Analysis on Wind Power Plant Voltage Quality and Design of STATCOM Control

Cai Liang*, Tuo Liu, Li Ma and Shangdong Yang
State Grid Energy Research Institute, Beijing, China
*Corresponding author

***Abstract*—Due to the randomness and volatility of wind power, the problems of voltage fluctuation, harmonic and so on will have a serious impact on the power quality of power grid. (Which produces a voltage fluctuations, harmonics and other power quality problems will severely affected power grid.) The wind turbine (generator system) simulation model is established based on the Gansu Hexi grid-scale wind power projects, power quality characteristics of wind turbine grid is analyzed and the impact on the grid is proposed. STATCOM is proposed for power quality control to wind farm, and technical solutions is designed, the results of simulation analysis demonstrate the effect of STATCOM control. It provided a reference to the future management of power quality.**

Keywords-wind power; power quality; STATCOM; control

I. INTRODUCTION

China has abundant wind resources, and as an important direction for the development of new energy, the scale development momentum of the wind power is strong [1]. Wind power station use the wind as the power source, due to the random variation of wind speed and wind direction, the output of the wind power will also fluctuate randomly, resulting in the grid voltage fluctuation. The influence of wind shear, tower shadow and so on, which are inherent in the wind turbine, can also cause the voltage fluctuation of the power grid, and then make the grid appear flicker phenomenon [2]-[3]. Due to the application of converter of variable speed wind turbine, lots of harmonics will be generated and injected into the power grid, causing power quality problems worsen, thus it is necessary to analyze the power quality characteristics of the station and put forward the control measures [4]-[6]. The development of power electronic technology provides a solid technical basis for the problems of power quality, take the STATCOM as an example, which and other power electronic devices represent the development direction of the power quality control technology at the present stage. Relying on the large-scale wind power access network project in Hexi area of Gansu Province, this paper analyzes the characteristics of power quality of wind warm, and provides protection for wind power access and power grid security and stability operation.

II. ANALYSIS ON WIND PLANT VOLTAGE QUALITY

A. Principle and Classification of Energy Conversion for Wind Turbine Generator System

The progress of wind power generation is that the natural wind rotating the impeller and driving the wheel rotation, which change wind energy into electrical energy, and then send the mechanical energy to the generator rotor by means of the transmission mechanism in order to drive the rotor to generate electricity, which achieve the conversion of mechanical energy to electrical energy, and finally, the electric is inject into the power grid through the booster substation.

The relationship between the output power of the wind turbine and the wind speed can be expressed as:

$$\begin{cases} P = \dfrac{1}{2}\rho A v^3 C_p(\lambda, \beta) \\ \lambda = \dfrac{\omega R}{v} \end{cases} \tag{1}$$

In the formula,

P ——output power of the wind turbine (W)
ρ ——air density (kg/m^3)
A ——blade sweep area (m^2)
v ——wind speed (m/s)
λ ——tip sweep ratio
ω ——impeller speed (rad/s)
R ——impeller radius (m)
β ——Pitch angle
C_p ——wind energy utilization coefficient

According to the operation mode, the control principle or the topological structure of the wind turbine, there are many kind of classification methods, and in this paper, the main types of variable speed wind turbine based on doubly fed induction generator are discussed.

B. Model Building of Wind Turbine Generator System

The power quality characteristics of the wind farm are affected by the type of the wind turbine, the structure of the wind turbine and the speed of the wind, etc., and also affected

by the structure parameters of the network injected. During the simulation of regional power grid, the most important concern should be the most serious impact of wind farm on power grid. Since the wind farm is usually made up of hundreds of wind turbine, and there may be a number of wind farms in a regional power grid. It is complicated and meaningless to model all the turbines in all wind farms, thus the method of equivalent current source is adopted to simulate the power quality disturbances in the power grid of the wind farm.

Considering the most used of the wind turbine are variable speed turbines, therefore, this paper focuses on the model of variable speed wind turbine. The model diagram is shown in Fig.1. Setting the capacity of the wind turbine is 140MVA, the equivalent of 70 double fed wind turbines and each one with the capacity of 2MVA. The simulation model can be used to achieve constant reactive power control and constant power factor control, but can't be controlled by variable pitch control. The wind turbine is linked into 110KV system bus, and the bus is connected with the load of 60MW+7MVar, in order to eliminate the influence of system parameters on the power quality characteristic of wind turbine, the simulation set of short circuit capacity is large, equivalent to the ideal power supply.

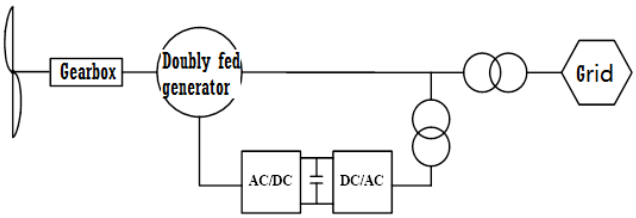

FIGURE I. VARIABLE SPEED (DFIG) WIND TURBINE SIMULATION MODEL.

C. *Simulation and Analysis of Power Quality Characteristics*

1) *Analysis of Voltage Deviation Characteristic*

Fig II is the reactive power and voltage curves in the 110kV side of the wind farm under the change of wind turbine output when the use of the method is constant reactive power control (110kV side reactive power is constant 20MVar) and constant power factor control (110kV side power factor constant is 0.98). Known by Figure a, the reactive power absorbed by the wind power generator is small, and the bus voltage of the system can be kept at about 1.0p.u. From Figure b we can see that the reactive power can be kept constant under the change of wind turbine output so as to ensure that the bus voltage of the system side is basically constant.

From what has been analyzed above, we can see that it is flexible to the double fed induction generator to achieve constant reactive constant reactive power (lead and lag) and constant power factor control, so it has little influence on the voltage deviation of the power network. In addition, it can be used as a useful supplement to the power grid, which plays a role in regulating the power grid.

2) *Analysis of Voltage Fluctuation*

In this section, the voltage fluctuation characteristics of wind turbine under the influence of wind speed were simulated, analyzed the variation of the output power of the wind turbine and the change of the 110kV high side voltage of wind turbine in three wind disturbance. From the result of the simulation we can see that under the change of the wind speed, the output power of the wind turbine is fluctuating, but the changes of the network voltage value is small, the basic can be maintained at about 1.0p.u.

3) *Analysis of Harmonic Characteristic*

Since there is a high power AC-AC converter existed in the

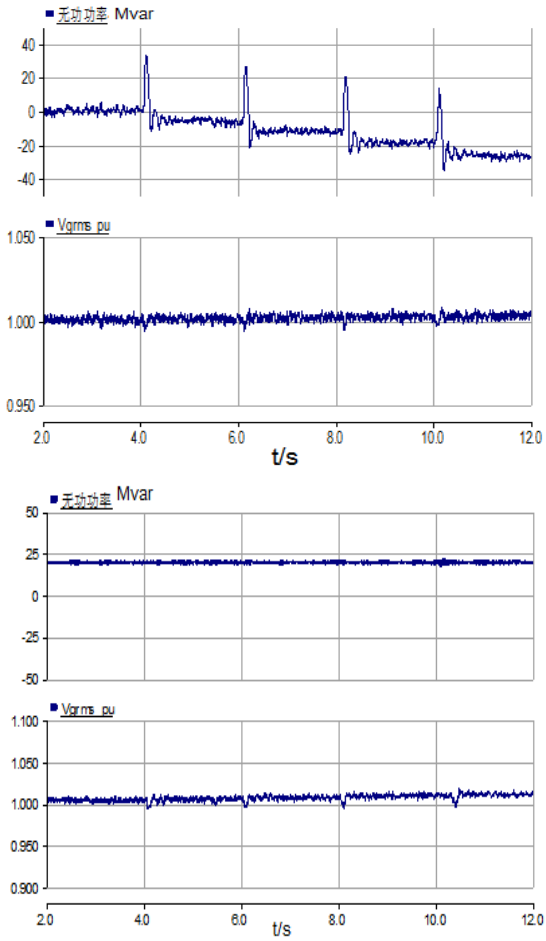

FIGURE II. VOLTAGE BIAS SIMULATION RESULTS. (A) CONSTANT POWER FACTOR CONTROL. (B) FIXED REACTIVE POWER CONTROL.

double fed induction generator, the control method adopted by the converter directly determines the harmonic characteristic of the wind turbine. Table I are the simulation results of the harmonic current value and the rate of the system side 110kV bus when the double fed wind turbine is in the case of 70% output. In this simulation, the CRPWM control method is adopted in the rectifier side of the double fed generator, the SPWM control method is adopted in the inverter side, and no filter is added. Under this condition, the content of each harmonic is higher, and the content of 3th, 5th, 7th harmonic is the most, and there are plenty of even harmonics.

TABLE I. HARMONIC CURRENT OF THE VARIABLE SPEED WIND TURBINE

Harmonic frequency	Containing rate (%)	Harmonic current value(A)
2	2.99	14.67
3	8.28	40.59
4	2.90	14.22
5	9.46	46.37
6	2.49	12.20
7	6.04	29.61
8	2.63	12.88
9	1.88	9.19
10	1.94	9.51
11	2.24	10.98
12	2.35	11.53
13	2.99	14.67
14	5.84	28.62
15	1.80	8.84
16	2.10	10.28
17	0.37	1.82
18	0.48	2.33
19	2.64	12.93
20	1.05	5.16
21	1.09	5.35
22	0.92	4.50
23	1.18	5.76
24	1.80	8.82
25	0.73	3.57
Fundamental current(A)	490	

III. DESIGN OF STATCOM CONTROL SCHEME

A. *Principle of STATCOM*

Figure III is the schematic diagram of the structure of STATCOM access system, in which the DC side is the energy storage capacitor, providing DC voltage support for STATCOM. The VSC invertor is usually made up of several inverters in serious or parallel connection, and its main function is to transform the DC voltage into the AC voltage whose size, frequency and phase can be controlled [10].

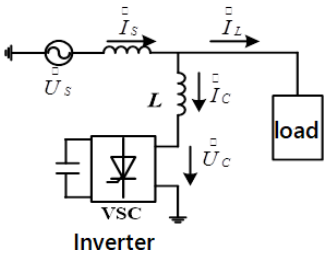

FIGURE III. SCHEMATIC DIAGRAM OF STATCOM SYSTEM

B. *Design of Management Scheme*

In this paper, the control scheme design of a wind farm in Hexi area of Gansu is selected. The installed capacity of wind farm is 49.5MW, and the wind turbine is FD82 double fed induction generator. After the booster of the box transformer, the wind turbine is fed into the 35kV line and then through a 35/363kV main transformer connected to the 330kV power grid.

Fig IV. are the changes of active and reactive power of wind farm under the change of wind speed. During the simulation, the constant power factor of wind farm is set to 0.98, and we can see from the simulation results, the maximum reactive power can reach 12Mvar under the condition of the simulation. So it is needed to be equipped with quick adjustment reactive power compensation.

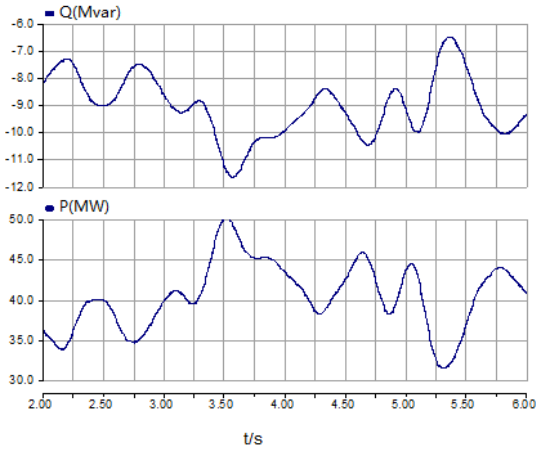

FIGURE IV. THE OUTPUT POWER UNDER CHANGING IN WIND SPEED

Fig V shows the frequency spectrum of each harmonic voltage of the 35kV side when the output of the wind turbine is 45MW, among which, the 5th and 7th harmonic has the highest rate, so it should be equipped with a reasonable 5th and 7th filter.

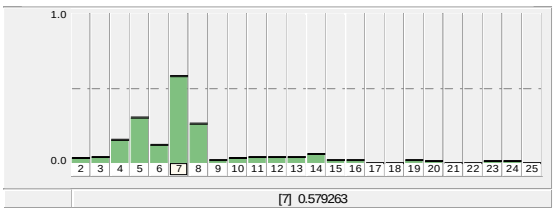

FIGURE V. HARMONIC VOLTAGE SPECTRUM (35KV SIDE)

From the analysis, it's known that the voltage deviation and voltage fluctuation caused by harmonic and reactive power fluctuation are the main power quality problems of wind farm. So it is an effective method to take the LC filter and STATCOM dynamic adjustment of reactive power to manage it.

a) Design of LC Filter

The interval of power factor of wind power generator is (0.95~1), and the maximum reactive power of wind farm is 16.26Mvar. Considering a certain margin, the capacitance of the LC filter can be designed as 18Mvar (the 5th filter branch is 9Mvar and the 7th filter branch is 9Mvar), and the reactive power control objectives can be achieved by packet switching in order to meet the different output power of the wind farm. LC filter is installed in the 35kV bus side of the wind farm.

b) Design of STATCOM

The voltage level of the device designed is 10kV, considering the high voltage resistance and the cost of the device, the Y chain cascade structure is adopted, which is connected with the system by the reactance, and is connected to the 35kV bus side of the wind farm by 10/35kV boost transformer. From the calculating, we can gain that the reactance value is 6.5mH when the inductive reactive power output of the device is maximum.

The design of the DC voltage of the device depends on the size of the output capacitive reactive power, since the capacitive reactive power compensation of wind farm is mainly completed by the LC filter, so the output voltage of the device can be equal to or slightly higher than the phase voltage of the 10kV system(5.77kV). According to the modulation ratio is generally 0.85 or so, we can get the DC voltage of the device should not be less than 9.6kV. Taking into account the current commonly used IGBT module voltage level is 1200V, the DC voltage is usually designed in 0.9kV, then we can get 11 cascaded H bridges. According to the redundancy design of N+1, the number of the modules is 12.

C. Analysis of Control Effect

Based on the results of the above scheme, the STATCOM control effect of the wind farm is simulated and analyzed. Setting the wind farm to emit 40MW active power under the action of wind disturbance, then put all the LC filter bank in 3s, and put the STATCOM in 6s. Figure VI shows the simulation waveforms of the input or output of the LC filter and the STATCOM. In the figure, when the reactive power is positive, the device emit capacitive reactive power, when the reactive power is negative, the device absorb reactive power, but it is opposite to STATCOM. From the figure we can see, after the input of the LC filter, the inductive reactive power (-7.5Mvar~11.4Mvar) absorbed by the wind farm was compensated to capacitive reactive power (6.4Mvar~10.4Mvar) or so. When the STATCOM is put into the system, the compensation device absorbs inductive reactive power, which makes the system side reactive power -1.7Mvar to +1.7Mvar. Comparison of reactive power curve of wind farm with the input of the LC filter and the reactive power of STATCOM shows that the device basically can track the reactive power required by the compensation.

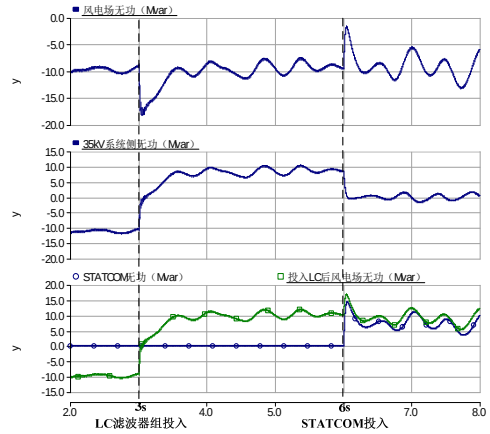

FIGURE VI. FIG.VI. REACTIVE POWER CONTROL SIMULATION RESULTS OF STATCOM

Fig.VII. shows the variation curve of the total harmonic distortion rate of the 35kV side bus. The simulation results show that the total harmonic distortion rate of the system can be reduced from 4.1% to 1.9% after the input of the LC filter.

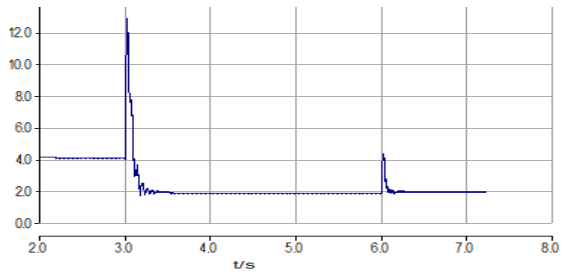

FIGURE VII. STATCOM HARMONIC MAP OF WIND FARM

IV. CONCLUSION

In this paper, the mechanism of voltage deviation, voltage fluctuation, flicker and harmonic problems caused by the connected between the wind turbine and grid are analyzed, and the simulation modeling of the typical wind turbine is carried out. On the basis of the analysis of the power quality characteristics of the wind farm, considering the factors such as the compensation effect and the comprehensive cost, the control scheme of the power quality of the wind farm is designed in detail, which is based on the STATCOM application. The simulation results show that STATCOM has good control effect on all kinds of power quality problems of wind farm. The research results provide a theoretical basis for the analysis of the influence of wind farm on power quality of power grid.

REFERENCES

[1] Dai huizhu,Chen mozi,Wang weisheng,et a1.The status of wind power development and technical supports in China[J]. ElectricPower, 2005, 38(1):80-84.

[2] GaoXiuying.On the Issue of the Quality of Power and the Measures

of Improvement [J]. Applied Energy Technology, 2010, 4:41-45

[3] Wu Qiong. The study to the power quality problems of wind farm connected to the grid [D]. Nanchang: Nanchang University, 2008.

[4] Chi YongNing,Liu Yanhua,Wang Weisheng,et a1.Study on impact of wind power integration on power sysytem[J]. Power System Technology, 2007, 31(3):77-81.

[5] Technical Rule for connecting wind farm into power grid.STATE GRID. Q/GDW 392-2009.

[6] Hu Wen-jin, Wu Zhigang, Zhang Yao, Zhong Qing. Analysis and Evaluation on the Electric Power Quality of the Wind Farm [J]. Prceedings of the CSU-EPSA,2009,21(4):82-87

[7] Sun Tao,Wang Wei sheng,Dai Hui zhu,et al.Voltage fluctuation and flicker caused by wind power generation[J] . Power System Technology, 2003, 27(12):63-70.

[8] Wu Yi-chun, Ding Ming. Simulation Study on Voltage Fluctuations and Flicker Caused by Wind Farms [J]. Power System Technology,2009,33(20):125-130

[9] Brenna, M., Foiadelli, F., Zaninelli, D. Electromagnetic Model of High Speed Railway Lines for Power Quality Studies [J]. IEEE transactions on power system,2010,25(3):1301 – 1308

[10] Shen Dong,Jiang Qirong,Han Yingduo.A per-unit STATCOM model and analysis of open lop response time constant[J].2000,20(7):56-6l.