Robust Control Design of Power System Stabilizer Using Fuzzy Logic Controller

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Abstract: - In this paper is presented the study of fuzzy logic power stabilizer for stability of a single machine infinite bus (SMIB). The performance of the system with fuzzy logic based power system stabilizer is compared with the system having conventional power system stabilizer and system without power system stabilizer. The results show that the system with fuzzy logic controller is capable of stabilizing the system under different conditions.

Key-Words: - fuzzy logic control, conventional power system stabilizer, single machine, infinite bus.

1 Introduction

Conventional power system stabilizer is used in existing power system stabilizers is contribution in enhancing power system dynamic stability.

The parameters of CPSS are determined based on linearized model of the power system around a nominal operating point where they can provide good performance. Since power systems are highly nonlinear systems, with configurations and parameters that change with time, the CPSS design based on the linearized model of the power system cannot guarantee its performance in a practical operating enviromentent.

To improve the performance of conventional power system stabilizer CPSS, numerous techniques have been proposed for their design, such us using genetic algorithm, neural networks, fuzzy logic and many other nonlinear control techniques [1].

2 Synchronous machine model

The single machine infinite bus power system (SMIB) model used to evaluate of FPSS (Fuzzy Power System Stabilizer) is shown in figure 1 [2].

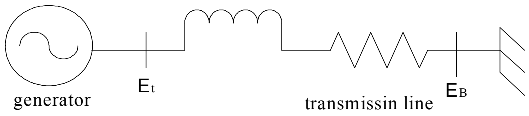


Fig. 1 The equivalent circuit of synchronous machine connected to infinite bus

The SMIB consists of a synchronous generator, a turbine, a governor, an excitation system and a transmission line connected to an infinite bus. The block diagram of SMIB with classical model is presented in figure 2.

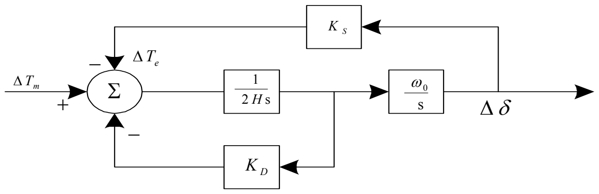


Fig. 2 Block diagram of SMIB

From the block diagram results:

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

The characteristic equation is

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

Comparing with general form

$$s^2 + 2\xi\omega_0 s + \omega_n^2 = 0 \tag{3}$$

Results

$$\omega_0 = \sqrt{\frac{K_s\omega_0}{2H}}, \tag{4}$$

$$\xi = \frac{1}{2}\frac{K_D}{\sqrt{K_s \cdot 2 \cdot H \cdot \omega_0}}. \tag{5}$$

The thyristor excitation system with AVR in presented in figure 3.

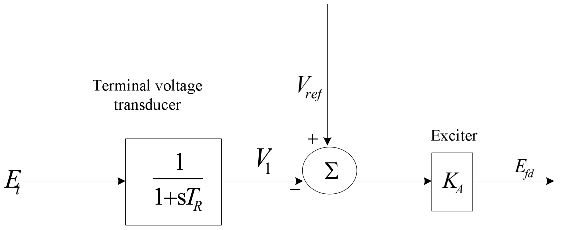


Fig. 3 Thyristor excitation system with AVR

In figure 4 is presented the block diagram representation with exciter and AVR. The constants K_2, K_3 and K_4, that appear in figure 3, are usually positive. As long as K_4 is positive, the effect of field flux variation due to armature reaction is to introduce a positive damping torque component. K_4 is negative when a hydraulic generator without damper windings is operating at light load and is connected by a line of relatively high resistance to reactance ratio to a large system [3].

Also K_4 can be negative when a machine is connected to a large local load, supplied partly by the generator and partly by the remote large system.

In this paper the thyristor excitation system is considered.

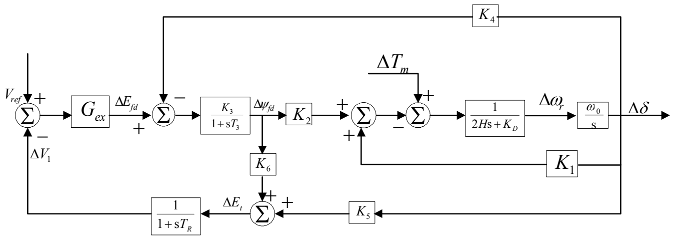


Fig. 4 The block diagram representation with exciter and AVR

The coefficient K_6 always positive whereas K_5 can be positive or negative depending upon operating condition. And external network impedance is $R_e + jX_e$. The value of K_5 has a significant bearing on influence of AVR on the damping of system oscillations.

2.1 Design of CPSS

The basic function of power system stabilizer is to add damping to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signals. To provide damping, the stabilizer must produce a component of electrical torque in phase with rotor speed deviations. The block diagram of CPSS is presented in figure 5.

The CPSS consists phase-lead compensation block, a signal washout block and a gain block. The signal input is the rotor speed deviation $\Delta\omega_r$ [2].

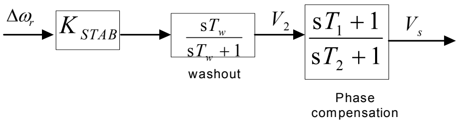


Fig. 5 Block diagram of CPSS

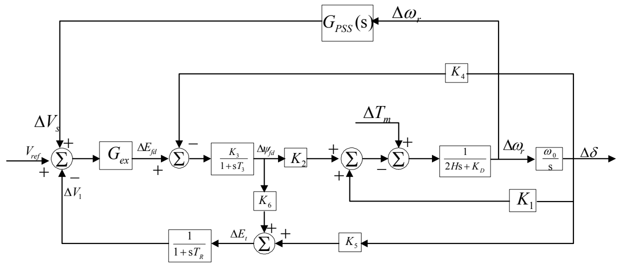


Fig. 6 Block diagram representation with AVR and PSS

The parameters for generator, AVR, excitation system and CPSS are given in [2]. The complete state-space, including the CPSS, has the following form (with $\Delta T_m = 0$).

$$\begin{bmatrix} \dot{\Delta\omega}_r \\ \dot{\Delta\delta} \\ \dot{\Delta\Psi}_{fd} \\ \dot{\Delta V}_1 \\ \dot{\Delta V}_2 \\ \dot{\Delta V}_s \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & 0 & 0 & 0 \\ a_{21} & 0 & 0 & 0 & 0 & 0 \\ 0 & a_{32} & a_{33} & a_{34} & 0 & a_{36} \\ 0 & a_{42} & a_{43} & a_{44} & 0 & 0 \\ a_{51} & a_{52} & a_{53} & 0 & a_{55} & 0 \\ a_{61} & a_{62} & a_{63} & 0 & a_{65} & a_{66} \end{bmatrix} \cdot \begin{bmatrix} \Delta\omega_r \\ \Delta\delta \\ \Delta\Psi_{fd} \\ \Delta V_1 \\ \Delta V_2 \\ \Delta V_s \end{bmatrix}, \qquad (6)$$

Where

$$a_{11} = -\frac{K_D}{2H},\ a_{12} = -\frac{K_1}{2H},\ a_{13} = -\frac{K_2}{2H},\ a_{21} = \omega_0 = 2\pi f_0,$$

$$a_{32} = -\omega_0 \frac{R_{fd}}{L_{fd}} m_1 L'_{ads},\ a_{33} = -\omega_0 \frac{R_{fd}}{L_{fd}}\left(1 - \frac{L'_{ads}}{L_{fd}} + m_2 L'_{ads}\right),$$

$$a_{34} = -\omega_0 \frac{R_{fd}}{L_{adu}} K_A,\ a_{36} = \frac{K_5}{T_R},\ a_{42} = \frac{K_5}{T_R} = a_{43},\ a_{44} = -\frac{1}{T_R},$$

$$a_{51} = K_{STAB} \cdot a_{11},\ a_{52} = K_{STAB} \cdot a_{12},\ a_{53} = K_{STAB} \cdot a_{13},$$

$$a_{54} = \frac{1}{T_w},\ a_{61} = \frac{T_1}{T_2} a_{51},\ a_{62} = \frac{T_1}{T_2} a_{52},\ a_{63} = \frac{T_1}{T_2} a_{53},$$

$$a_{65} = \frac{T_1}{T_2} a_{55} + \frac{1}{T_1},\ a_{66} = -\frac{1}{T_2}.$$

3 Fuzzy logic based power system stabilizer

The fuzzy logic controller (FLC) design consists of the following steps:

- Identification of input and output variables;
- Construction of control rules;
- Establishing fuzzification method and fuzzy membership functions;
- Selection of the compositional rule of inference;
- Defuzzification method, so transformation of the fuzzy control statement into specific actions.

The variables for FLPSS are speed deviation, acceleration and voltage. The speed deviation and acceleration are inputs variables and voltage is the output variables. In practice, only shaft speed is readily available.

The acceleration signal can be derived from speed signals measured at two successive sampling using

$$\Delta\omega(k) = \frac{\Delta\omega(k) - \Delta\omega(k-1)}{\Delta T}. \qquad (7)$$

Each of the input and output variables are seven linguistic fuzzy: NB (Negative Big), NM (Negative Medium), NS (Negative Small), Ze (Zero), PS (Positive Small), PM (Positive Medium), PB (Positive Big).

The triangular membership functions are used to define the degree of membership. The variables are normalized by multiplying with gains K_{in1}, K_{in2} and K_{out} so that their value lies between -1 and 1. The membership function for inputs and outputs are shown in figure 8.

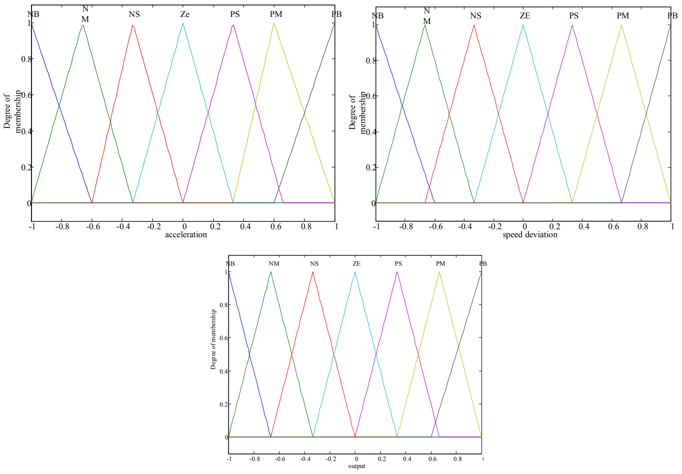


Fig. 8 The membership functions for acceleration (input 1) speed deviation (input 2) and voltage (output)

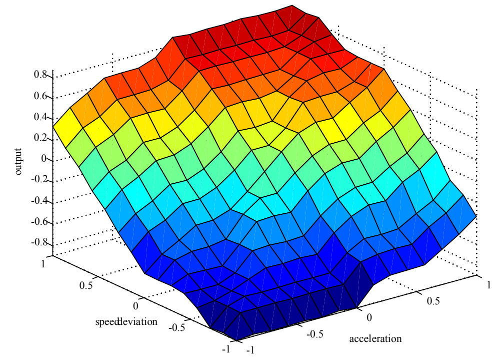


Fig. 9 The structure of control

The two inputs, speed and acceleration, results in 49 rules for each machine. All the 49 rules are explained in table 1.

The stabilizers output is obtained by applying a particular rule expressed in the form of membership functions. Finally the output membership function of the rule is calculated. The surface of control is shown in figure 9.

Table 1 Rule base of fuzzy logic controller

	in2						
in1	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NM	NS
Nm	NB	NM	NM	NM	NS	NS	ZE
NS	NM	NM	NS	NS	ZE	ZE	PS
Ze	NM	NS	NS	ZE	PS	PS	PM
PS	Ns	ZE	ZE	PS	PS	PM	PM
PM	ZE	PS	PS	PM	PM	PM	PB
PB	PS	PM	PM	PB	PB	PB	PB

4 Simulation results

In figure 10 is presented the Simulink model for simulations of SMIB with constant field voltage. The characteristics showing the variation in speed, angular position and electric torque are presented in figure 11. It observes that the oscillations are more pronounced when a system is perturbed with constant field voltage after witch it becomes stable. The excitation system parameters are $K_A = 200$ and $T_r = 0,02$. The time response of the angular speed, angular position for a 5% step change in mechanical input is presented in figure 12. The performance when analyzed with K_5 positive and negative. The positive K_5 is possible for low value of external system reactance and low generator outputs, the damping is positive and thus the system is stable.

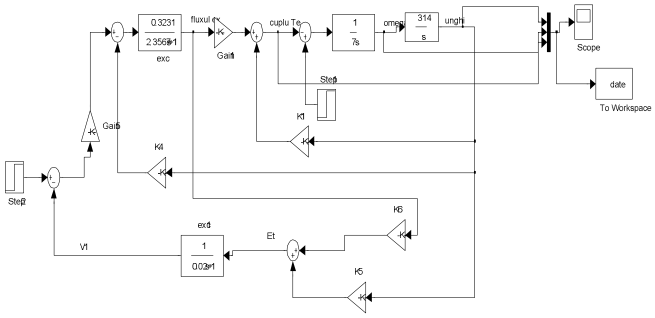


Fig. 10 The SMIB model realized in Simulink

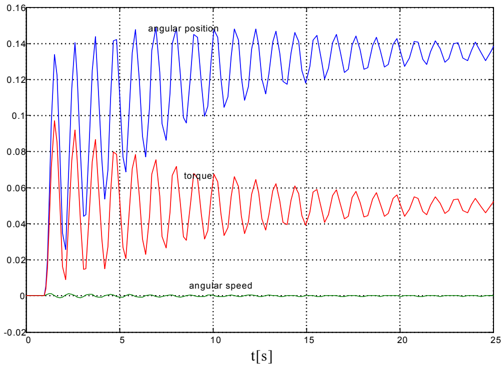
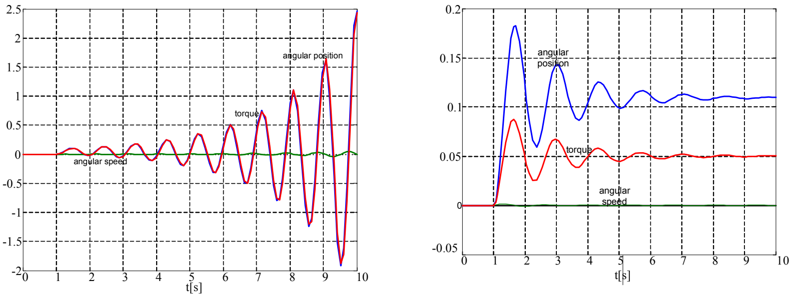


Fig. 11 System response for 5% change in mechanical input

The model used in Simulink to analyze the effect of fuzzy logic controller in damping small signal oscillations when implemented on SMIB system is shown in figure 13. To compare the performance of CPSS and fuzzy logic based CPSS, the step response are shown in figures 14 and 15.

From figures above it can be perceived that with the application of fuzzy logic the rise time and settling time of the system decreases. The system reaches its steady state value much earlier with fuzzy logic power system stabilizer compared to CPSS for negative K_5. For positive value K_5 overdamped response and settling time remains largely unchanged.



With $K_5>0$ With $K_5<0$

Fig. 12 The time response of the angular speed, angular position for a 5% step change in mechanical input

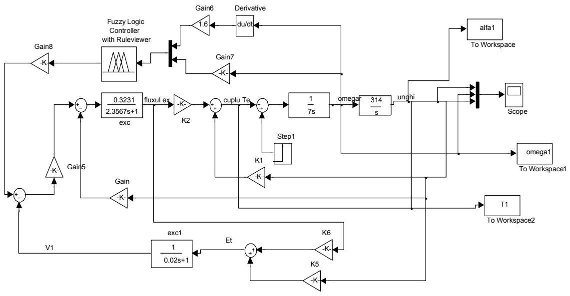
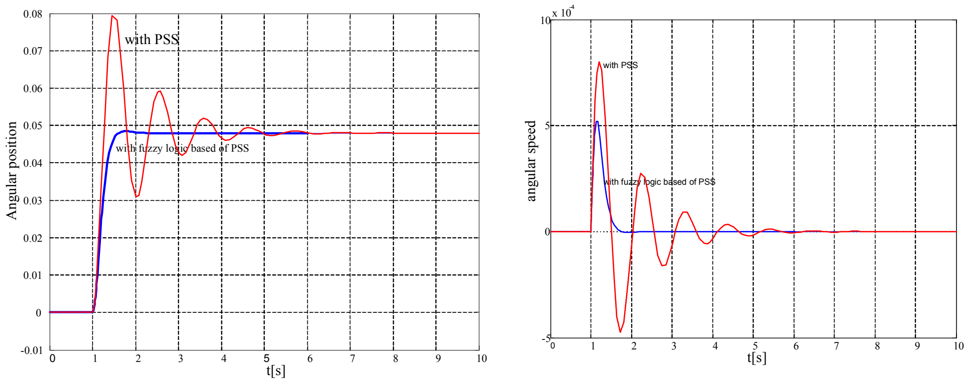


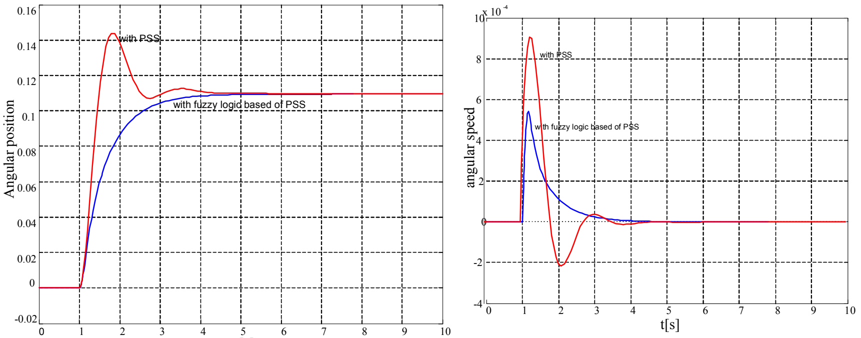
Fig. 13 The Simulink model with Fuzzy logic controller based of CPSS



with K_5 <0

with K_5 <0

Fig. 14 Angular position and angular speed for 5% change in input with CPSS and FLPSS with K_5 <0



With K_5>0

With K_5>0

Fig. 15 Angular position and angular speed for 5% change in input with CPSS and FLPSS with K_5 >0

4 Conclusion

In this paper is presented the study of fuzzy logic power stabilizers for stability enhancement of a single machine infinite bus system. The fuzzy logic controller based of CPSS shows the better control performance than power system stabilizers in terms of settling time and damping effect. The overdamped response is resulted with positive K_5, which is normally not encounterd in practical situations. So, it can be concluded that the performance of the proposed FPSS is much better and the oscillations are damped.

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