E3S Web of Conferences **441**, 01014 (2023) https://doi.org/10.1051/e3sconf/202344101014
CELCT 2023

Comprehensive Benefit Evaluation Analysis And Application Research of Energy Storage

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ABSTRACT. In recent years, the penetration rate of renewable energy in the power system has increased year by year, and the allocation of energy storage is an important development trend to improve the operation stability of the grid-connected power system containing renewable energy. This paper first analyzes the basic concept and operation principle of energy storage devices, and then explains the costs and benefits of energy storage devices. Finally, the industrial park and energy storage power station are used as practical application scenarios to verify the correctness of the proposed method. The example results show that energy storage should be installed in a place where the system network loss is minimal and the reliability of power supply can be maximized, and the capacity of the energy storage system should match the load capacity of the bus bar of the installation site, so as to achieve the greatest comprehensive benefits.

1 Introduction

With the maturity of production and manufacturing technology of energy storage devices, energy storage has been widely used in power grids, playing an important role in power grid regulation, and has achieved high economic efficiency. In order to better play the value of the energy storage device, it is necessary to optimize the location and capacity of the energy storage device. Literature [1] introduced the capacity optimization allocation method of energy storage power station, but did not analyze the installation position of energy storage power station. Literature [2] conducted a comprehensive evaluation from the technical perspective of energy storage, but did not conduct an evaluation and analysis from the economic perspective. Literature [3] analyzed the comprehensive operating benefits of grid-connected photovoltaic optical storage systems, but did not calculate the comprehensive benefits of energy storage from the perspective of the whole life cycle. Under the above background, this paper first analyzes the cost and benefit of energy storage in the whole life cycle, and then takes industrial parks and energy storage power stations as application scenarios to analyze the energy storage optimization configuration method based on the optimal system comprehensive benefit. The following is a specific analysis and introduction.

2 Overview of Energy Storage Devices

Energy storage devices include many types, such as supercapacitor energy storage, battery energy storage, etc. [4], which have been applied in actual energy storage power stations. Among them, battery energy storage also includes a variety of different types, and the performance parameters of the main battery energy storage technologies are shown in Table 1.

Table 1 Performance comparison of major battery energy storage technologies

Class	Power Upper Limit	Specific Capacity (Wh/Kg)	Specific Power （W/Kg）	Cycle Life （Times）	Charge And Discharge Efficiency （%）	Self-Discharge (%/Month)	Environmental Performance	Technology Maturity
Lead Acid	Tens of MW	35~50	75~300	500~1500	0~80	2~5	Middle	Good
Nimh	Tens of MW	85	160~230	2500	0~65	15~30	Good	Good
Ion	Count MW	150~200	200~315	1000~10000	0~95	0~1	Good	Good
Sodium-Sulfur	A dozen MW	150~300	90~230	4500	0~90	-	Good	Good
Fluid Flow	Count MW	80~130	50~140	13000	0~80	-	Good	Good

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For lead-acid batteries, its application experience is relatively rich, and the manufacturing cost is relatively low, but it will have a certain impact on the environment during the application process, so it has been gradually replaced by other battery types. Sodium-sulfur batteries, flow batteries, etc. are important trends in the development and application of energy storage batteries in the future, and their batteries have large capacity, relatively high charge and discharge efficiency, and also have high service life, which are its important application advantages [2-3]. At the same time, for the application scenarios of energy storage, it mainly includes two types: the grid side and the user side, which is also the main way to apply the energy storage regulation system.

3 Comprehensive Benefit Analysis of Energy Storage

For the comprehensive benefits of energy storage, including the cost and benefit of energy storage, the following is a systematic analysis.

3.1 Cost analysis of energy storage

The cost of energy storage mainly includes initial investment costs, later operation and maintenance costs and decommissioning costs. First of all, for the initial investment cost, including energy storage equipment fee, transportation fee, commissioning fee, site fee, feasibility study, initial setup, acceptance and design fee, etc., as shown in (1) below:

$$C_{captial}=C_{s1}+C_{s2}+C_{s3}+C_{s4}+C_{s\ studyable}+C_{s\ initial\ setup}+C_{s\ acceptance}+C_{s\ devise} \quad (1)$$

In the formula: the C_{s1} 、 C_{s2} 、 C_{s3} 、 C_{s4} are energy storage equipment fees, transportation costs, commissioning fees, and site fees.

For O&M costs, the calculation formula is shown in Equation (2) below:

$$C_{OMs,t}=c_{OM,t}P_{smax} \quad (2)$$

Formula: $c_{OM,t}$ the operation and maintenance cost per unit capacity of the energy storage device; Including operation cost C_y and maintenance cost C_w; P_{smax} is the capacity of the energy storage device.

For the cost of decommissioning, when the energy storage device reaches the end of its service life, labor costs and environmental protection costs need to be spent in the disposal process, and the calculation formula is shown in (3) below:

$$C_{res}=C_{labor\ costs}+C_{environmental\ fees}-C_{salvage\ value} \quad (3)$$

wherein, the residual value of the energy storage device is calculated as shown in Equation (4) below:

$$C_{salvage\ value}=\Sigma C_{captial}(1-2/N_i)^{Ni} \quad (4)$$

Formula: N_i is the full life cycle of the energy storage device. At the same time, the average annual cost of energy storage devices is shown in Equation (5) below:

$$C_a=[C_{captial}+\frac{C_{res}}{(1+r)^{N_i}}+\sum_{t=1}^{N_i}\frac{C_{OMs,t}}{(1+r)^t}]\times\frac{r(1+r)^{N_i}}{(1+r)^{N_i}-1} \quad (5)$$

Formula: r is the annual discount rate.

3.2 Benefit analysis of energy storage

The benefits of energy storage mainly include reducing grid expansion, reducing system network loss, low storage and high arbitrage, reliability benefits, etc., and the calculation methods of various benefits are detailed below.

First of all, for reducing grid expansion, when the system is at the peak of load, by discharging the energy storage device, thereby reducing grid expansion, calculated as shown in Equation (6) below:

$$E_{s1}=\lambda_d C_d \eta P_{smax} \quad (6)$$

Formula: λ_d is the depreciation rate of grid assets; C_d is the cost of the unit capacity of the power grid; η is the energy storage efficiency; P_{smax} is the rated power of the energy storage device.

For reducing the efficiency of the system network loss, when the load peaks, the in-situ balance of the load can be achieved through the discharge of the energy storage device, thereby reducing the system network loss, calculated as shown in Equation (7) below:

$$E_{s2}=\sum_{1}^{365}\sum_{i=1}^{24}(\xi_{if}-\xi_{il})e_i \quad (7)$$

In the formula: ξ_{if} and ξ_{il} are the network loss before and after the energy storage device is connected; e_i is the price of electricity.

For low storage and high arbitrage, due to the different on-grid electricity prices in different periods, energy storage can obtain a more objective low storage and high arbitrage [5-6] by charging at low prices and discharging at high prices, calculated as shown in equation (8) below:

$$E_{s3}=n\sum_{i=1}^{24}(P_i^+-P_i^-)e_i \quad (8)$$

Formula: P_i^+ and P_i^- are the discharge and charging power of the energy storage device under the i period, respectively; The number of times the energy storage device is put into operation per year.

For reliability benefits, after connecting to the energy storage device, the power supply reliability of the system can be improved to a certain extent, as shown in Equation (9) below:

$$E_{s4}=(ENSI_{fs}-ENSI_{ls})*IEAR \quad (9)$$

In the formula: $ENSI_{fs}$ and $ENSI_{ls}$ are the lack of power supply in the system before and after the energy storage is added, and IEAR is the evaluation rate of power loss loss.

The annual comprehensive benefits of energy storage devices are:

$$E = \mathrm{E}_{s1} + \mathrm{E}_{s2} + \mathrm{E}_{s3} + \mathrm{E}_{s4} \tag{10}$$

3.3 Comprehensive benefit evaluation model and parameter setting of energy storage device

For the comprehensive benefit evaluation model of energy storage device, the maximum comprehensive benefit of energy storage device is the objective function, as shown in equation (11) below:

$$\max \ f = E\text{-}C_a \tag{11}$$

The constraints in the comprehensive benefit evaluation model of the energy storage device include the capacity constraints of the energy storage device, the state of charge constraints, the number of charge and discharge constraints, and the system power balance constraints.

Parameter Settings in the comprehensive benefit evaluation model of energy storage device are shown in the following table.

Table 2 Parameter Settings of energy storage device

Figure	Definition	Value	Figure	Definition	Value
$\mathrm{C_d}$	Unit cost of grid	100（Ten thousand yuan /MW）	IEAR	Customer outage loss evaluation rate	6（Ten thousand yuan /MW•h）
λ_d	Depreciation rate of fixed assets of power grid equipment	3%	$P_{s\max}$	Maximum power stored	0.3MW
η	Energy storage efficiency	80%	r	Discount rate	8%
N	Battery life	20 years	$\mathrm{e_i}$	Feed-in tariff	Peak electricity price is 0.088 Ten thousand yuan /MWh， The trough price is 0.0408 Ten thousand yuan /MWh
n	Annual number of energy storage operations	360	Cy	Unit operating cost of energy storage system	429.8（Ten thousand yuan /MW）
T	Duration of charging the energy storage device	6h	Cw	Unit maintenance cost of energy storage system	73.68（Ten thousand yuan /MW）

4 Example Analysis of Energy Storage Optimal Configuration

4.1 Basic information of the study

The example selected this time is the 10kV outlet line of a substation in a certain area, and its wiring mode is single-radiation overhead line. The 10kV distribution network is connected to the industrial park load and is equipped with an energy storage station, and its wiring diagram is shown in Figure 1 below.

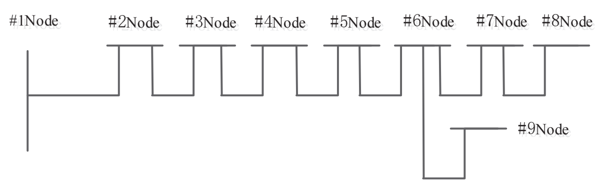

Figure 1 Single-radiation overhead line wiring diagram

In this distribution system, multiple segmented switches are set up, and when a certain section of the distribution network fails, the fault range can be narrowed by the segmented switch, thereby improving the power supply reliability of the distribution network. The transformer connected to the trunk line is 10KV/380V, which can be regarded as a load node. There are a total of 8 load nodes in the figure. The composition of the peak load time of each load node is shown in Table 3.

Table 3 Load composition of the system

Numbering	P(MW)	Q(MW)	Numbering	P(MW)	Q(MW)
1	0.29	0.03	5	0.36	0.12
2	0.38	0.12	6	0.28	0.09
3	0.33	0.11	7	0.36	0.12
4	0.31	0.01	8	0.35	0.12

The following example will be used to analyze the impact of the installation location and installation capacity of the energy storage power station on the comprehensive benefit of energy storage in the distribution network, including the load side, the middle of the line and the power supply side, which are the main application scenarios of energy storage devices.

The peak load time of the distribution network is 13 hours, the load trough is 8 hours [7-8]. When the system is at the peak of the load, the energy storage power station is running in the discharged state as a power source. When the system is in the trough of the load, the energy storage power station is running in the charging state as a load, thereby other functions of regulating the load of the system [9-10]. The total load of the power distribution system is 2.66MW, and for the installed capacity, 0.7MW, 0.9MW and 1.2MW batteries are installed, respectively.

4.2 Analysis of study results

In the above power distribution system, when the energy storage power station is installed at the power side node 2, the middle side node 5, and the load side node 8, the installed capacity is 0.7MW and remains unchanged. Based on the calculation of the above three places, the results show that the reliability benefit of the installation on the middle side of the line is the largest, and the network loss is the smallest. At the same time, the cost-benefit calculation of installation in the above three places is shown in Table 4 below:

Table 4 Results of cost-benefit calculations

Index	Power Side	Middle Side	Load Side
Cost	431 Thousand	431 Thousand	431 Thousand
Benefit	1432.3 Thousand	1620.8 Thousand	1599.8 Thousand
Net Benefits	1001.3 Thousand	1189.8 Thousand	1168.8 Thousand

It can be seen that when installed on the middle side of the line, the net benefit is the largest, because it can reduce the network loss at the same time, the reliability benefit is also the largest, so the installation site of energy storage should be installed in the place where the network loss is the least and the reliability can be maximized. Next, change the installed capacity and invest 0.9MW and 1.2MW respectively to see the net benefit shown in Table 5 below:

Table 5 Cost-benefit calculations

Index	0.7MW	0.9MW	1.2MW
Cost	431 Thousand	526 Thousand	668.5 Thousand
Benefit	1620.8 Thousand	2004.5 Thousand	2580 Thousand
Net Benefits	1189.8 Thousand	1478.5 Thousand	1911.5 Thousand

It can be seen that as long as the energy storage system is reasonably installed, the net benefit is gradually increasing. However, it does not mean that the capacity of the energy storage system can always increase, and the capacity of the energy storage system should match the load capacity of the bus bar at the installation site, so as to achieve the greatest comprehensive benefits. Since energy storage power stations can be invested by both users and users [11]. When the energy storage power station is invested in the power grid, the low storage and high arbitrage benefits obtained by energy storage belong to the power grid. When the energy storage power station invests for the user, the low storage and high arbitrage benefits obtained by energy storage belong to the user. No matter who invests, the construction of energy storage systems can achieve considerable economic benefits.

5 Conclusion

With the increase of the proportion of new energy in the power system, the energy storage system will play an increasingly critical role in the operation control of the power system in the future. In fact, energy storage is a dominant factor in the integration of renewable sources, playing a significant role in maintaining a robust and reliable modern electricity system[12]. In order to apply energy storage more reasonably, this paper constructs a comprehensive benefit evaluation model of energy storage in the whole life cycle, and takes the maximum comprehensive benefit as the objective function to optimize the location and installation capacity of energy storage. The results show that the energy storage should be located in the middle side of the line with the lowest network loss and the highest power supply reliability, and the configured capacity should match the load capacity to achieve the optimal operation of the energy storage.

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