Optimization of Pumping Station Energy Consumption Model Based on Improved PSO Algorithm

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Abstract. In order to solve the problems of low operating efficiency and high operating cost of pumping stations in wastewater treatment plants, a model with the minimum daily power consumption cost of pumping stations as the optimization objective is established. Taking the improved particle swarm optimization algorithm as the model solving algorithm, through the practical application of the sewage pumping station, it is found that the improved particle swarm is far superior to the basic particle swarm in the stability of the algorithm. Under the improved particle swarm optimization algorithm, the daily power consumption of the sewage pumping station optimization scheme is lower than that of the basic particle swarm and the empirical scheme.

Keywords: wastewater treatment plant; pumping station energy saving; improved particle

1 Introduction

Wastewater treatment is an important measure to ensure the health and safety of human society. On the optimal operation of sewage pumping stations, there have been many studies at home and abroad, mainly focusing on the study of optimization methods. Xu et al. [1] used partial variable frequency pump as the speed control pump to reduce the pump speed and improve efficiency. Guo Siyuan et al. [2] used intelligent control to achieve energy saving based on marshalling rotation and dynamic liquid level control algorithm. Staden A J V [3] and Zhang et al. [4] used integer programming method to study the daily operation of pumping stations to achieve energy saving. Zhou [5] established a dynamic programming model to determine the optimal head ; establish nonlinear programming model to achieve optimal speed. References [6-9] used genetic algorithm to solve the optimal scheduling model, energy saving is obvious. Feng et al [10] The results show that the simulated annealing particle swarm algorithm is obviously better for the solution speed and accuracy of the pump station optimization problem.

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2 Mathematical Model for Power Consumption Optimization of Pumping Stations

2.1 Pump Basic Performance Curve

The basic performance curves of the pump include flow-head curve, flow-power curve and flow-efficiency curve, which is the basis for the mathematical model of energy consumption optimization of the pumping station.
Fitting equati:

$$\text{Flow-Head: } H = S^2 a_0 - a_1 Q^2 \quad (1)$$

$$\text{Flow-Power: } P = S^3 b_0 + S^2 b_1 Q + S b_2 Q^2 \quad (2)$$

$$\text{Flow-Efficiency: } \eta = C_0 + C_1 Q/S + C_2 Q^2/S^2 \quad (3)$$

The piping characteristic curve of the pump set is:

$$H = H_{st} + k' Q^2 \quad (4)$$

Among them, H_{st} is the water level difference of the pump set, and k' is the piping characteristic coefficient under actual conditions. For variable frequency pumps, the high-efficiency zone is the area composed of ABCD, as shown in the figure 1

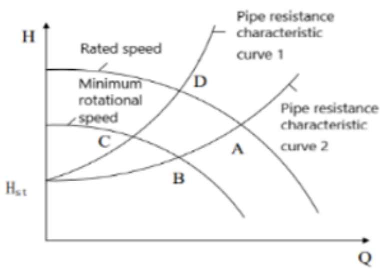

Fig. 1. High efficiency zone of variable frequency pump (Self-drawn)

2.2 Mathematical Model

Energy consumption optimization of pumping station refers to setting the minimum operating cost of sewage pumping station as the optimization goal under the premise of satisfying the discharge volume and head during the period and considering the water level in and out of the pool, and under this goal and constraint conditions, the optimal operating parameters of the sewage pumping station as a whole are calculated to obtain the optimal unit operation scheme.

2.2.1. Objective Function

Taking the minimum operating electricity cost of the pumping station per unit time period as the objective function, the definition of the objective function is:

$$P=\min[\sum_{i=1}^{I}\sum_{j=1}^{J}\frac{\rho g Q(i,j)H(i,j)}{\eta_{mot}(i,j)\eta(i,j)}t(i,j)\,d(i,j)] \tag{5}$$

In the formula:

P is the electricity fee for the operation of the entire pump station system during the dispatching operation period;

ρ,g represents the density of water and the acceleration of gravity;

H(i,j) and Q(i,j) are the pump head and flow rate for the ith pumping station for the jth period;

t(i,j) d(i, j) represents the number of working hours and local electricity price of the jth period of the i-th pump station

η_mot (i,j)η (i,j) indicates the efficiency of the motor and the efficiency of the pump during the jth time period of the ith pumping station.

2.2.2. Binding Conditions

(1) Inlet and outlet pool water level constraints

$$Z_{min}(i) \le Z(i) \le Z_{max}(i) \tag{6}$$

$$Z'_{min}(i) \le Z'(i) \le Z'_{max}(i) \tag{7}$$

The formula Z_{min}(i) Z_{max}(i) Z'_{min}(i) Z'_{max}(i) are the minimum and maximum water levels of the inlet and outlet pools of the i pumping station, respectively.

(2) Head constraint

Each pump head should meet the minimum inlet and outlet water level difference constraint, and meet in the efficient operation of the pump interval.

$$\begin{cases} H_i = H_j \\ H_i > H_\Delta \end{cases} i,j \in n \tag{8}$$

Where: H_Δ is the difference between the inlet and outlet water level of the pump station

(3) Flow constraints

Both to meet the flow capacity based on, but also in the efficient range of pump operation.

$$\begin{cases} Q = \sum_{i=1}^{I} Q_i \\ Q_{m_{in}} \le Q_i \le Q_{max} \end{cases} \tag{9}$$

3 Pumping Station Optimization Based on Improved PSO Algorithm

3.1 Elementary Particle Swarm Algorithm

The particle swarm optimization algorithm is proposed by American scientists. Its main idea is inspired by the modeling and simulation results of bird flock behavior.

The ith particle is at the velocity and position of the d+1 order

$$x_i^d = x_i^d + v_i^d \tag{10}$$

$$v_i^d = wv_i^d + c_1 r_1 \left(P_{best,i}^d - x_i^d\right) + c_2 r_2 \left(g_{best,i}^d - x_i^d\right) \tag{11}$$

c_1: individual learning factors, also known as individual acceleration factors;
c_2: social learning factor, also known as social acceleration factor;
r_1, r_2: random number on [0,1];
w: called the inertia weight, also known as the inertia coefficient.

3.2 Improve the Algorithm

The improved algorithm calculation process is shown in figure 2, solving steps are as follows:

1) Initialize the population size, determine the operating parameters and their value range, algorithm parameters, and initialize the position and velocity of the particles.

2) Calculate the fitness of each particle, compare the individual extreme value with the fitness value.

3) Set a sufficiently large initial temperature T (0) > 0 and perform the corresponding desuperheating operation.

4) The fitness value of p_i per particle at temperature T

5) Determine the global optimal substitution value from all p_i, p_i' using formulas (10) and (11) to update its position and speed.

6) Calculate and determine the particle target value, update and, and then desuperheating operation.

7) determine whether the termination condition is satisfied, if it is satisfied, the calculation ends and the results are output; otherwise return to step 4.

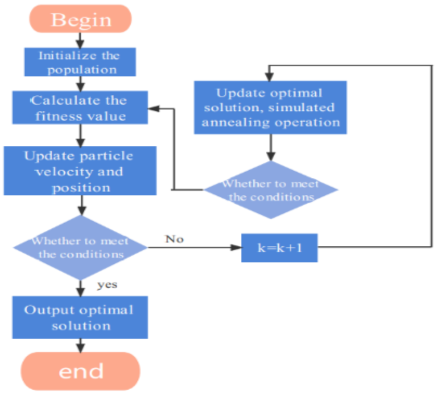

Fig. 2. Improved algorithm calculation process (Self-drawn)

4 Case Studies

4.1 Brief Description of the Project

Taking a sewage pumping station as an example, there are six 20Sh-9A 500S59A pump units, rated head 50m, rated flow 0.53m3 / s, power 400kw, motor efficiency 0.96, maximum daily sewage treatment 27.4kw. Select a certain operating data, according to the national standard time-sharing accounting pumping station operating costs, the basic price of electricity is 0.615 yuan / kWh, the actual daily electricity cost is 15462 yuan.

Table 1. Pumping station operating data (Self-drawn)

serial number	Flow rate (m^3/h)	Head(m)	Shaft power (kw)	Efficiency (%)
1	1100.1	54.86	309.8	66.07
2	1200.75	54.5	310.11	70.05
3	1423.84	53.59	311.88	77.68
4	1596.14	52.79	312.57	82.37
5	1607.32	52.74	313.62	82.63
6	1789.78	51.78	317.37	86.38
7	1854.76	51.42	317.89	87.43
8	1902.17	50.14	322.34	88.12
9	2074.61	49.09	329.97	89.89
10	2112.37	48.84	333.93	90.14

Matlab's cftool toolbox can be used to manipulate a variety of linear and nonlinear curve fitting. Put the data from the above table into the cftool toolbox to obtain the flow-head and flow-efficiency fitting plots, as shown in figure 3

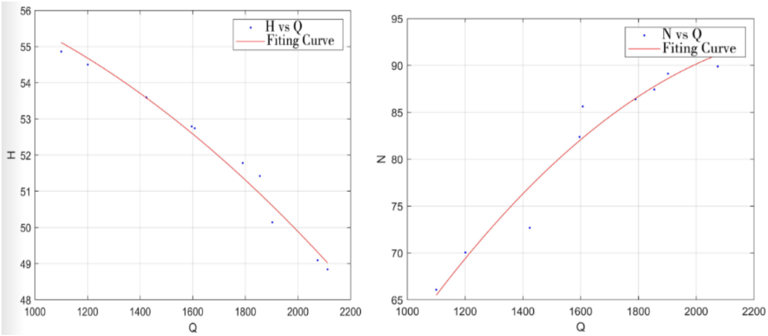

Fig 3. Flow-head and flow efficiency fitting curves (Self-drawn)

Fit equation:

$$H = 51.39 - 1.83 * 10^{-6}Q^2 \quad (12)$$

$$N = 3.52 + 0.07Q - 1.447 * 10^{-5}Q^2 \quad (13)$$

4.2 Optimization Comparison

The basic particle swarm algorithm and the improved particle swarm algorithm are used in turn to optimize the scheduling simulation of the system, in which the results of PSO and SA-PSO are shown in the figure 4, the performance of SA-PSO has been improved to a certain extent compared with the basic PSO.

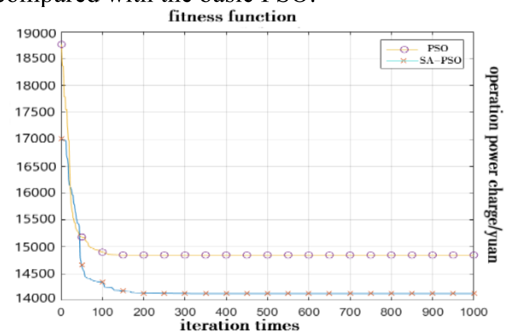

Fig. 4. Comparison of electricity consumption costs (Self-drawn)

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