazzami, "Artificial bee colony algorithm based approach for power system oscillation damping with PSS and STATCOM", International Journal of Research Studies in Electrical and Electronics Engineering, vol. 5, no. 1, pp. 27-39, 2019.

[18] A. A. Sadiq, M. Buhari, S. S. Adamu, H. Musa, "Coordination of multi-type FACTS for available transfer capability enhancement using PI–PSO", IET Generation, Transmission and Distribution, vol. 14, no. 21, pp. 4866-4877, Feb. 2020.

[19] S. Ghasemi, E. Gholipoor, "Reactive power optimization in the presence of FACTS devices using evolutionary algorithms based on fuzzy logic", Journal of Intelligent Procedures in Electrical Technology, vol. 6, no. 23, pp. 45-54, Autumn 2015.

[20] J. Khazaie, M. Mokhtari, M. Khalilyan, D. Nazarpour, "Sub-synchronous resonance damping using distributed static series compensator (DSSC) enhanced with fuzzy logic controller", International Journal of Electrical Power and Energy Systems, Vol. 43, No. 1, pp. 80–89, Dec. 2012.

[21] S. Galvani, B. Mohammadi-Ivatloo, M. Nazari-Heris, S. Rezaeian-Marjani, "Optimal allocation of static synchronous series compensator (SSSC) in wind-integrated power system considering predictability", Electric Power Systems Research, vol. 191, Article number: 106871, Feb. 2021.

[22] J. Gholinezhad, M. Ebaadian, M. Aghaerrahimi, "Coordinated design of PSS and SSSC damping controller considering time delays using biogeography-based optimization algorithm", International Journal of Smart Electrical Engineering, vol. 03, no. 04, pp. 239-246, 2014.

[23] R. Pillay Carpanen, B.S. Rigby, "A contribution to modelling and analysis of SSSC-based power flow controls and their impact on SSR", Electric Power Systems Research, Vol. 88, pp. 98–111, July 2012.

[24] N. Ullah, M. Asghar Ali, R. Ahmad, A. Khattak, "Fractional order control of static series synchronous compensator with parametric uncertainty", IET Generation, Transmission and Distribution, vol. 11, no. 1, pp. 289-302, May 2017.

[25] S. Panda, S.C. Swain, A.K. Baliarsingh, "Real-code genetic algorithm for roboust coordinated design of excitation and SSSC-based controller", Journal of Electrical Engineering, Vol. 8, No. 4, 2008.

[26] K. M. Son, J. K. Park, "On the robust LQG control of TCSC for damping power system oscillations", IEEE Trans. on Power Systems, vol. 15, no. 4, pp. 1306-1312, Nov. 2000.

[27] M.S. El-Moursi, B. Bak-Jensen, M.H. Abdel-Rahman, "Novel STATCOM controller for mitigating SSR and damping power system oscillations in a series compensated wind park", IEEE Trans. on Power Electronics, vol. 25, no. 2, pp. 429-441, Feb. 2010.

[28] L. Wang, Q.S. Vo, "Power flow control and stability ımprovement of connecting an offshore wind farm to a one-machine ınfinite-bus system using a static synchronous series compensator", IEEE Trans. on Sustainable Energy, Vol. 4, No. 2, pp. 358-369, April 2013.

[29] R. Kumar, R. Singh, H. Ashfaq, "Stability enhancement of multi-machine power systems using Ant colony optimization-based static Synchronous Compensator", Computers and Electrical Engineering, Vol. 83, Article 106589, May 2020.

[30] M. Ahmed, A. Vahidnia, M. Datta, L. Meegahapola, "An adaptive power oscillation damping controller for a hybrid AC/DC microgrid", IEEE Access, vol. 8, pp. 69482-69495, 2020.

[31] J. Bhukya, V. Mahajan, "Optimization of damping controller for PSS and SSSC to improve stability of interconnected system with DFIG based wind farm", International Journal of Electrical Power and Energy Systems, Vol. 108, pp. 314-335, June 2019.

[32] V.S. Cheung, H.S. Chung, K. Wang, A.W. Lo, "Paralleling multiple static synchronous series compensators using daisy-chained transformers", IEEE Trans. on Power Electronics, vol. 29, no. 6, pp. 2764-2773, June 2014

[33] S.M. Abd Elazim, E.S. Ali, "Optimal SSSC design for damping power systems oscillations via gravitational search algorithm", International Journal of Electrical Power and Energy Systems, Vol. 82, pp. 161–168, Nov. 2016.