Evaluation of the Credible Capacity of Wind Farms Considering Energy Storage

Hong-chang PENG1*, Bing CAO3, Chun-juan JIA1, Wei REN2, Ming-ming YANG1 and Qian-he ZHAI1

1School of Electrical Engineering Shandong University Jinan, China
2Material Company, State Grid Shandong Electric Power Company Jinan, P. R. China
3CGNPC new energy investment (Shenzhen) Co., LTD. Shandong Branch

*Corresponding author

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Abstract. Credible capacity in measure the value of intermittent power supply connected to the power system is of great significance. In this paper, we've established the probability model of the wind power, and given the operational characteristics of the energy storage device, it proposes a strategy of storage control, and then proposes a credible capacity calculation method for a wind-generated unified generator system. Using the non-sequential Monte Carlo simulation framework, based on the proposed savings and control strategy, it evaluates the effect of the storage capacity on the capacity of the wind power system. The effectiveness of the evaluation algorithm is tested by using the RTS-79 reliability example, and the results show that the proposed method can be used to evaluate the planning scheme of wind storage power generation system.

Introduction

The demand for energy shortage and energy conservation and emission reduction has led to the active development of low-carbon power technology in the world's power grids [1]. Among them, the application of wind power and energy storage technology has become more and more widespread.

The large-scale access of wind power around the world has resulted in significant changes in the power system. In the power system, power generation is introduced with uncertainty, intermittency and uncontrollable power supply, which challenges the real-time balance of power generation and load. Due to the intermittency of wind power units, the capacity of wind turbines with the same capacity is not the same as that of conventional thermal or hydroelectric generating units. Therefore, in the analysis of power system adequacy, wind power capacity cannot be treated in the same way as conventional turbines. So it is difficult to analyze the power balance in power planning.

For this reason, domestic and foreign scholars use the credible capacity to evaluate the contribution of wind power generation to system capacity [2-4], which means that the capacity of conventional units can be replaced by wind power units in the premise of reliability. The credible capacity of wind power makes it possible to compare intermittent wind power with the installed capacity of conventional units at the same level.

Literature [5] established the power generation reliability assessment model of wind power, photovoltaic power generation and energy storage system, and proposed a new coordinated scheduling strategy.

In the literature [6], when analyzing the distributed generation system of wind - light - biogas hybrid renewable energy, it is pointed out that landscape resources are complementary to each other and have better stability, reliability and economy.

But now reliable capacity evaluation object focused on wind power a single system, against the wind joint system reliable storage capacity of the related research is not much, literature [7] for Chinese wind and conventional energy from the outside, put forward the concept of energy by the
credible capacity and its calculation method, literature [8] analysis for the transmission line fault analysis on the influence of wind power credible capacity.

This article is based on the simulation model of non-sequential Monte Carlo method, established a probability model for wind turbine output, proposed a credible capacity calculation method for the system, discusses the different energy storage capacity of impact on the Credible. capacity of wind turbines.

Wind Power System Model

Wind Farm Output Model

Establish a mathematical model of the standard characteristic curve of wind turbines. The output curve can be expressed as a piecewise function. The piecewise function is:

\[
P = \begin{cases} 
0 & (V \leq V_{ci} \text{ or } V \geq V_{co}) \\
_P \frac{V - V_{ci}}{V_r - V_{ci}}, & (V_{ci} \leq V \leq V_{co}) \\
_P & (V \leq V < V_{co}) 
\end{cases}
\]

(1)

Where \( V_{ci} \) is the cut-in wind speed, when the wind speed is less than \( V_{ci} \), the output power of the wind turbine is zero. When the wind speed is greater than the cut-in wind speed, the output power of the wind turbine increases gradually with the increase of the wind speed. Until the wind speed reaches the rated wind speed \( V_r \), the output power of the electric energy is the rated power \( P_r \). At this time, the power output from the wind turbine is no longer a positive correlation with wind speed. \( V_{co} \) is the cut out the wind speed, when the wind speed is greater than this value, in order to prevent the wind turbine from rotating too fast, damage the fan, the wind turbine select shutdown, the fan exits operation, and no longer outputs power.

Wind Speed Model

The output power of the wind power system is determined by the local wind speed and the selected fan parameters. Therefore, when Monte Carlo simulation is performed, the randomness and time varying simulated wind speed must be taken into account first, and then the output power is simulated according to the fan output characteristics.

The Weibull distribution[9] is a probabilistic model with a simple form and a good fit to the actual wind speed distribution. It is widely used. The probability expression is:

\[
f(V) = \left(\frac{k}{c}\right) \left(\frac{V}{c}\right)^{k-1} \exp\left[-\left(\frac{V}{c}\right)^k\right]
\]

(2)

Corresponding probability distribution function is:

\[
F(V) = P(v < V) = 1 - \exp\left[-\left(\frac{V}{c}\right)^k\right]
\]

(3)

Where \( k \) is Weibull shape factor, \( c \) is the scale factor, using the probability function to calculate and simulate the wind speed, we must first transform the probability function and find the inverse function of the distribution function:

\[
V = c\left[-\ln(1 - F)\right]^{\frac{1}{k}}
\]

(4)

The wind speed modeling method is to extract random numbers between 0 and 1 into the formula (4).
Energy Storage System Model

Wind Storage System Model

This article uses centralized access wind storage system, the model is as FIGURE 1:

![Figure 1. Wind Storage System.](image)

Where \( P_w \) is wind turbine output power, \( P_b \) energy storage charge and discharge power, When the energy storage charge \( P_b \) is negative, it is equivalent to the load, and when the energy storage discharge \( P_b \) is positive, equivalent to the generator, \( P_{out} \) is wind power storage system output power, its value is:

\[
P_{out} = P_w + P_b
\]

When the wind power contributes excess energy, the energy storage control mode is the charging state. When the wind power is insufficient, the energy storage is invoked, and the energy storage perform centralized control and adjustment of the wind turbine output, make \( P_{out} \) is changed with the change of load under the condition that the normal unit capacity is constant.

Assuming that the output power of wind turbine at time \( T \) is \( P_{w,T} \) and remains unchanged from \( T \) to \( T + \Delta T \). The output power of the conventional unit is \( P_c \) and the real-time load power is \( P_{ref} \).

The energy storage charge discharge strategy is as follows:
When \( P_{w,T} + P_c > P_{ref} \):

\[
E_{s,T+\Delta T} = \min(E_0, E_{ref} - \min(P_s^{max}, P_{w,T} + P_c - P_{ref}) \cdot \Delta T \cdot \eta_S)
\]

When \( P_{w,T} + P_c < P_{ref} \):

\[
E_{x,T+\Delta T} = \min(E_f, \min(P_s^{max}, P_{ref} - P_{w,T} - P_c) \cdot \Delta T \cdot \eta_X)
\]

\( E_{s,T+\Delta T} \) and \( E_{x,T+\Delta T} \) are respectively the energy absorbed and released by the energy storage device during the time \( \Delta T \), when the wind turbine output fails to meet the current \( P_{ref} \), \( E_0 \) is energy storage system capacity, \( E_f \) is energy storage device remaining energy at this moment.

\( P_s^{max} \) and \( P_x^{max} \) are respectively Maximum charging and discharging power of energy storage device, \( \eta_S \) and \( \eta_X \) are respectively charge and discharge efficiency of energy storage device.

Assessment of the Credible Capacity of the Joint Wind and Storage System

Credible Capacity Definition

The access of wind power can improve the reliability of the system and reduce the probability of system power outages. However, the contribution of wind power to the reliability of the system is generally much smaller than that of a conventional unit of the same capacity.
So use the credible capacity to evaluate the contribution of wind power generation to system capacity which means that the capacity of conventional units can be replaced by wind power units in the premise of reliability.

**Reliability Calculation**

This article uses the Monte Carlo method[10] for reliability assessment[11]. The reliability indicator used is LOLP which is loss of load probability. LOLP is the probability of power loss due to problems with the transmission line or lack of active power. Its value is:

\[
LOLP = \sum_{i \in S} \frac{t_i}{T}
\]  

(8)

Where S is the system state collection during load shedding, \(t_i\) is the duration of the system state, T is the total simulation time.

**Credible Capacity Assessment**

Calculation of wind power capacity based on reliability assessment. Wind power credible capacity needs to add virtual unit capacity to the equivalent system without wind power and test repeatedly. With the increase of the capacity of the virtual unit in the system, the system reliability LOLP rises monotonically. The goal of the credible capacity calculation is to find an equivalent system with the same reliability as the original system. This article uses the chord method[12] to calculate. The calculating processes is shown in FIGURE II.

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**Figure 2. Process of credible capacity.**
Energy Storage System Model Examples and Results Analysis

This article uses the standard IEEE-RTS79 test system as a simulation platform for calculating reliability indices and credible capacity. In order to observe the change of reliability, we choose to reduce the installed capacity of some conventional units, the total installed capacity of the system is 2613MW. The conventional load of the system is the peak load per hour, with a peak load of 2850MW.

Wind turbines cut into the wind speed $V_c = 3 \text{ m/s}$, cut the wind speed $V_{cm} = 22 \text{ m/s}$, rated wind speed $V_r = 11.5 \text{ m/s}$, rated power $P_r = 2 \text{ WM}$. In this paper, wind turbines with a standard output of 2MW is used in the credible capacity assessment.

The energy storage device used in this paper is lithium ion battery energy storage. The simulation evaluation time is 100 years. $\Delta T$ is 1 hour. The battery pack is 200, $P_s^\text{max} = P_x^\text{max} = 100 \text{ KWh}$, $\eta_s = \eta_x = 0.8$.

According to the output characteristics of wind power units, combined with wind speed in a certain region, the wind power is connected to the network, and the credible capacity analysis is carried out by MATLAB simulation software.

Figure 3 shows the reliability results of the system when the wind power system runs separately. From Figure 3, it can be seen that with the increase of installed capacity of wind turbines, the reliability index lollp of the system has decreased, which means that the reliability level of the power grid has been improved. Therefore, the reliability of the power system can be improved obviously by using wind power as the power supply network.

Figure 4 shows the reliability index lollp of the combined wind storage system after energy storage access which the energy storage capacity accounts for 10% of wind turbine capacity.
From Figure 4, add 10% of energy storage under the original conditions, it can be seen from the figure that the lolp curve is translated downwards which shows that after the energy storage is added, the reliability level of the power grid has been further improved on the original basis, and the energy storage can improve the reliability of the wind power generation system.

As mentioned above, the credible capacity of a wind power generation system is based on the premise of equal reliability, and the size of the conventional unit capacity that the wind turbine can replace.

Figure 4 calculates the credible capacity of the wind power system before adding 40 WMh of energy storage and the credible capacity of the wind power system after adding 40 WMh of stored energy. It can be seen that the energy storage device has a great influence on the credible capacity, and the energy storage can effectively increase the credible capacity of the wind turbine.
Figure 6. Wind Power Credible Capacity under Different Energy Storage Ratios.

Figure 6 calculates the capacity of 300MW access fan unchanged, adding 0% storage, 5% storage, 10% storage, and 20% storage capacity.

It can be seen that the higher the proportion of energy storage access, the smaller and smaller the increase in credible capacity.

Conclusion

Based on the simulation model of non-sequential Monte Carlo method, this paper considers the reliability and credible capacity calculation method of wind-storage combined system under different energy storage capacity.

Comparisons of the credible capacity of wind turbines with different energy storage capacities was carried out. Based on the IEEE-RTS79 calculation example, this paper makes a simulation of Matlab program, proves the effectiveness of the evaluation method, and can get the following conclusions:

(1) Access to energy storage can improve the reliability of wind power generation systems.
(2) Access to energy storage can effectively increase the credible capacity of wind turbines.
(3) The higher the proportion of energy storage connected to the wind storage system, the greater the trusted capacity, but as the proportion increases, this increase becomes less obvious.

References


