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A NEW CONTROL STRATEGY FOR DFIG BASED WIND ENERGY SYSTEM USING BESS

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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, 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),vector control, Wind Energy Conversion System (WECS), Battery Energy Storage System (BESS).

INTRODUCTION
The worldwide concern about the environment has led to increasing interest in technologies for generation of renewable electrical energy. One way of generating electricity from renewable sources is to use wind turbines. 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. In addition, they aren't harmful to environment like fossil sources. The last few years showed a great increase in electrical power demand. This is coincided with increasing penetration of renewable energy sources in order to reduce global warming and promote carbon free technologies. Among different renewable energy sources, wind energy has the major share due to their relative inferior cost. In addition they have low maintenance requirements and clean operation. Therefore, wind energy can be built on a large scale with prospective economical benefits.

Power extracted from wind can be described in terms of air density, wind speed, rotor diameter and turbine efficiency.

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

Where ρ is the density of air, Cp is the Power Coefficient,
V is the wind speed and A is the area swept by rotor blades.

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. In normal operation, the use of power converters enables DFIGs to operate at optimal rotor speed, thus maximizing the power generation. 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-

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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.

At synchronous speed, the magnetic field of the rotor rotates at the same speed as the stator magnetic field. The DFIG then essentially operates as asynchronous machine with DC current in the rotor windings meaning no active power will be generated in the rotor windings and therefore all active power from the DFIG machine will flow from the stator to the grid. When the wind speed increases, the speed of the rotor increases above synchronous 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. Hence as a generator DFIG, power with constant voltage and constant frequency through stator, while rotor is supplied through a static power converter at variable voltage and variable frequency. The rotor circuit may absorb or deliver electric power.

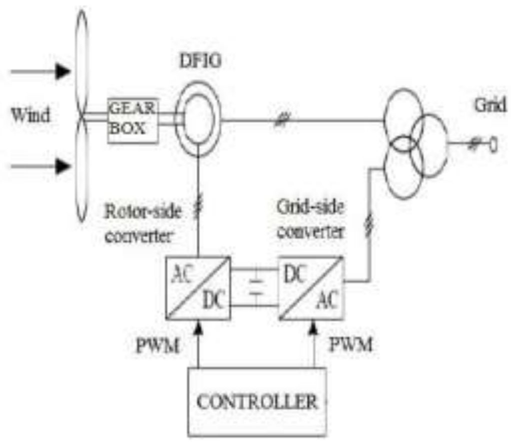

Fig. 1. Basic configuration of a DFIG wind turbine

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

$$V_{ds} = R_s I_{ds} - w_s \psi_{qs} + \frac{d\psi_{ds}}{dt} \quad \text{..................(1)}$$

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

$$V_{dr} = R_r I_{dr} - s w_s \psi_{qr} + \frac{d\psi_{dr}}{dt} \quad \text{..................(3)}$$

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

$$\psi_{ds} = L_s I_{ds} + L_m I_{dr} \quad \text{..................(5)}$$

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

$$\psi_{dr} = L_r I_{dr} + L_m I_{ds} \quad \text{..................(7)}$$

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

$$T_e = \frac{3}{2} n_p \left(\psi_{ds} I_{qs} - \psi_{qs} I_{ds} \right) \quad \text{……………….(9)}$$

$s\omega_s = \omega s - \omega r$ 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; Te is electromagnetic torque; and Lm, np, are generator mutual inductance, the number of pole pairs, and respectively.

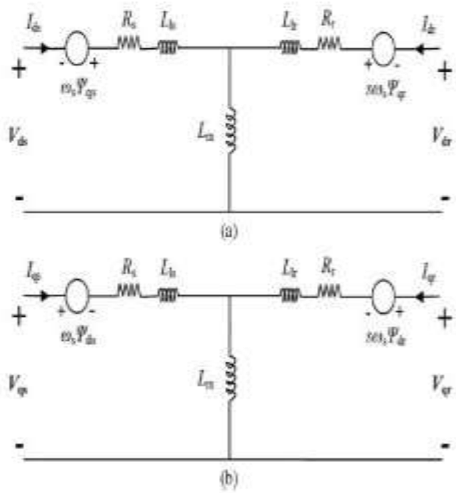

Fig 2. Equivalent Circuit of DFIG

CONTROL OF DOUBLY FED INDUCTION GENERATORS

Rotor Side Converter (RSC) is used to control the torque production of the DFIG through direct control of rotor currents.RSC does this by applying a voltage to the rotor windings that corresponds to the desired current. Controlling the rotor currents controls the slip and so the speed of the machine.RSC will operate at varying frequencies corresponding to the variable rotor speed requirements based on wind speed.RSC can use either a torque controller, speed controller, or active power controller to regulate the output power of DFIG.Typically a PI controller is used to control the torque,speed or power to its reference value.Whichever controller is used, the output of the controller is the reference rotor current required to generate the desired torque or power to obtain desired speed.

GSC is connected directly to the grid, it must output power at a fixed frequency, corresponding to the grid frequency.It is used to regulate the voltage of the DClink between the two converters.GSC contains an outer loop control that controls the DC link voltage attempting to control it to nominal value

For the rotor-side controller the d-axis of the rotating reference frame used for d-q transformation is aligned with air-gap flux. The actual electrical output power, measured at the grid terminals of the wind turbine, is added to the total power losses (mechanical and electrical) and is compared with the reference power obtained from the tracking characteristic. A Proportional-Integral (PI) regulator is used to reduce the power error to zero. The output of this regulator is the reference rotor current Iqr_ref that must be injected in the rotor by converter Crotor. This is the current component that produces the electromagnetic torque Tem. The actual Iqr component is compared to Iqr_ref and the error is reduced to zero by a current regulator (PI). The output of this current controller is the voltage Vqr generated by Crotor. The current regulator is assisted by feed forward terms which predict Vqr. The voltage at grid terminals is controlled by the reactive power generated or absorbed by the converter Crotor. The reactive power is exchanged between Crotor and the grid, through the generator. In the exchange process the generator absorbs reactive power to supply its mutual and leakage inductances. The excess of reactive power is sent to the grid or to Crotor

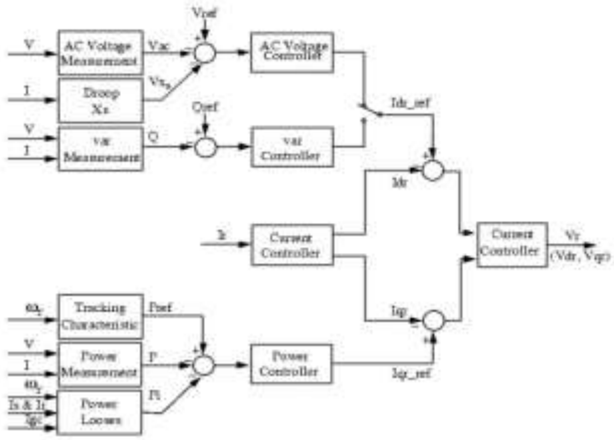

Fig.3. Rotor Side Converter Control

The Grid Side Converter (GSC) is used to regulate the voltage of the DC bus capacitor. For the grid-side controller the d-axis of the rotating reference frame used for d-q transformation is aligned with the positive sequence of grid voltage. This controller consists of:

1. A measurement system measuring the d and q components of AC currents to be controlled as well as the DC voltage Vdc.
2. An outer regulation loop consisting of a DC voltage Regulator.
3. An inner current regulation loop consisting of a current Regulator. The current regulator controls the magnitude and phase of the voltage generated by converter Cgrid (Vgc) from the Idgc_ref produced by the DC voltage regulator and specified Iq_ref reference.

GSC is used to regulate the voltage of dc link between two converters.It consists of an outer loop control that controls the dc link voltage, attempting to control it to the nominal value. GSC is connected directly to the grid , it must output power at a fixed frequency , corresponding to the frequency of grid.

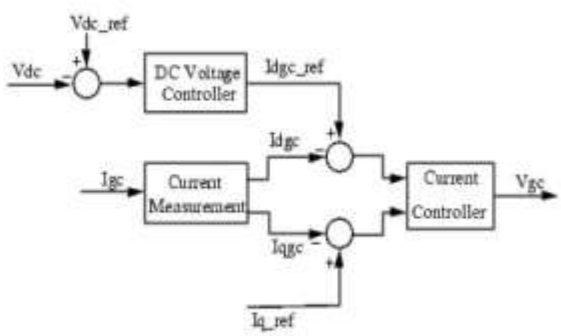

Fig.4. Grid Side Converter Control

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 flux seems most useful,as atleast for power grid operation, ψ_s is almost constant, because the stator voltages are constant in amplitude, frequency, and phase:

$$\psi_s=\psi_d \quad \ldots\ldots(10)$$

$$\psi_q=0 \quad \ldots\ldots(11)$$

$$\frac{d}{dt}\psi_q=0 \quad \ldots\ldots(12)$$

$$P = \frac{3}{2}\omega_1 \psi_d \frac{L_m I_{qr}}{L_s} \ldots\ldots\ldots\ldots\ldots (13)$$
$$Q = \frac{3}{2}\omega_1 \frac{\psi_d}{L_s}(\psi_d - L_m I_{dr}) \ldots\ldots (14)$$

Equation shows that under stator flux orientation (vector) control, the active power delivered (or absorbed) by the stator may be controlled through the rotor current I_{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:

$V_{dc}I_{dc}=(3/2)V_dI_d=P_r$
$V_q=0$
With the PWM depth m_1 and voltage of dc link V_{dc}
$V_d=(m_1/2\sqrt{2})V_{dc}$
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

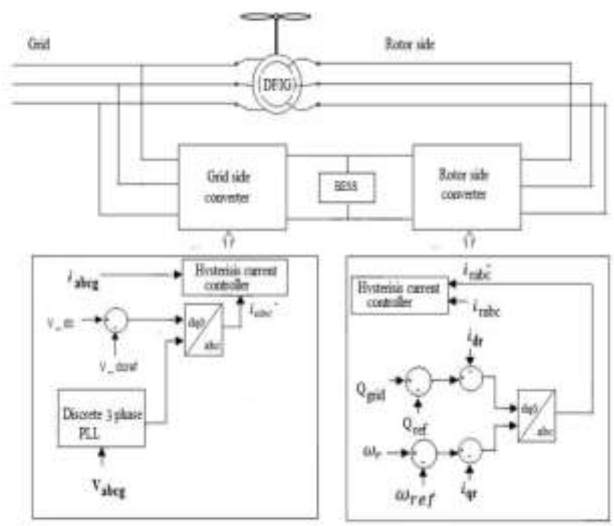

Fig. 5. Simulation Diagram

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 fig.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

$$C_b = \frac{(kWh)\times 3600\times 10^3}{0.5(V_{ocmax}^2 - V_{ocmin}^2)} \ldots\ldots\ldots\ldots\ldots\ldots (15)$$

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

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.

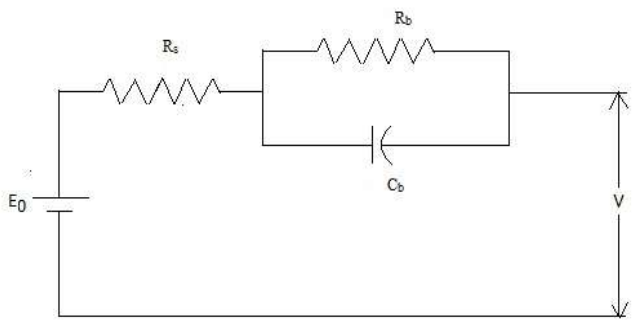

Fig. 6. Thevenin's Equivalent of BESS

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 waveforms for wind speed,torque,rotor currents, active power, and grid voltage are presented for different wind speeds.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.

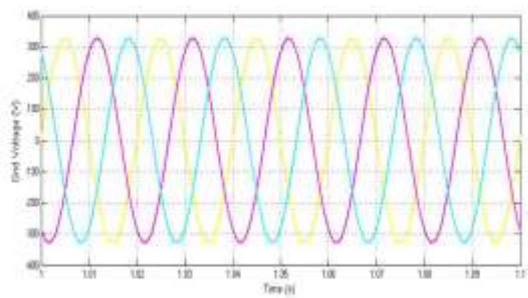

Fig. 7. Grid Voltage

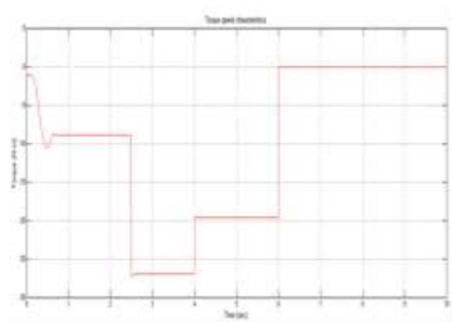

Fig.8. Torque

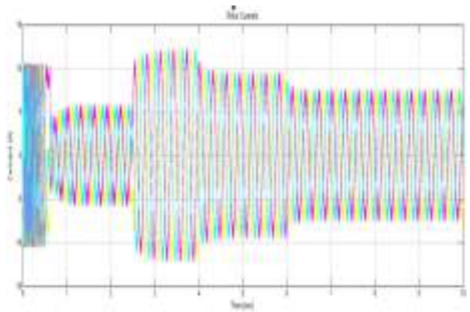

Fig.9. Rotor Currents

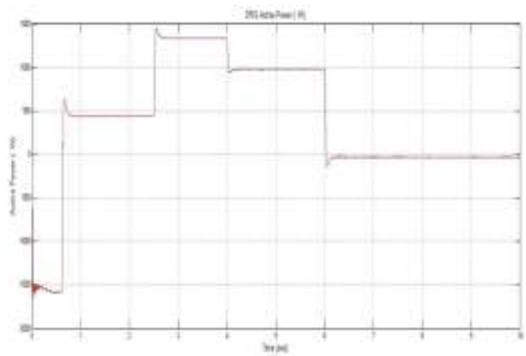

Fig. 10. Active Power by DFIG

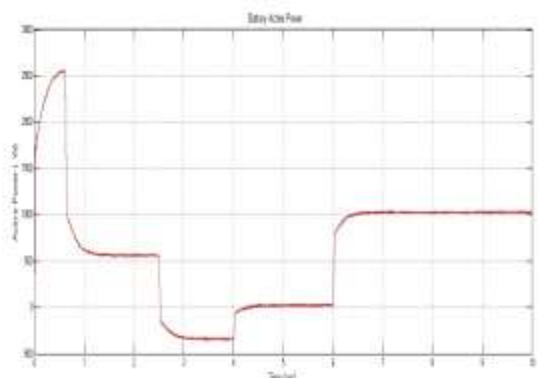

Fig.11. Variation of Active Power by Battery

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.

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