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Comparison of Four Different Power System Stabilizers

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Abstract. This paper compares four different power system stabilizers (PSS). The purpose of power system stabilizers is to enhance the damping of low frequency oscillations in power systems. The conventional power system stabilizer (CPSS) utilizes the rotor speed while the optimal power system stabilizer (OPSS) utilizes the full states of the machine model. The sub-optimal power system stabilizer (SOPSS) utilizes partial states of the machine model. The fuzzy power system stabilizer (FPSS) uses fuzzy logic theory to provide the required control signal. The effectiveness of these four different power system stabilizers are compared through the simulation of a single machine connected to an infinite bus.

Keywords: low frequency oscillations, power system stabilizers, optimal control, sub-optimal control, fuzzy logic.

1. Introduction

Power system operation is characterized by the random variation of the load condition, continuous change in generation schedule and network interconnection. Moreover, power systems are subject to different exogenous disturbances such as actions of different controllers, switching of lines or increasing such loads in the system. Such disturbances will initiate low frequency power system oscillations which should be consequently endangering the overall stability of the system. Ones the low frequency oscillations started, they would continue for a while and disappear, or continue to grow causing system separation. In modern power system operation, the low frequency power system oscillations initiated by disturbance have been one of the major concerns. The oscillations may sustain and grow to cause system separation if adequate damping is not available. Over last 25 years, the problems of low frequency power system oscillations have assumed importance. The frequency of oscillation is in the range of 0.2 to 2.0 Hz. The lower the frequency, the more widespread are the oscillations (also called inter – area oscillations). In the recent years many efforts have been dedicated to damp these low frequency oscillations, additional positive damping is required which can be provided by supplementary excitation control. In the late 1950's and early 1960's most of power systems used automatic voltage regulators (AVR) to provide useful damping to the power system to maintain the overall stability of the power system. Nowadays power system stabilizer (PSS) is one of the most important controllers in modern power systems for damping low frequency oscillations. Demello and Concordia [1] were the first to use the theory of phase compensation in the frequency domain to make a thorough analysis of a lead-lag compensator to provide an efficient excitation system for the synchronous machine to utilize the control signal in the excitation system. It can be providing more damping to the system so that the overall dynamic response of the power system is improved. Traditionally, the conventional power system stabilizer (CPSS) mostly used to obtain damping to the system using ($\Delta\omega_r$) as a stabilizing signal [1-4]. The conventional power system stabilizer (CPSS) will enhance the performance and the stability of the system. Optimal control theory has been utilized for the design of optimal power system stabilizers [5-7] to obtain optimal performance. Recently, alternative control schemes that does not require model identification, and required less computational efforts than the self tuning controllers and easier to be implemented on a microcomputer. Fuzzy logic based power system stabilizers is an example of such scheme

[8-17]. Most of previous studies in this field concentrated on the behavior of the conventional power system stabilizer (CPSS) in providing damping to the power system. In most of these studies the power system considered is a single machine infinite bus (SMIB) or multi-machine system with classical model for the synchronous machine (model 1.0). In this paper, the conventional power system stabilizer is modified to obtain an optimal power system stabilizer (OPSS) or a sub-optimal power system stabilizer (SOPSS). The optimal power system stabilizer (OPSS) uses all state variables of the system as stabilizing signals. The sub optimal power system stabilizer (SOPSS) uses partial state variables of the system as stabilizing signals. In this work, the design and effectiveness of the conventional (CPSS), the optimal (OPSS), the sub-optimal (SOPSS) and the fuzzy (FPSS) power system stabilizers are compared for a single machine connected to infinite bus.

2. Power System Models for Low Frequency Oscillations

The power system model for low frequency oscillation studies consists of the machine model, the exciter model and the stabilizer model.

2.1. The machine model

Mathematical models of synchronous machines vary from the classical model to the detailed model depending on the degree of detail used. Moreover the synchronous machine can be expressed by the fourth order model (δ, ω, E'_q and E'_d).

$$\left.\begin{aligned}
&\dot{\delta} = \omega_b(\omega_r - 1)\\
&M\dot{\omega} = T_m - T_e - D\omega_r\\
&T'_{d0}\dot{E}'_q = -E'_q - (x_d - x'_d)I_d + E_{fd}\\
&T'_{q0}\dot{E}'_d = -E'_d + (x_q - x'_q)I_q
\end{aligned}\right\} \tag{1}$$

2.2. The exciter model

The basic function of an excitation system is to provide direct current to the Synchronous machine field winding which will contribute in regulating the terminal voltage (V_t). The excitation system model can be represented by a single time constant system as shown in Fig. 1.

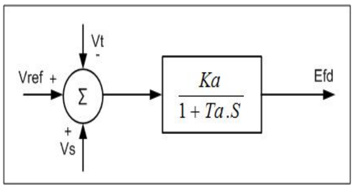

Fig. 1 Exciter Model

3. The Power System Stabilizer (PSS)

The main function of a power system stabilizer (PSS) is to introduce a component of electrical torque in the synchronous machine rotor that is proportional to the deviation of the actual speed from synchronous speed. When the rotor oscillates, this torque acts as a damping torque counter to the low frequency power system oscillations.

3.1. The conventional power system stabilizer (CPSS)

The most commonly used structure of a power system stabilizer is shown in Fig. 2. This comprises a gain, a washout filter, and phase compensation blocks.

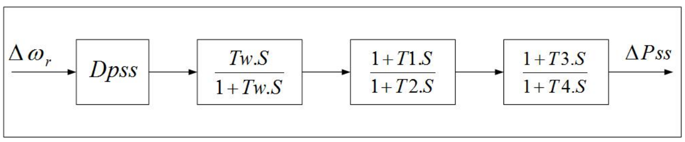

Fig. 2 Conventional Power System Stabilizer (CPSS)

3.2. The optimal power system stabilizer (OPSS)

The proposed optimal power system stabilizer (OPSS) is designed by feeding back all the system states to the inputs of the washout circuit and the phase lag-lead stages of the conventional PSS through the optimal gain matrix K as shown in Fig. 3.

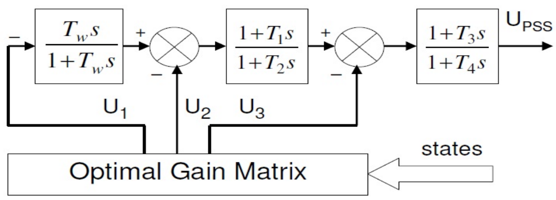

Fig. 3 Optimal Power System Stabilizer (OPSS)

The optimal gain matrix, K, is determined by solving the algebraic Riccati equation (ARE) minimizing the performance index J.

$$J = \int_0^\infty \left(\mathbf{x}^T\mathbf{Q}\mathbf{x} + \mathbf{u}^T\mathbf{R}\mathbf{u}\right)dt \tag{2}$$

where R and Q are positive and semi-positive definite matrices. The following algebraic Riccati equation (ARE) is solved for the symmetric matrix P.

$$\mathbf{PA} + \mathbf{A}^T\mathbf{P} + \mathbf{Q} - \mathbf{PBR}^{-1}\mathbf{B}^T\mathbf{P} = \mathbf{0} \tag{3}$$

and

$$\mathbf{K} = \mathbf{R}^{-1}\mathbf{B}^T\mathbf{P} \tag{4}$$

$$\mathbf{u} = -\mathbf{K.x} \tag{5}$$

3.3. The sub-optimal power system stabilizer (SOPSS)

The gain matrix of the optimal power system stabilizer is a full matrix which requires feeding back all the states to the input. Some of these states may be neglected leading to a suboptimal design which may be sufficient enough to achieve adequate damping. The rotor speed ($\Delta\omega$), the excitation voltage (ΔE_{fd}) and the power system stabilizer states are used for the proposed sub-optimal stabilizer as shown in Fig. 4.

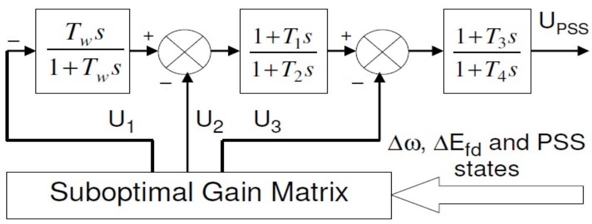

Fig. 4 Sub-optimal Power System Stabilizer (SOPSS)

3.4. The fuzzy power system stabilizer (FPSS)

In recent years, fuzzy logic has emerged as a powerful tool and is starting to be used in various power system applications. Fuzzy logic can be an alternative to classical control. It allows one to design a controller using linguistic rules without knowing the mathematical model of the plant. Fuzzy logic controllers have been widely used in fuzzy control design and applications, including power system stabilizers. The required stabilizing signal is to be generated based on fuzzy logic control. The application of fuzzy logic control for power system stabilizers was motivated by the work of Hiyama and Nakano [8]. Their proposed fuzzy controller has been demonstrated to be suitable for damping the low frequency oscillations of the power system. A fuzzy controller comprises of four stages: fuzzification, a knowledge base, decision making and defuzzification. The fuzzification interface converts input data into suitable linguistic values that can be viewed as label fuzzy sets. The knowledge base comprises knowledge of application domain and attendant control goals by means of a set of linguistic control rules. The decision making is the aggregation of output of various control rules that simulate the capability of human decision making. The defuzzification inference performs scale mapping, which converts the range of values of output variables into corresponding universe of discourse. The Hsu and Cheng [17] fuzzy power system stabilizer is one of power system stabilizers based on the concept of fuzzy logic theory. The fuzzy excitation controller proposed by Hsu and Cheng is shown in Fig. 5 where the measured generator angular speed deviation (Δω) and the calculated acceleration ($\Delta\dot{\omega}$) are used as input signals. These signals are first expressed in some linguistic variables using membership functions in fuzzy set notations before they are processed by the fuzzy controller. A set of decision rules expressed in linguistic variables are established based on previous experience with the study system to relate input signals with output (control) signal. These decision rules are converted into a fuzzy relation matrix (R) which can be stored in computer memory. Then, using the fuzzified input variables with the relation matrix, the membership values of the controller output signal expressed in fuzzy linguistic terms can be obtained. Finally the control signal is converted from linguistic term to numerical value before it is fed into the system. The scaling factors Sf1, Sf2 and Sf3 are the normalizing or scaling factors whose values are to be selected to get the optimal system performance.

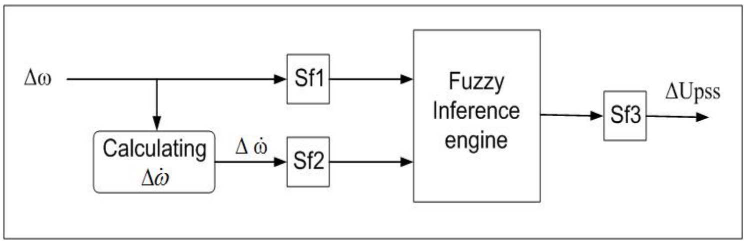

Figure.5 Fuzzy logic controller proposed by Hsu and Cheng

The decision rules are represented by linguistic variables which are established to relate the controller output to the controller input. These decision rules are expressed using linguistic variables such as large positive (LP), medium positive (MP), small positive (SP), zero (Z), small negative (SN), medium negative (MN), and large negative (LN). The decision are presented in the following table

		Speed Acceleration ($\Delta\dot{\omega}$)						
		LP	MP	SP	Z	SN	MN	LN
Speed deviation $\Delta\omega$	LP	LP	LP	LP	LP	MP	SP	Z
	MP	LP	LP	MP	MP	SP	Z	SN
	SP	LP	MP	SP	SP	Z	SN	MN
	Z	MP	MP	SP	Z	SN	MN	MN
	SN	MP	SP	Z	SN	SN	MN	LN
	MN	SP	Z	SN	MN	MN	LN	LN
	LN	Z	SN	MN	LN	LN	LN	LN

4. Simulation

Simulation is carried on a single machine connected to infinite bus through a link as shown in Fig. 6. The followings are the parameters of the machine, the exciter and the stabilizer. The rotor speed deviation results for a disturbance of 5% in the mechanical torque (ΔT_m) are shown in Fig. 7.

Machine (60 Hz)

M=108	D = 0	$x_d = 0.20$	$x_q = 0.18$
$x'_d = 0.03$	$x'_q = 0.02$	$T'_{d0} = 8.0$	$T'_{q0} = 0.4$

Exciter

$K_a = 10.0$	$T_a = 0.02$

Power system stabilizer

$D_{PSS} = 38.0$	$T_1 = 0.352$	$T_3 = 0.352$
$T_w = 5.0$	$T_2 = 0.010$	$T_4 = 0.010$

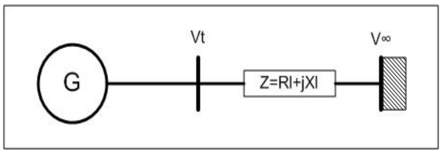

Fig. 6 Single machine to infinite bus

Z = j0.25pu

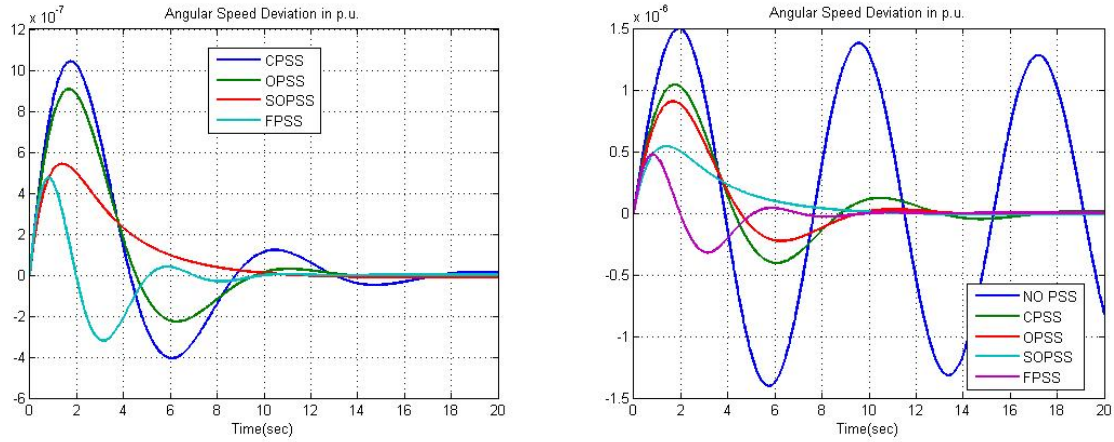

Fig. 7 Rotor speed deviations

5. Conclusions

A comparison between four different power system stabilizers has been carried out on a single machine connected to infinite bus. These four stabilizers are the conventional power system stabilizer (CPSS), the optimal power system stabilizer (OPSS), the sub-optimal power system stabilizer (SOPSS) and the fuzzy power system stabilizer (FPSS). Simulation results prove that the sub-optimal and the fuzzy stabilizers can give adequate performance.

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