eISSN: 2976-1190

Journal of Engineering and Sciences

Vol. 4, Issue 2, Nov 2025, 121-130

DOI: https://doi.org/10.3126/jes2.v4i2.78850

Journal homepage: [Journal of Engineering and Sciences (nepjol.info)](https://www.nepjol.info)

Publisher: Research Management Cell, Pashchimanchal Campus, Lamachour, Pokhara

A Comparative Evaluation of PID and Lead-Lag Controllers in an AVR-PSS Coordination

Soniya Karki[1,*], Bivek Kumar Mallik[1,*], Rajiv Pandit[1], Rohit Kumar Shah[1], Nutan Raj Pathak[1]

[1]*Department of Electrical Engineering, IOE, Pashchimanchal Campus, Tribhuvan University, Nepal*

*Corresponding Authors: soniyakarki581@gmail.com, bivekmallik123@gmail.com

(Manuscript Received: 15/05/2025; Revised: 03/09/2025; Accepted: 19/11/2025)

Abstract

An automatic Voltage Regulator (AVR) maintains a constant terminal voltage by adjusting the field current of the generator. It may respond more slowly to correcting small changes in voltage. This slower response can affect the equipment that is highly sensitive to minor voltage variations. So, an additional piece of equipment, a Power System Stabilizer (PSS), is used to enhance overall stability by damping oscillations, along with AVRs. There is a need for advancements in PSS design to improve reliability and enhance stability performance. The study of Automatic Voltage Regulator (AVR) and Power System Stabilizer (PSS) coordination with two controllers, a Lead-Lag compensator and a Proportional-Integral-Derivative (PID) controller, is carried out. Three-phase ground fault and load variations (an additional 10MW and 50 MVAR) were introduced into the system to evaluate performance. Evaluation was based on key performance metrics such as settling time, overshoot, undershoot, and damping ratio. The AVR without PSS showed poor performance, emphasizing the necessity of supplementary stabilization. Utilizing the robust capabilities of MATLAB-SIMULINK, the PID controller was finely tuned. PID-based PSS outperformed the others, achieving the fastest settling time and the highest damping ratio. The PSS with conventional lead-lag in MATLAB-SIMULINK exhibited higher overshoot and instability risks. This detailed evaluation confirms the PID controller's superiority over the traditional PSS system. These results were compared with other published research papers, further validating the superior performance of the PID controller. This paper helps researchers evaluate the performance of AVR with PSS and select a better controller to achieve better performance.

Keywords: ANFIS (Adaptive Neuro Fuzzy Inference System); AVR (Automatic-Voltage-Regulator); PSS (Power System Stabilizer); Fuzzy; MATLAB Simulink; PID (Proportional Integral Derivative).

1. INTRODUCTION

The Automatic Voltage Regulator (AVR) is a vital component of the excitation system. It essentially acts as the brain, continuously monitoring and adjusting the generator's voltage output to maintain a stable level. Without the AVR, the system voltage becomes unstable during a load change. With an AVR in the system, the voltage can be controlled to the preset value, helping maintain voltage regulation.

Along with voltage instability, oscillations also occur in the system due to fault or load changes. A power system stabilizer dampens such oscillations and helps maintain stability. The use of AVR along with PSS in the system gives both voltage regulation and dynamic stability, which is very important in today's power systems.

In the early 1960s, a power system stabilizer was used in conjunction with an exciting system to control voltage and damp oscillations, thereby improving overall stability (Kundur, 1993). The effects of load variations on an AVR with a lead-lag PSS system are analyzed, and stability is investigated (Hameed, 2023).

The PID controller, along with PSS, improves overall performance and increases system stability. The PID parameters should be finely tuned (Eze, 2021).

A Neuro-Fuzzy controller tuned with Particle Swarm Optimization is compared with a PID controller, and it is found that the Neuro-Fuzzy controller gives the best performance. It provides better transient response, settling time, and robustness under various load conditions (Usman, 2012).

Hence, PSS is used in conjunction with AVR to improve the system's stability and performance. The performance of the AVR-PSS coordination system can be enhanced with controllers such as PID and an adaptive neuro-fuzzy inference system (ANFIS) compared to the conventional PSS, which uses a lead-lag controller. Thus, this work presents a performance evaluation of an AVR, with and without PSS, using two different controllers (lead-lag and PID) in a real synchronous machine system.

2. Modeling of AVR with PSS system

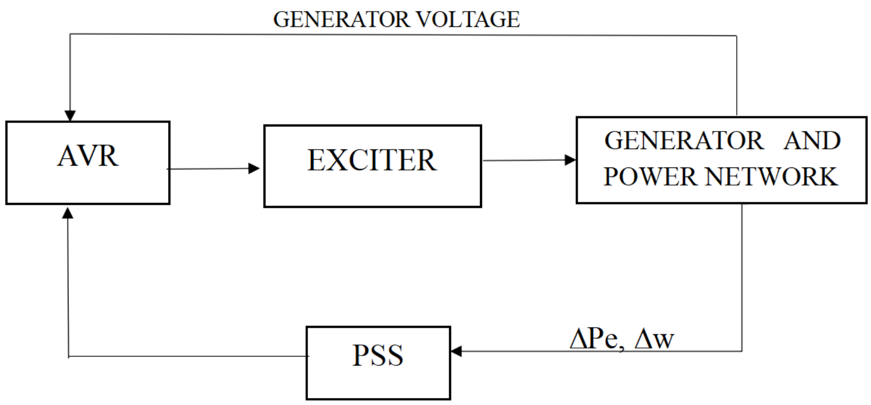

Figure 1: Block Diagram of AVR with PSS

The AVR takes the generator voltage as input, compares it with the reference voltage, and provides a signal to the exciter to adjust the field current, which helps stabilize the voltage. The Power System Stabilizer (PSS) is a supplementary control designed to damp electromechanical oscillations in the power system by providing an additional stabilizing signal to the AVR (IEEE Power Engineering Society, 1992). The PSS uses the rotor speed deviation and the output active power deviation as its primary inputs. PSS with different controllers is discussed in later sections; this section focuses only on the additional components of the AVR and the other parameters used in this paper.

The AVR system is further modeled using the following components: Amplifier, Exciter, Feedback Stabilizer, and Error Detection. The AVR system typically comprises four elements: the excitation unit, which supplies direct current to the generator's field winding; the amplifier unit, which amplifies the error signal to a usable level for the excitation unit; the generator and rectifier; and the sensor unit.

1.1 Amplifier Block

The amplifier model in the AVR system typically receives the error signal as input and produces an amplified voltage signal, V_a, which then serves as the input to the exciter unit.

1.2 Feedback Stabilizer (Lead-Lag Filter)

The feedback stabilizer provides damping to prevent oscillations and aid in signal stabilization.

1.3 Exciter (DC or AC Exciter)

The exciter is typically modeled as a first-order system. In this unit, V_a is fed into the exciter. The exciter output is then supplied to the generator's field winding and is sufficient to overcome the winding resistance.

1.4 Sensor

The sensor senses the terminal voltage, which is then compared with the reference voltage to form a closed loop. The error signal is amplified and fed to the exciter.

Table 1: AVR Parameters used (Hameed, 2023).

Components	Transfer Function	Gain	Time Constants
Amplifier	$K_A/(1+T_A s)$	300	T_A=0.001
Exciter	$K_E/(1+T_E s)$	1	T_E=0
Sensor	$K_R/(1+T_R s)$	0.001	T_R=0.1
Lead-lag Compensator	$(1+T_1 s)/(1+T_2 s)$	___	T_2,T_1=0

3. Modelling the AVR-PSS coordination system using lead-lag and PID controllers

A synchronous machine of 200 MVA and 13.8 kV is used and modeled with AVR-PSS coordination (Hameed, 2023). The primary goal of an AVR with PSS analysis is to evaluate voltage regulation and dynamic response at generator terminals.

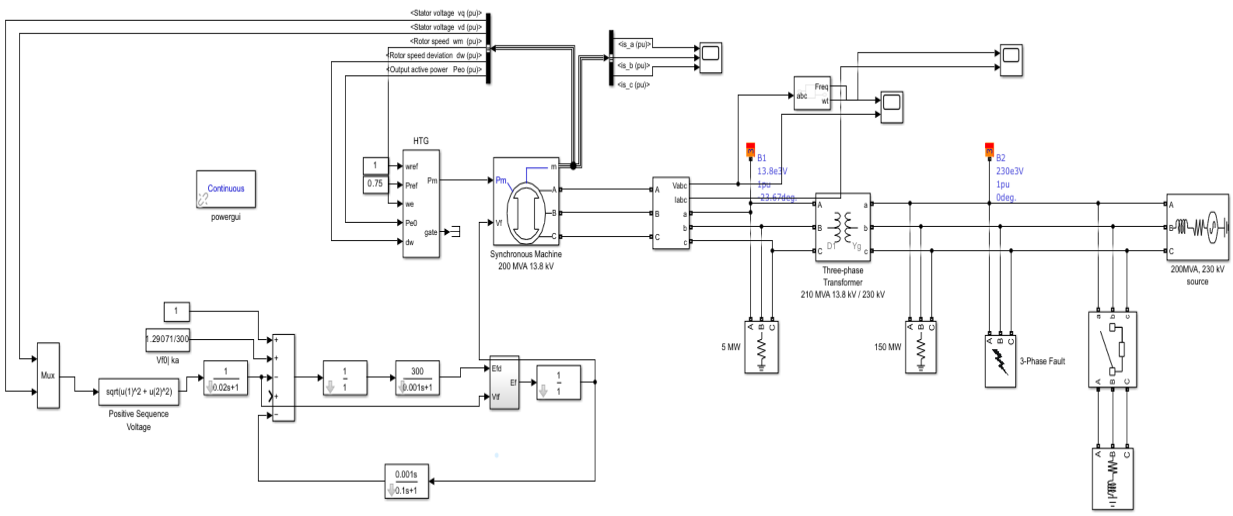

Fig. 2: Diagram of the AVR system without PSS

For this machine, exciter and stabilizer dynamics are more important and dominant than transmission-line impedance. For simplicity, the most standard AVR-PSS research models are followed, which do not include line or cable impedance (Hameed, 2023). In the Automatic

Voltage Regulator (AVR) with Power System Stabilizer (PSS) model, two controllers, Lead-Lag and PID, are used in sequence.

The diagram shows an AVR without PSS in the system. 5 MW and 150 MW loads are connected to the system. Fault is introduced into the system from 5 seconds to 5.2 seconds. A load variation of 10 MW and 50 MVAR is introduced at 9 seconds.

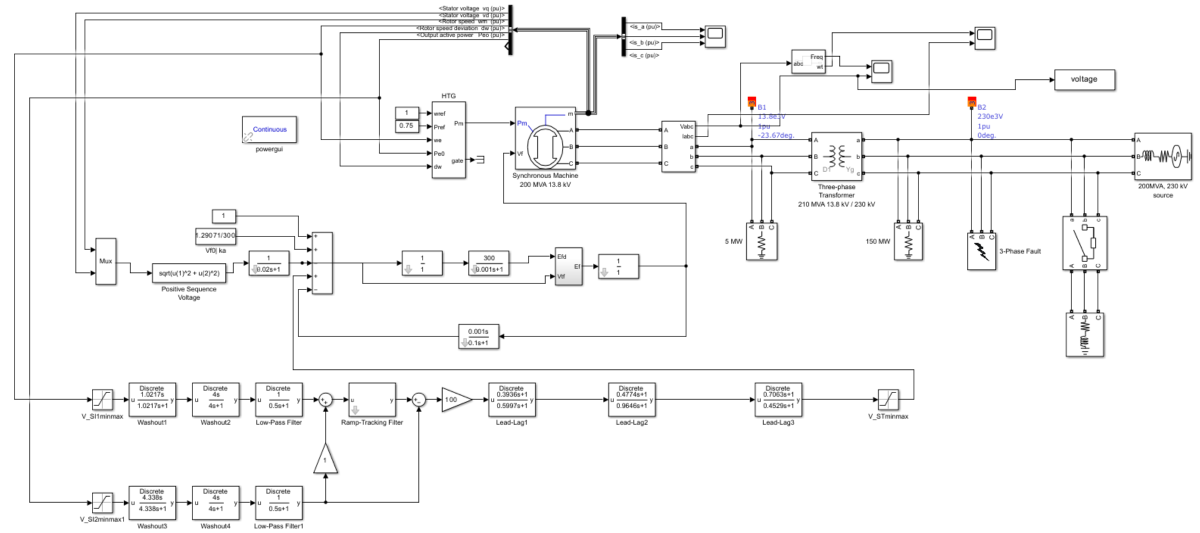

Fig. 3: Diagram of the AVR system with lead-lag PSS

The PSS with lead-lag takes inputs from the rotor speed and output active power and processes them through a series of filters and lead-lag compensators. Fault and load variations are introduced as before to evaluate the performance of the AVR along with PSS.

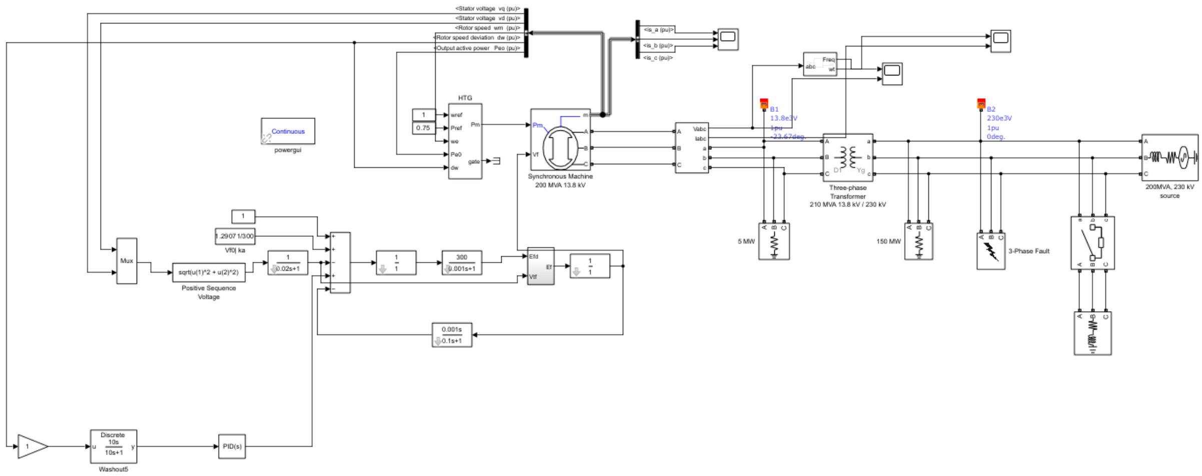

Fig. 4: Diagram of the AVR system with PID-based PSS

For the PID controller, the P, I, and D values were determined using the PID tuning method (Mosaad et al., 2019).

Then, it is used to analyze performance under fault and load conditions introduced into the system. The PID input is taken from rotor speed deviation, and the output is fed to the AVR, as shown.

3.1 LEAD-LAG controller

The PSS with lead-lag controller takes inputs from the rotor speed (RoWf) and active output power and processes them through a series of filters and lead-lag compensators. The signal is passed through washout filters to remove steady-state components and then through low-pass filters to smooth the signal, followed by a ramp-tracking filter that adapts to dynamic changes (Saadat, 1999). The signal is then fed through a three-stage lead-lag compensator to enhance phase compensation and damping improvement. Finally, the stabilized signal is fed to the excitation system.

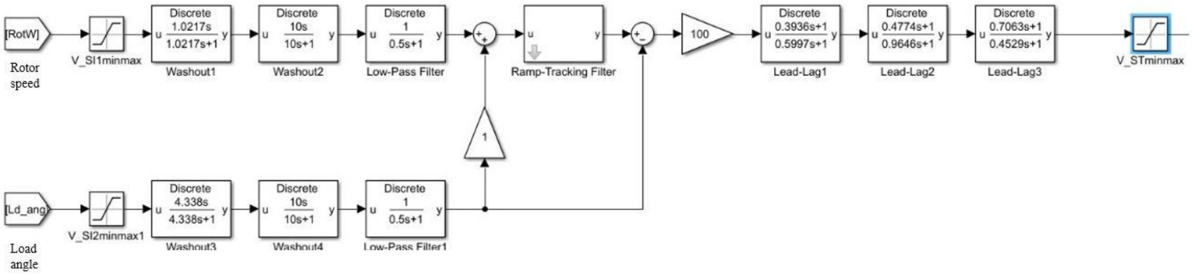

Fig. 5: Block Diagram of Lead-Lag controller

Table 2: PSS Parameters used (Hameed, 2023)

Components	Transfer Function	Gain	Time Constants
Washout 1	Tw1s/(1+Tw1s)	-----	Tw1s = 1.0217
Washout 2	Tw2s/(1+Tw2s)	-----	Tw2s = 4
Washout 3	Tw3s/(1+Tw3s)	-----	Tw3s = 4.338
Washout 4	Tw4s/(1+Tw4s)	-----	Tw4s = 4
Low Pass Filter 1	1/(1+TL1s)	-----	TL1s = 0.5
Low Pass Filter 2	1/(1+TL2s)	-----	TL2s = 0.5
Lead-Lag 1	(1+T1s)/(1+T2s)	-----	T1s = 0.3936 T2s = 0.5997
Lead-Lag 2	(1+T3s)/(1+T4s)	-----	T3s = 0.4774 T4s = 0.9646
Lead-Lag 3	(1+T5s)/(1+T6s)	-----	T5s = 0.7063 T6s = 0.4529
Gain Block	-----	100	T5s = 0.7063 T6s = 0.4529
Ramp-Tracking Filter	-----	-----	T1 = 0.5 , T2 = 0.1 M = 5 , N = 1

3.2: PID controller:

A Proportional-Integral-Derivative (PID) controller is a crucial control mechanism used for system stabilization and regulation (Saadat, 1999). It calculates the control signal by evaluating the difference between the desired set point and the current process value. The controller consists of three key components:

Proportional (P) Term: Produces an output that is directly proportional to the current error, helping to reduce steady-state error and enhance responsiveness.

Integral (I) Term: Integrates the error over time to eliminate steady-state error and correct long-term biases.

Derivative (D) Term: Addresses the rate of change of the error, aiding in system stabilization and reducing abrupt or oscillatory fluctuations.

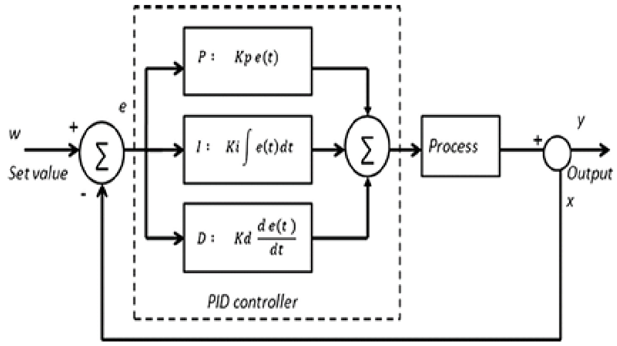

Fig. 6: Block Diagram of PID controller

In this investigation, the initial PID controller setup in Simulink uses the parallel form. The time domain is set to 'Continuous Time,' and the 'Internal' option is selected for the source. The 'Filter coefficient' (N) is set to 100.The compensator

$P + \frac{I}{s} + D\frac{N}{1+\frac{N}{s}}$ is used. The values of P, I, and D for this experiment are determined by PID tuning.

3.3: PID Tuning:

PID tuning involves selecting the appropriate gains K_p (proportional), K_i (integral), and K_d (derivative) for a PID controller to achieve the desired control performance. This process can be carried out through auto-tuning in MATLAB Simulink.

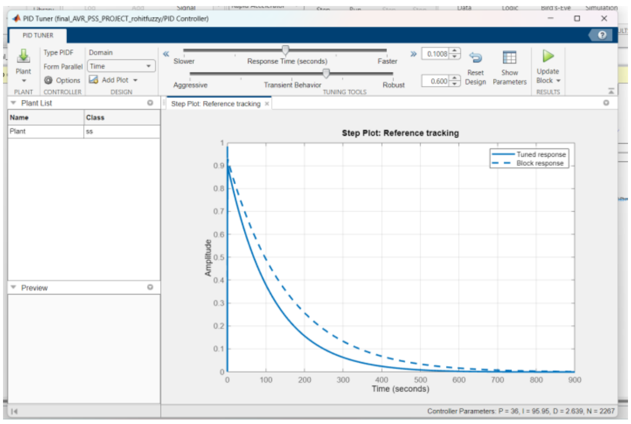

Fig. 7: PID tuning process

Table 3: After several tuning attempts, the best value obtained

Controller Parameters	Tuned
P	534.219021738815
I	866.925124958816
D	73.1438939399573
N	31789.3738563376

4. Result and Discussion

4.1 Frequency and Voltage response

Frequency and Voltage response of AVR without PSS and with lead-lag PSS and PID-based PSS for fault condition and load change condition

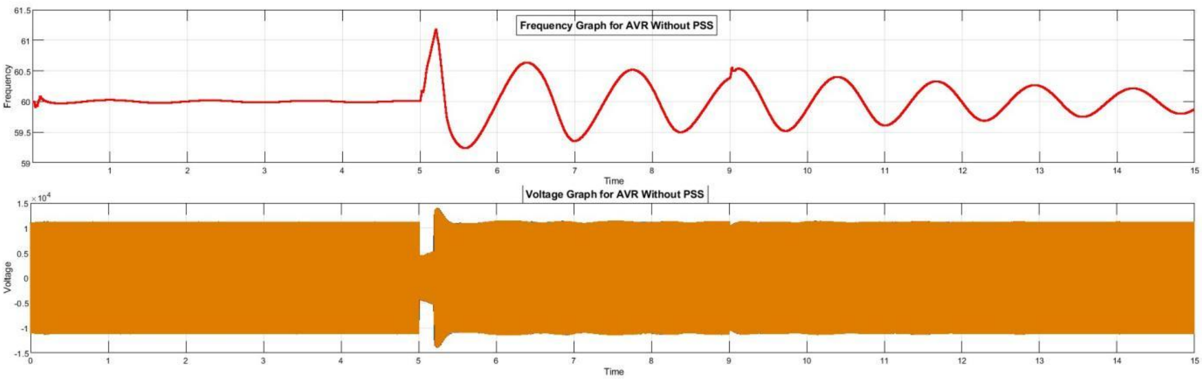

Figure 8: Frequency and Voltage graph of AVR without PSS

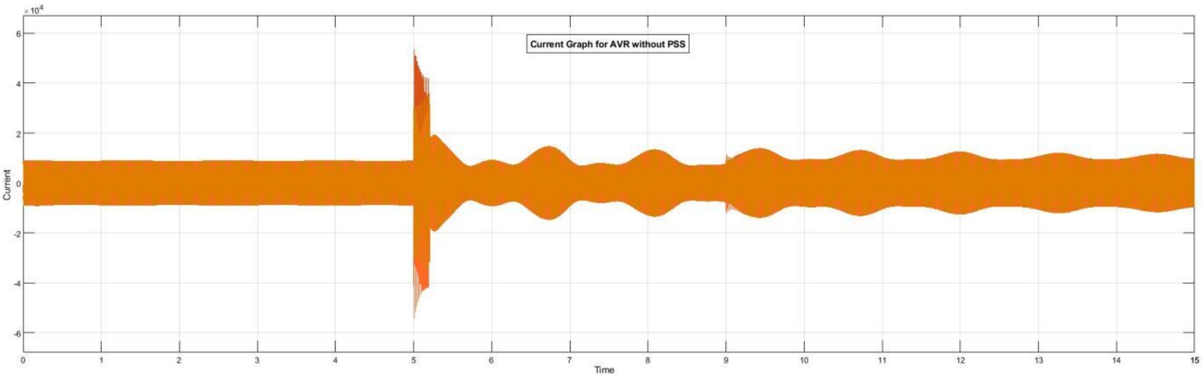

Figure 9: Current graph of AVR without PSS

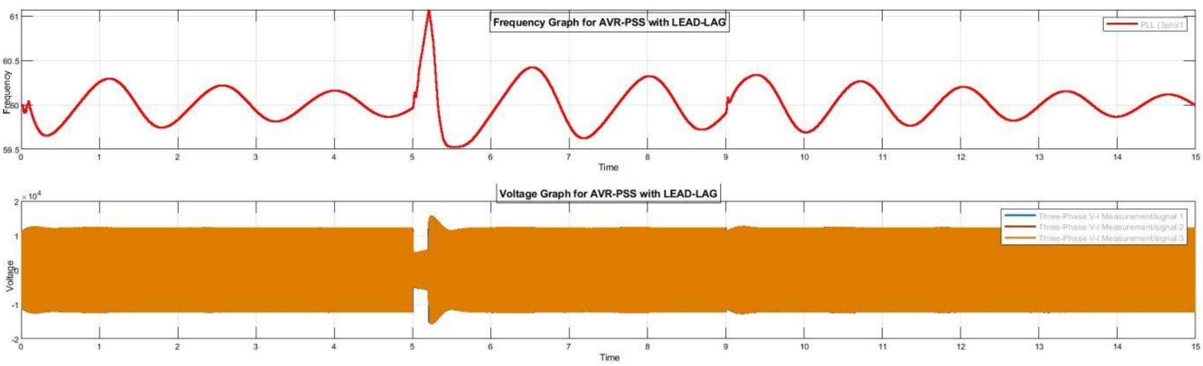

Figure 10: Frequency and Voltage Graph of AVR with lead-lag PSS

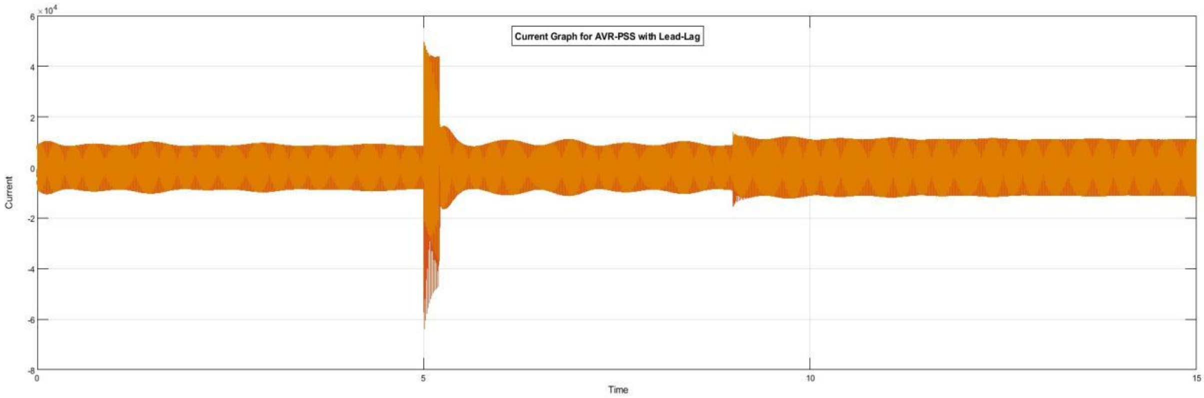

Figure 11: Current Graph of AVR with lead-lag PSS

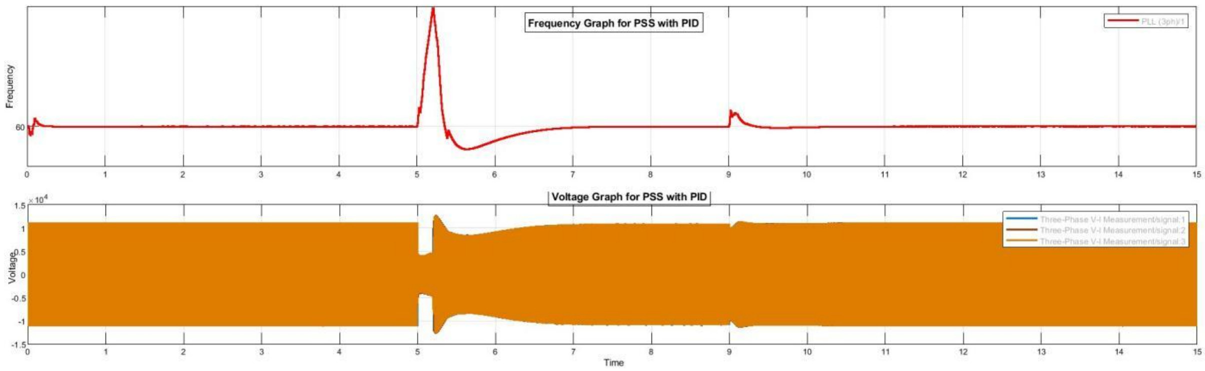

Figure 12: Frequency and Voltage Graph of AVR with PID-based PSS

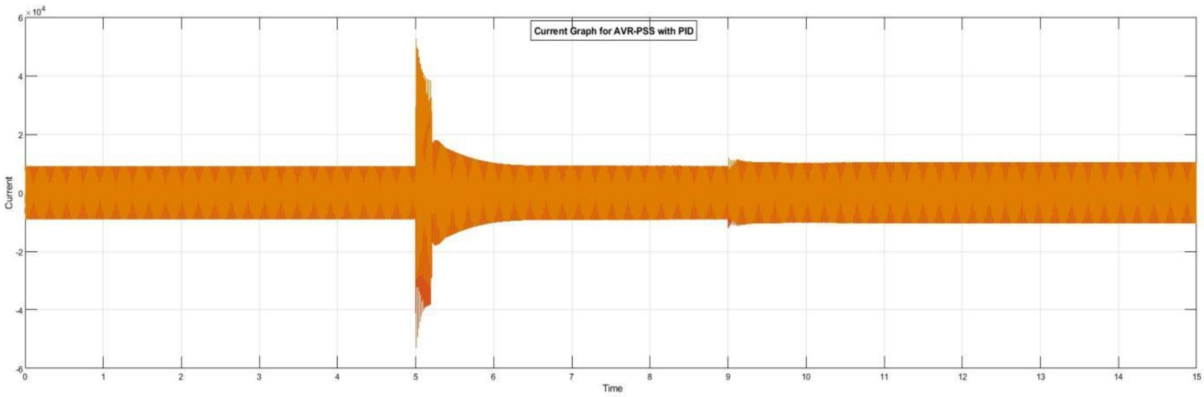

Figure 13: Current Graph of AVR with PID-based PSS

Figures 8, 10, and 12 show the voltage and frequency graphs of the AVR without and with PSS using two controllers. Similarly, figures 9, 11, and 13 show the current graphs of the AVR without and with PSS using two controllers. The three-phase-to-ground fault is created at five and cleared at 5.2 seconds for the transient fault. In this same graph, after 9 seconds, an additional 10MW of active load and 50MVar of reactive load are supplied to simulate load variation.

4.2 Overall Discussion

Table 4: Analytical Data of Various PSS Controllers for Stability Analysis

TYPES OF AVR WITH PSS	At Fault Condition				At Load changes			
	Settling time (sec)	Over shoot (%)	Under shoot (%)	Damping Ratio	Settling time (sec)	Over shoot (%)	Under shoot (%)	Damping Ratio
AVR without PSS	2.372	3.41	13.2	0.7323	1.227	1.43	10.635	0.721
AVR with PSS (PSS2B)	1.244	3.429	10.529	0.732	0.525	1.244	11.6	0.772
AVR with PSS (PID)	1.27	2.866	11.137	0.749	0.262	1.03	11.2	0.825

Final Ranking Based on Stability

1. Best Stability – AVR with PSS (PID Controller) (Fastest response, lowest overshoot, best damping)
2. Second Best – AVR with PSS (PSS2B) (Better than no PSS)
3. Worst Stability – AVR without PSS (Slow response, poor damping, higher oscillations)

5. Conclusion

A comparative study of AVR systems, with and without PSS, using different controllers, helps us assess system stability under two conditions: fault and load change. Under these conditions, PID-based PSS gives the fastest settling time, the lowest overshoot, and the highest damping ratio. These performances align with published findings by Mosaad (2019), Attia (2021), and Abdelaziz (2023), who also reported superior transient performance of optimized PID controllers compared to classical lead–lag PSS. The reduction in settling time (up to 70% during load changes) and the increase in damping ratio observed in this work are consistent with the 40–60% improvements reported in the literature. Thus, the obtained results validate that PID-based PSS provides better dynamic performance than AVR-only and lead-lag PSS. Further, research could focus on controllers such as ANFIS (Adaptive Neuro-Fuzzy Inference System) with advanced optimization techniques to achieve better performance.

Acknowledgement

We would like to express our sincere gratitude to Asst. Prof. Suraj Shrestha and Asst. Prof. Sandeep Dhami, Department of Electrical Engineering, Pashchimanchal Campus, Institute of Engineering, Tribhuvan University, for providing constant support and guidance throughout this research.

References

[1] Kundur, P. (1993). *Power system stability and control* (p. 315). McGraw-Hill Education.

[2] Hameed, J. H., Hashim, W. A., & Derbel, N. (2023). Impact of load variation on power system stability and performance of power system stabilizers: A case study of Peerdawd gas power station, Iraq. *International Journal of Power Electronics and Drive System (IJPEDS), 14*(4), 2119–2133. Retrieved from https://doi.org/10.11591/ijpeds.v14.i4.pp2119-2133

[3] Eze, P. C. (2021). Control techniques for enhancing the performance of the automatic voltage regulator in power system stability. *Multidisciplinary International*.Retrieved from https://www.mijrd.com/papers/v1/i1/MIJRDV1I10009.pdf

[4] Usman, J. (2012). Design of AVR and PSS for power system stability based on iteration particle swarm optimization. *International Journal of Engineering and Innovative Technology (IJEIT)*, (December 2012).

[5] Mosaad, A. M., Attia, M. A., & Abdelaziz, A. Y. (2019). Whale optimization algorithm to tune PID and PIDA controllers on the AVR system. *Ain Shams Engineering Journal, 10*(4), 755–767.Retrieved from https://doi.org/10.1016/j.asej.2019.07.004

[6] IEEE Power Engineering Society. (1992). *IEEE recommended practice for excitation system models for power system stability studies* (IEEE Std 421.5-1992). Retrieved from https://doi.org/10.1109/IEEESTD.1992.106975

[7] Saadat, H. (1999). Power system analysis. McGraw-Hill Education.Retrieved from /mnt/data/power system analysis - hadi saadat_320503100.pdf

[8] Attia, M. A., Abdelaziz, A. Y., & Mosaad, A. M. (2021). Performance enhancement of AVR using PSO-tuned PID controller. *Energy Reports, 7*, 6270–6280.

[9] Abdelaziz, A. Y., Attia, M. A., & Mosaad, A. M. (2023). Comparative study of AVR control systems considering a novel optimized PID-based model reference fractional adaptive controller. *Sustainability, 15*(12), 9381.