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Study of Genetic Algorithms on Optimizing PI Parameters in Prime Mover Simulation System

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Abstract

This paper proposes using the genetic algorithms to optimize the PI regulator parameter in the prime mover simulation system. In this paper, we compared the step response characteristics under the conditions of the genetic algorithms and traditional method by MATLAB simulation and field test tested the dynamic characteristics of the prime mover simulation system. The results proved that genetic algorithms can optimize PI parameters quickly .With this method the prime mover simulation system can meet the requirements of dynamic performance simulation

Keywords: Prime mover simulation, PI regulate, Genetic Algorithms, MATLAB simulation, Dynamic characteristic

1. Introduction

The prime mover simulation system is one of the important equipment in power system dynamic simulation, essentially the current speed comprehensive regulator of this system is a PI regulator[1] [2](regulator for short, as shown in the dashed line frame of Fig.1) .A group of suitable PI parameter, i.e., ratio coefficient k_α and integral time constant τ_L[2] [3] [9] is required to provide the prime mover simulation system with good dynamic performance and realize self-balanced characteristic simulation of the prime mover [2].

According to the traditional trial and error process [7], the optimal values of ratio coefficient K_α and time constant τ_L depend on experience and repeated test; Simulating units of different capacity, PI parameters are required to redeploy with different rated output power of the prime mover to maintain the dynamic characteristics as before [9] [10].This is time-consuming, additionally, we must carry on complicated field test. Using genetic algorithm we can obtain optimal PI parameters quickly, which could be directly applied to field operation. Even if the rated output power of prime mover varied, we just need to input new corresponding parameters. Based on these parameters, computer calculates corresponding optimal PI parameters which ensure better dynamic characteristic simulation. This method is not only suitable for the off-line PI regulator parameters calculation, but also the on-line PI parameters calculation of computer prime mover simulation system. We will discuss the genetic algorithm and its application in the prime mover simulation system and simulation tests in the following section.

2. Principle of the genetic algorithms optimizing PI parameters

The genetic algorithm is a optimization algorithm simulating natural selection and evolution process and its basic theorem is: firstly, encode PI parameters and initialize population by certain size, thus, each individual in the population represents a possible solution. Then according to fitness function, compute fitness value of each individual, which can be used to control regeneration operation. Finally perform crossover and variation operation in a probability .Thus, the population continues evaluating till the end of the optimization process [5] [6].

2.1Parameter coding

Encode the parameters need optimizing. Solutions to the control problem are real number, which can be regarded as manifestation of genetic algorithms, therefore it is appropriate to adopt the binary coding. Since the problem is combinatorial optimization problem involves 2 parameters, we may first carry on the binary coding to obtain two sub-strings, then connect these sub-strings to former an integral chromosome, namely individual. K_α and τ_L are parameters satisfied with: $K_{\alpha\min}<K_\alpha<K_{\alpha\max}$, $\tau_{L\min}<\tau_L<\tau_{L\max}$. K_α and τ_L is respectively determined as length of the sub-strings, according to the precision request. Thereupon the coding precision of the 2 parameters, K_α and τ_L is: $\delta_{K\alpha}=\frac{K_{\alpha\max}-K_{\alpha\min}}{2^{L_{K\varepsilon}}-1}$, $\delta_{\tau_L}=\frac{\tau_{L\max}-\tau_{L\min}}{2^{L_{\tau_L}}-1}$. According to experiences, the parameter range of K_α is determined as (0, 10); the parameter rang of τ_L is (0, 1). In this paper we set the value of K_α as precise as 2 decimals. Because the length of interval of K_α is 10-0=10, the interval(0, 10) must be divided into $10*10^2$ equal parts. And furthermore, the coding binary strings of K_α at least need 10 bits, considering $2^9<10*10^2<2^{10}$. Similarly, if we set the value of τ_L as precise as 3 decimals , the coding binary strings at least need 10 bits.

2.2 Control parameters selection[5]

The procure of control parameters selection should ensure high search efficiency as well as the ability to find optimal solution. Generally, M, scale of the control parameter group takes 20~100, cross probability Pc takes 0.4~0.9 and variation probability P_m takes 0.0001~0.1. In this paper , M=50, Pc=0.5, P_m=0.01.

2.3 Initial population generation

Firstly, on the basis of experience, we could determine the possible value of the two parameters: K_α and τ_L, then generate a initial population nearby these two values. With this method, the search spaces reduce rapidly and we can also obtain optimal solution in a short time.

2.4 Determination of object function and calculation of fitness value[5]

The fitness function indicates: the ability of individual adapt to environment is related to the object function we choose. The PI parameter optimization is problem seeking for the minimum value of object function, namely minimize performance index J. Here, J adopt ITAE performance index (integration of the product of time and absolute error): $J=\int_0^\infty t\,|\,e(t)\,|\,dt$ .Since the goal of genetic algorithms is seeking for solutions of the fit max, the object function must be transformed from seeking for the maximum value into seeking for the minimum value. This paper defines fitness function $f=1/f$. Thus, when the fit max has been found, we gain the solution of object function, that is optimization success .We can compute fitness value f_n of each individual n in community M and the total fitness value $\sum_{n=1}^{M} fn$ of the whole community.

2.5 Genetic operation

2.5.1 Selection operation [6]

The core of selection operation is to determinate selection operator, whose function is to choose some quite fine individuals from the current generation of community, and replication them in the next generation. Fitness ratio method is introduced in this paper, namely, the probability of individual to be selected and be inherited to the next generation is proportional to its fitness value. Individuals of big selection probability have more descendants in next generation, others will extinct in the evolution process. Detailed operation process: first computed the total fitness of the community $\sum_{n=1}^{M} fn$, then computed ratio of each individual to be inherited to the next generation: $p_n=fn\Big/\sum_{n=1}^{M} fn$, n=1,2..., M; Finally, the times of each individual to be selected were determined according to the random number from 0 to 1.

2.5.2 Crossover operation

In this paper, we apply single-point cross method to crossover operation. Detailed process as follows: [M/2]=25 pairs of individuals are formed by pairing . For each pair, we randomly define the cross point behind a locus. Consequently, there are L-1=19 possible crossover point in all. Exchange partial chromosomes of the individual at the crossover point with defined cross probability P_c=0.5, thus generate two new individuals.

2.5.3 Variation

In this paper, the basic bit mutation method is introduced to carry on the variation operation .For individual coding string, we randomly define gene value at one or several locus with the variation probability P_m=0.01 to carry on the variation operation. Detailed process as follows: with the variation P_m=0 .01,define each individual locus as a variation point, then employ each gene value of the variation point to complementary operation, thus a new individual generated.

2.6 Generation new population

Evaluate the new population and compute the fitness value of it.

2.7 Judgment of evolution termination condition

We can obtain a new generation of population through replication, crossover and variation .We employ this new population to the fitness function after coded. If the new population satisfies the termination condition, we can get optimal solution, or else, return to the step (5) till the condition is satisfied.

3. MATLAB Simulation and field test

Using the m language of MATLAB to compile corresponding software[11]. Its flow is illustrated in Fig.2:

3.1 MATLAB simulation

Equivalently transform system diagram of Fig.1 to Fig.3. As shown at Fig.3,the transfer function of the controlled object of PI regulator can be expressed as: $G(s)=\frac{k_{scr}\beta/R_a}{(\tau s+1)(\tau_R s+1)(\tau_I s+1)}$

3.1.1 test parameters

Parameters of direct current motor: P_{N1}=38.5KW, U_N=220V,n_N=1000r/min, maximum armature current 150%I_N, its feedback voltage of the direct current motor is 1V,when flowing rated current. The voltage amplification coefficient of thruster rectifier bridge K_0=82.5, the equivalent time-constant of rectifier bridge τ=2ms, total inductance L=2mH, total resistance of Armature circuit R_a=0.055Ω. current feedback filter time constant T_I=1ms;

(1)Transfer function of controlled object by corresponding regulator can be written as: $G_1(s)=\frac{28.50}{0.0394s+1}$

(2): P_{N2}=22KW, other parameters are same as (1); $G_2(s)=\frac{14.9985}{0.0394s+1}$

By means of MATLAB/SIMULINK simulation experiment, we can observe the response waveform at U_o when inputting a step signal at U_i in chart 3 .

3.1.2Contents of experiment

Test 1: Traditional method. The corresponding step response wave form based on different load level (P_{N1}=38.5KW, P_{N2}=22KW) but the same PI parameters (K_a=0.10, τ_L=0.02s) are illustrated in Fig.4-a, b:

Test 2: Genetic algorithms, when different rated power, different PI parameters, considering the following cases (1)Ka=0.21, τ L=0.0364s,(2) Ka'=0.404, τ L'=0.0364s, the corresponding step response waveform is shown in Fig.5-a,b.

Test 3: Genetic algorithms, When different rated power but the same PI parameters (Ka=0.21, τ L=0.0364s), (1)The corresponding step response waveform is shown in Fig.5-a, Fig.5-c.

The results above are arranged in table 1.

*3.2 Dynamic performance tes***t**

The simulation prime mover has been successfully developed and put into field operation. The dynamic performance test was carried on 15KVA simulation generator units, single unit with rated load, unit inertia time constant HJ remained unchanged, taken 4 groups of different combined parameters of the simulation prime mover system, suddenly dropped of 100% load and recorded waveform. The experiment content and its results are illustrated in table 2; the recorded waveforms are shown in Fig.6. Eugene value in the table is approximate value based on the speed waveform, speed overshoot and speed steady change rate are calculated on basis of the speed digital readout. Concussion times are determined based on the degree of speed deviation from stable value. In this experiment, the speed increased and tended to be stable after load rejection, no lower than the steady-state value. Thus, the concussion time is 0.5.

According to the waveform graph and test data, the model parameters of speed control system (δ,TS, T0)had different effects on dynamic characteristic. The law of dynamic characteristic accorded with the practical prime mover system.

4. Conclusion

(1)As the rated power of the simulation prime mover varying, we must readjust PI parameters so that the system maintain the original dynamic characteristics; (Shown in Fig. 4- a, b and Fig.5-a, (c); By means of employing genetic algorithms, we can quickly optimize and adjust the PI parameters, meanwhile, maintain the original dynamic characteristics. Furthermore it could effectively save debugging time and simplify debugging process.

(2)Application of genetic algorithms to determine PI parameters could provide the regulator good dynamic response characteristics (Fig.4- a and Fig.5-a);

(3)The law of dynamic characteristics of the prime mover simulation system accorded with fact, and met the requirements of dynamic simulation test of power system. (Fig.6 and Table.2)

At present, we take off-line calculation as applying genetic algorithm to determine PI parameters. It remains further study and research to realize on-line modification and optimization of PI parameters in the prime mover simulation system controlled by microcomputer.

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Table 1. Dynamic performance of step response simulation test

		overshoot	rise time	waveform	dynamic performance
Same rated power	traditional method	8.5%	1.04	Fig.4-a	poor
	genetic algorithms	0.1%	1.02	Fig.5-a	good
Same PI parameters traditional method	P_{N1}=38.5KW	8.5%	1.04	Fig.4-a	poor
	P_{N2}=22KW	7.6%	1.05	Fig.4-b	poor
same PI parameters Genetic algorithms	P_{N1}=38.5KW	0.1%	1.02	Fig.5-a	good
	P_{N2}=22KW	8.9%	1.07	Fig.5-c	poor
different PI parameters Genetic algorithms	P_{N1}=38.5KW	0.1%	1.02	Fig.5-a	good
	P_{N2}=22KW	0.1%	1.03	Fig.5-b	good

Table 2. Major eigenvalue of system (speed) process with different model parameters

Figure number	δ	TS	T0	Transient time	Over shoot	maximum amplitude time	concussio n times	stability
f	4.7	0.2	0.4	5.0	2.0	1.7	1.0	Ibid.
h	1.5	0.2	0.1	/	/	/	/	shock
e	2.6	0.2	0.3	4.0	2.4	1.2	0.5	Ibid.
g	2.6	0.2	0.4	6.4	3.0	1.5	1.0	Ibid.

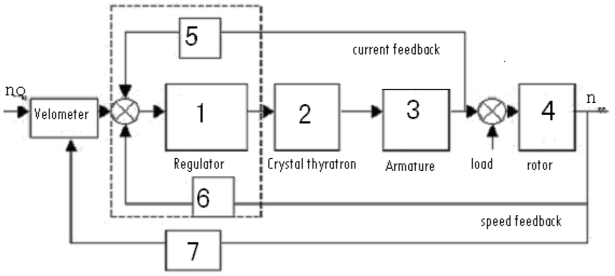


Figure 1. Principle of prime mover simulation system[2]

In Figure 1: 1—$\frac{(\tau_L s+1)k_\partial}{\tau_L s}$; 2—$\frac{k_{scr}}{\tau s+1}$; 3—$\frac{1/R}{\tau_R s+1}$; 4—$\frac{C_m}{J_n S}$; 5—$K_i$ = β/(1+T_iS); current feedback; 6—k_n speed feedback coefficient;7—k_n' speed feedback coefficient .where: k_α—proportionality coefficient of regulator; τ_L—integration time constant; τ_r, k_{sc}—the equivalent time constant of rectifier bridge and times of voltage amplification; τ_R ,R—time constant of the armature circuit and equivalent resistance; C_m—rotor coefficient; J_n—rotational inertia; S—differential operator; β—current feedback coefficient; Ti—current feedback filter time constant.

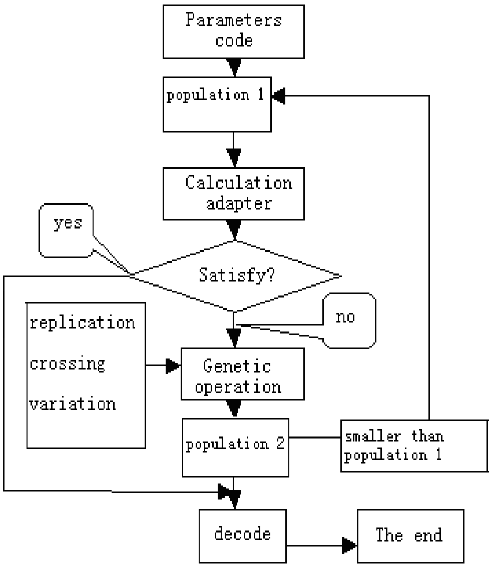


Figure 2. Genetic algorithms flow chart

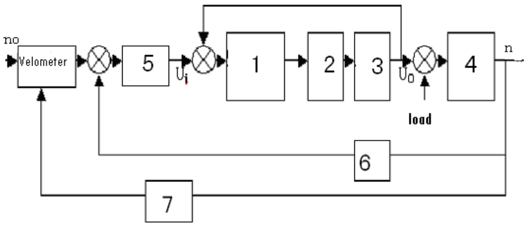
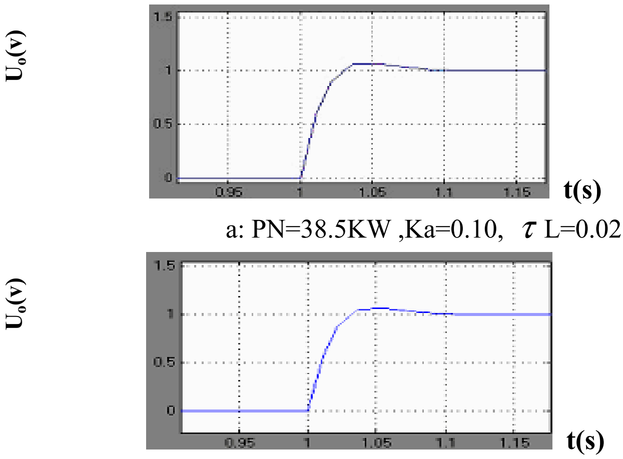


Figure 3. Prime mover simulation system equivalent diagram

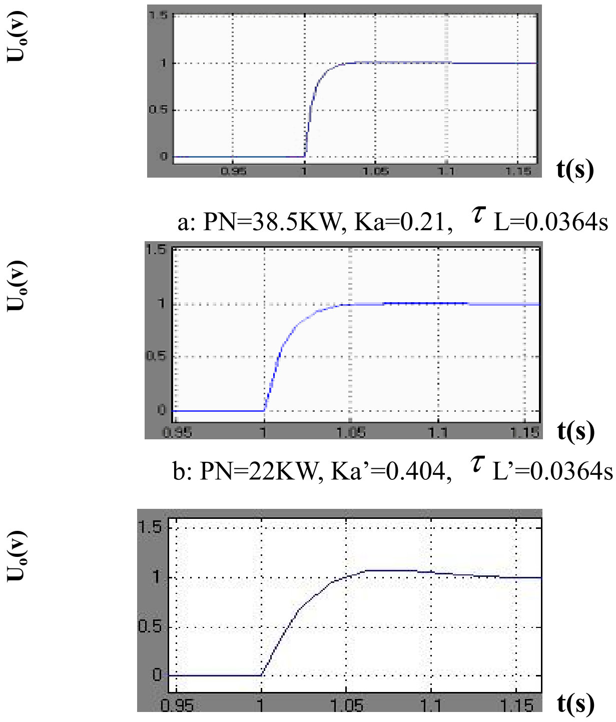
In Figure 3:1—$\frac{(\tau_L s+1)k_\partial}{\tau_L s}$;2—$\frac{k_{scr}}{\tau s+1}$; 3—$\frac{k_i/R}{\tau_R s+1}$; 4—$\frac{C_m}{J_n S}$;5—$1/k_i$;6—k_n ;7—k_n';



a: PN=38.5KW ,Ka=0.10, τ L=0.02s

b: PN=22KW, Ka=0.10, τ L=0.02s

Figure 4. traditional method different rated power same PI parameters step response curve



a: PN=38.5KW, Ka=0.21, τ L=0.0364s

b: PN=22KW, Ka’=0.404, τ L’=0.0364s

c: PN=22KW,Ka=0.21, τ L=0.0364s

Figure 5-a, b Genetic algorithms different rated power different PI parameters step response curve

Figure 5-a, c Genetic algorithms different rated power same PI parameters step response curve

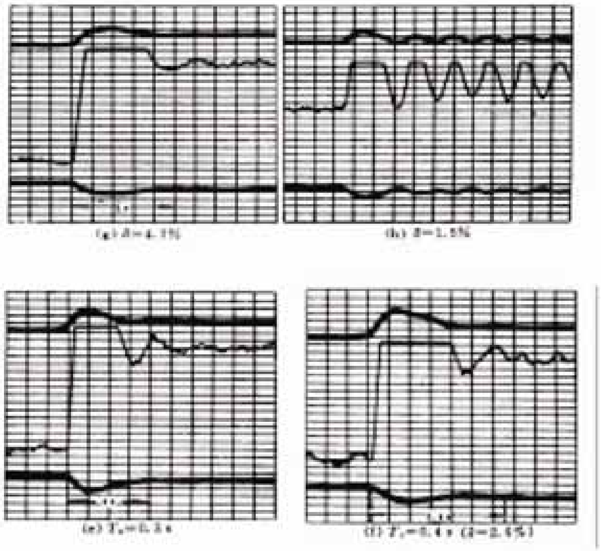


Figure 6. Wave-record chart of dynamic process of rejecting 100% load

In Figure 6. from top to bottom ,curves ordered: η speed deviation of the prime mover simulation speed control system, oil engine explanted displacement μ and speed n, where δ-difference coefficient , T_s - oil engine time constant, T_0 -steam inertia time constant