Reduction in Dc-Voltage Fluctuation Using Pi Controller in DFIG-Based Wind Energy Converters Under Normal and Fault Conditions

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Abstract - Variable-speed Wind Energy Conversion Systems(VSWECS) based on doubly fed induction generators (DFIG) share a prodigious part in today's wind power market. They offer the benefits of adjustable speed operation efficiently and can regulate active and reactive power independently. For a DFIG-based wind generation system, the grid-side converter (GSC) controls the common dc-link voltage and whereas rotor-side converter (RSC) controls DFIG's stator active and reactive power output. The fluctuations in dc-link voltage cut down the lifetime and reliability of capacitors in voltage source converters. This paper proposes a dc-link capacitor voltage control method for grid-side converter by incorporating PI controller. The analysis was performed for normal, under symmetrical fault andunsymmetrical fault conditions on DFIG integrated with grid.

Keywords- wind energy conversion system (WECS), DFIG, PI controller, dc-link voltage, symmetrical fault, unsymmetrical fault, RSC, GSC

I. INTRODUCTION

Wind energy has established itself as the fastest growing renewable energy source worldwide. Increasing penetration of wind energy conversion system (WECS) in the conventional power system has put tremendous challenge to the power systems operators as well as planners to ensure reliable and secure grid operation [1]. Grid utilities require extended reactive power supply capability not only during fault condition but also in steady-state operation [2]. As per the grid codes applicable in different countries, it is expected that the wind energy conversion systems should tolerate certain voltage disturbances such as unbalance and distortion without tripping. To fulfill these expectations the overall performance of the wind energy conversion systems needs to be improved.Amongst contemporary wind energy technologies, the doubly fed induction generator is extensively accepted in wind energy industry. Wind turbines based on doubly fed induction generator (DFIG), with converters rating ranging from 25% to 30% of the nominal rating of the machine have been widely used for multi-megawatt wind turbines [3].

DFIG is fundamentally a wound rotor induction generator in which controlling of rotor circuit is possible by power converters to accomplishadjustable speed operation. The stator winding of the DFIG is integrated with the grid via transformer whereas the connection of rotor to grid is made through AC-DC-AC converters. Harmonic filter is included in the converter to eliminate the distortions in power being fed to grid which were produced by solid state devices of power converters. The power flow from stator to grid is unidirectional whereas the direction of power flow between rotor circuit to grid depends upon the operating conditions those are governed by variable wind speed. The exchange of power between grid and rotor circuit takes place via rotor-side converter(RSC) and grid-side converter(GSC) which are coupled by coupling capacitor. The rotor circuit handles around 30% power of the stator circuit due to slip, so the required rating of the power converters incorporated in rotor circuit is also around 30% . This leads to increased overall efficiency and reduced cost of the system.

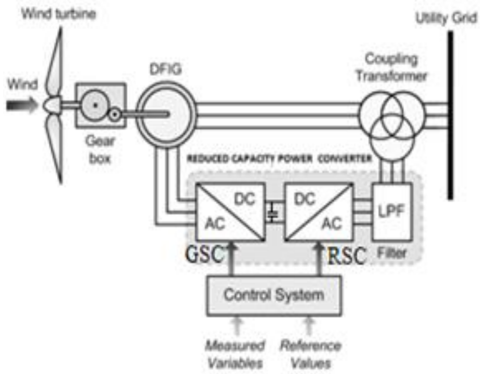

Fig. 1: DFIG connected to Grid

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The DFIG can operate in both sub- and super-synchronous speed. Availability of consistent wind is required for the reliable operation of the wind energy conversion system connected to grid. To extract the power available in wind at variable wind speeds, the variable speed operation of DFIG is satisfactory where the speed range requirements are small e.g. ±30% [4].

Fig. 1 depicts a configuration of DFIG based energy conversion system. The stator is integrated with LV distribution grid whereas rotor is linked with grid via RSC, GSC and harmonic filter. The converters, RSC and GSC are connected back-to-back via a common dc- link coupling capacitorThe fluctuations in dc-link voltage reduces the lifetime and reliability of capacitors in converters[5],[6],[7].Proposed PI controller is included in GSC controls to control the dc-link voltage. The control keeps the dc-link voltage stable under normal and symmetrical and unsymmetrical fault conditions to ensure reliable operation of coupling capacitor.

II. DFIG SYSTEM DESCRIPTION & MODELING

A DFIG-based wind turbine of 1.5 MW is coupled to a 25 kV busvia 575/25 kV transformer.25 kV bus is integrated with 120 kV grid via 5 km feeder and 25kV/120kV transformer.In the Fig. 2(i) the doubly-fed induction generator (DFIG) which is essentially of a wound rotor induction generator is integrated with grid, there is a direct coupling of stator with grid and IGBT based PWM converters in the rotor circuit establish the connection between rotor and grid. Both the PWM converters are coupled by dc-link capacitor of 10pF.

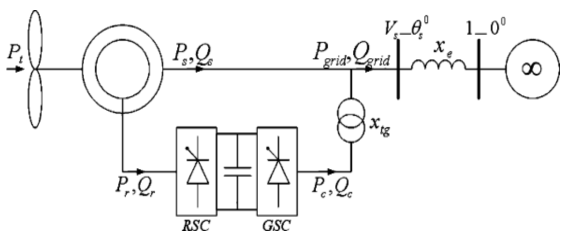

Fig.2(i):Active & Reactive Power Flow in DFIG System

Due to variable speed operation, the DFIG based wind energy conversion systems are capable of capturing maximum energy from the wind for lower wind speeds by optimizing the turbine speed. During gust of wind there are severe mechanical stresses and vibrations in the low speed and high speed shaft of the turbine and there effect can be minimized by adjustable speed of DFIG.

DC Link Voltage Control using PI Controller

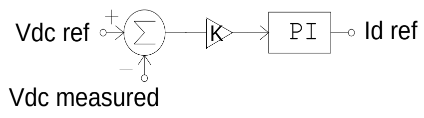

Fig.2 (ii): DC-Link Voltage controller

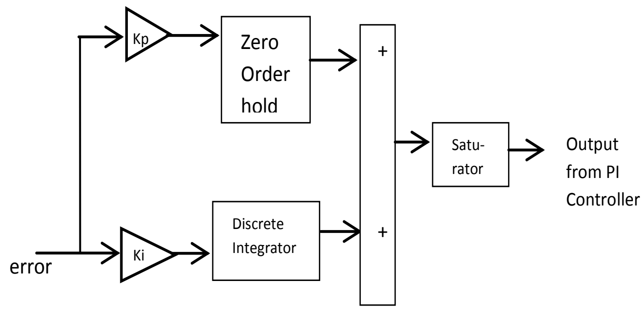

Fig.2(iii): PI Controller

With the help of PI controller of proportional gain Kp of 7 and integral gain Ki of 300, the voltageappearing across dc-link capacitor Vdcis regulated at 1150 V and reactive power is maintained at 0 Mvar. Under normal and faultcondition the Vdcis regulated around of 1150 V..The system is simulated under various conditions and corresponding results were obtained*using MATLAB/Simulink.*

III. DFIG RESPONSE TO VARYING OPERATING CONDITIONS

Case I : DFIG connected to grid under normal condition without control of DC link voltage V_{dc}:

The simulation results shown in fig 3(i) depicts large variation in Vdc. The reference DC link voltage is 1150 V.

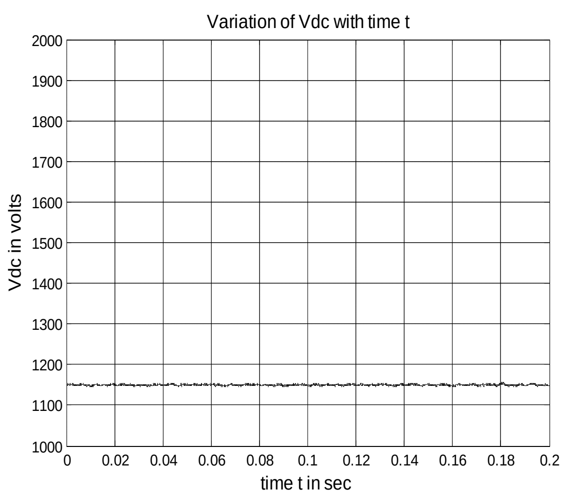

Fig. 3 (i):Simulation result for normal operation without control of Vdc

Case II : DFIG connected to grid under normal condition with control of DC link voltage V_{dc}PI controller:

With PI controller, the voltage of coupling capacitor is regulated at reference value of 1150 V as shown in the fig. 3(ii).

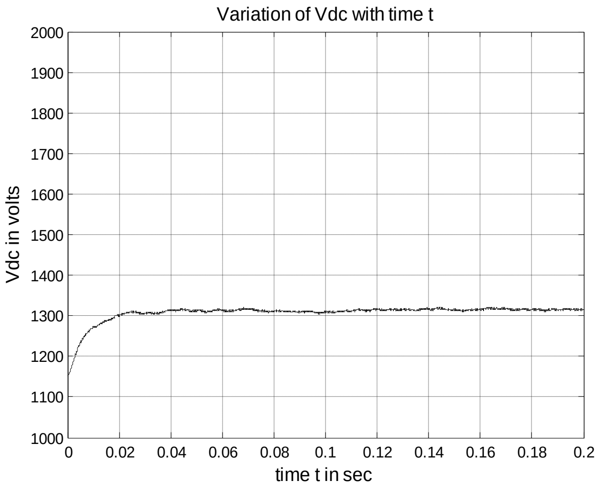

Fig. 3(ii): Simulation result for normal operation with control of Vdc by PI Controller

Case III : DFIG connected to grid with symmetrical fault (LLLG) on grid without control of DC link voltage:

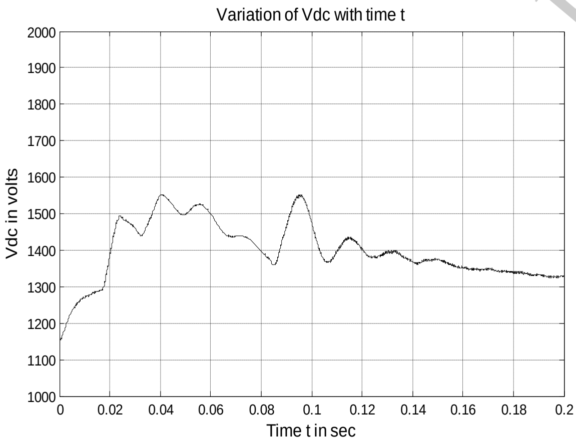

Fig. 3(iii):Simulation result for symmetrical fault without control of Vdc

Under the condition of symmetrical LLLG fault at the grid, Vdc varies with time when Vdc controller is not included as shown in Fig.3(iii).

Case IV : DFIG connected to grid with symmetrical fault (LLLG) on grid control of DC link voltage $V_{dc}$by PI controller:

With PI controller, the fluctuation in voltage are reduced as shown in the fig. 3(iv).

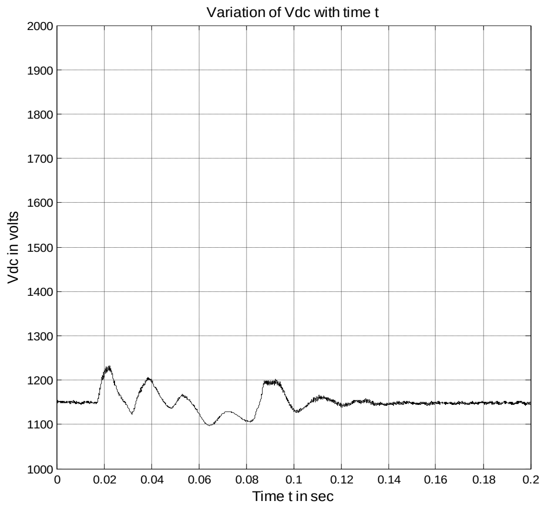

Fig. 3(iv): Simulation result for symmetrical fault with control of Vdc by PI controller

Case V : DFIG connected to grid with unsymmetrical fault (LLG) on grid without control of DC link voltage:

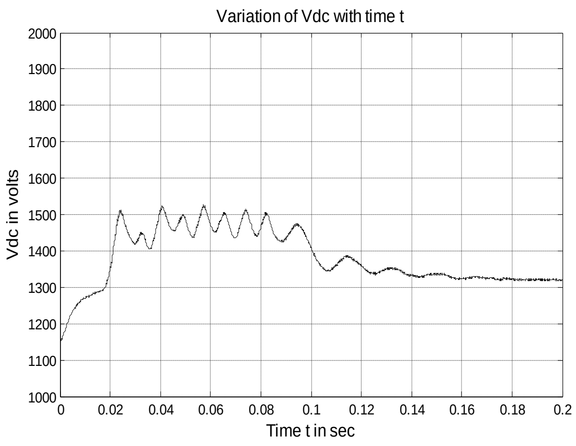

Fig. 3(v): Simulation result for unsymmetrical fault (LLG) without control of Vdc.

When an unsymmetrical LLG fault occurs on the bus, there are large variations in Vdc with time without Vdc controller as shown in Fig.3 (v). The peak value of Vdc is much greater than the ref value of 1150V.

Case VI : DFIG connected to grid with unsymmetrical fault (LLG) on grid control of DC link voltage V_{dc}PI controller:

With Vdc voltage controller, the variations in voltage of coupling capacitor are reduced and restricted around reference Vdc of 1150 V as shown in fig.3(vi).

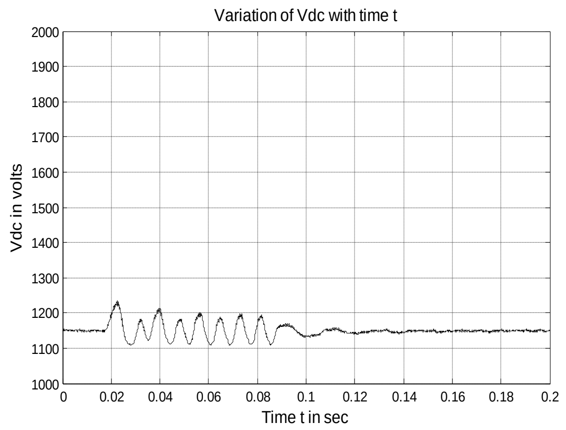

Fig. 3(vi):Simulation result for unsymmetrical fault(LLG) with control of Vdc by PI controller

Case VII : DFIG connected to grid with unsymmetrical fault (LG) on grid without control of DC link voltage:

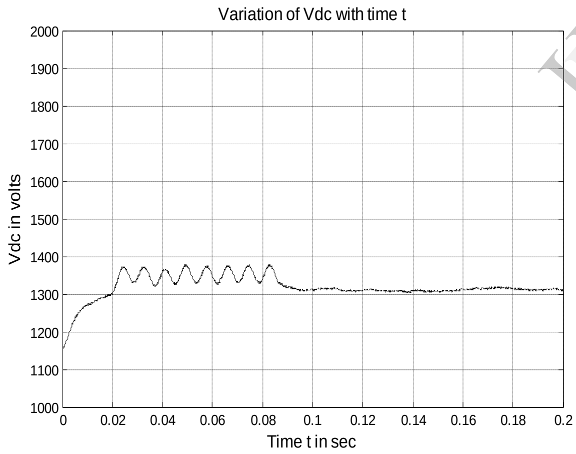

Fig. 3(vii):Simulation result for unsymmetrical fault (LG) without control of Vdc

When an unsymmetrical LG fault occurs on the bus, there are large variations in Vdc with time without Vdc controller. The peak value of Vdc is much greater than the ref value of 1150V as shown in Fig 3(vii).

Case VIII : DFIG connected to grid with unsymmetrical fault (LG) on grid control of DC link voltage V_{dcby} PI controller:

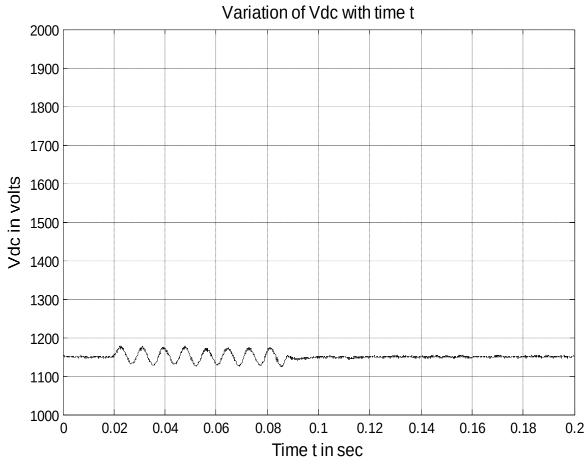

Fig. 3(vii) :Simulation result for unsymmetrical fault(LG) with control of Vdc by PI controller

By applying control for coupling voltage Vdc by PI controller the fluctuation in vdc are reduced substantially as shown in Fig 3(vii). Further peak of oscillations are reduced around 1150 V.

TABLE 1: Summary of simulation results with and without control of DC bus voltage (Vdc):

S.No.	Operating Condition	Range of Vdc (Volts)	
		Without PI Controller	With PI Controller
1	Normal	1140-1320	1140-1160
2	Symmetrical Fault (LLLG)	1160-1570	1100-1230
3	Unsymmetrical fault(LLG)	1160-1520	1100-1230
4	Unsymmetrical fault(LG)	1160-1380	1130-1180

IV. CONCLUSIONS

Grid code requires wind farms connected to grid to ride-through grid faults and provide active & reactive power support for grid-voltage recovery. In DFIG operation reliable operation of RSC & GSC converters is mandatory. As both the converters are connected via DC link capacitor, the reliability of coupling capacitor needs to be assured for stabilized DC bus voltage. Proposed PI controller included in GSC reduces the fluctuation in coupling capacitor voltage under normal operation as well under the condition of various grid faults as shown in Table-1. The reduction in variation of DC-link voltage is facilitated by the control scheme. The simulation results show satisfactory operation of controller for symmetrical as well as unsymmetrical fault at grid.

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