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The Optimal Operation Method of Integrated Solar Energy Storage and Charging Power Station Considering Multiple Benefits of Energy Storage#

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ABSTRACT

Integrated solar energy storage and charging power station is gradually being promoted and applied because of their energy-saving, environmental protection, and excellent economic characteristics. In this paper, the cost-benefit modeling of integrated solar energy storage and charging power station is carried out considering the multiple benefits of energy storage. The model takes five factors into account, e.g., power station charging service, electricity charge, capacity charge, energy storage cycle cost and network loss cost. Its goal is to improve the economy of the power station by comprehensively considering reducing the cost of electricity, extending the life of energy storage equipment, and reducing the loss of electric energy. The effectiveness of the proposed method is proved by an example analysis, and it is found that the capacity benefit and electricity benefit can be balanced by reasonable optimal scheduling.

Keywords: Integrated solar energy storage and charging power station, multiple benefits of energy storage, capacity efficiency, optimize scheduling

1. INTRODUCTION

In the context of the rapid growth of electric vehicle ownership, integrated solar energy storage and charging power station has become a research hotspot in the field of power system due to their good economic and environmental benefits[1].The installation of photovoltaic energy storage equipment can not only reduce the operating costs of power plants, but also reduce carbon emissions and protect the environment[2].

Energy storage is a key component in the scheduling process of photovoltaic storage and charging stations, and the existing research stations mainly consider the benefits of peak shaving and valley filling to reduce the power cost of power stations when modeling energy storage from the perspective of power station operators. Ref.[3][4] establishes an objective function based on the maximum economic benefit of the power station in the whole life cycle, and proposes a control strategy for the energy storage system based on the time-of-use electricity price policy. The results show that the profitability of the charging station is significantly improved and the payback period is shortened by rationally allocating the capacity of photovoltaic energy storage. Ref.[5][6][7] considers the benefits of energy storage peak shaving and valley filling, and establishes a planning model for integrated solar energy storage and charging power station with the goal of reducing load peak and reducing the investment cost of power stations.

There are also many existing studies that consider the loss of energy storage equipment and the social side benefits for modeling. Ref.[8][9] analyzes the charging and discharging of electric vehicle charging stations by considering the energy storage cost degradation model. Ref.[10][11]considers the benefits of the power station itself and the energy saving benefits of energy storage on the grid side and the social side, and models and analyzes the power station, proving that the installation of photovoltaic storage equipment can reduce power loss, reduce carbon dioxide emissions, and have significant benefits on the social side. Ref.[12] considered the uncertain factors affecting the operation of energy storage, and formulated the dispatching scheme of power grid and energy storage equipment with the goal of improving user satisfaction.

When modeling power stations, the benefits of energy storage are often concentrated in one or two separate projects. In this paper, the optimal scheduling model of integrated solar energy storage and charging power station is established by comprehensively considering the multiple benefits and to carry out calculations based on specific examples.

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2. COST-BENEFIT MODELING

Based on the perspective of the power station operator, the cost-benefit analysis of the integrated solar energy storage and charging power station is as follows.

2.1 Cost-benefit analysis

The total cost-benefit function of the integrated solar energy storage and charging power station is as follows, and the goal of optimizing the operation is to maximize the function:

$$I_{total} = I_{sale} - C_{eletric} - C_R - C_s - C_{net} \quad (1)$$

Among them I_{total} represents the daily net benefit of the power station, I_{sale} represents the benefit of the power station in providing charging services for electric vehicles, $C_{eletric}$ represents the cost of electricity charges, C_R represents cost of capacity electricity, C_s represents cost of energy storage cycle power loss, C_{net} represents cost of network loss penalty.

Charging services for electric vehicles are the main revenue of charging stations, which is calculated as follows:

$$I_{sale} = \sum_{t=1}^{24} \left(p_{sale} + p_{service} \right) P_{load}(t) \quad (2)$$

Among them, p_{sale} represents charging price for electric vehicles at charging stations $p_{service}$ represents an additional service fee per kilowatt-hour of electricity. $P_{load}(t)$ represents a load-time function of the charging station.

Optical storage and charging integrated power station adopts two-part tariff, which needs to pay electricity and capacity tariff. When the photovoltaic output of the power station and the electric energy stored by the energy storage device cannot meet the charging demand of electric vehicles, it is necessary to purchase electricity from the grid and pay the electricity and electricity bill. The calculation formula is as follows:

$$C_{eletric} = \sum_{t=1}^{24} P_{grid}(t) p_{buy}(t) \quad (3)$$

Among them, $P_{\mathrm{grid}}(t)$ represents the power of the grid, $p_{buy}(t)$ represents price of the power station to purchase electricity from the grid.

The capacity electricity fee is paid according to the maximum power purchased from the grid during the operation of the power station, and the calculation formula is as follows:

$$C_R = \frac{1}{30} c_R P_{gird}^{\max} \quad (4)$$

Among them, c_R represents electricity fee per unit capacity, $P_{gird}^{\max}$ represents the maximum value of the average load of the power station per 15 minutes.

On the premise of satisfying the charging needs of electric vehicles, the charging and discharging power of energy storage batteries should be reasonably regulated to reduce the circulating power, which is conducive to prolonging the life of energy storage batteries. The average charge and discharge cost of energy storage battery during the period t of investment payback period can be expressed as:

$$C_s(t) = \begin{cases} K_S P_{es}(t) \Delta t / \eta, P_{es}(t) > 0 \\ -K_S P_{es}(t) \eta \Delta t, P_{es}(t) < 0 \end{cases} \quad (5)$$

Among them, K_S represents the converted unit charge and discharge cost, $P_{es}(t)$ represents the energy storage power, $P_{es}(t) > 0$ represents energy storage discharge, $P_{es}(t) < 0$ represents energy storage charging, η represents charging and discharging efficiency.

In the process of purchasing/selling electricity from the power station to the grid, when the same energy is transmitted, if the power fluctuation is large, it will increase the energy loss in the transmission process. The grid hopes that the power curve when exchanging electric energy with the power station will be as smooth as possible, so the cost of purchasing the power grid is introduced, which is calculated as follows:

$$C_{net}\left(t\right) = p_{buy}(t) I_{line}^2(t) R_{line} \Delta t \quad (6)$$

Among them, $p_{buy}(t)$ represents the time-of-use electricity price of the power grid, $I_{line}(t)$ represents transmission line current, R_{line} represents transmission line resistance。

2.2 Constraints

The charge and discharge power of the energy storage system is limited by the power electronic converter, and the constraints are as follows:

$$\begin{cases} P_{\mathrm{ch}} \le P_{\mathrm{chmax}} \\ P_{\mathrm{disc}} \le P_{\mathrm{dismax}} \end{cases} \quad (7)$$

Among them, P_{ch} and P_{disc} represents the maximum charge/discharge power of the energy storage device, P_{chmax} and P_{discmax} represents the maximum charge/discharge power, depending on the power of the power electronic converter installed in the energy storage device.

For the entire optical storage and charge integrated power station system including electric vehicle load, there is the following balance:

$$P_{PV}(t)+P_{grid}(t)+P_{es}(t)=P_{load}(t) \quad (8)$$

Among them, $P_{load}(t)$ represents electric vehicle load power; $P_{PV}(t)$ represents photovoltaic power; $P_{grid}(t)$ represents grid power ; $P_{grid}(t)>0$ represents the system purchases electricity from the grid, $P_{grid}(t)<0$ represents system sells electricity to the grid; $P_{es}(t)$ represents power of the energy storage system;

For energy storage batteries, too deep charge and discharge will reduce battery life, so the SOC for energy storage has the following limitations:

$$1-D=SOC_{\min}\le SOC(t)\le SOC_{\max}=D \quad (9)$$

Among them, D represents maximum discharge depth of the energy storage battery, $SOC_{\min}$ represents minimum charge state value $SOC_{\max}$ represents maximum charge state value.

When a power station purchases/sells electricity to the power grid, the power of the power grid shall not exceed the maximum average load per 15 minutes prepared by the power station for paying capacity charges. The constraint expression is as follows:

$$\left\lfloor P_{grid}(t)\right\rfloor <= P_{grid}^{\max} \quad (10)$$

Among them, $P_{grid}(t)$ represents the grid power, $P_{grid}^{\max}$ represents maximum value of the average load per 15 minutes.

3. CASE ANALYSIS

In this paper, the objective function mentioned in the second section is programmed in MATLAB, and YAMLIP toolbox is called to solve it. The charging station is equipped with 40 fast charging piles, each of which has a power of 35kW and a maximum output power of 1400kW. Photovoltaic output and electric vehicle load curves are shown in the Figure 1. Other parameter settings used in the example are shown in Table 1.

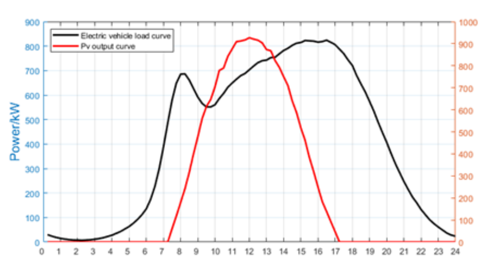

Fig. 1 PV output and EV load curve

Tab. 1 Example parameter Settings

The name of the parameter	Value
Installed energy storage capacity (kWh).	1000
Capacity electricity fee (RMB/kW*month).	48
The maximum charge-discharge power of energy storage (kW).	400
Charging price of electric vehicles (RMB/kWh).	0.8721
Charging service charge (RMB/kWh).	0.4738
Energy storage unit cost (yuan/kWh)	0.38
SOC upper limit	0.9
SOC lower limit	0.1
Initial SOC of the energy storage device	0.5
Efficiency of energy storage	0.9
Transmission line resistance (ohms)	0.16

In order to analyze the effect of each subitem in the model on the final scheduling result, four scheduling scenarios with different objective functions are set up in this paper. Among them, scenario 4 takes formula (1) as the objective function for scheduling and solving, which has the highest total benefits Scenarios 1-3 are solved by removing cycle power loss, capacity electricity cost and network loss cost from the objective function. The results of the four scenarios are summarized in Table 2, the operation results of scenarios 1-3 are shown in Figure 2, and the optimal scheduling results of scenario 4 are shown in Figure 3.

Tab. 2 Comparison of results of four scenarios

Number	1	2	3	4
Charging service	13426.70	13426.70	13426.70	13426.70
Electricity charge	2588.83	2914.83	2859.52	2859.52
Capacity charge	723.32	907.83	742.02	742.02
Network loss cost	224.06	172.60	169.71	165.81
Energy storage cycle cost	1360.42	519.83	611.38	611.38
Total benefits	8530.06	8911.60	9044.07	9047.96

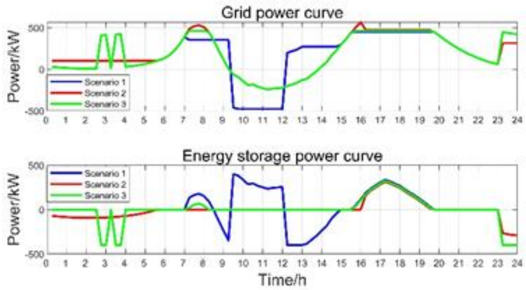

Fig. 2 Scenario 1-3 Power curve of power grid and energy storage

Since electricity costs account for the largest proportion of all costs, scenarios 1-4 will take them into account. As for the optimal scheduling curve of scenario 4 shown in Figure 3, the energy storage is charged at the night electricity price trough, and the electric vehicle is charged by discharge at the second peak of the daytime electricity price, thus transferring part of the peak load to the trough, which plays a role in reducing the power and electricity cost of the power station. The following is a comparison between Scenario 1-3 and scenario 4 to analyze the roles of each item in the objective function.

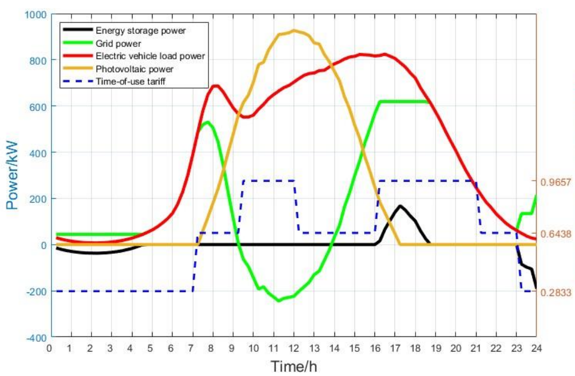

Fig. 3 Optimal scheduling result in scenario 4

Compare scenario 1 with scenario 4 to analyze the role of the energy storage cycle cost. Figure 4 shows the comparison of the daily charge and discharge times of energy storage before and after optimization. It can be seen from the figure that when the energy storage life cycle is considered in the objective function, the scheduling mode is reduced from two charges and two discharge per day to one charge and one discharge, and the daily loss is reduced from 1360.42 yuan to 611.38 yuan. This shows that the optimal scheduling mode of scenario 4 helps to extend the service life of the energy storage equipment and reduce the long-term operation cost of the power station without affecting the charging needs of users.

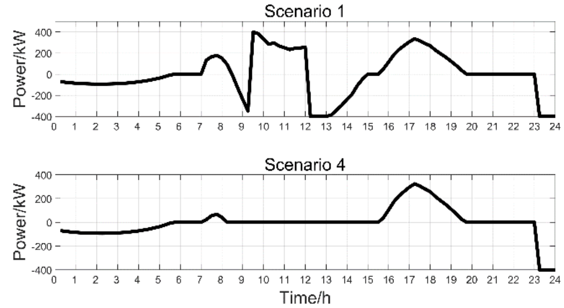

Fig.4 Comparison of energy storage charging and discharging curves between scenario 1 and scenario 4

Compare Scenario 2 with scenario 4 to analyze the role of the cycle charge term. As can be seen from Figure 5, compared with scenario 2, the maximum value of the power curve of the grid in scenario 4 decreases, thus preventing the increase of capacity electricity cost caused by excessive local power, and reducing the average daily capacity electricity cost from 907.83 yuan to 742.02 yuan, a decrease of 17.08%, with significant benefits.

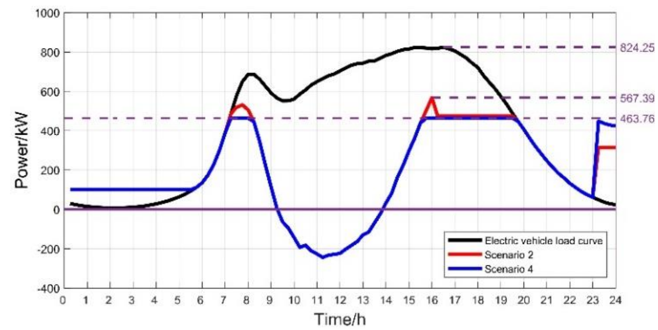

Fig.5 Comparison of power curves between Scenario 2 and Scenario 4

At the same time, due to the optimized scheduling mode, this part of the peak load is moved to the electricity price valley, thereby reducing the daily electricity costs by 55.31 yuan, achieving the double effect of reducing electricity and capacity costs.

Compare Scenario 3 with Scenario 4 to analyze the role of network loss cost item. It can be seen from Figure 6 that the power curve of the grid in scenario 3 has two obvious spikes at night. This is because when the energy storage is charged without considering the cost of network loss in the objective function, the power of the grid will change dramatically at night. In the case of transmitting the same electric energy, this scheduling mode will increase the loss of electric energy on the transmission line and increase the network loss cost of the power station. After optimization, the energy storage night charging curve of scenario 4 is smoothed, and the network loss cost item is reduced from 169.7 to 165.8, reducing the transmission loss.

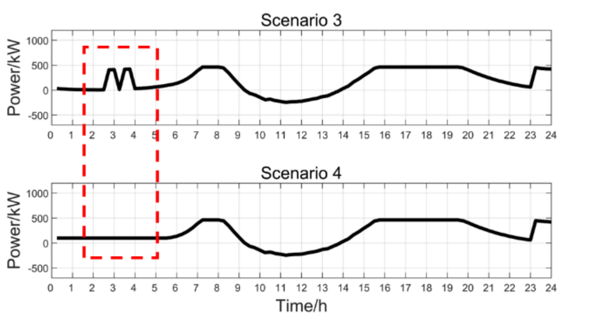

Fig.6 Comparison of grid power in scenarios 3 and 4

4. CONCLUSIONS

The analysis results show that each part of the scheduling model has played a corresponding effect, which is as follows:

(1)Considering the capacity charge in the dispatching model can cut the peak of the original grid load and avoid the increase of capacity charge caused by excessive local power. At the same time, because the peak of the load is at the peak of the electricity price, the transfer of this part of the load demand to the valley of the electricity price also reduces the electricity cost of the power station, which plays a role of killing two birds with one stone.

(2)After considering the energy loss of the energy storage cycle, the energy storage scheduling mode is reduced from two charges and two discharge to one charge and one discharge without affecting the user's charging, which extends the life of the device.

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DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

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