Modeling Of DFIG and Improving the LVRT Capability Of System Using Crowbar And Battery Energy Storage System

[1]T. Santhiya,[2]S. Nithya
[1]Assistant Professor,[2]Assistant Professor
[1]Department of EEE,
[1]SNS College of Technology, Coimbatore,Tamil Nadu

Abstract **- As the wind power penetration continues to increase, wind turbines are required to provide Low Voltage Ride-Through (LVRT) capability. To improve the low voltage ride-through (LVRT) capability of a wind turbine (WT) with Doubly Fed induction generator (DFIG), this paper deals with the implementation of a new model on the rotor side for enhancing the voltage dip during faults. The method comprises of auto switching Crowbar protection on to the rotor side for the enhancement of voltage and also a battery energy storage system (BESS) in the dc link side to reduce the ripples by absorbing the redundant power stored in the DC link capacitor. Generally , premature removal of crowbar does not achieve good results and post late removal will make the machine to absorb more reactive power from the grid so, an automatic Crowbar protection is been employed which automatically works according to the requirement. The combined protection and control strategy is being proposed in the simulation results.**

IndexTerms **- DFIG, BESS, LVRT, Crow bar, DC link Capacitor**

I. Introduction

In recent years, wind energy has become one of the most important and promising sources of renewable energy, which demands additional transmission capacity and better means of maintaining system reliability. The evolution of technology related to wind turbines that present many advantages compared to the fixed speed wind turbines. These wind energy conversion systems are connected to the grid through Voltage Source Converters (VSC) to make variable speed operation possible. The system that will be analyzed is a variable speed wind generator is directly connected to the grid while the rotor is connected through a back-to-back converter which is designed to stand only a fraction of the generator rated power. The advantages of the active and reactive power regulate independently capacity and excitation converters requires small capacity, the doubly fed induction generator (DFIG) has been widely used in the wind power system [1] - [2] . The voltage drop on the grid side will still connect the doubly fed induction generator to the grid. In order to achieve this need to overcome the low voltage ride through (LVRT) problem. When a sudden voltage drop [4] in the power grid, the stator and rotor will induce over-current due to the electromagnetic coupling of the electromagnetic coupling of the double-fed generators, this time the output of grid-side converter is limited, this time the output of the grid-side converter is limited, the energy accumulated in the DC side will cause DC-side voltage increase. To protect the rotor side converter, should switch the protective devices (crowbar)[5] to short circuit the rotor of the doubly-fed generator, in order to protect the DC side capacitors and to enable the DC-side voltage stability generally use unloading unit to consume the excess energy of the DC side [4], [5] present a storage battery, but only analyzed smooth out the output powers or to maintain a desirable power output as the wind speed varies. A control scheme which is auto-switching the crowbar according to the size of the rotor current is adopted for the crowbar protection to decrease the adverse effects on the system which is caused by the Crowbar premature or too late removable. A cascaded control scheme is applied for the battery energy storage devices to attenuate the transients DC voltage ripple in the DC bus when voltage sags in power failure situations. This paper presents a new approach for and control strategy to improve the transient performance of the doubly fed induction generator DFIG. In this the wind form consist of six 1.5MW wind turbines is simulated to verify this method. Each DFIG is equipped with an active crowbar and a battery energy storage device.

II. Modelling of Wind Turbine

Figure 1 schematically shows the proposed DFIG based wind turbine. DFIG uses power electronics converter. The converter connected to the rotor and stator will be directly connected to the grid compared to full converter. This is better as only 20%-30% of the total power goes through the converter and so design will be of smaller size, thus low cost and low power electronic losses. Stator ids directly connected to grid and rotor is connected to power electronics by means of slip rings & brushes. The rotor current is regulated by the power converter to control the electromagnetic torque and field current and thus the stator output voltage. DFIG can operate in sub-synchronous or in super synchronous operating modes due to the capability of converter to operate in bi-directional operation power mode.

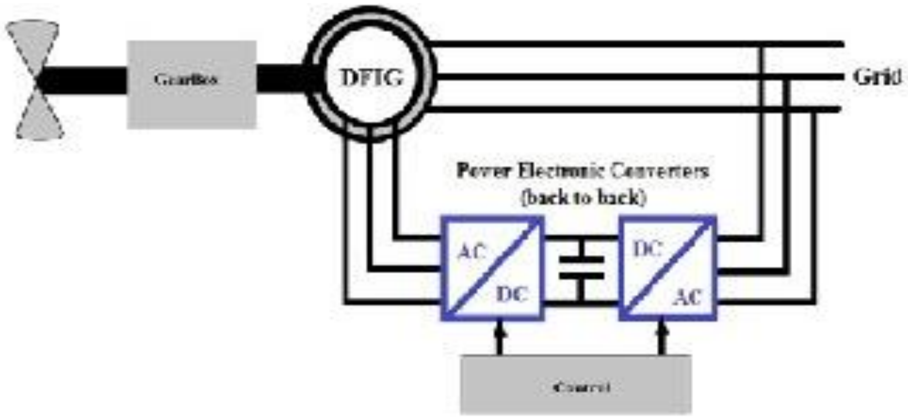

Fig. 1. Block Diagram of Doubly Fed Induction Generator

III. MODELLING AND CONTROLOF COMBINED SYSTEM

1) Modeling of Rotor Side Converter Controller :

The Rotor Side Converter controls the Real and Reactive power output from the stator. The induction machine is controlled using synchronously rotating dq reference frame. The independent control is achieved by using this dq transformation. Using stator flux orientation method the relationship between the torque and the dq axis voltages, currents and fluxes can be described by the following equation

$$V_{dr} = R_r i_{dr} + \sigma L_r di_{dr}/dt - \omega_{slip}\sigma L_r i_{qr} \quad (1)$$

$$V_{qr} = R_r i_{qr} + \sigma L_r di_{qr}/dt + \omega_{slip}(L_m i_{ms} + \sigma L_r i_{dr}) \quad (2)$$

$$\omega_{slip} = \omega_s - \omega_r$$

$$\sigma = 1 - L_{02}/(L_s L_r) \quad (3)$$

Where σ is a leakage factor. ω_s, ω_r are synchronous and rotor speed respectively.
The stator flux angle is calculated from

$$\lambda_{\alpha s} = \int (V_{\alpha s} - R_s i_{\alpha s})dt \quad (4)$$

$$\lambda_{\beta s} = \int (V_{\beta s} - R_s i_{\beta s})dt \quad (5)$$

$$\theta_s = \tan^{-1}(\lambda_{\beta s}/\lambda_{\alpha s}) \quad (6)$$

Assuming that the reactive power supplied by the Rotor Side Converter is zero that is i_{dr}* is set to zero.

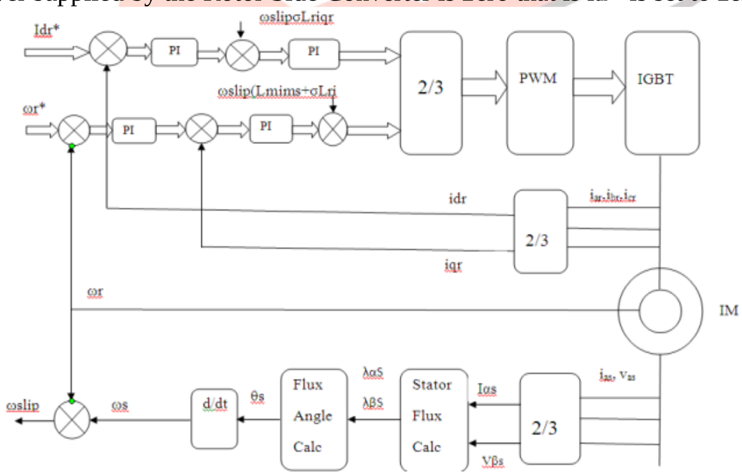

Fig. 2. RSC controller diagram

From rotor voltage equation we can get the d and q axis voltages as,

$$V_{dr}' = R_r i_{dr} + \sigma L_r di_{dr}/dt$$

$$V_{qr}' = R_r i_{qr} + \sigma L_r di_{qr}/dt$$

The actual and reference values of i_{dr} and i_{qr} are compared; the deviation value is given to the PI controller to reduce the steady state error.

2) Grid Side Converter Model:

The grid side converter controls the dc link voltage independent of the magnitude and direction of rotor power. GSC also modeled with synchronously rotating reference frame with d axis regulates the dc-link voltage and q axis regulates the reactive power.
The voltage balance equation across the inductors is,

$$[va\ vb\ vc] = R[\ ia\ ib\ ic] + Ld/dt[ia\ ib\ ic] + [va\ vb\ vc] \quad (7)$$

Where L and R are line inductances and resistances. For grid side converter the voltage equations in dq transformation is given as,

$$V_d = Ri_d + L\ di_d/dt - \omega_s Li_q + v_{d1} \quad (8)$$

$$V_q = Ri_q + L\ di_q/dt + \omega_s\ Li_q + v_{q1} \quad (9)$$

The active and reactive power is,

$$P = 3(v_d i_d + v_q i_q) \quad (10)$$

$$Q = 3(v_d i_d + v_q i_q) \quad (11)$$

DC link voltage can be controlled by controlling id. The control scheme thus utilizes current control loops for id and iq is given above figure.

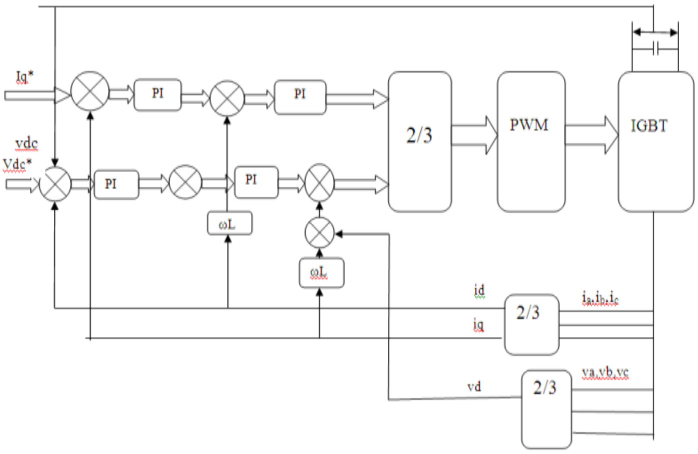

Fig. 3. GSC controller diagram

IV. Modelling Of DFIG with BESS and Active Crowbar

The Proposed DFIG based wind turbine with active crowbar and battery energy storage system. An active crowbar is composed of Three-phase Diode Bridge in series with a bypass resistor and an IGBT power switch. A switching function x is defined for the power switch, which makes the value 1 (Activated) when the switch is closed and 0 for its open state (Deactivate). The dynamic behavior of such system during grid faults is very sensitive to the value of the bypass resistor; the resistor should be properly selected to limit the over current and also to avoid large voltage ripples in DC-link. The battery energy stores energy in the electromechanical form, and is the most widely used for energy storage in a variety of application. When the battery is discharging state is positive while in charging state is negative. The state- of- Charge is 100% and for an empty battery is 0%. The wind turbine is connected to the DFIG through a gearbox and a coupling shaft system. The three phase rotor windings are connected to the grid through back to back four quadrant PWM power converters and three phase stator winding is directly connected to the grid. Power captured by the wind turbine is converted into electrical power by the stator and rotor winding. A battery energy storage system is connected to the DC link capacitor through a bidirectional DC/DC converter.

A combined protection scheme with Direct Torque Control (DTC) strategy [6] with feed forward compensation is adopted for the wind turbine operating under normal grid conditions. When the grid fault occurs, the crowbar is triggered if the overvoltage in the DC bus or the over-current in rotor winding exceeds the corresponding threshold value. In the mean time, rotor-side converter will be disconnected from rotor winding by cutting off the pulses of the power switches in the rotor side converter. During this fault interval, the controllability of the DFIG will behave as a squirrel cage induction generator with a variable rotor resistance and absorb large amount of reactive power from the grid which will lead to the system voltage dip further. An algorithm for the voltage dip detection caused by all types of faults is chosen. With the proposed control strategy, the Crowbar is activated and the rotor current exceeds the predefined threshold value 1.5pu. The crowbar will cut off and the rotor side converter is restarted if the rotor current decreases to be less than a safety value.

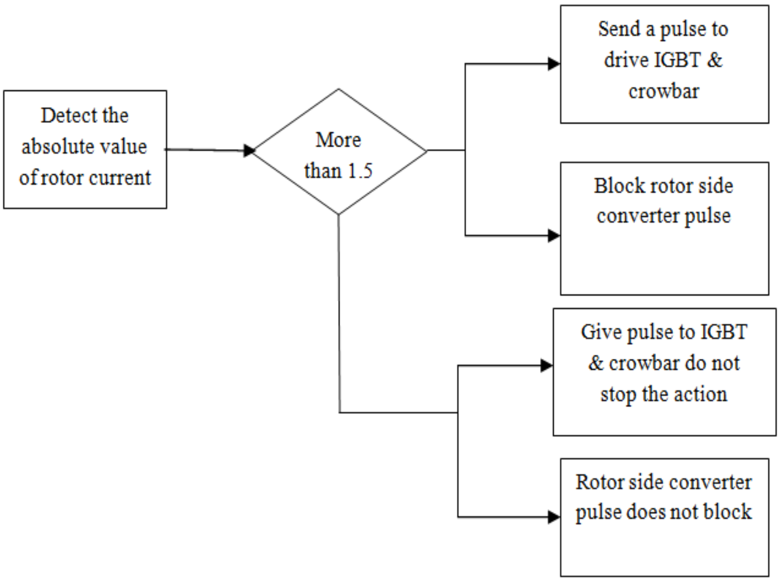

Fig. 4. Control strategy of the Crowbar

V. SIMULATION RESULT

A wind farm consisting of 9MW wind turbine driven DFIGs with the battery energy storage system is simulated using Matlab/Simulink to verify the effectiveness of the proposed system combined protection and control strategy including the auto switching control for the operation of crowbar protection and the cascade control strategy under fault condition. The diagram shown in figure 4. In the active crowbar design, a reasonable selection of resistance of the discharge resistors is important. A larger quantity of resistance value may the transient decay faster, but the larger resistance value cause Over-voltage the rotor side, so that counter-charge DC bus capacitor, and may also damage the rotor side converter. After comprehensive consideration and simulation comparison, the discharge resistor chosen as 0.06 pu. Figure 5(a) shows that for normal operation of DFIG for variable wind speed the rotor speed is maintained constant. The performance of DFIG equipped with active crowbar under symmetrical 3 phase short circuit grid fault. The voltage drops 2 less than 20% of the nominal value at 0.5sec and the voltage sags last for 500ms. The rotor side current increased to 2 to 4 times of nominal value between 0.5s and 1s. Instead state the D.C link voltage is maintained at 1200V by the grid side converter. During the fault condition the threshold value of rotor current and DC voltage are set as 1.5pu and 1400V resp. from fig (b) to (c) shows the operation of DFIG without crowbar and BESS. From fig (d) to (g) shows the operation of DFIG with crowbar and BESS. Fig (h) shows the operation of BESS during fault condition i.e., State of Charge (SOC), current (I), Voltage (V). Fig (i) shows the switching operation of crowbar during fault interval. Fig 6 shows the different switching operation of crowbar in different fault condition that is LLL, LLLG, LLG, LL, LG faults. In the comparative study for different faults LG fault is least severe for that reason there is no crowbar switching.

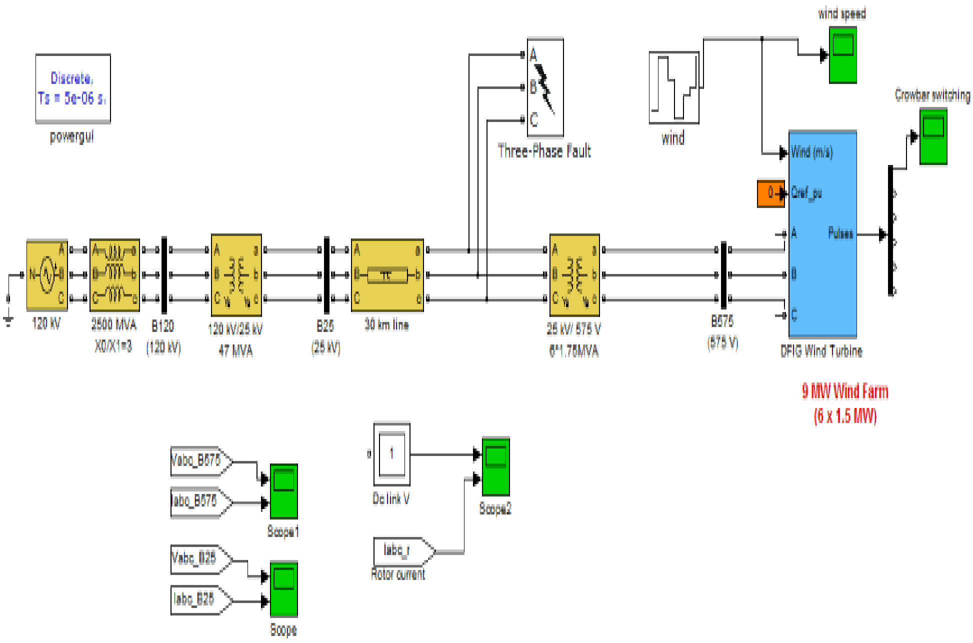

Fig. 5. Simulation of DFIG based System

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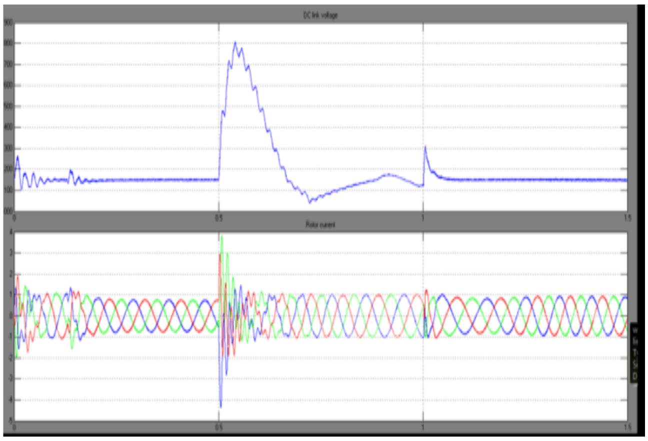

Fig.6. Operation of DFIG FOR LLL fault (dc-link & rotor current) without crowbar.

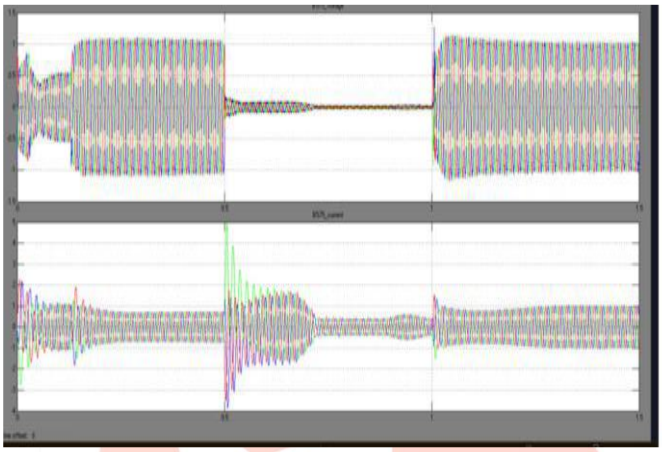

Fig.7. Operation of DFIG FOR LLL fault (V-B575 & I-B575) without crowbar

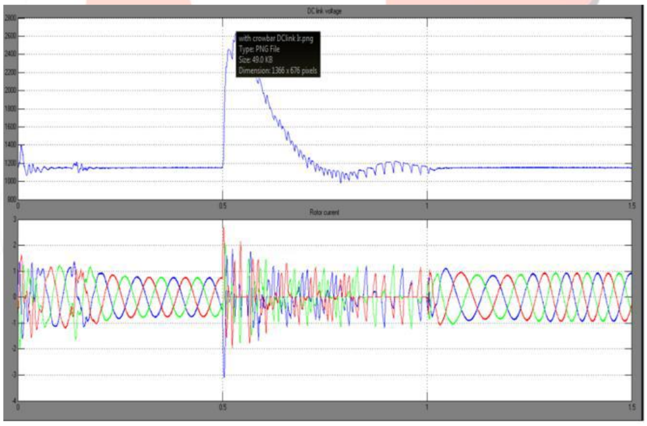

Fig.8. Operation of DFIG FOR LLL fault (dc-link & rotor current) with crowbar

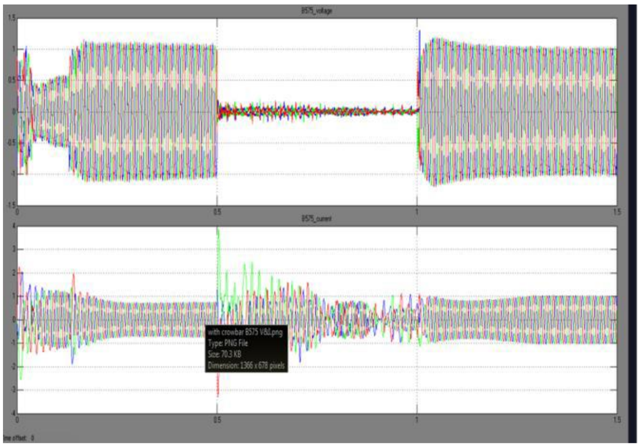

Fig.9. Operation of DFIG FOR LLL fault (V-B575 & I-B575) with crowbar

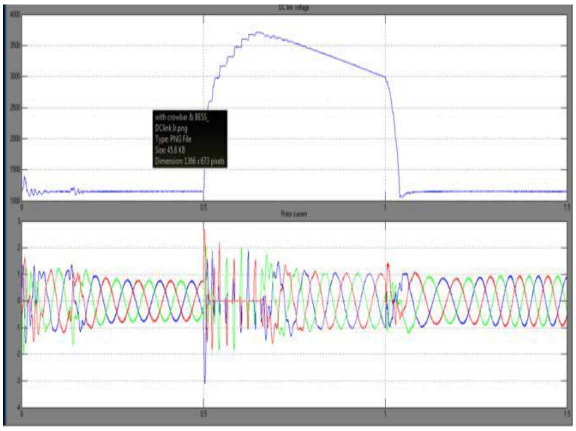

Fig 10. Operation of DFIG FOR LLL fault(DC-link & rotor current) with crowbar & BESS.

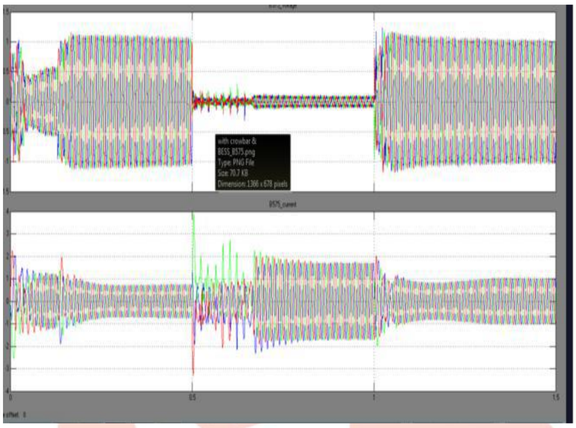

Fig.11. Operation of DFIG FOR LLL fault (V-B575 & I-B575)

VI. CONCLUSIONS

The mentioned control staregy of the Active Crowbar are not same as conventional 1 , which can auto – switching the crowbar according to the size of rotor current .A combined protection and control strategy including Active Crowbar and Battery Energy Storage System has been presented to enhance the LVRT capability of a Wind turbine driven by DFIG. this paper also presented a BESS connected to DC bus which is controlled to attenuate the DC voltage ripple via absorbing the redundant power stored in DC link capacitor during power system on fault condition which can protect the DC side capacitor , does improved LVRT capability. The 9MW DFIG wind turbine system developed in simulink with a combined control strategy. Simulation results shows that the combined protection and control strategy can well protected the rotor side converter and the DC side capacitor during the power system on fault condition, thereby better improved LVRT capability. And a comparative study of crowbar switching is analyzed for different fault condition i.e., LLL, LLLG, LLG, LL, LG Faults according to its size of rotor current. Future work will be done to satisfy the grid requirement power compensation of DFIG operating undergo grid fault and also to reduce harmonics in the system.

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