Development Path Design of Multi-subject Participation in Electricity Market Based on Value Analysis

Hui Song[1a], Sijie Liu[1b], Qiuna Cai[1c], Yue Zhao[1d], Haixiang Gao[1e], Pengcheng Zha[2f*], Xinyu Meng[2g]

[1]*Power Dispatching and Control Center of Guangdong Power Grid Co., Ltd., Guangzhou 510600, Guangdong Province, China;*
[2]*Beijing Tsintergy Technology Co., Ltd., Haidian District, Beijing 100084, China*
[a]*644611837@qq.com,* [b]*liusijie@gd.csg.cn,* [c]*814699445@qq.com,* [d]*871572424@qq.com,* [e]*sunby@tsintergy.com,* [f*]*zhapc@tsintergy.com,* [g]*mengxy@tsintergy.com*

Abstract

In the context of dual carbon, the proportion of new energy access continues to increase, and at the same time, the continuous development of energy storage, pumped storage and other technologies have enabled it to have the necessary technical conditions and standards to participate in the power market. The article first analyzes the value of thermal power, hydropower, new energy, energy storage, and pumped storage from the four dimensions of adequacy, controllability, flexibility, and environment. Then, based on the principles of market economics, it proposes the design principles for the participation of multiple subjects in the electricity market mechanism. Finally, starting from the different development stages of the market, it designs a market development path design that adapts to the participation of multiple subjects. The designed development path can provide a reference for various energy sources including new energy to participate in the construction of the electricity market mechanism.

Keywords*-multi-subject; electricity market; value analysis; development path*

1. Introduction

Under the background of "double carbon", the proportion of new energy access has been continuously increased. At the same time, the "Notice on Accelerating the Construction of Electric Power Spot Market" issued by the General Office of the National Development and Reform Commission and the General Department of the National Energy Administration proposed an orderly promotion of New energy participation in market transactions. In addition, with the continuous development of technology and the reduction of costs, energy storage and pumped hydro storage also have the basic conditions to participate in the electricity market. How to design a reasonable market transaction mechanism for a variety of power sources, based on giving play to the value characteristics of various power sources, ensure reasonable income for each subject, and form a reasonable and effective market mechanism of various types, which is to promote a high proportion of new energy consumption, the key issues that need to be solved to accelerate the construction of a new type of power system with multi-agent participation in the power market.

Some studies have analyzed the installed capacity, regulation capacity, and flexibility of pumped storage and conventional hydropower under the dual-carbon goal[1-2]; The market mechanism design method for independent energy storage to participate in frequency regulation auxiliary services, as well as the market mechanism design for improving the flexibility of the power system, a method for quantifying the value of flexible resources, a balanced market settlement mechanism that adapts to the flexible operation of the new energy power system, A capacity compensation mechanism to ensure the adequacy of flexible resources, and a revenue distribution method to promote the optimal allocation of flexible resources across regions[3-5]. There are also studies focusing on the design method of the

G. Vilas Bhau et al. (Eds.): MSEA 2022, ACSR 101, pp. 1480–1486, 2023.
https://doi.org/10.2991/978-94-6463-042-8_214

auxiliary service market, and analyzing the transaction mechanism of distributed photovoltaic, energy storage, and other power types participating in the frequency regulation auxiliary service transaction[6-9]. Some studies have compared the mainstream capacity compensation mechanisms at home and abroad and their adaptability to China. Through models and examples, they believe that a reasonable capacity compensation mechanism can effectively ensure the benefits of thermal power companies and encourage them to provide flexibility, thereby improving the overall economy of the power grid. performance and operational efficiency[10]. Some studies start with sufficiency assessment[11] and how abundant resources participate in system regulation[12] to study the effect of sufficiency on promoting new energy consumption.

The above studies focus on the market value of a single power source type and the corresponding market mechanism design or focus on the assessment or mechanism construction of the sufficiency or flexibility of the power system. There is no literature to analyze the current mechanism of multi-type power supply participating in the electricity market from the value dimension of multi-agent. Starting from the perspective of value realization and expected income recovery, this paper analyzes the principles of market design and the development path of the future electricity market to ensure the orderly and healthy operation of the market and the sustainability of market construction.

2. The Value Analysis of Multiple Subjects

The electrical characteristics of different power sources are quite different, and it is necessary to analyze the value of thermal power, hydropower, new energy, energy storage, and pumped hydropower from the four dimensions of adequacy, controllability, flexibility, and environment.

2.1. Capacity sufficiency

Generation capacity sufficiency refers to the ability of a power system to continuously meet users' demand for power and electricity and to maintain this ability during peak loads and component outages. Factors such as planned maintenance, plant load, and forced outage are considered in the verification of the unit's sufficiency value, and the initial capacity is adjusted. The initial capacity of the unit takes into account the difference in primary energy characteristics and the difference in power generation characteristics and uses statistical methods to determine the type of power source.

Thermal power units have the highest abundance value to the power grid, while hydropower units need to provide abundance value for the power grid in combination with water level conditions. New energy is affected by natural factors such as wind and light and has a low value for the adequacy of the power grid. Pumped storage can provide sufficient value for the power grid when it meets a certain control water level. Compared with ordinary hydropower stations, it is not affected by high and low water seasons. The adequacy value of energy storage to the grid is related to the current storage state of energy storage and the maximum depth of discharge.

2.2. Controllability

The output capacity of thermal power units is affected by the amount of stored coal or gas. On the premise that the performance of the unit is intact, thermal power units with sufficient coal and gas can operate normally within the rated capacity and the minimum operating output range. The output of the hydroelectric unit is affected by the flow rate and the water head. When the water level of the upstream reservoir is different, the water head of the operating unit is different. Therefore, when the reservoir's water level is low, even if the output gate of the unit is opened to the maximum, the output of the unit cannot reach the maximum. maximum. During the power generation process of the hydroelectric unit, the downstream water level will be affected differently by the discharge flow of the plant and the lower reservoir, so the downstream water level will be different from the design tailwater level. When the downstream water level is higher than the design tailwater level, a certain head loss is caused, thus limiting the output of the unit. The output of new energy has strong randomness and volatility and is related to natural factors such as wind speed and light. It is difficult to directly control the output, and the controllability is weak.

The size of energy storage to consume or release power is related to the initial state and rated storage capacity. Its operation control needs to consider the coordination and connection of different periods. At the same time, its two-way interaction with the power grid provides the power grid with the first three. The controllability cannot be replaced by the user, and the pumped storage has the controllability characteristics of both the hydropower station and the energy storage.

2.3. Flexibility

The flexibility of the power system is the ability of the system to deal with uncertainties under the premise of satisfying a certain economy and reliability. If a certain type of power supply unit can provide flexible adjustment capability for the power system, this type of power supply is considered to be a resource with a flexibility value.

At present, only hydropower units, thermal power units, energy storage, and pumped storage have flexibility value, and at the current level of technology, hydropower, energy storage, and pumped storage have

the best response rates for increasing or decreasing output, and their flexibility has the highest value, followed by gas-fired units in thermal power units, and finally coal-fired units.

2.4. Environmental value

The output of thermal power units needs to rely on the combustion of fossil fuels. The pollutants such as sulfur dioxide and soot emitted will cause great pollution to the environment and have a great negative impact on environmental value. The impact of hydropower on the environment is reflected in the impact of hydropower on the ecological environment of rivers during the early establishment of hydropower stations, including the water quality and temperature of natural river channels, river water quality, and regional climate and geology. New energy power generation is a relatively friendly output method, and almost no polluting substances are produced during the output process. The impact of energy storage on the environment is reflected in the untimely recycling of waste energy storage batteries and the leakage of energy storage chemicals.

Based on the above analysis, the following will compare and evaluate the adequacy value, controllability value, and flexibility value of thermal power, hydropower, new energy, energy storage, and pumped storage from four aspects: high, high, average, and poor. and environmental values.

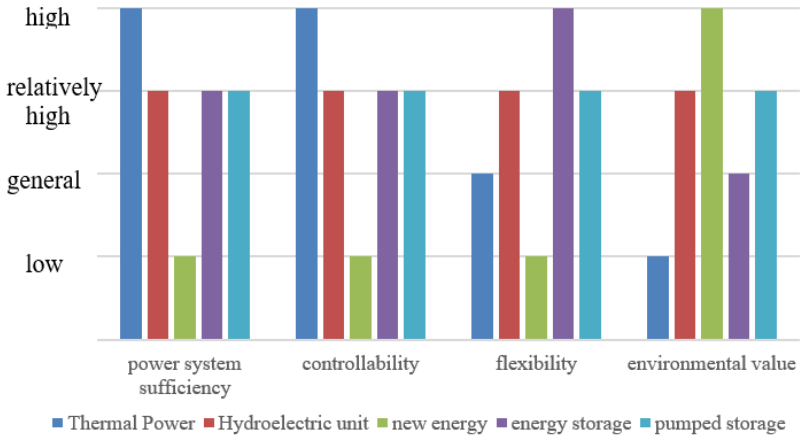

Fig.1 Comparison of the value of various types of power supply

3. Analysis of Expected Returns of Multi-subject Participation in Market

Under the background of building a new power system with new energy as the main body, the positioning of different types of market players is different from the existing role positioning, and the market value is also different. The figure shows the income and expenditure of different types of resources.

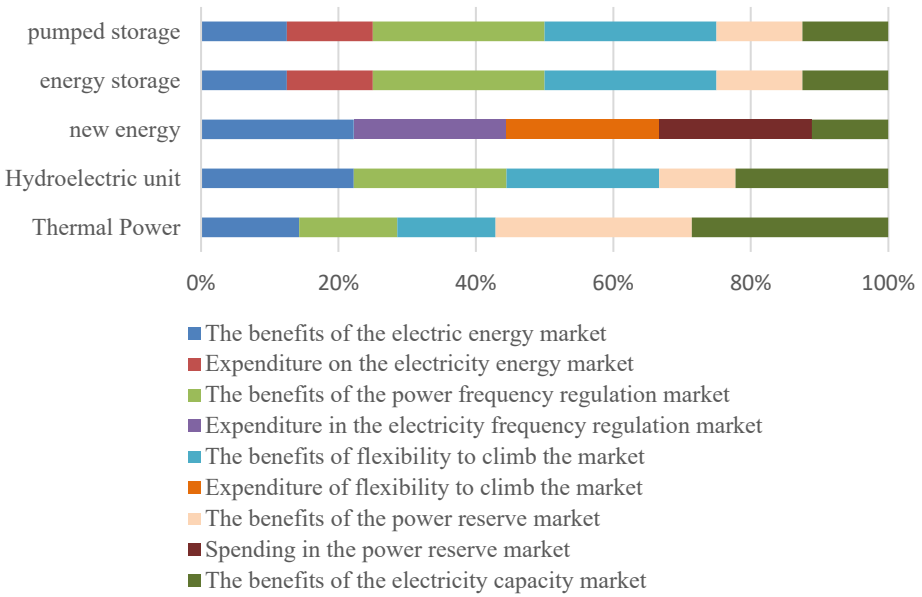

Fig. 2 Income and expenditure of different types of resources

As can be seen from the figure, as the proportion of new energy continues to increase, and the variable cost of new energy is much lower than the variable cost of thermal power units, thermal power units are positioned to ensure the safe and stable operation of the power grid in the context of the new power system, and the main source of cost recovery is In the reserve market and the capacity market, followed by the frequency regulation market and the flexible ramp market and the electric energy market. Hydropower units have excellent values of adequacy, controllability, and flexibility, and can benefit from the capacity market, frequency regulation market, flexibility ramping market, and backup auxiliary service market. Non-runoff hydropower stations can obtain benefits by participating in the backup market.

Under the new power system, new energy units will provide electric energy value to the power grid. At the same time, considering the confidence interval, its installed capacity can participate in the capacity market and provide sufficient value. The randomness and volatility of the output of new energy sources increase the demand for grid auxiliary services. Therefore, in the frequency regulation auxiliary services, the flexible ramping market, and the backup market, the corresponding auxiliary service costs should be shared with power users.

As independent entities, energy storage and pumped storage can participate in the electric energy market as a power source or load, and payor obtains related fees. Considering its excellent controllability and flexibility value, energy storage and pumped hydro storage can participate in the frequency regulation market and the flexibility climbing market to obtain major benefits. In addition, they can participate in the capacity market as well as the reserve market for a small benefit.

4. Design Principles for the Participation of Multiple Subjects in the Electricity Market

In the context of building a new power system with new energy as the main body, market members realize or obtain value through market transactions, and the following principles must be considered when designing the market pricing and settlement mechanism:

(1) Clarify the relationship between market transaction varieties, resource value, and resource cost.

The electricity market is an effective means to realize the allocation of electricity resources. Different market transaction varieties correspond to the realization of one or more values of market resources. Power grid resources include electric energy value, controllability value, flexibility value, abundance value, etc. Market resources realize their value by participating in different types of market transactions. For example, market adequacy value is realized through capacity markets, capacity compensation mechanisms, and scarcity pricing mechanisms. Market pricing and settlement mechanism are the core of market design, which determine the value recovery of market members, and the value of resources determines their market pricing.

(2) The market needs to meet the realization of the diversified value of resources.

Under the background of the construction of a new power system with large-scale access to renewable energy, the operation mechanism and stability characteristics of the power system are more complicated, and the value of electric energy will be more complicated. In addition to the capacity value and electricity value of the traditional power system, electricity also has various values such as flexibility and controllability. The construction of a market mechanism needs to provide access and value realization channels for diversified resources.

(3) The market mechanism design needs to properly take into account the long-term stable development of the power grid.

The goal of electricity market transactions is to maximize social welfare, that is, to minimize the cost of power generation. In the process of market transactions, at the production end, the optimal allocation of resources is achieved through the substitution of production factors, which is a power generation enterprise with different power generation costs. The replacement of electricity between renewable energy and other energy sources, including thermal power, can be called a "green" replacement. At the same time, the competitive nature of the market determines that some resources cannot achieve full coverage of their costs in the process of market transactions, resulting in losses or even bankruptcy in market transactions. In addition, while considering economic goals, it is also necessary to take into account the goals of low-carbon development and long-term safe and stable operation of the power grid.

5. Market development path design adapting to the participation of multiple subjects

Based on the aforementioned analysis of the value of multiple market entities and expected returns, starting from different development stages of the market, we will carry out the design of the market development path with the participation of multiple entities.

(1) The initial stage of market construction

At this stage, the awareness of market entities is insufficient and the proportion of new energy installed capacity is relatively low. Thermal power and hydropower are responsible for supply-demand balance, peak shaving, backup, and other auxiliary services in the market; new energy is not quoted to participate in the

market, and new energy revenue comes from guaranteed purchase hours + electric energy market; because the market has not yet formed a clear Price signal, energy storage mainly participates in the frequency regulation market; pumped storage mainly participates in the auxiliary service market, including peak regulation, black start, etc. (the cost is settled and shared in the transmission and distribution price).

In the initial stage of market construction, the system adequacy guarantee mechanism proposes to adopt a capacity compensation mechanism to compensate units that provide capacity resources according to the unified pricing of the government. The planning form determines the required spare capacity margin.

(2) Market construction and development stage

After the initial stage of the market, the awareness of market entities has matured, and the proportion of new energy installed capacity has increased. At this time, the competitiveness of thermal power units in the electric energy market is weakened, and they mainly participate in the capacity market to obtain benefits. New energy quotations participate in the electric energy market, and the number of guaranteed utilization hours declines. It is necessary to strengthen and improve the quota system assessment system to enhance the competitiveness of the new energy market; energy storage and pumped storage participate in auxiliary services and electric energy markets, and auxiliary services Give full play to the ability of flexible adjustment in the service market;

In the stage of market construction and development, the capacity market mechanism is recommended for the adequacy guarantee mechanism. In the initial stage of the market, all kinds of power sources, including thermal power, hydropower, and new energy, are mainly involved in the competition in the capacity market. Under certain conditions, energy storage and demand-side response can be used as a type of capacity resource to provide power capacity value, but the response characteristics are more complex, and the mechanism for participating in the capacity market also needs to be set more complex. To ensure the smooth start of the capacity market, in the capacity market In the initial stage, energy storage and demand response loads will not be included in the main capacity scope.

(3) The mature stage of market construction

The operation of the electricity market has become normalized, and a new type of electricity system with new energy as the main body has initially formed. The price of electricity in the spot market fluctuates violently, which brings huge risks to market entities. Building a financial derivatives market can provide effective risk hedging tools for various market entities, thereby improving market entities' ability to manage price fluctuations.

Financial derivatives include CFDs, power futures, capacity futures, power options, etc. Among them, the CFD is the medium and long-term trading plan. The electricity energy contract is used as the transaction object to form a time-sharing trading plan curve, and the settlement price reference point is agreed upon. Electricity Futures

In the mature stage of market construction, the capacity market has been fully developed and matured. Therefore, at this stage, it is recommended to gradually incorporate energy storage and demand response loads into the market scope, and tap the capacity value and potential of energy storage and demand response.

6. Conclusion

Under the background of the dual carbon goals, the installed capacity of new energy is increasing, and various energy technologies such as pumped hydro storage are developing continuously.

The technical characteristics of thermal power, hydropower, new energy, energy storage and pumped storage are quite different, so the expected benefits of various power sources in different markets are also different. Based on the design principle of the participation of multiple subjects in the power market, this paper proposes the development paths of the power market at different development stages according to the proportion of new energy installed capacity, as well as the types of power sources participating in the market and the source of revenue. The method proposed in this paper can provide a reference for the design of the mechanism for the participation of various energy sources, including new energy, in the electricity market.

Acknowledgments

This work was financially supported by the Science & Technology Project of China Southern Power Grid Corporation [036000KK52200041 (GDKJXM20200753)].

References

[1] Cheng Chuntian. (2021) Function Remolding of Hydropower Systems for Carbon Neutral and Its Key Problems. In: Automation of Electric Power Systems, 45(16): 29–36.

[2] Jiang Haiyang, Du Ershun, Zhu Guiping, et al. (2020) Review and the prospect of seasonal energy storage for power systems with a high proportion of renewable energy. In:Automation of Electric Power Systems,2020,44(19):194-207.

[3] Wu Shan, Bian Xiaoyan, Zhang Jingxian. (2021) A Review of Domestic and Foreign Ancillary Services Market for Improving Flexibility of New Power

System. In: Transactions of China Electrotechnical Society.

[4] Chen Hao, Jia Yanbing, Zheng Jin, et al. (2019) Research on market mechanism and scheduling strategy of frequency regulation auxiliary service of large-scale energy storage. In: Power System Technology, 43(10): 3606-3617.

[5] Li Bo, Chen Minyou, Zhong Haiwang. (2022) A Review of Long-term Planning of New Power Systems with Large Share of Renewable Energy. In: Proceedings of the CSEE, online.

[6] Huang Haiyu, Wang Chunming, Xia Shaolian, et al.(2020) Design and practice of peak regulation auxiliary service market for central China power grid considering positive and negative spinning reserve. In: Automation of Electric Power Systems, 44(16): 171–177.

[7] Shi Jiantao, Guo Ye, Sun Hongbin, et al. (2021) Review of research and practice on reserve market. In: Proceedings of the CSEE, 41(1): 123–134.

[8] Zhao Jinquan, Sun Zhonghao, Yang Yuhua, et al. (2021) Study on frequency regulation ancillary service trading mechanisms for a distributed photovoltaic generation. In: Journal of Global Energy Interconnection, 3(5): 477–486.

[9] Chen Hao, Jia Yanbing, Zheng Jin, et al. (2019) Research on market mechanism and scheduling strategy of frequency regulation auxiliary service of large-scale energy storage. In: Journal of Global Energy Interconnection., 43(10): 3606-3617.

[10] Wu Zhaoyuan, Zhou Ming, Wang Jianxiao. (2021) Mechanism Design of Capacity Payment for Incentivizing Flexibility of Thermal Power. In: Automation of Electric Power Systems, 45(6): 43–51.

[11] Zhang Lizi, Xu Tong, Song Shaoqun. (2020) Evaluation Method and Guarantee Mechanism of Power Generation Capacity Adequacy in Electricity Market. In: Automation of Electric Power Systems, 44(18): 55–62.

[12] Fan Pengfei, Zhang Lizi, Xie Guohui. (2012) Analysis Model for Accommodation Capability of Wind Power With Adequacy Resources Involved in System Regulation, 36 (5): 51–57.