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Construction of Short- and Long-term Optimization Dispatch System for Giant Hydropower Station Group

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This paper characterizes the operation dispatches of giant hydropower station cluster, whereby to propose variable-step size and chaotic annealing algorithms for optimization based on the objective function nonlinearity of short-term dispatch and the electro-hydraulic connection complexity of long-term dispatch. An example taken for computation proved that the proposed algorithm is highly reasonable and excellent. Short-term optimization dispatch system turns out that the variable-step-size algorithm, as a new approach for dispatching the hydropower station cluster, can reduce the coupling constraints on the dispatch when the electro-hydraulic connection is complex. The efficiency of solution is improved by the fixed step size variable in a simple process. It is feasible to work out the coupling constraints for short-term dispatch by introducing the mutative scale strategy. For the long-term optimization dispatch, it follows that the proposed algorithm can guarantee the global convergence of results and has diversified the populations. Adjustable crossover and mutation operators improve the adaptability of algorithm. The results from simulation reveal that the dispatch optimized by the algorithm proposed in this paper features less time-consuming, increased power generation and the feasible optimization solution.

1. Introduction

As there are many rivers in China, the water conservancy system has evolved more rapidly. In recent years, some giant and complex hydropower stations have sprung up from many large drainage basins, so that the rational and optimal dispatch for hydropower plants has set a new challenge for scholars. Unlike the traditional minitype water conservancy system, the cluster of giant hydropower stations, enormous as it is in scale, consumes higher power and enables pitch peak with a broader impact. The huge mass of resources will be consumed when hydropower system frequently responds to the electric application requirements. The unit oscillation further complicates the system operation (Catalão et al., 2010; Nacef et al., 2016; Zhou et al., 2002; Mandal & Chakraborty, 2008; Hota et al., 2009; Wang et al., 2018).

Currently, the objectives of optimal dispatch of hydropower station cluster are to minimize the cost, output the highest power or get the minimum residue load after system regulation. In allusion to the above objective functions, the scholars proposed a number of optimal dispatch algorithms for hydropower clusters, such as dynamic programming method, neural network method, genetic algorithm, simulated annealing algorithm, fuzzy decision method, POA algorithm (Akbari et al., 2018; Basu, 2004; Liu and Xu, 2017; Li et al., 2017; Naresh & Sharma, 2000; Lu et al., 2010; Lakshminarasimman & Subramanian, 2008; Mandal et al., 2008; Amjady & Soleymanpour, 2010; Gil et al., 2003). As the dispatch cycles of hydropower clusters are different, they can be divided into short-term and mid-long-term optimization dispatches (Kumar & Naresh, 2007; Yuan et al., 2008; Yu et al., 2007; Basu, 2004; Mandal & Chakraborty, 2009). The hydraulic connection between different hydropower stations lead these dispatch algorithms to having some limitations.

In this paper, the operation dispatch of large-scale hydropower station cluster is characterized. A variable step size algorithm and a chaotic annealing algorithm are hereby proposed based on the objective function nonlinearity of short-term dispatch and the electro-hydraulic connection complexity of long-term optimization dispatch. An example of computation is cited to reveal that the proposed algorithm has been proven to be reasonable and superior.

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2. Short-term optimization dispatch algorithm for hydropower station cluster

The purpose of short-term optimization of giant hydropower system is to address the demand for daily loads of power systems and to determine the upper and lower limits of hydropower operation. This is regarded as a typical nonlinear issue. Some parameters such as initial water level, flow velocity and operation constraint of reservoirs are key to solve the daily dispatch of hydropower station cluster. While the purposes of dispatch optimization are to reduce the cycles of startups and shutdowns of hydropower units, improve the system operation efficiency and eventually realize the power generation while effectively reducing the power line costs. In general, the residue load *f* available after adjustment of the water conservancy system is used to evaluate the optimization effect

$$\min f_1 = \max_{1\le t\le T}\left(C_t - \sum_{m=1}^{M} p_{m,t}\right) \tag{1}$$

t and m are the dispatch number and the hydropower station number, respectively; T and M are the total times of dispatches and the total number of reservoirs, respectively; C_t is the system load of the round t of dispatch; $p_{m,t}$ is the average output of the hydropower station m. Eq. 1 is optimized in this paper, then

$$\min F_1 = \frac{1}{P}\ln\left\{\sum_{t=1}^{T} e^{P\left[C_t - \sum_{m=1}^{M} p_{m,t} - \max_{1\le k\le T}\left(C_k - \sum_{m=1}^{M} p_{m,k}\right)\right]}\right\} + \max_{1\le t\le T}\left(C_t - \sum_{m=1}^{M} p_{m,t}\right) \tag{2}$$

When the Eq. 2 is calculated, the following divisor and control conditions are available:
(1) Water balance of upstream and downstream hydropower stations

$$V_{m,t+1} = V_{m,t} + 3600\times\left(Q_{m,t} - q_{m,t} - Ql_{m,t}\right)\Delta_t \tag{3}$$

$V_{m,t}$ is the reservoir capacity of the hydropower station m on the round t of dispatch; $Q_{m,t}$ is the water inflow capacity of the hydropower station m; $Ql_{m,t}$ is the corresponding waste water capacity; $Qn_{m,t}$ is the total flow.
(2) Upper and lower limits of hydropower output:

$$\underline{N}_t \le \sum_{m=1}^{M} p_{m,t} \le \overline{N}_t \tag{4}$$

The role of the above Eq. is to limit the total output of the hydropower station cluster and maintain the efficient and stable operation of the hydropower network.
(3) Output control of single hydropower station:

$$Z_{m,T} = Z'_{m,T} \tag{5}$$

(4) Power generation flow and eco-flow can be constrained according to the water conservancy and the maximum overcurrent and shipping, ecological water supplies.

(5) Constraint on hydropower output and reservoir water level means that after the output required for the generator unit reaches, the reservoir water level shall be maintained to ensure the daily regulation capacity and runoff of the reservoir

$$q_{m,t} \le \overline{q}_{m,t} \tag{6}$$

$$\underline{S}_{m,t} \le S_{m,t} \le \overline{S}_{m,t} \tag{7}$$

(6) For vibration and cavitation constraints of generator unit, the actual dispatch shall avoid the vibration zone

$$\left(p_{m,t-\alpha+1} - p_{m,t-\alpha}\right)\left(p_{m,t} - p_{m,t-1}\right) \ge 0, \alpha = 1,2,\ldots,te_m \tag{8}$$

$$\left(p_{m,t} - \overline{ps}_{m,t,k}\right)\left(p_{m,t} - \underline{ps}_{m,t,k}\right) > 0 \tag{9}$$

3. Long-term optimization dispatch algorithm for hydropower stations

3.1 Design

On the whole, the concept of long-term optimization dispatch of hydropower station cluster is roughly consistent with that of short-term optimization dispatch. The proposed algorithm is also required to improve its convergence speed and local search capacity. In the long-term optimization dispatch, the gross generation E of hydropower station cluster is taken as the objective function, which is maximized by optimization. The formula is

$$\max E = \sum_{i=1}^{N} \sum_{t=1}^{T} \left(p_i^t \Delta_t \right) \tag{10}$$

The meanings of parameters in the formula are described as above. Constraints in the formula 10 mainly include reservoir storage capacity, power generation flow, outputs and so on. The annealing genetic algorithm is adopted to improve the optimization dispatch with such an idea that the best individuals in the population are inherited to the next generation. Assume the probability that an individual x_i is selected is

$$P(x_i) = J_k(f_i) \Big/ \sum_{n=1}^{N} J_k(f_n) \tag{11}$$

J_k is the fitness function. The global annealing option is introduced into the proposed algorithm. In this way, the individuals in the new population can be ensured to converge to the optimal solution, thus avoiding the premature aging of the locally optimal solution after multiple iterations. The global annealing option mechanism is to ensure that the most individuals of each generation can inherit to the next generation, the specific formula is

$$J_k\left(f(x_i)\right) = \exp\left(f(x_i)/T_k\right) \tag{12}$$

$$P(x_i) = \exp\left(f_i/T_k\right) \Big/ \sum_{n=1}^{N} \exp\left(f_n/T_k\right) \tag{13}$$

The major parameters, i.e. crossover operator p_c and the genetic operator p_m are used to evaluate the performance of the algorithm, and the adaptive function to solve p_c and p_m:

$$P_c = \begin{cases} P_{c1} - \dfrac{(P_{c1} - P_{c2})(f' - f_{\text{avg}})}{(f_{\max} - f_{\text{avg}})}, & f' \geq f_{\text{avg}} \\ P_{c1}, & f' < f_{\text{avg}} \end{cases} \tag{14}$$

$$P_m = \begin{cases} P_{m1} - \dfrac{(P_{m1} - P_{m2})(f_{\max} - f)}{(f_{\max} - f_{\text{avg}})}, & f \geq f_{\text{avg}} \\ P_{m1}, & f < f_{\text{avg}} \end{cases} \tag{15}$$

p_{c1}, p_{c2}, p_{m1}, p_{m2} are relevant control parameters in the interval (0,1); f is the fitness; f_{max} and f_{avg} are the maximum and the average of the fitness set, respectively.

Based on the above analysis, the long-term optimization algorithm of hydropower station cluster is designed. Let the monomer elements in the algorithm be the water line values ($Z_{1,1}$, $Z_{1,2}$,…, $Z_{1,n}$,…, $Z_{t,n}$) of reservoirs in each time frame; n represents the statistical time frames and t is the number of hydropower stations. The calculation procedure is given as follows:

(1) Before calculation, set the initial population size, the maximum number of iterations, initial and end temperature, parameters p_{c1}, p_{c2}, p_{m1}, p_{m2}.

(2) Adjust the population to the initial level, use Eq. 13 as the fitness evaluation function, count and collect the best individuals in each round of iteration, delete those with the lowest fitness,

(3) Select individuals using Eq. 12 and 13, the evaluation options are mainly selective probability and relative fitness formulae.

(4) Perform crossover and mutation operations on the new population, finally determine whether the iteration is over and the optimal solution is output.

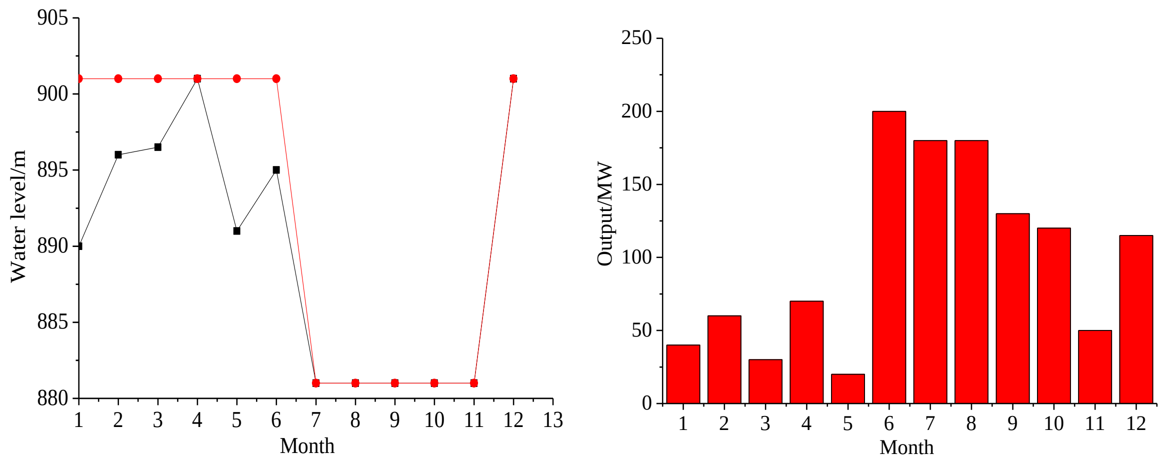
3.2 Example verification

To validate the feasibility of long-term optimization dispatch of hydropower stations, the drainage basin and hydropower station cluster as given in section 2.2 are chosen; the calculation time frame is expressed on the monthly basis; it is programmed in C ++; the performances of the algorithm in 25%, 50% and 75% inflow years are calculated, respectively, and compared to those available by the traditional algorithms POA and SGA. The initial population in SGA is taken as 200, the crossover probability as 0.7, the mutation probability as 0.15 and the maximum times of iterations are 200. The power generation and the calculation time of five types of hydropower stations under three different inflow water frequencies are shown in Table 1.

Table 1: Generated energy of hydropower station group in a typical year

Typical year	Algorithm	Station(Water content/10^8kWh)					Time/s
		No.1	No.2	No.3	No.4	No.5	
	POA	31.02	23.78	93.21	185.69	294.38	698
25%	SGA	31.02	23.99	87.35	187.82	291.79	157
	Proposed	31.18	23.86	93.78	187.33	295.64	252
	POA	30.87	17.11	80.12	163.14	267.45	691
50%	SGA	30.66	17.09	79.14	163.52	263.71	155
	Proposed	30.73	16.79	80.07	164.77	266.28	247
	POA	26.96	12.03	68.22	134.42	228.47	683
75%	SGA	26.94	12.05	67.10	135.31	229.02	158
	Proposed	27.04	12.07	69.31	136.65	231.86	251

It can be seen from the table that the dispatch improved by the algorithm in this paper is obviously better than that by POA and SGA algorithms. When the water inflow frequency is 25%, the proposed algorithm generates about 400 million kWh higher than the POA, takes 476s in computation shorter; totally generates about 1 billion kWh more than the SGA; when the frequency of effluent is 50%, the power generation of this algorithm basically remains the same as that of the POA, and 200 million kWh more than SGA, but the calculation time is shortened by about 444s. When the frequency of the effluent is 75%, the power generation of the proposed algorithm is about 300 million kWh higher than the POA. Because the POA is a dispatch optimization algorithm for traditional hydropower station cluster, the longer the calculation time, the more accurate it is. A good performance of this algorithm in terms of time-consuming and accuracy are once again reflected in the Table 1.



(a) (b)

Figure 5: Optimal operation results of proposed method in a normal flow year

When the inflow frequency is 50%, the water level and the output in the selected NO2 hydropower station in a year are shown in Fig. 5. As can be seen from the figure, the predicted water level calculated in this paper is not much different from the actual water level. The reservoir water level remains relatively high, which can effectively improve the power generation efficiency during the dry season. The changes in water level should be randomly adjusted by combination with flood prevention and power generation at any time in order to ensure a high water head generation and the safety level of reservoir flood control.

As shown in Fig. 6, the optimal dispatch fitness by 100 iterations in the proposed algorithm and the SGA are given, provided that the inflow frequency is 50%. As can be seen from the figure, the chaos annealing option is introduced in this paper, which improves the population fitness after initialization more significantly than the SGA. The algorithm proposed in this paper achieves global convergence when the number of iterations arrives at 34, while the SGA converges only at 45. This algorithm has a stronger global search capacity as the overall annealing is used.

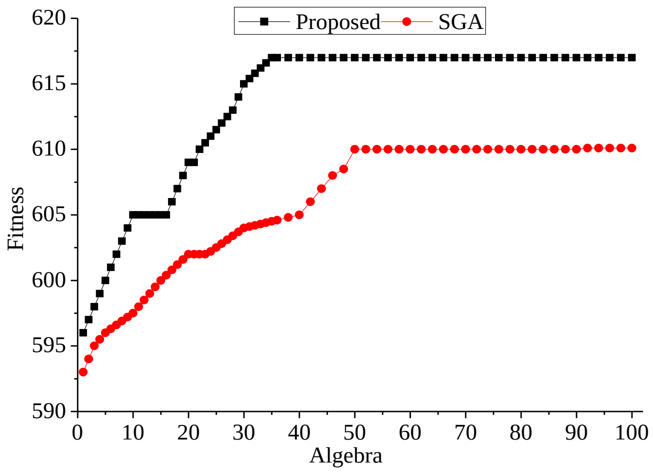


Figure 6: Evolution process in a normal flow year with different methods

4. Conclusion

In this paper, the operation dispatch of large-scale hydropower station cluster is characterized. Based on the objective function nonlinearity of short-term dispatch and the electro-hydraulic connection complexity of long-term optimization dispatch, the variable step size algorithm and the chaotic annealing algorithm are proposed. The example of computation is cited to prove the rationality and superiority of the proposed algorithm. The conclusions are drawn as follows:

(1) The short-term optimization dispatch turns out that the variable step size algorithm can reduce the coupling constraint on dispatch in the electro-hydraulic time frame, improve the efficiency of the solution by changing the fixed step size with simple calculation process, as a new type of dispatch approach for hydropower station cluster. It is feasible to solve the short-term coupled constraint by introducing a scale mutation strategy.

(2) The results of long-term optimization dispatch show that the proposed algorithm can ensure the global convergence of the results and effectively diversify the population. By adjusting the crossover operator and mutation operator, the algorithm's self-adaptability is improved. The results from simulation reveal that the optimal dispatch in this algorithm features less time-consuming and increased power generation, and feasible optimization solution.

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