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Power Flow Control of Wind Generation System Using DFIG

Preetiraj Maurya, Malaya S. Dash
Department of Electrical Engineering
Technocrats Institute of Technology, Bhopal, MP, India
pritiraj1993@gmail.com, malaya_rec@rediffmail.com

Abstract: - *Due to its clean and renewable nature, wind energy is becoming one of the world's important renewable sources of energy. Through its collaboration with other renewable sources of energy, such as solar energy, the world energy crisis can be solved in the future. Comparatively, with the past and due to the progressive integration of the nonlinear loads in the grid, the principal role of a Wind Energy Conversion System (WECS) is to capture the maximum power from the wind and improve the quality of power. Consequently, with the development of wind farms integrated into the grid, power quality could be better improved in the future. Variable speed wind generators are used in this work, which is more attractive than fixed speed systems because of their efficient energy production, improved power quality, and dynamic performance during grid faults. In this work, a design simulation model of wind power plant using doubly-fed induction generator with PI controller system for mitigation of power quality issue. The obtained results show that the output power (active and reactive) is free from harmonics and stable.*

Keywords: Wind generation, DFIG (Doubly fed Induction generator), PI controller, grid, power quality

1. Introduction

Wind power is a promising renewable, clean, and free energy source for power production. The airflow on earth is created due to the atmospheric air mass resulting from air pressure variation. This difference in air pressure results from solar heating of different parts of the earth's surface [1]. The continuous growth of the earth population and improving the standard of living are the main driving forces for the continuous growth of the energy demand. Although the energy use per unit of gross domestic product (GDP) is declining in most countries, the GDP increase is faster than efficiency growth, causing more and more recourses for energy production. It is forecasted that this trend will continue in the upcoming decades. Limited availability of fossil energy resources, such as coal, natural gas, oil and nuclear, urges renewable sources for electricity generation [2]. The increasing wind energy development has resulted in many new modelling and improved simulation methods. Wind power harnessing procedure has been a task for many years. Since long back, windmills were put into pumping water and grinding grain. Many new technologies such as pitch control and variable speed control methods have been tested and put forward since [3]. Nowadays, various essential things or objects compulsory for human life such as electricity, water, energy, foods and electricity are one of them without this, we can't imagine human life so smoothly, and there are various sources available to generate or produce electricity such as non-renewable energy sources and renewable energy sources. As we know that the non-renewable energy sources are soon exhausted, our main aim is to focus on renewable energy sources to generate more electricity and fulfil human life needs [4,5]. With the growing concern of WECS, the variable speed wind turbine using DFIG in a research paper [1] represents a development of model a simple DFIG wind turbine model in which the power converter is simulated as a controlled voltage source regulating the rotor current to meet the real and reactive power production. The basic knowledge above the DFIG system for the wind turbine has been given in the literature [2], representing how the DFIG is an excellent alternative for the VSWT system compared to the FSWT system and other adjustable speed generators. Paper [3] used the variable speed constant frequency technology with DFIG for WECS. To control the power electronics converter of DFIG, various controllers are used in RSC and GSC. For DC link voltage regulation, used LM-SMC controller on GSC. In literature [4], an autonomous WECS based on DFIG is studied and modelled. To regulate the output voltage and frequency under wind speed and load impedance variations, two different control strategies have been implemented to obtain n better performance than the PI controller. A sliding mode controller has been used.

2. Wind Energy Conversion System

The kinetic energy of air in motion is known as wind. When it comes in contact with wind turbine blades, this wind energy exerts a force on the blades, rotating the turbine. This means wind turbine converts the kinetic energy of air into mechanical energy, which is further used to convert it into electrical energy utilizing a generator coupled to it [6]. Generally, wind turbines have a much lower operating speed than the rated speed of the electric generator. A gearbox is used between turbine and generator to compensate for this mismatch, i.e., a generator is coupled to the turbine through this gearbox [7]. The whole arrangement of gearbox, power generator and other auxiliary devices like drive train and brake assembly is kept in housing called Nacelle. Nacelle, along with the turbine hub connected with turbine blades, is kept at a certain height from the ground with the help of the tower to maintain specific ground clearance for safe operation. In general, for medium and giant turbines, the height of the tower is generally chosen such that it will be slightly more significant than the rotor diameter. But towers are much taller than their rotor diameter [8,9].

2. A steady-state model of DFIG

DFIG is also a doubly-fed induction asynchronous machine (DFIAM) with wound rotor construction. Recently, DFIAM has become more popular WECS as it provides variable speed operations [10,11]. The fixed speed WECS were based on the synchronous generator with a rating of control equipment as a generator. The power control equipment is required to provide active and reactive power compensation during load/demand fluctuations. The steady-state model of the three-phase DFIG machine is obtained from an equivalent circuit diagram as shown in Figures 1(a) and 1(b).

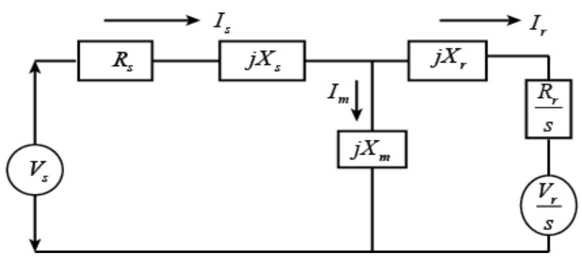

Figure 1(a) Equivalent Circuit of DFIAM with injected rotor voltage [12].

The rotor current Ir is expressed to obtain the equivalent circuits torque equation.

$$I_r = \frac{(V_S - V_r)/S_{slip}}{\left(R_s + \frac{R_r}{S_{slip}}\right) + j(X_{ls} + X_{lr})} \quad (1)$$

V_s and V_r are stator and rotor per phase steady state voltages, X_{ls}, X_{lr} stator and rotor leakage reactance, R_S and R_r are stator and rotor resistance. S_{slip} is a slip factor.

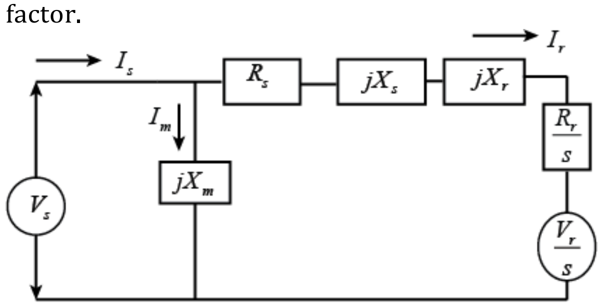

Figure 1(b) Equivalent approximated equivalent circuit of DFIAM with magnetizing branch transferred to stator [12].

The electromagnetic torque in an induction machine is the sum of air gap power and rotor fed power given by

$$T_e = (I_r^2 \left(\frac{R_r}{S_{slip}}\right) + P_R \quad (2)$$

Where T_e is the electromechanical torque from the stator side, P_R is the rotor fed active power.

The rotor fed active power is given,

$$P_r = \frac{V_r I_r \cos\theta}{S_{slip}} \quad (3)$$

The magnetizing current is given as,

$$I_m = \frac{V_s}{X_m} \ldots \quad (4)$$

The total input stator current per/phase is as

$$I_s = I_m + I_r \quad (5)$$

The relation gives stator flux linkages as

$$\Psi_m = L_{ls} I_s + L_m (I_s - I_r) \quad (6)$$

The stators active power as,

$$P_s = V_s I_s \cos\theta \quad (7)$$

Whereas the stators reactive power is given by

$$Q_s = V_s I_s \sin\theta \quad (8)$$

3. Methodology and Simulation Results

3.1 PI Controller arrangements

A typical structure of a PI control system [13,14] is shown in Fig.2, where it can be seen that in a PI controller, the error signal e(t) is used to generate the proportional and integral actions, with the resulting signals weighted and summed to form the control signal u(t) applied to the plant model. Mathematical description of the PI controller is given as,

$$u(t) = K_p \left[e(t) + \frac{1}{T_i} \int_0^t e(\tau)\, d\tau \right] = u_p(t) + u_i(t) \quad (9)$$

PI controller, u(t) is the input signal to the plant model, the error signal e(t) is defined as e(t)= r(t)-y(t), and r(t) is the reference input signal.

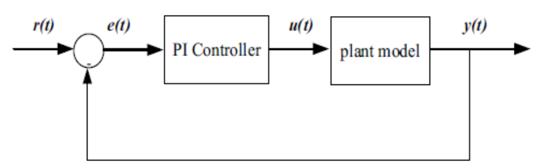

Fig. 2: A typical PI controls structure [13]

Simulation model of DFIG with PI controller

The wind turbine model shown in Figure 3 was built and designed in MATLAB/SIMULINK. The turbine's performance coefficient Cp is defined as the turbine's mechanical output power divided by wind power and a function of wind speed, rotational speed, and pitch angle. The front-end converter and mechanical system are shown in Figure 5, respectively.

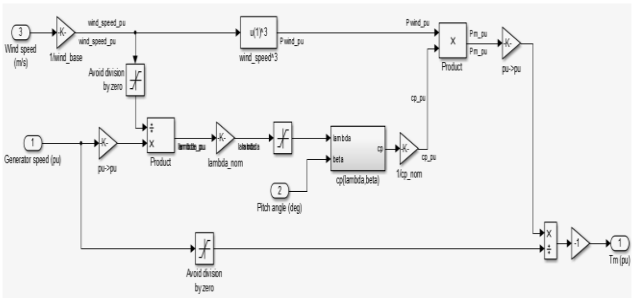

Fig.3 Simulation model of Wind turbine

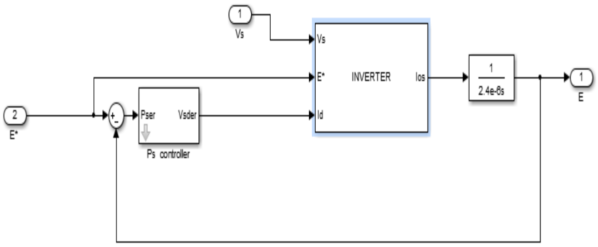

Fig.4. Front End converter

The mechanical system Simulink model is shown in Figure 5. It shows the mechanical part of the wind power system

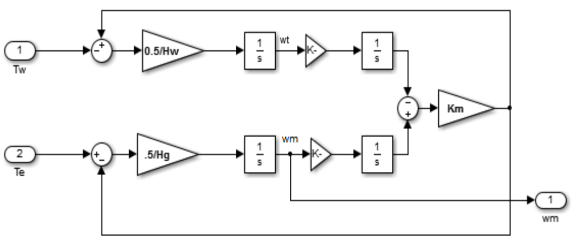

Fig. 5. Simulink model of Mechanical system

The Simulink model of DFIG with stator and rotor parameters are shown in fig.6. The complete simulation model of DFIG with active and reactive power controlled by PI controller is shown in fig.7.

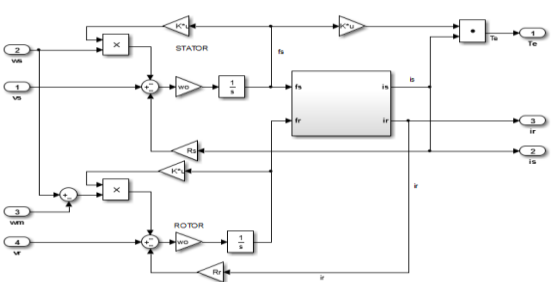

Fig. 6 DFIG Simulink model

The stator current for the d-q axis is shown in fig. 8, and it's a three-phase ac power. The active and reactive power controlled by DFIG with PI controller is shown in fig. 9 and fig. 10. Initially, we get the pulsating value of active and reactive power. But after some time, we get the smooth value of active and reactive power, which shows that our simulation model's design fulfils the objective of power quality improvement.

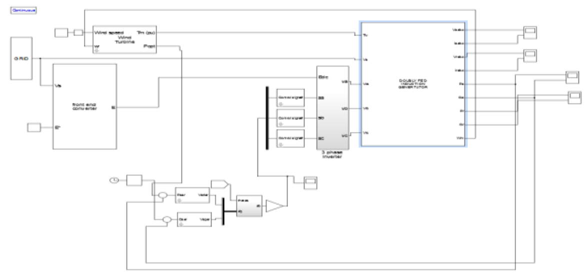

Fig. 7 Simulink model DFIG with PI controller

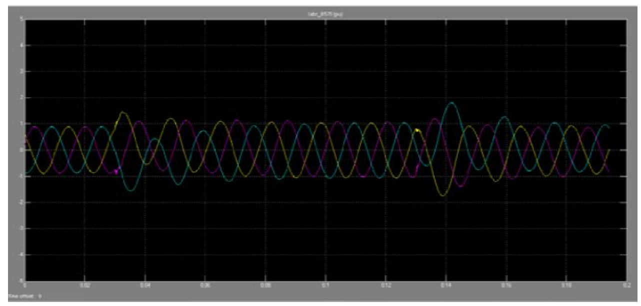

Fig. 8 Stator current for d-q axis

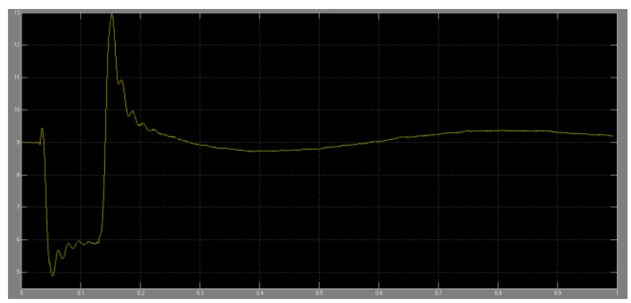

Fig.9 Active power

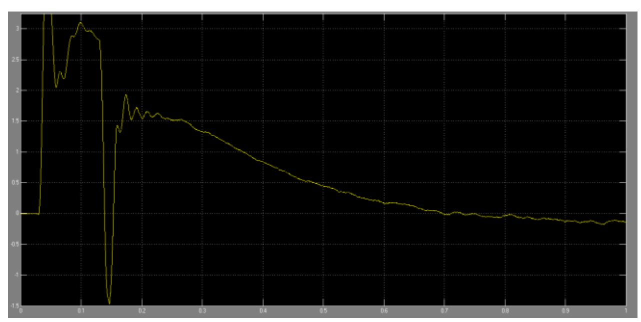

Fig.10 Reactive power

The stability of output power depends on the rotor current. Figure 11 shows the simulation results of the rotor current. The characteristic of rotor current gets stable after a few seconds. It also shows the stable operation of the output power. The torque characteristic of the DFIG system is shown in Figure 12. This characteristic represents the mechanical operation of the generator rotor.

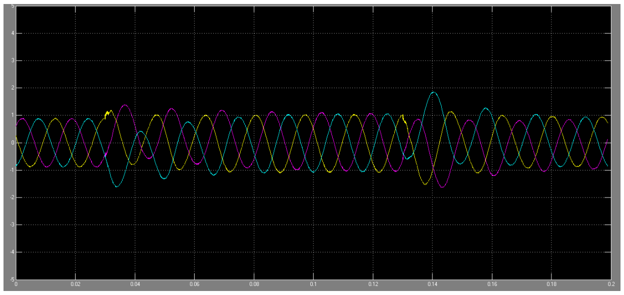
Fig. 11 Rotor currents for d-q axis

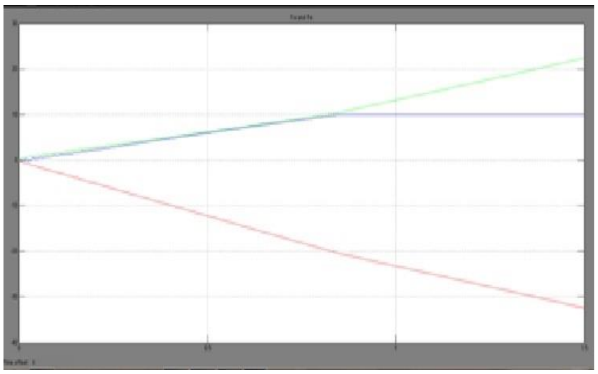
Fig.12. Torque characteristic

Conclusions

Modelling the wind turbine controls the amount of power extracted from the wind. The simulation results show that if the velocity of the wind keeps on increasing, the output power will also increase, and if the wind speed continues to rise further, a control system will be required to limit the output power. This is done by modelling the turbine blades to ensure a safe operating region for a wind turbine. A DFIG is used instead of a synchronous generator due to its nature of variable speed and improved amount of power quality, and also it reduces the cost of the converter used.

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