

# State of Art of Doubly Fed Induction Generator in a Wind Energy Conversion System

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**Abstract**— *The need for energy in the world is increasing day by day and renewable energy resources prove to be an excellent choice to meet the energy demand. Wind energy resource is one such renewable energy resources, but the speed variation of wind can cause undesirable fluctuations in output voltage frequency. But doubly fed induction generator can work with variable speed input while maintaining the grid frequency constant. This paper presents the state of art of doubly fed induction generator in a wind energy conversion system.*

**Keywords**— *Back to back converter, Doubly fed induction generator (DFIG).*

## I. INTRODUCTION

The demand for energy is tremendously increasing in the world. To meet the energy crisis we are forced to depend more on renewable energy resources. The use of such resources also helps us to create clean and healthy environment. Wind energy is one such promising renewable energy resources. But the major problem with wind energy is that the speed of wind varies continuously with time. Therefore we need a machine that can generate power at varying speeds while maintaining the grid frequency constant to utilize the wind energy efficiently. Doubly fed induction generator is one such machine that has the capability to generate power at varying wind speeds.

The advantages of using doubly fed induction generator have been studied over many years for wind energy conversion applications. The comparison of constant speed system with cage rotor induction machine, variable speed system with cage rotor induction machine and variable speed system with slip ring induction machine is done [1]. The comparison is done the basis of hardware components required, operating range and the energy output for a defined wind input. It was concluded that the fixed speed system is comparatively simple but the energy output is higher for variable speed system with slip ring induction machine.

The modeling and control of doubly fed induction generator was studied before. The modeling of a wind energy conversion system using this machine is studied [2] and the results thus obtained are compared with some

real results. The Doubly fed induction machine is connected to the grid and the voltage and frequency is maintained constant with the help of a double sided PWM converter placed between the grid and the rotor. The operation of the machine in both sub synchronous and super synchronous modes is analyzed. The stator power control of the machine is also studied here. For decoupling the active and reactive power, stator flux oriented vector control is used. The control strategy used here helps to control the power factor.

A novel approach of direct power control using three vectors is presented [3]. This method uses just one switching table to obtain the three vectors. The vector selection does not depend on the rotor speed. The duration of these vectors are also obtained in a simple way and is not parameter dependant. The conventional direct power control does not consider the zero vector to avoid the complexity in switching. But the zero vector has the ability to reduce ripples in the active and reactive powers. The conventional direct power control of induction motors have been studied [4] – [7] and also in DFIGs [8]. While considering the ripple reduction of one variable alone, this method seems to be a good. But for high power applications with low switching frequency the control method using three vectors, including the zero vector rather than two vectors during one control period seem to be a better choice.

The maximum power point tracking from the wind turbines have been studied using doubly fed induction generators. One such method is using the back to back converter to control the d- q components of the rotor current to control the stator active and reactive powers. The rotor side converter is used to extract maximum power from the wind while maintaining the stator at unity power factor [9]. The grid side converter supplies generated power to the grid above synchronous speed while it absorbs power from and supplies it to the rotor below synchronous speed.

Another method for obtaining maximum power from the wind is proposed [10]. A stand alone wind energy conversion system using a doubly fed induction generator integrated with a battery energy storage system is analyzed. The battery energy storage system is placed

between the rotor side and grid side converter. Using this proposed system power compensation, power leveling and harmonic compensation is achieved.

## II. DOUBLY FED INDUCTION MACHINE

A doubly fed induction machine can work in four modes. It works as a motor and generator in both sub synchronous (below synchronous speed) and super synchronous (above synchronous speed) speeds. In a doubly fed induction generator, supply is given to both the stator and rotor windings. The stator winding is directly connected to the grid and the rotor windings are connected to the grid through a power electronic converter.

In a DFIG the rotor produces a magnetic field whose speed is determined by the frequency of the ac current fed to the rotor winding. The frequency of the magnetic field passing through the stator depends on the mechanical speed of the rotor and the speed of the rotor magnetic field. The stator frequency, when both the magnetic field of the rotor rotates in the same direction as the rotor can be calculated as:

$$f_{stator} = \frac{n_{rotor} X N_{poles}}{120} + f_{rotor} \quad (1)$$

The stator frequency when both the magnetic field of the rotor rotates in opposite direction as the rotor can be calculated as:

$$f_{stator} = \frac{n_{rotor} X N_{poles}}{120} - f_{rotor} \quad (2)$$

The wound rotor doubly fed induction machine has the advantage that the slip power can be supplied to the grid instead of being dissipated as heat in the resistors. In a doubly fed induction generator, the rotor supplies power to the grid in super synchronous mode while it absorbs power from the grid in sub synchronous mode. While in a doubly fed induction motor the rotor supplies power to the grid in the sub synchronous mode and absorbs power from the grid in the super synchronous mode. Fig. 1 shows the doubly fed induction machine when both stator and rotor magnetic fields are in the same direction and when they both are in the opposite direction.

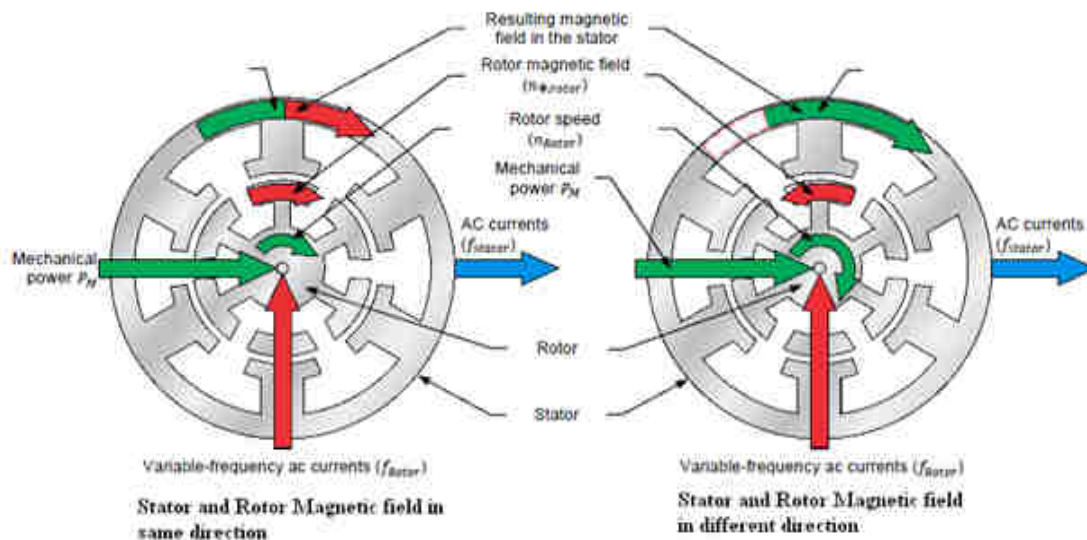


Fig.1: The schematic diagram of doubly fed induction machine with stator and rotor magnetic fields in the same direction and in the opposite direction

### A. Modeling Equations of DFIG

In a doubly fed induction machine, the Park's transformation is applied to the a,b,c model that allows to write a dynamic model in d-q reference frame. The stator and rotor side voltage equations are transformed to synchronously rotating reference frame.

The voltage equations at the stator side are given by equations (3) and (4).

$$V_{qs} = p\lambda_{qs} + \omega\lambda_{ds} + R_s i_{qs} \quad (3)$$

$$V_{ds} = p\lambda_{ds} - \omega\lambda_{qs} + R_s i_{ds} \quad (4)$$

The voltage equations at the rotor side are given by equations (5) and (6).

$$V_{qr} = p\lambda_{qr} + (\omega - \omega_r)\lambda_{dr} + R_r i_{qr} \quad (5)$$

$$V_{dr} = p\lambda_{dr} - (\omega - \omega_r)\lambda_{qr} + R_r i_{dr} \quad (6)$$

The active and reactive power at the stator side is given by equations (7) and (8) respectively.

$$P_s = \frac{3}{2}(V_{ds}i_{ds} + V_{qs}i_{qs}) \quad (7)$$

$$Q_s = \frac{3}{2}(V_{qs}i_{ds} - V_{ds}i_{qs}) \quad (8)$$

The electromagnetic torque equations based on the stator side components is given by equation (9).

$$T_e = -\frac{3P}{2}(\lambda_{ds}i_{qs} - \lambda_{qs}i_{ds}) \quad (9)$$

The flux linkage equations of d and q axis at the stator side are given by equations (10) and (11) respectively.

$$\lambda_{ds} = (L_{ls} + L_m)i_{ds} + L_m i_{dr} \quad (10)$$

$$\lambda_{qs} = (L_{ls} + L_m)i_{qs} + L_m i_{qr} \quad (11)$$

The flux linkage equations of d and q axis at the rotor side are given by equations (11) and (12) respectively.

$$\lambda_{dr} = (L_{lr} + L_m)i_{dr} + L_m i_{ds} \quad (12)$$

$$\lambda_{qr} = (L_{lr} + L_m)i_{qr} + L_m i_{qs} \quad (13)$$

Where p is the derivative symbol, P is the number of poles,  $\omega$  is the supply angular frequency and  $\omega_r$  is the rotor angular frequency.  $L_{ls}$  and  $L_{lr}$  refers to the leakage inductances at the stator and rotor windings respectively and  $L_m$  is the magnetizing inductance.  $R_s$  and  $R_r$  refers to the stator and rotor resistances of the machine per phase respectively. Fig. 2 shows the d-axis and q-axis equivalent circuit of doubly fed induction machine.

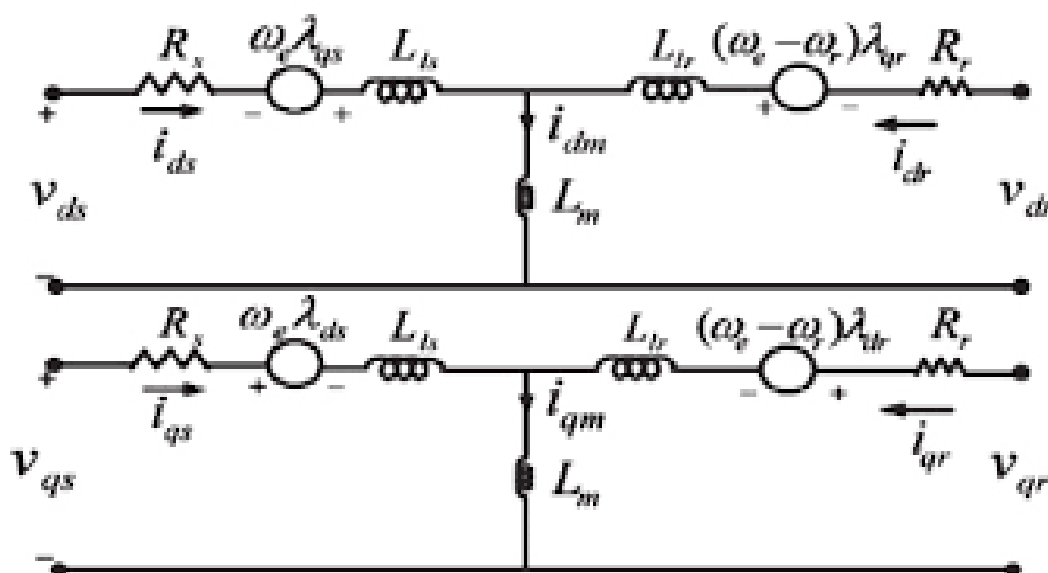


Fig. 2: The d-axis and q-axis equivalent circuit of doubly fed induction machine

### B. Advantages and Limitations

The advantages of DFIG include its ability of decoupled control of active and reactive power by controlling the rotor terminal voltages and thus making the power factor control possible. A wound rotor doubly fed induction generator is usually simple in construction and cheaper than a PMSG in case of wind power conversion applications.

The demerits of DFIG include its limited fault ride through capability and need for protection schemes, the need for complex control schemes and the need for slip rings and gear-box that require frequent maintenance.

### III. WIND ENERGY CONVERSION SYSTEM

Wind turbines can be fixed speed wind turbines or variable speed wind turbines. The fixed speed wind turbines use an asynchronous squirrel – cage induction generator. This system needs a switch to prevent the motoring operation of the machine during low wind speeds. It suffers from the limitation of reactive power consumption since there is no reactive power control. In fixed speed wind turbines, the fluctuations in the wind speed causes mechanical fluctuations which causes

electrical power fluctuations since there is no torque control loops. This power fluctuations cause problems at the point of connection of the machine to the grid.

A variable speed wind turbine uses a wound rotor induction generator directly connected to the grid. The rotor phase windings are connected to controlled resistances. By regulating the rotor resistances the slip and output power can be controlled.

A variable speed wind turbine using a doubly fed induction generator utilizes this slip power effectively and its rotor windings are connected to the grid through a back to back converter. The converter controls the rotor frequency and rotor speed. The speed range of DFIG is around 30 % of the synchronous speed of the machine. Hence the variable speed wind turbine systems using DFIG uses the wind power effectively.

In wind energy conversion system using DFIG the rotor of the generator will be driven by the wind turbine. The gear box is used to get adequate speed for the rotor. The stator of the machine is directly connected to the grid and the rotor is connected to the grid through an AC/DC/AC converter. The block diagram of the system is shown in Fig. 3.

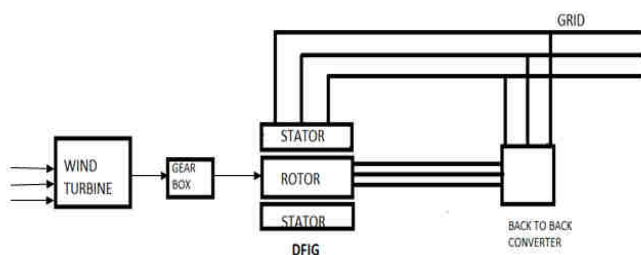


Fig.3: Block diagram of a wind energy conversion system using DFIG.

The power electronic converter is used to transfer the slip power of the rotor to and from the grid. The converter hence is rated to handle only about 25 – 30 % of the total rated power of the machine.

The rotor side and grid side converters are controlled to get the required active power of the stator. The expected stator power (pu) vs. rotor slip (pu) for different values of rotor voltages,  $V_r$  is shown in Fig. 4.

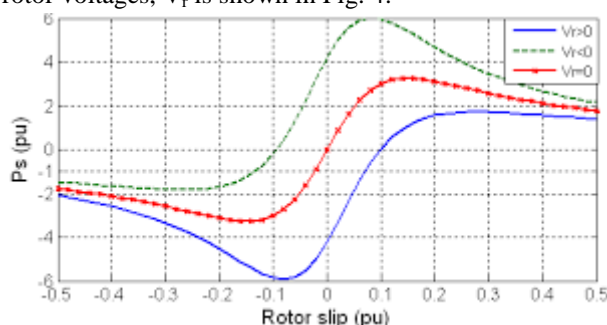


Fig.4: The plot of active stator power  $P_s$  (pu) vs. Rotor slip (pu)

#### IV. CONCLUSION

The state of art of doubly fed induction generator is completed. The construction and power control of doubly fed induction generator is studied. The modeling equations for DFIG have been obtained. The paper gives an overall idea on the characteristics, two modes of operation, advantages and limitations of the machine. Owing to the capability of DFIG, to generate power at variable speeds makes it more efficient and productive over other generators in a wind energy conversion system.

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