IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 1 Issue 6, August 2014.
www.ijiset.com

ISSN 2348 – 7968

A Survey on Low-Voltage Ride-Through Techniques for DFIG based Wind Turbines

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Abstract

The Doubly-Fed Induction Generator (DFIG) is the most widely used technology in wind turbines worldwide. The reaction to grid voltage disturbances is sensible in case of DFIG systems. Fault ride through (FRT) is an important feature for wind turbine systems to fulfil grid code requirements. This is one of the biggest challenges resulting in a massive deployment of wind farms. During a fault condition, the voltage at the Point of Common Coupling (PCC) drops immediately and the grid voltage reduces (voltage sag) imposed at the connection point of the DFIG to the grid induce large voltages in the rotor windings, resulting in high short circuit current, which can damage the rotor-side converter and disconnect from grid. This paper presents the various techniques to enhance the fault ride through capability of DFIG wind turbine.

Keywords: *Wind Turbine, Doubly-Fed Induction Generator (DFIG), Grid code requirements, Low-Voltage Ride-Through (LVRT).*

1. Introduction

Global warming has been attributed to the increase of the atmospheric gases concentration produced by the burn of fossil fuel. Wind power generation is an important alternative to mitigate this problem mainly due its smaller environmental impact and its renewable characteristic that contribute for a sustainable development. Three factors have made wind power generation cost-competitive, these are: (i) the state incentives, (ii) the wind industry that have improved the aerodynamic efficiency of wind turbine, (iii) the evolution of power electronics and new control methodology for the variable-speed wind turbine, that allows the optimal performance of wind turbine.

The development in the wind energy conversion technology has been rapidly increasing from the past two decades. There are basically three types of wind turbine technologies used for power generation [1]. They include: (i) fixed-speed wind turbine system using a standard squirrel-cage induction generator (SCIG), directly connected to the grid. (ii) variable speed wind turbine system with a multi-stage gearbox and a doubly fed induction generator (DFIG) and (iii) variable speed system with gearless wind turbine system with a direct-drive generator. The statistics of the installed capacities of wind farms worldwide is shown in Fig.1

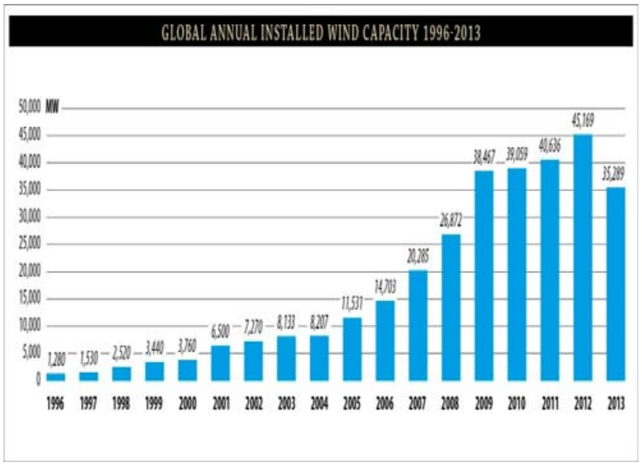

Fig.1. Global installation capacity of Wind Turbines

Among the wind turbine technologies, the turbines using doubly fed induction generator (DFIG) are the most widely used ones due to its variable-speed four-quadrant operation, its controllable capability of both active and reactive power separately, and its partially (30%) rated power converter [3]. But the DFIGs are too sensitive for grid voltage disturbances, for symmetrical and unsymmetrical voltage sags, that may damage rotor side converter and hence it requires additional protection for the rotor side power electronic converter. This paper describes the conventionally used and new technologies for the low-voltage ride through capability for wind turbine systems employing Doubly-Fed Induction Generator.

2. Doubly-Fed Induction Generator

DFIGs (Doubly-Fed Induction Generators) are variable speed generators with advantages compared to other solutions. They are used more in wind turbine applications due to its easy controllability, improved power quality and high energy efficiency. Fixed speed generators and induction generators had the disadvantage of having low power efficiencies at most speeds. To improve the efficiency, controlled power electronics converters are commonly used. Voltage source inverters are used to convert the voltage magnitude and frequency to match the grid values.

The DFIG wind turbine system is shown in Fig.2. The drive system operates in four quadrants. This implies that a bidirectional flow of power both in sub-synchronous and super-synchronous speed [2] is possible. The possibility of supplying and consuming reactive power enables the generator system to act as a power factor compensator. By the control of the back to back inverters, the control of the slip is made easy. In the case of the squirrel cage induction machine, as the rotor cannot be driven, the slip depends only on the stator and load inputs.

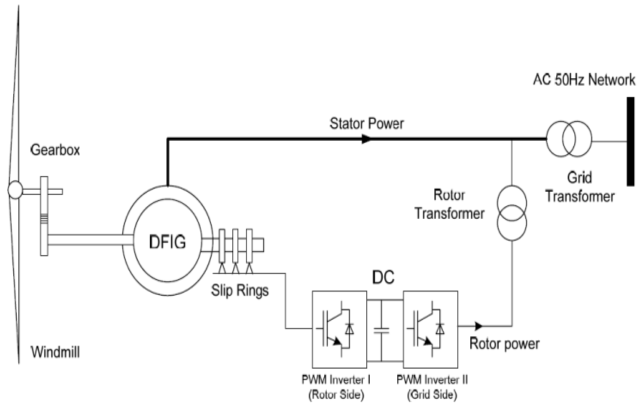

Fig.2. DFIG Wind Turbine System

As for synchronous machines, a relatively large torque may cause the machine to oscillate. The DFIG does not pose any synchronization problems. The rotor circuit is connected through slip to the back to back converter arrangement controlled by PWM strategies. Back to back converters consist of two voltage source converters (ac-dc-ac) having a dc link capacitor connected in between them. The generator side converter takes the variable frequency voltage and converts it into dc voltage. The grid side converter gets the ac input voltage from the dc link and voltage at grid parameters as output.

3. Grid Code Requirements

Increasing wind power penetration levels to the power systems of many regions and countries has led to the elaboration of specific technical requirements for the connection of wind farms to the grids. These requirements are concerned with grid codes issued by the system operators . The grid codes specifies that wind farms should contribute to power system control (frequency and also voltage), much as the conventional power generation stations, and withstand on wind farm behaviour in case of abnormal operating conditions of the network (such as in case of voltage dips due to network faults) [4]. Grid code requirements have been a major driver for the development of Wind turbine (WT) technology.

The grid code requirements typically refer to large wind farms connected to the transmission system, rather than smaller stations connected to the distribution network. The most common requirements include FRT capability, extended system voltage and frequency variation limits, active power regulation, power factor correction, frequency control, as well as reactive power and voltage regulation capabilities.

4. Fault Ride-Through Capability- Topologies

Even though DFIG wind turbine has several advantages, it faces two major problems. Firstly, it is very sensitive to voltage disturbances especially voltage dips (sag). If any fault occurs in the grid, there will be a very large voltage disturbance which leads to uncontrollable current in the rotor side converter that results in the damage of the power electronic switches. Secondly DFIG suffers from output power fluctuations [5].

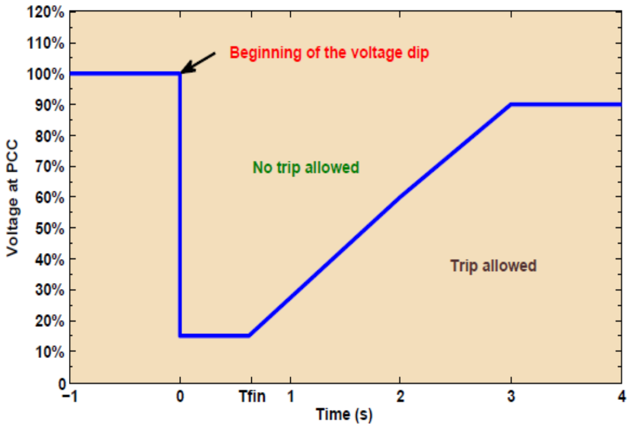

Fig.3. Typical LVRT curve

To protect the rotor circuit during fault conditions, usually the DFIG wind turbine is disconnected and remains unoperated until the fault is cleared which decreases its operational efficiency. So for the wind turbines to remain connected to the grid during the faults, various technologies have been developed to withstand the voltage dips. This withstanding capability of DFIG against voltage sags is called as Low Voltage Ride-Through (LVRT) or Fault Ride-Through (FRT) capability [6]. The typical Low Voltage Ride-Through (LVRT) curve is shown in Fig.3. The LVRT capability approaches can be divided mainly into two categories: (i) *Passive Methods:* they use additional components such as crowbar, blade-pitch angle control, energy capacitor system and DC bus energy storage circuit. (ii) *Active Methods:* includes several converter controls.

4.1 Passive Methods:

(a)Crowbar method:

It is the conventionally used method that uses a resistive network connected to rotor circuit in case of rotor over currents or dc-link over voltages and the rotor side converter (RSC) is disabled [7]. Fig.4. shows the schematic diagram of DFIG wind turbine with crowbar protection. A high short-circuit current is drawn by the machine when the crowbar is activated, which results in a large amount of reactive power drawn from the power network which is not acceptable by the grid code requirements.

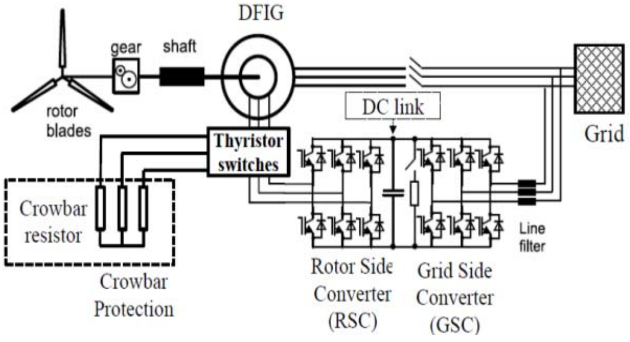

Fig.4. Schematic diagram of DFIG wind turbine with Crowbar protection

Its major disadvantage is that, the DFIG loses its controllability when the crowbar is triggered. During this, the DFIG absorbs a large amount of reactive power from the grid, which leads to further grid voltage reduction.

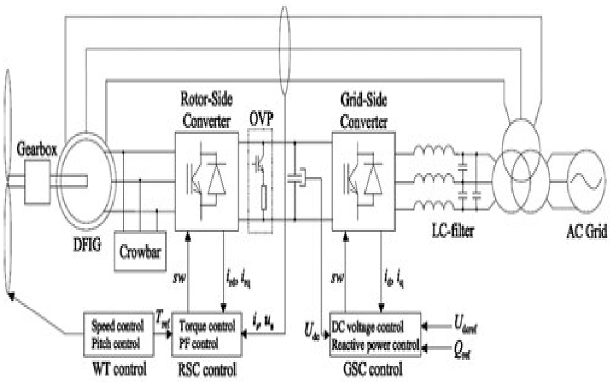

Fig.5. Crowbar in series with stator of DFIG

Another important aspect is that the crowbar resistance should also be carefully calculated in order to provide sufficient damping and minimum energy consumption. Considering these disadvantages, a new crowbar arrangement was proposed, in which the crowbar is connected in series with the stator windings as shown Fig.5.

(b) DC Chopper:

A braking resistor (DC chopper) is connected in parallel with the dc-link capacitor to limit the overcharge during the fault condition [9], [10]. A DFIG dc-link brake chopper is shown schematically in Fig.6.

The dc-link brake chopper shorts the dc-link through a power resistor when the dc-link voltage exceeds a fixed threshold level. The brake is used to maintain the dc-link voltage when transient rotor overcurrent occurs. There are six antiparallel diodes in the rotor-side converter that are highly rated to withstand short-circuit currents. The brake chopper works on a hysteresis band, i.e., the turn-OFF voltage is set below the turn-ON threshold value.

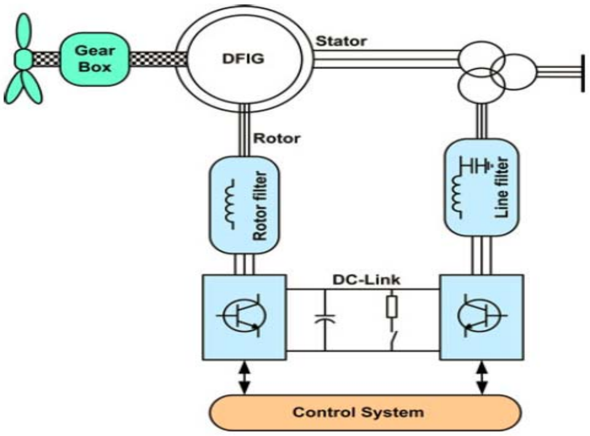

Fig.6. DFIG wind turbine with DC-link Brake Chopper

(c) Series Dynamic Braking Resistor:

The dc-link chopper has no effect on rotor overcurrent. To limit this overcurrent a dynamic resistor is connected in series with the rotor. It is controlled by a power electronic switch. The series dynamic braking resistor (SDBR) boosts the generator voltage and dissipates the active power [11]. At normal operation, the switch is ON and the resistor is bypassed. During the fault condition, the switch is OFF and the braking resistor is connected in series with the circuit. The DFIG rotor equivalent circuit with all protection schemes is shown in Fig.7.

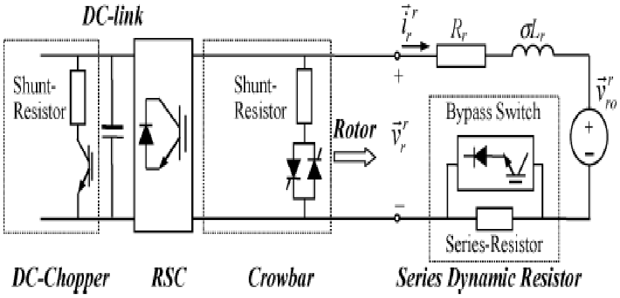

Fig.7. DFIG rotor equivalent circuit with all protection schemes

4.2. Active Methods:

With the control strategies of the rotor-side converter, the impact of fault on the DFIG wind turbine can be controlled. Maximum power tracking is used in all variable-speed wind turbines to increase their power conversion efficiency. Therefore, the converters used in wind turbines are designed in such a way that they should handle the maximum possible power that could be generated before reaching the cut-out wind speed [12].

(a) Decoupled DFIG:

In a decoupled operation the DFIG operates as an induction generator (IG) with the converter unit acting as a reactive power source (STATCOM) during a fault condition [13] as shown in Fig.8. The optimal crowbar resistance is obtained to exploit the maximum power capability from the DFIG during decoupled operation.

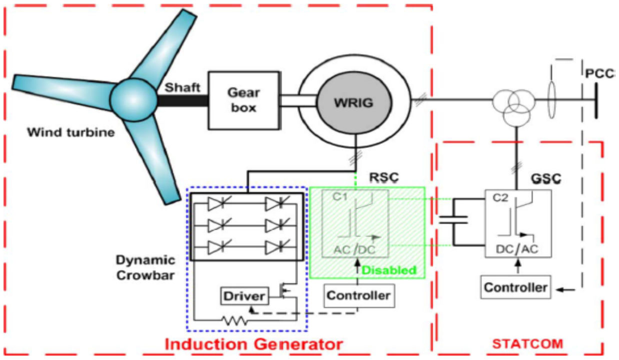

Fig.8. Schematic diagram of decoupled operation strategy

(b) Dynamic Voltage Restorer (DVR):

The protection of DFIG by an external power electronics device from the faulty grid voltage is the Dynamic Voltage Restorer. It is basically a voltage source converter that is connected in series with the grid through a coupling transformer in order to compensate the deteriorated line voltages [14]. It compensates voltage sag and the active power from DFIG is fed to the grid through DVR. Fig.9. shows the schematic diagram of DFIG with DVR and crowbar circuit.

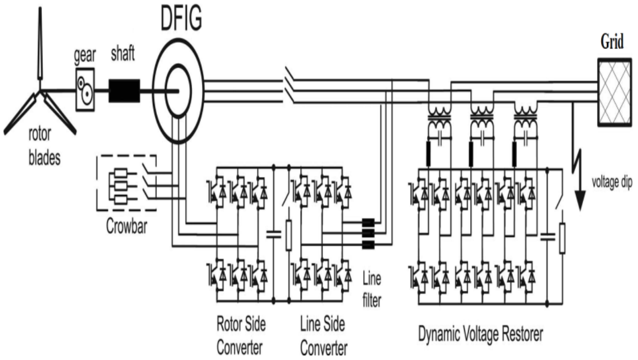

Fig.9. Schematic diagram of DFIG wind turbine with DVR

The aim of a DVR is to inject the compensating voltage and maintain the DFIG-based wind farm terminal voltage during fault conditions [16]. The main advantage of such an external protection device is reduced complexity in the DFIG system. The disadvantages are the cost and complexity of the DVR.

(c) Flux linkage tracking:

When the voltage sag is detected, the rotor flux linkage is controlled immediately to track a reduced fraction of the changing stator flux linkage by controlling the rotor-side converter, and in this way, the rotor current can be effectively reduced. Compared with other schemes, this method is very simple to implement [17], and the fault rotor current can be suppressed effectively with very small torque oscillation. Several other new technologies are in development to overcome this fault in wind turbine systems.

5. Conclusion

One of the biggest problems faced by the wind turbine farms is LVRT or FRT especially with the DFIG. This type of asynchronous generator is unfortunately sensitive to grid voltage disturbances. To overcome this drawback, various hardware and control strategies have been developed. The conventional crowbar circuit is essential for RSC for its protection from overcurrent during any fault. The passive methods require many storage devices that lead to increase in the system cost and complexity. With maximum power point tracking algorithms and other control strategies, the LVRT capability of DFIG wind turbine can be enhanced in turn increasing the system efficiency. Therefore, further researches should be focused on the robust control strategies of DFIG.

References

[1] Yi Zhang , Ula,S. "Comparison and evaluation of three main types of wind turbines", Transmission and Distribution Conference and Exposition, T&D. IEEE/PES 2008.

[2] Morren, Johan, de Haan, S.W.H.,"Short-Circuit Current of Wind Turbines With Doubly Fed Induction Generator", IEEE Transactions On Energy Conversion, Vol. 22, No. 1, March 2007.

[3] Polinder ,H., Abrahamsen, Atallah,K. McMahon, Ferreira, Jensen "Trends in Wind Turbine Generator Systems", IEEE Journal of Emerging and Selected Topics In Power Electronics, Vol. 1, No. 3, September 2013.

[4] Muyeen S.M., Takahashi R., Murata, T,Tamura, J., "A Variable Speed Wind Turbine Control Strategy to Meet Wind Farm Grid Code Requirements", Power Systems, IEEE Transactions on (Volume:25 , Issue: 1), Feb 2010.

[5] Wenyong Guo, Liye Xiao, Shaotao Dai "Enhancing Low-Voltage Ride-Through Capability and Smoothing Output Power of DFIG With a Superconducting Fault-Current Limiter–Magnetic Energy Storage System", IEEE Transactions on Energy Conversion, Vol. 27, No. 2, June 2012.

[6] Mohseni.M., Islam.S., Masoum.M.A.S., "Impacts of Symmetrical and Asymmetrical Voltage Sags on DFIG-Based Wind Turbines Considering Phase-Angle Jump, Voltage Recovery, and Sag Parameters", IEEE Transactions on Power Electronics, Vol. 26, No. 5, May 2011.

[7] Wessels.C, Gebhardt.F, Fuchs.F.W., "Fault Ride-Through of a DFIG Wind Turbine Using a Dynamic Voltage Restorer During Symmetrical and Asymmetrical Grid Faults", IEEE Transactions on Power Electronics, Vol. 26, No. 3, March 2011.

[8] Jin Yang, Fletcher.J.E., O'Reilly.J., "A Series-Dynamic-Resistor-Based Converter Protection Scheme for Doubly-Fed Induction Generator During Various Fault Conditions", IEEE Transactions On Energy Conversion, Vol. 25, No. 2, June 2010.

[9] Okedu.K.E., Muyeen.S.M., Takahashi.R.,Tamura.J., "Wind Farms Fault Ride Through Using DFIG With New Protection Scheme", IEEE Transactions on Sustainable Energy, Vol. 3, No. 2, April 2012.

[10] Pannell. G., Zahawi. B., Atkinson. D.J., Missailidis .P., "Evaluation of the Performance of a DC Link Brake Chopper as a DFIG Low-Voltage Fault-Ride-Through Device", IEEE Transactions On Energy Conversion, Vol. 28, No. 3, September 2013.

[11] Andrew Causebrook, David J. Atkinson, and Alan G. Jack**,**"Fault Ride-Through of Large Wind Farms Using Series Dynamic Braking Resistors", IEEE Transactions on Power Systems, Vol. 22, No. 3, August 2007.

[12] Chong H. Ng, Li Ran, and Jim Bumby, "Unbalanced-Grid-Fault Ride-Through Control for a Wind Turbine Inverter", IEEE Transactions on Industry Applications, Vol. 44, No. 3, May/June 2008.

[13] Lasantha Gunaruwan Meegahapola, Tim Littler, and Damian Flynn,"Decoupled-DFIG Fault Ride-Through Strategy for Enhanced Stability Performance During Grid Faults", IEEE Transactions On Sustainable Energy, Vol. 1, No. 3, October 2010.

[14] Christian Wessels, Fabian Gebhardt , "Fault Ride-Through of a DFIG Wind Turbine Using a Dynamic Voltage Restorer During Symmetrical and Asymmetrical Grid Faults", IEEE Transactions On Power Electronics, Vol. 26, No. 3, March 2011.

[15] Surour Alaraifi, Ahmed Moawwad, Mohamed Shawky El Moursi, ,Vinod Khadkikar, "Voltage Booster Schemes for Fault Ride-Through Enhancement of Variable Speed Wind Turbines", IEEE Transactions on Sustainable Energy, Vol. 4, No. 4, October 2013.

[16] Shuai Xiao, Geng Yang, Honglin Zhou, and Hua Geng, "An LVRT Control Strategy Based on Flux Linkage Tracking for DFIG-Based WECS", IEEE Transactions on Industrial Electronics, Vol. 60, No. 7, July 2013.

[17] Dawei Xiang, Li Ran, Peter J. Tavner, and Shunchang Yang, "Control of a Doubly Fed Induction Generator in a Wind Turbine During Grid Fault Ride-Through", IEEE

Transactions on Energy Conversion, Vol. 21, No. 3, September 2006.

[18] Jean Patric da Costa, Humberto Pinheiro, Thomas Degner, and Gunter Arnold, “Robust Controller for DFIGs of Grid-Connected Wind Turbines” IEEE Transactions on Industrial Electronics, Vol. 58, No. 9, September 2011.

[19] Massimo Bongiorno, Torbj¨orn Thiringer, “A Generic DFIG Model for Voltage Dip Ride-Through Analysis”, IEEE Transactions on Energy Conversion, Vol. 28, No. 1, March 2013.

[20] Theodoros D. Vrionis, Xanthi I. Koutiva, Nicholas A. Vovos, Gabriel B. Giannakopoulos, “Control of an HVDC Link Connecting a Wind Farm to the Grid for Fault Ride-Through Enhancement”, IEEE Transactions on Power Systems, Vol. 22, No. 4, November 2007.

[21] B. Silva, C. L. Moreira, H. Leite, and J. A. Peças Lopes, “Control Strategies for AC Fault Ride -Through in Multiterminal HVDC Grids”, IEEE Transactions On Power Delivery, Vol. 29, No. 1, February 2014.

[22] Longya Xu, Inoa. E., Yu Liu , Bo Guan, “A New High-Frequency Injection Method for Sensorless Control of Doubly Fed Induction Machines”, IEEE Transactions on Industry Applications, Vol. 48, No. 5, September/October 2012.

[23] Mishra. Y., Mishra. S, Fangxing Li, Zhao Yang Dong, “Small-Signal Stability Analysis of a DFIG-Based Wind Power System Under Different Modes of Operation”, IEEE Transactions On Energy Conversion, Vol. 24, No. 4, December 2009.

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