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Ship Power System Optimization based on Differential Evolution Algorithm

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Abstract

Ship power system is an independent power system, its stability is greatly affected by the excitation control system of generator. The adjustment of control parameters depends on the experience accumulated by engineers, which has some limitations. The high cost of real ship test and test results. Therefore, this paper uses MATLAB/Simulink to model and simplify the ship power system, and then uses differential evolution algorithm to optimize the parameters. Finally, the typical operating conditions such as sudden load operation and sudden asynchronous motor operation under a single generator are simulated. The performance of the control system is evaluated using ITEA index. The simulation results show that the differential evolution algorithm has better control effect.

Keywords

Ship Power System; Differential Evolution Algorithm; Parameter Optimization.

1. Introduction

Ship power system is a non-linear, highly synergistic and strongly coupled system composed of power generation equipment, power grid and ship load. Because of the small capacity of the ship power system and the large power of the electrical equipment on board, their stable operation cannot be separated from the stable power supply, so the control quality and control stability of the ship power system become more and more important. This paper uses the Differential Evolution Algorithm (DE) to adjust and optimize the control parameters of the ship power system. By using the control parameters as the population individuals of the DE algorithm, Thus, the positive optimization of control parameters is achieved, and the validity of the method is verified by simulation experiments.

2. Establishment of Simulation Model for Ship Power System

2.1 Model of Marine Diesel Engine and its Speed Control System

The ship's engine and speed control system are modeled using a second-order model.[1] The set and actual speeds are differentiated and entered into the main controller, which combines the main controller with the amplification unit to form a controller of proportional differentiation plus second-order inertia. The output speed of the engine is converted into a torque by integral, and the power signal is obtained by multiplying the torque with the speed. A simulation model is built in the Matlab/Simulink simulation environment as shown in Figure 1.

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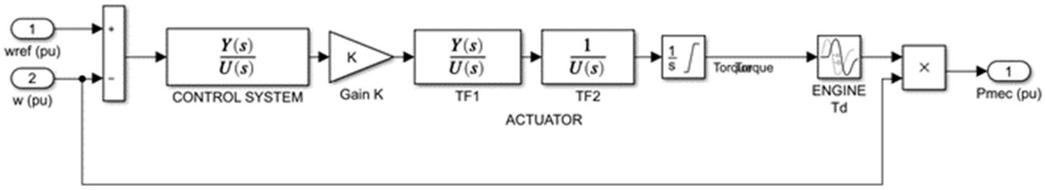

Figure 1. Prime mover and speed regulation system model

2.2 Excitation System Model

Referring to the excitation system model recommended by IEEE,[2][3] the mathematical model of brushless AC excitation system with controllable phase repetitive excitation is established.

1) Mathematical Model of Phase Complex Excitation Device:

$$\mathrm{U_r} = \sqrt{\left(\mathrm{U_d} - K\mathrm{I_q}x\right)^2 + \left(\mathrm{U_q} - K\mathrm{I_q}x\right)^2} \tag{1}$$

Where, $\mathrm{U_r}$ is the output voltage of phase compound excitation device; $\mathrm{U_d}$, $\mathrm{U_q}$ is the armature terminal voltage of d-axis and q-axis of synchronous generator respectively; $\mathrm{K}={}^{9\sqrt{2}}/_{\pi}$; x is phase-shifting reactance.

2) Mathematical model of voltage difference:

$$\begin{cases} \Delta U = \mathrm{U_{ref}} + \frac{\mathrm{U_{f0}}}{\mathrm{K_a}} - \mathrm{U_{tf}} + \mathrm{U_{stab}} - \mathrm{U_{ff}} \\ \mathrm{U_r} = \sqrt{(\mathrm{U_d})^2 + \left(\mathrm{U_q}\right)^2}\,\frac{1}{1+s\mathrm{T_r}} \end{cases} \tag{2}$$

Where $\mathrm{U_{ref}}$ is the voltage regulator reference voltage, $\mathrm{U_{f0}}$ is the initial value of voltage, $\mathrm{K_a}$ is the proportional gain coefficient, $\mathrm{U_{tf}}$ is the phase compound excitation voltage, $\mathrm{U_{stab}}$ is the ground zero voltage, $\mathrm{U_{ff}}$ is the feedback output voltage.

3) Mathematical model of compensator:

$$\mathrm{U_c} = \Delta U\,\frac{1+s\mathrm{T_c}}{1+s\mathrm{T_b}} \tag{3}$$

Where, $\mathrm{U_c}$ is the compensator voltage, $\mathrm{T_c}, \mathrm{T_b}$ are the lead and lag time constants respectively.

4) Mathematical model of amplifier:

$$\mathrm{U_a} = \mathrm{U_c}\,\frac{\mathrm{K_a}}{1+s\mathrm{T_a}} \tag{4}$$

Where $\mathrm{U_a}$ is the amplifier output voltage, $\mathrm{T_a}$ is the time constant.

5) Mathematical model of proportional saturation:

$$\begin{cases} \mathrm{E_{fd}} = \mathrm{U_a} + \mathrm{U_r} \\ 0 \le \mathrm{E_f} \le \mathrm{E_{fmax}} \\ \mathrm{E_f} = \mathrm{E_{fd}} \end{cases} \tag{5}$$

Where E_{fd} is the voltage of the voltage regulator, E_f is the proportional saturation link voltage.

6) Mathematical model of AC exciter:

$$U_f = \frac{E_{fd}}{T_e s + K_e} \tag{6}$$

7) Mathematical model of feedback link:

$$U_{ff} = \frac{sK_f}{1 + sT_{ff}} \tag{7}$$

Where T_{ff} feedback link constant.

3. DE Algorithm

The DE algorithm was proposed by Storn and Price of Berkeley University in 1995.[4] The DE algorithm is a heuristic algorithm based on group search, which uses real number encoding, simple variance operation based on difference and one-to-one competitive survival strategy to reduce the complexity of the algorithm operation. Figure 2 is the basic flow chart of the DE algorithm.[5] The initial population needs to be set up first, the fitness of the population is calculated, the initialization operation is carried out, and then the population is iteratively updated by mutation, crossover and selection to preserve the high-quality individuals. Favors approaching the global optimal solution. Differential evolution algorithm is simple in structure and easy to implement. It has been applied in many fields such as industrial control for parameter optimization of complex systems, and the actual results are satisfactory.

3.1 Alteration Operation

In each generation of search, the DE algorithm generates a target individual $t_i(g)$ for each individual $x_i(g)$ in the current population by mutation.[6] There are many mutation strategies that can be expressed as DE/a/b. Among them, a denotes the type of mutation operation base, Rand and best are two values, Rand denotes random selection of individuals as the basis of mutation operation, best denotes selection of the current optimal individuals as the basis of mutation, and B denotes the number of difference items during mutation, which is generally an integer. The four common mechanisms are as follows:

DE /best /1:

$$V_{i,G} = X_{best,G} + F\left(X_{r_{1,G}} - X_{r_{2,G}}\right) \tag{8}$$

DE /best /2:

$$V_{i,G} = X_{best,G} + F\left(X_{r_{1,G}} - X_{r_{2,G}}\right) + F\left(X_{r_{3},G} - X_{r_{4},G}\right) \tag{9}$$

DE /rand/1:

$$V_{i,G} = X_{1,G} + F\left(X_{r_{2,G}} - X_{r_{3,G}}\right) \tag{10}$$

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DE /rand/2:

$$V_{i,G} = X_{1,G} + F(X_{r_{2,G}} - X_{r_{3,G}}) + F(X_{r_{4,G}} - X_{r_{5,G}}) \quad (11)$$

Where $r_1, r_2, r_3, r_4, r_5 \in \{1,2,\dots,N\}$ is a distinct integer not equal to i, $X_{best,G}$ is the best individual in the g-generation population, and F is the zoom factor between 0 and 1.

3.2 Cross Operation

By replacing some of the variables of the current individual x_i with the strain of the target individual t_i, the test individual v_i is generated, thus retaining the better variables in the individual and enhancing the exploration of local regions. First, a uniformly distributed random number r between 0 and 1 is generated for each variable. If R is less than cr, the corresponding component of the target individual is accepted, otherwise the corresponding component of the current individual is retained. Specifically as follows:

$$v_{i,j}(g) = \begin{cases} t_{i,j}(g) & if\, rand_j[0,1) \le CR or (j = j_{rand}) \\ x_{i,j}(g) & other \end{cases} \quad (12)$$

Where Rand is an integer that is evenly distributed between 1 and d, ensuring that at least one dimension of the component is inherited from the target individual t_i.

3.3 Select Operation

The DE algorithm uses greedy selection, and for test individual $v_i(g)$ and current individual $x_i(g)$, a better choice is made for the next generation. The greedy selection mechanism ensures that the individuals of the next generation are better than those of the current population, so that the average performance of the population is better and the optimal solution is gradually reached.

$$x_i(g+1) = \begin{cases} t_i(g) & if\, f(t_i(g)) \le f(x_i(g)) \\ x_i(g) & other \end{cases} \quad (13)$$

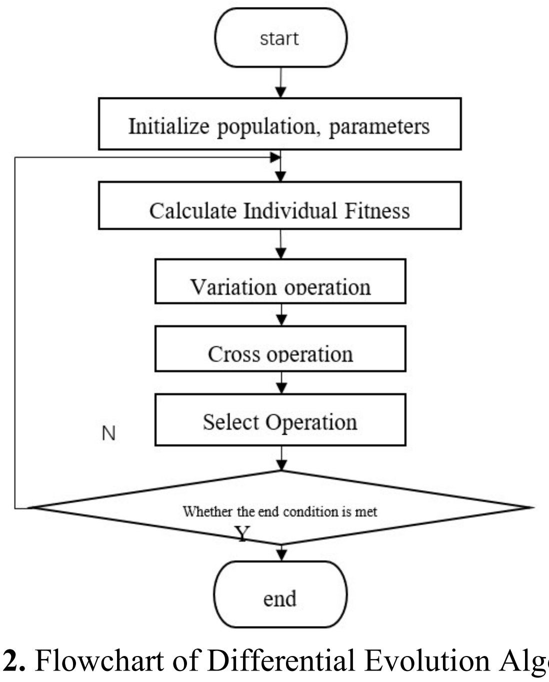

Figure 2. Flowchart of Differential Evolution Algorithms

4. Ship Power System Optimization based on DE Algorithm

The connection between the DE algorithm and the marine power system is a population (i.e. the control parameters of the marine power system), and the corresponding fitness values of the population. The performance index usage (14) of the reference time multiplied by the absolute error integral (ITAE) is used as the fitness value, which reflects the control accuracy and speed of the control system.[7][8][9] The smaller the value, the better, the better is the performance evaluation index of the control system with good engineering practicability and selectivity.

$$J_{ITEA} = \int_0^{\infty} t|e(t)|\,dt \tag{14}$$

Where t is time and e(t) is system error.

This paper uses the system error as the speed difference. Building a simulation model in the Matlab/Simulink simulation environment is shown in Figure 3.

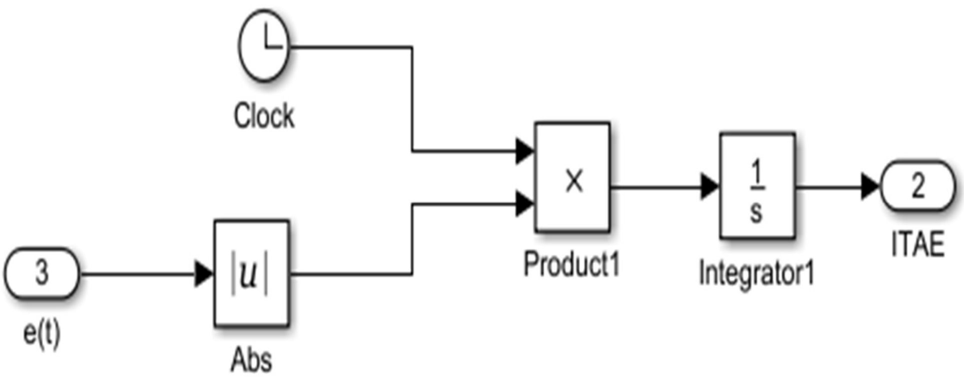

Figure 3. ITAE model diagram

The DE algorithm first randomly generates the initial population, assigns the individual values in the population to the parameters of the ship power system controller, then runs the Simulink model of the ship power system to get the corresponding fitness index of the group parameters, which is transferred to the DE algorithm as the fitness value of the population, and finally decides whether to quit.

Comparing ITEA indices of different methods to set parameters, we can see that DE algorithm with appropriate mutation strategy DE/rand/2 has lower tuning parameters, as shown in Table 1.

Table 1. ITEA Metrics for Different Methods

Raw	DE/best/2	DE/rand/2
0.1213	0.1126	0.5698

The simulation results are shown in the figure below. It can be seen from the result diagram that under the condition of sudden load, the speed fluctuation of the diesel engine with the positive parameters of DE algorithm is smaller than the manual fluctuation, and the time to return to the set value is shorter.

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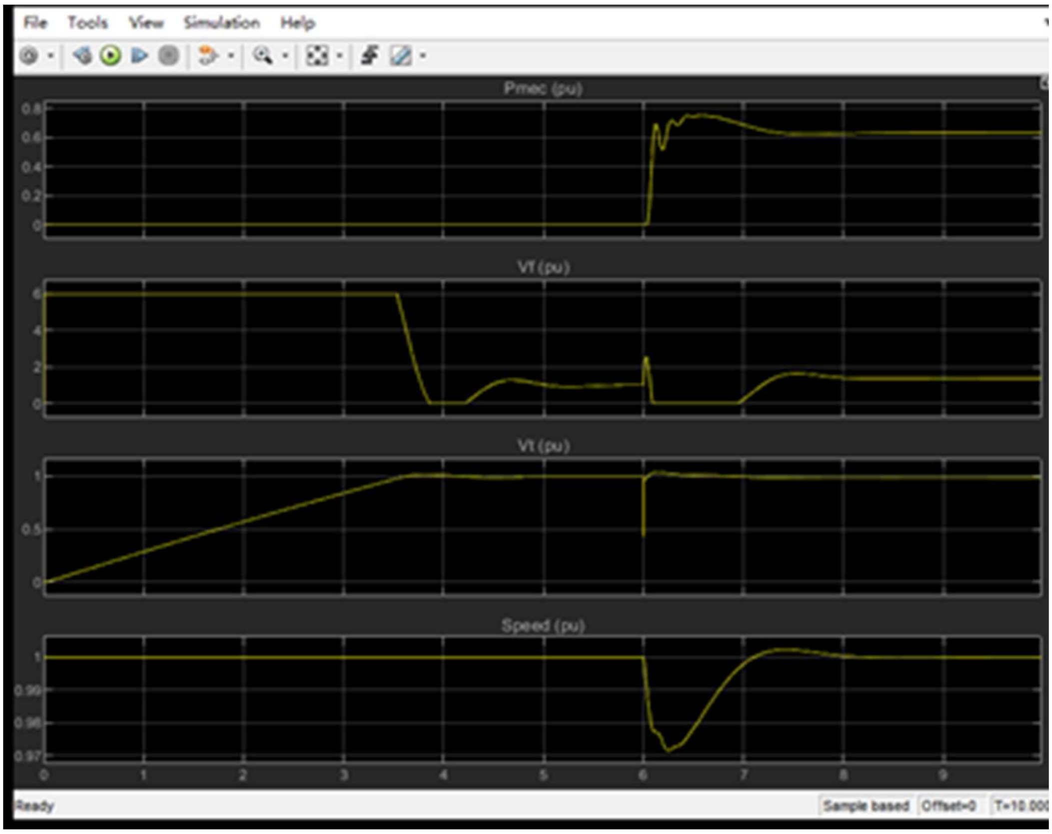

Figure 4. original

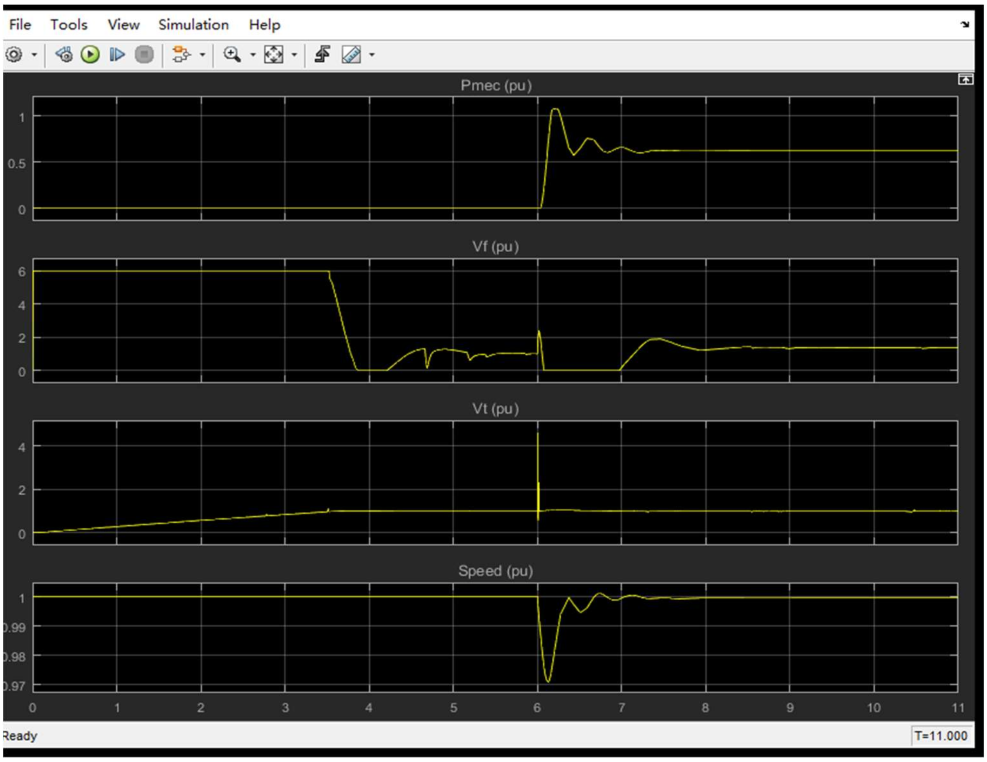

Figure 5. DE/rand/2

5. Conclusion

Through the simulation experiment of ship power system, it can be seen that the control parameters of ship power system optimized by de algorithm can make the ship power system return to the stable

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state faster when suddenly adding load or starting asynchronous motor, and basically achieve the expected index.

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