Research on Economic Dispatch Optimization Model of Small Hydropower Group Considering Power Supply Cost

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Abstract. Due to the large number of scattered small hydropower, disordered grid connection, unplanned power generation, and old equipment overvoltage, etc. It has brought great challenges to the power supply security of Sichuan Power Grid. Aiming at the minimum system power supply cost, the economic dispatch optimization of small hydropower groups within the system is realized. The nonlinear mixed integer 0-1 programming is solved by adaptive simulated annealing genetic algorithm. The results show that the total cost of power generation after the optimized power generation plan. It is lower than the cost of all the power stations in the flood season, further indicating that the scheduling optimization can effectively reduce the system power supply cost, and guide the Ya'an small hydropower group. Economic dispatch is of great significance.

1. Introduction

As a renewable and clean energy source, water resources are more environmentally friendly than thermal power generation and nuclear power. Sichuan Province is China's largest water resource storage province, and the hydropower reserves of small watersheds can reach 164 million kilowatts, ranking second in the country. Ya'an is located in the transition zone from Chengdu Plain to Qinghai-Tibet Plateau. The relative height difference is large, and the domestic precipitation is abundant. At the end of 2016, Ya'an Power Grid dispatched and managed 643 hydropower plants, 1315 generator sets, and hydropower generating installed capacity of 1,851,700 kilowatts. The ratio is 99.92%. However, Ya'an Power Grid has a relatively high installed capacity of hydropower. How to effectively eliminate large-scale hydropower has become an urgent problem for Ya'an local government and power grid companies.

Due to the periodicity and seasonality of rivers and rivers, the hydropower regulation performance is generally poor. The hydropower station with many years of regulation performance only accounts for 21%, resulting in the uneven distribution of hydropower group output during the year. The output during the flood season is very disparity. Only one-third of the average output of the abundance. In addition, the small hydropower stations connected to Ya'an are almost all of the small-flow hydropower, mostly in the mountains or in areas far from the city, with small scale and old facilities. And so on. At the current stage of operation, there are still two more pressing problems that need to be resolved, namely the overvoltage safety problem and the reverse price of electricity in the Ya'an area.

In order to improve the local consumption of Ya'an small hydropower, reduce the amount of on-grid electricity, and reasonably avoid price upside down, the above problem is regarded as the economic...
optimization scheduling problem of small hydropower stations. Domestic and foreign scholars have proposed many solutions, such as the traditional planning algorithm MI and intelligent algorithms.

In this article[5], the power generation reference flow of each reservoir in the cascade small hydropower group is used as the decision variable to establish the optimal small hydropower group scheduling model with the largest amount of power generation; The literature considers the energy loss of electromechanical and turbine generators, and hydropower[6]. The scheduling problem of the unit is modeled as a nonlinear mixed 0-1 planning problem. The two-stage method of dual d-ecomposition is used to solve this problem. In the literature [7], under the premise of ensuring dam safety, the cascade power station is in the scheduling period. The maximum power generation is the target, which is solved by the genetic algorithm of floating-point coding. The literature considers the economics and reliability of the operation of large and small hydropower systems, and the improved particle swarm optimization algorithm considering the constraint tolerance is used to solve the coordinated scheduling optimization model[8]; It proposed the maximum short-term coordinated optimization scheduling model for the expected value of water and electricity consumption, and applied heuristic search and correlation search method to solve[9,10].

In summary, this paper proposes a small hydropower project based on the Ya'an area where small hydropower is enriched during the flood season, and the high maintenance cost and the price of buying and selling electricity caused by the high failure rate of the old equipment of the local small all hydropower station in Ya'an. Local consumption and recommendations for meeting local load requirements. At the same time, considering the failure cost and depreciation cost allocation of each small hydropower station, on the basis of meeting the load demand of Ya'an area, the economic dispatch of Ya'an local small hydropower station is realized with the goal of minimizing the total cost of regional power supply. In addition, this paper chooses to improve the genetic algorithm to solve the above optimization scheduling problem.

2. Economic Dispatch Optimization Model for Small Hydropower Stations
Since the local power generation sources in Ya'an are almost all small hydropower stations, they are mixed and distributed, and there are some upstream and downstream water quantity links between some hydropower stations. Therefore, the construction of the model needs to consider the influence of the upstream power station on the downstream power station. When establishing the water balance relationship, it needs to be adjusted according to the presence or absence. The ability to divide small hydropower stations into two categories. Finally, the economic dispatch optimization model is set up with the minimum power supply cost of the system in Ya'an area.

\[
\min f = \min \sum_{t=1}^{T} \left\{ \sum_{i=1}^{M} \left[ C_{hi} P_{hti} \Delta t U_{i,t} + U_{i,t} \left( 1 - U_{i,t-1} \right) C_{mi,t} + U_{i,t-1} \left( 1 - U_{i,t} \right) C_{Di,i} \right] + p_t \Delta P_t \right\}
\]

\[
C_{hi} = C_{di} + C_{mi}
\]

\[
P_{hti} = A_i \cdot q_{i,t} \cdot h_{i,t}
\]

\[
P_t = \Delta P_t + \sum_{i=1}^{M} P_{hti} \cdot U_{i,t}
\]

The constraints are as follows:
Storage constraint
\[
v_{i,\min} \leq v_{i,t} \leq v_{i,\max}
\]

Power generation reference flow constraint
\[
q_{i,\min} \leq q_{i,t} \leq q_{i,\max}
\]

Water balance constraint
According to the water balance constraint, the water balance formula of the hydropower station with the ability to adjust the reservoir is divided.
\[ v_{r+1,j} = v_{r+1,t} + (n_{r+1,t} - Q_{r+1,t} + Q_{r,t}) \Delta t \]

Water balance formula for non-reservoir runoff small hydropower station

\[ n_{r+1,t} = Q_{r+1,t} \]

Power balance constraint

\[ P_i = \Delta P_i + \sum_{i=1}^{M} P_{hi,t} \cdot U_{i,t} \]

Discharge flow constraint

\[ Q_{r,\text{min}} \leq Q_{r,t} \leq Q_{r,\text{max}} \]

Hydropower station output constraint

\[ P_{hi,\text{min}} \leq P_{hi,t} \leq P_{hi,\text{max}} \]

Hydropower unit minimum operation and minimum shutdown time constraint

Unit minimum running time constraint:

\[ (U_{i,t} - U_{i,t-1}) + (U_{i,t+v-1} - U_{i,t+v}) \leq 1, t \in 1,2,\ldots,(T - v); v \in 1,2,\ldots,(T_{on} - 1) \]

Unit minimum shutdown time constraint:

\[ (U_{i,t} - U_{i,t}) + (U_{i,t+v} - U_{i,t+v-1}) \leq 1, t \in 1,2,\ldots,(T - v); v \in 1,2,\ldots,(T_{off} - 1) \]

End water level control constraint:

\[ Z_{Fi} = Z_{\text{t}} \]

3. Examples

3.1. Scene Settings

The economic dispatch of a small system in Ya'an area during the wet season, the generator set is all hydropower units, a total of five hydropower stations, namely H1, H2, H3, H4, H5. The internal power supply of the system is greater than the system power demand. Among them, hydropower station H1, H2 is the two with the ability of the reservoir to adjust daily. The small hydropower stations can be adjusted, and the remaining hydropower stations are all non-regulated runoff hydropower stations. The basic data of each hydropower station are shown in the following Table 1.

| Hydroelectric power station | Installed capacity | Minimum guaranteed output | Maximum output | Comprehensive processing coefficient K | Tail water level | Design water level | Maximum power generation |
|----------------------------|--------------------|---------------------------|----------------|----------------------------------------|-----------------|-------------------|-------------------------|
| H1                         | 32                 | 10                        | 32             | 8.2                                    | 329             | 425               | 30                      |
| H2                         | 25                 | 5                         | 25             | 8                                      | 142             | 167               | 17                      |
| H3                         | 13                 | 0                         | 13             | 8                                      | 240             | 78                | 20                      |
| H4                         | 10                 | 0                         | 10             | 7.8                                    | 80              | 50                | 23                      |
| H5                         | 4                  | 0                         | 4              | 7.5                                    | 30              | 30                | 17                      |

3.2. Simulation

This simulation is implemented by Matlab software, and the set parameters are substituted into the objective function and constraints of the built model, and then substituted. The calculation is performed in the written program algorithm. Considering the uncertainty of the results of the genetic algorithm, the results of each operation will be different. Perform 10 simulations, and the final result is the average of 10 simulation results. The output of each small hydropower station is shown in Table 2.

| Time | H1      | H2      | H3      | H4      | H5      |
|------|---------|---------|---------|---------|---------|
| 1:00 | 31.160  | 22.832  | 2.491   | 0       | 0       |
| 2:00 | 30.017  | 23.272  | 6.863   | 0       | 0       |
The maintenance cost is high. The higher the cost, the higher. The hydropower station is selected according to the cost sharing measurement method described in 1.2. In the above chart, the fixed cost sharing of the unit power of each hydropower station is obtained according to the cost sharing measurement method described in 1.2.

| Hydroelectric power station | Total investment | Annual average utilization (A) | Annual average utilization (B) | Annual average utilization (C) | Annual average maintenance cost | Failure cost sharing | Fixed cost allocation |
|-----------------------------|------------------|--------------------------------|--------------------------------|--------------------------------|---------------------------------|---------------------|---------------------|
| H1                          | 400 00           | 4 500                          | 14 400                         | 0.05555                        | 84.7488                         | 0.005 885          | 0.06144             |
| H2                          | 300 00           | 4 500                          | 11 250                         | 0.006866                       | 63.71                           | 0.005 663          | 0.07233             |
| H3                          | 150 00           | 4 200                          | 5 460                          | 0.09157                        | 127.716                         | 0.023 391          | 0.11496             |
| H4                          | 110 00           | 4 200                          | 4 200                          | 0.08702                        | 158.904                         | 0.037 834          | 0.12513             |
| H5                          | 400 00           | 4 000                          | 1600                           | 0.125                          | 105.936                         | 0.066 21           | 0.19121             |

In the above table, it can be seen that the fixed cost allocation of the unit power of each hydropower station is H5> H4> H3> H2> H1. The above results are due to the design of each hydropower plant. Due to the different degrees of aging, the H2, H4, and H5 equipment of hydropower stations are more serious. In daily operation, the failure rate is high and the maintenance cost is high. The higher the cost, the depreciation cost and the fault repair cost of the unit power generation are higher. The hydropower
station H2 equipment is the most serious, and its solidity. The cost allocation is the highest. Finally, the total cost of system operation is compared and analyzed. Scene 2 is solved by general genetic algorithm and improved genetic algorithm respectively. The results are shown in Table 4.

4. Conclusion
(1) Compared with the traditional genetic algorithm, the improved genetic algorithm is used to solve the multi-variable and multi-constraint nonlinear integer programming problems. The global search ability is stronger, avoiding the premature phenomenon, making the calculation result closer to the global optimal solution.

(2) Simultaneously from the holistic nature of system optimization, considering the new and old degree of hydropower equipment, the annual depreciation cost and fault repair cost are allocated to the unit power generation, and then the economics of hydropower station power generation are measured and judged, and finally the local small hydropower group dispatching in Ya'an is guided. Arrange and allocate the unit's electricity cost to the peak of the hydropower station or stop gene-rating electricity.

(3) To a certain extent, it can reasonably reduce the local aging of small hydropower equipment in Ya'an due to severe aging and frequent occurrence of overvoltage safety accidents. High cost of repairing faults, while avoiding economic problems such as price hung ups of electricity sales prices, reducing the power supply to local power systems in Ya'an. This has important research value and significance for promoting the development of local small hydropower industry.

Table 4. Scenario Total Cost Analysis

| Scenes     | Genetic Algorithm | Hydropower unit | Start-up cost | Grid power | Total cost  |
|------------|-------------------|-----------------|---------------|------------|------------|
| Scenes 1   | Traditional       | 174842.7703     | 8400          | -30.0911.61062 | 153 151.1597 |
| Scenes 2   | Improved          | 117075.3229     | 5750          | 21720.59299 | 144 545.9158 |

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