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Comparative Studies of Fuzzy Logic Base Power System Stabilizers in Enhancing Dynamic Stability of a Generator Connected to Infinite Bus

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Abstract: Power system stabilizers (PSS) are added to excitation system to enhance the damping during low frequency oscillations. This paper presents a study of fuzzy logic power system stabilizer for stability enhancement of a single machine connected to infinite bus (SMIB) power system. Recently fuzzy logic as a novel robust control design method has shown promising results. The emphasis in fuzzy control design center is around uncertainties in the system parameters and operating conditions. Fuzzy logic controller (FLC) 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. The proposed approach is found to have stable convergence characteristics and resulted in good voltage regulation and damping characteristics. The stabilizing signals were computed using the fuzzy membership functions with variations of angular speed and acceleration as the inputs. The simulations were tested under different operating conditions, with different membership functions using MATLAB /SIMULINK. The simulation results are quite encouraging and satisfactory.

Key words: Power System Stabilizer · Stability · Controller Design · Fuzzy Logic Controller

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 dueto 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 [1]. A high-gain fast-response AVR improves the voltage regulation and improves the ability of the power system to maintain synchronism when subjected to large disturbances. A PSS is directly connected to the AVR of synchronous generators and the main aim of PSS-AVR excitation control configuration is to provide damping and voltage regulation. On the other hand, the advancement in the bio-inspired and evolution techniques like Particle-Swarm Optimization (PSO) have led to a new approach in solving complex optimization problems.PSS is a device which provides additional supplementarycontrol loops to the automatic voltage regulators system and/or the turbine governing system of a generating unit [2-4]. The common feature of AVR/PSS controllers is that they are typically based on models established by approximate linearization of the nonlinear equations of a power system at certain operating point. But, in case of large disturbances, these linearized control techniques are not effective. In an attempt to cover a wider range of operating conditions, expert or rule-based controllers have also been proposed. Recently, fuzzy logic as a novel robust control design method has shown promising results.

A fuzzy Logic Controllers (FLCs) have attracted considerable attention as candidates for novel computational systems because of the variety of the advantages they offer over the conventional

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computational systems. The application of a power system stabilizer for improving the stability ofpower systems has received much attention. Fuzzy control appears to be the most suitable one, due to its robustness andlower computation burden. Fuzzy logic controller (FLC) is well-known with its potential to obtain superior speed control in high performance drives. It has proved by many performance analyses as well comparative studies either through simulation or experimental verifications [5-8]. A fuzzy controller is designed to emulate human deductivethinking, that is, the process people use to infer conclusions (decisionmaking) from what they know. Fuzzy control has been primarilyapplied to the control of processes through fuzzy linguistic. The most common fuzzy logic controllers are based on constant parameter fuzzy logic (CPFL). The CPFL controller has already been successfully implemented in high performance vector controlled drive [9, 10]. It is envisaged that it is possible to take full advantages of FLC for UUV application if the computational time of FLC is minimized. The Single Input Fuzzy Controller (SIFLC) is proposed. Synchronous generator stability can be enhanced either by monitoring his excitation and hence the field current via anexciter-based power system stabilizer (EPSS), or bycontrolling the governor through a so called governor powersystem (GPSS) which offers adjustment of mechanical torque. The inconvenience of this method is its slower simulation times and its important hardware resources request. Other researchers have attempted to implement FLC in the hardware for different applications during the past few years [11-13]. A fuzzy logic-based controller adjusts the system input to get a desired output by just looking at the output without any requirement of mathematical model for controlled system that are now being exploited in motorcontrol applications. For this reason, fuzzy logic-based controller systems differ from classical control systems and it is possible to get desired control actions for complex, uncertain and non-linear systems by using fuzzy logic controller (FLC) without the requirement of their mathematical models and parameter estimation. All along, fuzzy logic systems (FLSs) are the very important tool to approximate unknown nonlinearities in complex dynamic systems and have received considerable attention. Fuzzy logic has been successfully used in numerous fieldssuch as control systems engineering, power engineering, industrial automation and optimization. FLC has proven effective for complex, non-linear and imprecisely defined processes for which standard model based control techniques are impractical or impossible [14-16].

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 ofoperating 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.Limitations of fixed parameter of conventional PSS has to lead advanced control schemes such as self tuning, rulebased PSS and fuzzy logic control. For steady state operation, the system with fuzzy logic PSS settles down much faster than system with conventional PSS. For three- phase to groundfault operation, the oscillation under system with fuzzy logic PSS decays faster than under system with conventional PSS. And hence the design of PSS becomes model dependent. The major advantage of fuzzy logic controller is its model independency. But the parameters of fuzzy logiccontroller are determined by trial and error method. Thismethod is time-consuming and does not guarantee an optimal controller [17-19].

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.

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. 2.1.

Classical System Model: The generator is represented as the voltage E' behind Xd' as shown in Fig. 2.2. The magnitude of E' is assumed to remainconstant at the pre-disturbance value. Let δ be the angle by which E' leads the infinite bus voltage E_B. The δ changes withrotor oscillation. The line current and total power can be expressed as

$$I_t = \frac{E' \angle 0^\circ - E_B \angle -\delta}{jX_T} = \frac{E' - (E_B \cos\delta - j\sin\delta)}{jX_T} \quad (1)$$

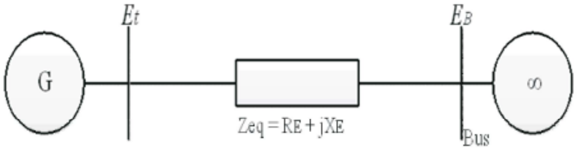


Fig. 2.1: Single Machine Infinite Bus System.

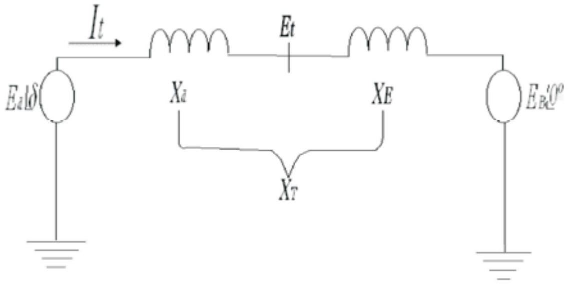


Fig. 2.2: Classical model of generator

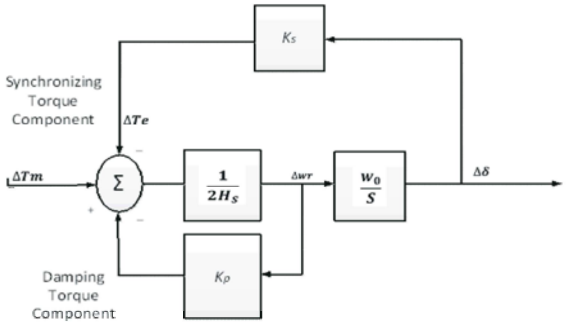


Fig. 2.3: Block diagram of single machine infinite bus system with classical model

$$S = P + jQ = \frac{EE_B \sin\delta}{X_T} + j\frac{E'(E' - E_B \cos\delta)}{X_T} \tag{2}$$

The above equation to describe small-signal performance is represented in schematic Fig. 2.3 [1].

From the block diagram we have [1]

$$\Delta\delta = \frac{w_0}{s}\left(\frac{1}{2Hs}(-K_s\Delta\delta - K_D\Delta\omega_r + \Delta T_M)\right) \tag{3}$$

$$\frac{W_o}{s}\left(\frac{1}{2Hs}\left(-K_s\Delta\delta - K_D\frac{\Delta\delta}{w_o}s + \Delta T_M\right)\right) \tag{4}$$

Solving the block diagram we get the characteristics equation:

$$S^2 + \frac{K_D}{2H}S + \frac{K_S W_O}{2H} = 0 \tag{5}$$

Comparing it with general form, the undamped natural frequency ω_n and dampingratio (δ) Are expressed as [1].

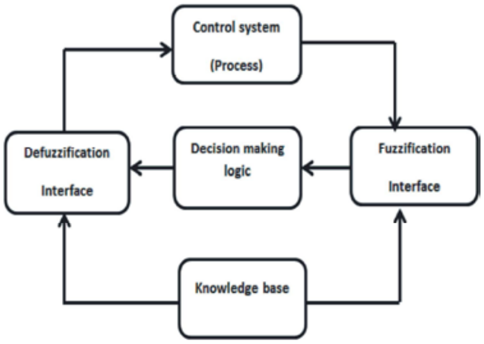


Fig. 3.1: Principle design of fuzzy logic controller

$$\omega_n = \sqrt{\frac{K_S\omega_0}{2H}} \tag{6}$$

$$\zeta = \frac{1}{2}\frac{K_D}{\sqrt{K_S 2H\omega_0}} \tag{7}$$

Methodology

PSS Model: Power System Stabilizer (PSS) is a device which provides additional supplementary control loops to the automatic voltage regulator system and/or the turbine governing system of a generating unit. PSS are often used as an effective and economic means of damping such oscillations. Adding supplementary control loops to thegenerator AVR is one of the most common ways of enhancing both small-signal (steady state) stability and large-signal (transient) stability. PSS is working in parallel with the excitation system in order to modify the power angle to increase the damping of the oscillation. Since the PSS and the excitation system are working in parallel, the performance of the excitation system is very important to PSS [4, 1].

$$\frac{Vpss^{(s)}}{Delta\ Speed^{(s)}} = K_S \cdot \frac{s}{s+.7142} \cdot \frac{s+6.49}{s+30.3} \tag{8}$$

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. 3.1 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[1].

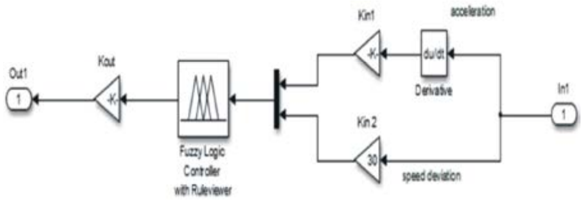


Fig. 3.2: Fuzzy logic based PSS

Table 4.1: Machine data

parameters	Numerical value
K_1	0.9831
K_2	1.0923
K_3	0.3864
K_4	1.4746
K_5	-0.1103
K_6	0.4477
K_E	0.08
T_E	0.25
K_D	0
H	6
D	0.95

Table 4.2: PSS Parameters designed by PSO

T1	T2	T3	T4	Kpss
0.3730	0.1096	0.7910	0.0819	7.1144

Table 4.31: machine data

Parameters	Numerical value
K_1	0.7635
K_2	0.8643
K_3	0.3230
K_4	1.4188
K_5	-0.1462
K_6	0.4166
K_E	200
T_E	0.0132
K_D	0
H	3.5

Table 4.31: machine data

Parameters	Numerical value
K_1	0.7635
K_2	0.8643
K_3	0.3230
K_4	1.4188
K_5	-0.1462
K_6	0.4166
K_E	200
T_E	0.0132
K_D	0
H	3.5

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 shown in Fig. 3.2. Performance of Fuzzy Logic controller is studied for the scaling factors having the values as Kin_1=2, Kin_2=30, K_{out}=0.01 [1].

Simulation Results

System 1: The studies were implemented using MATLAB/SIMULINK based on the system shown Fig 4.1. performance of single machine infinite bus system hasbeen studied (1) with AVR (2)FLC based PSS and (3) With PSS (lead-lag) designed by PSO. The machinedata is taken from Table 4.1 [4].

The variations of angular speed,angular position, torque and voltage are displayed in Fig 4.2 for the systems with 20% change of input torque. PSO is used in this paper to tune PSSparameters as described in the previous section. Table 4.2 presents the PSS parameters as designed by PSO taken from [4].

System 4.2: For the studies were carried out for the systems shown in Fig 4.3. The performance of single machine infinite bus system hasbeen studied (1) with AVR (2)PSS (3)With FLC.The machinedata is taken from references [1-3].

System 4. 2: For the studies were carried out for the systems shown in Fig 4.3. The performance of single machine infinite bus system hasbeen studied (1) with AVR (2)PSS (3)With FLC.The machinedata is taken from references [1-3].

Results are shown in Fig. 4.4 and Fig. 4.5 with fuzzy logic controller the variation in (a) Angular Speed, (b) Angular Position (c) Torque Variations and (d) Voltage Variations.with K_5 positive = 0.1462 and K_5 negative = -0.1462 respectively.

Fuzzy Infereence System: Fuzzy logic block is prepared using Fuzzy Inference System file in Matlab (R2013a) and the basic structure of this FIS editor file as shown in Fig. 4.6. This is implemented using following FIS (Fuzzy Inference System) properties as shown in Fig 4.6 4.9 [1].

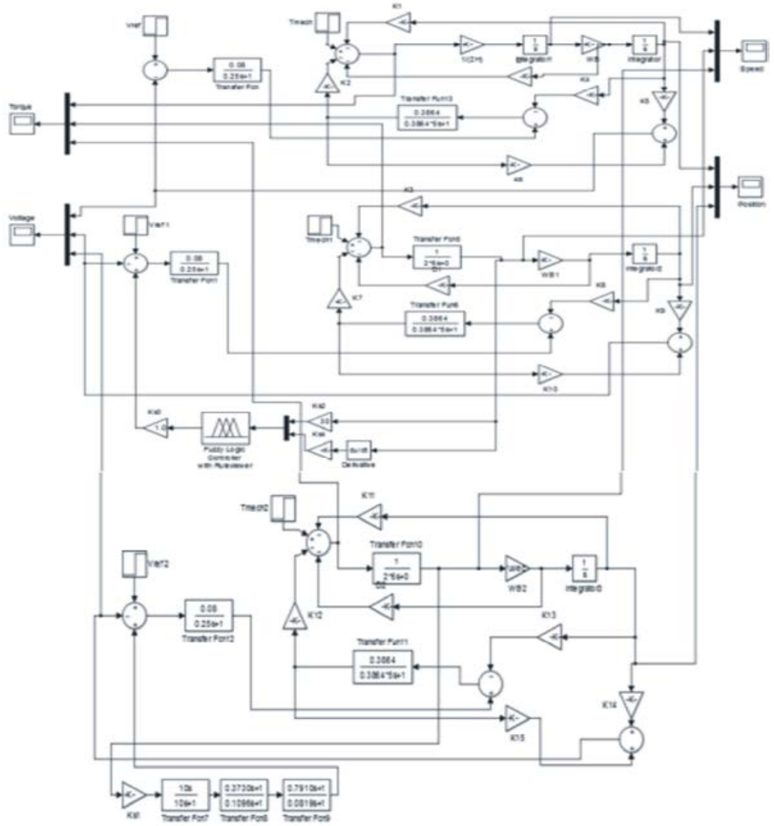
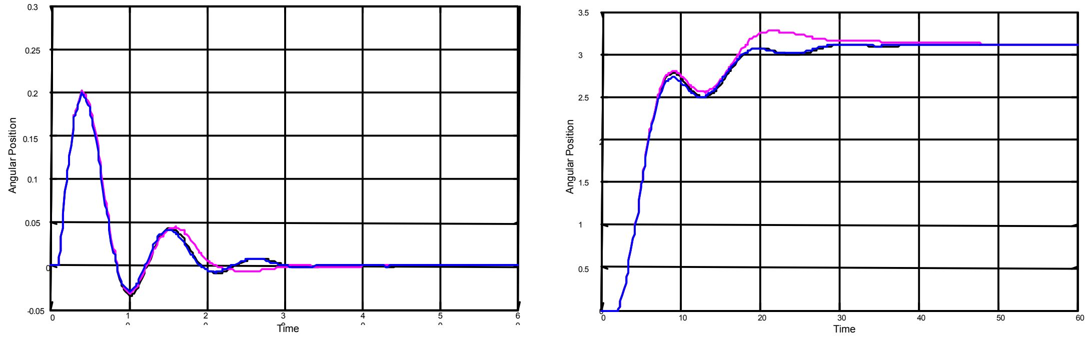
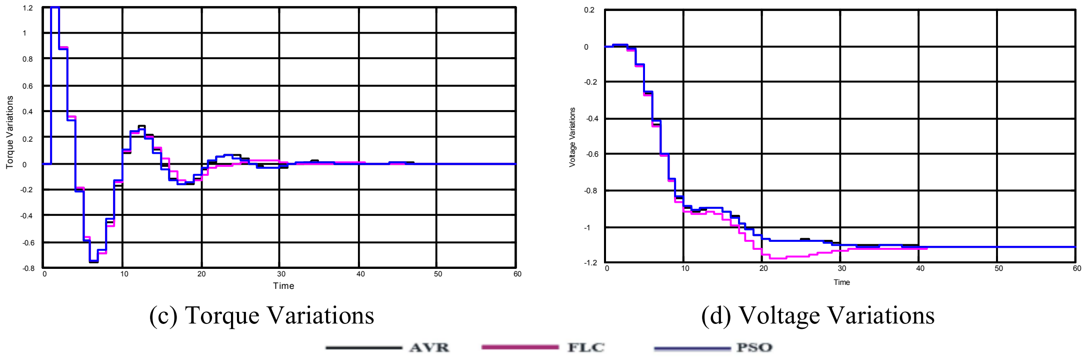


Fig. 4.1: Simulation models of AVR, FLC andPSO.



(a) Angular Speed

(b) Angular Position



(c) Torque Variations

(d) Voltage Variations

Fig. 4.2: Simulation result of AVR with FLC based PSS designedPSO with $K_{5=}$-0.1103.

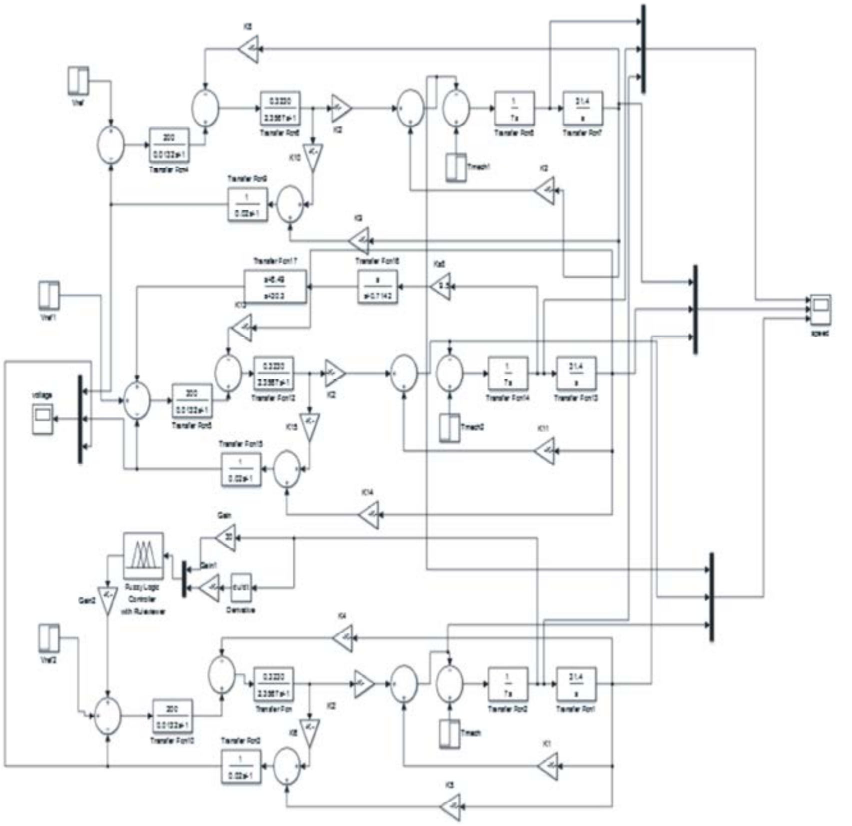
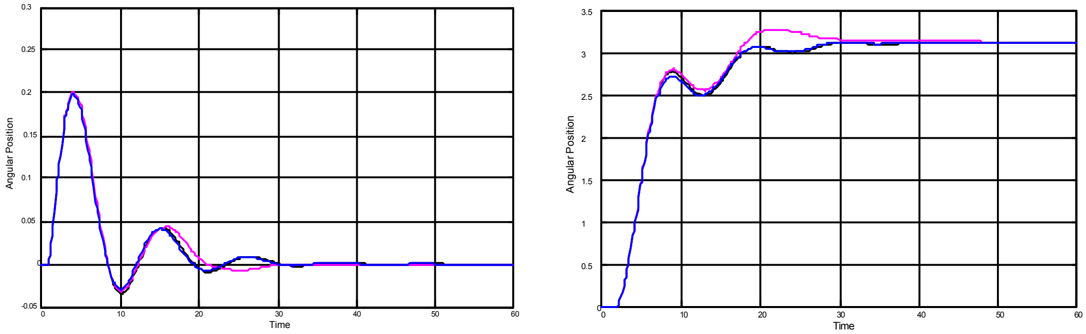
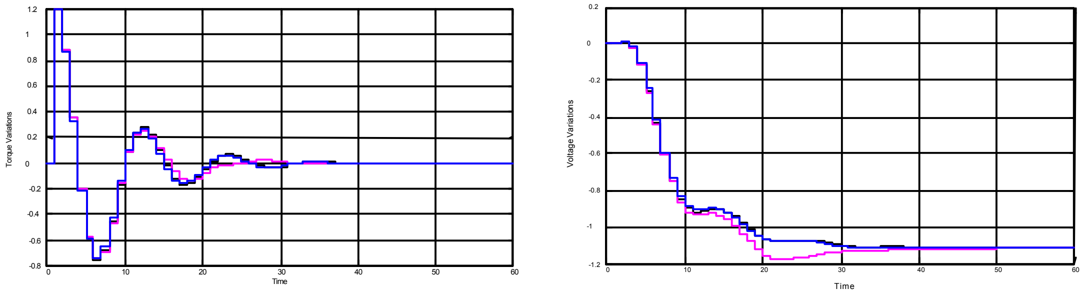


Fig. 4.3: Simulation models of AVR, PSS and FLC.



(a) Angular Speed (b) Angular Position



(c) Torque Variations (d) Voltage Variations

Fig. 4.2: Simulation result of AVR with FLC based PSS designedPSO with $K_{5=}$-0.1103.

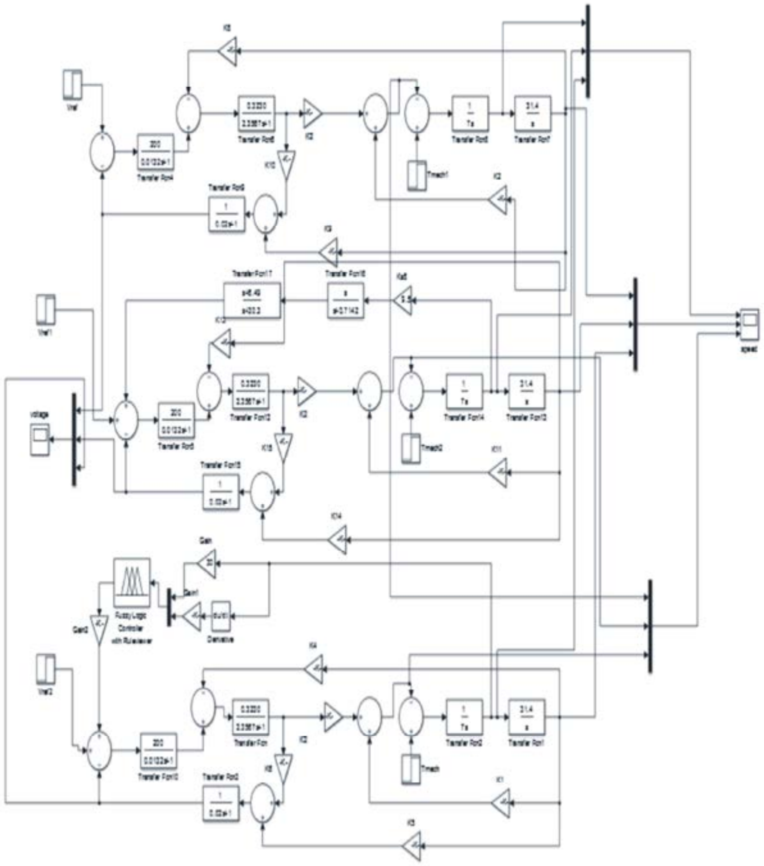
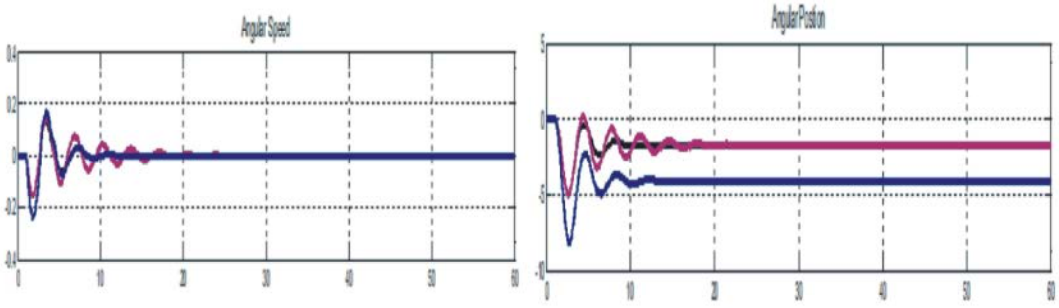
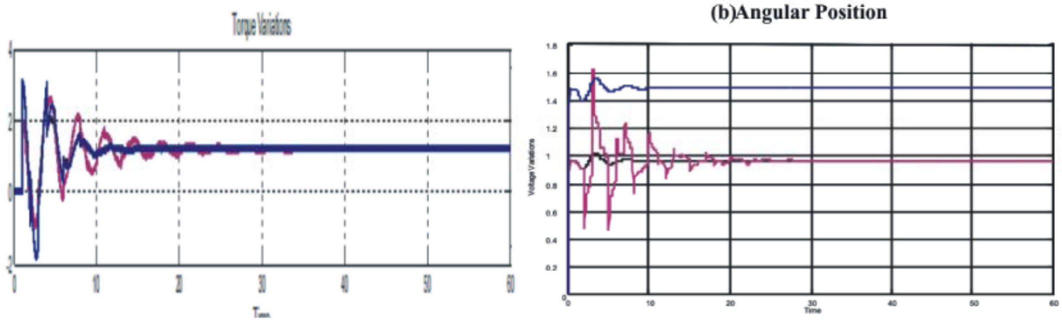


Fig. 4.3: Simulation models of AVR, PSS and FLC.



(b)Angular Position

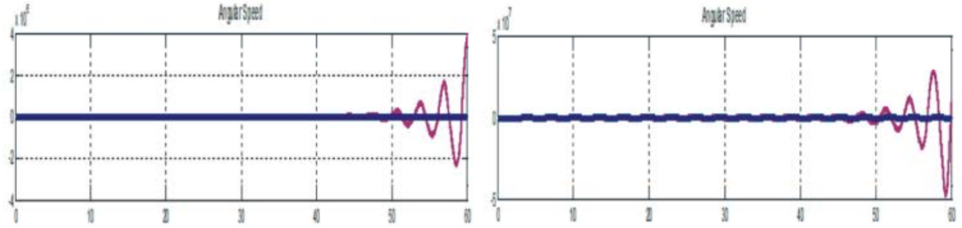


(c) Torque Variations

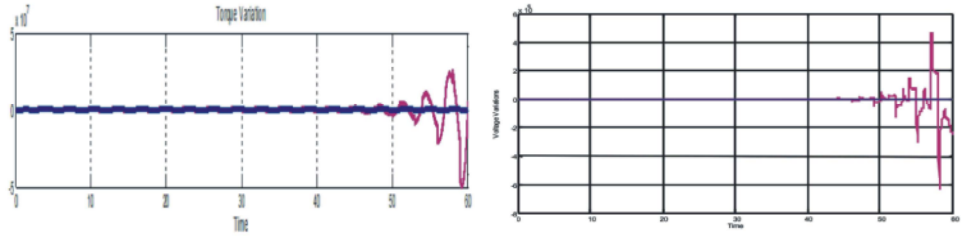
(d) Voltage Variations

AVR ▬ **PSS** ▬ **FLC** ▬

Fig. 4.4: Simulation results of AVR, PSS and FLC with k5 positive K_5= 0.1462.



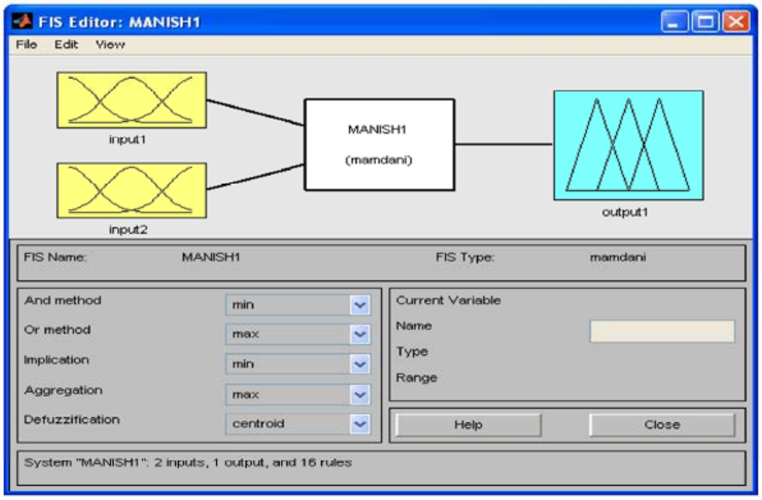
(a)Angular Speed **(b)Angular Position**



(c) Torque Variations **(d) Voltage Variations**

AVR —— PSS —— FLC ——

Fig. 4.5: Simulation results of AVR, PSS and FLC with k5 negative $K_{5=}$-0.1462.



FIS Name: MANISH1

FIS Type: mamdani

And method: min

Or method: max

Implication: min

Aggregation: max

Defuzzification: centroid

Current Variable

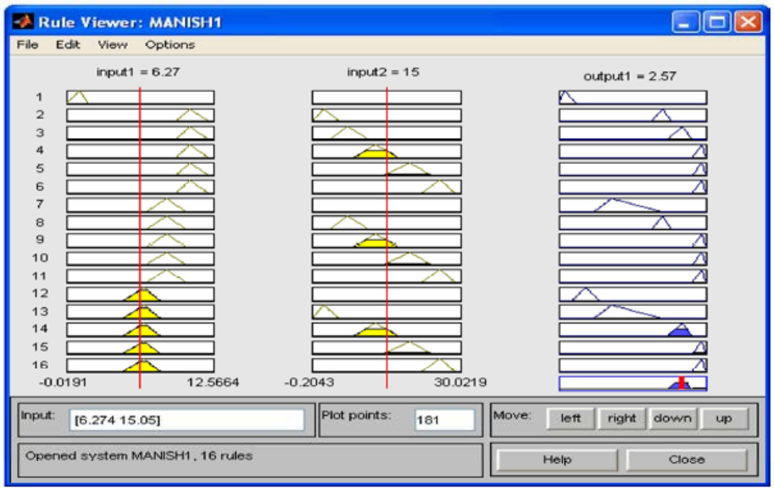
Name

Type

Range

System "MANISH1": 2 inputs, 1 output, and 16 rules

Fig. 4.6: Fuzzy Inference System



input1 = 6.27

input2 = 15

output1 = 2.57

Input: [6.274 15.05]

Plot points: 181

Opened system MANISH1, 16 rules

Fig. 4.7: Rule Viewer of Fuzzy Control

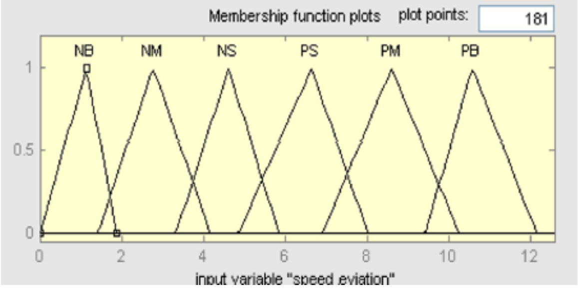


Fig. 4.8(a) Membership functions for speed deviation

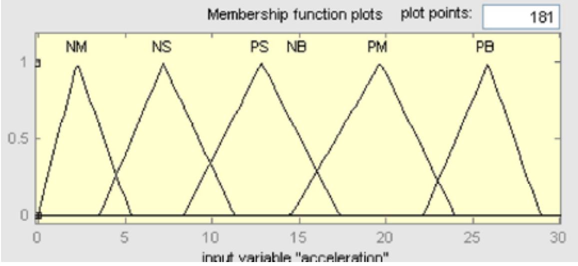


Fig. 4.8: (b) Membership functions for acceleration

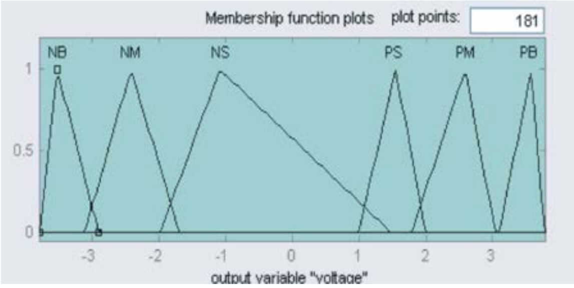
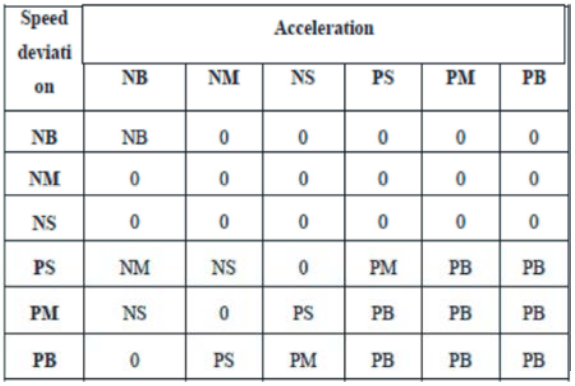


Fig. 4.8: (c) Membership functions for voltage



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. 4.9: Rule Base for Fuzzy Logic Controller

CONCLUSION

In these comparative studies, the fuzzy logic controller based power system stabilizer is designed for Single Machine Infinite Bus (SMIB) Power System. The performance of the power system with fuzzy logic power system stabilizer is better one since it is effective for all test conditions. The control signal, required, in all cases is with less magnitude. The proposed fuzzy logic controller based PSS is useful for power stations which work under small and large signal disturbances. Small change in the load torque disturbance that affects its efficiency and sometimes leads to unstable system. These disturbances cause oscillations at low frequencies that are undesirable since it affects the amount of transferred power through the transmission lines and leads to external stress to the mechanical shaft. To avoid such situation a power system stabilizer is added to the Automatic Voltage Regulator (AVR) to enhance stability in the dynamic range as well as in the first few cycles after a disturbance. This fuzzy logic controller is very suitable for the real time control of generators because of its simple control rules and its shorter computation time.The proposed PSS designbased on fuzzy logic controller enhances the system response and provide good damping to the oscillation.

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