International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075, Volume-4 Issue-3, August 2014

Analysis of DFIG Based Wind Turbine System during Different Types of Grid Fault

Kiran Singh, Chandasree Das

***Abstract*— The doubly fed induction generator (DFIG) based wind turbine(WT) system provides better power delivery towards the demand .This paper presents the performance of DFIG based wind turbine system during voltage dip caused due to different types of grid fault. Low-voltage ride-through (LVRT) capability of the system according to the grid connection requirement during these faults is studied and discussed in the paper. Further, power flow through the grid with different load conditions is compared and LVRT capability of the system is studied for each load condition. In addition to this, a 16 bus distribution system is connected to two generators and one DFIG based wind turbine system and the reactive power compensation is provided at two buses by using capacitors. The results obtained prove that due to the compensation provided the reactive power flow through those buses is reduced to a great extent and thereby improving systems stability and reliability. The design and response of the DFIG based wind turbine system during different fault conditions, various load conditions and integrated system consisting of DFIG based WT system and 16 bus distribution systems have been verified using MATLAB/ Simulink.**

***Keywords*—DFIG, Distrbution system, LVRT,Wind Turbine .**

I. INTRODUCTION

With the increase in penetration of wind in power generation, the dynamic behavior of the power system will change because of various technologies used for wind and conventional generators. The DFIG is the most widely used device for wind power generation. DFIG is a popular WT system due to advantages like it can operate in generator and motor mode for both sub and super-synchronous speed mode, also speed variation of ±30% around synchronous speed can be obtained, and the size of the converter is related to the selected speed range. Recently, the number of small size wind farm based on DFIG located within the distribution system is increasing at a very fast rate. As the penetration of wind power continually increases, more wind turbines are required to stay, grid connected during a grid fault to maintain the reliability during and after a short-term fault [1]. The capability of WT to stay connected to the grid during voltage dips is called as the low-voltage ride-through (LVRT) capability. In order to fulfill the LVRT conditions for DFIG based WTs, there are two important conditions to be considered during a fault condition.

Manuscript Received on August 23, 2014.

Mtech Student. Kiran Singh, Power Electronics, VTU/ BMSCE Bangalore, India.

Dr. Chandasree Das, EEE, VTU/ BMSCE, Bangalore, India .

The first is the over-current that can occur in rotor and stator circuits, while the second is over voltage in the DC-link, both leads to the unbalanced energy that cannot be transmitted into the grid. For reducing the inrush currents in the rotor and the DC-link over-voltage during the faults, an advanced control strategies for the rotor and grid side converters is used [2]–[9]

II. FAULT AND LVRT ANALYSIS

The schematic diagram of a grid-connected DFIG WT system is shown in Fig. 1 [10]. Figure shows that the DFIG WT system, which consists of wind turbine, DFIG, the back-to-back PWM converters, and the control system, is connected to the grid through a transformer.

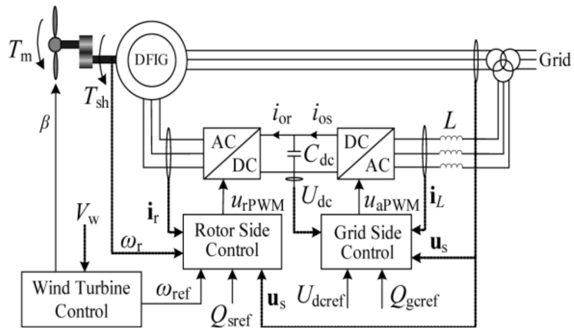

Fig 1. Schematic Diagram of the DFIG WT System [10].

An attempt has been taken in this paper to present effects of different types of fault like single line to ground fault, double line to ground fault and three phase short circuit fault on DFIG based wind turbine system. Further it is shown that on increasing load in between DFIG and grid, the amount of active power supplied to grid decreases. Therefore, before connecting any local load in between DFIG and grid its LVRT capability should be confirmed during normal as well as during fault conditions, otherwise it may lead to LVRT failure. In normal operation, the rotor side converter controls the real and reactive power outputs of the machine. The generator rotor speed increases through control of the rotor side converter during a grid voltage dip. The grid side converter has to transmit the active power from the dc-link to the grid so that the dc-link voltage is kept within limits. The grid side control scheme provides a compensation item, during the fault to smooth the fluctuations of the DC-link voltage [10]. The wind turbine control is achieved by driving the generator/turbine speed along the optimum power-speed characteristic curve, which corresponds to the maximum energy capture from the wind [11]. The pitch angle of the blade is controlled to optimize the power extraction of the WT and to prevent over rated power production in high wind.

III. REACTIVE POWER ANALYSIS

Further a 16 bus distribution system with capacitive support at any two buses is connected to the DFIG WT, and reactive power flow at those two respective buses is studied. It is found that by providing capacitive compensation, the reactive power flow through the system is reduced to a great extent. Simulation studies using Mat lab /Simulink have been conducted on a 1.5-MW DFIG WT to validate the effect of different types of fault on DFIG based wind turbine system and ability of the system to sustain LVRT during voltage dips is verified and for 16 bus distribution system reactive power flow reduction with capacitor has been verified which improves overall system stability and hence reliability of the system.

IV. RESULTS AND DISCUSSION

Different faults considered are as follows:

A. Single line to ground fault

In order to meet the ride-through requirement of a widely referred grid code [12], two typical single line to ground faults are imposed on the transmission power grid at the PCC due to which voltage drop to 15% of its nominal value for 200 ms, at wind speed of 8 m/s and 13 m/s respectively. When fault occurs the grid voltage dips for a period of 200 ms as shown in figure 2 for phase A and the effect on grid voltage in phase B and C is very less shown in figure 3 and figure 4. Fluctuations in rotor speed, real and reactive power supplied to the grid are shown in figure 5, 6 and 7 respectively. The fluctuations of stator and rotor current, and DC-link voltage, shaft torque and pitch angle are shown in figure 8, 9, 10,11and12 respectively. Hence, the WT system ride through the fault is achieved. All the simulation studies shown are for 13 m/s of wind speed.

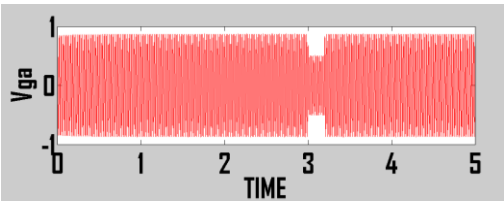

Figure.2 Grid voltage during Single line to ground fault for phase A

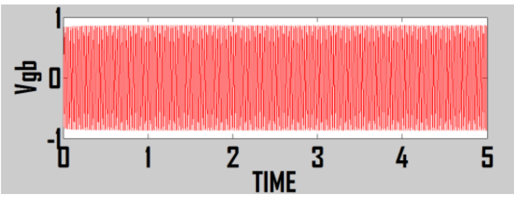

Figure.3 Grid voltage during Single line to ground fault for phase B.

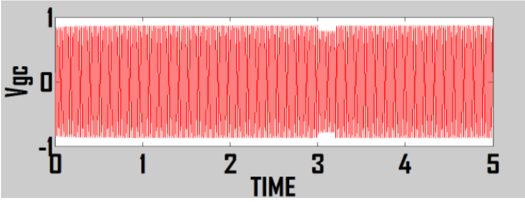

Figure.4 Grid voltage during Single line to ground fault for phase C.

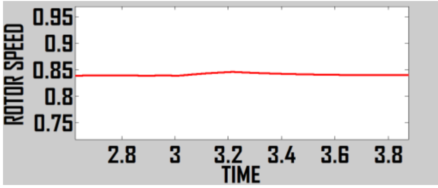

Figure.5 Rotor Speed.

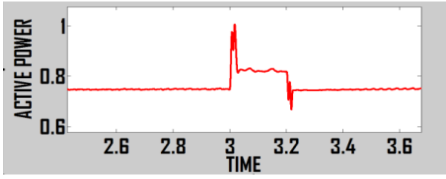

Figure.6 Active power to the grid.

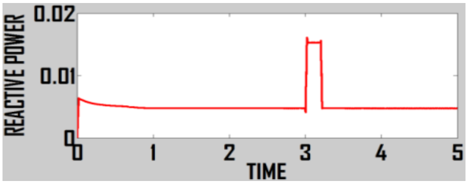

Figure.7 Reactive power to the grid

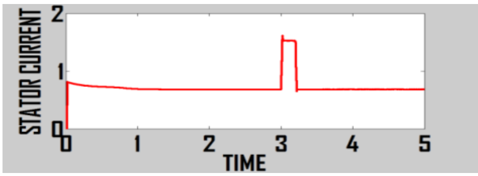

Figure.8 Stator current.

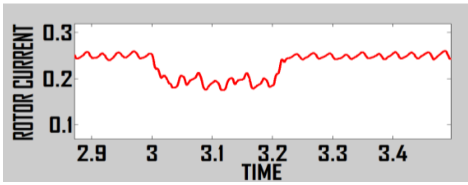

Figure.9 Rotor current.

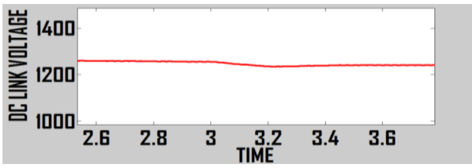

Figure.10 DC-Link Voltage.

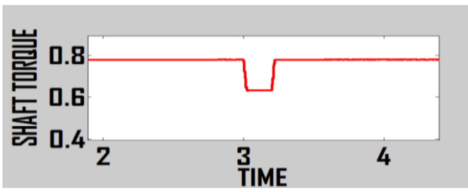

Figure.11 Shaft torque.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

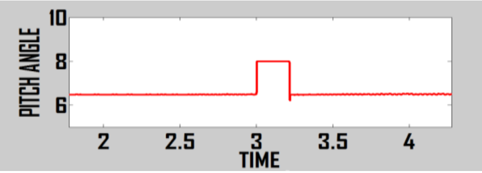

Figure.12 Pitch angle.

B. Double line to ground fault

For the analysis of double line to ground fault, in order to meet the ride-through requirement of a grid code , two typical double line to ground faults are imposed on the transmission power grid at the PCC, the voltage drops to 15% of its nominal value for 200 ms, at wind speed of 8m/s and 13m/s respectively. When the wind speed is 13 m/s, which is higher than the rated wind speed, the DFIG WT is operating at the rated rotor speed. The increase in rotor speed during the fault in this case is higher than its rated value, which will trigger the pitch control immediately. This limits the conversion of the electric energy into the kinetic one. When fault occurs the grid voltage dips for all the three phases for a period of 200 ms as shown in figure 13, 14 and 15. The transient behaviors of the rotor speed, real and reactive power are shown in figure 16, 17 and 18, fluctuations in rotor and stator current, DC link voltage, shaft torque and pitch angle are shown in figure 19, 20, 21, 22 and 23 respectively. It can be concluded that, the DFIG is able to maintain LVRT during the double line to ground fault. All the simulation studies shown are for 13 m/s of wind speed.

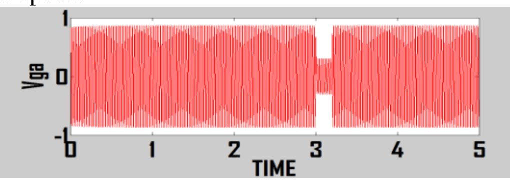

Figure.13 Grid voltage during double line to ground fault for phase A.

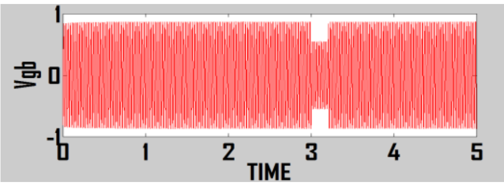

Figure.14 Grid voltage during double line to ground fault for phase B.

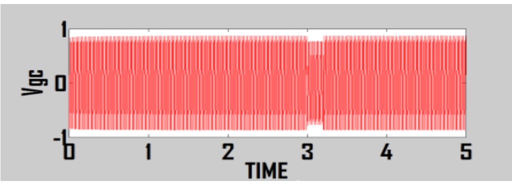

Figure.15 Grid voltage during double line to ground fault for phase C.

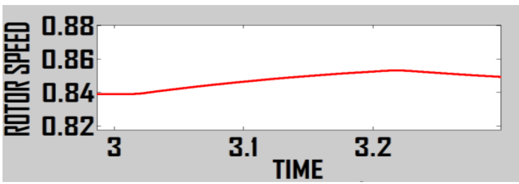

Figure.16 Rotor speed.

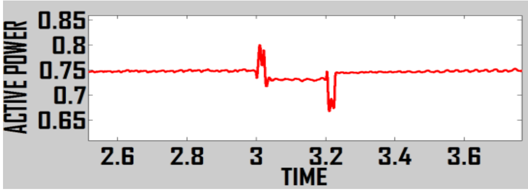

Figure.17 Real power to the grid.

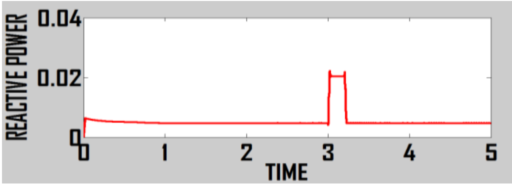

Figure.18 Reactive power to the grid.

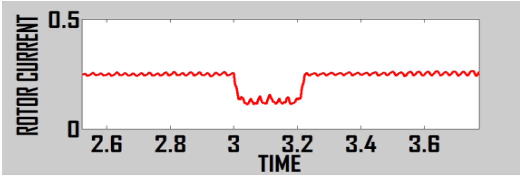

Figure.19 Rotor current.

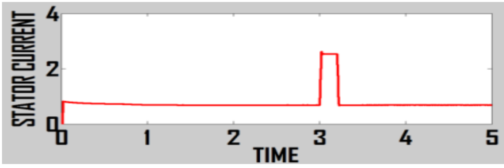

Figure.20 Stator current.

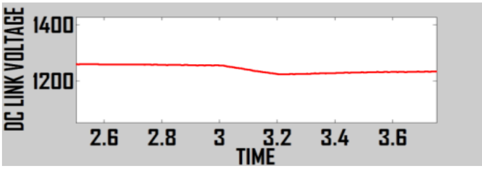

Figure.21 DC - link voltage.

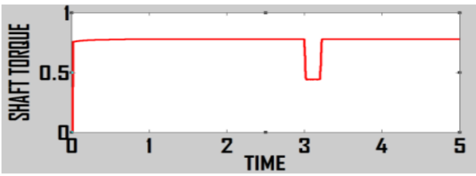

Figure.22 Shaft Torque.

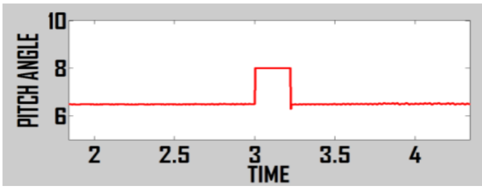

Figure.23 Pitch Angle.

C. Three phase short circuit fault

For the analyses of three phase short circuit fault, in order to meet the ride-through requirement of a widely referred grid code, two typical three phase short circuit faults are imposed on the transmission power grid at, the PCC when voltage drops to 15% of its nominal value for 200 ms, at wind speed of 8m/s and 13m/s respectively [10]. When fault occurs the grid voltage dips for a period of 200 ms at a wind speed of 13m/s for three phases are shown in figure 24, 25 and 26.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

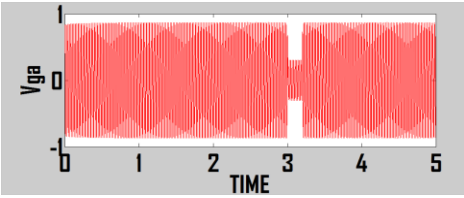

Figure.24 Grid voltage during three phase short circuit fault for phase A.

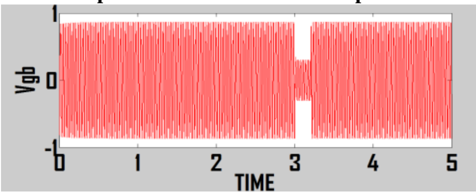

Figure.25 Grid voltage during three phase short circuit fault for phase B.

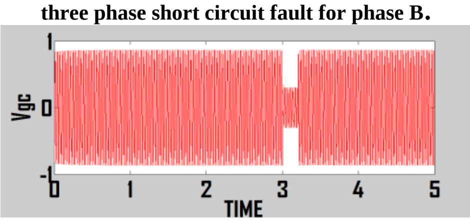

Figure.26 Grid voltage during three phase short circuit fault for phase C.

The effect of three phase short circuit fault on grid voltage is most severe. Fluctuations with regard to grid voltage, rotor speed, real power, reactive power, rotor and stator current and dc link voltage, shaft torque and pitch angle is maximum for three phase short circuit fault followed by double line to ground fault and then single line to ground fault.

D. Varying load condition

Further, power flow to the grid for varying load conditions is simulated and LVRT is verified. It is found that with additional load in between DFIG and grid, the active power to the grid settles down to 8.2 p.u from 8.3 p.u, when no additional load was connected. Additional load should be connected taking LVRT requirements under consideration. Active power flow to the grid during normal operation without and with additional load is shown in figure 27 and 29 respectively. LVRT during both load conditions are shown in figure 28 and 30.

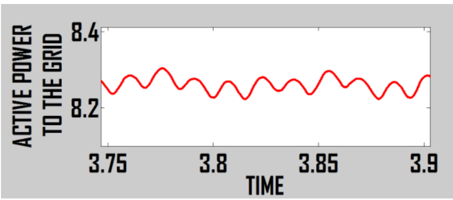

Figure.27 Active power to the grid for single load condition under normal operation.

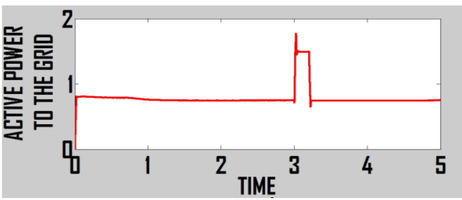

Figure.28 LVRT sustained during fault.

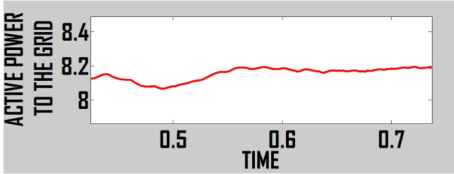

Figure.29 Active power to the grid with additional load.

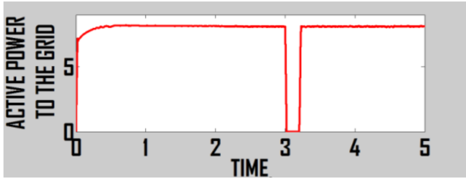

Figure.30 LVRT failure with an additional load during fault.

E. 16-Bus Distribution System

In the next part, the DFIG based wind turbine is integrated to a 16 bus distribution system and reactive power analysis is carried out. By providing capacitive compensation at bus no 5 and 11 reactive power requirement comes down to -1×10^{-6} VAR and 8.9×10^{-4} VAR for bus 5 and 11 respectively which was 0.026 VAR and 0.0275 VAR at bus number 5 and 11 respectively. Simulation results are presented in figure 31 and 33 with capacitive support and figure 32 and 34 shows reactive power flow through buses 5 and 11 without capacitive support respectively.

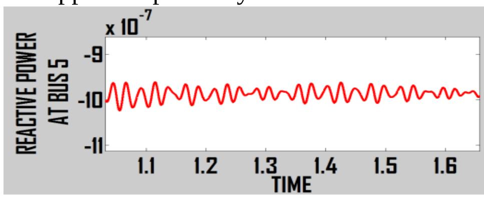

Figure.31 Reactive Power flow at bus 5 with capacitor.

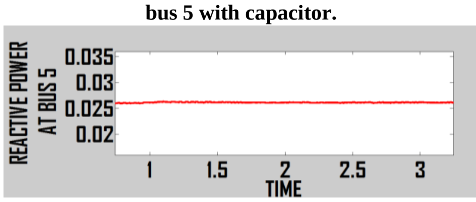

Figure.32 Reactive Power flow at bus 5 without capacitor.

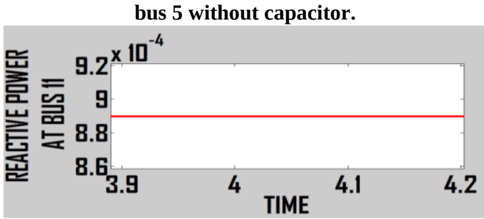

Figure.33 Reactive Power flow at bus 11 with capacitor

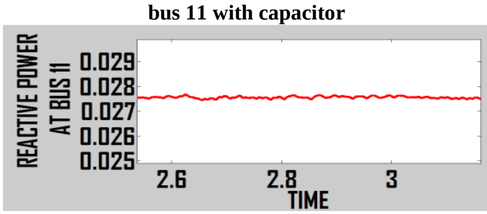

Figure.34 Reactive Power flow at bus 11 without capacitor.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

V. CONCLUSION

High penetration of WTs imposes a big challenge to the safe operation of power systems. To ensure the security of electricity supply with substantial wind power, the WTs must ride through during voltage dip caused due to different grid faults. The effect of three phase short circuit fault on grid voltage is most severe. Fluctuations with regard to grid voltage, rotor speed, real power, reactive power, rotor and stator current , dc link voltage, shaft torque and pitch angle is maximum for three phase short circuit fault followed by double line to ground fault and then single line to ground fault. While connecting a local load in between DFIG and grid LVRT requirements should be confirmed which otherwise may lead to LVRT failure during fault. At last the problem of reactive power loss in a 16 bus distribution system is minimized by providing capacitive support at the respective buses which improves power factor as well. Hence stability and reliability of the system is enhanced.

APPENDIX

The parameters of the studied DFIG WT are as follows:
Wind turbine:
cut-in wind speed: 4 m/s;
lower limit of the wind speed: 7m/s;
rated wind speed: 12 m/s;
inertia constant: H_t=3s;
damping coefficient: D_{sh}=0.01p.u;
shaft stiffness coefficient: K_{sh}=0.5p.u.;
time constant of the pitch servo: T_β=0.25s.
DFIG:
rated power: 1.5 MW;
rated voltage: 575 V;
rated current: 1505A;
rated rotor speed: 1.1p.u (with the synchronous speed as the base value);
inertia constant: H_g=0.5s;
friction coefficient: B =0.01p.u;
stator resistance: R_s=.00706 p.u;
rotor resistance: R_r =0,005p.u ;
stator leakage inductance: L_{ls} =0.171 p.u;
rotor leakage inductance :L_{lr} =0.156p.u;
mutual inductance: L_m=3.5p.u.
Converters:
Resistance of grid side inductor: R_L = 0.003p.u;
Inductance of grid side inductor: L = 0.3p.u;
DC-link capacitor: C_{dc} =0.06F[10].

REFERENCES

1. A. Thomas, Wind Power in Power Systems. New York: Wiley, 2005.
2. D.Xiang, L. Ran, P. J. Tavner, and S. Yang, “Control of a doubly-fed induction generator in a wind turbine during grid fault ride-through,”IEEE Trans. Energy Convers., vol. 21, no. 3, pp. 652–662, Sep. 2006.
3. M. Rathi and N. Mohan, “A novel robust low voltage and fault ride through for wind turbine application operating in weak grids,” inProc.IEEE Industrial Electronics Society Conf., Nov. 2005, pp. 6–10.
4. A. Hansen and G. Michalke, “Fault ride-through capability of DFIG wind turbines,”Renew. Energy, vol. 32, no. 9, pp. 1594–1610, Jul.2007.
5. J. Lopez, P. Sanchis, X. Roboam, and L. Marroyo, “Dynamic behavior of the doubly fed induction generator during three-phase voltage dips,”IEEE Trans. Energy Convers., vol. 22, no. 3, pp. 709–717, Sep. 2007.
6. L. Xu and P. Cartwright, “Direct active and reactive power control of DFIG for wind energy generation,”IEEE Trans. Energy Convers., vol.21, no. 3, pp. 750–758, Sep. 2007.
7. M. Rahimi and M. Parniani, “Transient performance improvement of wind turbines with doubly fed induction generators using nonlinear control strategy,”IEEE Trans. Energy Convers., vol. 25, no. 2, pp.514–525, Jun. 2010.
8. F. K. A. Lima, A. Luna, P. Rodriguez, E. H. Watanabe, and F. Blaabjerg, “Rotor voltage dynamics in the doubly fed induction generator during grid faults,”IEEE Trans. Power Electron.,vol. 25, no. 1, pp.118–130, Jan. 2010.
9. J. Liang, W. Qiao, and R. G. Harley, “Feed-forward transient current control for low-voltage ride-through enhancement of DFIG wind turbines,”IEEE Trans. Energy Convers., vol. 25, no. 3, pp. 836–843, Sep.2010.
10. Lihui Yang, Zhao Xu, Jacob Østergaard, Zhao Yang Dong and Kit Po Wong, “Advanced Control Strategy of DFIG Wind Turbines for Power System Fault Ride Through*,” IEEE Trans. Power system.*, vol. 27, no. 3, pp.713–722., May. 2012.
11. A. D. Hansen, P. Sørensen, F. Iov, and F. Blaabjerg, “Control of variable speed wind turbines with doubly-fed induction generators,” *Wind Eng.*, vol. 28, no. 4, pp. 411–434, 2004.
12. M. Tsili and S. Papathanassiou, “A review of grid code technical re-quirements for wind farms,” *IET Renew. Power Gen*., vol. 3, no. 3, pp. 308–332, Sep. 2009.