Research on Power Quality Based on Doubly-Fed Induction Wind Generator

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Keywords: Wind power, Doubly-fed asynchronous generator, Power quality.

Abstract. The influence of grid-connected wind power generation system on power quality has always been a focus of researchers. Doubly-fed induction generators are the most widely used wind turbine generators in the wind power industry, and their impact on the power grid during power generation and grid connection has also received widespread attention. In this paper, based on the power quality problem of double-fed induction generators connected to the grid, three aspects of voltage fluctuation, flicker and harmonics are analyzed respectively, and the influence of this model on grid power quality is analyzed.

Introduction

With the reduction of fossil fuel reserves and the increasingly severe environmental problems, the new energy power generation industry headed by wind power and photovoltaic has begun to develop rapidly. However, the grid-connected generation of these distributed generations meets the electricity demand of the users and also causes some pollution to the power quality of the grid. Compared with photovoltaic power generation, the quality of power generated during grid-connected wind power generation is more prominent. This paper starts with the doubly-fed asynchronous wind turbines that account for the most wind turbines in the market, and analyzes the impact of power quality in grid-connected state.

Impact of Wind Power Generation on Power Quality

As an unstable and intermittent energy source, wind energy has not evolved from a small power generation to a large-scale wind farm until the past 100 years, providing considerable power for the regional power system, but the problem of power quality generated by the wind turbine generating electricity and connecting it to the grid still exists. Not only the power and frequency fluctuations caused by uncontrolled changes in wind speed, but also the inevitable harmonic effects generated by the power electronics required for grid connection.

Voltage Fluctuation Caused by Grid-Connected Doubly-Fed Asynchronous Wind Turbines

The fluctuation of wind turbine output power is caused by the change of wind speed, and the power fluctuation is the root cause of voltage fluctuation[1].

Figure 1. Wind farm connected to the grid equivalent circuit.
As shown in the figure, $U_1$ is the voltage on the high voltage side of the boost station of the wind farm; $U_2$ is the grid voltage, and $Z$ is the line equivalent impedance. According to the load habit, the direction of flow of active power and reactive power is in the direction of flow into the wind farm, then the voltage deviation is

$$\Delta U \approx \frac{(PR+QX)}{U_1}$$

Regardless of the distributed capacitance, when $P$ increases, $Q$ also increases accordingly. If $PR+QX>0$, the terminal voltage of the power plant $U_1$ will be less than the grid voltage $U_2$; considering the distributed capacitance of the line, when the output of the wind farm is low, $U_1$ will above $U_2$ because of the capacitive charging power of the line.

The power obtained by wind turbines from wind energy is

$$P = \frac{1}{2} \rho A v^3 C_p(\lambda, \beta)$$

In the formula, $\rho$ is the air density, $A$ is the sweeping area, and $v$ is the wind speed, $C_p$ is the wind energy utilization coefficient (according to the Bates theory, the theoretical maximum is 0.593). The size of the wind energy utilization factor is related to the tip speed ratio $\lambda$ and the pitch angle $\beta$. For a fixed-pitch wind turbine, it is only related to the tip speed ratio $\lambda$. The tip speed ratio is defined as

$$\lambda = \frac{\omega R}{v}$$

$\omega$ and $R$ are the impeller speed and the impeller radius, respectively. It can be seen that affecting the output power of wind turbines, that is, the variable factors that may cause voltage fluctuations are air density, wind speed, impeller rotation speed and pitch angle. In addition, the tower shadow effect, yaw error, wind shear, and blade center of gravity asymmetry in the operation of the wind turbine can also cause voltage fluctuations; and in the wind turbine startup and shutdown and switching, etc. Power and voltage fluctuations occur at the end of the generator set and adjacent nodes.

At the same time, the short-circuit capacity of the grid point and the impedance ratio of the line have no small effect on the voltage fluctuation. The larger the short-circuit capacity, the smaller the voltage fluctuation caused, and when the impedance angle is maintained between $60^\circ$ and $70^\circ$, The voltage fluctuation is minimal[3].

**Flicker Caused by Grid Connection of Doubly-Fed Asynchronous Wind Turbines**

Flicker is a visual perception of unstable illumination intensity caused by voltage fluctuations. The flicker frequency that is noticeable to the naked eye is generally 0.1 to 35 Hz, and the flicker sensitivity frequency range is 6 to 12 Hz. Flicker can be measured by two indicators, the short-term flicker value $P_{st}$ and the long-term flicker value $P_{lt}$, which are the values reflecting the intensity of the flicker in several minutes and several hours, respectively[2].

Calculation of flicker coefficients available for continuously operating wind turbines

$$C(\phi_k) = P_{st} S_k / S_n$$

In the formula, the short circuit capacity of the power grid is $S_k$, the rated apparent power of the wind turbine is $S_n$. If multiple wind turbines are connected to the same point, the flicker coefficient generated by their interaction is

$$P_{st} = P_{lt} = \left(\sqrt{\sum_i (C_i(\phi_k, v_s) S_{n,i})^2}\right) / S_k$$

In the formula, the single-wind turbine unit flicker coefficient is $C_i(\phi_k, v_s)$, the rated apparent power of the single wind turbine is $S_{n,i}$, $N_{wt}$ is the number of wind turbines connected to the common point.

For the wind turbine during switching operation, to calculate the short-term and long-term flicker coefficient of a single wind turbine, the following formula can be used

$$P_{st} = 18N_{10} k_f(\phi_k) S_n / S_k$$

$$P_{lt} = 8N_{120} k_f(\phi_k) S_n / S_k$$
In the formula, the maximum value of the number of switching operations within 10 minutes is \( N_{10} \). \( N_{120} \) is the maximum number of switching operations within two hours.

To calculate the flicker coefficient of multiple wind turbines connected to the same common point, use the following formula:

\[
P_{st} = 18 \left( \sum N_{10,i} (k_{fl,i} \phi_{k} S_{n,i})^{3.2} / Sk \right)^{0.31} / Sk
\]

\[
P_{lt} = 8 \left( \sum N_{120,i} (k_{fl,i} \phi_{k} S_{n,i})^{3.2} / Sk \right)^{0.31} / Sk
\]

The relationship between the short-term flicker coefficient of a doubly-fed asynchronous wind turbine \( P_{st} \) and the turbulence intensity at different wind speeds is shown in the following table.

<table>
<thead>
<tr>
<th>The turbulence intensity</th>
<th>0.01</th>
<th>0.05</th>
<th>0.08</th>
<th>0.1</th>
<th>0.12</th>
<th>0.16</th>
<th>0.18</th>
<th>0.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V=9 \text{m/s} ) ( P_{st} )</td>
<td>0.008</td>
<td>0.02</td>
<td>0.028</td>
<td>0.046</td>
<td>0.062</td>
<td>0.082</td>
<td>0.09</td>
<td>0.096</td>
</tr>
<tr>
<td>( V=18 \text{m/s} ) ( P_{st} )</td>
<td>0.008</td>
<td>0.008</td>
<td>0.008</td>
<td>0.008</td>
<td>0.008</td>
<td>0.015</td>
<td>0.02</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Figure 2. Relationship between short-term flicker coefficients and turbulence intensity.

### Harmonics Caused by Grid-Connection of Doubly-Fed Asynchronous Wind Turbines

Wind power systems will inevitably use power electronic devices because of the need for grid connection, so the resulting harmonics are inevitable. The main sources of harmonics generated by the integration of the wind farm into the power grid are: (1) Harmonics generated by the power electronic devices required for the wind turbine itself to be connected to the grid; (2) Harmonics generated by resonance of the wind turbine parallel compensation capacitor and the line reactance wave[4].

For multiple wind turbine harmonic currents connected to a common point, the formula is as follows

\[
I_{h\Sigma} = \beta \sqrt{\sum (I_{h_i}/n_i)^h}
\]

\( I_{h\Sigma} \) is the h-harmonic current distortion at the common connection point, the number of wind turbines connected to the common point is \( N_{wt} \), the ratio of the i-th wind turbine transformer is \( N_i \), \( I_{h_i} \) is the distortion of the h-th harmonic current of the i-th wind turbine. Table parameters is \( \beta [3] \).

<table>
<thead>
<tr>
<th>Harmonic times ( h )</th>
<th>( \beta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( h &lt; 5 )</td>
<td>1.0</td>
</tr>
<tr>
<td>( 5 \leq h \leq 10 )</td>
<td>1.4</td>
</tr>
<tr>
<td>( h &gt; 10 )</td>
<td>2.0</td>
</tr>
</tbody>
</table>
The relationship between the excitation current frequency in the rotor of a doubly-fed wind power generator $f_r$ and the mechanical rotation speed of the rotor $n$, and the number of generator pole pairs is $p$ and the grid frequency $f_0$ is

$$f_0 = pn/60 + f_r$$

Therefore, the grid-side frequency of the converter can be controlled by adjusting the frequency of the excitation current in the rotor to reach the grid frequency.[6] The connection structure from the rotor to the power grid is the AC-DC-AC link of the rotor-side converter, DC bus, and grid-side converter, resulting in non-integer frequency fluctuation of the DC bus voltage and modulation of the power grid fundamental wave, forming the grid side Non-integer interharmonics. The main frequency of harmonics between the sides of the six-pulse converter is

$$f_h = 6k(1-s)f_0 \pm f_0 \quad (k=1,2,3,\cdots;s; f_0 \text{ is grid frequency})$$

Conclusion

The cause of voltage fluctuations and flicker in doubly-fed asynchronous wind turbine generators is the instability of wind energy absorbed by the wind turbine, and other factors such as tower shadow effect and yaw error. To minimize the effects of voltage fluctuations and flicker, expand the short-circuit capacity of the connection point and adjust the impedance angle to maintain it between 60° and 70°. The main source of harmonics for double-fed induction generators is the power electronic devices carried by wind turbines, in addition to interharmonics.

Reference


