



Modelling and Simulation of Doubly-Fed Induction Generator Coupled With Wind Turbine

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Abstract: This paper presents the modelling of DFIG based WT system and the simulation results performed for the system developed in Simulink environment of MATLAB 7.5.0 (R 2007b). A grid connected wind energy generation model is developed and simulated for normal operation and for some faults in the grid. The simulation results are shown with the model of DFIG based wind energy generation system.

Keywords: Wind energy conversion system, wind turbine, doubly-fed induction generator, digital signal processor

I. Introduction

Due to the unavailability of resources for generation through thermal energy and the environmental problems because of the thermal energy generation, the world is moving towards the renewable energy. Wind power is one of the most developing forms of the renewable energy all over the world. The reason behind the boom of wind energy industry is its capability of producing ecologically sustainable energy which is cost effective and easy to implement. China has the most installed wind energy capacity, followed by the United States, Germany, Spain and India in the world. India is ranked 5th in the world in installed capacity of the wind energy.

According to the Centre for Wind Energy Technology, Government of India- Growing concern for the environmental degradation has led to the world's interest in renewable energy resources. Wind is commercially and operationally the most viable renewable energy resource and accordingly, emerging as one of the largest source in terms of the renewable energy sector.

The Indian wind energy sector has an installed capacity of 18.551 GW (up to 31.02.2013) [2]. In terms of wind power installed capacity, India is ranked 5th in the World [3]. India is a major player in the wind energy market nowadays. The potential is far from exhausted. Indian Wind Energy Association has estimated that with the current level of technology, the 'on-shore' potential for utilization of wind energy for electricity generation is of the order of 102 GW [4].

The basic technology of wind energy generation is the conversion of the kinetic energy of wind to the mechanical energy using wind turbine which is then converted to the electrical energy by the use of electrical generator, gearbox and converters to have the control on the parameters of generated electricity.

There are two types of wind turbines on the basis of the speed of rotation: Fixed-speed and variable speed wind turbine. For the fixed speed wind turbines the connection of the generator is direct with the electrical grid. For a variable speed wind turbine the generator is controlled by power electronic equipment. The advantages with the variable-speed operation of wind turbines are; the possibilities to reduce stresses of the mechanical structure, acoustic noise reduction and the possibility to control active and reactive power.

The generators which are being used commonly for renewable energy are synchronous generator and induction generator which is further divided into the squirrel cage induction generator, wound rotor induction generator whose further classification is in the optislip induction generator and doubly-fed induction generator. DFIG is used for wind power commonly due to its advantages of having the better control, cost effective, improved system efficiency. DFIG can be used in the isolated mode of operation as well as in the grid connected mode successfully.

II. Modelling of the Grid Connected DFIG based Wind Turbine System

The DFIG based WT system is shown in the fig.1 which is basically the conceptual diagram, which tells about the level of control of the system. The DFIG's stator is connected to the grid directly while the rotor is excited by the AC/DC/AC converters which are basically back to back converter based on the IGBT. Grid side converter and the rotor side converter are connected with the DC link. These two converters are basically responsible for the control of the system as the voltage, current, power should be controlled and the conversion

of the wind energy into the mechanical energy should also be controlled. Grid side converter controls the voltage supplied to the DC link which then gives the supply to the rotor side converter which then excites the rotor depending upon the speed of the wind as the frequency of the generated output should be equal to the 50 Hz. i.e. the grid frequency in India.

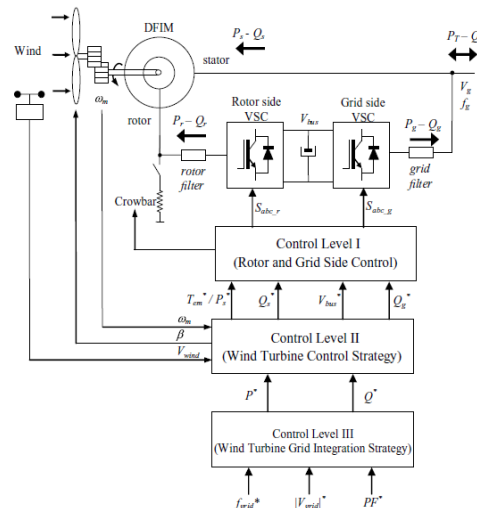


Fig.1: Conceptual diag. of DFIG based WT system [1]

- a) **Wind Turbine Model:** The modelling of the wind turbine is done mathematically based on the steady-state characteristics of wind turbine power. The characteristics of output power of the turbine is given by the following equation:

$$P_m = C_p(\lambda, \beta) \frac{\rho A}{2} V_{wind}^3 \quad (1)$$

Where,

P_m	Mechanical power output of turbine (W)
C_p	Performance coefficient of turbine
ρ	Air density (kg/m^3)
A	Turbine swept area (m^2)
V_{wind}	Wind speed (m/s)
λ	Tip speed ratio of the rotor blade tip speed to wind speed
β	Blade pitch angle (deg.)

The $C_p(\lambda, \beta)$ characteristics of wind turbine, modelled in Simulink by the use of the equation followed by:

$$C_p(\lambda, \beta) = C_1 \left(\frac{C_2}{\lambda_i} - C_3\beta - C_4 \right) e^{-C_5/\lambda_i} + C_6 \lambda \quad (2)$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad (3)$$

- b) **Asynchronous Machine Model:** The model used for DFIG is the asynchronous machine model. The electrical parts of the machine are represented in the fourth-order state-space model and the mechanical parts in the second-order system. The modelling is done in the d-q reference frame.
- c) **IGBT/Diodes AC/DC/AC Converter Model:** Grid side converter and rotor side converter are used to control the parameters of generated electricity. The GSC and RSC is based on the model of IGBT based three phase universal bridge which consists of the six power switches. GSC is an AC to DC converter and RSC is DC to AC inverter. The GSC connected with RSC with the DC link is shown in the fig. 2.
- d) **Grid-Filter Model:** A filter is used in the model developed in Simulink which is basically an R-L circuit. The grid filter model is shown in the fig. 3 where grid voltage (E_g), grid-filter current (i_f) and grid-filter voltage (V_f) are referred to stator.
- e) **Pulse Generator Model:** The pulse generator generates the pulse for rotor side converter as well as for the grid side converter. This is the system which is responsible of controlling the different parameters of the generated electricity. This system consists of the filter, PWM generator and the controller. The controller consists of GSC control system, RSC control system and the discrete phase locked loop system. The amount of power extraction from the wind is also controlled by this, which is achieved by varying the pitch angle.

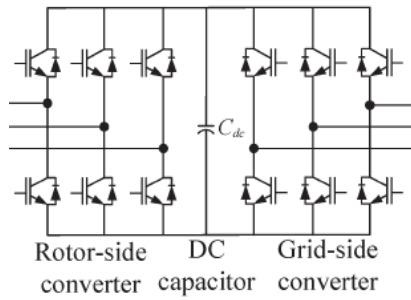


Fig. 2. Converters with DC link [6]

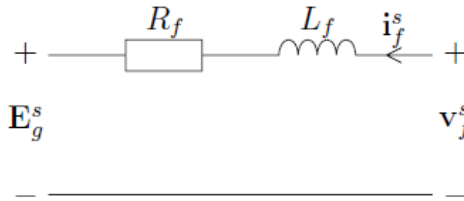
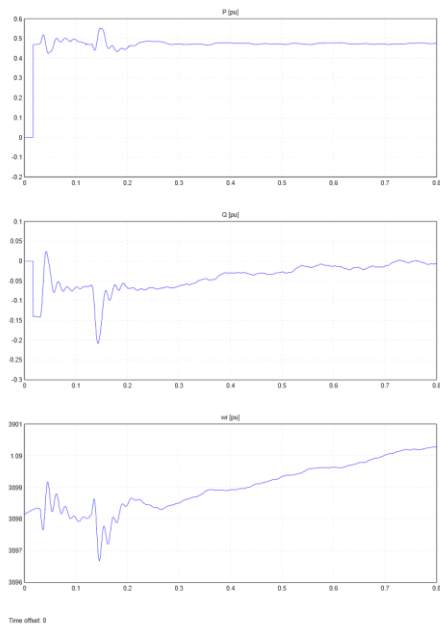


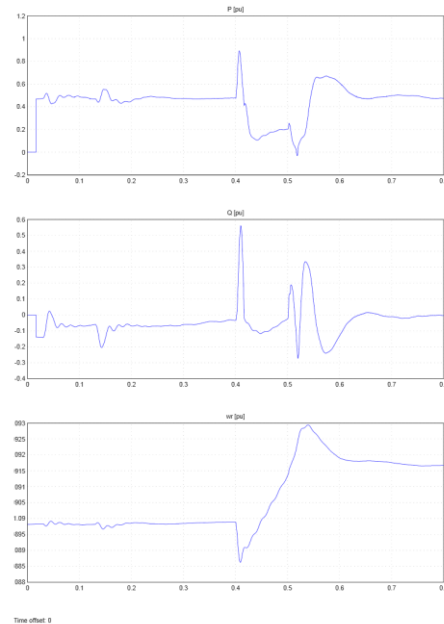
Fig. 3. Grid-filter model [6]

III. Simulation and its Results

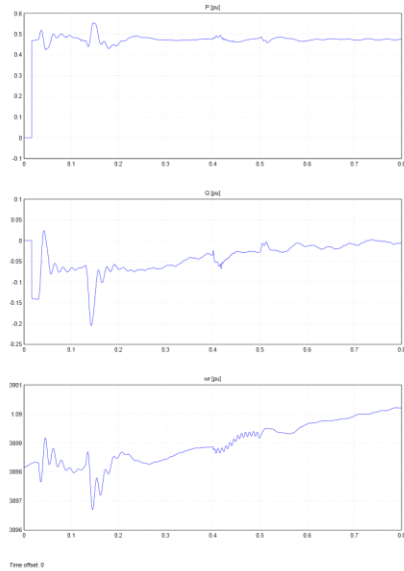
The DFIG based WT system is developed in Simulink environment of MATLAB 7.5.0 (R2007b). The model is of a 2 MW generator (DFIG) which is connected to the 33 kV grid. The system is simulated for 0.0 to 0.8 sec for normal operation of the system and for the faults which occurs for 0.4 to 0.5 sec for the Indian grid i.e. 50 Hz. Fig. 4 shows the pu real and reactive power, pu generator speed supplied by the DFIG for (a) for normal operation (b) LLL-G fault (c) L-G fault (d) LL-G fault and fig. 5 shows the profile of the voltage and current at bus B1 i.e. just before transformer and B3 i.e. after T-line for (a) for normal operation (b) LLL-G fault (c) L-G fault (d) LL-G fault. The fault is of 0.001Ω fault resistance and 0.001Ω ground resistance.



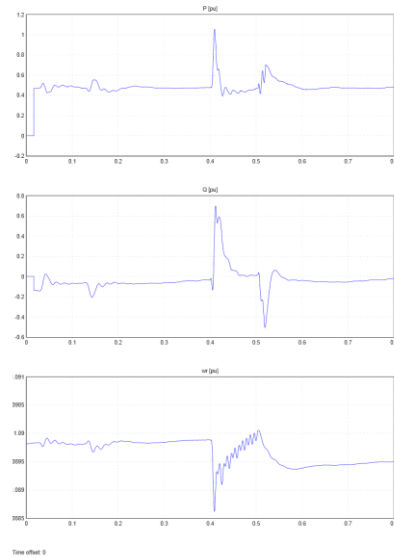
(a) Normal operation



(b) LLL-G fault

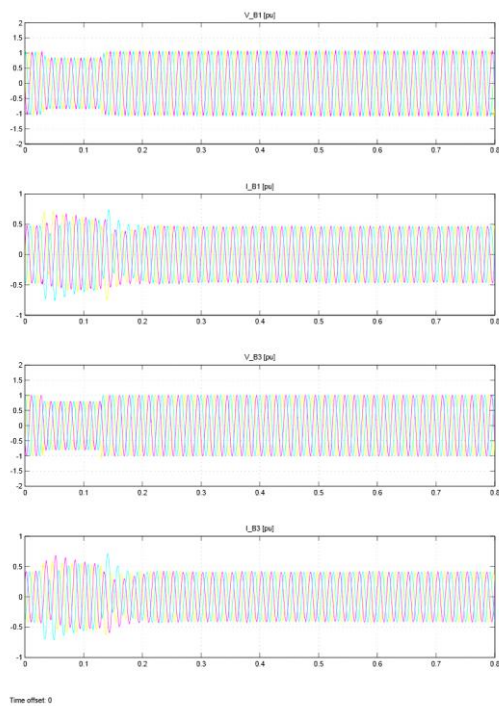


(c) L-G Fault

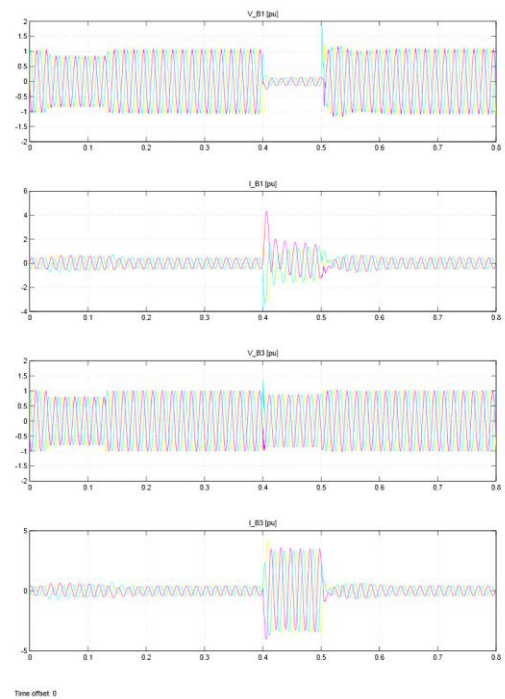


(d) LL-G Fault

Fig. 4: pu real power, reactive power, generator speed respectively



(a) Normal operation



(b) LLL-G fault

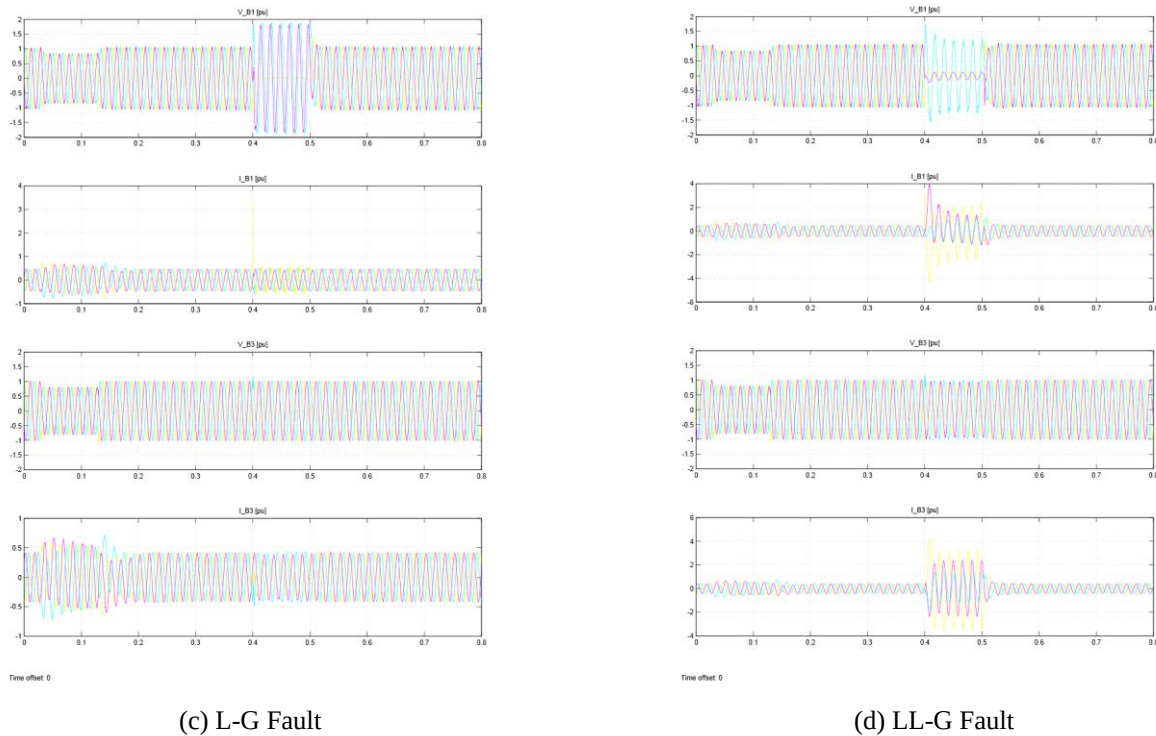


Fig. 5: pu voltage, current at bus B1 and B3 respectively

IV. Conclusion

The model developed in MATLAB/Simulink is simulated for normal operation and some often faults occur in Indian power sector. For normal operation of the DFIG based WT system the variation in the result settles down almost after the 0.15 sec which is due to some inductive elements present in the system and then the results are satisfactory. While for the LLL-G fault the curve of the voltage shows a sudden dip to almost zero and the rise in current occurs. For L-G fault the voltage at the bus B1 reduces to almost zero for the phase having fault and the current at B1 for that phase has a sudden increase. For LL-G fault the voltage for faulty phases at bus B1 reduces to a very low value and for the other phase i.e. the healthy phase it increases.

I. Appendix

Parameters of Simulated System:

Nominal mechanical power output of turbine: 1.5e6 W

Doubly-fed induction generator data: Rated Power: 2 MW, Stator line to line voltage (rms): 690 V, Frequency: 50 Hz., Stator R_s , L_{ls} (pu): 0.23, 0.18, Rotor R_r , L_{lr} (pu): 0.016, 0.016, Mutual Inductance (L_m): 2.9 pu, Inertia Constant (H): 0.685 s, Friction Factor (F): 0.01 pu, Pair of poles (p): 3.

II. References

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