ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

An ISO 3297: 2007 Certified Organization *Vol. 4, Special Issue 1, March 2015*

National Conference on Recent Advances in Electrical & Electronics Engineering (NCREEE 2015)

Organized by

Dept. of EEE, Mar Baselios Institute of Technology & Science (MBITS), Kothamangalam, Kerala-686693, India
On 26th & 27th March 2015

Stator Flux Control of DFIG based Wind Energy System with BESS

Rahul Charles C. M[1], Vinod V[2], Sudheesh S[3]

PG Student (Power System & Control), Govt. Engineering College, Barton Hill, Trivandrum, Kerala, India [1]

Assistant Professor, Dept. of EEE, Govt. Engineering College, Barton Hill, Trivandrum, Kerala, India [2]

M. Tech, Dept. of EEE, Saintgits College of Engineering, Kottayam, Kerala, India [3]

ABSTRACT: This paper presents a new control strategy for a grid connected Doubly Fed Induction Generator (DFIG).In order to decouple the active and reactive powers generated by the machine the stator-flux oriented vector control is applied. High performance control of power can be achieved by the proposed scheme, since it facilitates the decoupled control of active and reactive power. The proposed topology includes a Battery Energy Storage System (BESS) to reduce the power fluctuations on the grid due to the varying nature and unpredictability of wind. The power fed to the grid is always leveled, resulting in an efficient and reliable source of electrical power to the grid. The proposed strategy is then simulated in MATLAB-SIMULINK and the developed model is used to predict the behavior.

KEYWORDS: Doubly Fed Induction generator (DFIG), Wind Energy Conversion System (WECS), Stator Flux Oriented Reference Frame, Battery Energy Storage System (BESS).

I. INTRODUCTION

The worldwide concern about the environment has led to increasing interest in technologies for generation of renewable electrical energy. Among them Wind Energy Conversion System (WECS) currently carry significant weight in many developed countries. With favorable environmental and economic attributes, wind energy is gaining more and more attention all over the world. It is clean and sustainable fuel source and is the first renewable energy source to compete commercially both in terms of cost and quantity of generation, with significant future cost savings expected. Power extracted from wind can be described in terms of air density, wind speed, rotor diameter and turbine efficiency.

$$P= 0.5C_pA\rho V^3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where ρ is the density of air, $C_p$is the Power Coefficient, V is the wind speed and A is the area swept by rotor blades. Doubly Fed Induction Generator (DFIG) is a variable speed generator commonly used in wind farms. Ingeneral variable speed operation can improve the wind production further.

II. DOUBLY FED INDUCTION GENERATOR (DFIG)

The wind turbine driving DFIG wind power system consists of a wound-rotor induction generator and an ac/dc/ac insulated gate bipolar transistor (IGBT)-based pulse width-modulated (PWM) converter (back-to-back converter with capacitor dc link).The rating of the power converter is generally in the range from 25% to 30% of the rated power of the generator. A typical arrangement of a DFIG is shown in fig. 1.It is a Wound Rotor Induction Generator (WRIG) which provides power at constant or controlled voltage and frequency through the stator while the rotor is supplied through a static power converter at variable voltage and frequency.Both motoring and generating operation modes are feasible, provided the power electronics converter that supplies the rotor circuits via slip-rings and brushes is capable of handling power in both directions.When the wind speed increases, the speed of the rotor increases abovesynchronous speed, resulting in a negative slip and super synchronous operation. In this operation, power flows to the grid from both the stator windings and the rotor windings. As the wind speed decreases rotor speed decreases and the machine operates in sub- synchronous mode with positive slip.Rotor absorbs active power from the grid essentially borrowing power for rotor winding excitation.

Independent control of active and reactive power is achieved by using a stator voltage-oriented or stator flux-oriented approach for the control of the converters. The back-to-back converter consists of the rotor-side converter and the grid-side converter. The rotor-side converter controls the torque and the speed of the DFIG and the grid-side converter keeps the dc link voltage constant between the two converters. The DFIG is controlled by vector control strategy of the power converter.

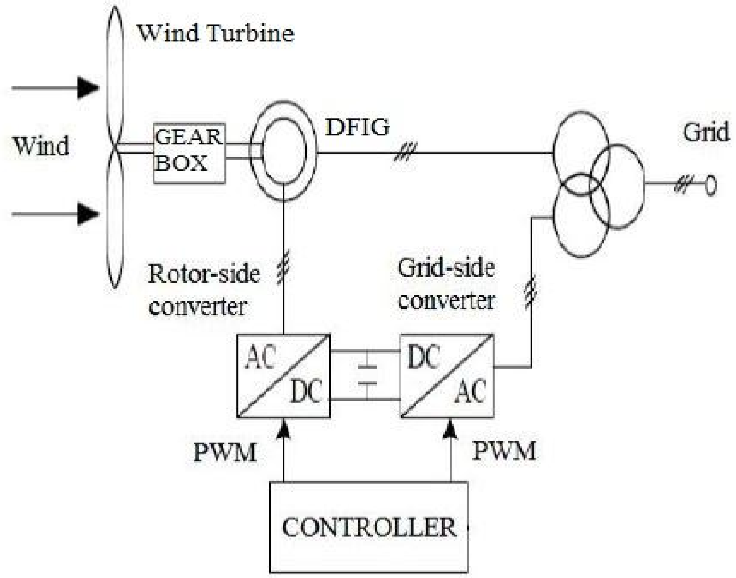

Fig. 1. Basic configuration of a DFIG wind turbine

III. EQUIVALENT CIRCUIT OF DFIG

An equivalent circuit of DFIG is depicted in Fig. 2, and the relation equations for voltage *V*, current *I*, flux Ψ, and torque *Te*involve are

$$V_{ds} = R_s I_{ds} - w_s \psi_{qs} + \frac{d\psi_{ds}}{dt} \quad \text{..................(2)}$$

$$V_{qs} = R_s I_{qs} + w_s \psi_{ds} + \frac{d\psi_{qs}}{dt} \quad \text{..................(3)}$$

$$V_{dr} = R_r I_{dr} - s w_s \psi_{qr} + \frac{d\psi_{dr}}{dt} \quad \text{.................. (4)}$$

$$V_{qr} = R_r I_{qr} + s w_s \psi_{dr} + \frac{d\psi_{qr}}{dt} \quad \text{...................(5)}$$

$$\psi_{ds} = L_s I_{ds} + L_m I_{dr} \quad \text{..................(6)}$$

$$\psi_{qs} = L_s I_{qs} + L_m I_{qr} \quad \text{..................(7)}$$

$$\psi_{dr} = L_r I_{dr} + L_m I_{ds} \quad \text{..................(8)}$$

$$\psi_{qr} = L_r I_{qr} + L_m I_{qs} \quad \text{..................(9)}$$

$$T_e = \frac{3}{2} n_p \left(\psi_{ds} I_{qs} - \psi_{qs} I_{ds}\right) \quad \text{..................(10)}$$

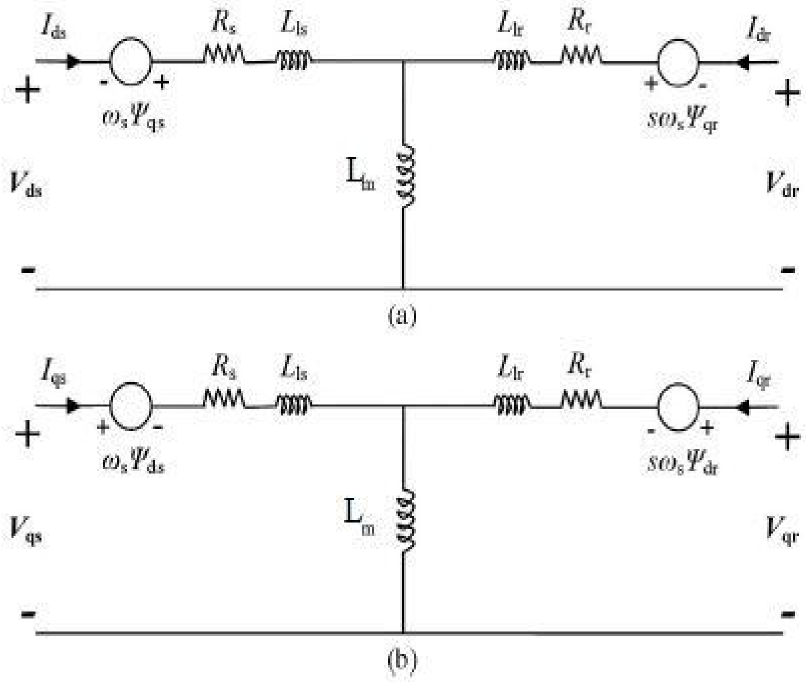

Fig. 2. Equivalent Circuit of DFIG

s$\omega_s = \omega_s - \omega_r$represents the difference between synchronous speed and rotor speed; subscripts r, s, d, and q denote the rotor, stator, d-axis, and q axis components, respectively; $T_e$is electromagnetic torque; and $L_{m,}n_p$, are generator mutual inductance, the number of pole pairs, and respectively

IV. STATOR FLUX ORIENTATION CONTROL

Vector Control stems from decoupled flux-current and torque-current control in AC drives.It resembles the principle of decoupled control of excitation and armature current in DC brush machines. When the DFIG is connected to the power grid, active and reactive powers are close-loop controlled, and they produce the reference flux and torque currents in vector control.Aligning the system of co-ordinates to stator fluxseems most useful,atleast for power grid operation,ψ_s is almost constant, because the stator voltages are constant in amplitude, frequency, and phase:

$$\psi_s=\psi_d \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(11)$$

$$\psi_q=0\ldots\ldots\ldots\ldots\ldots\ldots\ldots(12)$$

$$\frac{d}{dt}\psi_q=0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

$$P=\frac{3}{2}\omega_1\psi_d\frac{L_m I_{qr}}{L_s} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(14)$$

$$Q=\frac{3}{2}\omega_1\frac{\psi_d}{L_s}(\psi_d-L_m I_{dr})\ldots\ldots\ldots\ldots\ldots\ldots\ldots(15)$$

Equation shows that under stator flux orientation (vector) control, the active power delivered (or absorbed) by the stator may be controlled through the rotor currentI_{qr}, while the reactive power may be controlled through the rotor current I_{dr}.Both powers depend heavily on stator flux and frequency .This constitutes the basis for vector control of P and Q, by controlling the rotor currents I_{dr} and I_{qr} in synchronous co-ordinates. A pulse width modulation on the machine side converter is generally performed on rotor voltages, voltage decoupling in the rotor is required, again in synchronous co-ordinates. The source side converter is connected to power grid eventually via a step-up transformer in some embodiments. At the maximum slip, rotor voltage equals the stator voltage. In general, the source –side voltage converter uses a power filter to reduce current harmonics flow into the power source. Neglecting the harmonics due to switching in the converter and the machine losses and converter losses, the active power balance equation is as follows:

$V_{dc}I_{dc}=(3/2)V_dI_d=P$……………………..(16)
$V_q=0$ ....………………….. (17)
With the PWM depth m_1 and voltage of dc link V_{dc}
$V_d=(m_1/2\sqrt{2})V_{dc}$………………....……(18)
The dc link voltage may be controlled through I_d control.The reactive power from the power source to the source side converter may be controlled through I_q

V. DESIGN OF BESS

The design of a suitable rating of the BESS is very necessary for satisfactory operation of the proposed configuration of Wind Energy Conversion System (WECS).At higher wind speeds, power output of the WECS is higher as compared to the average power and therefore,the extra power is stored in the battery. At the lower wind speeds, the power is drawn from the battery to maintain the average power fed to the grid.Thus it is ensured that the power fed to the grid is always leveled resulting in an efficient and reliable source of electrical power to the grid.The MATLAB based modeling of the battery is done using the Thevenin's equivalent of it as shown in fig3.Since the battery is an energy storage unit, its energy isrepresented in kWh,when a capacitor is used to model a battery unit, the capacitance can be determined from

$$C_b = \frac{(kWh)\times 3600\times 10^3}{0.5\left(V_{ocmax}^2 - V_{ocmin}^2\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots(19)$$

Where V_{ocmin} and V_{ocmax} are the minimum and maximum open circuit voltage of the battery under fully discharged and charged conditions.

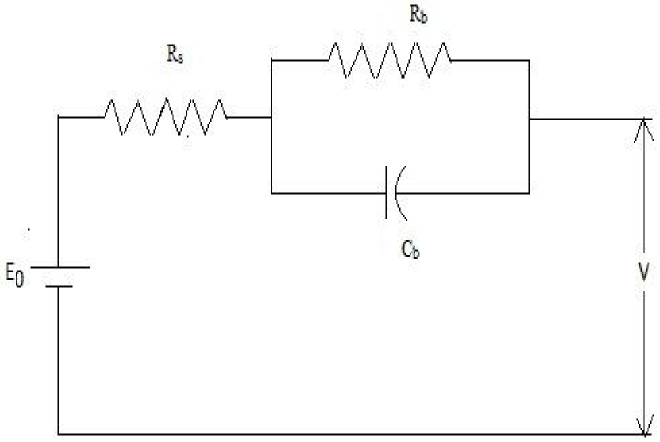

Fig. 3.Thevenin's Equivalent of BESS

In the Thevenin's equivalent model of battery,R_s is the equivalent resistance (external +internal) of parallel/series combination of a battery, which is usually a small value. The parallel circuit of R_b and C_b is used to describe the stored energy and voltage during charging or discharging.R_b in parallel with C_b represents self-discharging of the battery. Since the self-discharging current of the battery is small, the resistance R_b is large.

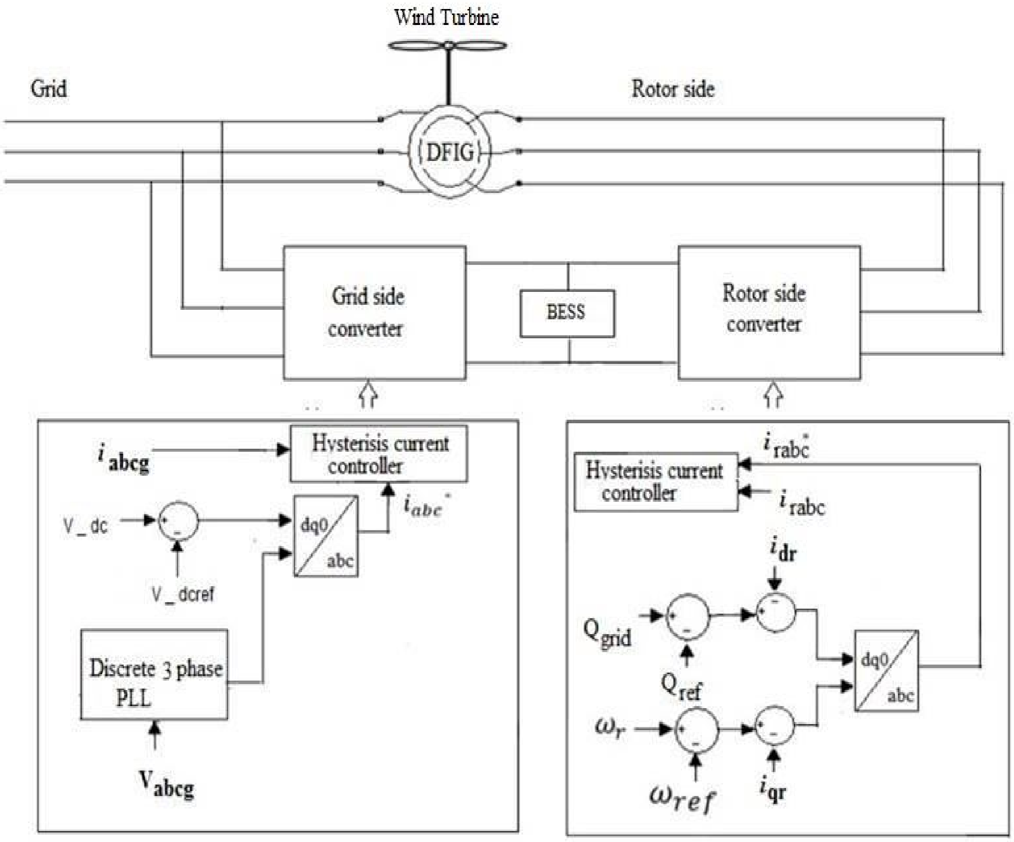

Fig. 4.Block Diagram of the Proposed System

VI. RESULTS AND DISCUSSION

The model of WECS with BESS is developed in MATLAB-SIMULINK and results are presented to demonstrate its behavior at different wind speeds. The simulation parameters are shown in table I. The waveforms for wind speed,torque,rotor currents, active power, and grid voltage are presented for different wind speeds. The simulation time used is 10 sec. The wind speed is varied from 0 to 20 m/s during the simulation that is the wind speed is varied above rated wind speed, rated wind speed and below rated wind speed. The variation in wind speed is shown in fig 5. Initially the wind speed is 10 m/s for this step input is applied. The wind speed is kept 10 m/s up to 2.5 sec then the wind speed is changed to 20 m/s. Then this speed is reduced to 13.7 m/s. Then at time t = 6 sec the speed is reduced to 0 m/sec.

Rated Power (P_{mec})	4 KVA
Pole Pairs (P_p)	2
Stator Voltage (U_s)	400 V
Frequency (f)	50 Hz
Stator Resistance (R_s)	1.405 Ω
Rotor Resistance (R_R)	1.395 Ω
Mutual inductance (L_m)	0.1722 H

Stator Inductance (L_S)	0.005839 H
Rotor Inductance (L_R)	0.005839 H
Friction Coefficient (B_g)	0.002985 Nms
Moment of Inertia (J_g)	0.131 kgm^2

Table 1.Machine Rating

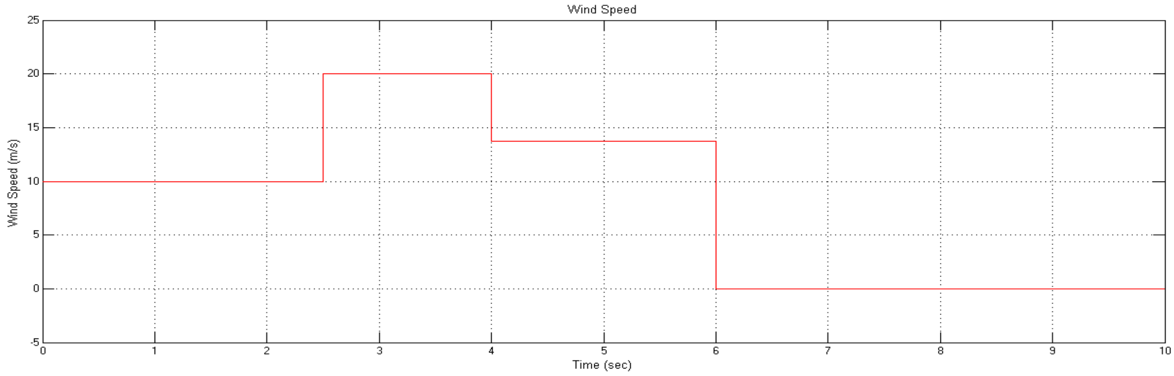

Fig. 5. Wind Speed Variations

On varying with wind speed the rotor injected current is also varied. Here the wind speed is varied time t= 2.5 sec, 4 sec and 6. In fig 6 corresponding to the variations in the rotor currents with respect to wind speed. When the wind speed is 10 m/s the rotor current is 6 A. At time t = 2.5 sec the wind speed is increased to 20 m/s the rotor current become 12.5 A. Then the wind speed is reduced to 13.7 m/s at time t = 4 sec at this time the rotor current also reduced and the new value of rotor current is 9.5 A. At time t = 6 sec again the rotor current is reduced to 7.5 A.

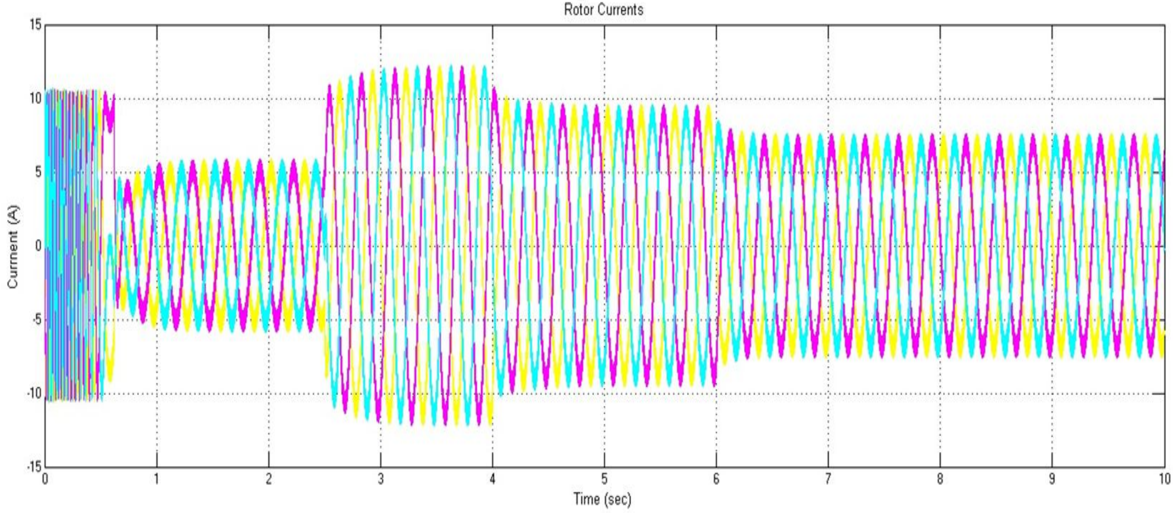

Fig. 6. Variation of rotor currents with respect to time

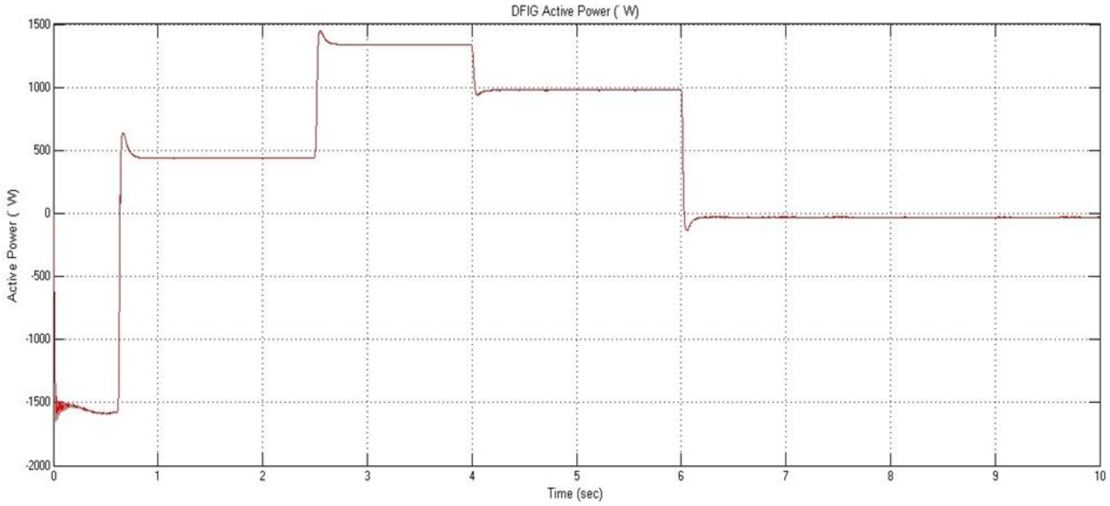

Fig. 7. Variation of active power by DFIG

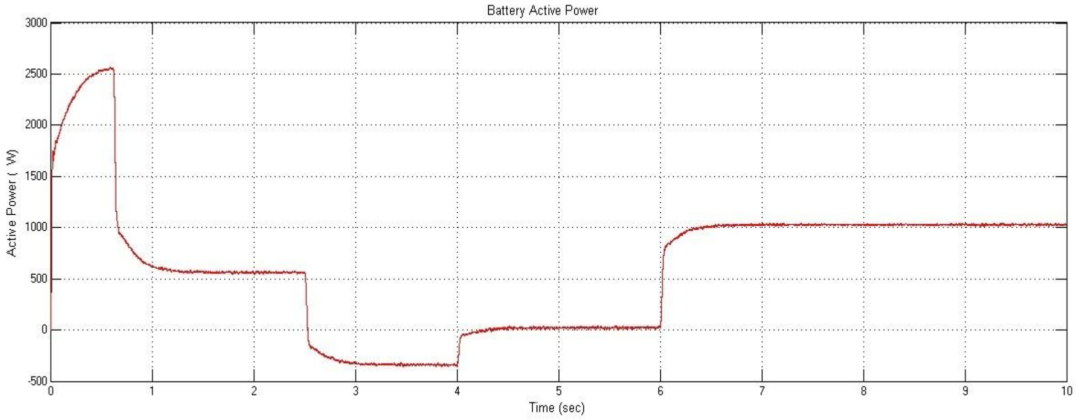

Fig. 8.Variation of active power from battery with respect to time

Time (sec)	Wind speed (m/s)	Stator power (W)	Battery power (W)
0-2.5	10	450	550
2.5-4	20	1400	-400
4-6	13.7	1000	0
6-10	0	0	1000

Table II. Active power of Stator and BESS

Though the wind speed varies from a low to high during a given period of time, the power fed to the grid and hence the overall energy supplied to the grid remains constant irrespective of these variations in wind speed as shown in table II .

VII. CONCLUSION

A configuration of DFIG based WECS with a BESS in the dc link has been proposed with a stator-flux oriented vector control strategy to maintain the grid power constant. The vector control allows easy decomposition of active and reactive powers on the stator side. The performance of the proposed control strategy on a DFIG based WECS with BESS has been demonstrated under different wind speeds. The modified control strategy is able to negotiate the grid power gusts, due to the variable wind speeds in an efficient way.

REFERENCES

[1] Yu Zou,Malik E Elbuluk,YilmazSozer, ”Simulation Comparison and Implementation of Induction Generator Wind Power Systems,” *IEEE Trans. Ind. Appl.*, vol. 49, No. 3, May/June 2013.
[2] Vijay Chand Ganti,BhimSingh,Shiv Kumar Aggarwal, “DFIG- based Wind Power Wind Power Conversion with Grid Power Levelling for Reduced Gusts,” *IEEE Transact. Sustainable Energy*.,Vol 3, no1 Jan 2012.
[3] E. Vittal, M. O’Malley, and A. Keane, “A steady-state voltage stabilityanalysis of power systems with high penetrations of wind,” *IEEE Trans.Power Syst*., vol. 25, no. 1, pp433–442, Feb. 2010.
[4] Z. Chen, J. M. Guerrero, and F. Blaabjerg,“A review of the state of the art of power electronics for wind turbines,” *IEEE Trans. Power Electron.*, vol. 24, no.8, pp. 1859–1875, Aug. 2009.
5] Y. Lei, A. Mullane, and G. Lightbody,”Modeling of the wind turbine with a doubly fed induction generator for grid integration studies,” *IEEE Trans. Energy Convers*., vol. 21, no. 1, pp. 257–264, Mar. 2006
[6] WECC Wind Generator Modeling Group, Generic Type-3 Wind Turbine- Generator Model for Grid Studies, Sep. 14, 2006, Version 1.1.
[7] L. Xu and P. Cartwright, “Direct active and reactive power control ofDFIG for wind energy generation,” *IEEE Trans. Energy Convers.*,vol. 21, no.3, pp. 750–758, Sep. 2006.
[8] S. Heier, *Grid Integration of Wind Energy Conversion Systems*. Hoboken, NJ, USA: Wiley,2006