Dynamic Stability Enhancement of Power System using Fuzzy Logic Based Power System Stabilizer

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***Abstract*— The power system is a dynamic system and it is constantly being subjected to disturbances. It is important that these disturbances do not drive the system to unstable conditions. For this purpose, additional signal derived from deviation, excitation deviation and accelerating power are injected into voltage regulators. The device to provide these signals is referred as power system stabilizer.**

The use of power system stabilizer has become very common in operation of large electric power systems. The conventional PSS which uses lead-lag compensation, where gain setting designed for specific operating conditions, is giving poor performance under different loading conditions. Therefore, it is very difficult to design a stabilizer that could present good performance in all operating points of electric power systems. In an attempt to cover a wide range of operating conditions, Fuzzy logic control has been suggested as a possible solution to overcome this problem, thereby using linguist information and avoiding a complex system mathematical model, while giving good performance under different operating conditions.

Keywords- Generator Excitation System, Synchronous Machine Model, Automatic Voltage Regulator (AVR), Power System Stabilizer, Fuzzy Logic Controller (FLC), PID, Controller Design, Robust control.

I. INTRODUCTION

The power system is a dynamic system. It is constantly being subjected to disturbances, according to which generator voltage angle changes. When these disturbances removed, a new corrective steady state operating condition is reached. It is important that these disturbances do not drive the system to unstable condition. The disturbances may be of local mode having frequency range of 0.7 to 2 Hz or of inter area modes having frequency range in 0.1 to 0.8 Hz, these swings are due to the poor damping characteristics caused by modern voltage regulators with high gain. A high gain regulator through excitation control has an important effect of eliminating synchronizing torque but it affects the damping torque negatively. To compensate the redundant effect of the voltage regulators in the excitation system, additional signals are proposed as a input signal in the feedback for the voltage regulators. The additional signals are mostly derived from excitation system deviation, speed deviation or accelerating power. This is accomplished by inserting a stabilizing signal into the excitation system voltage reference summing point junction. The device arrangement is to provide the signal is called “power system stabilizer”.

Excitation control is well known as one of the effective means to enhance the overall stability of electrical power systems. Present day excitation systems predominantly constitute the fast acting AVRs. A highly response excitation system is useful in increasing the synchronizing torque, thus improving the transient stability of the system i.e. to hold the generator in synchronism with power system during large transient fault condition. However, it produces a negative damping especially at high values of external system reactance and high generator outputs. Generator excitation controls have been installed and made faster to improve stability. PSS have been added to the excitation systems to improve the oscillatory instability it is used to provide a supplementary signal to excitation system. The basic function of PSS is to extend the stability limit by modulating generator excitation to provide the positive damping torque to power swing modes.

II. SYSTEM MODELING

The Mathematical Models needed for small signal analysis of Synchronous Machines, Excitation System and lead-lag power system stabilizer are briefly reviewed. The Guidelines for the selection of Power System Stabilizer parameters are also presented.

A. Synchronous Machine Model

The synchronous machine is vital for power system operation. The general system configuration of synchronous machine connected to infinite bus through transmission network can be represented as the mathematical models needed for small signal analysis of synchronous machine; excitation system and the lead-lag power system stabilizer are briefly reviewed. The guidelines for the selection of power system stabilizer parameters are also presented. The Thevenin’s equivalent circuit shown in Fig. 1.1

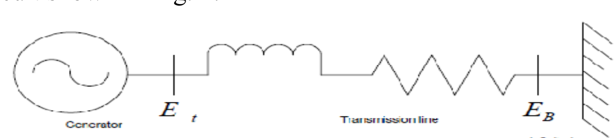

Fig. 1.1The equivalent circuit of synchronous machine connected to infinite bus.

B. Classical System Model

The generator is represented as the voltage E' behind Xd' as shown in Fig. 1.2. The magnitude of E' is assumed to remain constant at the pre-disturbance value. Let d be the angle by which E' leads the infinite bus voltage E_B. The d changes with rotor oscillation. The line current is expressed as –

$$I_t = \frac{E' \angle 0^0 - E_B \angle -\delta}{jX_T} = \frac{E' - (E_B \cos\delta - j\sin\delta)}{jX_T}$$

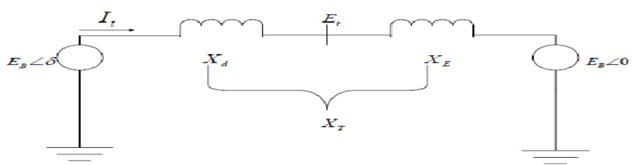

Fig. 1.2: Classical model of generator

$$S = P + jQ = \frac{E' E_B \sin\delta}{X_T} + j\frac{E'(E' - E_B\cos\delta)}{X_T}$$

With stator resistance neglected, the air-gap power (Pe) is equal to the terminal power (P). In per unit, the air-gap torque is equal to the air gap power.

The above equation to describe small-signal performance is represented in schematic Fig. 1.3.

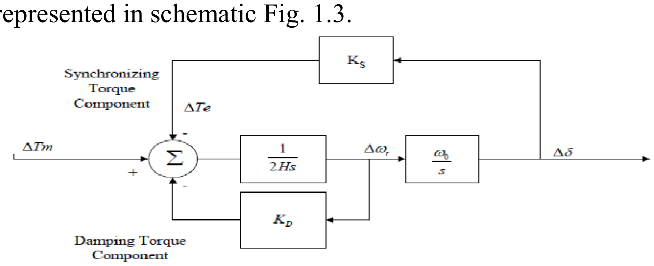

Fig. 1.3: Block diagram of single machine infinite bus system with classical model

From the block diagram we have:

$$\Delta\delta = \frac{\omega_0}{s}\left(\frac{1}{2Hs}\ (-K_s\Delta\delta - K_D\Delta\omega_r + \Delta T_M)\right)$$

$$= \frac{\omega_0}{s}\left(\frac{1}{2Hs}\ (-K_s\Delta\delta - K_D\frac{\Delta\delta}{\omega_0}s + \Delta T_M)\right)$$

Solving the block diagram we get the characteristics equation:

$$s^2 + \frac{K_D}{2H}s + \frac{K_s\omega_0}{2H} = 0$$

Comparing it with general form, the undamped natural frequency ω_n and damping ratio ξ are expressed as –

$$\omega_n = \sqrt{\frac{K_s\omega_0}{2H}}$$

$$\xi = \frac{1}{2}\frac{K_D}{\sqrt{K_s 2H\omega_0}}$$

III. Power System Stabiliser

The basic function of power system stabilizer is to add damping to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signals. For provide damping signal the stabilizer must produce a component of electrical torque in phase with rotor speed deviation. The Power System Stabilizer with the aid of block diagram as shown in Fig. 1.4

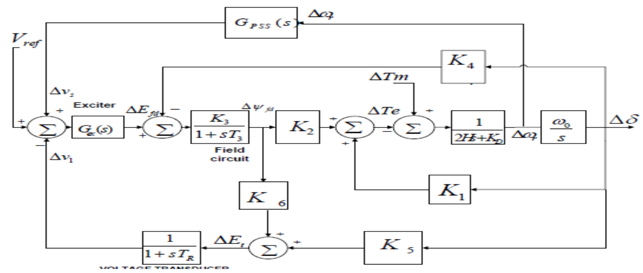

Fig. 1.4: Block diagram representation with AVR and PSS

Since the purpose of PSS is to introduce a damping torque component. A logical signal is use for controlling generator excitation is the speed deviation $\Delta\omega_r$. The PSS transfer function GPSS(s), should have appropriate Gain, Washout signals and Phase Compensation circuits to compensate for the phase lag between exciter input and electrical torque. The following is a brief description of the basis for the PSS configuration and consideration in selection of parameters.

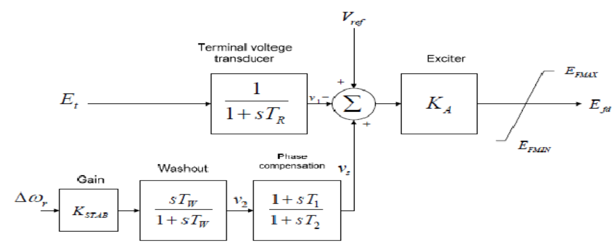

Fig. 1.5: Thyristor excitation system with AVR and PSS

III. Fuzzy Controller

The fuzzy control systems are rule-based systems in which a set of fuzzy rules represent a control decision mechanism to adjust the effects of certain system stimuli. With the help of effective rule base, fuzzy control systems can replace a skilled human operator. The fuzzy logic controller provides an algorithm which can convert the linguistic control strategy based on expert knowledge into an automatic control strategy. The Fig. 1.6 illustrates the schematic design of a fuzzy logic controller which consists of a fuzzification interface, a knowledge base, control system (process), decision making logic, and a defuzzification interface.

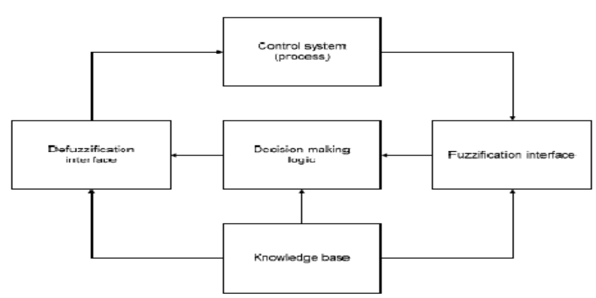

Fig. 1.6: The principle design of fuzzy logic controller

IV. Simulation Model And Result

The performance of single machine infinite bus system has been studied (1) Without Excitation System. (2) With Excitation System. (3) With Conventional PSS (lead-lag) and (4) with Fuzzy Logic based Power System Stabilizer. Schematic Models of Synchronous Machine, Excitation System and Conventional PSS are described. The machine data is taken from

TABLE- I

Parametres	Numerical values
P	0.9
Q	0.3
E_t	1.0
F	50
Xd	1.81
Xq	1.76
Xd1	0.3
XL	0
Xe	0.65
Ra	0.003
Tdo1	8.0
H	3.5
Ωo	314
K_D	0
T_R	0.02
E_{Tmag}	1.0
L_{adu}	1.65
L_{adu}	1.60
R_{fd}	.0006
L_{fd}	0.153
K_{sd}	0.8491
K_{sq}	0.8491
K_{sdI}	0.434
K_{sqI}	0.434
A_{SAT}	0.031
B_{SAT}	6.93
ψ_1	0.8
Frequency of oscillation (in rad/sec)	10

A. *Performance with constant field voltage-*

The model used in the simulink to study the response of the system with constant field voltage is shown in figure. In this representation the dynamic characteristics are represented in terms of K constant. The values of K constants are calculated using above parameters are-

K_1=0.7635, K_2=0.8643, K_3=0.3230, K_4=1.4188

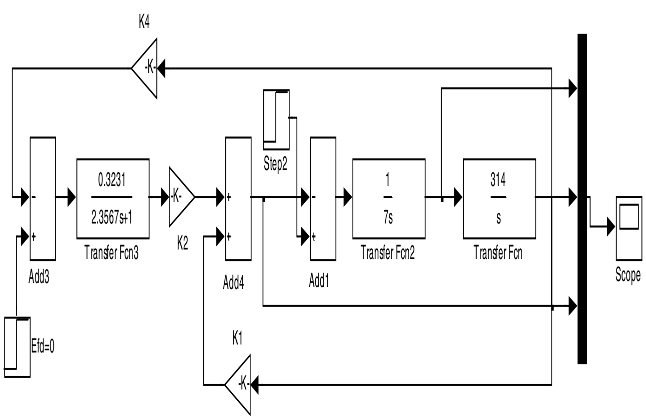

Fig 1.7: Simulink model for simulation of single machine infinite bus System with constant field voltage.

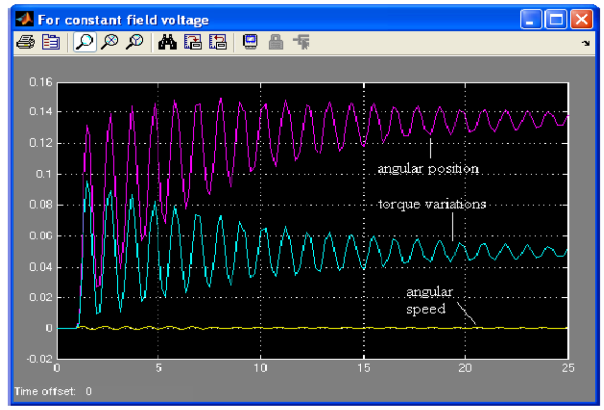

Fig 1.8: System response for a 5% change in mechanical input

B. *Performance with Excitation System only-*

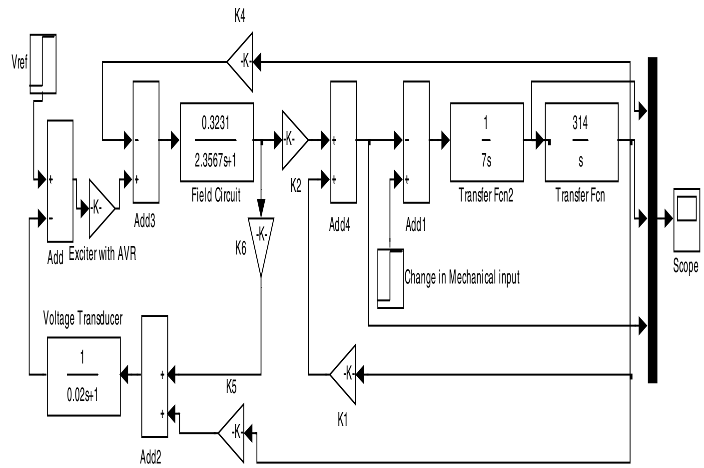

Fig 1.9: Simulink model for simulation of single machine infinite bus system with AVR only

The standard IEEE type ST1A excitation system model has been considered for the study and integrated it with the single machine infinite bus system. Correspondingly, the simulink model is shown in Fig 1.9. The excitation system parameters are taken as K = 200 and TR = 0.02.

The values of 'K' constants calculated using above parameters: K_1=0.7635, K_2=0.8643, K_3=0.3230, K_4=1.4188, K_5 = -0.1462, K_6=0.4166

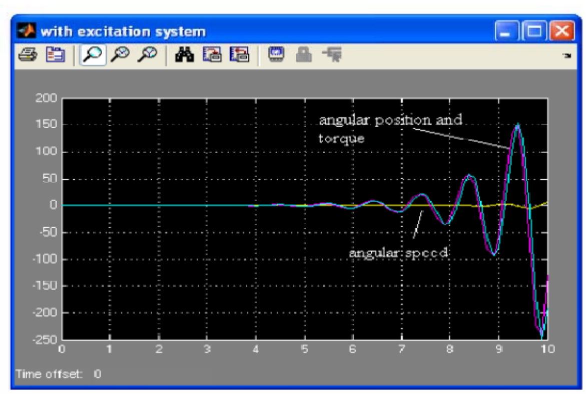

Fig 1.10: System response for a 5% change in mechanical input with K_5 negative

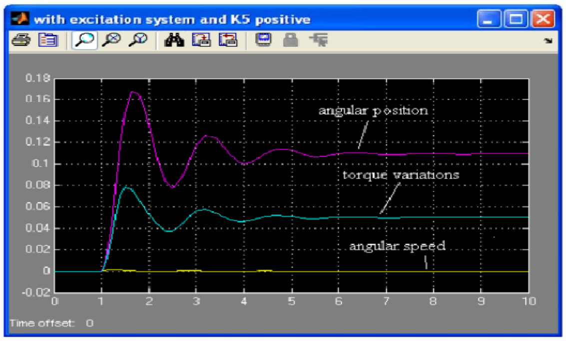

Fig 1.11: System response for a 5% change in mechanical input with K_5 positive

C. Performance with Conventional PSS lead-lag -

The simulink model of lead-lag power system stabilizer is shown in Fig. 1.12

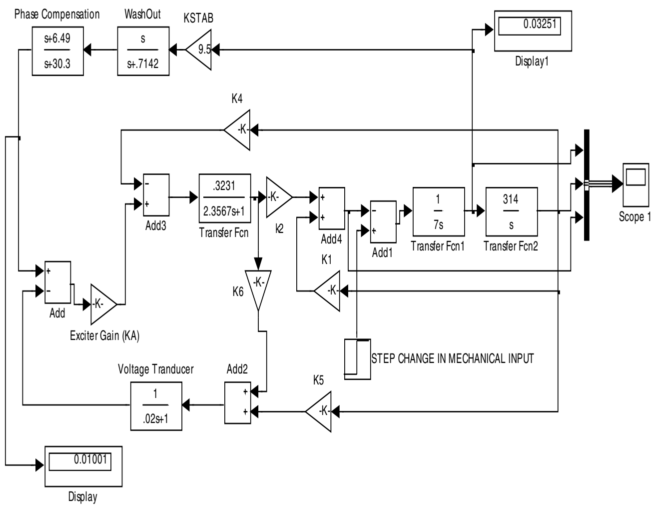

Fig 1.12 Simulink Model with AVR and PSS

The variation of angular position and angular speed with time for 0.05 pu increase in torque for negative and positive value of K_5 are shown in Fig 1.13 and Fig.1.14 respectively. The system is coming out to be stable in both the cases; however, the transients are more with negative K_5 whereas the higher angular position is attained with positive K_5.

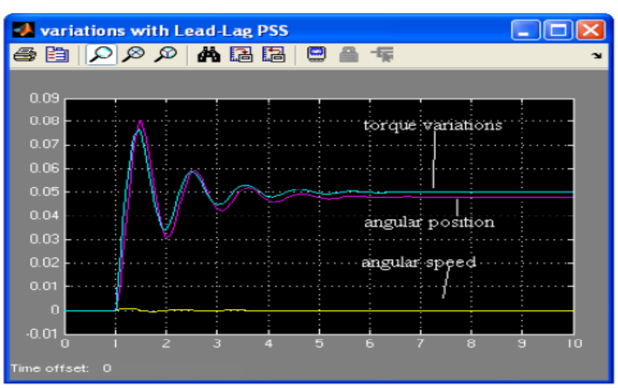

Fig 1.13: Variation of angular speed, angular position and torque when PSS (lead-lag) is applied with K_5 negative.

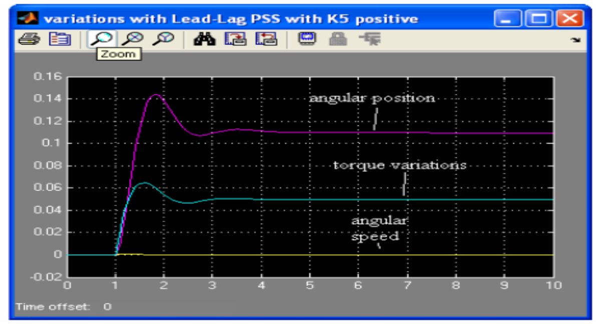

Fig 1.14: Variation of angular speed and angular position and torque when PSS (lead-lag) is applied with K_5 positive

D. Performance with Fuzzy Logic Based PSS-

The Model used in Simulink/Matlab to analyze the effect of fuzzy logic controller in damping small signal oscillations when implemented on single machine infinite bus system is shown below in Fig.1.15 and the details of the fuzzy controller are shown in Fig. 1.16. As shown in Fig. 1.16, the fuzzy logic controller block consists of fuzzy logic Block and scaling factors. scaling factors inputs are two & one for each input and one scaling factor for output which determine the extent to which controlling effect is produced by the Fuzzy Logic controller. Performance of Fuzzy Logic controller is studied for the scaling factors having the values as K_{in1}=1.62, K_{in2}=29.58, K_{out}=1.08.

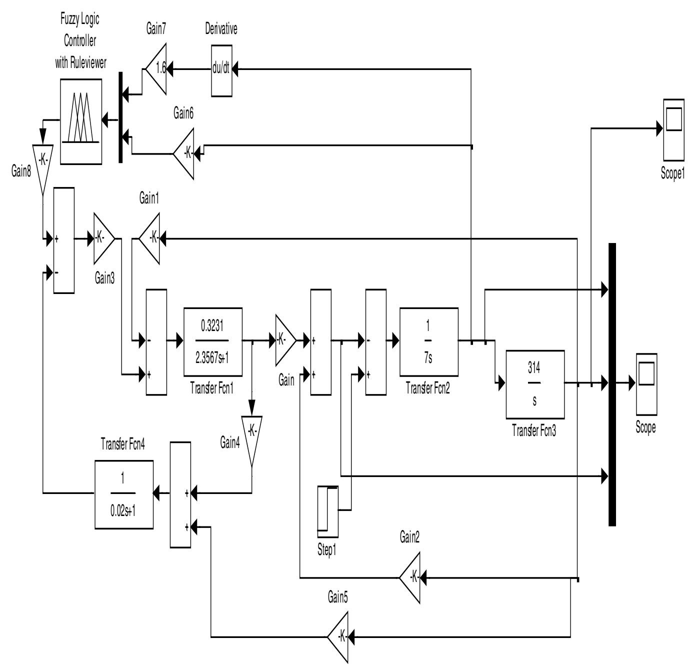

Fig 1.15: Simulink model with fuzzy logic based PSS

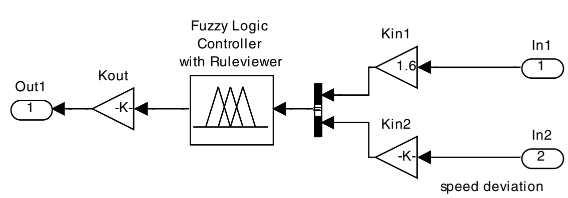

Fig 1.16: Fuzzy logic based PSS

V. FUZZY INFERENCE SYSTEM

Fuzzy logic block is prepared using FIS file in Matlab 7.8.0.347(R2009a) and the basic structure of this FIS editor file as shown in Fig 1.17. This is implemented using following FIS (Fuzzy Inference System) properties:

And Method: Min
Or Method: Max
Implication: Min
Aggregation: Max
Defuzzification: Centroid

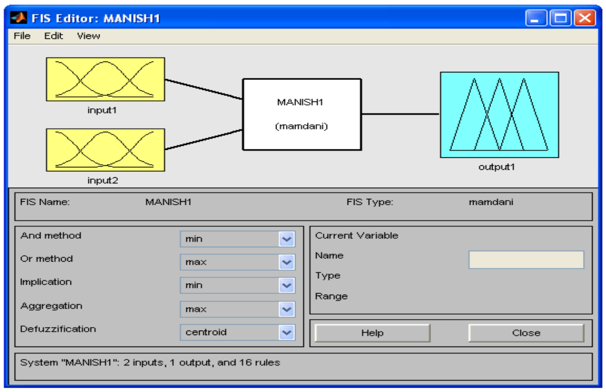

Fig 1.17: Fuzzy Inference System

Speed deviation	**Acceleration**					
	NB	**NM**	**NS**	**PS**	**PM**	**PB**
NB	NB	0	0	0	0	0
NM	0	0	0	0	0	0
NS	0	0	0	0	0	0
PS	NM	NS	0	PM	PB	PB
PM	NS	0	PS	PB	PB	PB
PB	0	PS	PM	PB	PB	PB

Fig 1.18: Rule Base for Fuzzy Logic Controller

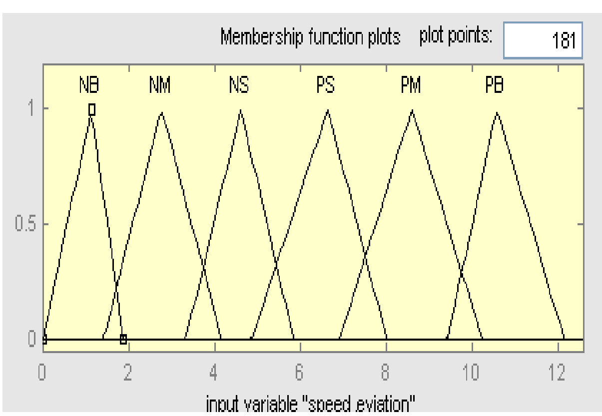

Fig. 1.19(a) Membership functions for speed deviation

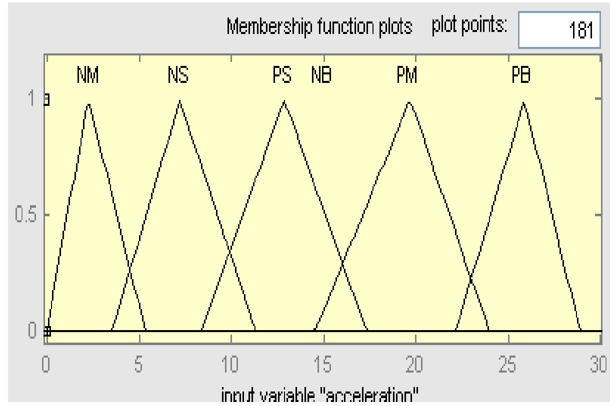

Fig. 1.19(b) Membership functions for acceleration

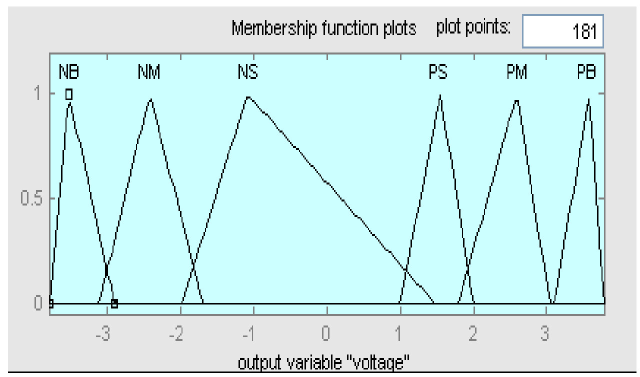

Fig. 1.19(c) Membership functions for voltage

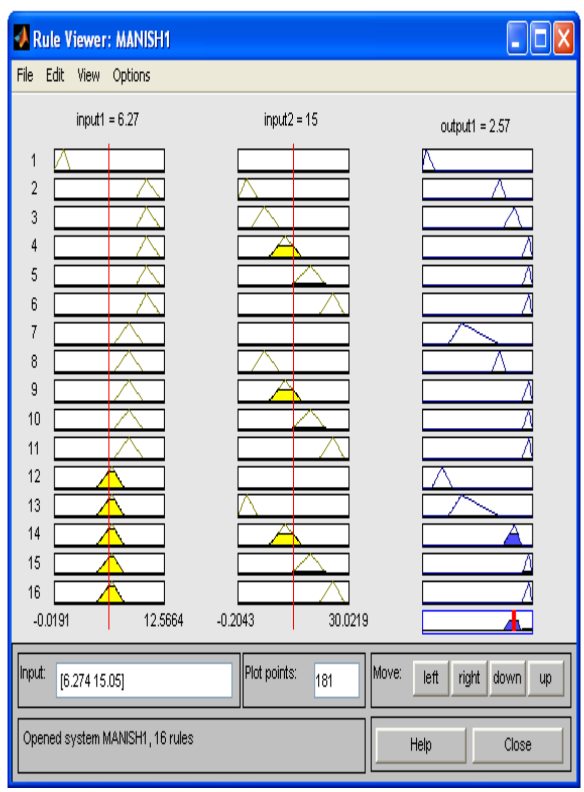

Fig 1.20: Rule Viewer of Fuzzy Controller

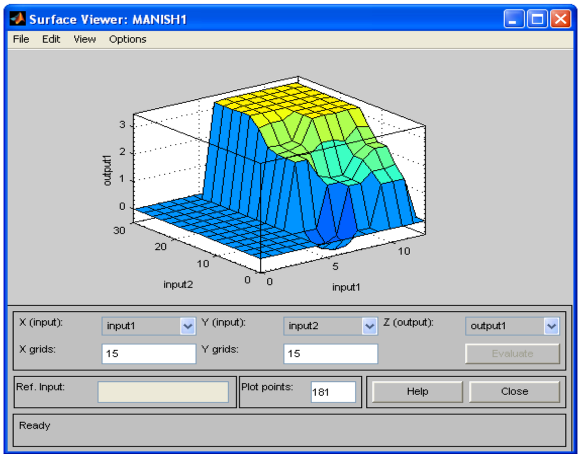

Fig 1.21: Surface Viewer of Fuzzy Controller

For the above FIS system Mamdani type of rule-base model is used result of which we get the output in fuzzified form. Precise output is produced by the Normal System which uses a defuzzification process to convert the inferred possibility distribution of an output variable to a representative Precise Value. In the above given Fuzzy Inference System this work is done using centroid Defuzzification Principle Method. In this system minimum implication together with the maximum aggregation operator is used.

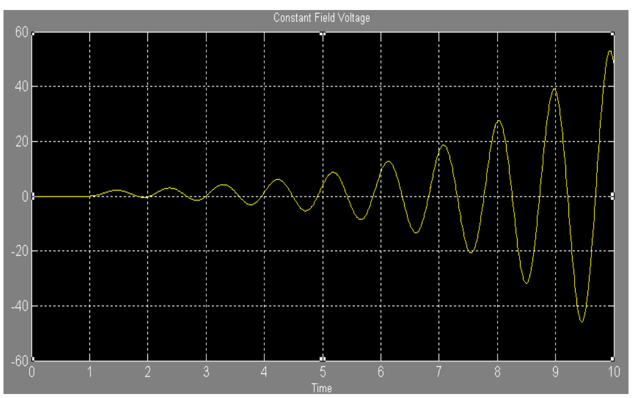

Fig 1.22: Simulation Result of Variation of angular speed when system with Fuzzy Logic Based PSS

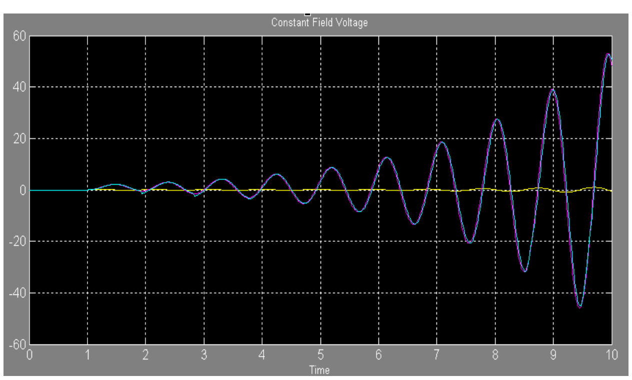

Fig 1.23: Simulation Result of Variation of angular speed, angular position and torque when system with Fuzzy Logic Based PSS

VI. SIMULATIO MODEL OF AVR WITH PSS

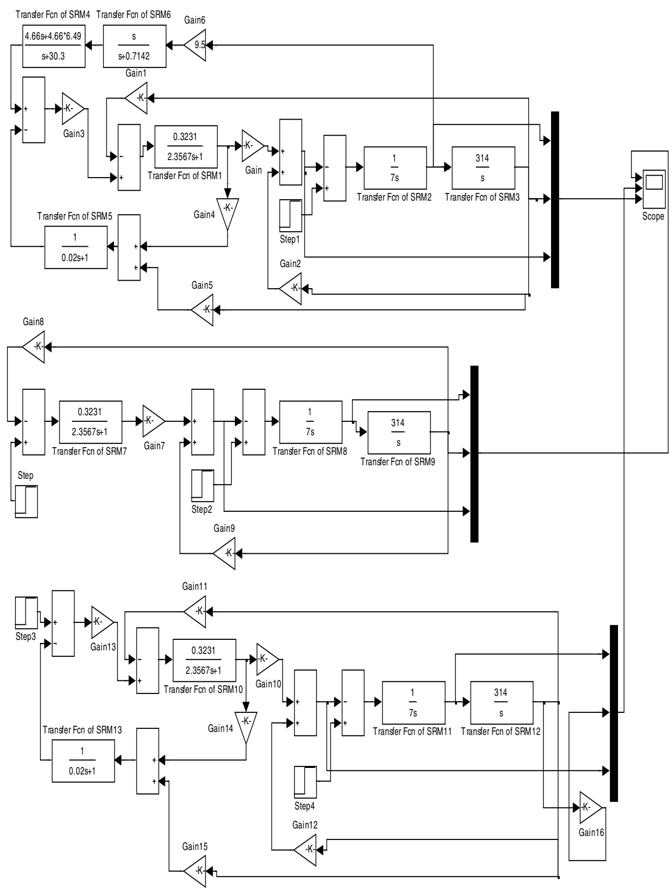

Fig. 1.24 Simulation Model of AVR with PSS

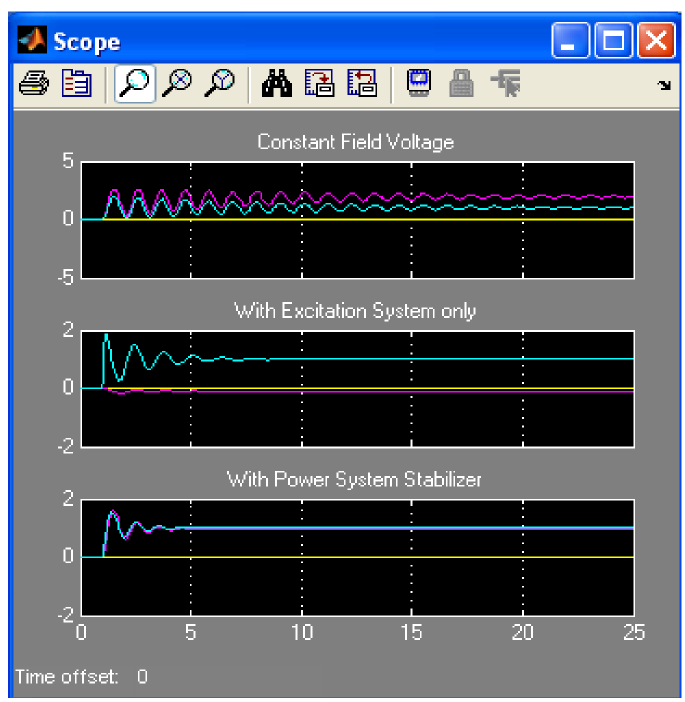

Fig. 1.25 Simulation Result of AVR with PSS

VII. COMPARISON OF RESULTS

To compare the performance of lead-lag PSS and fuzzy logic based PSS, the step response are shown in Fig. 1.26 and Fig. 1.27 for angular speed for the negative and the positive values of K_5.

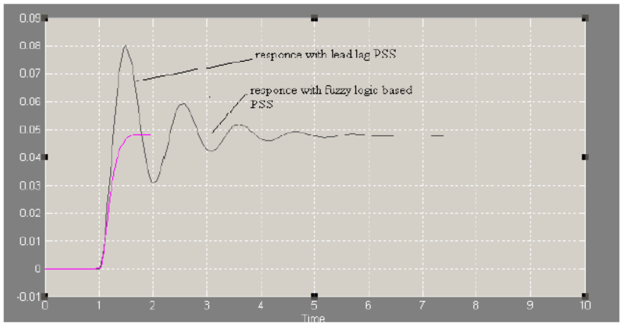

Fig 1.26: Comparison of angular position for a 5% change in mechanical input with conventional PSS (lead-lag) and fuzzy logic based PSS with K5 negative.

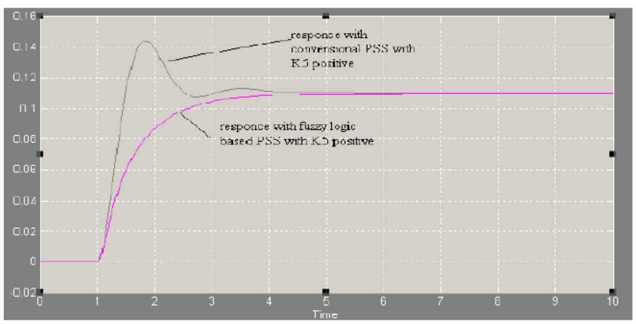

Fig 1.27: Comparison of angular position for a 5% change in mechanical input with conventional PSS (lead-lag) and fuzzy logic based PSS with K5 positive

These results are for 5% change in mechanical torque. From Fig. 1.26 and Fig. 1.27 it can be perceived that with the application of fuzzy logic the rise time and the settling time of the system decreases due to which system reaches its steady state value much earlier with Fuzzy Logic Power System Stabilizer compared to conventional power system stabilizer with negative K_5 and with the positive value of K_5, the sluggish response (over damped response) characteristic is resulted and the settling time remains largely unchanged.

The step response characteristics for angular position for both lead-lag PSS and fuzzy logic based PSS are compared in Fig. 1.28 and Fig. 1.29 for negative and positive values of K_5.

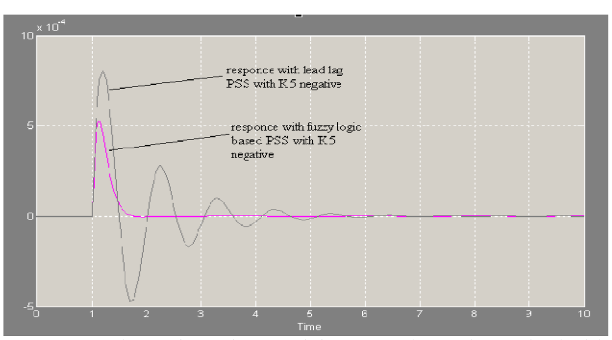

Fig 1.28: Comparison of angular speed for a 5% change in mechanical input with conventional PSS (lead-lag) and fuzzy logic based PSS with K5 negative.

From relative plots it can be retrieved that oscillations in angular speed reduces much faster with fuzzy logic power system stabilizer than with conventional power system stabilizer for both the conditions i.e. when K_5 positive and K_5 negative. The result is shown in Fig. 1.29 with fuzzy logic the variation in angular speed reduces to zero for 2 seconds, but in case of conventional power system stabilizer it takes about 6 seconds to reach to final steady state value and also the oscillations are less pronounced in fuzzy logic based PSS. Similar is the case with K_5 positive.

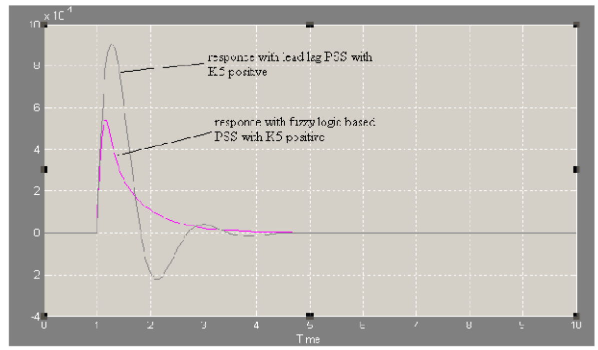

Fig 1.29: Comparison of angular speed for a 5% change in mechanical input with conventional PSS (lead-lag) and fuzzy logic based PSS with K5 positive.

Therefore, it can inferred that the fuzzy controller does not require any complex mathematical support and the response is much improved than with conventional PSS.

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