FUZZY APPLICATIONS TO SINGLE MACHINE POWER SYSTEM STABILIZERS

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ABSTRACT

Power system stabilizers (PSSs) are added to excitation system to enhance the damping during low frequency oscillations. This paper presents a study of fuzzy logic power system stabilizer (PSS) for stability enhancement of a single machine power system. In order to accomplish the stability enhancement, speed deviation ($\Delta\omega$) and acceleration ($\Delta\varpi$) of the rotor of synchronous generator of Kota Thermal were taken as the input to the fuzzy logic controller. These variables take significant effects on damping on damping of the generator shaft mechanical oscillations. The stabilizing signals were computed using the fuzzy membership functions depending on these variables. The performance of the fuzzy PSS is compared with the conventional power system stabilizer (CPSS). The simulations were tested under different operating conditions and change in reference voltage also tested with different membership functions. The simulation results are quite encouraging and satisfactory

Keywords: *Power System Stabilizer, Stability, Single Machine System, Thermal Power Station, Fuzzy Logic, Fuzzy Set Theory, Machine Dynamic, Simulink.*

1. INTRODUCTION

In the late 1950s and early 1960s most of the new generating units added to electric utility systems were equipped with continuously acting voltage regulators. As these units came to constitute a large percentage of generating capacity, it became apparent that the voltage regulator action had a detrimental impact upon the dynamic stability (or, perhaps more accurately, steady state stability) of the power system. Oscillations of small magnitude and low frequency often persist for long periods of time and in some cases can hinder power transfer capability. Power system stabilizers were developed to aid in damping these oscillations via modulation of the generator excitation. The art and science of applying power system stabilizers (PSS) has been developed over the past 40 to 45 years since the first widespread application to the Western systems of the United States. This development has brought an improvement in the use of various tuning techniques and input signals and in the ability to deal with turbine-generator-shaft torsional modes of vibrations [1].

In the past five decades the PSS have been used to provide the desired system performance under condition that requires stabilization. Stability of synchronous generator depends on a number of factors such as the setting of automatic voltage regulator (AVR). Many generators are designed with high gain, fast acting AVRs to enhance large scale stability to hold the generator in synchronism with the power system during large transient fault conditions. But with the high gain of excitation systems, it can decrease the damping torque of generator. A supplementary excitation controller referred to as PSS have been added to synchronous generators to counteract the effect of high gain AVRs and other sources of negative damping [2].

To provide damping, the stabilizers must produce a component of electrical torque on the rotor which is in phase with speed variations. The application of a PSS is to generate a supplementary stabilizing signal, which is applied to the excitation system or control loop of the generating unit to produce a positive damping. The most widely used conventional PSS is the lead-lag PSS, where the gain settings are fixed at certain value which are determined under particular operating conditions to result in optimal performance for that specific condition. However, they give poor performance under different synchronous generator loading conditions [3].

Conventional PSS (CPSS) is widely used in existing power systems and has made a contribution in enhancing power system dynamic stability. The parameters of CPSS are determined based on a linearised model of the power system around a nominal operating point where they can provide good performance. Since power systems are highly non-linear systems, with configurations and parameters that change with time, the CPSS design based on the linearised model of the power system cannot guarantee its performance in a practical operating environment [4],[5].

To improve the performance of CPSS, numerous techniques have been proposed for their design, such as using intelligence optimization methods (simulated annealing, genetic algorithm, Tabu search, fuzzy, neural networks and many other non linear techniques. The intelligent optimization algorithms are used to determine the optimal parameters for CPSS by optimizing an eigen value based cost function in an off-line mode. Since the method is based on a linearised model and the parameters are not updated on-line, therefore, they lack satisfactory performance during practical operation. The rule-based fuzzy logic control methods are well known for the difficulty in obtaining and adjusting the parameters of the rules especially on-line. Recent research indicates that more emphasis has been placed on the combined usage of fuzzy logic systems and other technologies such as neural networks to add adaptability to the design [6]-[8].

Applications of ANN to power systems are a growing area of interest. Considerable efforts have been placed on the applications of ANNs to power systems. Several interesting applications of ANNs to power system problems [1]-[5], indicate that ANNs have great potential in power system on-line and off-line applications. The feature of an ANN is its capability to solve a complicated problem very efficiently because the knowledge about the problem is distributed in the neurons and the connection weights of links between neurons, and information are processed in parallel.

Back-propagation is an iterative, gradient search, supervised algorithm which can be viewed as multiplayer non-linear method that can re-code its input space in the hidden layers and thereby solve hard learning problems. The network is trained using ANN technique until a good agreement between predicted gain settings and actual gains is reached.

During last three decades, the assessment of potential of the sustainable eco-friendly alternative sources and refinement in technology has taken place to a stage so that economical and reliable power can be produced. Different renewable sources are available at different geographical locations close to loads, therefore, the latest trend is to have distributed or dispersed power system. Examples of such systems are wind-diesel, wind-diesel-micro-hydro-system with or without multiplicity of generation to meet the load demand. These systems are known as hybrid power systems. To have automatic reactive load voltage control SVC device have been considered. The multi-layer feed-forward ANN toolbox of MATLAB 6.5 with the error back-propagation training method is employed.

2. FUZZY-LOGIC BASED POWER SYSTEM STABILIZER

In the design of fuzzy-logic controllers, unlike most conventional methods, a mathematic model is not required to describe the system under study. It is based on the implementation of fuzzy logic technique to PSS to improve system damping. The effectiveness of the fuzzy logic PSS in a single machine infinite bus is demonstrated by the Simulink program (Matlab Software). The non-linear model of single machine infinite bus system (SMIB) developed using Simulink. The performance of fuzzy logic PSS is compared with the CPSS and without PSS. The time-domain simulation performed on the test system will be employed to study the nonlinear response following steady state operation and large disturbance such as three phase fault [9].

The following Figure 1 shows the single machine connected to an infinite bus network through short transmission line of 0.568 + j0.2469 ohm impedance. From the block diagram, the stabilizing signal is introduced in the excitation system.

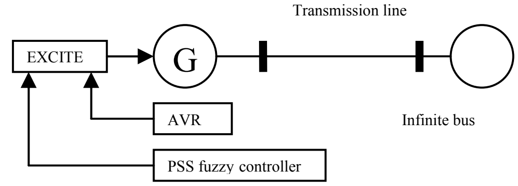

Figure 1: Synchronous Generator and Infinite Bus system

In contrast to a conventional PSS, which is designed in the frequency domain, a fuzzy logic

PSS is being designed in the time domain. A fuzzy logic controller determines the operating condition from the measured values and selects the appropriate control actions using the rule base created from the expert knowledge. Depending on the system state, the controller operates in the range between no control action and full control action in a non-linear manner. The fuzzy controller in itself has no dynamic component, *i.e.* it can immediately perform the desired control action.

The input to the ANN is the value of exponent of reactive power load-voltage characteristic (n_q) and the output is the desired proportional gain (K_P) and integral gain (K_I) parameters of the SVC. Normalized values of n_q are fed as the input to the ANN the normalized values of outputs are converted into the actual value. The process of determining the weights is called the training of the learning process. Prior to conducting the

3. FUZZY LOGIC PROCESS

The following Figure 2 shows the block diagram of fuzzy logic controller, it generally comprises four principle components: fuzzification interface, knowledge base, decision making logic and defuzzification interface. If the output from the defuzzifier is not a control action for a process, then the system is a fuzzy logic decision system.

The fuzzy controller itself is normally a two-input and a single-output component. It is usually a MISO system[8]

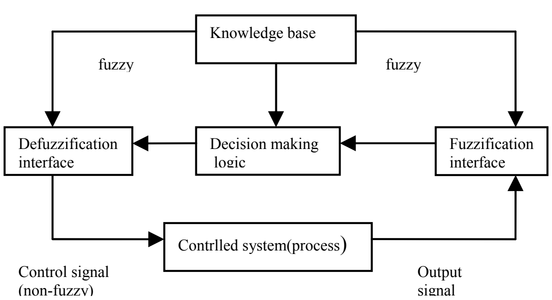

Figure 2: Principle Design of Fuzzy Logic

The first step in designing a fuzzy controller is to decide which state variables represent of system dynamic performance must be taken as the input signal to the controller. However, choosing the proper linguistic variables formulating the fuzzy control rules are very important factors in the performance of the fuzzy control system. System variables, which are usually used as the fuzzy controller inputs includes states error, state error derivative, state error integral or etc. In power system, based on previous experience. Generator speed deviation ($\Delta\omega$) and acceleration ($\Delta\varpi$) are chosen to be the input signals of fuzzy PSS [9].

As it was mentioned earlier, if the synchronous generator automatic voltage regulator is utilized in a proper way it is capable of damping electromechanically oscillations of the generator shaft. The input to the excitation system would be the

Control variable which is actually the output of fuzzy PSS. In practice, only shaft speed deviation is ready available. Hence, the acceleration signal can be derived from speed signals measured at two sampling instant by the following expression

$$\Delta\omega(kTs) = \frac{\Delta\omega(kTs) - \Delta\omega((k-1)Ts)}{Ts} \quad \text{--(1)}$$

where T_s is the sampling time. After choosing proper variables as input and output of fuzzy controller, it is required to decide on the linguistic variables. These variables transform the numerical values of the input of the fuzzy controller to fuzzy quantities. The number of these linguistic variables specifies the quality of the control which can be achieved using the fuzzy controller. As the number of the linguistic variables increases, the computational time and required memory increase. Therefore, a compromise between the quality of control and computational time is needed to choose the number of linguistic variables. For the power system under study, five linguistic variables for each of the input and output variables are used to describe them, as in the following table 1

LN	Large Negative
MN	Medium Negative
Z	Zero
MP	Medium Positive
LP	Large Positive

Table 1: Input and output linguistic variables

The two inputs; speed deviation and acceleration, result in 25 rules for each machine. Decision table in 2 shows the result of 25 rules, where a positive control signal is for the deceleration control and a negative signal is for acceleration control. The example of first rule is; rule 1: "*if speed deviation is LP (large positive) AND acceleration is LN (large negative) THEN PSS output of fuzzy is Z (zero)*".The stabilizer output is obtained by applying a particular rule expressed in the form of membership function.

There are different methods for finding the output in which Minimum-Maximum and Maximum Product Method are among the most important ones. Here the Minimum- Maximum method is used. Finally, the output membership function of the rule is calculated. This procedure is carried out for all of the rules and every rule an output membership function is obtained.

Accel.→ Speed dev.↓	**LN**	**MN**	**Z**	**MP**	**LP**
LP	Z	Z	MP	MP	LP
MP	MN	Z	Z	MP	MP
Z	MN	Z	Z	Z	MP
MN	MN	MN	Z	Z	MP
LN	LN	MN	MN	Z	Z

Table2: Decision table for PSS output

Since a non-fuzzy signal is needed for the excitation system by knowing the membership function of the fuzzy controller its numerical value should be determined. There are different techniques for defuzzification of fuzzy quantities such as Maximum Method, Height Method, and Centroid Method. In this method the Centroid Method is used.

3. CONVENTIONAL PSS

The input to the conventional PSS is speed deviation. The PSS gain K_s is an important factor as the damping provided by the PSS increase in proportion to an increase in the gain up to a certain critical gain value, after which the damping begins to decrease. The basic structure of the CPSS is as follows [2]

1. A phase compensation block

2. A signal washout block

3. A gain block

$$\text{PSSoutput}(s) = K_s \frac{(sT_W)(1+sT_1)(1+sT_3)}{(1+sT_W)(1+sT_2)(1+sT_4)} \times \text{Input}(s) \quad \text{--(2)}$$

on study at the Kota Thermal, we have determined the PSS and washout transfer function as

$$\text{PSS}(s) = \frac{11.0223(1+s0.3580)}{(1+s0.0862)} \quad \text{--(3)}$$

$$\text{Washout}(s) = \frac{5s}{1+5s} \quad \text{--(4)}$$

The conventional fixed power system stabilizer is designed using a linearized model of the system using control theory. Therefore, this provides optimum performance for a nominal operating condition and system parameters with the input being small enough to justify the linear model. However, its performance becomes suboptimal following variations in system parameters and loading conditions from their nominal values or when the disturbance applied is large.

4. CASE STUDY

(A) SINGLE M/C FOR ROBUSTNESS

Considering a single machine connected by a transmission line to an infinite bus power system as the Figure- 1 the power system modeled using Simulink and power system block set of MATLAB [11]. The parameters of SMIB of thermal power station (110MW) are given as:

H = 5.6, D = 0.0, T_{d0} = 6.84, T_e = 0.02, K_e = 100.0, X_e = 0.2, $X_{d'}$ = 1.97, $X_{q'}$ = 1.9

To develop the simulation environment in fuzzy logic tool box, the controller has incorporated with 25 rules and the surface view was observed as in the Figure 3. Note that output response have been observed namely the slip to study. The disturbances considered is a self clearing fault at generator terminal and cleared at/after 0.1 seconds. The limits of PSS input are taken as ± 0.2 and exciter limits (E_{fd}) are taken as ± 6 pu.

The following variations were observed in the simulation results as Vref observed, the power (P_{go}) and the impedance variations of the system. The simulation studies were done in the following conditions.

1. When the operating conditions of the system are taken as Power (P_{go}) as 0.5 pu, V_{ref} = 1.0 pu, X_e = 0.2 pu

   The response of the system in the form of correcting voltage and the slip is being observed as in Figure 3. The voltage response of system with fuzzy logic PSS can be observed in comparison to the system with conventional PSS. The settling time of system with fuzzy logic PSS is 9 to 10 seconds whereas to the system with conventional PSS takes 15 to 17 seconds after clearing the fault and also the maximum over-shoot is reduced in the system with fuzzy logic PSS.

2. When the initial condition to the system are taken as Power (P_{go}) as 1.0 pu, V_{ref} = 1.0 pu, X_e = 0.2 pu

The response of the system in the form of correcting voltage and the slip is being observed as in Figure 4. The voltage response of system with fuzzy logic PSS can be observed in comparison to the system with conventional PSS. The settling time of system with fuzzy logic PSS is 7 to 8 seconds whereas to the system with conventional PSS takes 12 to 13 seconds after clearing the fault and also the maximum over-shoot is reduced in the system with fuzzy logic PSS.

3. When the initial condition to the system are taken as Power (P_{go}) as 1.5 pu, V_{ref} = 1.0 pu, X_e = 0.2 pu

   The response of the system in the form of correcting voltage and the slip is being observed as in Figure 5. The voltage response of system with fuzzy logic PSS can be observed in comparison to the system with conventional PSS. The settling time of system with fuzzy logic PSS is 21 to 22 seconds whereas to the system with conventional PSS takes infinite time after clearing the fault and also the maximum over-shoot is reduced in the system with fuzzy logic PSS.

4. When the initial condition to the system are taken as Power (P_{go}) as 2.0 pu, V_{ref} = 1.0 +0.1 pu, X_e = 0.2 pu

   The response of the system in the form of correcting voltage and the slip is being observed as in Figure 6. The voltage response of system with fuzzy logic PSS can be observed in comparison to the system with conventional PSS. The settling time of system with fuzzy logic PSS is 20 to 21 seconds whereas to the system with conventional PSS takes 25 to 26 seconds after clearing the fault and also the maximum over-shoot is reduced in the system with fuzzy logic PSS.

5. When the initial condition to the system are taken as Power (P_{go}) as 1.0 pu, V_{ref} = 1.0 pu, X_e = 0.4 pu

   The response of the system in the form of correcting voltage and the slip is being observed as in Figure 7. The voltage response of system with fuzzy logic PSS can be observed in comparison to the system with conventional PSS. The settling time of system with fuzzy logic PSS is 10 to 12 seconds whereas to the system with conventional PSS takes infinite time after clearing the fault and also the maximum over-shoot is reduced in the system with fuzzy logic PSS.

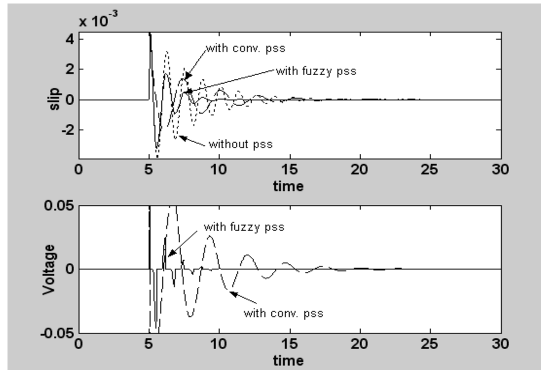

Figure 3: Slip Response without PSS, with CPSS and with fuzzy logic PSS for Pg0 = 0.5 pu, Vref = 1.0 pu, Xe = 0.2 pu. (Time is taken in seconds)

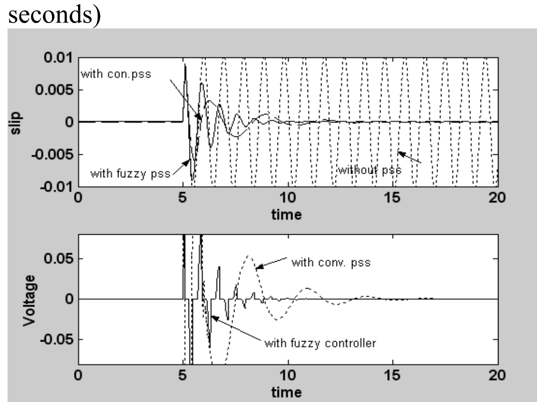

Figure 4: Slip Response without PSS, with CPSS and with fuzzy logic PSS for Pg0 = 1.0 pu, Vref = 1.0 pu, Xe = 0.2 pu. (Time is taken in seconds)

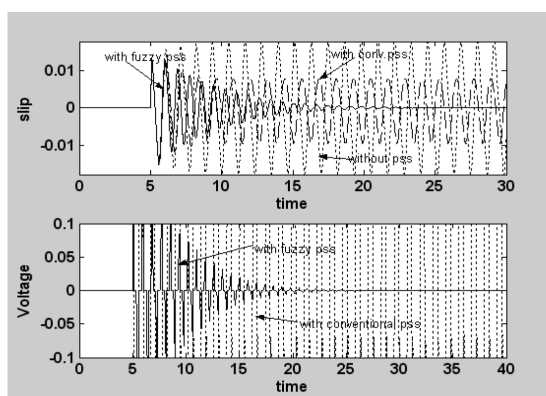

Figure 5: Slip Response without PSS, with CPSS and with fuzzy logic PSS for Pg0 = 1.5 pu, Vref = 1.0 pu, Xe = 0.2 pu. (Time is taken in seconds)

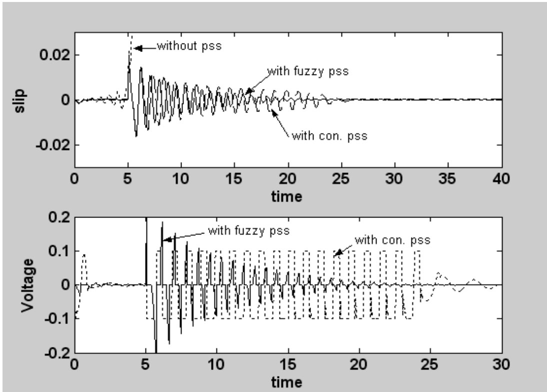

Figure 6: Slip Response without PSS, with CPSS and with fuzzy logic PSS for Pg0 = 2.0 pu, Vref = 1.0+0.1 pu, Xe = 0.2 pu. (Time is taken in seconds)

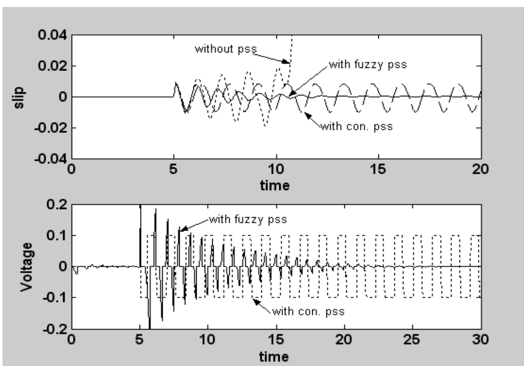

Figure 7: Slip Response without PSS, with CPSS and with fuzzy logic PSS for Pg0 = 1.0 pu, Vref = 1.0 pu, Xe = 0.4 pu. (Time is taken in seconds)

(B) SINGLE M/C WITH DIFFERENT MEMBERSHIP FUNCTIONS

The following variations were observed in the simulation results as V_{ref} observed, the power (P_{go}) and the impedance variations of the system. The simulation studies were done in the following conditions.

1. When the operating conditions of the system are taken as Power (P_{go}) as 0.5 pu, V_{ref} = 1.0 pu, X_e = 0.2 pu

   The response of the system in the form of correcting voltage and the slip is being observed as in Figure 8. The voltage response of system with triangular membership function provides with respect to trapezoidal and Gaussian function.

2. When the initial condition to the system are taken as Power (P_{go}) as 1.0 pu, V_{ref} = 1.0 pu, X_e = 0.2 pu

   The response of the system in the form of correcting voltage and the slip is being observed as in Figure 9. The voltage response of system with Gaussian membership function provides with respect to trapezoidal and triangular function.

3. When the initial condition to the system are taken as Power (P_{go}) as 1.55 pu, V_{ref} = 1.0 pu, X_e = 0.2 pu

   The response of the system in the form of correcting voltage and the slip is being observed as in Figure 10. The voltage response of system with Gaussian membership function provides with respect to trapezoidal and triangular function.

4. When the initial condition to the system are taken as Power (P_{go}) as 2.0 pu, V_{ref} = 1.0 pu, X_e = 0.4 pu

   The response of the system in the form of correcting voltage and the slip is being observed as in Figure 11. The voltage response of system with Gaussian membership function provides with respect to trapezoidal and triangular function.

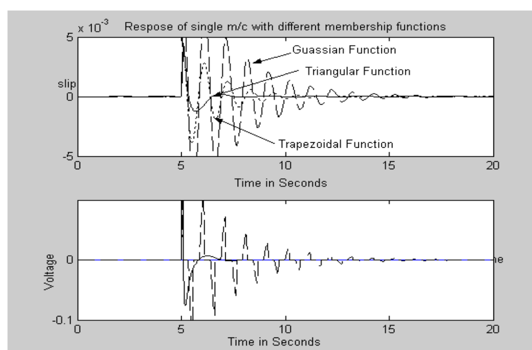

Fig.5.8 Figure 8: Slip Response with fuzzy logic PSS for Pg0 = 0.5 pu, V_{ref} = 1.0 pu, Xe = 0.2 pu. (Time is taken in seconds)

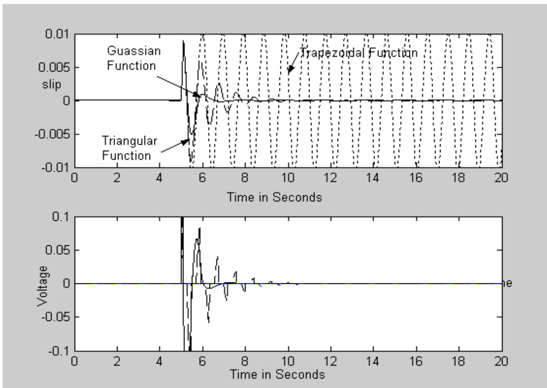

Figure 9: Slip Response with fuzzy logic PSS for Pg0 = 1.0 pu, V_{ref} = 1.0 pu, Xe = 0.2 pu. (Time is taken in seconds)

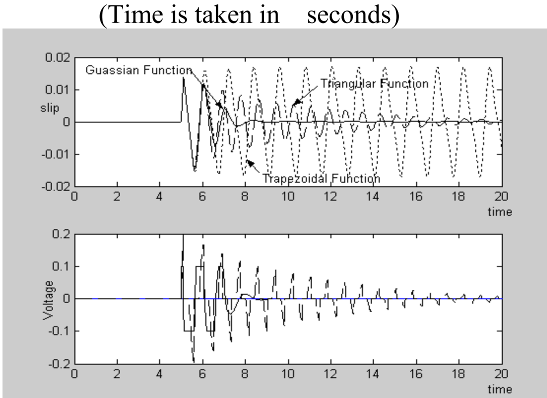

Figure 10: Slip Response with fuzzy logic PSS for Pg0 = 1.55 pu, V_{ref} = 1.0 pu, Xe = 0.2 pu. (Time is taken in seconds)

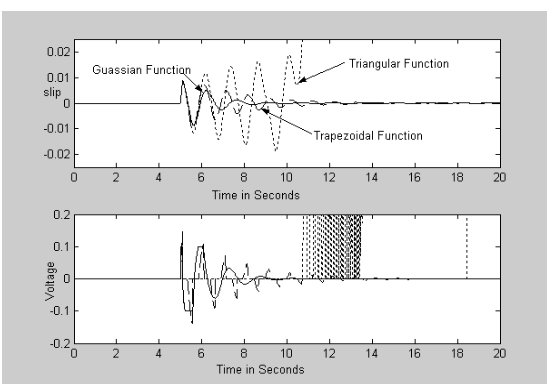

Figure 11: Slip Response for Pg0 = 2.0 pu, Xe = 0.4 pu. (Time is taken in seconds)

4. CONCLUSIONS

In this study the fuzzy logic power system stabilizer is designed for Single Machine and Multi-machine Power System. Speed deviation and acceleration of synchronous generator were taken as the input signals to the fuzzy logic controller. The performance of the power system with fuzzy logic power system stabilizer is better one since it is effective for all test conditions. It was also shown in the simulation results that the fuzzy logic power system stabilizer can decrease both maximum overshoot and settling time the slip. The control signal, required, in all cases is with less magnitude.

In continuation of the above i.e. robust analysis with the fuzzy logic PSS was also considered for different membership functions to define the fuzzy logic process. We considered the Triangular, Trapezoidal and Gaussian function to complete the fuzzyfication process. The system with fuzzy logic power system stabilizer by using the Gaussian function is effective for all test conditions. It was also shown in the simulation results that the fuzzy logic power system stabilizer using the Gaussian function can decrease both maximum overshoot and settling time of the slip. The control signal, required, in all cases is with less magnitude.

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