Study on the Influence of Large-Scale Wind Power Connecting to Power Grid on Voltage Quality Control

Shilong Zhang, Wei Zhang, Qingchao Liu, Chengzhi Lu
Huadian Electric Power Research Institute Co.Ltd. , China

Abstract. As a kind of clean renewable energy, wind power has important application value in the power generation industry. Wind power grid-connected has become one of the important development trends of new energy power generation. Based on large-scale wind power projects, in-depth research on the control of voltage quality in the paper is conducted by large-scale wind power grids. The influence of wind power generation on power quality of power grid is analyzed, and the problems of voltage fluctuation, flicker and harmonics are taken as research objects. Voltage fluctuation and flicker suppression techniques, and power harmonic suppression techniques have been studied as control methods for improving voltage quality. The experimental results prove that the research content of the paper has a good application effect, and it guarantees the voltage quality control for large-scale wind power access to the power grid.

1. Introduction
With the continuous improvement of the level of science and technology, the development speed of China's new energy industry has been far behind by many developed countries, especially the wind power and photovoltaic power generation industry. Since 2003, China's wind power industry has entered a relatively fast growth stage. By the end of 2015, the national wind power grid-connected capacity reached 129 million kilowatts, and the annual power generation was 186.3 billion kilowatt hours, which account for 3.3% of the country's total power generation. However, wind power generation is susceptible to natural factors and has certain randomness and volatility. It is easy to generate wind power penetration power after accessing the distribution network, which increase the difficulty of operation and scheduling of wind power networks, so it can affect the power quality of the entire power system. For example, harmonic pollution, voltage fluctuations, etc. occur in the operation of the power grid. How to seize opportunities and get out of the predicament of new energy companies has become an important topic worthy of in-depth study [1].

2. Influence of wind power generation on power quality of power grid

2.1. Voltage fluctuations and flicker
Voltage fluctuation refers to a series of relatively rapid or continuous changes in the voltage rms value. The magnitude of the voltage fluctuation can be described by the relative voltage variation characteristic $\alpha$ :

$$\alpha = \frac{\Delta \beta}{\beta_0}$$  \hspace{1cm} (1)

In equation (1), the voltage difference at the head end of the line is expressed as $\Delta \beta$; the line rated voltage is expressed as $\beta_0$. 


The characteristics of the wind turbine itself and the grid structure are the main factors causing voltage fluctuations in the wind farm. When the wind farm is running, the active power $V \geq 0$ is sent to the system, and the pressure drop on the wind farm outlet is:

$$\Delta \beta = \frac{PR + QX}{\beta_1}$$  \hspace{1cm} (2)

In equation (2): the line active power loss is expressed as $P$; the line reactive power loss is expressed as $Q$; the line resistance is expressed as $R$; the line reactance is expressed as $X$; the line voltage at the head end is expressed as $\beta_1$.

It can be seen from equation (2) that when the wind turbine output power, especially the reactive power fluctuation, the pressure drop on the wind farm outlet will fluctuate, which causes the wind turbine terminal voltage and grid-connected voltage fluctuations, and causes grid voltage fluctuations. The flicker phenomenon occurs when the output power of the wind turbine is fluctuating greatly [2]. The output power of the wind turbine is calculated as:

$$V = A G_v(x, y) \phi \epsilon^3$$ \hspace{1cm} (3)

In equation (3), the output power is expressed as $V$; the air density is expressed as $\lambda$; the windswept area is expressed as $\phi$; the wind speed is expressed as $\epsilon$; and the wind energy utilization factor is expressed as $G_v(x, y)$.

It can be known from equation (3) that the output power of the wind turbine is related to the wind speed and the air density, and the value fluctuates continuously with the wind between the zero power and the rated power, wherein the wind speed has a greater influence. Due to the randomness of wind speed of wind farms, frequent changes in fan power will cause frequent voltage fluctuations and flicker. In addition, due to factors such as tower shadow effect and yaw error, the torque fluctuation of fan impeller will cause fluctuation of fan output power. [3].

### 2.2. Harmonic

The constant-speed constant-frequency wind power generation system has no power electronic components involved in the operation, so no harmonics are generated. The soft grid-connected device contains power electronic components. When the unit is in operation, some harmonic current will be generated, but it is negligible because of the short time [4].

The variable-speed constant-frequency wind power generation system uses large-capacity power electronic components to generate severe harmonic pollution. The degree of harmonic interference depends on the overall design structure of the power electronic component device and its installation. The performance of the filtering device is also related to the short-circuit capacity of the grid [5]. In addition, when the reactive power compensation device of the wind power generator resonates with the line reactance, the harmonics will be seriously amplified.

### 3. Control method for improving voltage quality

#### 3.1. Voltage fluctuation and flicker suppression technology

The power supply network structure, load characteristics, and power system short-circuit capacity are important factors in determining voltage fluctuations and flicker levels. At the same time, frequent starting of a motor with a large power will also cause a great impact on the system. Therefore, in order to suppress voltage fluctuations and flicker, it is necessary to take corresponding measures from the aspects of selecting compensation devices, improving equipment performance, and improving power supply capability. Generally, the starting characteristics of the motor can be improved by step-down, adding a chopper, and a series resistor[6]. The retrofitting of power supply methods such as the installation of dedicated power supply lines can effectively reduce the severity of voltage fluctuations and flicker problems, but the relationship between investment and efficiency needs to be measured.
economically. Voltage fluctuations and flicker can also be well suppressed by using the fast-reactive power compensation device.

The wind farm voltage control can calculate the reactive power control amount of the wind farm by monitoring the voltage of the wind farm's grid point and combining the grid voltage reference voltage setting value [7]. Specifically, the wind farm voltage control can be implemented by a proportional-integral control link, and the reactive power control amount $Q_c$ of the wind farm is calculated according to the difference between the grid-connected point voltage actual value $U_m$ and its reference voltage set value $U_{ref}$. In the control process, according to the operating state of the reactive controller of the wind farm, the reactive power of the wind farm is constrained by the maximum control amount $Q_{max}$ and the minimum control amount $Q_{min}$, and the reactive power control amount of the wind farm must satisfy:

$$Q_{min} \leq Q \leq Q_{max} \quad (4)$$

Reactive power distribution strategy reactive power voltage control of wind farm is implemented by the DFIG in the wind farm. Therefore, it is necessary to consider how to allocate the reactive power of each DFIG. In the allocation process, you need to consider the reactive constraints of each DFIG. In the paper, when assigning reactive power control, the adjustment ability of each DFIG in the dynamic operation process is considered. Defining the controllable reactive power adjustment capability of the $i$-th DFIG is $K_i$ and $L_i$:

$$K_i = \frac{Q_{max,i} - Q_{q,i}}{Q_{max,i}} \quad (5)$$

$$L_i = \frac{Q_{q,i} - Q_{min,i}}{Q_{min,i}} \quad (6)$$

In equation (5,6), $Q_{max,i}$ is the reactive power upper limit of the $i$-th DFIG; $Q_{q,i}$ is the current reactive output value of the $i$-th DFIG; $Q_{min,i}$ is the reactive power lower limit of the $i$-th DFIG; $K_i$ is the reactive power increasing capability of the $i$-th DFIG; $L_i$ is the reactive power reduction capability of the $i$-th DFIG.

When assigning the reactive power control amount of each DFIG, first, the controllable reactive power adjustment capability of each DFIG is calculated according to equations (5) and (6), and DFIG that satisfies equation (4) is selected as the reactive power control unit; a value below 10% can be taken. When the reactive power adjustment capability of DFIG is large $\eta$, it indicates that this DFIG has certain reactive power adjustment capability, and this DFIG is called to perform reactive power control. When the reactive power adjustment capability of DFIG is less than $\eta$, it indicates that this DFIG basically does not have reactive power adjustment capability, and does not call this DFIG for reactive power control. It is assumed that the DFIG that satisfies the requirements constitutes a set $u$. When the voltage of the grid-connected point fluctuates, the reactive power control amount of the wind farm is calculated by measuring the voltage of the grid-connected point, and is allocated according to the reactive power adjustment capability of each DFIG.

3.2. Power Harmonic Suppression Technology

With the increasing demand for filtering effects and the advancement of fully-controlled power device technology, active power filters have begun to receive attention. The active power filter can passively absorb the fixed harmonics relative to the passive filter, and can dynamically generate a current that is consistent with the shape of the compensated harmonic and opposite in phase to cancel the harmonic current generated by the nonlinear load and achieve the purpose of suppressing harmonics. The active power filter has a fast response speed, and can realize dynamic tracking compensation. The filtering effect is not affected by system parameters, which can make it a good choice for suppressing power harmonics. In addition, other static var compensators such as reactors and capacitors can also suppress harmonics.
Active power filter is a new type of power electronic device for dynamically suppressing power system harmonics and compensating reactive power. It can dynamically compensate power system harmonics and varying reactive power that vary in size and frequency. The active power filter generally consists of two parts: a command current calculation circuit and a compensation current generation circuit. The function of the command current calculation circuit is to detect current components such as harmonics and reactive power in the compensation target current, and is therefore also referred to as a harmonic and reactive current detection circuit. The compensation current generating circuit is actually a harmonic current compensator capable of outputting a current corresponding to the harmonic component of the load current, so that cancel the harmonic current generated by the nonlinear load. The filter effect is shown in Table 1.

Table 1. Data comparison before and after filter input

| Harmonic times | Before the filter is put in | After the filter is put in |
|----------------|-----------------------------|---------------------------|
| Voltage        | THD (%)                     | Absolute value (%)        |
| Total amount   | 5.16                        | 2.25                      |
| Total amount   | 21.26                       | 4.46                      |
| Current        | THD (%)                     | Absolute value (%)        |
| 3              | 0.61                        | 0.31                      |
| 5              | 18.55                       | 3.63                      |
| 7              | 4.61                        | 1.47                      |
| 9              | 0.17                        | 0.03                      |
| 11             | 2.63                        | 0.61                      |
| 13             | 0.88                        | 1.37                      |
| PF             | 0.99                        | 1                         |

The data in Table 1 demonstrates the effect of dynamically suppressing power system harmonics and compensating reactive power using an active power filter. According to the data analysis, the actual effect of applying active power filter to the large-scale wind power inlet is shown in Figure 1.

Figure 1. Parameter changes of active power filter applied to large-scale wind power generation inlet
In Figure 2, the power parameter changes of the active power filter applied to the large-scale wind power generation inlet indicates that the device can detect the current components such as harmonics and reactive power in the compensation target current, so as to guide the control to reduce the harmonics. The effect is shown in Figure 2.

![Figure 2. Active power filter applied to harmonic changes in large-scale wind power inlets](image)

After parameter and actual effect analysis, the results of active power filter application before and after large-scale wind power access are evaluated as follows:

1. After the active filter is put into operation, the voltage and current waveforms are significantly improved.
2. After the active filter is put into operation, the voltage and current harmonics are obviously improved, the total distortion rate of voltage harmonics is reduced from 5.16% to 2.25%, and the total distortion rate of current harmonics is reduced from 21.26% to 4.46%.
3. The current harmonics are mainly 5, 7 and 11 times. After the filter is input in, the total harmonic current and the filtering rate of each major harmonic current are extremely high, which fundamentally solves the harmonic problem.
4. The power factor is kept above 0.99.

4. Conclusion

The development of science and technology has promoted the progress of the new energy industry, and wind power technology will be fully developed. As the grid-connected capacity of wind turbines increases, the impact on grid power quality will be more pronounced. In order to improve the safety and stability of wind power grid connection, relevant units should further strengthen research on wind power generation technology. By effectively dealing with harmonics, voltage flicker and fluctuations, etc., the power quality of the grid is ensured, and the stable operation of the entire power system is promoted.

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