# Reactive Power Compensation in Wind Energy System

**R. Uthra, D. Anitha, N. Kalaiarasi**

***Abstract--- Multiple Sources of generation is being introduced in current day power systems with an increasing number of wind energy systems being integrated due to the focuson creating a sustainable energy network in the future. When the networkis subjected to severe interruptions likevoltage sag or short circuit fault, the wind energy systems usually gets disconnected from the grid so that the system isprotected from voltage drops in the range of 0.2 to 0.3 pu. This becomes detrimental to the stability of the system with the largeintegration of wind generators in the power system network due to the loss of a considerable part of wind generators during a transient disturbance. The proposed scheme seeks toutilize an effective vector control strategy for reactive power compensation which assists in theaccelerated restoration of terminal voltage.***

***Index Terms--- LVRT, Reactive Power Compensation, Vector Control, Wind Energy.***

## I. INTRODUCTION

The need for clean energy has never been more urgent and harvestingenergy from wind has become widely accepted as one of the most prominent waysof addressing the issue. As wind energy systems become more prominent inour power grids it is essential for these systems to continue to provide thestability that traditional forms of thermal power stations offer. One majorproblem in present-day wind energy systems is their fault ride-through capability. Recent grid codes have indicated that wind energy systems muststay connected to the grid for a particular amount of time depending on theseverity of the fault. This is not helped by the fact that Doubly Fed Induction Generators (DFIG), which are the most favored generators in windenergy systems are adversely affected by voltage dips due to overvoltagesand overcurrents in the rotor windings as a result of the magnetic coupling that is presentbetween the stator and rotor. DFIGs are widely used because they providethe ability to regulate the active and reactive power output of the generatorirrespective of the input wind speed over a particular range, by manipulatingthe rotor currents through the use of converters. There have been numerous ideas cited for the enhancement of the fault ride through capability of thesesystems to tackle this complication. The most basic solution to protect thecomponents of the systems was to use a crowbar at the instant the fault occurred and subsequently disconnect the generator from the grid [1]–[3]. This is nolonger a viable option. Hence through the use of a vector control scheme thatmanipulates the converter outputs and hence the rotor current, the fault ridethrough capability of the system is provided. Along with the ability to ridethrough low voltages, the vector control scheme also provides reactive powercompensation which enhances the fault ride through capability of the systemby reducing the quantum of reactive power drawn by the generator from thegrid to re-establish air gap flux once the fault is cleared, hence preventingfurther voltage dips.

## II. CONTROL AND FUNCTIONS OF WIND ENERGY SYSTEMS

The basic wind energy system consists of a DFIG in which the stator is connected directly to the grid whereas the rotor is connected to the grid through back-to-back converters [9]. Therefore a variable AC voltage and frequency is fed to the rotor while the stator has a constant voltage and frequency supply as it is connected directly to the grid. This kind of a setup enables the control of rotor currents which successively manipulates the active and reactive power of the generator [4]-[7]. There are two converters, the rotor side converter (RSC) and the grid side converter (GSC) connected by a DC link and they are controlled by a vector control scheme.

*Rotor Side Controller*

The rotor side controller as shown in Figure 1 controls the rotor torque (or active power) and the reactive power of the DFIG. This is achieved through a vector control scheme [12]-[14]. To implement this, the three-phase rotor currents are measured and converted to its *dq* axis model equivalent. The reference frame is aligned along the stator flux making calculations much easier and hence enhancing controllability. This alignment is done using a phase-locked loop. Once the d axis current ($i_d$) and q axis current ($i_q$) are obtained they are fedto the PI controllers that make sure the id and iq values measured are equalto the reference or desirable values.The reference values are obtained based on the formulae that relate therotor *dq* currents to real power, speed, torque and reactive power as shown in (1), (2) and (3).

$$P_s = \frac{3}{2} V_{qs} i_{qs} \qquad (1)$$

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

$$T_{em} = -\frac{3}{2} p \frac{L_m}{L_s} |\psi_s| i_{qr} \qquad (3)$$

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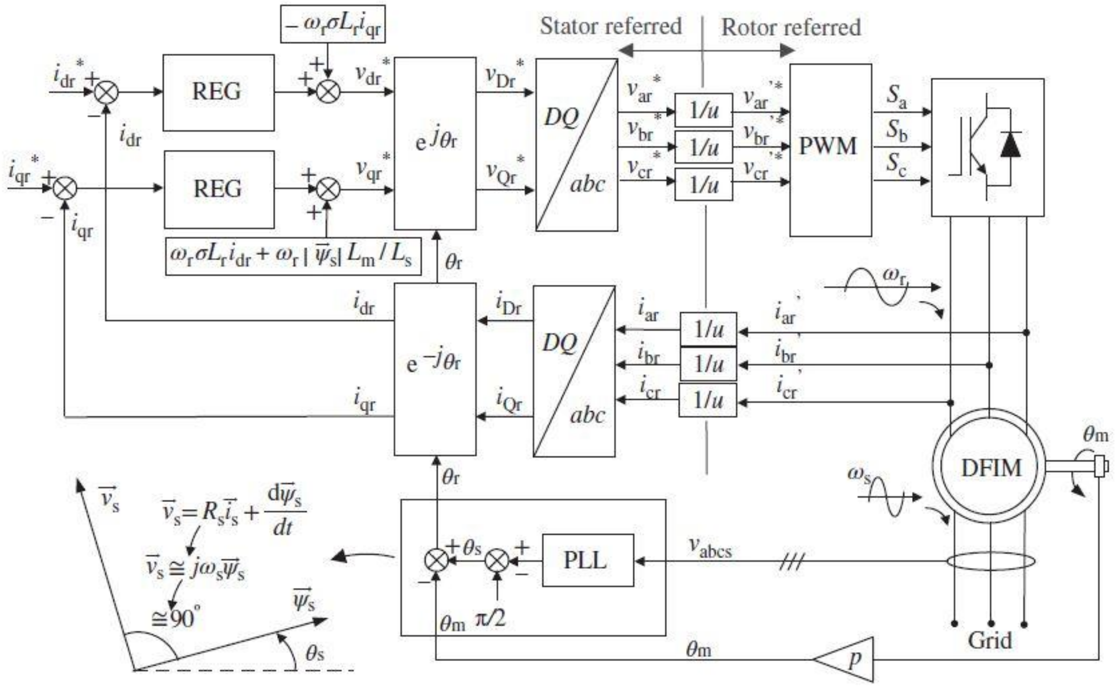


**Figure 1: Rotor Side Vector Control**

The output of the PI controllers are then used to obtain the *dq* voltagesbased on (4) and (5),which are then converted to their three phasevalues and given as pulses to the switches of the rotor side converter. Therefore, depending on the application speed or torque along with the reactivepower can be controlled.

$$V_{dr} = R_r i_{dr} + \sigma L_r \frac{d}{dt} i_{dr} - \omega_r \sigma L_r i_{qr} + \frac{L_m}{L_s}\frac{d}{dt}|\psi_s| \quad (4)$$

$$V_{qr} = R_r i_{qr} + \sigma L_r \frac{d}{dt} i_{qr} + \omega_r \sigma L_r i_{dr} + \omega_r \frac{L_m}{L_s}|\psi_s| (5)$$

*Grid Side Controller*

The grid side converter shown in Figure 2 controls the active power and reactive power that is exchanged between the rotor and the grid. It controls the active power indirectly by maintaining the DC link voltage constant at a desired value. This is achieved by using a vector control scheme which manipulates grid currents and voltages of the DC link between the two converters.

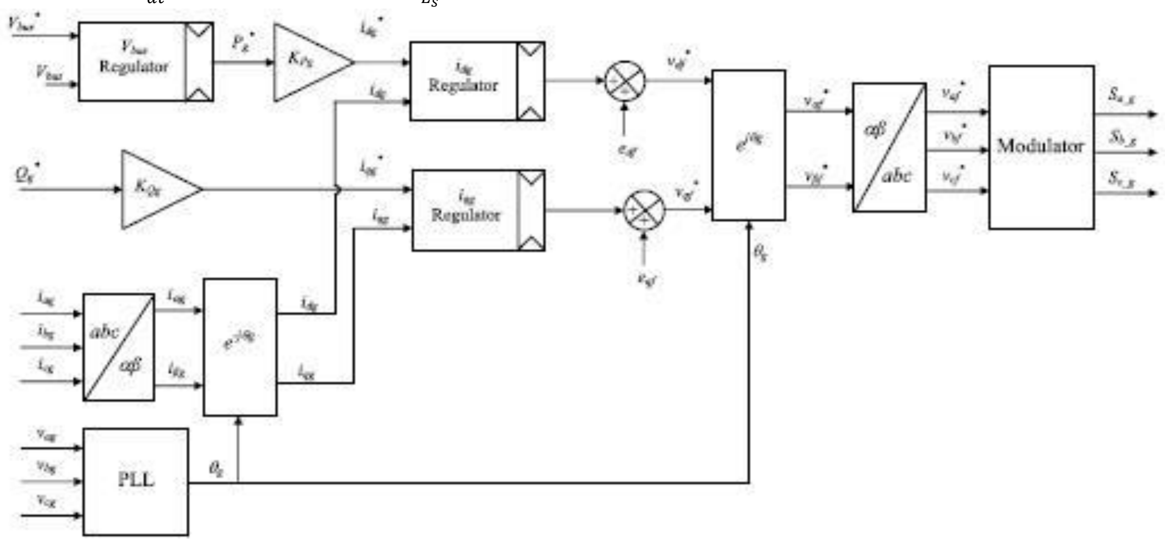


**Figure 2: Grid Side Vector Control**

The three-phase grid currents are measured and converted to their respective *dq* model equivalent values. The *dq* reference frame gets aligned to the space vector of grid voltage resulting in simplifying the equations and hence improving control. The alignment is done using a phase locked loop whose reference is the three-phase grid voltages. On achieving this, the measured grid currents from d axis and q axis is given to the PI controller to make sure the measured value is same as that of the reference value. Since the active power of the rotor has to flow through the DC link, by controlling the DC link voltage the active power is controlled. Therefore,a constant and desirable voltage is obtained by passing the DC link voltage through a PI controller. The reference id and iq values are then obtained through (6) and (7) that show the relation between active and reactive power with the *dq* currents.

$$P_g = \frac{3}{2} v_{dg} i_{dg} = \frac{3}{2}|\overrightarrow{v_g^a}| i_{dg} \qquad (6)$$


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$$Q_g = -\frac{3}{2} v_{dg} i_{qg} = -\frac{3}{2} \left|\overrightarrow{v_g^a}\right| i_{qg} \quad (7)$$

The output of the PI controllers is then used to find the *dq* voltages using the (8) and (9).

$$v_{df} = R_f i_{dg} + L_f \frac{di_{dg}}{dt} + v_{dg} - \omega_s L_f i_{qg} \quad (8)$$

$$v_{qf} = R_f i_{qg} + L_f \frac{di_{qg}}{dt} + \omega_s L_f i_{dg} \quad (9)$$

The *dq* values are then converted back to their three-phase equivalents and given as a reference to trigger switches in the grid side converter that provides active and reactive power control.

## III. LVRT AND REACTIVE POWER COMPENSATION

### *Symmetrical Fault Ride Through*

The most severe type of fault is a symmetrical fault where all three phases are affected simultaneously. This paper focuses only on the ride-through of a symmetrical fault. In the event of a voltage dip, the stator voltage falls rapidly since the stator happens to be connected to the grid directly in a DFIG system. The stator flux, on the other hand, does not decrease as rapidly as the stator voltage. The stator flux can be decreased faster by the rotor current which is controlled by the vector control scheme. Since the rotor current depends on the flux of the stator and the voltages of stator and rotor, when a voltage dip occurs in the stator it has to be accompanied by an increase in rotor voltage in order to reduce the amount of rotor currents [8]. This value is often much higher than its steady-state value during severe voltage dips and is beyond the design of the machine. Therefore, an active crowbar can be used instead, at the instant when the fault occurs as it can accelerate the decay of the stator flux [11]. This also means the loss of control for a short duration until the flux decays to a desirable value during which overcurrents are dissipated through the crowbar. Once the crowbar is disconnected and control is re-established a new steady state is obtained where the magnitudes are smaller due to the voltage dip, enabling the low voltage ride-through of DFIG [19]-[20].

### *Reactive Power Compensation*

During a voltage dip, there is a fall in electromagnetic torque but the mechanical torque remains unchanged as the wind hits the turbines irrespective of whether there is a fault in the system. This drop in electromagnetic torque causes an increase in the speed of the rotor which can be detrimental to the recovery of voltage once the fault is cleared as it increases the amount of reactive power needed to re-establish air gap flux. Once the fault is cleared, the electromagnetic torque is brought back to its value before the fault occurred but since the rotor speed is increased, the electromagnetic torque might not be able to compensate for the mechanical torque leading to an increase in the requirement of reactive power needed by the DFIG. This can cause a further dip in the voltage and hence de-stabilize the power system making the low voltage ride-through of the machine redundant. Therefore, it is essential to provide reactive power compensation which is done through the vector control scheme [15]-[18]. The reference values provided to the vector control scheme are manipulated when a voltage dip occurs so that the reactive power can be controlled in DFIG. Hence the rotor currents are also controlled such that reactive power is compensated during the fault, therefore, helping in the rapid re-establishment of the voltage in the system.

## IV. SIMULATION RESULTS

The following are the results of the simulated wind energy system with ratings as given in Table 1with each control scheme implemented sequentially.

### *Rotor Side Controller*

The input wind speed given was variable to emulate the variable wind speed in practical scenarios. Vector-controlled rotor side converter attains rated speed much faster as shown in Figure 3 and 4 with torque oscillations being reduced dramatically showing much-improved controllability.

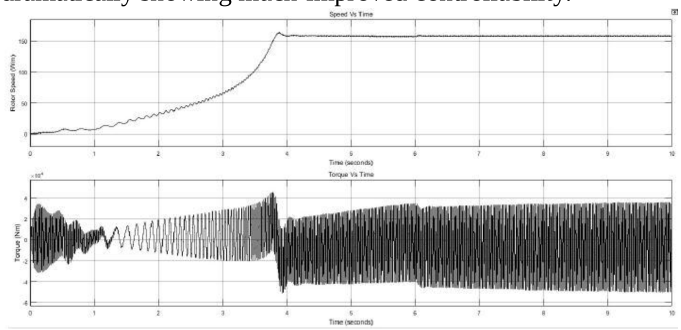

**Figure 3: Speed and Torque without RSC**

### *Grid Side Controller*

It is clear from the Figure 5 and 6 that the DC link voltage can be brought to a desirable value by giving a reference value in the vector control scheme. This ensures that both converters function well and the reactive power exchange with the grid is controlled.

### *Inclusion of a Capacitor Bank*

A capacitance bank is used to emulate the reactive power compensation achieved by the vector control scheme as shown in Figure 7. This is done to correlate the output of the main system to the one achieved by fabricating the hardware of the system to validate the outputs practically. As the real and reactive power outputs indicate, in both cases there is reactive power compensation during the fault period.

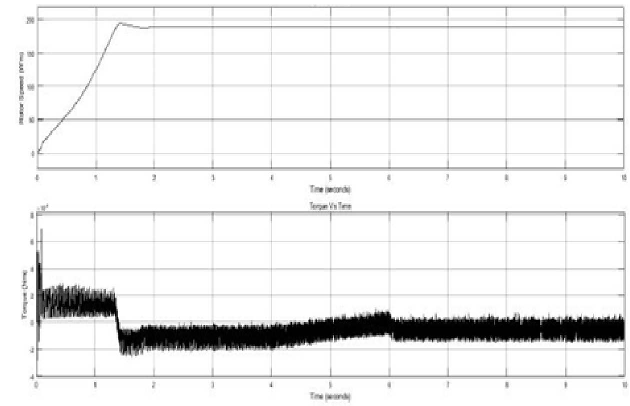

**Figure 4: Speed and Torque with RSC**


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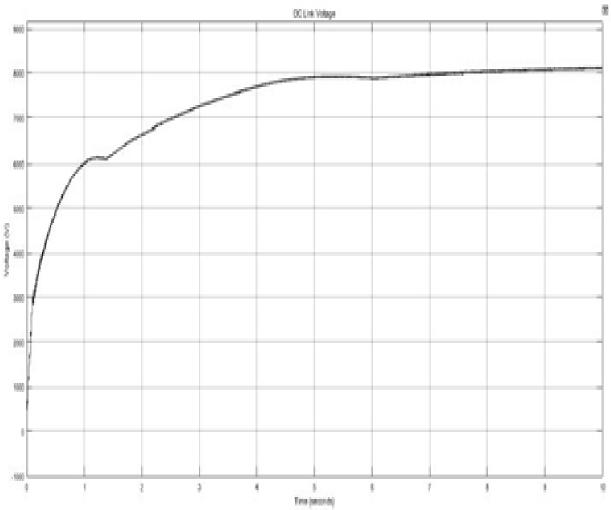

**Figure 5: DC Link Voltage without GSC**

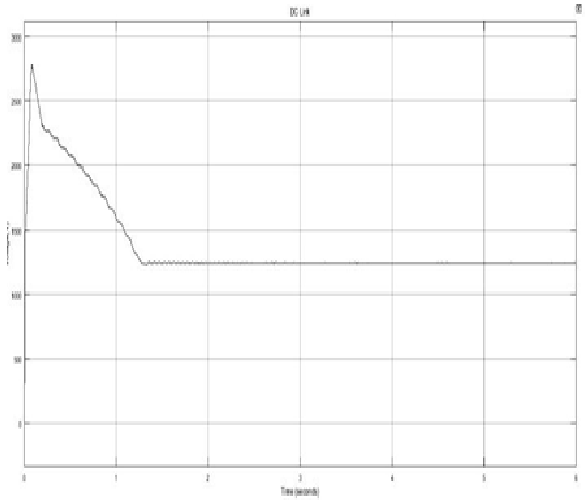

**Figure 6: DC Link Voltage without GSC**

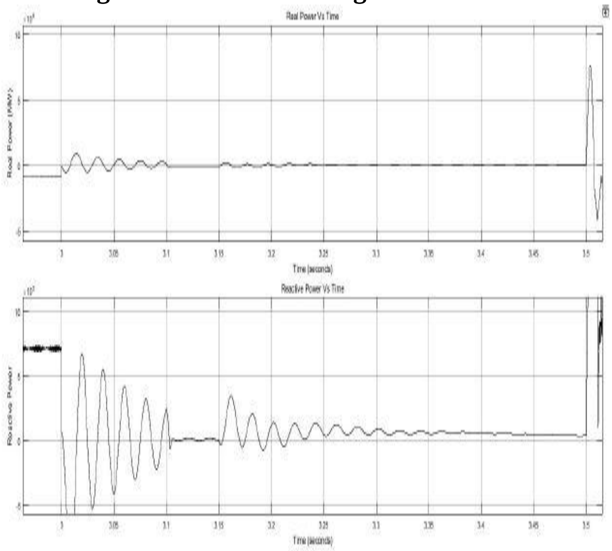

**Figure 7: Real and Reactive Power with Capacitor Bank**

A scaled-down version of the wind energy system hence can be implemented using hardware with the essential features of low voltage ride-through capability along with reactive power compensation. A capacitor bank is used for reactive power compensation as shown in Figure 8 and 9 for the restoration of voltage during fault which is depicted in the full-scale model.

**Table 1: DFIG Parameters**

| Characteristic | Value | Features |
|---|---|---|
| Synchronism | 1500 rev/min | Synchronous speed at 50 Hz |
| Rated power | 2 MW | Nominal stator three-phase active power |
| Rated stator voltage | 690 $V_{rms}$ | Line-to-line nominal stator voltage in rms |
| Rated stator current | 1760 $A_{rms}$ | Each phase nominal stator current in rms |
| Rated torque | 12.7 k·Nm | Nominal torque at generator or motor modes |
| Stator connection | Star | |
| $p$ | 2 | Pair of poles |
| Rated rotor voltage | 2070 $V_{rms}$ | Line-to-line nominal rotor voltage in rms (reached at speed near zero) |
| Rotor connection | Star | |
| $u$ | 0.34 | |
| $R_s$ | 2.6 mΩ | Stator resistance |
| $L_{\sigma s}$ | 87 μH | Stator leakage inductance |
| $L_m$ | 2.5 mH | Magnetizing inductance |
| $R'_r$ | 26.1 mΩ | Rotor resistance |
| $L'_{\sigma r}$ | 783 μH | Rotor leakage inductance |
| $R_r$ | 2.9 mΩ | Rotor resistance referred to the stator |
| $L_{\sigma r}$ | 87 μH | Rotor leakage inductance referred to the stator |
| $L_s$ | 2.587 mH | Stator inductance: $L_s = L_m + L_{\sigma s}$ |
| $L_r$ | 2.587 mH | Rotor inductance: $L_r = L_m + L_{\sigma r}$ |

## V. HARDWARE IMPLEMENTATION

The hardware implementation of the above simulation can be done using an economical approach which is shown in Figures 8 and 9. A capacitance bank can be used to provide reactive power compensation. The model can be scaled down as well. Since the paper deals with low voltage ride-through capability with the reactive power compensation of the grid the focus of the paper is in the grid side converter. Therefore, it is sufficient if we implement a scaled down model of the DC link voltage with the grid side converter and a capacitor bank to emulate the reactive power compensation of the vector control-based system. This can be correlated with the main simulation by implementing a capacitor bank in the original full-scale model as well.

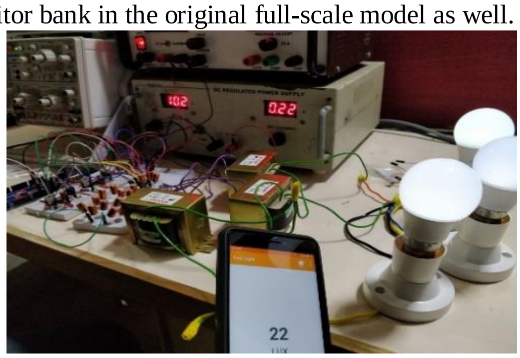

**Figure 8: Hardware without Compensation**

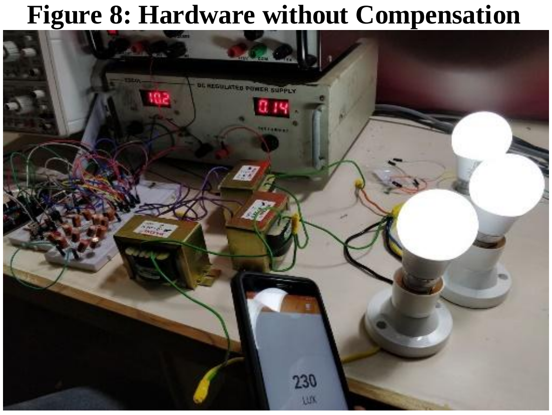

**Figure 9: Hardware with Compensation**



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## VI. CONCLUSION

This main focus of this paper is to improve the LVRT of the Wind Energy System using controllers that are based on a vector control principle. It discusses the various shortcomings of existing systems and provides improved capabilities using the vector-controlled converters. Simulation results support the claims of the proposed system with a comparative study of the existing systems to the vector-controlled converters scheme.Also, low voltage ride through capability with the added functionality of reactive power compensation is achieved by the vector control scheme. This is further validated using a scaled down hardware model of the essential features of the project. Hence, low voltage or fault ride through capability is achieved through the enhancement of reactive power compensation.

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