A peaking-regulation-balance-based method for wind & PV power integrated accommodation

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Abstract. Rapid development of China's new energy in current and future should be focused on cooperation of wind and PV power. Based on the analysis of system peaking balance, combined with the statistical features of wind and PV power output characteristics, a method of comprehensive integrated accommodation analysis of wind and PV power is put forward. By the electric power balance during night peaking load period in typical day, wind power installed capacity is determined firstly; then PV power installed capacity could be figured out by midday peak load hours, which effectively solves the problem of uncertainty when traditional method hard determines the combination of the wind and solar power simultaneously. The simulation results have validated the effectiveness of the proposed method.

1. Introduction
Since the beginning of "Twelfth Five-Year Plan", China's new energy has keep a rapid growth in capacity and electricity. Installed capacity of wind and PV power hit record highs for several years, and wind power capacity is concentrated on “Three North” Areas with PV power in Northwest as station mode and in Eastern Central regions as DGs. In 2016, cumulative installed capacity of wind and PV power are respectively of 148.64GW, 77.84GW [1], in which wind power installed capacity for five consecutive years, and PV installed capacity for two consecutive years occupy the world's first. Making efforts of almost 10 years, China's new energy development is in the forefront of world. In new energy development procedure, China has gained absolute advantage in "quantity" aspect, but "quality" is not satisfied, especially the intensification of curtailment of wind & PV power. As a result, the new energy consumption problem has become widely concerned by the community focus.

Domestic and foreign scholars have done a lot of work in the consumption of wind power. The basic method basically includes two kinds: one is based on the system balance method, rely on the power balance, the residual peak load space is used to determine the wind power installed capacity[2-7]; the other is based on the production simulation, in which the full-cycle wind power output data is input and installed capacity is determined under the reasonable curtailment ratio[8,9]. In the production simulation method, the completeness of data should be guaranteed as fundamental works, without extracting the typical features of load, power generation or power grid. Peaking-regulation-balance-based method need a series data of generation and load typical characteristic, in other words that the complementary data is not required, which also could give a new energy capacity without curtailment of wind power. However, if there are wind power and solar power in the same power grid, many combination of wind power and solar power capacity will meet the residual peaking regulation ability supporting by other power sources in power system. Therefore, different features of wind power and...
PV power output should be found by some indexes, in order to describe the relationships between new energy power and system load.

This paper analyzes the scale of new energy admired by peak regulation balance based on reference [5] and reference[9]. Taking into account of time distribution characteristics of wind power output and daily load, wind power installed capacity is determined at night peak load and valley load time. Based on wind power capacity, installed capacity of PV is determined as follow. The problem of combination of wind and PV power scale in the same power system is transformed into solvable way.

2. Mathematic model for integrated new energy accommodation

2.1. Basic idea

At the valley load time, the minimum load of the system, the minimum output of the system generation units, and the outgoing transmission line power would determine the space of wind power, which is the most difficult time for power system regulation. The corresponding wind power installed capacity can provide a certain guarantee capacity at the daily peaking load. However, in order to ensure the power balance at the peak of the system, it is necessary to determine the starting capacity of the system unit according to the peak load, system reserve, the transmission power, the capacity guarantee of wind power. Therefore, at the valley load time, the system starting unit can determine the pressure degree of system regulation. PV power generation is concentrated at the midday peak load time relative to that the wind power in anti-peaking characteristics with PV power in positive peaking characteristic. When PV power generation on the midday load period, the wind power can also provide a certain capacity to support the demand. Hence, the acceptance space of PV is determined by the midday peak load, the minimum output of the system units and the transmission power. Furthermore, by utilization of the PV output simultaneous rate, the installed capacity of the PV could be found.

To sum up, it is necessary to fully combine load valley and night peaking period to determine the capacity of the system operating unit and the size of wind power installed capacity, then based on the system operating unit capacity and wind power output, the PV acceptance space will be figured out.

2.2. Key parameters

2.2.1. Wind power $P_{WC}$ and PV power $P_{SC}$.

**Wind power guarantee capacity coefficient** $C_{W,BZ}$: corresponding to peak load period, reorder wind power output from large to small, at a certain rate (as 95%), the smallest output of wind power will be defined as $C_{W,BZ}$. This coefficient measures reliable capacity that wind power can provide for system power balance analysis [10].

**Wind power effective output coefficient** $C_{W,YX}$: corresponding to valley load, reorder wind power output from small to large, at a certain rate (as 95%), the maximum output of wind power will be named as $C_{W,YX}$. This coefficient measures the increase in peak load capacity after wind power integration [10].

According to the definition of wind power guarantee capacity coefficient $C_{W,BZ}$ and wind power effective output coefficient $C_{W,YX}$, this paper gives the output coefficient of wind & PV power at the midday peak load as follows:

**Wind power output coefficient** $C_{W,NN}$ at **midday**: corresponding to the midday peak load period, at a certain guarantee rate (95%), the wind power output will fall within the range of power value. The upper limit of the range is defined as the wind power output coefficient at midday. This coefficient measures the reliable power output provided by the wind power at noon.

**PV power output coefficient** $C_{S,CL}$: For a PV power plant or regional PV power plant group, at a certain guarantee rate (95%), the output will fall within a range of power values. The upper limit of the range is defined as the output coefficient of PV power generation. This coefficient measures the reliable capacity that can be provided by PV power after connecting to the grid.
2.2.2. Load and transmission line.
From load characteristics and peak load balance, valley load \( P_{LMIN} \), night peak load \( P_{LMAX,NT} \) and midday peak load \( P_{LMAX,NN} \), generally \( P_{LMAX,NT} > P_{LMAX,NN} \). And load peak-valley difference \( \Delta P = P_{TMAX} - P_{TMIN} \). The external power of transmission line is generally divided into two parts: one is \( P_{TMAX} \) at peaking time, the other is \( P_{TMIN} \) at valley time, in which the two time slices are corresponding to the peak and valley load of power system. For example, UHVDC's valley period is generally from 0:00 to 8:00 in morning and 22:00 to 24:00 in midnight, in other time peak power will take this to the peak and valley load of power system. For example, UHVDC's valley period is generally from 0:00 to 8:00 in morning and 22:00 to 24:00 in midnight, in other time peak power will take this to the peak and valley load of power system. For example, UHVDC's valley period is generally from 0:00 to 8:00 in morning and 22:00 to 24:00 in midnight, in other time peak power will take this to the peak and valley load of power system. For example, UHVDC's valley period is generally from 0:00 to 8:00 in morning and 22:00 to 24:00 in midnight, in other time peak power will take this to the peak and valley load of power system. For example, UHVDC's valley period is generally from 0:00 to 8:00 in morning and 22:00 to 24:00 in midnight, in other time peak power will take this to the peak and valley load of power system.

2.2.3. System units.[5]
System reserve capacity \( P_{RC} \): consider the reserve capacity for the system peaking load.

**Forced operation unit capacity \( P_{FO} \)**: the capacity could not participate in peaking regulation but must be keep operating is called forced operation unit capacity, including as thermal power unit capacity during the heating period, the run off hydro power capacity, nuclear power capacity and self-generation power plant. Varying from seasons and regions, forced operation unit capacity \( P_{FO} \) will be changed.

Adjustable capacity \( P_{PR} \) and the minimum technical output \( P_{MO} \): According to the proportion of power supply devices in different power grids, the total capacity of the operating units with the adjustment capacity is defined as \( P_{PR} \), and the total minimum output of these units is named as \( P_{MO} \). The ratio of the total output capacity of the minimum output capacity and the total capacity of the operating units with the adjustment capability is called the minimum output factor \( C_{MO} \), \( C_{MO} = P_{MO} / P_{PR} \).

**Operation unit capacity \( P_{OC} \)**: the sum of capacity required by the system operation, \( P_{OC} = P_{PR} - P_{FO} \).

2.3. Mathematic model
At night peak load time:

\[
P_{LMAX,NT} = P_{FO} + P_{PR} \cdot C_{MO} + P_{TNN} + P_{WC} \cdot C_{W,BZ} + P_{SC} \cdot C_{S,CL} \tag{1}
\]

At valley load time:

\[
P_{LMIN} = P_{FO} + P_{PR} \cdot C_{MO} + P_{TMIN} + P_{WC} \cdot C_{W,YX} \tag{2}
\]

At midday peak load time:

\[
P_{LMAX,NN} = P_{FO} + P_{PR} \cdot C_{MO} + P_{TNN} + P_{WC} \cdot C_{W,NN} + P_{SC} \cdot C_{S,CL} \tag{3}
\]

Subtract (2) from equation (1), there is formula (4):

\[
\Delta P_{L} = P_{LMAX,NT} - P_{LMAX,NN} = (P_{DC} - P_{FO}) - P_{PR} \cdot C_{MO} + (P_{TMAX} \cdot P_{TMIN}) + P_{WC} \cdot C_{W,BZ} - C_{W,YX} \tag{4}
\]

Further, and substitute \( P_{PR} = (P_{DC} - P_{FO}) \), \( \Delta P_{T} = P_{TMAX} - P_{TMIN} \) into (4), there is:

\[
R_{WC} = ((P_{DC} - P_{FO}) \cdot (1 - C_{MO}) + (\Delta P_{T} - \Delta P_{L}) - P_{RC}) / (C_{W,YX} - C_{W,BZ}) \tag{5}
\]

Change (1) into formula (6) as following:

\[
P_{OC} = P_{LMAX,NT} - P_{TMAX} - P_{WC} \cdot C_{W,BZ} + P_{RC} \tag{6}
\]

Substitute (6) into formula (5), there is:

\[
P_{WC} = \frac{(P_{LMAX,NT} - P_{TMAX} + P_{RC} - P_{FO}) \cdot (1 - C_{MO}) + (\Delta P_{T} - \Delta P_{L}) - P_{RC}}{(C_{W,YX} - C_{W,BZ} - C_{S,CL})} \tag{7}
\]

Considering the influence of wind power output on the acceptance of PV power generation space, after substituting (7) into (3), there is:

\[
P_{SC} = \frac{P_{LMAX,NN} - (P_{FO} + P_{PR} \cdot C_{MO} + P_{WC} \cdot C_{W,NN} + P_{TNN})}{C_{S,CL}} \tag{8}
\]

From (7), it is the night peak load \( P_{LMAX,NT} \), and peak-valley difference ratio \( \Delta P \) that will have positive correlation with wind power installed capacity, but minimum technology output parameter \( C_{MO} \) gives a negative effect on accommodation scale of wind & PV power. In fact, \( C_{MO} \) could be furthermore reduced by deep peaking transformation just as in Northeast and Northwest China in 2016.
The decrease of system reserve capacity will release more space to the new energy, and the scale increasing of transmission line will equally to enlarge system load level, directly acted on the adsorbing scale.

3. Example simulation
In Northwest of China, take one system with same development of wind and PV power conditions for example, and corresponding parameters are set as following:

**Load level:** system night peak load appeared at 20:00 with 24.17GW; valley load is at 05:00 with 20.31 GW; peak-valley difference rate is 16%; midday peak load is at 14:00 with 23GW.

**Power transmission:** at night peak and midday peak load time, transmission power are 4.92GW; and at valley load time, it is 3.52GW. The peak-valley transmission power difference is 1.4GW with peak-valley difference rate is 35.7%.

**Conventional power supply:** system reserve rate is 7%; system starting capacity is 29.28 GW; conventional power forced output is 7.13GW; considering thermal power, hydropower and other power regulation resource, the system integrated minimum technical output factor is 0.55.

**Wind & PV power output characteristics:** at night peak load time, wind power guarantee capacity coefficient is 0.05; at valley load time, wind power effective output coefficient set as 0.428; at midday peak load time, wind power output coefficient is 0.113 and PV power output coefficient is 0.402.

Based on (7) and (8), the installed capacity of wind & PV power without curtailment could be figured out as following: maximum capacity of wind power is $P_{WC}=20.74GW$, and PV power is $P_{SC}=15.10GW$.

4. Conclusions
This paper presents a method to consider the comprehensive absorption of wind power and PV power. In this method, wind power accommodation scale is firstly taken into account, with considering the influence of wind power during peaking and valley load period, which is calculated by characteristic of wind power output. On the basis of determining of wind power installed capacity, this paper considers the influence of wind power at the time of solar power, then accommodation scale of PV power could be figured out. The method has the advantages of clarified thought and clear concept, also gives the maximum scale of wind power and solar power without new energy power curtailment in the case of certain conditions such as power supply mix, power grid and load. When wind and PV power installed capacities are less than the space, basically, there is no abandoned wind and PV problem, which can effectively guide regional new energy development. About suitability, in “Three North” regions the installed capacity has exceeded local consumption ability with serve curtailment of wind and PV power, proposed model could be used for future planning years. On the contrast, in Central East China, despite of large scale of DGs, owing to more higher load level and stronger power grid, there is no curtailment phenomena happened by now. Hence, this method could give an illustration for consumption scales.

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