Research on Planning and Optimal Operation of Variable Speed Pumped Storage

Weiwei Yao, Changhong Deng*
School of Electrical Engineering and Automation, Wuhan University, Wuhan, China

*Corresponding author e-mail: dongch@whu.edu.cn

Abstract. Combining hydropower market economy and safe dispatching, the paper puts forward a mathematical model for optimal dispatching of variable-speed hydropower generating units, and an online transaction mode that takes into account energy saving and consumption reduction. The power generation sequencing method is determined according to the unit quotation method, and energy consumption indicators are introduced according to reservoir storage. Water volume, etc., adopt a differentiated power plan, open power generation rights trading, and adjust the trading market to ensure the economic benefits of hydropower plants while achieving the goals of energy conservation and environmental protection.

Keywords. Energy saving and environmental protection, power planning and optimized operation, variable speed unit.

1. Introduction
As a new institutional arrangement for my country's power resource dispatch, hydropower is of great significance to my country's implementation of energy conservation and environmental protection policies, promotion of energy conservation and emission reduction, and increase of the economic benefits of power plants. However, the construction of hydropower generation must serve the national macro-control, and constantly improve the market opportunity means to better serve the national macro-industry control [1]. In view of the characteristics of hydropower plants, such as the uncertainty and randomness of runoff, and the storage capacity of reservoirs, how to combine market mechanisms and power bidding on the grid, reasonable power generation dispatching is currently a problem that hydropower plants need to consider strictly. To this end, on this basis, the paper discusses the relationship between the optimal dispatching of hydroelectric power generation variable-speed units in hydropower plants and the electricity price bidding on the grid, and proposes an optimal dispatching algorithm for hydro-electric variable-speed generators for optimal unit dispatch. While improving the economic benefits of my country's hydropower plants, it also meets national energy conservation and emission reduction needs.

2. Online bidding transaction method for hydropower plants
The ultimate goal of variable-speed pumped storage optimization is to reduce the overall cost of power plants, including variable costs of energy consumption and fixed costs. For hydropower plants, due to uncertain factors such as dry periods and flood periods, there are also price distortions such as...
electricity pricing. Under the influence of competition and game between supply and demand, the operating rules of hydroelectric power generation have randomness in reducing power generation costs and saving energy consumption [2]. In other words, in the power generation environment, there is a problem of coordination and modification of energy-saving power generation dispatching and bidding mechanism. Therefore, the power generation declaration of hydropower generating units needs to be controlled by the dual indicators of on-grid power price and power generation rate to maximize economic benefits. Variable-speed pumped storage adopts a constrained mode of energy consumption, so the expression is as follows:

\[
\min P = \sum_{i} b_i Q_i \\
\text{s.t.} \quad \sum_{i=1}^{Iw} c_i Q_i \leq E_s
\]

In the above formula, i represents the serial number of the unit (i=1, 2, m); Qi is the bidding power of the water turbine generating variable speed unit i; bi represents the bid price; the constraint is the overall energy consumption constraint of the water turbine generating variable speed unit; Among them, Iw represents the set of winning units; ci represents the energy consumption characteristics of power generation units, and EEs represents the set total energy consumption index.

Under the condition of ensuring the reduction of the energy consumption of hydroelectric power generation, the power purchase cost of optimizing the allocation of electric energy resources can be effectively controlled and modified to reduce the constraints of the cost of power generation enterprises, which has played a role in saving costs and reducing energy consumption [3]. Applying this method to the power grid, the mathematical model of competitive bidding for saving the cost of generators and optimizing the dispatching of variable-speed generating units of hydro-turbine generators is expressed as follows.

2.1. Objective function setting
The goal is to maximize the power plant revenue, so the expression is as follows:

\[
R = \max \left( \sum_{b \in S} \sum_{i \in B_b} T_{b,i} R_{b,i} - \sum_{g \in G} \sum_{j \in A_g} N_{g,j} M_{g,j} \right)
\]

2.2. Constraints
Electricity balance: \( \sum_{b \in S} \sum_{i \in B_b} R_{b,i} - \sum_{g \in G} \sum_{j \in A_g} M_{g,j} = 0 \); transaction volume in the electricity purchase quotation stage: \( 0 \leq R_{b,j} \leq R_{\text{max},b,i} \); transaction volume in the electricity sale quotation stage: \( 0 \leq M_{g,j} \leq M_{\text{max},g,j} \); energy consumption of the variable-speed hydroelectric generating unit:

\[
\sum_{g \in G} \sum_{j \in A_g} C_{g,j} (M_{g,j}) \leq E_s
\]

In the above formula, R represents the collection point income; S represents the set of purchasers; G represents the set of power sellers; Bb represents the set of quotations of power purchaser S; Ag represents the set of quotations of power seller G; Rb,i represents purchase The electricity volume quoted by the electricity party b at the i stage, b \( \in S \), i \( \in B_b \); Mg,j represents the electricity volume quoted by the electricity seller g in the j paragraph, g \( \in G \), j \( \in A_g \); Ng,j represents the electricity seller g the electricity price declared in paragraph j; Tb,i represents the electricity price declared by
electricity purchaser b in paragraph i; Rmaxb,i represents the maximum allowable transaction electricity price quoted by electricity purchaser b in paragraph i; Mmaxg,j represents electricity seller g The maximum allowable transaction power of the j segment quotation; (CiPGi) represents the energy consumption characteristic function of the discharge unit i; Es represents the set total energy consumption index.

3. Optimal dispatch of energy storage for variable-speed hydroelectric generating units

The power generation efficiency of the hydropower plant can be determined by the power generation water efficiency and the water continuity of the hydropower variable speed unit. Water efficiency is the maximum power generation benefit during the dispatch period, and water continuity is the cumulative impact of the previous water use on the future. Figure 1 shows the working principal diagram of the variable-speed pumped generator set.

![Working principal diagram of variable speed pumped generator set](image)

Figure 1. Working principal diagram of variable speed pumped generator set

Set the number of generating units of a certain hydropower plant as N, according to the planned power generation time period as T, and deploying generating units based on the principle of maximizing social benefits. The benefits of hydropower plants are determined by electricity sales and energy [4]. Energy efficiency is determined by the water storage capacity of the hydropower plant, and the water storage capacity is determined by the energy-saving energy for power generation on the day. The expression is as follows.

\[
F = c \left[ V(T) - V(0) \right]
\]  

(4)

The best scheduling of hydroelectric generators is the highest overall profit, namely

\[
W = \max \left( R + F \right)
\]  

(5)

F represents the storage value of the hydropower plant at the end of the planned period; \( V(T) \) represents the storage capacity of the reservoir at the end of the period t; c represents the water value
at the end of the planned period, which is the planning coordination factor of the variable-speed hydroelectric generating unit in the power generation plan, reflecting the utilization of water resources Opportunity cost; \( \beta \) represents the average water consumption rate of the reservoir.

The first is the constraint condition of the water demand of the reservoir, the expression is: \( V_{i,min} \leq V_i \leq V_{i,max} \). The second is the power station output constraint, the expression is: \( N_{min} \leq N_i \leq N_{max} \). The third is the discharge restriction of the reservoir, the expression is: \( q_{min} \leq q_i \leq q_{max} \). The fourth is the water balance constraint condition, the expression is: \( V_{i+1} = V_i + Q - q_i \Delta t \).

Among them, \( V_{i,min} \) represents the minimum storage capacity at the end of period \( i \), which corresponds to the dead water level or annual falling water level storage capacity; \( V_{i,max} \) represents the maximum storage capacity at the end of period \( i \), which corresponds to the normal storage level or the flood control limit water level. \( N_{min} \) represents the minimum output, which is generally guaranteed; \( N_{max} \) Represents the maximum output, generally the installed capacity; \( q_{min} \) represents the minimum discharge flow, generally represents the discharge flow under the guaranteed output; \( q_{max} \) represents the maximum discharge flow; \( Q_i \) represents the average inbound runoff during the \( i \) period, representing the predicted value; \( q_i \) represents the average during the \( i \) period Quoting the flow; \( \Delta t \) represents the length of the period.

4. Variable-speed pumped storage planning service market operation mechanism

The calculation of energy storage planning demand mainly takes into account the change component of the load, the component of hydroelectric power generation, the component of the tie line plan, and the component of the unit plan. At the same time, the prediction deviation of each component is also taken into account in the algorithm. The formula is as follows. Figure 2 shows the variable-speed pumped storage plan.

**Figure 2. Variable-speed pumped storage planning**

\[
P = (P_{load} + \Delta P_{load}) - (P_{energy} - \Delta P_{energy}) - P_{line} - P_{G, plan} + \Delta P_{G, plan}
\]

Where: \( P \) is the planned capacity demand for AGC storage; \( P_{load} \) is the total planned capacity demand for storage caused by load changes; \( \Delta P_{load} \) is the load forecast deviation; \( P_{energy} \) is the
planned demand for storage caused by changes in the predicted power generation output of the hydropower plant; $\Delta P_{\text{energy}}$ is the hydropower plant Prediction deviation; $P_{\text{line}}$ is the planned change component of the tie line; $P_{G,\text{plan}}$ is the planned total planned output and energy storage of the planned unit; $\Delta P_{G,\text{plan}}$ is the deviation from the planned unit.

The factors that affect automatic power generation control include load characteristics and the proportion of energy generated by hydropower plants. In view of the different proportions of influencing factors, different evaluation proportions will be introduced according to the characteristics of the grid. In practical applications, it is generally necessary to adopt relevant control evaluation standards, such as CPS standards, according to the actual operation of the power grid, and then revise the calculated energy storage planned capacity [5]. At the same time, in order to meet the requirements of grid regulation performance and avoid the problem that the regulation capacity is sufficient but the regulation rate is insufficient to meet the requirements, it is necessary to introduce the rate of change of the deviation component in the calculation of the energy storage planning capacity. When purchasing energy storage planning capacity in the market, it is not only necessary to meet the energy storage planning capacity required for each time period, but also to put forward certain requirements for the adjustment rate of the units that provide energy storage planning services.

5. Optimized control strategy for energy storage planning

The thesis analyses the adjustment range generation of bidding hydropower units in the market environment, ARR calculation and the deployment strategy of energy storage planning units, and obtains a primary energy storage planning optimization strategy that adapts to the marketization of variable-speed pumped storage planning.

5.1. Regulation range control of energy storage planning rhythm

First of all, the adjustment range of a hydropower unit is mainly affected by its performance and operating limits. In the automatic power control mode, the basic power of the unit is the current actual power, which fluctuates within the adjustment range. The unit participates in the bidding of the variable-speed pumped storage planning service market, and the adjustment range is affected by the constraints of regular operation, as well as the market transaction results and the winning capacity. Therefore, in order to meet the market requirements of variable-speed pumped storage planning, the adjustment range of the storage planning unit must be determined. Determine the basic planned value of the hydropower unit in the power supply market, and use the planned value as the basis to increase the real-time adjustment range of the unit.

5.2. The deployment strategy of hydroelectric generating units for energy storage planning

With the establishment of the variable-speed pumped storage planning market, the dispatching of hydropower plant units cannot be prioritized and allocated according to the traditional proportions. Priority should be given to the quotations of the units in the variable-speed pumped storage planning market, integrated management of unit performance and service quotations. Factor, thus get the comprehensive ranking factor of each unit, and construct its unit adjustment priority ranking queue [6]. Arrange from top to bottom and from small to large according to the comprehensive ranking factor. The queues are sorted according to priority, and the units are called in order to control the ARR in the control area.

6. Precautions for optimal dispatching of hydropower and hydropower variable-speed generating units

6.1. Coordinating the relationship between upstream and downstream cascade hydropower stations

In view of the fact that the quotation content and transaction time of hydropower plants of different cascades are commercial secrets, and the information is closed to the outside world, it is necessary to
follow the principle of "openness, fairness and fairness", in line with "full utilization of water resources, and reasonable dispatch of water turbines. The original intention of "variable-speed generating units" is to coordinate the relationship between upstream and downstream cascade hydropower units during the bidding process to maximize benefits [7]. To this end, the upstream and downstream can adopt the principle of equal resources and benefit sharing for joint dispatch, and it is hoped that both upstream and downstream power stations can obtain the greatest economic benefits.

6.2. Formulate special power plan and peak shaving compensation policy
Due to the current meteorological conditions and limited water temperature forecasting technology, it is extremely difficult for the reservoir storage and power generation efficiency of the power plant after one day, especially for some run-off hydroelectric power stations that have no regulating capacity. For this reason, the above-mentioned hydropower stations’ actual situation is different. In the implementation of the power generation plan, it is easy to produce insufficient output or abandon the water of the variable-speed hydroelectric generating unit. In view of the above special circumstances, it is necessary to formulate special power plans and corresponding electricity price policies and peak-shaving compensation policies. Low-priced power sources are formulated for hydropower plants with poor regulation capabilities. Dispatchers adjust the power generation plan of hydroelectric power generation variable-speed units in real time and settle the benefits of “additional issuance” will be shared with peak-shaving power plants, which will benefit both parties and optimize the use of water resources.

7. Conclusion
In a competitive market environment, the customization of prices reflects the scarcity of water resources. In traditional hydropower optimization dispatching, only the maximization of power generation is often considered, and the influence of market electricity price is ignored, which is contrary to the market competition environment. While calculating the power generation efficiency, the water energy savings benefit is calculated, and the utilization of water resources is considered on the basis of the evaluation price model. In other words, when the electricity price is high, the variable speed unit of hydroelectric power generation has more generating points, and the power generation is reduced when the electricity price is low.

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