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Research on Distributed Energy Storage Operation Mode and Technical Economy under the Background of Energy Internet

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Abstract. Energy storage subverts the traditional concept of source-network-load, breaks the inherent property of power supply and consumption at the same time. Distributed energy storage plays an important role in the energy internet. The paper introduces the technical characteristics of distributed energy storage, builds typical application scenes under the energy internet environment. Given this background, two typical operation modes of customer-side distributed energy storage are proposed based on different operational objectives and constraints. After studying the basic strategy of the operating model and evaluating the distributed energy storage economy from the perspective of users and electricity retailers, it can be concluded that distributed energy storage is able to effectively improve system flexibility and energy utilization. Its economy is determined by various factors such as technical route, configuration capacity, and electricity price. A reasonable operation mode can promote the sustainable development of distributed energy storage.

1. Introduction

With flexible storage and two-way transmission capabilities, distributed energy storage enables power production and consumption to be decoupled from traditional real-time balance to different time scales, becoming an important element of energy internet. Distributed energy storage operation mode is the key factor for the prospect of the project [1]. With the rapid development of energy internet technology, research on diversification, differentiation and sustainability of distributed energy storage operation mode has become more and more important.

However, there are few documents on this topic, most research focus on energy storage ontology technology and application research [2, 3]. Energy storage is playing important roles in the power system, and three operation modes on power generation perspective, grid perspective and user perspective are presented, but lacking of detailed economic analysis [4]. Key technologies and planning of distributed energy storage on grid perspective have been introduced, and business models have important reference value for the study of operational models [5]. Some papers focus on value assessment of energy storage to support large-scale distributed photovoltaic access and the economics of distributed PV-storage systems, but the operation modes of these are relatively simple [6, 7]. The research on distributed energy storage operation mode under the background of energy internet focuses on the function of energy storage, provides differentiated services according to different application scenarios, and achieves certain economic benefits. The distributed energy storage studied in this paper mainly refers to the electrical energy storage. Based on the analysis of its technical characteristics, application scenarios of distributed energy storage under the energy internet background are proposed. This paper focuses on two typical operation modes of customer-side distributed energy storage, and the technical economy from the perspective of users and electricity retailers.

2. Technical characteristics and application of distributed energy storage

The technical characteristics of distributed energy storage lead to its basic functions and application areas. Firstly, in terms of technology types, distributed energy storage can be divided into energy type and power type. Energy-type distributed energy storage is mainly based on stored energy to provide long-term power support, while power-type distributed energy storage is of high power density and rapid response capability to provide instantaneous power support. Secondly, the distributed energy storage is the energy router of the energy internet, could support four-quadrant continuous operation, which enables flexible adjustment between active and reactive power. Furthermore, different from centralized energy storage power station, the distributed energy storage unit has a small capacity, takes up less space, and has low requirement on site environment, therefore can be flexibly installed according to local conditions.

Under the background of energy internet, the application areas of distributed energy storage are shown in Figure 1, mainly including distributed power supply side, distribution network, customer service and power auxiliary service.

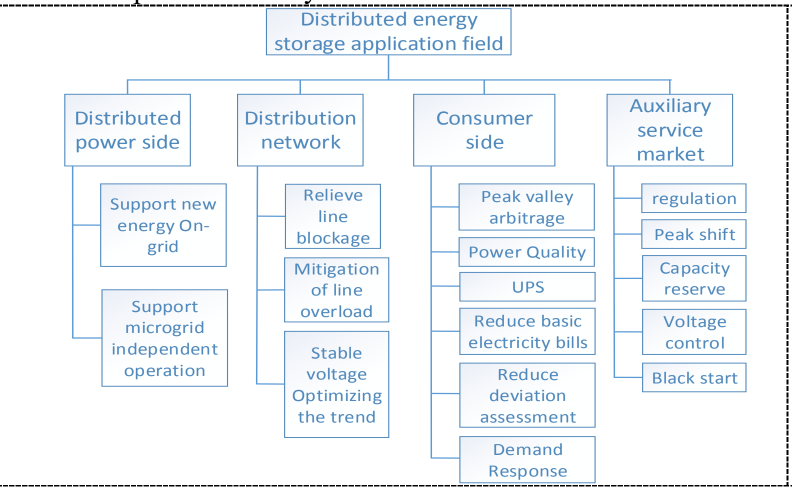

Figure 1. Distributed energy storage application field.

Within certain policy requirement and market rules, even different investment operations entities or different business models may perform same operation modes in various areas. Based on different operation objectives and constraints, operation modes are summarized as below. Mode 1 aims at reducing electricity price, mainly including peak and valley arbitrage, reduce basic electricity costs, etc. Mode 2 aims at reducing distribution network expansion and transformation investment, mainly including mitigating line congestion, reducing peak current, and improving distributed power access level. Mode 3 aims at increasing distributed power investment return, such as improving distributed PV self-use rate under optical storage mode. Mode 4 aims at improving power supply reliability, including user-side power quality improvement and uninterruptible power supply. Mode 5 aims at power balance, such as providing ancillary services. Mode 6 aims at energy-saving system time-division multiplexing and achieving above multiple values superimposed targets including user-side energy optimization management, regional resource aggregation sharing, etc.

Operation mode is an important factor of project management in terms of sustainable development. Take the functional characteristics of distributed energy storage as a starting point and provide customized services according to different application scenarios, so as to achieve different operation modes. The two operating models of customer-side distributed energy storage will be studied below.

3. Improve the self-sufficiency rate of distributed power supply

3.1. Energy peaks and valleys arbitrage gains of independent distributed energy storage

Separately install energy storage and utilize gap between peak and valley to reduce electricity bills. According to the ‘two peaks, two flats and one valley’ time-sharing electricity price mechanism in Jiangsu Province, the 1MWh lead carbon battery energy storage system is installed, and the overall conversion efficiency is 80%. If battery is charged and discharged once a day (charge at valley and discharge at peak), electricity fee will be reduced by 10,000 CNY/year. If charged and discharged two times a day (charge at valley and during flat section once respectively, and discharge twice at peak), electricity fee will be reduced 413,000 CNY/year. Comprehensive cost of lead carbon battery system is 1,500 CNY/kWh, and maintenance cost is 20,000 CNY/year. With 8% benchmark return on investment, the dynamic investment payback periods of two operating modes are 8.85 years and 4.74 years respectively.

3.2. PV-storage operation model to improve the rate of distributed power

Distributed power sources are encouraged to be used locally. If the load is unchanged, the self-use rate reduces with increasing the capacity of distributed power. Adopting the operation mode of distributed power combination with energy storage can increase the self-sufficiency rate of distributed power supply and even the internal consumption and reduce the total cost of electricity consumption. It is an important development direction of distributed energy storage.

The PV-storage model involves a large number of variables and mutual coupling. In order to highlight the value of energy storage in increasing the utilization rate of distributed power supply, we will analyze its return on investment, based on assumption that PV installation is fixed, and energy storage capacity is continuously increased. The annual benefits are as follows:

$$Q_{on\_grid} - Q_{cess} \geq 0,\ \ E_{pv-cess} = 365[Q_{cess}\eta(M_{high} + M_{comp}) + (Q_{on\_grid} - Q_{cess})M_{pole}] - C_{CN}^{'} \tag{1}$$

$$Q_{on\_grid} - Q_{cess} < 0,\ \ E_{pv-cess} = 365[Q_{on\_grid}\eta(M_{high} + M_{comp}) + (Q_{cess} - Q_{on\_grid})\eta(M_{high} - M_{low})] - C_{CN}^{'} \tag{2}$$

$$Q_{on\_grid} = P_{pv}N_h(1 - k_{sel})/365 \tag{3}$$

In the formula, $E_{pv\text{-}cess}$ is annual income after conversion of PV power generation into optical storage mode, 10,000 CNY. Q_{on_grid} is electricity from PV to grid, MWh. Q_{cess} is the energy storage capacity, MWh. P_{pv} is PV installation, MW. N_h is the PV annual utilization hours. k_{sel} is the PV utilization rate. M_{high}, M_{low}, M_{comp} and M_{pole} are peak electricity price, low valley electricity price, PV compensation electricity price, PV grid benchmark price, CNY/kWh. $C^{'}_{CN}$ is equivalent annual value of energy storage investment, 10,000 CNY /year.

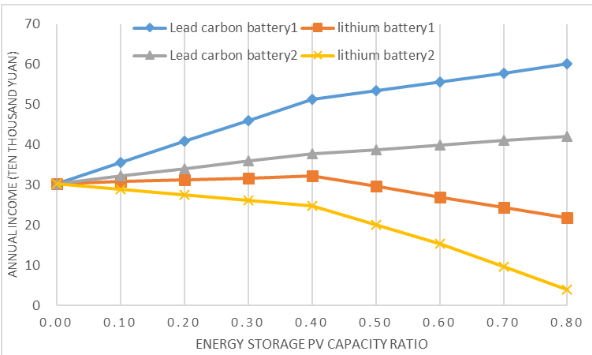

Figure 2. Diagram of annual revenue of PV-storage model.

Table 1. Detailed data of annual revenue of PV-storage model n.

Unit: 10,000 CNY

Energy storage PV capacity ratio	Lead carbon battery1	lithium battery1	Lead carbon battery2	lithium battery2
0.00	30.24	30.24	30.24	30.24
0.10	35.63	30.86	32.25	28.83
0.20	40.82	31.28	34.06	27.45
0.30	46.00	31.70	35.86	26.16
0.40	51.19	32.12	37.67	24.81
0.50	53.40	29.55	38.78	19.93
0.60	55.61	26.99	39.89	15.27
0.70	57.81	24.43	40.99	9.61
0.80	60.02	21.87	42.10	3.95

Take one industrial customer in Jiangsu as an example. The distributed PV installed capacity is 1MW, of which the self-use rate is 60%. In order to gradually increase the self-use of electricity, the customer configures distributed energy storage, store the on-grid electricity and utilize during the peak electricity price period. The installed capacity is gradually increased, and the income is shown in Figure 2 and Table 1. The abscissa is the proportion of the installed capacity of the energy storage to the average daily power generation of the PV. The ordinate is annual income after the PV power generation is converted into the optical storage mode. The energy storage cost remains the same.

Lithium battery 1 and lead carbon battery 1 shows benefit brought by gap of peak-valley price, which is 0.9326 CNY/kWh. Lithium battery 2 and lead carbon battery 2 shows benefit brought by gap of peak-valley price, which is 0.8 CNY/kWh. It can be concluded that if 40% of the electricity is all on the grid, with annual income 301,400 CNY, the lead carbon battery will obviously make more profit than the lithium battery due to its lower capacity cost. If the energy storage capacity reaches 40% and completely eliminates the on-grid electricity, and if we continue to increase the energy storage capacity, i.e. the newly added energy storage capacity is only used for peak and valley arbitrage, the benefits will be significantly reduced, even less than the direct access of PV. Under 0.8 CNY/kWh gap of peak-valley price, lead carbon battery can only break even as capacity increases and will make a loss when the capacity exceeds 40%. The lithium battery lowers overall benefit at the initial stage of configuration, and the economic benefit become lower with the increase of capacity.

Therefore, the profit of the PV-storage model is closely related to the peak-valley spread, battery type and configuration capacity. Currently, only provinces with large peak-valley spreads may make a profit by utilizing low-cost energy storage systems. In areas with high peak price, if energy storage is only used for peak and valley arbitrage, its value is lower than that of PV-storage.

4. Regional resource aggregation and sharing, to realize value superposition

The load configured distributed energy storage cannot balance with its own supply and demand under different conditions. Energy exchange between small systems and the power grid is still necessary. At the same time, the small-scale decentralized storage energy does not have the conditions to participate in other market segments under the rules of capacity access and trading mode. By coordinating the energy storage, utilizing distributed power supply and load in the control area to form a regional energy internet system, it will achieve resource sharing and energy optimization management, which could further improve equipment utilization, enables diversified value-added services, and reduces overall costs. This point-to-range operation mode is an important way for electricity retailers and resource aggregators to provide quality services while reduce electricity expenses and enhance competitiveness.

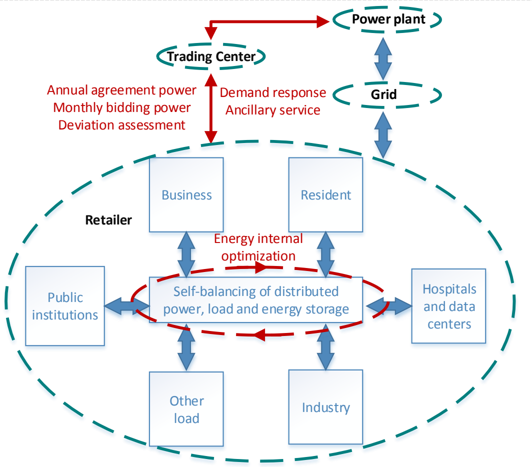

Figure 3. Electricity retailers operation diagram.

Table 2. Basic information of the electricity retailer in a certain business area.

Load type	Distributed PV /MW	Energy storage /MW/MWh	Electricity consumption /10,000 kWh	Purchase contract price/Li/kWh
Public institutions	12	10/20	472	-55
Business	2	/	842	-20
Resident	12	10/20	1003	-60
Hospital, data center	/	70/140	725	-55
Industry	20	60/140	3352	-23
Other load	/	/	249	-50
Total	46	150/320	6643	-34.98(Weighted value)

As is shown in Figure 3, it is an operation diagram of one electricity retailer in Guangdong. Based on forecast of regional load, the electricity retailer adds monthly bidding power to annual agreed power supply as regional planned power for the next month. The user type, monthly electricity consumption, distributed PV capacity, energy storage capacity, and gap between the purchase contract of the consumer and the electricity retailer are shown in Table 2, where the negative value of the purchase contract indicates the electricity retailer's income.

4.1. Revenue of regional network energy optimization management

The distributed PV self-use rate in the electricity sales area is 60%, and the surplus electricity is injected to the grid. By integrating energy storage resources (except for hospital and data center) and executing centralized management, the distributed PV power will all be internally consumed in the electricity sales area. The rest energy storage capacity will make a profit through peak-valley price gap and reduce total amount of electricity purchased from the trading center without reducing total amount of electricity traded with end users, which indirectly lowers the user's purchase contract price difference. As is shown in Figure 4, with investment of energy storage capacity, the contract price gap has been reduced from -34.98 PCT/kWh to -36.83 PCT/kWh, assuming total sales of electricity is 66.43 million kWh, revenue will increase by 129,900 CNY.

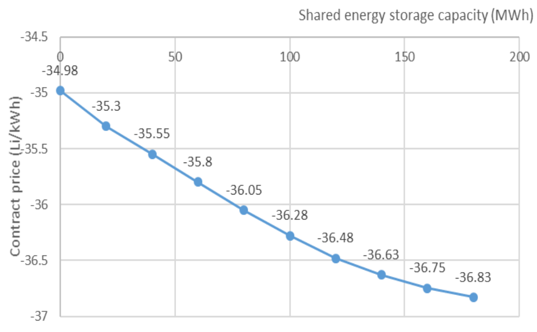

Figure 4. Diagram of the price on customer-side purchase contract for difference.

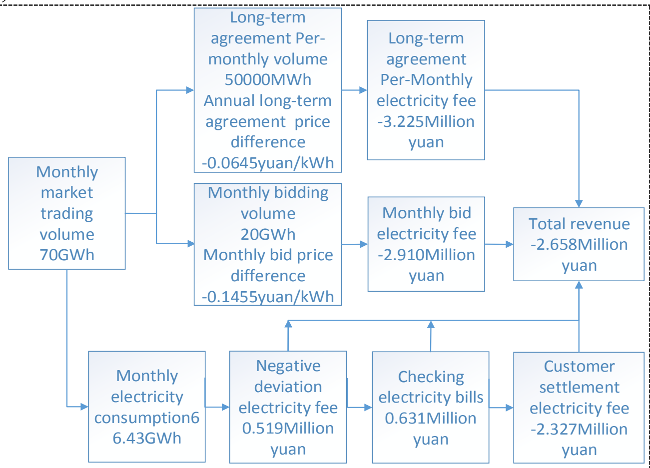

Figure 5. Electricity market revenue of electricity retailer.

4.2. Reduce power sales deviation assessment

Figure 5 shows revenue settlement of the company under total electricity consumption of 66.43 million kWh. The allowable deviation of the trading rules of the Guangdong power market is ±2%, and the evaluation is based on the double-month bidding price difference. The deviation assessment electricity fee is shown in Equation 4.

$$C_{N-pc} = 2(|Q_C - Q_M| - Q_M * 2\%) p_{pc} \tag{4}$$

In the formula, $C_{N\text{-}pc}$ is the deviation assessment electricity fee, 10,000 CNY. Q_C, Q_M are consumption electricity and market purchase electricity, 10,000kWh. p_{pc} is the unit deviation power assessment fee, CNY/kWh.

Before settlement period, if 180MWh energy storage (excluding hospital and data center) in the electricity sales area is fully charged, total electricity consumption will be 66.61 million kWh, and the total revenue will be 2.733 million CNY, with an increase of 75,000 CNY compared with the former. The sales deviation assessment will reduce by 58,000 CNY.

4.3. Income of participation in auxiliary service

The energy storage facility enters the charging state following power dispatching agency's instructions to conduct services, and 0.05 million CNY/MWh will be compensated according to the rules of Notice on Printing and Distributing the Two Rules of the Southern Region. Except the storage installed in hospital and data center, the left storage with the capacity of 180MWh can participate in auxiliary services. The maximum income can reach 80,000 CNY one time.

4.4. Reduce power outage losses

$$E_{KK} = A_S R_{IEA} E_{RCE} = \frac{1}{2} P_{\max} T A_S R_{IEA} \quad (5)$$

In the formula, E_{RCE} is the expected value of stored energy remaining, MWh. P_{max} is the battery rated charge and discharge power, MW. T is the discharge time, h. A_S is the annual power outage rate. R_{IEA} is the customer power outage loss evaluation rate, 10,000 CNY/MWh, and it is possible to obtain the GDP output value of the unit's electricity in the region.

In 2017, the average annual power outage time of urban users in Guangdong Province was 4.2 hours. Reliability of power supply was 99.952% and output value of electricity was 22.76 million CNY/MWh. The 150MW energy storage in the electricity sales area can generate 597,000 CNY of GDP during the equivalent average monthly power outage.

In summary, resource sharing based distributed energy storage can participate in multiple power supply and auxiliary service markets in a time-sharing manner, bringing various benefits to users, power sales companies and resource aggregators. However, the operation of this model needs to be established with detailed market rules and policy framework. It also needs to be further researched whether the value of energy storage due to multiple services can be accumulated.

5. Conclusions

Distributed energy storage is the key equipment for flexible energy conversion and comprehensive utilization, and is foundation for the development of energy internet. This paper introduces the technical characteristics and basic application modes of distributed energy storage, especially focuses on operation mode and technical economy under the background of energy internet. In the distributed self-sufficiency mode of distributed power supply, the economics of general industrial and commercial users' optical storage facilities are closely related to factors such as peak-to-valley price gap, battery type and capacity allocation. Aggregate sharing mode can realize multi-value superposition of distributed energy storage, improving efficiency of energy utilization and economic benefit. In conclusion, the sustainability and diversity of distributed energy storage operation model still relies on its cost saving, perfection of market rules and policy encouragement.

Acknowledgments

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