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Doubly Fed Induction Generator for Wind Energy System

Rashmi Sharma[1], Vineeta S. Chauhan[2], Hinal Shah[3]

Assistant Professor, Department of Electrical & Electronics Engineering, Indus University, Ahmedabad, Gujarat, India[1]

Assistant Professor, Department of Electrical & Electronics Engineering, Indus University, Ahmedabad, Gujarat, India[2]

Assistant Professor, Department of Electrical & Electronics Engineering, Indus University, Ahmedabad, Gujarat, India[3]

ABSTRACT: This paper focuses on the study of Doubly-Fed Induction Generator (DFIG) based wind as wind power is the world's rapid growing source of energy and is gaining popularity in the growing wind market for the production of electricity. In DFIG system a bidirectional converter in the rotor circuit is able to work as a generator in both sub-synchronous and super-synchronous modes. DFIG is connected with back-to-back converters in which the machine-side converter controls the rotor speed by using the v/f control technique while the grid-side converter controls the dc-link voltage and ensures the operation by making the reactive power drawn by the system. The performance of DFIG is studied during the operation of sub-synchronous and super-synchronous generating modes using MATLAB/SIMULINK.

KEYWORDS: Wind Energy Conversion System, DFIG , Rotor Speed, Generated Voltage and Current

I.INTRODUCTION

Wind power is the conversion of wind energy into a suitable form of energy, such as using wind turbines to generate electricity, windmills for mechanical power, wind pumps for water pumping, or sails to propel ships. The total amount of economically extractable power available from the wind is considerably more than present human power use from all sources. Wind power, as an alternative to fossil fuels, is abundant, renewable, clean, and produces no greenhouse gas emissions during operation. Wind power is the world‘s rapid growing source of energy. Electrical Energy production from wind turbines has been under the main focus for the past decade in power production. Lot of research work is going on renewable energy, specifically from extracting power from sun and from wind. Wind power provides an eco-friendly power generation and helps to meet the national energy demand when there is a diminishing trend in terms of non-renewable resources.

The wind energy conversion system (WECS) includes wind turbines, generators, and the controlling mechanism. Wind Turbines are mainly classified into horizontal axis wind turbines and vertical axis wind turbines. Modern wind turbines use horizontal axis wind turbines (HAWT) with two or three blades and operate either downwind or upwind configuration. This HAWT can be designed for a constant speed application or for the variable speed operation. Among these two types variable speed wind turbine has high efficiency with reduced mechanical stress and less noise. Variable speed turbines produce more power than constant speed type, comparatively, but it needs sophisticated power converters and control equipments to provide fixed frequency and constant power factor. The generators used for the wind energy conversion system mostly of either doubly fed induction generator (DFIG) or permanent magnet synchronous generator (PMSG) type. DFIG have windings on both stationary and rotating parts, where both windings transfer significant power between shaft and grid. In DFIG the converters have to process only about 25-30 percent of total generated power (rotor power connected to grid through converter) and the rest being fed to grid directly from stator. Whereas, converter used in PMSG has to process 100 percent power generated, where 100 percent refers to the standard WECS equipment with three stage gear box in DFIG. Majority of wind turbine manufacturers utilize DFIG for their WECS due to the advantage in terms of cost, weight and size. But the reliability associated with gearbox, the slip rings and brushes in DFIG is unsuitable for certain applications. The basic block diagram of DFIG system is show in the figure1.

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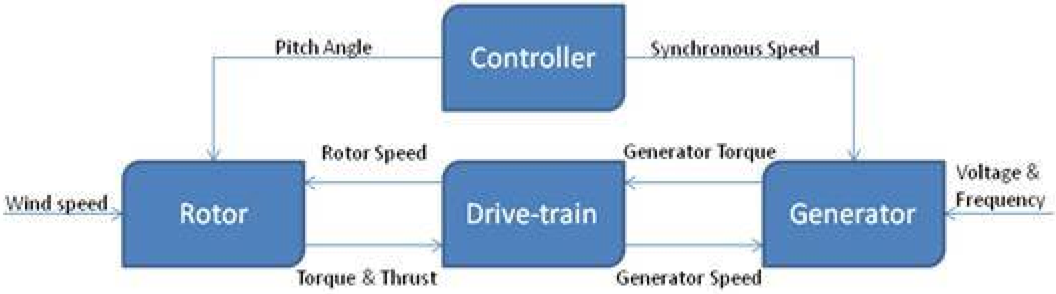

Fig. 1 The Block diagram of Wind Energy Conversion System

II. BACKGROUND OF WIND TURBINES:

Wind turbines produce electricity by using the power of the wind to drive an electrical generator. Passing over the blades, wind generates lift and exerts a turning force. The rotating blades turn a shaft inside the nacelle, which goes into a gearbox. The gearbox adjusts the rotational speed to that which is appropriate for the generator, which uses magnetic fields to convert the rotational energy into electrical energy. The power output goes to a transformer, which converts the electricity from the generator at around 700V to the appropriate voltage for the power collection system, typically 33 kV. A wind turbine extracts kinetic energy from the swept area of the blades. The power contained in the wind is given by the kinetic energy of the flowing air mass per unit time. That is

$$P_{air} = 0.5\rho A V^3$$

Where P_{air} is the power contained in wind (in watts) , ρ is the air density (1.225 kg/m^3 at 15°C and normal pressure), A is the swept area in (square meter), and is the wind velocity without rotor interference, i.e., ideally at infinite distance from the rotor (in meter per second).Although the above equation gives the power available in the wind, the power transferred to the wind turbine rotor is reduced by the power coefficient; Cp Power Coefficient (Cp) is a measure of wind turbine efficiency often used by the wind power industry. Cp is the ratio of actual electric power produced by a wind turbine divided by the total wind power flowing into the turbine blades at specific wind speed. Cp is given as

$$C_p = \frac{Actaul\ \ Electrical\ \ Power\ \ \ produced}{Wind\ \ \ Power\ \ \ Into\ \ \ Turbine}$$

Maximum value of Cp is defined by the Betz limit, which states that a turbine can never extract more than 59.3% of the power from an air stream. In reality, wind turbine rotors have maximum Cp values in the range 25-45%.

III. DOUBLY FED INDUCTION GENERATOR

An induction generator is a type of AC electrical generator that utilizes the principles of electromagnetic introduction to produce electrical power. Induction generators operate by mechanically turning their rotor in generator mode, giving negative slip. In most cases, a regular AC asynchronous motor is used as a generator, without any internal modifications. In induction generators the magnetizing flux is established by a capacitor bank connected to the machine in case of stand-alone system and in case of grid connection it draws magnetizing current from the grid. It is divided in two parts i.e Grid connected Induction generator and standalone systems.

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Wind turbines use a doubly-fed induction generator (DFIG) consisting of a wound rotor induction generator and an IGBT-based PWM converter. The DFIG is an induction machine where the rotor and stator both are connected to electrical sources; hence the name given is 'doubly-fed Induction generator'. Three phase supply is given to the rotor which develops the three phase rotating magnetic field. Torque is developed because of interaction of the two magnetic fields i.e stator and rotor magnetic field. The magnitude of the torque depends on the strength of the two fields and the angular displacement between the two fields. The stator winding of the generator is connected to the grid while the rotor winding is fed at variable frequency through the IGBT based converter. The DFIG technology has the advantage that it extracts maximum energy from the wind for low wind speeds by optimizing the turbine speed, also by minimizing the mechanical stresses on the turbine during sudden gusts of wind [1]. The optimum turbine speed producing maximum mechanical energy for a given wind speed is proportional to the wind speed. Another benefit of the DFIG technology is the ability for power electronic converters to generate or absorb reactive power, thus there is no need for installing capacitor banks as in the case of squirrel-cage induction generator. To control the wind turbine gear boxes or electronic controls can be used. The basic block diagram of DFIG System is show in figure 2.

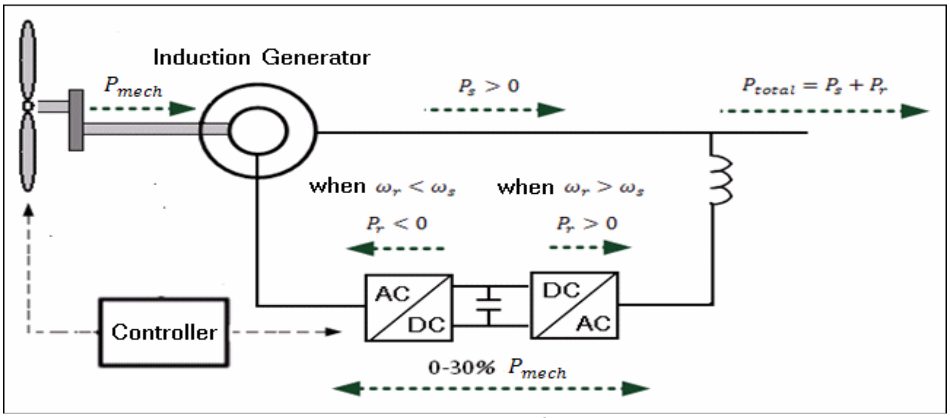

Fig. 2 The Block diagram of DFIG System

The converters are basically a PWM converters which uses sinusoidal PWM technique to reduce the harmonics present in the wind turbine conversion system. To control the speed stator is directly connected to the AC mains, whilst the wound rotor is fed from the Power Electronics Converter via slip rings to allow DIFG to operate at a variety of changing wind speeds. In-between two converters a DC link capacitor is inserted which allows the storage of power from induction generator for further generation and to achieve full control of grid current, the DC-link voltage must be boosted to a level higher than the amplitude of grid line-to-line voltage. With the rotor-side converter it is possible to control the speed and torque of the DFIG and the power factor at the stator terminals. The grid-side converter works at the grid frequency in order to generate or absorb a controllable magnitude of reactive power from the supply. An isolated transformer is connected between the grid-side inverter the grid. The rotor-side converter works at different frequencies, depending on the wind speed. The back-to-back arrangement of the converters provides a mechanism of converting the variable voltage, variable frequency output of the generator (as its speed changes) into a fixed frequency, fixed voltage output compliant with the grid. The DC link capacitance is an energy storage element that provides the energy buffer required between the generator and the grid [2].

At present most of the DFIG power electronics system utilises a two-level six pulse IGBT based switching converter, Two-level refers to the number of voltage levels that can be produced at the output of each bridge leg of the converter. A two-level converter can typically output zero volts or Vdc, where Vdc is the voltage of the dc link. The output of the system is changed by changing the width of the pulse by pulse width modulation techniques. The switching cycle is usually fixed, and the width of the pulse of Vdc adjusted in order to change the output voltage. Generally Voltage source inverter technique (VSI) is used which is capable of generating any voltage with arbitrary frequency and phase within the limits of dc link voltage and switching frequency.

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The mechanical power and the stator electric power output are computed as follows:

$$P_m = T_m\omega_r$$
$$P_s = T_{em}\omega_s.$$

For a lossless generator the mechanical equation is:

$$J\frac{d\omega_r}{dt}=T_m-T_{em}.$$

In steady-state at fixed speed for a lossless generator

$$T_m = T_{em} \text{ and } P_m = P_s + P_r.$$

It follows that:

$$P_r=P_m-P_s=T_m\omega_r-T_{em}\omega_s=-T_m\frac{\omega_s-\omega_r}{\omega_s}\omega_s=-sT_m\omega_s=-sP_s,$$

where *s* is defined as the slip of the generator:

$$s = (\omega_s-\omega_r)/\omega_s.$$

V. SIMULATION OF WIND TURBINE DFIG SYSTEM

The study of simulink block diagram A 8 MW wind farm consisting of six 1 MW wind turbines connected to a 25 kV distribution system exports power to a 120 kV grid through a 30 km, 25 kV feeder. Wind turbines using a doubly-fed induction generator (DFIG) consist of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter. The switching frequency is 1620 Hz. The stator winding is connected directly to the 60 Hz 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. The optimum turbine speed producing maximum mechanical energy for a given wind speed is proportional to the wind speed [3]. The basic simulink model for DFIG system is show in the figure3.

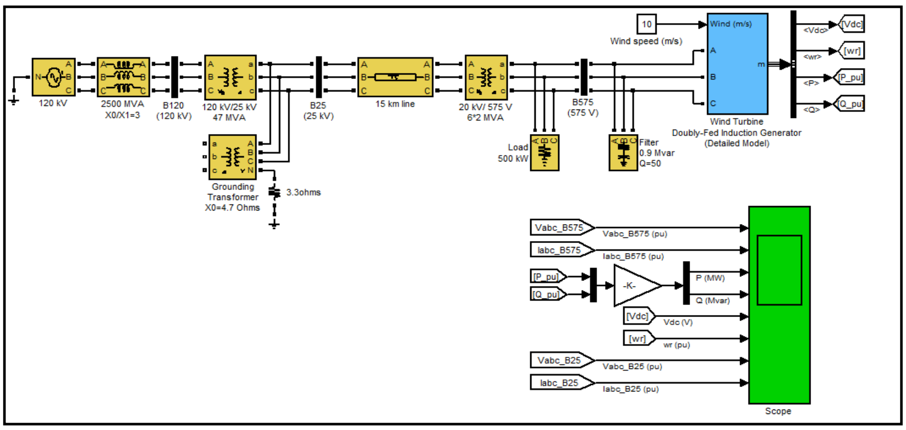

Fig. 3 The DFIG simulink model

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At first the DFIG wind farm produces 4.8 MW. This active power corresponds to the maximum mechanical turbine output for a 12m/s wind speed excluding the electrical and mechanical losses in the generator. The corresponding turbine speed is 1.06 pu of generator synchronous speed. The DC voltage is regulated at 1200 V and reactive power is kept at 0 Mvar. At t=0.05 s the positive-sequence voltage suddenly drops to 0.6 p.u. causing an oscillation on the DC bus voltage and on the DFIG output power. During the voltage sag the control system regulates DC voltage.The three phase regulated output voltage is shown in figure 4.

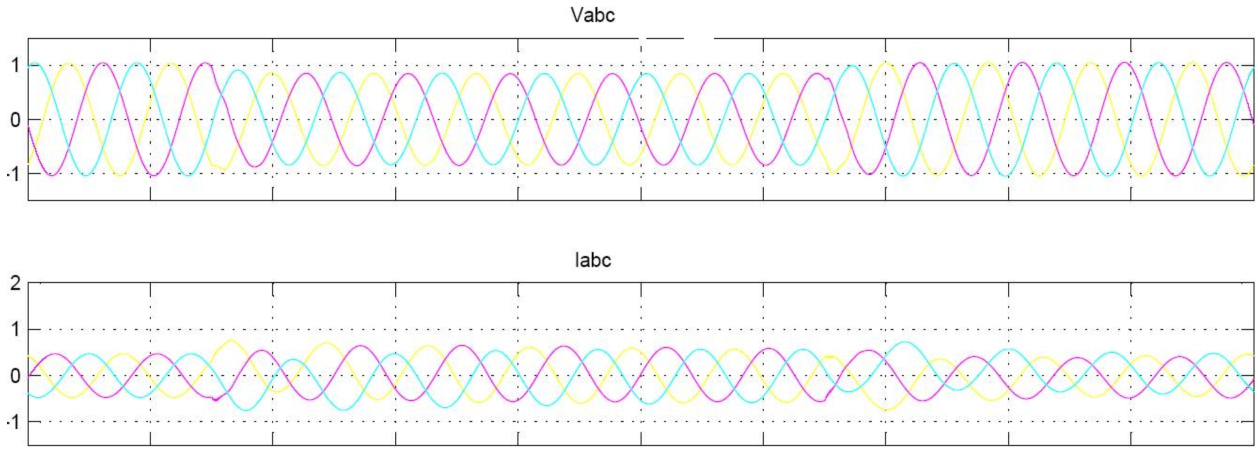

Fig. 4 The three phase voltage and current

In this simulation the wind speed is maintained constant at 12 m/s. The control system uses a torque controller in order to maintain the speed at 1.06 pu. The reactive power produced by the wind turbine is regulated at 0 Mvar. The waveforms for active and reactive power are shown in figure 5.

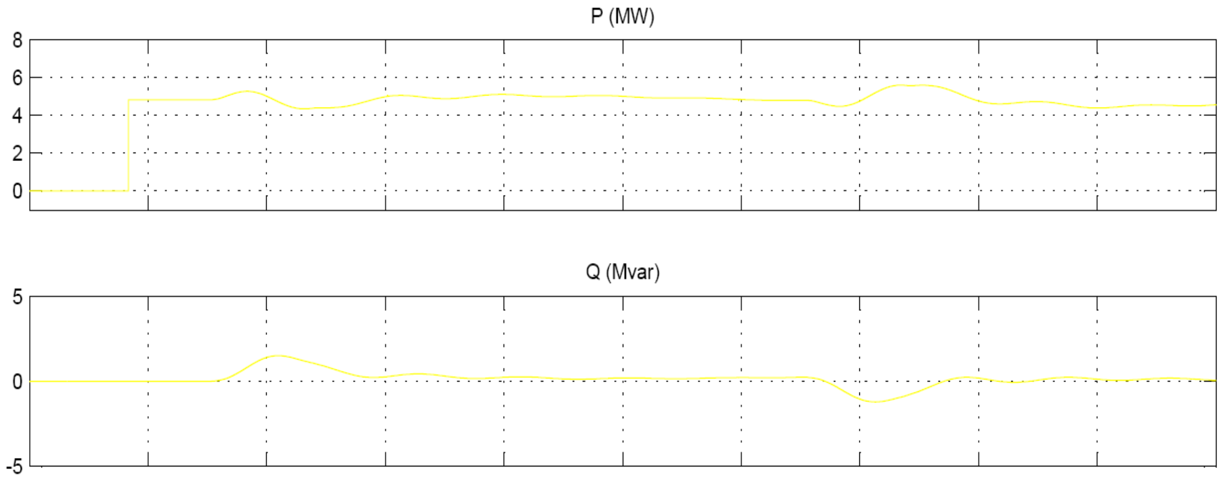

Fig. 5 Waveforms of active and reactive power

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VI. CONCLUSION

The electrical energy efficiency of wind turbine systems equipped with doubly-fed induction generators in comparison to other wind turbine generator systems has been carried out and a detailed models of the DFIG have been studied with required parameters .The various response of the system are observed in both super and sub-synchronous generating mode of operation. The control scheme of machine-side converter and grid-side converter has been simulated by using MATLAB/SIMULINK. This shows that the DFIG technology has the benefit of extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical ad thermal 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.

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