Power System Stabilizer Parameters Optimization Using Immune Genetic Algorithm

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Abstract. In the past few decades, the power system stabilizer (PSS) is widely used as the most efficient and economical measure to suppress the low frequency oscillation. The optimal parameters of PSS is of great significance for improving the stability of power system. This paper uses immune genetic algorithm to optimize the PSS parameters of a single machine infinite bus power system (SMIB). The result shows that the immune genetic algorithm is superior to the traditional genetic algorithm in restraining the damp oscillations caused by disturbance.

1. Introduction

In recent years, with the continued development of China's economic construction, expanding power systems, the operating constraints of modern integrated power system are increasing. The application of grid interconnection, heavy-duty, fast automatic voltage regulator will reduce system damping. When the damping becomes weaker or even negative, it's easy to arise low frequency oscillation phenomenon. As the main measure to suppress low frequency oscillation phenomenon, the power system stabilizer (PSS) is widely used.

PSS is an additional part of the excitation regulator. Its purpose is to generate a damping torque for the synchronous machine to suppress the system's low-frequency oscillation [1]. Its input signal is usually the speed/frequency/power of the synchronous generator, and the output signal is used as an additional signal input of the excitation voltage regulator.

Several approaches based on modern control theory have been applied to PSS design problem. These include optimal control adaptive control, variable structure control and intelligent control [2]. With the development and promotion of intelligent algorithms, various intelligent optimization algorithms are increasingly involved in the design and coordination of power system stabilizer parameters, such as fish school algorithms, simulated annealing algorithms, genetic algorithms, neural networks, particle swarm algorithms, etc. In [3], the gradient class method is taken to research the optimal configuration of PSS under the muti-operation mode, however, the calculation results are easily trapped in local extremes. In [4], PSS parameters are adjusted by mean of fuzzy logic method based parameter tuner according to on-line measurements. In [5], the NSGA2 algorithm is used to propose two objective functions with the largest damping ratio and the smallest real part of the eigenvalue, forming a multi-objective mathematical model of PSS. Several literatures have been proposed using the genetic algorithm (GA) to tune PSS [6-10]. In [6], the GA is adopted, but its convergence is not good, moreover, it needs to optimize two objective functions at the same time, which causes its poor operability. The artificial intelligence method is still in the preliminary stage in the design of PSS and has not been put into actual production and operation. It needs to be further studied.

The objective of this paper is to find optimal parameters of PSS by immune genetic algorithm (IGA) to guarantee the stability of the system when the perturbation appears on the system. It is applied on a single machine infinite bus (SIMB) power system model. Simulation shows that IGA can achieve better results than traditional GA.

The rest of the paper is organized as follows. The power system model is described in section 2. The immune genetic algorithm is introduced in detail and it's method of optimizing power system stabilizer parameters is described in section 3.Then the simulations results are discussed in section 4.Finally, the conclusion is presented in section5.

2. Power system model

2.1. Synchronous machine model

Fig.1 present the single machine infinite bus (SMIB) power system. The system consists of a single machine equipped with PSS connected to the network through transmission lines.

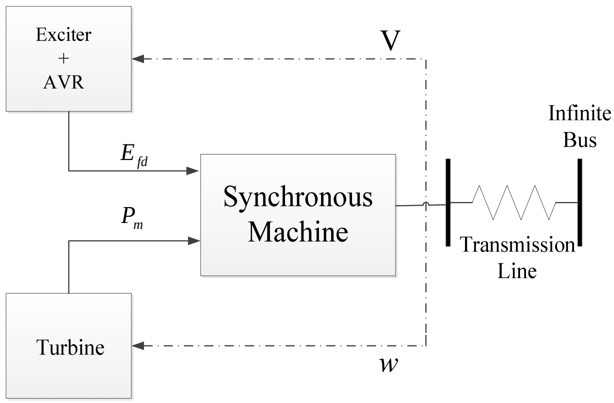

Figure 1. SMIB power system.

Linearizing the stable operating point of the system, we can write the incremental equation of the system state variable, and obtain the dynamic equations of the synchronous generator.

$$\begin{aligned}
&\Delta\dot{\delta} = w_0\Delta\omega \\
&\Delta\dot{\omega} = \frac{1}{M}(-\Delta P_e - D\,\Delta\omega) \\
&\Delta\dot{E}_q^{'} = \frac{1}{T_{d0}^{'}}(-\Delta E_q + \Delta E_{fd}^{'}) \\
&\Delta\dot{E}_{fd}^{'} = -\frac{1}{T_A}\Delta E_{fd}^{'} - \frac{K_A}{T_A}(\Delta V_t - \Delta u_{pss})
\end{aligned} \tag{1}$$

Where δ: the power angle of the generator. w_0: The synchronous machine speed. ω: The rotor speed of the generator. M: the inertia constant. D: the damping constant. P_e: The active electrical power E_q: the EMF in the quadrature axis. $T_{d0}^{'}$: The direct axis transient open-circuit time-constant.

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E'_{fd} : The equivalent EMF in the excitation coil of the generator. T_A : The time-constant of AVR. K_A : The gain of AVR. u_{pss} : The stable control signal of PSS.

2.2. PSS structure

In this paper, the PSS takes the rotor speed deviation of the generator as the input signal and adopts the lead-lag correction model [10].

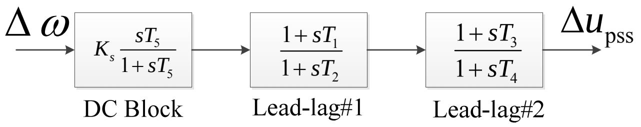

Figure 2. PSS mathematical model.

DC Block: the steady terminal voltage of the machine should not be affected by the change in the steady-state value of the input signal of PSS. Therefore, in the control of the PSS, a DC Block is connected in series, and it can be used in the steady state process for allowing the oscillating signal to pass and its output value is zero when the steady state value is reached.

Lead-lag Link: in order to ensure that a pure damping torque is finally generated by the PSS and the excitation system, the phase of the signal output by the PSS must be more advanced than. In practical applications, two links can be used to compensate the phases of the low frequency band and the high frequency side, respectively.

3. Immune genetic algorithm

In order to solve the problem of poor degradation and convergence of the children generation in the basic genetic algorithm, the immune operation is integrated into a new genetic optimization algorithm. This method is a heuristic random search algorithm combining deterministic and random selection. It is considered as a simple simulation of humoral immunity in biological adaptive immune response. This response process is accomplished through antibody learning antigens [12].

The objective function of the optimization problem in the algorithm corresponds to the invading antigen, and the antibody produced by the immune system represents the solution to the optimization problem.

We can summarize the main stages of the immune genetic algorithm as follows:

(1) Antigen identification: enter the objective function of the practical question to be solved.

(2) According to the range of parameters, the initial antibody population was generated. If the memory cell pool is empty, the initial population is randomly generated; otherwise, the population diversity in the memory cell is calculated, and if the condition is satisfied, the memory cell is extracted, and if the condition is not satisfied, the initial population is randomly generated.

(3) Through the proliferation and differentiation of T cells and B cells, antibodies are produced, and the affinity is calculated to adjust the antibody concentration. In the algorithm, a concentration function is added to the selection operator of the genetic algorithm to adjust the antibody concentration.

(4) Promoting or inhibiting the production of antibodies. The procedure makes sure the antibody with high affinity and low concentration of antigen is promoted; otherwise, the antibody is inhibited.

(5) Searching for the best and worst individuals and randomly add some new antibodies. This can guarantee the convergence of the algorithm and can also jump out of local traps under extreme conditions.

(6) Updating antibody population.

(7) Condition judgment. If the best individual's damping ratio in the antibody population satisfies the requirement or the calculated algebra exceeds the maximum algebra, the calculation is terminated. Otherwise, return to step 2.

The necessary steps of the genetic algorithm can be summarized in the flowchart shown in Fig.3.

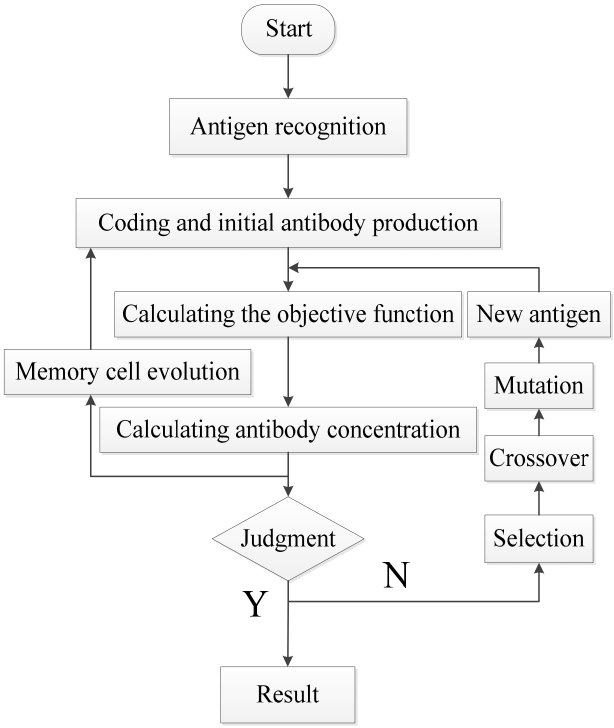

Figure 3. Immune genetic flowchart.

The design problem can be formulated as the following constrained optimization problem, where the constrains are PSS parameter bounds:

$$\begin{aligned} 0.01 \le K_s \le 20 \\ 0.01 \le T_1 \le 0.5 \\ 0.01 \le T_2 \le 0.5 \end{aligned} \tag{2}$$

We have chosen to minimize the variation of the angular speed. According to the objective function J(fitness) defined by the following criterion:

$$J = ITAE = \int t \cdot |\Delta\omega|\, dt \tag{3}$$

The immune genetic algorithm has the function of immune memory, which can ensure fast convergence to the global optimal solution. Increasing the immune operation based on the selection, crossover, and mutation of the basic genetic algorithm will add the possibility that antibodies with lower fitness will evolve to antibodies with higher fitness. By promoting or inhibiting the production of antibodies, the self-regulating function of the immune system is reflected.

4. Result and discussion

In this chapter, we will use MATLAB/SIMULINK to make some analysis of the physical changes of the synchronous machine under specific faults. Through comparison, it is concluded that the immune genetic algorithm optimized PSS parameters have a superior effect on maintaining the stability of the power system.

The parameters of the SMIB power system we used are shown in "Tab.1":

Table 1. The SMIB setting

The synchoronous machine parameters
$X_d = 1.18; X_q = 1; X_d' = 0.295; T_{d0}' = 5.004s; H = 3.2;$ $D = 0; T_J = 7s$
AVR parameters
$K_A = 50;\ T_A = 0.02;\ T_5 = 10; T_3 = 0.3; T_4 = 0.03;$ $E_{Fmax} = 5; E_{Fmin} = -5;$
The system parameters before fault
$V_t = 1; f = 50Hz; P_e = 0.7376; X_L = 0.3$

The original and optimized PSS parameters values are given in "Tab.2"

Table 2. PSS parameter

Parameters	Original values	Optimized values by genetic algorithm (GA)	Optimized values by immune genetic algorithm(IGA)
Ks	5	9.5797	9.7789
T1	0.3	0.4659	0.4274
T2	0.03	0.4790	0.4890

To highlight the PSS parameters optimization by immune genetic algorithm, we apply a default in the SMIB power system.

The following fault sequences are simulated:

(1) The system is in a pre-fault steady state.

(2). Increasing active power input to 1.4pu at 2 seconds.

(3). Restoring active power input to the original state at 3 seconds.

The "Fig.4" to "Fig.7" shows respectively the response variation of the rotor angle δ, the rotor speed ω ,the terminal voltage V_t , the excitation voltage E'_{fd} .

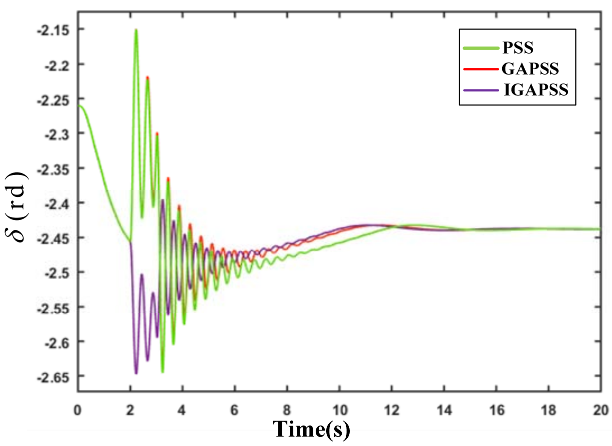

Figure 4. Power sngle responses.

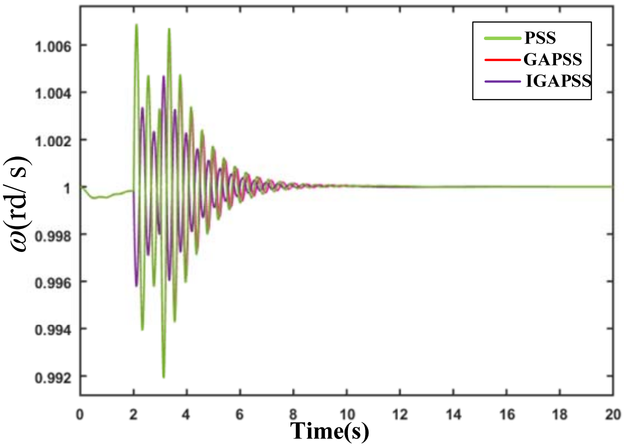

Figure 5. Rotor speed responses.

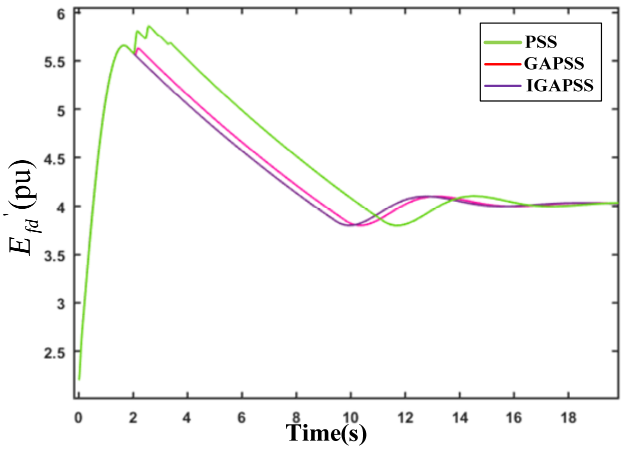

Figure 6. Excitation voltage response

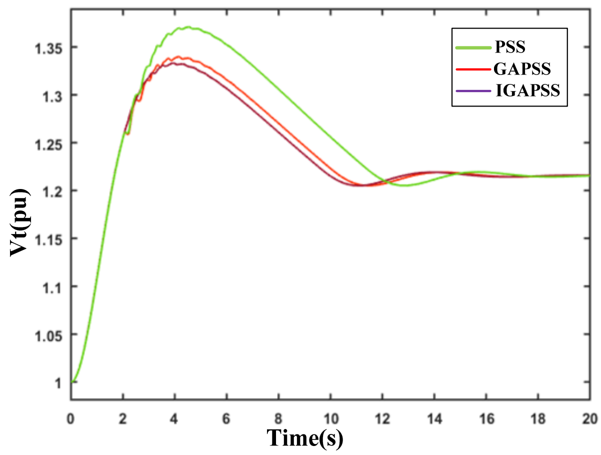

Figure 7. Terminal voltage response

Obviously, the system equipped with a PSS optimized by immune genetic algorithm has a great effect on improving the stability of the system. When a fault occurs, the oscillation amplitude of each physical quantity of the synchronous generator is smaller, and the steady state can be recovered more quickly.

5. Conclusion

This paper introduces the application of immune genetic algorithm in the optimization of PSS parameters. And through simulation analysis, the change of each physical quantity of the synchronous machine configured with different PSS under a given fault condition is obtained.

The above shows that the optimization effect of IGA is obviously better than that of GA. After optimizing the PSS parameters, the stability of the system has been greatly improved.

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