Study on the influence of different energy storage modes on the confidence capacity of renewable energy

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Abstract. Renewable energy has typical intermittent characteristics, strong random fluctuation of output, and insufficient support capacity at peak load. Therefore, the power supply guarantee of high proportion of renewable energy power system is facing severe challenges. Renewable energy allocation and energy storage can solve the problem of random volatility of renewable energy to a certain extent. In this context, based on the operation mechanism of electrochemical energy storage, this paper establishes the Renewable energy + Energy storage operation optimization model considering the operation safety characteristics of electrochemical energy storage. In order to provide technical support for the planning and construction of related enterprises, the paper explores the effectiveness of large-scale renewable energy configuration of electrochemical energy storage, and analyzes the impact of different energy storage operation modes which is solved by CPLEX. The results indicate that renewable energy configuration energy storage can improve its confidence capacity and reduce the peak valley difference rate of net load, but the specific effect is closely related to the operation mode of energy storage.

Keywords: Energy storage, Operation mode, Renewable energy, Confidence capacity.

1 Introduction

In order to achieve the goal of "carbon peaking, carbon neutralization" (hereinafter referred to as "double carbon"), accelerate the pace of green development and promote the leap of non-fossil energy is imminent. As the central link of energy utilization, the construction of a new type of power system with renewable energy as the main body is an important measure[1]proposed by the ninth meeting of the central financial and Economic Committee to achieve "carbon peak, carbon neutral". In the future, renewable energy will usher in the historical opportunity of leapfrog development, become the main force of electric

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energy increment, and realize the transformation from "supplementary energy" to "main energy".

Because of its random fluctuation, intermittence and uncontrollability, renewable energy has low confidence capacity, weak ability to participate in power balance, or does not participate in power balance at all. The stability and power supply guarantee ability of high proportion renewable energy power system will be severely challenged. With the gradual increase of the proportion of renewable energy, the requirements of power grid for renewable energy are gradually upgraded from "friendly grid connection" to "friendly grid connection + active support"[2]. Energy storage facilities have the characteristics of energy time-lapse, rapid response and flexible layout, which are important technical means to promote the absorption of renewable energy and enhance the active support capacity of renewable energy. At present, 23 provinces (autonomous regions) in China have issued relevant policies and measures of "renewable energy + energy storage" to boost the large-scale development of energy storage on the power side.

In the analysis of renewable energy supporting power supply security, the capacity value of renewable energy is expressed as the creditable capacity, that is, the confidence capacity. At present, large researches on renewable energy allocation and energy storage has achieved phased results. References [3-5] respectively put forward optimization configuration methods of energy storage system from the perspectives of suppressing wind and solar output fluctuations and increasing the proportion of renewable energy consumption. References [6-8] analyzed the application scenarios of renewable energy side configuration and storage from unit level, power station level and regional grid level, Among them, the research on energy storage system to improve the active support capacity of renewable energy mainly focuses on the participation in inertia support and primary frequency modulation[9-11]. Based on the capacity correlation constraint of energy storage application value, reference [12] evaluated the business models of large-scale promotion of energy storage in different mode scenarios.

However, the research on renewable energy allocation and energy storage mainly focuses on the optimization of allocation methods, application scenarios, business models and other contents, and there is no quantitative analysis on the impact of energy storage on improving the confidence capacity of renewable energy and its operation mode. Based on this, based on the operation mechanism of energy storage system, this paper builds the Renewable energy + Energy storage operation optimization model considering the operation safety characteristics of energy storage facilities. In order to provide technical support for the planning and construction of relevant enterprises, the paper studies the effectiveness of large-scale renewable energy allocation of energy storage resources, and explores the impact of different operation modes of energy storage.

2 Installation and planning of renewable energy in China

By the end of 2020, the total wind power generation capacity in China will reach 72.5 billion kwh, accounting for 20.8% of the total wind power installed in 2020, respectively, accounting for 70% of the total wind power generation capacity. At the same time, the overall level of renewable energy consumption and utilization is relatively high, with the utilization rate of wind power and photovoltaic power reaching 96.5% and 98.0%, respectively. The renewable energy utilization rate target[13]of China and key provinces in 2020 proposed in the clean energy consumption action plan (2018-2020) has been fully completed.

In the future, China will comprehensively promote the large-scale development and high-quality development of renewable energy. According to the "14th five year plan for modern energy system"[14]and "implementation plan for promoting high-quality development of renewable energy in the new era"[15], by 2025, China's total installed power generation capacity will reach about 3 billion kilowatts, of which the proportion of non- fossil energy consumption will increase to about 20%;By 2030, the proportion of non- fossil energy consumption will reach about 25%, and the total installed capacity of wind power and photovoltaic power generation will reach more than 1.2 billion kilowatts. Under the catalysis of carbon peaking and carbon neutrality goals, the power development has changed from traditional coal-fired power to renewable energy.

3 Construction of renewable energy allocation and energy storage operation model

3.1 Energy storage principle of renewable energy allocation

Renewable energy has the characteristics of "extremely hot without wind", "extremely cold without light", "late peak without light", and "large installed capacity, small power". In the peak load period, the effective output of renewable energy is low, which increases the risk of power balance. From September to October 2021, due to the inverted price of coal and the lack of willingness to generate electricity, large-scale and output of coal-fired power generation units are blocked, and renewable energy can not provide stable power, resulting in the shortage of power supply. More than 20 provinces and cities have taken orderly power consumption measures, especially in Northeast China, where renewable energy accounts for a large proportion of renewable energy sources, which highlights that renewable energy will become the main power source in the future.

With the vigorous development of China's renewable energy industry, new development models emerge in endlessly. The development mode of Renewable energy + Energy storage has become the main research direction to improve the power balance guarantee ability of renewable energy. In 2021, the National Development and Reform Commission of China and the State Energy Administration jointly issued the "notice on encouraging renewable energy power generation enterprises to build or purchase peak shaving capacity and increase the scale of grid connection"[16], which requires that the peak shaving capacity should be built according to the power ratio of 15% (for more than 4 hours) at the initial stage, and the grid connection priority should be given to those with more than 20% hook up ratio; "guidance on accelerating the development of renewable energy storage" [17] pointed out that by 2025, the renewable energy storage will be transformed from the initial stage of commercialization to large-scale development, and the installed capacity will reach more than 30 million kilowatts. By 2030, the renewable energy storage will be fully market-oriented. At the same time, local governments have issued relevant policies to promote the implementation of energy storage power stations.

With the intensive introduction of renewable energy + energy storage policy documents, the Renewable energy + Energy storage mode will usher in explosive growth in the future. Based on this, in order to explore the effectiveness of renewable energy configuration energy storage on improving its confidence capacity, and further promote the effective utilization of energy storage measures, this paper configures electrochemical energy storage according to the power of 15% and the duration of 4 hours for the future renewable energy grid connection.

3.2 Technical characteristics of energy storage

Electrochemical energy storage technology has the advantages of high energy density, response time, low maintenance cost, flexibility and convenience, which is the focus of the development of power system energy storage industry [18]. According to the different requirements of different application scenarios for the power capacity ratio (W: wh, referred to as C), electrochemical energy storage can be roughly divided into three types: capacity type (≤ 0.5 C), energy type (≈ 1 C) and power type (≥ 2C). The higher the ratio, the higher the power density of the battery, but the lower the capacity density. Among them, the renewable energy configuration electrochemical energy storage belongs to the capacity battery[19] widely used in two hour peak load and valley load reduction scenarios.

Among all kinds of capacity batteries, lithium iron phosphate battery has been widely used in practical engineering due to its high energy density, good temperature characteristics and safety[20].

Table 1. Performance parameters of lithium iron phosphate battery[21].

	Working temperature (℃)	Energy density (W·h/kg)	Energy conversion efficiency(%)	Discharge depth (%)	Cycle life (frequency)	Monthly self discharge (%)
Lithium iron phosphate battery	-20~55	90	> 80	> 95	2500	< 5

3.3 Energy storage simulation model of renewable energy allocation

In this paper, sequential production simulation method is used to analyze the effectiveness of renewable energy allocation and energy storage. The input of the model is wind power, photovoltaic output, annual load time series, grid boundary parameters and electrochemical energy storage parameters. The corresponding energy storage operation mode is set and solved by CPLEX.

(1) Energy storage constraints

According to the actual situation, the electrochemical energy storage is used for daily regulation. The voltage is set to be constant during the charging and discharging process, and the charging and discharging current is kept constant in an optimized time step, and the battery performance is not affected by the changes of external temperature and humidity in one scheduling cycle. At the same time, in order to ensure the safe charge discharge and service life of the energy storage facilities, the nuclear power status of the energy storage facilities is determined（SOC）and charging and discharging power are limited as follows:

$$SOC_{min}(t) \leq SOC(t) \leq SOC_{max}(t) \tag{1}$$

$$P_{maxc}(t)=\min\left\{P_{maxc}, \frac{N_{bat}[SOC_{max}\text{-}SOC(t\text{-}1)]}{\Delta t\eta_s}, P_{Wind\ power\ /\ photovoltaic}(t)\right\} \tag{2}$$

$$P_{maxd}(t)=\min\left\{P_{maxd}, \frac{N_{bat}\eta_s[SOC(t\text{-}1)\text{-}SOC_{min}]}{\Delta t}\right\} \tag{3}$$

SOC_{min} and SOC_{max} are the upper and lower limits of the state of charge of the energy storage battery respectively; P_{maxc} and P_{maxd} are the maximum power of charging and discharging under the rated state of energy storage facilities respectively; η_s is the charging and discharging power of energy storage battery; N_{bat} is the capacity of energy storage facilities; $P_{Wind\ power\ /\ photovoltaic}(t)$ are the Photovoltaic or Wind power. It is required that the energy storage charging and discharging power shall not exceed its installed capacity, and the charging power shall not exceed the real-time output of renewable energy. The energy storage charging and discharging process shall meet the energy balance of the energy storage equipment, and the energy storage charge and discharge capacity shall not exceed its energy capacity.

4 Example analysis

In order to verify the validity of the model proposed in this paper, the relevant data information of Beijing Tianjin Tangshan Region Power Grid is obtained through investigation and analysis.

4.1 Basic data[22]

(1) Current situation of electric power

In 2020, the total electricity consumption of Beijing Tianjin Tangshan Region Power Grid will reach 379.509 billion kwh, with an average annual growth rate of 3.1% during the 13th Five Year Plan period. In 2020, the maximum load of Beijing-Tianjin-Tangshan region power grid will be 67.44 million kilowatts, with an average growth rate of 4.3% during the 13th Five Year Plan period. By the end of 2020, the installed capacity of Beijing-Tianjin-Tangshan region power grid has reached 105.9912 million kilowatts, including 72.7607 million kilowatts of thermal power and 4882 million kilowatts of conventional hydropower; The installed capacity of pumped storage is 1.07 million kilowatts; The installed capacity of wind power is 20.6142 million kilowatts; The installed capacity of photovoltaic is 11.0143 million kilowatts.

(2) Planning

Considering the in-depth promotion of the coordinated development strategy of Beijing, Tianjin and Hebei, the deepening reform of the supply side structure, the slowing down of the development of high energy consuming industries, and the accelerated development of high-tech industries and modern service industries, the power demand of Beijing Tianjin Tangshan Region Power Grid will maintain a steady growth. It is estimated that by 2030, the total electricity consumption of Beijing Tianjin Tangshan Region Power Grid will reach 596.2 billion kwh, and the maximum power consumption load will be 113.5 million KW.

As a key area to implement the national regional development strategy, Beijing Tianjin Tangshan region has an urgent task to implement the carbon peaking and carbon neutrality goals. In order to meet the growth demand of local non- fossil energy, the Beijing Tianjin Tangshan region power grid needs to greatly increase the scale of wind power and photovoltaic power generation due to resource constraints. According to the weight of non-hydropower consumption responsibility[23], it is estimated that the installed capacity of wind power and photovoltaic power will reach 6549 and 55.26 million kilowatts respectively by 2030.

(3) Energy storage operation mode

According to the principle of energy storage allocation, it is estimated that 6.73 million kilowatts of wind power and 6.64 million kilowatts of photovoltaic energy will be added in 2030. Around the problems of "peak load regulation" and "supply guarantee" after large-scale renewable energy access, this paper sets up three kinds of energy storage operation modes, in which the peak valley difference rate of net load is an important factor to characterize the difficulty degree of peak shaving, and the confidence capacity of renewable energy is an important characterization of its supporting capacity. Therefore, the optimization is carried out with the net load peak valley ratio and confidence capacity as the objective.

Scenario 1: renewable energy is not equipped with energy storage;

Scenario 2: 15% energy storage is configured for renewable energy, and only peak valley difference of net load is considered for energy storage;

Scenario 3: 15% energy storage is configured for renewable energy, and the energy storage takes into account the enhancement of renewable energy guarantee capacity coefficient and the reduction of peak valley margin of net load;

Scenario 4: 15% energy storage is allocated for renewable energy, and the energy storage priority is to improve the renewable energy guarantee capacity coefficient, and then to reduce the peak valley margin of net load

4.2 Result analysis and discussion

(1) Renewable energy confidence capacity analysis method

Based on the stochastic model of grid load and wind power output, this paper calculates the output of wind power and photovoltaic power at the time when the maximum load occurs every day in the whole year, calculates the output under a certain guarantee probability condition, and comprehensively analyzes the capacity contribution rate of wind power and photovoltaic power in the peak period by combining the different output situations of wind power and photovoltaic power in four seasons. The guarantee capacity is the guarantee factor.

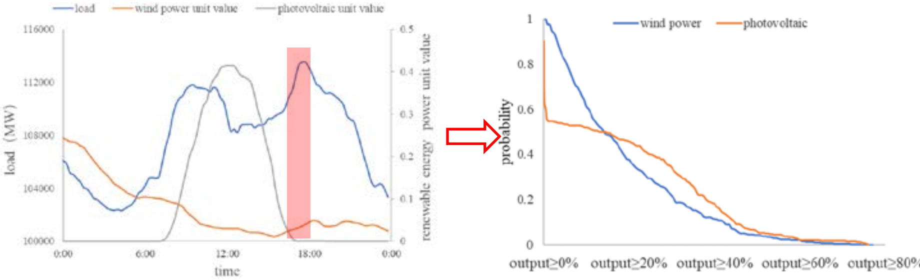


Fig.1. Schematic diagram of analysis method.

(2) Renewable energy confidence capacity of Scenario 1

The maximum daily load of Beijing Tianjin Tangshan Region Power Grid mainly occurs from 17:00 to 19:00, with a probability of more than 60%, followed by 10-11:00 at noon. However, the wind power output has strong randomness, and the maximum output time fluctuates randomly, and the distribution of each point in 24 hours has no special aggregation. The probability of occurrence of wind power from 23:00 to 1:00 the next day is more than 35%, which has strong anti-peak regulation characteristics. Photovoltaic power generation has strong regularity, and the probability of maximum output occurring from 11:00 to 13:00 is the highest, which is more than 85%.

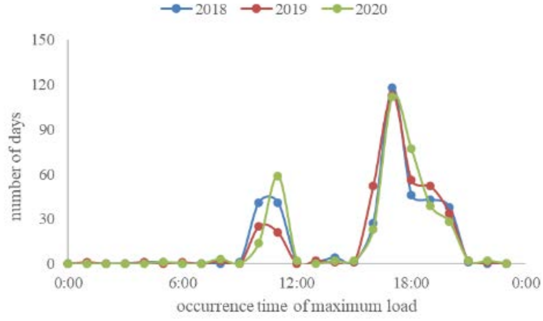


Fig.2. Probability statistics of maximum load output time of Beijing Tianjin Tangshan Region Power Grid from 2018 to 2020.

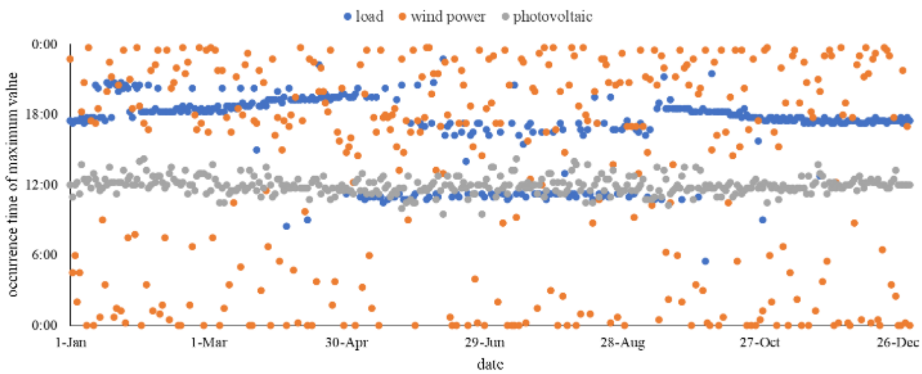


Fig.3. Time distribution of maximum load and renewable energy output of Beijing Tianjin Tangshan Region Power Grid in 2020.

Wind power output fluctuates randomly, so whether the original load peak occurs at night or in the daytime, there is a certain probability to meet the peak load requirements. In the whole year, the guaranteed capacity coefficient of wind power can be 2.9% considering the probability of guaranteed output being 95%.At the same time, the wind power output has obvious seasonal characteristics, which is larger in spring and smaller in summer. Under the 95% probability, the guaranteed capacity coefficients of spring, summer, autumn and winter are 7.3%, 1.9%, 2.8% and 3.6%, respectively.

When the peak load occurs at night, it is difficult for PV to play the role of capacity guarantee. In the whole year, the peak load of Beijing Tianjin Tangshan Region Power Grid usually occurs at night, and the probability of no light in the late peak is more than 60%, which makes it difficult for photovoltaic power grid to meet the requirement that the probability of guaranteed output is greater than 70%.If the output duration and load distribution characteristics are considered, the guaranteed capacity coefficient of PV in summer can reach 4.8% under 95% probability, and it is still 0 in other seasons.

Table 2. Renewable energy confidence capacity characteristics of Beijing Tianjin Tangshan Region Power Grid.

Confidence capacity	Confidence probability of wind power output					Confidence probability of photovoltaic output				
	0.7	0.8	0.9	0.95	1	0.7	0.8	0.9	0.95	1
Spring	19.2%	16.2%	11.3%	7.3%	3.0%	0.0%	0.0%	0.0%	0.00%	0.0%
Summer	6.9%	5.1%	2.9%	1.9%	0.6%	25.3%	18.7%	11.6%	4.8%	0.0%
Autumn	13.2%	10.1%	6.5%	2.8%	1.0%	0.0%	0.0%	0.0%	0.00%	0.0%
Winter	19.2%	13.1%	4.6%	3.6%	0.8%	0.0%	0.0%	0.0%	0.00%	0.0%
Annual	13.2%	8.5%	4.7%	2.9%	0.6%	0.0%	0.0%	0.0%	0.00%	0.0%

(3) Analysis of charging and discharging characteristics of energy storage

In scenario 2 - 4, the optimization objective of energy storage operation mode is to minimize the difference between peak and valley of net load, that is, discharge at peak time of net load and charging at valley value of net load. Due to the influence of photovoltaic output characteristics, the maximum net load of Beijing Tianjin Tangshan Region Power Grid mostly appears at about 18:00 p.m., when the energy storage is discharged; The minimum value usually appears around 12 o'clock in the afternoon, when the energy storage is charged.

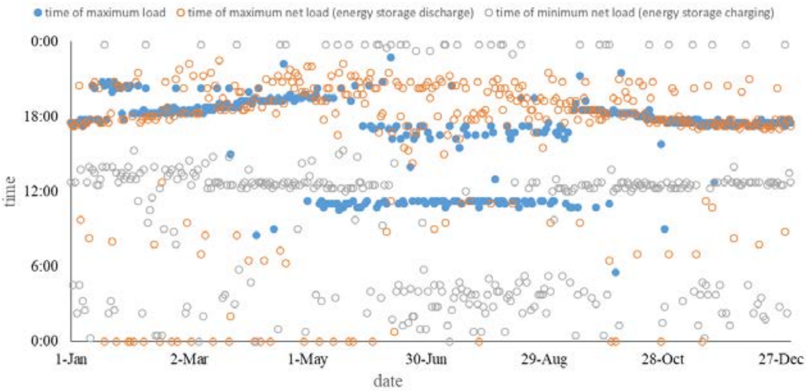
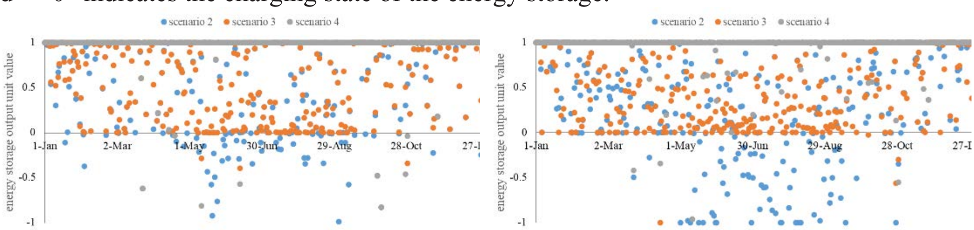


Fig.4. Charging and discharging rules (1).

The difference is that compared with scenario 2, the energy storage in scenario 3 and scenario 4 is in the state of discharge at the time of maximum original load, even reaching full power discharge. The ordinate of the figure below shows the ratio of the energy storage charging and discharging power to the installed capacity; "> 0" indicates the discharge state and "< 0" indicates the charging state of the energy storage.



a) Wind power configuration energy storage b) Photovoltaic configuration energy storage

Fig.5. Charge discharge law of energy storage (2).

(4) Energy storage effectiveness analysis

When the confidence probability is 95%, the renewable energy allocation energy storage can significantly improve the renewable energy confidence capacity. The wind power confidence capacity increases from 2.9% to 6.1%, 7.3% and 17.9%, respectively, and the photovoltaic capacity increases from 0% to 15.0%. Scenario 4 has the largest increase in the renewable energy confidence capacity, which is the energy storage configuration capacity. When the confidence probability is 100%, the confidence capacity of wind power is reduced to 0% in scenario 1, which is mainly due to the characteristics of charging and discharging of energy storage, which leads to the decrease of guarantee output of wind power and energy storage at about 12:00 p.m., resulting in the reduction of wind power confidence capacity.

Table 3. Changes of renewable energy confidence capacity under different scenarios.

Confidence capacity	Confidence probability of wind power output					Confidence probability of photovoltaic output				
	0.7	0.8	0.9	0.95	1	0.7	0.8	0.9	0.95	1
Scenario 1	13.2%	8.5%	4.7%	2.9%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%
Scenario 2	23.3%	18.3%	10.8%	6.1%	0.0%	10.4%	7.0%	1.8%	0.0%	0.0%
Scenario 3	24.2%	18.9%	12.3%	7.3%	0.6%	10.9%	7.1%	2.4%	0.0%	0.0%
Scenario 4	28.2%	23.5%	19.7%	17.9%	15.5%	15.2%	15.2%	15.1%	15.0%	15.0%

In scenario 2-4, the renewable energy allocation and energy storage can effectively reduce the daily peak valley difference of net load and improve the renewable energy consumption capacity. Affected by the operation mode of energy storage, the effect of energy storage on reducing daily peak valley difference of net load is poor in scenario 4, but the difference is not obvious due to the small energy storage capacity.

Table 4. Variation of annual average daily peak valley difference of net load under different scenarios in Beijing Tianjin Tangshan Region Power Grid.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Wind power	25.24%	18.22%	18.47%	18.49%
photovoltaic		22.76%	22.78%	22.81%

5 Conclusion

In order to analyze the effectiveness of electrochemical energy storage for renewable energy allocation, based on the operation mechanism of energy storage system, this paper establishes the Renewable energy + Energy storage operation optimization model considering the operation safety characteristics of energy storage facilities, and applies CPLEX to solve the problem

(1) The confidence capacity of renewable energy is low, and the power support capacity of renewable energy is insufficient at peak load. Based on the output characteristics of renewable energy, no matter the peak load occurs in the daytime or at night, wind power has a certain probability to meet the requirements of peak load, but when the peak load occurs at night, photovoltaic will be difficult to play a role in ensuring capacity. From the year-round scale, under the condition of 95% guarantee probability, the wind power confidence capacity coefficient of Beijing Tianjin Tangshan Region Power Grid is 2.9%, and photovoltaic power is 0.

(2) The renewable energy configuration energy storage can improve its confidence capacity and reduce the peak valley difference rate of net load, but the specific effect is closely related to the operation mode of energy storage. When the wind energy storage capacity is increased by 15% compared with the actual wind energy storage mode, the wind energy storage capacity should be increased by 15% according to the actual situation. Therefore, the operation mode of energy storage system should be reasonably determined according to specific application scenarios and requirements.

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