Optimization of Hydropower Reservoir System Operations based on Improved CSO-PSO

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Abstract: The chicken swarm optimization is a fresh swarm intelligence algorithm that simulates the hierarchical system and foraging behavior in the chick group. Compared with the traditional intelligent algorithm, it has better convergence performance. In the process of operation, it is found that the convergence speed of traditional algorithm is very slow and readily falls into the local optimal solution,,and it is extremly difficult to obtain the global optimal solution, which makes the calculation process more prone to blindness. Based on the blindness in the optimization process of the chicken swarm algorithm, a particle swarm optimization and improved chicken swarm optimization (ICSO-PSO) algorithm is proposed in this paper. The particle swarm optimization (PSO) algorithm is introduced in the update process of the rooster position. Based on the optimal operation model of Hydropower Reservoir System, the ICSO-PSO algorithm is used to optimize the hydropower reservoir system operation problem. Analyze different optimization algorithms through case studies, the applicability of the optimization of hydropower reservoir system operations based on improved CSO-PSO is demonstrated to be effective.

1 INTRODUCTION

Reservoir operation is the process of adjusting the water balance relationship and redistributing the inflow runoff under the system considering the scheduling objectives of flood control, irrigation, power generation, water supply and related constraints (Duan, 2014), to guarantee the safety of the dam of reservoirs and auxiliary facilities. Optimal dispatch is superior to conventional dispatch in dealing with difficult problems in reservoir dispatching (Zhang, 2005). Reservoir optimal dispatching is to establish single-objective or multi-objective dispatching rules for reservoir operation, optimize the boundary conditions of reservoir operation, and maximize the benefit of reservoir dispatching operation objectives.

With the continuous advancement of science and technology, a variety of optimization models have been formed, which have gradually been used in reservoir dispatching. The main optimization algorithms include linear programming, dynamic programming, and bionic population intelligence algorithms (Wang et al., 2009). Among them, the biomimetic population intelligent algorithm is a new type of intelligent optimization algorithm that simulates the living habits and natural survival rules of biological groups. In 2014, Meng Xianbing et al (2014) proposed a population intelligence optimization algorithm, CSO algorithm, which achieved good optimization results by grouping and updating the population based on the foraging behavior of chicken swarm, and it has been applied in some fields. Banerjee and Chattopadhyay (2015) used the CSO algorithm to improve the serial concatenated convolutional Turbo code. Kong and Wu (2015) studied the chicken position update formula by quoting the learning factor in the Chicken swarm optimization, thus it has been demonstrated that this algorithm is superior to other optimization algorithms in solving high-dimensional optimization problems. Hafez et al. (2016) took the CSO algorithm as part of the evaluation function and proposed a feature selection system and applied it to the data set. In 2016, Chen and Mao (2016) applied the CSO algorithm to the wireless sensor network node localization algorithm and achieved good location accuracy. Mu et al. (Mu et al., 2016) applied the CSO algorithm to optimizing the robot's movement trajectory in 2016.

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In actual optimization problems, the solution update method of the CSO algorithm is relatively simple, which sometimes causes the solution process to fall into a local optimum, which affects the solution accuracy and convergence speed. Therefore, while continuously improving the CSO algorithm, it has become the focus of research to enable it to have better optimization capabilities. Wu et al. (2018) introduced the crossover operator to the improvement of the CSO algorithm when applying the CSO algorithm to the optimization of reentry trajectory, thereby solving the problem that the algorithm easily plunges into local optimality. Wei and Chi (2017) cited the dissipative structure in the CSO algorithm, and the global optimization capability and convergence speed of the original chicken swarm algorithm have been significantly improved

Therefore, an algorithm called ICSO-PSO has been proposed, which combines the advantages of the Chicken Swarm Optimization and Particle Swarm Optimization (PSO) algorithm (Li, 2009). The improvement of cock's update method in the previous CSO algorithm leads to improving the solution accuracy and convergence speed of the algorithm. This paper applied the ICSO-PSO algorithm to the reservoir operation optimization, the feasibility and effectiveness of the ICSO-PSO algorithm is further demonstrated.

2 PROBLEM FORMULATION

2.1 Basic Principles of Chicken Swarm Optimization Algorithm

The CSO algorithm is presented based on the research on chicken swarm hierarchy and foraging behavior (Zhang & Zhang. 2018). When solving the problem, the chicken swarm is compartmentalized into several groups according to the fitness of each chicken in the swarm, and each group is comprised hens, roosters and chicks. With the three different groups of chicks, the dominance relationship in the chicken group is updated every G generation. Everyone in the algorithm is represented as a feasible solution to the problem. The three groups of hens, roosters and chicks are searched in the solution space in their own way. By comprehensively comparing the fitness values of these groups of hens, roosters and chicks, the global optimal individual and global optimal value can be found. Among them, the foraging method of the chicks is following the hen, and the foraging method of the hen is to follow the rooster, so the rooster plays a leading role in the foraging of the entire chicken swarm. Correspondingly, the advantage of the rooster is greatest in the foraging competition, followed by the hen, and the most disadvantaged is the chick, so the hen protects its own chicks who live together. The fitness value of the object function to its location represents the superior performance of each chicken in the swarm.

At the same time, the entire chicken swarm is classified by the fitness value of the function, and the problem optimal solution to be optimized is represented by the spatial position of the best individual in the chicken swarm. Suppose the foraging range is D-dimensions, the chicken swarm is G groups (randomly divided), and each group contains N chickens. Among them, the rooster number is R, the hen number is H, and the chick number is M (Hafez et al., 2016). The mathematical expression is as follows:

(1) Rooster's foraging behavior

For roosters, those with higher fitness values have a larger food search space than those with lower fitness values. The position update equation of the rooster i in dimension j at time t is as follows:

$$x_{i,j}^{t+1} = x_{i,j}^{t} \times [1 + N(0, \sigma^2)] \tag{1}$$

$$\sigma^2 = \begin{cases} 1, & \text{if} \quad f_i \le f_k \\ \exp\left(\frac{f_k - f_i}{f_i + \varepsilon}\right), & \text{otherwise} \\ & k \in [1, N_R], k \ne i \end{cases} \tag{2}$$

Where $N(0, \sigma^2)$ is a Normal distribution with mean 0 and standard deviation σ^2.k is a rooster's index, which is randomly selected from the rooters group (k≠i). f is the objective function value. ε is the constant smallest in the computer, and its function is to avoid the denominator in the formula being 0.

Equations (1) and (2) simulate the rooster's random moving foraging behavior and the competition behavior between different groups of roosters, respectively.

(2) Foraging behavior of hens

For hens, they usually follow their spouse's rooster to forage, but the other side of the shield, they also randomly steal food from other chickens. This process is in competition with other chickens. In addition, stronger hens have an advantage over weaker hens in grabbing food. The position update equation of the hen i in dimension j at time t is as follows:

$$x_{i,j}^{t+1} = x_{i,j}^{t} + S_1 \times Rnd \times \left(x_{r_1,j}^{t} - x_{i,j}^{t}\right) + S_2 \times Rnd \times \left(x_{r_2,j}^{t} - x_{i,j}^{t}\right) \tag{3}$$

$$S_1 = \exp\left(\left(f_i - f_{r_1}\right)/(\mathrm{abs}(f_i) + \varepsilon)\right) \quad (4)$$

$$S_2 = \exp\left(f_{r_2} - f_i\right) \quad (5)$$

where Rnd is a random number over [0,1], r_1 is a rooster index, which is the i-th hen's group-mate, at the same time, r_2 is a chicken index (rooster or hen), which is randomly selected from the swarm, and the foraging ability of r_2 is stronger than that of hen i. $r_1 \neq r_2$. Therefore, $S_2 < 1 < S_1$, when S_1=0, hen i can only steal food from other chicks, and when S_2=0, hen i will forage within its own territory.

(3) Foraging behavior of chicks

For chicks, they will hunt around their mothers for food. The position update equation of the chick i in dimension j at time t is as follows:

$$x_{i,j}^{t+1} = x_{i,j}^{t} + F\left(x_{m,j}^{t} - x_{i,j}^{t}\right) \quad (6)$$

where m is the hen followed by the i-th chick, F ($F \in [0,2]$) is a parameter, which means that the chick would follow its mother to forage for food.

2.2 The ICSO-PSO

In the operation of the algorithm, it is founded that the traditional chicken swarm algorithm converges slowly, and it readily caught in a local solution, and it is difficult to gain the overall optimal solution. Therefore, in order to obtain the overall optimal solution, the PSO algorithm is introduced (Shi, 2018)

The ICSO-PSO algorithm uses the PSO algorithm to optimize and improve the rooster position update formula in the CSO algorithm. Roosters are the dominant group within the groups, and they are closer to the position of the optimal solution. However, in the standard CSO algorithm, the rooster adopts the position update method based on the normal distribution, so that the position update of the rooster only changes in the same direction, and it is difficult to fluctuate left and right. Therefore, the method of updating the position based on the normal distribution has certain advantages. The blindness of the algorithm reduces the convergence speed of the algorithm. To solve this problem, this paper proposes the location update method of PSO algorithm to improve the search breadth of rooster in CSO algorithm. The improved position update formula of the rooster is as follows:

$$x_{i,j}^{t+1} = x_{i,j}^{t} + v_{i,j}^{t} \quad (7)$$

$$v_{i,j}^{t+1} = w \times v_{i,j}^{t} + r_3 \times \mathrm{Rnd} \times \left(p_{best} - x_{i,j}^{t}\right) + r_4 \times \mathrm{Rnd} \times \left(g_{best} - x_{i,j}^{t}\right) \quad (8)$$

where $v_{i,j}^{t}$ is the velocity of hen i in dimension j at time t.; p_{best} and g_{best} respectively denotes the personal best position and the global best position in the iterative process of the algorithm; r_3 and r_4 are the learning factors. w is the inertia weight.

3 RESERVOIR OPTIMAL DISPATCH BASED ON IMPROVED CHICKEN SWARM OPTIMIZATION

During the flood season, the dispatch of hydropower stations essentially involves two aspects, namely flood control and power generation. The flood characteristics, regional composition and actual flood control requirements and reservoir engineering storage and discharge control capabilities should be comprehensively considered, and the conflicts between flood control and power generation, flood control safety and economic benefits should be properly handled. When the flood is small and ensuring safety, the focus of reservoir operation should be to maximize the power generation. When floods are large and a large amount of flood discharge and water discards are inevitable, flood control dispatching is the main focus, followed by power generation.

When there is large flood, the optimal dispatching of hydropower stations focuses on improving the utilization rate of water, thereby increasing the power generation of the reservoir and reducing the amount of water discarded by the reservoir. That is, in the case of satisfying all constraint conditions, maximize the target benefit of the reservoir operation.

3.1 Objective Function

Reservoir scheduling involves solving the unit commitment problems. The problem is more complicated, and supplementary conditions are needed. The corresponding optimization problem can be delivered as:

$$OBJ\ :\ E = \max \textstyle\sum_{t=1}^{T} kQ_f H_i \Delta t \quad (9)$$

where E is the maximum power generation, k is the comprehensive output coefficient of the hydropower station, Q_f is the generation flow of the period t , Δt is the calculation period, T is the total hours of the calculation period.

3.2 Constraints

(1) Water Balance Equation

$$V_{t+\Delta t} = V_t + (Q_r - Q_y - Q_f - Q_{out}) \times \Delta t \quad (10)$$

where $V_{t+\Delta t}$ and V_t respectively represent the storage capacity of the reservoir at time t+Δt and t, Q_r represents the inflow flow of the reservoir during the period Δt, Q_y represents the diversion flow between the reservoirs, Q_f shows the power generation flow of the reservoir. Q_{out} represents the abandoned reservoir water flow.

(2) Flow Constraint

$$Q_{min} \le Q_{out} \le Q_{max} \quad (11)$$

where Q_{out} shows the outflow of the reservoir in the period Δt, ; Q_{min} and Q_{max} respectively represent the minimum discharge flow and the maximum discharge flow.

(3) Water Level Constraint

$$Z_{min} \le Z_t \le Z_{max} \quad (12)$$

where Z_t is water level of the reservoir at the end of time t, Z_{min} and Z_{max} respectively represent the lowest and highest water levels that the reservoir is allowed to reach at time t after considering the benefit and safety needs.

(4) Output Constraint

$$N_{min} \le N_t \le N_{max} \quad (13)$$

where N_t is the average output of the hydropower station in the period t, N_{min} is the minimum allowable output of the hydropower station, N_{max} is the maximum allowable output of the hydropower station.

3.3 Optimization Model Solving Steps

The method of referencing the ICSO-PSO algorithm to solve the problem in the optimal operation of the reservoir is:

(1) Population Initialization

Set the reservoir water level $Z = (z_1, z_2, \cdots, z_T)$ corresponding to the reservoir at the end of each period as the position of each chicken in the T-dimensional foraging space $x_i = (x_{i1}, x_{i2}, \cdots, x_{iT})$. T is the D in the text. Combining with the water level constraint conditions, select the corresponding value for the initial position of each chicken according to formula (14), and assign the number of iteration t to 0. which is

$$x_{i,j}^0 = x_{jmin} + Rnd \times (x_{jmax} - x_{jmin}) \quad (14)$$

where $x_{i,j}^0$ is the initial position of the i-th chicken in dimension j, x_{jmax} and x_{jmin} are the upper and lower bounds of the j-th dimension of the foraging space, namely the water level Z_{min} and Z_{max} values of the power station.

(2) Classification Of Chicken Swarm

Randomly divide the chicken swarm obtained by initialization in step (1) into G group, and calculate the fitness value $f_i = (x_i)$ according to the position of each chicken in each group, and classify each group of chickens based on it. Among them, the chickens with the best fitness value are classified as roosters, the relatively weakest chickens are classified as chicks, and the others are classified as hens.

(3) Chicken Swarm Foraging

In the swarm, each rooster forages according to formula (1) and formula (7), each hen forages according to formula (3), and each chick forages according to formula (6), so that the position is updated.

(4) Swarm Update

According to the updated position of each chicken in the swarm, the fitness value $f_i = (x_i)$ corresponding to this position is calculated, use it as a basis to classify each group of chickens again the same as step (2) division method. Remember the number of iterations as t=t+1

(5) Termination of Judgment

If it is satisfied that the iterations number t reaches the maximum maxgen, or the fitness value $abs(f_{best}^t - f_{best}^{t-5}) \le \varepsilon$ corresponding to the best chicken in the swarm, then terminate the iteration and go to (6) ; otherwise, go to (3) and loop iteratively.

(6) Output Result

Output the location of the optimal chicken and the corresponding fitness value, which is the reservoir water level value $Z = (z_1, z_2, \cdots, z_T)$ and the corresponding maximum power generation at the end of each period of the reservoir.

4 OPTIMIZED SCHEDULING INSTANCE CALCULATION

4.1 Basic Information of Reservoir Operation

In this paper, a comprehensive annual regulating reservoir is selected as the research object, and the inflow process line of the reservoir, the water level storage capacity and the downstream water level and flow relationship of the reservoir are all known. The normal storage level of the reservoir is 160.00m, the minimum is 136.00m, and the limit is 155.00m; the installed capacity is 320,000 kW, the designed guaranteed power output is 125,000 kW, and the comprehensive power output coefficient is 8.5. Optimize the water level of the reservoir at the end of each month to optimize the power generation during the operation period. Operating environment: Microsoft Visual Basic 6.0.

4.2 Analysis of Optimization Results

In order to reasonably verify the effectiveness and feasibility of the ICSO-PSO algorithm, a relatively common dynamic programming algorithm (DP) (Li, 2016) was selected to optimize the operation of the reservoir, and the optimization effects of the two were compared. The algorithm parameters are set as follows: Discrete the feasible region of DP water level by 1000 points; In ICSO-PSO, 10 groups of chickens are selected, the number of chickens in each group N is 1000, the rooster number is 0.3N, the hen number is 0.6N, and the chick number is 0.1N, and F is a random number in the interval [0, 2]. In addition, the learning factor $r_3 = r_4 = 1.49445$; $w = \left(\frac{0.5+Rnd}{2}\right)$; when the scheduling goal and related constraints are the same, the maximum number of iterations (maxgen) is assigned 100 times, and then repeatedly test 10 times independently. The result of ICSO-PSO optimization algorithm is randomly selected once for detailed analysis, showing in Table 1~3 and Figure 1~2.

Table 1: Comparison of discharge flow and downstream irrigation and shipping water between two optimization algorithms

time	downstream irrigation and shipping water /(m^3/s)	ICSO-PSO		DP	
		discharge flow/(m^3/s)	difference /(m^3/s)	discharge flow /(m^3/s)	difference /(m^3/s)
november	204.82	200.09	0.09	200	4.82
december	201.69	204.96	4.96	200	1.69
january	205.3	201.09	1.09	200	5.3
february	204.74	203.83	3.83	200	4.74
march	202.95	202.37	2.37	200	2.95
april	322.06	322.33	2.33	320	2.06
may	442.43	440.13	0.13	440	2.43
june	360.38	360.35	0.35	360	0.38
july	302.34	306.56	6.56	300	2.34
august	346.59	344.69	84.69	260	86.59
september	393.7	400.6	160.6	240	153.7
october	350	350	150	200	150

It can be seen from Table 1 that this optimization algorithm can meet the water demand of downstream irrigation and shipping, and for the discharge, both optimization algorithms are feasible.

Table 2: Power Generation Analysis of Two Optimization Algorithms

time	ICSO-PSO	DP	ICSO-PSO is better than DP algorithm's power ratio /(%)
	power generation / (million kW·h)	power generation / (million kW·h)	
november	117.77	120.45	-2.22
december	117.81	115.89	1.66
january	111.92	114.10	-1.91
february	108.72	109.00	-0.26
march	102.65	102.64	0.01
april	154.12	153.32	0.52
may	206.53	206.53	0.00
june	173.82	172.84	0.57
july	159.69	157.07	1.67

august	193.61	194.41	-0.41
september	232.52	228.41	1.80
october	205.48	205.48	0.00
year	1884.64	1880.14	0.24

It can be seen from Table 2 that the power generation dispatched by the ICSO-PSO optimization algorithm for four months is lower than that of the DP optimization algorithm, and six months is higher, two months is equal, but the annual power generation capacity dispatched by the ICSO-PSO optimization algorithm is better than the DP optimization algorithm, generating 0.24% more.

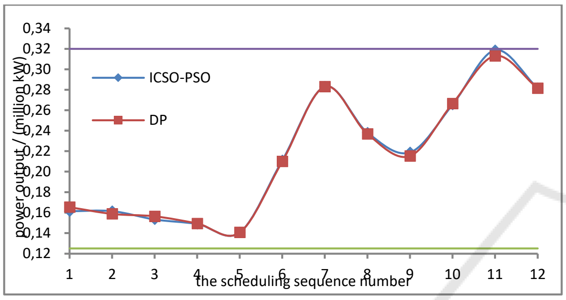

Figure 1: Comparison of the output of two optimal dispatch.

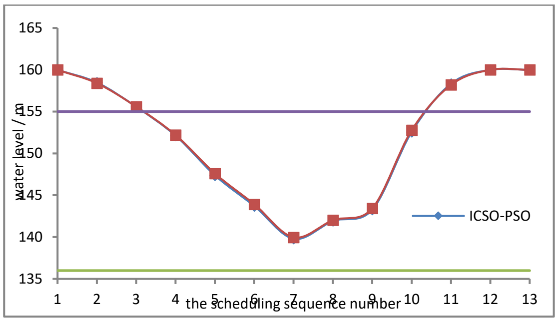

Figure 2: The dispatching process of two optimization algorithms

Note: The scheduling sequence number starts from November and ends in October of the following year.

It can be shown from Figure 1 that both optimization algorithm could meet the power output requirements of the power plant. For power output, both optimization algorithms are feasible.

Table 3: Comparison of two optimization algorithms.

algorithm	test count	maximum power generation/ (million kW·h)	average power generation/ (million kW·h)
DP	——	1880.15	——
ICSO-PSO	10	1884.48	1882.67

It can be shown from Table 3 that the ICSO-PSO algorithm optimized dispatching is 2.49 million kW·h more than the DP. Obviously, the ICSO-PSO algorithm is better than DP. It can be seen from Table 1~3 and Figure 1~2 that the ICSO-PSO algorithm has better optimization results , that is, the algorithm has good optimization performance when dealing with the optimization operation of the reservoir, so it is feasible to use the ICSO-PSO algorithm to solve the optimization operation of the reservoir; and in the simulation optimization process, it is found that the ICSO-PSO algorithm prevents the premature phenomenon of the original algorithm due to the blindness of location update during the optimization process.

5 CONCLUSION

This paper combines the original chicken swarm algorithm with the particle swarm algorithm and presents an improved chicken swarm algorithm (ICSO-PSO), which introduces a corresponding PSO optimization algorithm for the rooster position update method. It strengthens the role of the leader in the optimization process, improves the calculation efficiency, solves the problem of dimension disaster and locally optimal solution, reduces the blindness of the optimization process, and improves the convergence rate in the optimization process. By comparing with the DP optimization algorithm, the ICSO-PSO optimization results are better. Therefore, the ICSO-PSO can be used as an effective tool for solving optimization problems.

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