Novelty Journals

ISSN 2394-9678

International Journal of Novel Research in Electrical and Mechanical Engineering
Vol. 2, Issue 1, pp: (36-40), Month: January - April 2015, Available at: www.noveltyjournals.com

Simulation Based Comparative Analysis of DFIG-Based Wind Farms and Conventional Wind Farms with Synchronous Generator

[1]Neha Verma, [2]Arun Pachori

[1] PG Student, [2]Associate Professor, Department of EE, Government Engineering College, Jabalpur, India

***Abstract:* This paper presents the simulation based comparative analysis of DFIG (Doubly Fed Induction Generator) based wind farms and conventional wind farms with synchronous generator connected to power grid. A suitable model of doubly fed induction generator for wind turbine system is developed in MATLAB/Simulink, then this model is analysed by simulating it in time domain. This Model simulation analysis is used to study the effect on system stability while replacing conventional generation system with synchronous generator by DFIG-based wind generation system. The results show that the oscillatory behaviour associated with the dominant mode of the synchronous generator is improved when the DFIG-based wind turbine is connected to the system.**

***Keywords*: Wind Energy Generation, Synchronous Generator, Doubly Fed Induction Generator, System Stability, MATLAB Simulation.**

1. INTRODUCTION

With the strong enhance in renewable energy generation during the last few years, particularly in the wind energy generation, new grid codes have been released, stipulating particular requirements concerning grid support during steady-state operation and grid faults. However, most of the renewable energy generation systems are based on other generation principles and use modern control hardware such as power electronic devices like DFIG. By contrast, the control of a conventional power plant with SG is rather slow. The dynamic behaviour during and immediately after fault clearing is dominated by the inertial response of the SG, which then is followed by transients affected by the excitation system. The conventional concept of synchronous generator (SG) is directly connected to the power system via a power transformer and the control of terminal voltage is by the field excitation. The rotor windings of the DFIG-based wind turbines are connected with the use of two back-to-back converters, while the stator windings are connected directly to the network via a power transformer. The control of terminal voltage by the DFIG is performed by the two back-to back converters. The rotor side converter (RSC) and also the grid side converter (GSC) can inject reactive power simultaneously. The investigation presented in this paper compares the performance of both power plants in order to better understand the positive and negative impacts on the stability. The models are developed using the *MATLAB*/*Simulink* toolbox *SimPowerSystems.* To highlight the differences, in the behaviour of a conventional power plant equipped with SG and a wind farm consisting of DFIG-based wind turbines with the same total capacity, will be compared based on simulation results. Out of these, doubly fed induction generator is more preferable because of its several advantages. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind. Another advantage of the DFIG technology is the ability for power electronic converters to generate or absorb reactive power, thus eliminating the need for installing capacitor banks.

2. SYSTEM TO INVESTIGATE GRID SUPPORT CAPABILITY OF GENERATORS

The following single line diagram shows the system to investigate the grid support capability of DFIG and SG. This single line diagram is used to study the steady-state and dynamic performance of a 10 MW wind farm connected to a distribution system. The wind farm consists of five 2 MW wind turbines connected to a 25 kV distribution system exporting power to a 120 kV grid through a 30 km 25 kV feeder. The single-line diagram of this wind turbine system is illustrated as below in the figure 1.

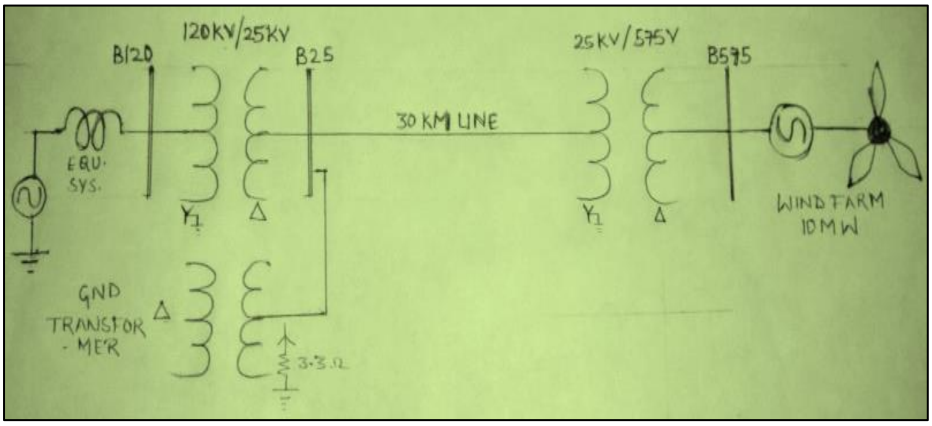

Figure1. Single-Line Diagram of the Wind Farm Connected to a Distribution System

The wind turbine has a protection system monitoring voltage, current and machine speed. The DC link voltage of the generators is also monitored. Wind turbines use a doubly-fed induction generator (DFIG) or synchronous generator (SG) as both machines will compared on basis of same system's response. A MATLAB/simulink model has been developed with the reference of this single line diagram to investigate the simulation result for the respective data of wind energy generation system connected to power grid. This model is well suited for observing harmonics and control system dynamic performance over relatively short periods of times (typically hundreds of milliseconds to one second).

3. WIND TURBINE GENERATORS

- **Synchronous Generator:**

A synchronous generator operates at the synchronously rotating speed of an alternating current system to which it is connected. A synchronous generator requires direct current to be supplied to the rotor winding via slipping to produce the rotor's magnetic flux. The prime mover (wind) drives the generator rotor forming a rotating magnetic field that induces a voltage in the stator windings of the unit. The windings of the stator are arranged so that a three-phase voltage is produced. Interactions of rotating magnetic field of synchronize rotation, which inducts a three-blade voltage. The wind turbine presented in this paper consists of a synchronous generator connected to a diode rectifier, a DC-DC IGBT-based PWM boost converter and a DC/AC IGBT-based PWM converter. The Type 4 technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind.

- **Doubly Fed Induction Generator:**

The term 'doubly fed' refers to the fact that the voltage on the stator is applied from the grid and the voltage on the rotor is induced by the power converter. This system allows a variable-speed operation over a large, but restricted, range. The converter compensates the difference between the mechanical and electrical frequency by injecting a rotor current with a variable frequency. Both during normal operation and faults the behaviour of the generator is thus governed by the power converter and its controllers. The power converter consists of two converters, the rotor-side converter and grid-side converter, which are controlled independently of each other. The rotor-side converter controls the active and reactive power by controlling the rotor current components, while the line-side converter controls the DC-link voltage and ensures a converter operation at unity power factor. Wind turbines using a doubly-fed induction generator (DFIG) consist of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter. The stator winding is connected

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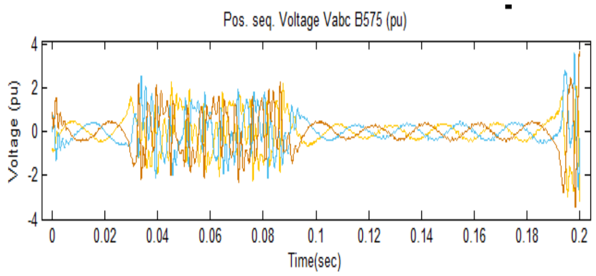
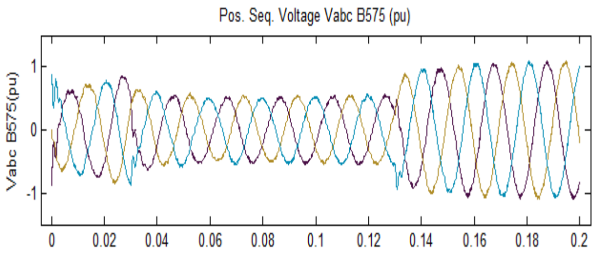
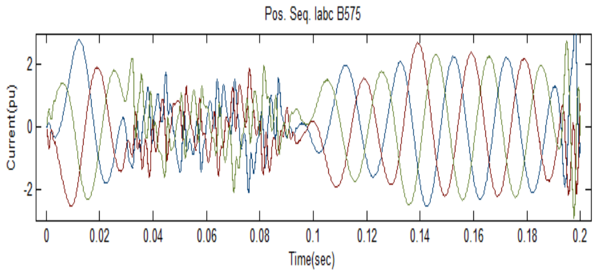
directly to the 50 Hz grid while the rotor is fed at variable frequency through the AC/DC/AC converter. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind.

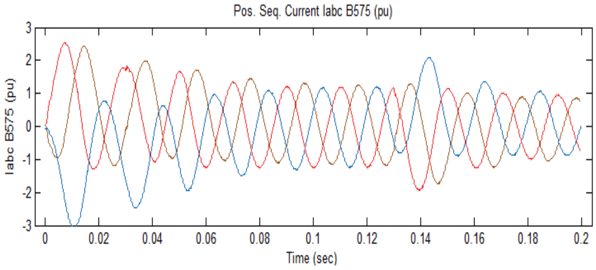
4. SIMULATION RESULT

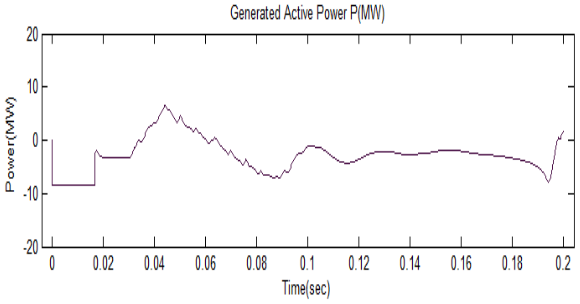
Simulation has been performed for both models of SG and DFIG for comparative analysis of system stability. In these models wind speed is maintained constant at 15 m/s. The reactive power produced by the wind turbine is regulated at 0 Mvar. This paper represents the steady-state operation of wind turbine and its dynamic response to voltage sag resulting from a remote fault on the 120-kV system. Initially wind farm produces 10 MW. The corresponding turbine speed is 1 p.u. of generator synchronous speed. The 120 kV voltage source is programmed to create six-cycle 0.5 p.u. voltage drop at t=0.03 sec. The DC voltage is regulated at 1100 V and reactive power is kept at 0 Mvar. At t=0.03 s the positive-sequence voltage suddenly drops to 0.5 p.u. causing an increase on the DC bus voltage and a drop on the wind turbine output power. During the voltage sag the control systems try to regulate DC voltage and reactive power at their set points (1100 V, 0 Mvar). The system recovers after fault elimination in approximately in 4 to 6 cycles. After simulation the waveforms obtain for both DFIG and SG model are shown below.

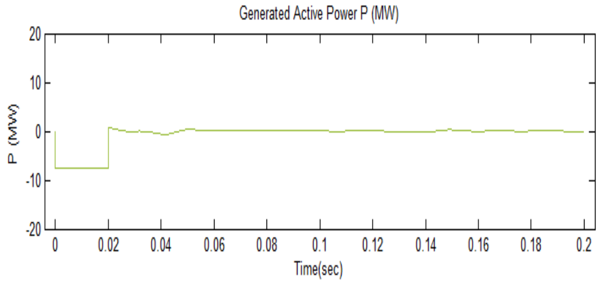


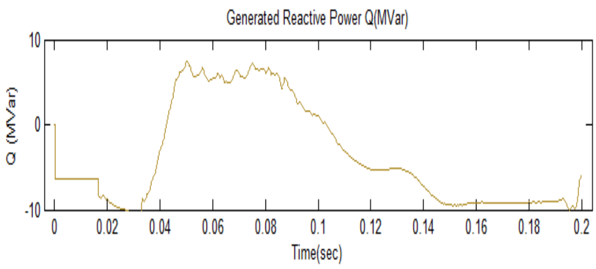


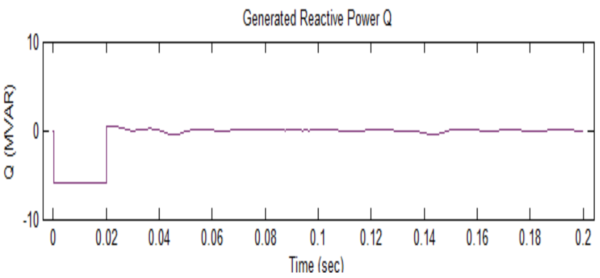












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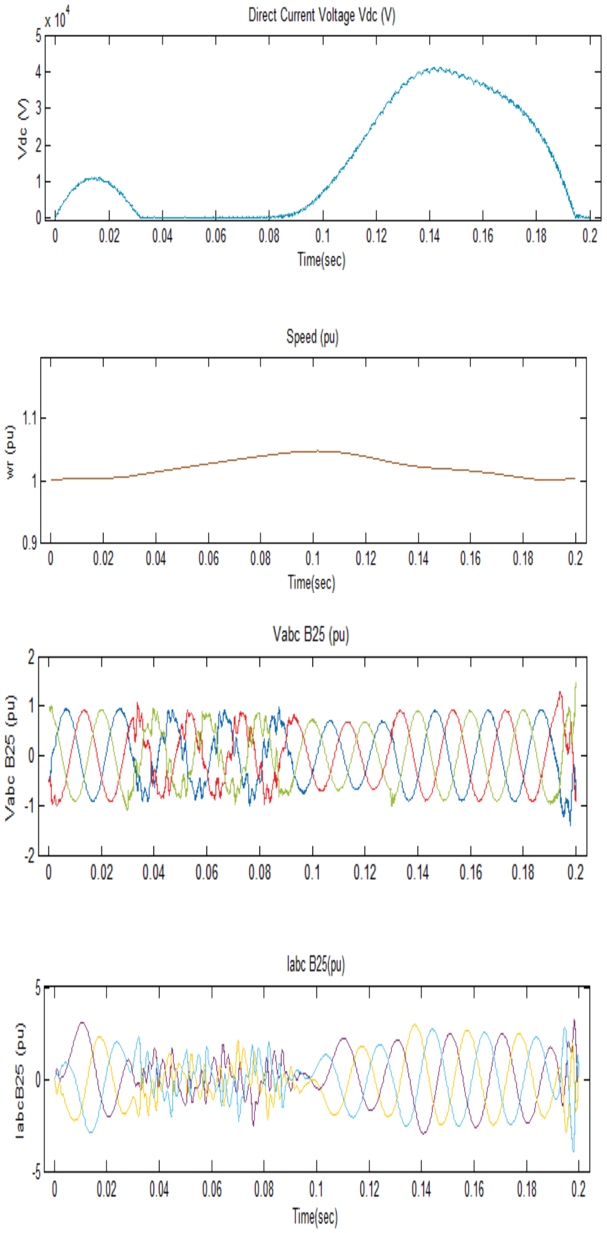
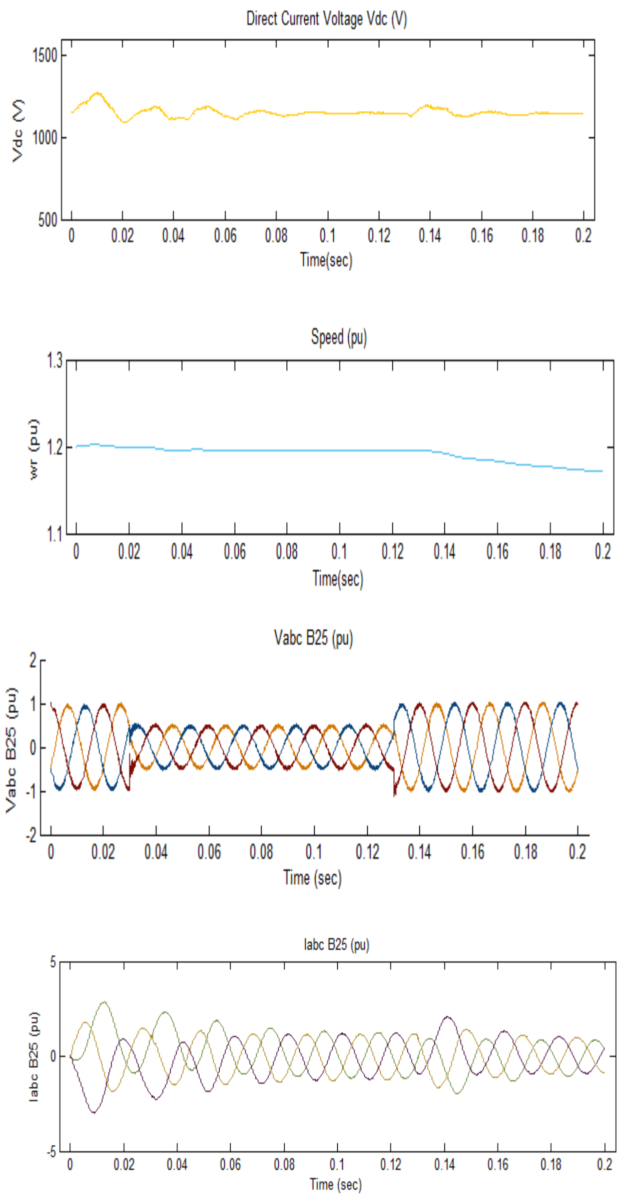


Simulated waveforms of SG



Simulated waveforms of DFIG

As shown in the figure series of output waveforms of synchronous generator and doubly fed induction generator respectively in this section, it is found data the response of synchronous generator is more oscillatory in nature as compare to DFIG. During the voltage dip the SG feeds in a higher reactive current compared to the DFIG system. After fault clearing the DFIG reduces the reactive current to zero immediately, whereas the SG goes to under excited mode for at least one second. This fact in combination with the increased active current in-feed countervails the voltage return. The result shows that the oscillatory behaviour associated with the dominant mode of the synchronous generator is improved when the DFIG-based wind turbine is connected to the system.

5. CONCLUSION

In this paper a comparison between a conventional power plant and a DFIG-based Wind warm has been done based on the technical options and limits concerning grid voltage support during faults. A MATLAB/Simulink model is developed by using SimPowerSystemsToolbox of simulink and simulating it, in the time domain based on instantaneous values. For the comparison of both generation concepts the system configurations described in second section have been simulated.

During voltage sags, the SG feeds in more reactive current than the DFIG-based wind farms and thus gives a stronger support to the grid voltage; however for smaller voltage dips resulting from distant faults, the DFIG can feed higher reactive currents. While the fast control of the DFIG allows the adjustment of the reactive currents within the current limits of the system during faults. Due to the differences in the behaviour of the studied systems, modern grid codes could formulate requirements that are more dedicated to the generation concepts. This could be done by stipulating higher gains for the voltage support characteristics in converter based generators during both grid faults and voltage recovery after grid faults, and by consideration of the real technical limits of the systems. The comparison between DFIG and SG operating during voltage sag is proposed in this paper. The results are presented and discussed considering the performance of terminal voltages and the reactive power injections. The DFIG has some limitations to control the terminal voltage during fault; however, it can operate without disconnecting from the network.

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