Power System Stabilizer Design based on Model Reference Adaptive System

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Abstract: Power System Stabilizers (PSS) are used to generate supplementary damping control signals for the excitation system in order to damp the Low Frequency Oscillations (LFO) of the electric power system. The PSS is usually designed based on classical control approaches but this Conventional PSS (CPSS) has some problems in power system control and stability enhancement. To overcome the drawbacks of CPSS, numerous techniques have been proposed in literatures. In this paper a new method based on Model Reference Adaptive System (MRAS) is considered to design PSS. To show effectiveness of the proposed method, the MRAS-PSS is compared with a conventional PSS which is tuned by using Genetic Algorithms (GA) (GA-PSS). The simulation results clearly indicate the effectiveness and validity of the proposed method.

[Fariborz Parandin, Ali Mohammadi, Hosain Sariri. **Power System Stabilizer Design based on Model Reference Adaptive System**. *J Am Sci* 2012;8(7):751-755]. (ISSN: 1545-1003). http://www.americanscience.org. 110

Keywords: Power System Stabilizer, Low Frequency Oscillations, Model Reference Adaptive Control, Genetic Algorithms

1. Introduction

Large electric power systems are complex nonlinear systems and often exhibit low frequency electromechanical oscillations due to insufficient damping caused by adverse operating [1]. These oscillations with small magnitude and low frequency often persist for long periods of time and in some cases they even present limitations on power transfer capability [1]. In analyzing and controlling the power system's stability, two distinct types of system oscillations are recognized. One is associated with generators at a generating station swinging with respect to the rest of the power system. Such oscillations are referred to as "intra-area mode" oscillations. The second type is associated with swinging of many machines in an area of the system against machines in other areas. This is referred to as "inter-area mode" oscillations. Power System Stabilizers (PSS) are used to generate supplementary control signals for the excitation system in order to damp both types of oscillations [1]. The widely used Conventional Power System Stabilizers (CPSS) are designed using the theory of phase compensation in the frequency domain and are introduced as a lead-lag compensator. The parameters of CPSS are determined based on the linearized model of the power system. Providing good damping over a wide operating range, the CPSS parameters should be fine tuned in response to both types of oscillations. Since power systems are highly nonlinear systems, with configurations and parameters which alter through time, the CPSS design based on the linearized model of the power system cannot guarantee its

performance in a practical operating environment. Therefore, an adaptive PSS which considers the nonlinear nature of the plant and adapts to the changes in the environment is required for the power system [1]. In order to improve the performance of CPSSs, numerous techniques have been proposed for designing them, such as intelligent optimization methods [2-6], Fuzzy logic [7-8] and many other techniques [9-10]. Also the application of robust control methods for designing PSS has been reported in [11-14].

This paper deals with a adaptive design method for the stability enhancement of a single machine infinite bus power system using Model Reference Adaptive System. To show effectiveness of the MRAS, this method is compared with the GA-PSS. Simulation results show that the proposed method guarantees robust performance under a wide range of operating conditions.

Apart from this introductory section, this paper is structured as follows. The system under study is presented in section 2. Section 3 describes about the system modeling and system analysis. The power system stabilizers are briefly explained in section 4. Section 5 is devoted to explaining the proposed methods and design methodology. Eventually the simulation results are presented in section 6.

2. System under study

Figure 1 shows a two area power system [15]. In this system, the first area is a single generator and the second area is aggregation of a large number of generators. The second area performs like an infinite bus. The system data are completely presented in [15]. In the simulation process, the second area is simulated as a single generator with inertia M = 1000 Mj/MVA. The detailed model of system can be depicted as Figure 2.

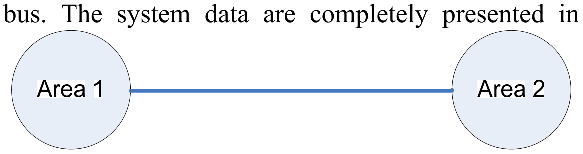

Figure 1: Two area power system

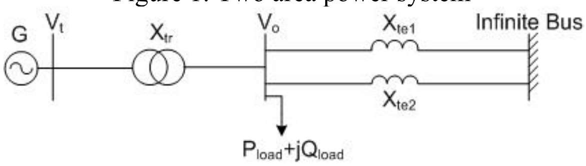

Figure 2: A single machine infinite bus power system

3. System modeling and analysis

3. 1. Non-Linear dynamic model

A non-linear dynamic model of the system is derived by disregarding the resistances and the transients of generator, transformers and transmission lines [15]. The nonlinear dynamic model of the system is given as (1).

$$\begin{cases} \dot{\omega} = \dfrac{\left(P_m - P_e - D\Delta\omega\right)}{M} \\ \dot{\delta} = \omega_0(\omega - 1) \\ \dot{E}'_q = \dfrac{\left(-E_q + E_{fd}\right)}{T'_{do}} \\ \dot{E}_{fd} = \dfrac{-E_{fd} + K_a\left(V_{ref} - V_t\right)}{T_a} \end{cases} \tag{1}$$

3. 2. Linear dynamic model of the system

A linear dynamic model of the system is obtained by linearizing the non-linear dynamic model around the nominal operating condition. The linearized model of the system is obtained as (2). Also, the dynamic model of the system in the state-space form is obtained as (3) [15].

$$\begin{cases} \Delta\dot{\delta} = \omega_0\Delta\omega \\ \Delta\dot{\omega} = \dfrac{-\Delta P_e - D\Delta\omega}{M} \\ \Delta\dot{E}'_q = (-\Delta E_q + \Delta E_{fd})/T'_{do} \\ \Delta\dot{E}_{fd} = -\left(\dfrac{1}{T_A}\right)\Delta E_{fd} - \left(\dfrac{K_A}{T_A}\right)\Delta V \end{cases} \tag{2}$$

$$\begin{bmatrix} \Delta\dot{\delta} \\ \Delta\dot{\omega} \\ \Delta\dot{E}'_q \\ \Delta\dot{E}_{fd} \end{bmatrix} = \begin{bmatrix} 0 & \omega_0 & 0 & 0 \\ -\dfrac{K_1}{M} & 0 & -\dfrac{K_2}{M} & 0 \\ -\dfrac{K_4}{T'_{do}} & 0 & -\dfrac{K_3}{T'_{do}} & \dfrac{1}{T'_{do}} \\ -\dfrac{K_A K_5}{T_A} & 0 & -\dfrac{K_A K_6}{T_A} & -\dfrac{1}{T_A} \end{bmatrix} \times \begin{bmatrix} \Delta\delta \\ \Delta\omega \\ \Delta E'_q \\ \Delta E_{fd} \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ \dfrac{1}{M} & 0 \\ 0 & 0 \\ 0 & \dfrac{K_A}{T_A} \end{bmatrix} \times \begin{bmatrix} \Delta T_m \\ \Delta V_{ref} \end{bmatrix} \tag{3}$$

3.3. Analysis

In the nominal operating condition, the eigen values of the system are obtained using analysis of the state-space model of the system presented in (3) and these eigen values are shown in Table 1. It is clearly seen that the system contains low damped modes and therefore the system needs to Power System Stabilizer (PSS) for stability.

Table 1 - The eigen values of the system without PSS

-66.5597
-36.8528
-21.6297
-0.2869 + 6.4821i
-0.2869 - 6.4821i
-0.4523 + 2.7148i
-0.4523 - 2.7148i
-1.8333
-1.0000

4. Power system stabilizer

A Power System Stabilizer (PSS) is provided to improve the damping of power system oscillations. Power system stabilizer provides an electrical damping torque (ΔT_m) in phase with the speed deviation $(\Delta\omega)$ in order to improve damping of power system oscillations [15]. The PSS configuration is as (4) where, $\Delta\omega$ is the speed deviation in per unit. This type of PSS consists of a washout filter and a dynamic compensator. The washout filter in which its time constant is T_w is used to reset the steady state offset in the PSS output and is fixed as 10 s in this paper. The dynamic compensator is made up to two lead–lag stages with time constants, T_1–T_4 and an additional gain K_{DC}. As referred before, many different methods have been applied to design power system stabilizers so far. In this paper a new Model Reference Adaptive System (MRAS) is considered design PSS. In the next section, the proposed method is briefly introduced.

$$U = K_{DC} \frac{ST_W}{1+ST_W} \frac{1+ST_1}{1+ST_2} \frac{1+ST_3}{1+ST_4} \Delta\omega \tag{4}$$

5. Model Reference Adaptive System

The model reference adaptive system may be regarded as an adaptive servo system in which the desired performance is expressed in term of a reference model. Such system gives the desired response to a command signal, as a convenient way to give specifications for a servo problem. A block diagram of the system is shown in Fig. 3. The system has an ordinary feedback loop composed of the process and the controller and another feedback loop that adjusts the controller parameters. The parameters adjustment is performed based on the tracking error, defined as the difference between the output of the system and the output of the reference model. The ordinary feedback is called the inner loop, and the parameters adjustment loop is called the outer loop [16].

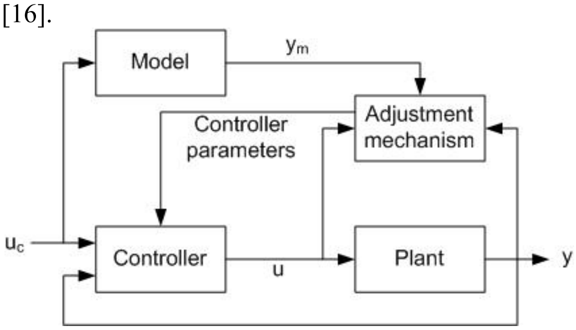

Figure 3: Block diagram of model reference adaptive system

5. 1. Controller design using MRAS

To controller design, in first the power system transfer function is obtained by using (3). Then a reference model is considered to reflect the desired specifications. Figure 4 shows the structure of proposed MRAS which has been made in MATLAB software.

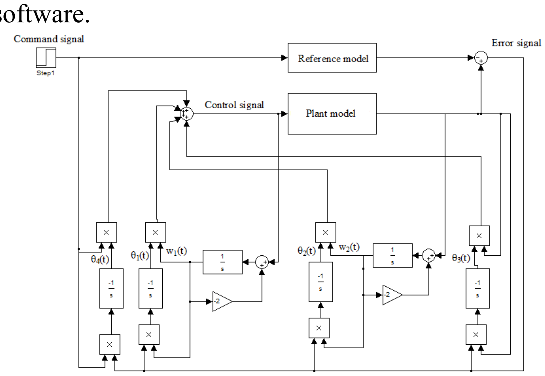

Figure 4: MRAS controller in MATLAB

6. Simulation results

In this section, the proposed MRAS is evaluated on the test system (single machine infinite bus power system). To show effectiveness of the proposed method, GA-PSS is considered for comparing as follows [17]:

Table 2 - PSS parameters using GA

K_{DC}	T_1	T_2	T_3	T_4
2.69	0.1	0.01	0.4	0.01

In order to study the PSS performance under system uncertainties, three operating conditions are considered as follow:
i : Nominal operating condition
ii: Heavy operating condition (50 % changing parameters from their typical values)
iii: Very heavy operating condition (100 % changing parameters from their typical values)
Also, a commonly used index as Integral of the Time multiplied Absolute value of the Error (*ITAE*) is used to assessment of the methods. This index is defined as follows:

$$ITAE = \int_0^t t|\Delta\omega|dt \tag{5}$$

To demonstrate the robustness performance of the proposed method, The *ITAE* is calculated following three phase short circuit at bus 1 at all operating conditions (Nominal, heavy and Very heavy) and results are listed in Table 3. Following disturbance, the MRAS-PSS has better performance than the GA-PSS at all operating conditions. Where, the MRAS-PSS has lower *ITAE* index in comparison with GA-PSS, therefore the MRAS-PSS can damp out power system oscillations more successfully.

Also, the simulation results are presented in Figures 5-8. The results demonstrate that the MRAS-PSS has a better performance than GA-PSS at all operating conditions. With changing operating condition from nominal toward heavy, the conventional PSS goes to fluctuation, but the adaptive PSS alters its parameters and shows a robust response.

Table 3- The calculated ITAE

	MRAS-PSS	GA-PSS
Nominal	0.1794	0.1478
Heavy	0.2304	0.1821
Very heavy	0.3391	0.2561

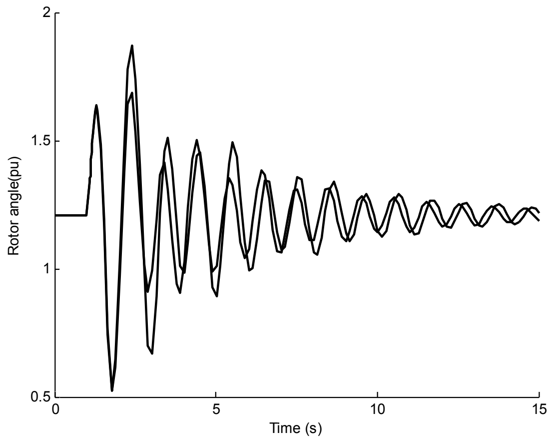

Figure 5: Rotor angle response following three phase short circuit in bus 1 in the nominal operating condition. (Solid: MRAS-PSS; Dashed: GA-PSS)

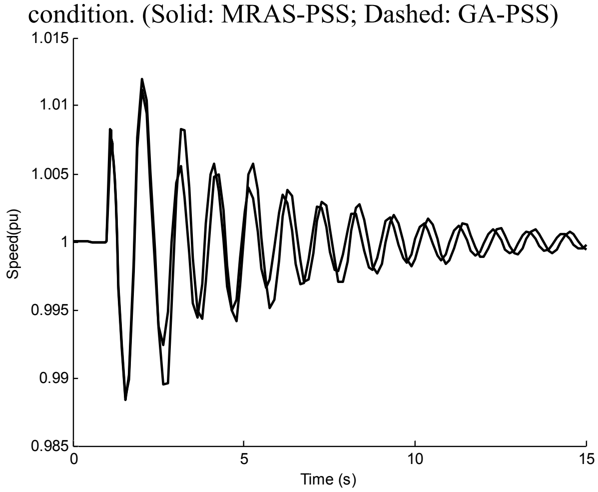

Figure 6: Speed response following three phase short circuit in bus 1 in the nominal operating condition. (Solid: MRAS-PSS; Dashed: GA-PSS)

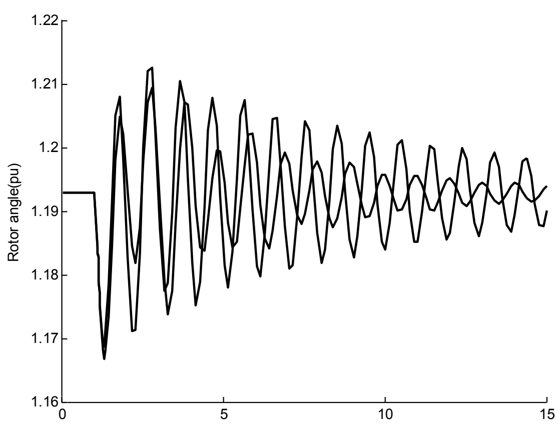

Figure 7: Rotor angle response following three phase short circuit in bus 1 in the heavy operating condition. (Solid: MRAS-PSS; Dashed: GA-PSS)

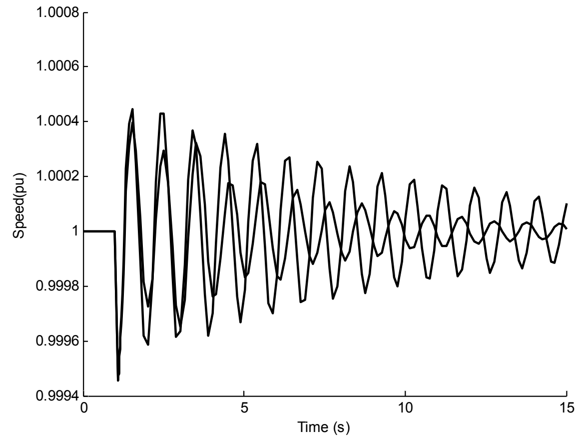

Figure 8: Speed response following three phase short circuit in bus 1 in the heavy operating condition. (Solid: MRAS-PSS; Dashed: GA-PSS)

7. Conclusions

In this paper a new Model Reference Adaptive System (MRAS) has been successfully proposed to design PSS. The proposed method was applied to a typical single machine infinite bus power system containing system parametric uncertainties and various loads conditions. The simulation results demonstrated that the designed optimal MRAS is capable of guaranteeing the robust stability and robust performance of the power system under a wide range of system uncertainties.

Acknowledgement

This paper is a result of an approved research project in Islamic Azad University, Islamabad-Gharb branch. Therefore we know necessary to thank this academic unit staunch for its most grateful support.

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