Implementation of AI Based Power Stabilizer Using Fuzzy and Multilayer Perceptron In MatLab

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***Abstract*— Systematic investigation of an Automatic Voltage Regulator (AVR) indicates one significant tradeoff in the effectiveness of Excitation System i.e. rapid response with high gain of the AVR induces undesirable damped oscillations in an Electrical power system, which slow down the rotor speed; To overcome this problem, Power system stabilizer (PSS) is used in parallel with excitation system (ES), by injecting extra stabilizing signals to minimize the side effect induced by AVR. The PSS must be self-tuned for adjusting parameters and managing different loading conditions. Therefore, this work is mainly focused on Multilayer Perceptron (MLP) feed-forward neural network and fuzzy logic system controllers to tune and adjust the PSS parameters to achieve better enhancement instability for varying load conditions. In this research work, PSS is designed with different controllers in MATLAB/ Simulink. The development of the PSS is achieved by using different controllers like ProportionIntegrator (PI), Proportion-Integrator-Differentiator (PID) and Artificial Intelligence (AI) based fuzzy and MLP controller. Simulation test results of Voltage and Frequency show the robustness of MLP type PSS as compared to PI, PID, and Fuzzy PSS in terms of minimized overshoot peak value, settling time and rise time for varying loading conditions.**

***Index Terms*— Artificial Intelligence; Fuzzy Logic; MLP; Synchronous Generator; Power System Stabilizer(PSS);**

I. Introduction

Electrical Power system consists of inter-related subsystems. Synchronous alternator (SG) is an important source of electrical energy and widely used in power systems. The power system is mainly prone to several disturbances due to its dynamic and transient performance [1]. So, to maintain the stability of the power system, these transients must be taken care of to ensure a reliable and secure supply of electricity. [2].

In a power system, reliability is the key factor, but varying terminal voltages and frequency oscillations tend to compromise the reliability of the system [3]. To maintain terminal voltages and curtail frequency oscillations, AVR and Load frequency controller (LFC) are used respectively [4]. The negative damping of AVR can be compensated by the PSS. PSS adds counter stabilizing signals to mitigate oscillations generated by AVR and LFC [5]. Generator must be equip with apparatus make it able to coop with varying load conditions and simultaneous flickering [6]. The effectiveness of PSS depends upon the controller it contains [7]. In this situation, the stability of the power system becomes the focus of interest and

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remains one of the greatest challenging problems facing the power community [8].

Block diagram of PSS contains three main components, power system stabilizer has zero output under steady-state condition, therefore, washout block is cascaded with the block of PSS to ensure its zero output under steady-state condition [5] Phase compensator maintains phase lead parameters between exciter and generator torque. [9] .Usually more than two first order blocks are added to aquire phase compensation.

II. Methodology

A. Background

Mathematical modeling is a technique of simulating real-life situations/systems. Mathematical equations can be used to forecast the system's behavior in the future. For the

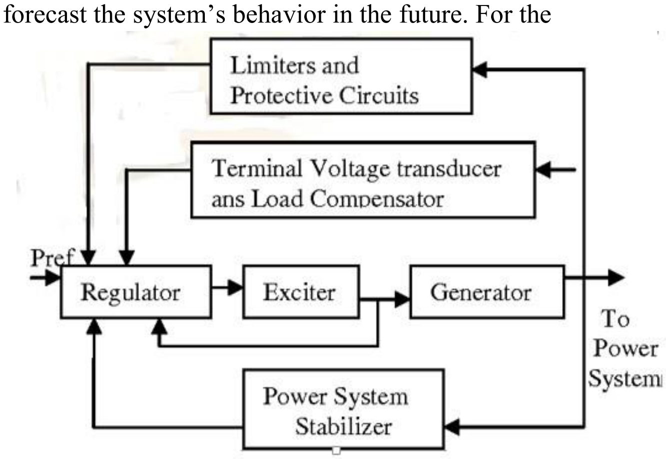

Fig. 1: Concept diagram of Power System stabilizer

development and planning of electrical and mechanical systems, they play a very important role [3-9]. For appliance of any excitation control system, it is important to develop its mathematical modeling first. State-space and transfer functions opt for linear systems and state-space modeling is selected for a non-linear system [8-5].

Single Machine Infinite Bus (SMIB) system is implemented in Matlab for the dynamic stability of the power system. SMIB could be represented by a Thevenin's equivalent circuit [10-12]. Traditional PSSs i.e lead lag and PIDs assumed as a base [8-13].

This article establishes comparison between traditional PSS models with artificial intelligence based cognitive controllers in simulink interface. During supervised training, the backpropagation (BP) theorem is employed. The input and

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output patterns are compiled as these are the direction for newly born neuron as a training map.

Simulation results of terminal voltage and frequency for MLP primarily based PSS are estimated to point out improved performance via step signal. It is expected that the planned MLP can offer fast response and smart damping of the SG at a broader spectrum of operation situations. It would considerably address the transient and dynamic responses of the system by avoiding the problems faced in conventional PSS. Equations which fulfills the whole simulation model of machine are as given below:

$$E'_{q\Delta} = \frac{K_3 E_{FD\Delta}}{1+K_3\tau'_{do}s} - \frac{K_3 K_4 \delta_\Delta}{1+K_3\tau'_{do}s} \quad (1)$$

$$T_{e\Delta} = K_1\delta_\Delta + K_2 E'_{q\Delta} \quad (2)$$

$$V_{t\Delta} = K_5\delta_\Delta + K_6 E'_{q\Delta} \quad (3)$$

To complete the simulation model, we have used the following linearized form of swing equation.

$$\tau_j \acute{\omega}_{\Delta} = T_{m\Delta} - T_{e\Delta} \quad (4)$$

Now, the values of K1, K2, K3, K4, K5 & K6 could be represented as:

$$K_1 = \frac{x_q - x_d}{(x_e - x'_d)} I_{qo} V_\infty \sin\delta_o + \frac{E_{qo} V_\infty \cos\delta_o}{(x_e + x_q)}$$

$$K_2 = \frac{(V_\infty \sin\delta_o)}{(x_e + x'_d)}$$

$$K_3 = \frac{(x_e + x'_d)}{(x_e + x_d)}$$

$$K_4 = \frac{(x_d - x'_d)}{(x_e + x'_d)} V_\infty \sin\delta_o$$

$$K_5 = \frac{x_q}{(x_e+x_q)}\frac{V_{do}}{V_{to}} V_\infty \cos\delta_o - \frac{x'_d}{(x_e+x'_d)}\frac{V_{qo}}{V_{to}} V_\infty \sin\delta_o$$

$$K_6 = \frac{x_e}{(x_e + x'_d)}\frac{V_{qo}}{V_{to}}$$

Where,
Rotor's rotation angle of the alternator is represented by **K_1**. **A**ngle of rotation of rotor due to fluctuation in the axis of flux linkages of alternator is represented by **K_2**.
Impedance Factor is represented by **K_3**.
Demagnetization component is represented by **K_4**. **C**hange in **V_t** of the generator at constant flux linkage is represented by **K_5**. **C**hange in **V_t** of the alternator at uniform generator rotor angle is represented by **K_6**. Sensor model:

$$\frac{V_S(s)}{V_t(s)} = \frac{K_R}{1+\tau_R s} \quad (5)$$

Amplifier model: [1-3]

$$\frac{V_A(s)}{V_E(s)} = \frac{K_A}{1+\tau_A s} \quad (6)$$

Exciter model: [1]

$$\frac{V_F(s)}{V_A(s)} = \frac{K_E}{1+\tau_E s} \quad (7)$$

Generator model:[1]

$$\frac{V_t(s)}{V_F(s)} = \frac{K_G}{1+\tau_G s} \quad (8)$$

B. Ziegler-Nicholas Tuning Method

The gain of a PID controller is tuned by different methods, where the Ziegler Nichols method is one of them. It is the basic and easy method to determine the closed-loop systems on the live tuning method [5]. There are two steps by which we can get the tuning values of the controller [14]. Here in this method, the ultimate gain of a proportional controller and ultimate period of deviations are estimated for overall dynamic stability of the system. Table1.1 shows the particular regulator's gain.

III. Math

In Figure.3 shows the complete model of alternator along with AVR and MLP based PSS in MATLAB Simulink system. This model is developed under the reflection of the IEEE model, the value of standardized parameters and synchronized data types. This model shows the whole system tools (parameters) necessary to run the simulation.

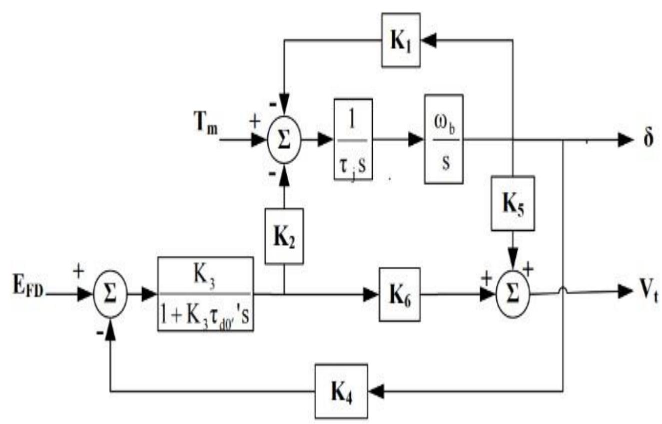

Fig. 2: Alternator's Block Diagram[2-19]

TABLE I
Units for Magnetic Properties

Type	Kp	Ki
P	0.5 K_u	------
PI	0.45 K_u	0.5 $\frac{K_u}{T_u}$
PID	0.6 K_u	1.2 $\frac{K_u}{T_u}$

A. Implementation of Multi-layer perceptron (MLP)

An MLP lies in class of feed forward neural networks (FFNN) in which operations are performed in multilayers mechanism[13,14,15].This article presents methods to mitigate voltage and frequency deviations using AI based controller trained via neural network toll in MatLab.Initially considering model parameters, stability margins of SIMB is determined via Nicholas Criteria . gains of proportional , Intigral and derivative has been implemented on software and tuned accordingly [9,15-17].

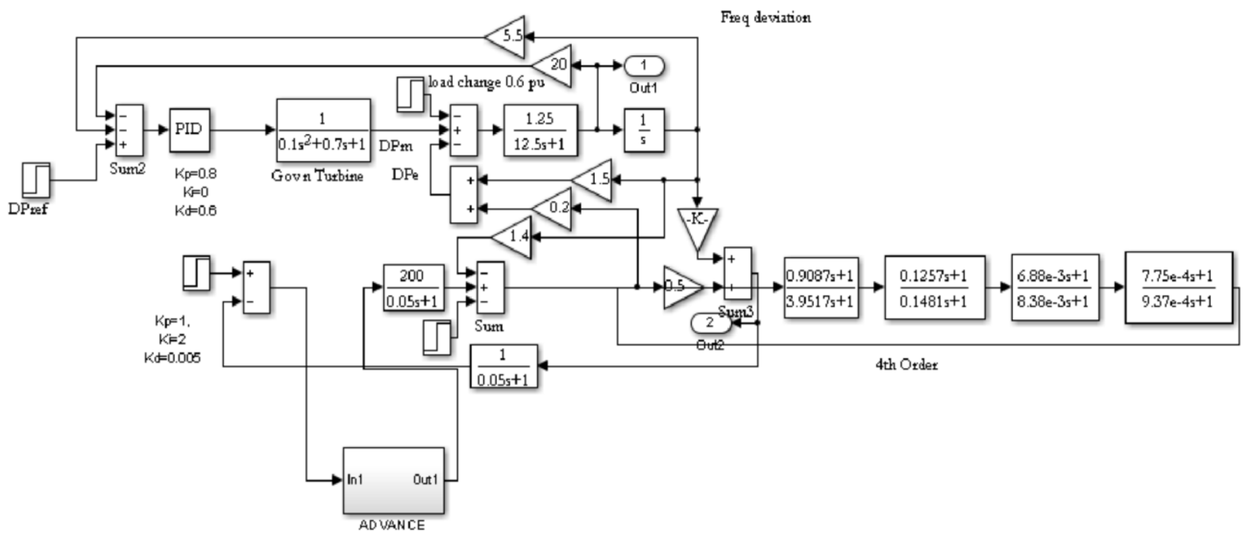

Fig. 3: Simulated diagram of synchronous generator along with MLP

After successful implementation of PID , newly born MLP is generated in MatLab using neural network toll .This newly baby neuron is connected in parallel with well trained , well tuned PID for sake of supervised training using using back propagation algorithm under sigmoid function. Figure.4 illustrates the internal structure of MLP based on multilayers. It consists of one input layer, one output layer and a multi hidden layer in between. As the number of hidden layers increases, the system will become more efficient and give accurate results, but that will also increase the complexity of the system.

MLP has been trained by BP theorem procedure of neural network. In this research paper, MLP has been used to design a special type of conventional PSS through the training mechanism. Training data SS containing inputs and operating

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modes are achie ved from well-tuned Proportional Integral Derivative type P [14,15].

The PID PSS is assumed to be the teacher of the newly born MLP controller, So, as the training is simulated in conjunction with PID, the trained MLP will work in the same manner as its tutor; It will give good response under all conditions. The response of trained MLP will be constant after the training process. The MLP type regulator will have a good response for normal and for varying loading conditions [1-17].

B. Implementation of Fuzzy Logic

Fuzzy Logic is a process of reasoning that is similar to human reasoning. The method of fuzzy logic follows the method of decision taking like humans, that includes all middle possibilities between digital values i.e. yes and no. The fuzzy PSS has four components in it. These are Fuzzifier, Knowledge base, Inference Engine and Defuzzifier. Following ‘if, then’ rules are used in this research.

- If terminal voltages are lower, then excitation goes up.
- If terminal voltages are normal, then no change in excitation.
- If terminal voltages are high, then excitation goes down.

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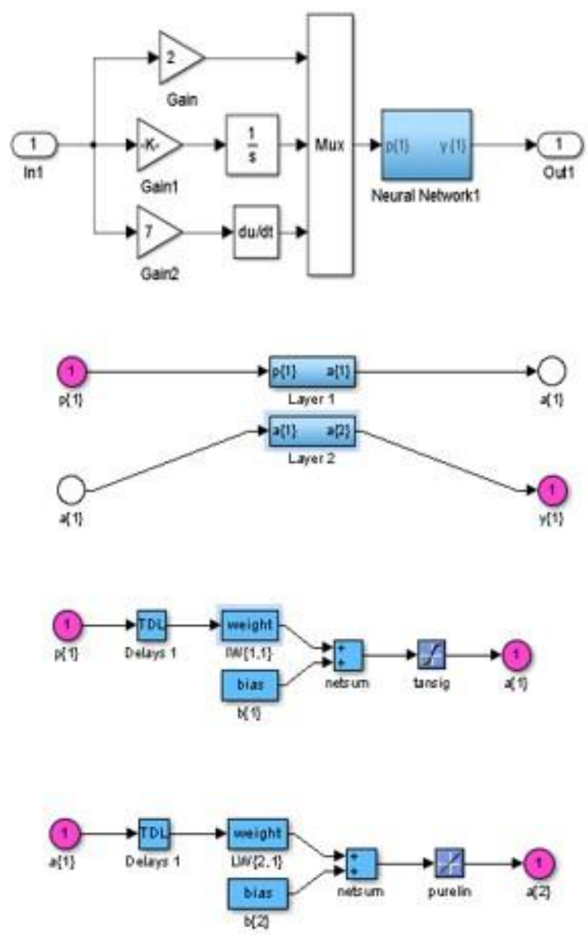

Fig. 4: Alternator's Block Diagram[2,19]

IV. Results And Discussions

This segment, the model results of terminal voltage and frequency deviations of power system stabilizer, without controller and with conventional PSS, PID –PSS and AAN BASE fuzzy and MLP PSS are thoroughly observed; The simulation of corresponding transfer function of PSS with different regulatory systems are related to investigate regulator on Simulink. The model time for all systems is 1 second for voltage and 15 seconds for frequency.

Figure.5 compares the terminal voltage response of PSS without controller to the PSS with different regulator schemes.

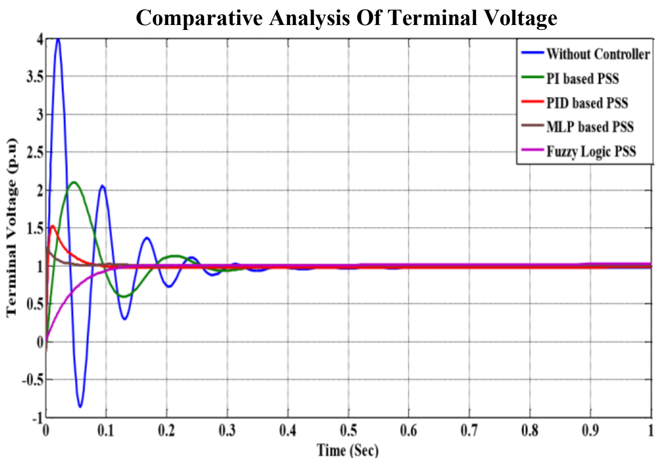

Fig. 5: Combined Terminal Voltage Response

PSS without any controller shows the number of oscillations with maximum overshoot and high settling time as compared to the PI and PID controller based PSS, as they show better output in disparity with PSS without any PSS controller, the figure also shows the output of an Artificial Neural Network based PSS like MLP and Fuzzy, the response of this particular PSS is very close to steady-state.

Figure 6 compares the frequency response of PSS without controller of PSS to the PSS with different regulatory schemes.

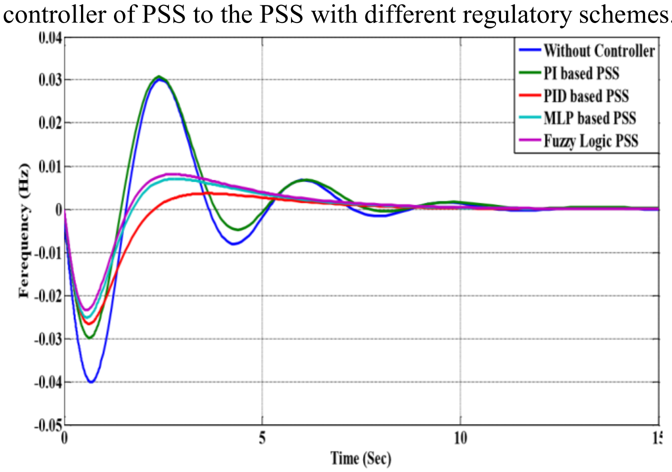

Fig. 6: Combined Frequency Response

From Figure.6 it can be seen that the frequency output of PSS without any controller has the maximum number of oscillations, with maximum overshoot and more settling time as compared to the PI and PID controller-based PSS. There can also be seen the results of an ANN-based PSS like MLP and Fuzzy PSS offering response nearest to the steady-state.

Figure 7 compares the terminal voltage response for different loading conditions of PSS without any controller to the PSS with different regulator schemes.

Figure 7 represents the voltage graph of various PSS for

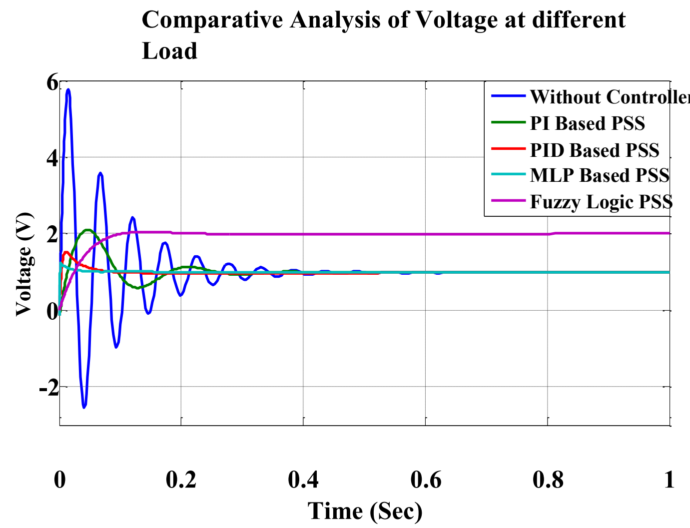

Fig. 7: Combined Terminal Voltage Response different loading conditions. PSS without any controller shows the number of oscillations with maximum overshoot and more settling time as compared to the PI and PID controller-based PSS as they offer better output in disparity with PSS without any PSS controller. It can be seen from the results of ANN Based PSS like MLP and Fuzzy that fuzzy response is also not satisfactory for varying loading conditions because it only offers a good response for specific logic; But in contrary to that, an MLP based PSS offers better response also for varying loading nature.

Figure 8 compares the frequency response of PSS for different loading condition without controller PSS to the PSS with different regulatory schemes.

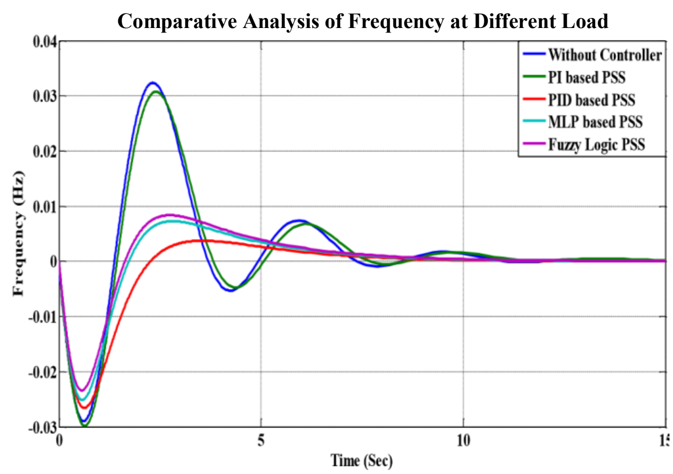

Fig. 8: Combined Frequency Response at Different Load

Fig.8 Shows the frequency output of various PSS for different loading conditions. PSS without any controller shows the number of oscillations with maximum overshoot and more

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settling time as compared to the PI and PID controller-based PSS as they offer better output in disparity with PSS without any PSS controller. ANN Based PSS like MLP and Fuzzy that fuzzy response is also not satisfactory for varying loading conditions because it only offers good response for specific logic; But in contrary to that, an MLP based PSS offers better response also for varying loading nature.

V. Analysis of Results

In this segment, we will compare the output of voltage plus frequency of Power system stabilizer for different regulatory schemes i.e. PSS without any controller, PI bases PSS, PID based PSS and finally ANN type PSS like FUZZY and MLP for maintaining synchronism and correcting dynamic and transient stability of voltages and Frequency. It can be concluded that the MLP Based controller is an extra vigorous and self-tunable PSS controller to achieve stability at various abnormal conditions faced by Power System.

VI. Conclusion

This work proposes the suitable applicability of multilayer perceptron feed-forward neural network type PSS as controller to tune the PSS for achieving better and enhanced stability. This MLP based PSS has many advantages like lowest rise time, smallest overshoot value and lowest settling time as compared to PI, PID controllers. MLP has a very fast response and it has the ability of self–learning and adaptation. Also, there is another big advantage of MLP-PSS over PI, PID that it is used for nonlinear loads. From observation and test results it is concluded that the fuzzy controller has a better response than PI, PID. But in comparison to MLP and fuzzy, the fuzzy has some disadvantages as it cannot be used for a more complex system and due to fixed rules, its behavior changes during varying loading conditions. Henceforth, MLP offers better performance in complex systems. It was also observed from Simulink results at different loading conditions that the output of terminal voltages plus frequency of MLP based PSS are much better than other controllers. According to the size and quality, it can be trained by using different training methods.

TABLE II
Comparison of voltage response of PSS with various control schemes

S. No	Types of PSS Used	Overshoot (per unit)	Settling Time (sec)	Rise time (sec)
1	No controller	4	0.44	0.02
2	PI Based PSS	1.6	0.5	0.04
3	PID Based PSS	1.4	0.12	0.02
4	PSS (FUZZY)	1.02	0.1	0.003
5	PSS (MLP)	1.2	0.14	0.005

TABLE III
Comparison of Frequency response of PSS with various control schemes

S. No	Types of PSS Used	Overshoot (per unit)	Settling Time (sec)	Rise time (sec)
1	No controller	4	0.44	0.02
2	PI Based PSS	1.6	0.5	0.04
3	PID Based PSS	1.4	0.12	0.02
4	PSS (FUZZY)	1.02	0.1	0.003
5	PSS (MLP)	1.2	0.14	0.005

TABLE IV
Comparison of Voltage response of PSS with various control schemes at Different Loadings

S. No	Types of PSS Used	Overshoot (per unit)	Settling Time (sec)	Rise time (sec)
1	No controller	5	0.45	0.02
2	PI Based PSS	2.2	0.4	0.01
3	PID Based PSS	1.52	0.13	0.01
4	PSS (FUZZY)	1.26	0.15	0.005
5	PSS (MLP)	1.2	0.14	0.005

TABLE V
Comparison of Frequency response of PSS schemes with various control at Different Loadings

S. No	Types of PSS Used	Overshoot (per unit)	Settling Time (sec)	Rise time (sec)
1	No controller	0.029	11	0.5
2	PI Based PSS	0.03	12	0.5
3	PID Based PSS	0.025	5	0.4
4	PSS (FUZZY)	1.26	0.14	0.005
5	PSS (MLP)	1.2	3	0.3

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