

Tuning Approach for Power System Stabilizer PSS4B using Hybrid PSO

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Abstract. As a multi-band PSS, PSS4B draws wide attention for its great potential in constraining the ultra-low frequency oscillations. In this paper, the crossbreed operation in genetic algorithm is introduced to particle swarm optimization (PSO) algorithm to form a hybrid PSO, so as to optimize PSS4B parameters. According to the single machine infinite system model, the phase frequency characteristic of excitation system without compensation is calculated by Heffron-Philips model. Based on phase frequency characteristic, the PSS4B parameters are tuned and excellent phase compensation effect is obtained. In Matlab/Simulink platform, the time domain dynamic response without PSS, adding PSS2B and PSS4B is compared and analyzed in detail. Simulation results show that the optimized PSS4B can provide effective damping in different frequency bands and have strong applicability.

1. Introduction

With the interconnection of China's large-scale power grids and high-gain excitation systems being put into operation, the level of system damping is continuously declining, which increases the dynamic stability risk of the power system [1].

Since the PSS2B power system stabilizer can't take into account both the high-band and low-band suppression effects on oscillations [2], a multi-band power system stabilizer is proposed by Hydro-Québec, which is included in the IEEE standard and named PSS4B [3]. The literature [4] proposed a phase and amplitude coordination tuning method for PSS4B parameters, but the phase compensation effect of the low frequency band still needs to be strengthened. In literature [5], one parameters tuning method for only the high-frequency band time constants is proposed, but the method is dependent on the experience of the engineering staff. To enhance the damping of the rotor oscillations and system stability, an efficient tuning approach known as harmony search algorithm is applied to PSS4B stabilizer [6]. Rimorov D *et al.* present a methodology for PSS4B parameters optimisation based on an improved modal performance index. By taking the proposed modal performance index as objective function, the properly selected constraints ensure stability of the closed-loop system and robustness of the proposed design [7]. In [8], the parameters to be optimized for PSS4B are divided into two kinds. Based on the particle swarm optimization (PSO) algorithm, a method of optimizing two types of parameters in turn is proposed. However, the method has a large amount of calculation and the process is relatively complex.

In this paper, a hybrid PSO is employed to optimize PSS4B parameters. Firstly, a single machine infinite system model is established, and the phase frequency characteristic of excitation system



without compensation is calculated based on the Heffron-Philips model [9]. Then, producing the largest positive damping torque by PSS is chosen as the goal, the hybrid PSO algorithm is used to convert the problem into a set of PSS4B parameters optimization process with inequality constraint. Finally, the dynamic response characteristics without PSS, adding typical PSS2B [3] and PSS4B are compared in detail. It shows that the optimized PSS4B has good low-frequency oscillation suppression effect over a wide frequency range.

2. PSS4B parameter optimization model

2.1. Optimization variables of PSS4B

According to the center frequency method [3], the PSS4B parameters setting are mainly reflected in the center frequency F_L , F_I , F_H and the corresponding band gains K_L , K_I , and K_H . The two-stage lead-lag phase compensation time constants for three frequency bands are optimization variables to be tuned, as shown in Fig. 1.

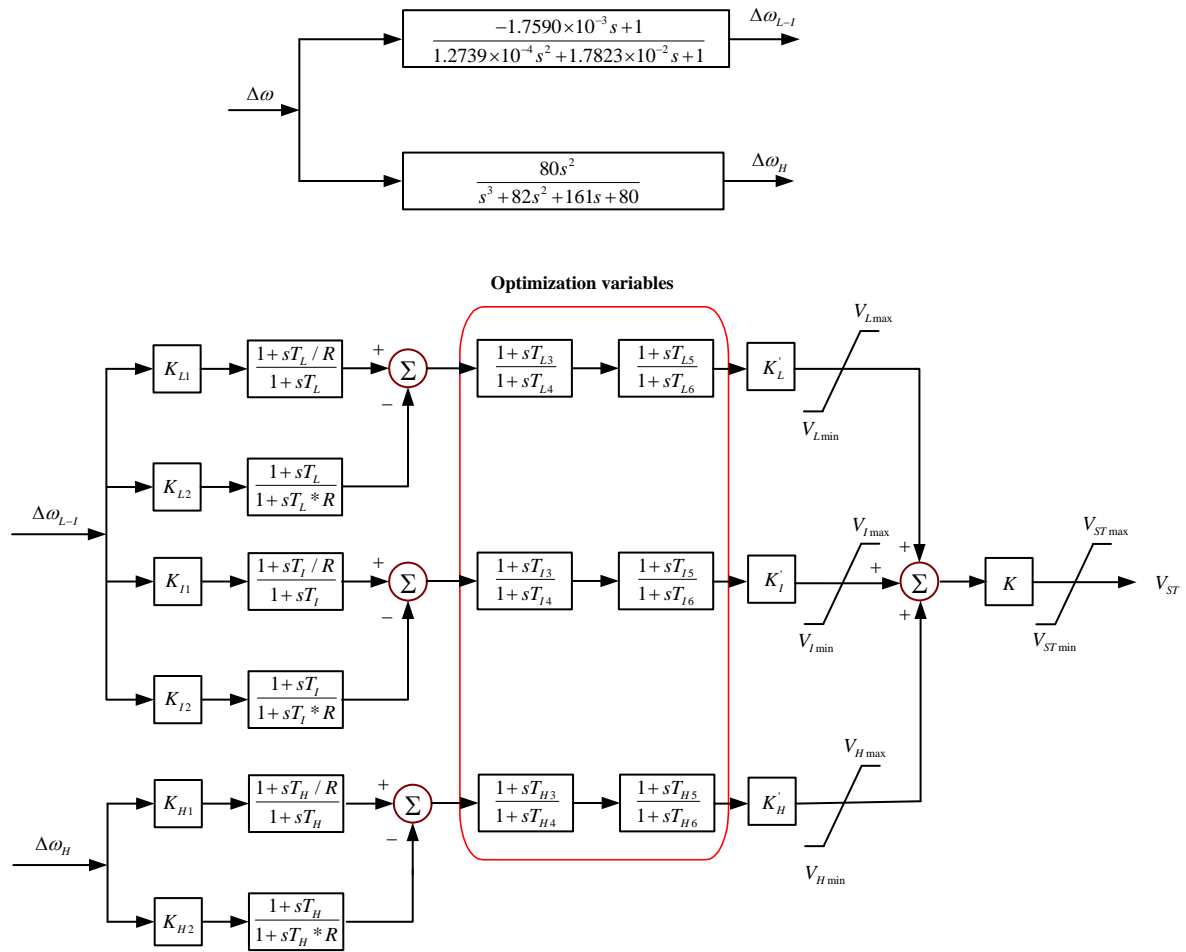


Figure 1. Optimization variables of PSS4B.

2.2. Hybrid PSO algorithm implementation process

According to the principle of phase compensation [9], the additional torque generated by PSS is in phase with the $\Delta\omega$ axis to generate the maximum positive damping torque. Assume the phase-frequency characteristic of the excitation system without compensation is φ_x , and the phase-frequency characteristic of PSS4B is φ_s . Then the phase setting relationship between the two phase-frequency characteristic is

$$\varphi_x + \varphi_s(\Delta\omega) = 0^\circ \quad (1)$$

And the objective function of the optimization model is as follows:

$$\min J = \sum_{n=1}^N |\varphi_x(f_n) + \varphi_s(f_n)| \quad (2)$$

with

$$\begin{cases} 0.04\text{Hz} < f_n < 2\text{Hz}, \varphi \in [-15^\circ, 15^\circ] \\ T_{L3}, T_{L4}, T_{L5}, T_{L6} \in [0.0001, 10] \\ T_{I3}, T_{I4}, T_{I5}, T_{I6} \in [0.0001, 10] \\ T_{H3}, T_{H4}, T_{H5}, T_{H6} \in [0.0001, 10] \end{cases} \quad (3)$$

Among them f_n is the frequency point within the low-frequency oscillation range of 0.1~2.0Hz, $T_{k3} \sim T_{k6}$ ($k=L, I, H$) are the two-stage lead-lag phase compensation time constants of PSS4B, namely the optimization variables.

The PSO initializes a group of random particles whose number of particles is N . All particle positions and velocities are vectors determined by the particle dimension D , and all particles have a fitness value determined by an optimized function, namely the fitness function. In each iteration process, all particles derive the individual optimal solution ***pbest*** and the population optimal solution ***gbest*** according to the fitness function, and update the velocity and position according to the following formula:

$$v_{i,j}(t+1) = wv_{i,j}(t) + c_1r_1[pbest(t) - x_{i,j}(t)] + c_2r_2[gbest(t) - x_{i,j}(t)] \quad (4)$$

$$x_{i,j}(t+1) = x_{i,j}(t) + v_{i,j}(t+1) \quad (5)$$

$$X_i = [x_{i,1}, x_{i,2}, \dots, x_{i,D}], i = 1, 2, \dots, N \quad (6)$$

$$V_i = [v_{i,1}, v_{i,2}, \dots, v_{i,D}], i = 1, 2, \dots, N \quad (7)$$

Where w is inertia weight, c_1 and c_2 are positive learning factor, r_1 and r_2 are uniformly distributed random numbers between 0 and 1.

In this paper, the crossbreed operation in the genetic algorithm is used to select a specified number of particles to be placed in the hybridization pool, according to the probability of crossbreed in each iteration process. The parent particles produce the same number of progeny particles, and the parent particles are replaced with the progeny particles to form a hybrid PSO algorithm. If the set number of iterations is satisfied, the search is stopped and the optimal solution ***gbest*** of the population is given.

In the PSS4B parameter optimization model, the time constants $T_{L3} \sim T_{L6}$, $T_{I3} \sim T_{I6}$, and $T_{H3} \sim T_{H6}$ for three bands are optimization variables, *i.e.*, a set of particles of the hybrid PSO algorithm, and the dimension is 12. The process of this optimization algorithm is shown in Fig. 2.

3. Simulation example and verification

3.1. Phase-frequency characteristic of excitation system without compensation

In order to test the low-frequency oscillation suppression effect of the PSS4B, a single machine infinite system model is built in Matlab/Simulink platform. The apparent power of the generator is 200MVA and rated voltage is 13.8kV.

The literature [9] pointed out that the theoretical phase-frequency characteristic of excitation system without compensation is the phase angle characteristic between the voltage superposition point and the torque ΔM_{e2} on the Heffron-Philips model, as shown in Fig. 3. According to the infinite system model, the operating conditions of the generator can be obtained. The Heffron-Philips model with open-loop power angle in Fig. 3 can be used to plot the phase-frequency characteristic of excitation system [9], as shown in Fig. 4.

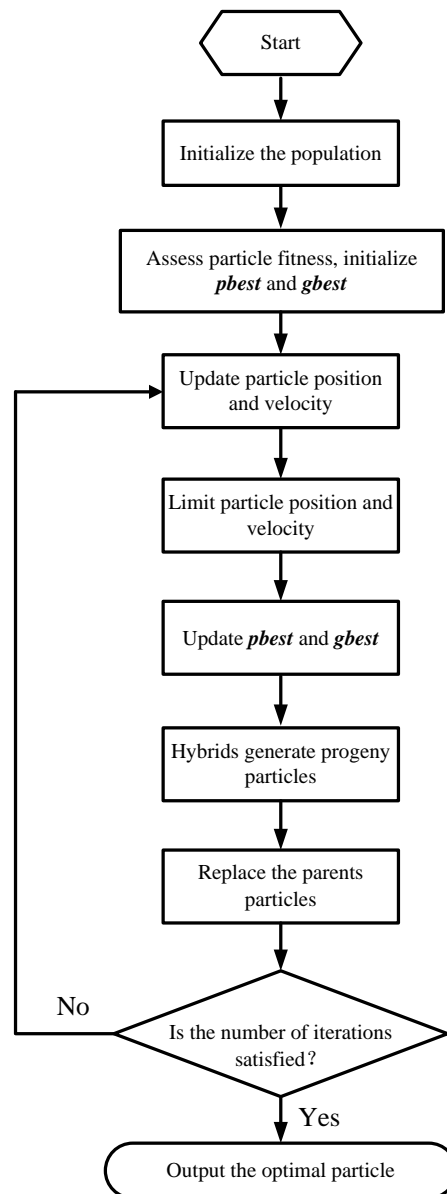


Figure 2. The flowchart of Hybrid PSO Algorithm.

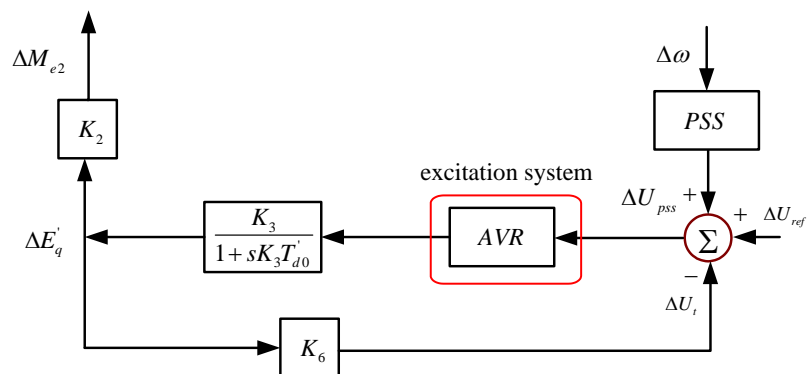


Figure 3. Heffron-Philips model with open-loop power angle.

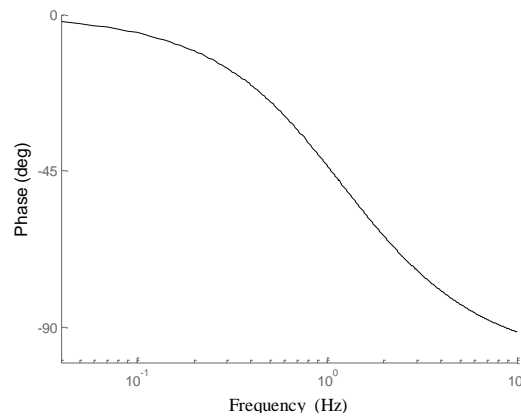


Figure 4. Phase-frequency characteristic of the excitation system without compensation.

Based on the phase-frequency characteristics in Fig. 4, the PSS4B parameters optimization model is used to obtain the optimized parameters. Select the centre frequency and band gain of PSS4B with $F_L = 0.04\text{Hz}$, $F_I = 0.6\text{Hz}$, $F_H = 6\text{Hz}$ and $K_L = 20$, $K_I = 40$ and $K_H = 80$. The optimization results for three bands are $T_{L3} = 1.4460$, $T_{L4} = 1.8800$, $T_{L5} = 1.6662$, $T_{L6} = 0.8213$; $T_{I3} = 0.7656$, $T_{I4} = 1.2222$, $T_{I5} = 1.3091$, $T_{I6} = 1.4657$; and $T_{H3} = 0.8442$, $T_{H4} = 0.0001$, $T_{H5} = 0.0628$, $T_{H6} = 0.6676$.

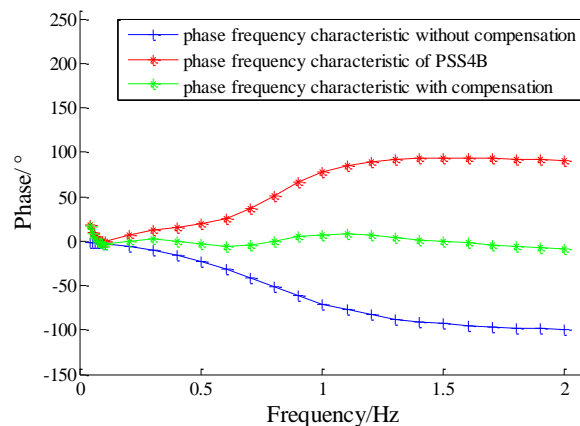


Figure 5. Phase-frequency characteristic of excitation system with compensation after PSS4B parameters optimization.

After optimizing the PSS4B parameters, the phase-frequency characteristics of excitation system with compensation in the frequency range of 0.04~2.0Hz is shown in Fig. 5. It can be seen that the phase-frequency characteristic of excitation system with compensation is close to zero, which means the phase compensation effect is very good.

3.2. Time domain dynamic response

In the Matlab/Simulink single machine infinite system model, the band gains K_L , K_I , and K_H are changed in the same proportion, and the final gain value of the PSS4B can be determined by the critical gain method. According to Heffron-Philips model, the natural oscillation frequency of the generator is determined by the mechanical inertia. Therefore, the oscillation mode at different local oscillation frequencies can be simulated by modifying the inertia moment of the generator. A 5% step test is conducted on the excitation voltage of the generator, and the damping effects without PSS, adding typical PSS2B [3] and optimized PSS4B are compared at four typical frequencies 1.6Hz, 0.77Hz, 0.34Hz and 0.1Hz. The simulation results are shown in Fig. 6.

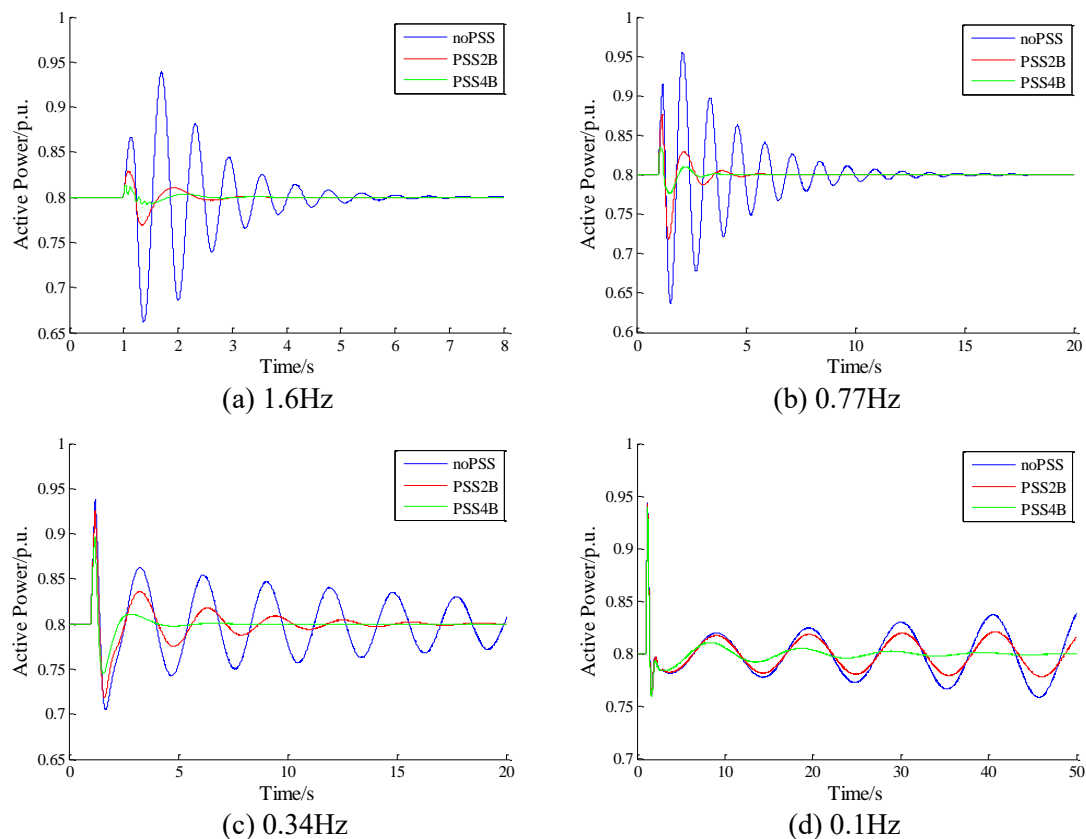


Figure 6. Dynamic response results comparison at different oscillation frequencies.

When the local oscillation frequency is 1.6Hz and 0.77Hz respectively, the excitation system can suppress the oscillations effectively with PSS2B and PSS4B, and the PSS4B has better effect.

As can be seen from Fig. 6(c), when a large inertia moment is set, the local oscillation frequency gradually decreases. Adding PSS2B requires longer time to suppress oscillations, while adding PSS4B can suppress the power oscillation within one and half cycle. When the local oscillation frequency is 0.1Hz, system without PSS has begun to oscillate, and PSS2B can't quell the power oscillation. At this time, the PSS4B can still calm oscillation down within three cycles. Dynamic response results comparison shows that optimized PSS4B can suppress low-frequency oscillations in a wider frequency range and improve the stability of the system.

4. Conclusions

In this paper, a hybrid PSO algorithm is applied to the parameters optimization process of PSS4B. The time domain simulation results without PSS, PSS2B and optimized PSS4B are compared in the single-machine infinite system simulation model. The results show that the PSS4B optimized by hybrid PSO algorithm has good low-frequency oscillation suppression effect over a wide frequency range. In the future, we will focus on the application of PSS4B in multi-machine systems.

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