International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 8 (2015) pp. 21237-21252

http://www.ripublication.com

# Analysis of Low Frequency Oscillations In Synchronous Generator Rotor Using Power System Stabilizer

**A M kaleeswarran[1]**
*School of EEE, Sastra University*
*kaleeswarransundaram@gmail.com*
**M.Balasubramanian[2]**
*School of EEE, Sastra University*
*mbsmanian16@eee.sastra.edu*
**E Ezhilvendhan[3]**
*School of EEE, Sastra University*
*ezhilvendhan3@gmail.com*

## Abstract

The Low Frequency Oscillation (LFO) are pertaining to the small signal stability of a power system. It is very harmful to obtain the uttermost power transfer due to the LFO. The ultimate aim of this project is to reduce the low frequency oscillation (0.2-2Hz) (i.e.) local plant mode and inter plant modes of oscillation. The role of power system stabilizer has become really common in the mental process of heavy electric power system. The dominant generator can be determine by using Eigen value analysis. Furthermore the proposed PSS is designed based on the lead compensator design is employed in place of phase compensation. The performance of the designed PSS has been verified in an exceedingly SMIB System.

**Keywords:** Low Frequency Oscillation, Power System Stabilizer (PSS), Automatic Voltage Regulator (AVR), Phase lead compensator.

## Introduction

In power electrical system operation stability is important aspects. This is because to maintain the system under rated frequency and voltage [1-2]. Northern America where the first country to report this type of oscillation in 1964during the trial interconnection of northwest and south west power pool. The disturbance occur due to changes in load includes electromechanical oscillation of electrical generator. These oscillations is called power swing. This type of oscillation should be effectively damped to take care of the system stability [6, 7]. This electro mechanical oscillation is of two types; (i) local mode oscillation, the frequency of oscillation is ranges from

0.1Hz to 0.7Hz. Its behavior is mainly limited to the local area of the system in the vicinity of the power plant. The other type of oscillation is an inter plant mode of oscillation. The frequency of this oscillation is ranging between 0.8Hz to 2.0Hz [8]. This type of oscillation occurs within the generator of one plant and the generator of another plant. These oscillations will disturb the system and this tends to failure of the shaft. So this oscillation should be eliminated to maintain the stability of the system. The AVR is essential for controlling the terminal voltage of the system. If the gain of the AVR is increased the damping torque coefficient has become more negative, with this negative damping the System oscillation will tend to grow and there will be oscillated in the power flow. To overcome this problem of negative damping due to AVR, it is necessary to incorporate PSS. The PSS is used in the system to add damping to the electro mechanical oscillation. The use of PSS has successful in improving the both economical and the system stability with the help of PSS the oscillation is damped and the system stability is achieved. There are different kinds of power system available in world wide. Such as fossil fuel, nuclear fuel, hydro fuel in which the rating are of different types. The low frequency oscillation will occur in generator of different characteristics, this oscillation can be reduced by installing controller in the proper place. For this reason we need to identify the perfect location for the installation of PSS. In this proposed work the provision of PSS has been performed with the help of Eigen value analysis. This Eigen value analysis is done to find the dominant generator. For this dominant generator the PSS is allotted. Furthermore the phase lead compensator design is implemented [11]. This design will replace the existing transfer function block in phase compensator of the PSS block.

## Eigenvalue Analysis

The Eigenvalue analysis is an important tool to find the frequency of oscillation of the generator. The Eigenvalue may be of a real, Negative real, or complex eigenvalue. The real part of the Eigenvalue gives the damping and the negative part gives the frequency of oscillation. The complex eigenvalue will give the oscillating frequency of the generator. By analyzing this Eigenvalue we can know the characteristic of the dynamic states of the system. Hence this Eigenvalue analysis is appreciated globally.

## Case Study

In this paper I consider a 4 machine as a test system. This test system is used to compare how the proposed method performs. This model consists of 4 machines on each side of the transmission line. The model has been splited into 4 generator for analyzing purpose. The Eigen value analysis can be calculate based on this model.

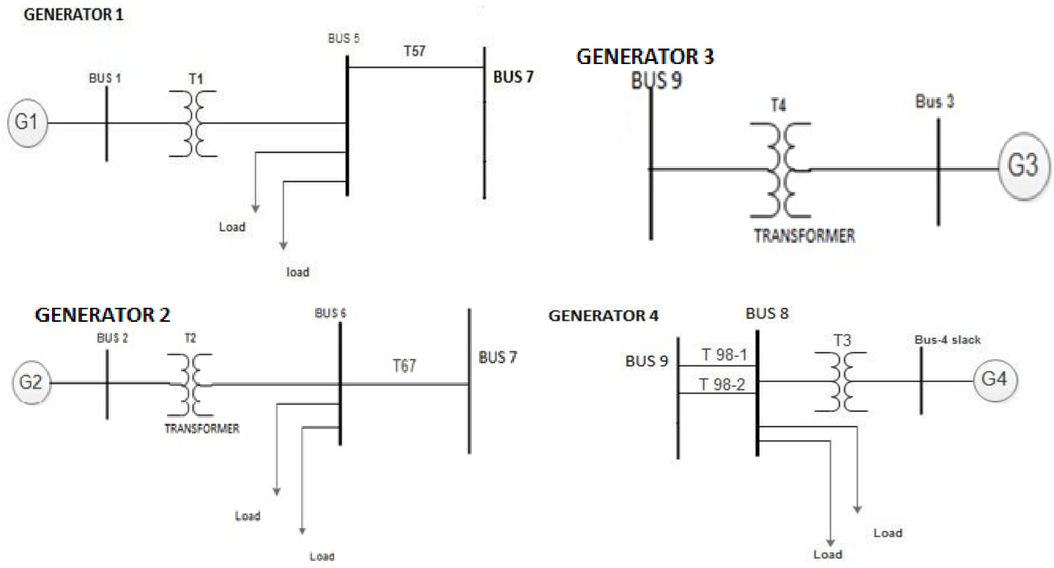



**Figure 1:** Synchronous Generator System Connected to Infinite Bus

## System Modelling

The mathematical modelling of a synchronous machine is needed for the small signal stability analysis. Let us see detail about the modeling.

### *A.Synchronous Machine Model:*

The synchronous machine model is vital for power system operation. This model represents the association of a generator to the infinite bus through the transmission network can be presented as the mathematical model for small signal stability analysis. Based on this machine model excitation system and the machine model can be viewed in detail [8]. The Thevenin's equivalent circuit is shown in fig: 2

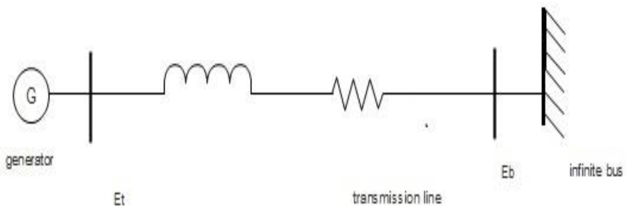



**Figure 2:** Synchronous Machine Model

### *B.Classical System Model:*

The system represent the classical model in which the $E'$ represent the generator voltage behind $X_d'$. The magnitude $E'$ should be remained in pre- disturbance value. The $E'$ leads the infinite bus voltage $E_b$ by the angle$\delta$, during the rotor oscillation (disturbance) the $\delta$ angle changes.

$$It = \frac{E'\angle 0^{\circ} - Eb\angle -\delta}{jXt} = \frac{E' - (Eb\,cos\delta - jsin\delta)}{jXt} \tag{1}$$

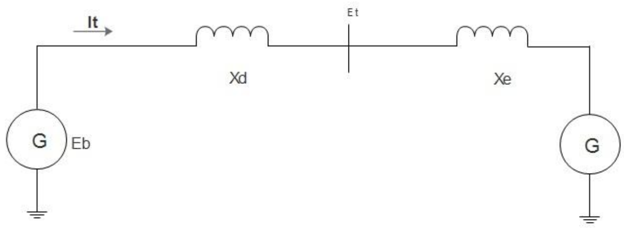



**Figure 3:** Classical Generator Model

## Power System Stabilizer

The PSS was developed to aid in damping the oscillation. The activity of PSS is to delay as far as possible to the power system by giving supplemental damping to the wavering of the synchronous machine rotor through the generator excitation. To give damping, stabilizer must deliver a part of electrical torque on the rotor which is in stage with the velocity deviation. This supplementary control is exceptionally helpful amid line outage and expansive force exchange. Yet the force framework precariousness emerges in certain condition because of negative damping impact of the PSS on the rotor. During the severe disturbance, a PSS may actually make the generator under its control to lose the synchronism in an effort to control its exciting field.

## General Procedure for Selection of PSS

### *(i) Phase lead compensator*

The damper must be supplied to the stabilizer to keep the electrical torque in phase with the speed variations. Subsequently, the PSS ought to have essential phase lead character to try and off the phase lag between the electrical torques. For the change in the system condition the phase characteristic has to be compensated. A comprise should be put in and a characteristic acceptable for a sure vary of frequency, usually (0.1-2.0Hz) [8]. This may result in optimum damping at any one of the frequencies. The frequency response between the exciter input and the generator electrical torque, needed for determining the phase compensation.

### *(ii) Stabilizing Signal – Wash out Block:*

The washout block act as a high pass filter that removes the DC signal and while not steady amendment in speed would modify the terminal potential drop. For native mode of oscillation, a washout block time constant is 10s or higher could also be demanded so as to lessen the section lead at low frequency. The over compensation may lead to low value of $T_{w,}$ which reduces damping as well as synchronizing torque component.

***(iii) Stabilizer Gain:***

By breaking down the total vary of values of the system parameter the stabilizer gain (KSTAB) needs to be thought of. The value of the stabilizer gain ought to be ready in accordance with the most damping. Withal, it's going to limit by alternative constraints. The set value should operate in a satisfactory manner without compromising the stability of another system.

## Simulation Output

***AVR Model***

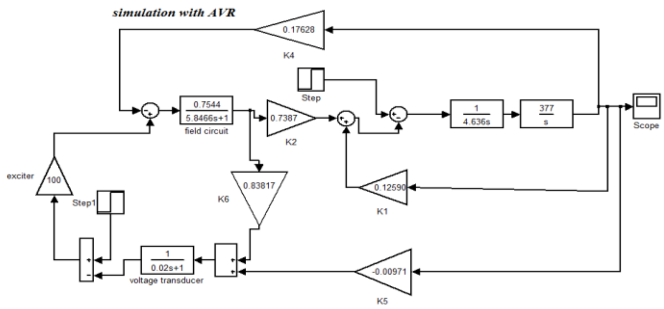



**Figure 4:** AVR model

**Output of AVR Model**

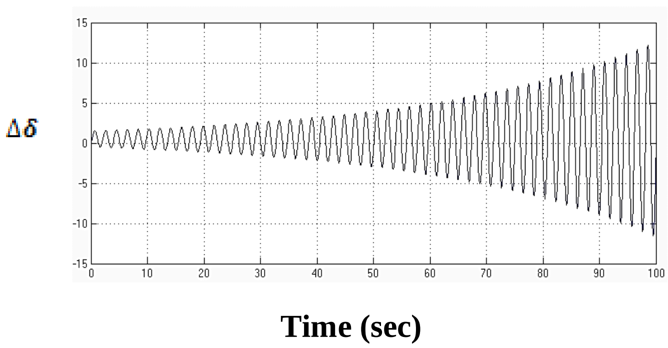



**Figure 5:** Output of AVR Model

**Performance of Generator 1**

The model used in the simulink to study the response of the system with rotor angle is shown in figure. The values of K constants are calculated using the parameter of the table 1

K1 = 0.12590, K2 = 0.7387, K3 = 0.7544, K4 = 0.17628, K5 = -0.00971, K6 = 0.83817.

**Simulation with AVR and PSS**

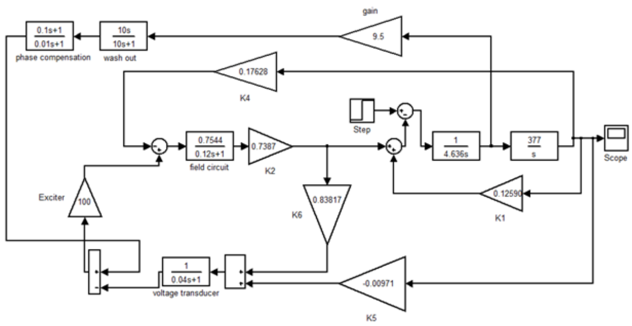
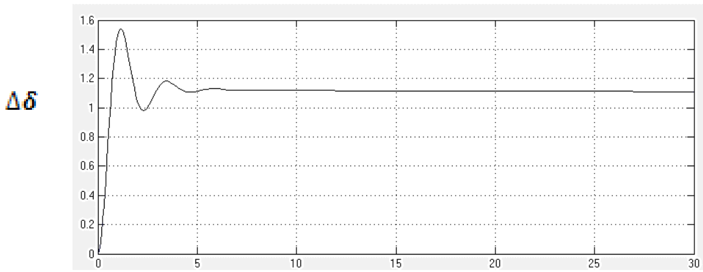



**Figure 6:** Simulation with AVR and PSS for Generator 1

**Rotor Oscillation of Generator 1**




**Time (sec)**

**Figure 7:** Output of Generator 1

**Performance of Generator 2**

The values K constant can be calculated by using the data available in the table 1.

K1 =0.065661, K2 = 1.02564, K3 = 0.56808, K4 = 0.11772, K5 = -0.031747 K6 = 0.75131.

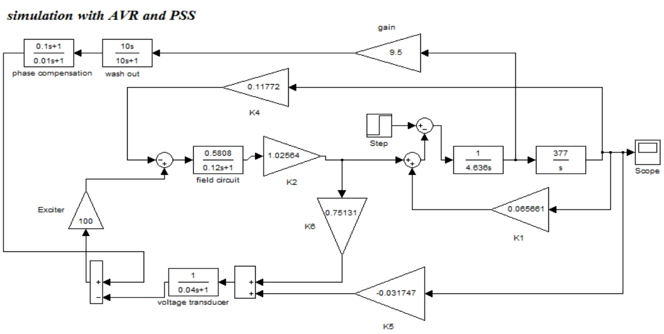



**Figure 8:** Simulation with AVR and PSS for Generator 2

## Rotor Oscillation of Generator 2

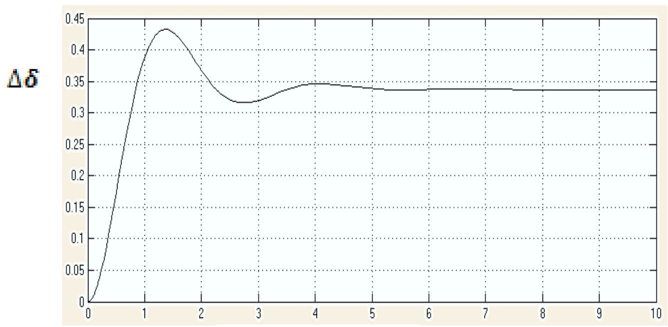



**Figure 9:** Output of Generator 2

## Performance of Generator 3

The values of constant K values can be obtained from the Table 1
K1 = 0.0032729 K2 = 0.65410 K3 = 0.88271 K4 = 0.004669 K5 = -0.06155 K6 = 0.863159.

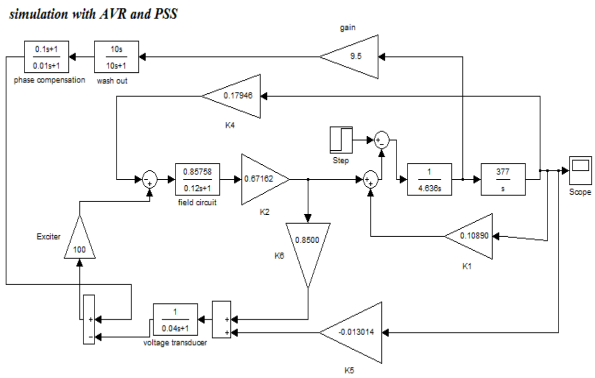



**Figure 10:** Simulation with AVR and PSS for Generator 3

## Rotor Oscillation of Generator 3

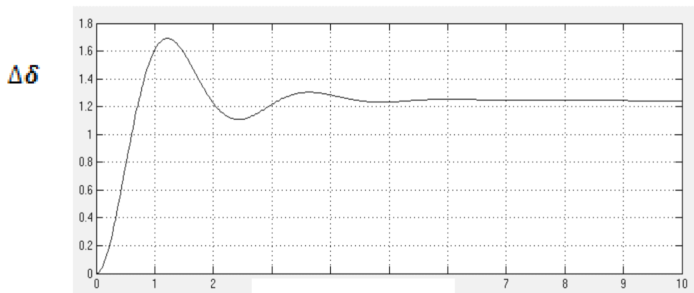



**Figure 11:** Output of Generator 3

**Performance of Generator 4**

The constant K values can be calculated from the table 1

K1 = 0.10890, K2 = 0.67162, K3 = 0.85758,
K4 = 0.17946, K5 = -0.01301, K6 = 0.8500.

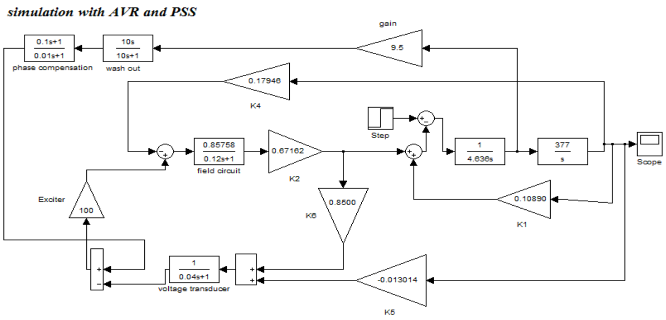



**Figure 12:** Simulation with AVR and PSS for Generator 4

**Rotor Oscillation of Generator 4**

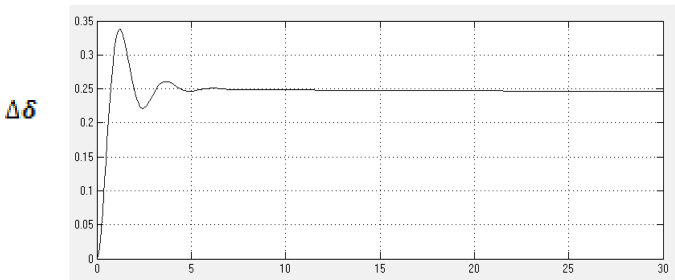



**Figure 13:** Output of Generator 4

The performance of single machine infinite bus system has been studied with the assistance of IEEE nine bus system.The machine data have been taken from the following table

**Table 1:**

| Symbol | Unit | G1 | G2 | G3 | G4 |
|---|---|---|---|---|---|
| S | Mva | 60,000 | 1,300 | 4,400 | 70,000 |
| H | s | 2.318 | 2.642 | 3.960 | 3.930 |
| P | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| Q | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| F | 50 | 50 | 50 | 50 | 50 |
| $r_a$ | $Pu^*$ | 2.0 | 2.0 | 2.0 | 2.0 |

| | | | | | |
|---|---|---|---|---|---|
| $X_l$ | Pu* | 0.0046 | 0.0019 | 0.0031 | 0.0010 |
| $X_d$ | Pu* | 0.155 | 0.246 | 0.110 | 0.135 |
| $X'_d$ | Pu* | 2.110 | 2.183 | 1.700 | 1.790 |
| $X''_d$ | Pu* | 0.280 | 0.413 | 0.245 | 0.220 |
| $X_q$ | Pu* | 0.215 | 0.339 | 0.185 | 0.180 |
| $X'_q$ | Pu* | 2.020 | 2.157 | 1.640 | 1.715 |
| $X''_q$ | Pu* | 0.215 | 0.332 | 0.185 | 0.215 |
| $X_0$ | Pu* | 0.150 | 0.174 | 0.100 | 0.060 |

Pu*: on the generator rated MVA base

## Designing the Phase Lead Compensator

A compensator having the characteristics of lead network is called phase lead compensator. If a sinusoidal signal is applied to lead network, then in steady state output will have phase lead characteristic with respect to the input. The lead compensator increase the band width which improve the specific response and also reduce the amount of over shoot. Lead compensator improves the transient response, whereas there is a small change in steady state, generally lead compensator is provided to make a UN stable system to a stable system [11].

A lead compensator is basically a high pass filter and so it amplifies high frequency noise signal. For designing the phase lead compensator

$$a=\frac{1+\sin\varphi m}{1-\sin\varphi m} \quad (2)$$

$$w=\omega m\frac{1}{\sqrt{aT}} \quad (3)$$

$$a=\frac{R1}{R2} \quad (4)$$

$\varphi m - The\ lag\ angle.$

The phase compensation circuits is used to compensate the phase lag between the exciter input ($\Delta Te$ *and* $\Delta Vs$) and electrical (air-gap) torque.

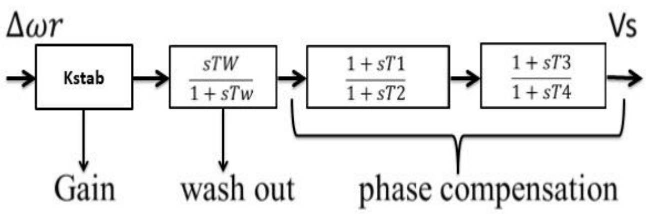



**Figure 14:** Block Diagram of PSS Block.

In this power system stabilizer block the gain block is responsible for producing the required damping torque. The wash out block will function as the high pass filter. The compensator block is responsible for compensating the phase lag between the $\Delta Te$ and

$V_s$. I am going to replace the traditional transfer function block into phase lead compensator design which I proposed.

**Design of phase lead compensator**

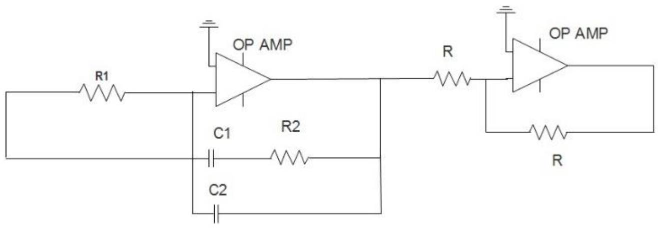



**Figure 15:** Phase Lead Compensator Design

The values of R1, R2, R, C1, and C2 can be found using the equation (2), (3), (4).

**Calculation of Phase Lag in Generator:**

$$\frac{\Delta\psi_{fd}}{\Delta_{V_s}} = \frac{K_3 K_A}{sT_3 + K_3 K_6 K_A} \quad \textbf{(5)}$$

$$\frac{\Delta T_{pss}}{\Delta_{V_s}} = K2 \frac{\Delta\psi_{fd}}{\Delta_{V_s}} \quad \textbf{(6)}$$

By using the formula (5), (6) the phase lag of the particular generator can be calculated. The calculation exactly tell about the phase lag of a particular generator. This phase lag has to be compensated by using the mat lab.

**Simulation for Phase Lead Compensator**

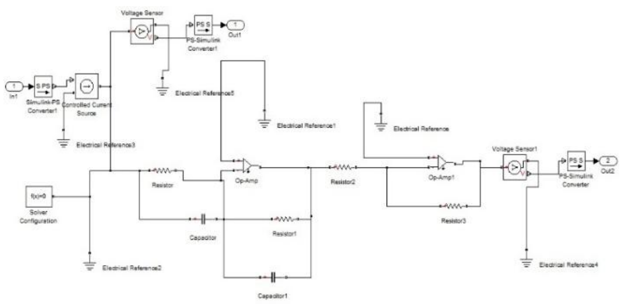


**Figure 16:** Simulation of Phase Lead Compensator Design

This design can be used instead of phase lead compensator –transfer function block. Simulation can be done by using the above design. By compensating the phase lag the system stability is achieved.

**Simulation with Phase Lead Compensator**

**For generator 1:**

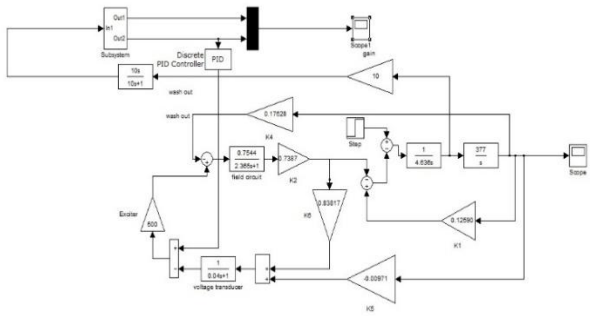



**Figure 17:** Simulation of Phase Lead Compensator Design for Generator 1

**Output of phase lead compensator block:**

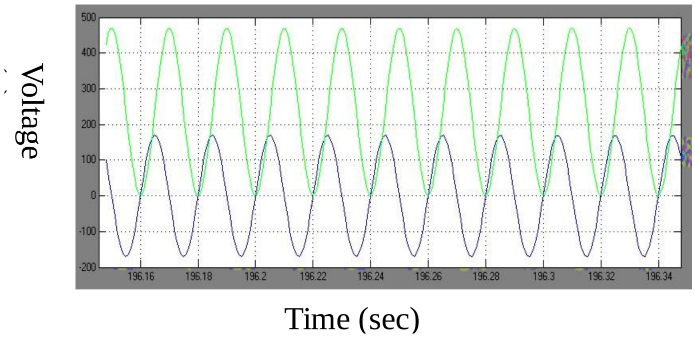



**Figure 18:** Output from Phase Lead Compensator Block

**Output of generator 1**

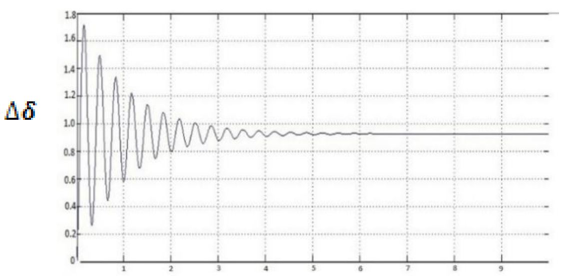



**Figure 19:** Output of Generator 1

**Simulation For generator 2**

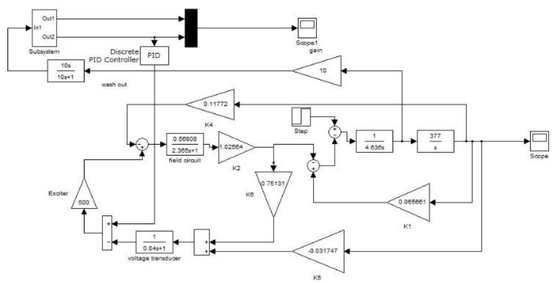


**Figure 20:** Simulation of Phase Lead Compensator Design for Generator 2

**Output of phase lead compensator block:**

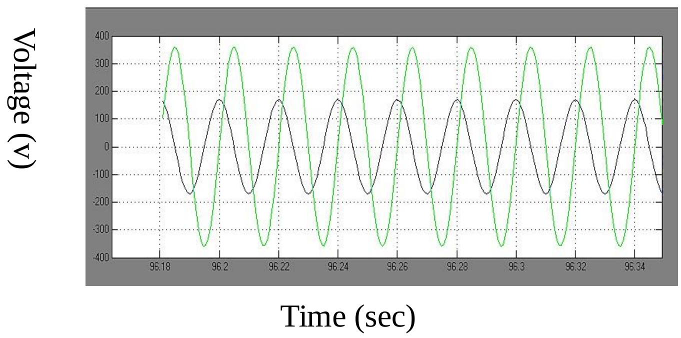



**Figure 21:** Output from Phase Lead Compensator Block

**Output of generator 2**

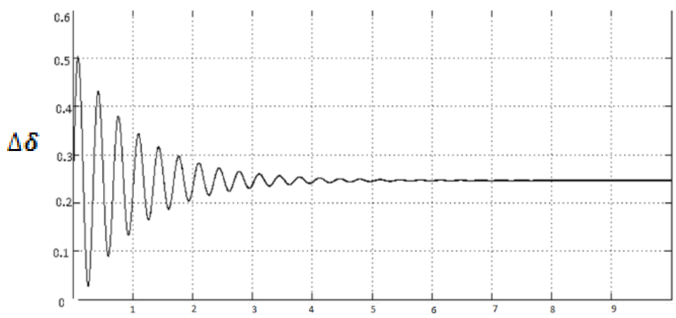



**Figure 22:** Output of Generator 2

**Simulation for Generator 3**

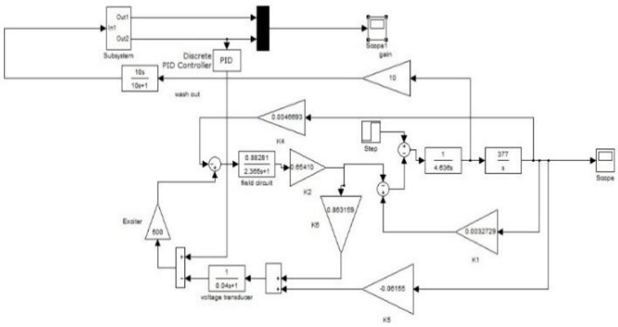
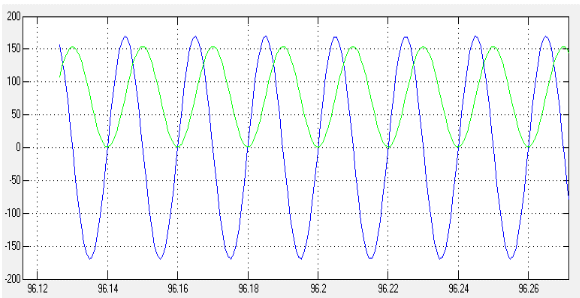


**Figure 23:** Simulation of Phase Lead Compensator Design for Generator 2

**Output of phase lead compensator block:**

Voltage (v)




Time (sec)

**Figure 23:** Output from Phase Lead Compensator Block

**Output of Generator 3**

$\Delta\delta$

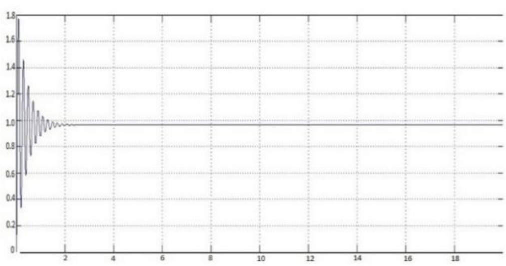


**Figure 24:** Output of Generator 3

**Simulation for Generator 4**

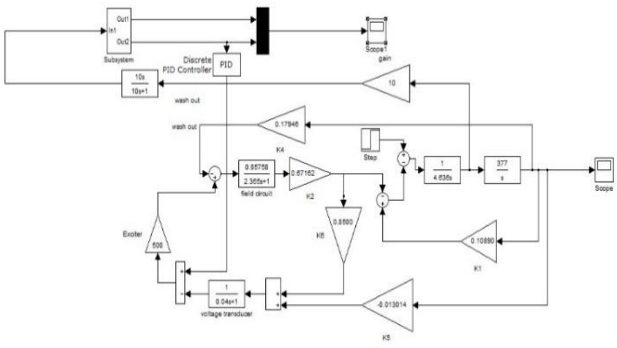


**Figure 23:** Simulation of Phase Lead Compensator Design for Generator 4

**Output of phase lead compensator block:**

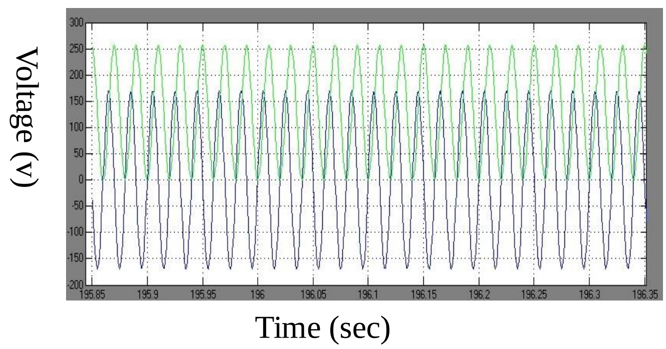



**Figure 24:** Output from Phase Lead Compensator Block

**Output of generator 4**

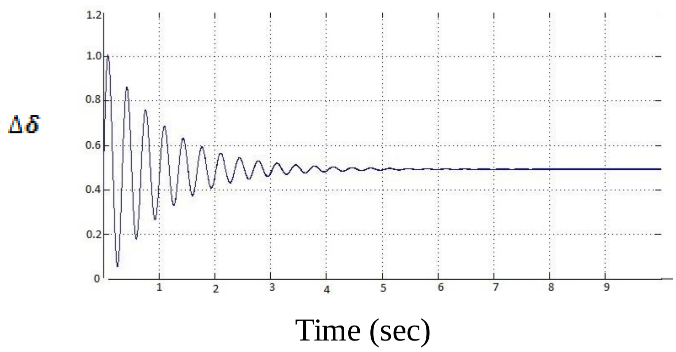



**Figure 25:** Output of Generator 4

With the help of this phase lead compensator design the phase lag is compensated and the system stability is achieved.

## Conclusion

The low frequency oscillations are damped with the help of Power System Stabilizer. The AVR produced the negative damping torque (Kd), which led to growing oscillation in the generator. This will affect stability of the system. To avoid such condition PSS is installed in the system, this will damp out the negative damping torque due to AVR. PSS provides enhanced system stability. The phase lead network provides compensation over the entire frequency range. Simulation is performed with phase lead compensator design and the system stability is achieved.

## References

[1] Fereidouni A R, Vahidi.B, Hoseini Mehr.J, Tahmasbli.M, Improvement Of Low Frequency Oscillation Damping By Allocation And Design Of Power System Stabilizer In Multi-Machine Power System Stabilizer. Electrical Power and Energy System 52(2013) 207-220.

[2] Larsen.L V, Swann D.A, Applying Power System Stabilizer Part III: Practical Consideration. IEEE Transaction on Power Apparatus and System. Vol.Pas.100, No.6 June 1981.

[3] Kundur.P, Kiein.M, Rogers G.J, Zywno M.S, Application of Power System Stabilizers for Enhancement of Overall System Stability. IEEE Trans Power System 1989:4: 614-26.

[4] Dysko A, Leithead WE, O'Reilly J. Enhanced Power System Stability By Coordinated PSS Design. IEEE Trans Power Syst 2010; 25:413–22

[5] Balwinder Singh Surjan, Ruchira Garage Power System Stabilizer Controller Design for SMIB System Stability Study. International Journal of Engineering and Advanced Technology ISSN-2249-8958, Volume-2 Issue-1, October 2012.

[6] Rajaa Vikhram.G.Y, Latha S, Design Of Power System Stabilizer For Power System Damping Improvement With Multiple Design Requirements. International Journal of Soft Computing and Engineering ISSN; 2231-2307, VOLUME – 2, Issue – 5, NOVEMBER-2012.

[7] Manish Kushwaha Mrs.Ranjeeta Khara Dynamic Stability Enhancement Of Power System Using Fuzzy Logic Based Power System Stabilizer. 2013 International Conference on Power, Energy and Control (ICPEC).

[8] Kunder P, Power System Stability and Control. New York, USA: McGraw – Hill 1994 0-07-035958 –X.

[9] Http://Psdyn.Ece.Wisc.Edu/IEEE_Benchmarks.

[10] Bergen R. Power System Analysis. Englwood Cliffs: Prentice-Hall; 1986.

[11] Farid Golnaraghi, B.C Kuo Automatic Control System USA: John Wiley & Sons, Inc. ISBN-3 978-0470-04896-2.

[12] Anderson PM, Fouad AA. Power System Control and Stability. Second Ed. Manhattan, USA: John Wiley & Sons; 2003. 978-0-471-23862-1.