Transaction Decision Model of Wind and Storage Joint System in Spot Market

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Abstract. This paper is focus on the application of energy storage on the power side to participate in the consumption of clean energy. First, the impact of energy storage on the consumption of clean energy on the power side will be analyzed. Then, a real-time spot market decision-making model of energy storage participating in clean energy is established. Finally, the effectiveness of the proposed optimization is analyzed through simulation examples to verify the positive role of energy storage on the power generation side and clean energy consumption on the participation side.

Keywords: Wind Power Consumption, Energy Storage System, Spot Market

1. Introduction

In the past decade, the utilization of clean energy has made great progress in China, and the related technologies have made great progress, which has greatly reduced the unit cost of clean energy power generation [1]. A number of large-scale wind power bases and photovoltaic power bases have been successively built in northern provinces of China. The successful completion of these bases will help China to improve its power generation structure, save energy, reduce pollutant emissions, realize a low-carbon society and ensure sustainable development [2, 3]. However, the power generation structure of our country is still unreasonable, and thermal power generation occupies the majority. In 2019, the pyroelectric motor assembly machine accounts for 67% of the national installed capacity. It can be seen that the follow-up development potential and development space of clean energy in China is very huge, especially the wind power installation has been developed to a certain extent, but the speed of new installation slows down, while the total number of photovoltaic power generation forms is not large at present, and there is still a lot of room for improvement. Clean energy sources on the power generation side are mainly centralized access and utilization. The proportion of heating units in 3-North and other concentrated absorption areas of clean energy is relatively large, especially in winter and spring heating season, hydropower dry season and high wind, which make it more difficult to absorb clean energy [4-6]. According to relevant statistical analysis, only 6% of China's pumped storage, gas and other flexibly regulated power supply. In contrast, the proportion of flexible power
supply in major clean energy countries is relatively high, accounting for 1.5 times or even 8.5 times the installed capacity of clean energy [7, 8]. Therefore, it is necessary to carry out scientific research in relevant fields and explore how to improve the capacity and quantity of wind and solar energy consumption through specific policies and technical measures. Because the characteristic of energy storage system is that it can store energy and send out energy quickly, it can effectively suppress power fluctuation, improve power system stability, improve the capacity of grid connected clean energy, and effectively make up for the fluctuation of clean energy failure, so as to solve the given clean energy of large-scale centralized power grid and ensure the safety of power system Stable operation provides a new solution.

At present, among the mature energy storage technologies, the advantages of battery energy storage technology are very obvious, which is characterized by large storage capacity and strong adaptability to the application environment. Therefore, it is very suitable for power generation side, with large-scale clean energy power generation, to promote clean energy consumption [9]. Although after years of development, the energy storage technology in China still needs to be further improved. It is necessary to carry out scientific research, explore optimization methods, realize the joint optimal control of energy storage system and thermal power generation system on the power generation side, and then promote the consumption of clean energy. This kind of research has important application value [10].

2. Analysis on the Influence of Energy Storage on Clean Energy Consumption on Power Generation Side

In traditional power system, the generation side is relatively controllable, and the load is random and uncertain. The traditional peak regulation capability of power grid is mainly reflected in two aspects: when the load power is reduced, the adjustable unit reduces the output to realize the active power balance of power grid. When the load power increases, the adjustable unit output increases to make up for the active power gap [11]. With the large-scale development of the clean energy of electric, wind power, photovoltaic power generation, such as stochastic volatility, the power grid power, stochastic volatility, increased power generation side for power grid peak shaving have had an impact, large-scale clean energy given use need between the power of the random fluctuations and random wave load balance between supply and demand in real time [12]. Energy storage has two main functions on the power generation side: 1) participate in multi-power unit planning, achieve smooth output, peak filling and other functions through collaborative optimization with large-scale clean energy generating sets; 2) participate in generating set scheduling, achieve large-scale consumption of clean energy through collaborative optimization with traditional generating systems and wind/photovoltaic generating sets.

3. Energy Storage Participation in Clean Energy Day Ahead Scheduling Optimization Model

The research goal of this paper is to apply the energy storage system to the power generation side of the power system, so as to promote the conversion of clean energy to electric energy and improve the consumption of clean energy. In addition, the paper uses the two-stage optimization theory to realize the day ahead prediction of the number of wind energy, wind power generation, and ultra short-term prediction of power load demand. On this basis, a day ahead optimization model of clean energy consumption is established, and the capacity of clean energy consumption is improved through the optimal allocation of energy storage on the power generation side.

3.1 Day Ahead Spot Market Decision

The optimization goal of this model is to minimize the expected generation cost, and the specific objective function is as follows:

$$\min W = \sum_{i=1}^{T} \sum_{j=1}^{I} \sum_{k=1}^{H} p(C_{ij}^{\text{ran}} + C_{ij}^{\text{hol}} + C_{ij}^{\text{en}} + C_{ij}^{\text{raw}})$$  \hspace{1cm} (1)
In the formula, $W$ represents the expected cost of dispatching the system ahead of schedule; $C_{i,t}^{es}$ represents the cost of energy storage system; $s_{i,t}^{es}$ represents the unit start and stop costs and coal consumption costs of coal-fired power plants respectively; and $C_{i,t}^{w}$ represents the probability of wind farm output scenario.

$$C_{i,t}^{es} = a + bP + cp^t$$  \hspace{1cm} (2)

$$C_{i,t}^{w} = [u_s(1 - u_s)]N$$  \hspace{1cm} (3)

$$N = \left \{ \begin{array}{ll} N_{i,t}^{hot}, T_{i,t}^{min} < T_o^{off} < H_i^{off} \\ N_{i,t}^{cold}, T_o^{off} > H_i^{off} \end{array} \right \}$$  \hspace{1cm} (4)

$$H_i^{off} = T_{i,t}^{min} + T_{i,t}^{cold}$$  \hspace{1cm} (5)

In the formula, $a, b, c$ Respectively represent the fuel cost coefficient of i generating unit ; $N_{i,t}^{cold}$ represents the cold start cost of generator i; $T_{i,t}^{extra}$ represents the minimum allowable shutdown time of unit i; $N_{i,t}^{hot}$ represents the hot start cost of unit i; $T_o^{off}$ represents the continuous shutdown time of unit i at time $t$, $T_{i,t}^{start}$ indicates cold start time of unit i; $H_i^{off}$ represents the sum of the minimum unit shut down and cold start time.

Energy loss and opportunity cost will inevitably occur when charge discharge conversion is carried out in energy storage system. Compared with energy loss cost, other costs are relatively small. Therefore, the main operating cost of energy storage system is this energy loss cost. Its calculation formula is as follows:

$$C_{i,t}^{c}(t) = \sum_{n} M(t)[(p_{i,n}^{c}(t) - g_{i}^{c}(t))]$$  \hspace{1cm} (6)

$p_{i,n}^{c}$, $g_{i}$ represent the discharge and charging power of energy storage system.

The constraints of the day ahead scheduling model include the following aspects:

1. Power balance constraints of power system
2. Maximum generation capacity and minimum generation constraints of thermal power units in the system
3. Capacity constraints of energy storage equipment in the system
4. Amplitude constraint of demand side response in system

3.2 Real Time Spot Market Decision

In this stage, the minimum net load of the system (i.e. the load minus the load borne by the remaining thermal power units after wind power generation and energy storage system generation) should be taken as the first optimization objective, and the minimum generation cost should be taken as the second optimization objective to modify the unit output arrangement.

On the actual implementation day t, based on the wind energy prediction and wind power generation power prediction, adjust the previously formulated generation scheduling plan according to certain procedures. The adjustment method is as follows: first, according to the requirements of the power system, the operation mode of the energy storage system is changed, in order to minimize the impact of wind power generation fluctuations on the thermal power units in the power system. Secondly, all the units in the current power system are adjusted to optimize the total cost of power generation and realize the operation in the state of cost minimization. Finally, the adjusted generation scheduling is obtained.

1. Output correction model of energy storage system

Aiming at the minimum net load of the system, the output power of the current energy storage system is optimized. The specific objective function is as follows:
\[ \min D^t = \left| \sum_{i=1}^{s} f_{i,s} - \sum_{i=1}^{s} f_{i,s} + \sum_{i=1}^{s} f_{i,s} + \sum_{i=1}^{s} f'_{i,s} \right| \] (7)

\( f_{i,s} \) represents the power generation capacity of the energy storage system before dispatching; \( f_{i,s} \) represents the maximum power generation capacity of wind turbines with the greatest probability of occurrence; \( f'_{i,s} \) represents the forecast value of ultra short term wind power at time \( t \) before the day \( t \); \( G_{i,j} \) represents the output of the modified energy storage system at time \( t \); \( D^t \) modify the wind power fluctuation after the output of energy storage system at time \( t \).

In the process of optimization, it is very necessary to consider that the generation power of the optimized energy storage system should also be verified to ensure that it meets the constraints. At the same time, the condition of charge discharge constraint should be considered.

(2) Thermal power unit output correction model

Taking the minimum coal consumption of the unit as the objective, the power generation of thermal power unit in operation is modified, and the objective function is as follows:

\[ \min C = \sum_{i=1}^{T} \sum_{t=1}^{H} \sum_{k=1}^{M} P_i C_{i,k} \] (8)

Where, \( C_{i,k} \) represents the coal consumption cost of the system power generation after the output of the thermal power unit is corrected. The output of the unit shall meet the following constraints after correction:

\[ \sum_{i=1}^{T} f_{i,s}(1-a_{i,s}) + \sum_{i=1}^{T} f_{i,s} + \sum_{i=1}^{T} f_{i,s}(1-b_{i,s}) = L_t - \Delta L_t + \sum_{i=1}^{T} f'_{i,s} \] (9)

\[ u_t f^\text{min}_{i,s} \leq u_t f_{i,s} \leq u_t f^\text{max}_{i,s} \] (10)

\( f_{i,s} , f'_{i,s} \) respectively represent the corrected output of energy storage system; \( u_t \) indicates the start and stop state of the unit in the pre dispatch stage, this stage is known quantity; \( f_{i,s} \) indicates the corrected output of thermal power unit \( t \) at \( M \).

3.3 Power Planning Optimization Model for Energy Storage to Improve Wind Power Consumption

After considering the participation of energy storage, in order to maximize the overall benefit, it is necessary to consider multiple stakeholders of the system, thermal power, wind power and energy storage system, and establish the optimization goal of maximizing the sum of the three profits.

\[ \max Z = C_1 + C_2 + C_3 \] (11)

\( C_1 \) represents the profit of thermal power unit; \( C_2 \) represents the profit of the wind farm; \( C_3 \) represents the profit of energy storage system.

In order to ensure sufficient benefits of energy storage system, the price relation of charge and discharge shall meet the following conditions:

\[ p_{c,cha} \geq p_{d,dis} / (1 - \theta) \] (12)

\( \theta \) represents the rate of energy storage and consumption.

At the same time, the cumulative impulse discharge rate of the energy storage system shall also meet the following requirements:

\[ \sum_{i=1}^{T} Q_{i,s}(1-\theta) = \sum_{i=1}^{T} Q_{i,s} \] (13)

4. Conclusion
A power generation side energy storage participation in clean energy consumption optimization model is established. First of all, the operation mode and method of installing energy storage system on the power generation side are analyzed to explore its role in promoting clean energy consumption. The research results show that the application value and energy consumption effect of energy storage system are mainly reflected in two aspects: coordinated scheduling with power generation units and participation in multi power unit planning. These research results lay a solid foundation for the follow-up study. Then, aiming at the problems of generating unit scheduling and multi-power unit planning, the optimization model of day-ahead and time-ahead two-side scheduling of energy storage participating in clean energy and the power planning model including energy storage system to improve wind energy consumption were respectively constructed. Finally, local optimization due to local convergence is considered. In order to solve this possible problem, which may lead to the model cannot get the optimal solution, a new improved algorithm based on particle swarm optimization is proposed, based on the improvement of chaos binary system, to achieve the overall optimal solution. The research results show that the optimization of power generation structure can be realized by introducing energy storage system into power generation side, the smooth output of the unit can be realized, the promotion and promotion of clean energy consumption can also be realized, which is conducive to improving the proportion of clean energy generation in grid connection, promoting the low-carbon operation of the modern power system and the sustainable development of the society.

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