A Quantitative Analysis of Wind Curtailment Strategy in Multiple Temporal and Spatial Scales

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Abstract—In order to solve the actual needs of developing strategies to improve the capacity of wind power consumption, this paper analyses the factors affecting the capacity of wind power consumption in multiple temporal and spatial scales, as well as measures to improve regional wind power consumption capacity. The calculation model for the contribution of wind curtailment factors is proposed, quantitative modelling the contribution of various factors. By the contrast of contribution, operators could visually assess the extent of the impact factors, which allow them to set up coping strategies according to the severity level of issues.

Keywords-wind curtailment strategy; quantitative analysis; contribution; mutiple temporal and spacial scales

I. INTRODUCTION

The wind curtailment problem is common in “Three Northern Regions” in China, bothering both the government and grid operators. It’s technically difficult to split the impact of certain factors, because that wind curtailment is a comprehensive problem containing several correlative issues. Recently, most scholars have studied certain issue independently, such as the impact of transmission mode [1, 2]. However, study that considers and compares the various factors from the perspective of the whole network is needed.

This paper analyses the factors affecting the capacity of wind power consumption in the multiple temporal and spatial scales, quantitatively models the contribution of various factors, and allows operators to set up coping strategies according to the severity level of issues.

II. A WIND CURTAILMENT FACTOR SYSTEM IN MULTIPLE TEMPORAL AND SPATIAL SCALES

Follow the logic of wind power electricity generation, transmission and distribution, the factors affecting the capacity of wind power consumption are divided into several issues, as Table. 1: wind resource issue, wind power prediction accuracy issue, wind turbine running performance issue, reactive compensation issue, transmission capacity issue, electricity energy formation issue, load characteristics issue and imbalance issue of supply and demand. Certain factor is related to several evaluation indexes. The factors affecting the capacity of wind power consumption will be presented in multiple temporal and spatial scales [3], as Fig. 1, to discriminate the impact scope and scale of different factors.

A. Wind resource issue

The impact of wind resource issue is mainly reflected in the average wind power density and available wind power density [4]. When the wind power density varies within the available range of the normal operation, wind turbines work and produce electricity. This condition is settled by nature, which should be serious considered before a wind farm is built.

B. Wind power prediction accuracy issue

Wind power prediction is included in the basis of the monthly wind power balance and dispatching management.

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Currently, the prediction accuracy varies; long-term wind power prediction has not carried out well. Both limit the ability of wind power integration [5]. When strategy of improving wind power prediction accuracy is proposed, the extent is limited to 100% and the cost will increase dramatically.

TABLE I. WIND CURTAILMENT FACTOR SYSTEM

Issues No.	Issues	Index No.	Evaluation Indexes
A	Wind Resource Issue	1	Average Wind Power Density
B	Wind Power Prediction Accuracy Issue	2	the Prediction Accuracy of Wind Power
C	Wind Turbine Running Performance Issue	3	Rate of Wind Turbine Output
D	Reactive Compensation Issue	4	the Voltage Stability of Parallel Point
E	Transmission Capacity Issue	5	Transmission Power of Tie-line
F	Electricity Energy Formation Issue	6	Thermal Unit Penetration
		7	Heating Unit Penetration
		8	Wind Power Penetration
		9	Spinning Reserve Capacity
G	Load Characteristics Issue	10	the Load Peak and Off-peak Difference
		11	Net Peak Valley Load Difference
H	Imbalance Issue of Supply and Demand	12	the Ratio of Wind Power Installed Capacity to Maximum Load

C. Wind turbine running performance issue

There are requirements that wind turbine must have low voltage ride through (LVRT) capability to ensure safety and stability. In addition, some can adjust the blade angle to smooth the wind power output. The rate of change of wind power output can be calculated as follows [3], as in

$$\rho\% = \frac{P(t+T)-P(t)}{P_{base}} \times 100\%. \quad (1)$$

$\rho\%$ is used to reflect the fluctuations of power output, which tells the running performance in a way.

t is the moment of calculation.

T represents time interval.

$P(t)$ represents wind power output on moment t.

$P(t+T)$ is wind power output on moment $(t+T)$.

P_{base} refers to the rated power of wind power generator or wind farm.

D. Reactive compensation issue

High-power electronic equipment integrated brings up new demands for reactive compensation. The lack of reactive power compensation leads to abnormal voltage level, limiting the ability to accept wind power [6]. Accordingly, the solution to this issue is deploying proper reactive power compensator.

E. Transmission capacity issue

Wind farms are generally located in remote areas far from load centres, depending on transmission lines to send out electricity. Strategy of investing in new transmission line is limited by cost-benefit analysis [7]. Planning new loads such as desalinator [8, 9, 10] and data center makes it possible to use wind power locally.

F. Electricity energy formation issue

The proportion of wind power, thermal power and hydropower, to a certain extent, shows the regulation ability. According to operation data of power grid in the northeast of China, during winter heating period, the heating units accounts for about 50% of total thermal power, which greatly weakened the peaking capacity of grid. Further, in order to secure stable operation of the power system, wind power penetration does not exceeds 20% generally [11].

G. Load Characteristics issue

The characteristics of load varies in different seasons of the same year. The smaller the difference between peak and valley load, the more capable of wind power consumption [12].

H. Imbalance issue of supply and demand

In parts of the region, the amount of wind power capacity exceeds the maximum power load. Therefore, considering the supply and demand balance of the power system is an important part of the analysis of wind power consumption ability.

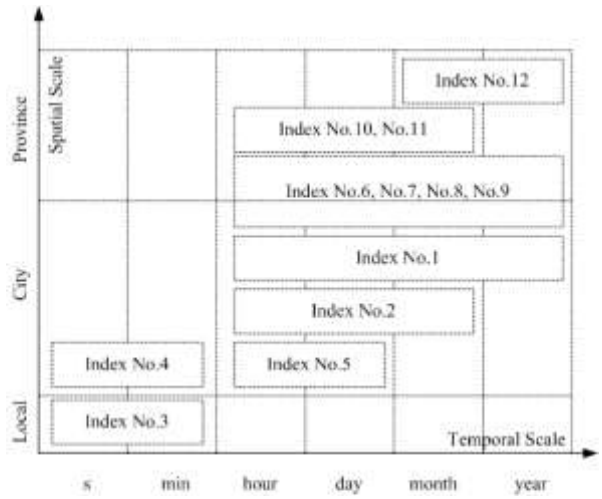

Figure 1. A wind curtailment factor system in multiple temporal and spatial scales

III. THE CALCULATION MODEL FOR THE CONTRIBUTION OF WIND CURTAILMENT FACTORS

After analyzing the factors in multiple temporal and spatial scales, the calculation model for the contribution of wind curtailment factors is established to quantify the contribution of various factors to wind curtailment problem, which can be applied in problem diagnosis and strategy development. The model can be shown as in

$$C_i = f_i \times \frac{R_i - S_i}{S_i} \times 100\%. \quad (2)$$

C_i represents the contribution of i-factor.

f_i is impact factor, which means the increment of wind curtailment (10000kWh) under unit increment of i-factor's evaluation index, obtained by historical data or simulating calculation.

R_i is the real value of i-factor's evaluation index, which can be obtained from operating database.

S_i is the standard value of i-factor's evaluation index setting by historical data.

Meanwhile, statistical methods based on historical data are the most direct and authentic analyzing methods of wind power law [3]. Commonly, it is proposed to set S_i equal to the rated value, such as rated power and rated voltage. When it comes to the prediction accuracy of wind power, S_i should be set according to guide rule, such as 80% in local grid.

If several evaluation indexes are considering in one issue and the number of indexes is N, the contribution of i-issue can be calculated as in

$$\begin{cases} C_{i-issue} = \sum_{j=1}^{N} a_j C_j \\ \sum_{j=1}^{N} a_j = 1 \end{cases}. \quad (3)$$

a_j is impact factor, which means the increment of wind curtailment (10000kWh) under unit increment of j-index, obtained by historical data or simulating calculation.

Finally, calculate the contribution of various factors and issues, which affect the capacity of wind power consumption, in order to normalize and compare the severity level of different issues.

IV. EXAMPLES

Taking a grid in "Three Northern Regions" in China as an analysis example.

According to statistic data of sample power grid, the amount of wind power consumption reached the maximum on November (during heating period), while wind resource utilization dropped. The average of wind power penetration is 20%. Wind power generation throughout the year is approximately 500 GWh and the average wind resource utilization of wind power generation is roughly 77%. To discuss the factors contributing to wind curtailment during heating period, the sample grid is analyzed under the conditions that the spatial scale is city and the temporal scale is month.

Take "Wind Power Prediction Accuracy Issue" or instance. Referring to the experiment done by [13], shown as Table. 2, the decrement of wind curtailment under unit increment of wind power prediction accuracy is 576 (10000kWh). Therefore the impact factor f_i of the prediction accuracy is -576. The real operation data is 85%, while standard value S_i is 80% according to guide rule. Then, use (2) to obtain C_i of wind power prediction accuracy issue.

TABLE II. EXAMPLE OF A GRID IN "THREE NORTHERN REGIONS"

Evaluation Indexes	Impact Factor(fi)	Standard Value (Si)
The prediction accuracy of wind power	-576*	80（%）
Thermal unit penetration	6739.2	80（%）
Transmission power of tie-line	-691.2*	1750（MVA）
The load peak and off-peak difference	748.8	400（10,000kWh）

(fi is negative when the decrease of index leads to the increase of wind curtailment amount)

According to wind curtailment factor system, the contribution of issues can be presented as Table. 3 and Fig. 2.

TABLE III. THE CONTRIBUTION OF ISSUES FOR EXAMPLE GRID

Issues	Contribution(Ci)
Wind Power Prediction Accuracy Issue	-36.0
Electricity Energy Formation Issue	834.0
Transmission Capacity Issue	79.0
Load Characteristics Issue	262.1

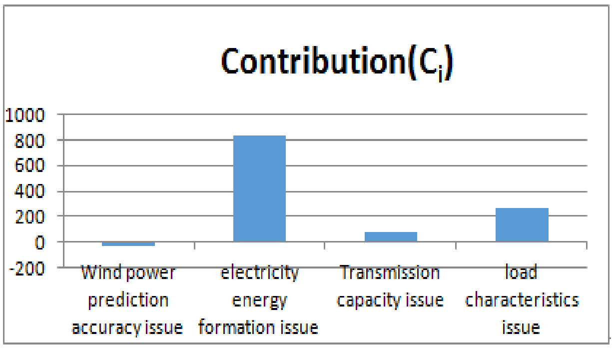

Figure 2. A wind curtailment factor system in multiple temporal and spatial scales

The result indicates that the problem of electricity energy formation issue is more serious than other issues. The contribution value of electricity energy formation issue is 834, which means that, compared to the standard thermal unit penetration (80%), the amount of thermal power generation takes a larger slice of electricity supply. And unit decrement of thermal unit penetration (1%) can increase 834.0(10,000 kWh) of wind power consumption. Meanwhile, the prediction accuracy is preciser than standard value, which, by contrast, brings extra 36.0

(10,000 kWh) of wind power consumption. It is recommended that grid operators should put more emphasis on optimizing electricity energy formation. Relative strategies include decreasing the thermal unit penetration, decreasing the heating unit penetration, increasing the spinning reserve capacity and deploying storage devices.

V. CONCLUSION

A wind curtailment factor system in multiple temporal and spatial scales is proposed and the contribution of wind curtailment factors is quantified by calculation model. The example shows the visualization and normalization of this analysis method, which can be applied in problem diagnosis and strategy development.

Furthermore, there are several conditions that should be noted:

1) The cost and benefit of certain strategy could be discussed to assess the economic efficiency.

2) The variation range of indexes mentioned in calculation model should be considered.

3) Based on this research, the optimize combination of several strategies should be discussed.

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