Anand. V. Satpute, Subroto Dutt / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 3, Issue 4, Jul-Aug 2013, pp.667-671

Transient Analysis of Wind Based-DFIG

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ABSTRACT

Demand for wind power has increased considerably due to technological advances and favorable government policies. As a result, large wind farms with multi-megawatt capacity are connected to sub-transmission and transmission systems. With high penetrations of wind energy, performance of the overall system is affected by the technical impacts introduced by wind turbine generators (WTG). Fault current contributions from WTGs will have a significant impact on the protection and control of the wind farm as well as the interconnected system. This paper initially describes the modeling aspects of Doubly- Fed Induction Generator (DFIG) during steady state and faulty conditions. Vector decoupling control strategy has been adopted to establish the mathematical model of DFIG based wind generator. Further, a 9 MW wind farm with 6 units of 1.5 MW DFIG is modeled in Matlab/Simulink and, voltage and current waveforms are presented and discussed for 3- phase fault, phase to phase fault and phase to ground fault created at the generator terminal and close to MV bus.

Keywords: Decoupled control, doubly-fed induction generator, dynamic performance, mathematical modeling, wind power.

I. Introduction

India is a rapidly transforming country. Due to liberalization and globalization, steady growth was witnessed in India‘s GDP for the last two decades. Energy is the life line for economic growth. India‘s current primary commercial energy requirements are mostly fed by conventional fuel sources such as coal, oil, natural gas, hydro and nuclear that totals to about 520 million tonnes of oil equivalent (mtoe) and this is expected to raise to 740 mtoe by end of 12th plan i.e., 2016-17. Currently India is importing energy to the 19 mtoe and this has to increase to 280 mtoe to meet the above demands. This will be highly expensive, hence it is necessary to harness renewable energy resources like solar, wind, biomass, etc. to meet part of the demand. In this paper an attempt is made to use the available technology to tap wind power and generate electricity. The transmission system operators (TSOs) currently demand more reliability to wind power technologies; therefore, standards with regard to the connection, operation, and maintenance of such power plants become more restrictive. In this scenario, simulation tools such as MATLAB, where the distributed generation networks can be analyzed in deep, have gained a great importance for designing advanced functionalities and control strategies to improve the integration of wind energy.

Wind turbines can either operate at fixed speed or variable speed. For fixed speed wind turbines, the induction generator is directly connected to the electrical grid accordingly. Since the speed is almost fixed to the grid frequency and most certainly not controllable, it is not possible to store the turbulence of the wind in form of rotational energy.

For a variable speed wind turbine the generator is controlled by power electronic equipment. There are several reasons for using variable-speed operation of wind turbines among those are possibilities to reduce stresses of the mechanical structure, acoustic noise reduction and the possibility to control active and reactive power. These large wind turbines are all based on variable- speed operation with pitch control using a doubly-fed induction generator. Today, variable-slip, i.e., the slip of the induction machine is controlled with external rotor resistances, or doubly- fed induction generators are most commonly used by the wind turbine industry for larger wind turbines.

In order to guarantee the safety and reliability for wind power integration operation, it is of great significance to establish an appropriate wind power generator system model and analyze electro- magnetic transient
characteristics.

II. Basic concepts of DFIG

The basic layout of a DFIG is shown in Fig.1

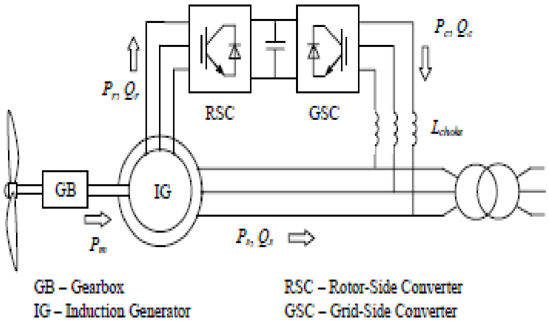

Fig.1. DFIG connected to a grid.

A doubly-fed induction generator is a standard wound rotor induction machine with its stator windings directly connected to grid and its rotor windings connected to the grid through an AC/DC/AC converter.AC/DC converter connected to rotor winding is called rotor side converter and another DC/AC is grid side converter. Doubly-fed induction generator (DFIG) is used extensively for high-power wind applications. DFIG's ability to control rotor currents allows for reactive power control and variable speed operation, so it can operate at maximum efficiency over a wide range of wind speeds. The aim of this paper is to develop a control method and analysis of dynamic performance of DFIG's rotor control capabilities for unbalanced stator voltages, grid disturbances and dynamic load condition.

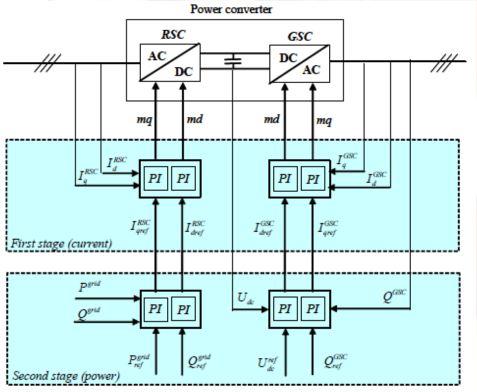

Fig.2.Control structure of DFIG

In modern DFIG designs, the frequency converter is built by self-commutated PWMconverters, a machine- side converter, with an intermediate DC voltage link. Variable speed operation is obtained by injecting a variable voltage into the rotor at slip frequency. The injected rotor voltage is obtained using DC/AC insulated gate bipolar transistor based voltage source converters (VSC), linked by a DC bus. By controlling the converters, the DFIG characteristics can be adjusted so as to achieve maximum of effective power conversion or capturing capability for a wind turbine and to control its power generation with less fluctuations. Power converters are usually controlled utilizing vector control techniques, which allow decoupled control of both active and reactive power.

III. Case study

The purpose of this study is to understand the behavior of a wind farm with DFIGs, under different faulty conditions. A 9 MW wind farm with six DFIG based wind turbine generators, each having a capacity of 1.5 MW has been considered in this study. Various symmetrical and asymmetrical faults have been created at the generator terminal and at the MV Bus. Time domain voltage and current waveforms at generator terminal and at the MV bus are observed for 0.02 seconds. Simulations start at t=0 sec and faults are created at t=0.02sec. Faults are cleared after

0.02 sec at t=0.04 sec. Fault resistance has been kept constant at 0.001Ω.

3.1Three Phase fault

3.1.1 At the generator terminal

A three phase fault is created at the generator terminal at t=0.02s and cleared at t =0.04s.Fig.3 shows the voltage and current waveforms at the generator terminal and close to MV bus. During the fault, voltages of all three phases reach very low values as shown in Fig.3. Ideally this should reach to zero, but in practice, there will be some fault resistance and hence will have a very small magnitude voltage values. Generator terminal current will suddenly increase at the instant of fault initiation followed by a rapid decay as determined by the transient impedance of the generator.

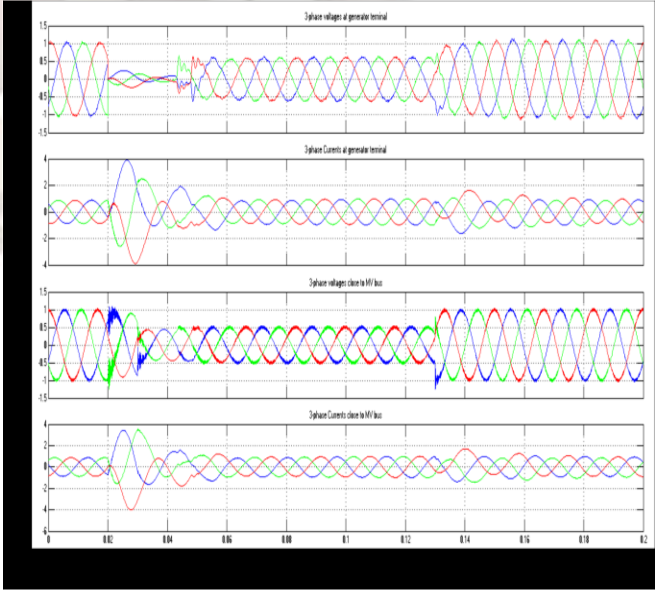

Fig. 3 Voltages and currents at generator terminal

and MV bus for a 3-phase fault at generator terminal Voltage drop on the MV bus is marginal when compared to the voltage drop at the generator terminal. This is due do the positive sequence generator step-up transformer impedance, positive sequence impedance of the collector cable section and the fault resistance.

During the fault period, current at MV bus jumps to a high value and will not experience an appreciable decay as shown in fig.3. This is due to the feeding from the other generators and from the power system.

3.1.2 At MV Bus

A three phase fault is created at the medium Voltage bus at t=0.02s and cleared at t=0.04s. Voltage and current waveforms at generator terminal and MV Bus are shown in Fig.4. There is voltage collapse at the instant of the fault initiation and a small residual voltage is present during the fault period. This may be due to the additional fault loop impedance introducedby step up transformers and cables. Results are similar to a three phase fault at the generator terminal.

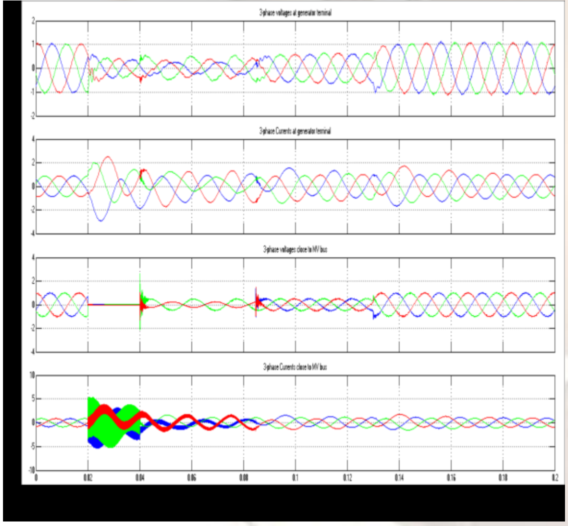

Fig. 4. Voltages and currents at generator terminal and

MV bus for a 3-phase fault at MV Bus

4.2. Phase- Phase fault

4.2.1 At the generator terminal

A phase to phase (phase ‗a‘ to phase ‗b‘) fault is created at generator terminal at t=0.02s and cleared at t=0.04s.

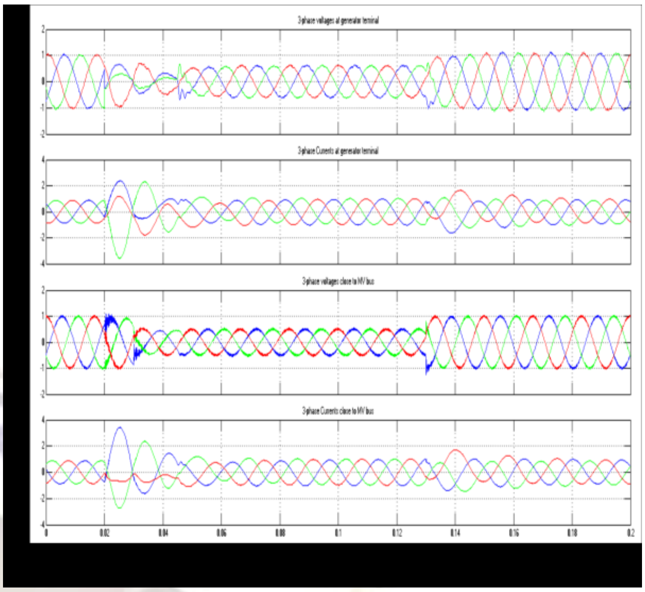

Fig.5 Voltages and currents at generator terminal and MV bus for a 3-phase fault at generator terminal Current going through phase ‗a‘ should return through phase ‗b‘ during the fault condition. After the fault initiation, this can be seen as $I_a=-I_b$, phase ‗a‘ current and phase ‗b‘ current going in opposite directions as shown in Fig.5. Ideally, phase ‗c‘ current should decay to zero. Initially there is a marginal drop of phase ‗c‘ current and afterwards a transient condition results. This is due to the feeding from other wind generators and from the power system.

4.2.2 At MV Bus

A phase to phase (phase ‗a‘ to phase ‗b‘)fault is created at MV bus at t=0.02s and cleared at t=0.04s.Voltage and current waveforms are obtained at generator terminal and MV bus as shown in Fig.6.

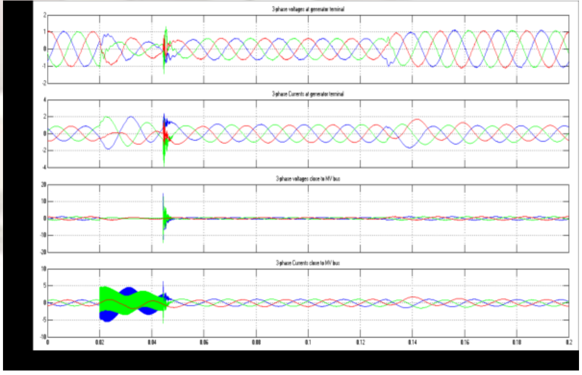

Fig. 6.Voltages and currents at generator terminal and MV bus for a Phase-phase fault at MV Bus.

3.3 Phase- ground fault

3.3.1 Phase- ground fault at generator terminal

A phase to ground fault is created at Generator terminal at t=0.02s and cleared at t=0.04s. The voltage and current waveforms are obtained at generator terminal and MV bus as shown in Fig.7. Current waveforms at generator terminal for the single phase to ground fault on generator terminal is shown in fig. 8. Ideally, phase ‗b‘ (green color) and phase ‗c‘ (red color) currents should drop to zero, and phase ‗a‘ (blue color) should experience an over current. A marginal increase in phase ‗a‘ (blue color) is observed and a reduction in phase ‗b‘ and ‗c‘ voltages can be seen in Fig.7.

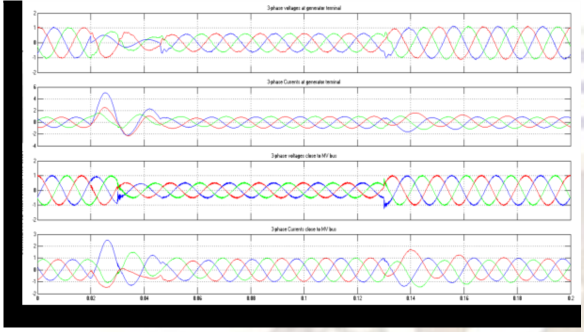

Fig.7.Voltages and currents at generator terminal and MV bus for a Phase-ground fault at generator terminal.

C.2 Phase- ground fault close to MV Bus

A phase to ground fault is created close to MV Bus at t=0.02s and cleared at t=0.04s.The voltage and current waveforms are obtained at generator terminal and MV bus as shown in Fig.8.

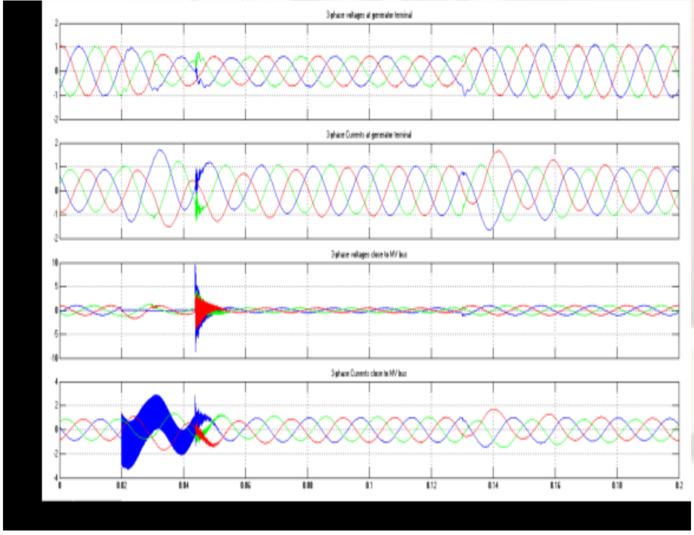

Fig.8 Voltages and currents at generator terminal and MV bus for a Phase-ground fault at MV Bus

IV. Conclusion

This paper presents a study of the dynamic performance of variable speed DFIG coupled with wind turbine and the power system is subjected various symmetrical and unsymmetrical faults located at various locations in the power system. The dynamic behavior of DFIG under power system disturbance was simulated using MATLAB platform using vector control concept. Accurate transient simulations are required to investigate the influence of the wind power on the power system stability.

The DFIG considered in this analysis is a wound rotor induction generator with slip rings. The stator is directly connected to the grid and the rotor is interface via a back to back partial scale power converter (VSC). Power converter are usually controlled utilizing vector control techniques which allow the decoupled control of both active and reactive power flow to the grid.

TABLE 1 Below. Effect of various faults created at locations X and Y within the power system. Location X, Y denote at generator terminal and at MV bus respectively. In this paper, a 9 MW wind farm is modelled and simulated for symmetrical and asymmetrical faults at generator terminal and at MV bus in the power system. Voltage and current waveforms are presented and compared with those under ideal fault conditions. Authors conclude that understanding fault current behavior will help in selecting proper instrument transformers, switchgear and control gear, and in designing effective protection systems.

Fault		Variations of quantities			
		near generator terminal		close to MV Bus	
Type	Location	Voltages	Currents	Voltages	Currents
3 phase fault	X	-70%	+300 %	-50%	+300 %
	Y	-50%	+250 %	-100%	+500 %
Phase (A)-phase (C) fault	X	-20%	+100 %	-50%	+300 %
	Y	-50%	+100 %	-100%	+400 %
phase (A)-ground fault	X	-50%(A),-20%(B,C)	+400 % (A), +100 % (B,C)	-50% (A,B,C)	+150 % (A), +20% (B,C)
	Y	-20% (A)	+100 % (A)	-100% (A), No change(B,C)	+200 % (A), +90% (B,C)

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