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A Multi-Level Fuzzy Power System Stabilizer to Improve Dynamic Stability

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ABSTRACT

The electrical power system is the one of the largest complex and dynamic system on earth. This system is continuously subjected to small disturbances that might cause loss of synchronism and also breakdown of entire system. For this purpose, Power system stabilizers (PSS) are used to generate supplementary control signals for the excitation system in order to damp these low frequency power system oscillations. The additional signals are derived from speed deviations, excitation deviations and accelerating power are injected into the automatic voltage regulator. The conventional power system stabilizer (CPSS) uses lead-lag compensation techniques, where gain settings are fixed for specific operating condition. In an attempt to cover wide range of operating conditions fuzzy logic controllers are the best. The fuzzy logic uses linguistic information and avoids complex mathematical models, while ensuring better performance.

In this project, a novel design of multi-level fuzzy controller for power system stabilizer to damp the low frequency power system oscillations is described. The control objective is to enhance the stability and to improve the dynamic response of the SMIB system. The system is modeled as standard K-coefficients in second order. Its control structure is designed to bring fore an intelligent upper level fuzzy controller and a lower level direct fuzzy controller. This fuzzy controller performance is observed for different membership functions like triangular, Gaussian and trapezoidal. The performance of the proposed controller shows improved results when compared to conventional and direct fuzzy controllers. This work is executed in SIMULINK environment and performance is investigated for disturbances subjected to inputs of different membership functions.

KEYWORDS: *Power System Stabilizer, Dynamic Stability, Single Machine System, Multi Machine System, Fuzzy Logic, Matlab/Simulink*

I. INTRODUCTION

The Power System is an extremely non-linear and dynamic system, with operating parameters continuously varying. Stability is consequently, a basis of the initial operating condition and the nature of the interruption .Power system stability has been acknowledged as an important crisis for secure system process ever since the 1920s. Numerous main blackouts caused by power system instability have illustrated the significance of this occurrence. At the same time power systems have evolved throughout continuing development in interconnections, make use of new technology and controls, and the improved operation in extremely stressed conditions, dissimilar forms of system instability have come out. The voltage stability, frequency stability and inter-area oscillations have become greater concerns than in past. Power system stability is similar to the stability of any dynamic system, and has fundamental mathematical under pinning. Stability is a condition of equilibrium between opposing for1ces. Here Depending on the network topology, system operating situation and the form of interruption, diverse sets of opposing forces may experience continuous imbalance leading to different outward appearance of unsteadiness.

A proper description of power system stability:

Power system stability is the tendency of a power system to develop restoring forces equal to or greater than the disturbing forces to maintain testate of equilibrium.

This definition applies to an interconnected power system as a whole. The power system is a exceedingly nonlinear structure that operates in a relentlessly varying environment situation such as loads, generator outputs and key operating parameters modify endlessly. Strength and stability of an electric power system is therefore a possession of the system motion in the region of an equilibrium set, so as called as the initial operating situation. In a symmetry set, the various contrasting forces that are present in the system are identical instantaneously (as in the case of equilibrium points) or over a sequence.

Power systems are subjected to an extensive variety of turbulence minute and big, which affect the generator voltage angle to modify. Little disturbances in the shape of load changes take place repeatedly. The system is obliged to be able to regulate to the changing conditions and function acceptably.

The term dynamic stability is a class of rotor angle stability. It being used frequently to indicate small-signal stability in the incidence of automatic controls (mainly, the generation production excitation controls) as different from the classical "steady-state stability" devoid of generator controls.

The major disturbances in power system reason root the generator voltage angle to alter. When this instability dies out, a new satisfactory steady state operating situation is reached. It is significant that these disturbances do not force the system to unstable state. The disturbances may possibly be of local mode include frequency range of 0.7 to 2 Hz or of inter area modes include frequency range in 0.1 to 0.8 Hz. These swings are outstanding to the poor damping distinctiveness caused by modern voltage regulators with elevated increase in gain.

An elevated high gain regulator in the course of excitation control has an imperative effect to eliminate synchronizing torque but it affects the damping torque unenthusiastically. To recompense the unnecessary effect of these voltage regulators, other supplementary signals are to introduce in feedback loop of voltage regulators. The extra signals are mostly resulting from speed divergence, excitation divergence or accelerating power. This is achieved by injecting a stabilizing signal into the excitation system voltage reference summing point junction. The piece of equipment set of connections to provide suitable damping signal is called "power system stabilizer".

Low-frequency oscillations, linked to the small-signal stability of a power system are harmful to the goals of utmost power transmit and power system security. Automatic voltage regulators (AVRs) assist to get better the steady-state stability of power systems, nevertheless are not as useful for maintaining stability at some stage in transient conditions. The accumulation of power system stabilizers (PSSs) in the AVR control loop provides the resources to damp these oscillations. The further added AVRs and PSSs are planned to act upon local capacity such as bus voltage, generator shaft speed, or the rotor angle of the connected machine. This category of feedback control is practical for local and control mode oscillations.

A distinctive PSS consists of phase return stage, signal failure stage and gain block. To provide damping, PSS must offer a constituent of electrical torque on the rotor in phase with speed deviation. PSS input signal includes generator speed, frequency and power. Designed for whichever input signal, the transfer function of PSS is obliged to balance for gain and phase characteristics of excitation system, generator and the power system. These collectively determine the transfer function from the stabilizer output to the component of electrical torque which can be modulated via excitation control.

The PSS, despite the fact that damping the rotor oscillations can lead grounds to instability of turbine generator shaft torsion mode. Selection of shaft speed pick-up location and torsion notch filters are used to attenuate the torsion mode frequency signals. The PSS gain and torsion filter will affect the exciter damping ratio adversely. The benefits of accelerating power as input signal for PSS attenuates the shaft torsion modes intrinsically and mitigate the necessities of the filtering in major stabilizing lane.

II. Typical System Modeling

The typical system modeling consists of synchronous machine, excitation system and power system stabilizer.

A. Synchronous Machine Model

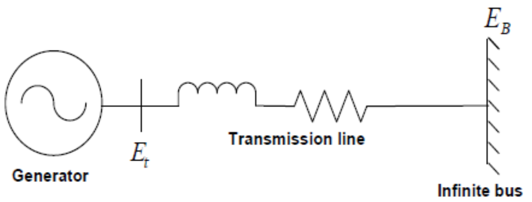

Fig.1: Synchronous Machine linked To Infinite Bus

The above diagram Fig.1 demonstrates the synchronous machine associated to infinite bus in the path of transmission line. The principal equations for machine model are:

$$p\Delta\omega_r = 1/2H(\Delta T_M - \Delta T_e - K_d\Delta\omega_r)$$

$$p\Delta\delta = \omega_0\Delta\omega_r$$

$$\text{Where, } \Delta T_e = K_1\Delta\delta + K_2\Delta\psi_M$$

$$\Delta\psi_{fd} = K_3/(1+pT_3).[\Delta E_{fd} - K_4\Delta\delta]$$

At this juncture TM is prime mover input and Te is electrical Output torque, H is inertia constant, ω and δ are speed and rotor angle correspondingly.

B. Excitation System

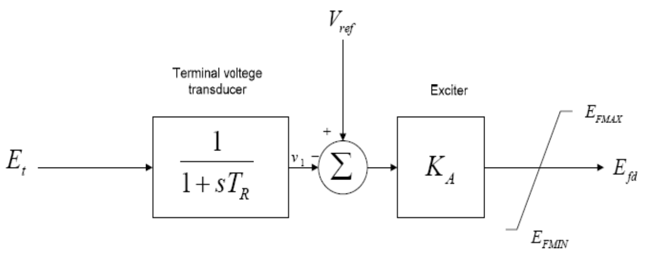

Fig.2: Block diagram of excitation system

Excitation system is competent of responding quickly to a disturbance so as to improve transient stability and of modulating the generator field so as to augment small scale stability. The responsibility of an exciter is to make available necessary field current in rotor winding of an alternator. Terminal voltage transducer senses generator terminal voltage rectifies and filters it to dc amount. Exciter offer dc power to synchronous machine field winding, constituting the power angle of excitation system.

C. Power System Stabilizer (PSS)

Power system stabilizers (PSS) are emergent to aid in damping these oscillations via modulations of excitation system of generators. The accomplishment of a PSS is to extend the angular stability limits of a power system by providing supplemental damping to the oscillation of synchronous machine rotors through the generator excitations.

III. Ideal Fuzzy Logic Controller (F L C)

The fig-3 gives you an idea about block diagram of fuzzy logic controller. It consists of four fundamental components: Knowledge Base, Fuzzification Interface, Defuzzification Interface and Decision Making Logic.

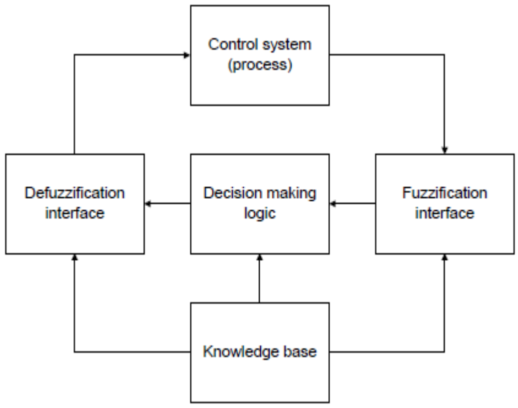

Fig. 3: Fuzzy Logic Controller block Diagram

The fuzzy controller is a two inputs and single output constituent. It is typically a MISO system.

1. *Knowledge Base:*

This includes description of fuzzy membership function and the required rules which clearly precise the control goals using linguistic variables. It also stores the knowledge concerning all input-output fuzzy relationships.

2. *Fuzzification Interface:*

This converts the crisp amount into fuzzy amount. Here are quite a lot of ways to assign membership values to fuzzy variables in similarity with the probability density functions to random variables. The development of membership value assignment is done by instinct, logical reasoning, procedural methods or algorithm approach.

3. *Defuzzification Interface:*

This has the ability to reduce a fuzzy set into a crisp single-valued, amount. It possibly will also be termed as “rounding it off”. The assortment of method is done on the foundation of the computational complexity involved and applicability to the situations measured.

4. *Decision Making Logic:*

Here this module converts the contingent decision from linguistic variables. It is the kernel of an FLC system and it has the potential to simulate human decisions by performing approximate reasoning to attain desired control strategy.

IV. CONVENTIONAL POWER SYSTEM STABILIZER (P S S)

The fundamental arrangement of conventional PSS is exposed in fig-4. It includes three components of blocks: phase compensation block, signal washout block and gain block. The phase lag between exciter input and generator electrical output make available by phase compensation block with appropriate phase lead characteristic. The signal washout block gives out as high pass filter. The stabilizer gain Kst determines the quantity of damping.

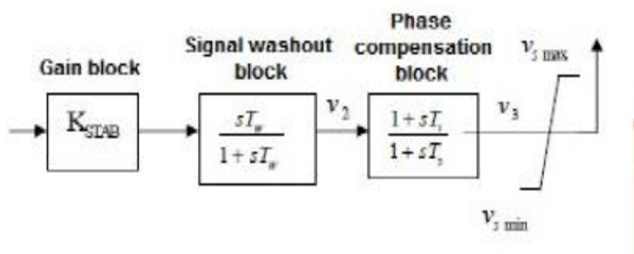

Fig. 4: Block Diagram of Conventional PSS

The transfer function of conventional PSS is represented as:

$$\Delta v_2 = \frac{pT_W}{1+pT_W}(K_{STAB}\Delta\omega_r)$$

$$\Delta v_s = \frac{1+pT_1}{1+pT_2}(\Delta v_2)$$

Now TW is washout filter time constant.

V. FUZZY LOGIC BASED PSS

The power system stabilizer is used to get better the performance of synchronous generator. On the other hand, it results into poor performance under a variety of loading conditions when put into practice with conventional PSS. Consequently, the necessity for fuzzy logic PSS arise. The fuzzy controller used in power system stabilizer is usually a two-input and a single-output component. It is typically a MISO system. The two inputs are change in angular speed and rate of change of angular speed while output of fuzzy logic controller is a voltage signal. An alteration of feedback voltage to excitation system as a function of accelerating power on a unit is used to improve the stability of the system. The stabilizing signals are computed using the standard fuzzy membership functions depending in the lead these variables.

The variables selected for this controller are speed deviation, acceleration and voltage. Here the speed deviation and acceleration are the input variables and voltage is the output variable. The numbers of linguistic variables relating the fuzzy subsets of a variable vary according to the application. By and large an odd number is used. A logical number is seven. But, increasing the number of fuzzy subsets results in an equivalent increase in the number of rules. Every linguistic variable has its fuzzy membership function. The membership function maps the crisp values interested in fuzzy variables. The triangular membership functions are used to classify the degree of membership. Every one of the input and output fuzzy variables is assigned seven linguistic fuzzy subsets varying from negative big (NB) to positive big (PB). Every subset is connected with a triangular membership function to form a set of seven membership functions for each fuzzy variable.

TABLE-1

Membership functions for fuzzy variables

NB	NEGATIVE BIG
NM	NEGATIVE MEDIUM
NS	NEGATIVE SMALL
ZO	ZERO
PS	POSITIVE SMALL
PM	POSITIVE MEDIUM
PB	POSITIVE BIG

Fuzzy Rule Base:

A set of rules which classify the relation between the input and output of fuzzy controller can be set up using the accessible knowledge in the area of designing PSS. These rules are distinct using the linguistic variables. The two inputs, speed and acceleration, result in 49 rules for every machine. The characteristic rules are having the subsequent structure:

The first Rule 1: If speed deviation is NM (negative medium) AND acceleration is PS (positive small) then voltage (output of fuzzy PSS) is NS (negative small).

The second Rule 2: If speed deviation is NB (negative big) AND acceleration is NB (negative big) then voltage (output of fuzzy PSS) is NB (negative big).

The third Rule 3: If speed deviation is PS (positive small) AND acceleration is PS (positive small) then voltage (output of fuzzy PSS) is PS (positive small). And so on.

All the **49 rules** leading the mechanism are explained in Table 2 wherever all the symbols are defined in the basic fuzzy logic expressions.

TABLE-2
Fuzzy Rules

Speed Deviation	Acceleration						
	NB	**NM**	**NS**	**ZO**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NB	NM	NM	NS
NM	NB	NM	NM	NM	NS	NS	ZO
NS	NM	NM	NS	NS	ZO	ZO	PS
ZO	NM	NS	NS	ZO	PS	PS	PM
PS	NS	ZO	ZO	PS	PS	PM	PM
PM	ZO	PS	PS	PM	PM	PM	PB
PB	PS	PM	PM	PB	PB	PB	PB

The stabilizer output will be obtained by applying a meticulous rule articulated in the form of membership functions. Lastly the output membership function of the rule is intended. This process is carried out for all of the rules and with every rule an output is obtained. Using min-max inference, the commencement of the ith rule consequent is a scalar value (Vs) which equals the minimum of the two antecedent conjuncts' values. For instance if speed deviation belong to NB with a membership of 0.3 and acceleration belong to NM with a membership of 0.7 then the rule outcome i.e. Voltage signal (Vs) will be 0.3. Using fuzzy rules revealed in table-2, Conventional PSS will be replaced in Fuzzy controller block.

VI. Simulation Output Results

A. Performance with Conventional PSS (Lead-Lag)

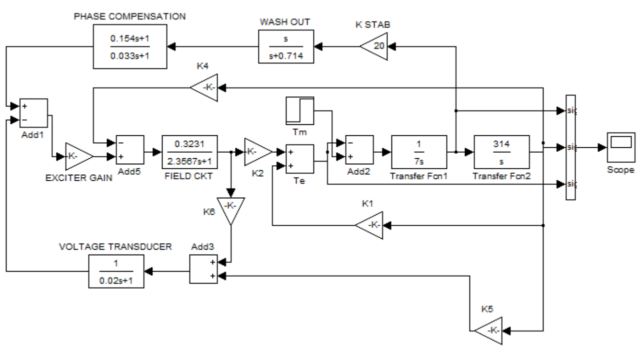

Fig 5: Typical SIMULINK model with AVR and PSS

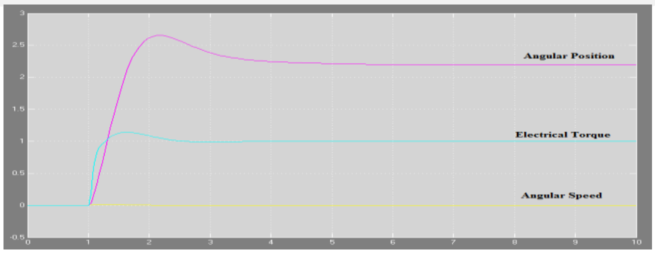

Fig 6: Variation of angular position, angular speed and torque when PSS (lead-lag) is applied with K5 positive

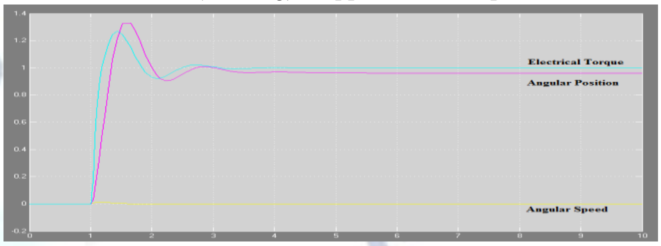

Fig 7: Variation of angular position, angular speed and torque when PSS (lead-lag) is applied with K5 negative

The variation of angular position and angular speed with time for 0.05 p.u boost in torque for positive and negative value of K5 are exposed in Fig-6 and Fig-7 correspondingly. The system is approaching out to be stable in both the cases; on the other hand, the transients are more with negative K5 whereas the higher angular position is attained with positive K5.

B. Performance with Fuzzy Logic Based PSS

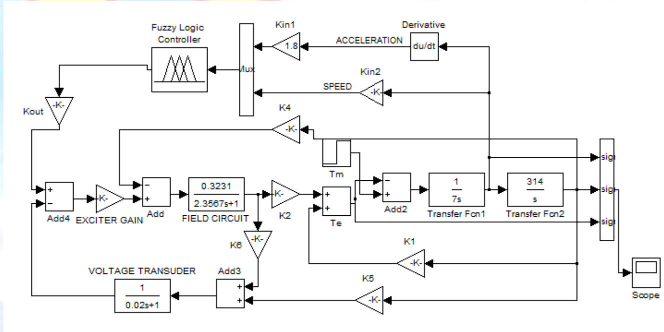

Fig 8: Typical SIMULINK model with fuzzy logic based PSS

Fuzzy logic block is build up by using Fuzzy Interface System file in MATLAB and the fundamental structure of this file is as revealed in Fig-8.

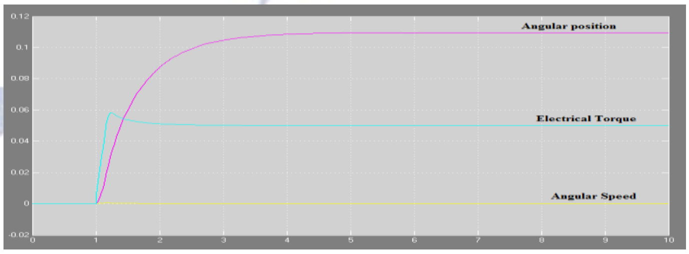

Fig 9: System response for a 5% change in mechanical input for Fuzzy logic based PSS with triangular MF

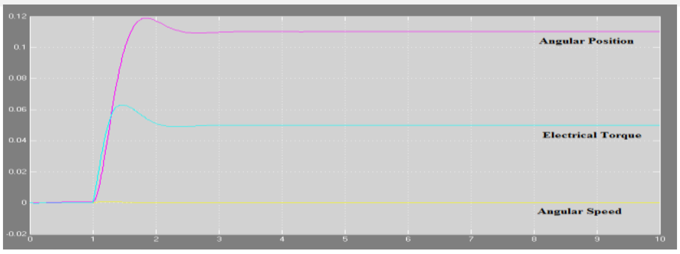

Fig 10 System response for a 5% change in mechanical input for Fuzzy logic based PSS with Gaussian MF

C. Performance with Multi-Level Fuzzy Logic Based PSS

The variation of angular position and angular speed for a 5% step boost in mechanical input is given away in Fig-9 for the negative K5with both fuzzy using triangular memberships. Fig -10 demonstrate system response with both fuzzy using Gaussian memberships. It depicts that angular speed and angular position stabilizes to a meticulous value without overshoot and oscillations and settling time is less than 2 seconds.

The SIMULINK model build up to analyze the effect of multi-level fuzzy logic controller to damp small signal oscillations when implemented on SMIB is made known below in Fig.11

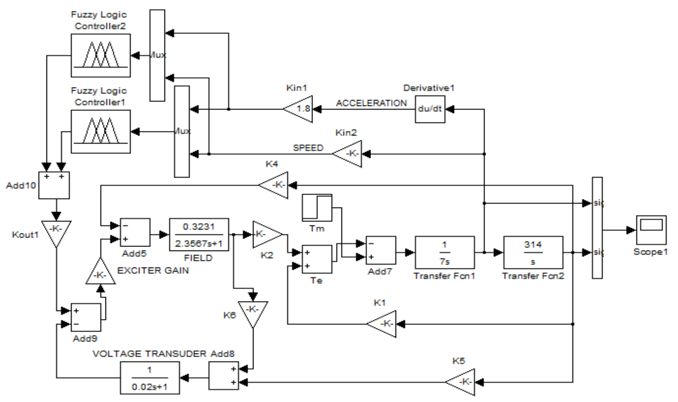

Fig 11: SIMULINK model with multi-level fuzzy logic based PSS.

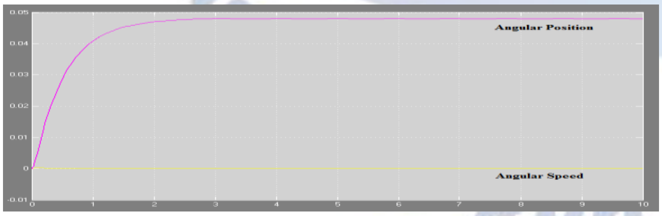

Fig 12: For 5% step change in mechanical input with lower fuzzy (triangular MF) and upper fuzzy (triangular MF)

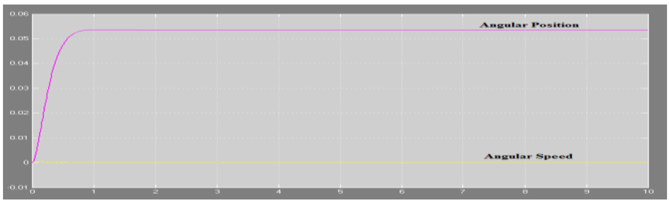

Fig 13: For 5% step change in mechanical input with lower fuzzy (Gaussian MF) and upper fuzzy (Gaussian MF)

TABLE-3

Comparison of Angular Position for dissimilar controllers

Parameter	Controller	Maximum Overshoot(M_p)	Settling Time(t_p) in sec
Angular Position	Constant Voltage	2.650	> 25
	AVR	3.654	8
	AVR & conventional PSS	1.329	4
	Direct fuzzy Triangular	0.109	3
	Direct fuzzy Gaussian	0.118	3
	Multi-Level Fuzzy Triangular	No	< 2
	Multi-Level Fuzzy Gaussian	No	< 2

From Table 3 it can be experiential that fuzzy logic based PSS with triangular membership function accomplishes better performance than the Gaussian membership function. Direct fuzzy controller with triangular membership function has a smaller amount overshoot and settling time. A better performance can be experiential with Multi level Fuzzy based PSS.

TABLE-4

Comparison of Angular speed for dissimilar controllers

Parameter	Controller	Settling Time(t_p) in sec
Angular Speed	Constant Voltage	> 25
	AVR	8
	AVR & conventional PSS	4
	Direct fuzzy Triangular	3
	Direct fuzzy Gaussian	3
	Multi-Level Fuzzy Triangular	< 2
	Multi-Level Fuzzy Gaussian	< 2

From Table 4 we can scrutinize the settling time of angular speed for different controllers and it is obvious that settling time has been reduced from 25 sec to less than 2 sec with the use of fuzzy controllers as an alternative of conventional Power System Stabilizers. Triangular membership function based fuzzy logic controllers has attained improved performance than the fuzzy logic controllers with Gaussian membership function.

VII. Conclusion

This project is developed to damp low frequency oscillations in power system using a controller based on multi-level fuzzy controller in single machine infinite bus system. Initially the effectiveness of conventional power system stabilizer in damping power system stabilizer is reviewed then fuzzy logic and multi-level fuzzy logic controllers are introduced taking speed deviation and acceleration of synchronous generator as the input signals and voltage as the output signal subjected to triangular and Gaussian membership functions. The outputs of the proposed controller are compared with conventional PSS and direct fuzzy controlled PSS which are simulated in this study. However the choice of membership function has an impact on the damping effect. The comparison shows that the proposed MLFC based PSS has shorter settling time, less over shoot and better dynamic response. The performance of MLFC with triangular membership functions is superior compared to other membership functions. The proposed controller is robust and more effective in damping of low frequency oscillations and will enhance the power system

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