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Robust fuzzy logic power system stabilizer designed using hopf bifurcations

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Abstract

Electrical power system is an interconnection of various elements comprising non-linear elements, electrical parts and mechanical parts making it more complex. Power system shifts to the state of instability when its eigenvalues shifts to the right side of s-plane. The point where the system eigenvalues shifts from left to right side of s-plane can be identified by existence of imaginary eigenvalues. This is known as saddle node bifurcations or Hopf bifurcation. The power system exhibits undamped oscillations in this condition. This condition is used for effective tuning of stabilizers. Conventional Power System Stabilizer (CPSS) parameters are tuned to stabilize the power system. The lack of robustness of CPSS has gained interest towards the development of new power system stabilizers for improving the stability of power system over wide range of operating condition. In this paper a Fuzzy PID stabilizer is presented to improve the stability of power system. To accomplish the best damping characteristics deviation in speed ($\Delta\omega$), deviation of speed derivative ($\Delta\dot{\omega}$) and power angle ($\Delta\delta$) are taken as input to type-2 fuzzy logic controller. The proposed controller is implemented in small signal model of power system. The performance of the proposed controller is tested over different operating conditions. The efficacy of the proposed controller is compared with Convectional Power System Stabilizer.

Keywords: Power system stability, Power System Stabilizers, Type-1and Type-2 Fuzzy Logic Control System

1. Introduction

Power system stability is the ability of an electrical power system, for a given initial operating conditions, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact. The stability of complex power system is gaining more attention and will receive more attention in future. Power system is a multi-variable, dynamic nonlinear system consisting of transmission lines, synchronous alternators, transformers, switching relays and compensators. Automatic voltage regulators (AVRs) are used in generator excitation system to keep the terminal voltage of synchronous generator within limits. Load variations in power system results in electromechanical oscillations. These oscillations should be damped to acceptable limitation failing may result in instability. These power system oscillations can be suppressed by equipping Power System Stabilizers. Power System Stabilizers (PSS) generate supplementary signals to excitations system to suppress these electromechanical oscillations [2].

The Conventional Power System Stabilizers are led-lag phase compensators tuned for specific operating points for linearized model of power system [3-4]. The CPSS Because of nonlinear characteristics of power systems, CPSS is not capable to adapt large changes in operating conditions [5]. Adaptive power system stabilizers are proposed to deal with the variation of operating conditions [6-7]. The Fuzzy Logic Power System Stabilizer (FLPSS) was developed to improve the dynamic stability of power systems under wide range of operating conditions. FLPSS shows better performance in dynamic stability compared with CPSS. The constructed FLPSSs rely on expert knowledge which usually consists of uncertainties to certain degree. Therefore, the corresponding fuzzy membership functions parameters [8-12]. This fuzzy logic is also known as fuzzy logic.

2. Power System Model

The power system under study is a single machine connected to an infinite bus through a tie-line. The infinite bus is represented by the thevenin equivalent of a large inter connected power system. The machine is outfitted with a static exciter. The non-linear model of the system is described using following differential equations [1].

$$\dot{\delta} = \omega_0 \omega \tag{1}$$

$$\dot{\omega} = \frac{(T_m - T_e)}{M} \tag{2}$$

$$\dot{E}'_q = \frac{1}{T'_{do}}\left(E_{fd} - \frac{x_d + x_e}{x'_d + x_e} E'_q + \frac{x_d + x'_d}{x'_d + x_e} V \cos\delta\right) \tag{3}$$

$$\dot{E}_{fd} = \frac{1}{T_E}\left(K_E E_{ref} - K_E V_t - E_{fd}\right) \tag{4}$$

The above equations can be linearized around an operating point for small deviations and is considered from [19].

2.1. Tuning of Conventional Power System Stabilizers

For the system considered to analyse the enhancement of stability margin, the limit cycles are controlled by designing an adaptive lead-lag PSS, whose parameters tuned are K, T_1, T_2 and Washout time constant, T_w is considered as 10 seconds. The single stage PSS with Wash-Out is in the form

$$U = G_{PSS} \times \Delta\omega \tag{5}$$

$$G_{PSS} = \frac{sT_w}{1+sT_w} \times K \times \frac{1+sT_1}{1+sT2} \tag{6}$$

The parameters of Power System stabilizer (PSS) can be derived from conventional methods or Meta heuristic methods [19-20].

The hopf bifurcations of the power system without controller can be identified by observing the eigenvalues of the system state matrix for variations of system real and reactive power. The eigenvalues state matrix shifts from left half of s-plane right half. At a particular set of P, Q the system eigenvalues become imaginary. At this loading the system exhibits undamped oscillation and the eigenvalues are said to be under hopf bifurcations. This loading is taken for effectively tuning conventional power system stabilizer. The power system stabilizer tuned for this loading condition will work effectively wide range of operating conditions.

2.2 Tuning of Fuzzy Logic Power System Stabilizer

The analytical structure of three input three output T1 FLPSS similar to PID Controller is designed heuristically with 27 rules listed in Table 1 [18].

Table 1: Rules for three input three membership function**s**

Rule	DE	DEE	E	output	Rule	DE	DEE	E	output
1	P	P	P	NB	**14**	N	N	N	PB
2	P	P	N	NS	**15**	N	N	Z	PM
3	P	P	Z	NM	**16**	N	Z	P	Z
4	P	N	P	NM	**17**	Z	Z	Z	PS
5	P	N	Z	Z	**18**	Z	Z	N	PM
6	P	N	N	NS	**19**	Z	P	P	NM
7	Z	Z	P	NM	**20**	Z	P	N	Z
8	N	Z	Z	NS	**21**	Z	P	Z	NS
9	N	Z	Z	Z	**22**	Z	N	P	ZE
10	N	P	P	NM	**23**	Z	N	N	PM
11	N	P	Z	Z	**24**	Z	N	Z	PS
12	N	P	N	PS	**25**	Z	Z	P	NS
13	N	N	P	PS	**26**	Z	Z	Z	Z
					27	Z	Z	N	NS

In the Type-1 FLPSS controller, the gains are converted to adaptive gains by introducing FLC at the input of the PID Controller. The parameters are tuned by using a systematic approach [18].

The analytical structure of fuzzy logic power system stabilizer is shown in fig.1

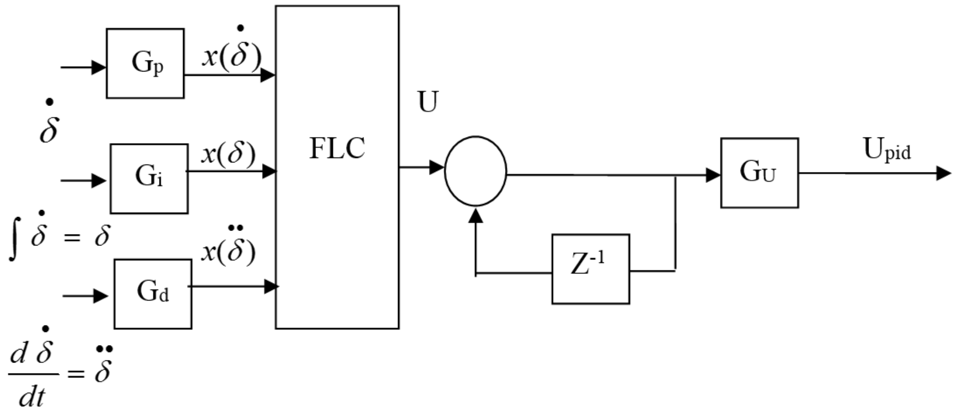

Fig 1: Analytical Structure of Three input Fuzzy Controller

The loading condition that results in hopf bifurcations of power system with imaginary eigenvalues is used for tuning of fuzzy logic power system stabilizer.

2.4 Test System

The System under study in is a thermal generating station consisting of four 555MVA, 24KV, and 60Hz units. The network reactance's are in p.u. on 2220 MVA, 24 KV base (referred to LT side of step-up transformer). Resistances are assumed to be negligible.

Equivalent generator parameters in p.u:

X_d = 1.81, $X_d{}'$ = 0.3, X_q = 1.76, $T_{do}{}'$ = 8sec,
H = 3.5MJ/MVA, Vt = 1.0

Exciter: k_E = 25, T_E = 0.05Sec.

3. Results and Discussion

The response in speed deviation and rotor angle deviation of SMIB at a loading of P+jQ= 1+j0 is shown in fig. 2 and fig. 3.

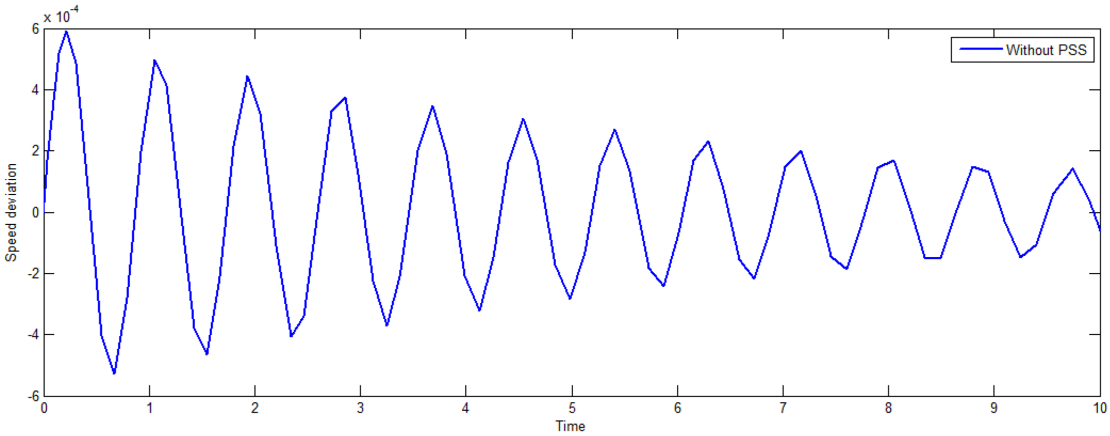

Fig 2: Response in speed deviation of SMIB without controller for P=1, Q=0

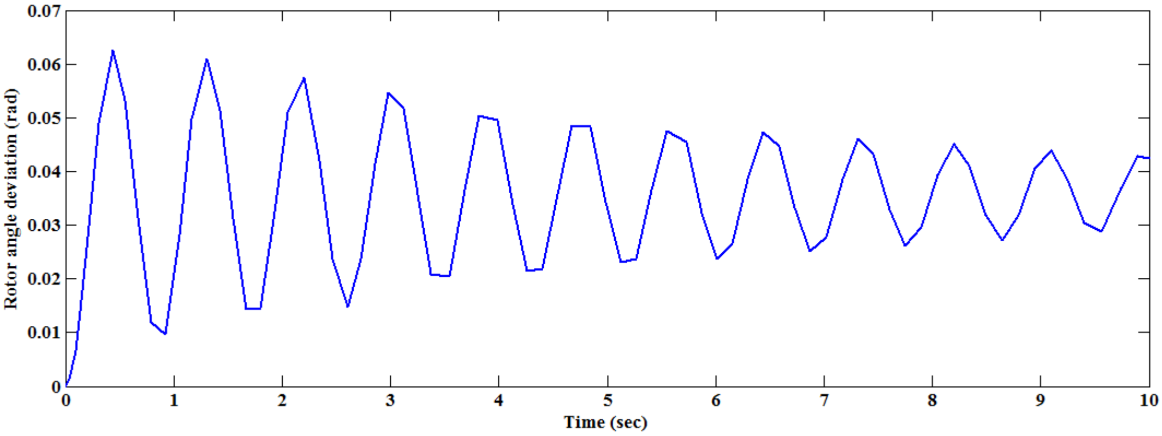

Fig 3: Response in rotor angle deviation of SMIB without controller for P=1, Q=0

The real and reactive power loading on the system is varied. The system exhibits imaginary eigenvalues at a loading of P+jQ= 1.6-j0.6238. The response in rotor angle deviation of SMIB under this loading is shown in fig. 4.

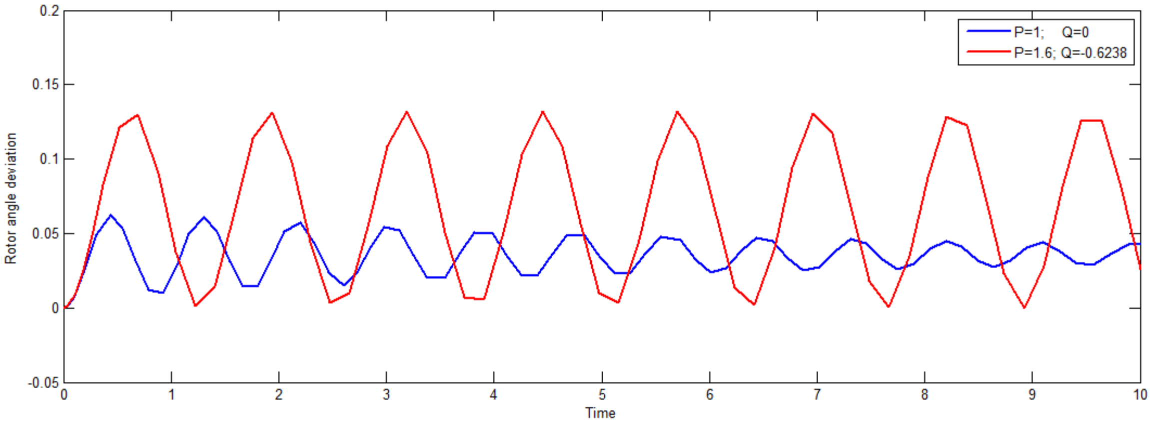

Fig 4: Response in rotor angle deviation of SMIB without controller under hopf bifurcations

The CPSS is tuned for the loading condition that is resulting in hopf bifurcation of the power system. The CPSS tuned for this loading is effectively working under wide range of operating conditions. The response in speed deviation and rotor angle deviation of SMIB under the loading of hopf bifurcation are given in fig.5 and fig.6.

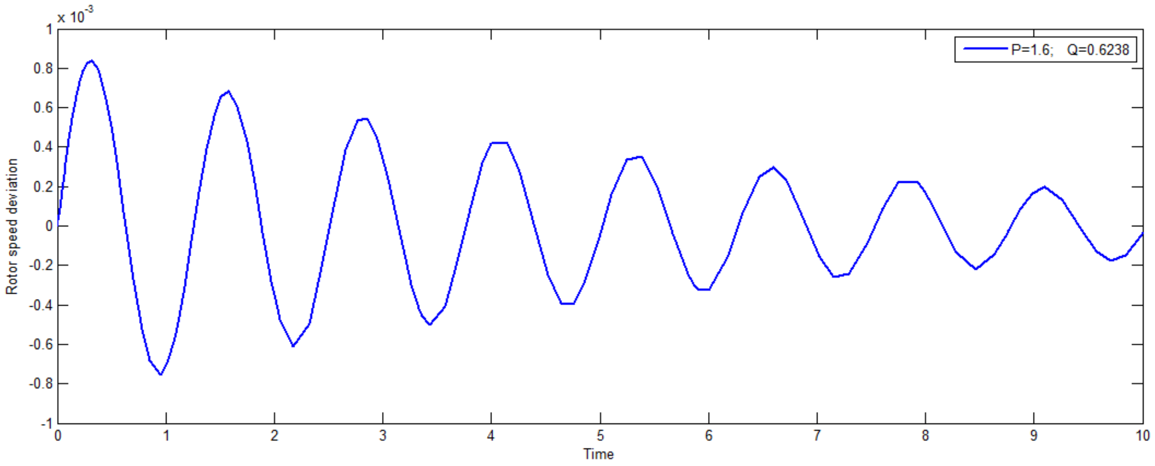

Fig 5: Response in speed deviation of SMIB with CPSS for P=1.6, Q=-0.6238

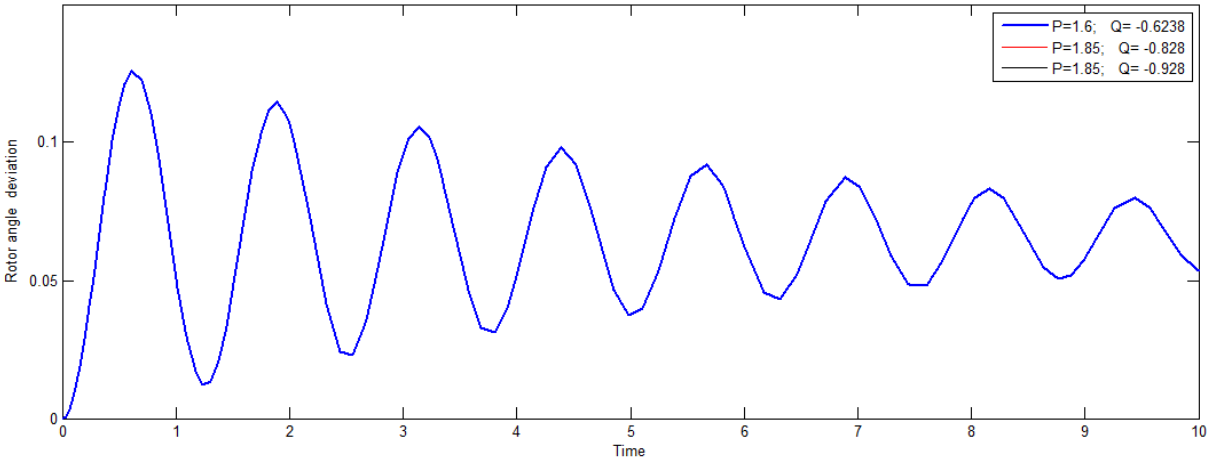

Fig 6: Response in rotor angle deviation of SMIB with CPSS for P=1.6, Q=-0.6238

The same loading condition is used for tuning of fuzzy logic power system stabilizer. The FLPSS is working more effectively over wide range of operating conditions. Fig. 7 shows the response in rotor angle deviations of SMIB equipped with FLPSS under the hopf bifurcation loading condition.

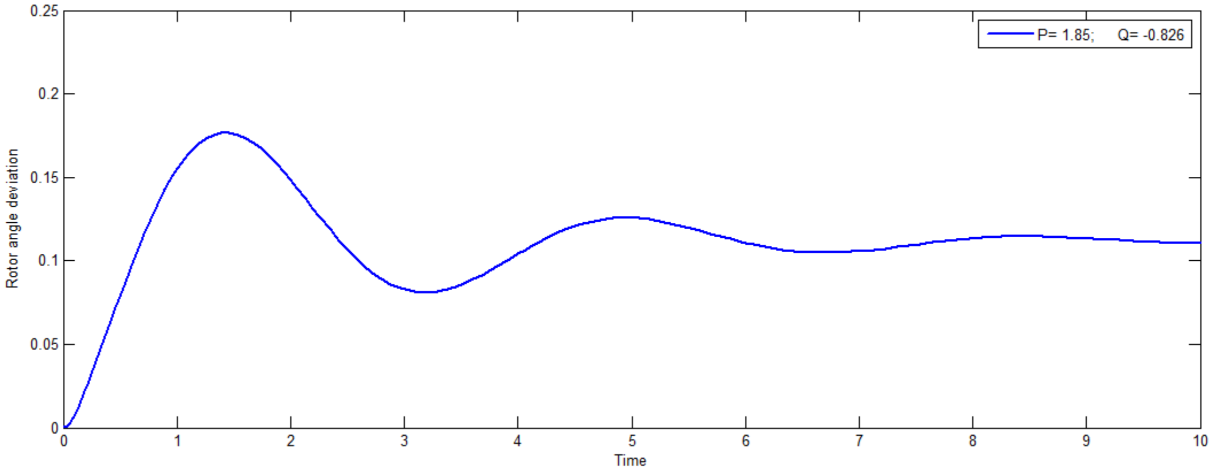

Fig 7: Response in rotor angle deviation of SMIB with FLPSS for P=1.6, Q=-0.6238

The response in rotor angle deviation of SMIB with different controllers is shown in fig. 8.

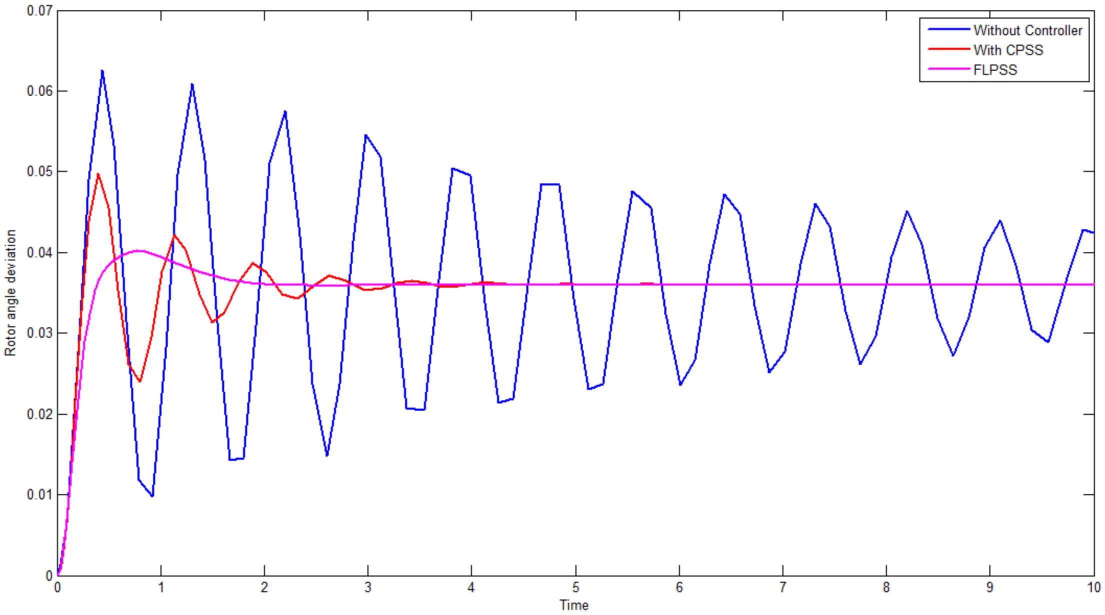

Fig 8: Response in rotor angle deviation of SMIB with different controllers for P=1, Q=0

The response in speed deviation of SMIB equipped with different controllers is shown in fig. 9

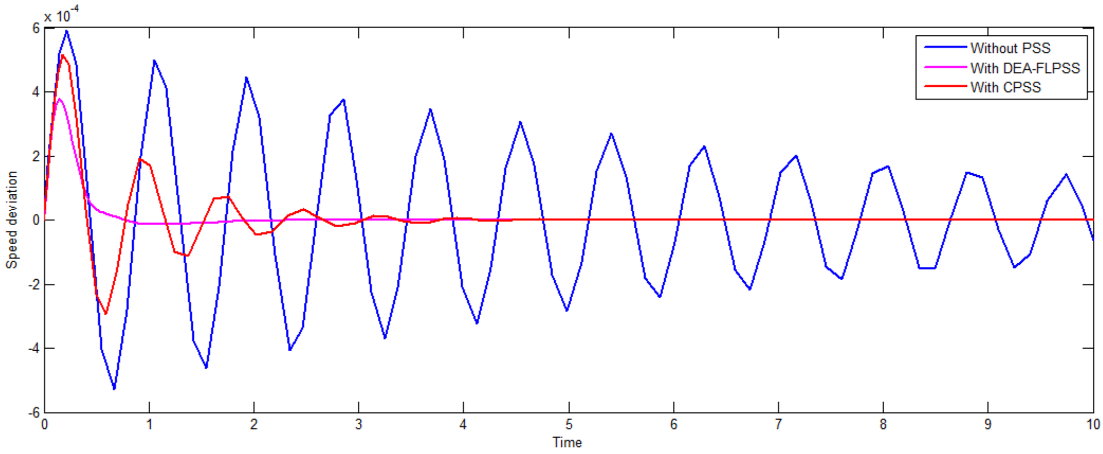

Fig 9: Response in speed deviation of SMIB with different controllers for P=1, Q=0

From the results it can be observed that the FLPSS tuned for loading condition resulting hopf bifurcation is working effectively when compared to CPSS.

3. Conclusions

In this paper a FLPSS designed for loading condition that results in hopf bifurcations of power system is effectively working over wide range of operating conditions. The proposed controller is showing its superiority over the CPSS tuned for same loading condition. From simulation results we conclude that the FLPSS tuned for loading condition resulting hopf bifurcation is working effectively when compared to conventional power system stabilizer.

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