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Harmonic Analysis by Modeling and Simulation of the Wind Farm Based on DFIG

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***Abstract*—With the enlargement of the wind scale, the negative effects of wind power became more and more serious, and turn to be great obstacle of the further utilization of the wind resource. In the paper, a simulation model of a wind farm based on variable speed constant frequency double-fed induction generators (DFIG) was set up using the electro-magnetic transient simulation software EMTP_RV, and the voltage harmonics was analyzed at the common connection point where the wind farms were connected to the grid. Various possible situations were investigated, such as different wind speeds, the presence or absence of system background harmonics, and three phases unbalanced and balanced system voltage, and according to the simulation results, put forward the solutions and measures to solve the problems. The researching work has an important theoretical meaning and pragmatic value for the programming, designing, and operation of the wind farms in the grid.**

***Index Terms*—Modelling, simulation, wind farm, harmonic.**

I. INTRODUCTION

As an important new energy, wind energy is unlimited, clean and renewable. Many countries in the world tend to focus on wind power generation for these traits. China's total installed capacity of wind power is estimated to be 1.3 hundred million kW in 2015, 2.5 hundred million kW in 2020 and will exceed 5 hundred million kW in 2030. Wind power will provide 10% of national electricity supply in 2020, which will rise to 16.7% by 2030 [1]. As the capacity of wind farms increases, so does the potential effects on the power system, making the study of those projects are crucially important. The problem of harmonic waves has always been concerned as a critical electrical quality problem in the power system. Compare to other types of power generation, variable speed wind turbines of double-fed induction generator (DFIG) are used more widely. The converter has a capacity is 25%~30% of its generating capacity and the active and reactive power can be control independently by the generator in the DFIG wind power system [2], [3].

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The harmonic wave problem that occurs in the grid-connected wind power system should be paid much attention. It has huge negative effects on the operation of power system, which can reduce equipments' efficiency and working life, producing pulsation and noise etc. [4], [5]. By analyzing wind farm harmonic model, the harmonica contents can be calculated by the software and differing means of reducing the harmonic contents can be found depending on the feature of the harmonic source; moreover, the origin could be traced by harmonic frequency spectrum when problems occurring in the system. In this paper, a wind farm model was set up to simulate and analyze the voltage harmonic at the common connection point where the wind generators are connected to the power system. Various possible situations are investigated, such as different wind speeds, the presence or absence of system background harmonics, and three phases unbalanced and balanced system voltage. According to the simulation results, put forward the solutions and measures to solve the problems. It's very useful to analyze and suppress wind farms harmonic waves.

II. MATHEMATICAL MODEL

A. *Wind speed model*

Due to the random, intermittent, and volatile nature of wind speed, in order to accurately describe the wind speed characteristics, in this paper, the wind speed's mathematical model was created using a combination of four components that are *basic wind*, *gust wind*, *gradient wind* and *noise wind*.

Basic wind describes the steady energy of a special wind field; it is determined approximately by the measurement of Weibull Distribution Parameters.

Gradient wind describes a wind field's steady energy that is changing slowly over time; it can be expressed as a superposition of a gradient component and the basic wind speed

$$v_{\omega r}(t)=\begin{cases}0, & (t<T_{sr}),\\ A_{\omega r}\dfrac{(t-T_{sr})}{(T_{er}-T_{sr})}, & (T_{sr}\le t\le T_{er}),\\ A_{\omega r}(t>T_{er}), & (t>T_{er}).\end{cases} \quad (1)$$

In the above expression, $A_{\omega r}$ is the maximum of gradient wind; T_{sr} and T_{er} are the starting time and ending time of the gradient wind respectively.

Gust wind describes a sudden change in wind energy

$$v_{\omega g}(t)=\begin{cases}0, & (t<T_{sg}),\\ A_{\omega g}\dfrac{1-\cos(2\pi(t-T_{sg}))}{T_{eg}-T_{sg}}, & (T_{sg}\le t\le T_{eg}),\\ A_{\omega g}(t-T_{eg}), & (t<T_{sg}).\end{cases} \quad (2)$$

In (2), $A_{\omega g}$ is gust wind maximum; T_{sg} and T_{eg} are the starting time and the ending time of the gust respectively.

Noise wind describes a random change in wind energy.

$$v_{\omega n}(t)=2\sum_{i=1}^{n}\sqrt{S_v(\omega_i)\Delta\omega}\cos(\omega_i t+\phi_i). \quad (3)$$

In the above expression, ω_i is the i-th component of the angular frequency; $\Delta\omega$ is the discrete spacing of random components; f_i is the random variable of uniform probability density distribution between 0 and 2π; $S_v(\omega_i)$ is the amplitude of the ith random component.

B. Wind turbine and transmission device model

A wind turbine transforms wind energy into mechanical energy. According to the Bates theory, the captured power by a wind turbine is:

$$P_w=\frac{1}{2}\rho\pi Av^3C_p(\lambda,\beta), \quad (4)$$

$$\lambda=\omega R/v. \quad (5)$$

In the above expression, P_w is the captured mechanical energy in the wind turbine (w); ρ is air density (kg/m^3); A is the impeller sweeping area (m^2); v is wind speed (m/s); C_p is the wind power utilization coefficient, as well as is the function of tip speed ratio λ and pitching angle β; R is paddle radius.

Due to a wind turbine having a larger rotary inertia, wind power driving the generator will involve a certain amount of time delay, so the characteristics of the transmission gear can be simulated by a first-order inertia link

$$\frac{dP_m}{dt}=\frac{1}{\tau}(P_w-P_m). \quad (6)$$

In the above expression, τ is the inertial time constant. P_m is the generator axis mechanical power.

C. Rotor side converter model

The mathematical model of a variable speed constant frequency generator under a dq synchronous rotating coordinate system is shown as follows:

$$\begin{bmatrix}u_{sd}\\u_{sq}\\u_{rd}\\u_{rq}\end{bmatrix}=\begin{bmatrix}pL_s+R_s & -\omega_1L_s & pL_m & -\omega_1L_m\\ \omega_1L_s & pL_s+R_s & \omega_1L_m & pL_m\\ pL_m & -(\omega_1-\omega_r)L_m & pL_r+R_r & -(\omega_1-\omega_r)L_r\\ (\omega_1-\omega_r)L_m & pL_m & (\omega_1-\omega_r)L_r & pL_r-R_r\end{bmatrix}\begin{bmatrix}i_{sd}\\i_{sq}\\i_{rd}\\i_{rq}\end{bmatrix}. \quad (7)$$

In (7), u and i are respectively the voltage quantity and current quantity, the indexes s and r are respectively the stator and rotor components, The indexes d and q are respectively the d and q axis components; L and R are respectively the inductance and resistance quantities, P is the differential operator, ω_1 is the synchronous coordinate rotation angular velocity, and ω_r is the rotor rotating electrical angular velocity.

Generator flux can be given as follows

$$\begin{bmatrix}\psi_{sd}\\\psi_{sq}\\\psi_{rd}\\\psi_{rq}\end{bmatrix}=\begin{bmatrix}L_s & 0 & L_m & 0\\ 0 & L_s & 0 & L_m\\ L_m & 0 & L_r & 0\\ 0 & L_m & 0 & L_r\end{bmatrix}\begin{bmatrix}i_{sd}\\i_{sq}\\i_{rd}\\i_{rq}\end{bmatrix}. \quad (8)$$

If the stator flux linkage is defined in the same direction as the d axis of rotating coordinate system, that is $\psi_{sd}=0$, the following expression can be obtained:

$$\begin{cases}\psi_{sd}=\psi_s,\\ \psi_{sq}=0.\end{cases} \quad (9)$$

By ignoring the stator coil resistance, the following expression can be obtained:

$$\begin{cases}u_{sd}=0,\\ u_{sq}=|us|.\end{cases} \quad (10)$$

Additionally, the expressions of generator stator side output active power and reactive power can be obtained:

$$\begin{cases}P_s=u_{sd}i_{sd}+u_{sq}i_{sq}=u_{sq}i_{sq},\\ Q_s=u_{sq}i_{sd}-u_{sd}i_{sq}=u_{sq}i_{sd}.\end{cases} \quad (11)$$

In the above expressions, when the generator terminal voltage is a fixed value, the output of the active power and reactive power respectively are proportional to the stator q axis current i_{sq} and stator d axis current i_{sd}. According to (11), active power and reactive power can be decoupled. If $\omega_{slip}=\omega_1-\omega_r$, (7) can be simplified to the following:

$$\begin{cases}u_{rd}=(L_r-\dfrac{L_m^2}{L_s})pi_{rd}+R_ri_{rd}-\omega_{slip}(L_r-\dfrac{L_m^2}{L_s})i_{rq}+\\ \quad +\dfrac{L_m}{L_s}p\psi_{sd},\\ u_{rq}=(L_r-\dfrac{L_m^2}{L_s})pi_{rq}+R_ri_{rq}+\omega_{slip}(L_r-\dfrac{L_m^2}{L_s})i_{rd}+\\ \quad +\omega_{slip}\dfrac{L_m}{L_s}\psi_{sd}.\end{cases} \quad (12)$$

The above expression shows that the decoupling control of the generator can be realized by adding compensation to the rotor voltage. The compensation is as follows:

$$\begin{cases}e_{rd}=+\omega_{slip}(L_r-\dfrac{L_m^2}{L_s})i_{rd}+\dfrac{L_m}{L_s}p\psi_{sd},\\ e_{rq}=-\omega_{slip}(L_r-\dfrac{L_m^2}{L_s})i_{rd}+\omega_{slip}\dfrac{L_m}{L_s}\psi_{sd}.\end{cases} \quad (13)$$

The relational expression of the compensated current and voltage is shown` as follows:

$$\begin{cases} -R_r i_{rd} + u_{rd}^* = (L_r - \dfrac{L_m^2}{L_s}) p i_{rd}, \\ -R_r i_{rq} + u_{rq}^* = (L_r - \dfrac{L_m^2}{L_s}) p i_{rq}. \end{cases} \quad (14)$$

A. Grid side converter model

In a dq synchronous rotating coordinate system, the grid side converter mathematical model is shown as follows:

$$\begin{cases} u_{ld} = -L\dfrac{di_d}{dt} - Ri_d + \omega_1 L i_q + u_{sd}, \\ u_{lq} = -L\dfrac{di_q}{dt} - Ri_q - \omega_1 L i_d + u_{sq}, \end{cases} \quad (15)$$

where U_{ld} and u_{lq} are respectively the grid side converter voltage d-axis and q-axis components, u_{sd} and u_{sq} are respectively the grid voltage d-axis and q-axis components, i_d and i_q are respectively the grid side converter d-axis and q-axis components of AC input current.

Using the grid voltage oriented vector control method, the grid voltage is orientated to the d-axis direction, so the d-axis of the reference frame has the same direction as the grid voltage, and the q-axis is 90° ahead of the d-axis. Thus, as the grid voltage q-axis component $u_{sq}=0$, the active power P_r and reactive power Q_r , which flow to the grid from the grid side converter, can be shown as follows:

$$\begin{cases} P_r = u_{sd} i_d + u_{sq} i_q = u_{sd} i_d, \\ Q_r = u_{sq} i_d - u_{sd} i_q = -u_{sd} i_q. \end{cases} \quad (16)$$

The above expression shows that, if the grid voltage is a constant, the flowing active power and reactive power from the grid side converter to the grid will be separately controlled by i_d and i_q; if $P_r>0$ and $Q_r>0$, it shows the converter absorbs active power and reactive power from the grid; if $P_r<0$ and $Q_r<0$, it shows the converter provides active power and reactive power to the grid; if $P_r=0$ and $Q_r=0$, it shows there is no active power and reactive power.

By simplifying (15), the following expression can be obtained:

$$\begin{cases} u'_{sd} = Ri_d + L\dfrac{di_d}{dt}, \\ u'_{sq} = Ri_q + L\dfrac{di_q}{dt}. \end{cases} \quad (17)$$

By adding compensation, the cross coupling of the input current can be eliminated; and by introducing the feed forward compensation, the reference voltages u_{ld}^* and u_{lq}^* can be obtained:

$$\begin{cases} u_{ld}^* = -u'_{sd} + (w_1 L i_q + u_{sd}), \\ u_{lq}^* = -u'_{sq} - w_1 L i_d. \end{cases} \quad (18)$$

III. WIND FARM MODEL

The first-stage of a wind farm installation project installed 17 wind power generators, and each generator capacity was 1500kW, so the total installed capacities were 22.5MW. A special output power line was built from the wind farm to the power grid for the transmission of energy. This wind farm adopted the generator-transformer unit connection mode, and used 17 Box-type transformers, each of the Box-type transformer's capacity were 1600kVA, and each of their voltage level were 0.69/35kV. They were then connected by triple-circuits to the 35kV bus in the+

110kV booster substation, where a 31500kVA two-winding transformer was installed, and its voltage ratio was 110/35kV. In this 110kV booster substation, the 35kV side adopted single bus wiring, and the 110kV side was connected to the power grid through an overhead line.

The local conditions of the wind farm and grid were fully considered to build the simulation model using the electromagnetic transient simulation software EMTP-RV. In this paper, the power quality problems were analyzed not only in the current wind farm's first-stage installed capacity, but also in the future adding an additional 30MW second-stage installation capacity of the wind farm.

IV. SIMULATION WITHOUT CONSIDERATION OF SYSTEM BACKGROUND HARMONICS

Without consideration of system background harmonics, a simulation model of the wind farm's first-stage installed capacity was built using the software EMTP-RV, and the harmonics were analyzed at four stages of power output, where the 17×1.5MW wind generators' output power were 30%, 60%, 90%, 100%. In the simulation analysis, the step length was set to 50 µs and the simulation time was 20s. The harmonics of the 35kV bus voltage were analyzed at the point of common coupling (PCC), where wind generators were connected to the grid, and the harmonic content was shown in Table I. for the different generators' output power, representing different wind speeds. After simulating the addition of the 30MW capacity of the second-stage of the wind farm's installation to the existing 22.5MW, the harmonics of the 35kV bus voltage were also analyzed under the same output power conditions, and the harmonic content is shown in Table II.

TABLE I. 35KV BUS VOLTAGE'S HARMONIC CONTENT OF THE FIRST-STAGE INSTALLATION CAPACITY WITHOUT CONSIDERATION OF THE SYSTEM BACKGROUND HARMONIC (%).

Harmonic order	30%	60%	90%	100%	
	7 m/s	9m/s	11 m/s	13m/s	15 m/s
2	0.06	0	0	0	0
5	0.52	0.43	0.36	0.32	0.44
7	0.32	0.31	0.27	0.24	0.28
11	0.21	0.16	0.13	0.14	0.13
13	0.09	0.08	0	0	0
17	0.08	0	0	0	0
19	0.06	0	0	0	0

TABLE II. 35KV BUS VOLTAGE'S HARMONIC CONTENT OF ADDING THE SECOND-STAGE INSTALLATION CAPACITY WITHOUT CONSIDERATION OF SYSTEM BACKGROUND HARMONIC.

Harmonic order	30%	60%	90%	100%	
	7 m/s	9m/s	11 m/s	13m/s	15 m/s
2	0.07	0	0	0	0
5	0.73	0.63	0.41	0.41	0.50

Harmonic order	30%	60%	90%	100%	
	7 m/s	9m/s	11 m/s	13m/s	15 m/s
7	0.47	0.36	0.28	0.28	0.32
11	0.32	0.23	0.15	0.17	0.18
13	0.13	0.09	0.09	0.07	0.06
17	0.12	0.10	0.06	0.06	0
19	0.06	0.05	0	0	0

V. Simulation with Consideration of System Background Harmonics

To give consideration to conditions where the wind farm was connected to the power grid in windy conditions, and wind turbines were shut down in windless conditions, the data of harmonics and negative sequences were measured, and the average in PPC was taken. The simulation model was then built using those values. The harmonics of the 110kV bus voltage were analyzed, and the simulation results showed that the 3rd harmonic content was 0.33%; the 5th harmonic content was 2.20%; the 7th harmonic content was 1.33%, the 9th harmonic content was 0.18%; the 11th harmonic content was 0.08%; the13th harmonic content was 0.23%; the 15th harmonic content was 0.13%; the 17th harmonic content was 0.21%; the 19th harmonic content was 0.31%; the 21st harmonic content was 0.27%; the 23rd harmonic content was 0.46%; and the 25th harmonic content was 0.28%.

After adding the system background harmonics in the 110kV grid into simulation model, the harmonics were again analyzed at the same four stages of power output. All other conditions of the simulation remained the same, and the harmonic content are shown respectively in Table III and Table IV.

TABLE III. 35KV BUS VOLTAGE'S HARMONIC CONTENT OF THE FIRST-STAGE INSTALLATION CAPACITY WITH CONSIDERATION OF SYSTEM BACKGROUND HARMONICS (%).

Harmonic order	30%	60%	90%	100%	
	7 m/s	9m/s	11 m/s	13m/s	15 m/s
2	0.05	0.07	0.07	0.08	0.07
3	0.20	0.17	0.19	0.19	0.17
5	1.61	1.50	1.48	1.47	1.42
7	1.39	1.25	1.11	1.10	1.15
9	0.17	0.17	0.18	0.18	0.17
11	0.15	0.14	0.13	0.11	0.10
13	0.27	0.19	0.11	0.11	0.11
15	0.08	0.11	0.11	0.11	0.11
17	0.10	0.14	0.21	0.20	0.20
19	0.25	0.25	0.25	0.24	0.25
21	0.18	0.20	0.21	0.23	0.23
23	0.29	0.36	0.40	0.41	0.40
25	0.22	0.23	0.23	0.23	0.23

TABLE IV. 35KV BUS VOLTAGE'S HARMONIC CONTENT WITH THE ADDITION OF THE SECOND-STAGE INSTALLATION CAPACITY WITH CONSIDERATION OF SYSTEM BACKGROUND HARMONICS (%).

Harmonic order	30%	60%	90%	100%	
	7 m/s	9m/s	11 m/s	13m/s	15 m/s
2	0.07	0.08	0.08	0.09	0.08
3	0.17	0.21	0.27	0.28	0.26
5	1.30	1.17	1.28	1.24	1.12
7	1.37	1.14	0.90	0.90	1.02
9	0.18	0.20	0.22	0.22	0.17
11	0.22	0.21	0.24	0.24	0.15
13	0.19	0.14	0.13	0.11	0.13
15	0.06	0.10	0.08	0.09	0.08
17	0.12	0.19	0.21	0.20	0.16
19	0.18	0.19	0.27	0.28	0.25
21	0.14	0.18	0.18	0.19	0.19
23	0.21	0.38	0.35	0.34	0.36
25	0.16	0.23	0.24	0.23	0.21

VI. Simulation under Unbalanced Three-phase Voltage

In this study, interaction effects between the wind farm and the grid were also studied under an unbalanced three-phase voltage. According to Chinese Standards as set in GB/T15543-2008 „Power Quality · Three-phase Voltage Permissible Unbalance": the allowable value of unbalanced voltage in PCC is 2% in normal conditions, and not exceeding 4% in a short time; every user who is connected to the PCC, will cause unbalanced voltage in the PPC, and the allowable value of unbalanced voltage is 1.3% in normal conditions.

Under the condition where the maximum allowable value of unbalanced grid voltage is 2%, the harmonics of 35kV bus voltage at PC was analyzed in different wind speeds involving low wind speed (LWS), medium wind speed (MWS), and high wind speed (HWS). The results of simulation analysis in first-stage installation capacities and adding second-stage installation capacity of the wind farm are shown respectively in Table V and Table VI.

TABLE V. 35KV BUS VOLTAGE HARMONIC CONTENT OF THE FIRST-STAGE INSTALLATION CAPACITY UNDER UNBALANCED TREEE-PAHASE VOLTAGE (%).

	2	3	4	5	6	7	8
WWS	1.83	0.09	0.14	0.63	0.30	0.30	0.14
MWS	1.83	0.11	0.15	0.54	0.26	0.30	0.12
SWS	1.84	0.13	0.16	0.45	0.23	0.30	0.12

TABLE VI. 35KV BUS VOLTAGE HARMONIC CONTENT WITH THE ADDITION OF THE SECOND-STAGE INSTALLATION CAPACITY UNDER UNBALANCED TREEE-PAHASE VOLTAGE (%).

	2	3	4	5	6	7	8
WWS	1.90	0.09	0.25	0.89	0.54	0.19	0.09
MWS	1.90	0.03	0.18	0.64	0.44	0.16	0.07
SWS	1.90	0.03	0.18	0.64	0.44	0.16	0.06

VII. Harmonic Analysis

According to Chinese Standards as set in GB/T 14549-1993 "Power Quality Harmonics in Public Supply Network", the allowable values of the voltage harmonics are shown in Table VII.

TABLE VII. THE ALLOWABLE VALUE IN PUBLIC SUPPLY NETWORK (GRID NOMINAL VOLTAGE: GNV; VOLTAGE TOTAL HARMONIC DISTORTION RATE: VTHDR; EVERY HARMONIC VOLTAGE CONTAINS RATE: EHVCR).

GNV (kV)	VTHDR (%)	EHVCR (%)	
		odd	even
0.38	5.0	4.0	2.0
6	4.0	3.2	1.5
10	4.0	3.2	1.5
35	3.0	2.4	1.2
66	3.0	2.4	1.2
110	2.0	1.6	0.8

The simulation results of the 35kV bus voltage at PPC showed that the total harmonic distortion rate and every harmonic distortion rate were the highest when wind generators output power was 30%. So it's necessary to research the mutual relations between every harmonic content and harmonic total distortion rate of the bus voltage at PPC with the installed capacities. The simulation results are shown respectively as Table IX and Table VIII whether the system background harmonic are considered or not in simulation analysis.

TABLE VIII. RELATIONS BETWEEN EVERY HARMONIC CONTENT AND HARMONIC TOTAL DISTORTION RATE (TDR) WITH INSTALLED CAPACITIES(IC) WITHOUT CONSIDERATION OF THE SYSTEM BACKGROUND HARMONICS (%).

IC (MW)	2	5	7	11	13	17	19	TDR
17×1.5	0.06	0.52	0.32	0.21	0.09	0.08	0.06	0.69
17×1.5+30	0.07	0.73	0.47	0.32	0.13	0.12	0.06	0.98

TABLE IX. RELATIONS BETWEEN EVERY HARMONIC CONTENT AND HARMONIC VOLTAGE TOTAL DISTORTION RATE (TDR) WITH INSTALLED CAPACITIES WITH CONSIDERATION SYSTEM BACKGROUND HARMONIC (%).

IC(MW)	2	3	5	7	9	11	13
17×1.5	0.05	0.20	1.61	1.39	0.17	0.15	0.27
17×1.5+30	0.07	0.17	1.30	1.37	0.18	0.22	0.19
IC(MW)	**15**	**17**	**19**	**21**	**23**	**25**	**TDR**
17×1.5	0.08	0.10	0.25	0.18	0.29	0.22	2.238
17×1.5+30	0.06	0.12	0.18	0.14	0.21	0.16	1.964

From the data in Table VII, a conclusion can be drawn when without consideration of the system background harmonics, the first-stage's 17×1.5MW wind generators output power is 30%, every harmonic content and harmonic total distortion rate are in the range of the Chinese Standard; when adding the addition 30MW installation capacity, every harmonic content and harmonic total distortion rate are also in the range of the Chinese Standard. TableⅥ shows that every harmonic content and harmonic total distortion rate are also in the range of the Chinese Standard with consideration of the system background harmonic in the first-stage 17×1.5MW installation capacity. It can be also concluded that, after adding the 30MW installation capacities, every harmonic content and harmonic total distortion rate are also in the range of the Chinese Standard.

Several conclusions and suggestions can be put forward from the above analyses:

1) Wind generators connected to the grid will inevitably generate harmonic pollution in the power system, so this kind of wind generator that produces lower frequency harmonics and less pollution should be selected first.

2) According to simulation result under the same wind generators installation capacity in different output power, the bus voltage harmonic content is the highest at PPC when generators output power is 30%, within the consideration of the four kinds of output power at 30%, 60%, 90% and 100%. The more the generators output power is, the less voltage harmonic contents are at PPC.

3) Comparing to Table VIII and Table IX, the study has showed that when there is no background harmonics in the system, the harmonic content is increasing with wind generators installation capacities those connected to the grid, and the harmonics are mainly the 3rd, 5th, 7th and 15th. When there are background harmonics in the system, after the wind generators connected to grid, low frequency harmonics, such as 5th and 7th, increasing slowly with the installation capacity.

4) Before the wind farm is connected to the grid, it's very important not only to evaluate the power quality at PPC whether meet the Chinese Standard, but also to analyze the possible negative influences caused by wind generators connected to the grid, so as not to limit the additional installed capacities for the future.

5) Under unbalanced three-phase voltage conditions; the 2^{nd} voltage harmonic content is 1.84% at PPC in the first-stage installed capacity of the wind farm and the 2^{nd} voltage harmonic content is 1.90% when adding the 30MW installed capacities, so both of them are in the range of the Chinese Standard. The present negative sequence voltage of the system has no influence on normal operation of wind generators in the above simulation analysis.

VIII. CONCLUSIONS

Due to the wind's randomness, intermittence and seasons lead to the output of wind power not smoothly, so that the stability and security of the electric power system will be reduced. Researching the wind power effects on power system and doing some needed simulation analysis to the wind power system are very helpful for the operation of the power system and wind power plants.

Harmonics is an important power quality problem when the wind farm is connected to the grid. Because the harmonic frequency is considerably greater than the power system frequency, and the power grid is a complex system, the harmonics could be amplified and even to oscillate in some conditions. So it would be given more attention to harmonic problem of the wind power system. In this paper, a simulation model of a real wind farm was built, and the harmonics were analyzed in various possible conditions, and consideration was given not only to the first-stage installation capacity, but also the addition of a second-stage installation capacity. Efficient solutions and practical suggestions are proposed as a result of simulation analysis. The researching work has an important theoretical meaning and pragmatic value for the programming, designing, and operation of wind farms in the grid.

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