

Optimization of hydraulic turbine governor parameters based on WPA

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Abstract. The parameters of hydraulic turbine governor directly affect the dynamic characteristics of the hydraulic unit, thus affecting the regulation capacity and the power quality of power grid. The governor of conventional hydropower unit is mainly PID governor with three adjustable parameters, which are difficult to set up. In order to optimize the hydraulic turbine governor, this paper proposes wolf pack algorithm (WPA) for intelligent tuning since the good global optimization capability of WPA. Compared with the traditional optimization method and PSO algorithm, the results show that the PID controller designed by WPA achieves a dynamic quality of hydraulic system and inhibits overshoot.

1. Introduction

With the adjustment of China's energy structure, the proportion of hydropower is increasing, and the regulation capacity of hydraulic units is more demanding than ever before. PID control is widely used in hydraulic turbine governing system due to its good adjustment ability and simple algorithm. In order to improve the dynamic characteristics of the unit, it is necessary to optimize the parameters of PID [1]. The PID parameter setting has always been the hot spot of the attention. The traditional Z-N method, orthogonal method and simplex method are simple and convenient, it is difficult to satisfy the requirements of complex power system by the low calculation accuracy. In recent years, with the development of intelligent algorithm, PSO [2] and GA [3] have also been applied to the PID parameter setting, and achieved a certain effects. However these algorithms exist some defects: PSO is easy to fall into local optimum and GA iteration is relatively slow.

The Wolf pack algorithm (WPA) is a new intelligent algorithm. In 2011, Liu proposed a Wolf pack algorithm (WCA) [4] based on the hunting behavior of wolves. Wu Shenghu have further developed the WCA [5] and put forward the WPA based on three kinds of intelligent behaviors and three artificial wolves, the algorithm is also shown to be convergence. Compared with GA and PSO al, the optimization mechanism of WPA is different, which can avoid the problem of premature convergence and has better robustness [5]. WPA has been successfully used in reservoir scheduling [6], and binary knapsack problems [7], and TSP [8] problems, and achieved good results

This paper, based on the ITAE index, adds the overshoot punishment, establishes the objection function. WPA is used to optimize the parameters of the hydraulic turbine governor. Finally, the algorithm is compared with the T.Stein method and PSO algorithm to verify the effectiveness of WPA.



The paper was organized as follows: In Section 2, the model of hydraulic turbine governing system is described; the introduction of WPA in Section 3; Section 4 describes the steps of optimization of turbine governor parameters based on WPA; followed by an example in Section 5 and conclusion in Section 6.

2. Model of hydraulic turbine governing system

The hydraulic turbine governing system mainly includes: PID governor, Servo system, hydraulic system, and load system. Its overall structure is shown in Figure 1.

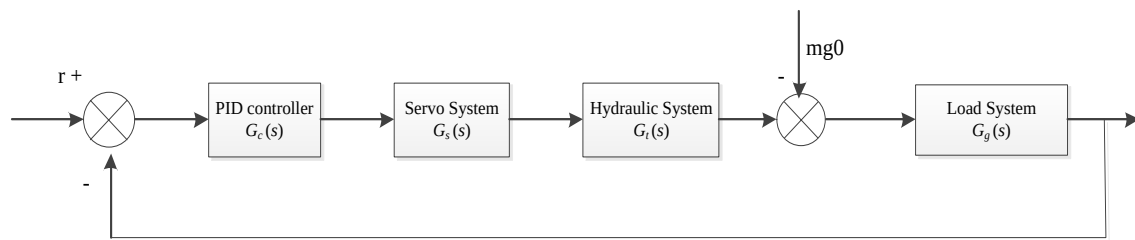


Figure 1. The structure of hydraulic turbine governing system

The transfer functions of the servo system is

$$G_s(s) = \frac{1}{1 + T_y s} \quad (1)$$

Where, s is Laplace operator; T_y is servomotor reaction time constant;

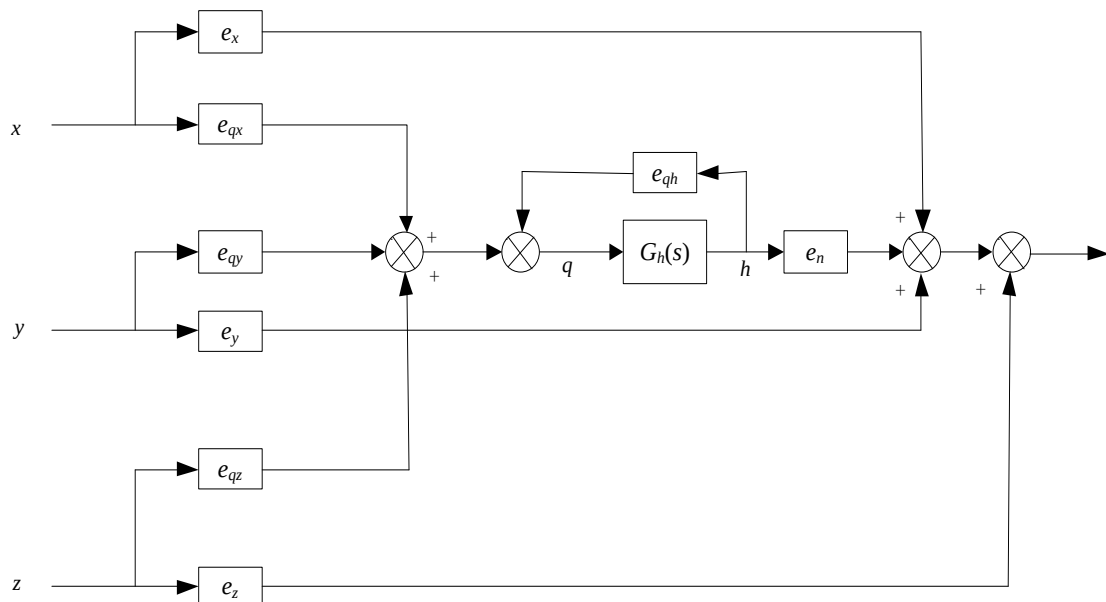


Figure 2 The linear model of the hydro-turbine and penstock system

A typical diagram of hydro turbine and penstock system is show in Figure 2. We suppose that the cross-sectional area of the penstock is constant. Then the transfer function of Hydraulic system is:

$$G_t(s) = \frac{e_y + (e_h e_{qy} - e_{qh} e_y) G_h(s)}{1 - e_{qh} G_h(s)} \quad (2)$$

where, e_y is the derivative value of torque with respect to wicket gate; e_h is the derivative value of torque with respect to water head; e_{qy} is the derivative value of flow rate respect with respect to turbine s-speed; e_{qh} is the derivative value of flow rate with respect to water head; $G_h(s)$ is transfer function of water hammer, and rigid water hammer model can be written as:

$$G_h(s) = -T_w s \quad (3)$$

Where, T_w is water inertia time constant;

The transfer functions of the hydraulic system is

$$G_t(s) = \frac{e_y - (e_h e_{qy} - e_{qh} e_y) T_w s}{1 + e_{qh} T_w s} \quad (4)$$

The transfer functions of the load system is

$$G_g(s) = \frac{1}{(T_a + T_b)s + e_n} \quad (5)$$

Where, T_a is unit inertia time constant; T_b is load inertia time constant; e_n is the adjusting coefficient of generator.

The transfer function of the PID controller is:

$$G_c(s) = k_p + \frac{k_i}{s} + k_d s \quad (6)$$

Where, k_p is proportional adjustment coefficient, k_i is integral adjustment coefficient, k_d is differential adjustment coefficient.

3. Wolf pack algorithm

WPA divided wolf pack into the chief wolf, the explorative wolf and the attack wolf. The chief wolf makes decisions and be responsible for the whole pack's command according to the hunting information they feel. Explorative wolves belong to the acumen, they can explore the environment by themselves in an adjustable range, and move to the place which is the concentration of strongest flavours. Attack wolves catch their prey according to the chief wolf's call. In the practical algorithm design, all the wolves are artificial, explorative wolves and attack wolves can swap their roles according to each iterative value, and can enhance the searching capability of the algorithm. The wolf pack algorithm mainly includes: the initiation of wolves, the production of chief wolf, the scouting of the explorative wolf, the call of the chief wolf, the hunting of the attack wolves, the renew of the wolves.

3.1. The initiation of the wolves and the emergence of the chief wolf.

N individuals are generated randomly in the solution space, and the objective function value is worth the size to emerge the chief wolf. There are only one chief wolf in the wolves, and the chief wolf does not engage in scouting and hunting, only summon the wolves.

3.2. The scouting of the explorative wolf.

Snub explorative wolves are determined according to the objective function value. S_num is a random integer between $[0.2N, 0.3N]$, and the explorative wolves will detect the surrounding area with fixed step. The i th wolf is forward to the p th direction. Afterwards it can be expressed as equation (7) in the position of the d th dimension space.

$$x_{id}^p = x_{id} + \sin(2\pi * \frac{p}{h}) \times h_invid \quad (7)$$

Where h_invid is scouting step. Every explorative wolf after scout should compares with current individual. The position of the wolf is updated only if it is superior to the current individual. If the investigation to the individual objective function value is greater than the chief wolf, the chief wolf is update-ted, then calls the wolves directly.

3.3. The call of the cheif wolf.

The cheif wolf calls attack wolves. The attack wolves (the wolf except the chief wolf) run to the chief wolf with a larger step. The position of i th attack wolf in the d th dimension after the $k+1$ iteration is as follow:

$$x_{id}^{k+1} = x_{id}^k + h_sum \times \frac{(g_d^k - x_{id}^k)}{|g_d^k - x_{id}^k|} \quad (8)$$

Where h_sum is beleaguering step. If attack wolf finds a better position than the chief wolf in the sum-moning, it can replace the chief wolf, and calls the wolves. The attack wolves enter the siege radius and stop. The siege radius is as follow:

$$L_{near} = \sum_{i=1}^{NL} \sum_{d=1}^D |x_{id}^d - x_{lead}^d| / NL \times w \quad (9)$$

$$NL = \left\lfloor N \times (1 - \frac{1}{\beta}) \right\rfloor \quad (10)$$

Where, β is the renew ratio of wolves; x_l is position of NL wolf that closest to the chief wolf; w is the judging factor. The distance between the attack wolf and the chief wolf is calculated by the Manhattan distance between two vectors.

3.4. The hunting of the attack wolves.

After the attack wolves entered the siege radius, the distance to the chief Wolf is very close, which required a smaller step to be used for hunting. The position of i th attack wolf in the d th dimension after the $k+1$ iteration is as follow:

$$x_{id}^{k+1} = x_{id}^k + \lambda \times h_bel \times |g_d^k - x_{id}^k| \quad (11)$$

where, $-1 < \lambda < 1$, h_bel is hunting step; g_d^k is the position of the chief wolf in the d dimensional space at the k iteration; x_{id}^k is the position of the attack wolf d dimensional space at the k iteration. The individual after each iteration needs to compare with the current individual. If better than current individual, the position of the attack wolf is updated; otherwise, the position of the attack remains unchanged.

3.5. The renew of the wolves.

After the hunting behavior, the wolves should be renewed: N_{eli} wolves need be eliminated, while N_{eli} new wolves are produced. The value of N_{eli} can be a random integer between $[N/2\beta, N/\beta]$.

4. Optimization of hydraulic turbine governing system based on WPA

4.1. Objective function.

In order to get better regulation quality, the overshoot penalty is added on the integral of time-weighted absolute value of the error (ITAE), the objective function is shown in equation 10.

$$J = \int_0^{\infty} t |e(t)| dt + w_1 \sigma \quad (12)$$

Where, $e(t)$ is the error, σ is the overshoot, w_1 is the relative weight.

4.2. Step of the optimization.

Step 1: Determine the number of population N , the maximum number of iterations k_{max} , the judging factor w , the scouting step h_{invid} , the summoning step h_{sum} , the beleaguering step h_{bel} , the renew ratio of wolves β and initialize wolves in solution space.

Step 2: According to equation 12, seeking out the chief wolf, the explorative wolves, and the attack wolves. The explorative wolves scout as equation 7, until the chief is updated or achieve the max number of scouting. Then, enter the Step 3.

Step 3: The chief wolf summons the attack wolves. The attack wolves update as equation 8. In the process of a raid, if the chief wolf is updated, restart the Step3. Until all the attack wolves have entered the siege radius L_{near} , go to Step4.

Step 4: The attack wolves beleaguer as equation 11. If the chief wolf is updated, restart the Step4. Until all the attack wolves achieve the max number of beleaguering, go to Step4.

Step 5: If achieve the maximum number of iterations k_{max} , then output the best individual and draw the figure. Otherwise, renew the wolves, and enter Step 2.

5. Optimization example

The structure of hydraulic turbine governing system is shown in Figure 1. and its parameters are as follows $T_y=0.2$ s, $e_y=0.74$, $eqh=0.491$, $eh=1.46$, $eqy=0.789$, $e=1.066$, $T_w=1.62$ s, $T_a=6.67$ s, $T_b=2.001$ s, $en=1$. The parameters of the algorithm: the iteration number of PSO and WPA algorithm is 50, and the number of k_{max} is 30. In the PSO scheme, the inertial values decay from 0.9 to 0.4 with the number of iterations. The learning factors c_1 and c_2 take 1. In the WPA scheme, the explorative wolves ratio is 0.3, the judging factor w is 20, and the renew ratio of wolves β is 4. The traditional methods is T.S-tein method, which is widely used in reality. The step response is used as the corresponding dynamic quality index which shown in Figure 3 and the dynamic quality comparison of step response table is shown in Table 1:

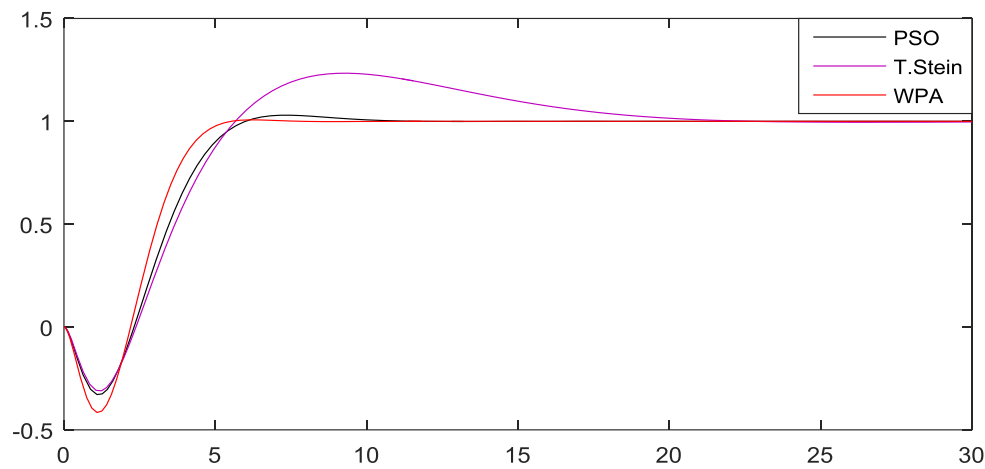


Figure 3. The step response of hydraulic turbine governing system

Table 1. The dynamic quality comparison of step response

Optimization scheme	k_p	k_i	k_d	The value of objective function J	Overshoot $\sigma/\%$	Adjustment time t_r/s
T.Stein	3.203	0.565	2.223	8.8776	23.3795	19.1468
PSO	3.5679	0.3368	2	7.0196	2.9502	8.5879
WPA	4.0659	0.3585	2.8305	6.9285	0.6938	4.8181

As shown in the Figure 3 and Table 1, the adjustment time optimization by WPA is obviously shorter than PSO and T.stein method, which the overshoot is reduced. The results shows the effectiveness of the algorithm.

6. Conclusion

Since the hydro turbine generator is a very complicated nonlinear system, how to set the PID controller parameters suitable is the key point of maintaining system stability. A good dynamic quality is important to the hydropower station and the power grid, which makes the optimization of turbine governor parameters is of great necessary. In this paper, WPA is used to perform the intelligent tuning of the hydraulic turbine governing system, and the improved ITAE criterion is used as the objective function to inhibit overshoot. Finally, an example is used to illustrate the simulation results. The results show that compared with T.Stein method and PSO, the parameters optimized by WPA achieve better dynamic quality of the hydraulic turbine governing system.

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