IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

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To cite this article: Zhicheng Xu *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **634** 012059

IOP Conf. Series: Earth and Environmental Science **634** (2021) 012059 doi:10.1088/1755-1315/634/1/012059

Economic analysis of energy storage multi-business models in the electricity market environment

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Abstract. At present, with the continuous technical and economic improvement of the energy storage, the large-scale application of energy storage is possible. However, the current energy storage development still has the problem of insufficient business models and single energy storage income. With the continuous improvement of China's electricity market mechanism, a flexible market environment will provide more feasible business models and market space for energy storage development. This paper simulates the charging and discharge strategy of electrochemical storage in the market environment and the income situation under the "stack value" applications. The results show that a flexible market mechanism and multi-functional applications in the market environment are beneficial to the improvement of the energy storage economy.

1. Introduction

Solving the balance pressure of the power system caused by the increase in the share of renewable energy is becoming a new development opportunity for battery energy storage system (BESS). Energy storage can play its value in a variety of ways, and the mature ancillary service market has opened up new revenue channels for energy storage. The diversification of income sources is the key to optimizing the energy storage business model. In the current Chinese energy storage market, most projects rely on a single source of income. Changes in electricity market policies and intensified market competition will directly affect project revenue. How to establish multiple income channels and achieve stable income expectations will be the key to the development of future energy storage projects.

The energy storage business model depends on the deployment plan, application scenarios, and the project's grid-to-network configuration [1-5]. Establishing a diversified source of income and establishing a transparent compensation mechanism are the keys to proving reasonable energy storage investment and realizing the stable and sustainable development of the energy storage market. Literature [6-7] describes that the multi-value application of energy storage is an important way to improve the economics of energy storage.

Based on the establishment of the energy storage model, the energy storage control strategy is constructed, and the profit model after the superposition of the energy storage value is analyzed. As a result, in the market environment, energy storage through the value superposition model is a key means to improve the economics of energy storage.

2. Battery Energy Storage Modeling

Understanding the characteristics of the energy storage system and modeling it rationally, and establishing a suitable charging and discharge model of the energy storage system, is an important prerequisite to ensure the correct implementation of the various control strategies proposed. The BESS system in this paper is designated as BESS, a single energy storage system consisting of batteries, and the SOC and battery charge and discharge power of BESS are modeled below respectively [8-10].

2.1. BESS charge and discharge process modeling

The state of charge (SOC) of the battery represents the percentage of the battery's remaining charge as a percentage of the rated capacity under the same conditions and is an important measure of the battery's current chargeable discharge margin. When the battery is fully charged, SOC is 1 and when the battery is fully discharged, SOC is 0. The relationship between *t*-moment energy storage system charge status $S_{\mathrm{SOC}}(t)$ and the remaining charge $E(t)$ and BESS rated capacity S_{Ah} can be expressed as:

$$S_{\mathrm{SOC}}(t)=E(t)/S_{\mathrm{Ah}} \tag{1}$$

S_{Ah} is the total capacity of BESS in MWh.

The recursive relationship to the SOC of the system charge state at the time of BESS charge and discharge is as follows:

Charging process:

$$S_{\mathrm{SOC}}(t+\Delta t)=(1-\rho)S_{\mathrm{SOC}}(t)+\frac{P_{\mathrm{ch}}(t)\Delta t\eta_{\mathrm{ch}}}{S_{\mathrm{Ah}}} \tag{2}$$

Discharge process:

$$S_{\mathrm{SOC}}(t+\Delta t)=(1-\rho)S_{\mathrm{SOC}}(t)+\frac{P_{\mathrm{disch}}(t)\Delta t}{S_{\mathrm{Ah}}\eta_{\mathrm{disch}}} \tag{3}$$

In the upper model, ρ is the self-discharge rate of the BESS system in %/min; $P_{\mathrm{ch}}(t)$ and $P_{\mathrm{disch}}(t)$ represent the charging and discharge power of BESS at the t-moment, MW, and take positive values when charging and negative values when discharged; η_{ch} and η_{disch} represent the charging and discharge efficiency of the BESS system, respectively.

2.2. BESS model constraints

(1) The SOC constraint

In order to protect the battery and extend its service life and prevent damage to the battery due to overcharge or over-discharge, it is necessary to charge and discharge within the minimum-maximum load state allowed, taking the SOC upper and lower limits are $S_{\mathrm{SOC,min}}$ and $S_{\mathrm{SOC,max}}$, respectively.

$$S_{\mathrm{SOC,min}}\le S_{\mathrm{SOC}}(t)\le S_{\mathrm{SOC,max}} \tag{4}$$

(2) Charge and discharge power constraints

In addition to energy constraints, to ensure that the bidirectional inverter operates within the high-efficiency range, it is required that the charge and discharge power of the energy storage system should also be within a reasonable range, otherwise the entire system will operate at the inefficient point.

$$P_{\mathrm{ch}}^{\min}(t)\le P_{\mathrm{ESS}}(t)\le P_{\mathrm{ch}}^{\max}(t)\ ,\ \left(P_{\mathrm{ESS}}(t)>0\right) \tag{5}$$

$$P_{\mathrm{disch}}^{\min}(t) \le P_{\mathrm{ESS}}(t) \le P_{\mathrm{disch}}^{\max}(t) \text{ , } \left(P_{\mathrm{ESS}}(t) < 0\right) \tag{6}$$

The above maximum-minimum charge and discharge power threshold is determined by the current residual power $E(t)$ of the energy storage power station and the maximum continuous charging power $P_{\mathrm{BESS}}^{\max,\mathrm{ch}}$ and the maximum continuous discharge power $P_{\mathrm{BESS}}^{\max,\mathrm{disch}}$, so it is a current variable, the maximum allowable value is as follows:

$$P_{\mathrm{ch}}^{\max}(t) = \min\left\{P_{\mathrm{BESS}}^{\max,\mathrm{ch}}, \frac{E_{\max} - (1-\rho)E(t-\Delta t)}{\eta_{\mathrm{ch}}\Delta t}\right\} \tag{7}$$

$$P_{\mathrm{disch}}^{\max}(t) = \min\left\{P_{\mathrm{ESS}}^{\max,\mathrm{disch}}, \frac{\left[(1-\rho)E(t-\Delta t) - E_{\min}\right]\eta_{\mathrm{disch}}}{\Delta t}\right\} \tag{8}$$

3. Energy storage control strategy

In the electricity market environment, energy storage is often used in such scenarios as energy transfer such as peak shaving, so the establishment of energy storage charge and discharge control strategy is an important way to play the energy storage in the market environment.

As shown in Figure 1, the system load for a day is shown in the graph. The red curve in the graph is the photovoltaic (PV)output curve. In order to improve the correlation between PV output and load, BESS adjustment must be used to make the PV output and the load fluctuation part (that is, after removing the base load) as consistent as possible. Taking into account the day and night characteristics of PV power generation, ideally, the PV power generation trend adjusted by BESS is exactly the same as the trend of the daytime load fluctuation part (that is, the solid line part of curve2 in Figure 1).

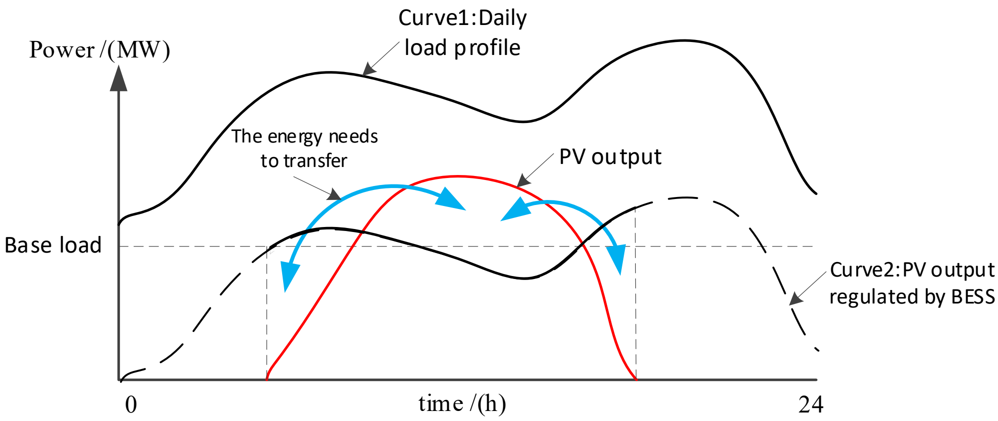

Fig 1 The process of BESS controlling for improving PV-load similarity

At this point, the BESS control target is solid-line PV and BESS force to follow the load, the target function is as follows:

$$\mathrm{obj:}\min\sum_{t=1}^{N_{\mathrm{count}}}\left(P_{\mathrm{bat\_sys}}(t) + P_{\mathrm{PV}}(t) - P_{\mathrm{load}}(t)\right)^2 \tag{9}$$

Among them, N_{count} represents the number of periods in the statistical period T with Δt as the time window, $P_{\mathrm{load}}(t)$ represents the t-moment load size.

4. Energy storage value-stack streams

In the early stage of energy storage development, energy storage mainly played a role in a single business model. As the power market environment improves, the energy storage can play a variety of services [11-13]. Taking a grid-connected "new energy+energy storage " project in China as an example, this paper illustrates the economic comparison between the single business model and the combined business model.

(1) Energy storage value assessment under a single business model

The simulation analysis shows that the investment payback period of the energy storage system under a single business model is 8.78 years.

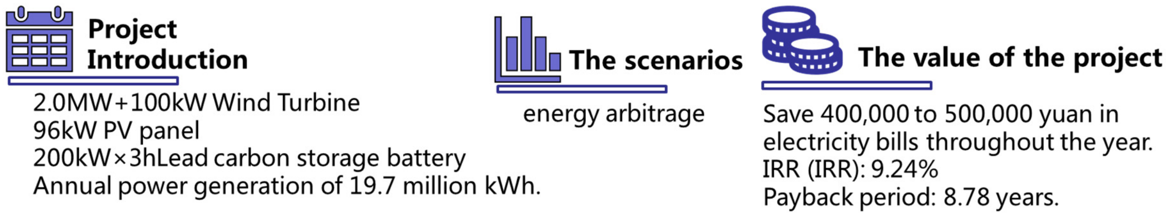

Fig 2 Economic analysis of energy storage in a single business model

(2) Energy storage value assessment under the combined business model.

When the electricity market mechanism continues to improve, energy storage can give full play to different functions to improve its economy. In response to this actual case, energy storage can simultaneously perform multiple functions such as energy arbitrage, power quality optimization, demand side response, demand for electricity charges management.

1) Reduce the basic capacity cost

When energy storage is used in the management of electricity demand, the basic capacity investment and installation cost of 100kW can be reduced, and the annual benefit is about 500,000 yuan.

2) Demand-side response benefit

According to the demand-side reward of 5-12 yuan/kW, the project can receive about 600,000 yuan in rewards throughout the year.

3) Gain by providing reactive compensation

The original operating power factor of the park was around 0.85, with a total fine of 200,000 per year. After the installation of energy storage, the power factor was increased to 0.95, and 300,000 rewards from the grid would be awarded.

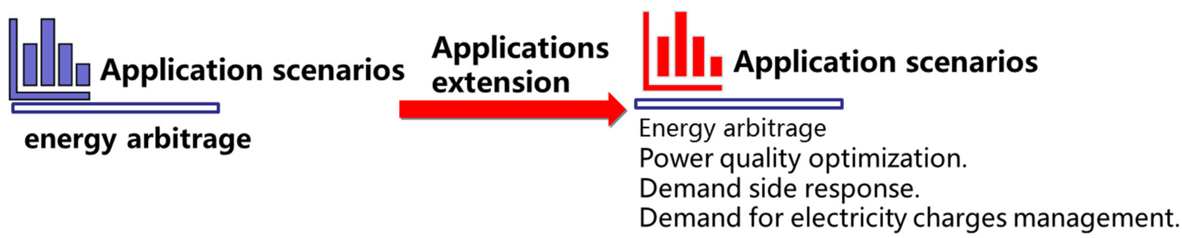

Fig 3 Multi-application expansion of energy storage in a market environment

The results in following figure show that the payback period was shortened to 5.2 years. The single business model is not yet economical and has a long payback period. The above examples show that under the power market environment, energy storage can greatly improve its economy through value overlay, which is conducive to the future large-scale development of energy storage. The combined business model can greatly increase the energy storage value, and the priority order of each business model can have a greater impact on its value.

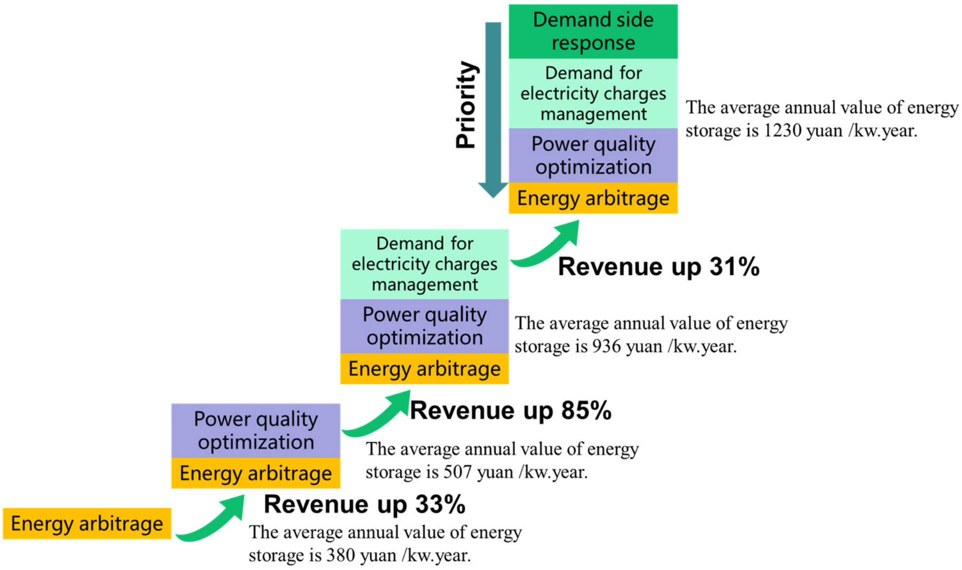

Fig 4 Energy storage economy improvement under multiple business models

5. Conclusions

This paper focuses on the expansion of the business model of energy storage system under the environment of electricity market. By constructing the energy storage charge and discharge model, the economic analysis of energy storage system under single business model and multi-business model is constructed, and it is concluded that the energy storage system can improve the energy storage system economy greatly under the environment of free electricity market.

Acknowledgments

This work was supported by State Grid Corporation's Technological Project of China (Strategic planning and market mechanism research on energy green transition with re-electrification as the core).

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