A Method for Determining Hourly Generation Schedules of a Large Hydropower Station with Monthly Trading Electricity

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Abstract: The trans-provincial and trans-regional power transmission of the southwest giant hydropower station involves complex multi-dimensional hourly generation curve decomposition with monthly energy demands. This needs to consider complex power grid peak shaving and other needs, which is an important problem to be solved urgently for the monthly power generation and operation of the hydropower station. This study constructs a monthly contracted electricity curve decomposition model suitable for trans-provincial and trans-regional power transmission giant hydropower stations. Considering the differences in electricity prices of three types, i.e. guaranteed quantity and guaranteed price, guaranteed quantity bidding and marketization, as well as the complex constraints of power grid peak shaving, market and power station operation, this paper puts forward the secondary planning goal of maximizing the total revenue of multi provincial and multi variety power generation, The mixed integer linear programming method is used to solve the model efficiently. The model is verified through two different application scenarios of a real hydropower station in dry season and flood season. The results show that under the boundary conditions of peak load regulation that meet the requirements of the power grid, the power generation income of the power station can be effectively improved by optimizing the multi-scale and multi variety power and output distribution of the two provinces and giving priority to the distribution of market-oriented power to the peak load and flat section.

1 INTRODUCTION

Since 2015, China has started a new round of electricity market reform(Jia, et al., 2022; Shen et al., 2022). A unified market and a two-level operation mode of regional and provincial power grids, and medium - and long-term trading operation mechanism with sound systems and rules are initially developed. In this case, how to ensure the performance of the long-term traded electricity is very important, especially for hydropower stations. Due to the uncertainty of inflow and the boundary restrictions of relevant dispatching constraints(Wang, et al., 2019), the medium and long-term trading electricity may not be fully implemented or the traded electricity may not be traded but the power plant is over generated. Performing the trading electricity of hydropower plants is one of the key issues to participate in the electricity market transaction.

There are several difficulties in performing long-term contract electricity. First, there are restrictions on the proportion of electricity in all power-receiving provinces, and the distribution proportion of different types of electricity needs to be controlled separately. Moreover, the load curves of different provinces are discrepant, such as the peak and valley loads. Second, the total distribution proportion should be considered for the power of multiple varieties, and the output distribution process of all varieties should be equal to the total power generation capacity of the hydropower plant. In addition, this problem also involves various complex constraints of hydropower operations, with strong space-time coupling. Mathematically, it is a very complex high-dimensional nonlinear

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optimization problem. At present, some research works have focused on the decomposition of transaction electricity curve. For example, some works considered the short-term operation constraints of cascade hydropower stations and relevant constraints of the daily electricity contract decomposition curve. In this work, the maximum comprehensive income model of transaction electricity decomposition is constructed(Xie, et al., 2021; Xu et al., 2019). Another works developed an optimization model based on the day-ahead actual needs of power grids, taking into account the objectives of power purchase economy, energy conservation and consumption reduction, and fairness of bidding and non-bidding unit dispatching(Cheng, et al., 2020).

This study constructs a monthly contracted electricity curve decomposition model suitable for trans-provincial and trans-regional power transmission giant hydropower stations. Considering the differences in electricity prices of three types, i.e. guaranteed quantity and guaranteed price, guaranteed quantity bidding and marketization, as well as the complex constraints of power grid peak shaving, market and power station operation, this paper puts forward the secondary planning goal of maximizing the total revenue of multi provincial and multi variety power generation, The mixed integer linear programming method is used to solve the model efficiently. The model is verified through two different application scenarios of a real hydropower station in dry season and flood season. The results show that under the boundary conditions of peak load regulation that meet the requirements of the power grid, the power generation income of the power station can be effectively improved by optimizing the multi-scale and multi variety power and output distribution of the two provinces and giving priority to the distribution of market-oriented power to the peak load and flat section.

2 CASE STUDY: XILUODU HYDROPOWER STATION

Xiluodu hydropower station is the third largest hydropower station in China. It is an important backbone power supply for the "West to East Power Transmission" in the main stream of Jinsha River. It is equipped with 18 700MW-hydropower units, equally distributed on the left and right banks respectively, with a total installed capacity of 12600 MW. The power station is located at the junction of Sichuan and Yunnan. During the wet season, all the power is transmitted to Guangdong and Zhejiang. In the dry season, when the electricity demand in Yunnan and Sichuan is met, all the remaining electricity will be sent out. According to the national hydropower integration arrangement, during the wet season, all the electric power of Xiluodu Hydropower Station will be consumed by Zhejiang and Guangdong at the ratio of 1:1. In the dry season, 30% of the retained electricity is consumed by Yunnan and Sichuan at the ratio of 1:1, and the rest by Zhejiang and Guangdong at the ratio of 1:1. Considering the electricity replacement among cascade hydropower stations in the lower reaches of the Jinsha River, in the actual operation, 30% of the retained electricity of Xiluodu hydropower station in the dry season is consumed by Sichuan and Yunnan at the ratio of 7:23.

Table 1 Scheme for absorbing energy production of Xiluodu Hydropower Plant.

Province		Zhejiang	Sichuan	Guangdong	Yunnan	Total
Flood season	Left bank	50%	-	-	-	50%
	Right bank	-	-	50%		50%
Dry season	Left bank	35%	7%	-	-	42%
	Right bank	-	-	35%	23%	58%

3 MATHEMATICAL MODEL

3.1 Notation

$NMAX_x$	Maximum power at a period of ten days
R	Ratio of two power-receiving provinces(Guangdong and Yunnan)
Q	Monthly energy demand
$E_{k,v}$	Trading electricity of variety *v* at province *k*
$EMAX_{k,v,x}$ $EMIN_{k,v,x}$	Maximum and Minimum of trading electricity of variety *v* at province *k* for each a period of ten days
$Dcoef$	A coefficient for non-work day
$\underline{c_{k,h}}$, $\overline{c_{k,h}}$	Minimum and maximum of hourly coefficient
$coef_{k,h}$	A coefficient of normal price for market electricity in province *k* at period *t*
$P_{k,1}$, $P_{k,2}$, $P_{k,3}$	Prices of three types of electricity, namely, quantity-price guarantee electricity, quantity guarantee electricity, and market electricity
$a_{k,v,d}$	A daily coefficient for variety *v* of province *k* in day *d*
$b_{k,v,x,t}$	A hourly coefficient for variety *v* of province *k* in period *t of* the *v*th ten days
$n_{k,v,d,t}$	Generation for variety *v* of province *k* in period *t of* the *d*th day.

3.2 Objective

With the requirements for contracted electricity and peak shaving of Guangdong and Yunnan Power Grids, an hourly generation scheduling model with maximizing the total power generation income is developed. By optimizing the hourly generation curves among provinces, ten days and varieties, the monthly electricity income is maximized as far as possible. Therefore, the objective function can be described by the total income of three varieties, i.e. quantity-price guarantee electricity, quantity guarantee electricity, and market electricity.

$$Max\ \mathrm{F}_1 = \sum_{k=1}^{K}\sum_{d=1}^{D}\sum_{t=1}^{T}(n_{k,1,d,t} \cdot P_{k,1} + n_{k,2,d,t} \cdot P_{k,2} + n_{k,3,d,t} \cdot P_{k,3} \cdot coef_{k,t}) \quad (1)$$

3.3 Constraints

The above objective function is subject to important operation constraints, listed in the following.

(1) Power balance constraint

$$n_{k,v,d,t} = NMAX_x \cdot a_{k,v,d} \cdot b_{k,v,x,t} \quad (2)$$

(2) Energy production constraints

$$\frac{\sum_{v=1}^{3}\sum_{d=1}^{D}\sum_{t=1}^{T} n_{1,v,d,t}}{\sum_{v=1}^{3}\sum_{d=1}^{D}\sum_{t=1}^{T} n_{2,v,d,t}} = R \quad (3)$$

$$\sum_{k=1}^{K}\sum_{v=1}^{V}\sum_{d=1}^{D}\sum_{t=1}^{T} n_{k,v,d,t} = Q \quad (4)$$

$$E_{k,v} = \sum_{d=1}^{D}\sum_{t=1}^{T} n_{k,v,d,t} \qquad v \neq 3 \quad (5)$$

$$EMIN_{k,v,x} \leqslant \sum_{d \in D_x}\sum_{t=1}^{T} n_{k,v,d,t} \leqslant EMAX_{k,v,x} \quad (6)$$

(3) Other operation constraints

$$\begin{cases} a_{k,v,d} = \underset{d' \epsilon D_{x'}}{Max}\left(a_{k,v,d'}\right) \quad d \epsilon D_{workday} \quad (v \neq 3) \\ x = x' \quad d \epsilon D_x \end{cases} \quad (7)$$

$$\frac{a_{k,v,d}}{\underset{d \epsilon D_x}{Max}\left(a_{k,v,d}\right)} = Dcoef \tag{8}$$

$$\begin{cases} \sum_{k=1}^{K}\sum_{v=1}^{V} a_{k,v,d} = 1 & if\ d \in D_{workday} \\ \sum_{k=1}^{K}\sum_{v=1}^{V} a_{k,v,d} = Dcoef & if\ d \in D_{holiday} \end{cases} \tag{9}$$

$$\underline{c_{k,t}} \leq \frac{b_{k,v,x,t}}{\underset{t=1}{\overset{T}{Max}}(b_{k,v,x,t})} \leq \overline{c_{k,t}} \tag{10}$$

$$(b_{k,v,x,h-\triangle+1} - b_{k,v,x,h-\triangle}) \cdot (b_{k,v,x,h} - b_{k,v,x,h-1}) \geqslant 0 \tag{11}$$

$$b_{k,3,x,h} = bmarket_{k,x,pml} \tag{12}$$

$$A_{k,v,d} = \frac{a_{k,v,d}}{\max\limits_{\tilde{d} \in D_x}\left(a_{k,v,\tilde{d}}\right)} \tag{13}$$

$$B_{k,v,x,t} = \frac{b_{k,v,x,t}}{\max\limits_{t \in T}\left(b_{k,v,x,t}\right)} \tag{14}$$

4 SOLUTION METHOD

Mathematically, the above trading electricity decomposition model is a very complex large-scale nonlinear optimization problem. It has high dimensions and many nonlinear constraints, making it difficult to solve. In order to realize the efficient solution of the model, it is necessary to treat the complex constraints equivalently. In the following, the processing strategies of decomposition coefficients of daily and hourly generation curves are proposed, respectively.

Because the daily coefficient has a maximum function, a temporal variable $MD_{k,v,x}$ is introduced to describe the maximum of $a_{k,v,d}$ at the current ten days. The daily coefficient of each province at each ten days should be limited in the following.

$$MD_{k,v,x} = a_{k,v,d} \qquad d \epsilon D_{workday} \tag{15}$$

$$\underline{l}_{k,d} \cdot MD_{k,v,x} \leqslant a_{k,v,d} \leqslant \overline{l}_{k,d} \cdot MD_{k,v,x} \quad d \epsilon D_{holiday} \tag{16}$$

$$MD_{k,v,x} \geqslant a_{k,v,d} \tag{17}$$

For all provinces and varieties, the sum of generation on working days should be equal to the maximum power in current ten days, and there should be a limit on non-working days.

$$\sum_{k=1}^{K}\sum_{v=1}^{V} a_{k,v,d} = 1 \quad d \epsilon D_{workday} \tag{18}$$

$$\underline{l}_{k,d} \leqslant \sum_{k=1}^{K}\sum_{v=1}^{V} a_{k,v,d} \leqslant \overline{l}_{k,d} \quad d \epsilon D_{holiday} \tag{19}$$

Similarly, the hourly coefficients require temporal variables $MH_{k,v,x}$ and $\lambda_{k,v,x,t}$ to make the model easily solve.

$$\underline{c}_{k,t} \cdot MH_{k,v,x} \leqslant b_{x,k,v,t} \leqslant \overline{c}_{k,t} \cdot MH_{k,v,x} \tag{20}$$

$$MH_{k,v,x} \geqslant b_{k,v,x,t} \tag{21}$$

$$\lambda_{k,v,x,t} \cdot MH_{k,v,x} = \lambda_{k,v,x,t} \cdot b_{k,v,x,t} \tag{22}$$

With the equivalent transformation of the above constraints, the optimization model can be transformed into a mixed integer quadratic programming model and solved by a mathematical solver.

5 CASE STUDY

This study takes the right bank of Xiluodu hydropower station as the case study. Here, some actual data are used to test the model. The monthly trading electricity is set as $9.736*10^8$kWh. The ratio of electricity for Guangdong Province and Yunnan Province is set as 1.5.

According to the above solution method, we can get hourly generation curve of each type of power station in the first, middle and last ten days when the hydropower station sends power to Guangdong and Yunnan. Figure 1 shows the output process of the power station in the first, middle and last ten days. Figure 2 shows the hourly coefficients in ten days for Guangdong and Yunnan, respectively. Figure 3 shows the generation schedules of the hydropower station in two different days.

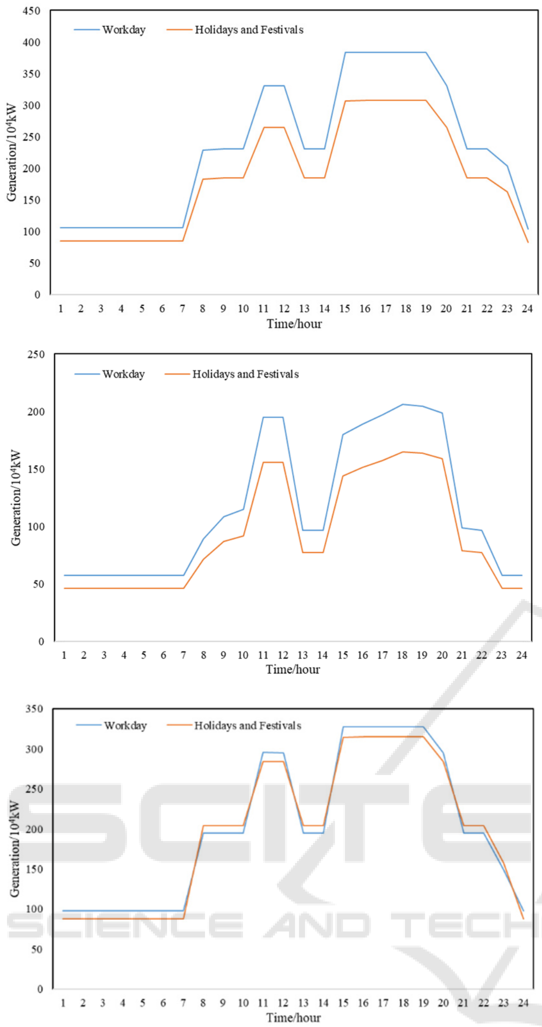
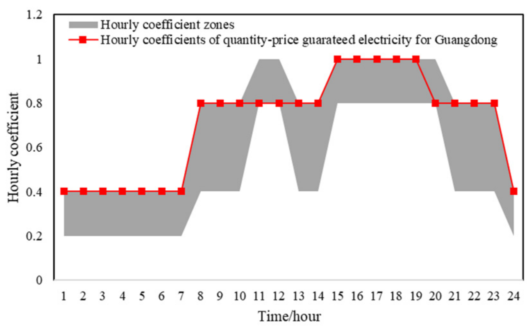


Figure 1: Typical generation schedules of the hydropower station for three ten days.



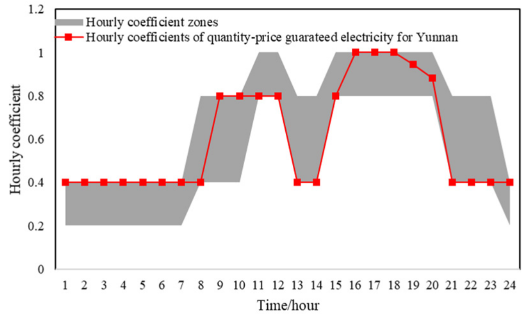


Figure 2: Hourly coefficients for Guangdong and Yunnan

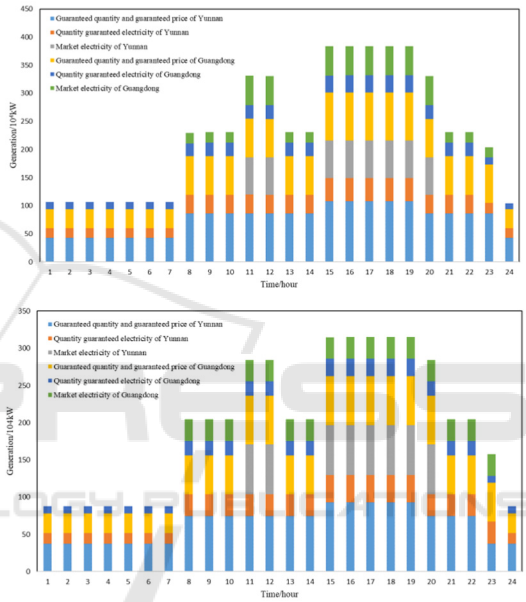


Figure 3: Generation schedules of different types of electricity.

Firstly, the rationality is analysed. In the example of dry season, the total monthly electricity in right bank of Xiluodu is 973.6 million kWh, and the electricity delivered to Guangdong and Yunnan is 584million kWh and 389.6 million kWh respectively, meeting the given requirements for cross provincial power transmission ratio; The two priority electricity varieties of guaranteed quantity and guaranteed price and guaranteed quantity bidding are 725.6 million kWh and 248.0 million kWh respectively, and the results obtained are completely consistent with the given parameters. At the same time, according to the distribution proportion requirements of the two provinces, the distribution results of electricity of each variety are also consistent with the specified power transmission proportion; The ratio of guaranteed quantity, guaranteed price and guaranteed quantity bidding electricity in each province and each ten day period is within the allowable fluctuation range of 20% above and below the ratio of the monthly guaranteed quantity, guaranteed price and guaranteed quantity bidding, meeting the set boundary requirements; The time-sharing coefficients of ten days in Figure 2 and figure 3 are within the given purple value range, meeting the peak shaving requirements proposed by the power grid.

The efficiency of the model optimization results is further analysed. According to the electricity decomposition results in the dry season months, on the premise of meeting the peak load regulation requirements of the power grid, the market-oriented electricity in the first ten days, the middle ten days and the last ten days is basically distributed in the load peak and normal sections with relatively high electricity prices, of which 100% of Guangdong's market-oriented electricity is distributed in the high peak hours, because its market-oriented electricity price is the highest in the peak hours, that is, 1.1 times of the benchmark price, so as to maximize the power generation income, This distribution method is reasonable. 63% of the market-oriented electricity in Yunnan is distributed in the peak load and 37% in the normal load section. The main reason is that the market-oriented electricity price in Yunnan is lower than that in Guangdong. Through the coordinated distribution of multi varieties across provinces, the market-oriented electricity will be preferentially arranged in the peak period in Guangdong, which has the highest electricity price. In this way, in order to meet the requirements for the proportion of the two varieties of electricity in Yunnan, i.e. the quantity and price guarantee and the quantity and bidding guarantee, Yunnan needs to arrange a large proportion of priority electricity during peak hours, so a part of market-oriented electricity is allocated at periods with middle loads.

6 CONCLUSION

This paper mainly focuses on the hourly generation scheduling model of a large hydropower station when the monthly contract electricity is given. Using monthly actual data, the following conclusions are obtained. 1) The hourly generation scheduling model can adapt to the power decomposition requirements of multiple provinces, multiple market varieties and multiple time scales. The dispatching scheme obtained conforms to the actual production habits, reflecting good adaptability and practicality. 2) Taking into account the requirements of differentiated peak shaving of multiple power grids, and aiming at maximizing the monthly electricity revenue of the hydropower station, it can effectively take into account the interests of power grids and hydropower enterprises. The hourly coefficients in the middle and late ten days of the monthly electricity declaration are consistent with the peak-valley trend. Within the boundary conditions of peak shaving, it is reasonable to arrange the market-oriented electricity in the peak and flat load sections with higher electricity prices as far as possible.

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