IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

Mathematical Modeling of DFIG Based Wind Energy Conversion System

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Abstract: Among all the renewable energy sources, the Doubly Fed Induction Generator (DFIG) based wind turbine generator system with variable-pitch control, variable speed scheme is most popular in power industry. This system can be operated either in grid connected or standalone mode. For study of complete WECS, i.e. the modeling, control of DFIG based WECS is required in both operating modes during steady state and dynamic state to operate it for better performance. In this paper, a DFIG-based wind turbine generator model connected to a constant source voltage and constant frequency grid is modelled in the MATLAB/SIMULINK and its corresponding generator and turbine control structure is implemented. Control structure of WECS is explained. The steady state behavior of the overall wind energy conversion system is studied. In this paper rotor side converter (RSC) and grid side converter (GSC) are controlled by stator voltage-oriented control with PI controller.

Index Terms **- DFIG, WECS, SVOC, wind turbine, active power, reactive power, decoupled control.**

I. INTRODUCTION

Wind energy system is the most economical and efficient energy system among other renewable energy systems such as solar power, tidal and geothermal. Wind energy is abundant and it does not release any harmful chemicals or gases to the environment. The wind energy conversion system (WECS) is conversion efficient and environmentally friendly, thus making it a more favourable choice for renewable energy. [1]. Wind power technologies have undergone vast advancement over past 15 years compared to the traditional power technologies. The advances in wind energy conversion system mainly consist of advancement in electrical machines, grid integration technologies, bi-directional power electronics conversion and control strategies etc. Now a days WECS has special control methods such as control of both speed and voltage, limiting the required output power and real and reactive power flow of the WECS. Around the world there are lots of researches going on WES and the technology is being developed to offer great deal of capability. For better performance of the WES, an comprehensive understanding of power systems, machines, control schemes and power electronic converters is required.

II. WIND ENERGY CONVERSION SYSTEM

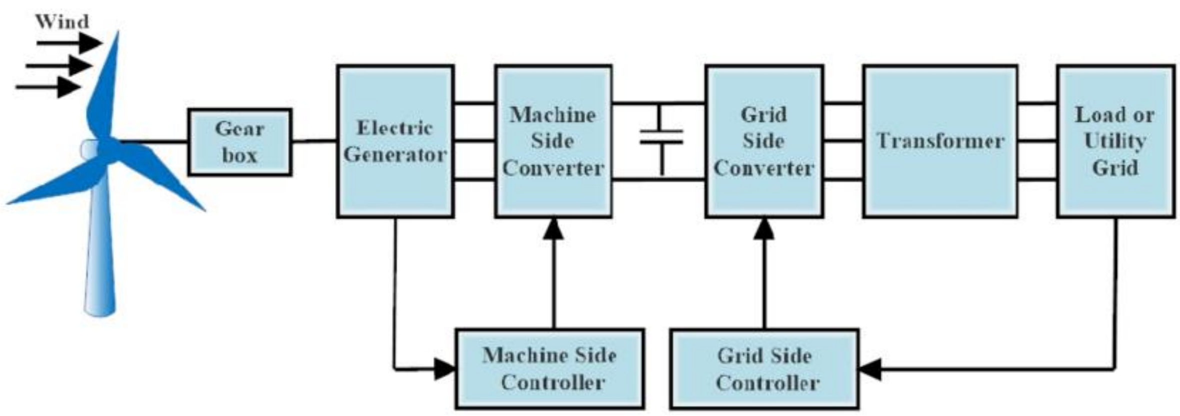

Fig. 1. Components of WECS connected to GRID

Grid connected WECS consists of wind turbine and electro mechanical components that converts the kinetic energy of wind to the electrical energy as represented in Figure 1 [2].The wind turbine system is designed with gearbox, generator, and rotor blades along with the power electronic converters. Low-speed shaft is coupled to the high-speed shaft through a two or three-stage drive train (gear box), which is further connected to the generator [3] [4].

III. MODELING OF GRID CONNECTED WECS

As shown in the Figure 2 a variable speed wind turbine-generator system is connected to the grid. The stator of the doubly-fed induction generator (DFIG) is connected directly to the grid, while the rotor of DFIG is connected to the grid through a bidirectional power converter and a three phase transformer. The back to back power converter consists of two converters, i.e., rotor side converter (RSC) and grid side converter (GSC) and dc-link capacitor is connected between the two converters. The grid-side converter is used to maintain a constant reference voltage across the capacitor and maintain unity power factor operation. The rotor side converter controls the active and reactive power that stator supplied to the load or grid. It also controls the torque and speed of generator. Crowbar protection is used to protect DFIG from fault ride through.

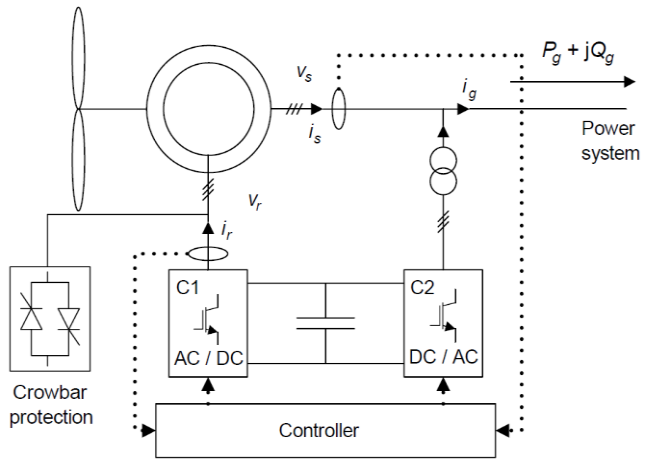

Fig.2. Typical configuration of a DFIG wind turbine [2]

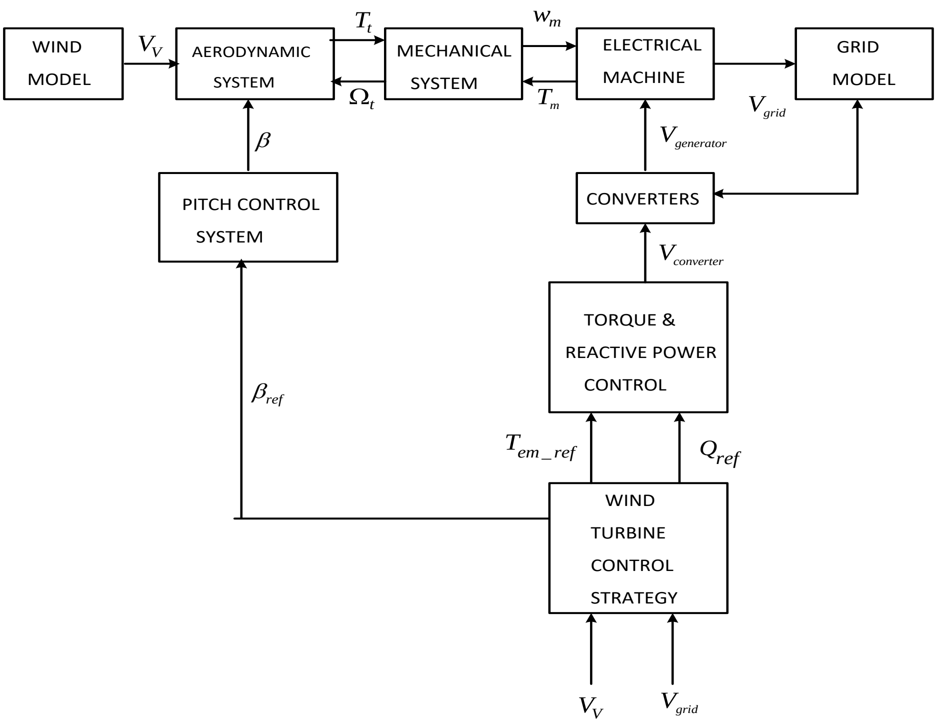

Figure 1: Model Block diagram of WECS [4]

IV. STATOR VOLTAGE ORIENTED CONTROL OF DOUBLY FED INDUCTION GENERATOR

In wind energy conversion system with DFIG, the stator terminals are directly connected to the grid, because voltage and frequency of grid are constant under the normal operating conditions. Figure 4 shows the vector diagram of stator voltage oriented control operating at unity power factor in super-synchronous mode. The SVOC is designed by aligning stator voltage vector Vs along the d-axis of the synchronous reference frame. The d-axis and q-axis component of stator winding voltages are:

$v_{qs} = 0$ and $v_{ds} = v_s$ (1)

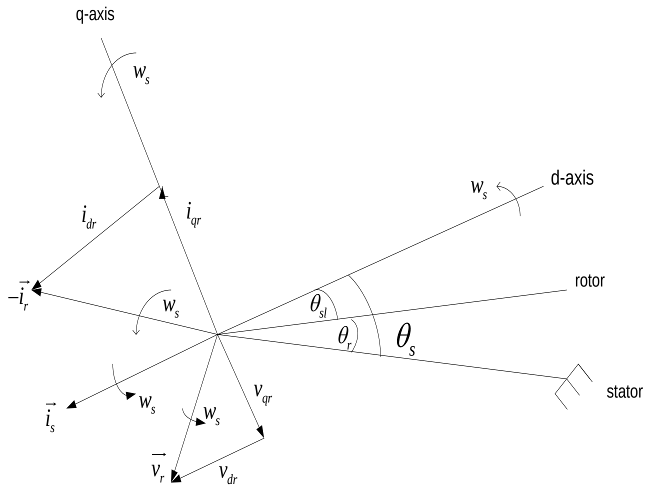

Fig.4.vector diagram of DFIG with SVOC in the super synchronous mode [5]

A. PITCH ANGLE CONTROL

The pitch angle controller is only activated at high wind speeds. In such situations, the rotor speed can no longer be controlled within its limits by increasing the generated power, as this would lead to overloading of the generator and/or the converter.

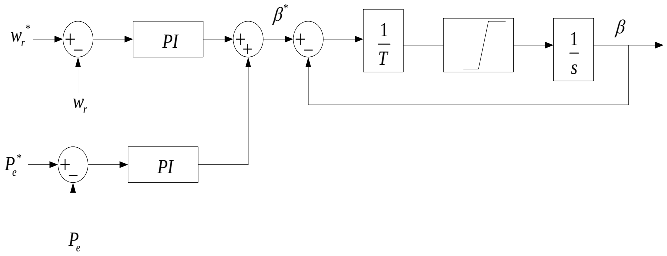

Fig.5. Wind turbine pitch controller [2]

B. DESIGN OF ROTOR SIDE CONVERTER

The rotor-side converter controls the electromagnetic torque T_e, flow of active power Ps and reactive power Qs of the stator. The electromagnetic torque of the generator

$$T_e = -\frac{3PL_m}{2w_s L_s} i_{dr} v_{ds} \quad (2)$$

Equation 2 shows that, the T_e is a function of d-axis component of rotor current and stator voltage.

The active and reactive power of stator can be expressed in terms of dq axis component of stator voltage and current as:

$$P_s = \frac{3}{2}(v_{ds}.i_{ds} + v_{qs}.i_{qs})$$
$$Q_s = \frac{3}{2}(v_{qs}.i_{ds} - v_{ds}.i_{qs}) \quad (3)$$

In the SVC, v_{qs}= 0 so equation 3 can be written as

$$P_s = \frac{3}{2} v_{ds}.i_{ds}$$
$$Q_s = -\frac{3}{2} v_{ds}.i_{qs} \quad (4)$$

Solving eqn 4 by putting i_{ds} and i_{qs} values and neglecting stator resistance i,e R_S= 0 We get

$$i_{dr} = -\frac{2L_s}{3v_{ds}L_m} P_s$$
$$i_{qr} = \frac{2L_s}{3v_{ds}L_m} Q_s - \frac{v_{ds}}{w_s L_m} \quad (5)$$

Equation 4 represents that active power and reactive power depends on d-axis current and q-axis component of stator current respectively.

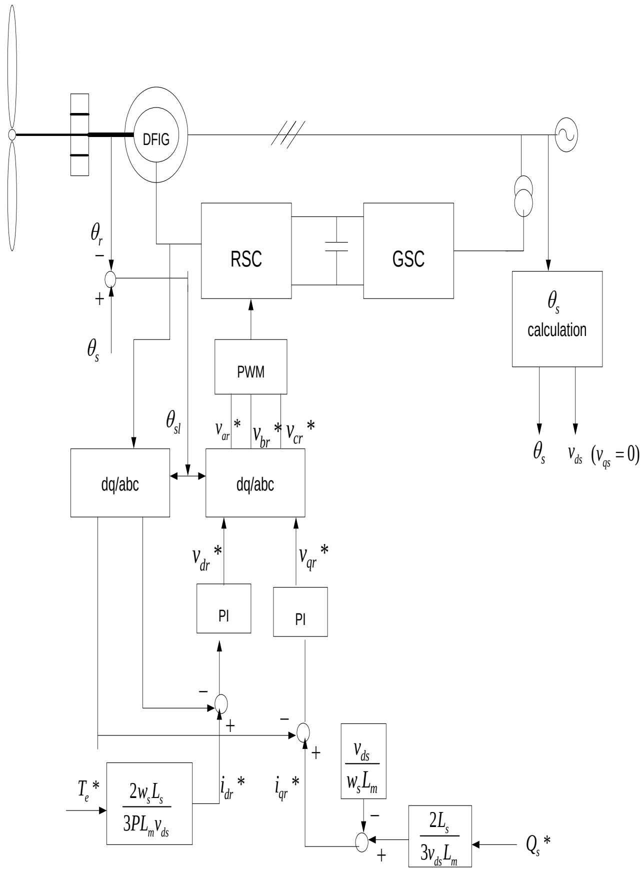

Fig.6. Block diagram RSC controller [5]

C. GRID SIDE CONVERTER CONTROL DESIGN

To implement SVOC scheme to GSC , grid voltage vector is need to alinge along the d-axis.

so, $v_{qg} = 0$ and $v_{dg} = v_g$. (6)

The active and reactive power supplied to grid are given by

$$P_g = \frac{3}{2}(v_{dg} i_{dg} + v_{qg} i_g) = \frac{3}{2} v_{dg} i_{dg}$$

$$Q_g = \frac{3}{2}(v_{qg} i_{dg} - v_{dg} i_{qg}) = -\frac{3}{2} v_{dg} i_{qg} \quad (7)$$

Putting Vqg = 0, q-axis grid reference current for reactive power control can be written as

$$i_{qg}{}^{*} = \frac{Q_g^{*}}{-1.5 v_{dg}} \quad (8)$$

Where Q_g^{*} is the reference reactive power and is maintain as zero for unity PF operation, negative for leading PF operation, and positive for lagging PF operation.

Neglecting losses in inverter ,the following relation valid .

$$P_g = \frac{3}{2} v_{dg} i_{dg} = v_{dc} i_{dc} \quad (9)$$

Assuming the GSC to operate under the rated conditions, and the modulation index $m_a$to be 0.8, the DC reference voltage is expressed as:

$$V_{dc}^{*} = \frac{\sqrt{6} V_{ai1}}{m} = \frac{\sqrt{6}}{0.8} = 3.06 \text{ PU } (V_{ai1} = 1 \text{ PU}) \quad (10)$$

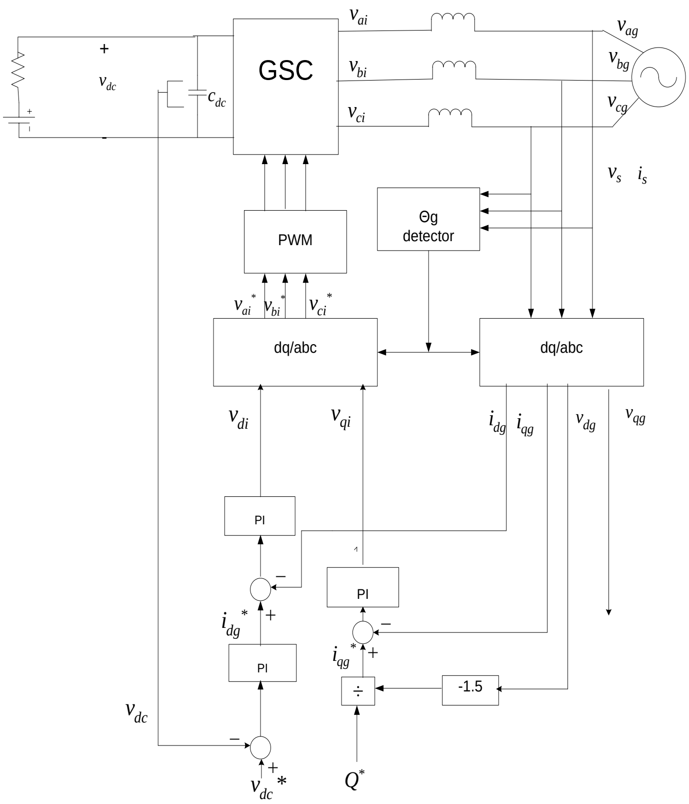

Fig.7. Block diagram of a DFIG wind energy system with stator voltage oriented control to GSC [5]

VI.SIMULATION RESULTS

A. Simulation Result of wind speed

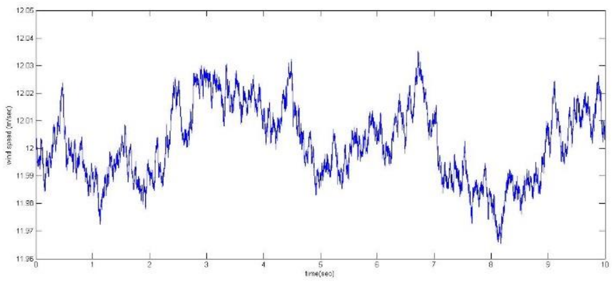

Fig.8.Wind Speed Vs time

B. Steady state Simulation Results of DFIG based WECS in super synchronous mode

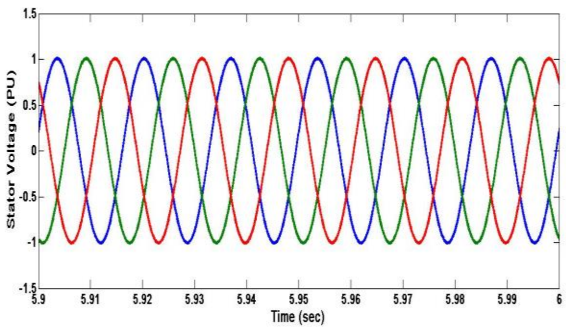

Fig.9. DFIG Stator voltage Vs time

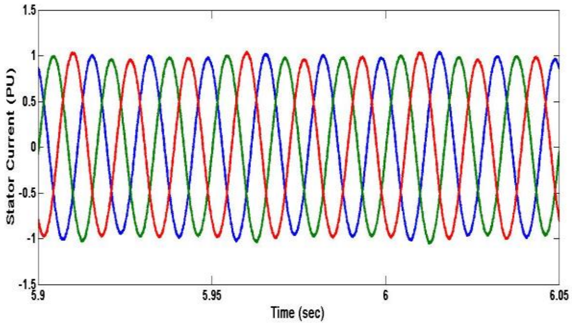

Fig.10. DFIG Stator Current Vs time

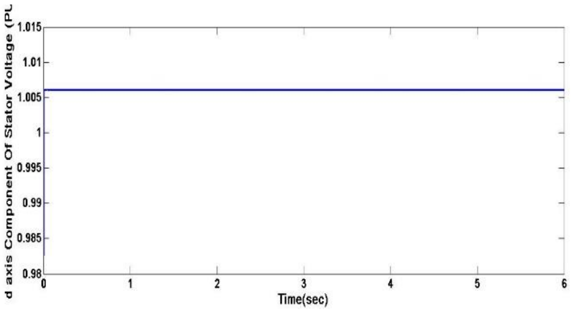

Fig.11. Stator d- axis voltage component Vs time

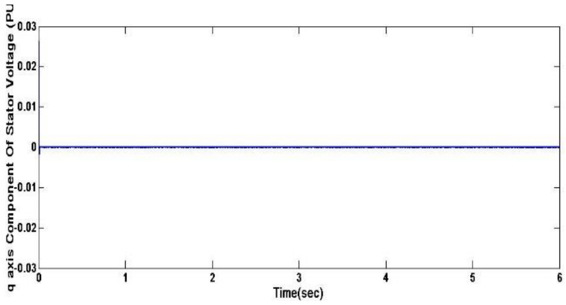

Fig.12. Stator q- axis voltage component Vs time

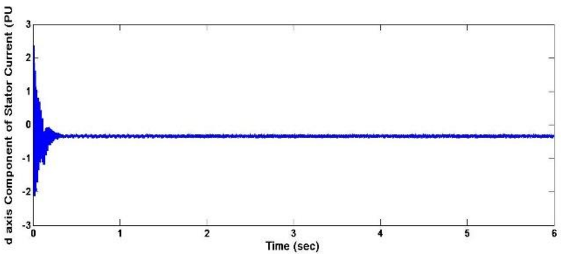

Fig.13. Stator d- axis current component Vs time

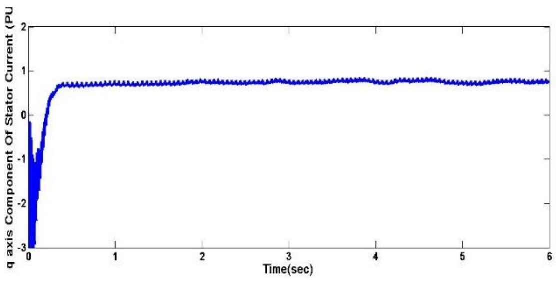

Fig.14. Stator q- axis current component Vs time

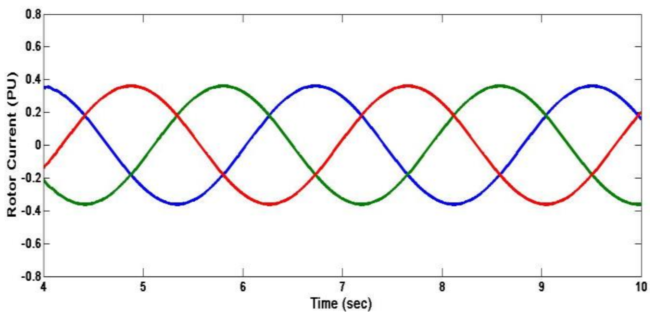

Fig.15.Rotor Current Vs time

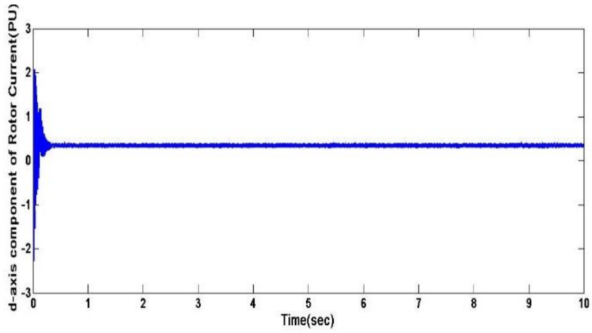

Fig.16. Rotor d- axis current component Vs time

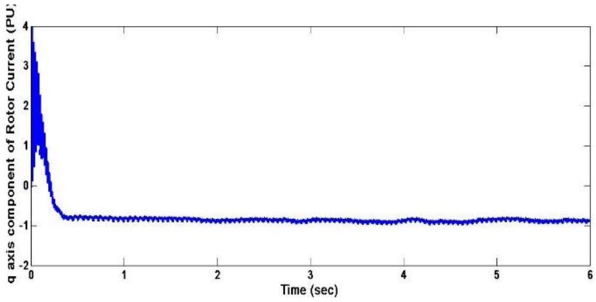

Fig.17. Rotor q- axis Current component Vs time

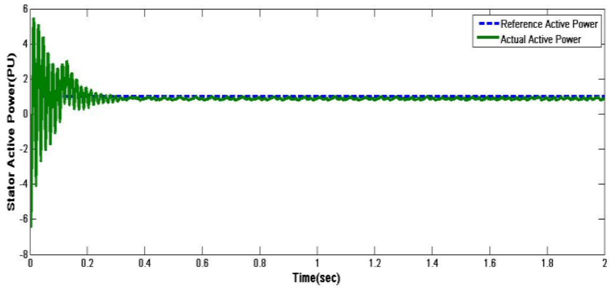

Fig.18.Stator Active Power Vs time

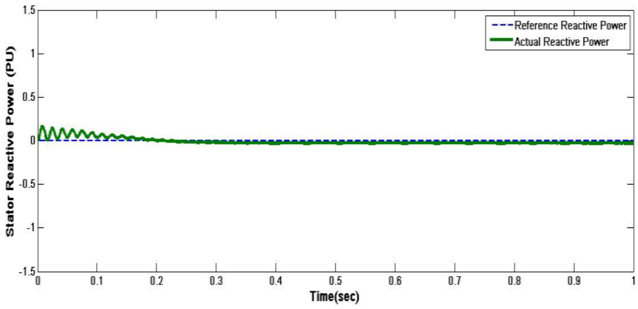

Fig.19.Stator Reactive Power Vs time

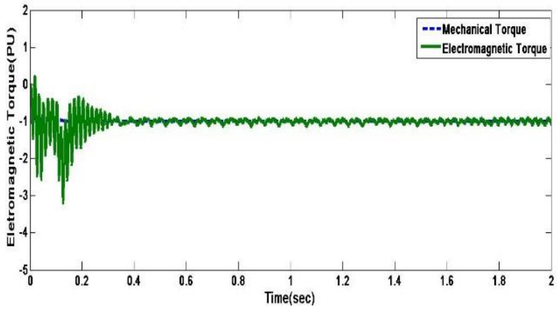

Fig.20.Electromagnetic Torque Vs time

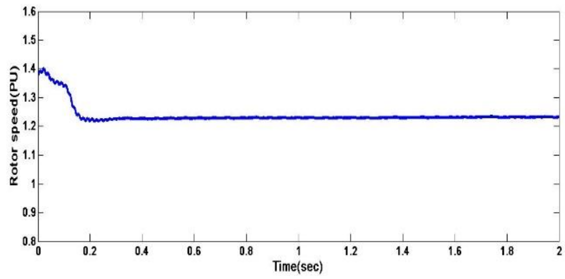

Fig.21.Rotor Speed Vs time

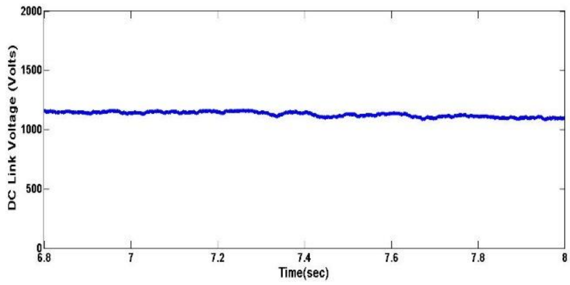

Fig.22.DC link Voltage Vs time

VII. CONCLUSION

This paper contains a detail study of modeling of DFIG and control of DFIG based WECS using synchronously rotating reference frame components (d-q components).DFIG back-to-back converter is controlled by using decoupled d-q stator vector control technique. DFIG grid side converter controls the DC link capacitor voltage by balancing the real power between DFIG machine side and grid side converter and compensate DFIG reactive power as much as possible.
Rotor side converter controls the stator active and reactive power and electromagnetic torque. d-axis component of rotor current controls the active power flow and electromagnetic torque where- as q-axis component of rotor current controls the stator reactive power.

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