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Power System Stabilizer Parameters Designing Based on Genetic Simulated Annealing Algorithm

Xiaocong Li, Zhanying Wang, Junhua Xu, and Baochao Chen

Abstract—**Power system stabilizer (PSS) is one of the most effective measures to damp the power system low frequency oscillation, the entire parameter estimation is generally more complex and difficult. According to the measured generating set uncompensated phase frequency characteristics, this paper use the objective function which is minimizing the sum of the absolute value to design PSS parameters, and the absolute value is composed of the difference between the square of required compensation phase in excitation system and the square of phase provided by PSS. Accordingly, this paper puts forward a kind of PSS parameter design method based on genetic simulated annealing algorithm. The parameter design method is applied to a hydroelectric power station generator No. 1 of China South power grid and then the results of the simulation show that using PSS parameter design method based on genetic simulated annealing algorithm can effectively damp the power system low frequency oscillation, and at the same time, simulation results verify the accuracy and validity of the method.**

Index Terms—**Power system stabilizers, genetic simulated annealing algorithm, parameters setting, dynamic stability.**

I. INTRODUCTION

The phenomenon of Low frequency oscillations have been appeared repeatedly in power systems of the domestic and overseas. The study found the weak natural damping of the interconnection in power grid is the main reason of this phenomenon. However, weak damping will be impaired if the excitation regulator is not appropriate, and system will even generate negative damping. The use of Power System Stabilizer(PSS) is the most cost-effective way to damp low frequency oscillations [1], [2] and the positive damping of power system will be steadily rised if PSS is installed in the excitation regulator. The positive damping can improve the stability of power system and rise system damping, and then damp low-frequency oscillations of power system [3], [4].

There have been increasing interests in the optimization of the parameters of PSS which can provide adequate performance over varying operating conditions. In the parameter optimization of PSS, several approaches, such as Gradient method, linear programming optimization method and Levenberg-Marquardt Method, etc., have been proposed. However, these methods have higher requirements for objective function and initial value and they are valid only for the specific problem. Then people propose a method called Genetic Algorithm (GA) [5] to estimate parameter for nonlinear model. GA is widely used in many fields due to its highly parallel processing ability, strong robustness and global searching ability.

One of the problems of GA is its convergence behaviour. Initially, the cost of solutions improves rapidly, but then it becomes very difficult to obtain further improvement. Most run-time is in late stage in the process, only a small improvement, very slowly. This work is motivated by the need to overcome this downside. Simulated Annealing Algorithm (SAA) [6] has strong optimization ability and it can make search process avoid falling into local optimal solution. But the ability to grasp the whole process of the search is not enough, so as to lower the simulated annealing operation efficiency and effectiveness. In order to improve the optimization performance and efficiency of Genetic Algorithm, this paper uses GA and SAA advantages to constitute a hybrid method called Genetic Simulated Annealing Algorithm (GSAA) [7], [8].

This paper use the objective function, which is minimizing the sum of the absolute value, to design PSS parameters, and the absolute value is composed of the difference between the square of required compensation phase in excitation system and the square of phase provided by PSS. Then use GSAA to design the PSS parameters. Finally, the experimental results for phase compensation problem will be compared with original data setting on Section III. The simulation results show that the GSAA-PSS has a good ability to damp low frequency oscillation and it can meet the demand of control accuracy.

II. PSS PARAMETER OPTIMIZATION PROBLEM

A. The Theory of PSS

Low frequency oscillations, ranging from 0.2 to 3 Hz, appear in power systems when there are power exchanging between large areas of interconnected power systems or when power is transferred over long distances under medium to heavy conditions. PSS is an additional control of generator excitation system working through Automatic Voltage Regulator (AVR). Besides speed deviation as feedback, PSS also can introduce accelerating power deviation ΔP_a and electric power deviation ΔP_e as feedback, and then PSS can compensate lag characteristics of excitation system.

B. PSS Parameter Design

The system considered in this paper is based on Phillips−Heffron (a single machine infinite bus) as shown in

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Fig. 1. It shows that due to a PSS with speed input, the phase compensation block should be designed to compensate the phase lag between the reference voltage of automatic voltage regulator and the electrical torque of generator to ensure the generator angle held constantly. DL/T1231—2013 *Guide for Setting Test of Power System Stabilizer* provision: the torque vector hysteresis of local oscillation frequency should be lag axis of $\Delta\omega$ $0° \sim 30°$. PSS should not cause synchronous torque significantly weakened.

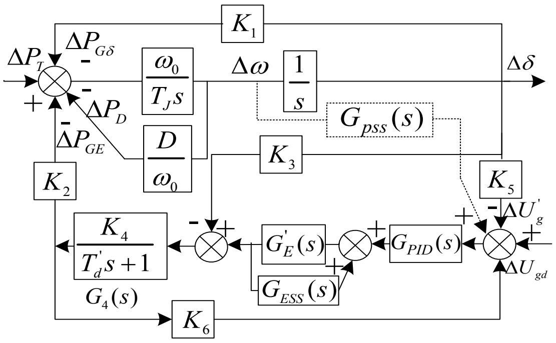


Fig. 1. Phillips−Heffron model of a single-machine infinite-bus power system.

After setting of PSS parameters, electromagnetic torque produced by PSS should be lag the signal of $-\Delta P_e$ 60°~120° in the range of 0.1~2.0Hz frequency. The phase of compensation characteristics of excitation system $\varphi_{ek} + \varphi_{pssk}$ should be around -90°. The phase provided by PSS compensate the phase lag caused by excitation system. That is to say, PSS should provide $-\frac{\pi}{2} - \varphi_e$ to meet the demand of system (φ_e represents the uncompensation characteristics phase of excitation system). Therefore, we provide a optimization model of phase parameters:

$$\min J = \min \sum_{k=0.1}^{2} \left| (-\frac{\pi}{2} - \varphi_{ek})^2 - \varphi_{pssk}{}^2 \right| \qquad (1)$$

$$s.t.\ \ T_{i\min} \le T_i \le T_{i\max} \quad i = 1 \sim 2N$$

where, N is the number of phase compensation block , $k \in [0.1, 2]$ Hz is low frequency oscillation frequency, φ_{ek} is the corresponding phase of uncompensation characteristics of excitation system, φ_{pssk} is the corresponding phase provided by PSS, T_i is the time constant of phase compensation block.

III. PARAMETERS OPTIMIZATION OF PSS BASED ON GSAA

A. Genetic Simulated Annealing Algorithm

GSAA makes use of the characteristic of Simulated Annealing Algorithm that can accept the worsen solution to overcome the shortcoming of Genetic Algorithm that premature convergence, so that Genetic Algorithm can achieve the global optimal solution. Meanwhile, Genetic Algorithm can overcome the downside of Simulated Annealing Algorithm that depends on the parameters of cooling schedule, so that Simulated Annealing Algorithm is robust to parameters (see Fig. 2).

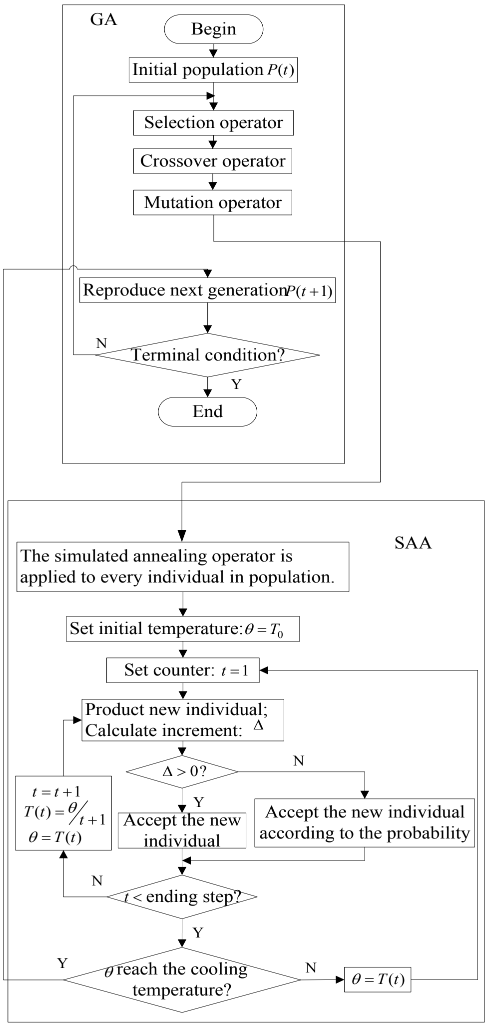


Fig. 2. Flowchart of optimization.

B. Optimizing Parameters of PSS Model by the GSAA

There are two models of PSS recommended by IEEE standard [9]: one is PSS1A and the other one is PSS2A. The rationality of the model of PSS parameters directly influence the effect of the phase compensation. When design the PSS parameter , the frequency or speed channel will not be needed to consider , we only consider the channel of electric power u_{S12} shown in Fig. 3.

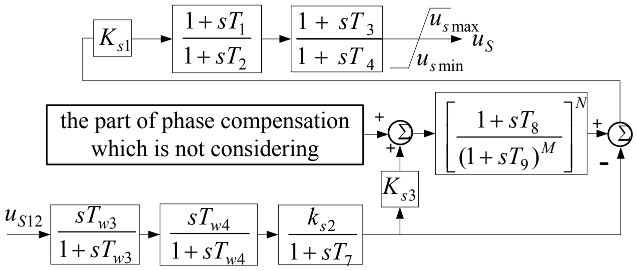


Fig. 3. PSS2A phase compensation block diagram.

The purpose of this paper is to optimize the parameters of a simple structure PSS such that adequate damping is provided for a wide range of operating conditions. Therefore, the widely used structure of the Conventional PSS made of a double stage lead-lag unit, a double stage blocking unit and a washout is used to stabilize the system. The PSS can be described as:

$$\begin{aligned} G_{PSS}(s) &= K_{S1}G'_{PSS}(s) \\ &= K_{S1}\frac{sT_{W3}}{1+sT_{W3}}\frac{sT_{W4}}{1+sT_{W4}}\frac{K_{S2}}{1+sT_7}\frac{1+sT_1}{1+sT_2}\frac{1+sT_3}{1+sT_4} \end{aligned} \quad (2)$$

where, K_{s1}, K_{s2} are the gain that provides adequate damping to the system; T_{w3}, T_{w4} are the blocking time; T_7 is the washout time; $T_1 \cdots T_4$ are the time constants (with no units).

In this paper, we are mainly designing the four time constants T_1, T_2, T_3, T_4 of lead-lag unit. The parameters' value directly determine whether the phase compensation provided by PSS meet the demand of system. Nonlinear mathematical expressions of PSS can be described as:

$$\begin{aligned} \varphi = 90 + (&\arctan 2\pi f T_1 + \arctan 2\pi f T_3 - \arctan 2\pi f T_2 \\ &- \arctan 2\pi f T_4 - \arctan 2\pi f T_{w3} - \arctan 2\pi f T_7)180/\pi \end{aligned} \quad (3)$$

20 group 1 d data is obtained by 20 times: f_i, φ_i, i = 1, 2,..., 20. We can acquire a set of equation A general form of valuation issue for PSS parameters:

$$\begin{cases} \min f(\overset{p}{x}) \\ a_i \le x_i \le b_i \quad i = 1,2,3,4 \end{cases} \quad (4)$$

The objective function $f(\overset{p}{x})$ is a norm of value error of measured value and PSS model parameter. The theoretical value is zero. Decision variable $\overset{p}{x}$ is PSS parameters to be estimated $(x_1, x_2, x_3, x_4)^T$. $[a_i, b_i]$ is the change interval of initial parameters' value.

The process of optimizing parameters of PSS model designed by the GSAA is as follows:

1) Initial population $P(0)$ is make up of N initial point which is randomly generated (This study selects the real number coding scheme). Setting up the annealing parameters (Including initial temperature T_0 and evolution algebra k = 0, maximum evolution algebra k).
2) From the beginning of $k = k+1$, carry out the following operations: (a) Introduce SA operator. Every individual of the population $P(k)$ is optimized respectively by SA method when the temperature is T_0, and then a new population $P(k+1)$ will be generated. (b) Calculate the individual adaptive value $F_i = 1/f_i$ in the new population $P(k+1)$. f_i is corresponding objective function of the individual i. Obviously, the smaller the objective function value is, the better the performance of the individual is. (c) Introduce Metropolis criterion. Crossover operation is performed with probability P_c and determine whether to accept a new individual. If the new the offspring is superior to the parent, the new the offspring will replace the parent. (d) Similarly, processing interlace operation using the probability P_m. The criterion is the same with (c).
3) The judgment of convergence condition. If the adaptive value of several generations is not exceeding precision ε or have been completed the evolution algebra K, the loop termination will be over. The optimal solution is the individual of adaptive value of current population. Otherwise, the temperature parameters will be reduced according to the temperature parameters $T_0 = \alpha T_0$. Going to (2).

Related parameters of GSAA are setted to as follows: The number of iterations = 200; Population size = 300; Crossover rate P_c = 0.6; The mutation rate P_m = 0.02; Annealing rate v = 0.9. The scope of undetermined parameters as set to: $T_1, T_3 : [0, 2]$, $T_2, T_4 : [0.01, 0.2]$. According to the parameters settings, we can fit the parameters by using GSAA.

IV. PSS PARAMETERS OPTIMIZATION AND NONLINEAR TIME-DOMAIN SIMULATION

The parameters of single machine infinite power system as follows: x_d = 0.9694, x_q = 0.659, x'_d = 0.3582, x_e = 0.4, D = 2, T_j = 2.16, T'_{do} = 2.16, U = 1. Considering the objective functions given in (1), the proposed approach employs GSA algorithms to solve this optimization problem and search for an optimal set of PSS parameters, the operating conditions are considered as: $P = 0.9pu$, $Q = 0.1$, $U_f = 1.1005pu$.

A. Excitation System Phase Frequency Characteristics Analysis

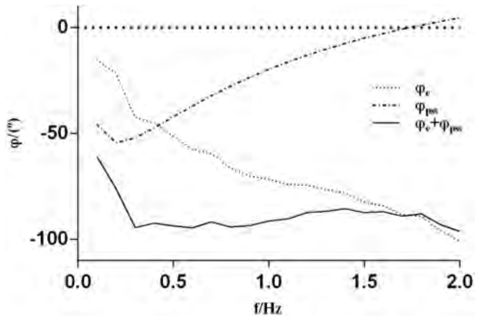
First, we should measure the phase of uncompensation characteristics of excitation system when the generator operating in the full load condition. Then the PSS parameters will be designed using the data showed in Table I: GSAA-PSS. The leading phase φ_{pss} provided by PSS will be obtained through calculating. Therefore, we can receive the phase of compensation characteristics of excitation system $\varphi_e + \varphi_{pss}$ through making φ_{pss} and φ_e together (see Fig. 4).

According to the terms of the DL/T1231 2013, the positive damping torque provided by PSS make the compensation characteristics phase of excitation system lag axis of $-Pe$ 60° ~120° in the range of frequency $0.1 \sim 2\,\text{Hz}$. It is the best situation if the compensation characteristics phase of excitation system lag axis of $-Pe$ -90° in the same range.

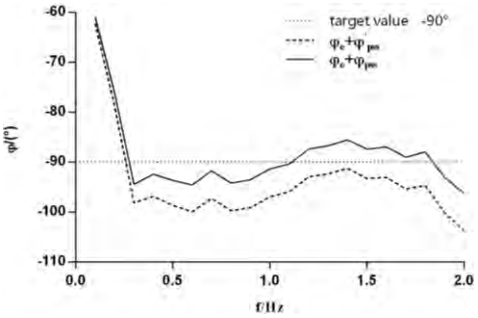
At the moment, we compare the curve of the compensation characteristics phase of excitation system showed in Fig. 5(b). Solid line $\varphi_e + \varphi_{pss}$ represents the curve of the compensation characteristics phase of excitation system designed by GSAA-PSS. Dashed line $\varphi_e + \varphi'_{pss}$ represents the curve of the uncompensation characteristics phase of excitation system designed by Org-PSS. From Fig. 5(b) we can see that the solid curve, which represents the compensation characteristics phase of excitation system, fluctuations around -90° in the range of frequency $0.1 \sim 2\,\text{Hz}$ .That is to say, the optimized PSS completely meet the standard requirements. Thereby, the effect of phase frequency characteristics of compensation characteristics of excitation system is very ideal.

TABLE I: PARAMETERS OF PSS

PSS	T_1	T_2	T_3	T_4
Org-PSS	0.15	0.02	0.1	0.02
GSAA-PSS	0.2	0.01	0.06	0.01



(a) $\varphi_e + \varphi_{pss}$



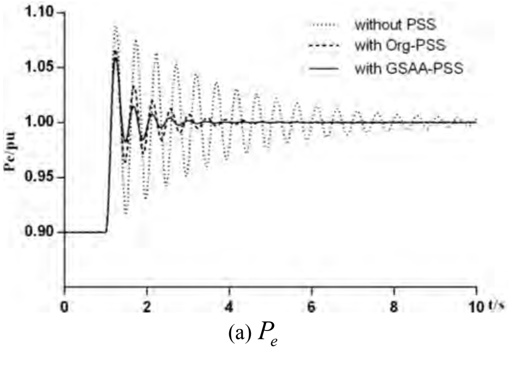
(b) compare $\varphi_e + \varphi_{pss}$ and $\varphi_e + \varphi'_{pss}$

Fig. 4. Phase diagram of compensation characteristic.

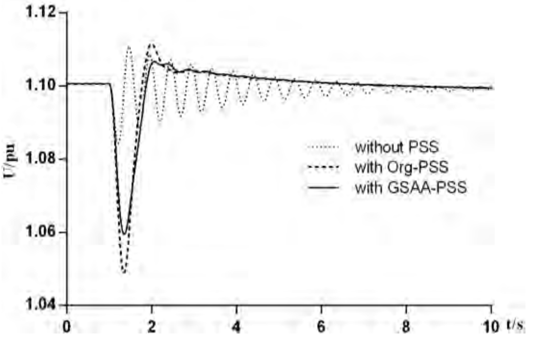
B. Nonlinear Time-Domain Simulation

In order to verify the effectiveness of PSS parameter designing method, we regard a hydroelectric power station no. 1 generator setting in southern power grid as an engineering example. PSS2A model is used in this hydroelectric power station no. 1 generator. According to the rules of DL/T1231—2013 *Guide for Setting Test of Power System Stabilizer*, we solve the objective function through the method proposed by this paper.

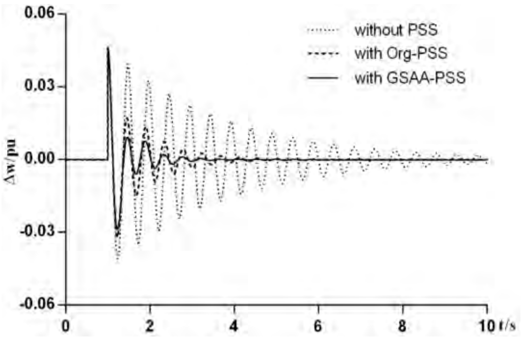
The performance of the designed GSAA-PSS was investigated on a power system model of a single-machine infinite-bus power system. For time-domain simulations, one scenario has been considered to demonstrate the effectiveness and the robustness of the proposed PSS. The system is submitted to a small disturbance by applying 10% step change in the active power. The active power ,terminal voltage and speed deviation of generator due to designed PSS for this scenario are shown in Fig. 5.



(a) P_e



(b) U_f

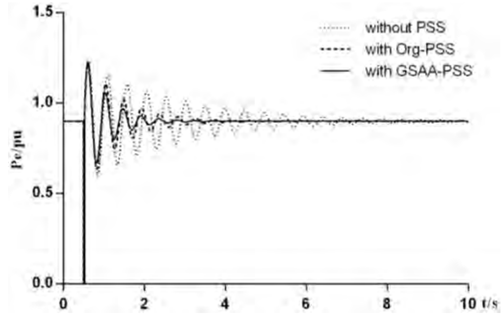


(c) $\Delta\omega$

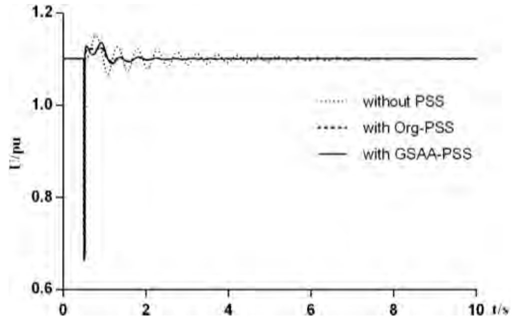
Fig. 5. System responses to P_e regulated.

With the generator operating at an active power of 0.9 *pu* and a reactive power of 0.1 *pu* applying 10% step change in the active power was applied in the machine. System response without PSS and with the Org-PSS and GSAA-PSS under the same condition was shown in Fig. 5(a). The system without PSS is highly oscillatory. Although the Org-PSS is effective in damping the oscillations, the GSAA-PSS settles the oscillations smoothly and quickly. It can be seen that all controllers are able to damp the oscillations and improve the system dynamic stability. GSAA-PSS settles within 2.8 seconds with less overshoots and undershoots. However Org-PSS settles within 3.5 seconds. Fig. 5(b) shows the responses of the terminal voltage whereby GSAA-PSS significantly outperforms Org-PSS with less overshoots and undershoots and a faster settling time. And both of them are better than the system without PSS. Fig. 5(c) indicates using the parameters obtained by the proposed method can more effectively quell oscillations than the original parameters.

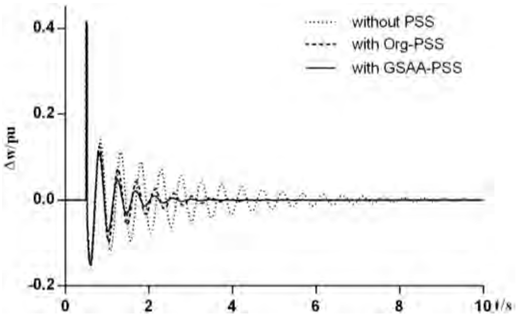
Fig. 6(a) shows that when there is a serious disturbance in the same power system, the system with PSS can rapidly improve the system damping and restrain the system oscillation; can reactive power to enhance the transient stability and the ability of resisting disturbance. Compared with the Org-PSS method, the GSAA-PSS method ensures that the overshoot amplitude of every state variable and adjusting time is better. Fig. 6(b) shows that the system with PSS can quickly and effectively maintain system voltage stability; can prevent generator terminal voltage rise caused by load disappeared or speed rise. Fig. 6(c) show the system with PSS can rapidly improve the system damping and restrain the system oscillation; can stabilize the generator speed and improve the power-angle stability in a short time; can prevent the generator out-of-step phenomenon caused by the sudden load rejection.



(a) P_e



(b) U_f



(c) $\Delta\omega$

Fig. 6. System responses to a three phare fault.

V. SUMMARY

We optimized the PSS parameters by a GSAA whose evaluation function considers the oscillation of the phase angle. The problem of tuning the parameters of the PSS has been converted into an optimization problem. We carried out simulations for 5% step change in the reference voltage at light and heavy operating points to verify the robustness of the GSAA-PSS. Modal analysis shows that all the PSSs are capable of improving the dynamic stability of the system. In particular, GSAA-PSS performs better than Org-PSS for all cases that have been discussed. These results have been validated in Time domain simulations where GSAA-PSS outperformed Org-PSS with faster settling times and less overshoots and undershoots.

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