Review on operation mechanism and platform architecture of Distributed Energy Storage

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Abstract. "Distributed generation and Energy storage technology" has become a widely promoted operation mode to ensure reliable power supply when the distributed generation connected to the grid. In order to realize the unified regulation of energy storage, this paper summarizes the auxiliary operation function, market profit model and market operation mechanism of energy storage from three sides of generation, grid and users. The Distributed Energy Storage Operation Platform constructed through the strategy of "Hierarchical and Partitioned". The good interaction between energy storage users and power grid realized through the comprehensive services of the platform. Several types of user categories and incentive mechanism under the interaction mode of grid and users sides summarized. Finally, the operation mechanism of distributed energy storage market summarized and prospected.

1. Introduction
A large number of distributed generation connected to the grid, which promotes the innovation of traditional grid structure. As an effective technology to improve the power quality of distributed generation, energy storage technology is promoting the development of its market. The process of energy storage market is transiting from "auxiliary" to "independent". The backbone of energy storage market constructed by the operation platform between power grid and users, and the core is the operation mechanism of energy storage.

Aiming at the unified integration of energy storage resources and market operation mechanism, this paper summarizes the market operation mechanism of energy storage from the generation side, grid side and user side. The operation platform of energy storage market constructed by the strategy of "hierarchical partition ", and the interactive mode between users and power grid is given. Finally, through the division of different user categories and incentive mode, the market operation of energy storage summarized and prospected.

2. Operation mechanism of energy storage market
2.1. Operation mode of generation side
At present, the market operation mechanism of energy storage focused on the generation side is mainly to cooperate with the conventional units and generate benefits in maintenance and compensation. Reference [1] points out that the introduction of battery energy storage can improve the regulation performance of AGC. Taking the 330MW thermal power unit of Tianjin-Beijing-Tangshan...
power grid as an example, the annual income of AGC equipment with 9MW battery energy storage calculated to be about 9.08 million yuan. Similar conclusions have obtained in references [2], the response speed and performance index of AGC system improved by introducing electrochemical energy storage, and considerable benefits obtained.

2.2. Operation mode of power grid side

The energy storage in power grid side mainly has the following functions:

1) Provide grid load management: Cooperate with power grid for peak load shifting, peak load regulation, frequency modulation, network loss reduction, emergency power support, etc.

2) Alleviate overload and loss: When the power system overloaded, such as connecting distributed energy storage device at the end of the line or the bus at the low voltage side of the transformer, the overload and aging of the line equipment can alleviate, the capacity expansion can improve and the reserve capacity can reduce.

3) Guarantee power supply at special time: During peak power consumption and seasonal short-term power fault, distributed energy storage can effectively shorten the fault recovery time and ensure power supply during the fault period.

4) Guarantee the stability of distributed power grid: Aiming at the problems of "wind abandonment", "light abandonment" and "islanding effect" in distributed generation and Micro-grid, such as the allocation of distributed energy storage at the AC and DC buses can effectively alleviate the above phenomena and ensure grid connection and self-balancing.

Therefore, through the auxiliary operation of the above distributed energy storage, the profit-making modes of the grid side energy storage market are as follows: 1) Profit from "high storage and low release" through the price difference between peak and valley of time of use price. 2) Profit from compensation and subsidy to reduce replacement cost and ensure high-quality power supply. 3) Profit from demand response of stable power supply of auxiliary distributed generation. The corresponding operation mechanism of energy storage market on the grid side is as follows: 1) Management of grid load. 2) Response of grid load. 3) Accommodation of distributed generation.

Reference [3] divides the investment and construction of distributed energy storage facilities into two modes: regulation operation and market operation. The regulation operation and market operation mode show in the figure:

![Fig 1 Regulation and market model of distributed energy storage](image)

To sum up, the operation mechanism and investment mode of energy storage in the grid side obtained through three profit models. In the next chapter, the operation mechanism of the user side is corresponding to the power grid side, and the operation platform between "grid-user" is constructed.

2.3. Operation mode of user side

Compared with the three mechanisms on the grid side, the operation mechanism of energy storage market on the user side are as follows: 1) Management of demand side. 2) Response of demand side. 3)
Consumption of distributed generation. Distributed energy storage on the user side is widely dispersed and spatiotemporal, it is difficult to conduct unified regulation and control. Therefore, it is important to build an operation platform that can regulate and control the distributed energy storage in the centralized area. The requirements of platform are as follows: 1) It can adjust measures to local conditions and effectively reduce the regional differences and resource waste. 2) In the face of the demand response of the power grid, it can effectively implement on-demand distribution, and take into account the consumption of new energy in nearby areas, in order to prevent unnecessary losses caused by long-distance transmission. 3) Finally, we should be able to make overall plans to achieve balanced development of various periods and regions.

3. Construction of platform and incentive mechanism for user categories

3.1. Construction of management and operation platform

The construction of the energy storage management and operation platform is inseparable from the strategy of "hierarchical partition". "Hierarchical" based on the combination of "Internet plus" and the power industry, and the control of electric power volume transformed into data volume control. "Partition" based on the different location of each energy storage power station, which can simulate based on Particle Swarm Optimization algorithm and Ant algorithm. The cloud platform of energy storage established in reference [4] realizes the access of small energy storage devices and electric vehicles with the media of "plug and play device". Reference [5] proposed a kind of "cloud energy storage" based on the three main lines of market, operation and object. Compared with the physical energy storage equipment, this "cloud energy storage" method using the third party is more flexible, but there are many factors considered. Reference [6] builds an energy storage platform based on the information link in the computer field, and supervises the platform through the "energy cloud" generated by a large amount of data. To sum up, combined with the operation platform proposed in references [4-6], the construction of the operation platform of distributed energy storage given as follows:

![Operation platform of distributed energy storage](image)

The whole energy storage platform divided into four layers by the "hierarchical partition" strategy, including access layer, transport layer, management layer and operation layer. The operation layer connected with the user terminal. Users can observe the remote information of the energy storage platform and energy storage facilities through mobile phones. The operation process of the whole
energy storage platform is as follows: starting from the management layer, the management platform of energy storage is equivalent to a "management portal". New users need to complete registration on the management platform, and the user can interact with the grid only after the qualification checked. On the user terminal of the operation platform, users can respond to the demand issued by the grid company. Among them, the access layer used to ensure that the energy storage facilities on the user side access the platform smoothly. Through equipment monitoring and data acquisition equipment, the energy storage facilities charge and discharge electrical flow converted into information flow, which uploaded to the management platform through the Internet or wireless network in the transport layer, and stored in the intranet. In the management platform, the uploaded data are scheduled and evaluated, and the energy storage cluster participating in the response is scheduled and absorbed. The operation layer and the management layer are two-way joint, that is to say, after the management platform carries out energy management, it allocates the users who have responded according to their needs, and continues to publish the following requirements on the platform to complete the cycle of the operation platform.

Fig. 3 Interaction mode between management/operation platform and users

3.2. Users categories and incentive mechanism of energy storage

According to the construction of energy storage platform between power grid and users in the previous chapter, the management platform and operation platform have launched corresponding operation services, such as energy storage participating in grid auxiliary operation, peak shaving, energy consumption, etc. Another important operation mechanism of energy storage platform is to encourage users to participate in platform response. This needs a series of incentive measures:

1) Differentiated on grid price incentives for different users: facing different users, the installed capacity, equipment capacity and power generation of each user are quite different, so the response to the platform is not the same. Therefore, we can establish the model of user partition response and evaluate the user response to classify the user. At present, fuzzy c-means (FCM) algorithm based on Mahalanobis distance is commonly used, which can cluster different users. The response characteristic index can predict by "demand response potential entropy":

$$PE = \frac{1}{n} \sum_{i=1}^{n} x_i \log x_i$$  \hspace{1cm} (1)$$

Among them, n is the number of times the user participated in the response collection, and $x_i$ is the power consumption of the user participating in the response. Reference [7], this paper can roughly divide "generation energy storage" users into five categories:

① The electric quantity is large, there is a large surplus except the self-supply, and the potential entropy is large, which can actively participate in.

② The electric quantity is large, most of which is used for self-supply, and the potential entropy is medium, which can general participate in.


③ The electric quantity is medium, there is surplus and stable except the self-supply, and the potential entropy is large, which can actively participate in.

④ The electric quantity is medium, there is surplus but scattered except the self-supply, and the potential entropy is medium, which can general participate in.

⑤ The electric quantity is small, it is only self-supply and unstable, the potential entropy is small, so it can passively participate in.

According to the above five categories of users, differentiated electricity prices should be implemented "according to different users", in order to promote users to participate in the response of online generation. The revenues $R_{\text{ave}}$ of generation and energy storage in energy saving and power sales are as follows [14]:

$$R_{\text{ave}} = \sum_{m=1}^{M} \sum_{i=1}^{I} \alpha \lambda_{i} Q_{\text{Gim}}$$

Among them, $Q_{\text{Gim}}$ is the generation capacity of type i users in m months, $\lambda_{i}$ is the differentiated electricity price of type i users on grid, and $\alpha$ is the proportion of on grid.

To sum up, the platform divide users into five categories, implements different response services in the face of "on-demand rationing" of various users, and encourages deep-seat interaction between users and power grid through differentiated electricity price.

2) Based on the "time of use price" to encourage the charging and discharging of the incentive:

According to the above discussion on the profit model of distributed energy storage, one of the profit mechanisms is to make profit through the price difference between peak and valley of time of use price, and the benefits are as follows:

$$R_{\text{gap}} = \sum_{n=1}^{N} \sum_{j=1}^{J} \lambda_{j} Q_{\text{sell}}^{\text{peak}} \Delta t_{j} \eta - \sum_{n=1}^{N} \sum_{k=1}^{K} \lambda_{k} Q_{\text{buy}}^{\text{valley}} \Delta t_{k} \eta$$

Among them, $Q_{\text{sell}}^{\text{peak}}$ is the electricity sold at peak time, $Q_{\text{buy}}^{\text{valley}}$ is the electricity purchased at valley time. $n$ is divided into several peak and valley periods, $\lambda_{j}$ and $\lambda_{k}$ represent the electricity price in peak and valley period, $\Delta t_{j}$ and $\Delta t_{k}$ respectively represent the continuous period of peak and valley time, and $\eta$ represents the charging and discharging efficiency. The annual income calculated on a daily basis.

3) Government subsidies and national policy incentives:

Policy based incentives are based on certain indicators, such as technical, economic, and social benefits. Some policy incentives and bidding incentives can derive from the comprehensive evaluation of each index. For example, "the northeast electric power auxiliary service market operation rules" launched in 2018 describes the incentive policy of energy storage auxiliary peak shaving in detail. According to the policy compensation, the benefits are as follows:

$$R_{\text{subsidy}} = \sum_{n=1}^{N} \sum_{i=1}^{I} Q_{\text{Gim}} \cdot T_{i}$$

Among them, $Q_{\text{Gim}}$ is the power generation of type i users in m month, and $T_{i}$ is the policy subsidy income paid to all kinds of users on a monthly basis.

4. Conclusion

In view of the unified integration of energy storage resources and the operation mechanism of energy storage market, this paper summarizes the operation mechanism of distributed energy storage in the generation side, grid side and user side. Based on the operation mechanism of grid and user, the management and operation platform of energy storage constructed based on the "hierarchical partition" strategy. The main conclusions are as follows:

1) There are three kinds of auxiliary operation functions of distributed energy storage in power grid, and they can make profits through these three auxiliary modes. Its investment and construction mode
can be divided into regulation operation and market operation. There are three operation mechanisms in the power grid side and user side.

2) Based on the "hierarchical partition" strategy, the platform between the grid and users of distributed energy storage constructed. Energy storage platform divided into four layers: access layer, transmission layer, management layer and operation layer. The user terminal is set under the operation layer. Users can complete the bidirectional interaction between the energy storage equipment and the grid operation platform through the mobile terminal.

3) The management platform and the operation platform are interconnected cooperation. Users can participate in the requirements issued by the platform and respond to them to realize the interaction between them. After the construction of the platform, the grid can divide users into five categories, and implement differential pricing for five categories of users. Through a series of incentive forms to promote the double-layer interaction between the user and the grid.

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