Research on Optimal Decision Method for Self Dispatching of Independent Energy Storage Power Stations under the Dual Settlement Market Model

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Abstract. This article analyzes the current situation of energy storage participating in market transactions as an independent market entity, and proposes a decision-making method for optimizing charging and discharging declaration based on predicted electricity prices in advance. Based on the predicted electricity prices, optimization decision-making is carried out and judgment is set. The threshold for energy storage charging and discharging electricity price difference and the threshold for policy adjustment price difference are set. When the price difference threshold conditions are met, the optimization decision-making process is entered, which improves the efficiency of energy storage power station optimization decision-making.

Keywords: Energy storage power station, Dual settlement mode, Electricity market, renewable energy, Scheduling optimization

1 Introduction

Under the dual carbon goal, the collaborative interaction between source, network, load, and storage has become an inevitable requirement for the operation of the power system [1]. Energy storage can effectively solve the challenges caused by the large-scale integration of renewable energy into the power system [2]. On the one hand, energy storage can reduce peak to valley load, increase valley load to promote the consumption of renewable energy, and reduce peak load to delay capacity investment demand; On the other hand, energy storage can solve the problem of frequency stability caused by the randomness and volatility of wind and solar output, and improve the reliability of the power grid. With the advancement of electricity marketization reform, the construction and operation of energy storage will mainly be achieved in the context of marketization. Therefore, it is urgent to solve the related problems of energy storage participating in the electricity market[3].

Currently, in the electricity spot market represented by Shandong[4], energy storage is allowed to participate in market transactions as an independent market entity in a self scheduling mode. Independent energy storage power stations participating in electricity market transactions in a self scheduling mode need to declare their daily charging and

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discharging plans to the trading center one day in advance. The declared plans and actual charging and discharging decisions directly affect the settlement of the day-ahead market and real-time market[5]. Independent energy storage power stations participate in electricity market transactions in a self scheduling mode, and declare their daily charging and discharging plans to the trading center one day in advance. The declared plans and actual charging and discharging decisions directly affect the settlement of the day-ahead market and real-time market.Therefore, from the perspective of energy storage power plants, it is necessary to predict the daily and real-time electricity prices on the operating day in advance, and make optimization decisions for charging and discharging declaration based on the predicted electricity prices to maximize their own profits.

2 Self-scheduling optimization decision-making method of independent energy storage system under double settlement mode

2.1 Present situation of self-scheduling optimization decision-making method for energy storage power station

At present, there are two main methods for self-scheduling optimization decision-making of energy storage power stations. Firstly, according to the historical trend of electricity price, the operators charge and discharge in a fixed period of time every day. Because the electricity price is constantly changing under market conditions, it is difficult for the operator 's experience to judge the low and high points of the daily electricity price. This method of relying on manual experience will cause the income of the energy storage power station to decline. The second method is to make decisions based on the forecasted day-ahead electricity price. In this way, because only the day-ahead electricity price is considered, and the settlement method of the dual settlement market model is ignored, in some cases, the energy storage power station will lose the arbitrage opportunity in the day-ahead market and the real-time market, and the income will also decrease[6]. Therefore, the self-scheduling optimization decision of energy storage power station under the dual settlement mode must consider both the reasonable selection of charging and discharging periods and the possibility of arbitrage space between the day-ahead market and the real-time market [7].

1) Daily electricity price prediction and real-time electricity price prediction based on deep learning and kernel density estimation

The spot trading price of electricity is mainly influenced by two aspects: the supply side supply and demand side demand, and the supply side and demand side jointly determine the spot price of electricity. The influencing factors on the supply side include: the supply of conventional thermal power units, the supply of electricity from outside the province, and the output of new energy; The influencing factors on the demand side mainly include changes in load. Among the above influencing factors, external power from the province is generally transmitted according to the predetermined power transmission curve, while conventional units are adjusted based on new energy and load changes. The uncertain factors mainly include new energy output and load changes. The most important factor affecting the output and load changes of new energy is meteorology. The key to predicting spot electricity prices is to consider the impact of meteorological factors and predict the total output and total electricity load of new energy in provincial power grids.

2.2 Self-scheduling optimization decision-making method of independent energy storage system under double settlement mode

The overall idea of this decision-making method is as follows: Firstly, pre-judgment is made according to the predicted day-ahead electricity price and real-time electricity price. The judgment content includes whether the peak-valley price difference on the operating day meets the charging and discharging threshold, and whether there is arbitrage space between the day-ahead and real-time. If one of them meets, the charging and discharging optimization decision is made. If it does not meet, the charging and discharging operation will not be carried out on the operating day.The schematic diagram of the self scheduling optimization decision-making method for independent energy storage systems under dual settlement mode is shown in the following **Figure 1**.

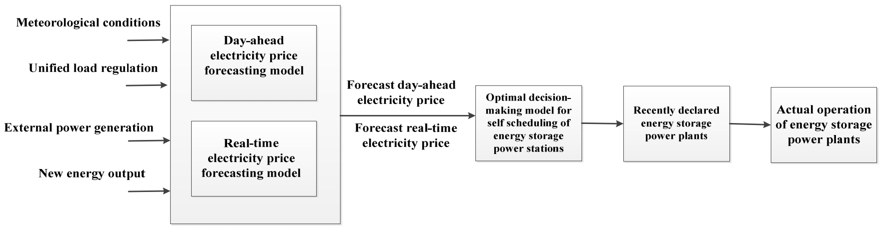

Figure 1. Schematic diagram of independent energy storage self scheduling optimization decision-making under the dual settlement market model

1) Daily electricity price prediction and real-time electricity price prediction based on deep learning and kernel density estimation

The spot trading price of electricity is mainly influenced by two aspects: the supply side supply and demand side demand, and the supply side and demand side jointly determine the spot price of electricity. The influencing factors on the supply side include: the supply of conventional thermal power units, the supply of electricity from outside the province, and the output of new energy; The influencing factors on the demand side mainly include changes in load. Among the above influencing factors, external power from the province is generally transmitted according to the predetermined power transmission curve, while conventional units are adjusted based on new energy and load changes. The uncertain factors mainly include new energy output and load changes. The most important factor affecting the output and load changes of new energy is meteorology. The key to predicting spot electricity prices is to consider the impact of meteorological factors and predict the total output and total electricity load of new energy in provincial power grids.

2) Optimized decision-making judgment

The charging and discharging price difference threshold is set to $\Delta Q(Yuan/MWh)$,which can be reasonably set according to the construction, operation and maintenance cost of energy storage power station. The policy adjustment spread threshold is set to β（$yuan/MWh$）, which means to characterize the radical level of the user's adjustment of his declaration strategy. The smaller the value, the more radical the user 's adjustment strategy is, and the larger the value, the more conservative the user 's adjustment strategy is. The confidence level of the predicted t-period day-ahead and real-time spread is ξ_t, which means the confidence level of the spread.If the formula (1)or (2)is satisfied,Then enter the second step of optimization decision-making, if not satisfied, the operation day does not charge and discharge operation.

$$\max(Q_t^{DA}) - \min(Q_t^{DA}) \geq \Delta Q \tag{1}$$

$$abs(Q_t^{DA} - Q_t^{RT})\xi_t \geq \beta \tag{2}$$

The meaning of equation (1) is that the peak valley difference of the predicted day-ahead electricity price is greater than the set threshold for the difference in charging and discharging electricity prices; The meaning of equation (2) is that the daily and real-time price difference predicted during the t period is greater than the set policy adjustment price difference threshold.

3) Self-scheduling optimization decision of energy storage power station

The self-scheduling optimization decision model of independent energy storage power station is established. The optimization variable is the charging and discharging power of the independent energy storage power station in the day-ahead market and the real-time market in each trading period during the operation day. The optimization goal is to maximize the daily profit of the independent energy storage power station. The optimization goal is as follows informula (3):

$$\begin{cases} \max F = F_1 + F_2 - F_3 - F_4 \\ F_1 = \sum_{t=1}^{T} (P_{t,dis}^{DA} - P_{t,ch}^{DA}) Q_t^{DA} \Delta T \\ F_2 = \sum_{t=1}^{T} (P_{t,dis}^{PT} - P_{t,ch}^{RT} - P_{t,dis}^{DA} + P_{t,ch}^{DA}) Q_t^{DA} \Delta T \\ F_3 = \sum_{t=1}^{T} P_{t,dis}^{RT} F_{kc} \Delta T \\ F_4 = \sum_{t=1}^{T} (P_{t,ch}^{PT} - P_{t,dis}^{RT}) Q_{net} \Delta T \end{cases} \tag{3}$$

Among them, F_1 represents the income of the energy storage power station in the day-ahead market, and ΔT is the time interval of each period in the electricity market. $P_{t,ch}^{DA}$ and $P_{t,dis}^{DA}$ respectively represent the charging and discharging power of the energy storage power station in the day-ahead market t period, and Q_t^{DA} is the predicted electricity price in the day-ahead market t period. F_2 represents the income of the energy storage power station in the real-time market. $P_{t,ch}^{RT}$ and $P_{t,dis}^{RT}$ represent the charging and discharging power of the energy storage in the real-time market t period, respectively, and Q_t^{RT} is the predicted electricity price of the real-time market t period. F_3 represents the construction and operation and maintenance cost of the energy storage power station, and F_{kc} is the cost of the energy storage power station, including the construction and operation and maintenance cost. F_4 represents the transmission and distribution fees and fund additional fees that the energy storage power station needs to pay, and *Qnet* is the transmission and distribution fees and fund additional fees of the unit power consumed by the energy storage power station that needs to be paid to the power grid company.And In the above formula, and $P_{t,ch}^{DA}, P_{t,dis}^{DA}, P_{t,ch}^{RT}, P_{t,dis}^{RT}$ are the variables to be optimized.

The constraints that the above optimization objectives need to meet include :

a.Day-ahead market constraints are in informula (4),(5),(6)

$$U_{t,dis}^{DA} + U_{t,ch}^{DA} \le 1 \tag{4}$$

$$0 \le P_{t,dis}^{DA} \le P_{\max}^{dis} U_{t,dis}^{DA} \tag{5}$$

$$0 \le P_{t,ch}^{DA} \le P_{\max}^{ch} U_{t,ch}^{DA} \tag{6}$$

Among them, $U_{t,h}^{DA}$ and $U_{t,dis}^{DA}$ represent the charging state variables and discharge state variables of the energy storage system during the day before market period *t*[8]. When the value is 1, the energy storage system is in a charging/discharging state, and when the value is 0, the energy storage system is not in a charging/discharging state. $P_{\max}^{ch}$ and $P_{\max}^{dis}$ respectively represent the maximum charging and discharging power of the energy storage system.

b.Real time market constraints

$$U_{t,dis}^{RT} + U_{ch}^{RT} \le 1 \tag{7}$$

$$0 \le P_{t,dis}^{RT} \le P_{\max}^{dis} U_{t,dis}^{RT} \tag{8}$$

$$0 \le P_{t,ch}^{RT} \le P_{\max}^{ch} U_{t,ch}^{RT} \tag{9}$$

$$E_t^{RT} = E_{t-1}^{RT} + \frac{(P_{t,ch\eta ch}^{RT} - P_{t,dis}^{RT} / \eta dis) \Delta t}{E_{rate}} \tag{10}$$

$$0 \le E_t^{RT} \le 1 \tag{11}$$

Real time market constraints are informula (7),(8),(9),(10).Among them, $U_{t,h}^{DA}$ and $U_{t,dis}^{DA}$ represent the charging state variables and discharge state variables of the energy storage system during the day before market period *t*. E_t^{RT} is the state of charge of the energy storage station during time *t*. η_{ch} is the charging efficiency of the energy storage station, and η_{dis} is the discharge efficiency of the energy storage station[9]. E_{rate} is the total capacity of the energy storage power station.

c.The convergence constraints of day-ahead and real-time market strategies

$$\begin{cases} P_{t,dis}^{DA} = P_{t,dis}^{RT} \\ P_{t,ch}^{DA} = P_{t,ch}^{RT} \end{cases}, -\beta \le \xi_t (Q_t^{DA} - Q_t^{RT}) \le \beta \tag{12}$$

In formula (12),when the confidence of the day-ahead and real-time spreads is less than a given threshold, the day-ahead and real-time decisions are consistent. When it is greater than a given threshold, different decisions can be made[10]. The day-ahead market only conducts financial settlement without considering the actual execution, so it does not need to consider the energy storage state of charge constraint.

3 Example application

Apply the method proposed in this paper. An independent energy storage power station with an installed capacity of 100MW/200MWh, the charging and discharging efficiency of the energy storage power station is 90%, the initial state of charge is 0, the transmission and distribution fee and the fund additional fee are 200 yuan/MWh, the charging and discharging price difference threshold is 200 yuan/MWh, and the strategy adjustment price difference threshold is 100 yuan/ MWh.The self-scheduling optimization decision results of the energy storage power station are shown in **Figure 2** and the results of optimization decision are shown in **Figure 3.**

From the electricity price curve, it can be seen that there are two electricity price peaks and two electricity price valleys on the operating day. The energy storage station can perform two charging and two discharging operations, but the actual execution strategy is indeed two charging and two discharging, charging at two electricity price valleys and discharging at two electricity price peaks; From the trends of real-time electricity prices and day-ahead electricity prices, it can be seen that in most time periods, the real-time electricity prices are higher than the day-ahead electricity prices, and the price difference is greater than the strategy adjustment price difference threshold. Therefore, in the optimization results, the day-ahead declaration strategy has been adjusted. During the period when the day-ahead electricity prices are lower than the real-time electricity prices, the declared power has been reduced, achieving arbitrage in the day-ahead and real-time markets. Under this condition, the expected revenue of the operating day energy storage power station is 726871 yuan. If the arbitrage behavior of energy storage stations is not considered, the threshold of the strategy adjustment price difference can be increased to 1000 yuan/MWh. The declared and real-time execution strategies of energy storage stations are consistent, and the expected revenue of energy storage stations is 218551 yuan.

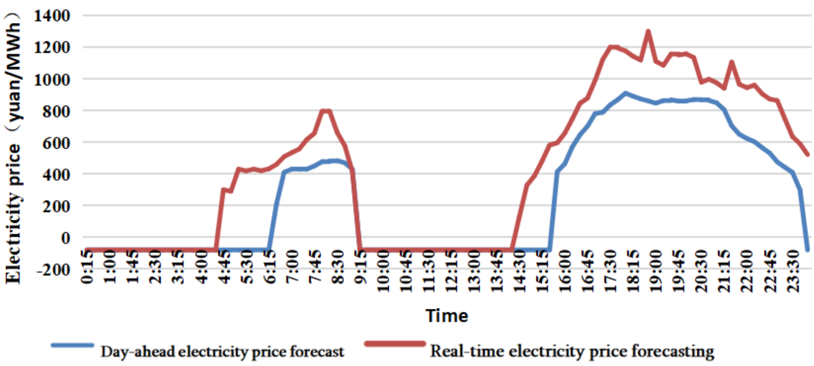

Fig. 2. Forecast curve of daily electricity price and real-time electricity price on a certain operating day

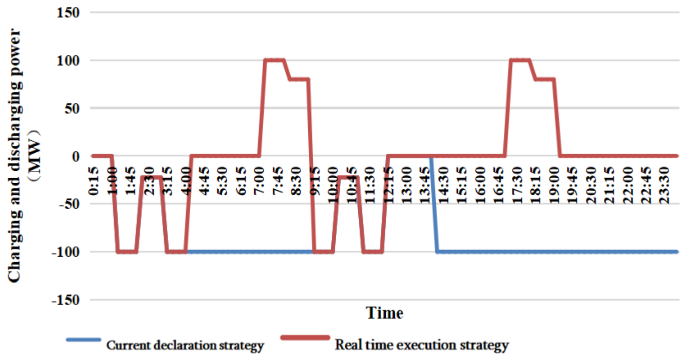

Fig. 3. Optimization decision results of a certain operating day energy storage power station

4 Summarize

This article proposes a self scheduling optimization decision-making method for independent energy storage power plants under the dual settlement electricity market model. This method starts from the settlement mode of the electricity market and establishes a self scheduling optimization decision-making model for energy storage stations. It not only considers the profit of the charging and discharging electricity price difference of energy storage stations, but also considers the possibility of financial arbitrage between the day-ahead market and the real-time market, which can better improve the profits of energy storage stations participating in the electricity market.

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