Voltage Stability Analysis of Wind Farm Integration into Transmission Network

Yongning Chi, Yanhua Liu, Weisheng Wang, *Member IEEE*, Huizhu Dai

***Abstract* -- In some regional grids in China, wind power penetration will increase rapidly because of the abundant wind resources in those areas and the government policy impetus. However, the power system security and stability may be affected due to the higher wind power penetration. Because majority of the wind farms with higher installed capacity intends to be connected into the transmission network of 220kV voltage level, their impacts are becoming more widespread. In the grid impact studies of wind power integration, voltage stability is the mostly concerned problem that will affect the operation and security of wind farms and power grid. In this paper, the detailed wind turbines steady-state model and dynamic model are used to explore the wind power integration impact on voltage stability of the power system; the load flow calculation (P-V curve and V-Q curve) and dynamic contingency study are conducted; the different impacts on voltage stability of integrating wind farms based on different wind turbines technologies are illustrated and the following conclusions are presented:**

a. Wind turbines equipped with simple induction generator are not provided with reactive power regulation capability. Voltage stability deterioration is mainly due to the large amount of reactive power absorbed by the wind turbine generators during the continuous operation and system contingencies.

b. Wind turbines equipped with doubly fed induction generator (DFIG) controlled by the PWM converters are provided with reactive power regulation capability; can absorb or supply reactive power during normal operation. The adverse affect on local network voltage stability is mitigated so that more wind power installed capacity can be incorporated into the grid.

c. The transient voltage stability characteristics of wind turbines with DFIG are better than wind turbines with induction generator because of the voltage control capability of the DFIG based wind turbines; The DFIG based wind turbines have a better voltage recovery performance than the IG based wind turbines with same rating.

***Index Terms* -- Wind power integration; Wind turbines; Induction generator (IG); Doubly Fed Induction Generator (DFIG); Dynamic model; Load flow; Voltage stability.**

This work was supported in part by the Sino-German Project “China Wind Power Center”.

Yongning Chi is with China Electric Power Research Institute. Beijing, China. (E-mail: chiyn@epri.ac.cn).

Yanhua Liu is with North China Electric Power University. Beijing, China. (E-mail: liuyh@epri.ac.cn)

Weisheng Wang is with China Electric Power Research Institute. Beijing, China. (E-mail: wangws@epri.ac.cn)

Huizhu Dai is with China Electric Power Research Institute. Beijing, China. (E-mail: daihz@epri.ac.cn).

I. NOMENCLATURE

D_M, D_G	Turbine rotor and generator rotor damping coefficient
E'	Voltage behind the transient impedance
H_M, H_G	Turbine and generator shaft inertia
u	Voltage
i	Current
K_S	Shaft stiffness coefficient
θ_s	Shaft twist angle
$\omega_s, \omega_M, \omega_G$	Synchronous speed, wind turbine rotor speed, generator rotor speed
P_m	Pulse-width modulation factor
P, Q	Active and reactive power
R	Resistance
R_{eq}, X_{eq}	Equivalent resistance and reactance
s	Rotor slip
X, X', X_m	Steady-state, transient, and magnetizing reactance
T_0'	Rotor circuit time constant
T_E, T_M	Electromagnetic and mechanical torque
$\dot{V}, \dot{I}$	Phase voltage and phase current
	Symbols
p	Differential operator
	Suffices, Superscripts
ac, dc	Alternating current, Direct current
d, q	Direct and quadrature axis components
s, r	Generator's stator and rotor components

II. INTRODUCTION

Following the issue of the *Renewable Energy Law* to give impetus to the development of renewable energy by government in China; a large number of wind farms are currently interconnected into transmission network of 220kV voltage level with higher installed capacity. Being connected to higher voltage level, their impacts are becoming more widespread. There are several technical constraints that may limit wind power integration to a transmission power system, either steady-state or dynamic. A majority of large wind farms in China, including proposed large wind projects, are geographically far away from load centers and connected into relatively weak transmission network. The presence of wind

1-4244-0111-9/06/$20.00©2006 IEEE.

farms in such weak transmission network incurs serious concerns about system security and stability. Power system utilities concerns are shifting focus from the power quality issues to the stability problems caused by the wind power integration.

In the grid impact studies of wind power integration, the voltage stability issue is a key problem because a large proportion of wind farms in China are based on fixed speed wind turbines equipped with simple induction generator (IG). Induction generators consume reactive power and behave similar to induction motors in the duration of system contingency, which will deteriorate the local grid voltage stability. Also variable speed wind turbines equipped with doubly fed induction generator (DFIG) are becoming more widely used for its advanced reactive power and voltage control capability. DFIG make use of power electronic converters and are thus able to regulate their own reactive power, so as to operate at a given power factor, or to control grid voltage; But because of the limited capacity of the PWM converter [1]-[4], the voltage control capability of DFIG can't catch up with that of the synchronous generator. When the voltage control requirement is beyond the capability of the DFIG, the voltage stability of the grid is also affected.

In this paper the voltage stability of power system with large wind farm is studied in an actual wind farm interconnection project in china. Both steady-state voltage stability analysis and transient voltage stability analysis are conducted. Wind turbines model used in load flow calculation and dynamic simulation is implemented in the power system simulation tool DIgSILENT/PowerFactory [5] [6]. The continuation power flow approaches such as P-V curve and V-Q curve and dynamic contingency simulation are used to explore the mechanism of the voltage stability of the power system with high wind power penetration. The difference of the impacts on power system voltage stability with wind farms based on different wind turbine technologies is presented.

III. Models of Wind Turbines

Wind turbines model based on different generator technologies such as simple induction generator or doubly fed induction generator with identical rated power (1.5MW) are presented in this work. As in Figure 1, a simple configuration of different types of wind turbines concept is shown.

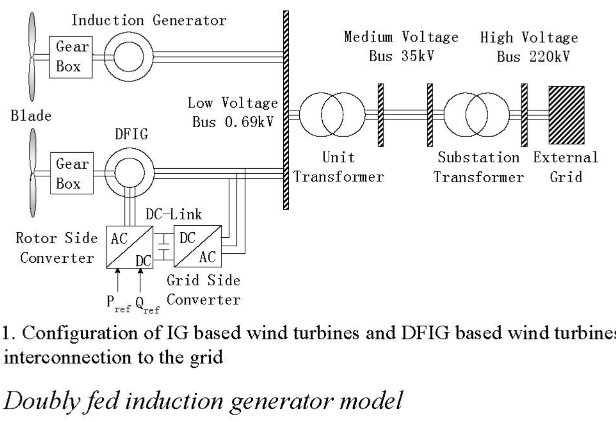

Fig.1. Configuration of IG based wind turbines and DFIG based wind turbines and interconnection to the grid

A. Doubly fed induction generator model

The DFIG is a wound-rotor induction generator whose stator is directly connected to the grid, but the three phase rotor windings are connected through slip rings to the grid via a partially rated power electronics converter. A typical configuration of a DFIG is shown schematically in Figure 1. The DFIG can be regarded as a traditional induction generator with a nonzero rotor voltage.

For representation of DFIG models in power system stability studies [2] [4] [7], the stator flux transients are neglected in the voltage relations. By eliminating the rotor currents and expressing the rotor flux linkages in terms of E'_d and E'_q , the dynamic equations of DFIG are derived:

$$\begin{cases} u_{ds} = R_s i_{ds} - X'_s i_{qs} + E'_d \\ u_{qs} = R_s i_{qs} + X'_s i_{ds} + E'_q \\ T'_0 p E'_d = -E'_d - (X_s - X'_s) i_{qs} + \omega_s T'_0 u'_{qr} + s\omega_s T'_0 E'_q \\ T'_0 p E'_q = -E'_q + (X_s - X'_s) i_{ds} - \omega_s T'_0 u'_{dr} - s\omega_s T'_0 E'_d \\ T_E = u_{ds} i_{ds} + u_{qs} i_{qs} \end{cases} \quad (1)$$

Where $u'_{dr} = u_{dr} X_m / (X_r + X_m)$; $u'_{qr} = u_{qr} X_m / (X_r + X_m)$, The power converter in such wind turbines only deals with slip power, therefore the converter rating can be kept fairly low, approximately 20% of the total generator power. The PWM converter inserted in the rotor circuit allows for a flexible and fast control of the generator by modifying magnitude and phase angle of the rotor voltage. The controllability of reactive power help DFIG equipped wind turbines play a similar role to that of synchronous generators.

Under steady-state conditions, the flux transient's items disappear. In figure 2, the steady-state equivalent circuit of the DFIG is given [2] [7].

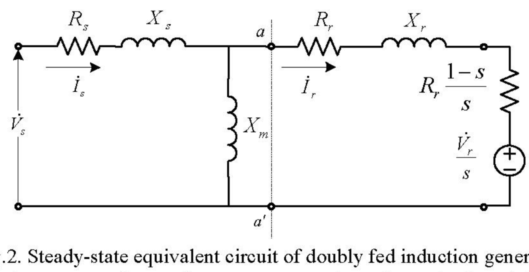

Fig.2. Steady-state equivalent circuit of doubly fed induction generator

During normal steady-state operation the wind turbines or the wind farm can be considered as a PQ node or a PV node depending on the control strategy that the wind farm adopted [8].

B. Induction generator model

The rotor of induction generator is a wound-rotor or a squirrel-cage rotor with a short circuit winding not connecting to an external voltage source [9] - [11]. The dynamic equations of IG can be obtained by eliminating the u'_r items in equations (1). The steady-state equivalent circuit of the induction generator is given in Figure 3.

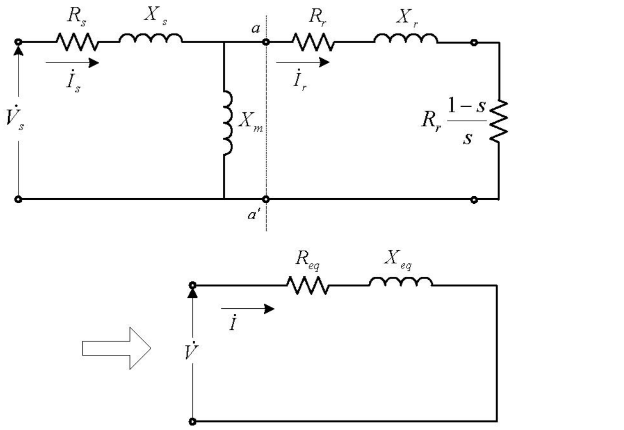

Fig.3. Steady-state equivalent circuit of induction generator

From the equivalent circuit of induction generator in Figure 3, the active power and reactive power expression are easily derived.

$$P_e = \frac{V^2 R_{eq}}{\sqrt{{R_{eq}}^2 + {X_{eq}}^2}} \qquad Q_e = \frac{V^2 X_{eq}}{\sqrt{{R_{eq}}^2 + {X_{eq}}^2}} \tag{2}$$

It can be seen that the induction generator active power and reactive power is closely related to the terminal voltage V and the slip s of the induction generator.

C. Shaft system model

During transient voltage stability study of wind farm integration, the shaft system model of wind turbines should be taken into account. Under normal operating conditions, variable speed generators are "decoupled" from the grid; torsional shaft oscillations are filtered by the converters with appropriate controls. However, during heavy faults such as 3 phase short circuit fault in the network, generator and turbine acceleration can only be simulated with sufficient accuracy of shaft models. Shaft characteristics of wind generators are quite different from other types of generators due to the relatively low stiffness of the turbine shaft. This results in torsional resonance frequencies in a range of about 0.5 to 2 Hz. The proposed shaft model is described by a two-mass model, represented by turbine and generator inertia [1] [5].

The two-mass model represents the shaft torsional twist is given by the following equations:

$$\begin{cases} 2H_M \dfrac{d\omega_M}{dt} = T_M - K_S\theta_S - D_M\omega_M \\ 2H_G \dfrac{d\omega_G}{dt} = K_S\theta_S - T_E - D_G\omega_G \\ \dfrac{d\theta_S}{dt} = \omega_0(\omega_M - \omega_G) \end{cases} \tag{3}$$

D. Converter model

The converter consists of two voltage source converters connected back-to-back and enables variable speed operation of the wind turbines by decoupling control that controls the active power and reactive power of the generator separately [2] – [6]. The rotor-side and grid-side converters are usually set-up by six-pulse bridges illustrated in figure 4.

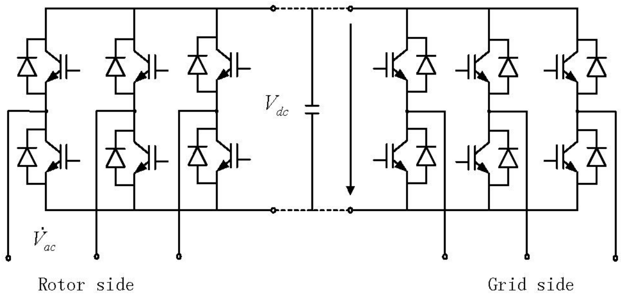

Fig.4. VSC-PWM converter configuration

Assuming an ideal DC-voltage and PWM modulation, the fundamental frequency line to line AC voltage and the DC voltage can be related to each other as follows:

$$\begin{aligned} V_{acd} &= \frac{\sqrt{3}}{2\sqrt{2}} P_{md} V_{dc} \\ V_{acq} &= \frac{\sqrt{3}}{2\sqrt{2}} P_{mq} V_{dc} \end{aligned} \tag{4}$$

The AC-voltage phase angle is defined by the PWM converter. The pulse-width modulation factor P_m is the control variable of the PWM converter which is valid for $0 \le P_m < 1$. The converter model is completed by the power conservation equation:

$$V_{dc} I_{dc} + \sqrt{3}\,\mathrm{Re}(\dot{V}_{ac} I_{ac}^*) = 0 \tag{5}$$

This equation assumes a loss-less converter. Because the switching frequency of PWM converters is usually very high (typically several hundreds Hz), switching losses are the predominant type of losses. Since the average switching losses are basically proportional to V_{dc}^2, switching losses can be considered by a resistance between the two DC-poles in a fundamental frequency model [4].

E. Control strategy of DFIG based wind turbines

DFIG make use of power electronic converters and are thus able to regulate their own reactive power, so as to operate at a given power factor, or to control grid voltage.

The rotor-side converter is controlled by a two stage controller in figure 5. The first stage consists of fast current controllers regulating the generator rotor currents to reference values that are specified by a slower power-controller which is the second stage controller. There are two independent PI controllers, one for the d-axis component, and one for the q-axis component. The output of the current controller defines the pulse-width modulation factor P_m in stator voltage orientation.

Voltage control can also be realized by replacing the reactive power controller by a voltage controller defining the d-axis current reference. Up to now, this feature of the DFIG based wind turbine is mainly used to keep the generator reactive power neutral. However, as wind power penetration in power systems is increasing, it will probably be desirable for wind turbines to provide voltage control. The controller shown in Fig. 5 can regulate either the voltage or the power factor, but the maximum possible reactive power production is defined by the converter ratings.

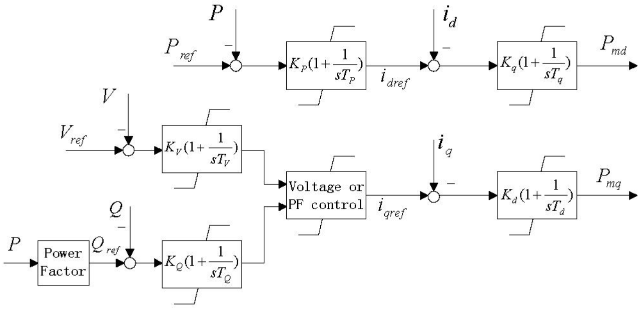

Fig.5. Rotor side converter control strategy diagram

The control concept of the grid-side converter is very similar to the rotor-side controller concept. Further describe seen in paper [1] [4].

F. Wind farm model

In order to reduce the complexity of the analysis, a group of identical generators comprising each wind farm can be replaced by an equivalent generator. This aggregated wind farm model must have the same voltage, current and power response at the point of interconnection. The normalized (per unit) parameters of the aggregated model are the same as that of an individual generator, but the rated power is the sum of the whole group of generators.

IV. Description of Studied System

The power system simulation software PowerFactory 13.1 is used in this study. The studied system is an actual regional power grid integrating a large wind farm into 220kV transmission network via bus 1 (POI: point of interconnection). The single line diagram of this studied grid is illustrated in Figure 6.

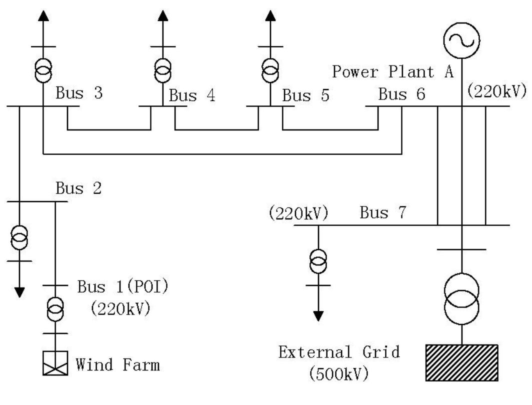

Fig.6. Single line diagram of the studied systems

The local grid incorporating wind power is in the peripheral of the regional grid. The synchronous generator models in the grid consist of AVR and prime mover model. The six order synchronous generator model considering the variation of E''_d 、 E''_q 、 E'_d 、 E'_q is adopted. The load model is a 50% const impedance and 50% motor model. The models and the parameters of the power system are all given by the utility.

V. Steady-state Voltage Stability Anylysis

Wind farms based on different generator technologies would have a distinctive impact on the power system voltage stability [11] - [13]. In this section, the steady-state voltage stability limit of wind farms based on different wind turbine technologies is assessed. Three cases are conducted: case (1) wind turbines equipped with no-load compensated induction generator; case (2) wind turbines equipped with full-load compensated induction generator; case (3) wind turbines equipped with DFIG controlling the POI as a PQ node with Q = 0MVar. All these cases simulation results are compared to discover the wind power integration impact on voltage stability.

A. P~V curve analysis of wind farm with different generator

Wind farms based on different types of wind turbines are interconnected into the transmission grid. When the active power output of wind farm is low, the POI voltage does not affected significantly but when wind power injects into the POI increasing largely then the voltage decreases fast. The P~V curves of the wind farms as wind farm active power output increasing are plotted in Figure 7.

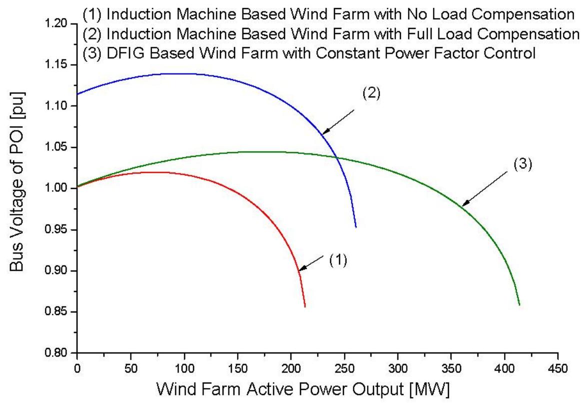

Fig.7. P~V curves of wind farms based on different wind turbines technology

It can be seen from Figure 7 that the steady-state voltage stability limits of induction generator based wind farm with no-load compensation is only 213MW. When more real wind power injects into the POI than 213MW, the voltage will collapse. When the DFIG based wind farm with constant power factor control that control the POI as a PQ bus with Q= 0 MW, the steady-state voltage stability limits are increased largely to 424MW. When 350MW real wind power injects into the grid, the voltage stability margin can be acceptable.

It must be noted that induction generator based wind farm with full-load compensation can enhance the voltage stability limit, but not very obviously; the full-load shunt capacitor compensation should not be put into use in low wind power output totally or else that will arise bus voltage higher than acceptable voltage level such as the curve (2). In actual operation of wind farm with full-load compensation, the shunt capacitor should be switched on gradually along with the active power output increasing. Due to the shunt capacitors compensation, the voltage collapse value in case (2) equal to 0.95 pu is higher than that in case (1) or case (3) equal to 0.85 pu. Because the reactive power output of shunt capacitors is proportional to V^2, as the grid voltage decreasing, the capacitors cannot provide the rating reactive power. The shunt capacitor's reactive power capability is limited in case of lower voltage and cannot improve the voltage stability of the local grid fundamentally.

B. V~Q curve analysis of wind farm with different generator

V~Q curve is a powerful tool to analysis the steady-state voltage stability limits and reactive power margins of the grid by describing the relationship between the bus voltage and the injected reactive power into the same node [12]. It illustrates the reactive power distance from the normal operation point to the voltage collapse point. In this studies, the V~Q curves of different active power output of wind farms based on different types of wind turbines are shown in figure 8 to figure 10.

In the case of induction generator based wind farm with no-load compensation, there is a 13MVar reactive power margin when the wind farm active power output is 200MW; in the case of DFIG based wind farm, there is a 12MVar reactive power margin when the wind farm active power output is 400MW. The acceptable injected real wind power in case (3) double than that in case (1) because the DFIG based wind turbines can provide the reactive power to keep a constant power factor of the whole wind farm and reactive power exchange zero in the POI. This characteristic of DFIG based wind farms would enhance the voltage stability of the local grid integrating wind power.

High demand of reactive power is the major characteristic of large wind farms that causes voltage problems to power networks. The larger the wind farm, the more severe this effect could be. If the network is not able to meet the wind farm reactive power requirement, the wind power penetration into the power system should be limited.

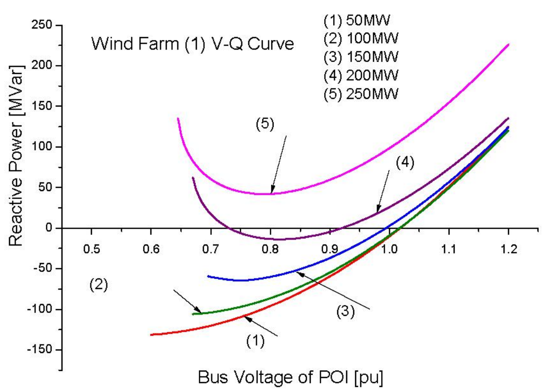

Fig.8. V~Q curve of wind farm based on IG with no-load compensation

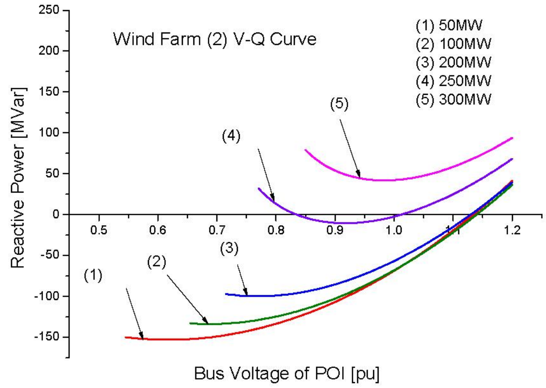

Fig.9. V~Q curve of wind farm based on IG with full-load compensation

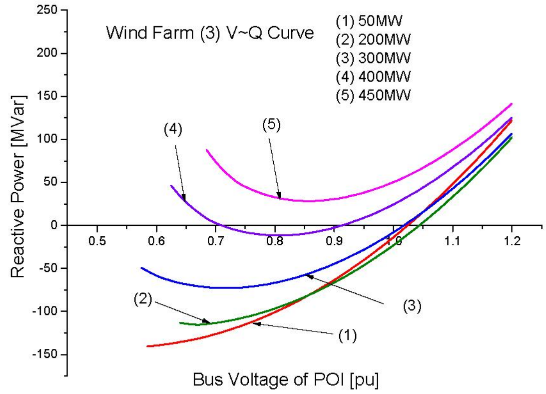

Fig.10. V~Q curve of DFIG based wind farm

VI. Transient voltage stability anylysis

In the transient voltage stability analysis of wind power integration, the voltage recovery issue of grid-connected wind turbines after the clearance of an external short-circuit fault is a basic topic. If the terminal voltage of the grid-connected wind turbines can be restored, the wind turbines can still be connected into the grid and keep in service. If the voltage cannot be restored, the wind turbines need to be tripped or it will collapse the local grid voltage.

For transient voltage stability study in this paper, the three phase short-circuit fault on the line from bus 3 to bus 6 is simulated at the simulation time t = 1s. After the fault clearance, the transmission line will be tripped simultaneously.

A. Transient voltage stability of IG based wind farm

In the case of wind farm with induction generator, the fault critical clearing time is calculated with the wind farm installed capacity increasing. The simulation results are shown in table 1.

TABLE 1
FAULT CRITICAL CLEARING TIME OF IG BASED WIND FARM

Wind farm installed capacity (MW)	critical clearing time(s)
50	0.636
100	0.133
150	0

Along with the wind farm installed capacity increasing, the fault critical clearing time is reduced significantly. When the wind farm installed capacity is above 150MW, the fault critical clearing time is reduced to 0 s. Which means even if the fault clearing time is infinite small, the induction generator terminal voltage cannot be restored because the network is weakened due to the tripped line. The transmission network should not meet the reactive power demand of the wind farm with high output and the local loads so that the voltage collapse is occurred.

When the power system relay protection is considered, the line with 3 phase short-circuit fault will be tripped in 0.1s. The wind turbines generator terminal voltage profile; speed and reactive power consumption is given in figure 11 and figure 12. The wind turbines protection system doesn't be taken into account.

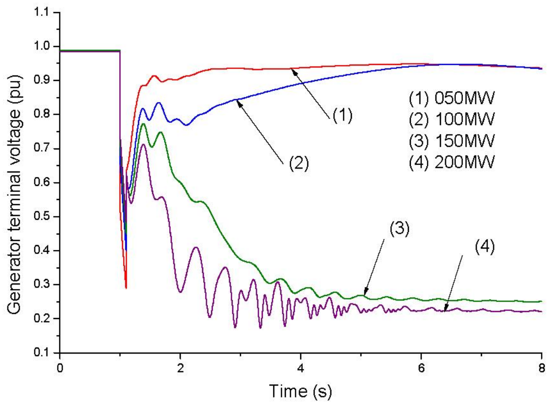

Fig.11. Voltage recovery of IG based wind farm

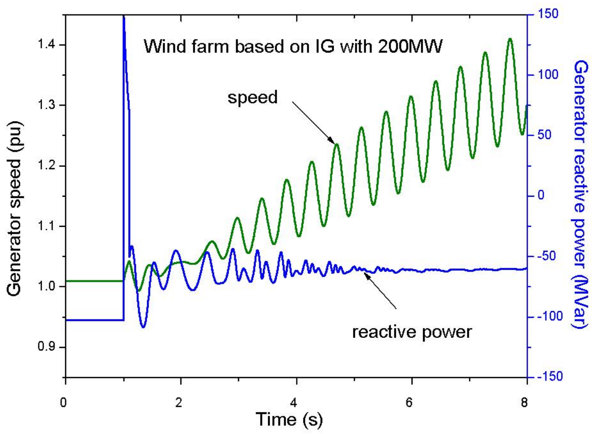

Fig.12. IG speed and reactive power after 3 phase short-circuit fault

It can be seen that when the wind farm installed capacity exceed 150 MW, the wind farm's voltage cannot be restored after the fault clearance; the wind turbine generator speed is accelerated up to over-speeding. Because wind turbines based on induction generator still need reactive power consumptions during the voltage recovery period and the tripped line weakens the network configuration, the local network transient voltage stability will be destroyed.

B. Transient voltage stability of DFIG based wind farm

In the case of wind farm with doubly fed induction generator, the fault critical clearing time is calculated with the wind farm installed capacity increasing. The simulation results are shown in table 2.

TABLE 2
FAULT CRITICAL CLEARING TIME OF DFIG BASED WIND FARM

Wind farm installed capacity (MW)	critical clearing time(s)
200	> 1
250	0.48
300	0

When the wind farm installed capacity is lower than 200MW, the fault critical clearing time is larger than 1 s; the transient voltage stability of local grid is greatly larger than in the case of induction generator. More wind power installed capacity increasing; the fault critical clearing time is also reduced demonstrating that the transient voltage stability is deteriorated. When the wind farm installed capacity reaches 300MW, the fault critical clearing time is reduced to 0 s. When the power system relay protection is considered, the line with 3 phase short-circuit fault will be tripped in 0.1s. The wind turbines generator terminal voltage profile; speed and reactive power consumption is given by figure 13 and figure 14. The wind turbines protection system doesn't be taken into account.

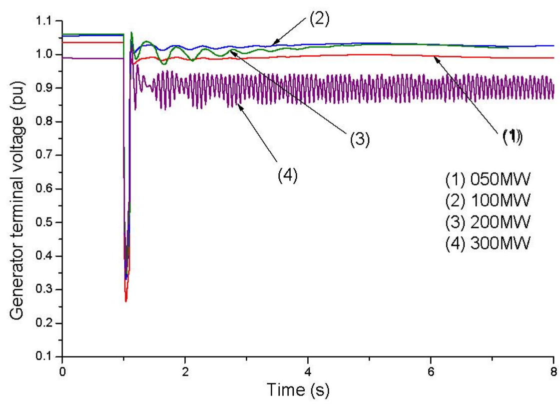

Fig.13. Voltage recovery of DFIG based wind farm

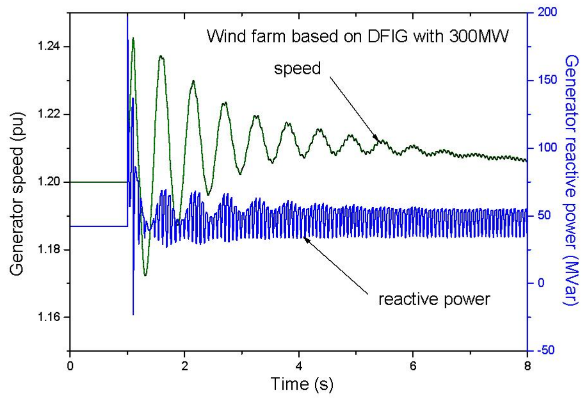

Fig.14. DFIG speed and reactive power after 3 phase short-circuit fault

In all the study cases, the DFIG based wind turbines have a better voltage recovery performance than the same rating IG based wind turbines. Due to the control capability to regulate reactive power and voltage, the DFIG wind turbines will mitigate the adverse affect on voltage stability of the local transmission grid. Even if the wind farm installed capacity reaches 300MW, the control system of the DFIG also can prevent the generator speed from over-speeding after the fault clearance; but there is an imbalance between the wind turbines mechanical power and electric power because the low voltage following the fault that limits the wind farm active power output, which results in the oscillation of the speed, power and voltage of the wind farm. In actual operation, it can be resolved by tripping some wind turbines or by adopting pitch control to reduce the mechanical power of the wind turbines.

VII. Conclusion

In this paper the wind power integration impact on voltage stability are studied both in steady-state and in transient state. The differences of the impact of wind farms with different types of wind turbines are compared. The following conclusions are drawn:

a. Wind turbines equipped with simple induction generator are not provided with reactive power regulation capability. Voltage stability deterioration is mainly due to the large amount of reactive power absorbed by the wind turbine generators during the continuous operation and system contingencies.
b. Wind turbines equipped with doubly fed induction generator (DFIG) are capable of reactive power regulation; can absorb or supply reactive power by the PWM converters. The adverse affect on local network voltage stability is mitigated so that more wind power installed capacity base on DFIG can be incorporated into the grid.
c. The transient voltage stability characteristics of wind turbines with DFIG are better than that of wind turbines with induction generator because of the voltage control capability of the DFIG; The DFIG based wind turbines have a better voltage recovery performance than the same rating IG based wind turbines.

VIII. References

[1] Vladislav Akhmatov, "Analysis of Dynamic Behavior of Electric Power Systems with Large amount of Wind Power," Ph.D. dissertation, Dept. Electric Power Eng., Ørsted-DTU, Denmark, April 2003.

[2] Y. Lei, A. Mullane, G. Lightbody, R. Yacamini, "Modeling of the Wind Turbine with a Doubly Fed Induction Generator for Grid Integration Studies," *IEEE Trans. Energy Conversion*, vol. 21, issue 1, pp. 257-264, March. 2006.

[3] R. Pena, J. C. Clare, G. M. Asher, "Doubly fed induction generator using back-to-back PWM converters and its application to variable speed wind-energy generation," *IEE proc.-Electr. Power Appl.*, Volume 143, Issue 3, May 1996 Page(s):231 - 241

[4] Poller.M.A, "Doubly-fed induction machine models for stability assessment of wind farms," *Power Tech Conference Proceedings, IEEE Bologna,* Volume 3, 23-26 June 2003 Page(s):6 pp.

[5] "Dynamic Modeling of Doubly-Fed Induction Machine Wind-Generators," Digsilent GmbH, Germany, Tech. Rep., Aug. 2003.

[6] A. D. Hansen, C. Jauch, and P. Sorensen, "Dynamic Wind Turbine Models in Power System Simulation Tool Digsilent," Risø National Laboratory, Risø, Denmark, Tech. Rep. Risø-R-400(EN), Dec. 2003.

[7] A. Feijo, J. Cidrs, and C. Carrillo, "Third order model for the doubly-fed induction machine," *Elect. Power Syst. Res.*, vol. 56, pp. 121–127, Mar.2000.

[8] N.W. Miller, J. J. Sanchez-Gasca, W.W. Price, "Dynamic modeling of GE 1.5 and 3.6MW wind turbine generators for stability simulations," *Proc. IEEE Power Engineering Society General Meeting*, vol. 3, Jul. 2003, pp. 1977–1983.

[9] K. Nandigam, B. H. Chowdhury. "Power flow and stability models for induction generators used in wind turbines," *IEEE Power Engineering Society General Meeting,* Vol.2, 6-10 June 2004 Page(s):2012 - 2016

[10] P. Kunder, *Power System Stability and Control*, New York: McGraw-Hill, 1994.

[11] F.Q.Zhou, G.Joos, C.Abbey, "Voltage Stability in Weak Connection Wind Farms," *Power Engineering Society General Meeting, 2005. IEEE.* Volume 2, 12-16 June 2005 Page(s): 1483-1488.

[12] C. W. Taylor, *Power system voltage stability*, New York: McGraw-Hill, 1994.

[13] L. T. Ha, T. K. Saha, "Investigation of Power Loss and Voltage Stability Limits for Large Wind Farm Connections to a Sub-transmission Network," *Power Engineering Society General Meeting, 2004. IEEE,* 6-10 June 2004 Page(s):2251-2256 Vol.2.

IX. Biographies

Yongning Chi received the B.Eng and M.Eng degrees in 1995 and 2002 respectively, both from Shandong University, China, all in electrical power system engineering. He is currently a Ph.D. candidate with China Electric Power Research Institute in Beijing. His most recent research involves integration of wind power into the Jilin power grid in Northeast China. His primary fields of interest are wind power integration impact on power system and power system stability analysis.

Yanhua Liu received the B.Eng degree from Taiyuan Technology University, in 1997, and M.Eng degree from North China Electric Power University in 2000 with the specialty of power system engineering. She is a Lecturer in North China Electric Power University and pursuing her doctor degree in China Electric Power Research Institute in Beijing. Her primary fields of interest are wind power integration and wind power planning.

Weisheng Wang received his Bachelor degree and Master degree at Xi'an University of Technology, Doctor degree at Xi'an Jiaotong University, in July 1990, July 1993 and Dec. 1996, respectively, all in Electrical Engineering. Now, He is a senior engineer in China Electric Power Research Institute. His areas of research interest are power system and wind power generation.

Huizhu Dai graduated from Department of Electrical Engineering, Tsinghua University in July 1962. From 1981 to 1983, she worked in Leihigh University and Cornell University, USA as a senior visiting scholar. Now, she is a professor in China Electric Power Research Institute. Her areas of research interest are power system and wind power generation.