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To cite this article: Xiaoping Jiang *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **774** 012136

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Research on Modeling and Control Strategy of Hydraulic Turbine Governing System Based on Improved Genetic Algorithm

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Abstract. The mathematical model of the turbine governing system is obtained by modeling analysis. Under the premise of this model, the improved genetic algorithm is used to optimize the parameters in the parameter identification of the turbine governing system, and the high-precision parameter identification of the turbine governing system is realized, and an accurate mathematical model of the turbine governing system is established. In terms of control strategy, through theoretical analysis of conventional PID, fuzzy control and genetic algorithm, a fuzzy PID control based on genetic algorithm optimization (GA-fuzzy PID) is designed to realize the adaptive and adjustment ability of PID control. Compared with the traditional PID control, it has better control effect, and it is easier to make the turbine adjustment system achieve stability, quickness and accuracy. **keywords :** hydraulic turbine, regulation system, improved genetic algorithm, optimization fuzzy PID

1 Introduction

Hydropower is of great significance to ensure the safety of China's power supply, because of its superior start-up and regulation performance, the important tasks such as frequency regulation and peak regulation in the grid system are generally undertaken by the hydropower system. which plays a very important role in stabilizing the power grid frequency and voltage within the permissible range and balancing the load demand of the power grid. As an important part of hydropower, the water turbine regulation system plays an important role in energy conversion. Therefore, the water turbine adjustment system works in the harsh and changeable environment, its safe and stable operation has been greatly challenged, at this time to ensure its safe and stable operation is very necessary. The water turbine adjustment system is composed of the water diversion system, the follow-up system, the governor, the turbine, the generator and other components, and it is a complex nonlinear control system consisting of hydraulic,



electric power and machinery. Due to the limitation of objective conditions on the site of hydropower station, it is difficult to perfect and detailed real machine test of the dynamic characteristics of the hydroturbine adjustment system, so it is necessary to carry out theoretical analysis of the system through the model simulation test. In the process of simulation research, a key part is to establish an accurate dynamic mathematical model of the actual object, and the establishment of an accurate mathematical model depends on the actual measurement and further identification of the parameters. The identification of the hydraulic turbine regulation system is mainly for better control of the operation of the system, and the reliable operation of the system is also inseparable from the parameter setting and performance optimization of the controller. Therefore, the parameter tuning and control strategy of the hydro-turbine regulating system become very important.

2 Mathematical model of water turbine regulation system

2.1 Mathematical model of the turbine governor unit

The water turbine governor can be divided into three kinds, namely: auxiliary relay type governor, intermediate relay type governor and regulator type governor. In this study, a regulator-type governor is proposed. This type of governor generally uses a parallel PID-type regulator structure.

In general, the permanent transfer coefficient is usually taken $b_p \approx 0$, Then the transfer function of the governor is

$$G_r(s) = K_p + \frac{K_I}{s} + K_D s \quad (2-1)$$

In the formula, when only the buffer time constant T_y of the main servomotor is considered in the electro-hydraulic servo system of the turbine governor, the transfer function of the governor can be written as

$$G_y(s) = \frac{1}{T_y s} \quad (2-2)$$

Then the mathematical model block diagram of the turbine governor control system is shown in Figure 2-1.

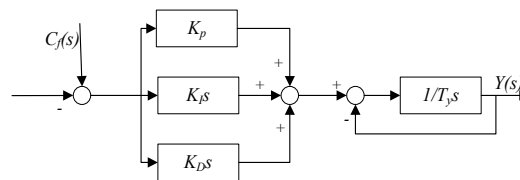


Figure 2-1. Control block diagram of microcomputer governor for hydraulic turbine

2-2 Mathematical control model of mixed-flow turbine and water diversion system unit

Control system selects mixed-flow turbine generator set, the e_{qx} is 0, Can be ignored, so get the mixed-flow turbine and water diversion system unit of the mathematical control model structure diagram as shown in Figure 2-2.

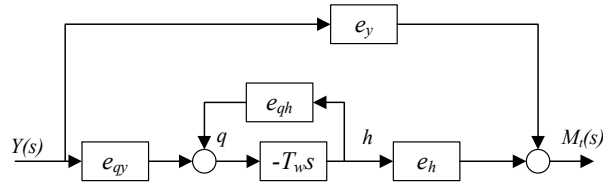


Fig 2-2. The structure block diagram of hydraulic turbine and pressure diversion system

2-3 Mathematical model of generators and load units

This paper studies the dynamic characteristics of the control system of a single hydro-generator with load. At this time, the mathematical control model of the generator adopts the first-order differential equation, and the generator is regarded as a rotating rigid body and its motion equation is

$$J \frac{d\omega}{dt} = M_t - M_g \quad (2-3)$$

In formula, $J = \frac{GD^2}{4g}$, M_t is mainly dynamic force distance for water turbine, M_g is

generator resistance torque.

$$M_t = M_{t0} + \Delta M_t + \frac{\partial M_t}{\partial \omega} \Delta \omega \quad (2-4)$$

$$M_g = M_{g0} + \Delta M_g + \frac{\partial M_g}{\partial \omega} \Delta \omega \quad (2-5)$$

(2-4) (2-5) in the (2-3) and take the relative deviation to obtain

$$T_a \frac{dx}{dt} + e_n x = m_t - m_g \quad (2-6)$$

In formula, $e_n = e_g - e_x$, $x = \frac{\Delta \omega}{\omega_r}$, $m_t = \frac{\Delta M_t}{M_r}$, $m_g = \frac{\Delta M_g}{M_r}$, $T_a = \frac{GD^2 n_r^2}{3580 P_r}$

The transfer function for the generator is solved as:

$$G_g(s) = \frac{1}{T_a s + e_n} \quad (2-7)$$

Many of the generator loads are rotating machinery, with a certain degree of mechanical inertia, according to the relevant data T_b is

$$T_b = (0.24 - 0.030) T_a \quad (2-8)$$

From this, the transfer function of generator and load link can be obtained:

$$G_g(s) = \frac{X(s)}{M_t(s) - M_{g0}(s)} = \frac{1}{(T_b + T_a)s + e_n} \quad (2-9)$$

The mathematical model control structure diagram of the generator and the load link can be obtained by (2-9):

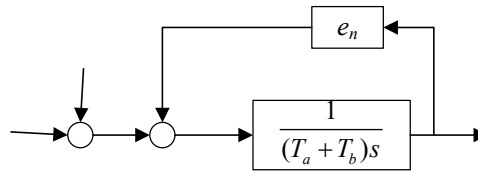


Fig 2-3. The structure block diagram of generator and load unit control

2-4 Mathematical model of water turbine regulation system

From the analysis of the above-mentioned control units and the establishment of the model, the model control structure diagram of the Francis turbine regulating system can be obtained as shown in Figure 2-4:

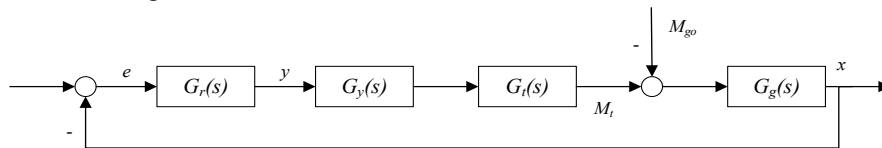


Fig 2-4. The structure block diagram of control system for Francis hydraulic turbine

From this structure, the transfer function of the mixed-flow turbine adjustment system is:

$$G(s) = \frac{G_r(s)G_y(s)G_t(s)G_g(s)}{1 + G_r(s)G_y(s)G_t(s)G_g(s)} \quad (2-10)$$

In this chapter, by analyzing the mathematical models of each subsystem, the overall control mathematical model of the hydro-turbine regulating system is obtained, which is ready for the following simulation test.

3 Fuzzy PID Regulating System of Hydraulic Turbine Based on Genetic Algorithm

3.1 Adaptive Fuzzy PID Control

On the basis of conventional PID control technology, coupled with adaptive fuzzy control technology constitutes an adaptive fuzzy PID control technology. The two-dimensional fuzzy controller of the hydro-turbine regulating system contains two input variables and three output variables. Its fuzzy inference system generally uses the Mamdani fuzzy inference system with 2 inputs and 3 outputs. Its parameter setting structure is shown in Figure 3-1. As shown, it is based on the structure diagram of the hydraulic turbine regulation system of the adaptive fuzzy PID controller as shown in Figure 3-2.

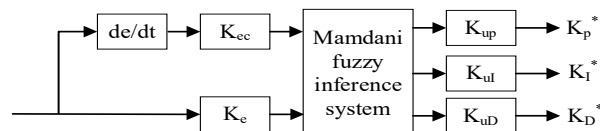


Fig 3-1. Adaptive fuzzy PID controller parameter setting

3.2 Genetic algorithm

Genetic algorithm is an adaptive global optimization algorithm, which simulates the natural evolution process in Darwin's theory of biological evolution to search for the optimal solution.

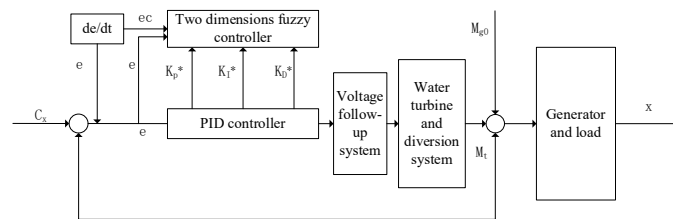


Fig 3-2. Adaptive fuzzy PID controller structure

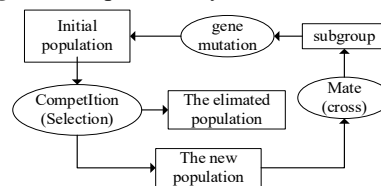


Fig 3-3. Evolutionary process

It can be seen from Figure 3-3 that organisms living in the natural environment have a competitive relationship at all times. With the competition of groups, the part of individuals that cannot adapt to the environment will be eliminated, and the part of individuals that adapt to the environment will be eliminated. It is retained to form a new population. This new population will reproduce individuals. In the resulting subgroups, individuals will mutate, and a new population will be generated again. At this time, the new population will become the initial population again. Compete, survive the fittest, adapt to the new environment again, and just keep repeating. Based on the above principle introduction, the genetic algorithm is to apply a series of genetic optimization operations such as selection, crossover, and mutation to the current population to produce a new generation of populations, and gradually evolve the new population to approach or directly contain the optimal The individual solution set of solutions uses the technology of group search. The basic flowchart of genetic algorithm is shown in Figure 3-4.

3.3 Application of genetic algorithm in hydraulic turbine regulating system

In the simulation analysis of the hydro-turbine regulating system, a set of initial PID parameters need to be solved for the controller of the system. The initial parameter value can be solved by an empirical formula. Based on this initial value, this study uses genetic algorithm to optimize the fuzzy control, so as to optimize the control parameter value of the control system under this working condition. In this paper, the fuzzy inference of the hydro-turbine regulating system is carried out. There is no corresponding empirical knowledge on how to make decisions on the control parameters based on the speed deviation and other information, and there is no complete experience in determining the membership functions of the controller variables. However, due to genetic algorithm It has the advantages of solving a wide range of problems, so this research uses genetic algorithm to optimize and determine the fuzzy rules and membership functions.

3.4 Control Model Simulation of Hydraulic Turbine Governing System

According to the control model of the hydraulic turbine governing system established in the previous article, MATLAB/simulink is used to build a control simulation model, and the research and analysis are carried out through this model. This article only conducts simulation under rated conditions. The basic parameters of the simulation target Francis turbine are as follows:

Model of the turbine: HL180-LJ-1700

Stand-alone capacity: Pz.=600MW

Rated head: Hr.=104m

Limited Data: Qz.=641.33m³

Rated speed: nz.=90.9r/min

Rated output: Pz.=612.21MW

Flying speed: n_s=176r/min

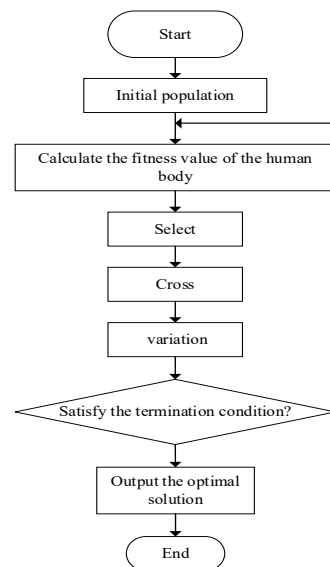


Fig 3-4. Basic flow chart of genetic algorithm

According to the comprehensive characteristic curve of the hydraulic turbine model, the transfer function can be obtained, and the obtained value can be brought into equation 2-10 to obtain the mathematical model of the controlled object under the rated operating condition:

$$G_0(s) = G_y(s)G_t(s)G_g(s) = \frac{1}{0.3s+1} \cdot \frac{0.667s+1.315}{0.549s+1} \cdot \frac{1}{7.686s+1.5} \quad (3-1)$$

3.4.1 General PID simulation

The basic parameters of the turbine adjustment system are: $T_a=6.1s, T_w=0.9s, T_y=0.3s, e_n$ is 1.5. The model in its simulink is shown in Figure 3-5. According to the above control model, Ziegler-Nichols tuning method is used to tune the PID parameters of each control system.: $K_p=3.652$, $K_i=1.631$, $K_d=0.571$.

After inputting the PID parameter setting values under rated conditions into the model in Fig. 3-5, adjust the switches K1 and K2 to the top, and then run the simulation model. The response curve when the rated working condition of the regulation system is changed can be obtained, as shown in Figure 3-6. It can be seen from the figure that the control system fluctuates 1.5 times under this working condition, and after calculation, it can be concluded that the time of the first wave peak is 2.67s, when the system fluctuation error falls within the interval $[-0.0002, 0.0002]$ The adjustment time within the range is 17.02s.

Adjust the selector switch K1 to the bottom and K2 to the top respectively, and input the step response to obtain the step response curve of the conventional PID control of the regulation system under rated conditions as shown in Figure 3-7.

As shown in Figure 3-7 step response curve, under rated conditions, when the turbine regulating system adopts conventional PID control, the calculation shows that the rise time of the control system $t_s=3.827s$, the overshoot $\%3.17$, and the adjustment time $t_p=13.61s$

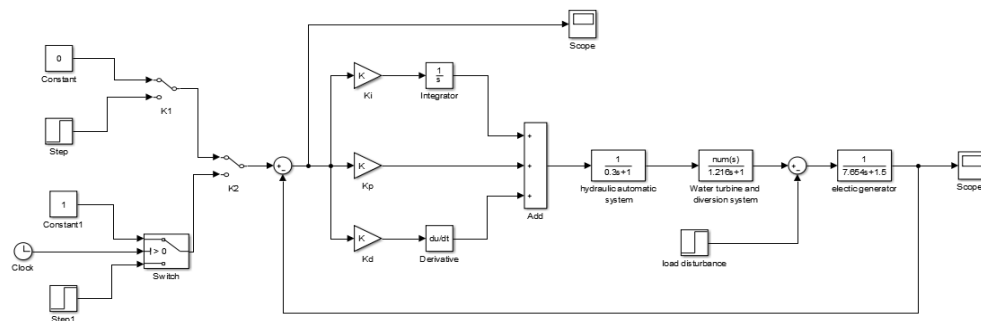


Fig 3-5. Schematic diagram of conventional PID control simulation model for Francis Turbine Governing System

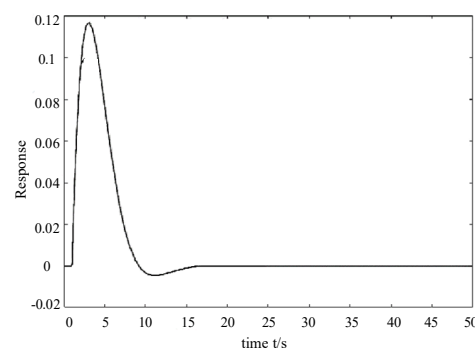


Fig 3-6. The No-load step response curves of the rated conditions

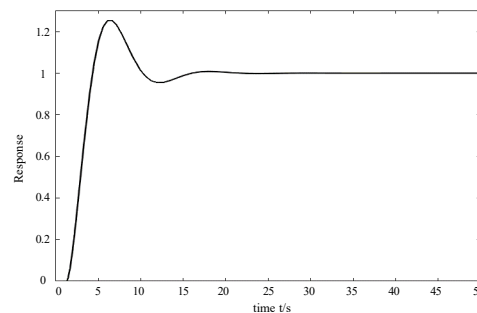


Fig 3-7. The normal PID control step response curve of the rated condition

3.4.2 Modeling and Analysis of Adaptive Fuzzy PID Simulation Optimized by Genetic Algorithm

After a lot of research and simulation experiments, it can be found that when the quantization factors of the three PID parameters remain unchanged, the adaptive fuzzy PID controller optimizes the fuzzy rules and membership functions at the same time and only optimizes the fuzzy rules. The control period is The effect is almost exactly the same. Therefore, we can carry out a large number of simulation tests on this basis, and select the membership functions of the

deviation e and the error variation ec and their division ranges according to the simulation test results. Experiments prove that this does not affect the control effect of the system. Based on the characteristics of deviation e , it is divided into 15 grades for division. The specific division range and membership function are shown in Figure 3-8.

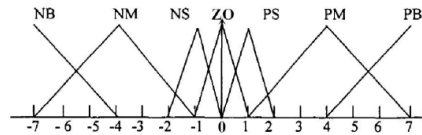


Fig 3-8. Deviation of fuzzy partition

The PID three parameters K_p , K_i , K_d are also binned according to the method shown in Figure 3-8. Using such a binning method of the PID parameters can simplify the system to solve the PID change. After this method is adopted, the control system will be mainly based on the system deviation e , and the deviation change ec will be used as the auxiliary. The system is subject to small disturbances and the resulting changes in the deviation will not have a greater impact on the control system, so that the control system avoids unnecessary swings in the system, and thus the control system has better robustness.

Under rated conditions, the PID parameter values are obtained through genetic algorithm, and the value range and scale factor of the control parameters are determined: $K_p = 9.2$, $K_i = 1.86$, $K_d = 0.35$; PID parameter value range is: K_p : [7, 11], K_i : [0.5, 3], K_d : [0.05, 0.45]; The scale factors of PID parameters are: $C_p = 0.9$, $C_i = 0.1$, and $C_d = 0.12$.

The data in Tables 3-1, 3-2, and 3-3 are the control rules of each parameter obtained by using the genetic algorithm after a sufficient number of iterations.

Table 3-1. K_p of fuzzy control rules table

e	ec						
	NB	NM	NS	O	PS	PM	PB
NB	PB	PB	PM	PM	PS	PS	0
NM	PB	PB	PM	PS	PS	0	0
NS	PM	PM	PM	PS	0	NS	NS
0	PM	PM	PS	0	NS	NM	NM
PS	PS	PS	0	NS	NS	NM	NM
PM	PS	0	NS	NM	NM	NM	NB
PB	0	0	NM	NM	NM	NB	NB

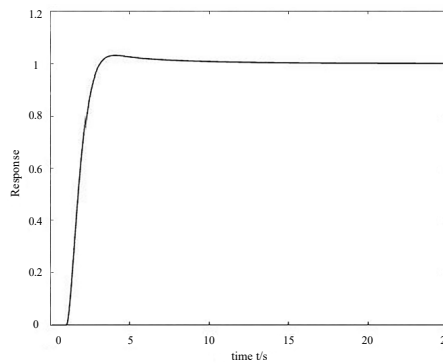
Table 3-2. K_i of fuzzy control rules table

e	ec						
	NB	NM	NS	O	PS	PM	PB
NB	NB	NB	NM	NM	NS	0	0
NM	NB	NB	NM	NS	NS	0	0
NS	NM	NM	NS	NS	0	PS	PS
0	NM	NM	NS	0	PS	PM	PM
PS	NS	NS	0	PS	PS	PM	PB
PM	0	0	PS	PS	PM	PB	PB
PB	0	0	PM	PM	PS	PB	PB

Table 3-3. Kd of fuzzy control rules table

e	ec						
	NB	NM	NS	O	PS	PM	PB
NB	NB	NB	NM	NM	NS	0	0
NM	NB	NB	NM	NS	NS	0	0
NS	NM	NM	NS	NS	0	PS	PS
0	NM	NM	NS	0	PS	PM	PM
PS	NS	NS	0	PS	PS	PM	PB
PM	0	0	PS	PS	PM	PB	PB
PB	0	0	PM	PM	PS	PB	PB

Under the given frequency and load rejection disturbance, the hydraulic turbine regulating system is used to simulate and analyze the control system under rated operating conditions using the fuzzy PID control method optimized by the genetic algorithm. And set the simulation sampling time to 0.001s, and the overall simulation time to 20s. The simulation results are shown in Figure 3-9.

**Fig 3-9.** The Step response diagram of fuzzy PID control under rated working condition

After calculation, it can be known that when the fuzzy PID control optimized by the genetic algorithm is used in the adjustment system, the rise time of the control system is $t_s = 2.566s$, the maximum peak value is $n_{max} = 1.086$, the overshoot amount is $\delta = 8.6\%$, and the adjustment time is $t_p = 8.80s$.

Through the use of conventional PID control and fuzzy PID control based on genetic algorithm optimization to carry out simulation research and analysis on the control model of the hydraulic turbine governing system, the dynamic performance parameters under each simulation are compared and analyzed. See Table 3-4.

Table 3-4. Under the rated conditions, performance parameters of the step response

Control Strategy	Rise Time	Maximum peak	Overshoot	Adjustment time
	t_s	n_{max}	$\delta\%$	t_p
PID control	3.827s	1.173	17.3%	13.61s
Improved fuzzy PID control	2.566s	1.086	8.6%	8.80s

It can be seen from Table 3-4 that when the turbine governing system adopts fuzzy PID control based on genetic algorithm optimization under rated operating conditions, the dynamic

performance parameters in the table are significantly improved compared to conventional PID control. The rise time and adjustment time of the control system have been significantly improved, only the peak value has no big difference compared with the conventional PID control, but there are still some improvements .

4 Conclusion

In this paper, the mathematical model of the hydraulic turbine regulating system is obtained through modeling analysis. Under the premise of this model, the conventional PID control and the fuzzy PID control based on genetic algorithm optimization are used to control the hydraulic turbine regulating system stably under rated conditions. It shows that compared with conventional PID control, the dynamic performance parameters of the system under the fuzzy PID control optimized by genetic algorithm have been improved, the system stability is better, and the system response becomes faster.

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