Signal Processing and Renewable Energy
March 2022, (pp. 99-111)
ISSN: 2588-7327
eISSN: 2588-7335

Analysis and Simulation Dynamic Behavior of Power System Equipped with PSS and Excitation System Stabilizer

Arman Fattollahi [1,2], Majid Dehghani *[1,2], Mohammad Reza Yousefi [1,2]

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

Received: 24-Sep-2021, Revised: 02-Nov-2021, Accepted: 10-Jan-2022.

Abstract

Power system is a nonlinear and temporal variable system. Different parts of the system change at different times and times with changing loads or loss of generators and disturbances. Power system stability and attenuation of low frequency fluctuations are very important. To increase the damping power and stability of the dynamic system, power system stabilizers are used to reduce fluctuations by generating additional control signals for the generator excitation system. In this paper, to improve the stability of the power system dynamic, a power system stabilizer based on synergistic control theory with an excitation system stabilizer according to a simplified nonlinear power system is used. The power system stabilizer has been studied in a single machine system connected to an infinite bus. The results show that the use of power system stabilizer and excitation system stabilizer for all nonlinear dynamic systems performs better than synergistic PSS, conventional PSS, and a system without stabilizer.

Keywords: Stability, Power System Stabilizer (PSS), Excitation System Stabilizer (ESS), Dynamic Behavior.

1. INTRODUCTION

Power systems are always subject to various disruptions [1]. In other words, electromechanical oscillations are an inherent phenomenon in power systems, which result from the dynamic behavior of the system in transferring the operating point after the occurrence of the disturbance [2].

A way to prevent these types of oscillations is to add additional control loops

---

***Corresponding Authors Email:** dehghani@pel.iaun.ac.ir

[3]. Low frequency electromechanical oscillations in an interconnected power system usually continue for a long time [4,5]. In some cases, these oscillations may place limitations on the transmission system [6]. Synchronous generators have two automatic controllers, one for regulating the terminal voltage and the other for frequency control [7]. The controllers indirectly affect the active output power and reactive power of the synchronous generator [8,9]. The voltage regulator controller operates faster than other controllers and is more stable than the speed controller for the system [10].

Power system stabilizer (PSS) is the most common controller for improving the damping of electromechanical oscillations [11]. This controller helps to eliminate oscillation by generating an additional control signal for the excitation system [12]. Conventional PSS using lead-lag compensators operate according to the linear power system model, and various methods have been proposed in studies to improve its performance [13].

A microcontroller-based PSS is designed in [14], that increases the dynamic stability of the single-machine infinite-bus power system by improving damping in the low frequency oscillation. Also, the system stability is investigated by the eigenvalues and the results of dynamic simulations are provided in the time domain.

A method for designing of PSS (lead-lag compensation type) based on sliding mode control (SMC) technique is presented in [15], 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.

A novel bat algorithm-based method is proposed for designing the parameters of power system stabilization and power oscillation damping in a multi-machine power system in [16], which aims to ensure the minimum damping rate in low frequency electromechanical oscillation modes.

To minimize low-frequency oscillations in a power system, an interval type-2 fractional order fuzzy proportional integral derivative-PSS is proposed in [17], where speed deviation and acceleration are considered as input signals. Also, a hybrid firefly algorithm-particle swarm optimization scheme for optimizing the parameters is used.

The power system is nonlinear and variable with time, and its setpoints are always variable, so the good performance of the CPSS, which is based on the linear system model, cannot be guaranteed for the power system in very dynamic operating conditions.

Synergy control theory is a nonlinear method and is consistent with the nonlinear and dynamic nature of the power system.

This paper uses a nonlinear model of a single machine power system. Synergistic power system stabilizer (SPSS) and excitation power system (ESS) are used to dampen power system fluctuations. The simulation results are compared with the results [18]. The rest of this article is set out as follows.

2. SYNERGETIC CONTROL METHOD

In this section an overview about designing synergetic control based on compressed regulator is presented. Given a nonlinear system in the following state space from [19,20,21]:

$$\dot{x} = f(x, u, t) \tag{1}$$

where x and u are the system state variable vector and the input vector respectively. In this method, control variable φ is defined as follows:

$$\varphi = \varphi(x, t) \tag{2}$$

Then consider that the φ must satisfy the following equation, by synergetic control the system is forced to act in φ=0.

$$T\dot{\varphi} + \varphi = 0, T\rangle 0 \tag{3}$$

where T is time constant and φ is control variable. φ specifications that include: goal of control, restrictions output, and settling time is defined by the designer. By using the chain differentiation obtained:

$$\dot{\varphi} = \frac{d\varphi}{dx}\dot{x} \tag{4}$$

Therefore, the control law can be found as:

$$u = u(x, \varphi(x, t), T, t) \tag{5}$$

It can be seen that the control output depends not only on the system state variable, but also on the selected φ and time constant T. From the synthesis procedure of synergetic controller shown above, it is clear that the synergetic controller works on the full nonlinear system and does not need any linearization or simplification on the system model at all as is necessary for application of traditional control theory [22,23].

3. POWER SYSTEM MODEL

Fig. 1 shows the connection of a machine to the infinite bus with the controllers. In this system, a synchronous generator is powered by a turbine and a governor and is excited by an external excitation system. The excitation system is controlled by an automatic voltage regulator (AVR), an excitation system stabilizer (ESS) and a power system stabilizer (PSS). The equations of the single-machine system connected to the infinite bus are given in various papers [24,25]. Fig. 2 shows the excitation system stabilizer (ESS) [26,27].

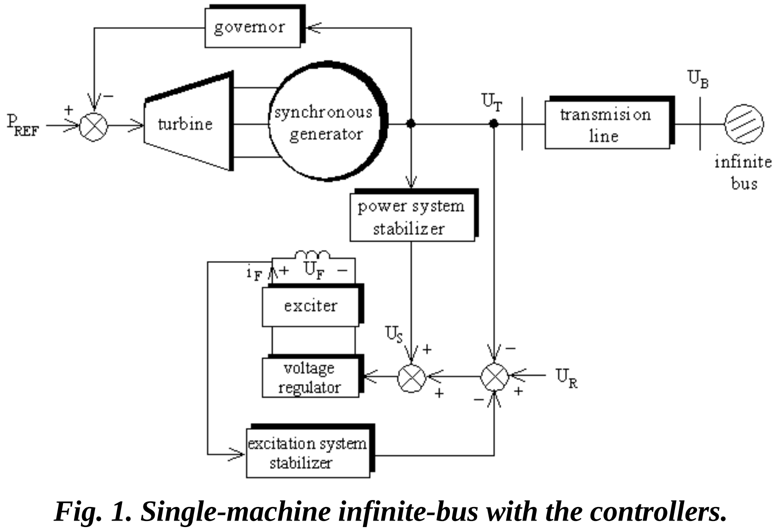

Fig. 1. Single-machine infinite-bus with the controllers.

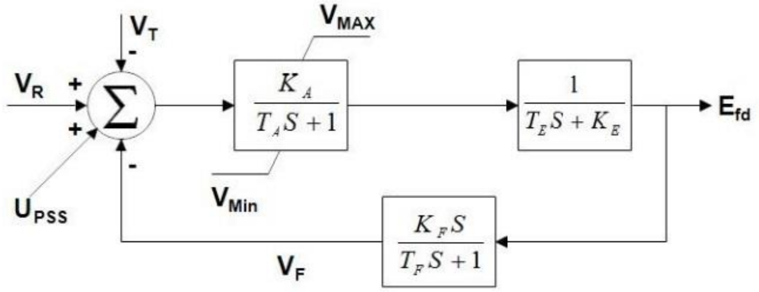

Fig. 2. DC1 IEEE excitation system model

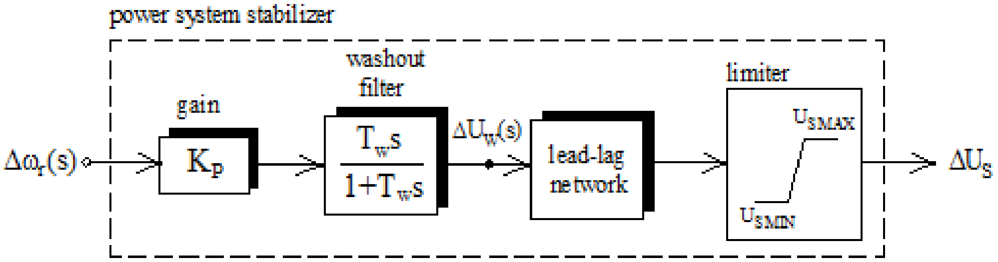

Fig. 3. Block diagram of conventional power system stabilizer (CPSS).

3.1. Power System Stabilizer.

In this paper, two types of conventional power system stabilizer (CPSS) and the synergetic power system stabilizer (SPSS) are used.

CPSS consists of an amplifier, a washout filter, two lead-lag compensators, and a limiter. The block diagram of CPSS is shown in Fig. 3. In CPSS, the input signal (control signal) stabilizing the power system is the rotor speed deviation ($\Delta\omega_r$).

In SPSS for stabilizing the generator speed, rotor speed deviation and output active electrical power deviation of generator (ΔP_e) are used [28,29].

For designing SPSS, the control variable defines as follow:

$$\varphi_1 = K_1(\omega - \omega_{ref}) - (P_e - P_{ref}) \qquad (6)$$

where K1 is a constant coefficient and ω_{ref} and P_{ref} are the reference values of output active power and rotor angular speed of the generator respectively. As mentioned in the second part, the objective of the synergetic controller is to force the system to operate on φ_1=0. Therefore:

$$T_1 \dot{\varphi}_1 + \varphi_1 = 0 \qquad (7)$$

T_1 represents the system converge speed in to the manifold of φ_1=0 and K_1 is the value of the controller parameter, and always T_1> 0.

The chain derivation rule and by using the equation of P_e, PSS output can be obtained as follow:

$$U_{PSS} = \frac{1}{K_E} E'_q + \frac{E'_q - E_b \mathrm{Sin}\delta}{K_E X'_{dE}} (X_d - X'_d) - V_R$$
$$- \frac{T'_{d0} E'_q \mathrm{Cos}\delta}{K_E \mathrm{Sin}\delta} 2\pi f(\omega - \omega_0)$$
$$+ \frac{T'_{do} K_1 X'_{dE}}{K_E E_b \mathrm{Sin}\delta} \frac{1}{2H} [P_m - P_e - K_D(\omega - \omega_0)]$$

$$-\frac{T'_{d0}\,X'_{dE}}{K_E E_b \mathrm{Sin}\delta}\frac{1}{T_1}[K_1(\omega-\omega_{ref})-(P_e-P_{ref})] \qquad (8)$$

UPSS represents the desired control function for PSS.

4. SIMULATION RESULTS

In this section, to evaluate the effect of the control method on the dynamic stability of the power system, a simulation of a single-machine power system connected to an infinite bus in the time domain is performed. Nominal parameters for the power system are given in Table 1 [30]. Simulation results are obtained using MATLAB software.

Three types of disturbances are investigated, including step change in reference terminal voltage, step change in input mechanical power, and three-phase short circuit fault.

In each scenario, the power system (a) without PSS (No PSS), (b) with CPSS, (c) with SPSS, and (d) with SPSS and ESS (new PSS) are compared.

Table 1. ***System parameters studied for simulation.***

Quantity	Parameters
Generator	X_d=1.2, X'_d=0.6, X_q=0.55, X_L=0.1, X_T=0.1, T'_{d0}=6.5s, P_m=1, D=5, H=3s, f=60hz
ST1 IEEE excitation system	T_A=0.01s, K_A=50, K_E=1
DC1 IEEE excitation system	T_A=0.02s, T_E=0.8s, T_F=0.2s, K_A=50, K_F=0.3, K_E=1
CPSS parameters	K_{PSS}=5.5, T_W=3s, T_1=0.7s, T_2=0.11s, T_3=0.7s, T_4=0.11s, $U_{Pss,Max}$=1.5, $U_{Pss,Min}$= -1.5
SPSS parameters	K_1=0.1, T_1=0.1, $U_{Pss,Max}$=1.5, $U_{Pss,Min}$= -1.5

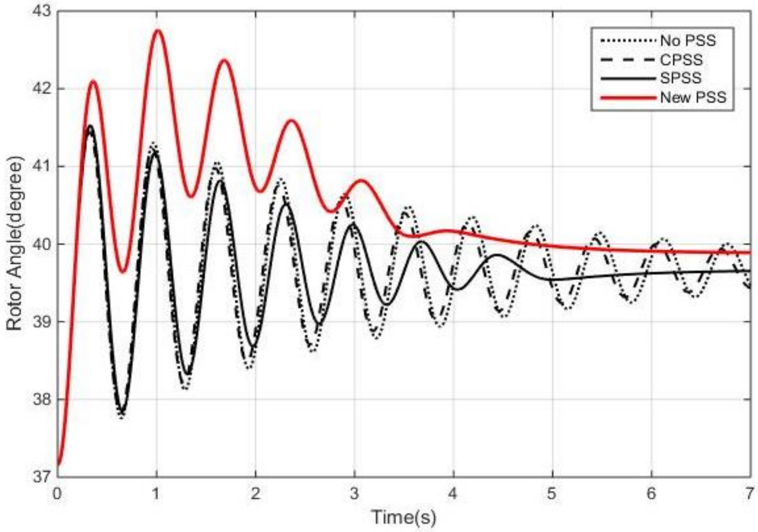

Fig. 4. Rotor angle response to step change in the input mechanical power.

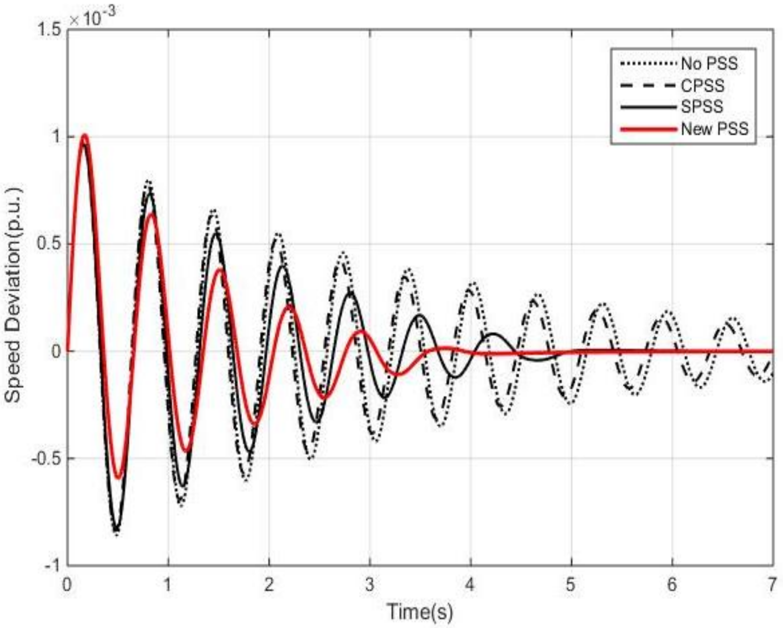

Fig. 5. Speed deviation response to step change in the input mechanical power.

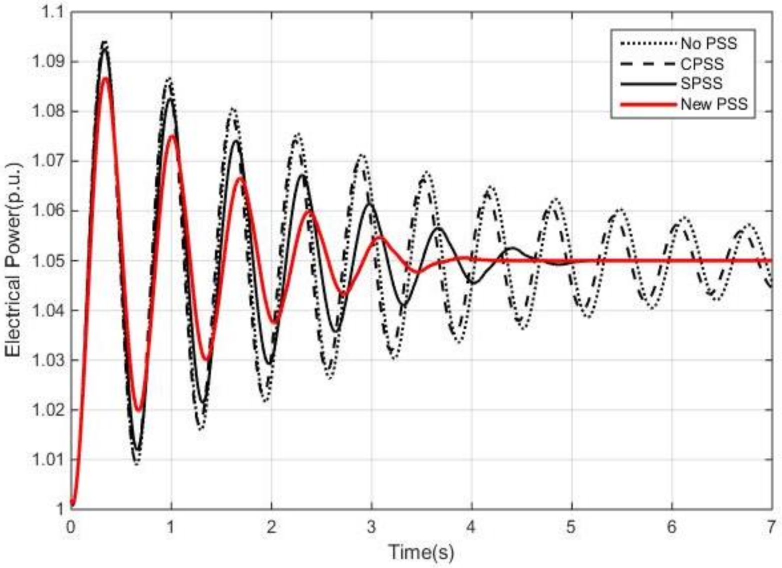

Fig. 6. Active electrical power response to step change in the input mechanical power.

4.1.Change in the Input Mechanical Power

In this case, a step change of 0.05 in the mechanical power of the input occurs at time zero.

The simulation results including rotor angle, speed deviation and active electrical power are shown in Figs. 4, 5 and 6, respectively. The combination of SPSS and ESS compared with CPSS, caused a reduction the 33.54% in maximum overshoot, and the 52.5% in settling time. Also, compared to SPSS, there is a 31% reduction in the maximum ups, and 24% in the settling time of the generator-torque rotor response speed.

4.2.Change in reference terminal voltage

In this case, a 0.05pu step change occurred in the generator reference terminal voltage at 0 sec. The simulation results are shown in Figs. 7, 8, and 9.

As can be seen, the simultaneous use of power system stabilizer and excitation system stabilizer has better results than NOPSS, or CPSS, or SPSS power system in damping oscillation. The new stabilizer compared to the CPSS Creates 46.1% reduction in the maximum overshoot and 80% reduction in settling time and compared

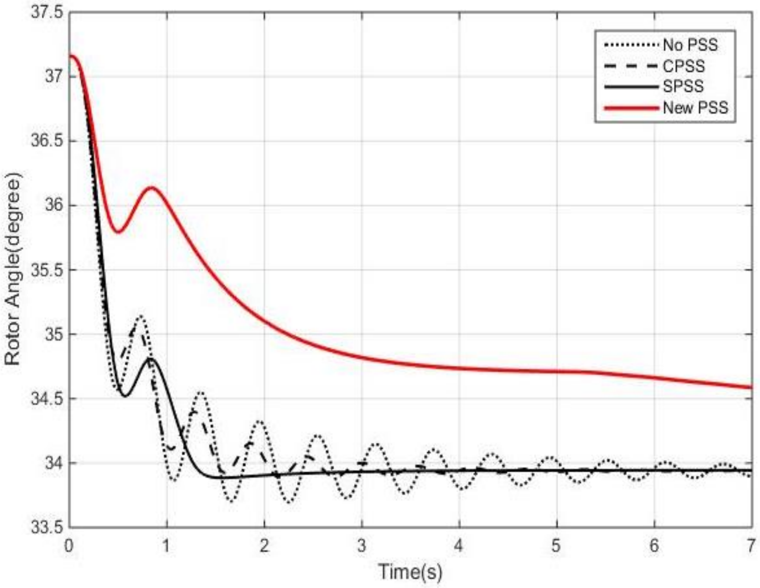

Fig. 7. Rotor angle response to step change in reference terminal voltage.

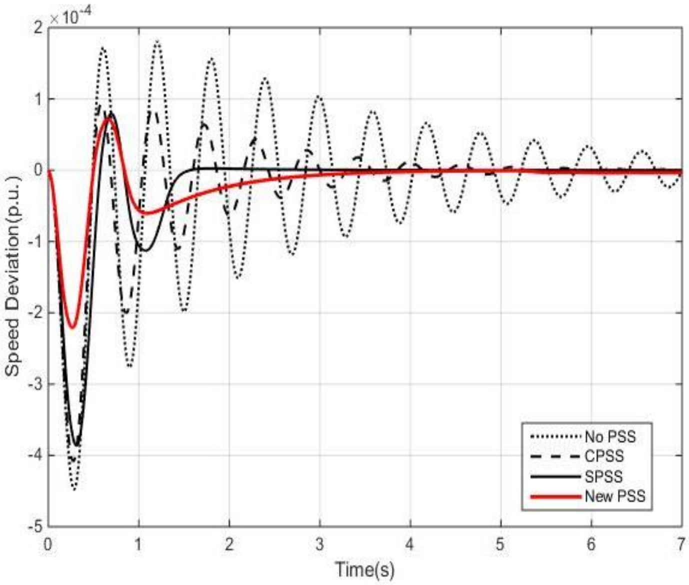

Fig. 8. Speed deviation response to step change in reference terminal voltage.

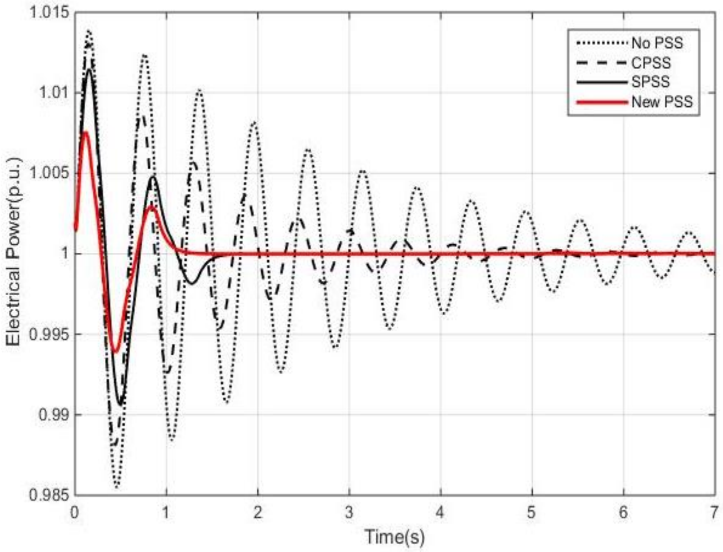

Fig. 9. Active electrical power response to step change in reference terminal voltage.

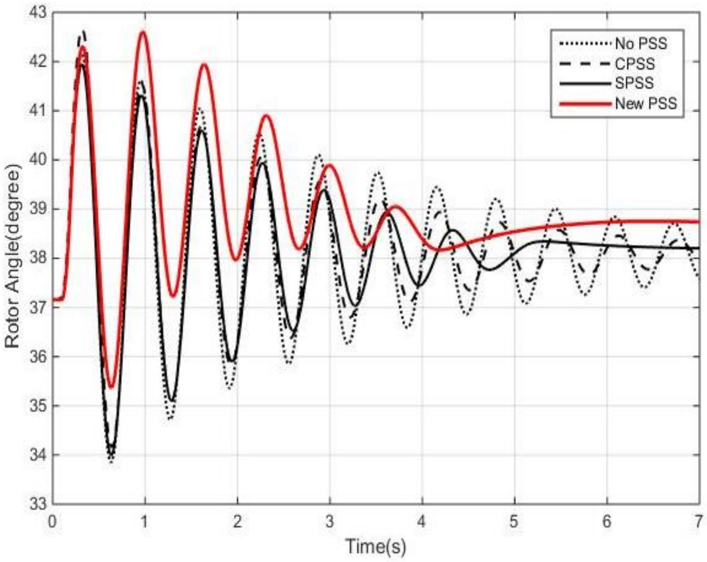

Fig. 10. Rotor angle response to three-phase short-circuit fault.

to the SPSS creates 43% reduction in the maximum overshoot and 29% reduction in settling time of generator rotor speed response.

4.3. Three-Phase Short-Circuit Fault

In this case, a three-phase short-circuit fault occurred on the infinite bus at 0 sec, and then one of the parallel transmission lines was switched off at 0.1 sec when the fault was cleared.

The results of the simulations which indicate more damping impact of using the combined synergetic power system stabilizer and excitation system stabilizer compared to non-PSS, or the CPSS, or the SPSS are shown in the Figs. 10, 11, and 12. The new PSS compared to the CPSS Creates 11% reduction in the maximum overshoot and 44% reduction in settling time and compared to the SPSS creates 8% reduction in the maximum overshoot and 20% reduction in settling time of generator rotor speed response.

Comparison of simulation results for three disturbances in power system, which in this section, time-domain simulations for these disorders are shown, is listed in Table (2).

As can be seen, the new PSS reduces the maximum height and decreases the settling time compared to the CPSS and SPSS.

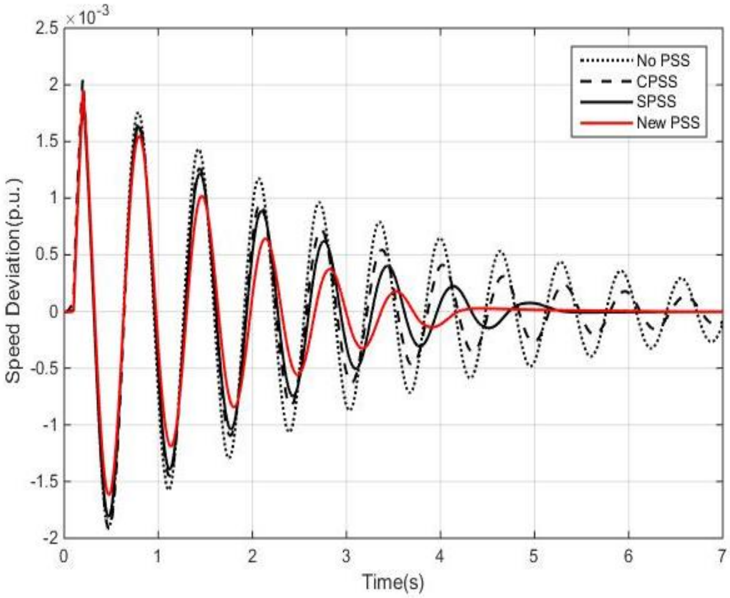

Fig. 11. Speed deviation response to three-phase short-circuit fault.

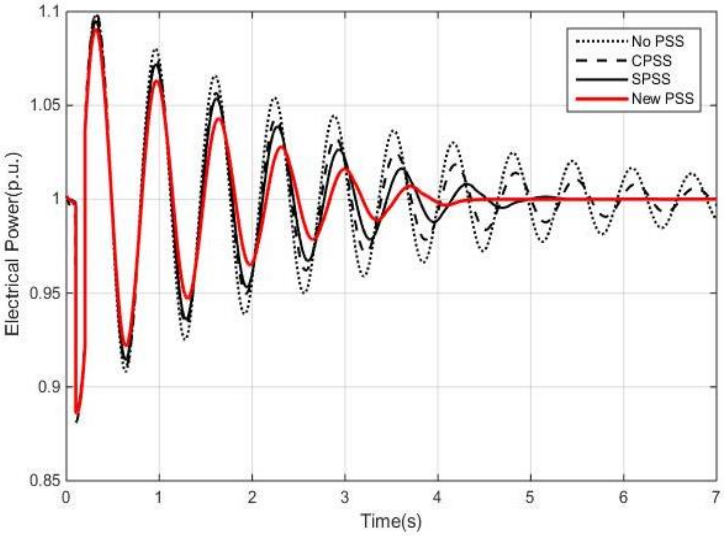

Fig. 12. Active electrical power response to three-phase short-circuit fault.

Table 2. ***Comparison of simulation results for three disturbances in power system.***

Type of disturbance in the system	maximum overshoot		settling time	
	CPSS	SPSS	CPSS	SPSS
Three-phase short-circuit fault	11% reduction	8% reduction	44% reduction	20% reduction
Change in the input mechanical power	33.54% reduction	31% reduction	52.5% reduction	24% reduction
Change in reference terminal voltage	46.1% reduction	43% reduction	60% reduction	29% reduction

5. CONCLUSION

Synthesis of synergistic power system stabilizer (SPSS) and exciter system stabilizer (ESS) have been used to control electromechanical oscillation. In this paper, a single machine infinite bus system is used for testing and comparing the approach. In this method, the linearization problems of the nonlinear power system model, such as simplification and ignoring various parameters, have been solved. The new stabilizer was investigated with three different disturbances, including step change in reference terminal voltage, a step change in input mechanical power, and three-phase short-circuit fault. The synergetic power system stabilizer and exciter system stabilizer in more effective and stronger compared to system with non-PSS or with the CPSS and or with SPSS.

REFERENCES

[1] E. Hosseini, G. Shahgholian, "Output power levelling for DFIG wind turbine system using intelligent pitch angle control", Automatika, Vol. 58, No. 4, pp. 363-374, 2017.

[2] G Shahgholian, A Movahedi, "Coordinated control of TCSC and SVC for system stability enhancement using ANFIS method", International Review on Modelling and Simulations, Vol. 4, No. 5, pp. 2367-2375, 2011.

[3] G. Shahgholian, S. Fazeli-Nejad, M. Moazzami, M. Mahdavian, M. Azadeh, M. Janghorbani, S. Farazpey, "Power system oscillations damping by optimal coordinated design between PSS and STATCOM using PSO and ABC algorithms", Proceeding of the IEEE/ECTI-CON, Chiang Mai, Thailand, pp. 1-6, July 2016.

[4] G. Fan, F. Yang, P. Guo, C. Xue, S.G. Farkoush, J.K. Majd, “A new model of connected renewable resource with power system and damping of low frequency oscillations by a new coordinated stabilizer based on modified multi-objective optimization algorithm”, Sustainable Energy Technologies and Assessments, vol. 47, Article Number: 101356, Oct. 2021.

[5] N. Taheri, H. Orojlo, F. Ebrahimi, "Damping controller design in offshore wind power plants to improve power system stability using fractional order PID controllers based on optimized

exchange market algorithm", Journal of Intelligent Procedures in Electrical Technology, vol. 13, no. 51, pp. 91-110, Dec. 2022.

[6] 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.

[7] Z. Ping, X. Li, W. He, T. Yang, Y. Yuan, “Sparse learning of network-reduced models for locating low frequency oscillations in power systems”, Applied Energy, vol. 262, Article Number: 114541, March 2020.

[8] G. Chen, Z. Li, Z. Zhang, S. Li, "An improved ACO algorithm optimized fuzzy PID controller for load frequency control in multi area interconnected power systems", IEEE Access, vol. 8, pp. 6429-6447, 2020.

[9] G. Shahgholian, K. Khani, M. Moazzami, "The Impact of DFIG based wind turbines in power system load frequency control with hydro turbine", Journal of Iranian Dam and Hedroelectric, Vol. 1, No. 3, pp. 38-51, Winter 2015.

[10] F. Liu, Y. Li, Y. Cao, J. She, M. Wu, "A two-layer active disturbance rejection controller design for load frequency control of interconnected power system", IEEE Trans. on Power Systems, vol. 31, no. 4, pp. 3320-3321, July 2016.

[11] 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.

[12] G. Zhang et al., "Deep reinforcement learning-based approach for proportional resonance power system stabilizer to prevent ultra-low-frequency oscillations", IEEE Trans. on Smart Grid, vol. 11, no. 6, pp. 5260-5272, Nov. 2020.

[13] S. Ghosh, Y.J. Isbeih, M.S. El Moursi, E.F. El-Saadany, "Cross-Grampian model reduction approach for tuning power system stabilizers in large power networks", IEEE Trans. on Power Systems, vol. 35, no. 3, pp. 1911-1922, May 2020.

[14] A. Abedini, G. Shahgholian, B. Fani, “Power system dynamic stability improvement using PSS equipped with microcontroller”, *International Journal of Smart Electrical Engineering*, vol. 10m no. 2, pp. 67-76, Spring 2021.

[15] 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.

[16] E.L. Miotto, P.B. Araujo, E.V. Fortes, B.R. Gamino, L.F.B. Martins, "Coordinated tuning of the parameters of PSS and POD controllers using bioinspired algorithms", IEEE Trans. on Industry Applications, vol. 54, no. 4, pp. 3845-3857, July-Aug. 2018.

[17] P.K. Ray, S.R. Paital, A. Mohanty, Y.S.E. Foo, A. Krishnan, H.B. Gooi, G.A.J. Amaratunga, "A hybrid firefly-swarm optimized fractional order interval type-2 fuzzy PID-PSS for transient stability improvement", IEEE Trans. on Industry Applications, vol. 55, no. 6, pp. 6486-6498, Nov.-Dec. 2019.

[18] Z. Jiang, "Design of a nonlinear power system stabilizer using synergetic control theory", Electrical Power Systems Research, vol. 79, no. 6, pp. 855-862, June 2009.

[19] A. Fattollahi, G. Shahgholian, B. Fani, “Decentralized synergistic control of multi-machine power system using power system stabilizer”, Signal Processing and Renewable Energy, vol. 4, no. 4, pp. 1-21, Autumn 2020.

[20] L. Xiao, L. Zhang, F. Gao, J. Qian, "Robust fault-tolerant synergetic control for dual three-phase PMSM drives considering speed sensor fault", IEEE Access, vol. 8, pp. 78912-78922, 2020.

[21] M. Lotfi-Forushani, B. Karimi, G. Shahgholian, “Optimal PID controller tuning for multivariable aircraft longitudinal autopilot based on particle swarm optimization algorithm”, Journal of Intelligent Procedures in Electrical Technology, vol. 3, no. 9, pp. 41-50, June 2012.

[22] A. Fattollahi, “Simultaneous design and simulation of synergetic power system stabilizers and a thyristor-controller series capacitor in multi-machine power systems”, *Journal of Intelligent Procedures in Electrical Technology*, vol. 8, no. 30, pp. 3-14, Summer 2017.

[23] Z. Jiang, "Design of a nonlinear power system stabilizer using synergetic control theory", Electrical Power Systems Research, vol. 79, pp. 855-862, 2009.

[24] G. Shahgholian, P. Shafaghi, S. Moalem, M. Mahdavian, "Damping power system oscillations in single-machine infinite-bus power system using a STATCOM", Proceedding of the IEEE/ICCEE, pp.130-134, Dubai, Dec. 2009.

[25] B. Ahmadzade, G. Shahgholian, F. M. Tehrani, M. Mahdavian, "Model predictive control to improve power system oscillations of SMIB with fuzzy logic controller", Proceeding of the IEEE/ICEMS, pp. 1-5, Beijing, China, Aug. 2011.

[26] J.H. Al-Gizia, M.W. Mustafaa, N.A. Al-geelanib, M.A. Alsaedi, "Sugeno fuzzy PID tuning, by genetic-neutral for AVR in electrical power generation", Applied Soft Computing, vol. 28, pp. 226-236, March 2015.

[27] M.A. Mahmud, "An alternative LQR-based excitation controller design for power systems to enhance small-signal stability", International Journal of Electrical Power and Energy Systems, vol. 63, pp. 1-7, Sec. 2014.

[28] A. Shoulaie, M. Bayati-Poudeh, G. Shahgholian, “Damping torsional torques in turbine-generator shaft by novel PSS based on genetic algorithm and fuzzy logic”, Journal of Intelligent Procedures in Electrical Technology, vol. 1, no. 2, pp. 3-10, Sept. 2010.

[29] G. Shahgholian, "Power system stabilizer application for load frequency control in hydro-electric power plant", Engineering Mathematics, Vol. 2, No. 1, pp. 21-30, Feb. 2017.

[30] P. Kundur, M. Klein, G. Rogers, "Application of power system stabilizers for enhancement of overall system stability", IEEE Trans. on Power Systems, vol. 4, no. 2, pp. 614-626, May 1989.