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Digital Simulation of Reduced Rule Fuzzy Logic Power System Stabilizer for Analysis of Power System Stability Enhancement

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ABSTRACT

In this paper a linearized Heffron-Philips model of a Single Machine Infinite Bus power system with a Fuzzy Logic Power System Stablizer (PSS) is developed. The designed fuzzy-based PSS adjusts two inputs by appropriately processing of the input angular speed and angular acceleration signal, and provides an efficient damping. The behavior of the SMIB system with & without PSS has been compared/ verified by selecting appropriate fuzzy rules with the help of simulation work carried out in MATLAB/ SIMULINK environment. The performance of the SMIB system has improved significantly compared to SMIB system without PSS. The results of the simulation show that the fuzzy PSS is more effective in damping LFO compared to conventional controllers. Further this paper investigates the design and implementation of a reduced rule fuzzy logic power system stablizer. Fuzzy controllers use a rule base to describe relationships between the input variables and output. Implementation of a detailed rule base increases in complexity as the number of input variables grow. if each input has 7 fuzzy sets, a fuzzy controller with two inputs needs 49 rules. The implementation of a controller with such a large rule base is a tedious task. We propose a reduced rule fuzzy logic power system stabilizer. The effectiveness of the reduced rule fuzzy logic power system stablizer is illustrated with simulations carried out in MATLAB.

Index Terms

Low Frequency Oscillations (LFO), Damping, Fuzzy Logic Controller (FLC), Fuzzy Set Theory, Simulink.

1. INTRODUCTION

Low frequency electromechanical oscillations (LFO), with frequencies ranging from 0.1 to 2 Hz are inherent to electric Energy systems. The conventional controllers are designed for specific operating conditions. These stabilizers can not maintain the desired level of performance as system operating condition change. Fuzzy logic [1-4] provides a remarkably simple way to draw definite conclusions from vague, ambiguous or imprecise information. Unlike classical logic, which requires a deep understanding of a system, exact equations & precise numeric values; Fuzzy logic incorporates an alternative way of thinking. It allows modeling complex

Systems using a higher level of abstraction originating from our knowledge and experience. Fuzzy Logic controller [5-10] has proven to be a successful control approach to many complex non-linear systems [11-14] or even systems not easily amenable to analytical treatment. The paper is organized as follows; Section II describes the modelling of proposed system and its linearized model. The design of the conventional and proposed FLC is detailed in Section III. The computer simulation results are presented and discussed in Section IV. The conclusion is mentioned in Section V. Appendix A includes various parameters of the system and controllers.

2. POWER SYSTEM MODELING

The study system consists of a synchronous machine connected to an infinite bus through a transmission line (Fig. 1).

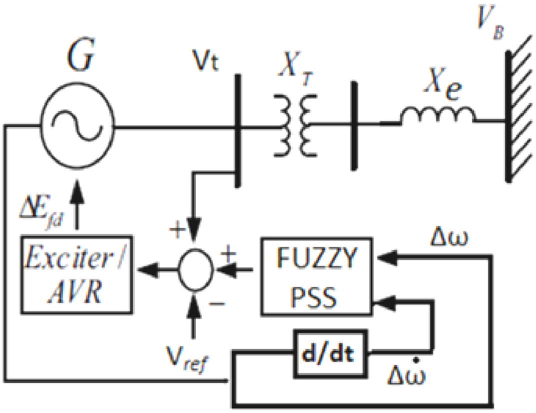


Fig. 1 SMIB Energy System

The fourth-order nonlinear system is described by the following set of equations.

$$\dot{\delta} = \omega$$

$$\dot{\omega} = \frac{1}{M}(T_m - T_e - D.\omega)$$

$$\dot{e}'_q = \frac{1}{T'_{d0}}\left(E_{fd} - e'_q - (x_d - x'_d)i_d\right)$$

$$\dot{E}_{fd} = \frac{1}{T_a}\left[K_A(V_{ref} - V_t)\right] - \frac{1}{T_a}E_{fd}$$

To calculate the parameters of Heffron-Phillips model, the fourth-order model is linearised.The linearised form of the model is:

$$\begin{bmatrix} \Delta\dot{\delta} \\ \Delta\dot{\omega} \\ \Delta\dot{e}'_q \\ \Delta E_{fd} \end{bmatrix} = \begin{bmatrix} 0 & \omega_b & 0 & 0 \\ -K_1/M & -D/M & -K_2/M & 0 \\ -K_4/T'_{d0} & 0 & -1/K_3 T'_{d0} & 1/T'_{d0} \\ -K_a K_5/T_a & 0 & -K_a K_6/T_a & -1/T_a \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta\omega \\ \Delta e'_q \\ \Delta E_{fd} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ K_a/T_a \end{bmatrix} \Delta U_{PSS}$$

$$[\Delta\omega] = [0 \quad 1 \quad 0 \quad 0] \begin{bmatrix} \Delta\delta \\ \Delta\omega \\ \Delta e'_q \\ \Delta E_{fd} \end{bmatrix} + [0]\Delta U_{PSS}$$

Fig.2.shows the block diagram of Single Machine infinite bus model (SMIB). This diagram was developed by Heffron and Phillips [1952] to represent the dynamics of a single synchronous generator connected to the grid through a line. This model is a well-known model for synchronous generators. This model is a linear model; still it is quite accurate for studying low frequency oscillations and stability of power systems. It has also been successfully used for designing classical power system controllers, which are still active in most power utilities.

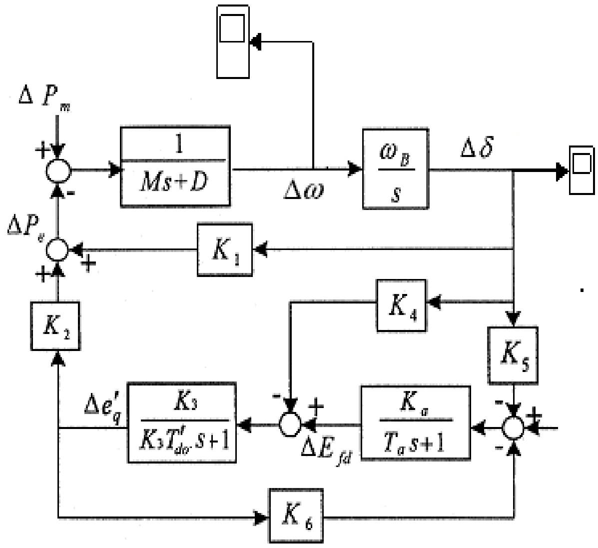


Fig. 2 Heffron and Phillips Model without Controller

3. CONTROLLERS

3.1 Conventional LEAD- LAG Power System Stablizer

The basic structure of Lead-Lag controller [15-18] is shown in Fig.3. The lead - lag combination of compensators is used to achieve desired transient behavior and low steady state error. The input to controller is speed deviation (**Δω**). It consists of gain block, washout block and compensator block. An optimum controller can be obtained by proper tuning of parameters **Tw,** T_1, T_2 and gain Ks with a suitable heuristic technique.

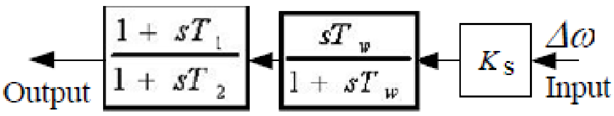


Fig. 3 Structure of conventional Power System Stablizer

The gain Ks of conventional controller is chosen such that it provides necessary damping.

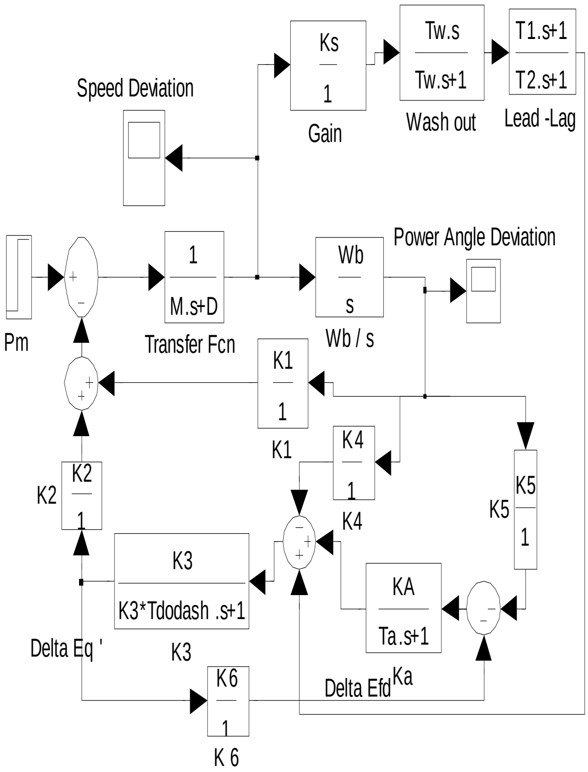


Fig. 4 MATLAB/SIMULINK Model of Plant Controlled by conventional Power System Stablizer

The controller gain Ks is an important factor as the damping provided by the PSS increase in proportion to an increase in the gain up to a certain critical gain value, after which the damping begins to decrease. The phase compensator block is used to make the system "settle down" quickly. The output of the controller has to be gradually driven to zero in steady state. Therefore a washout transfer function [Tw.S/ (Tw.S+1)], which has a steady state gain zero is used .The value of washout time constant **Tw,** may be in the range of 1-20 sec. The conventional Lead-Lag controller is designed using a linearized model of the system. Therefore, this provides optimum performance for a nominal operating condition and system parameters with the input being small enough to justify the linear model. However, its performance becomes suboptimal following variations in system parameters and loading conditions from their nominal values or when the disturbance applied is large.

3.2 Fuzzy Controllers and Fuzzy Basis Functions

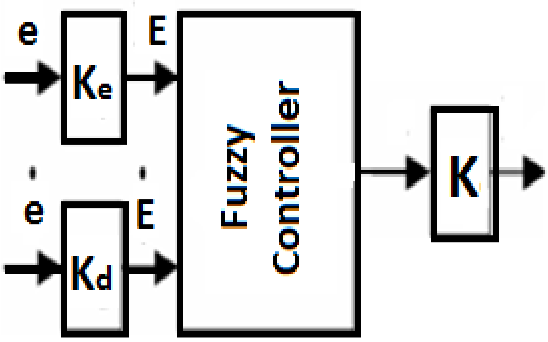
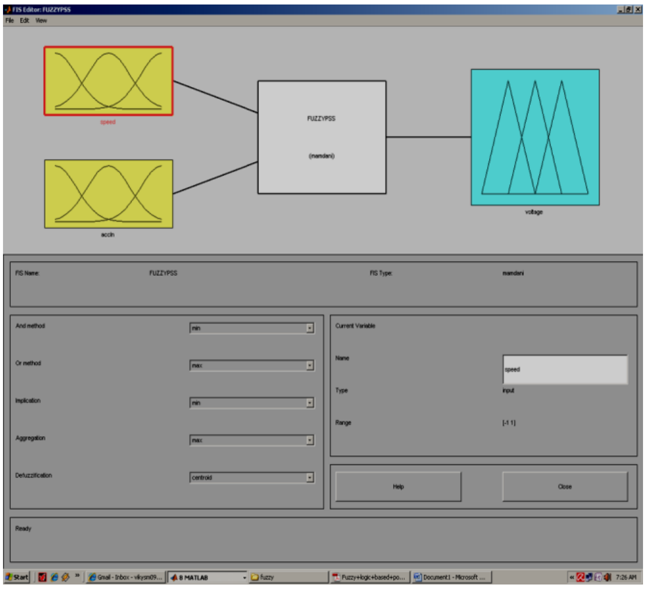


Fig. 5 Basic Structure of a Fuzzy Logic Power System Stablizer

3.2.1 Design of FLC in MATLAB

Fig. 6 shows a FIS Editor with two input variable blocks, one output variable block and Mamdani FLC [19-23] block. The designing process is carried out with the help of MATLAB 7.5.

Fuzzy controller Design process involves 3 steps: fuzzification, fuzzy rules and defuzzification.



FIS Name: FUZZYPSS
FIS Type: mamdani
And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid
Current Variable
Name: speed
Type: input
Range: [-1 1]

Fig. 6 FIS Editor FLC

3.2.2. Fuzzification

Fuzzification process is used for converting speed and its derivative to the fuzzy values. The step defines the membership functions of controller. Seven membership functions is generating better result proved by some testing so as in Table 1, seven membership functions are defined. The linguistic labels of membership functions are marked as in fig. 7, NB (Negative Big), NM (Negative-Medium), NS (Negative-Small), ZR (Zero), PS (Positive-Small), PM (Positive-Medium), PB (Positive-Big)Membership functions are used to convert the fuzzy values between 0 and 1for inputs and output value both.

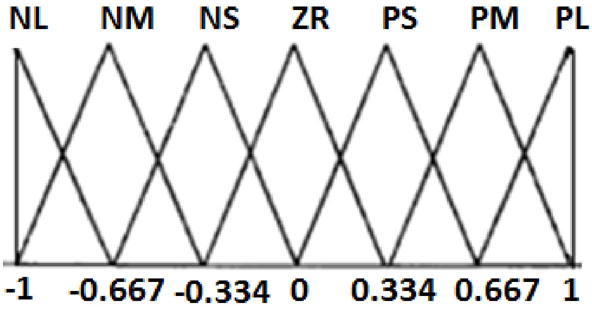


Fig. 7 Membership functions for Fuzzy controller for input and output variables

Table 1. Design Parameters of FLC

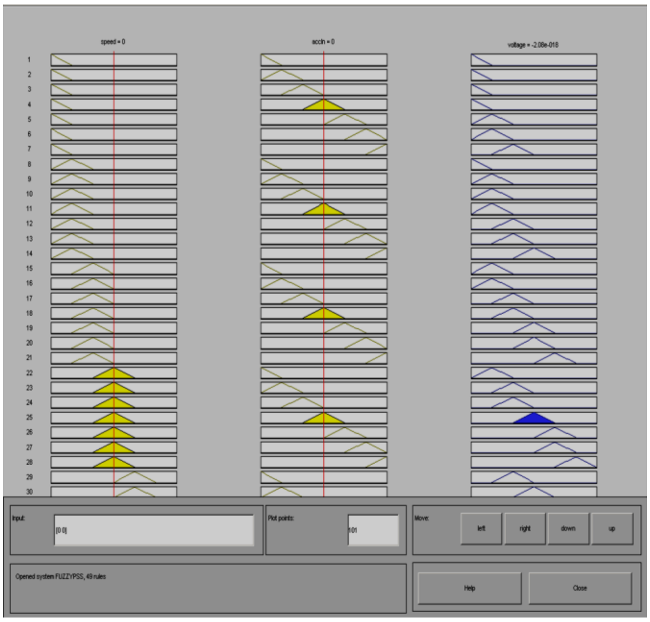
Speed dev. ↓	ACCELERATION						
	NB	NM	NS	ZR	PS	PM	PB
NB	NB	NB	NB	NB	NM	NM	NS
NM	NB	NM	NM	NM	NS	NS	ZR
NS	NB	NM	NM	NM	NS	NS	ZR
ZR	NM	NS	NS	ZR	PS	PS	PM
PS	NS	ZR	ZR	PS	PS	PM	PM
PM	ZR	PS	PS	PM	PM	PM	PB
PB	PS	PM	PM	PB	PB	PB	PB

3.2.3 Fuzzy Rules

Fuzzy rules are defined to reduce the error in the system after analyzing the function of controller. For each fuzzy value there are seven membership functions, so 49 combinations of speed and acceleration are possible. There is an output for each of the membership functions and the linguistic label can be determined by using IF–THEN fuzzy rules [24] in the following form:

If speed deviation is a_i and acceleration deviation is b_j then fuzzy output is c_{ij}.

Where a_i, $b_j$and cij are fuzzy subsets defined in Fig. 8.



Input: [0 0]

Plot points: 101

Opened system FUZZYPSS, 49 rules

Fig. 8 Rule Viewer

3.2.4 Defuzzification

At last Defuzzification is done. In this step the fuzzy values which are obtained from inference engine converts into the specific values. For the inference Mamdani's minimum fuzzy implication and Max–Min compositional rule are used.

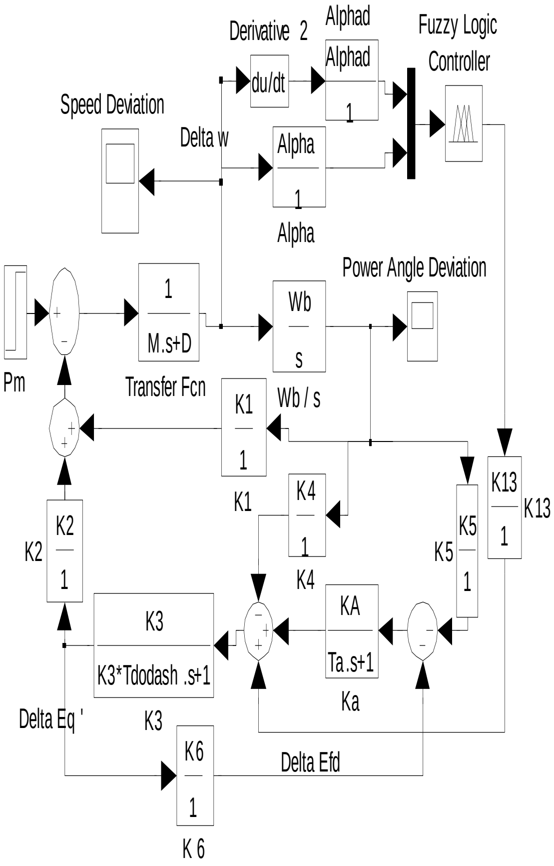
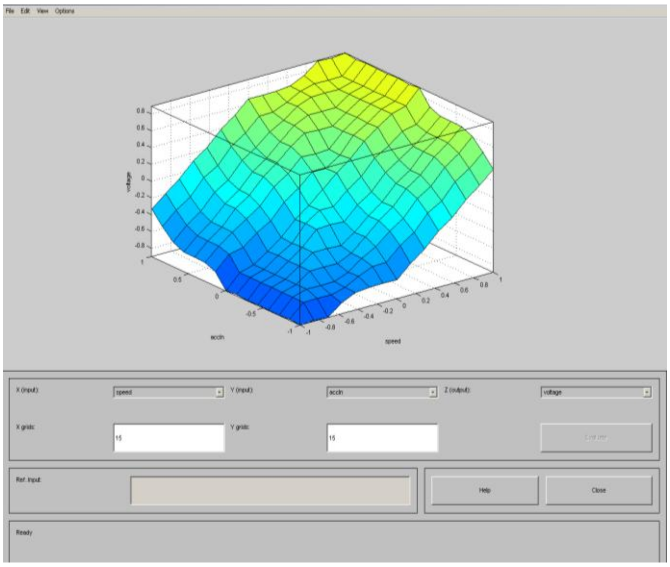


Fig. 9 MATLAB/SIMULINK Model of Plant Controlled by FLC

For the defuzzification centroid method is used. At first, we design a parameters satisfying FLC, according to design rules and with assumption given in previous section. Fig.9.shows the Heffron Phillips MATLAB/SIMULINK Model of Single Machine Infinite bus (SMIB) equipped with FLC**.**



X (input): speed

Y (input): accln

Z (output): voltage

X grids: 15

Y grids: 15

Ready

Fig. 10 Surface Viewer

3.3 Reduced Rule Fuzzy Based Power System Stabilizer

In previous section for a two input fuzzy controller 7 membership functions for each input were used. Due to the need for a large rule-base, the design of such a PSS is a tedious task. In the proposed fuzzy pss, only two fuzzy membership functions are used for the two inputs angular speed and acceleration and three membership functions for the output parameter are shown in Fig.11-12. Depending upon whether the output is increasing or decreasing, 4 rules were derived for the fuzzy logic controller (Table 2). These four rules are sufficient to cover all possible situations.

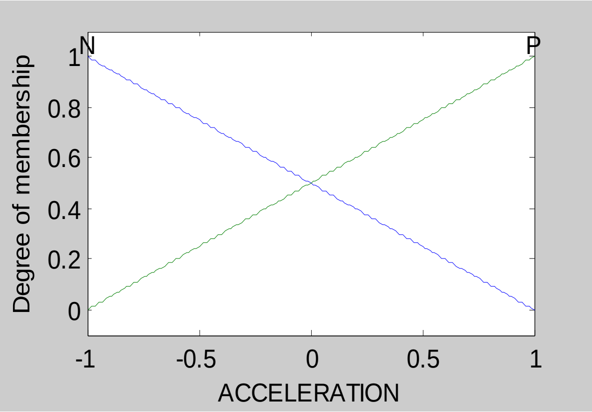


Fig. 11: New Reduced MFs for inputs angular speed and acceleration. N: Negative, P: Positive

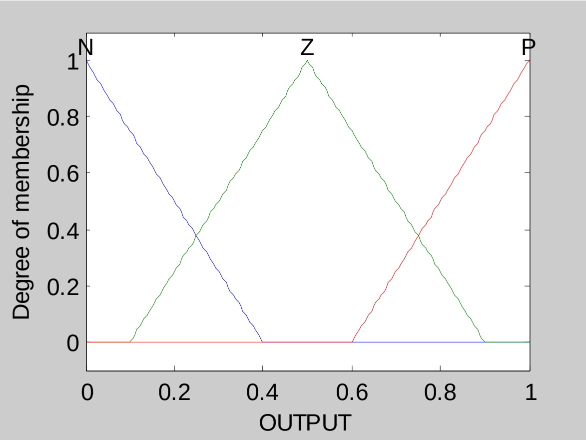


Fig. 12: New Reduced MFs for output. N: Negative, P: Positive, Z: Zero

Table 2. Reduced rule base of a fuzzy PSS

OUTPUT		ACCELERATION	
		N	P
SPEED	N	N	Z
	P	Z	P

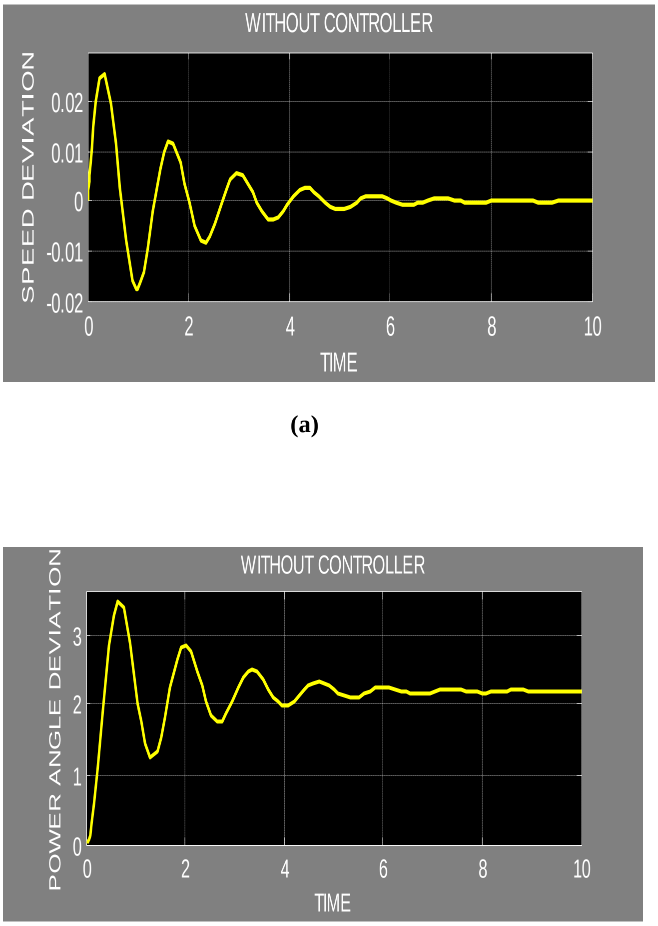
4. SIMULATION RESULTS

Fig.13-16 shows the output of the plant without Controller, controlled by conventional controller, FLC and Reduced Rule fuzzy pss respectively with 5% change in Mechanical input. The System parameters (a) Speed Deviation (Δω) (b) Power angle Deviation (Δδ) of Generator obtained with the proposed controllers are given in Table III.

The Output of SMIB system without PSS (a) Speed Deviation (Δω) (b) Power angle Deviation (Δδ) of Generator are shown in Fig. 13. The above response clearly shows that system has large overshoot (Mp), large settling time (ts) & ess = 0 and ess= 2. The Output of SMIB system with conventional PSS (a) Speed Deviation (Δω) (b) Power angle Deviation (Δδ) of Generator are shown in Fig. 14. The above response shows that system has still larger overshoot (Mp), larger settling time (ts) & ess = 0 and ess= 2 for Speed Deviation and Power angle respectively .This can be further improved by fine tunning of controller parameters.

The Output of SMIB system with Fuzzy PSS (a) Speed Deviation (Δω) (b) Power angle Deviation (Δδ) of Generator are shown in Fig. 15. The above response shows that system has smaller overshoot (Mp), smaller settling time (ts) & ess = 0 and ess= 2 for Speed Deviation and Power angle respectively.

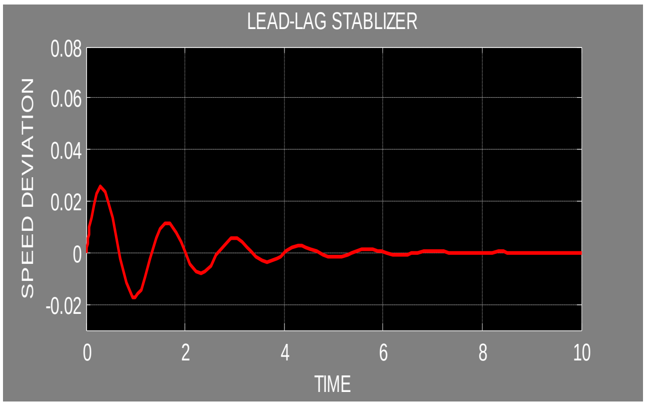
The Output of SMIB system with Reduced Rule Fuzzy PSS (a) Speed Deviation (Δω) (b) Power angle Deviation (Δδ) of Generator are shown in Fig. 16. The above response clearly shows that system has much smaller overshoot (Mp), much smaller settling time (ts) & ess = 0 for both Speed Deviation and Power angle. Therefore the proposed Fuzzy logic Power system stabilizer with smaller rule base provides better performance comparing with the conventional power system stablizer and Fuzzy Logic Power system stabilizer .



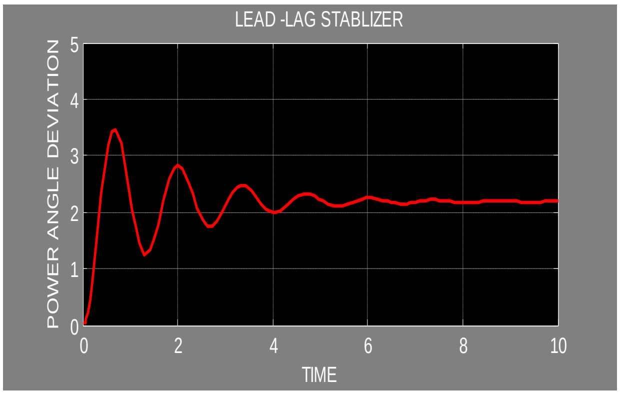
(a)

(b)

Fig. 13 Output of SMIB system without PSS (a) Speed Deviation (Δω) (b) Power angle Deviation (Δδ) of Generator

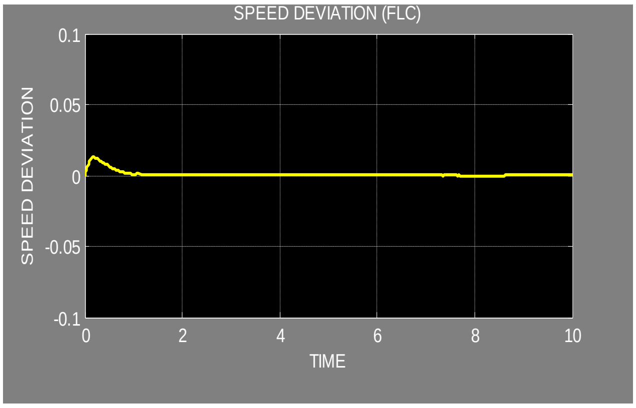


(a)

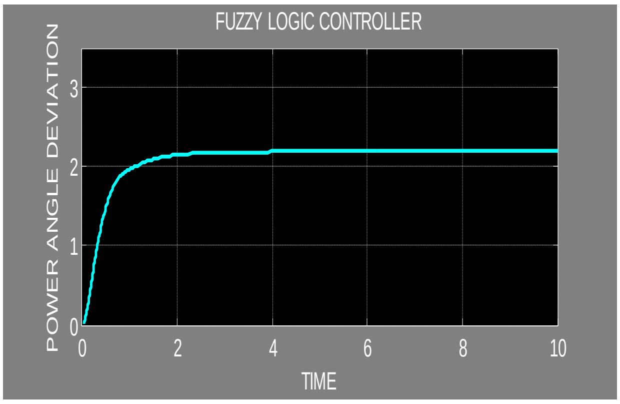


(b)

Fig. 14 Output of SMIB system with conventional PSS (a) Speed Deviation (Δω) (b) Power angle Deviation (Δδ) of Generator

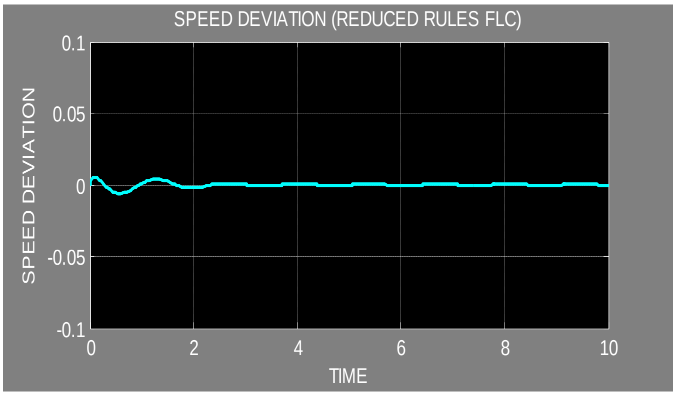


(a)

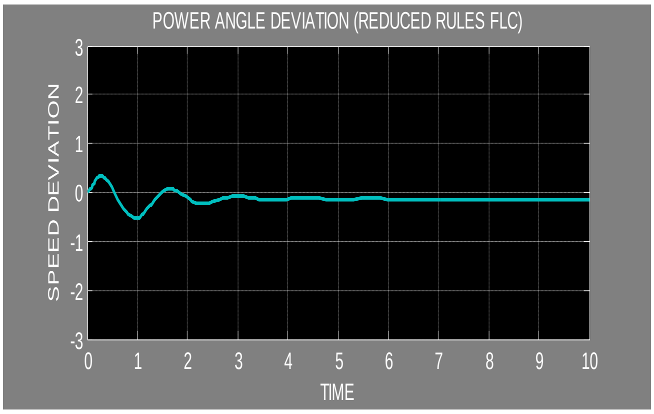


(b)

Fig. 15 Output of SMIB system with Fuzzy Logic PSS (a) Speed Deviation (Δω) (b) Power angle Deviation (Δδ) of Generator



(a)



(b)

Fig. 16 Output of SMIB system with Reduced Rule base PSS (a) Speed Deviation (Δω) (b) Power angle Deviation (Δδ) of Generator

Table 3. System Parameters with different Controllers

S . No.	**System Parameter**	**With Conventional PSS Controller**	**Fuzzy PSS**	**Reduced Rule FUZZY PSS**
1	**Speed deviation (δω)**	**large overshoot (Mp), Peak Value= 0.025 pu, large settling time (ts),** ***ess = 0***	**Smaller overshoot (Mp), Peak Value= 0.0125 pu, Smaller Settling time (ts),ess = 0**	**Smaller Overshoot (Mp), Peak Value= 0.0125 pu, Smaller Settling time (ts),ess = 0**
2	**Power angle deviation (δδ)**	**large overshoot (Mp), Peak Value= 3.5 pu, large settling time (ts),** ***ess= 2***	**Smaller Overshoot (Mp), Peak Value= 2.1 pu, Smaller Settling time (ts), ess= 2**	**Smaller Overshoot (Mp), Peak Value= 0.4 pu, Smaller Settling time (ts), ess = 0**

5. CONCLUSION

In this paper a fuzzy based Power system stabilizer is designed. The whole work is carried out in MATLAB 7.5 (b). The proposed method is then simulated on a SMIB Energy system with FLC and conventional controller using complete state space model.TheMatlab/Simulink simulations results show that in the presence of small disturbances in the system, fuzzy controller is more effective compared to the conventional controller.The Fuzzy Logic Power system stabilizer gives gives zero steady state error and smaller overshoot and settling time than conventional power system stablizer. The simulation results further confirms that the proposed Reduced Rule Fuzzy logic Power system stabilizer with simple design approach and smaller rule base can provide better performance comparing with the conventional power system stablizer and Fuzzy Logic Power system stabilizer .

APPENDIX

Parameter values
Generator: M= 7.0 s., D = 0, Xd=1.8, Xq=1.76, Xd '=0.3, Tdo' = 7.2940, Wb=314
Exciter :(IEEE Type ST1): K_A=200, T_A=0.02 s.

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