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. 3, Special Issue 5, December 2014

Control Strategy for DFIG Wind Turbine to Enhance LVRT under Various Faults

Gayathri.S.Nair[1], Krishnakumari.T[2]

M.Tech Scholar, Dept. of EEE, ASIET Kalady, Mahatma Gandhi University, Kottayam, Kerala, India[1]

Professor, Dept. of EEE, ASIET Kalady, Mahatma Gandhi University, Kottayam, Kerala, India[2]

ABSTRACT: This paper presents a new control method 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 been 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. The new method is found to be very effective in achieving LVRT capacity during symmetrical and unsymmetrical fault**.**

KEYWORDS: Doubly fed induction generator, low voltage ride through capability, symmetrical and unsymmetrical fault, wind turbine, series dynamic resistor, pitch control, crowbar, active crowbar, demagnetising current injection.

I. INTRODUCTION

The energy demand is increasing day by day. Conventional fossil fuelled power plants emit greenhouse gases 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 indispensible. Among the various renewable sources, wind energy has gained much attraction in the past few years because of its availability and eco-friendly nature. 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.

II. CONTROL METHODS

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. However 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 WTs. 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

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. 3, Special Issue 5, December 2014

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 result in the reactive power absorption, also the oscillations of the DFIG electrical torque and rotor instantaneous power arises, 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 METHOD

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.

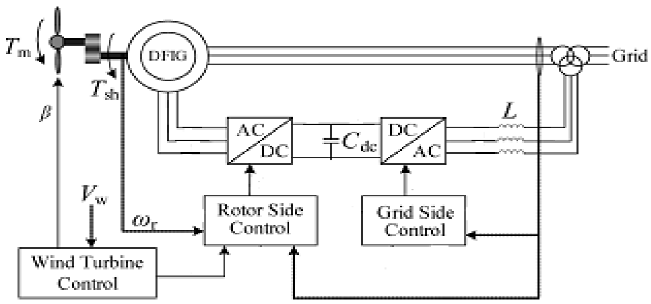

Fig. 1 Schematic diagram of DFIG WT with all control.

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.

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. 3, Special Issue 5, December 2014

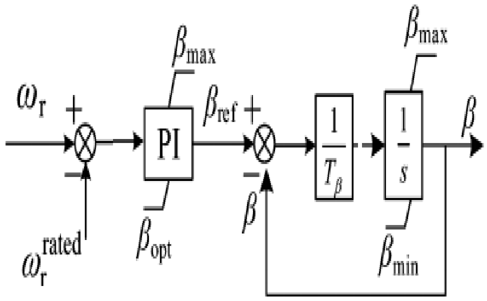

Fig.2 Pitch control

B. Rotor Side Converter control(RSC)

In order to decouple the rotor excitation current and the electromagnetic torque, the induction generator is controlled in the stator-flux oriented reference frame. The proportional-integral (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 at least one of the monitored parameters, including 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.

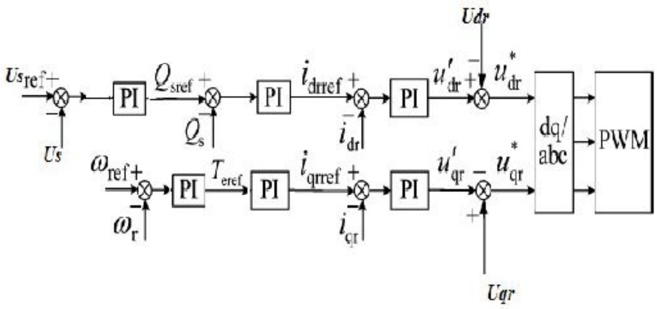

Fig.3 RSC control scheme

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.

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.

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. 3, Special Issue 5, December 2014

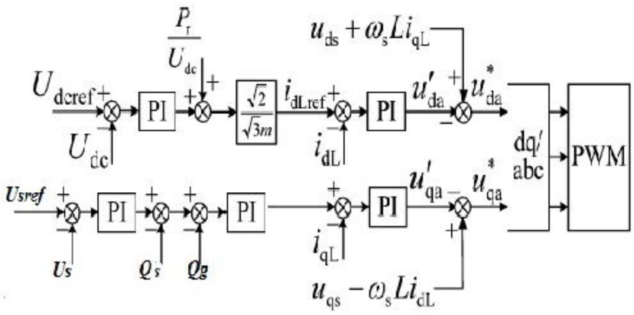

Fig.4 GSC control scheme

IV. ANALYSIS

The DFIG WT under study is connected to the grid transmission level via a radial link as shown in Fig.5 . The complete DFIG WT system model has been developed and simulated in Matlab/Simulink. Components of the simulation model are built from the SimPowerSystems block in Matlab/Simulink library.

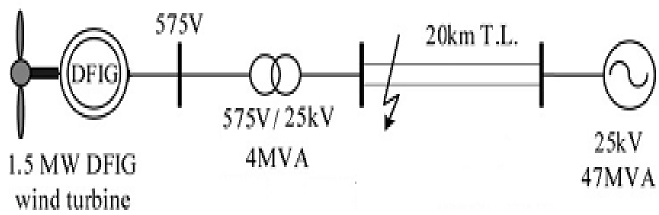

Fig.5 Single line diagram for the studied system.

The waveforms in Fig.6 shows the behaviour of DFIG WT system under normal operation .The output waveforms in Fig.7 shows the behaviour of DFIG WT system under symmetrical fault and having no control . With no proper control provided to the DFIG WT system, when voltage dips occurs the system parameters will be a affected severely. Fault with a 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.

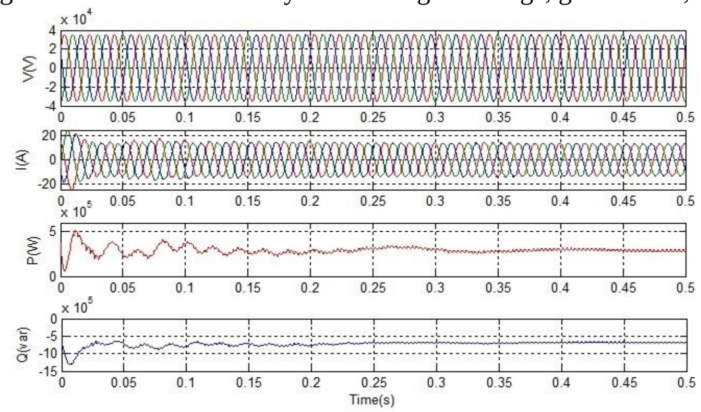

Fig.6 Normal operation. a)grid voltage b)current c)active power d)reactive power

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. 3, Special Issue 5, December 2014

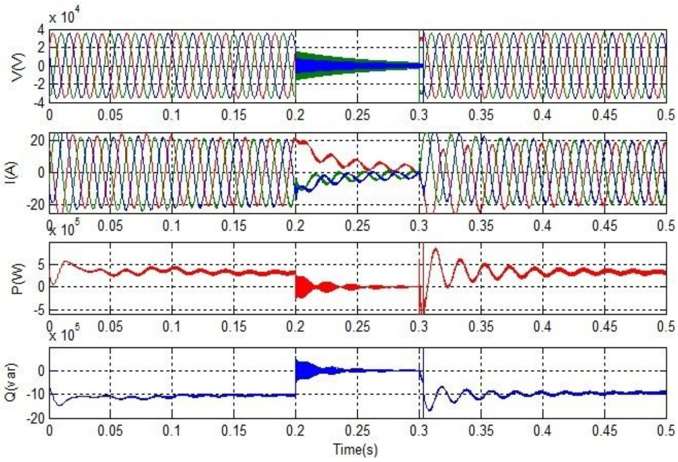

Fig.7 Output waveforms of DFIG WT under symmetrical fault with no control.a)grid voltage b)current c)active power d)reactive power

The waveforms in Fig.8 shows the behaviour of DFIG WT system under SLG fault with fault at phase R with no control.The waveforms in Fig.9 shows the behaviour of DFIG WT system under LL fault with fault at phase Y and B with no control. The waveforms in Fig.10 shows the behaviour of DFIG WT system under LLG fault with fault at phase Y and B and having no control.

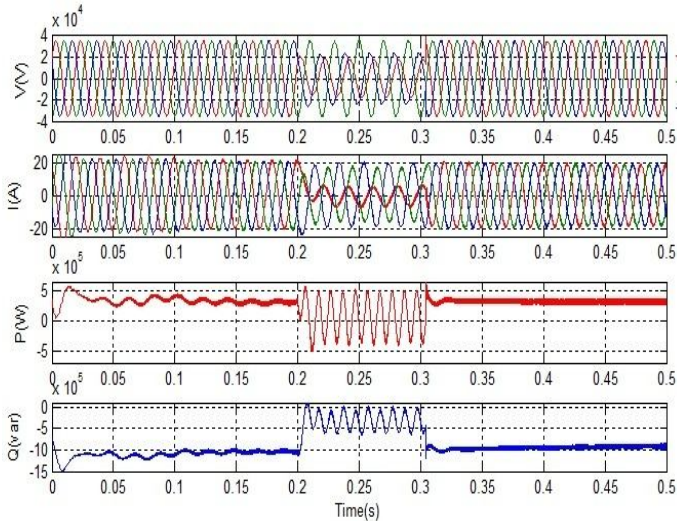

Fig.8 Output waveforms of DFIG WT under SLG fault with fault at phase R no control.a)grid voltage b)current c)active power d)reactive power

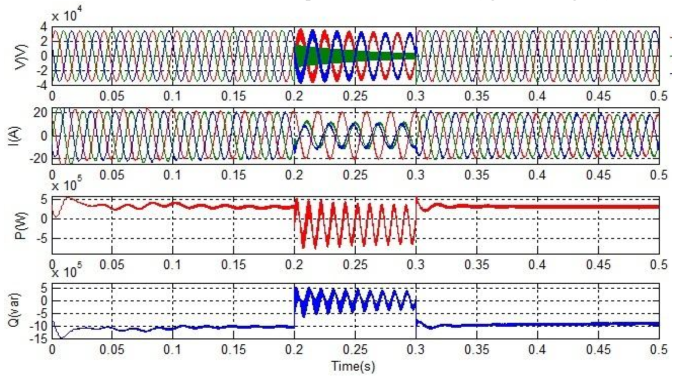

Fig.9 Waveforms of DFIG WT under LL fault with fault at phase Y and B with no control.a)grid voltage b)current c)active power d)reactive power

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. 3, Special Issue 5, December 2014

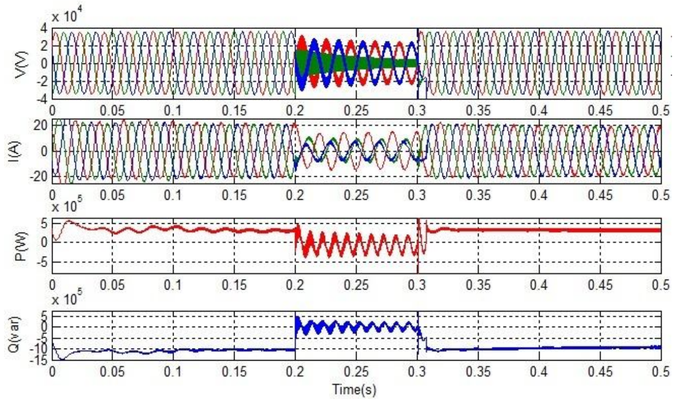

Fig.10 Waveforms of DFIG WT under LLG fault with fault at phase Y and B with no control.a)grid voltage b)current c)active power d)reactive power

With SLG fault with fault at phase R without no proper control. By analysing the graph it can be seen that, during the fault period 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. With LL fault with fault at phase Y and B. From the graph it can be seen that, during the fault period the voltage, current, real and reactive power are distorted and fluctuates. With LLG fault with fault at phase Y and B. By analysing the graph it can be seen that, during the fault period voltage, current, real and reactive power fluctuations occur. Hence if proper control is not given, the fault will affect the system.The output waveforms in Fig.11 shows the behaviour of DFIG WT system under symmetrical fault and with new control.The waveforms in Fig.12 shows the behaviour of DFIG WT system under SLG fault with fault at phase R with new control.The waveforms in Fig.13 shows the behaviour of DFIG WT system under LL fault with fault at phase Y and B with new control. The waveforms in Fig.14 shows the behaviour of DFIG WT system under LLG fault with fault at phase Y and B and having new control.

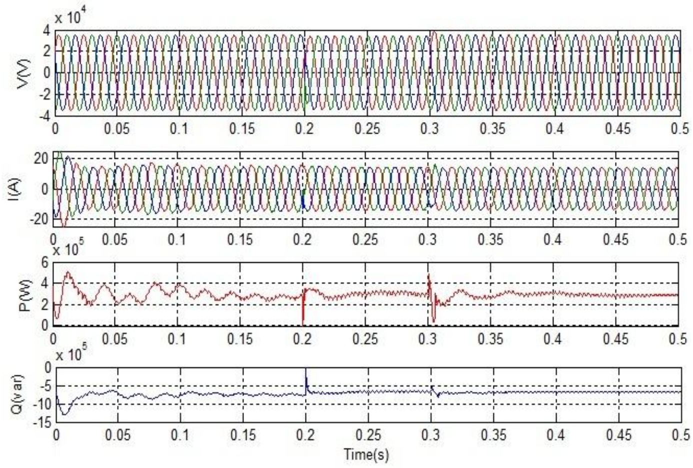

Fig.11 Waveforms of DFIG WT under symmetrical fault with proposed control method a)grid voltage , b)current ,c)active power ,d)reactive power

With new control, it can be seen that, during symmetrical three phase fault there is no grid voltage dip and the grid current remains without any fluctuation. Also the real and reactive powers does not dips to zero. Only small fluctuation occurs in the real and reactive power. Hence the new control for RSC and GSC effectively controls the grid voltage, grid current, real and reactive powers during three phase symmetrical fault.

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. 3, Special Issue 5, December 2014

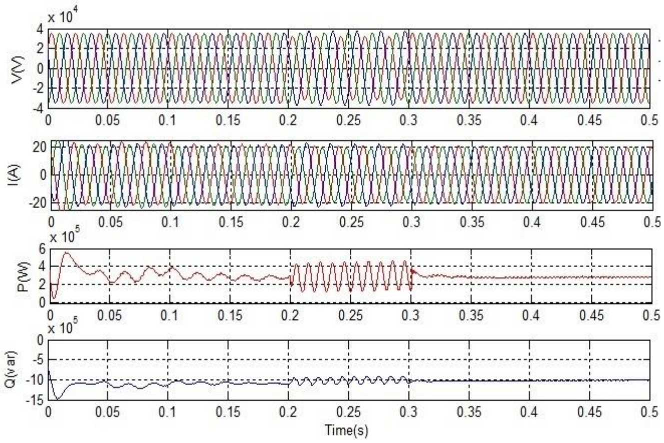

Fig.12 Waveforms of DFIG WT under SLG fault with fault at phase R with new control.a)grid voltage b)current c)active power d)reactive power

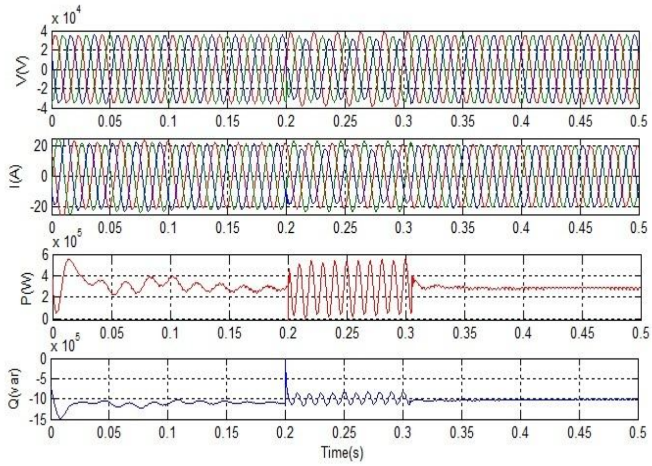

Fig.13 Waveforms of DFIG WT under LL fault with fault at phase Y and B with new control.a)grid voltage b)current c)active power d)reactive power

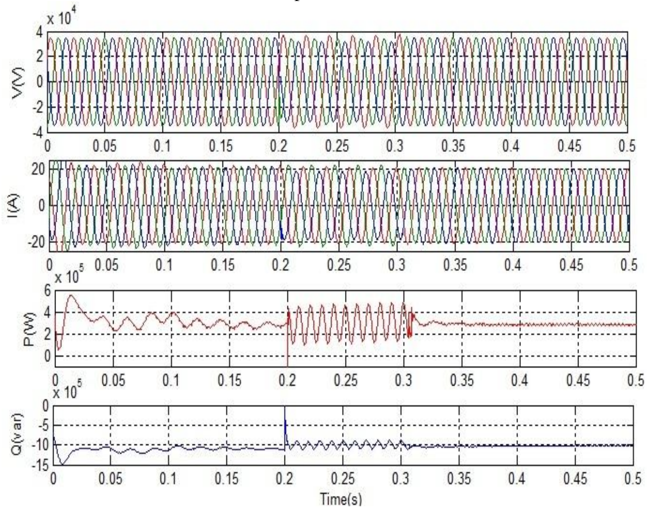

Fig.14 Waveforms of DFIG WT under LLG fault with fault at phase Y and B with new control.a)grid voltage b)current c)active power d)reactive power

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. 3, Special Issue 5, December 2014

On providing new control it can be seen that during SLG faultwith 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 fluctuations 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 with fault at phase Y and B, the voltage and current fluctuation is less. The real and reactive power does not becomes zero during the fault period. Also during the LLG fault, with fault at phase Y and B it can be seen that with the new control provided, the voltage dip is less and current fluctuation is less. The real and reactive powers does not become zero.

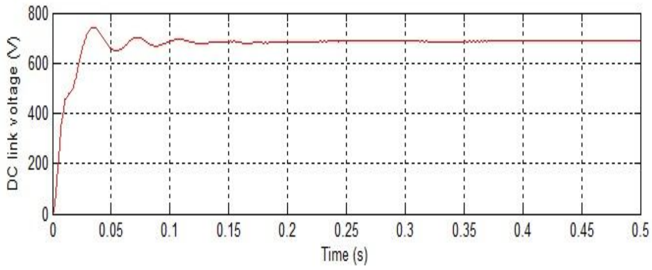

Fig.15 DC link voltage under normal operation method

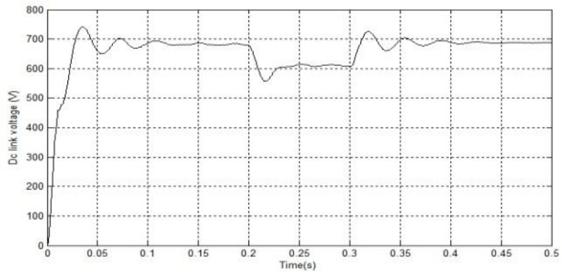

Fig.16 DC link voltage under symmetrical fault with new control

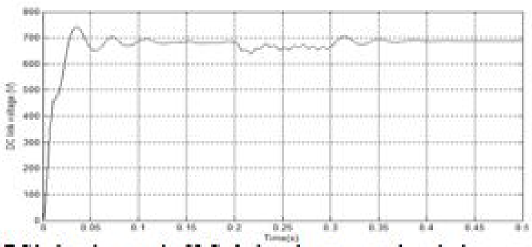

Fig.17 DC link voltage under SLG fault with new control method

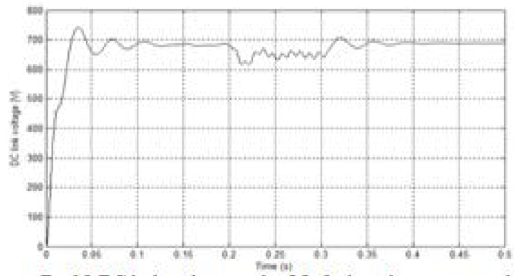

Fig.18 DC link voltage under LL fault with new control method

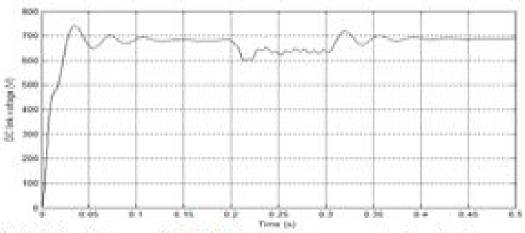

Fig.19 DC link voltage under LLG fault with new control method

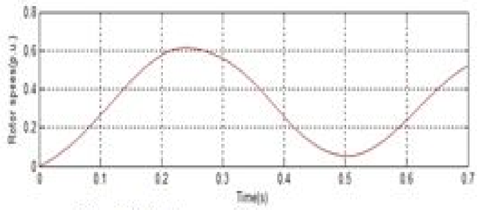

Fig.20 Rotor speed

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

The conventional control methods includes crowbar protection, active crowbar, series dynamic resistor and STATCOM. In these methods DFIG will be disconnected from the grid during the fault. As the penetration of wind power continues to increase, more wind turbines are required to remain connected during grid faults, and contribute to

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. 3, Special Issue 5, December 2014

system stability after fault clearance. To achieve the LVRT requirement for DFIG WTs, the over current and the DC link over voltage during fault should be considered properly. From the output waveforms of the simulation it can be seen that, without proper control, when fault occurs the grid side voltage and reactive power becomes zero. Thereby it affects the stability of the system. Also large voltage and current fluctuations occur at the rotor side. This will adversely affect the DFIG system since it is very sensitive to grid disturbances.

But by providing the new RSC and GSC control, the voltage, current, real and reactive power remains within the safe operating value during the unsymmetrical fault. In crowbar control, real and reactive power becomes zero during fault. Hence the new control method is the best method to enhance LVRT capability of DFIG WT. Even if during unsymmetrical fault, fluctuations occur in real and reactive power, the new control effectively controls voltage and current. By providing the new RSC and GSC control ,the voltage, current, real and reactive power remains within the safe operating value during the symmetrical and unsymmetrical faults. In crowbar control, real, reactive power becomes 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 .

REFERENCES

[1] A. Thomas, *Wind Power in Power Systems*. New York: Wiley, 2005.
[2] Energy statistics 2012 (Nineteenth Issue) Central Statistics Office Ministry Of Statistics And ProgrammE Implementation Government Of India New Delhi
[3] I. Erlich, J. Kretschmann, J. Fortmann, S. Mueller-Engelhardt, and H.Wrede, "Modeling of wind turbines based on doubly-fed induction generators for power system stability studies," *IEEE Trans. Power Syst.*, vol. 22, no. 3, pp. 909–919, Aug. 2007.
[4] J.Yang, J. E. Fletcher, and J. O'Reilly, "A series dynamic resistor based converter protection scheme for doubly-fed induction generator during various fault conditions," *IEEE Trans. Energy Convers.*, vol. 25, no. 2, pp. 422–432, Jun. 2010.
[5] J. López, E. Gubía, E. Olea, J. Ruiz, and L. Marroyo, "Ride through of wind turbines with doubly fed induction generator under symmetrical voltage dips," *IEEE Trans. Ind. Electron.*, vol. 56, no. 10, pp. 4246–4254, Oct. 2009.
[6] L. G. Meegahapola, T. Littler, and D. Flynn, "Decoupled-DFIG fault ride-through strategy for enhanced stability performance during grid faults," *IEEE Trans. Sustain. Energy*, vol. 1, no. 3, pp. 152–162, Oct. 2010.
[7] J. Yao, H. Li, Y. Liao, and Z. Chen, "An improved control strategy of limiting the DC-link voltage fluctuation for a doubly fed induction wind generator," *IEEE Trans. Power Electron.*, vol. 23, no. 3, pp. 1205–1213, May 2008.
[8] J. Lopez, P. Sanchis, X. Roboam, and L. Marroyo, "Dynamic behaviour of the doubly fed induction generator during three-phase voltage dips," *IEEE Trans. Energy Convers.*, vol. 22, no. 3, pp. 709–717, Sep. 2007.
[9] Srinath Vanukuru ,Sateesh Sukhavasi,"Active and Reactive Power Control Of A Doubly Fed Induction Generator Driven By A Wind Turbine", International Journal of Power System Operation and Energy Management,vol.1,no. 2, pp. 2231- 4407 ,2011.
[10] H. Li Z. Chen ,"Overview of different wind generator systems and their comparisons", IET Renew. Power Gener., vol. 2, No. 2, pp. 123-138,2008
[11] D. Xiang, L. Ran, P. J. Tavner, and S. Yang, "Control of a doubly-fed induction generator in a wind turbine during grid fault ride-through," *IEEE Trans. Energy Convers.*, vol. 21, no. 3, pp. 652–662, Sep. 2006
[12] Lihui Yang, Zhao Xu, Jacob Østergaard, Zhao Yang Dong, and Kit Po Wong, "Advanced control strategy of DFIG wind turbines for power system fault ride through," *IEEE Trans. Power Syst.*, vol. 27, no. 2, pp. 713–721, May. 2012.
[13] Abdelbaqi, omar." LVRT for DFIG" university of Wisconsin Milwaukee, august 2010
[14] C. Millais, S. Teske. Wind force 12: a blueprint to achieve 12% of the world's electricity from windpower by 2020. Greenpeace European Wind Energy Association, 2004.
[15] Chad Abbey, *Géza Joos,* "Supercapacitor Energy Storage for Wind Energy Applications", *IEEE Trans. Ind. Appl*, vol. 43, no. 3, May/June 2007
[16] L. Xu and P. Cartwright, "Direct active and reactive power control of DFIG for wind energy generation," *IEEE Trans. Energy Convers., vol.*21, no. 3, pp. 750–758, Sep. 2007.