ACTIVE AND REACTIVE POWER CONTROL OF A DFIG BASED WIND ENERGY CONVERSION SYSTEM BY VECTOR CONTROL

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ABSTRACT

The paper deals with a design and implementation of a doubly fed induction generator (DFIG) wind energy conversion system (WECS) connected to the power grid. A back-to-back AC/DC/AC converter is incorporated between the stator and the rotor windings of a DFIG, in order to obtain variable speed operation. The DFIG can be controlled from sub-synchronous speed to super synchronous speed operation. The main objective of the paper is to control the flow of the Active and Reactive powers produced by the DFIG based wind energy conversion system. A vector control strategy with stator flux orientation is applied to both the grid side converter and the rotor side converter for the independent control of Active and reactive powers produced by the DFIG based wind energy conversion system. The system along with its control circuit was simulated in a Matlab/simulink and the results are presented and discussed.

Keywords: Active and Reactive powers, back-to-back converters, DFIG, Vector control, WECS

I. INTRODUCTION

Renewable energy sources are abundant all over the world and can easily be accessed. In the past, most of the electricity generated in the world was generated from the conventional sources of energy such as: Gas, oil, hydrothermal and coal. These are non renewable energy sources that emits large amount of carbon dioxide into the atmosphere, which results in the global warming there by polluting the environment [1, 2].

Nowadays due to the rapid development of modern electricity production technologies, the old methods are being replaced. Among these technologies renewable energy sources are the most widely used due to their smaller size, low cost per unit and their environmental friendly nature [1].

Among all the renewable energy sources wind energy conversion system is the promising and fastest growing source of energy in the world, this renewable and clean source of energy have always been available and its being employed for electricity generation over the years. The rising share of wind energy conversion system, in the existing power system has created many opportunities and challenges [2].

The main objective and aim of this paper is the control of the active and reactive power produced by the stator of the DFIG. The paper is divided into five sections; the first section gives the introduction, the second section discusses the operating principles of the system, the third section gives the dynamic model of a DFIG. The vector control of DFIG based wind energy conversion system for efficient and good performance is discussed in section four. The last section gives the simulation results and conclusion.

II. OPERATING PRINCIPLES OF A DFIG

The stator is directly connected to the AC mains, where as the wound rotor is fed from the Power Electronic Converters via slip rings to allow DIFG to operate at a variety of speeds in response to changing wind speed. The idea is to introduce a frequency converter between the variable frequency induction generator and fixed frequency grid. The DC capacitor linking stator-side and rotor-side converters allows the storage of power from induction generator for further generation [8]. 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. The slip power can flow in both directions, i.e. to the rotor from the supply and from supply to the rotor and hence the speed of the machine can be controlled from either rotor-side or stator-side converter in both super and sub-synchronous speed ranges. As a result, the machine can work as a generator or a motor in both super and sub-synchronous operating modes realizing four operating modes [8][10]. Below the synchronous speed in the motoring mode and above the synchronous speed in the generating mode, rotor-side converter operates as a rectifier and stator-side converter as an inverter, where slip power is returned to the stator. Below the synchronous speed in the generating mode and above the synchronous speed in the motoring mode, rotor-side converter operates as an inverter and stator-side converter as a rectifier, where slip power is supplied to the rotor. At the synchronous speed, slip power is taken from supply to excite the rotor windings and in this case machine behaves as a synchronous machine [8].

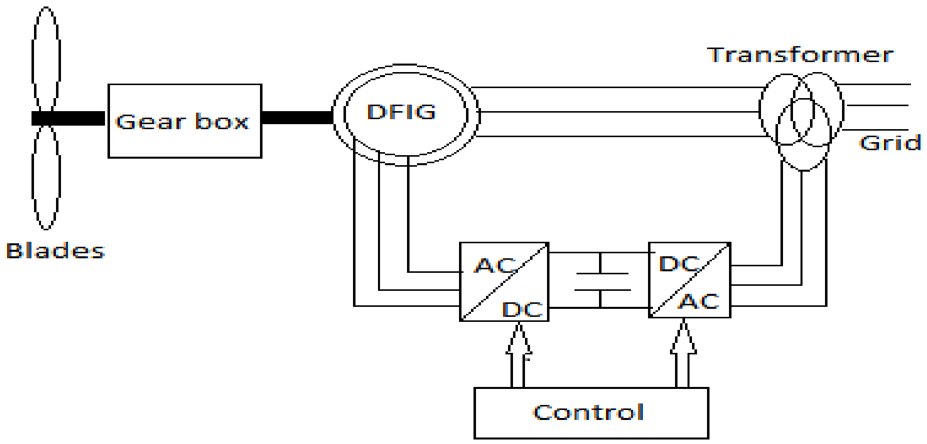

Fig. 1 Power Flow Diagram of DFIG

This arrangement has a number of advantages which include: rotor speed variation from sub-synchronous speed to super synchronous speed based on the wind speed, independent control of the active and reactive powers, and reduced flicker [4]. Generally two control schemes namely mechanical and electrical control system represent the overall control schemes of DFIG, which are both characterized by different objectives. However, the main aim is to control the power injected into the grid. The active power supply to the grid is generally controlled by the rotor side converter (RSC) whereas the reactive power injection is controlled by both the rotor side and grid side converters (GSC) as in [2]. The grid side converter also can realize the control of the DC link voltage and network power factor by using the grid voltage oriented vector control strategy [4].

III. DYNAMIC MODELLING OF A DFIG

In order to investigate the actual behavior of the DFIG, dynamic equation needs to be considered for more realistic observation. From the view point of the machine's control, the d-q representation of an induction machine leads to control flexibility [4]. The dynamic behavior of the DFIG in synchronous reference frame can be represented by the Park equations, provided all the rotor quantities are referred to the stator side. The stator and rotor voltages are expressed as follows [3-4]:

$$V_{ds} = R_s I_{ds} + p\varphi_{ds} - \omega_s \varphi_{qs} \qquad \text{Where} \quad p = \frac{d}{dt}$$
$$V_{qs} = R_s I_{qs} + p\varphi_{qs} + \omega_s \varphi_{ds} \tag{1}$$
$$V_{dr} = R_r I_{dr} + p\varphi_{dr} - (\omega_{s-} \omega_r)\varphi_{qr}$$
$$V_{qr} = R_r I_{qr} + p\varphi_{qr} + (\omega_{s-} \omega_r)\varphi_{dr}$$

The flux linkage equations of the stator and rotor can be related to the current and expressed as:

$$\varphi_{ds} = L_{ss} I_{ds} + L_m I_{dr}$$
$$\varphi_{qs} = L_{ss} I_{qs} + L_m I_{qr} \tag{2}$$
$$\varphi_{dr} = L_{rr} I_{dr} + L_m I_{ds}$$
$$\varphi_{qr} = L_{rr} I_{qr} + L_m I_{qs}$$

The electromagnetic torque developed by the DFIG is related to the torque supplied by the turbine and can be expressed as:

$$T_e = 1.5p(\varphi_{ds} I_{qs} - \varphi_{qs} I_{ds}) \tag{3}$$

For stable operation and independent control of the active and reactive powers of the system, a model based on PI controllers is developed as shown in figure 2 using the dynamic model equations below.

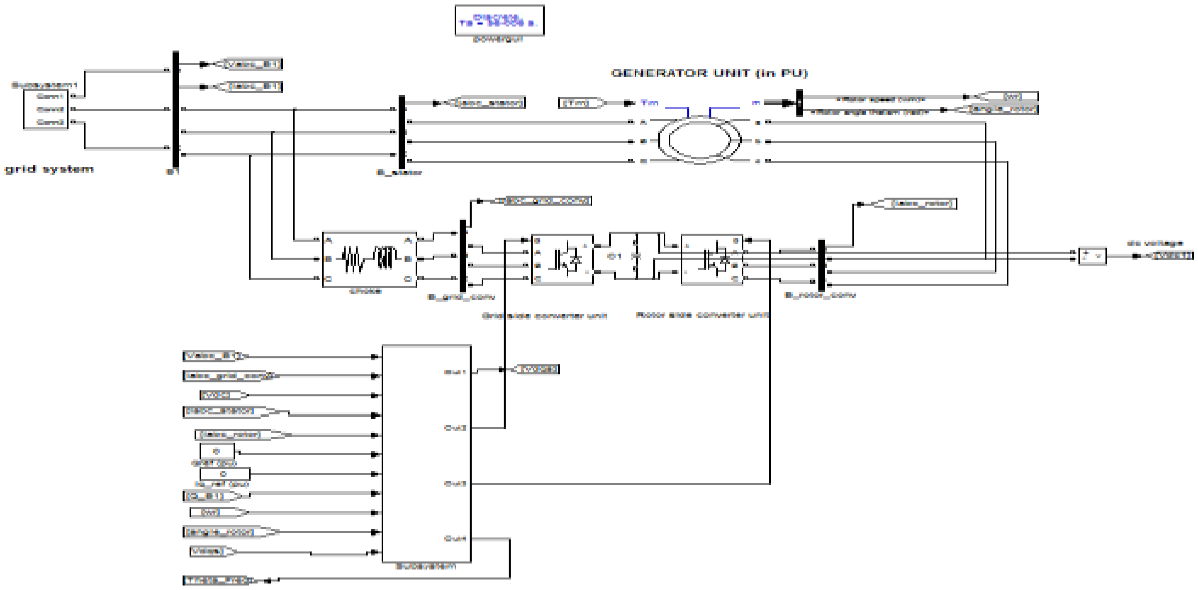

Fig. 2 Closed loop diagram of a DFIG WECS

IV. THE VECTOR CONTROL STRATEGY

The vector control concept is used for controlling a DFIG system, which is based on the transformation of a three phase variables to the synchronous frame variables, in d-q reference frames. The reference frame is aligned to the stator of the machine rotating at synchronous speed, in which the q-axis component of the rotor current is controlled to achieve the control of active power production by the DFIG while the d-axis component of the rotor current is controlled to achieve the control of reactive power production. The grid side converter is controlled to maintain the DC-link voltage constant.

The following assumptions are considered in the simulation of vector control strategy [4].

- Stator voltage drop across resistance is neglected.
- The q-axis leads the d-axis by 90^0 in the direction of rotation
- The stator flux vector is aligned with the d-axis of the stator
- The amplitude and frequency of the stator or grid voltage is assumed to be constant.
- The magnetizing current of the stator is assumed to be determined by the grid.

The above assumptions lead to the following

$$V_{ds} = 0 \quad \varphi_{ds} = \varphi_s$$
$$V_{qs} = V_s \quad \varphi_{qs} = 0 \tag{4}$$

Neglecting stator resistance

$$V_{ds} = 0 = p\varphi_{ds} - \omega_s\varphi_{qs}$$
$$V_{qs} = V_s = p\varphi_{qs} + \omega_s\varphi_{ds}$$
$$V_{dr} = R_r I_{dr} + p\varphi_{dr} - (\omega_{s-}\omega_r)\varphi_{qr} \tag{5}$$
$$V_{qr} = R_r I_{qr} + p\varphi_{qr} + (\omega_{s-}\omega_r)\varphi_{dr}$$

And the fluxes becomes

$$\varphi_{ds} = L_{ss} I_{ds} + L_m I_{dr}$$
$$0 = L_{ss} I_{qs} + L_m I_{qr}$$
$$\varphi_{dr} = L_{rr} I_{dr} + L_m I_{ds} \tag{6}$$
$$\varphi_{qr} = L_{rr} I_{qr} + L_m I_{qs}$$

Then,

$$V_{dr} = R_r I_{dr}\left(L_{rr} - \frac{L_m^2}{L_{ss}}\right) pI_{dr} - \left[(\omega_{s-}\omega_r)\left(L_{rr} - \frac{L_m^2}{L_{ss}}\right)\right] I_{qr} \tag{7}$$
$$V_{qr} = R_r I_{qr} + \left(L_{rr} - \frac{L_m^2}{L_{ss}}\right) pI_{qr} + (\omega_{s-}\omega_r)[\left(L_{rr} - \frac{L_m^2}{L_{ss}}\right) I_{dr} + \frac{L_m V_s}{\omega_s L_{ss}}$$

The active and reactive powers produced in the stator, the rotor fluxes and voltages can be written in terms of rotor currents as:

$$P_s = -\frac{L_m V_s}{L_{ss}} * I_{qr}$$
$$Q_s = -\frac{V_s^2}{\omega_s L_{ss}} - \frac{L_m V_s}{L_{ss}} * I_{dr} \tag{8}$$

Then, the reference currents interms of the active and reactive powers can be written as:

$$I_{qr} = -\frac{L_{ss} P_s}{L_m V_s}$$
$$I_{dr} = \left(Q_s - \frac{V_s^2}{\omega_s L_{ss}}\right) * -\frac{L_{ss}}{V_s L_m} \tag{9}$$

V. SIMULATION RESULTS

The DFIG based wind energy conversion system was simulated, for the active and reactive power control on the matlab/simulink platform. In this section the simulation results for the system operation are shown.

The stator dq-axis currents are shown in Figure (5) & (6). These figures represent a good pursuit, except that the present of oscillations during the transient time. A very good decoupling between the two components of the currents is obtained, which ensures the decoupling between the components of the rotor currents shown in

Figure (3) and (4), and eventually result in decoupling the active and reactive powers shown in Figure (7) and (8) respectively, which leads to a good control of the power flow between the grid and the machine at all time. The grid side voltage and currents waveforms are shown in figure (9) and (10), figure (11) shows the dc link voltage.

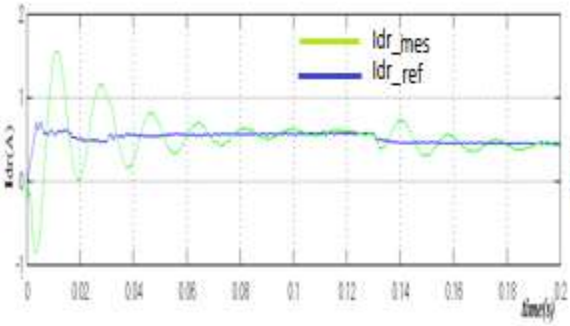

Fig. 3 Rotor d-axis currents

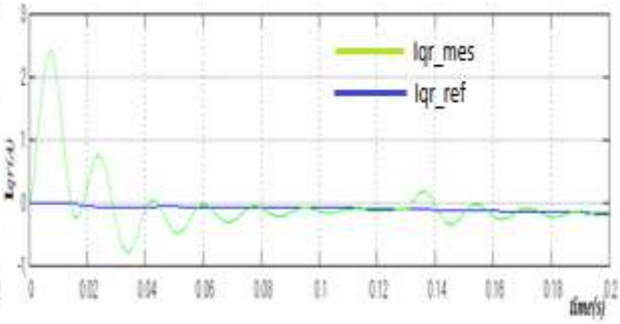

Fig. 4 Rotor q-axis currents

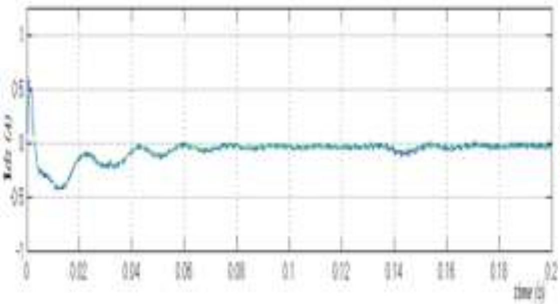

Fig. 5 Stator d-axis currents

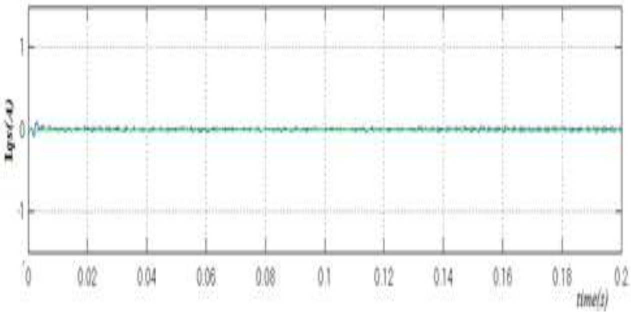

Fig. 6 Stator q-axis currents

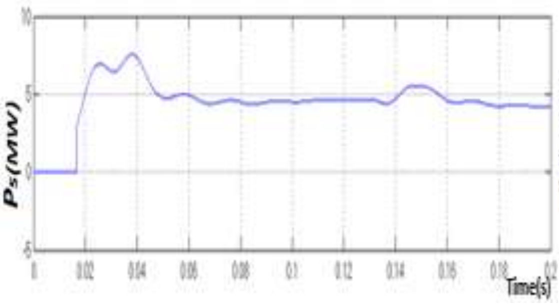

Fig. 7 Stator Active power

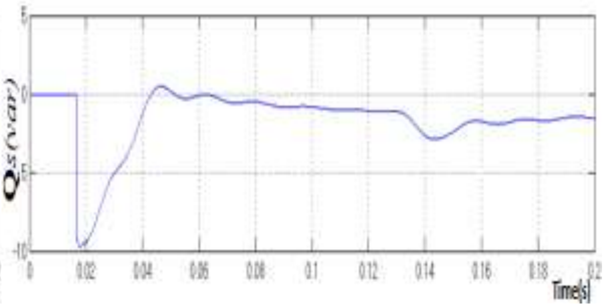

Fig. 8 Stator Reactive power

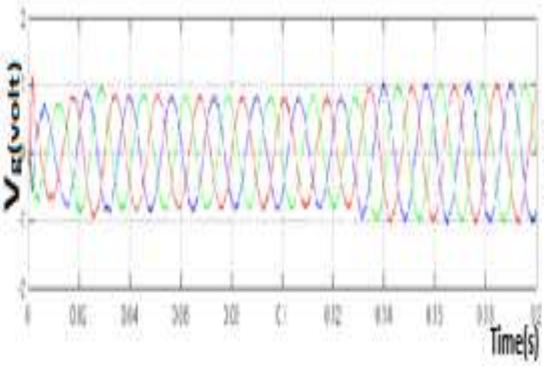

Fig. 9 Grid voltage waveforms

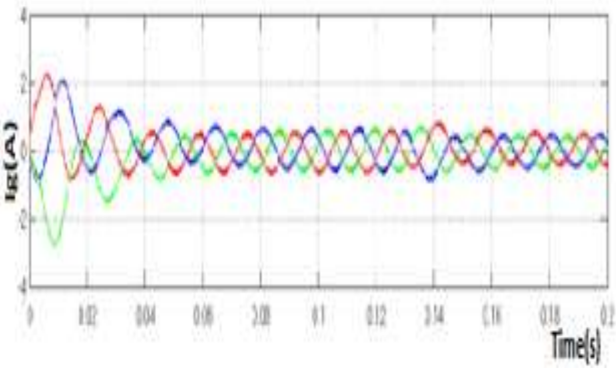

Fig. 10 Grid current waveforms

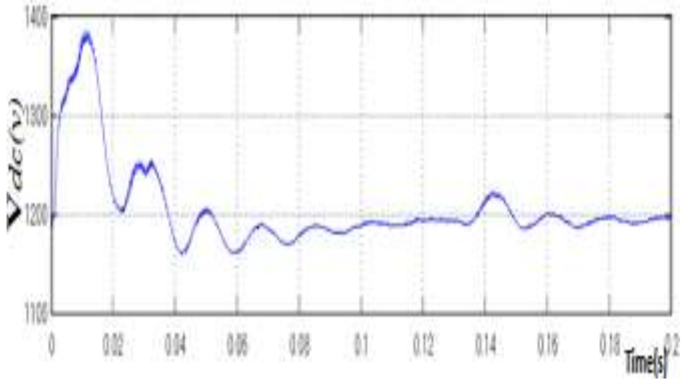

Fig. 11 DC-Link voltage

VI. CONCLUSION

The simulation of the system was carried out on a matlab/simulink, using the parameters listed below. And its overall control system model has been presented in this paper. The simulation test confirms the dynamic performance and the independent control of active and reactive powers by the vector control scheme.

Machine Parameters

Parameters	values
Power	7.5MW
Voltage	575V
Frequency	60HZ
Pole pairs	3
Stator resistance	0.0071
Rotor resistance	0.0050
Stator inductance	0.171
Rotor inductance	0.1560
Magnetizing inductance	2.9
Inertial constant	5.04
DC link capacitor	0.060
DC voltage	1200V

VII. ACKNOWLEDGMENT

The authors would like to thank and acknowledge the help and the support of our able professor Dr. S.S. Dash and Dr. N. Challammal of EEE Dept. SRM University, Chennai.

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