Scientific Journal Impact Factor (SJIF): 1.711
International Journal of Modern Trends in Engineering and Research
ISSN (ONLINE) : 2349 - 9745
ISSN (PRINT) : 2393 - 8161

Enhancement of Small Signal Stability by Using Power System Stabilizer

Ritesh Ukandrao Chirde[1]
[1]*Veermata Jijabai Technological Institute,*
Matunga, Mumbai.

Abstract— A complex assemblage of equipment and circuits for generating, transmitting, transforming, and distributing electrical energy constitutes an electric power system. Power system stability has been recognized as an important problem for secure system operation. Different types of stabilities have been discussed in this paper; especially small signal stability is explained in detail. The power system stabilizer (PSS) increases stability limits by modulating generator excitation to provide damping to the oscillations of synchronous machine rotors (0.2-2.5 Hz). Thus PSS is used to improve the small signal stability. In this paper, a test power system is considered and PSS is implemented on the excitation system of synchronous machine. The simulations are performed in Matlab/Simulink environment. The results show that PSS appreciably reduces the damping time of oscillations.

Keywords— stability; excitation system; synchronizing torque; damping torque; power system stabilizer

I. INTRODUCTION

Electric power system is a network of electrical components used to supply, transmit and use electric power. An example of an electric power system is the network that supplies a region's homes and industry with power - for sizable regions, this power system is known as the grid and can be broadly divided into the generators that supply the power, the transmission system that carries the power from the generating centers to the load centers and the distribution system that feeds the power to nearby homes and industries. Smaller power systems are also found in industry, hospitals, commercial buildings and homes. The majority of these systems rely upon three-phase AC power - the standard for large-scale power transmission and distribution across the modern world.

As power systems have evolved through continuing growth in interconnections, use of new technologies and controls, and the increased operation in highly stressed conditions, different forms of system instability have emerged. For example, voltage stability, frequency stability and interarea oscillations have become greater concerns than in the past. At present the demand for electricity is rising phenomenally especially in developing country like India. This persistent demand is leading to operation of the power system at its limit. On top of this the need for reliable, stable and quality power is also on the rise due to electric power sensitive industries like information technology, communication, electronics etc. In this scenario, meeting the electric power demand is not the only criteria but also it is the responsibility of the power system engineers to provide a stable and quality power to the consumers. These issues highlight the necessity of understanding the power system stability.

Beginning in the late 1950's and early 1960's most of the new generating units added to electric utility systems were equipped with continuously-acting voltage regulators. As these units increased in number, it seemed that the voltage regulator action could damage the dynamic stability (or perhaps more properly steady state stability) of the power system. Oscillations of small magnitude and low frequency often persisted for long periods of time and sometimes caused limitations on power transfer capability. Power system stabilizers were developed to assist in damping these oscillations by modulating the generator excitation [1]-[2]. The art and science of applying power system stabilizers has evolved remarkably over the past one and a half decade since the first widespread application to the Western Systems of the United States.

The initial development and application of PSS were in the early 1960s on four hydraulic plants. Stabilizers using shaft speed (Delta-Omega) as input signals were successfully designed and applied to these units and subsequently to several other hydraulic units [3].

In this paper, small signal stability is discussed. A test power system under fault condition is considered and the impact of power system stabilizer on it is studied. The paper is categorized in different sections. Section II provides formal introduction about power system stability. Section III throws some light on small signal stability, section IV and V explains excitation system and power system stabilizer respectively. In the final simulation part, different output waveforms of the test system are analyzed with and without PSS connected into the system.

II. POWER SYSTEM STABILITY

"Power system stability is the ability of electrical power system, for given operating condition, to regain its state of operating equilibrium after being subjected to a physical disturbance, with the power system variables bounded, so that the entire system remains uninterrupted". Traditionally, stability problem is concerned with maintaining synchronous operation i.e. synchronous machines should remain "in step". This aspect of stability is influenced by the dynamics of generator rotor angles and power angle relationship.

A. Small disturbance or small signal stability

It is the ability of the system to remain in synchronism when subjected to small disturbances. If a disturbance is small enough so that the nonlinear power system can be approximated as a linear system, then the study of rotor angle stability of that particular system is called as small-disturbance angle stability analysis. Small disturbances can be small load changes like switching on or off of small loads, line tripping, small generators tripping etc.

B. Large disturbance or transient angle stability

It is the ability of the system to remain in synchronism when subjected to large disturbances. Large disturbances can be faults, switching on or off of large loads, large generators tripping etc. When a power system is subjected to large disturbances they will lead to large excursions of generator rotor angles. Since there are large rotor angle changes the power system cannot be approximated by a linear representation like in the case of small-disturbance stability.

C. Voltage stability

It is the ability of the system to maintain steady state voltages at all the system buses when subjected to a disturbance. If the disturbance is large then it is called as large-disturbance voltage stability and if the disturbance is small it is called as small-disturbance voltage stability. The main difference between voltage stability and angle stability is that voltage stability depends on the balance of reactive power demand and generation in the system where as the angle stability mainly depends on the balance between real power generation and demand.

D. Frequency stability

It refers to the ability of a power system to maintain steady frequency following a severe disturbance between generation and load. It depends on the ability to restore equilibrium between system generation and load, with minimum loss of load. Frequency instability may lead to sustained frequency swings leading to tripping of generating units or loads.

III. SMALL SIGNAL STABILITY

It is the ability of the interconnected synchronous machines of power system to remain in synchronism. The stability problem involves the study of electromechanical oscillations inherent in the power systems. In this problem, the fundamental factor is the manner in which the power outputs of synchronous machines vary as their rotor oscillates.

The important characteristic that has a bearing on power system stability is the relationship between interchange power and angular positions of the rotors (δ) of synchronous machines. This relationship is highly non-linear. Consider the sample model given below,

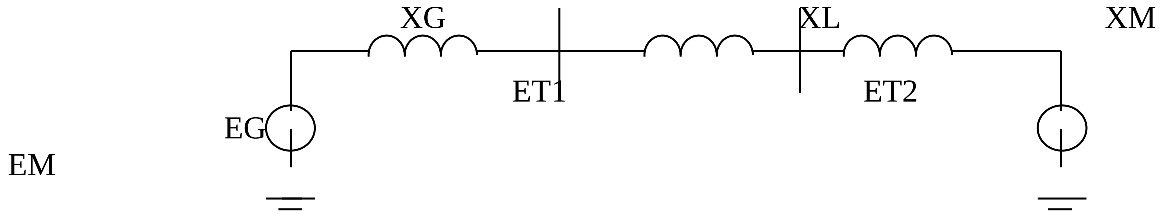


Figure 1. Sample model

The power transferred from the generator to the motor is the function of angular separation (δ) between the rotors of the two machines. This angular separation is due to three components.

a. Generator internal angle (δG)
b. Angular difference between terminal voltages of generators
c. Internal angle of the motor (δM)

The power transferred from generator to motor is given by,

$$P = \frac{E_G E_M}{X_T} \sin(\delta)$$

Where *XT = XG + XL + XM*

When there are more than two machines, their angular displacements affect the interchange of power. However, limiting values of power transfers and angular separation are the complex functions of generation and load distribution. When there is a perturbation in the electric power system, the change in electrical torque of a synchronous machine can be resolved into two components as follows,

$$\Delta Te = TS\Delta\delta + TD\Delta\omega$$

where $TS\Delta\delta$:- The synchronizing torque component which is in phase with rotor angle perturbation $\Delta\delta$
$TD\Delta\omega$:- The damping torque component which is in phase with the speed deviation $\Delta\omega$.

System stability depends on the existence of both components of torque for each of the synchronous machines. Shortage of sufficient synchronizing torque results in instability through an aperiodic drift in rotor angle. On the other hand, lack of sufficient damping torque result in oscillatory instability [4].

IV. EXCITATION SYSTEM

The basic function of excitation system is to provide direct current to the synchronous machine field winding. Additionally, the excitation system performs control and protective functions by controlling the field voltage and thereby field current. The control functions include the control of voltage and reactive power flow, and enhancement of system stability. The protective functions make sure that the capability limits of the equipments are not exceeded.

A. Excitation system requirements

The performance requirements of the excitation system are determined by considerations of the synchronous generator as well as the power system.

i. **Generator considerations.** The important requirement is that the excitation system should maintain the terminal voltage of the synchronous generator as the output varies by supplying and automatically adjusting the field current. This requirement can be pictured from the generator V-curves. Normally, the exciter rating varies from 2.0 to 3.5 kW/MVA generator rating. Besides this, excitation system must be able to respond to transient disturbances with field forcing consistent with the generator instantaneous and short-term capabilities. In this regard, the generator capabilities are

Volume 02, Issue 05, [May– 2015] ISSN (Online):2349–9745; ISSN (Print):2393-8161

limited by several factors e.g. rotor insulation failure due to high voltage, rotor heating due to high field current etc. To ensure the best utilization of the excitation system, it should be capable of meeting the system needs by taking full advantage of the generator's short term capabilities without exceeding their limits.

ii. **Power considerations.** From power system perspective, the excitation system should contribute to effective control of voltage and enhancement of system stability. It should be capable of responding rapidly to a disturbance so as to respond to a transient stability, and of modulating generator field so as to enhance small signal stability.

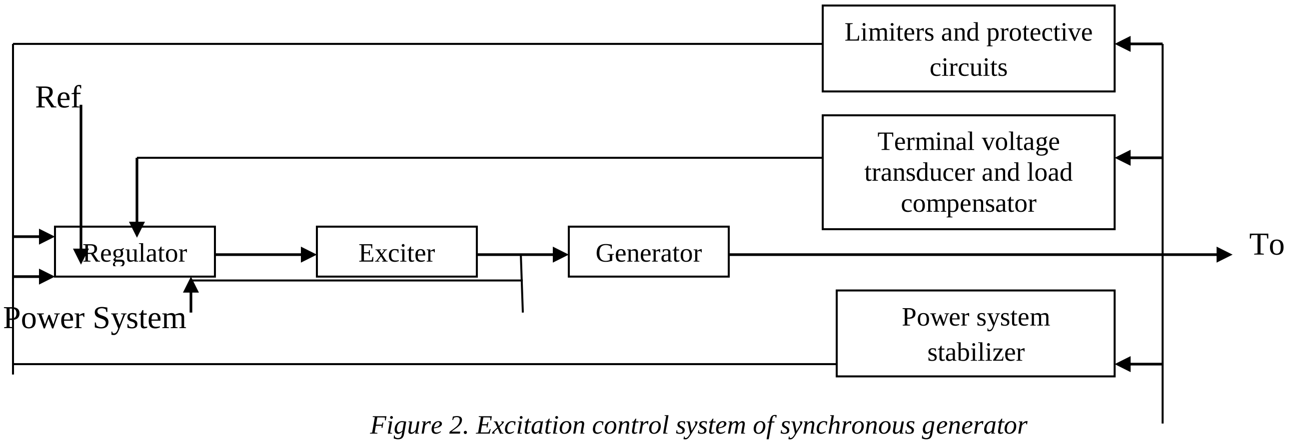


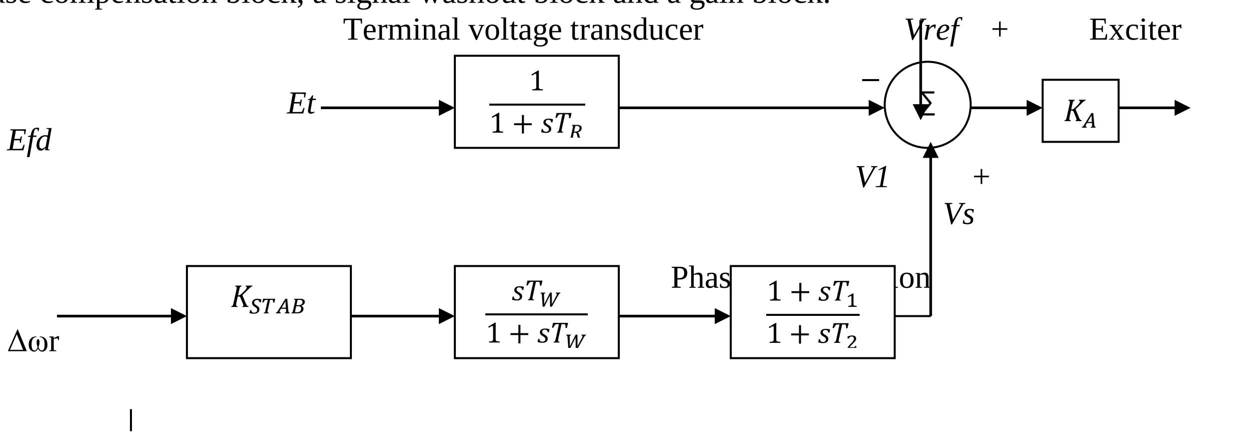
Figure 2. Excitation control system of synchronous generator

In the early 1960's, there was expansion of excitation systems by adding auxiliary stabilizing signals to the terminal voltage error signal, to control the field voltage to damp power system oscillations. This part of excitation control is referred as the power system stabilizer. This combination of auxiliary stabilizing signals contributes to enhancement of the overall system dynamic performance. Figure (2) presents the excitation control system of a synchronous generator.

V. POWER SYSTEM STABILIZER

The basic function Power System Stabilizer (PSS) includes widening of stability limits by modulating generator excitation for provision of damping to the oscillations of synchronous machine rotors (0.2- 2.5 Hz) with respective to one another, inadequate damping of which may restrict the ability to transmit power. This is achieved by modulating the generator excitation so as to develop a component of electrical torque in phase with rotor speed deviation.

The basic structure and performance of PSS is illustrated by considering a thyristor excitation system as shown in figure (3). It shows the block diagram of excitation system including Automatic Voltage regulator (AVR) and PSS. The PSS representation in the figure (3) consists of three blocks: A phase compensation block, a signal washout block and a gain block.



Volume 02, Issue 05, [May– 2015] ISSN (Online):2349–9745; ISSN (Print):2393-8161

Power System Stabilizer

Figure 3. Thyristor excitation system with AVR and PSS

The phase compensation block provides the appropriate phase-lead characteristic to compensate for phase lag between the exciter input and the generator electrical torque. The signal washout block serves as a high-pass filter, with the time constant *TW* high enough to allow signals associated with oscillations in ωr to pass unchanged. Steady changes in speed would modify the terminal voltage without it. It allows the PSS to respond only to changes in speed. *TW* may be in the range of 1-20 seconds. The stabilizer gain *KSTAB* determines the amount of damping introduced by the PSS. Ideally, the gain should be set at a value corresponding to maximum damping; however it is often limited by other considerations. In applying the PSS, care should be taken that not only the small signal stability but also the overall stability is enhanced.

A. Input signals

Shaft speed, integral of power and terminal frequency are among the commonly used input signals to PSS. Based on the stabilizer input signal employed, the implementation details will differ.

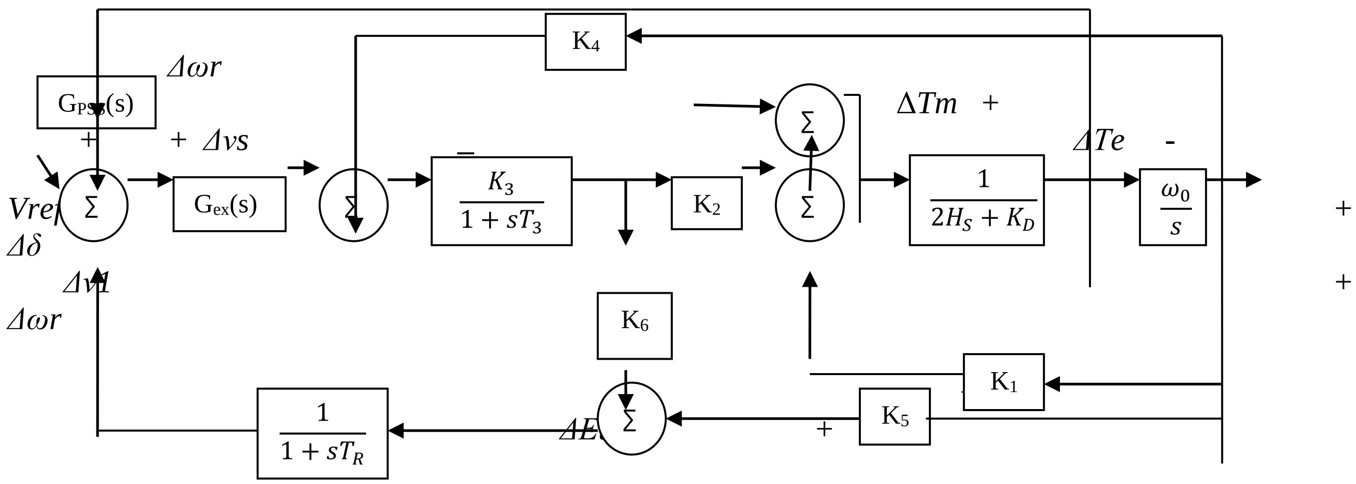
i. **Speed input.** Since the main action of the PSS is to handle the rotor oscillations, the input signal of rotor speed has been the most frequently advocated in the literature. Controllers based on speed deviation would ideally use a differential-type of regulation and a high gain. Since this is unrealistic, the lead-lag structure is commonly used. However, one of the constraints of the speed input PSS is that it may excite torsional oscillatory modes.

ii. **Power input.** A power input PSS design was proposed as a solution to the torsional interaction problem suffered by the speed-input PSS. The power signal used is the generator electrical power, which has high torsional attenuation. Due to this, the gain of the PSS may be increased without the resultant loss of stability, which leads to greater oscillation damping.

iii. **Frequency input.** In case of frequency input stabilizer it has been found that frequency is highly sensitive to the strength of the transmission system - that is, more sensitive when the system is weaker - which may offset the controller action on the electrical torque of the machine. Other limitations include the presence of sudden phase shifts following rapid transients and large signal noise induced by industrial loads. On the other hand, the frequency signal is more sensitive to inter-area oscillations than the speed signal, and may contribute to better oscillation attenuation.

B. Small signal stability enhancement

The theoretical basis for a PSS may be illustrated with the aid of block diagram shown in figure (4). Since the purpose of PSS is to introduce a damping torque component, a logical signal to use for controlling generator excitation is the speed deviation $\Delta\omega r$.



The PSS transfer function, GPSS(s), should have appropriate phase compensation circuit to compensate for the phase lag between the exciter input and the electrical torque. Ideally, with the phase characteristics of GPSS(s) being an exact inverse of the exciter and the generator phase characteristics to be compensated, the PSS would result in a pure damping torque at all oscillating frequencies.

VI. SIMULATIONS

Here, a test system is considered in which a synchronous machine is connected to the 10000 MVA generating station via a transformer and transmission line and is feeding to the load of 15 MW. A three phase fault is applied on the transmission line. Two cases are examined here, first is without application of PSS and the second one is with application of PSS.

Rotor speed deviation is given an input to PSS. Simulink model of the power system with PSS connected is presented below.

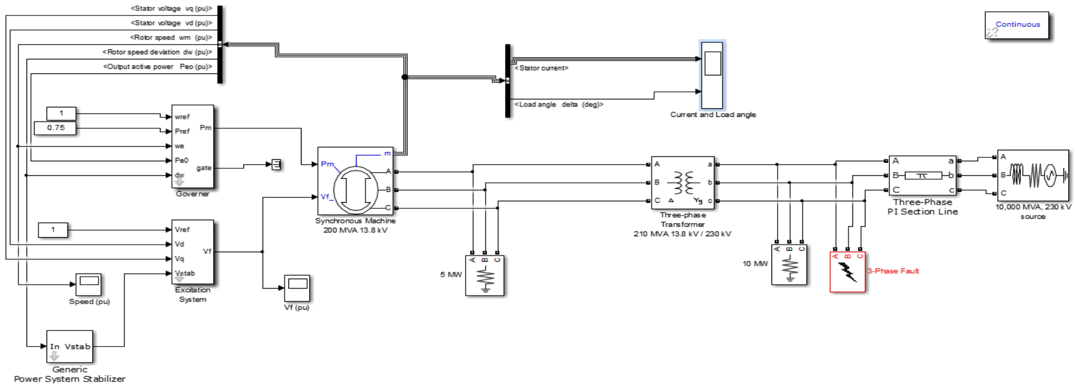


Figure 5. Simulink model of the test system

Now different parameters are compared for two cases i.e. with PSS connected and without PSS connected.

A. Stator current and load angle

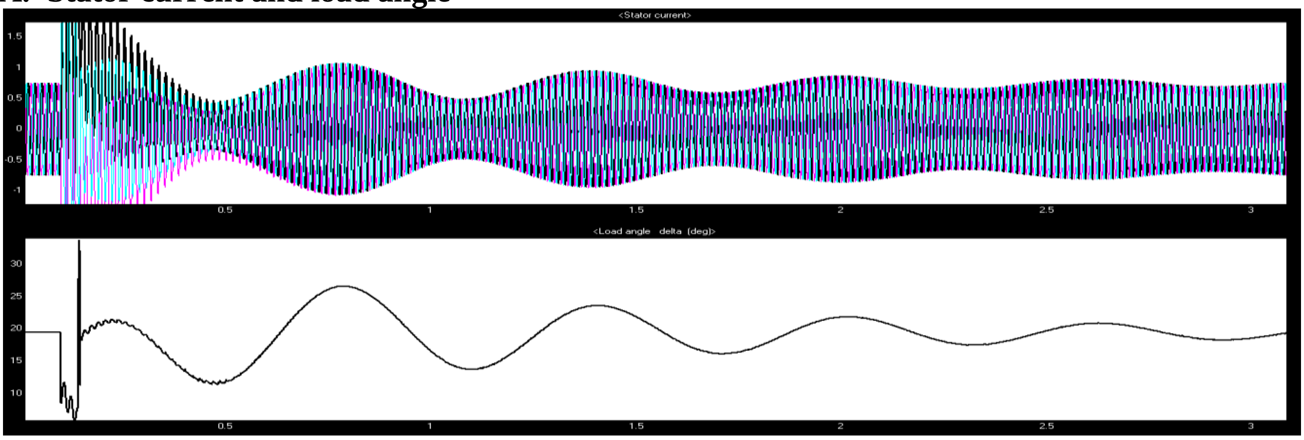


Figure 6. Without PSS

Volume 02, Issue 05, [May– 2015] **ISSN (Online):2349–9745; ISSN (Print):2393-8161**

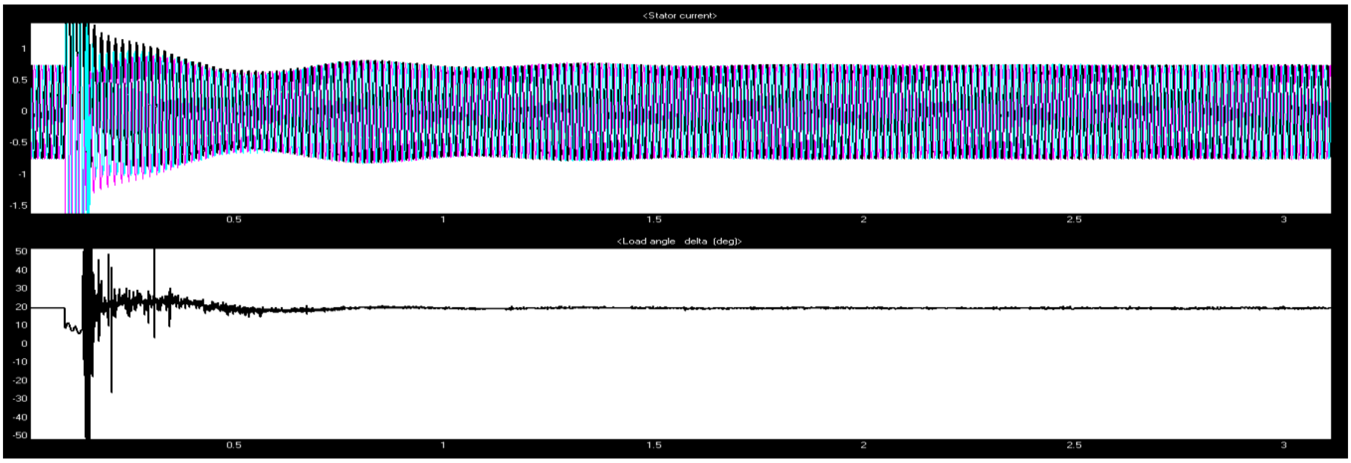


Figure 7. With PSS

B. Rotor speed oscillations

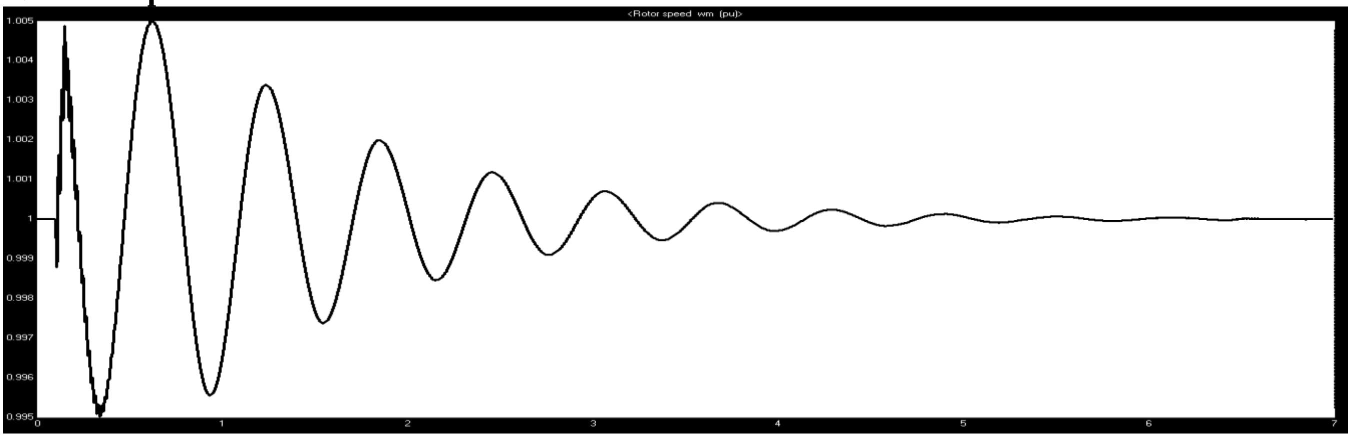


Figure 8. Without PSS

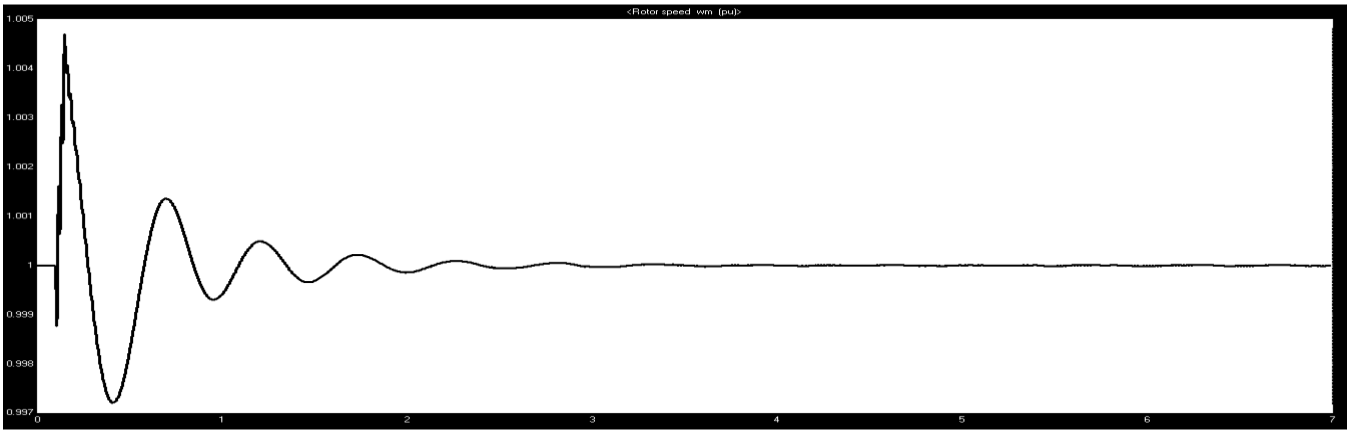


Figure 9. With PSS

C. Field voltage of synchronous machine

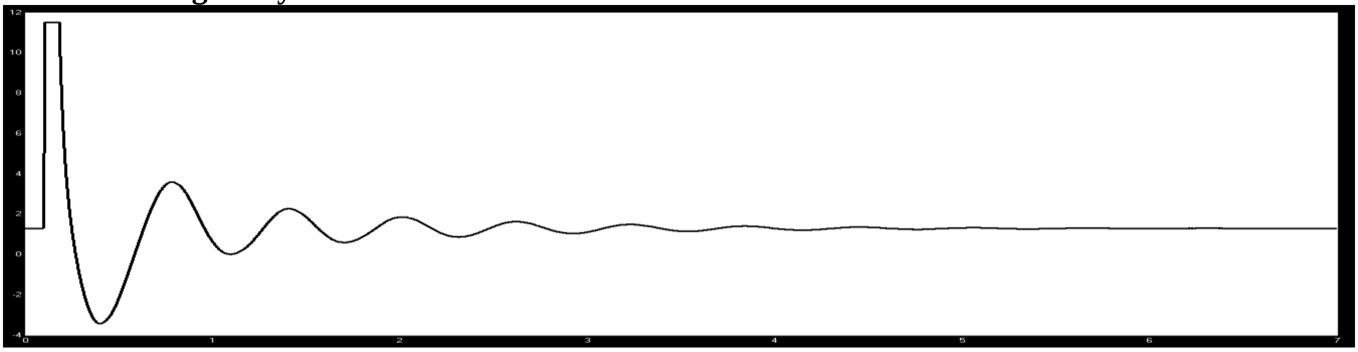


Figure 10. Without PSS

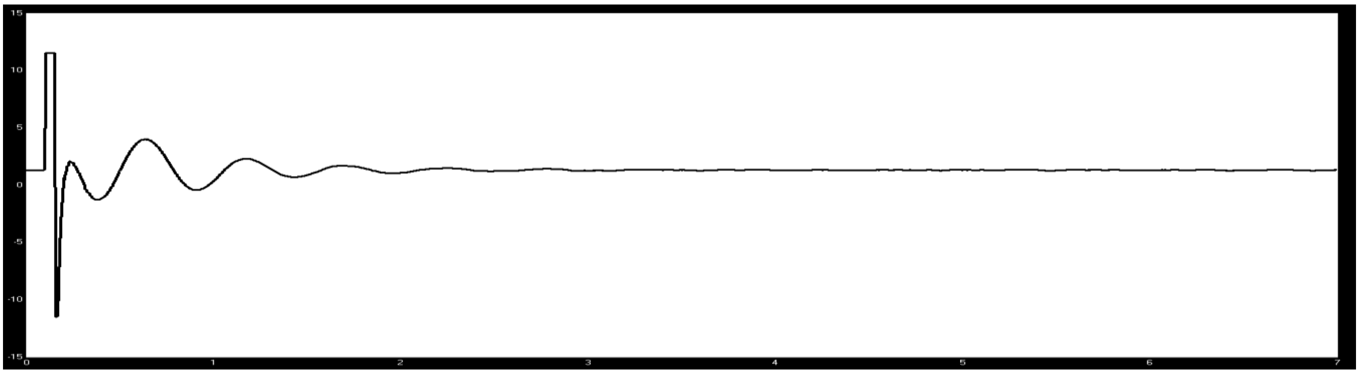


Figure 11. With PSS

VII. CONCLUSION

The power system stability has been explained briefly, along with excitation system and power system stabilizer. Rotor speed deviation is given as an input to the power system stabilizer; the implementation details vary according to the input applied to the power system stabilizer. Small signal stability is also discussed in brief. In this paper, power system stabilizer has been successfully implemented on a test power system. The output waveforms suggest that the damping time is considerably reduced by the introduction of power system stabilizer into the power system.

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