Improvement of LVRT Capability of Wind Energy System by Using STATCOM

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Abstract: This paper presents an improvement in Low Voltage Ride Through capability of wind farm. With the continued growth of wind power installed capacity, as well as the continual emergence of large-capacity wind farm, the impact of wind power on the grid will not be ignored. Studying on the performance characteristics of wind turbine and analyzing the effects on grid and the generators are of great significance to ensure the grid-connected wind turbine safe and reliable operation. In this paper the dynamic model of the induction generator and of wind turbines is built in MATLAB. Additionally, the static synchronous compensator (STATCOM) model and a vector control method are prompted. The simulation of a single machine infinite bus system containing a wind farm is conducted, which includes two different kinds of wind turbines. By comparing the active power, reactive power, and the output voltage of two different kinds of wind turbines, the effect of STATCOM on low Voltage ride-through capability of wind generators is analyzed when the grid voltage dropped. Simulation result shows that STATCOM has played a big role in maintaining the transient voltage stability of the power system and improves the fault ride-through capacity of wind farms

Index Terms - Doubly-fed induction generator, fault ride through, induction generator, STATCOM, wind farm

I. INTRODUCTION

During the last decades wind energy has grown rapidly and became most competitive form of renewable energy. With increasing of the scale of wind power, concern on the impact of wind power the grid aroused widely. Once large-scale wind power disconnect from the power grid, the stability of power grid will be seriously affected. Therefore, it is crucial to maintain the wind farms connect to the grid in the case of grid fault in certain degree. To achieve the aim, the wind farm should have fault ride-through (FRT) capability. When the voltage in the grid is temporarily dropped, the wind farm is required to keep connected with the grid during a certain length of time, even supporting the grid with reactive power.

STATCOM, as a kind of popular reactive synchronous compensator, is widely used in improving FRT ability of wind farm. Currently, doubly-fed induction generator of wind turbine (DFIG) and the conventional constant speed wind turbine is the majority of wind farms. The characteristics of these turbines are totally different. The induction generator of wind turbine need more reactive power from grid than DFIG, for there is no converter between generator and grid. The induction generator of Wind turbine realizes FRT with the help of STATCOM, by which the FRT characteristics of DFIG can be improved either. In order to analyze FRT capability of the wind farm consist of different turbines with the help of STATCOM a STATCOM model and wind farm model(including squirrel cage induction wind turbine and general doubly-fed wind turbine) is set up by using PSASP, and the simulation is carried out on wind farm in case of three-phase short circuit fault. By comparing the active power, reactive power, and the output voltage of two different kinds of wind turbines, the effect of STATCOM on FRT capability of wind generators is analyzed when the grid voltage dropped. At last, some beneficial conclusions are obtained.

II. MATHEMATICAL MODEL OF INDUCTION GENERATOR

The model of induction generator is based on the rotor winding transient component, and the stator winding transient component is neglected.

Stator voltage equations of induction generator are as follows,

$$U_x = -r\,I_x + x' I_x + E' \ldots\ldots\ldots\ldots$$
$$U_y = -r\,I_y + x' I_x + E'y \ldots\ldots\ldots\ldots \quad (1)$$

Where,

$$U = U_x + j\,U_y$$
$$I = I_x + j\,I_y$$
$$E' = E'_x + j\,E'_y$$

Transient equation of induction generator in synchronous reference system:

$$\begin{cases} T'_{d0}\frac{dE'_x}{dt} = -E'_x - (x' - x)I_y + 2\pi f_0 T'_{d0} s E'_y \ldots\ldots\ldots \\ T'_{d0}\frac{dE'_y}{dt} = -E'_y - (x' - x)I_x + 2\pi f_0 T'_{d0} s E'_x \ldots\ldots\ldots \end{cases} \quad (2)$$

Where, $T'_{do} = \frac{x_2 + x_m}{2\pi f_0 r_2}$ is a time constant of rotor winding when the stator winding is open circuited, Where *U*, *I*, *E* are stator voltage, stator current and the transient potential, r_1, r_2, x_1, x_2, x_m are stator resistance, rotor resistance, stator reactance, rotor reactance and per unit magnetizing reactance respectively, $x = x_1 + x_m$ is per unit transient reactance. $x' = x_1 + \frac{x_2 x_m}{x_2 + x_m}$ is per unit transient reactance.

III. MATHEMATICAL MODELING OF STATCOM

A static synchronous compensator (STATCOM) is a power electronic device based on the principle of voltage source converter, which possesses the characteristics of quick response and smooth regulation and can quickly adjust the reactive power of the power grid. Fig. 1 is the schematic diagram of STATCOM.

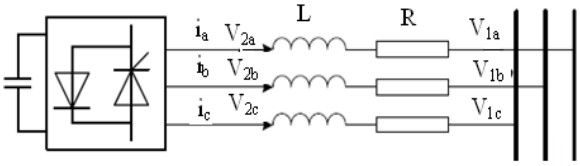

Fig. 1 The diagram of STATCOM

The voltage equation of STATCOM in the system is:

$$\begin{bmatrix} V_{1a} \\ V_{2b} \\ V_{3c} \end{bmatrix} = R \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + L \begin{bmatrix} di_b/dt \\ di_c/dt \\ di_a/dt \end{bmatrix} + \begin{bmatrix} V_{2a} \\ V_{2b} \\ V_{2c} \end{bmatrix}$$

Where, V_{1a}, V_{1b}, V_{1c} are the voltage of grid, V_{2a}, V_{2b}, V_{2c} and i_a, i_b, i_c are STATCOM voltage and current, R is the resistance and L is the inductance between grid and STATCOM. When the coordinate system is converted to *d-q* Coordinates, then, the voltage equation can be described as follow:

$$\begin{bmatrix} V_{1d} \\ V_{1q} \end{bmatrix} = R \begin{bmatrix} i_d \\ i_q \end{bmatrix} + L \begin{bmatrix} d_{id}/dt \\ d_{iq}/dt \end{bmatrix}$$

$$+ L \begin{bmatrix} 0 & -\omega \\ \omega & 0 \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} V_{2d} \\ V_{2c} \end{bmatrix}$$

If make the d-axis direction the same with voltage direction, Then, $V1q=0$ and the decoupled control of active and reactive power can be achieved.

$$P = \frac{3}{2} V_{1d}\, i_d = V_{dc} i_{dc}$$
$$Q = -\frac{3}{2} V_{1d} i_q$$

Where, $V_{1q}=0$, V_{dc} and i_{dc} are the DC link voltage and current. The DC link voltage can be controlled by regulating the *i*d, which can compensate for the loss of the converter; the reactive power of STATCOM can be controlled by regulating the i_q , which can control the voltage. The vector control technique is selected in this paper for its fast dynamics and decoupled control ability. By use of this technique the control of the DC link voltage and reactive current is decoupled like in the control of torque and flux in the field oriented control of motor drives.

IV. SIMULATION ANALYSIS

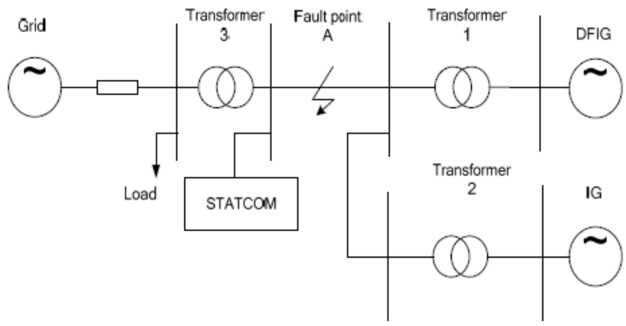

Fig. 2 Simplified diagram of wind farm connected with the grid

Simulation example is shown in Fig. 2. It is showed in Figure 3 that the 18MW wind farm is connected to the infinite power system. The wind farm consists of six 1.5MW doubly-fed turbines and twelve 750kW induction wind turbines, and the output voltage is 690V. Through the high-voltage transformer 1 and transformer 2, the output voltage is raised to 10kV, which is raised to 110kV later through transformer 3 and is connected to infinite- bus system by 110 kV transmission lines 10km in length. The grid is shown as an infinite voltage source. The load is 2MW, and the impedance of transmission lines is 0.6764+j1.3528 ohms.

Operation of wind turbine is subject to the grid operating conditions. When the fault occurs, the turbine may be stopped under disturbances or fluctuations of wind speed, which leads to lack of active power in system. It not only brings economic loss to the wind farm but also causes a loss to system stability. When the wind farm is damaged by serious fault, such as three-phase short circuit fault, the wind turbine must have low voltage ride-through capability. Six wind turbines can be equal to one by assuming that all the wind turbines are operated under the same condition. The low-voltage protection of wind farm is set as 0.75 p.u. and execution delay is 0.1 s. When the three-phase short circuit fault occurs at point A at the 5th second, the fault is restored at 5.1 s. In this case, the wind farm is simulated with STATCOM and without STATCOM respectively. The simulation results are given with active power, reactive power and output voltage of the wind induction generators, which are shown in Fig. 3, 4 and 5.

It is shown in the simulation results that when STATCOM is not installed in the wind farm and the three-phase short circuit fault occurs at point A, the induction motor will be accelerated because of the imbalance between the mechanical torque and the electromagnetic torque. This process will also absorb a large amount of reactive power, and the 690V bus voltage can only be recovered to 0.7 p.u. With the rotate peed rises continuously, the turbine goes out of control. With STATCOM installed in the wind farm, the 690 V bus voltage

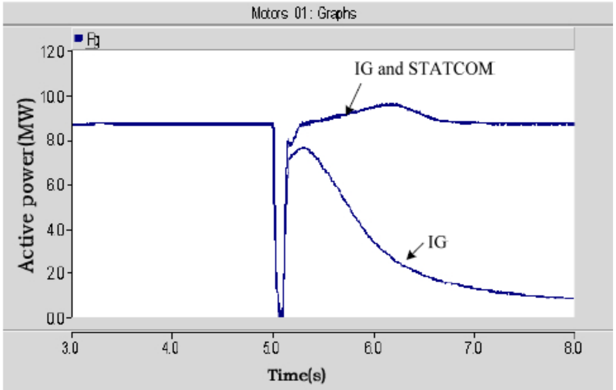

Fig. 3 Active power of IG during point A three phases short-circuit

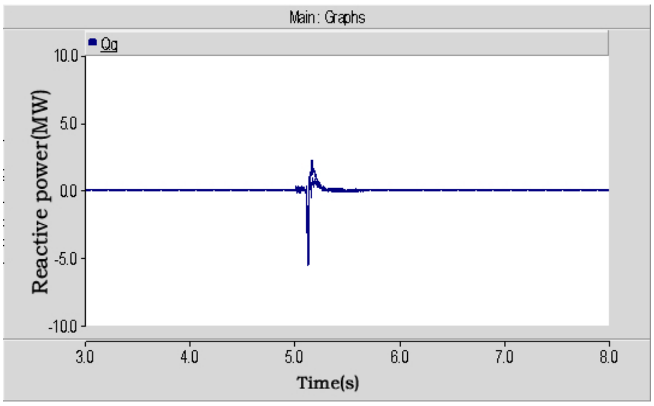

Fig. 7 Reactive power of DFIG during point A three phases short-circuit

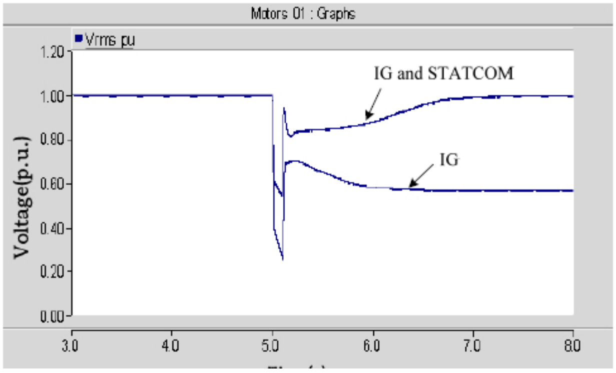

Fig. 4 Reactive power of IG during point A three phases short-circuit

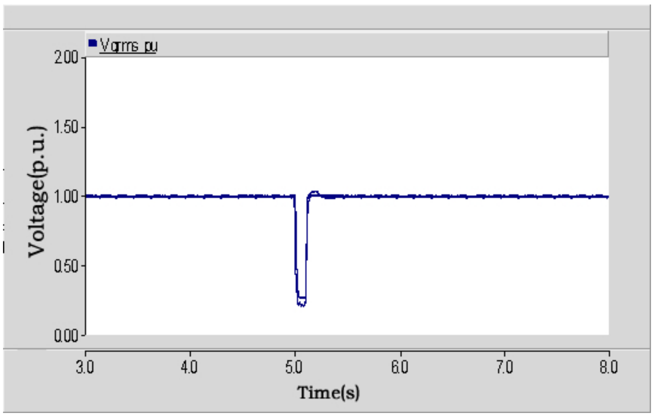

Fig. 8 Voltage of DFIG during point A three phases short-circuit

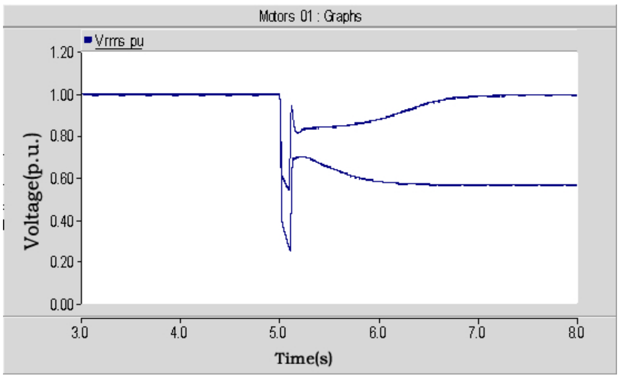

Fig. 5 Voltage of IG during point A three phases short-circuit

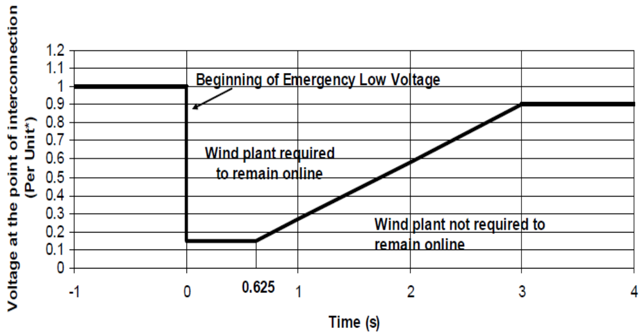

Fig. 9 Fault Ride-Through Requirement of Wind Turbine System (WTS)

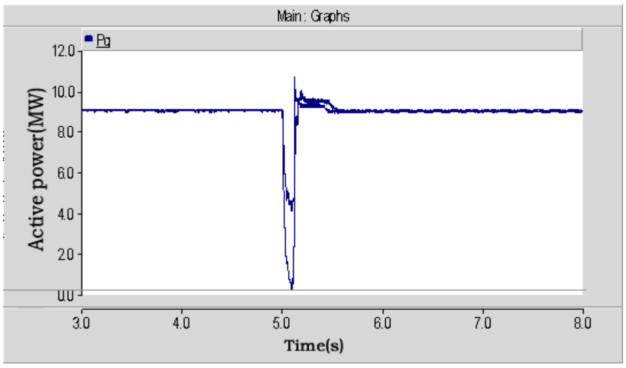

Fig.6 Active power of DFIG during point A three phases short-circuit

The increasing and expansion of wind power has set some new problems to power system. The power system with large scale wind power will involve problems not only in steady state operation but also in contingency condition. FRT requires keep the WTs on the grid during faults so that they can contribute to the stability to the power transmission system. Experts have done many re-searches about the behaviors of WTs

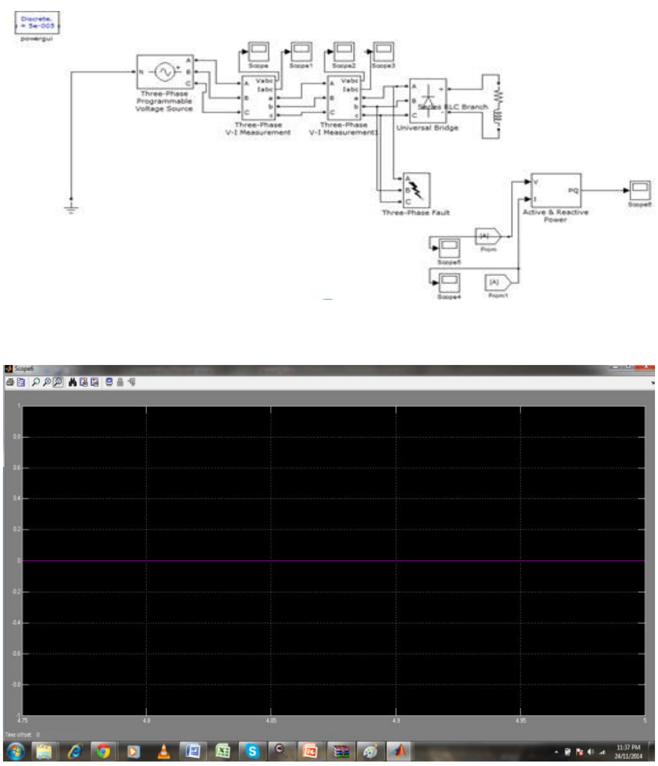

Fig. 10 Simulation and result of three Phase active and reactive power measurement at RL load

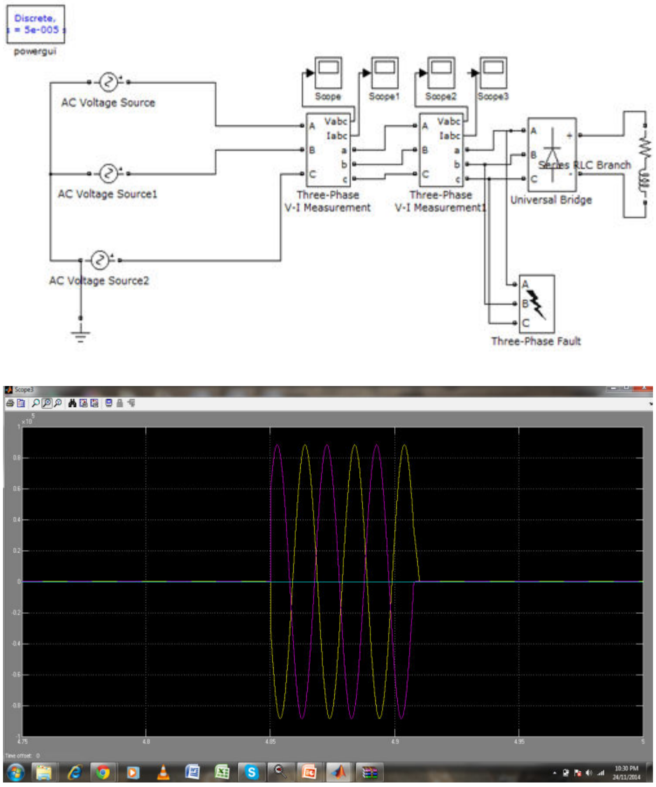

Fig. 12 Simulation and result of measurement of voltage and current during 3 phase fault

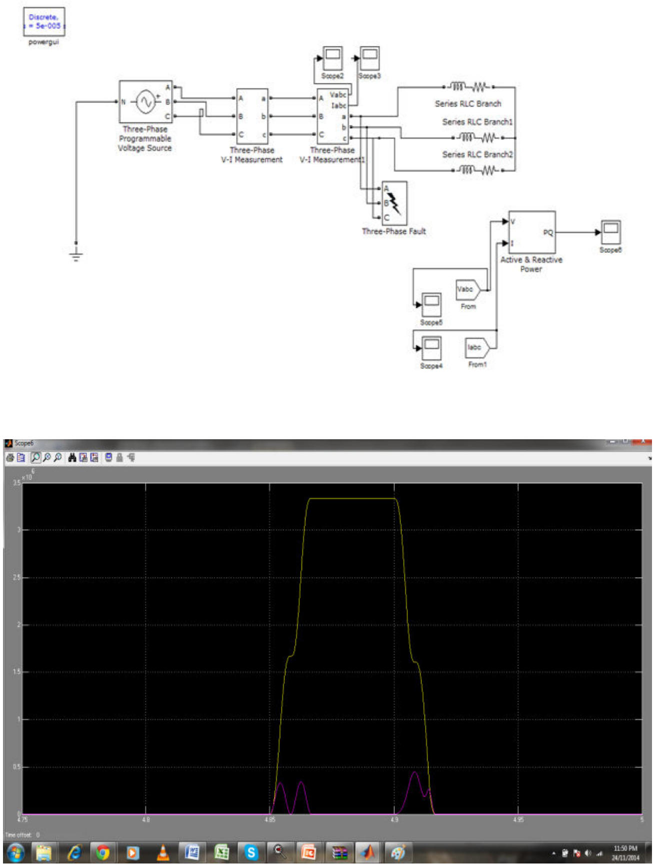

Fig. 11 Simulation and result of Measurement of active and reactive power for 3 phase RLC load

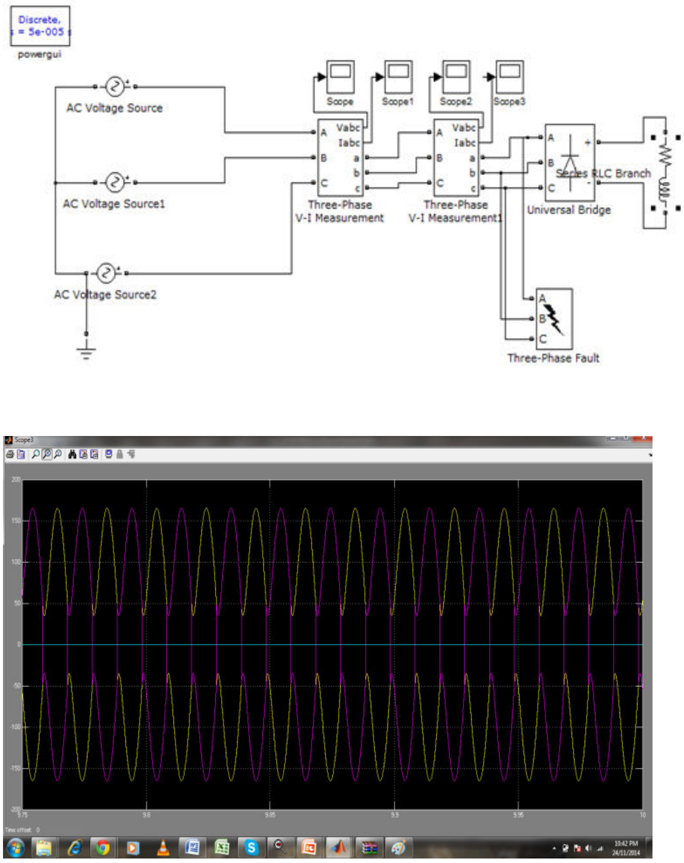

Fig. 13 Simulation and result of Measurement of voltage and current at RL load

V. CONCLUSION

Thus by using facts devices the Fault ride through capability of wind farm can be improved at the time of fault condition. When the grid fault occurs fact device can provide sufficient reactive power to satisfy the need of induction generator in wind farm and active and reactive power of DFIG can be controlled by using convertors. From the literature we can say that DFIG proved to be better than IG and the fault sustaining capability of DFIG is better. This project will give the results in improvement in FRT capability of DFIG and IG by considering all power system faults.

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