Low Voltage Ride-through Capability Enhancement of Doubly Fed Induction Generator based Wind Turbines Under Voltage Dips

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ABSTRACT

Based on the advantages of doubly fed induction generator (DFIG)-based wind turbine (WT). This paper proposes a new control strategy to improve the ride-through capability of DFIG-based WTs in the event of a grid fault. The proposed method is performed by using the DFIG converters control and the addition of the damping resistances connected to the DC circuit, to follow the requirements defined by the grid codes. The proposed ride-through solution limits the peak values of the DC link voltage, the rotor inrush current, electromagnetic torque and DFIG transient response at the times of occurrence and clearing the fault. The proposed solution is simulated and compared with the crowbar solution using MATLAB/Simulink environment.

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1. INTRODUCTION

Wind energy is gaining increasing importance throughout the world. This fast development of wind energy technology has large implications for a number of people and institutions. As WTs become larger and level of penetration becomes higher in electrical power systems, grid operators have modified the grid codes. According to these new grid codes, WTs must remain connected to the grid and supply reactive power to guarantee the grid voltage during the grid faults. This ability of WTs is called the fault ride through (FRT) capability [1], and more specifically for voltage dips, low voltage ride through (LVRT) capability [2],[3]. Nowadays, DFIG is the most used generator for WTs due to the advantages of variable-speed ability, higher energy capture, improved power quality and using converters rated for partial-scale converters [4]. On the other hand, because the stator of the DFIG is directly connected to the grid, it is very sensitive to the grid disturbances, particularly voltage dips [5]-[12]. The transients voltages on rotor side during grid faults, are higher than the stator side, and thus the rotor side converter (RSC) and intermediate DC circuit are particularly susceptible to be destructed due to voltage transients. Also, the voltage sag at the stator terminals due to the grid faults causes the rotor over-currents, DC-link over voltage and torque oscillations that could lead to destruction of the power converter and mechanical parts. So, without a proper control strategy, the DFIG is unable to stay connected to the grid during the grid faults [5]. Likewise, the DFIG system is not controlled during the critical time of grid faults and the system cannot support the grid. Previous approaches of researches have been presented to address DFIG FRT issues. The most common FRT solution is to short circuit the rotor windings with the crowbar circuit [6]-[7]. When the rotor over-current is detected, The crowbar circuit short circuits the rotor windings when the rotor overcurrent is detected, which isolates the

RSC from the rotor to protect the converter, while the DFIG operation is changed to a squirrel cage induction generator (SCIG) operation, which absorbs reactive power from the grid. In [8], the authors proposed the use of an energy storage system (ESS) that is connected to the DC-link of DFIG. This ESS can regulate the DC-link voltage during grid faults. Although RSC can still operate in the grid fault, it needs to be sized accordingly to account fault which increases complexity and cost of the system. In [9], a FRT scheme is proposed using an additional Series Grid-Side Converter (SGSC). The SGSC is connected to the DC-link and to the open terminals of DFIG stator windings that regulates the stator flux to be compatible with the voltage at the grid connection point of DFIG during grid fault which improves LVRT. This solution also needs additional hardware which adds to the complexity and cost of the system. In [10] the authors proposed an efficient control scheme to improve the LVRT capability of the DFIG under balanced voltage dips, by using a passive resistive hardware called stator damping resistor (SDR) located in series with the stator windings. The SDR method can enhance the DFIG voltage dip behaviour by reducing the peak rotor fault current and minimizing transient oscillations of electrical torque and DFIG transient response, but connecting resistances with stator creates a large dissipation and may disconnect generator. In [11], stator flux is regulated by improving rotor current control. During grid fault, a large EMF (Electromotive force) induced in the rotor circuit which is the result of DC and negative sequence components induced in the stator flux linkage of DFIG. A modified RSC control which controls the rotor current can be used to oppose the DC and negative-sequence components of the stator flux linkage. The advantage of this solution is that it does not need any additional cost. But the efficiency of this method depends on the severity of the fault and pre-fault condition of the WT. Consequently, it is only suitable for small dips.

LVRT is a part of the grid code which in the event of grid voltage sag, the WTs are required to remain connected to the grid for a specific amount of time before being allowed to disconnect, this specific amount of time can be different from one grid code to another moreover the severity of the fault might be different as well. Figure1 depicts requirements of the WECS during voltage dips in different countries as an example [12].

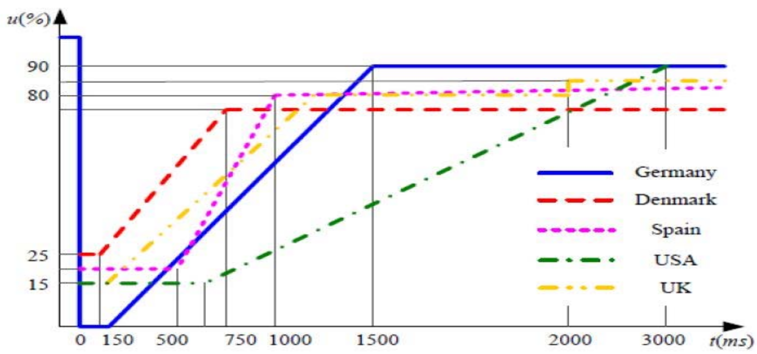

Figure 1. Requirements of the WECS during voltage dips in different countries [12]

Furthermore, some utilities require that the WTs help support grid voltage during faults. LVRT depends on the magnitude of voltage drop at the Point of Common Coupling (PCC) during the fault and the time taken by the grid system to recover to the normal state [13].

In order to overcome the aforementioned problems, this paper proposes a control strategy to improve the FRT capability of the DFIG during grid faults including grid voltage sag conditions. The proposed solution involves the use of damping resistances as well as bypass switching devices coupled with DC circuit.

This paper has been organized as follows: In Section 2, DFIG WT system modelling and control is described. In Section 3, the proposed FRT control strategy is discussed and in Section 4, the simulation results with the proposed solution and with the crowbar solution are shown and compared. Finally, the conclusions are summarized in Section 5.

2. MODELLING AND CONTROL OF DFIG SYSTEM

Typical configuration of the WT using DFIG is shown in Figure 2. The generator is connected to the turbine via shafts and a gearbox. The DFIG is fed from both stator side which is directly connected to the grid, and rotor side that is connected to a back-to-back converter and from there to the grid. In this way, variable speed operation becomes possible as mechanical and electrical rotor frequencies are decoupled. The difference between frequencies is compensated by a power electronic converter which injects the rotor current with variable frequency. The aerodynamic power control of this type of WT is normally performed by pitch control. A well-known method for DFIG power converter protection is using Crowbar circuit. The overall protection scheme is that during a voltage sag the gate of RSC is turned off and the rotor is connected to the Crowbar circuit, DFIG starts to act as a conventional induction generator.

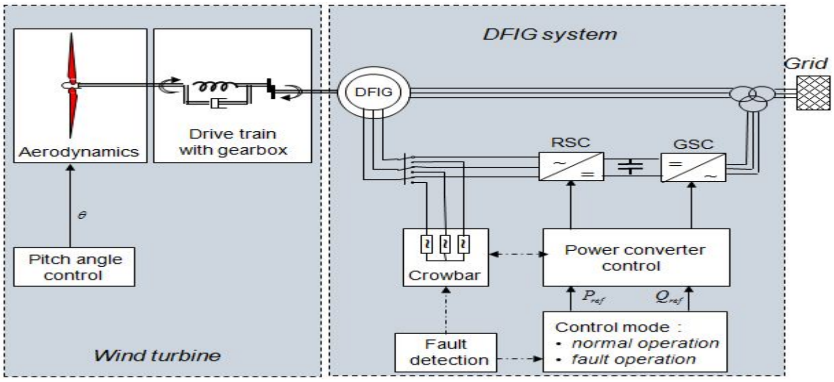

Figure 2. The schematic diagram of the grid connected DFIG based wind turbine system

2.1. DFIG model

The equations of the electrical model of DFIG in synchronous reference frame (dq-frame) are expresed as [14]:

$$V_{ds} = R_s i_{ds} + \frac{d\psi_{ds}}{dt} - \omega_s \psi_{qs} \tag{1}$$

$$V_{qs} = R_s i_{qs} + \frac{d\psi_{qs}}{dt} + \omega_s \psi_{ds} \tag{2}$$

$$V_{dr} = R_r i_{dr} + \frac{d\psi_{dr}}{dt} - s\omega_s \psi_{qr} \tag{3}$$

$$V_{qr} = R_r i_{qr} + \frac{d\psi_{qr}}{dt} + s\omega_s \psi_{dr} \tag{4}$$

$$\psi_{ds} = L_s i_{ds} + L_m i_{dr} \tag{5}$$

$$\psi_{qs} = L_s i_{qs} + L_m i_{qr} \tag{6}$$

$$\psi_{dr} = L_r i_{dr} + L_m i_{ds} \tag{7}$$

$$\psi_{qr} = L_r i_{qr} + L_m i_{qs} \tag{8}$$

Where V, i are the voltage and current; R, L are the resistance and inductance; ψ is the magnetic flux; L_m is the generator mutual inductance; Subscripts s, r, d, and q refer to the stator, rotor, d-axis and q-axis components respectively; $L_s = L_{ls} + L_m$; $L_r = L_{lr} + L_m$; $s\omega_s = \omega_s - \omega_r$ represents the difference between synchronous speed and rotor speed; L_{ls} and L_{lr} are stator and rotor leakage inductances.

Active power flows through rotor and stator of the generator and combination of both constructs the total active power. Total active and reactive powers equations of DFIG are expressed as [15]:

$$P = P_s + P_r = \frac{3}{2}(V_{ds}\, i_{ds} + V_{qs}\, i_{qs} + V_{dr}\, i_{dr} + V_{qr}\, i_{qr}) \tag{9}$$

$$Q = Q_s + Q_r = \frac{3}{2}(V_{qs} i_{ds} - V_{ds}\, i_{qs} + V_{qr} i_{dr} - V_{dr} i_{qr}) \tag{10}$$

2.2. Control of DFIG

The power electronic part of the DFIG consists of two voltage-source converters (RSC and GSC) and a capacitor in between that is called DC-link. The overall control objectives of variable speed operation of WTs are divided into electrical power transfer control and generator speed control. The generator speed controller is associated with RSC and its goal is to control the active and reactive power of the DFIG independently. Though the GSC keeps the DC-link voltage constant regardless of the direction of the rotor power flow and generates an independent reactive power which is injected into the grid.

The stator voltage vector is selected to be aligned to the d-axis of the d-q synchronous frame, as result: ($V_{ds} = V_s, V_{qs} = 0$)

By considering the GSC to be reactive neutral ($i_{qs} = 0$) and the converters are primarily used to supply the active power from the rotor to grid [16]. So, from equation (9) the relation between active power and the currents connected GSC to the grid can be deduced as:

$$P_r = \frac{3}{2} V_s i_d,\ i_q = 0 \tag{11}$$

In steady-state and by neglecting stator resistance R_s: $\frac{d\psi_{ds}}{dt} = 0$, $\frac{d\psi_{qs}}{dt} = 0$ and from equations (7) and (8): $\psi_{ds} = 0$, $\psi_{qs} = -\frac{V_s}{\omega_s}$. The equations between stator currents and rotor currents can be deduced as:

$$i_{ds} = -\frac{L_m}{Ls} i_{dr} \tag{12}$$

$$i_{ds} = -\frac{1}{Ls}(L_m i_{dr} + \frac{V_s}{\omega_s}) \tag{13}$$

Considering the assumptions as above and from equations (9) and (10), the expressions of the active and reactive power:

$$P_s = \frac{3}{2} V_s i_{ds} = -\frac{3}{2}\frac{L_m}{L_s} V_s i_{dr} \tag{14}$$

$$Q_s = -\frac{3}{2} V_s i_{qs} = \frac{3}{2}(\frac{V_s^2}{\omega_s L_s} + \frac{L_m V_s i_{qr}}{L_s}) \tag{15}$$

In order to achieve independent control of the stator active power P_s, and reactive power Q_s by means of rotor current regulation (Fast control current), the instantaneous three-phase rotor currents i_{abcr} are sampled and transformed to d-q components i_{dr} and i_{qr} in the stator-voltage oriented reference frame. The reference values for i_{dr} and i_{qr} (i_{dref} and i_{qref}) can be determined directly from P_s, and Q_s commands respectively.

The active power set point of the converter is generated by the rotor speed controller. The reactive power set point is based on terminal voltage or power factor controller.

In the grid side control, generally DC-link voltage V_{dc} is compared with the reference U_{ref}^{DC} DC link voltage and error is fed to PI controller to maintain constant DC-link voltage.

Considering both the control strategies on the stator and the rotor sides, the schematic of the vector control structure is depicted in Figure 3.

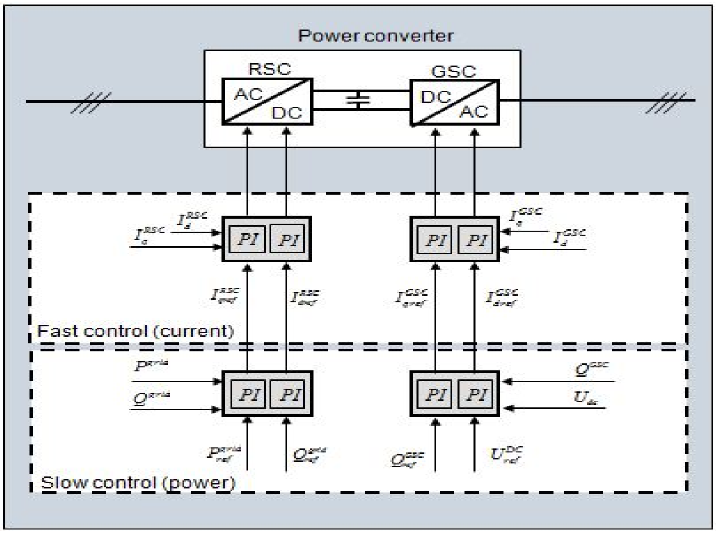

Figure 3. Rotor side and grid side controllers

3. THE PROPOSED LVRT CONTROL STRATEGY

In this section, the control strategy is proposed to improve the LVRT capability of the DFIG during the grid faults. The schematic diagram of the damping resistances and the bypass switching devices in the DFIG system is shown in Figure 4.

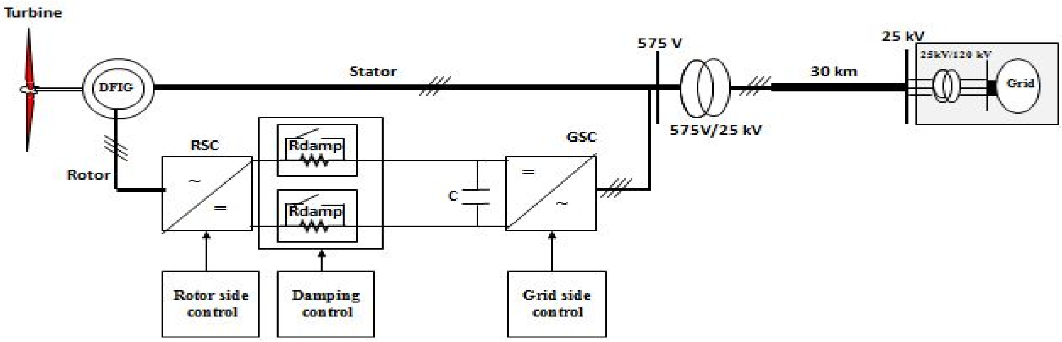

Figure 4. Simulation configuration of DFIG system under grid fault

3.1. Analysis of DFIG behaviour during grid voltage dips

In order to facilitate the analysis of DFIG, the Park model in the stationary coordinate system is used as [17]:

$$V_s = R_s i_s + \frac{d\psi_s}{dt} \tag{16}$$

$$V_r = R_r i_r + \frac{d\psi_r}{dt} - j\omega\psi_r \tag{17}$$

$$\psi_s = L_s i_s + L_m i_r \tag{18}$$

$$\psi_r = L_r i_r + L_m i_s \tag{19}$$

Where ω is the rotor electrical speed.

From (16)-(19) the rotor voltage can be obtained as:

$$V_r = \frac{L_m}{L_s}\left(\frac{d}{dt} - j\omega\right)\psi_s + \left[R_r + \sigma L_r\left(\frac{d}{dt} - j\omega\right)\right]i_r \quad (20)$$

Where: $\sigma = \frac{L_m^2}{L_s L_r} - 1$

The stator flux induced in the potential of the rotor side as expressed in (20), when voltage dips occur in the power grid, the stator voltage follows the change of grid voltage, but flux cannot be change, leading to the appearences of the transient DC component of the stator flux, positive and negative sequence components.

Ignoring the voltage drop on the stator resistance, the relationship between the components of the stator flux and the stator voltage components under the fault, are expressed as:

$$\psi_s^{'} = \psi_{sDC}^{'} + \psi_{sp}^{'} + \psi_{sN}^{'} = \left(\frac{U_s}{j\omega_1} - \frac{U_{sp}^{'}}{j\omega_1} - \frac{U_{sN}^{'}}{-j\omega_1}\right)e^{-\frac{t}{\tau s}} + \frac{U_{sp}^{'}}{j\omega_1} + \frac{U_{sN}^{'}}{-j\omega_1} \quad (21)$$

Where: $\psi_s^{'}$ is the stator flux during the fault; $\psi_{sDC}^{'}$ is the transient DC stator flux during the fault; $\psi_{sp}^{'}$ and $\psi_{sN}^{'}$ are respectively the positive and negative sequence of the stator flux during the fault; U_s for the instantaneous stator voltage before the fault; $U_{sp}^{'}$ and $U_{sN}^{'}$ are respectively the positive and negative sequence of the stator voltage diring the fault; τ is the stator flux time constant of the transient DC component; ω_1 is stator angular spead.

Due to the rotation of the rotor windings, each sequence of stator flux component will induce a corresponding electrical potential in the rotor winding. In the rotor reference frame, each sequence component can be expressed as:

$$U_{rp}^{r} = |U_{sp}^{'}|s\frac{L_m}{L_s}e^{js\omega_1 t} \quad (22)$$

$$U_{rN}^{r} = |U_{sN}^{'}|(2-s)\frac{L_m}{L_s}e^{-j(2-s)\omega_1 t} \quad (23)$$

$$U_{rDC}^{r} = -j\omega_r\frac{L_m}{L_s}\left(\frac{U_s}{j\omega_1} - \frac{U'_{sp}}{j\omega_1} - \frac{U'_{sN}}{-j\omega_1}\right)e^{-t/\tau s}e^{-j\omega_r t} \quad (24)$$

Where: s is the slip; , U_{rp}^{r}, U_{rN}^{r} and U_{rDC}^{r} are positive sequence, negative sequence and the DC components of the stator transients induced in the rotor side. The value of the slip generally between -0.3 and 0.3 [18], and from the equation (22)-(24): the positive sequence component is proportional to the slip (s), the negative sequence component is proportional to (2-s) and the DC component is proportional to the speed. Superposition of these components could cause the rotor windings to induce a large EMF, and due to the limited capacity of the RSC, the latter cannot provide enough voltage to regulate the EMF during fault, which will lead to the rotor overcurrent.

From these equations we can size a controller for the rotor current with inserting damping resistances coupled with the DC circuit.

3.2. Methodology of damping resistances activation

The DFIG operation is divided into three operating phases: pre-fault, during fault and post-fault. In normal conditions, the damping resistances protection is inactive. The LVRT protection steps for voltage dips are given in Figure 5 and described below:

- The grid is monitored for voltage sag occurrences. Once a grid voltage dip is detected, the damping resistances (DR) are activated. In this step, DFIG is demagnetized and the damping of the transient response is improved. Otherwise the monitoring continues.
- The damping resistances remain activated and the voltage of DC circuit (Vdc) is monitored. If Vdc decreases below a certain threshold DR are disabled. Otherwise, the process continues.

- The grid is monitored for clearance of the previously detected fault. After the fault has been cleared, DR are again activated.
- Once the grid fault is eliminated, the process returns to the first step where the grid is monitored again. The RSC switches to normal operation mode to resume real and reactive power control with rated grid voltage.

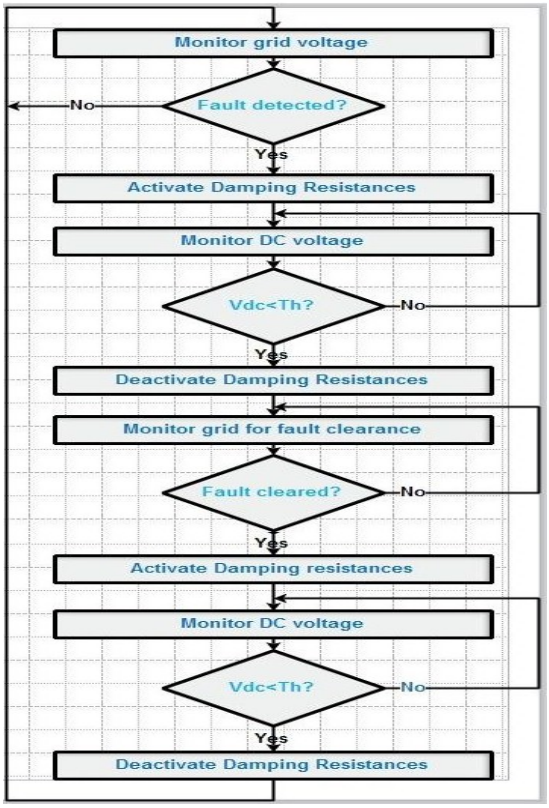

Figure 5. Flow chart of proposed LVRT strategy

4. SIMULATION AND RESULTS

The system under study, given in Figure 4, consists of a 9MW wind farm (six 1.5MW DFIG based WT) exporting power to a 120kV grid through a (30km, 25kV) feeder and transformers (25kV/120kV) and (575V/25kV). In this study, the simulations were conducted using MATLAB/SIMULINK software, coherent model of the six generators is used. Simulation parameters of the DFIG system are presented in Table 1.

Table 1. Simulation parametres of DFIG system

Parameters	Values
Rated power	9 MW
Power coefficient	0.9
Rated voltage	575 V
Rated frequency (F)	50 Hz
Stator resistance (R_s)	0.00706 pu
Rotor resistance (R_r)	0.005 pu
Stator leakage inductance (L_{ls})	3.07 pu
Rotor leakage inductance (L_{lr})	3.056 pu
Stator and rotor mutual inductance (L_m)	2.9 pu
Number of pole pairs (p)	6

In this section the DFIG ride-through capability is simulated for a three phases voltage dip, in which the grid voltage in three phase drops to 15% of its nominal value (85% voltage dip) at t=0.9s and lasts for 300ms. In this paper, two distinct cases are investigated and compared. In the first case (Figure 6), the proposed LVRT approach is applied, and the second case (Figure 7) demonstrates the DFIG with the crowbar circuit protection.

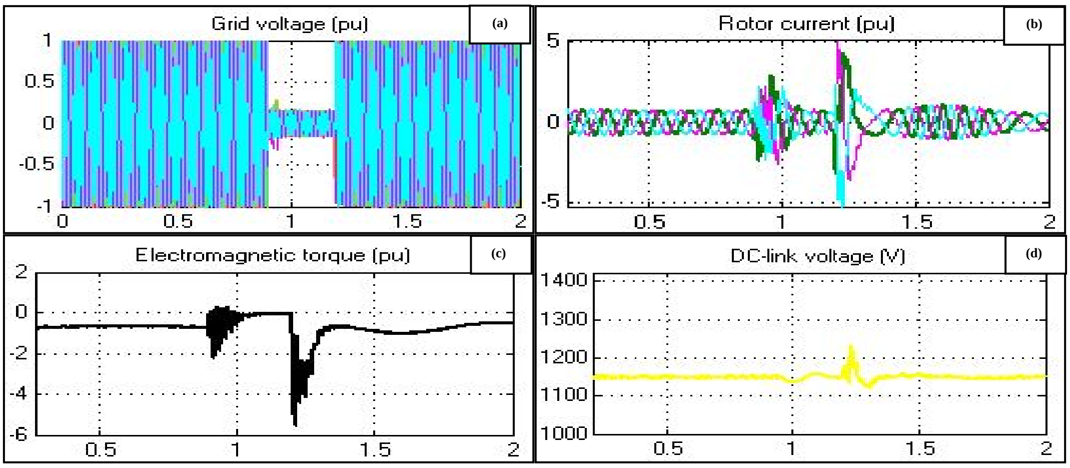

Figure 6. Simulation results of DFIG system with the proposed LVRT strategy under 85% three phases voltage dip, (a) Grid voltage, (b) Rotor current, (c) Electromagnetic torque and (d) DC link voltage

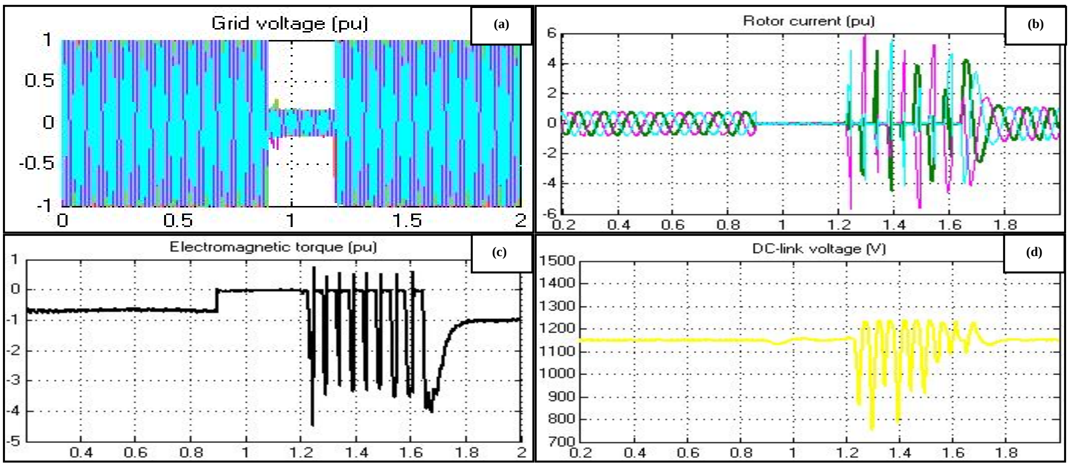

Figure 7. Simulation results of DFIG system with the conventional crowbar protection, (a) Grid voltage, (b) Rotor current, (c) Electromagnetic torque and (d) DC link voltage

Figure 6 and Figure 7 illustrate grid voltage, rotor current, electromagnetic torque and DC-link voltage waveforms, with the proposed LVRT approach (Figure 6) and with the crowbar circuit protection (Figure 7). By applying the proposed LVRT solution, the simulations show positive results, thus the electrical values i.e. rotor current, electromagnetic torque and DC-link voltage have passed to reasonable values and much better than those obtained using the crowbar circuit protection. This improvement of the electrical values above-mentioned will allow: (i) The WT to remain connected to the grid for a longer times, responding to the requirements of the grid code without much trouble and without making damages to the equipment of the WT, (ii) Avoid mechanical stress due to the important oscillations during fault. So with the proposed LVRT solution the oscillations and the impact on the functioning of the DFIG including converters and capacity are significantly reduced. On the other hand, with the use of crowbar circuit protection it is observed that during the fault the rotor current and DC link voltage almost zero due to the isolation of the converters (considered as important part in the overall operation of the WT) from the rotor which loses the control of DFIG, this impact will results frequent breakdowns of the WT, current and accidental disconnections of the WT from the grid, poor quality of service, grid code not respected, very high maintenance cost and the cost of the WTs disconnection is very penalizing for both the producers and the grid operators. So it is clear that the performance of the proposed LVRT approach is more efficient compared to the crowbar circuit protection.

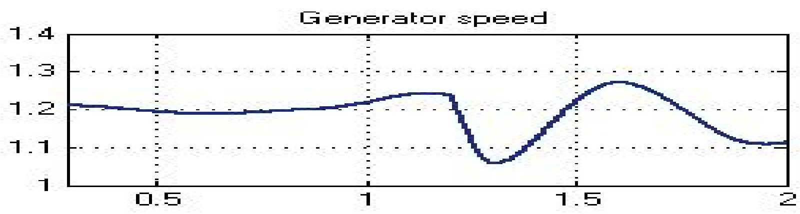

Figure 8. Generator speed under 85% three phases voltage dip with the proposed LVRT approach

Figure 8 depicts the generator response with 85% three phases voltage dip with the proposed LVRT approach. As shown in Figure 8, the operating speed before the fault is 1.205pu and the maximum generator speed during the fault is 1.244pu. Thus, the generator slips during and after the fault is within the allowable range and the back-to-back converter is able to handle the slip power. Furthermore, growth of the generator speed during the fault is relatively low. Therefore, the system does not face angle-speed instability.

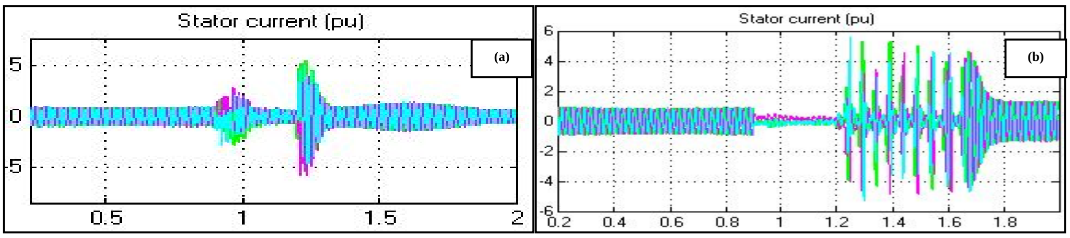

Figure 9. Evaluation of DFIG stator current, (a) with the proposed LVRT approach (b) with the conventional crowbar protection

Figure 9 depicts three phases stator current with the proposed LVRT (Figure 9a) and the crowbar circuit protection (Figure 9b). Figure 9a shows that the stator currents take acceptable values during and after clearing the fault, in the opposite Figure 9b shows that the stator currents almost zero during the fault and take very high values after clearing the fault (up to 5.9 times the nominal value), so it is clear that after LVRT compensation the stator currents are balanced.

5. CONCLUSION

This paper presents a LVRT strategy to maintain the production of DFIG-based WTs and prevent deterioration of the converters when the power grid is experiencing a fault. The strategy presented is based on the use of the damping resistances and switching devices connected to the DC circuit. The results of the simulation of the system show that the proposed strategy regulates the DC voltage and significantly reduces the peak values of the rotor, stator current, and the electromagnetic torque, it also minimizes the oscillations of the electromagnetic torque and the intermediate circuit voltage during the fault and improves the FRT capability of the DFIG. As result the WT equipments will be well protected and the important cost of replacement of such equipment will be avoided, also the WT operating time is maximized. Therefore, the proposed solution is more efficient than the crowbar solution.

REFERENCES

[1] Manju Aggarwal, Madhusudan Singh, SK. Gupta, "Fault Ride-Through capability of DSTATCOM for Distributed Wind Generation System", *International Journal of Power Electronics and Drive System (IJPEDS)*, vol/issue: 6(2), pp. 348~355, 2015.

[2] Anju M., R. Rajasekaran, "Power System Stability Enhancement and Improvement of LVRT Capability of a DFIG Based Wind Power System by Using SMES and SFCL", *International Journal of Electrical and Computer Engineering (IJECE)*, vol/issue: 3(5), pp. 618~628, 2013.

[3] YANG Bai-jie, CHAO Qin, YUAN Tie-jiang, YI Hai-dong, "Research of STATCOM Impact on Wind Farm LVRT and Protection", *TELKOMNIKA*, vol/issue: 10(8), pp. 2117~2124, 2012.

[4] Yu Zou, Malik E. Elbuluk, Yilmaz Sozer, "Simulation Comparisons and Implementation of Induction Generator Wind Power Systems", *IEEE Transactions on Industry Applications*, vol/issue: 49(3), 2013.

[5] Graham Pannell, David J. Atkinson, Bashar Zahawi, "Minimum threshold crowbar for a fault ride through grid code compliant DFIG wind turbine", *IEEE Transactions on Energy Conversion*, vol/issue: 25(3), 2010.

[6] Zhang L., Jin X. and Liangyu Z., "A novel LVRT control strategy of DFIG based rotor active crowbar", In: Power and Energy Engineering Conference (APPEEC), 2011 Asia-Pacific, Wuhan, 25-28 March 2011, pp. 1-6.

[7] Jon Vidal, Gonzalo Abad, Joseba Arza and Sergio Aurtenechea, "Single-Phase DC Crowbar Topologies for Low Voltage Ride Through Fulfillment of High-Power Doubly Fed Induction Generator-Based Wind Turbines", *IEEE Transactions On Energy Conversion*, vol/issue: 28(3), pp.768–781, 2013.

[8] C. Abbey, G. Joos, "Effect of low voltage ride through (LVRT) characteristic on voltage stability", In: Power Engineering Society General Meeting, 2005, IEEE, vol. 2, pp. 1901-1907, 12-16 June 2005.

[9] Flannery PS., Venkataramanan G., "Evaluation of Voltage Sag Ride-Through of a Doubly Fed Induction Generator Wind Turbine with Series Grid Side Converter", In: Power Electronics Specialists Conference, 2007, Orlando, FL, USA, pp.1839-1845, 17-21 June 2007.

[10] Rahimi M., Parniani M., "Efficient control scheme of wind turbines with doubly fed induction generators for low voltage ride-through capability enhancement", *IET Renew. Power Gener.*, vol/issue: 4(3), pp. 242–252, 2010.

[11] Dawei Xiang, Ran L., Tavner PJ., Yang S., "Control of a doubly fed induction generator in a wind turbine during grid fault ride-through", *Energy Conversion, IEEE Transactions*, vol/issue: 21(3), pp. 652-662, 2006.

[12] Iov F., Hansen A., Sorensen P., et al., "Mapping of grid faults and grid codes", *RISØ Report*, 2007.

[13] Hua Geng, Cong Liu, Geng Yang, "LVRT Capability of DFIG-Based WECS Under Asymmetrical Grid Fault Condition", *Industrial Electronics, IEEE Transactions*, vol/issue: 60(6), pp. 2495–2509, 2013.

[14] A. Moualdia, MO. Mahoudi, L. Nezli, O. Bouchhida, "Modelling and Control of a Wind Power Conversion System Based on the Double-Fed Asynchronous Generator", *International Journal Of Renewable Energy Research*, vol/issue: 2(2), 2012.

[15] Liu chun, Kang Yong, Chen Jian, Kevin Lee, Lin Xinchun, Liu Xiaohu, Xu Feidong, "Simplified Active and Reactive Power Control of Doubly Fed Induction Generator and the Simulation with STATCOM", Applied Power Electronics Conference and Exposition, APEC 200, Twenty-Fourth Annual IEEE, pp. 1927-1931, 15-19 Feb 2009.

[16] Wei Qiao, Venayagamoorthy GK., Harley RG., "Real-Time Implementation of a STATCOM on a Wind Farm Equipped With Doubly Fed Induction Generators", *Industry Applications, IEEE Transactions*, vol/issue: 45(1), pp. 98-107, 2009.

[17] Lopez J., Sanchis P., Roboam X., Marroyo L., "Dynamic behavior of the doubly fed induction generator during three-phase voltage dips", *Energy Conversion, IEEE Transactions*, vol/issue: 22(3), pp. 709–717, 2007.

[18] Norouzi AH., Sharaf AM., "Two control schemes to enhance the dynamic performance of the STATCOM and SSSC", *Power Delivery, IEEE Transactions*, vol/issue: 20(1), pp. 435- 442, 2005.

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