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An Optimized Proportional Integral Derivative (PID) based Power System Stabilizer (PSS) for Damping of Active Power Oscillations

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Abstract:
Rising load demand and possibilities of short interruptions either due to temporary faults or equipment switching may lead to transient instability in terms of growing oscillations and eventually result in cascaded outages if not being damped properly and timely. To dampen such oscillations, the power system stabilizers (PSS) are invariably installed to regulate the excitation of synchronous generators. In this research, a comparative analysis among the two design variants of PSS i.e., Lead Lag and PID, is performed by comparing the overshoot and settling time of generator active power after disturbance, to observe the effect of each on the system characteristics and nominal conditions. The settling time with PID based PSS is reduced by 46% in case of three phase short circuit fault and 80% in case of the single line to ground fault as compared to Lead Lag PSS. Thus, the results obtained show a better performance of PID based PSS having better overshoot response and reduced settling time for symmetrical and unsymmetrical faults.

Keywords: *Active power oscillations, Lead-Lag PSS, PID-based PSS*

1. Introduction

Notwithstanding the improved security and tolerance of modern power systems towards temporary and permanent contingencies, the issues of stability and protection have been prevailing yet [1][2]. The stability of a power system refers to the condition where it maintains the state of equilibrium for normal operation and retains its acceptable characteristics after being subjected to local or global disturbances. The common disturbances include faults and load switching that introduce low-frequency oscillations into the power system and may lead to oscillatory instability if not being damped out adequately. One of the promising ways to compensate for such oscillations is to install Power System Stabilizer (PSS) at the excitation of the synchronous generator, as shown in Fig. 1.

The PSS aims at expanding the system stability limit with the help of modulation of generator excitation So that it can dampen the power swing modes with additional positive damping torque [3].

The modeling and design of different types of PSS have been well-studied in the literature. Using the static output feedback (SOF) control approach, the researchers in [4] have proposed the direct implementation of PSS having PID properties and compared it with various existing passive architectures. The idea is, however, simple and feasible to implement, but it does not ensure global stability. A novel PSS structure to ensure the global transient stability of a Microgrid system is discussed in [5]. The method has been evaluated against the

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loading and faulty conditions considering the small-signal and transient stability criterion.

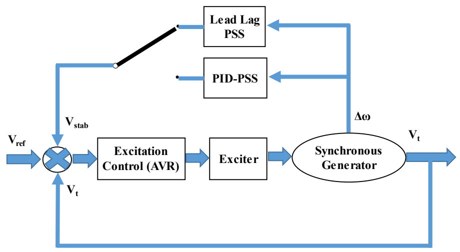

Fig. 1. Conceptual representation of installation of PSS into the power system

In [6], the researcher has exploited the concept of model predictive control (MPC) to design a robust architecture of PSS for improving the dynamic stability of a single-machine infinite bus (SMIB) system. This system, owing to its predictive nature, can adapt to unknown conditions but is computationally ill condition and has a marginally slow response time.

Considering above discussed approaches, the overall objectives of this paper are:

1. To formulate and model the two designs of PSS, i.e., Lead- Lag and PID.
2. To investigate the effects of installing these types of PSS onto the characteristics of the power system in the simulated environment of MATLAB Simulink.

To evaluate and compare the performance of these PSS designs in terms of overshoot and settling time.

2. Literature Review

Various researchers have analyzed the performance of PSS with different computational methodologies [7]. Authors in [8] worked on the analysis of steady-state stability and improved it using eigenvalues and conventional PSS for a thermal power plant in Jamshoro, Pakistan, taken as a case study. Most of the power plants are equipped with a conventional power system stabilizer (CPSS), which is of the Lead-Lag type and has fixed parameters [9]–[12]. However, Lead-Lag based conventional PSS lacks reliability against different loading conditions. [4]. Industrial utilities have used proportional-integral-derivative (PID) controllers for their essential functionality and simplicity in structure. To function properly for a wide range of operating conditions, PID-based PSS is proposed in [13]. Also, PID controller-based PSS structure has been presented for system stability enhancement by applying the controller on a generator connected with the infinite bus, and its performance has been compared without PSS, with proportional-integral (PI-PSS), and with proportional-integral-derivative (PID-PSS).

In [14], the researchers investigated the performance of a large hydro station using PID-based PSS against the damping of active power oscillations. The gains of the installed PSS model were chosen considering the frequency characteristics of the system under different loading and faulty conditions. Likewise, the case study in [15] examined the PID-based PSS model for a multi-machine system, but the gains were determined using particle swarm optimization considering the dynamic stability characteristics of the power system. The results of three different loading conditions from eigenvalue analysis show that the PID-based PSS has improved steady state and dynamic performance compared with the Lead-Lag PSS [16]. While tuning for stabilizer parameters has been presented in [17]–[20].

3. Research Methodology

To design a robust PSS model that is not only resilient to external disturbances, thereby providing positive damping to local mode oscillations but also ensures optimal behavior by injecting torque variations in phase with speed deviations by considering the loading characteristics of the system. To evaluate the performance and effectiveness of the designed PSS model, its dynamic damping test is carried out to validate that the resultant model can dampen active power oscillations effectively. For this purpose, two different models of PSS, i.e., Lead-Lag and PID, are designed and analyzed in this paper.

3.1. Lead-Lag PSS Model

The block diagram representation of the Lead-Lag PSS model is shown in Fig. 2. Where the stabilizing gain K_{stab} determines the amount of damping provided and plays an essential role in the damping of active power oscillations. By increasing the gain value, damping increases up to a certain point, beyond which further increase in gain results in a decrease in damping. The wash-out filter is of a high-pass type used to remove the low-frequency components or to prevent steady changes in speed from modifying the field voltage and enables the stabilizer to act upon the speed deviations only. The phase compensation is used to eliminate the phase lag between the exciter input (i.e., PSS output) and the resulting electrical torque of the synchronous generator [3]. The input to this model can be either the speed deviation ($\Delta\omega$) or the acceleration power (P_a) i.e., the difference of mechanical power (P_m) and electrical power (P_e), as expressed by the equation shown in (1).

$$P_a = P_m - P_e \tag{1}$$

Whereas the output is the stabilizing voltage (V_{stab}) with upper and lower bounds to restrict the terminal voltage of the synchronous generator within predefined limits. The overall transfer function of this PSS model is expressed by the equation shown in (2).

$$\frac{V_{stab}}{\Delta\omega} = K_{stab}\frac{sT_W+s^2T_WT_1}{1+s(T_2+T_W)+s^2T_WT_2} \tag{2}$$

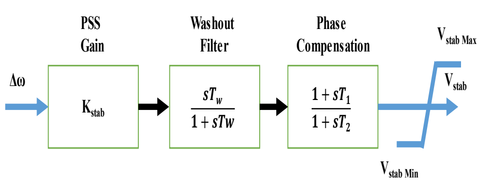

Fig. 2. Block diagram of Lead-Lag PSS Model

The choice of Tw, T1, and T2 depends upon the characteristics of the power system and the rating and configuration of the synchronous machine. The sufficient condition to determine their values states that the poles of the equation shown in (2) should be real and lie on the negative complex plane. The parameters given in equation (2) are enumerated in Appendix A.

3.2. PID-based PSS Model

The Lead-Lag architecture, however, is simple and easy to realize but does not guarantee global stability and robustness against varying operating conditions under all disturbances. The standard PID controller with unity feedback is exploited to achieve state stabilization of rotor swings, as shown in Fig. 3.

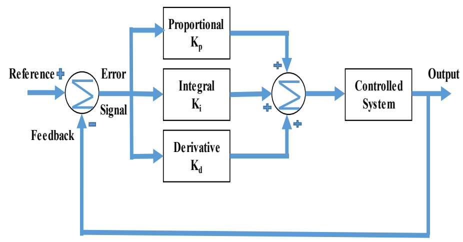

Fig. 3. Schematic representation of PID-based PSS Model

This design works on an error signal originating either in speed (ω) or acceleration power (P_a), as mathematically described by the equation shown in (3).

$$V_{stab} = K_P(\omega_d - \omega_c) + K_I\int(\omega_d - \omega_c)dt + K_D(\dot{\omega}_d - \dot{\omega}_c) \tag{3}$$

Where K_P, K_I, and K_D are the controller gains, ω_d and ω_c represent desired and current rotor speed, respectively, and their associated acceleration are denoted by $\dot{\omega}_d$ and $\dot{\omega}_c$. The output of the controller is a voltage signal (V_{stab}), like the Lead-Lag PSS, given to the excitation system, which as a result, produces the additional torque responsible for the damping of active power oscillations.

For this PSS model, asymptotic stability is achieved by the proper selection of gain matrices. The optimal choice of these gain matrices is made in such a way that equation shown in (4) is satisfied [21].

$$\ddot{e} + K_D\dot{e} + K_I\int edt + K_Pe = 0 \tag{4}$$

4. Results and Discussion

The presented models of PSS have been evaluated onto the Simulink model of a thermal power plant connected with an infinite bus, i.e., single machine infinite bus (SMIB) under symmetrical and unsymmetrical fault. The two-evaluation metrics, i.e., overshoot, i.e., % of the rise in the value of respective quantity over to its nominal value and settling time, i.e., the duration within which the system has retained its normal state. The generator active power for the presented PSS models against a three-phase short circuit (symmetrical) fault at constant loading conditions is shown in Fig. 4 to Fig. 7.

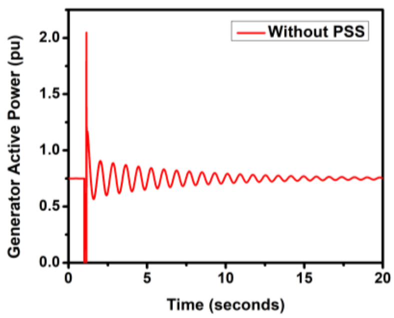

Fig. 4. Generator Active Power against three-phase short circuit fault without PSS

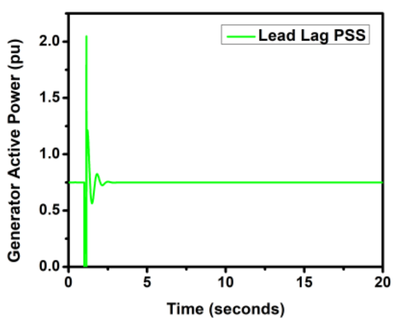

Fig. 5. Generator Active Power against three-phase short circuit fault with Lead-Lag PSS

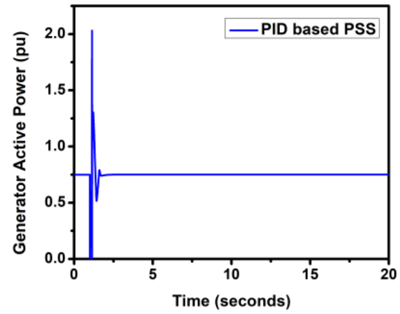

Fig. 6. Generator Active Power against three-phase short circuit fault with PID-based PSS

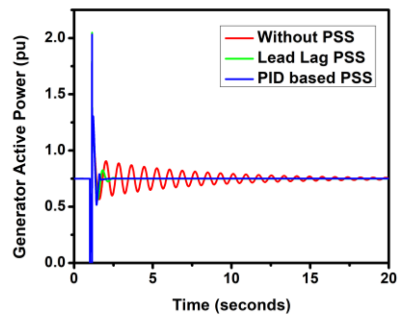

Fig. 7. Generator Active Power against three-phase short circuit fault with different PSS

TABLE I. SUMMARY OF OVERSHOOT AND SETTLING TIME AGAINST THREE-PHASE SHORT CIRCUIT FAULT

Model	**Three Phase Short Circuit Fault**	
	Generator Active Power	
	Overshoot (pu)	Settling Time (s)
Without PSS	0.41	>10
Lead-Lag PSS	0.45	1.3
Optimized-PID PSS	0.35	0.7

The fault occurs at 1 sec, as can be seen from Tables I and II, that owing to the severity of three-phase short circuit fault, large and high frequency deviations and transients are observed into the output power of the generator as compared to a single line to ground fault. Further, PID-based PSS is robust and effective in mitigating the local area oscillations with reduced overshoot and settling time.

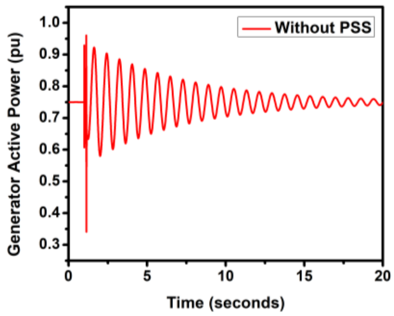

Fig. 8. Generator Active Power against the single line to ground fault without PSS

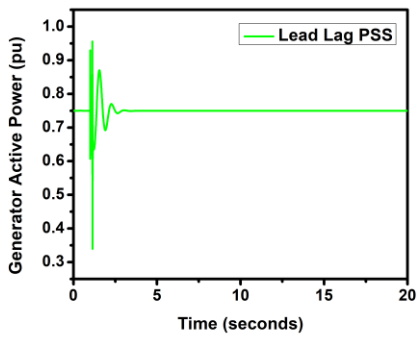

Fig. 9. Generator Active Power against the single line to ground fault with Lead-Lag PSS

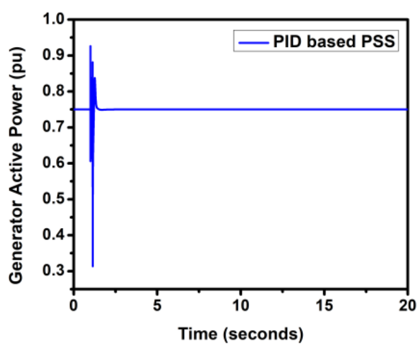

Fig. 10. Generator Active Power against the single line to ground fault with PID-based PSS

In comparison, the Lead-Lag PSS performs better than without PSS in both scenarios, with reduced overshoot and settling time. The generator active power for the presented PSS models against the single line to ground (unsymmetrical) fault at constant loading conditions is shown in Fig. 8 to 11.

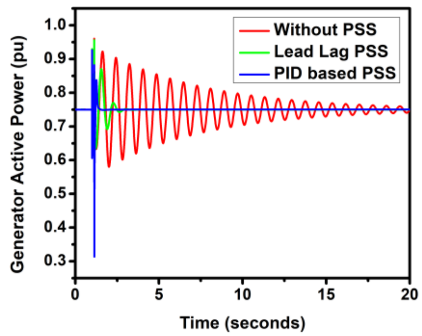

Fig. 11. Generator Active Power against the single line to ground fault with different PSS

TABLE II. SUMMARY OF OVERSHOOT AND SETTLING TIME AGAINST SINGLE LINE TO GROUND FAULT

Model	Single Line to Ground Fault Generator Active Power	
	Overshoot (pu)	Settling Time (s)
Without PSS	0.17	>10
Lead-Lag PSS	0.12	1.3
Optimized-PID PSS	0.08	0.26

It is evident from Table I and II that the PID-based PSS shows lesser overshoot as well as settling time compared to Lead-Lag and without PSS. On the other hand, Lead-Lag PSS performs better than without PSS, but unfortunately, it under-performs in achieving less overshoot and settling time than PID-based PSS.

5. Conclusion

This research analyzed and discussed the characteristics and effects of integrating the different designs of PSS into the performance of the overall power system. The power system under investigation was the thermal power plant in the MATLAB Simulink environment, and the models of respective PSS were designed by considering the rating, loading, structural properties of the power system, and as well as severity of the simulated contingencies. It has been observed that the PID-based PSS adapts well to varying conditions irrespective of the nature and severity of the conditions and has reduced overshoot and reduced settling time, thus providing better damping efficiency but requiring explicit tuning of its hyper-parameters. Whereas the Lead-Lag design, however simple and uses intrinsic properties of the system, has lower damping efficiency than PID-based PSS and reasonable settling time. The settling time with PID-based PSS is reduced by 0.6 seconds in case of a three-phase short circuit fault and 1.04 seconds in case of a single line to ground fault as compared to Lead-Lag PSS. Therefore, it can be concluded that with respect to the oscillations in generator active power, PID-based PSS performs better.

Considering this, in future work, the model of the fuzzy system will be exploited to achieve such results. Other than this, an iterative learning approach will be used that will update its internal state based on the varying dynamic conditions of investigated power system.

Acknowledgment

This is to declare that there is no conflict of interest.

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APPENDIX A

TABLE III. PARAMETERS FOR THE LEAD-LAG PSS

Parameter	Value
K_{stab}	20
T_w	2
$V_{stab\ Max}$	0.15
$V_{stab\ Min}$	-0.15

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