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Power System Dynamic Stability Enhancement Using a New PID Type PSS

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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. To overcome the drawbacks of CPSS, numerous techniques have been proposed in literatures. In this paper a PID type PSS (PID-PSS) is considered for damping electric power system oscillations. The parameters of this PID type PSS (PID-PSS) are tuned based on Hybrid Genetic Algorithm optimization method. The proposed PID-PSS is evaluated against the conventional power system stabilizer (CPSS) at a single machine infinite bus power system considering system parametric uncertainties. The simulation results clearly indicate the effectiveness and validity of the proposed method.

Key words: Electric Power System Stabilizer, Low Frequency Oscillations, Genetic Algorithm Optimization, PID type PSS

INTRODUCTION

Large electric power systems are complex nonlinear systems and often exhibit low frequency electromechanical oscillations due to insufficient damping caused by adverse operating. 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 (Liu et al., 2005). 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 (Liu et al., 2005). 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 (Liu et al., 2005). In order to improve the performance of CPSSs, numerous techniques have been proposed for designing them, such as intelligent optimization methods (Linda and Nair, 2010; Yassami et al., 2010; Sumathi et al., 2007; Jiang et al., 2008; Sudha et al., 2009) and Fuzzy logic method (Hwanga et al., 2008; Dubey, 2007). Also many other different techniques have been reported by Chatterjee et al. (2009) and Nambu and Ohsawa (1996) and the application of robust control methods for designing PSS has been presented by Gupta et al. (2005), Mocwane and Folly (2007), Sil et al. (2009) and Bouhamida et al. (2005). This paper deals with a design method for the stability enhancement of a single machine infinite bus power system using PID-PSS which its parameters are tuned by Hybrid Genetic Algorithm Optimization method. To show effectiveness of the new optimal control method, this method is compared with the CPSS. Simulation results show that the proposed method guarantees robust performance under a wide range of operating conditions.

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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 is presented in section 4. The power system stabilizers are briefly explained in section 5. Section 6 is devoted to explaining the proposed methods. The design methodology is developed in section 7 and eventually the simulation results are presented in section 8.

2. System under Study:

Fig. 1 shows a single machine infinite bus power system (Kundur, 1993). The static excitation system has been considered as model type *IEEE – ST1A*.

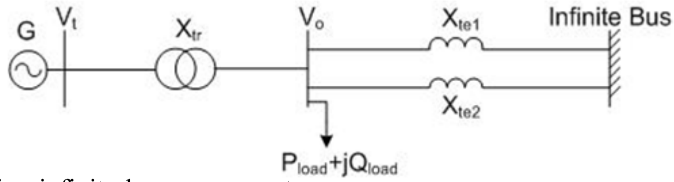


Fig. 1: A single machine infinite bus power system

3. Dynamic Model of the System:

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 (Kundur, 1993). The nonlinear dynamic model of the system is given as (1).

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

3.2. Linear Dynamic Model:

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) (Kundur, 1993).

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

Fig. 2 shows the block diagram model of the system. This model is known as Heffron-Phillips model (Kundur, 1993). The model has some constants denoted by K_i. These constants are functions of the system parameters and the nominal operating condition. The nominal operating condition is given in the appendix.

3.3. Dynamic Model in State-space Form:

The dynamic model of the system in the state-space form is obtained as (3) (Kundur, 1993).

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

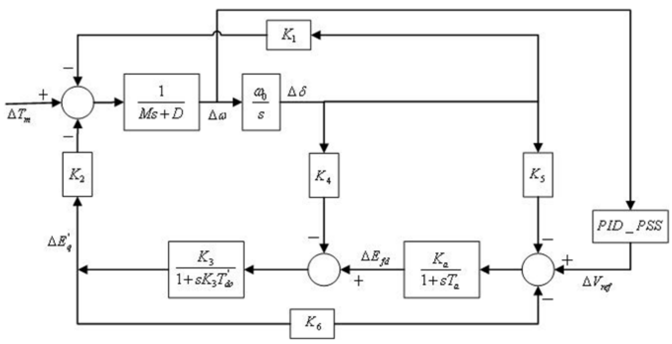


Fig. 2: Heffron-Phillips model of the power system

4. 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 has two unstable poles at the right half plane and therefore the system is unstable and needs the Power System Stabilizer (PSS) for stability.

Table 1: The eigen values of the closed loop system

-4.2797
-46.366
+0.1009 + j4.758
+0.1009 - j4.758

5. 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 *(* T_m) in phase with the speed deviation (ω) in order to improve damping of power system oscillations (Kundur, 1993). As referred before, many different methods have been applied to design power system stabilizers so far. In this paper a new hybrid optimal method based on the Genetic Algorithm techniques is considered to tuning parameters of the PID-PSS. In the next section, the proposed method is briefly introduced and then designing the PID-PSS, based on the proposed methods, is done.

6. The Proposed Method:

In this paper a Hybrid Genetic Algorithm optimization method is considered to adjustment PID-PSS. For more introductions, the proposed methods are briefly introduced in the following subsections.

6.1. Genetic Algorithms:

Genetic Algorithms (GA) are global search techniques, based on the operations observed in natural selection and genetics (Randy and Sue, 2004). They operate on a population of current approximations-the individuals-initially drawn at random, from which improvement is sought. Individuals are encoded as strings (Chromosomes) constructed over some particular alphabet, e.g., the binary alphabet {0.1}, so that chromosomes values are uniquely mapped onto the decision variable domain. Once the decision variable domain representation of the current population is calculated, individual performance is assumed according to the objective function which characterizes the problem to be solved. It is also possible to use the variable parameters directly to represent the chromosomes in the GA solution. At the reproduction stage, a fitness value is derived from the raw individual performance measure given by the objective function and used to bias the selection process. Highly fit individuals will have increasing opportunities to pass on genetically important material to successive generations. In this way, the genetic algorithms search from many points in the search space at once and yet continually narrow the focus of the search to the areas of the observed best performance. The selected individuals are then modified through the application of genetic operators. In order to obtain the next generation Genetic operators manipulate the characters (genes) that constitute the chromosomes directly, following the assumption that certain genes code, on average, for fitter individuals than other genes. Genetic operators can be divided into three main categories (Randy and Sue, 2004): Reproduction, crossover and mutation.

7. Design Methodology:

In this section the PID-PSS parameters tuning based on the Genetic Algorithms is presented. The PID-PSS configuration is as (4).

$$\text{PID} - \text{PSS} = K_P + \frac{K_I}{S} + K_D S \tag{4}$$

The parameter ΔE_{ref} is modulated to output of PID-PSS and speed deviation Dw is considered as input to PID-PSS. The optimum values of K_P, K_I and K_D which minimize an array of different performance indexes are accurately computed using a Genetic Algorithms. In this study the performance index is considered as (5). In fact, the performance index is the Integral of the Time multiplied Absolute value of the Error (*ITAE*).

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

The parameter "t" in performance index is the simulation time. It is clear to understand that the controller with lower performance index is better than the other controllers. To compute the optimum parameter values, a 0.1 step change in reference mechanical torque (DTm) is assumed and the performance index is minimized using Genetic Algorithms. The following genetic algorithm parameters have been used in present research.

- Number of Chromosomes: 3 Population size: 48
- Crossover rate: 0.5 Mutation rate: 0.1

The optimum values of the parameters K_P, K_I and K_D are obtained using Hybrid Genetic Algorithms and summarized in the Table 2.

Table 2: Obtained parameters of PID-PSS using hybrid Genetic Algorithms optimization method

PID Parameters	K_P	K_I	K_D
Obtained Value	63.396	9.9974	11.9952

8. Simulation Results:

In this section, the proposed optimal PID-PSS is applied to the under study system (single machine infinite bus power system). To show effectiveness of the proposed optimal PID-PSS, A classical lead-lag PSS based on phase compensation technique (CPSS) is considered for comparing purposes.

The detailed step-by-step procedure for computing the parameters of the classical lead-lag PSS (CPSS) using phase compensation technique is presented in (Kundur, 1993). Here, the CPSS has been designed and obtained as (6).

$$\text{CPSS} = \frac{35(0.3S+1)}{(0.1S+1)} \tag{6}$$

In order to study the PSS performance under system uncertainties (controller robustness), three operating conditions are considered as follow:

i : Nominal operating condition

ii: Heavy operating condition (20 % changing parameters from their typical values)

iii: Very heavy operating condition (50 % changing parameters from their typical values)

In the nominal operating condition, the eigen values of the system with CPSS and optimal PID-PSS are obtained and listed in Table 3. It is clear to see that the eigen values of the system with optimal PID-PSS are farther than the imaginary axis and the system stability margin is more than CPSS method.

Table 3: The eigen values of system with different PSSs

Optimal PID-PSS	CPSS	Without PSS
-0.1928	-3.4256	-4.2797
-4.0859	-4.0503	-46.366
-6.3377	-46.3704	+0.1009 + j4.758
-46.3738	-3.2991 + j57.32	+0.1009 - j4.758
-307.3592	-3.2991 - j57.32	

Also to demonstrate the robustness performance of the proposed method, The *ITAE* is calculated following a 10% step change in the reference mechanical torque *(DT_m)* at all operating conditions (Nominal, heavy and Very heavy) and results are shown at Table 4. Following step change at DT_m, the optimal PID-PSS has better performance than the CPSS at all operating conditions. Where, the optimal PID-PSS has lower *ITAE* index in comparison with CPSS, therefore the optimal PID-PSS can damp power system oscillations more successfully.

Table 4: The calculated ITAE

	Optimal PID-PSS	CPSS
Nominal operating condition	3.9652×10^{-4}	5.5686×10^{-4}
Heavy operating condition	3.4632×10^{-4}	7.2451×10^{-4}
Very heavy operating condition	2.8288×10^{-4}	8.9021×10^{-4}

Also the control effort signal is one of the most important factors to compare responses. The parameter ΔV_{ref} which is shown in Fig. 2, is the output of controller and is considered as the control effort signal. The control effort signal is computed as (7).

$$\text{Control\_Effort} = \int_0^t t\left|\Delta \text{Vref}\right| dt \tag{7}$$

The control effort has been calculated following a 10% step change in the reference mechanical torque (DT_m) at all operating conditions (Nominal, Heavy and Very heavy) and results are shown at Table 5. It is clear to see that following step change at DT_m, the optimal PID-PSS has lower control effort than the other methods at all operating conditions. This means that the optimal PID-PSS damps power system oscillations by injecting lower control signal.

Table 5: The calculated control effort signal

	Optimal PID-PSS	CPSS
Nominal operating condition	0.0321	0.0327
Heavy operating condition	0.0400	0.0490
Very heavy operating condition	0.0359	0.0721

Although the control effort and performance index results are enough to compare the methods, but it can be more useful to show responses in figures. Fig. 3 shows ω at nominal, heavy and very heavy operating conditions following 10% step change in the reference mechanical torque (DT_m). It is clear to see that between all operating conditions, the optimal PID-PSS has better performance than the other method in mitigating oscillations

Conclusions:

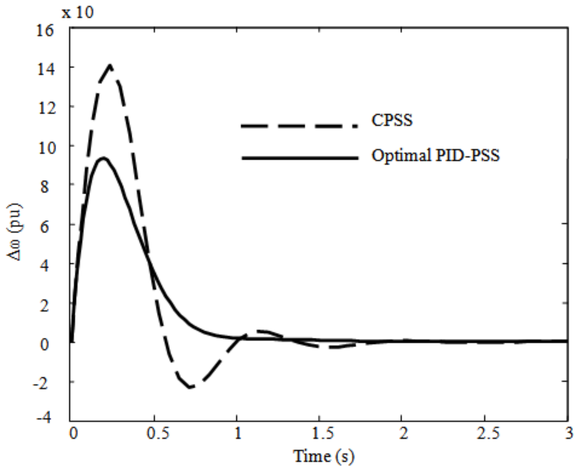
In this paper a new hybrid optimal PID-PSS based on Genetic Algorithms optimization method has been successfully proposed. The design strategy includes enough flexibility to set the desired level of stability and performance, and to consider the practical constraints by introducing appropriate uncertainties. Also the final designed optimal PID-PSS is low order and its implementation is easy and cheap. 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 PID-PSS is capable of guaranteeing the robust stability and robust performance of the power system under a wide range of system uncertainties.

Appendix:

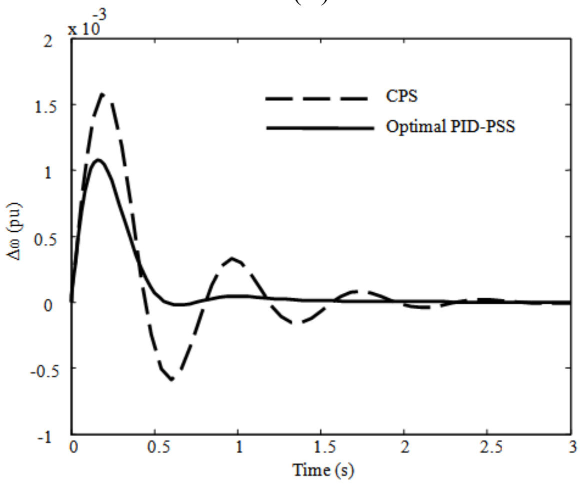
The nominal parameters and operating conditions of the system are listed in Table 6.

Table 6: The nominal system parameters

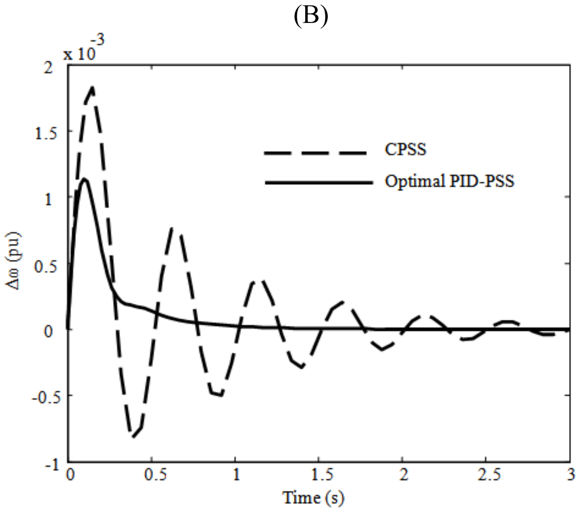
Generator	M = 10 Mj/MVA	T'_{do} = 7.5 s	X_d = 1.68 p.u.
	X_q = 1.6 p.u.	$X'd$ = 0.3 p.u.	D = 0
Excitation system		K_a = 50	T_a = 0.02 s
Transformer		X_{tr} = 0.1 p.u.	
Transmission lines	X_{te1} = 0.5 p.u.	X_{te2} = 0.9 p.u.	
Operating condition	V_t =1.05 p.u.	P=1 p.u.	Q=0.2 p.u.



(A)



(B)



(C)

Fig. 3: Dynamic responses ω following 0.1 step in the reference mechanical torque (Tm)
a: Nominal operating condition b: Heavy operating condition c: Very heavy operating condition 9.

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