Reliability analysis of wind power output capacity in a regional power grid

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***Abstract*—With the increasing installed capacity of wind power in China, the problem of wind power acceptance level is becoming increasingly prominent. It is urgent to analyze the factors and put forward measures in the regional power grid to decrease the wind power curtailment ratio. In this paper, the wind resource characteristics, power load characteristics and peak-load regulation capacity of a regional power grid in recent years are analyzed. Based on the method of effective load carrying capacity, the reliability of wind power output capacity is analyzed according to different power load and peak-load regulation variation characteristics in a regional power grid. At the same time, the curtailment ratio and the inter-regional power regulation are taken as factors to analyze the wind power acceptance level. The research has a certain reference value for power grid planning and operation, especially for regional power grids with different wind resources and power load characteristics and peak-load regulation capability.**

***Index Terms*—regional power grid, wind power acceptance level, wind power curtailment, effective load carrying capacity.**

I. Introduction

As a clean and renewable energy source, wind energy has received more and more attention from all over the world. However, the uncertainties, intermittent and uncontrollable of wind power generation pose challenges to power system in maintaining the real-time balance between power generation and load. If accurate calculation and analysis of wind power capacity credibility is not executed, it may lead to wind power curtailment and waste of resources. Therefore, domestic and foreign scholars have done a lot of research work on the calculation of wind power capacity credibility.

In reference [1]-[2], the Copula function was used to describe the relationship between the forces of adjacent wind farms in space, and the method for evaluating the reliability of multi-wind farm capacity was proposed. Reference [3] used the method of solving the reliable capacity based on sequential Monte Carlo simulation to compare and analyze the influence of different wind speed models and reliability indicators on the reliability evaluation of wind power capacity. In reference [4], due to the sensitivity of the traditional Monte Carlo simulation to rare events, a Monte Carlo method based on cross entropy was proposed, which can improve the sampling efficiency of the traditional Monte Carlo method. In reference [5], the conditional reliability indices for adequacy evaluation were proposed, and the reliability assessment process of power systems based on the partitioned multi-objective risk method (PMRM) was discussed.

In addition, many new algorithms were applied to the study of capacity reliability. In reference [6], based on Markov chain, a model was established that can quickly analyze the reliability of power system operation. In reference [7], the Latin hypercube sampling method was combined with the important sampling method, and applied to power system reliability assessment, which can reduce the sampling variance and avoid a large number of repeated sampling of the normal state of the system. Reference [8] proposed a method to improve the simulation accuracy and calculation speed of the time interval sampling method by selecting the appropriate sampling interval and using the correction coefficient to correct the loss of load duration indicator directly related to the sampling frequency. Reference [9] improved the statistical averaging method based on wind power output data, and proposed a hybrid method. In reference [10], a method was proposed to evaluate the comprehensive capacity reliability of wind power and photovoltaic power in dense renewable energy areas. Reference [11] proposed an index called net load carrying capability (NLCC) to evaluate the contribution of a generating unit to the flexibility of a power system. Reference [12] proposed an evaluation method for variable generation (VG) acceptability with an adequate level of power system flexibility.

In this paper, firstly, the factors affecting the wind power acceptance level are analyzed, and then the wind power capacity reliability analysis model is build based on the wind power output model and the effective load carrying capacity method. Finally, with a regional power grid named A, the wind power output probability, the power load characteristics and the peak shaving characteristics are described separately, and then the wind power acceptance level is analyzed.

II. FACTORS AFFECTING THE WIND POWER ACCEPTANCE LEVEL

In power grid, the main factors affecting wind power acceptance level are as follows.

A. *Constraint of Grid Power Balance*

The load and generator output in power grid is a dynamic balancing process. The active power of the generator should be satisfied with the active power of the system load. The power balance constraint is as shown in equation (1).

$$\sum_{i=1}^{n} P_{Gi} - \sum_{i=1}^{n} P_{Li} = 0 \tag{1}$$

Among them, P_{Gi} is the active output of the i_{th} generator, and P_{Li} is the i_{th} load active power. P_{Gi} should meet $P_{MIN} \le P_{Gi} \le P_{MAX}$, that is, the minimum technical output requirement of the generator set. When the wind turbine is connected to the grid, there may be a wind power curtailment due to the minimum technical output limit of other conventional units.

B. *Constraint of Thermal Power Unit Peaking Capacity*

When the load and wind turbine output fluctuate, the output change of the conventional thermal power unit is as shown in equation (2).

$$\Delta P_{Gi} = P_{Li} + (-P_{Wi}) - P_{Gi-1} \tag{2}$$

Among them, ΔP_{Gi} is the change amplitude of the unit output during a certain period of time, P_{Li} is the active load of the system at the i_{th} moment, P_{Wi} is the active output of wind power at the i_{th} moment, and P_{Gi-1} is the active output of the thermal power unit at the *i-1* moment.

Due to the limitation of the output regulation rate (climbing rate) of the conventional thermal power unit, when the power output fluctuation of the wind turbine unit causes the power variation of the conventional unit to be greater than the maximum climbing rate, the wind turbine will exhibit a wind power curtailment phenomenon.

C. *Constraint of Power Transmission Capacity*

The power transmission capacity of the power grid is an important factor affecting the wind power acceptance level. The cross-regional flow of power in a large-scale power grid can make full use of the spare capacity of the whole system to make up for the insufficient peaking capacity of the regional power grid units, and thus improve the level of wind power acceptance.

III. WIND POWER CAPACITY RELIABILITY ANALYSIS MODEL

A. *Wind Power Output Model*

Under the premise of ignoring the wake of the fan and electrical loss, the power output of the wind turbine mainly depends on the wind speed at the high point of the hub. The wind turbine output model can be represented by a piecewise function as shown in equation (3).

$$p(V) = \begin{cases} 0 & (V \le V_C) \cup (V \ge V_{C0}) \\ \dfrac{P_R}{V_R^3 - V_C^3}(V^3 - V_C^3) & V_C \le V \le V_R \\ P_R & V \ge V_R \end{cases} \tag{3}$$

Where V is the wind speed, V_C is the cut-in wind speed, V_{C0} is the cut-out wind speed, V_R is the rated wind speed, P_R is the rated power of the wind turbine, and $p(V)$ is the corresponding output power when the wind speed is V.

B. *The Effective Load Carrying Capacity for Wind Power Evaluation*

The effective load carrying capacity is used as the evaluation index of the credible capacity. Under the condition of maintaining the same level of reliability, the method is to increase the load capacity after the system is newly added, and use the LOLE (loss of load expectation) as the evaluation indicators of systemic risk. The mathematical expression obtained by the definition of ELCC (effective load carrying capability) is:

$$F(C, L) = F(C + \Delta C, L + \Delta L) \tag{4}$$

$$ELCC = Load_{add} / C_{PVN} 100\% \tag{5}$$

Where F is a function of installed capacity and load and system risk indicators, C is the original installed capacity of the system, ΔC is newly added power rated capacity, L is the original load of the system, ΔL is the additional load that can be satisfied by the new power supply. Then, the ΔL that holds the formula (4) is newly added to the power source, and the capacity reliability of the wind power station can be obtained by the formula (5). F does not have a certain expression. Given a certain C, the risk index can be solved by simulation calculation, and it is more complicated to solve C by a risk index, and iterative hypothesis testing method is preferred.

IV. WIND POWER ACCEPTANCE LEVEL IN REGIONAL POWER GRID

In this section, with a regional power grid named A, the wind power output probability, the power load characteristics and the peak shaving characteristics are described separately, and then the wind power reliability is analyzed.

A. *Wind Power Output Probability Based on Peak Load Period*

The capacity credibility of wind power output based on peak load period reflects the correlation between wind resources in a region and the electric load in the region, that is, the positive peaking characteristics of wind power. For large-scale power grids, when the installed capacity of wind power is small, this indicator has little impact on the peak shaving capability of the system. When the scale of wind power continues to expand and the local power grid has insufficient power regulation, it is necessary to consider the impact of this indicator on the peaking capacity of the power grid. In the analysis of wind power capacity of regional power grids, this indicator has a positive impact on wind power capacity.

The wind power output capacity during the peak load period needs to be statistically or predictive of the historical curve of wind power generation. The data points in the curve are arranged in time series, which require a large amount of operational data to provide support.

Fig.1 shows the Weibull characteristics of wind resources at three representative locations P_1, P_2 and P_3 in region A. Fig.2 shows the output statistics of the regional power grid in the peak load period of 4 years. Under the condition of 90% confidence, the maximum output of wind power in the peak load period is 11% and the minimum is 3%. For the grids connected to multiple wind farms, due to the simultaneous wind problem between different regions, the total output of wind power during the peak load period of the grid is less than the above statistical value. For this, there are anti-peak characteristics of wind resources and grid load characteristics, and the wind power output level corresponding to peak load period is small.

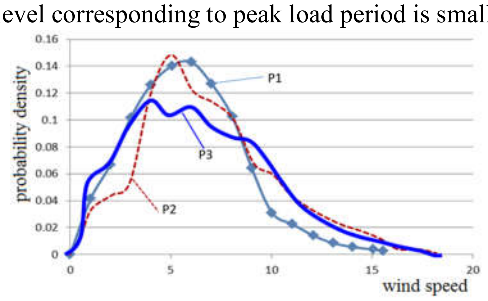

Fig. 1. Typical characteristic of the wind resources in region A

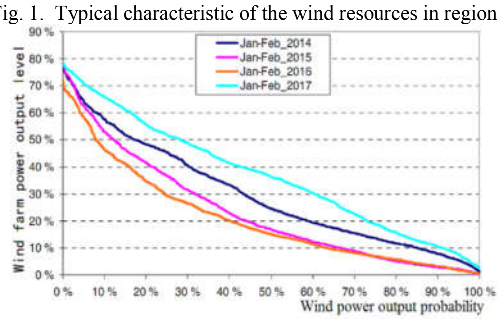

Fig. 2. Wind power output probability based on peak load period

B. Power Load Characteristics

Fig.3 shows the load curves of the regional power grid in recent 4 years. The maximum load of the regional power grid basically shows an increasing trend year by year, and the growth rate is faster. Fig.4 is the load peak-valley differences corresponding to Fig.3 and the typical daily index changes of load characteristics is shown in Table I.

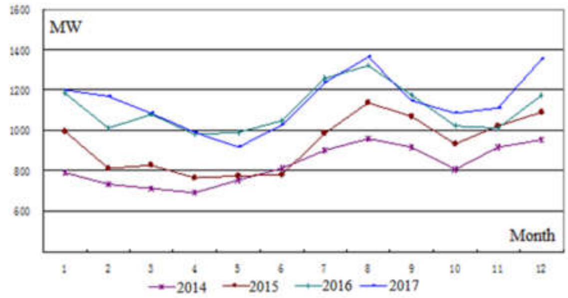

Fig. 3. Load curve in region A power grid

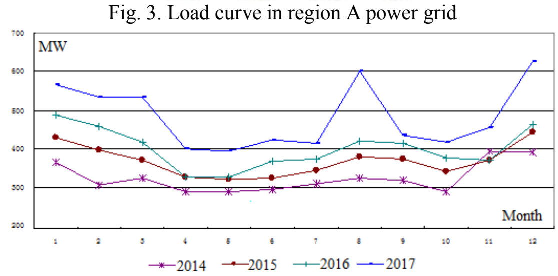

Fig. 4. Load peak valley difference in region A power grid

TABLE I
TYPICAL DAILY INDEX CHANGES OF LOAD CHARACTERISTICS

year	Mon/Day	Load Max (MW)	peak-valley difference (MW)
2014	Apr 22	600.6	238.1
	Aug 21	921.6	299.6
	Oct 21	799.0	288.0
	Dec 23	925.3	356.5
2015	Apr 21	679.2	271.8
	Aug 16	1097.2	292.8
	Oct 20	910.1	306.2
	Dec22	981.0	321.6
2016	Apr 20	928.2	268.5
	Aug 17	1321.3	420.9
	Oct 19	985.3	351.1
	Dec21	1147.7	432.0
2017	Apr 18	859.4	342.7
	Aug 17	1235.1	391.0
	Oct 17	1069.6	397.2
	Dec20	1248.5	535.2

C. Wind Power Acceptance Level

Table II is the estimated peak load balance state of the regional power grid in year 2020 and 2025, the acceptance level is calculated by Fig.5, and the corresponding acceptance level is 1249MW and 409MW. The acceptance level in 2025 is less than 2020 for the increase of load and the reduction of peak shaving capacity. The symbols in Fig.5 are listed in Table III.

TABLE II
PEAK LOAD BALANCE TABLE OF REGIONAL POWER GRID A (MW)

Item name		Year 2020	Year 2025
Load peak		2290	3393
Load valley		1420	2104
Inter-regional power		244	1604
peak-valley difference		870	1289
Spinning reserve		183	271
Monthly imbalance coefficient		0.86	0.86
Peak demand(P_D)		931.4	1380
Peak shaving capacity (Total)		1177	1462
1	hydropower	190	190
2	Pumped storage	120	240
3	Thermal power	867	1032
Peak shaving surplus		245	82

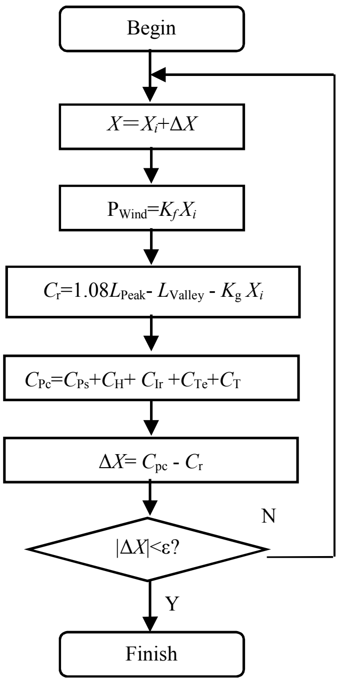

Fig. 5. Wind power acceptance level calculation flow chart

The wind power curtailment ratio and the inter-regional power regulation ratio are used as factors to analyze the impact on wind power acceptance. Table IV is the wind power acceptance level in different curtailment ratio. Table V is the wind power acceptance level in different inter-regional power regulation capability.

It is seen from Table IV that the regional grid's acceptance capacity of wind power is increased under the setting of a certain amount of wind power curtailment. The acceptance level will be affected by the system load level, and the wind power acceptance level will decrease as the regional grid load increases.

TABLE III
SYMBOL AND DESCRIPTION

Symbol	Description
X	Wind power acceptance level
X_i	X at the ith iteration
P_{Wind}	Wind power output
K_f	Wind power confidence capacity factor during peak load period
K_g	Reliability coefficient of wind power
L_{Peak}	Load peak
L_{Valley}	Load valley
C_r	Peaking capacity requirement
C_{Pc}	Peak shaving capacity
C_{Ps}	Pumped storage peaking capacity
C_H	Hydroelectric peaking capacity
C_{Ir}	Inter-regional peaking capacity
C_T	Thermoelectric peaking capacity
C_{Te}	Thermal peaking capacity

TABLE IV
WIND POWER ACCEPTANCE LEVEL IN DIFFERENT CURTAILMENT RATIO (MW)

Curtailment ratio(%)	Year 2020	Year 2025
0	1249	409
1	1316	431
2	1391	455
3	1474	482
4	1569	512
5	1676	545
10	2544	818

TABLE V
WIND POWER ACCEPTANCE LEVEL IN DIFFERENT INTER-REGIONAL POWER REGULATION CAPABILITY (MW)

Inter-regional power regulation ratio(%)	Year 2020	Year 2025
0	1249	409
1	1262	489
2	1274	570
3	1287	650
4	1299	730
5	1311	810
10	1373	1211

It can be seen from Table V that under the power adjustment ratio between certain regions, the regional power grid has improved the acceptance capacity of wind power. The acceptance level will be affected by the peaking ability of the system. If the peaking ability of the system is relatively large, the influence of inter-regional power regulation on the acceptance level of wind power will be reduced.

V. CONCLUSION

In this paper, the regional power grid's acceptance capacity for wind power is analyzed. From the research point of view, the power load level and power grid peak shaving ability are the main factors affecting wind power acceptance level. In order to improve the wind power acceptance level, in some cases wind power curtailment is necessary. Improving the power regulation capability between regional grids should be the fundamental way to improve the Wind power acceptance level.

In the calculation of wind power acceptance level in this paper, the capacity reliability of intermittent power supply needs to use the reasonable installed capacity. The reasonable installed capacity not only depends on the intermittent resource characteristics, but also depends on the grid size, power supply structure and load levels and many other factors, which is a complex problem.

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