Influence of wind power grid connection on power quality and reactive power compensation scheme

Jingjing Yang¹, Song Wang²*, Yan Tian², Ruining He², Pengtao Dong¹, Mingjie Huang¹, and Xiaoliang Liu¹
¹Weifang Power Supply Company, State Grid Shandong Electric Power Company, Weifang, China
²School of Mechanical, Electrical & Information Engineering, Shandong University, Weihai, China
*Corresponding author e-mail: wszbs3@sdu.edu.cn

Abstract. In order to explore the influence of wind power grid connection on power quality and its control scheme, this paper builds a wind power generation system model in PSCAD software, and studies the changes of active power, reactive power, DC bus voltage and harmonics of wind farm when wind speed changes according to the models of basic wind, gust wind, gradual change wind and random wind. And compare the electrical energy indexes before and after the installation of reactive power compensation devices SVC and STATCOM to verify the control effect of the reactive power compensation devices on the electrical energy quality.

1. Introduction
The large-scale development of wind power is one of the most important means for all countries in the world to deal with the increasingly urgent environmental deterioration and the strategic demand for energy security. The installed capacity of wind power in our country is also increasing year by year. However, due to the randomness of wind power, the output of the wind farm cannot be controlled. After large-scale wind power being connected to the grid, the level of power grid indicators such as voltage deviation, voltage fluctuation, flicker and harmonics will obviously drop [1]. In order to ensure that the power quality meets the requirements, it is necessary to analyze the power quality, judge various factors affecting it, and improve the power quality.

In this paper, basic wind, gust wind, gradual change wind and random wind are analyzed and simulated in theory, and explore the output of wind power grid-connected system when wind speed changes. The wind power grid-connected system model is built on the PSCAD software platform, and the control effects of reactive power compensation control devices SVC and STATCOM on the power quality are analyzed respectively, which verifies the feasibility of adding reactive power compensation devices to improve the power quality and reactive power compensation [2].

2. Wind speed model and its influence on grid connection

2.1. Wind speed model
The simulated air volume usually consists of four wind speed models, namely, basic wind model, gust model, gradual change wind model and random wind model, which is single or combined.
Basic wind model. The basic wind model is usually established by Weibull distribution (Weibull) parameters obtained from wind speed measurements at the location of the wind farm. The mathematical expectation of Weibull distribution is

\[ \bar{v} = A \tau \left(1 + \frac{1}{K} \right), \quad (1) \]

where \( \bar{v} \) is basic wind, m/s; \( A \) is scale parameters of bull distribution; \( \tau \left(1 + \frac{1}{K} \right) \) is gamma parameter.

When consider the simulation of seconds, the basic wind can be set to a constant, which is set to 11 m/s in this model.

Gust model. Gusts can usually be used to express sudden changes in wind speed. The expression of gusts \( v_{WG} \) is as follows.

\[ v_{WG} = \begin{cases} 0, t < t_{IG} \\ v_{cos} \times t_{IG} < t < t_{IG} + t_G \\ 0, t > t_{IG} + t_G \end{cases} \quad (2) \]

\[ v_{cos} = \frac{MaxG}{2} \left[1 - \cos \left(2 \pi \frac{t - t_{IG}}{t_G} \right) \right]. \quad (3) \]

Where, \( MaxG \), \( t_G \), \( t_{IG} \) are respectively expressed as gust maximum, acting time and starting time.

Fig.1 depicts a simulated gust with a basic wind speed of 11 m/s, a maximum of 5 m/s, an acting time of 1s and a starting time of 3s.

As can be seen from Fig.1, the wind speed produced a gust of wind with a maximum speed of 5 m/s from 11 m/s at 3 seconds. The maximum wind speed reached 16 m/s and then returned to 11 m/s at 4 seconds.

Gradient wind model. The gradual change wind model is usually used to reflect the gradual change of wind speed. Fig. 2 shows a simulated gradual change wind with a basic wind speed of 11 m/s, a maximum of 5 m/s, a duration of 2s, and a starting time of 3s.

As can be seen from Fig. 2, the wind speed changed from 11 m/s to 11 m/s at 3 seconds, with a maximum speed of 5 m/s. The maximum wind speed reached 16 m/s and then returned to 11 m/s at 5s.

Random wind model. The random characteristics of random wind speed changes can be expressed by random noise wind speed components. Fig.3 is a simulated random wind speed sequence with a basic wind speed of 11 m/s, a noise amplitude control parameter of 0.05 rad/s, a surface resistance coefficient of 0.0192, and a disturbance range of 600 m.

2.2. Influence of wind speed change on grid connection

During this transient simulation process, the wind speed will slowly change around the nominal speed of 11 m/s, and the active power, reactive power, DC bus voltage and harmonic changes of the wind farm are observed in Fig.4.
From Fig.4 (a) to (e), it can be seen that when the wind speed is higher or lower than the nominal value, the change trend of the active power output from the wind farm is similar to that of the wind speed. But there is a certain lag. The reactive power, DC bus voltage and harmonics all fluctuates in a small range. From the simulation images obtained, it can be seen that the change of wind speed will affect the power quality of the system to some extent.

3. Reactive power compensation device for wind farm

The control of wind farm power quality is usually embodied in reactive power compensation and harmonic suppression. In terms of reactive power compensation, it can be divided into static reactive power compensation and dynamic reactive power compensation [3].

3.1. Wind farm management based on static var compensator (SVC)

SVC can control itself to absorb or emit reactive power according to the changes in control parameters of power system. It has fast response, reliable operation, wide application range and low price, which is widely used in power systems [4].

In order to absorb and adjust the inductive or capacitive reactive power at the same time in common power systems, TCR and TSR are usually used to form reactive power compensation devices. The single-phase schematic diagram of TCR and TSC is shown in Fig.5.

![Figure 5. Thyristor controlled reactor and thyristor switching capacitor single-phase schematic diagram](image)

The wind farm simulation model with SVC installed for power quality control is shown in Fig.6.
Figure 6. Wind farm simulation model with SVC

In the simulation model, the parameters of the SVC module are set to be consistent with the overall parameters of the wind farm. The transformer capacity is set to 5.5 MVA, and the primary side rated voltage is 154 KV and the secondary side is 33 KV. The fault type is designed as a three-phase short circuit to ground. The fault occurs at 2s and lasts for 0.1s. The waveform diagram of the system simulation is shown in Fig.7 to Fig.11.

Figure 7. Active power of wind farm grid connection before and after SVC installation

Figure 8. Reactive power of wind farm grid connection before and after SVC installation

Figure 9. Outlet voltage wind farm grid connection before and after SVC installation

Figure 10. DC bus voltage of wind farm grid connection before and after SVC installation

Figure 11. Harmonic voltage of wind farm grid connection before and after SVC installation
According to the simulation waveform, after adding SVC, the power quality is significantly improved. It can be seen that the active power fluctuation caused by the failure of the wind farm is obviously smoother after installing SVC. At the same time, the reverse spike of reactive power is not as steep as it was. Meanwhile, the export voltage of the wind farm also returns to normal quickly, and the fluctuation of DC bus voltage decreases obviously. Therefore, after adding SVC, when the voltage of the wind farm drops, SVC sends out reactive power, which makes the voltage of the wind farm outlet rise and keep constant. When the wind farm voltage rises, it absorbs reactive power and lowers the voltage value. SVC smoothes the voltage fluctuation and has a good control effect on the power quality.

3.2. Wind farm management based on static synchronous compensator (STATCOM)

STATCOM is a reactive power dynamic compensation device composed of bridge power electronic converter and large capacity capacitor [5]. The dynamic reactive power compensation can be realized by changing the magnitude of the voltage applied to the reactor and controlling whether STATCOM draws ahead or lags behind the current from the power grid. Compared with SVC, STATCOM has faster response speed, wider operating range and smaller harmonic current content. Since the current transmission lines are mostly three-phase four-wire systems, the most commonly used structure is the three-bridge arm circuit.

![Figure 12. Circuit of STATCOM with three-arm voltage type](image)

Fig.12 shows the main circuit diagram of the voltage-type three-bridge arm STATCOM. Six power electronic switches complete the converter function and the DC capacitor stores energy. Under normal working conditions, the voltage of the capacitor connected to the DC side keeps constant, so it can be regarded as a voltage source.

![Figure 13. Equivalent circuit and vector diagram of STATCOM](image)

The single-phase equivalent circuit and vector diagram of STATCOM is shown in Fig.13.

Set the grid voltage to \( \hat{U}_S \) and STATCOM output voltage to \( \hat{U}_{ST} \). The voltage \( \hat{U}_L \) on reactor X between the grid and STATCOM is the vector difference between the two. Ignoring the active power loss, only changing the magnitude of \( \hat{U}_{ST} \) can control whether STATCOM’s current \( \hat{I}_S \) drawn from the power grid is ahead or behind. STATCOM absorbs capacitive reactive power when \( \hat{U}_{ST} \) is greater than \( \hat{U}_S \); When \( \hat{U}_{ST} \) is less than \( \hat{U}_S \), the voltage leads the current by 90 degrees and absorbs the reactive power.

The wind farm simulation model with STATCOM is shown in Fig.14.
In the simulation model, the parameters of STATCOM module are set to be consistent with the overall parameters of the wind farm. The transformer capacity is set to 550 MVA, and the rated voltage on the primary side and the rated voltage on the secondary side are 154 KV and 33 KV respectively. The fault type is designed as a three-phase short circuit to ground. The fault occurs at 2s and lasts for 0.1s [6]. The waveform diagram of system simulation is shown in Fig.15 to Fig.19.
The simulation results show that the active power and reactive power of wind farm is more stable and the overshoot of active power is obviously reduced after installing STATCOM. Especially reactive power, output curve and its stability show that STATCOM plays a great role in the reactive power compensation process. For DC bus voltage, the output voltage waveform overshoot is small, and the output voltage is not overshoot. At the same time, STATCOM has faster response speed than SVC, so it can adjust the output voltage of the wind farm faster. As for harmonic voltage, the waveform after adding STATCOM is smoother and softer, which shows that it has good control effect on harmonic voltage.

4. Conclusions
The wind farm composed of doubly-fed asynchronous wind turbine is simulated and analyzed, and its active power and reactive power output under different wind speeds is analyzed. Through simulation analysis, it can be seen that when the wind speed changes, the active power output from the wind farm will be greatly influenced, and there will be some lag, while the reactive power, DC bus voltage and harmonic wave fluctuation will be relatively small.

SVC and STATCOM reactive power compensation devices are added to the established wind farm model respectively, and the compensation functions of the two reactive power compensation devices to the power quality are analyzed respectively. Through simulation research and analysis, both of the two power compensation devices can have a positive impact on power quality control. The specific performance is that they can reduce voltage fluctuation and voltage deviation and compensate the reactive power output. Compared with SVC, STATCOM has faster response speed and better output characteristics, thus it is more advanced and efficient.

Acknowledgments
The authors wish to thank the corporate researchers in the common laboratory for the generous help of simulation program and experiment.

References
[1] Bai Hongbin, Wang Ruihong, “Influence of the Grid-connected Wind Farm on Power Quality,” Proceedings of the CSU-EPSA, pp.120-124, Feb. 2012.
[2] Feijoo, A.E., Cidras J, “Modeling of Wind Farms in the Load Flow Analysis,” IEEE Transactions on Power Systems, pp.110-115, Vol. 15, 2000.
[3] Jiabing Hu, Yikang He, Lie Xu, et al, “Improved Control of DFIG Systems During Network Unbalance Using PI-R Current Regulators,” IEEE Transactions on Industrial Electronics, pp. 439-451, Vol. 56, 2009.
[4] Cai Zhi, Liu Jianzheng, Wang Jian, Liu Shu, “Simulation Research on Control Modes of Doubly-Fed Wind Power Generator Based on PSCAD,” Electrical Technology, pp. 61-64, May. 2008.
[5] Bostjan Blazic; Igor Papic, “STATCOM Control for Operation with Unbalanced Voltages,” 2006 12th International Power Electronics and Motion Control Conference, pp. 1454-1459, 2006.
[6] Liu Wei, “Evaluation and Control Measures on Power Quality of Wind Power Grid,” Beijing Jiaotong University. 2014.