Simulation of Power Quality Issues of Wind power integrated systems and results analysis

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Abstract: The randomness of wind energy and its uncertainty of forecasting have caused serious power quality problems, which restrain the further development of wind farms. Therefore, it is a hot topic to research and solve the power quality problems of wind farms. This paper describes the important aspects of power quality problems about the voltage fluctuations and flicker, harmonic, voltage deviation of the wind farm combined with the measured data of Baolian wind farm. Finally, the loss of a real wind farm is also considered by a simulation model.

Key Words: Wind energy, Sower quality, Baolian wind farm

6) Introduction

With strongly support of the government, wind power play an important role in the field of electric energy due to its unique merits, such as economic, environmental and other technological issues. By the end of 2016, the capacity of wind power integration is about 134,000 MW in china. However, with more and more wind power being integrated into the power grid, the impact of wind farm's power quality cannot be ignored, that is, the randomness of wind power and its uncertainty of forecasting bring a series of problems. Secondly, due to the wind farms always adopt double fed wind power generator and direct driven wind power gener-ator, these two models all contain back-to-back power electronic converters, and they will produce a certain amount of harmonics during the working process, the har-monic current produced by single turbine is not large, but the harmonic problems caused by all turbines in a wind farm cannot be ignored. Besides, there may exist mutual influ-ence between each wind turbine, which makes harmonic problem more serious. In addition, transformers and cables may also cause harmonic resonance, which can amplify the specific harmonic. Finally, the wind farms also have another problems such as voltage fluctuations, flicker. These typical problems of wind farms will increase the loss of electricity equipment, and even lead to the wind farm off-grid opera-tion, and can result in huge economic losses [1, 2]. There-fore, it is necessary to analyze the power quality of the wind farm, and comprehend its harmonic characteristics, which will contribute to improve the operating conditions and efficiency of the wind farm.In order to ensure measurement for power quality prob-lems and keep the power system stable, Chinese Power Quality standard, IEC 61400-21 standard 2008 and IEEE standard have specified the rating of the system parameters and its allowable variation range [3, 4, 5, 6, 7]. In addition, IEC standard also presents measurement method of related parameters, which has been widely acceptable and utilized. The main content of this paper is exploring the distribu-tion law of power quality in the wind farm according to the operation data of Baolian wind farm, such as harmonic distribution, voltage deviation, voltage flicker, voltage fluctuation and so on. Firstly, the topological structure of Baolian wind farm is introduced, and the basic operation principle of wind power integrated system is described simply. Secondly, the main aspect of power quality is pre-sented, and summarizing its basic meaning simply. Then, according to the actual wind farm data, the voltage fluctua-tion, flicker, harmonic current and voltage deviation are analyzed in detail and try to find its distribution character-istic as well. Then, the operation loss of the wind farm is obtained by a simulation model. Conclusion is given in the last part.

5) The Structure of Baolian Wind Farm

Baolian wind farm is located in the central of Hunan Province, its topological structure is shown in Fig. 1. The wind farm consists of 25 permanent magnet direct drive wind turbines, the installed capacity of each turbine is 2MW. Each turbine is connected to the cable by a booster trans-former, then all the wind turbines connect with a grid-connected transformer by the cable, and the wind power can transmit to the grid by the grid-connected trans-former. Besides, the wind farm using inductive filtering to achieve the purpose of

harmonic suppress [8]. The wind farm has been tested for a long time, and we obtained the real data of wind farm operation. This paper mainly analyzes the problems of voltage fluctuation, voltage flicker, har-monics and so on.

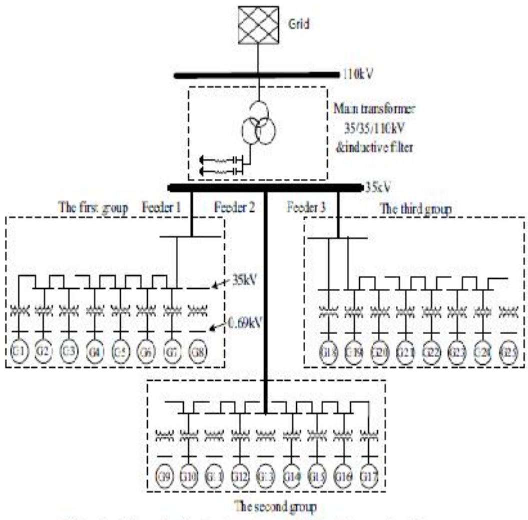

Fig. 1: Topological structure of Baolian wind farm

5) Power Quality Problems

3.1 Voltage Fluctuations and Flicker

Voltage fluctuations refer to the change of the output voltage RMS value. voltage fluctuations in wind farm are generally divided into two types: 1) the voltage swell and sag caused by the wind turbines frequently startup and shutdown; 2) when the wind turbines in continuous opera-tion, the voltage fluctuations can caused by the uncertain wind speed, the wind turbine parameters and the grid con-ditions. Besides, severe voltage fluctuations may cause flicker on the load side [9, 10, 11]. Generally, in order to reduce voltage fluctuation of the first type, we can configure the capacitance or inductance reactive power

compensation device at the wind turbines side, but this approach doesn't work in the second situation.

In order to reduce the impact of voltage fluctuation, the international standards strictly define the range of voltage fluctuations in wind farms. According to the flicker occur-rence rule, it can be divided into two types: short time flicker P_{st} and long time flicker P_{lt} [3, 4, 5, 6, 7]. The flicker limit value of each voltage level in the wind farm is

given in the standard "Power quality - Voltage fluctuation and flicker", as shown in Table 1. When users connected to the PCC are at the same voltage level, the flicker limits should refer to the value in the brackets [5].

Table 1: Flicker Limits Under Various Voltage Levels

System Voltage Level	LV	MV	HV
P_{st}	1.0	0.9(1.0)	0.8
P_{lt}	0.8	0.7(0.8)	0.6

Voltage flicker measurement method proposed in IEC standard is the most widely used [6]. Fig. 2 represents the measurement procedures for flicker during the continuous operation of the wind turbines. Firstly, we should measure voltage sequence u(t) and current sequence i(t), which wind speed distribution is between the cutting speed and 15m/s; secondly, u(t) and i(t) are used to simulate the voltage fluctuation in the virtual network to obtain the virtual volt- age sequence Ufic(t). Then, according to the voltage flicker algorithm proposed in the IEC 61000-4-15, the flicker value Pst of the virtual voltage sequence Ufic(t) can be calculated. Moreover, each flicker value should be normalized to flicker coefficient C k), and calculate the cumulative function of flicker coefficient on the basis of the weight procedure. It's worth noting that the procedure can be applied to a single or mul-tiple wind turbines. The digital differentiation can used to reduce flicker measurement deviation [12].

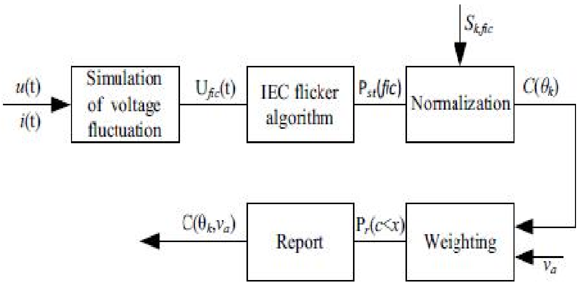

Fig. 2: Measurement procedures for flicker during continuous operation of the wind turbines

In the following sections, the voltage fluctuations and flicker are analyzed in detail according to the measured data of Baolian wind farm, in addition, the measurement point is located at the high voltage side of the grid-connected transformer. As shown in Fig. 3, we can find that the three-phase

voltage is fluctuation with the wind varies, and their value is higher than the nominal voltage; the maximum voltage reaches 69.23kV, and the minimum voltage value is 65.09kV. It can be clearly seen that the voltage during the daytime is lower than the voltage at night, which is due to the large power consumption during the daytime. Further-more, there is several significant voltage drops during the measurement period, which may be resulted from suddenly increase current.

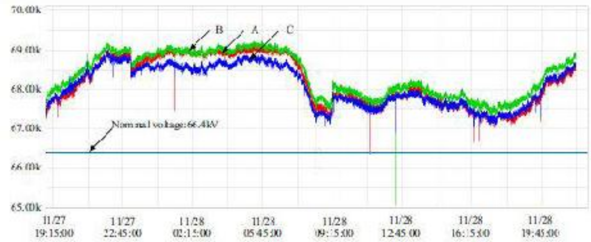

Fig. 3: Voltage fluctuations in the high voltage side of grid-connected transformer

The voltage flicker during the measurement period is shown in Fig. 4. It is shown that the

maximum value of P_{st} is 0.3, and there are 7 times serious flicker, while the maxi-mum value of P_{lt} is not more than 0.2. All flicker can within the flicker limits as shown in Table 1.

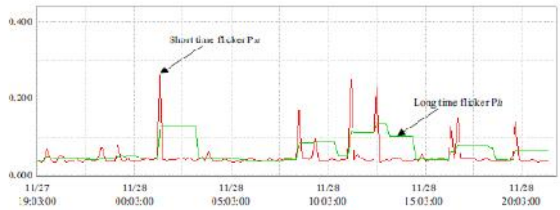

Fig. 4: Flicker in high voltage side of grid-connected transformer

3.2 Harmonic Current

Converter will produce harmonics when it works, and the interaction between different converters is also an important factor to make the harmonics serious. Low order harmonics is the main component in the harmonic spectrum of the wind farm. In addition, there are also interharmonics in the har-monic spectrum, which content is not much but almost cover the whole harmonic current spectrum It is very significant to study the characteristics of har-monic transmission. Generally speaking, the harmonic transmission can be divided into two cases, one case is harmonic propagation from a single wind turbine to others or the public grid; the other case is harmonic spreads from the

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public grid to the wind turbines. The research in [13] shows that the current on the point of common coupling (PCC) is mainly affected by harmonic source come from public grid because the harmonic propagation from public grid to each wind turbine will cause resonance among the different turbines, so as to aggravate the waveform distor-tion.

In the following paragraph, the harmonic currents are analyzed in detail according to the measured data of Baolian wind farm. Fig. 5 shows the harmonic current spectrum in high voltage side of

grid-connected transformer. It can be seen from the Fig. 5 that the main components of harmonics are the 2nd, 3rd, 4th, 5th and 7th harmonics, in which the 4th and 5th harmonics are relatively higher.

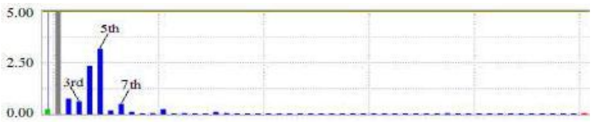

Fig. 5: Harmonic current spectrum in high voltage side of grid-connected transformer.

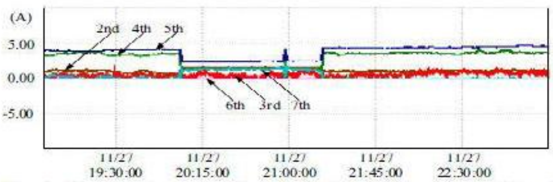

Fig. 6: Harmonic current trend chart in high voltage side of grid-connected transformer

The trend chart of several major harmonic current com-ponents is shown in Fig. 6. It can be seen that the content of the 3rd harmonic is lower than most of others, but it's fluctuation is relatively large. In most cases, the 4th har-monic fluctuations is the same as the 5th harmonic and they show the opposite trend with the 7th harmonic. For better analyze the characteristics of the each har-monic current, the following figures describe the scatter diagram of harmonic currents (the horizontal or vertical coordinates of each point respectively represent active cur-rent and reactive current). Fig. 7(a, b, c, d, e, f) are scatter diagrams of the 2nd, 3rd, 4th, 5th, 6th and 7th harmonic currents. The following figures show that the scatter plot of the 2nd, 3rd, 4th, 5th and 6th order harmonic currents mostly on the negative plane of Y axis, namely, reactive current of these harmonics are mostly negative. The scatter plot of 6th harmonic current arrangement rule and its ordinate is posi-tive.

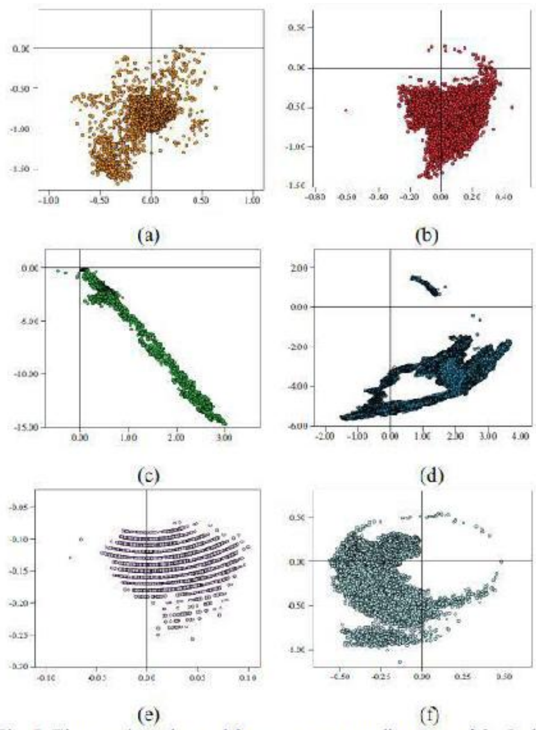

Fig. 7: Figure a, b, c, d, e and f represent scatter diagrams of the 2nd, 3rd, 4th, 5th, 6th and 7th harmonic currents respectively.

		A	B	C
95%	Probability Value of 2nd /A(RMS)	1.01	1.05	0.4
95%	Probability Value of 3rd /A(RMS)	1.08	1.66	1.55

95%	Probability Value of 4th /A(RMS)	3.12	3.57	4.69
95%	Probability Value of 5th /A(RMS)	5.45	5.65	5.05
95%	Probability Value of 6th /A(RMS)	0.18	0.24	0.1
95%	Probability Value of 7th /A(RMS)	0.75	0.93	0.8

Table 2: 95% Probability Value of the 2nd, 3rd, 4th, 5th, 6th and 7th Three-phase Harmonic Currents

In order to further study whether the harmonic value of the wind farm can meet the requirement or not, the maxi-mum 95% probability value of the three-phase harmonic currents are given and it can be found that the value of phase B is almost higher than the others. The maximum 95% probability value and allowable value of the three-phase harmonic currents is shown in Table 3. The results show that the 2nd, 3rd, 5th and 7th order harmonic currents of Baolian wind farm are less than the specified value, but the 4th order harmonic current exceed the national standard.

——	2nd	3rd	4th
The Maximum 95% Probability Value of the Three-phase /A RMS	1.05	1.66	4.69
Allowable Value */A RMS	8	6.4	4

Continued table

	5th	6th	7th
The Maximum 95% Probability Value of the Three-phase /A RMS	5.65	0.24	0.93
Allowable Value */A RMS	6.4	2.67	4.53

Table 3: The Maximum 95% Probability Value and Allowable Value of the 2nd, 3rd, 4th, 5th, 6th and 7th Harmonic Currents

Fig. 8 shows the distribution of the interharmonics in Baolian wind farm. The diagram indicates that the 3.5th interharmonic accounted for a larger percentage of low order interharmonics, its value is still relatively low but the existence of interharmonics will not only lead to voltage fluctuation and flicker but also caused synchronous oscilla-tion and other issues, so we should also consider it when measures are taken to control harmonics [14].

3.2.1.Voltage deviation

Voltage deviation refers to the situation that the actual voltage is not equal to the nominal voltage amplitude for a long time, including overvoltage and undervoltage. Wind speed fluctuation is the main reason that can cause voltage deviation. Based on the characteristics of small resistance and large inductance in power system, the reactive power is the most important factor which affects the voltage devia-tion, as shown in formula (1). In addition, the node voltage deviation in the distribution network is related to the load and the system voltage level, and the short-circuit capacity of the PCC directly affects the voltage deviation when wind farm integrated to power grid [15].The measured voltage in Baolian wind farm is generally higher than the nominal voltage, so when we explore whether the voltage deviation of the wind farm is qualified or not, we just research the maximum value of the phase-B's voltage (as shown in Fig. 3, phase B's voltage is higher than others). Fig. 9 and Fig. 10 show the probability distribution of voltage deviation on the 35kV side and the 110kV side, respectively. The results show that the voltage deviation on the 35kV side is mostly distributed in the range of 7%-9.5%, in which the maximum value is close to 10%; while the voltage deviation on the 110kV side is mostly distributed in the range of 6%-9%, which is lower than the voltage devia-tion on 35kV side. So the voltage deviation of both sides all meet the Chinese standard [4].

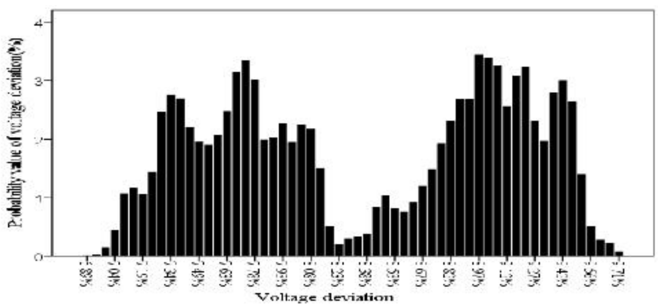

Fig. 9: Probability distribution of voltage deviation of phase B in 35kV side

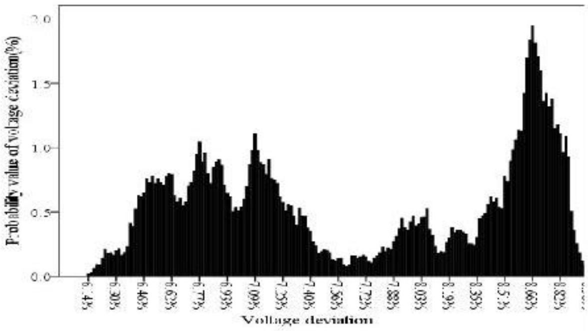

Fig. 10: Probability distribution of voltage deviation of phase 110kV side

The efficiency of the wind farm is determined by its op- it the main components that produce loss include transformer, converter and cable. The wind turbine's losses composed of copper consumption, core loss and mechanical loss, and the iron loss and mechanical loss are fixed value [16]. The losses of the transformer is determined by load ratio, no-load loss and short circuit loss Converters' losses including switching losses and conduction losses. The factors that affect the cable loss are the terminal voltage and cable parameters.[17] According to the parameters of the Baolian wind farm, we established a simulation model in DIgSILENT to inves-tigate the relationship between the operation losses and the wind turbines output, as shown in Fig. 11. With the increase of wind turbine output, cable and transformer losses also increase. In the beginning, the losses of wind turbines transformer and cable is greater than the losses of main transformer. In addition, the losses growth rate of wind turbines transformer and cable is higher than the losses growth rate of main transformer

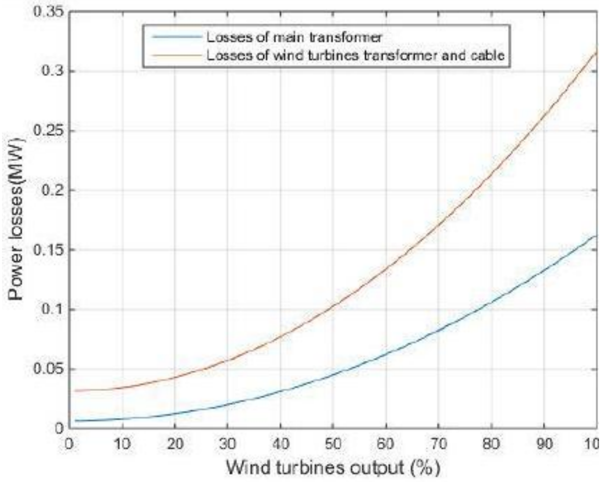

Fig. 11: Simulation loss of Baolian wind farm

5 Conclusion

The analysis of power quality and loss of wind farm is of great significance to the safe and stable operation of wind power integrated system. This paper describes the important aspects of power quality problems about the voltage fluctu-ations and flicker, harmonic, voltage deviation of the wind farm combined with the measured data of Baolian wind farm. Besides, exploring the essence of wind power quality through voltage fluctuation figure, scatter diagram, plots of probability distribution and so on. Finally, according to the simulation model in DIgSILENT, we obtain the relationship between wind turbines output and the losses of transformer and cable.

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