ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 6, June 2014

COMPARISON BETWEEN ISOLATED AND GRID CONNECTED DFIG WIND TURBINE

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Abstract: The conventional resources of energy are depleting .These resources will be finished after few years, therefore new sources of energy will be required which does not use fossil. To overcome these problems in recent years, wind energy has become one of the most important and promising sources of renewable energy, which demands additional transmission capacity and better means of maintaining system reliability. To harness the wind energy efficiently the most reliable system in the present era is grid connected doubly fed induction generator. The rotor side converter (RSC) usually provides active and reactive power control of the machine while the grid- side converter (GSC) keeps the voltage of the DC-link constant. The GSC can supply the required reactive current very quickly while RSC passes the current through the machine resulting in a delay. Both converters can be overloaded, so the DFIG is able to provide considerable contribution to grid voltage support during short circuit periods. This paper deals with the introduction of DFIG, AC/DC/AC converter control and finally the SIMULINK/MATLAB simulation for isolated IG as well as for grid connected DFIG and corresponding result and waveforms are displayed.

Keywords: Wind turbine, DFIG, AC/DC/AC converter, converter control system.

I. INTRODUCTION

Now a day, wind energy has become a viable solution for energy production, in addition to other renewable energy sources. One way of generating electricity from renewable sources is to use wind turbines that convert the energy contained in flowing air into electricity. With increased penetration of wind power into electrical grids, doubly fed induction generator wind turbines are largely used due to their variable speed feature and hence influencing system dynamics. DFIG offers the advantages of speed control for a reduction in cost and power losses. This paper presents the modeling and simulation of wind turbine doubly fed induction generator in wind farm. In the DFIG system, the power electronic interface controls the rotor currents in order to control the electrical torque and thus the rotational speed. Because the power electronics only process the rotor power, which is typically less than 25% of the overall output power [5]. DFIG offers the advantages of speed control for a reduction in cost and power losses.

The continuous trend of having high penetration of wind power, in recent years, has made it necessary to introduce new practices. For example, grid codes are being revised to ensure that wind turbines would contribute to the control of voltage and frequency and also to stay connected to the host network following a disturbance. Additionally, in order to model back-to back PWM converters, in the simplest scenario, it is assumed that the converters are ideal and the DC link voltage between the converters is constant.

II. DOUBLY FED INDUCTION GENERATOR

Wind turbines use a doubly-fed induction generator consisting of a wound rotor induction generator and AC/DC/AC IGBT- based PWM converter. The DFIG technology allows extracting maximum power from the wind for low speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind. The optimum turbine speed producing maximum mechanical energy for a given wind speed is proportional to the wind speed. Another advantage of DFIG technology is the ability for power electronic converters to generate or absorb reactive power, thus eliminating the need for installing capacitor banks as in the case of squirrel cage induction generator. Here V_r is the rotor voltage and V_{gc} is grid side voltage. The AC/DC/AC converter is basically a PWM converter which uses sinusoidal PWM technique to reduce the harmonics present in the wind turbine driven DFIG system. Here C_{rotor} is rotor side converter and C_{grid} is grid side converter. To control the speed of wind turbine gear boxes or electronic control can be used. Fig. shows the basic diagram of doubly fed induction generator with converters.

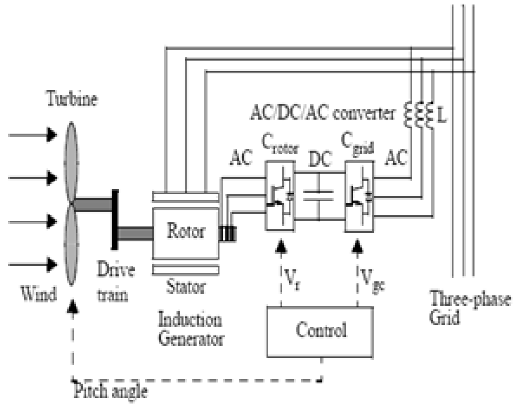

Fig.1 Basic diagram of DFIG with converters

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INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
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III. WIND CHARACTERISTIC

A wind turbine can extract part of the power from the wind, which is limited by belz limit (maximum 59%). This fraction is described by the power coefficient of wind turbine C_p, which is function of the blade pitch angle and the tip speed ratio. Therefore, the equation (1) described the mechanical power of the wind turbine extracted from the wind,

$$P_m = 0.5\rho\ A\ V^3 C_p\ (\beta, \lambda) \qquad (1)$$

Where ρ is air density, A is the area swept by blades, V is wind speed, β is a blade pitch angle and λ is the tip speed ratio. Equation (2) shows the tip speed ratio given as,

$$\lambda = \omega R / V \qquad (2)$$

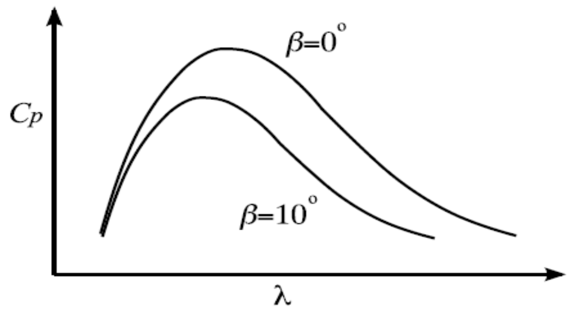

Fig. 2 Shows the typical performance coefficient vs. tip speed ratio curve with varying the blade pitch angle

It can be seen that λ should be held constant to harness maximum power from the wind. The turbine rotational speed must therefore increase as the wind speed increases. When the wind turbine reaches its maximum rotational speed however, blade pitch angle control can be employed to shed the excess wind power. Increasing the blade pitch angle decreases the optimum C_p and λ value as shown in fig. above.

IV. CONVERTER CONTROL SYSTEM

A. Rotor side converter control system

The back to back PWM converter has two converters, one is connected to rotor side and another is connected to grid side. Control by both converters has been discussed as shown in fig,

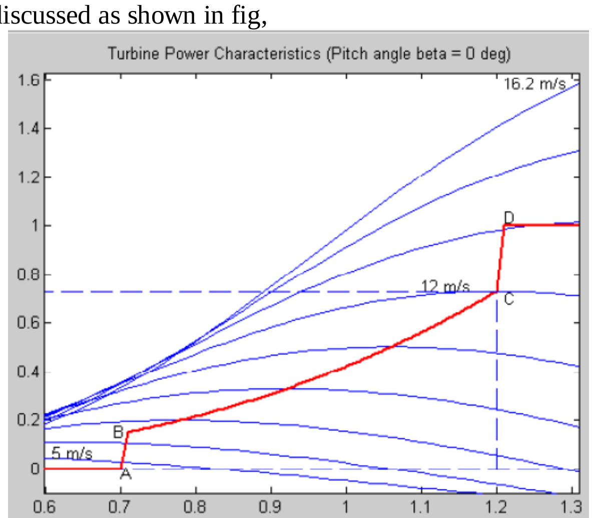

Fig. 3 Turbine power characteristic

The rotor side converter is used to control the wind turbine output power and the voltage measured at the grid terminals. The power is controlled in order to follow a pre-defined power-speed characteristic, named tracking characteristic. This tracking characteristic is defined by four points: A, B, C,D. from zero up to point A the reference power is zero. Between point A and point B the tracking characteristic is a straight line. Between point B and point C the tracking characteristic is a straight line. Between point B and point C it is locus of maximum power of the turbine. Tracking characteristic is a straight line from point C to point D. the power at point D is one per unit. Beyond point D the reference power is a constant equal to one per unit.

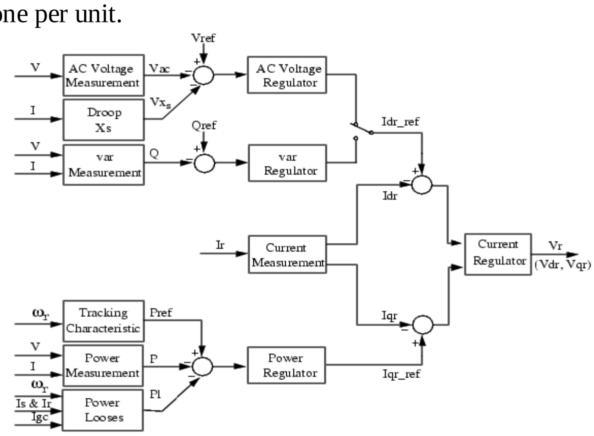

Fig. 4 Rotor converter control block diagram

The actual electrical output power, measured at the grid terminals of the wind turbine, is added to the total power losses (mechanical and electrical) and is compared with the reference power obtained from the tracking characteristic. A proportional-integral (PI) regulator is used to reduce the power error to zero. The output of this regulator is reference rotor current $\mathbf{I_{qr\_ref}}$ that must be injected in the rotor by converter $\mathbf{C_{rotor}}$. This is the current component that produces the electromagnetic torque T_{em}. The actual $\mathbf{I_{qr}}$ component is compared to $\mathbf{I_{qr\_ref}}$ and the error is reduced to zero by a current regulator (PI). The output of this current controller is the voltage V_{qr} generated by C_{rotor}. The voltage at grid terminals is controlled by the reactive power generated or absorbed by the converter C_{rotor}.

B. GRID SIDE CONVERTER CONTROL SYSTEM

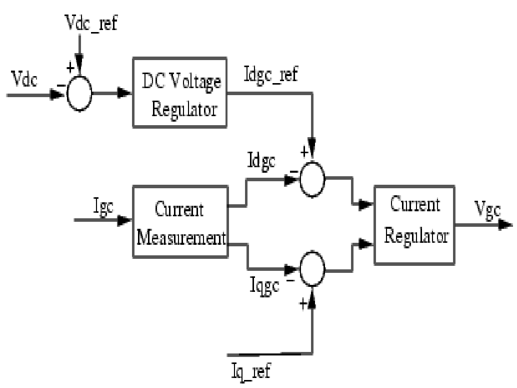

Fig. 5 Grid side converter control

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The grid side converter is used to regulate the voltage of the DC bus capacitor. For the grid side controller the d-axis of the rotating reference frame used for d-q transformation is aligned with the positive sequence of grid voltage. the current regulator controls the magnitude and phase of the voltage generated by converter C_{grid} (V_{gc}) from the I_{dgc}_ref produced by DC voltage regulator and specified I_{q_ref}. the current regulator is assisted by feed forward terms which predict the C_{grid} output voltage.

B.PITCH CONTROL SYSTEM

The pitch angle is kept constant at zero degree until the speed reaches point D speed of tracking characteristic. Beyond point D the pitch angle is proportional to the speed deviation from point D speed. The wind speed should be selected in such that the rotational speed is less than the speed at point D.

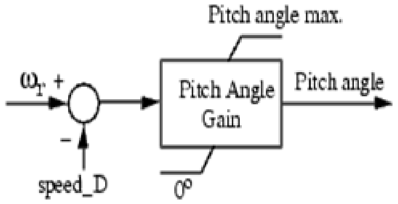
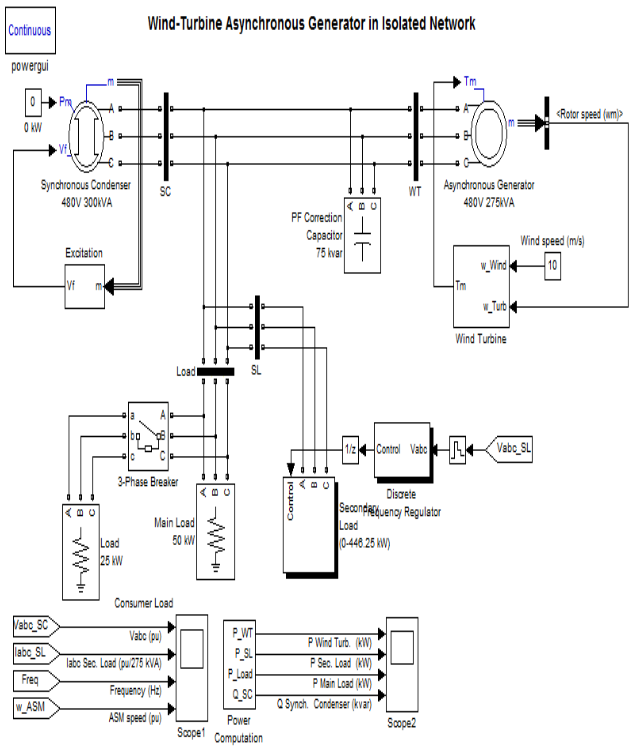


Fig. 6 Pitch angle converter control

V. WIND TURBINE DRIVEN ISOLATED INDUCTION GENERATOR MODEL SIMULATION IN SIMULINK

Fig. 7 shows the generic model of isolated doubly fed induction generator driven wind turbine. Wind turbine is connected to doubly fed induction generator to convert mechanical energy to electrical energy. A 3- phase capacitor bank is connected to compensate reactive power.



the wind speed (10m/s) is such that the wind turbine produces enough power to supply the load. The diesel generator (not simulated) is stopped and the synchronous machine operates as a synchronous condenser with its mechanical power input (Pm) set at zero. the dynamic performance of the frequency regulation system when an additional 25 kW customer load is switched on.

Synchronous condenser is a device identical to synchronous motor whose shaft is not connected to anything but spins freely. Its purpose is not to convert electrical power to mechanical power or vice- versa, but to adjust conditions on the electrical power transmission grid. Its field is controlled by a voltage regulator to either generate or absorb reactive power as needed to adjust the grid voltage or to improve power factor.

Unlike a capacitor bank, the amount of reactive power from a synchronous condenser can be continuously adjusted. Reactive power from a capacitor bank decreases, when grid voltage decreases. While a synchronous condenser can increase reactive current as voltage decrease. However, synchronous machine have higher energy losses than static capacitor banks. At low wind speeds both the induction generator and the diesel-driven synchronous generator are required to feed the load. When the wind power exceeds the load demand, it is possible to shut down the diesel generator. In this all-wind mode, the synchronous machine is used as a synchronous condenser and its excitation system controls the grid voltage at its nominal value. A secondary load bank is used to regulate the system frequency by absorbing the wind power exceeding consumer demand.

Wind turbines use squirrel cage induction generator. The stator winding is directly connected to the 60 Hz grid and the rotor is driven by variable pitch turbine. The pitch angle is controlled in order to limit the generator output power at its nominal value for winds exceeding the nominal speed (9 m/s). in order to generate output power the IG speed must be slightly above the synchronous speed. Speed varies approximately between 1 pu at no load and 1.005 pu at full load. Reactive power absorbed by the IGs is partly compensated by capacitor banks connected at each wind turbine low voltage bus (400 kvar for each pair of 1.5 MW turbine) and the rest of reactive power required to maintain the 25-kv voltage at bus B25 close to 1 pu is provided b a 3-Mvar STATCOM with a 3% droop setting.

OUTPUT CHARACTERISTIC

Turbine response to change in wind speed

the wind speed (10m/s) is such that the wind turbine produces enough power to supply the load. The diesel generator (not simulated) is stopped and the synchronous machine operates as a synchronous condenser with its mechanical power input (Pm) set at zero. The demo illustrates the dynamic performance of the frequency regulation system when an additional 25 kW customer load is switched on.

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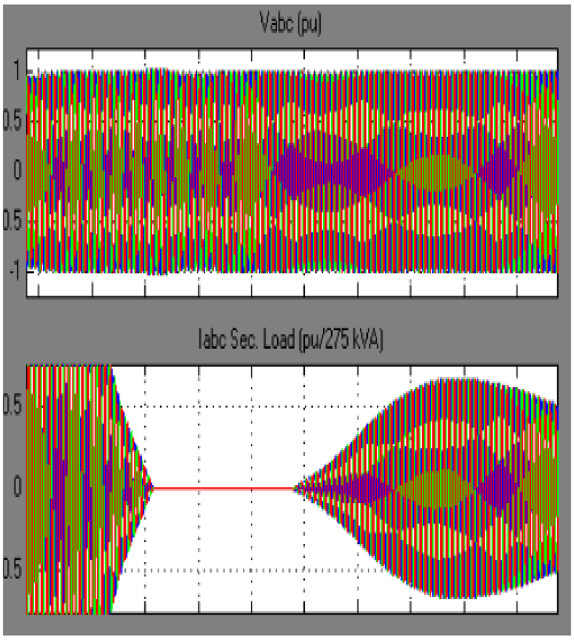

Fig. 8 Characteristic of load voltage and load current

Fig. shows the waveform of load voltage and load current. 9-MW wind farm is simulated by three pairs of 1.5MW wind turbines. Wind turbines use squirrel cage induction generator. The stator winding is directly connected to the 60 Hz grid and the rotor is driven by variable pitch turbine. The pitch angle is controlled in order to limit the generator output power at its nominal value for winds exceeding the nominal speed (9 m/s). in order to generate output power the IG speed must be slightly above the synchronous speed. Speed varies approximately between 1 pu at no load and 1.005 pu at full load.

A. Operational characteristics of a doubly- fed induction generator (DFIG) connected to grid side

A 9-MW wind farm consisting of six 1.5MW wind turbines connected to a 25-kv distribution system exports power to a 120-kv grid through a 30-km, 25-kv feeder. A 2300V, 2-MVA plant consisting of a motor load and of a 200-kw resistive load is connected on the same feeder at bus B25. Both the wind turbine and motor load have a protection system monitoring voltage, current and machine speed. The DC link voltage of DFIG is also monitored. This section illustrates application of sim power systems software to study the steady state and dynamic performance of a 9MW wind farm connected to a distribution system. Wind turbines use a doubly-fed induction generator consisting of a wound rotor induction generator and an AC/DC/AC IGBT based PWM converter. The stator winding is connected directly to the 50Hz grid while the rotor is fed at variable frequency through the AC/DC/AC converter. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind. For wind speeds lower than 10 m/s the rotor is running at sub synchronous speed. At high wind speed it is running at super synchronous speed. Turbine speed optimization is obtained between point B and point C on this curve.

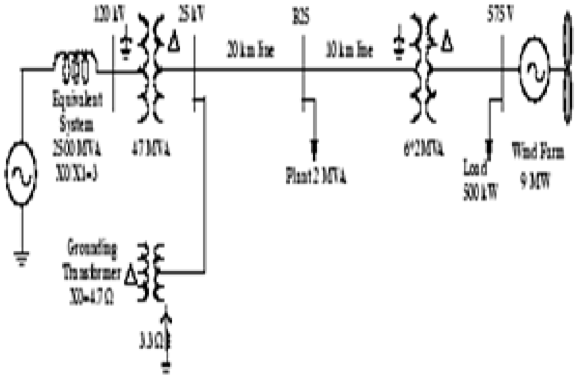

Fig. 9 Single line diagram connected to distribution system

Another advantage of DFIG technology is the ability for power electronic converters to generate or absorb reactive power, thus eliminating the need for installing capacitor banks as in the case of squirrel cage induction generators.

VI. SIMULINK DIAGRAM

This is the Simulink diagram for a doubly fed induction generator connected to grid side with wind turbine protection schemes involved for protection from single phase fault and ground faults. The system is connected to a 120 kv, 3-phase source which is connected to 9 MW wind farm by step don transformer, fault protection and pi-transmission line. Wind turbine protection block is also mentioned in which positive sequence voltage and current and DC voltage are given as input and for their corresponding values trip data is used to see whether it should be tripped or not. The different values for tripping may be AC over voltage, under voltage, overcurrent, undercurrent, DC overvoltage, over speed, and under speed.

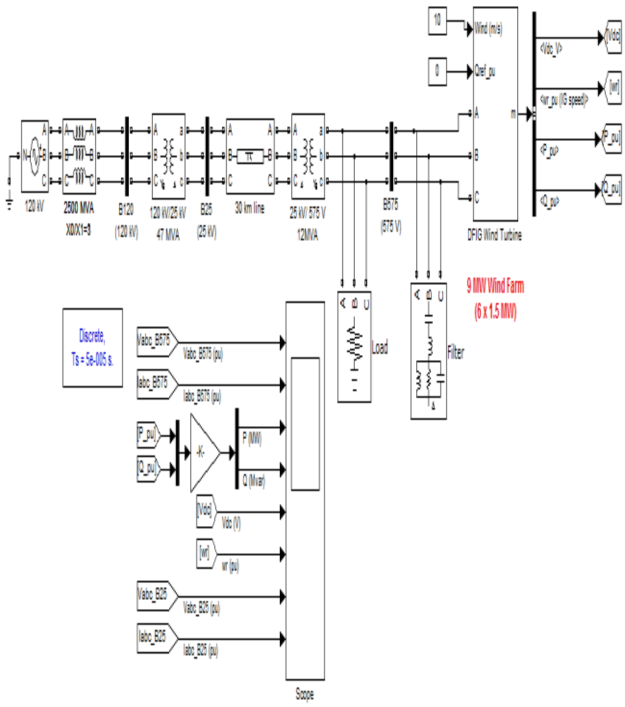

Fig. 10 simulation diagram of grid connected wind turbine

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A. Waveforms

For each pair of wind turbine the generated active power starts increasing smoothly (together with the wind speed) to reach its rated value of 3MW in approximately 8s. over that time frame the turbine speed will have increased from 1.0028 pu to 1.0047 pu. Initially the pitch angle of the turbine blades is zero degree. When power exceeds 3MW, the pitch angle is increased from 0 degree to 8 degree in order to bring output power back to its nominal value.

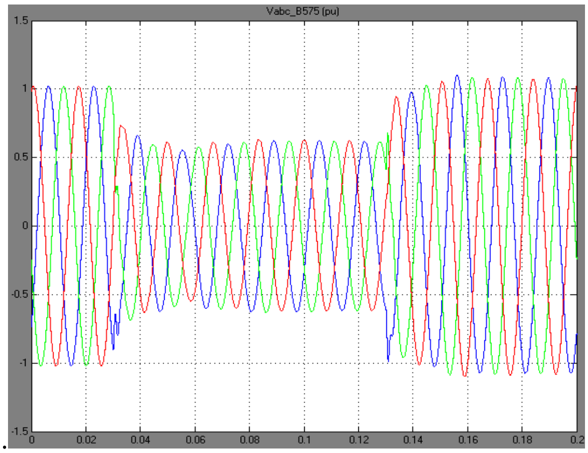

Fig. waveform of Vabc B575V

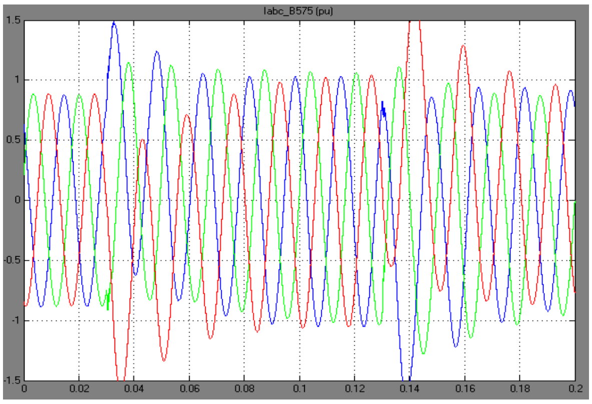

Fig. waveform of Iabc B575V

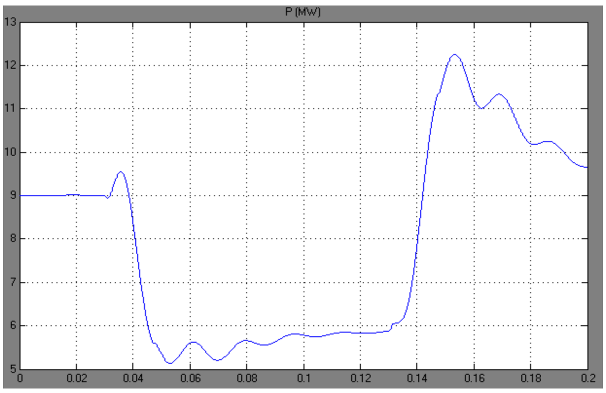

Fig. waveform of real power

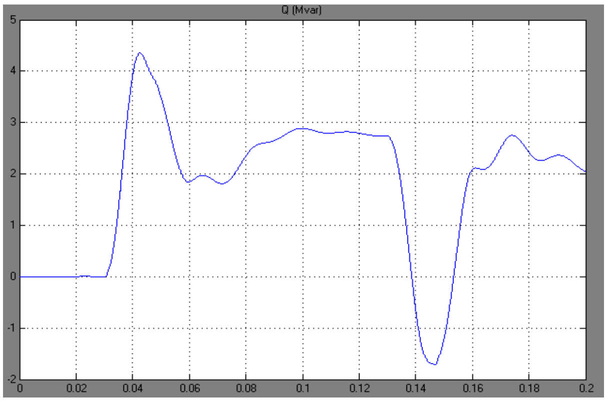

Fig. waveform of reactive power

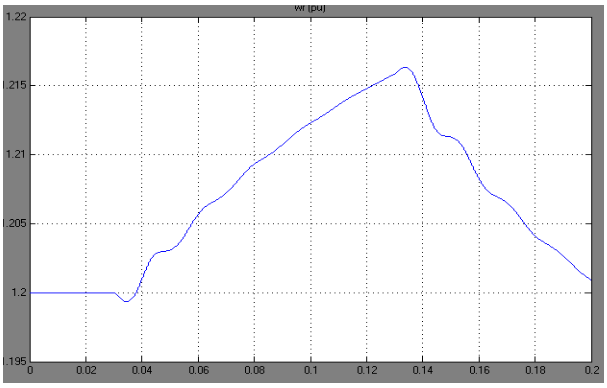

Fig. waveform of rotor speed in PU

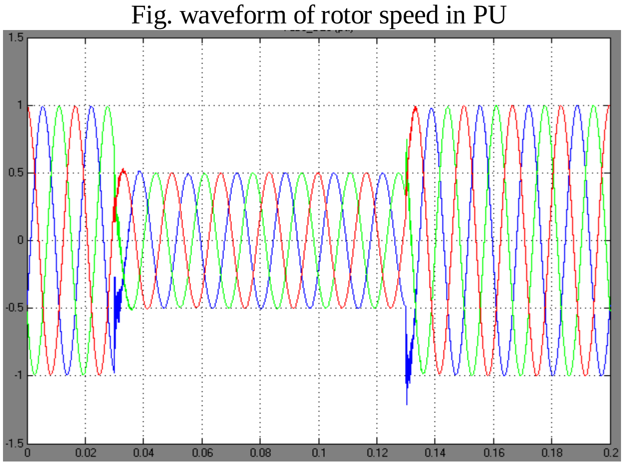
Fig. waveform of Iabc B25V

For each pair of wind turbine the generated active power starts increasing smoothly (together with the wind speed) to reach its rated value of 3MW in approximately 8s. Over that time frame the turbine speed will have increased from 1.0028 pu to 1.0047 pu. Initially the pitch angle of the turbine blades is zero degree. When power exceeds 3MW, the pitch angle is increased from 0 degree to 8 degree in order to bring output power back to its nominal value.

CONCLUSION

The Basic principle of DFIG and it's controls using AC/DC/AC converter has been described in this paper. First simulation of a wind turbine isolated (not connected to grid) induction generator has been shown. But for best efficiency the DFIG system is used which is connected to grid side and has better control. The rotor side converter (RSC) usually provides active and reactive power control of the machine while the grid side converter (GSC) keeps the DC-link voltage constant. So finally we simulated grid side and wind side parameters and the corresponding results have been displayed. DFIG proved to be more reliable and stable system when connected to grid side with the proper converter control systems. The model is discrete time version of the wind turbine DFIG (phasor) of MATLAB/sim power system.

REFERENCES

[1] S. Muller, M. Deicke, and R.W. De Doncker, "Doubly fed induction generator system for wind turbines," IEEE Ind. Appl. Mag., vol.8, no.3, pp. 26-33, May 2012.

[2] S. Muller, M. Deicke, and R.W. De Doncker, "A new control strategy of variable speed wind turbine generator for three-phase grid-connected applications," Transmission and Distribution Conference and Exposition: latin America, 2008 IEEE/PES, pp. 1-8, aug. 2008.

[3] R. Pena, J.C. Clare, G.M. Asher, "study of doubly fed induction generator and its applications to variable speed wind energy generation," IEEE proceedings on Electrical Power Applications, vol. 143, no. 3, may 2010, pp. 231-341.

[4] F. Blaabjerg and Z. C. and S. Kramer, "Power electronics as efficient interface in dispersed Power generation systems," IEEE Transactions on Power Electronics, vol. 19, pp. 1184–1194, Sept 2008.

[5] "Wind Turbines with Doubly-Fed Induction Generator Systems with Improved Performance due to Grid Requirements" D. Ehlert and H. Wrede.

[6] J. Morren and S. de Haan, "Short-circuit current of wind turbines with doubly fed induction generator ,"Energy Conversion, IEEE Transactions on, vol. 22, no. 1, pp. 174–180, March 2010.

[7] K. Buehring and L.L. Freris, "Control policies for wind energy conversion systems", IEE Proc., Vol. 128, part C, No. 5, pp. 253-261, 2005.

[8] "Doubly-Fed Induction Generator for Variable Speed Wind Energy Conversion Systems- Modeling & Simulation" B. Chitti Babu ,K.B .Mohanty

[9] K. Raiambal and C. Chellamuthu, "Modeling and Simulation of Grid Connected wind electric generating system," TENCON '02. Proceedings. 2002 IEEE Region 10 Conference on Computers, Communications, Control and Power Engineering, vol. 3, pp.1847–1852, October 2002.

[10] Ming Yin, Gengyin Li, Ming Zhou and Chengyong Zhao, "Modelling of the Wind Turbine with a Permanent Magnet Synchronous Generator for Integrat," Power Engineering Society General Meeting, 2007. IEEE, pp. 1-6, June 2007.

[11] Dr. John Schonberger, Plexim Gmbh "Modeling a DFIG Wind Turbine System using PLECS" Technopark strasse Zurich, December 2008 pp. 2-3

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