Comparative Study on Different Energy Storage Modes Promoting the Consumption of Distributed Generation

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Abstract: In order to promote the use of clean energy, the government has issued policies to encourage the installation of supporting energy storage facilities for distributed generation projects. If each distributed generation project is equipped with energy storage facilities, there may be problems with low energy storage utilization and excess energy storage capacity. This paper takes the maximum consumption of distributed generation sources as the optimization goal, and proposes a shared energy storage mode in which energy storage equipment is shared by distributed generation. By comparing the two models, it is concluded that the shared energy storage model can improve the utilization rate of energy storage and promote the consumption of renewable energy.

1. Introduction

In order to promote the use of clean energy, the government has issued policies to encourage the installation of supporting energy storage facilities for distributed generation projects. With its unique advantages of fast power control and flexible energy management, energy storage can be used to peak load shifting, providing a solution for the safe and effective consumption of high-permeability distributed generation. This has eased the network congestion and clean energy consumption in the power grid to a certain extent. If each distributed generation project is equipped with energy storage facilities, there may be problems with low energy storage utilization and excess energy storage capacity.

In reference[1], in view of the temporal complementarity of energy consumption among different users, shared use of a single energy storage unit is a promising business model in the near future. Reference[2] analyzes the practical benefits of using shared energy storage in residential communities by comparing individual and shared energy storage operations economically (in terms of electricity cost) and operationally (in terms of energy storage use) with various parameter settings. Reference[3] proposes an approach of optimal planning the shared energy storage based on cost-benefit analysis to minimize the electricity procurement cost of electricity retailers. Reference[4] proposes a shared ESS aware real-time pricing model that achieves a very attractive trade-off between the service provider’s and end user’s interests. Reference[5] studies capacity allocation of an energy storage (ES) device which is shared by multiple homes in smart grid. Reference[6] studies the trade-off between fairness and freedom in the energy storage sharing and develop new energy storage sharing strategies for buildings. Reference[7] demonstrates that the approach allows fully exploiting the potential of storage systems sharing to reduce individual users’ energy consumption costs and limit the peak average ratio of the energy profiles. Reference[8] proposes a new methodology to enable high penetration of photovoltaic generation in low voltage distribution networks by using shared battery storage and variable tariffs. In reference[9], an energy management methodology is proposed for neighborhood area networks (NANs) composed of a shared energy storage system (ESS) and multiple consumer premises equipped with a distributed generation system, aiming to use ESS unit as a key tool for demand response (DR) programs.

Based on the concept of shared economy, this paper proposes a shared energy storage mode in which energy storage equipment is shared by distributed generation, and takes the maximum consumption of distributed generation sources as the optimization goal. Compare the two modes of self-use energy storage and shared energy storage, and conduct simulation to prove the scientificity and feasibility of the research.

2. The Shared Energy Mode

2.1. Subjects

The distributed generation consumption model contains four main bodies, namely, distributed wind power aggregator, distributed photovoltaic aggregator, distribution companies, and power consumer. Distributed wind power aggregator and distributed photovoltaic aggregator respectively integrate distributed wind power and distributed photovoltaic power in the distribution network area on a large scale to conduct power transactions and provide power supply services to power consumer. At the same time, distributed generation cannot directly participate in transactions alone, and must be coordinated and planned by distributed power aggregator. The distribution network company purchases electricity through thermal power plants to ensure reliable electricity consumption for power consumer, and can actively adjust output to help absorb new energy.

2.2. Shared Energy Storage Mode

As the proportion of distributed generation in the electric distribution network continues to increase, the intermittent characteristic of and uncertain load have many effects on electric distribution network planning and operation [10]. The overall advantage of shared energy storage lies in flexible “sharing”. Therefore, distributed wind power and distributed photovoltaic can store the excess electricity in the shared energy storage device during the peak period of their respective power generation, and select the appropriate time period to store the The electricity is released again. On the basis of conventional energy storage to promote consumption, shared energy storage helps different distributed generation to achieve time complementarity, which can maximize the advantages of consuming renewable energy and also improve the utilization rate of energy storage equipment. The shared energy storage mode is shown in Figure 1.

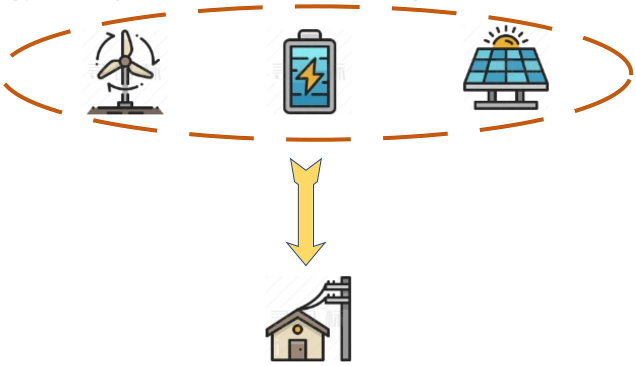

Figure 1. Shared energy storage mode

3. Mathematical Modelling

3.1. Distributed Wind Power Aggregator

Distributed wind power aggregator integrates distributed generation sources in the distribution network to conduct power transactions on a large scale. Here, the power constraints of wind power generation are mainly considered.

$$W_{min}^{wind} \leqslant W_{t}^{wind} \leqslant W_{max}^{wind} \tag{1}$$

In formula (1), W_{min}^{wind} and W_{max}^{wind} are respectively the upper and lower limits of the output of wind power generation at time t, and W_t^{wind} is the actual output of wind power generation at time t.

$$W_t^{wind} = W_{up,t}^{wind} + W_{abandon,t}^{wind} \tag{2}$$

$$W_t^{windup} = W_t^{windtoC} + W_t^{windRent} \tag{3}$$

In formulas (2) and (3), $W_{up,t}^{wind}$ and $W_{abandon,t}^{wind}$ are respectively the on-grid power and wind curtailment in period t; $W_t^{windtoC}$ and $W_t^{windRent}$ are respectively the power supplied by wind power to users during the t period, and the power injected into energy storage equipment.

3.2. Distributed Photovoltaic Aggregator

Distributed photovoltaic aggregator integrates distributed generation sources in the distribution network area on a large scale for power trading. Here, the power constraints of photovoltaic power generation are mainly considered.

$$W_{min}^{PV} \leqslant W_t^{PV} \leqslant W_{max}^{PV} \tag{4}$$

In formula (4), W_{min}^{PV} and W_{max}^{PV} are respectively the upper and lower limits of wind power output during t period, and W_t^{PV} is the actual output of wind power during t period.

$$W_t^{PV} = W_{up,t}^{PV} + W_{abandon,t}^{PV} \tag{5}$$

$$W_{up,t}^{PV} = W_t^{PVtoC} + W_t^{PVRent} \tag{6}$$

In formula (5) and (6), $W_{up,t}^{PV}$ and $W_{abandon,t}^{PV}$ are the on-grid power and power of solar energy curtailment in period t respectively; W_t^{PVtoC} and W_t^{PVRent} are the power supplied by photovoltaic power generation to users during the t period and the input power injected into energy storage equipment.

3.3. Shared Energy Storage

If each distributed generation project is equipped with energy storage facilities, there may be problems with low energy storage utilization and excess energy storage capacity. Shared energy storage adopts the mode of sharing its own energy storage equipment to improve operation efficiency and promote the consumption of renewable energy. The charging and discharging constraints of energy storage are as follows.

$$W_{min}^{SESO} * B \leqslant W_t^{ch} \leqslant W_{max}^{SESO} * B. \tag{7}$$

$$W_{min}^{SESO} * (1 - B) \leqslant W_t^{dch} \leqslant W_{max}^{SESO} * (1 - B) \tag{8}$$

In formulas (7) and (8), W_{min}^{SESO} and W_{max}^{SESO} are the lower limit and upper limit of the energy storage charge and discharge power respectively; W_t^{ch} and W_t^{dch} are the internal charging power and discharge power of the energy storage in t period, respectively; B is a 0-1 variable.

Energy storage should ensure that energy storage equipment meets the state of charge (SOC) balance before and after each transaction cycle. That is, the initial state and the end state of the remaining capacity of the energy storage device meet the following conditions.

$$SOC_{min} \leqslant SOC_t \leqslant SOC_{max} \tag{9}$$

$$SOC(0) = SOC(T) \tag{10}$$

In formulas (9) and (10), SOC_t is the state of charge of the energy storage device in t period; $SOC_{min}$and SOC_{max} are the lower limit and upper limit of the state of charge of the energy storage device in t period respectively; $SOC(0)$ and $SOC(T)$ are respectively the state of charge of the energy storage device at the beginning and end of the cycle.

3.4. Distribution Company

Since distributed generation cannot fully guarantee the power load required in the distribution network area, the distribution network company guarantees the basic power consumption of users by purchasing electricity from thermal power plants. The power supply constraints of the distribution network company are as follows.

$$W_{min}^{DC} \leqslant W_{t}^{DC} \leqslant W_{max}^{DC} \tag{11}$$

In formula (11), W_{min}^{DC} and W_{max}^{DC} are the lower limit and upper limit of power output of the distribution network company to ensure the power consumption of power consumer.

3.5. Power Consumer

Power consumers want reliable and stable power supply. Therefore, the power balance constraint conditions are as follows.

$$load_{t}^{C} + \frac{W_{t}^{ch}}{0.95} = W_{t}^{dch} * 0.95 + W_{t}^{windtoC} + W_{t}^{PVtoC} + W_{t}^{DC} \tag{12}$$

In formula (12), $load_{t}^{C}$ is the power load of the power consumer during t period.

3.6. Objective Function

The objective function is determined by taking the maximum consumption of distributed generation as the target.

$$maxZ = Q_{Wind} + Q_{PV} \tag{13}$$

In formula (13), Q_{Wind} and Q_{PV} are the consumption of wind power and photovoltaic power in the cycle respectively.

4. Analysis of Examples

4.1. Basic Data

A distribution network region was taken as an example for analysis, and a day was divided into 96 time periods. The total installed capacity of distributed wind power in the distribution network area is 120MW, the total installed capacity of distributed photovoltaic is 110MW, and the electricity load of power consumer is known data. For self-use energy storage mode, this paper configured 10MW/20MWh energy storage for distributed wind power aggregator and distributed wind power aggregator according to 20%. Energy storage devices of both parties are independent from each other and do not interfere with each other. For the shared energy storage mode, a 20MW/40MWh configuration is adopted. The objects of energy storage facilities are no longer limited to themselves, but shared and used by both parties. The energy storage charge and discharge depth are 10% to 90%, and the charge and discharge efficiency are 95%. The commercial solver Gurobi is used for solving, and Matlab is used for graph drawing and data analysis.

4.2. Comparison of SOC

In the self-use energy storage mode, the SOC of the energy storage equipment is shown in Figure 2. When the remaining capacity of the energy storage equipment is sufficient, that is, the SOC is not less than 0.1, the energy storage equipment of the distributed wind power aggregator is between 45-63 Time period and period 69-79 are basically idle. For distributed photovoltaic aggregator, their energy storage equipment is also idle during the period 1-23 and period 88-96. This shows that energy storage resources have not been fully utilized, causing waste. Under the same conditions, for the shared energy storage mode, the SOC of the energy storage device is shown in Figure 3. The energy storage device is only idle for a total of 14 periods. By comparing Figure 2 and Figure 3, it can be seen that the shared energy storage mode adopted by distributed aggregator can improve the utilization rate of energy storage.

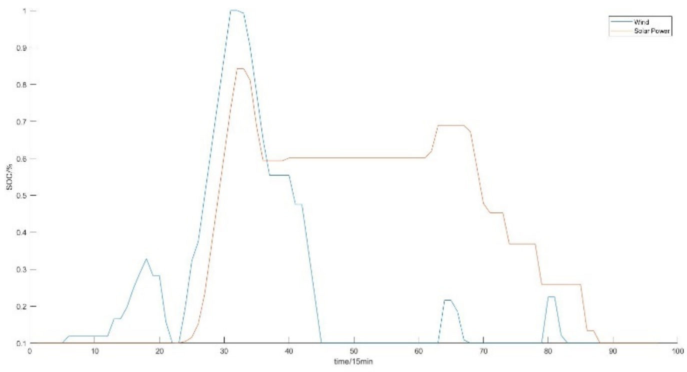

Figure 2. SOC in self-use energy storage mode

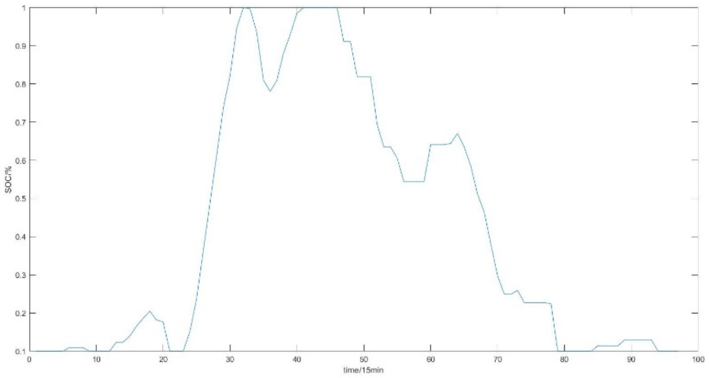

Figure 3. SOC in shared energy storage mode

4.3. Comparison of Renewable Energy Consumption

The specific results of renewable energy consumption under different energy storage modes are shown in Table 1. Comparing the two modes under the same conditions of energy storage configuration, it can be seen that adopting the shared energy storage mode, the consumption of renewable energy increased by 3.31MWh and the curtailment of wind power decreased by 6.9315MWh. Although the curtailment of solar power increased by 3.6187MWh, the total curtailment has been reduced by 3.31MWh. Thus, in terms of promoting consumption, of renewable energy shared energy storage mode has a better effect than self-use energy storage mode.

Table 1. Comparison of renewable energy consumption

Energy storage mode	On-grid energy (MWh)	Wind power curtailment (MWh)	Solar power curtailment (MWh)	Total curtailment (MWh)
Self-use	1854.75	13.3422	11.0961	24.4383
Shared	1858.06	6.4107	14.7148	21.1255

5. Conclusion

In order to avoid problems such as low utilization rate of supporting energy storage equipment for distributed generation projects and excess energy storage capacity, this paper takes the maximum consumption of distributed generation as the optimization goal, and proposes a shared energy storage mode in which energy storage equipment is shared by distributed generation. By comparing the two models, the following conclusions are as follows.

1) The shared energy storage mode breaks the limitation of the ownership of energy storage equipment. Energy storage equipment is shared by multiple parties, which solves the problem of

idle energy storage equipment to some extent and improves the energy storage utilization rate.

2) In the shared energy storage mode, by integrating energy storage resources, the shared energy storage equipment has a larger power and higher capacity, which plays a more obvious role in alleviating the tension of power balance, and further promotes the consumption of renewable energy.

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