Journal of Energy Technologies and Policy
ISSN 2224-3232 (Paper) ISSN 2225-0573 (Online)
Vol.4, No.12, 2014

Comparative Evaluation between Direct Connected and VSC-HVDC Grid Connected Wind Farm

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Abstract
Nowadays, the penetration level of wind power generation plants has reached a high level. The double Fed Induction Generator (DFIG) based wind turbines are the most preferred type, due to their advantages. Following the impact of wind power plant onto power system, they are now requested by the utilities through grid codes to participate to the grid support and stabilization. For the safety of network operations, an evaluation of DFIG grid connection methods is needed to provide a performance platform in grid connection interface choice and grid codes requirement.This paper presents a comparative study of dynamic behavior of two methods of DFIG wind turbine connection to the grid: direct method and the connection through high voltage direct current transmission system (VSC-HVDC), during the fault.
Keywords: Mathematical model of DFIG, fault ride-through (FRT)/ low voltage ride-through (LVRT) requirement, impact of FRT/LVRT on wind farm, VSC-HVDC, MATLAB/Simulations

1. Introduction

Actual energy crisis, unpredictability in fossil fuel price and ecological concerns have raised the trends towards renewable energies such as wind energy, solar energy, biomass, wave energy, fuel cell etc. Today among the renewable energies available ,wind energy represents the fastest growing technology in energy production space globally today and this trends is going on as projections of future suggests 422 GW of wind power that would be installed by 2020,compared to the current 273 GW in 2011 (Ackerman,2005;WWEA ,2012).

This expected high penetration of wind power into the existing power system raised concerns regarding the impacts of large wind power plants, as intermittent generation units, on the stability of existing power networks. For the safety of network operations from those issues, utilities in many countries have put in place measures and requirements known as grid codes for large wind farms to be connected to transmission or distribution systems (WEC, 2013). Modern grid codes request from wind power plants not only the fault ride through capability but also their contribution to the network stability and ancillary service provision, as do conventional generation units (Jian *et al, 2012)*. Among those requirements are 1) active power control 2) frequency control 3) voltage and reactive power issues 4) fault ride-through (FRT)/low voltage ride-through (LVRT) (Julekhabi & Jadhav,2013).

Among different types of wind turbines, Double Fed Induction Generator (DFIG) turbine is the leading on the market with a share of more than 60% of the installed worldwide wind turbines are of this type. It is preferred due its various advantages such as high energy efficiency, variable speed, reduced mechanical stress on turbine and power electronics convertor having low rating and cost (Julekhabi &Jadhav, 2013). There are two ways of interconnecting the DFIG wind turbine to the grid: 1) the conventional way, where the machine stator windings are connected to the grid at the point of common connection (PCC) via collection and/or transmission transformers, while the rotor windings of the DFIG are connected to the grid through the converter in parallel with the stator at the point of common connection (PCC). 2) the other method is the connection to the grid through an HVDC link; this method is VSC-HVDC based and presents an advantage of decoupling reactive and active power which is sought for the grid support as required by grid codes (Lihui *et al*,2012).

With direct method of DFIG connection to the grid, when fault occurs on the grid, it produces voltage dip. If this low voltage is seen, the disconnection of power plant is performed in order to protect the wind farm from the negative impact of voltage dip. However this disconnection of wind farm produces unfavourable effect on remaining generating units. In order to conform to the grid codes fault ride-through (FRT)/ low voltage ride-through (LVRT) requirement, different methods of DFIG control are investigated in (Mansour &Syed,2012).

In this paper a comparison of dynamic behavior of both DFIG's grid connection methods, is performed through Matlab/Simulink simulations of the system.

2. DFIG wind turbine

The configuration of a basic double fed Induction generator is shown in Figure 1. The rotor is connected to the grid through converters. The function of rotor side converter is to implement power control of wind power generation system. The control objective of grid side converter is to maintain the stability of the DC link voltage and to adjust power factor (Meihua *et al*,2011).

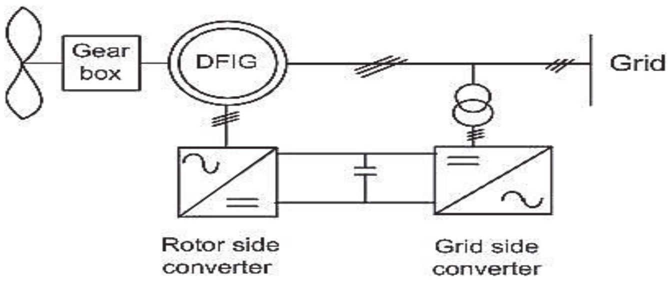

Figure 1. DFIG based wind generation configuration

The control of power and voltage is achieved by control the magnetizing current from the grid by the rotor side converter. As it is shown on DFIG equivalent circuit modeled in dq frame on Figure 2. The mathematical model derived from it, gives equations (1) to (4), with V-dqs and V-dqr as the stator and rotor voltages in dq reference frame while l_{dqs} and l_{dqr} are currents of both stator and rotor in the dq reference frame as well. ω_e and ω_r are angular frequencies of supply and rotor respectively, λ_{dqs} and λ_{dqr} are the dq stator and rotor flux linkages. R_s And R_r are stator and rotor resistances respectively.

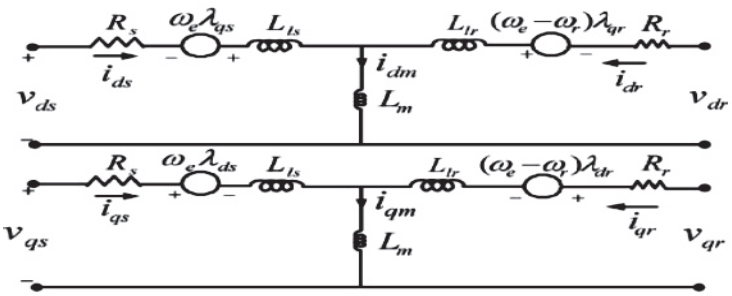

Figure 2. DFIG equivalent circuit model

$$V_{ds} = R_s\, i_{ds} + \frac{d\lambda_{ds}}{dt} - \omega_e \lambda_{qs} \tag{1}$$

$$V_{qs} = R_s\, i_{qs} + \frac{d\lambda_{qs}}{dt} + \omega_e \lambda_{ds} \tag{2}$$

$$V_{qr} = R_r\, i_{qr} + \frac{d\lambda_{qr}}{dt} + (\omega_e - \omega_r)\lambda_{dr} \tag{3}$$

$$V_{dr} = R_r\, i_{dr} + \frac{d\lambda_{ds}}{dt} - (\omega_e - \omega_r)\lambda_{qr} \tag{4}$$

Where:

$\lambda_{qs} = L_s\, i_{qs} + L_m i_{qr}$; $\lambda_{ds} = L_s\, i_{ds} + L_m i_{dr}$

$\lambda_{qr} = L_r\, i_{qr} + L_m i_{qs}$; $\lambda_{dr} = L_r\, i_{dr} + L_m i_{ds}$

$L_s = L_{ls} + L_m$; $L_r = L_{lr} + L_m$

And where for both models:

L_{ls} = Stator leakage inductance
L_{lr} = Rotor leakage inductance
L_m = Magnetizing inductance
L_r = Total rotor inductance

L_s = Total stator inductance
The control of reactive and active power of a DFIG is achieved by adjustment of rotor q axis current, i_{qr}, as according to Shri *et al* (2012), the power is given by

$$P_s = \frac{3}{2}\left(V_{ds}\, i_{ds} + V_{qs} i_{qs}\right) = -\frac{3}{2} * \frac{L_m}{L_s} * V_{qs} i_{qr} \tag{5}$$

$$Q_s = \frac{3}{2}\left(V_{ds}\, i_{ds} - V_{qs} i_{qs}\right) = \frac{3}{2} * \frac{L_m}{L_s} * V_{qs}\left(i_{ms} - i_{qr}\right) \tag{6}$$

3. VSC-HVDC system
Figure 3 shows the schematic diagram of a 2-terminal VSC-HVDC transmission system connecting a large wind farm to AC grid. With VSC-HVDC system it is possible to control reactive and active powers independently. The reactive power flow can be controlled separately in each converter by the ac voltage that is requested or set manually without changing the dc voltage. The active power flow can be controlled by dc voltage on the dc side or the variation of frequency of ac side, or set manually. Thus, the active power flow, the reactive power flow, the ac voltage, the dc voltage and the frequency can be controlled when using VSC-HVDC (Tsili &Papathanassiou, 2009).

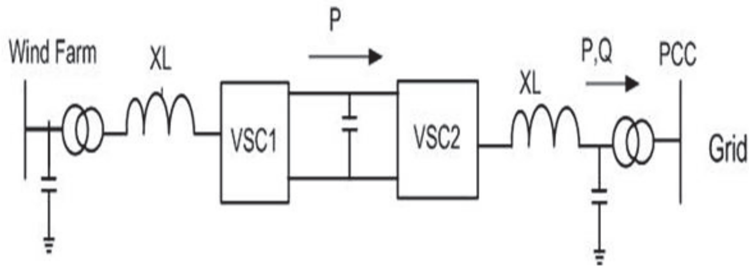

Figure 3. Schematic diagram of a VSC-HVDC system

The control system of the VSC-HVDC, shown on Figure 4, is based on a fast inner current control loop controlling the ac current. The ac current references are supplied by the outer controllers. The outer controllers include the dc voltage controller, the ac voltage controller, the active power controller, the reactive power controller or the frequency controller. The reference value of the active current can be derived from the dc voltage controller, the active power controller and the frequency controller. The reference value of the reactive current can be obtained from ac voltage controller and reactive power controller.

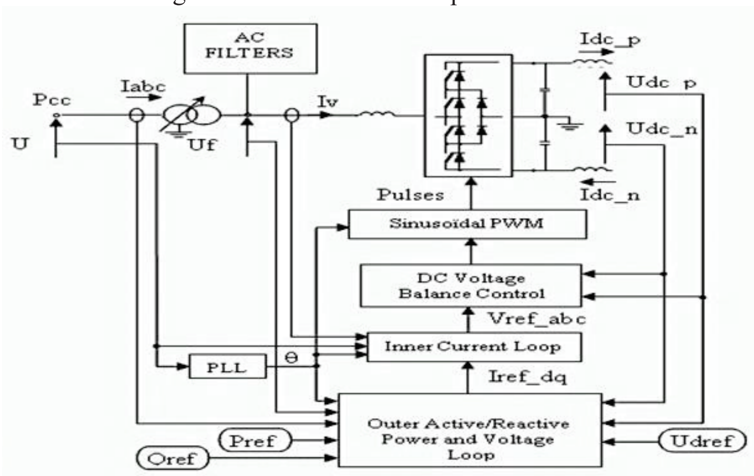

Figure 4. VSC-HVDC converter control system

4. System description
The set up for the comparative study of the dynamic behaviour of a direct and VSC-HVDC grid connected DFIG wind farm is shown in Figures 5 and 6 respectively. Simulations were carried out using MATLAB/Simulink.

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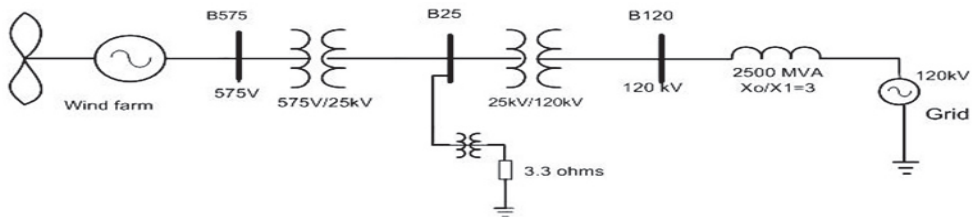

Figure 5. Single line diagram of a DFIG wind farm direct connection to grid

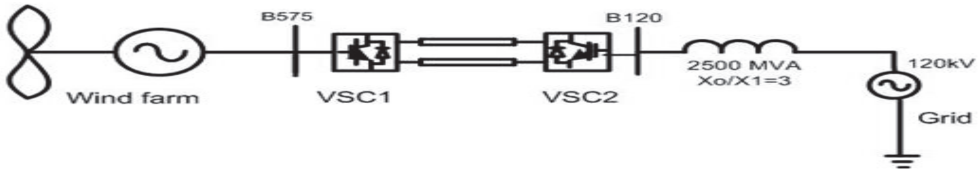

Figure 6. Single line diagram of a DFIG wind farm VSC-HVDC grid connected

As shown in Figures 5 and 6, a wind farm of 120 kV/ 150 MW is connected to a 120 kV/60 Hz AC grid represented by synchronous generator. The wind farm is connected using a direct method and through a HVDC-VSC system. For both methods, a symmetrical fault is introduced on grid side in order to observe their dynamic responses.

5. Simulations results

Figure 7 shows simulations results of a wind farm connected to grid directly. A fault is introduced at t=1.5s for a duration of 120 ms on grid side, voltage on grid side Vabc_B120 goes to zero. The fault reflects directly onto the wind farm side, where an increase of current Iabc_B575 and a decrease of voltages Vabc_B575 are observed. That in turn causes a sudden increase in generator speed *wr*.

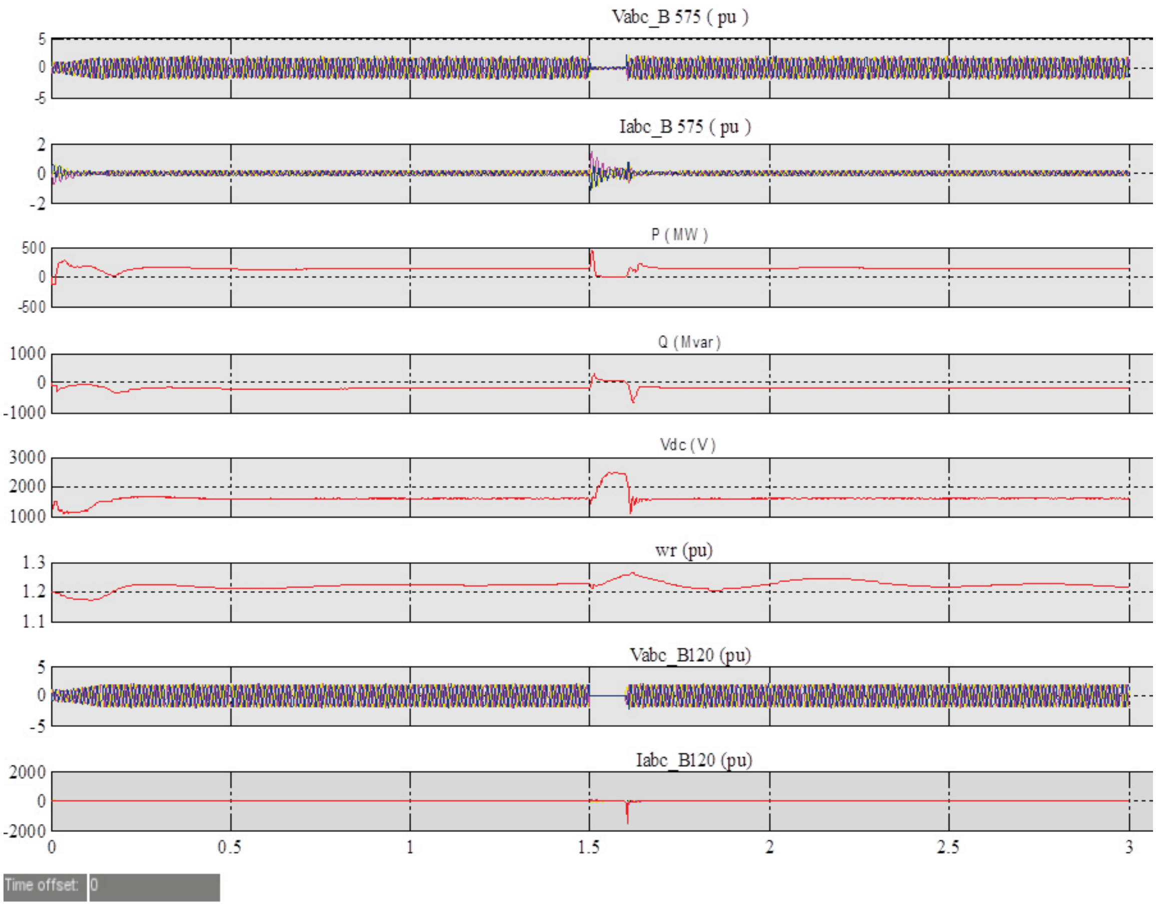

Figure7. Simulation results of a DFIG wind farm directly connected to grid

Simulations results for VSC-HVDC grid connected DFIG based wind farm are shown on Figure 8. Same as previously, a symmetrical fault is introduced at t=1.5 s for period of 210 ms. When a fault occurs, the grid side voltages Vabc_B120 drop to zero while short circuit currents Iabc_B120 are high. The wind farm side is less affected as only voltage sag is observed on Vabc_575 all along fault duration, the power generated P (MW) increases for the support of the grid and the generator speed *Wr* increases slightly.

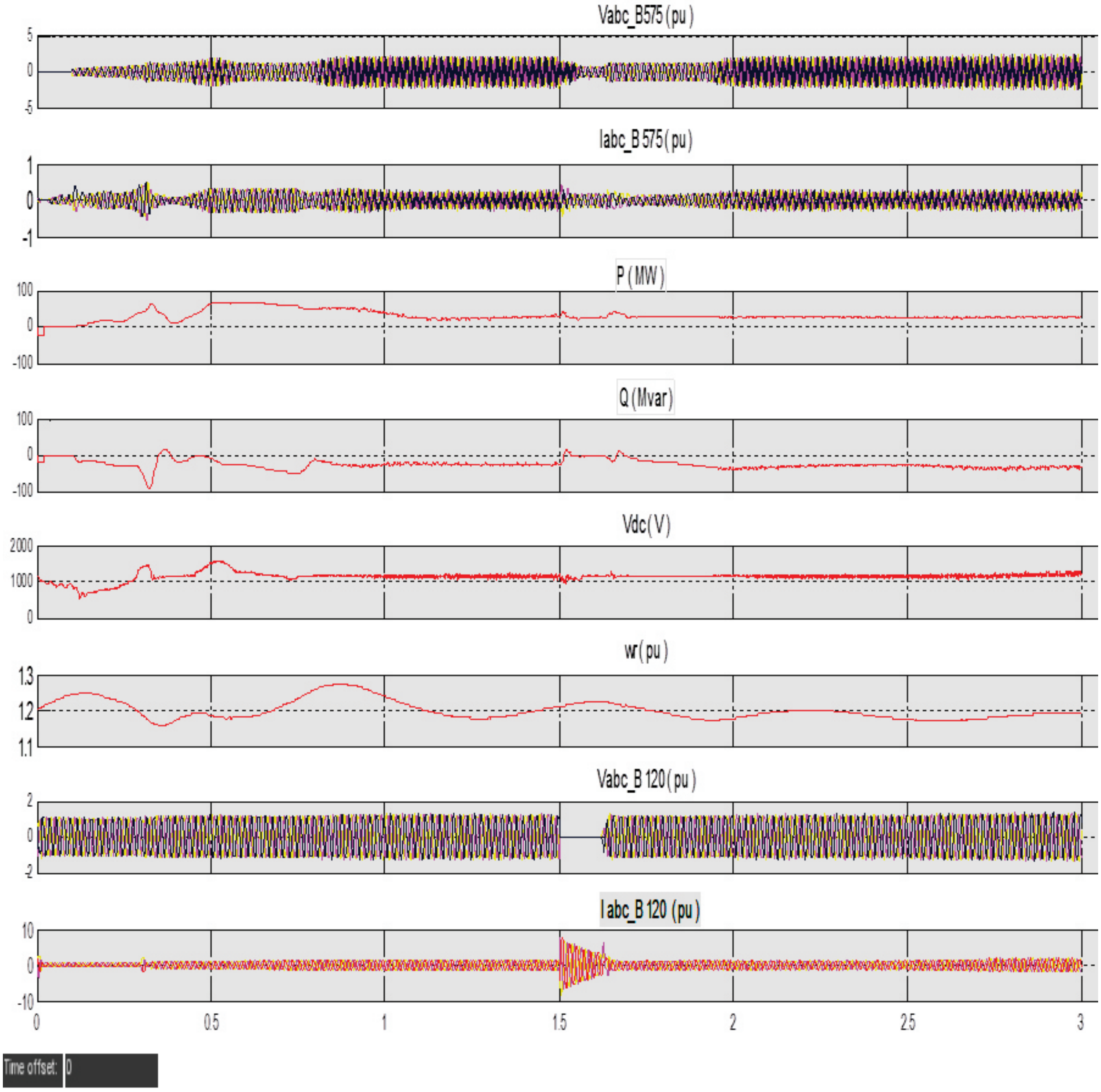

Figure 8 Simulation results of a DFIG wind farm VSC-HVDC grid connected

5. Conclusion

Fault-ride through behaviors of both methods of DFIG connection to the grid is presented in this paper. The VSC-HVDC grid-connection of DFIG based wind farm is the best method compared to the direct-connection method. As the latter shows that the fault on the grid side directly affects the wind farm operation according to the grid codes and hence would not be able to remain connected and participate in grid support. While for the VSC-HVDC as interface for wind farm connection to grid, during the fault the wind farm is less affected such that it can rather contribute to the stabilization of the grid. Though performing well, the VSC-HVDC grid connection method for DFIG based wind farm is expensive therefore an improvement of direct grid connected method is needed to achieve a low cost interface as well as the improvement in terms of control, voltage regulation and reactive power dispatch.

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