Design of Power System Stabilizer using Intelligent Controller

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***Abstract*— The design of two level power system stabilizer (PSS) is discussed in this paper. First level is conventional PSS, while the second level is designed using following two methods: fuzzy inference system (FIS) and adaptive neuro-fuzzy inference system (ANFIS). Speed deviation and derivative of speed deviation, the rotor angle of synchronous generator are taken as the input to the controller and voltage signal is the output of the controller. The main function of the conventional power system stabilizers is to enhance the damping of low frequency oscillations in power system, while the power system stabilizer which is designed using fuzzy inference system and adaptive neuro-fuzzy inference system improves the total response to achieve the required results. This technique is applied on a single machine infinite bus (SMIB) power system. The adaptive neuro-fuzzy inference system damps out the low frequency oscillations and enhances the power system dynamic stability in the better manner than the conventional power system stabilizer.**

***Keywords*— PSS, Fuzzy logic controller, ANFIS, SMIB.**

I. INTRODUCTION

Power system are inter connected, complex and non-linear systems extends to large geographical area, control of these power system is a difficult task. Power system is subjected to frequent disturbance, due to Loads which are very random, unpredictable and fluctuating in nature, faults, changes in transmission line parameters, generation rescheduling to operate power system in economical, balanced, reliable manner. Any disturbance in any particular area may affect the entire power system and leads to electro-mechanical low frequency oscillations. These oscillations are classified into four types (a) Interplant oscillations 2-3 Hz,(b) local mode oscillations 0.8-1.6 Hz, (c) inter area mode 0.2-0.7 Hz, (d) Exciter mode 1.5-2.5.[1]. These frequency oscillations effects the turbine values as they are critically designed for a particular speed, it decreases the performance of the component of power system, prolonged and high amplitude oscillations may lead to loss of synchronism and more effects the dynamic stability of the power system. The power system stabilizer (PSS) add damping signal to the rotor oscillations of the generator, it is done using auxiliary stabilizing signal(s) in order to control its excitation. With automatic voltage regulator (AVR) and additional control signals like, power deviation or speed deviation, frequency deviation. PSS is designed such a way that an additional torque coaxial with the rotational speed deviation is introduced, as a result increase in damping of low-frequency oscillation [1]. In order to provide damping, the stabilizer should produce an electric torque component in phase with the deviations of the rotor speed. If the generator transfers function and the exciter transfer functions are pure gains, a direct feedback of rotor speed deviations can be given. But in real cases the exciter and the generator has phase characteristics and frequency dependent gain. So that PSS transfer function must have suitable compensation circuit in order to compensate the phase lag in between input of the exciter and electric torque.

The power system is subjected to frequent oscillations so PSS should be fast enough to respond to those oscillations. Conventional PSS with AVR has low response time, In order to improve the response this paper presents a new design procedure using simple fuzzy logic controller and Adaptive Nero Fuzzy Inference System (ANFIS) for power system stabilizer. A fuzzy logic (or) ANFIS system-based PSS able to modify its own variables online with respect to the working conditions and can able provides good damping over a wide range of operating conditions.

II. SYSTEM MODELLING

A. Synchronous Machine Model

The power system stabilizer is designed for single machine infinite bus system (SMIB). The circuit diagram is shown in the fig.1. The generating systems swing in unison is lumped to form a single machine and it is connected to the infinite bus through the transmission line and modelled using thevenin theorem.

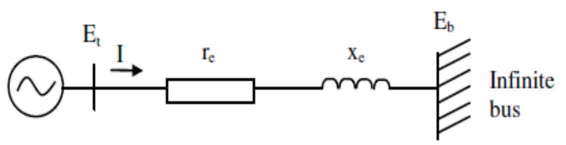

Fig.1.Synchronous Generator model.

$$P\Delta\omega_r=\frac{1}{2H}[\Delta T_m\text{-}K_S\Delta\delta-K_D\Delta\omega_r] \quad (1)$$

$$P\Delta\delta=\omega_0\Delta\omega_r \quad (2)$$

Where,

Δw_r is the per unit angular speed deviation of the rotor. H is the per unit inertia constant. T_m is the applied mechanical torque. K_D is the damping torque coefficient. ω_0 is the rotor speed in rad/sec. K_s is the synchronizing torque coefficient. δ is the rotor angle in electrical radians.

$$\Delta T_e=K_1\Delta\delta+K_2\Delta\psi_{fd} \quad (3)$$

$$\Delta\psi_{fd}=\frac{K_3}{1+pT3}[\Delta E_{fd}\text{-}K_4\Delta\delta] \quad (4)$$

Where $\Delta\psi_{fd}$ and ΔE_{fd} are variation of field flux linkage and variation of exciter output voltage respectively. Thus,

$$K_1=\Delta T_e/\Delta\delta\ with\ constant\ \psi_{fd} \quad (5)$$

$$K_2=\Delta T_e/\Delta\psi_{fd}\ with\ constant\ \text{rotor angle } \delta \quad (6)$$

B. Excitation System Model

The field windings of synchronous machine are always supplied with direct current from DC generator called exciter .Former practise was for a power station to have an exciter bus feed by a number of exciter operating in parallel and supplying power to the fields all the AC generator in the power station is called common excitation bus scheme. The present practice is for each AC generator to have its own exciter which is usually direct connected to main generator this is called unit exciter scheme. There are many excitation schemes are available, we modelled thyristor excitation system as shown in figure.2. The main objective of the AVR is to enhance excitation system to control the field current of the synchronous machine. The field current is controlled so as to regulate the terminal voltage of the machine. As the field circuit time constant is high (of the order of a few seconds), fast control of the field current requires field forcing. Thus exciter should have a high ceiling voltage which enables it to operate transiently with voltage levels that are 3 to 4 times the more. Or in other words the main action of the PSS is to act on the machine angular stability limits by providing a supplementary damping to the oscillations of the synchronous machine through the generator excitation.

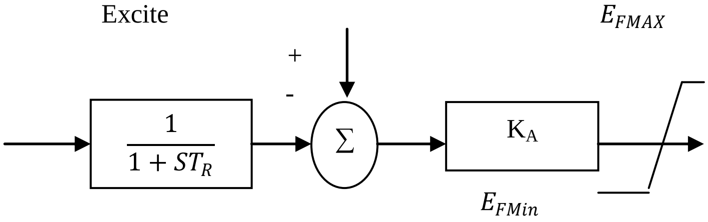

Fig.2.Thyristor excitation system

The equations governing the exciter model are:-

$$P\Delta_{v1}=\frac{1}{T_R}(\Delta E_t\text{-}\Delta_{v1}) \quad (7)$$

$$E_{fd}=K_A(V_{ref\,-V_1}) \quad (8)$$

Where V_{ref} is the reference voltage to the excitation system , V_1 is the sensed voltage, K_A is the constant, T_R is the terminal voltage transducer time constant, ΔE_t is the change in system voltage. The output of the generator is controlled by Automatic Voltage Regulator (AVR) which alters the excitation level according to variation in the network. The practical power system is subjected to frequent disturbances so AVR must have fast response. In order to increase the response of AVR power system stabilizer is used.PSS combined with AVR acts on the excitation system.

C. Power System Stabilizer

Power system stabilizer is used in the proposed system will improve the damping effect to the electromechanical oscillations, which are frequent. The PSS capable to produce a electric torque component in phase with the rotor speed deviations.

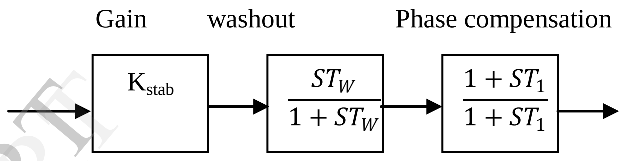

Fig.3.Components of PSS.

The PSS consists of phase compensation block which is used to adjust the phase gains to match with the excitation system or it produces phases lead characteristics. It has a gain block which is used to set the amount of damping required. Signal washout block act as a high pass filter to eliminate the lower frequencies. Other filter sections are usually added to reduce the impact on torsional dynamics of the generator, and to prevent voltage errors due to a frequency offset. The lead-lag filters are tuned so that speed oscillations give a damping torque on the rotor. By varying the terminal voltage the PSS affects the power flow from the generator, which efficiently damps local modes.

The PSS is designed for AVR based in the figure 4, where the K_1, K_2, K_3, K_4, K_5, K_6 are 1.591, 1.5, 0.333, 1.633, -0.12 and 0.3. Parameters T_1, T_2,Tw, K_{stable}, T_3,T_r,K_d and H are 0.1543, 0.033s, 1.4s, 9.5, 1.91, 0.02s, 0.0, 3 these are the transfer function and constant values of the components of the PSS [1]

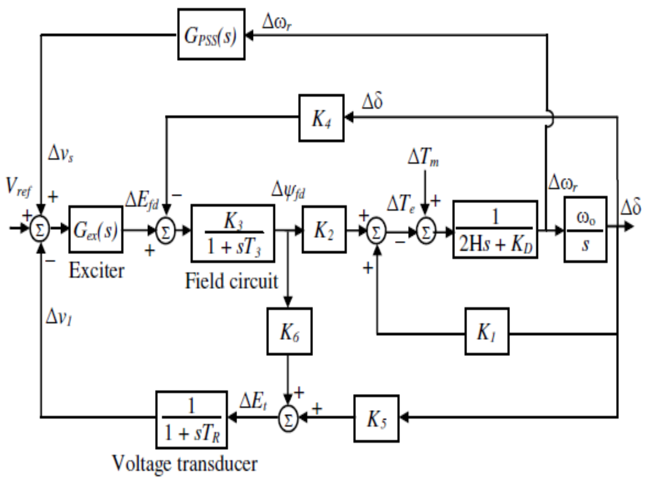

Fig.4.Block diagram of PSS

III. Fundamentals of Controllers

A. Fundamentals of Fuzzy logic

Fuzzy logic is a many-valued logic in which the fuzzy logic variables has truth values ranging in different degrees in between 0 and 1, known as their membership values. Fuzzy logic has ability to handle the uncertainties in the system by using a simple IF-THEN rule based approach, so that eliminating the need for a mathematical model of the system which is complex. This is especially useful in complex systems for which a complete mathematical model representation may not be possible because it contains many dependent variables. Even in fuzzy logic systems, complex city of the model is more when there is more number of input and output variables. Mamdani type FLC [3] has been designed in this paper. As shown in Fig. 4, a FLC consists of four principal components a fuzzification interface, a rule base, inference logic, and a defuzzification interface. The fuzzification interface converts the binary logic inputs into fuzzy variables, while the defuzzification interface converts the fuzzy variables into binary logic outputs. This conversion is achieved by means of a membership function. The rule base is a collection of IF-THEN rules that describe the control strategy. The output from each rule in the rule base is deduced by the inference logic to arrive at a value for each output membership function. The "fuzzy centroid" of the composite area of the output membership function is then computed in order to obtain a binary output value. This fuzzy control is used for PSS, to obtain fast response and to minimize the response time.

B. ANFIS Architecture

ANFIS are a type of multilayer feed forward adaptive networks which are functionally equivalent to the fuzzy inference systems. ANFIS uses a feed forward network, to set fuzzy decision making rules that can decide required output. Let us consider two inputs 'x' and 'y' and output 'P'the fuzzy inference rules can be formed as

Rule 1: IF *x* is A_1 and *y* is B_1 THEN = Q

Rule 2: IF *x* is A_2 and *y* is B_2 THEN = P

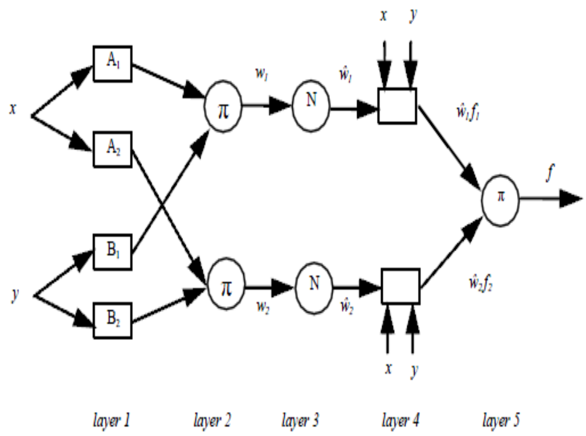

Fig.4.Structure of ANFIS

An ANFIS contains of five layers as shown in fig.4, in order to implement various node functions to learn and to tune parameters in a FIS using a hybrid learning mode. In the forward pass, with fixed premise parameters, to update the consequent parameters the least squared error estimate approach is employed and the backward pass is used to pass the errors. In the backward pass, the gradient descent method is applied to fix the consequent parameters and to update the premise parameters. Premise and consequent parameters will be identified for MF and FIS by repeating the forward and backward passes. When we give input and output data ANFIS creates a Fuzzy Inference System to which parameters of the membership functions are adjusted.

Layer 1: Every node in this layer is a square node with a node function (the member ship value of the premise part

$$O_i^1 = \mu_{Ai}(x) \tag{9}$$

Where, x is the input to the node i, and A_i is the linguistic label associated with this node function.

Layer 2: Every node in this layer is a circle node labelled Π which multiplies the incoming signals. Each node output represents the firing strength of a rule.

$$O_i^2 = \mu_{Ai}(x)\mu_{Bi}(y) \text{ Where i=1,2.} \tag{10}$$

Layer 3: Every node in this layer is a circle node labelled N (normalization). The i^{th} node calculates the ratio of the i^{th} rule's firing strength to the sum of all firing strengths.

$$O_i^3 = \overline{w_i} \tag{11}$$

Layer4: Every node in this layer is a square node with a node function

$$O_I^4 = \overline{w_i}\, f_i = \overline{w_i}(P_i x + Q_i y + R_i) \qquad (12)$$

Layer5: The single node in this layer is a circle node labelled Σ that computes the overall output as the summation of all incoming signals

$$O_I^5 = \text{system output}$$

IV. Implementation of PSS

A. Fuzzy based PSS

In order to design the fuzzy based power system stabilizer, the input variables are identified usually includes state error, state error derivate, state error integral and others [1],[6] . In this paper we have taken, two inputs as the changes in angular speed and rate of change of angular speed or derivative of angular speed. The output of the fuzzy controller is a voltage signal that is combined with AVR given to the exciter. This fuzzy controller will considers the use of triangular membership function because they can simplify the process if computation and easy to interpret. Thus the membership functions designed are shown in Fig.5,6 for inputs and Fig.7. for output. The intervals for both inputs are set normalized to be in the range of [-1, 1]. The membership function of a variable is expressed into seven fuzzy sets defined as Negative Big (*NB*), Negative Medium (*NM*), Negative Small (*NS*), Zero (*Z*), Positive Small (*PS*), Positive Medium (*PM*) and Positive Big (*PB*) as shown in table 1. After defining the membership functions, rules is formed based on the experience and the desired output. The membership function is designed for for both inputs and for output as shown in figure5, 6,7.

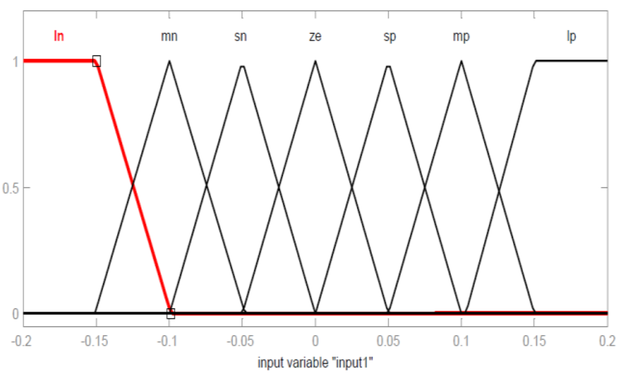

Fig.5.Membership functions for input1 -speed deviation

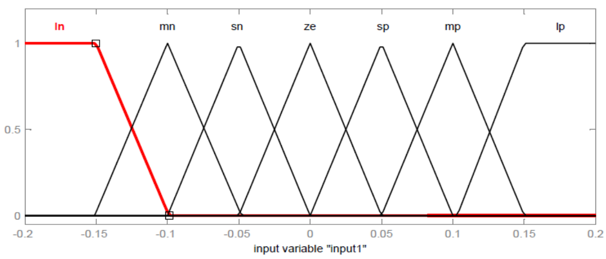

Fig.6.Membership functions for input 2- derivative of speed deviation.

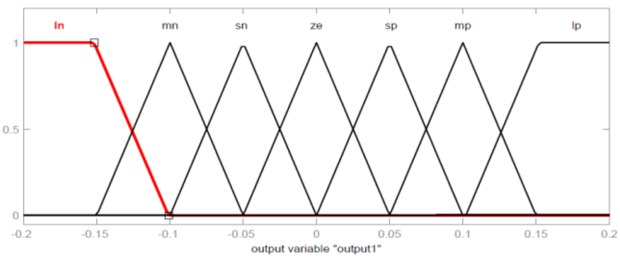

Fig.7. Membership functions for output- voltage signal.

The rules are obtained from the knowledge basis or from the experience, the input values and the output values are matched using this rules as shown in table 1. The MATLAB fuzzy logic toolbox where the fuzzy based controller is designed has a capability to show the rule views for the particular input and output pair.

Table1. Rule for fuzzy based PSS.

$\Delta\dot{\omega}_r \backslash \Delta\omega_r$	LN	MN	SN	ZE	SP	MP	LP
LN	LP	LP	LP	MP	MP	SP	ZE
MN	LP	MP	MP	MP	SP	ZE	SN
SN	LP	MP	SP	SP	ZE	SN	MN
ZE	MP	MP	SP	ZE	SN	MN	MN
SP	MP	SP	ZP	SN	SN	MN	LN
MP	SP	ZE	SN	MN	SN	MN	LN
LP	ZE	SN	MN	MN	LN	LN	LN

There are four different phases while designing ANFIS, initially we want to identify the input and output data and for all the input and output pairs, data is collected. The obtained data is loaded in After training the data FIS Structure is formed by using hybrid learning algorithm and containing seven triangular membership functions. Finally a fis structure is designed.

This abstained fis structure which is self tuned using back propagation algorithm so that it can handle most complex non linear problems.The ANFIS toolbox, 90% of the data is used for training the architecture and remaining 10% is used for testing. When the results are in linear to the trained data then the data is correct as shown in figure8

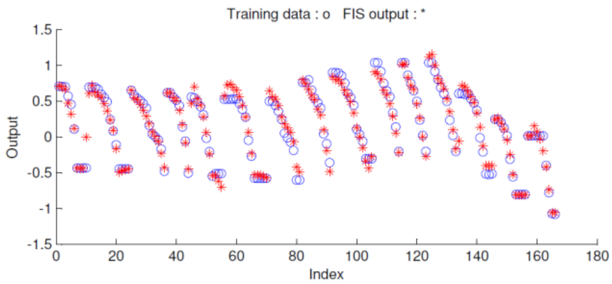

Fig.8.Trained data

The modeled ANFIS structure consists of seven membership functions which are trained under back propagation algorithm and least square estimates where the errors are low. This ANFIS structure is used for PSS to obtain fast response.

V. RESULTS AND DISCUSSIONS

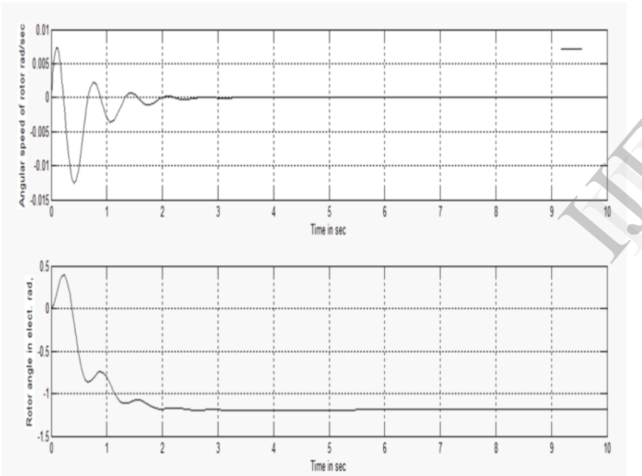

Fig.9. Speed deviation and Angular position for fuzzy PSS

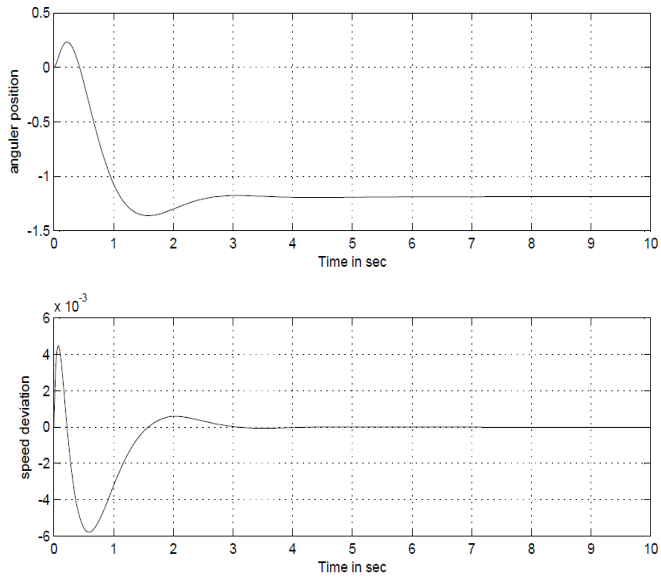

Fig.10.Speed deviation and Angular position for ANFIS PSS

In this paper, machine model and the controller is designed by using SIMULINK in MATLAB software, the fuzzy logic based PSS is modelled using FIS Editor, by using the system data of synchronous machine (1). The performance is observed for 0.5 p.u. change in mechanical torque as shown in figure 9.

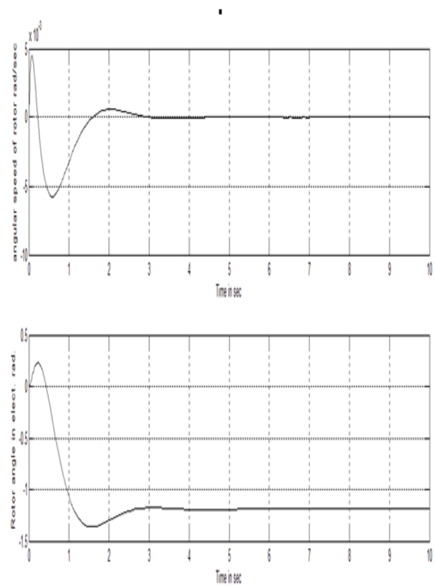

Fig.11. Speed deviation and Angular position for fuzzy PSS

Figure 11 shown above is the output response obtained from the ANFIS based PSS which is designed in ANFIS toolbox in

MATLAB software. The performance is observed for a small o.5p.u. change in the mechanical torque.

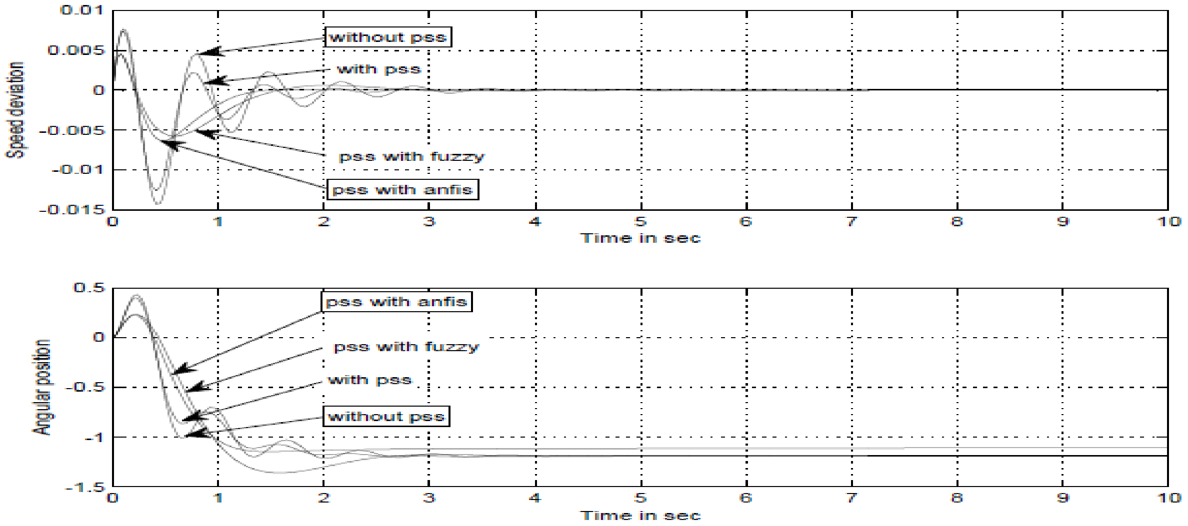

Fig.12.Speed deviation and Angular position for conventional, fuzzy and ANFIS PSS

The simulation has been conducted for other values of mechanical input change of 1.0 p.u, 1.5. p.u, 0.5. p.u. values. By observing all the simulation output, as shown in figure 12 for a small change in mechanical input of 0.1 p.u. the conventional controllers has more overshoot and settling time, than the second level.

VI. CONCLUSION

The optimal design of Power System Stabilizer (PSS) involves a deep understanding of the dynamics of the single machine infinite bus system. In this project, PSS is designed using fuzzy logic, and ANFIS techniques with the simplification in design and without dealing without mathematical model. Where as conventional PSS which uses lead-lag compensation, where gain settings are designed for particular conditions and cannot operate under different disturbances. With the simulation results obtained, is observed that of all controllers ANFIS based PSS shows better control performance in terms of settling time and damping effect. It can handle non-linear inputs and can operate in different disturbance Therefore, it is suggested that ANFIS based PSS can be implemented in practical power system after testing in a prototype so that the dynamic stability of the power system can be increased.

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