Cross-Regional Analysis of New Energy Consumption Capacity

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Abstract: An assessment of the new energy consumption capacity of the grid can help to improve new energy efficiency and its planning and development. The annual capacity of multi-regional new energy consumption is affected by the new energy installed capacity of each region, the output of thermal power units, the load size, and the exchange capacity between regional tie lines. In this paper, a real-time data processing method of a province is proposed, and a raw data processing method with dimensionality reduction equivalent is proposed. From the perspective of new installed capacity of new energy across regions, we obtain the assessment of the capacity of wind power photovoltaic bases in a given scenario, and propose new installed capacity for wind, light and energy storage power stations.

Key words: new energy consumption; new energy assessment; mixed integer programming; production simulation

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With the rapid growth of new energy scales in China, there is a serious phenomenon of abandoned wind and light in some areas. We need to adjust the development layout of new energy[1] in order to develop renewable energy represented by wind power and photovoltaic power generation, and not to increase the pressure of abandoned wind and light at the same time. New energy consumption has been combined with power grid planning[2]. To promote the sustainable and healthy development of new energy power generation, new energy planning is needed. Taking wind power as an example, the main factors affecting wind power consumption are system peaking capacity, system standby level, tie-line power constraints. In addition, the characteristic of the unit during the heating period is also one of the factors affecting the consumption of new energy[3]. Based on the annual load time series data, new energy installed capacity and output time series data, unit characteristics and tie-line characteristics, etc., day-to-day or monthly system simulation analysis can be performed to evaluate the new energy consumption of the system[4-5].

Most of them currently use the mathematical optimization method to calculate the capacity for consumption of wind energy, light energy, or their overall capacity through time-series production simulations. Their objective function will also vary depending on the evaluation indicators, or aim to minimize power generation costs (coal consumption)[6], or to maximize power generation revenue[7], or maximize new energy output[8], or for multiple targets. As far as the research object is concerned, there are many factors that can lead to abandoned wind and light[9]. Through calculation, we can find the key factors affecting the consumption of new energy[10]. Ref. [11] analyzed their influence on the proportion of

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abandoned wind from the perspective of peaking capacity, minimum output of thermal power, and delivery mode. Ref. [7] analyzed its impact on new energy utilization from the perspective of new energy installed capacity. Ref. [12] studied its influence on the abandonment rate from the perspective of grid blockage. Refs. [13 – 15] calculate the annual indicator by simplifying the model using a random time series.

Selecting different parameters and performing production simulations on systems with different parameters, the effects of different factors on new energy consumption can be obtained. This paper simplifies the production model and improves the solution speed. Finally, the wind power photovoltaic base capacity evaluation in a given scenario is evaluated, and the installed capacity of wind, light and energy storage power stations is given.

1 Influencing Factors of New Energy Consumption in Cross-Regional Joint Power Grid

The analysis of the impact on new energy utilization is to serve the planning and construction of new energy. The degree of influence of different factors on new energy consumption capacity can be expressed in a certain form. Refs. [3 – 4, 11] reflects the relationship between various factors on wind power consumption capacity in the form of a graph. The relationship between the wind rate and the standby rate, load rate and other factors can be obtained through the establishment of regression model. However, from the above methods, when analyzing the consumption capacity of various factors, all factors and their impact on new energy utilization are analyzed respectively. In this section, multi-factor will be taken into consideration to obtain renewable energy efficiency rate more comprehensive.

1.1 Single-region new energy consumption analysis

Power system has the characteristics that electric energy cannot be stored in large quantities, which means electricity should be generated when ready to use. Therefore, it is necessary to meet the real-time power system balance constraints. From the point of view on power, there are three factors affecting the consumption of new energy, load scale, new energy scale, upper limit of tie-line power, those can be expressed by function:

$$U = f(P_{\text{load}}, P_{\text{renew}}, P_{\text{line}}, P_{\text{gen}}) \tag{1}$$

where U indicates the new energy utilization rate; P_{load} indicates the load scale, which is a time series including the load magnitude at each moment; P_{renew} indicates the new energy scale, which is a time series containing the new energy output at each moment; P_{gen} indicates the time series includes every moment of the conventional unit output, which plays a more significant role in the heating period; P_{line} indicates the upper limit of the tie-line between the area and the outside, which is a scalar.

Fig. 1 shows the curve of wind power output and load for a typical day in a province. Under the goal of improving system capacity, the power system scheduling will put the order of wind power and photovoltaic power generation in the front. As can be seen from the figure, since wind energy has certain intermittent, volatility and anti-peak characteristics, when the new energy output exceeds the acceptable range of the system, abandoned wind and light will be generated in order to ensure the dynamic balance of the system. When considering the power exchange of the tie line and the thermal power unit in period of heat supply, the abandonment rate of the new energy will change based on the original load.

When the transmission power of the tie-line is sent out, the consumption space of the new energy will rise, and it will rise as the upper limit of the power increases. When the transmission power is received, the consumption space will drops as the upper limit of the power becomes larger. When there is a heating unit that must be opened during the heating period, the consumption space

of new energy will decrease.

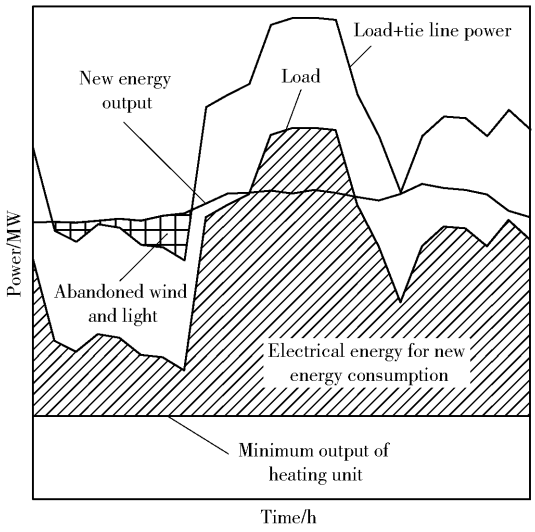

Fig. 1 Schematic of wind and photovoltaic curtailment

1.2 Multi-regional new energy consumption analysis

When multiple regions are used, the number of factors affecting the consumption of new energy will double with the number of regions. The consumption capacity of new energy in each region can be expressed as a function:

$$\begin{cases} U_z = f(P^z_{\text{load}}, P^z_{\text{renew}}, P^z_{\text{line}}, P^z_{\text{gen}}) \\ P^z_{\text{line}} = g(P^{\bar{z}}_{\text{load}}, P^{\bar{z}}_{\text{renew}}, P^{\bar{z}}_{\text{line}}, P^{\bar{z}}_{\text{gen}}) \end{cases} \tag{2}$$

where z represents the region z, and $\bar{z}$ indicates other regions excluding region z. Each variable in the above formulas represents the same meaning. It can be seen that although the influencing factors remain unchanged in multiple regions, the load conditions and the new energy output of other regions will affect the region through the tie-line, which will affect the direction and quantity of the total transmission power of the tie-lines connecting the region.

The consumption capacity of new energy in the zone containing multiple regions can be expressed as a function:

$$U = f(P^z_{\text{load}}, P^z_{\text{renew}}, P^z_{\text{line}}, P^z_{\text{gen}}),$$
$$z = \text{A}, \text{B}, \text{C}, \text{D}, \cdots \tag{3}$$

where A, B, C, D are the area numbers.

Therefore, there are multiple coupling parameters in the new energy consumption capability function of multi-region. According to the analysis, the load between different regions, the output of new energy, and the number of thermal power unit, especially during the heating period are different. There are some areas where new energy output is large but the load is small, or the load is large but the output is small. These conditions can be resolved by switching the power through the tie-line, but the existing power limit of tie-line connecting these areas is certain, which ultimately leads to restrictions on the new energy consumption capability.

1.3 Influence of multi-zone bottom load capacity parameters

The assessment of new energy consumption capacity for grid construction planning focuses on the impact of expanding new energy installed capacity on the consumption capacity under existing constraints. The addition of new energy installation capacity of different sizes in different regions will have a different impact on the overall energy utilization of the grid[16]. For the planning of new installed capacity of new energy, it can be assumed that other scenarios are unchanged, that is, the load, the lower limit of the tie line, the parameters of the thermal power unit are unchanged. The installed capacity of the new energy is taken as a variable parameter to study its impact on the new energy consumption capacity.

The function form is simplified to

$$U = f(P^{\text{A}}_{\text{renew}}, P^{\text{B}}_{\text{renew}}, P^{\text{C}}_{\text{renew}}, \cdots) \tag{4}$$

The table of functions can be obtained through the enumeration method, that is, production simulation can be generated according to time series in order to determine the new energy consumption capacity under different planning conditions, so that the reference of the new installed capacity and region of new energy can be given.

2 New Energy Consumption Analysis Model

From the point of view of the evaluation method, the evaluation time period of the new

energy consumption capacity of the whole year time scale is long. At present, there are mainly the following methods: the constraint factor method and the mathematical optimization method[5]. The constraint factor method is mainly based on the factors that restrict the grid acceptance of new energy, or from the peaking capacity of the system[11], or from the power transmission capacity, or from the heating unit[3], to analyze the new energy acceptance capacity. The evaluation index of new energy consumption can be obtained from the perspective of the system as a whole, but this method only calculates for some constraints, and ignores some constraints inside the grid operation. The mathematical optimization method is to establish an optimization model and consider various constraints of grid operation. This method is to select the objective function according to the requirements, combine the time series data of the grid with the parameters of the unit through the optimization algorithm to simulate the operation of the grid ,then obtain data indicators for new energy acceptance[6-7].

2.1 Objective function

There are several options for the objective function based on the time series production model: by minimizing power generation costs, such as minimizing coal consumption, or by maximizing power generation profit. For the selection of the objective function of the production model serving the new energy consumption planning, priority is given to the renewable energy generating units such as wind energy, solar energy, ocean energy and water energy without adjustment capability according to the order table of the power generation scheduling of the energy-saving power generation dispatching unit. Therefore, maximizing the new energy sourced by the grid is chosen as the objective function of the model:

$$F = \max \sum_{z=\mathrm{A}}^{\mathrm{D}} \sum_{t=1}^{T} P_{\mathrm{w},t}^{z} k_{\mathrm{w,t}}^{z} + P_{\mathrm{pv},t}^{z} k_{\mathrm{pv,t}}^{z} \tag{5}$$

where z indicates the system area label and the total number of areas is Z. In this calculation 4 areas are taken as an example, respectively marked as A, B, C, D. t indicates the time period subscript, and the total number of time periods is T(set to 8 760 h for the whole year). $P_{\mathrm{w},t}^{z}$ indicates the overall predicted output for all wind turbines in the z-zone. $P_{\mathrm{pv},t}^{z}$ indicates the overall predicted output for all PV power stations in the z-zone during the t-period. $k_{\mathrm{w,t}}^{z}$ indicates the actual wind output coefficient for the z-zone during the t-period, $1-k_{\mathrm{w}}^{z}$ indicates the wind-power abandonment rate for the z-zone. $k_{\mathrm{pv,t}}^{z}$ indicates the actual PV output coefficient for the z-zone during the t-period, $1-k_{\mathrm{pv}}^{z}$ indicates the PV abandonment rate for the z-zone.

2.2 Constraints

①The power balance constraint is

$$\sum_{i=1}^{n^z} P_{G,i,t}^{z} k_{i,d}^{z} + P_{\mathrm{w,t}}^{z} k_{\mathrm{w,t}}^{z} + P_{\mathrm{pv},t}^{z} k_{\mathrm{pv,t}}^{z} + P_{ot,t}^{z} = L_t^z + \sum_{l=1}^{L^z} \Delta P_{l,t}^{z}$$
$$t = 1,2,\cdots,T;\ z = \mathrm{A,B,C,D} \tag{6}$$

where $P_{G,i,t}^{z}$ indicates the output of the thermal power unit i in the z-zone. $k_{i,d}^{z}$ indicates the start-stop state of the thermal power unit i in the z-zone, which is 0-1 variable, where 0 means stop and 1 means start. $P_{ot,t}^{z}$ indicates the overall output for all other power sources in the z-zone. L_t^z indicates the fixed power load in the z-zone during the t-period. l indicates the number of lie lines for power exchange between the partitions, and the total number of lines in the z-zone is L^z. ΔP_l^z indicates the exchange power of the l-line in the z-zone during the t-period, where positive values indicate output and negative values indicate input.

②The thermal power unit output limit is

$$P_{G,i,\min}^{z} \leqslant P_{G,i,t}^{z} \leqslant P_{G,i,\max}^{z},\ i = 1,2,\cdots,n^z$$

where $P_{G,i,\max}^{z}$ and $P_{G,i,\min}^{z}$ represent the maximum and minimum output of the thermal power unit i in the z-zone. The upper and lower limits of the thermal power output differ during the heating period and the non-heating period. Usually the heating period is from November to March.

③The exchange power constraint is

$$\Delta P^z_{l,\min} \leqslant \Delta P^z_{l,t} \leqslant \Delta P^z_{l,\max}, l = 1,2,\cdots,L^z$$

where $\Delta P^z_{l,\min}$ and $\Delta P^z_{l,\max}$ represent the maximum and minimum power of the l power exchange tie line in the z-zone, where positive values indicate output power and negative values indicate input power.

④ The peaking constraint (considered by day) is

$$\sum_{i=1}^{n^z} P^z_{G,i,\max} k^z_{i,d} \geqslant (1+\gamma) L^z_{d,\max} + \sum_{l=1}^{L^z} \Delta P^z_{l,\max} - (1-\beta_{\mathrm{w}}) P^z_{\mathrm{w},t-\max} - (1-\beta_{\mathrm{pv}}) P^z_{\mathrm{pv},t-\max} - P^z_{ot,t-\max},\ t = 1,2,\cdots,T;\ z = \mathrm{A,B,C,D}$$

where $P^z_{\mathrm{w},\max}$, $P^z_{\mathrm{pv},\max}$ and $P^z_{ot,\max}$ indicate the wind power, photovoltaic and other power output at the moment of the appearance of load maximum on the d-day. γ is the system rotation reserve rate which is generally 8% – 10%. β_{w} indicates the wind power reserve ratio, and $1-\beta_{\mathrm{w}}$ indicates the coefficient of wind power incorporation balance, i. e. the prediction accuracy (confidence level). β_{pv} indicates the photovoltaic reserve ratio, and $1-\beta_{\mathrm{pv}}$ indicates the coefficient of photovoltaic incorporation balance, i. e. the prediction accuracy.

⑤The climbing constraints of units are

$$P^z_{G,i,t} - P^z_{G,i,t-1} + k^z_{i,t}(P^z_{G,i,\max} - P^z_{G,i,\min}) + k^z_{i,t-1}(P^z_{G,i,\min} - \Delta p^{\mathrm{up}}) \leqslant P^z_{G,i,\max}$$

when output rise or start-up, and

$$P^z_{G,i,t-1} - P^z_{G,i,t} + k^z_{i,t-1}(P^z_{G,i,\max} - P^z_{G,i,\min}) + k^z_{i,t}(P^z_{G,i,\min} - \Delta p^{\mathrm{down}}) \leqslant P^z_{G,i,\max}$$

when output decline or shut-down,

$$t = 2,3,\cdots,T$$

These constraints not only ensure the speed limit of output climbing in two adjacent period at start-up, but also ensure that the output is minimum (in the formula, it is a less-than-equal sign, but it is desirable to improve the formula to be an equation) during the first period after start-up (the state changes from 0 to 1) and the last period before shut-down (the state changes from 1 to 0). If the current state of the current period is 1, it indicates the limit of the force rise and fall. In the formula, $\Delta p_i^{\mathrm{up}}/\Delta p_i^{\mathrm{down}}$ represent the maximum lift/lower output of the thermal power unit i in an unit time.

To speed up the calculation, the minimum boot time and minimum shutdown time are simplified in this model. According to the actual operation of the power grid, the thermal power unit seldom starts and stops frequently within one day, and the number of actions in a week is limited. Therefore, in this model, the 8 760-hour-unit-commitment-sequence is simplified to 365-day-unit during the whole year. The number of variables and the constraint dimension are greatly reduced. Compared with the unprocessed original 8 760-boot-sequence, the calculation results are similar, but the calculation speed is greatly improved, which is suitable for traversing the influence of different installed capacity changes on the new energy consumption capacity.

2.3 Variable parameters

Since the influence of different installed capacity on the new energy consumption capacity is studied, $P^z_{\mathrm{w},t}$ and $P^z_{\mathrm{pv},t}$ in the model are variable parameters. Since the above problem is a mixed integer programming problem, when the problem scale is small, a multi-parameter mixed integer planning can be used. But when the problem scale is large and the variables are numerous, it can be solved by the enumeration method.

3 Analysis and Evaluation of New Energy Consumption Capacity

3.1 Research object

Taking a provincial power grid in China as an example, the power grid is divided into four regions. Fig. 2 is a schematic diagram of a four-region-power grid. There are 6 tie lines between the four regions and each of the zones meets the power balance. The target function seeks the lowest amount of abandoned wind and light in the four cooperative zones.

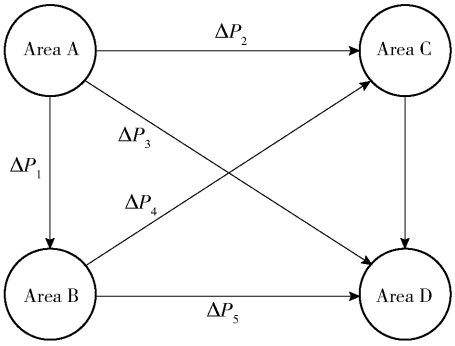

Fig. 2 Regional power grid

3.2 Production simulation results

After production simulation, the upper and lower limits of the output and the equivalent load of the thermal power unit can be obtained. As shown in Fig. 3, it can be easily judged from the figure. When the equivalent load is lower than the lower limit of the output of the unit, abandoned wind will occur. These moments mostly occur during the heating period or when the load fluctuates drastically during the non-heating period.

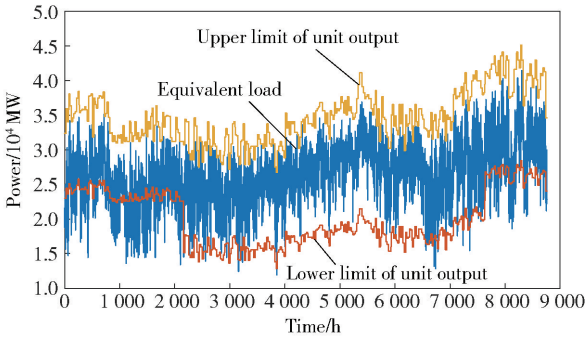

Fig. 3 Production simulation results of a province

In the case of the initial installed capacity, through the processing of the production simulation results, the wind-abandonment rate of each region is obtained. As shown in Fig. 4, the phenomenon of abandoned wind mostly occurs during the heating period. Because the number of the unit which must be started at this time increases, the minimum output of the thermal power unit becomes larger. In addition, it can be seen that there is a clear difference in the abandonment rate of light in different areas. The C-area has the lowest abandonment rate, and the A and D areas have the highest abandonment rate.

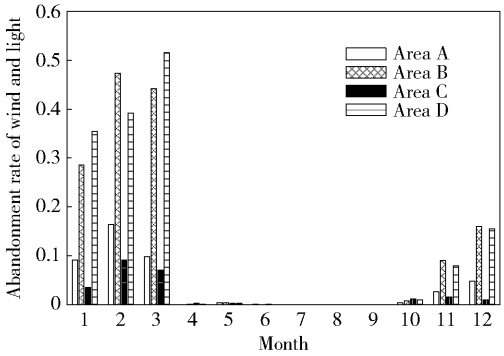

Fig. 4 Rate of wind and photovoltaic curtailment

For a given new energy consumption level to find the installed capacity, we only need to obtain new energy utilization under different installed capacity, and finally get the function table through repeated production simulation, as shown in Tab. 1.

Tab. 1 Impact of new energy installed capacity

Installed capacity change	85%	90%	95%	100%	105%	110%
New energy utilization	0. 951 38	0. 947 67	0. 943 82	0. 930 95	0. 935 43	0. 930 95
Abandoned wind rate	0. 047 242	0. 051 899	0. 056 533	0. 071 923	0. 066 588	0. 071 923
Abandoned light rate	0. 050 949	0. 053 104	0. 055 524	0. 062 744	0. 060 351	0. 062 744
Thermal power utilization hours	4 121. 23	4 095. 754 5	4 070. 629 6	3 997. 899 2	4 021. 709 2	3 997. 899 2

It can be seen from the table that the change in installed capacity will have an impact on the new energy consumption capacity of the entire region. For the new energy installed capacity under the specified new energy utilization target, it is possible to find the most suitable installed capacity by repeatedly performing production simulation.

4 Conclusion

Since the capacity of the trans-regional new energy grid is affected by many factors, and the

regions will also influence each other through the tie line. For the consumption assessment of the new energy, it is necessary to study the impact on new energy consumption capacity under different installed capacity. Taking the capacity of wind farm and photovoltaic power generation as variable parameters, the function of new energy utilization rate and installed capacity for multi-zone are established. The simplified model can be used for time series production simulation, and installed capacity of different region can be evaluated. This paper analyzes the multi-zone power grid in a certain area. According to the results, the added installed capacity of new energy has different effects in different regions and this method can be made for a reference to the planning of added installed capacity of new energy.

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