Development of Ancillary Services in the Electricity Market of China and its Joint Market Optimization Model

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Abstract. As an important part of power system, ancillary services have been widely developed. This paper introduces the ancillary service and its marketization trend in China. Considering the rapid development of China's renewable energy, an optimization model for the joint optimization model of the ancillary service market and the energy market is established in this paper. The proposed model can effectively consider the electricity market with high penetration of renewable energy and is suitable for the future development of China's electricity market.

1. Introduction

Ancillary services are services provided by power producers, grid utilities, and power consumers to maintain the safe and stable operation of power systems and ensure power quality [1]. Common types of power ancillary services include frequency regulation, peak shaving, system reserve, and voltage regulation. It should be noted that the peak shaving ancillary service is a transitional product for immature spot electricity market [2]. After the spot market matures, peak shaving can be achieved through the real-time market or balancing mechanism in the spot market.

Ancillary service market is a market manner to provide ancillary service mechanism. In contrast, another way to provide ancillary service products is the administrative order method. At present, China's electricity market construction is gradually advancing [3], and the electricity market mainly includes the electric energy market (including the medium-and-long term market, spot market), ancillary service market, etc. As an important part of the electricity market system, the power ancillary service market plays an important role in ensuring the safety and reliability of the power system, promoting the consumption of renewable energy, and improving the economics and fairness of system operation [4].

This paper introduces the types of ancillary services, the development of ancillary services before the reform of China's electricity market (ancillary service rules) and the trend of ancillary services after the reform of the electricity market (ancillary service market). Finally, a general optimization model for the joint optimization model of the ancillary service market and the energy market is established. The proposed model can effectively consider the electricity market under the connection of new energy and is suitable for the future development of China's electricity market with high penetration of renewable energy.

2. Types of ancillary services

Various types of ancillary service products are as follows:
2.1. Frequency regulation
Frequency regulation ancillary service mainly refers to the service that can automatically respond to the regional control deviation through the automatic power generation control device in the secondary frequency regulation reserve of the generator. Frequency regulation adjusts the power generation output in real-time according to a certain adjustment rate, and meets the requirements of the regional deviation control. Its adjustment effect is measured by the frequency regulation mileage.

2.2. Peak shaving
Through short-term power adjustment, the output of power generation can be matched with the change of load to achieve the balance of power and electricity.

2.3. System reserve
System reserve ancillary service mainly refers to the service that the unit provides power reserve capacity for system operation. Reserve capacity refers to the capacity that the unit needs to reserve in advance to provide reserve services for the system. During real-time operation, system uses this part of the reserve capacity according to real-time scheduling needs.

2.4. Voltage regulation
Voltage regulation ancillary service mainly refers to the service provided by the unit for the system to meet the voltage regulation needs. Power system voltage regulation refers to the technical measures taken to keep the operating voltage of each voltage center point in the power system within the prescribed allowable range.

3. Marketization trend of ancillary service in China

3.1. Evolution of ancillary service rules to ancillary service market
With the continuous growth of renewable energy sources and the deepening of market construction, the "administrative order" mechanism becomes difficult to reflect the market value of ancillary services, and it is difficult to mobilize market entities' enthusiasm of providing ancillary services.

As the construction of the ancillary service market continues to advance, the "administrative order" mechanism will be gradually converted to the market mechanism, and finally the market will optimize the allocation of resources. At the same time, the "administrative order" mechanism cannot be completely withdrawn at present, but should be continuously adjusted and improved to adapt to the development and changes of the power grid and power generation [5].

3.2. Construction of ancillary service market in China
China's earliest attempt to establish an ancillary service market started in the Northeast region. Until now, some areas of China have made great progress in the construction of ancillary services market. At the regional level, Northeast, North China, East China, and Northwest have carried out peak shaving ancillary service transactions, and Central and Southwest China are preparing. Regional ancillary services are mainly peak shaving, and some regions have launched peak reserve, black start, etc. At the provincial level, Fujian, Gansu, Ningxia, Shaanxi, Shandong, Jiangsu, Xinjiang, Chongqing, and Guangxi Provinces have carried out peak shaving ancillary service market, and some provinces have carried out frequency regulation ancillary service market.

4. Joint optimization model of the ancillary service market and energy market
In markets with high penetration of new energy, the combined cost of electricity purchases will be reduced through the joint optimization of energy with the reserve ancillary service markets. To this end, a general model is established in this paper.

The joint optimization model of energy and reserve ancillary market consists of the optimization goals and constraints related to the reserve service market on the basis of the clearing model of spot
energy market. Based on the safety constrained economic dispatch (SCED) method, output curves of
units, node electricity price, first-level reserve and second-level reserve are calculated.

Among them, according to whether the unit is online, the operation reserve is divided into rotating
reserve and non-rotating reserve. According to the speed of resource response time, the rotating
reserve is divided into first-level reserve and second-level reserve, in which the first-level reserve
response time is within 10min, and the second-level reserve response time is between 10~30min.

4.1. Objective function
Total cost of electricity purchase by consumers (or electricity retail companies) in the time horizon is
minimized as follows:

\[
\min \sum_{t=1}^{T} \sum_{i=1}^{I} \left[ C_{i,t}(P_{i,t}) + C_{i,t}^{R10} R_{10,i,t} + C_{i,t}^{R30} R_{30,i,t} \right]
\]

where \( R_{10,i,t} \) and \( R_{30,i,t} \) are the winning capacity of first-level reserve and second-level reserve of unit
\( i \) at time \( t \), respectively; \( i=1 \ldots I \) and \( t=1 \ldots T \); \( C_{i,t}^{R10} \) and \( C_{i,t}^{R30} \) are the bidding price of first-level reserve
and second-level reserve of unit \( i \) at time \( t \), respectively; \( P_{i,t} \) is the winning output of unit \( i \) at time \( t \);
\( C_{i,t}(P_{i,t}) \) is the winning price of winning output \( P_{i,t} \).

4.2. Constraint

4.2.1. Power constraint of bidding section of unit.

\[
P_{i,t} = P_{i,tn} + \sum_{n=1}^{N} P_{n,i,t}
\]

\[
0 \leq P_{i,tl,i} \leq P_{i,tn,i}
\]

where \( N \) is the number of bidding segments of the unit \( i \), \( n=1 \ldots N \).

4.2.2. Output constraint of unit.

\[
P_{i,tn} \leq P_{i,t} + R_{10,i,t} + R_{30,i,t} \leq P_{i,tn}\]

4.2.3. Ramping constraint of unit.

\[
-\Delta P_{i,tn} \leq P_{i,t} - P_{i,t-1} \leq \Delta P_{i,tn}
\]

4.2.4. Power balance constraint.

\[
\sum_{i=1}^{I} P_{i,t} = L_t
\]

4.2.5. Power transmission constraint.

\[
-P_{i,tn} \leq \sum_{i=1}^{I} (k_{i,j} P_{j,t}) + \sum_{b=1}^{B} (k_{i,b} P_{b,t}) \leq P_{i,tn}
\]

4.2.6. Reserve constraint.

\[
R_{10,i,t} \leq R_{10,i,t}
\]
where $R_{30,i,t}^{\text{max}}$ and $R_{30,i,t}^{\text{max}}$ are the upper bound of winning capacity of first-level reserve and second-level reserve of unit $i$ at time $t$, respectively.

4.2.7. Reserve ramping constraint.

$$R_{10,i,t} \leq \Delta R_{10,i,t}^{\text{max}}$$

$$R_{10,i,t} + R_{30,i,t} \leq \Delta R_{30,i,t}^{\text{max}}$$

where $\Delta R_{10,i,t}^{\text{max}}$ is the upper bound of first-level reserve ramping rate in 10 minutes of unit $i$ at time $t$, $\Delta R_{30,i,t}^{\text{max}}$ is the upper bound of first-level reserve ramping rate plus second-level reserve ramping rate in 30 minutes of unit $i$ at time $t$.

4.2.8. System reserve demand constraint.

$$\sum_{i=1}^{I} R_{10,i,t} \geq R_{10,t}$$

$$\sum_{i=1}^{I} (R_{10,i,t} + R_{30,i,t}) \geq R_{10,t} + R_{30,t}$$

where $R_{10,t}$ and $R_{30,t}$ are the first-level reserve demand and the second-level reserve demand in the power system at time $t$.

4.3. Constraint

The proposed model in (1)–(13) is a linear programming model and can be solved by classic business solving software. By the joint optimization of energy and system reserve, the renewable power uncertainty can be better considered in the electricity market.

5. Conclusion

This paper focuses on the development of ancillary services in the electricity market in China and its joint market optimization model. An optimization model for the joint optimization model of the ancillary service market and the energy market is established in this paper, which can effectively consider the electricity market with high penetration of renewable energy and is suitable for the future development of China’s electricity market.

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