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Hydropower market electricity distribution model based on large system decomposition theory

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Abstract. In electricity market, large hydropower can participate in the medium or long term power trading and spot market transactions by crossing different regions and provinces. Therefore, limited hydropower resources can be eliminated in multi-time scale and multi-province regions. Because of market complexity, the final income of power generation enterprises is closely related to the market electricity distribution strategy adopted. Based on the theory of large system decomposition, this paper establishes a model of market electricity distribution for multi-transaction varieties. With the goal of maximizing the annual sale of electricity, the model managed the power generators to participate in various market transactions, so as to support the development of sales strategy for large hydropower.

1. Introduction

Considering the complexity of market environment, large hydropower should improve its utilization efficiency and maximize the annual sales of electricity, so as to improve profits. It should co-ordinate various electricity generators to participate in different market transactions.

The traditional reservoir generation scheduling method aims at maximum generating capacity, but in complex electricity market environment, the criterion of maximum power generation can’t meet the requirement of optimal dispatching of hydropower stations any more [1]. Many scholars at home and abroad have studied the optimal dispatching of hydropower in market environment, and the system decomposition theory has been widely used. Li Ailing (1997) studied on large-system decomposition-coordination method for optimal dispatching of Hydropower station Reservoir Group system[5] ; Samnang and others (2007) study improved genetic algorithm used to joint optimal dispatching of Cascade hydropower stations facing power market[4] ; Yuan Wenlin and others (2011) studied application research of co-evolution particle swarm optimization algorithm for Cascade Reservoir generation optimal dispatching in power market environment[3].

To integrate closely with the medium and long term and spot market construction in China, this paper uses the large system decomposition and coordination strategy to study the distribution of electricity in the large hydropower market, and establishes large hydropower market electricity allocation model based on system decomposition theory, which is advantageous to the rational distribution of hydropower resources in the complex market environment of large hydropower, and
uses the market characteristics of different regions and different transaction types to pursue the maximum profit of power market.

2. Large system theory
The theory of large system studies automation and effective control of engineering and non-engineering large scale system which is large in size, complex in structure, diverse in target, comprehensive in function and involves many factors[2]. Large systems are systems that have some complexity on both the structure and the dimensions, with multi-objective, multi-attribute, multi-level, multivariable and other characteristics[6].

There are four factors: the actual electricity generation and the contract electricity quantity existence deviation, the future transaction electricity price forecast deviation, each trade variety settlement, the transaction and so on difference, and different plant stations’ cascade optimal dispatch leading to the coordination system’s characteristics of complexity, uncertainty, unsuitable solution and multiple constraint conditions.

Therefore, the paper uses large system decomposition and coordination method to solve the optimization problem of multi-trade variety market coordinated transaction strategy. The fundamental idea is to decompose the large system from the coupling variable into a series of easily solved sub problems, and to approximate the optimal solution of the original problem by adjusting the iteration of the size of the coupling variable continuously.

3. Decomposition-coordination model of large system power generation

3.1 Determination of the overall optimal objective
The overall goal of large hydropower participating in the electricity market is to improve the company's power generation income, while satisfying the requirements of national plans and benefits.

Overall goal: The annual sale of electricity revenue optimization

\[
E = \sum_{i=1}^{J} \sum_{j=1}^{I} \sum_{n=1}^{A} T(i, j, n) P(i, j, n)
\]

Where, \(T(i, j, n)\) is the amount of electricity turnover of the type I trading varieties from No. \(n\) plant in J Province, \(P(i, j, n)\) is the trading price of the type I trading varieties from No. \(n\) plant in J Province.

3.2 Power generation decomposition and coordination process
The maximization of the annual sale of electricity is achieved through a series of sales transactions throughout the year. Theoretically, in order to obtain the global optimization, it is necessary to solve the whole year's transaction comprehensively. But in practice, this is very difficult to achieve, the main reason is that for a long time after the power station to water, electricity, electricity price prediction is difficult to be accurate.

Therefore, in the actual sale of electricity transactions, we should decompose the annual sale of electricity revenue optimization target to specific each sale of electricity transactions to form a specific transaction for each of the child issues. This method of decomposing the overall optimization problem into various sub problems is called the large system decomposition and coordination algorithm, and its core problems include:

- Decomposition: According to the status and role of each transaction, the sub objective function of each specific transaction is given;
  - Call the electricity price
  - Coordination: According to the goal of overall optimization, the boundary conditions of each seed optimization problem are given.
This problem can be decomposed into three-layer optimization problem when the model of power plant is solved by the decomposition and coordination principle of large system. The lower-level child problem is to optimize the distribution of annual and monthly trading power, when the distribution amount of electricity allocated to each receiving area at each plant is known, and the initial ratio of the power distribution to each receiving area is generally given first; the second layer is to adjust and optimize from the 0-100% according to the percentage of total electricity in the receiving area, when the power amount of each plant is known, which gives the optimal distribution of the overall benefit and the optimal allocation strategy for each period. The top level involves water resources allocation and allocation in various basins of large hydropower enterprises, and the power distribution of each plant station is optimized according to the principle of water balance and flow balance.

3.3 System decomposition and coordination model

Take the medium-term monthly transaction as an example, the complete solution steps are as follows:

1) based on decomposition and coordination strategy, the objective function of large system can be expressed as:

\[
E = \sum_{i=1}^{j} \sum_{j=1}^{h} \sum_{n=1}^{i} Q_0 \times a_n \times b(j, n) \times c(i, j, n) \times P(i, j, n)
\]

Where:
- \(Q_0\) represents total annual power generation,
- \(a_n\) represents the total electricity consumption of the stations,
- \(b(j, n)\) represents the electricity volume ratio of each receiving area accounting for the total power generation in the N plant,
- \(c(i, j, n)\) represents the power consumption of each trading type in each plant and each receiving area,
- \(P(i, j, n)\) represents the forecast price for the corresponding electricity quantity;

2) give \(a_n, b(j, n)\) initial value, and initialize;

3) Calculate the forecast price of each period in target market by price forecasting procedure;

4) solve the optimal distribution of the remaining electricity in each market during the whole planning period, to get the \(a_n, b(j, n)\) maximum selling efficiency of the enterprise;

5) use the optimization method to change \(b(j, n)\) value, repeat steps 4, to obtain the optimal allocation strategy \(c(i, j, n)\) of the plant and station.

3.4 The division of controllable variable and uncontrollable variable

According to the provisions of the basic rules and the United States PJM, Nordic and Australian power market construction, for the medium-term monthly transactions, the impact of the Yangtze River Power sales revenue can be divided into the various variables:

1) Controllable variable (decision variable):
   - Trading volume of bilateral negotiated transactions;
   - The transaction price of the bilateral negotiated transaction;
   - The amount of declaration for a centralized bidding transaction.

2) Non-controllable variables (known variables in subsystem optimization decisions):
   - The decomposition value of the generation contract before the decision period;
   - The transaction price of the power generation contract before the decision period;
   - Market turnover before the decision period;
   - Prediction of generation capacity in the future decision-making period
   - Prediction accuracy of generation capacity in future decision-making period
   - Contact line transmission capacity in the future decision-making period

The optimization model of the sale transaction is to give the decision scheme of the controllable variables, and to predict and obtain all the uncontrollable variables as the known conditions of the
optimal decision.

4. Subsystem generation optimization model

1) Objective function: 
\[ E = \sum_{i} \sum_{j} \sum_{r} T(i, j, r) P(i, j, r) \]  

2) Line transmission constraints: 
\[ \sum_{i} \sum_{j} \sum_{n} T(i, j, r) \leq F_{\text{MAX}} \]  

\( F_{\text{MAX}} \) is a collection of plant stations connected by line \( k \); the transmission volume of the line is composed of the volume of the decision before the decision-making and the transmission capacity expected in the decision period.

3) Power generation capacity constraints: 
\[ \sum_{i} \sum_{j} T(i, j) \leq P_{\text{MAX}} \]  

\( I_i \) is the collection of trading breeds within the decision-making period, \( P_{\text{MAX}} \) is the generation capacity predictive value during decision period in the decision-making points, it is worth noting that the power generation capacity constraints need to be reduced after the predicted generation capacity minus the prior generation and the priority generating portion, while the prediction of power generation capacity should take into account the accuracy of the prediction with the change of the time scale of the decision period to revise the power generation capacity.

According to the prediction accuracy of the power generation capacity of the correction, can introduce risk factors, set the risk control range (can be set by experts), in the scope of the prediction deviation of the greater the risk coefficient, the risk factor control in the allowable range, the power generation capacity will also change.

4) Upper limit of declaration electricity in the power generation market

5. Numerical example analysis

To verify the validity of the proposed model, a large hydropower station is used as an example to calculate the optimal distribution of monthly hydro power, the installed capacity of the water plant is 800MW, the ensured output 173MW, annual average generation 2.85 GWh, and the allowed minimum and maximum output of each period is 50MW and 800MW.

As the spot market is counted at the time of day, data volume requirements are too large, this example will be in accordance with the spot market price of electricity monthly statistics, because the forecast span is relatively long, and the spot market power is mainly in the medium and long-term trading power is not met part, so it will be included in the monthly centralized bidding power together to optimize.

In the example, the hydropower station is a separate plant, namely \( b_{nl} \) is 1, there’s two areas of electricity receiving (A and B), the initial value of \( b_{nl} \) is set to 0.5. 0.5, the electricity market price forecast is shown in Table 1, the transmission limit for the contact line is 240MWh.

| Table 1. Electricity Market price forecast data |
|----------------------------------------------|
| Month | Bilateral (Yuan/kwh) | Focus (Yuan/kwh) | Bilateral (Yuan/kwh) | Focus (Yuan/kwh) | Power generation Capacity (GWH) |
|-------|----------------------|------------------|----------------------|------------------|-------------------------------|
| 0     | 0.15                 | 0.17             | 0.13                 | 0.15             | 3200                          |
| 1     | 0.21                 | 0.27             | 0.20                 | 0.26             | 267                           |
| 2     | 0.16                 | 0.22             | 0.15                 | 0.21             | 267                           |
| 3     | 0.20                 | 0.28             | 0.17                 | 0.26             | 267                           |
1) Given the price predicted by the market transactions, the effect of the A area on the total utility is shown in Figure 1. It is shown that the greater the proportion of the amount of electricity in the A area is, the best total hydropower benefit is 5 million 658 thousand and 200 yuan. When the amount of electricity in the A area is about 60%, the surplus electricity is exactly allocated in the other region electricity market, if it continues at this time. Increasing the electricity consumption in the A area will inevitably lead to a reduction in the overall market efficiency.

![Figure 1. The influence of the A area power on the overall benefit](image)

2) The final power distribution optimization results are shown in Table 2:

| Month | Area A Bilateral (MWH) | Centralized (MWH) | Area B Bilateral (MWH) | Centralized (MWH) |
|-------|------------------------|-------------------|------------------------|-------------------|
| 0     | 219.76                 | 173.22            | 153.26                 | 120.22            |
| 1     | 55.42                  | 70.00             | 36.78                  | 47.13             |
| 2     | 41.09                  | 55.96             | 27.74                  | 38.30             |
| 3     | 50.53                  | 72.12             | 31.71                  | 47.05             |
| 4     | 46.50                  | 63.73             | 30.41                  | 42.64             |
| 5     | 44.14                  | 55.22             | 28.63                  | 36.50             |
| 6     | 53.74                  | 72.92             | 34.63                  | 48.24             |
| 7     | 45.50                  | 63.18             | 29.07                  | 41.62             |
| 8     | 37.09                  | 52.95             | 24.16                  | 35.42             |
| 9     | 44.49                  | 61.95             | 28.17                  | 40.57             |
| 10    | 53.55                  | 67.45             | 35.89                  | 45.76             |
| 11    | 45.42                  | 64.02             | 29.04                  | 42.24             |
| 12    | 45.10                  | 54.95             | 28.84                  | 35.83             |

Total revenue is 565.82 Million Yuan.
6. Summary
Aiming at the problem of multi-transaction various selections in power market, this paper uses the
theory of large system decomposition, then divides complex large system problems into three levels.
Finally, it achieves an optimal solution through continuous iteration. This model realizes the optimal
allocation of electricity in large hydropower market among multi-regions, multi-time scales and
multi-transaction types.

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