STUDY OF ACTIVE AND REACTIVE POWER FLOW IN DFIG BASED WIND ENERGY CONVERSION SYSTEM

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Abstract-This paper presents the model of Wind Energy Conversion System (WECS) using Doubly fed induction generator(DFIG).This model consist of Asynchronous machine(wound rotor) and back to back PWM converters. The DFIG and converter model are established in the d-q model. The active and reactive power is plotted and the dynamic simulation results are tested using MATLAB/SIMULINK.

Key words- Wind Energy Conversion System (WECS), doubly fed induction generator (DFIG), Pulse width modulation converters, MATLAB/SIMULINK.

I.INTRODUCTION

Over the past few decades the energy demand is increasing rapidly. To meet the required load demand nonrenewable sources for power generation is not sufficient. To meet up the required load demand renewable energy sources like wind power is came into picture. Harnessing power from wind can be traced approximately 4000 years ago; there has been a renewed interest in the subject in recent years with increasing in advancements in the generators and aerodynamic design, and improvement in power electronic technology makes the Capture of power from wind has increases from several KW to MW. It is expected that the capture of wind power will increase further especially in off shore wind power plants.

The choice of machine used and the type of power electronic converter used depends on the size of wind energy conversion system (WECS).There are several configurations for generation of power from wind .For power applications below 2MW doubly fed induction generators are preferable beyond which direct driven permanent magnet synchronous generators are used.

It is obvious that grid integrated wind energy conversion systems generates constant frequency that is determined by grid. However it is advantageous to vary mechanical speed of the turbine/generator to maximize power capture with fluctuating wind velocity.

II.WIND ENERGY CONVERSION

In Wind energy conversion system the amount of power harnessed from wind is

$$P=\frac{1}{2}\rho A C_p(\lambda,\beta) v^3_{wind} \qquad (1)$$

Where P=wind power captured

ρ=density of air (kg-m^3)

A=Area of blade swept (m^3)

V_{wind}=velocity of wind(m/sec)

$C_p(\lambda,\beta)$= Power coefficient;

Where

$$C_p(\lambda,\beta)=0.5176\left(\frac{116}{\lambda_i}-0.4\beta-5\right)e^{-21/\lambda_i}+0.0068\lambda \qquad (2)$$

where

$$\frac{1}{\lambda i} = \frac{1}{\lambda + 0.08\beta} - \frac{1}{1 + \beta^3} \qquad (3)$$

λ is the tip speed ratio which is define as the ratio of blade tip speed to the wind speed.

$$\lambda = \frac{\omega R}{v} \qquad (4)$$

According to Beltz limit the maximum power extracted from wind is 59.3% so the maximum value of the power co-efficient C_p is 0.593. the value of C_p is determined by the aerodynamic behavior of the blades.

Consequently, the output power is determined by the cp and the value of the velocity by considering the value of the density (ρ) and area of swept area (A) as constant .The below figure1 shows the power developed by the wind as wind speed varies.

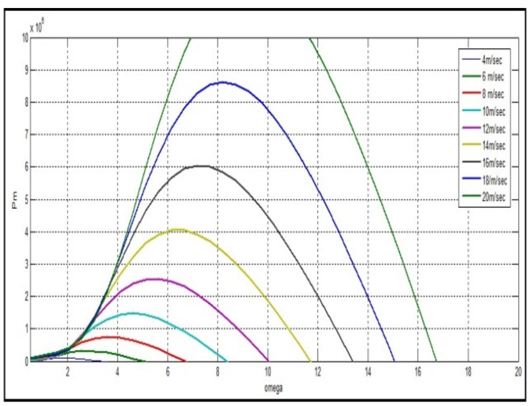

Fig.1 Pm VS ω for various wind speeds

The above fig shows the mechanical power developed with rotor speed for various velocities.

From this we can observe that by varying wind velocity.

III.DFIG OPEARATION

Doubly Fed Induction Machine (DFIG) machine is a wound rotor induction machine in which both stator and rotor are connected to electrical sources. It has a capability to deliver power from both stator and rotor [3].

DFIG can be operated in two modes1) sub synchronous mode and 2) super synchronous mode when the speed is above the synchronous speed it is operated in super synchronous mode. In this mode slip is negative. Power delivered to the grid is through stator and rotor [1],[3]. When speed is less than synchronous speed it is operated in sub synchronous mode in this mode slip is positive. The power delivered to the machine is through only stator. The rotor takes power from the grid. When the slip is zero no power is flow through the rotor, the stator delivers maximum power through it.

The following are the equations of DFIG machine[5][6].

The voltage equations for DFIG Machine are

$$v_{ds} = R_s i_{ds} + p\lambda_{ds} - \omega\lambda_{qs} \qquad (5)$$

$$v_{qs} = R_s i_{qs} + p\lambda_{qs} + \omega\lambda_{ds} \qquad (6)$$

$$v_{dr} = R_r i_{dr} + p\lambda_{dr} - (\omega - \omega_r)\lambda_{qr} \qquad (7)$$

$$v_{qr} = R_r i_{qr} + p\lambda_{qr} + (\omega - \omega_r)\lambda_{dr} \qquad (8)$$

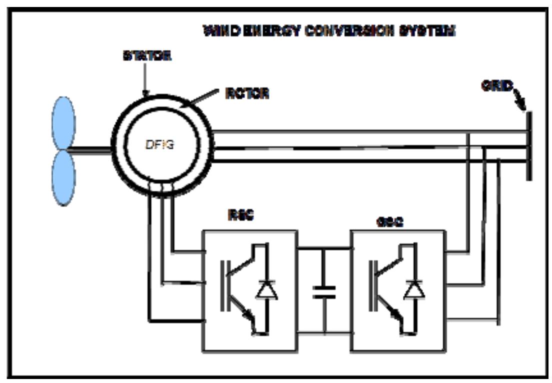

Fig.2 DFIG Based wind Energy Conversion

$$\lambda_{ds} = L_s i_{ds} + L_m i_{dr} \qquad (9)$$

$$\lambda_{qs} = L_s i_{qs} + L_m i_{qr} \qquad (10)$$

$$\lambda_{dr} = L_r i_{dr} + L_m i_{ds} \qquad (11)$$

$$\lambda_{qr} = L_r i_{qr} + L_m i_{qs} \qquad (12)$$

The flux equations are written in matrix form and by applying inverse transform the equations become

$$\begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \end{bmatrix} = \frac{1}{D_1}\begin{bmatrix} L_r & 0 & -L_m & 0 \\ 0 & L_r & 0 & -L_m \\ -L_m & 0 & L_s & 0 \\ 0 & -L_m & 0 & L_s \end{bmatrix}\begin{bmatrix} \lambda_{ds} \\ \lambda_{qs} \\ \lambda_{dr} \\ \lambda_{qr} \end{bmatrix} \qquad (13)$$

$$D_1 = L_s L_r - L_m^2 \qquad (14)$$

$$\frac{d\omega_r}{dt} = \frac{P}{J}(T_e - T_m) \qquad (15)$$

$$T_e = \frac{3PL_m}{2}(i_{qs}i_{dr} - i_{ds}i_{qr}) \qquad (16)$$

It is clearly observed that the value of torque depends on the rotor dq axis currents**.** By controlling the dq axis currents controlling of electromagnetic torque is possible.

IV.POWER ELECTRONIC CONVERTERS

In variable speed operation of the WECS the converters are used to control the speed/Torque of the generator and active and reactive power of the grid [1]. The rotor of the generator is connected to grid through a back to back PWM (Pulse Width Modulation) technique [4].

The two back to back converters are connected by a capacitor in which the power is stored in static form .The stored energy in the capacitor is converted to AC which is connected to grid through an Inverter. There are eight possible ways of switching each converter. The upper arm and lower arm switches will work in opposite states. The output current is zero in two of eight switching states. The pulse signals are generated using pulse width modulation technique. By comparing sinusoidal modulated wave with the triangular carrier wave the pulse signals were generated. The pulse signals in the upper arm and the lower arm are connected in opposite states. The pulse signals are produced by separate algorithm [2].

The voltage across the capacitor is V_{dc}.The stored energy in the capacitor is converted to an 3 phase AC signal with a fundamental component in output 'a' phase voltage of

$$V_{a1} = \frac{m_a V_{dc}}{\sqrt{6}} \qquad (17)$$

Where m_a is the modulation index of a phase voltage. The obtained three phase voltage is given back to grid.

V.ACTIVE AND REACTIVE POWER EQUATIONS

The equations for the Active and Reactive Power for stator and rotor are given below [5].

$$P_s = \frac{3}{2}(v_{ds}i_{ds} + v_{qs}i_{qs}) \qquad (18)$$

$$Q_s = \frac{3}{2}(v_{qs}i_{ds} - v_{ds}i_{qs}) \qquad (19)$$

$$P_r = \frac{3}{2}(v_{dr}i_{dr} + v_{qr}i_{qr}) \qquad (20)$$

$$Q_r = \frac{3}{2}(v_{qr}i_{dr} - v_{dr}i_{qr}) \qquad (21)$$

Using these equations the active and reactive power of stator and rotor are find out and plotted using Matlab/Simulink. From the above equations, it is clear that the power fed from stator and rotor is controlled using dq axis currents of stator and rotor.

VI.RESULTS AND DISCUSSIONS

The model of wind energy conversion system developed in the above figure is developed in Matlab/Simulink and the results are presented to view its behavior.

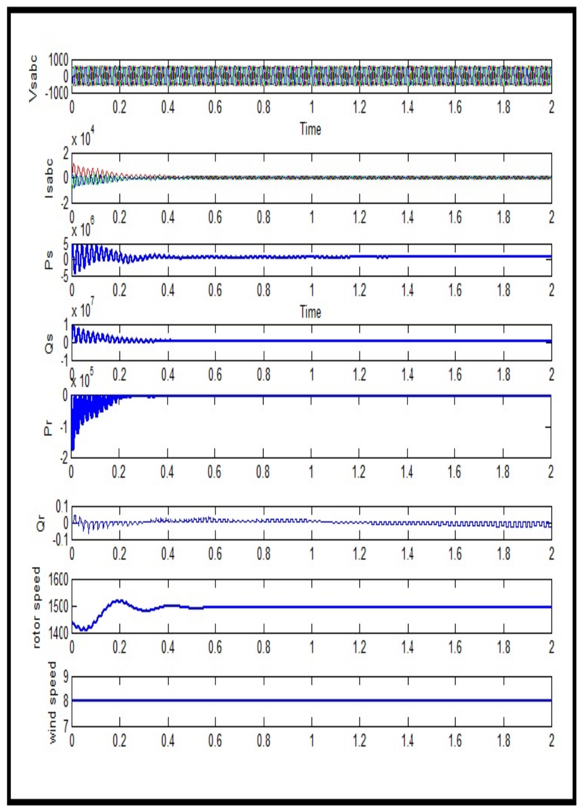

Fig.3 Performance characteristics for wind speed of 8m/sec

Fig 3 shows the various parameters of the DFIG based wind energy conversion system for the wind speed of 8m/sec. From the above graph it is observed that at wind speed of 8m/sec the rotor is rotating at a speed of 1493 it is below the synchronous speed. The rotor is rotating with a slip of 0.0047 it means that the rotor is in the sub synchronous mode. Only stator is supplying power to grid. So, Ps is positive and Pr is negative. It is observed in the graph clearly.

In Fig 4 at a wind speed of 12m/sec the speed of the rotor is increased to 1529 rpm.so, the rotor is rotating with a slip if -0.0193.The machine in super synchronous mode power transferred to grid is through both stator and rotor. So, Ps and Pr are positive.

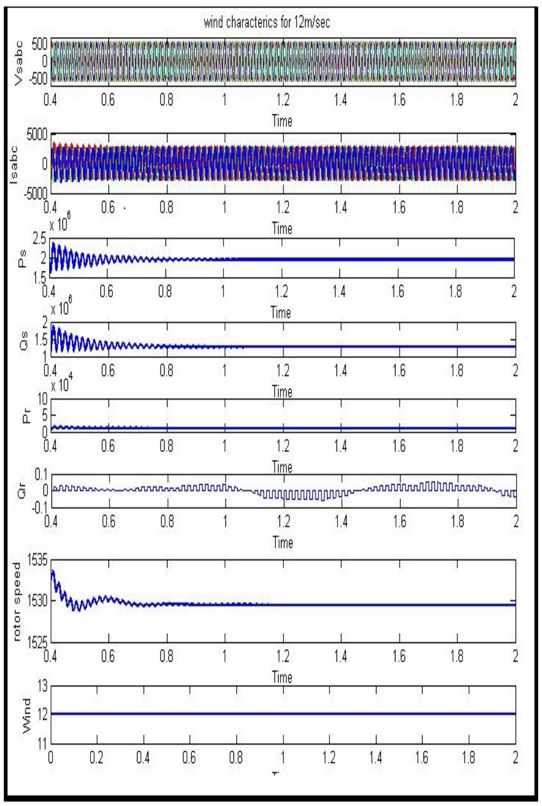

Fig.4 Performance characteristics for 12m/sec

In both cases the voltage of the grid, voltage of the of the capacitive link, are maintained constant.
The machine is operating under unity power factor mode so the reactive power supplied by the rotor of the induction machine is 0.

VII.CONCLUSION

The detailed modeling of DFIG based asynchronous machine is done, the modeling of AC/DC/AC converter is done .with this the power captured by the wind is measured and plotted with respect to time. which has been shown in above figures. DFIG has been operated in the unity power factor region so maximum power fed to grid is through grid and around 25-30% of power is fed through rotor under super synchronous mode. The power electronic converters are modeled for 30% of the rated power.

APPENDIX

The specifications of the wind turbine has given below
Cut-in wind speed 4m/sec
Rated wind speed 14m/sec
Cut out wind speed 20m/sec
Rotor diameter 82m
Swept area 5281m^2

Parameters of DFIG:

Rated power=1.5MW,
f=50Hz,
V(rms)=690V;
P(pole pairs)=2;
Sator winding Resistance=2.65mΩ;
Rotor winding Resistance=2.63mΩ;
Stator leakage Inductance=0.1687mH;
Rotor leakage Inductance=0.1334mH;
Magnetizing Inductance=5.4749mH

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