Study on Renewable Energy Accommodation Capacity Assessment Method Based on Time Series Production Simulation

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Abstract. In order to solve the problem of low accommodation rate of renewable energy in a single region, considering the output characteristics of wind power and photovoltaic, grid constraints and cross regional power exchange, an optimization model of renewable energy accommodation capacity in a cross regional power grid year is established. This paper analyzes the factors restricting the accommodation capacity of renewable energy, and determines the access scale of renewable energy units according to the characteristics of different power grid scale, load and power supply structure. And then taking the annual maximum accommodation capacity of renewable energy as the goal, the time series production simulation model is established, considering the constraints such as regional load balancing, power transmission and output of the network cable, unit output, unit optimization power ramp rate and renewable energy output. To improve the renewable energy accommodation capacity, the three factors of power system interconnection level, power regulation performance and load characteristics can be considered.

1. Introduction
In recent years, the scale of development and utilization of renewable energy in China has continued to expand rapidly. In 2020, China's new installed capacity of wind power is 71.67 million KW and photovoltaic power generation is 48.2 million KW, far exceeding market expectations. In March 2021, the government proposed "deepening power system reform and building a new power system with renewable energy as the main body" as the key measure to achieve carbon peak by 2030. This means that in the future power system, wind power and photovoltaic will be used as the main energy, while thermal power will be used as auxiliary energy [1]. However, the access of high proportion of renewable energy makes the operation characteristics of power system complex. The fluctuation and intermittence of renewable energy make the real-time balance of power more difficult. The current power system grid structure is not enough to support such a large-scale and high proportion of renewable energy access. The installed scale of renewable energy has exceeded the limit level that the current system can absorb [2]. The phenomenon of power abandonment of renewable energy is frequent, and the waste of scenery resources is serious. Therefore, in order to reduce the power rejection rate of renewable energy, it is necessary to reasonably consider the location and capacity of renewable energy, and accurately evaluate the renewable energy accommodation capacity of the system, which has important guiding significance for the planning and development of renewable energy and future power system.

At present, there are three common assessment methods of renewable energy accommodation capacity: typical day method, random production simulation method and time series production simulation method [3]. Among them, the time series production simulation method adopts the time
series data of renewable energy and load, and can simulate the accommodation capacity of renewable energy in the power system period by period by considering the factors such as unit startup and shutdown, peak shaving capacity and climbing rate [4]. Compared with the typical daily analysis method, the annual power balance method of renewable energy based on time series simulation can better reflect the annual characteristics of renewable energy, so it is more suitable to guide the planning of renewable energy. This paper determines the access scale of renewable energy units according to the characteristics of different power grid scale, load and power structure. Aiming at the annual maximum accommodation capacity of renewable energy, the time series production simulation model is established, considering the constraints such as peak shaving adequacy, power balance, system reserve capacity, thermal power unit output and thermal power unit climbing [5].

2. Restrictive Factors of Renewable Energy Accommodation Capacity

2.1 Renewable Energy Characteristics
At present, renewable energy is mainly wind power and photovoltaic. Its main characteristics are randomness and volatility, which are difficult to predict and uncontrollable. Among them, the regularity of photovoltaic is relatively predictable, and the wind power is intermittent and volatile [6]. Because the traditional energy cannot meet the rapid response, in order to ensure the reliability of power supply, it has caused serious abandonment of renewable energy and great pressure on large-scale grid connection.

2.2 System Load Characteristics
The load characteristic of the system is mainly the load peak valley difference, which seriously affects the accommodation capacity of renewable energy. Under the same conditions, the smaller the load peak valley difference, the higher the accommodation capacity. However, at present, China's load has the characteristics of high power accommodation capacity in summer, low power accommodation capacity in winter, high power accommodation capacity in the evening and low power accommodation capacity in the daytime, which cannot match the output characteristics of renewable energy. Therefore, good load characteristics are also the key factor affecting the accommodation capacity of renewable energy.

2.3 Grid Transmission Capacity
At present, renewable energy is mainly concentrated in North and Northwest China, while heavy industry and high load areas are located in the eastern coastal zone, so renewable energy cannot be consumed locally. At this time, power grid dispatching and transmission capacity are the key factors. However, at present, the external transmission of power grid is fixed time fixed power transmission, which cannot meet the randomness of renewable energy and ensure the stability of frequency.

2.4 System Peak Shaving Capacity
At present, the peak regulation capacity of the system is mainly thermal power peak regulation and hydropower peak regulation. Hydropower peak regulation has high flexibility, but it is limited by geographical factors, while thermal power peak shaving has the limitations of slow response, climbing rate and so on [7]. Therefore, the peak shaving capacity of the system is also the key factor affecting the accommodation capacity of renewable energy. Specific peak regulation margin = thermal power peak regulation capacity + hydropower peak regulation capacity - load peak valley difference - peak valley difference of outgoing power.

To sum up, the factors affecting the accommodation capacity of renewable energy are shown in Figure 1.
3. Mechanism of Renewable Energy Accommodation Capacity Assessment

Before the power system is connected to large-scale renewable energy, the randomness of the system is mainly caused by the random fault shutdown of conventional units and lines. Conventional units track load fluctuations by adjusting output to maintain system power balance. The random volatility and non-storability of wind and solar energy resources determine the random volatility of wind power and solar power generation [8]. When large-scale renewable energy power is connected to the power system, conventional units also need to adjust output to stabilize the fluctuation of renewable energy output. When the fluctuation of load and renewable energy output exceeds the system regulation range, it is necessary to limit the renewable energy output, and wind and light will be abandoned.

The operation area between the electric load and the minimum technical output of conventional units is the system regulation space, that is, the maximum accommodation capacity of renewable energy in theory, as shown in Figure 2.

Assume the renewable energy accommodation capacity $P_a(t)$ at time $t$ as:

$$P_a(t) = P_l(t) - \sum_{i=1}^{j} Z_i(t) \cdot P_{s,i,min}(t) = P_l(t) - \sum_{i=1}^{j} Z_i(t) \cdot \beta_i P_{s,i,max}(t)$$
In the formula, $P_l(t)$ is the load at time $t$; $P_{s,i}\text{,}\min(t)$ is the smallest technical output of the $i$-th conventional unit at time $t$; $P_{s,i}\text{,}\max(t)$ is the capacity of the $i$-th conventional unit at time $t$; $\beta_i$ is the minimum technical output coefficient of the $i$-th conventional unit; $Z_i(t)$ is a binary variable, representing the operating status of the $i$-th unit at time $t$; $I$ is the number of all conventional units in the system [9].

Let $P_{re}(t)$ represent the theoretical power of renewable energy at time $t$, then the renewable energy consumption power $P_x(t)$ at time $t$ meets:

$$
\begin{align*}
P_x(t) &= P_a(t), \quad P_{re}(t) > P_a(t) \\
P_x(t) &= P_{re}(t), \quad P_{re}(t) \leq P_a(t)
\end{align*}
$$

The renewable energy limited power $P_y(t)$ at time $t$ meets the following requirements:

$$
\begin{align*}
P_y(t) &= P_{re}(t) - P_a(t), \quad P_{re}(t) > P_a(t) \\
P_y(t) &= 0, \quad P_{re}(t) \leq P_a(t)
\end{align*}
$$

4. Renewable Energy Accommodation Capacity Assessment Model Based on Time Series Production Simulation

4.1 Times Series Production Simulation

Time series production simulation is to gradually optimize the output of each generator set under a certain load with hourly steps [10]. At present, it is widely used in power system dispatching, power generation production planning, power balance and renewable energy accommodation capacity calculation at home and abroad. Time series production simulation can be divided into short-term time series production simulation and medium and long-term time series production simulation according to the length of simulation time. The former refers to the simulation time of several hours to tens of hours, which can provide guidance for daily or weekly power system operation; while the latter refers to providing reliable real-time data for power grid dispatching planning by simulating long-term renewable energy operation mode and boundary conditions [11]. However, when the time series production simulation method takes year as the calculation time scale, it is difficult to apply this method in renewable energy accommodation capacity due to the factors such as too large time span, complex model, too many variables and many spatial dimensions.

In order to comply with the actual situation and optimize the operation of renewable energy, this paper uses the time series production simulation method to simulate the real operation of the system in hourly units according to the annual data of wind power, photovoltaic and load, considering the generation constraints and operation conditions of the unit [12]. This method has good accuracy in calculating the annual accommodation capacity value, and can obtain the annual optimal accommodation capacity value of renewable energy, which provides an effective basis for energy development planning.

4.2 New Energy Grid Model

Time series-based production simulation refers to a time series simulation method that simulates the operating conditions of each generator set under given load conditions and calculates the production cost of the power generation system. System load and generator output can be regarded as a time series that changes with time. The balance between system load and unit output is regarded as the balance between supply and demand between product and demand. Under this constraint, the objective function is optimized to obtain the optimal index. The new energy production simulation model is established based on the time-series production simulation method. The time-series production simulation retains
the characteristics of the change in the shape of the load curve with time, and simulates the operation of the system in a specific time interval.

Considering the large coverage area of the actual power grid and the complex structure of the power grid, it takes a lot of time to establish a detailed physical model of the power grid to carry out long-term time-series production simulations, which is difficult to use in actual production, and the grid structure design is unlikely to have many line overloads. Therefore, in this paper, the power grid model is aggregated and equivalent to more suitable for the practical requirements of simulation. The grid aggregation model is to simplify the complex actual grid into one or more aggregate grids according to the purpose and requirements of calculation and analysis, as shown in Figure 3.

Figure 3. New Energy Grid Model

The grid aggregation model does not consider the detailed grid topology, and each power source and load is no longer affected by its physical location. It is the basis for calculating the new energy absorption capacity of the target grid. The modeling idea of dividing the provincial power grid into several aggregated power grid calculations can not only significantly improve the calculation efficiency of the model, but also reflect the actual operating conditions of the power grid.

4.3 Objective Function

The renewable energy accommodation capacity assessment model must fully consider the operation and output characteristics of various conventional units in the actual power system, including thermal power and hydropower units, including startup and shutdown characteristics, climbing characteristics of the unit, minimum output characteristics, etc. In addition, some special types of units should also be taken into account, e.g. the thermodlectric coupling characteristics of cogeneration units and the pumping and discharging characteristics of pumped storage units need special treatment. Therefore, the assessment model of renewable energy accommodation capacity is based on the output characteristics of power transmission and distribution of interconnection lines, maintenance plan, renewable energy power prediction curve, system load prediction curve, bus load prediction curve, network topology, unit generation capacity and power plant operation constraints, and comprehensively considering the system balance constraints, power grid security constraints, power constraints and unit operation constraints, and adopts the optimization assessment algorithm considering security constraints to obtain the assessment results of renewable energy accommodation capacity.

The objective function of the renewable energy time series production simulation model is to maximize the renewable energy accommodation capacity in the optimization cycle. Considering that the output of renewable energy varies with different centralized installation locations, the renewable energy of different aggregated power grids can be calculated separately, so the objective function in the optimization cycle can be expressed as:

$$\max \sum_{t=1}^{T} \sum_{n=1}^{N} \left( P_n(t,n) + P_{nw}(t,n) \right)$$

In the formula, $N$ is the total number of aggregated grids included in the system; $n$ represents an aggregate grid; $T$ represents the total length of scheduling time; $t$ is the simulation time step; $P_n(t,n)$ is
the wind power output of aggregate grid \( n \) in period \( t \); \( P_{pv}(t,n) \) is the photovoltaic power generation output of the aggregate grid \( n \) in period \( t \).

4.4 Constraints

a) Regional load balancing constraints. The regional load balancing constraints is as follow:

\[
\sum_{j=1}^{J} P_j(t,n) \cdot S_j(t,n) + P_{w}(t,n) + P_{pv}(t,n) + L_i(t) = P_i(t,n)
\]

In the formula, \( \sum_{j=1}^{J} P_j(t,n) \cdot S_j(t,n) \) is the sum of the total power of all conventional units in the \( n \)-th period of the aggregated power grid; \( L_i(t) \) is the transmission power of the \( i \)-th transmission line in period \( t \); \( P_i(t,n) \) is the load power in the \( n \)-th period of the aggregated power grid.

b) Constraints on the power transmission and output of the network cable.

\[
-L_{i,max} \leq L_i(t) \leq L_{i,max}
\]

In the formula, \( L_{i,max} \) and \( -L_{i,max} \) are the upper and lower limits of the transmission capacity of the \( i \)-th network line; SET current reference direction as: the inflow area is in the positive direction, and the outflow area is in the negative direction. So \( L_i \) can take a positive or negative value, which represents the direction of power transmission.

c) Unit output constraints.

\[
0 \leq \Delta P_j(t,n) \leq [P_{j,max}(t,n) - P_{j,min}(t,n)] \cdot S_j(t,n)
\]

\[
P_j(t,n) = P_{j,min}(t,n) \cdot S_j(t,n) + \Delta P_j(t,n)
\]

In the formula, \( \Delta P_j(t,n) \) is the optimized power size of conventional units; \( S_j(t,n) \) represents the operating status of unit \( j \) in period \( t \).

d) Unit optimization power ramp rate constraints.

\[
P_j(t+1,n) - P_j(t,n) \leq \Delta P_{j,up}(n)
\]

\[
P_j(t,n) - P_j(t+1,n) \leq \Delta P_{j,down}(n)
\]

In the formula, \( \Delta P_{j,up}(n) \) and \( \Delta P_{j,down}(n) \) are respectively the up-grade rate and the down-grade rate of the \( j \)-th unit.

e) Output constraint of heating unit during heating period.

We respectively carry out mathematical modeling of the back pressure cogeneration thermal power unit and the exhausted cogeneration thermal power unit. The linear relationship between the power output and heat output of the back pressure unit is as follows:

\[
P_{BYj}(t) = C_{j,n} \cdot Q_j(t)
\]

The working condition curve of the steam extraction cogeneration thermal power unit is more complicated, and its linear constraint formula is shown as follow:

\[
Q_j(t) \cdot C_{j,b} \leq P_{CQj}(t) \leq P_{CQj,\text{max}} - Q_j(t) \cdot C_{j,v}
\]

In the formula, \( C_{j,b} \) and \( C_{j,v} \) are thermoelectric ratio coefficients; \( Q_j(t) \) is heat output; \( P_{BYj}(t) \) is the output of the back pressure unit during the heating period; \( P_{CQj}(t) \) is the output of the extraction steam unit during the heating period. The thermoelectric coupling characteristics of the back pressure type unit and the exhaust type unit are shown in Figure 4.
f) Renewable energy output constraints.

\[
0 \leq P_w(t,n) \leq P_w^*(t,n) \\
0 \leq P_{pv}(t,n) \leq P_{pv}^*(t,n)
\]

In the formula, \(P_w^*(t,n)\) refers to the time series output of wind power when the capacity of the machine is fixed at time \(t\); \(P_{pv}^*(t,n)\) refers to the photovoltaic time series output when the machine capacity is fixed at time \(t\).

Synthesizing the expressions of the objective function and constraints, we construct a renewable energy accommodation capacity assessment model based on time series production simulation. The model can be mathematically reduced to solving mixed integer linear programming (MIP). The core algorithm for solving MIP is branch and bound method, of which basic idea is to search all feasible solution spaces of constrained optimization problems [13].

5. Conclusion

This paper analyzes the factors restricting the accommodation capacity of renewable energy, and determines the access scale of renewable energy units according to the characteristics of different power grid scale, load and power supply structure. And then taking the annual maximum accommodation capacity of renewable energy as the goal, the time series production simulation model is established, considering the constraints such as regional load balancing, power transmission and output of the network cable, unit output, unit optimization power ramp rate and renewable energy output.

To improve the renewable energy accommodation capacity, three factors can be considered: power system interconnection level, power regulation performance and load characteristics.

a) Power system interconnection level. In areas rich in renewable energy resources, the load level is usually limited. After large-scale renewable energy installation and grid connection, it puts forward higher requirements for the transmission capacity of the power system. Therefore, the construction of cross regional transmission channel of renewable energy is the key factor affecting the accommodation capacity of renewable energy.

b) Power regulation performance. Affected by the resource endowment, the installed power supply is mainly coal-fired thermal power units. Under the current technical conditions, the peak shaving capacity of thermal power units is limited, so it is impossible to quickly track the output fluctuation of renewable energy. Therefore, carrying out the technical transformation of deep peak shaving of thermal power units is the key factor affecting the accommodation capacity of renewable energy.

c) Load characteristic. The operation characteristics of power system require real-time dynamic balance of power generation and accommodation capacity, and the output of renewable energy
must be less than or equal to the load power at each time. Therefore, from the perspective of improving the load output level, the implementation of power substitution and demand side response is the key factor affecting the accommodation capacity of renewable energy.

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