



Comparison of Crowbar Control and Novel Control Methods for DFIG Wind Turbine to Enhance LVRT Capability under Various Faults

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ABSTRACT: This paper presents a comparison between conventional crowbar control and new control method. The new control method includes control for both the rotor and grid side converters to enhance the low-voltage ride-through (LVRT) capacity of the DFIG WT. By providing suitable control for RSC and GSC converter switching circuit, the parameters voltage, current, real and reactive power, DC link voltage, rotor speed are controlled. In addition to this the pitch control is also provided. With the aid of the grid side control scheme the DC-link voltage fluctuation can be effectively reduced. The new control method for the grid side controller can effectively reduce the high transients that may occur during the faults. This new control can enable both active and reactive supports to the faulted grids from WT which is difficult for the crowbar based control. In this paper the crowbar control scheme is compared with proposed control method and the new method is found to be very effective in achieving LVRT capacity during symmetrical and unsymmetrical fault.

KEYWORDS: Active crowbar, Crowbar, Demagnetising current injection, Doubly fed induction generator, Low Voltage Ride Through, Pitch control, Series dynamic resistor, symmetrical and unsymmetrical fault, wind turbine.

I. INTRODUCTION

The energy demand is increasing and the conventional fossil fuelled power plants which emit greenhouse gases alone cannot meet the energy demand and also these sources are getting depleted at a very fast rate. Moreover their prices are also rising. For these reasons, the need for alternative energy sources has become indispensable. Among the various renewable sources, wind energy has gained much attraction in the past few years because of its availability and eco-friendly nature. Wind is a by-product of solar energy. Approximately two percentage of the sun's energy reaching the earth is converted to wind energy. The surface of the earth heats and cools unevenly, thus creating atmospheric pressure zones that make air flow from high-to low-pressure areas. Large sized wind turbines (WT) are of two types, fixed and variable speed. Variable speed WT utilizes the available wind resource more efficiently than fixed speed WT. Doubly fed induction generator (DFIG) is a popular variable speed WT system. The advantages of using DFIG in WT systems are, its capability for better reactive power management, needs only low power converter-inverter circuits, no sudden variation in torque with variation in speed and hence the output power will be smooth. But wind power system based on the DFIG is very sensitive to grid disturbances. A sudden dip in the grid voltage would cause over-currents and over-voltages in the

rotor windings and if these exceed the limit it will destroy the converter if no protection elements are installed. In the conventional protection methods, the DFIG will be disconnected from the grid during the fault. The ability of WT to stay connected to the grid during voltage dips is termed as the low-voltage ride-through (LVRT) capability. To achieve the LVRT requirement for DFIG WTs, the over-current that can occur in rotor and stator circuits and the DC-link over-voltage during fault should be considered properly. These issues are not solved by the existing control methods. So a novel control strategy for DFIG wind Turbine to enhance LVRT capability is introduced which solves the existing problems faced by DFIG WTs.



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II. CONTROL STRATEGIES FOR DFIG WIND TURBINE

The DFIG is the most commonly used device for wind power generation. The rotor terminals are fed with a symmetrical three-phase voltage of variable frequency and amplitude. The variable voltage is supplied by a voltage source converter. The variable frequency rotor voltage allows the adjustment of the rotor speed to match the optimum operating point at any practical wind speed. But DFIG is very sensitive to grid disturbances. When grid voltage dip occurs due to fault, over-currents and transients may occur in the rotor windings. If these exceed the limit, then it will destroy the converter if no protection is provided. Following are the various control strategies used for the DFIG WT's. In crowbar protection method [3], during the faults, the rotor side converter will be blocked, and the crowbar circuit will be installed across the rotor terminals and it will damp the over-current in the rotor circuit. And thus when fault occurs, the rotor converter and the generator are disconnected from the grid. During this period they stop generating electric power into the grid. Moreover, this will affect the performance of DFIG considerably. Because this protection converts the DFIG into the squirrel cage induction generator. This results in the reactive power absorption, also the oscillations of the DFIG electrical torque and rotor instantaneous power arise, which have severe impacts on the grid. After the fault is removed, the grid-side converter can be controlled again to establish the dc-link voltage. But, the dc-link voltage is likely to be fluctuated during this period and this will affect the rotor current control [7]. In active crowbar control scheme [4] the crowbar resistance is connected when necessary and thus reduces the duration of its usage.

In SDR method this a dynamic resistor is put in series with the rotor and this limits the over current in rotor. During normal operation, the switch is on and the resistor is bypassed. A dc-chopper is connected in parallel with the dc-link capacitor to limit the overcharge during low grid voltage. Thus protects the IGBTs from overvoltage and can dissipate energy, but this has no effect on the rotor current. Reactive power and electrical torque fluctuations during the fault are less. In demagnetizing current injection method, which allows the turbine to ride through the fault without the need of connecting a crowbar. This solution requires large capacity of current in the rotor converter and due to this it is

not preferred. So as an advancement of this technique a solution combining the crowbar and the use of demagnetizing

currents was introduced [5]. The rotor converter current can be reduced by combining the crowbar with the demagnetizing current. The inverter then injects a demagnetizing current and produces a reactive power. As the magnitude of current to be injected increases, the size of inverter increases and hence the cost increases. The STATCOM also helps in improvement of power quality. But the usage of big STATCOMs [6] in the wind park will result in high cost [5] of these systems and hence this will discourage their utilization.

III. NEW CONTROL STRATEGY

Wind turbines convert kinetic energy into mechanical energy. The kinetic energy of wind is captured by the rotor blades, which is then converted to mechanical energy. The mechanical energy is converted into electrical energy by the generator. Turbine is connected to rotor of the generator through a gearbox. Gearbox is used to step up low angular speeds of the turbine to high rotational speeds of generator. The DFIG WT system includes the wind turbine, drive train, pitch angle control, DFIG, rotor and grid side converters and their control, dc link capacitor, filter and transformer to connect to the system to grid. The control should be provided in order to keep voltage, current, rotor speed, dc bus voltage, real and reactive power within the safe operating values under the grid disturbances.

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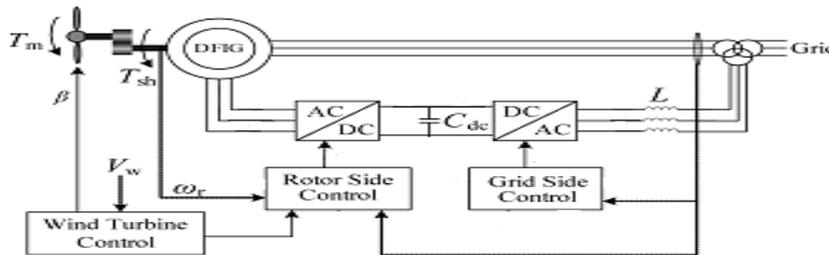


Fig. 1 Schematic diagram of DFIG WT with all control.

A. PITCH CONTROL

A Proportional-Integral (PI) controller is used to control the blade pitch angle in order to limit the electric output power to the nominal mechanical power. The pitch angle of the blade is controlled to optimize the power extraction of the WT as well as to prevent over rated power production in high wind. When the generator speed exceeds rated speed, the pitch control is active and the pitch angle is tuned so that the turbine power can be restricted to its rated value.

B. ROTOR SIDE CONVERTER CONTROL(RSC)

The PI controllers are used for regulation in the rotor speed and reactive power (outer) control loops as well as the rotor current (inner) control loops. When a fault occurs, the incoming power from the wind and the power flowing into the grid are imbalanced. This results in the transient excessive currents in the rotor and stator circuits. When the rotor current, stator current, DC-link voltage and grid voltage, exceeds its safe operating limit due to the grid fault, the proposed method will be triggered. As a result, the rotor side controller will increase the generator rotor speed by reducing the generator torque to zero during the fault. The new control strategy will not cause excessive mechanical stress to the WT system. But, the over-speed of the WT can be effectively restrained by the pitch control, which will be activated immediately when the rotor speed becomes higher than the rated value.

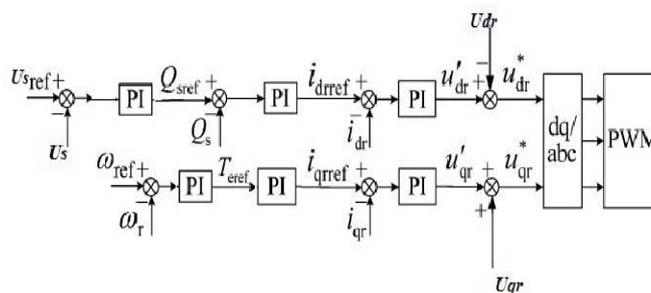


Fig.2 RSC control scheme

C. GRID SIDE CONVERTER (GSC) CONTROL

The PI controllers are used for regulation in the DC-link voltage (outer) control loop and the grid side inductor current (inner) control loops. In normal operation, when the power flowing through the grid and rotor side converters is balanced, then $i_{or} = i_{os}$. When the grid voltage dips, they may not be equal due to the instantaneous unbalanced power flow between the grid and rotor side converters, and therefore the DC-link voltage may fluctuate. In order to reduce the fluctuation of the DC-link voltage, the item (P_r/U_{dc}) reflecting the instantaneous variation of the output power of the rotor side controller is directly set as the reference of the during the grid fault.

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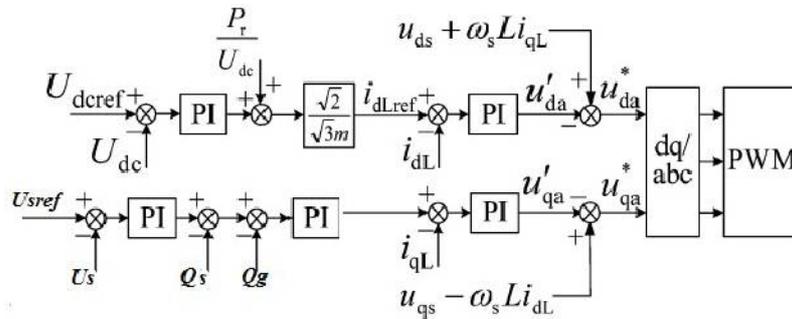


Fig.3 GSC control scheme

IV. ANALYSIS

The complete DFIG WT system model has been developed and simulated in Matlab/Simulink. Under normal operation all the parameters remain within the safe operating limit. With no proper control provided to the DFIG WT system, when voltage dips occurs the system parameters will be affected severely. Fault with duration of 100 ms is used here. The fault period is 0.2 s to 0.3 s. With symmetrical three phase fault and no control, when fault occurs, the grid voltage dips to almost zero voltage. The grid current is severely disturbed during the fault period. Also the real power dips to zero. The reactive power also dips to zero during the fault period. So if control is not given the fault will severely affect the grid voltage, grid current, real and reactive power. With unsymmetrical fault with no control, the voltage and current waveforms are highly distorted. Also large fluctuations occur in the real and reactive power. The real power fluctuates around zero and reactive power settles around zero during the fault period.

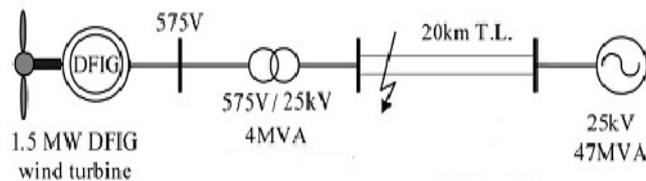


Fig.4 Single line diagram for the studied system.

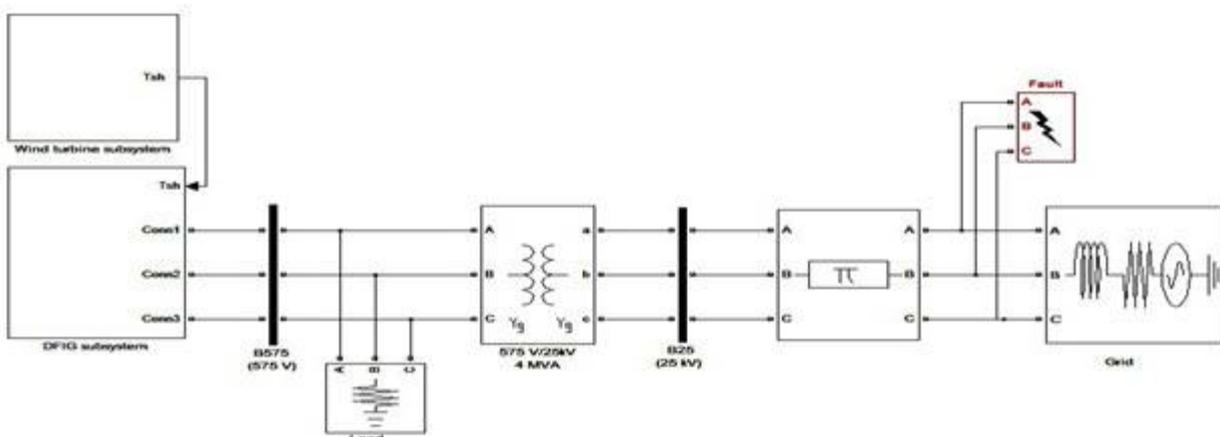


Fig.5 Simulink model of DFIG wind turbine system.

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In crowbar control method resistance are added in series to the rotor during the fault condition. The conventional crowbar is activated as long as the fault exists in the system. The controllability of the DFIG is lost and as a result the DFIG behaves as a squirrel cage induction generator. DFIG absorbs reactive power from the grid which may lead to voltage dips in the system. When the crowbar is triggered the RSC is disabled. Thus, continuous reactive power control cannot be provided during the voltage dip. By analysing the waveforms of crowbar control, it can be seen that, during symmetrical three phase fault the grid voltage dips to around 90%. Grid current have fluctuations, but the only advantage of the crowbar control is that it limits the over current in the circuit during fault. The grid real and reactive powers dips to zero during the fault period.

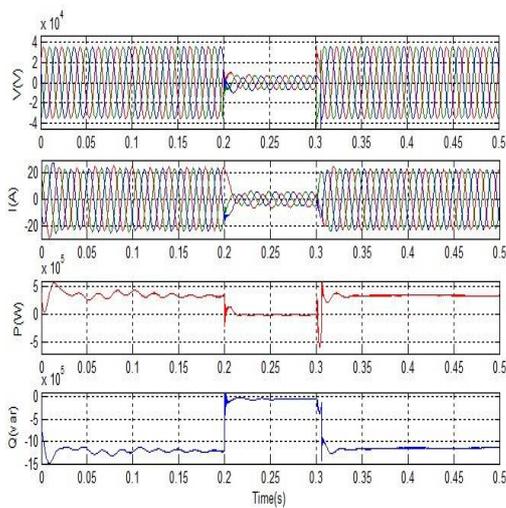


Fig .6 Symmetrical fault with crowbar control

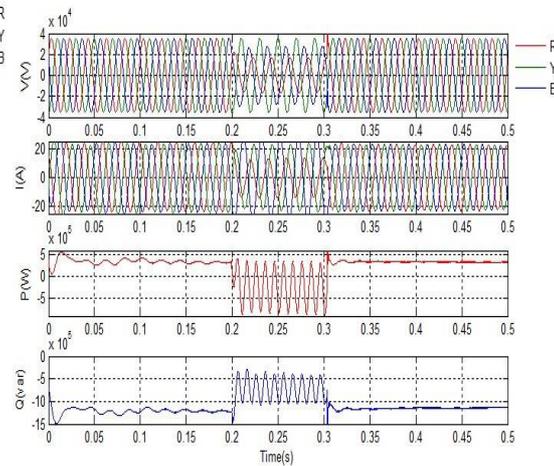


Fig .7: SLG fault with crowbar control

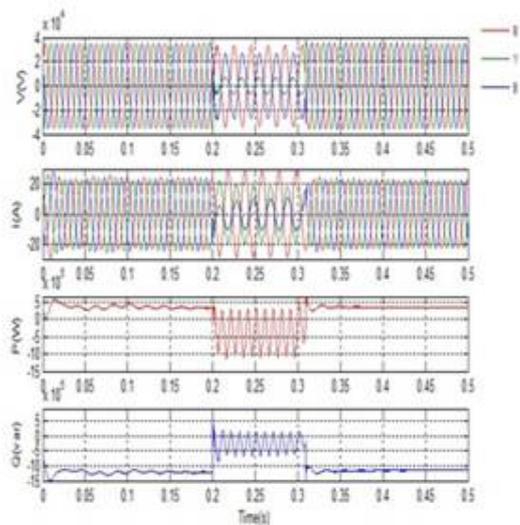


Fig 8: LL fault with crowbar control

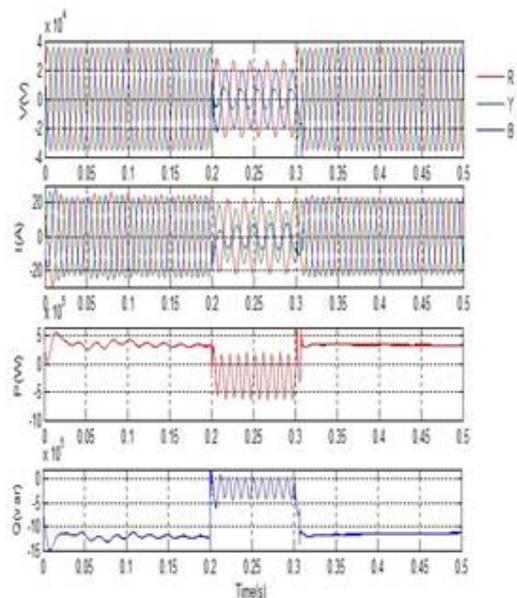


Fig 9: LLG fault with crowbar control

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On providing crowbar control it can be seen that during SLG fault period with fault at phase R, large fluctuation and dips occur in grid voltage. Also large fluctuation occur in grid current, but the over current is limited by the crowbar. The real power fluctuates highly around zero and becomes negative during the fault period. The reactive power fluctuates. During LL fault with fault at phase Y and B, it can be seen that voltage dips occur. Also current fluctuation occurs. The real power fluctuates around zero and becomes negative. The reactive power fluctuates around zero during the fault period. During LLG fault with fault at phase Y and B also, voltage dips occur, current fluctuations occur, real and reactive power fluctuates around zero. Hence the crowbar control cannot provide LVRT capability during symmetrical and unsymmetrical faults.

The output waveforms in Fig.10,11,12 and 13 shows the behaviour of DFIG WT system under symmetrical fault, SLG, LL and LLG fault respectively with new control.

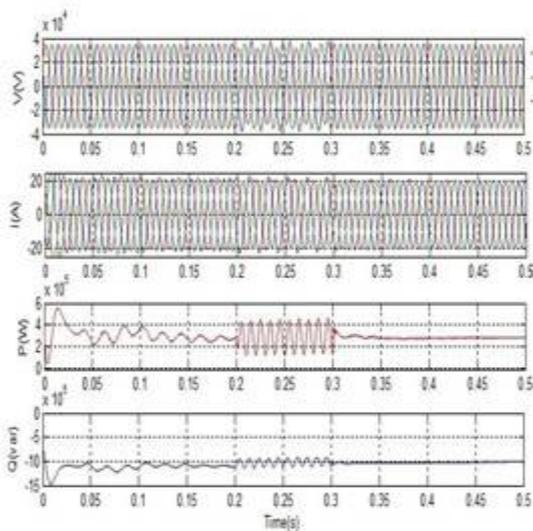


Fig.10 symmetrical fault with new control

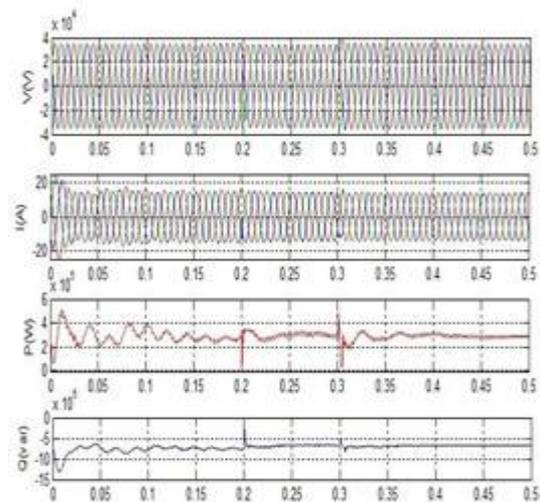


Fig.11 SLG fault at phase R with new control.

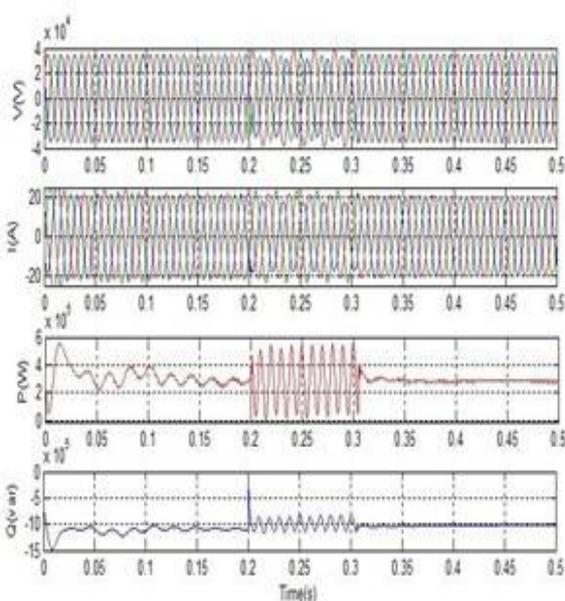


Fig.12 LL fault at phase Y & B -new control.

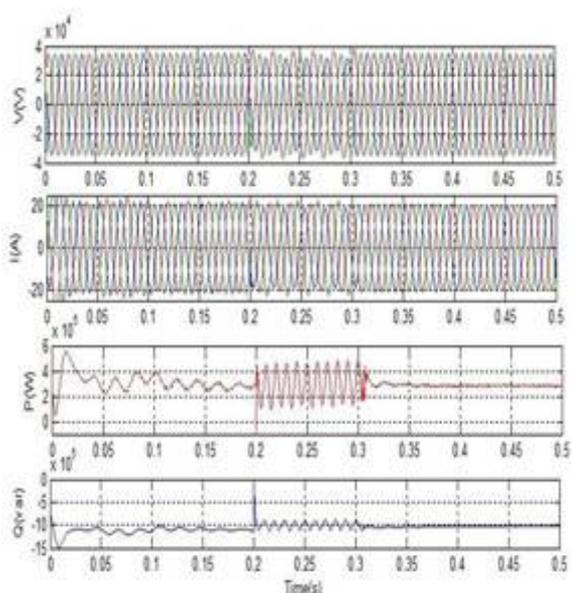


Fig.13 LLG fault at phase Y & B -new control

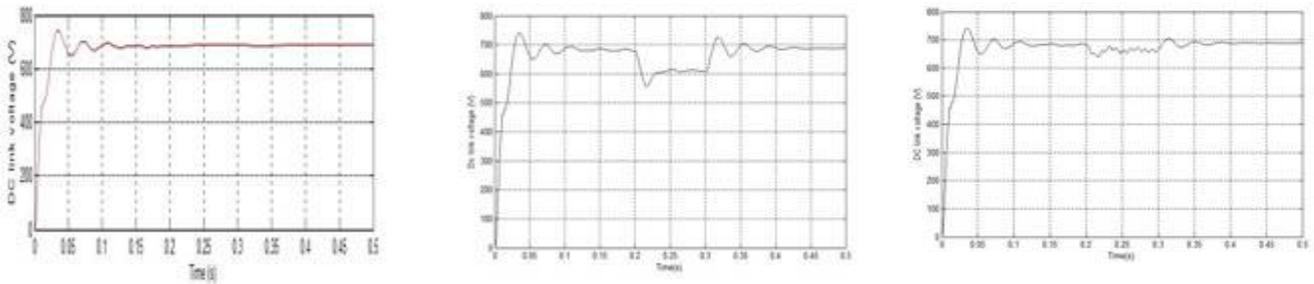
By providing the new RSC and GSC control, the voltage, current, real and reactive power remains within the safe

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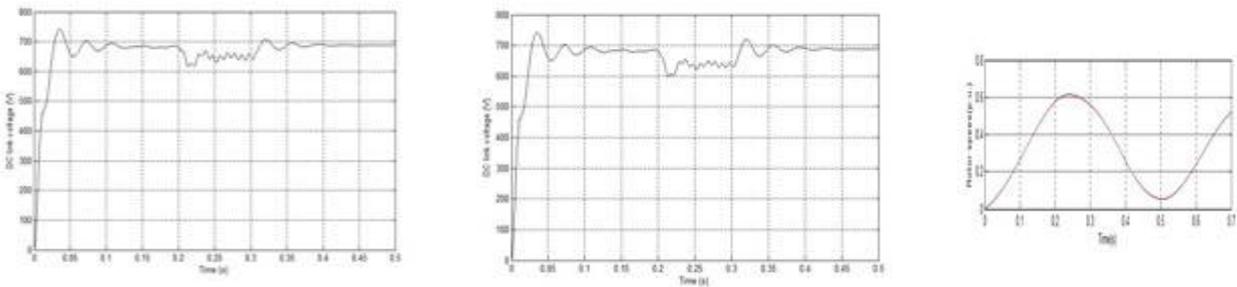
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operating value during the symmetrical fault. On providing new control it can be seen that during SLG fault with fault at phase R, the voltage dip is very less and also the voltage fluctuation is very less compared to the crowbar control. Also the fluctuation in the current is also less compared to the conventional control method. The real power does not becomes zero or negative during the fault but only small fluctuation occurs. Also the reactive power does not become zero during the fault period. During LL fault and LLG fault with fault at phase Y and B, the voltage and current fluctuation is less. The real and reactive power does not become zero during the fault period.



(a) (b) (c)
Fig.14 DC link voltage with new control a)normal operation b)symmetrical fault c) SLG fault



(a) (b) (c)
Fig.15 DC link voltage with new control a) LL fault b)LLG fault c) Rotor speed

During normal operating condition, the dc link voltage remains at constant value. With new control, it can be seen that, during symmetrical three phase fault the fluctuation in DC link voltage is less. Hence the new RSC and GSC control effectively controls the DC link voltage during symmetrical three phase fault. New control of RSC and GSC control the DC link voltage remains within the safe operating value under unsymmetrical fault also. Hence the new control for RSC and GSC can provide LVRT capability during symmetrical and unsymmetrical faults. As the wind speed changes, the rotor speed also changes.

V. CONCLUSION

As the penetration of wind power continues to increase, more wind turbines are required to remain connected during grid faults. The new control strategy enables the DFIG to continue the electricity production even during fault occurs. The new strategy also introduces a compensation item to the grid side controller in order to suppress the DC-link over-voltage during the faults. The new control strategy is able to effectively suppress the transients in the current and the DC-link voltage. Compared with the conventional crowbar protection, the DFIG WT installed with the new control strategy gives a better transient behaviour in event of short-term grid voltage dip. By using the new control strategy little impact will be resulted to the WT mechanical construction and the occurrence of the crowbar interruption can also be minimized. By providing the new RSC and GSC control, the voltage, current, real and reactive power remains within the safe operating value during the symmetrical fault. In crowbar control, real, reactive power becomes



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zero during symmetrical fault. Even if during unsymmetrical fault, fluctuations occur in real and reactive power, the new control effectively controls voltage and current. Hence the new control method is the best method to enhance LVRT capability of DFIG WT.

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