Shared Energy Storage Operation Mode and Optimized Operation Strategy for Internet Companies' Investment

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Abstract—In recent years, the development of the Internet has penetrated into all walks of life, and several large Internet companies are actively embracing the new era by developing new businesses in the energy sector, including investment in new energy power plants and energy storage plants. This paper mainly analyzes the investment and operation mode of energy storage plants and the competition of energy storage plant operation to grid companies, and finally constructs an energy storage sharing model with the goal of maximizing the net profit of grid companies and the highest revenue of energy storage plants invested by Internet enterprises. The calculation example shows that the operation mode and operation strategy proposed in this paper are better in terms of economy and practicality, and are of great significance to achieve a win-win situation for both Internet companies and power grids.

Keywords-energy storage plants; shared energy storage; Internet companies; multi-objective particle swarm algorithms

1. Introduction

In the general background at home and abroad, all industries are actively responding to the call for energy saving and emission reduction, among which the carbon emission problem of the Internet industry has been attracting much attention [1-3]. The advantages of the rooftop photovoltaic power plants currently invested by Internet companies are low transmission and distribution losses with cheap costs, which are mutual independence [4]. Internet companies are still in the initial stage of investment in energy storage power plants, and Internet companies are waiting for large-scale investment in energy storage power plants from the point of view of the invested rooftop photovoltaic power plants [5].

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2. The investment and operation mode of energy storage power plant

Internet companies are currently investing in new energy power plants, mostly rooftop photovoltaic plants, and equipped with distributed energy storage plants. Internet companies need to consider the aggregation effect for the investment and construction of energy storage plants, and cluster the dispatch of each storage device to fully exploit the dispatchable potential of new energy sources and meet the minimum requirements for providing services to the power grid[6].

2.1. Operation mode considering aggregation effect

2.1.1. Operational constraints

The charging and discharging power constraint of a single energy storage device is given by the following equation.

$$\begin{cases} 0 \le P_{cha.i}^{t} \le P_{cha.i}^{\max} \\ 0 \le P_{disc.i}^{t} \le P_{disc.i}^{\max} \end{cases} \tag{1}$$

Where: $P^{t}_{cha.i}$, $P^{t}_{disc.i}$ is the charging and discharging power of the i_{th} energy storage device in the aggregation device at moment t; $P^{max}_{cha.i}$、 $P^{max}_{disc.i}$ is the maximum charging power and the maximum discharging power of the i_{th} energy storage device in the aggregation device.

2.1.2. Scheduling objective function

The predicted power of the whole distributed energy storage system is as following relationship.

$$\tilde{P}^{t} = \tilde{P}_{in}^{t} + \sum_{i}^{n} P_{net.i}^{t} \tag{2}$$

Where: $\tilde{P}_{in}^{t}$ is the total predicted injected power at each moment after filtering without considering energy storage devices; n is the number of energy storage devices.

2.2. Profit model of investing in distributed energy storage power plant

2.2.1. Cost

1) Initial investment cost

Initial investment cost refers to the total amount of capital invested by Internet companies at the beginning of investing in distributed energy storage power plants. The following equation shows the calculation of initial investment costs.

$$C_1 = (C_p \cdot P_{\max} + C_e \cdot E_{\max}) \tag{3}$$

Where: C_1 is the initial investment cost; C_p is the unit power investment cost; C_{1e} is the unit capacity investment cost.

2) Operation and maintenance costs

The equipment needs to be maintained or replaced due to wear and tear, aging and other reasons. The following equation shows the calculation of operation and maintenance costs.

$$C_2 = \sum_{k=1}^{n} C_{rp} P_{\max} + C_{re} E_{\max}) + \sum_{t=1}^{T} C_d \left[W_c(t) + W_d(t) \right] \tag{4}$$

Where: C_{rp} is the unit power operation and maintenance cost; C_{re} is the unit capacity operation and maintenance cost; C_d is the unit power dynamic cost; $W_c(t)$ and $W_d(t)$ are the annual charging power and annual discharging power of the distributed energy storage system.

2.2.2. Benefits

1) Demand-side response benefits

$$R_{de} = P_{st} \cdot t \cdot N \cdot E_c \tag{5}$$

Where: R_{de} is the revenue of demand-side response; P_{st} is the rated power of each storage device; t is the number of days of power demand response execution per year; N is the number of power demand response executions per day; E_c is the capacity tariff of each storage device.

2) Recovery of the revenue from the amount of discarded light

$$R_{qg} = 30 \sum_{y=1}^{12} \sum_{n=1}^{N} \left[E_{cmn.f} - E_{cmn.g} (2 - \mu) \right] P_{st} \tag{6}$$

Where: R_{qg} is the revenue of recovering the discarded energy; $E_{cmn.f}$ is the electricity price at the peak of the n_{th} hour user in the m_{th} month; $E_{cmn.g}$ is the electricity price at the trough of the n_{th} hour user in the m_{th} month; μ is the charging and discharging conversion efficiency.

2.3. Competition from energy storage plants to grid companies and their response

Internet companies investing in energy storage plants usually adopt the independent investment model. After the construction of energy storage power station, Internet companies can basically realize self-generation and self-storage of surplus power, smoothing power curve to meet the demand for electricity.

Take the distributed energy storage power plant built by lead-carbon batteries as an example, it should consider the direct economic benefits of Internet companies investing in energy storage power plants when providing services of peak cutting. The direct economic benefit index R_{de} is calculated by the following equation:

$$R_{de} = \frac{E_{c.dis} - E_{c.cha}/\mu}{I/(Y \cdot D) + C} \tag{7}$$

Where: $E_{c.dis}$ is the discharge tariff; $E_{c.cha}$ is the charging tariff; I is the initial investment in output power; Y is the cycle life; D is the depth of charge and discharge; C is the operating cost of output power.

The gross profit of Internet companies investing in distributed energy storage plants is around 5%, which has a notable impact on the grid.

3. Response strategy and analysis of calculation cases

The grid side, energy storage side and user side are considered as a whole to realize the sharing of energy storage capacity and energy storage power, and a multi-objective particle swarm algorithm (MO-PSO) based energy storage sharing strategy is proposed to build an energy storage sharing model with the goal of maximizing the net profit of grid companies and the highest revenue of energy storage plants invested by Internet companies.

3.1. Objective function

3.1.1. Net profit of grid companies

$$\begin{cases} B_{tra} = \sum_{t=1}^{T} \sum_{i}^{I} \left[(P_i(t) - P_{tra.i}(t)) \cdot R_{tra.i}(t) \right] \\ B_{cut} = \sum_{t=0}^{T-1} \sum_{j=1}^{J} \left(E_{cut.j}(t) \cdot R_{cut.j}(t) \right) \end{cases} \tag{8}$$

Where: B_{tra}, B_{cut} are the transferable load compensation and curtailable load compensation obtained by user; T is the total time period of load demand response; $P_i(t)$, $P_{tra.i}(t)$ are the active power before and after user i participates in demand-side response at time t; $E_{cut.j}(t)$ is the power curtailed by user j at time t; $R_{tra.i}(t)$, $R_{cut.j}(t)$ are the grid company is the compensation price of transferable load in time t signed with user i, and the compensation price of interruptible load in time t signed between grid company and user j.

The methodology of cost is shown in the following equation.

$$\begin{cases} C = C_{st.p} - C_{st.s} + C_p - C_{env} \\ C_{st.s} = \sum_{t=1}^{T} E_{st.s}(t) R_{st.s}(t) \\ C_p = \sum_{t=1}^{T} R(t) E(t) \\ C_{env} = \sum_{t=1}^{T} E_{CO_2}(t) R_{CO_2} \end{cases} \tag{9}$$

Where: C is the system cost; $C_{st.p}$ is the expenditure of the grid company to purchase energy storage rights from Internet companies; $C_{st.s}$ is the revenue of the grid company to sell energy storage rights to customers; C_p is the cost of power purchase by the grid company; C_{env} is the environmental benefit; $E_{st.s}(t)$ is the total charge of energy storage rights sold by the grid company in time period t; $R_{st.s}(t)$ is the time period t energy storage the price of the right to use sold.$R(t)$ and $E(t)$ are the electricity price and power purchased from the grid; $Eco2(t)$ is the clean energy power purchased by the grid company in time t; $Rco2$ is the carbon emission reduction benefit obtained by the grid company after purchasing clean energy in the valley hours.

This gives the formula for calculating the net profit W_1 of the grid company.

$$W_1 = R_{sale} - C - B_{cut} \tag{10}$$

Where: R_{sale} is the power sales revenue of the grid company.

3.1.2. Internet business earnings

$$W_2 = \sum_{t=1}^{T} E_{dis}(t) U(t) R_{serv} - C_{ESS} \tag{11}$$

Where: W_2 is the revenue of distributed energy storage plants invested by Internet companies; $E_{dis}(t)$ is the total charge volume of shared energy storage sold in time period t; $U(t)$ is the charging and discharging state in time period t; R_{serv} is the service cost of shared energy storage; and C_{ESS} is the operating cost of distributed energy storage plants.

3.2. Constraints

3.2.1. utilization rate of wind power and photovoltaic power generation

The constraint range is as follows.

$$RATE = \sum_{t=1}^{24} E_{DRE}(t) \Big/ \sum_{t=1}^{24} L_1(t) \geq RATE_N \tag{12}$$

Where: *RATE* is the distributed power generation utilization rate; $E_{DRE}(t)$ is the power supplied to the load by the distributed power source in time *t*; $L_l(t)$ is the load after dispatch in time *t*; $RATE_N$ is the rated distributed power generation utilization rate.

3.2.2. User satisfaction

$$S = 1 + \frac{\sum_{t=1}^{T} P_L(t) R_L(t) - R_{after}}{\sum_{t=1}^{T} P_L(t) R_L(t)} \tag{13}$$

Where: *S* is customer satisfaction; $P_{L(t)}$ and $R_{L(t)}$ are customer electricity consumption and tariff at time *t*; R_{after} is the customer electricity cost after customer participation in demand response.

4. Case analysis and simulation

The distribution network analyzed in this paper contains two distributed photovoltaic plants, two wind farms, three energy storage plants and three small and medium-sized commercial and industrial customers. The shared energy storage capacity involved in the dispatch is 2400kWh. The maximum power of three industrial and commercial users using shared energy storage for charging and discharging is 585kW. The maximum and minimum values of the charge state are 0.9 and 0.1 respectively, and the cost of energy storage service is 0.62 RMB per kWh. The carbon emission reduction subsidy that power grid companies can receive for purchasing new energy generation in the intraday real-time power market is RMB 0.12 per kWh.

The resulting solution yields profit of ￥4568.2 for the power grid company and ￥2142.5 for the distributed energy storage plant built by the Internet company.

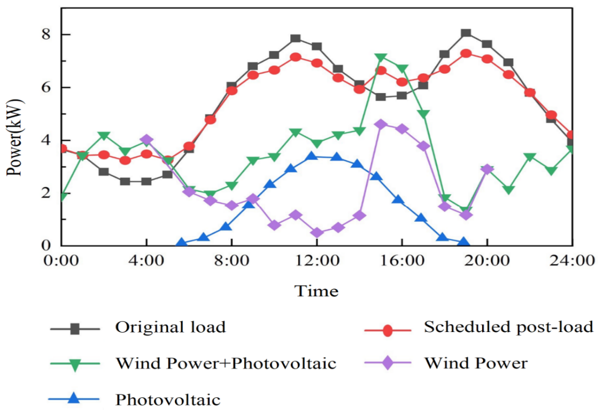

Fig.1 Load and active output change curve after scheduling.

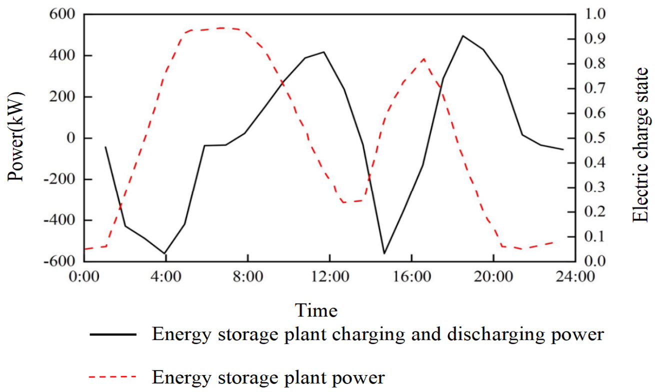

Fig.2 Shared energy storage plant charging and discharging power and electricity.

As shown in Figure 1, according to the comparison between the original load change curve and the post-dispatch load change curve, it can be seen that the energy storage system is in charging state when the load is low or the scenery is sufficient; when the load is high, the energy storage system is in discharging state. The energy storage charging and discharging power and power state after scheduling is shown in Figure 2.

By purchasing the right to use the utility's energy storage, customers purchase power during periods when real-time electricity prices are lower, and the power grid company's renewable energy purchases during these periods then increase. When the real-time electricity price is high, users make use of the energy storage power, which reduces the power purchased by the grid company during peak hours, realizing peak shaving and valley filling, and ensuring the balance between supply and demand. Based on the optimal scheduling results, the power purchase strategy of the grid company is given. The average price of electricity purchased in the market was RMB0.759 per kWh at 53.21% of the previous day; the average price of electricity purchased in the real-time market was RMB0.702 per kWh. The total power purchase cost and total power sales revenue after dispatch were 3.87% and 2.12% lower respectively compared with those before dispatch, and in addition, the carbon emission reduction subsidy of RMB 5,182.6 was obtained.

A comparison of the data before and after the dispatch is shown in Table 1. As can be seen from the data in the table, the net profit of the grid companies increased by 48.1%. The net profit of energy storage power plants increased by 22.1%.

Table 1. Comparison of data from Power Grid company

	Grid company earnings/￥	Energy storage plant revenue /￥	User satisfaction	Utilization rate of new energy generation /%
Pre-dispatch	3102.3	1853.9	1.000	90.27
After scheduling	4609.7	2139.9	1.018	96.01

5. Conclusion

From the perspective of win-win situation of both parties, we propose a multi-objective particle swarm algorithm (MO-PSO) based energy storage sharing strategy and build an energy storage sharing model with the goal of maximizing the profit of power grid companies and the highest revenue of energy storage plants built by Internet companies, which achieves the optimal economy.

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