DFIG-Based Wind Farms and Their Performance with Thermal Connected Grid

[1] Bhola Jha,[2] K.Ram Mohan Rao and [1] G. Vinay Kumar
[1] K. L. College of Engineering, Vaddeswaram
[2] M. J. College of Engineering and Technology, Hyderabad

Abstract

The increasing wide spread use of wind generation on the power networks imposes the requirement that the wind farms should be able to contribute to the network support and operation as do conventional thermal generation stations based on synchronous generators. In this connection, this paper proposed a test system consisting of 120 KV grid connected to a thermal plant and three Doubly-Fed Induction Generator (DFIG) - based wind farms. The modeling of the system is implemented on MATLAB/SIMULINK platform. An efficient pi controller scheme is used for the DFIG system for maintaining the desired active power and reactive power. The responses of the total system under healthy and faulty conditions are addressed. The obtained results are presented to exhibit the effectiveness of the controller and validate the performance of the grid interconnected test system.

Keywords: DFIG, pi controller, fault, modeling.

1. Introduction

Wind generation is one of the mature and cost effective resources among different renewable energy technologies [1]. The increasing wide spread use of wind generation on power system networks imposes the requirement that wind farms should be able to contribute to network support and operation as do conventional generating stations based on synchronous generators [2]. If the wind generation does not provide appropriate network support, then as the proportion of conventional and wind generation varies, the changes produced in the operational characteristics of the network will make it increasingly difficult for the network operator to provide the required level of stability and security [3], [4]

The emerging grid code proposals for the wind farm connection will, of necessity, become increasingly demanding of the performance in connected wind farms with respect to voltage, frequency, reactive power, active power and fault ride through capabilities [5].

Grid issues including fault ride-through analysis are found in papers [6]-[9]. But, Grid integration with many DFIG-based wind farms is not addressed. This paper presents an effective grid interfacing of DFIG-Based wind farms. In this paper a test system is proposed, consisting of one thermal plant and three DFIG-Based wind farms, each operating under different wind speed, connected to a 120 KV grid. Sinusoidal waveform retention of DFIG and thermal plant along with the grid validate the effectiveness of grid interfacing for the proposed system. Modeling and control strategy are described. The performance analysis of various parameters like voltage, frequency, active power, reactive power of test system is extended under fault conditions also. So, this paper encourages large penetration of wind energy and meeting the requirements of emerging grid codes.

MATLAB/SIMULINK [10] is used for simulation of the proposed system. The results obtained validate the good performance of the system and exhibit the effectiveness of the controller.

This paper is divided into five sections. Section I describes the introduce-tion, II explains DFIG modeling and control, III indicates the system overview, IV highlights the results and discussion and V ends with conclusion.

2. Doubly-Fed Induction Generator Modeling and Control

Power captured by the wind turbine is converted into electrical power by DFIG-based wind farm which is shown in Fig. (1). The generator assures efficient power production at variable speed. The speed variability is made possible by directionally dependent transfer of slip power via converters. In sub synchronous speed, the stator of DIFG feeds all the generating electrical power to the grid, and additionally makes slip/rotor power Pr available, which is fed from converter to the rotor via slip rings. However in the super synchronous mode, total power consists of the components fed by stator of DFIG plus rotor power Pr, which is fed from the rotor to grid via converter. The control system generates pitch angle, and the voltage command signals Vr & Vgc for C_{rotor} and C_{grid}, respectively, in order to control the power of wind turbine, DC voltage, and voltage at grid terminals. C_{rotor} and C_{grid} have the capability for generating or absorbing reactive power and could be used to control the reactive power or the voltage at grid terminals.

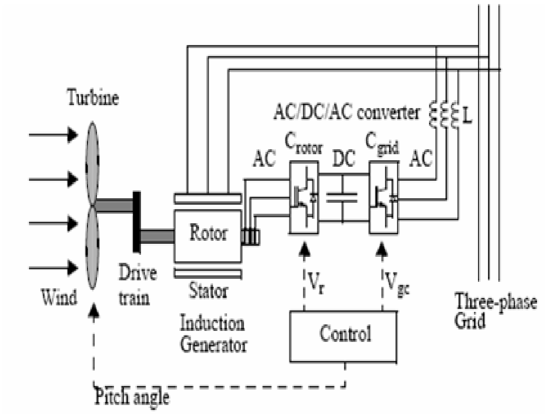

Fig. 1 The wind turbine and the doubly-fed induction generator system

For the rotor side controller, the d-axis of the rotating reference used for d-q transformation, is aligned with air gap flux. The actual electrical output power, measured at the grid terminals of the wind turbine, is added to the total power losses (mechanical and electrical) and is compared with the reference power obtained from the tracking characteristics. A Proportional-Integral (PI) regulator is used to reduce the power error to zero. The output of this regulator is the reference rotor current I_{qr_ref} that must be injected in the rotor by converter C_{rotor}. This is the current compo-nent that produces the electromagnetic torque T_{em}. The actual I_{qr} component is compared to I_{qr_ref}, and the error is reduced to zero by a current regulator (PI). The output of this current controller is the voltage V_{qr} generated by C_{rotor}. The current regulator is assisted by feed forward terms which predict V_{qr}. The voltage at grid terminals is controlled by the reactive power generated or absorbed by the converter C_{rotor}. The reactive power is exchanged between C_{rotor} and the grid, through the generator. In the exchange process the generator absorbs reactive power to supply its mutual and leakage inductances. The excess of reactive power is sent to the grid or to C_{rotor}. The control loop is illustrated in Fig. (2).

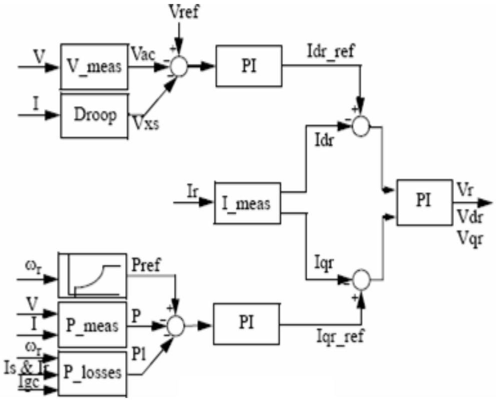

Fig. 2 rotorside controller

The converter C_{grid} is used to regulate the voltage of the DC bus capacitor. The control system is illustrated in Fig (3). For the grid-side controller, the d-axis of the rotating reference frame that is used for d-q transformation, is aligned with the positive sequence of grid voltage. This controller consists of:

1. A measurement system measuring the d and q components of AC currents to be controlled as well as the DC voltage V_{dc}
2. An outer regulation loop consisting of a DC voltage regulator: The output of the DC voltage regulator is the reference current I_{dgc_ref} for the current regulator (I_{dgc} = current in phase with grid voltage which controls active power flow).
3. An inner current regulation loop consisting of a current regulator: The current regulator controls the magnitude and phase of the voltage generated by converter C_{grid} (V_{gc}) from the I_{dgc_ref} produced by the DC voltage regulator and specified I_{q_ref} reference. The current regulator is assisted by feed forward terms which predict the C_{grid} output voltage.

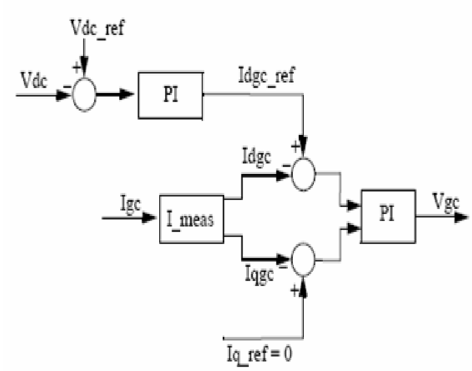

Fig. 3 grid side controller

3. Test System Overview

Three Wind Power Plants at 575V and one Thermal Power Plant at 22KV are stepped up to Grid voltage 120 KV and then interconnected as shown in Figure: 4. As per the data from Total Harmonic Distortion (THD) block, appropriate harmonic filters at the appropriate locations of transmission line are placed to suppress the harmonics, and specific filters are placed to reduce the ripples. Fault is created near the wind power plant 2. An interconnected 120 KM ring feeder line is connected to different loads at various places. Performances are addressed under healthy and faulty conditions.

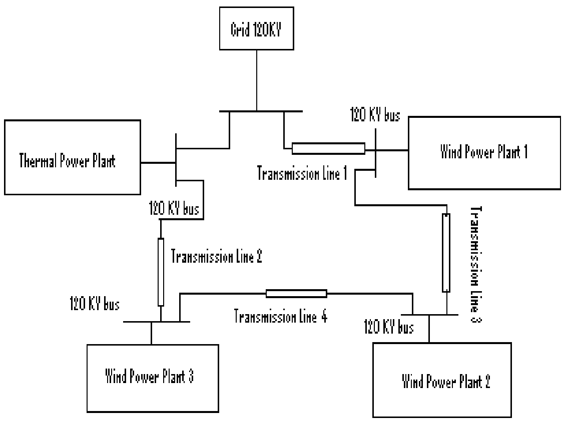

Fig. 4 System Overview

4. Results and Discussion

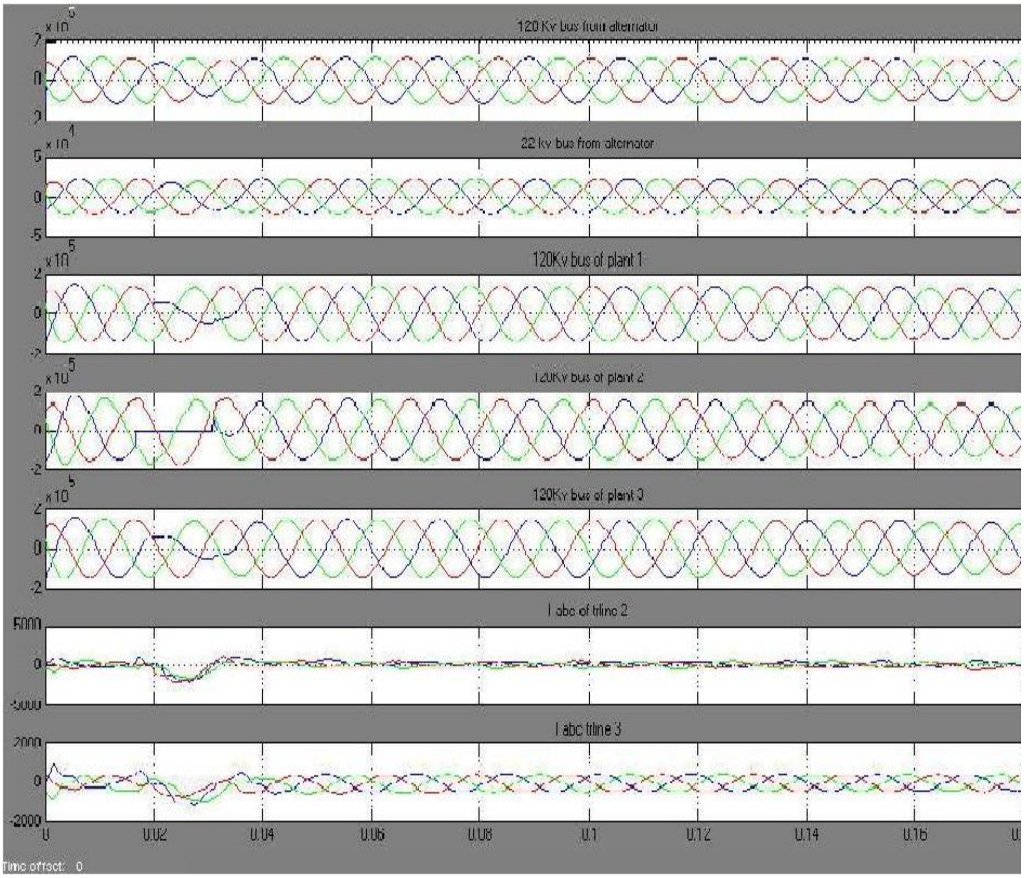

Fig. a Grid

In the above Fig a, the second waveform is the voltage output of thermal plant whose magnitude is 22 KV. This 22 KV is stepped up to 120 KV by a 600MVA transformer which is shown in the first waveform of Fig a. The waveform appears to be purely sinusoidal after placing appropriate three phase filters. The selection of three phase filters is achieved based on the data received from THD block. Voltage flickering due to loads is compensated by placing proper shunt capacitors. Third, fourth and fifth waveforms of Fig a represent the waveforms of 120 KV buses of wind plant 1, 2 and 3, respectively, under healthy and faulty conditions. Retention of the sinusoidal waveforms of the thermal and wind plants validate the perfect grid integration. Line to ground fault is created near wind power plant 2 for a time period of 0.0133 sec. A fault near wind plant 2 affects the wind plants 1 and 3 a little more as compared to the thermal plant which is clearly observed in the above waveforms. The fault effect on the thermal plant appears to be almost negligible. After the clearance of the fault, the system voltages regain their original shape. The currents are seen to lose their sequence during the fault period and regain their positions after clearance of the fault which is observed in waveforms 6 and 7.

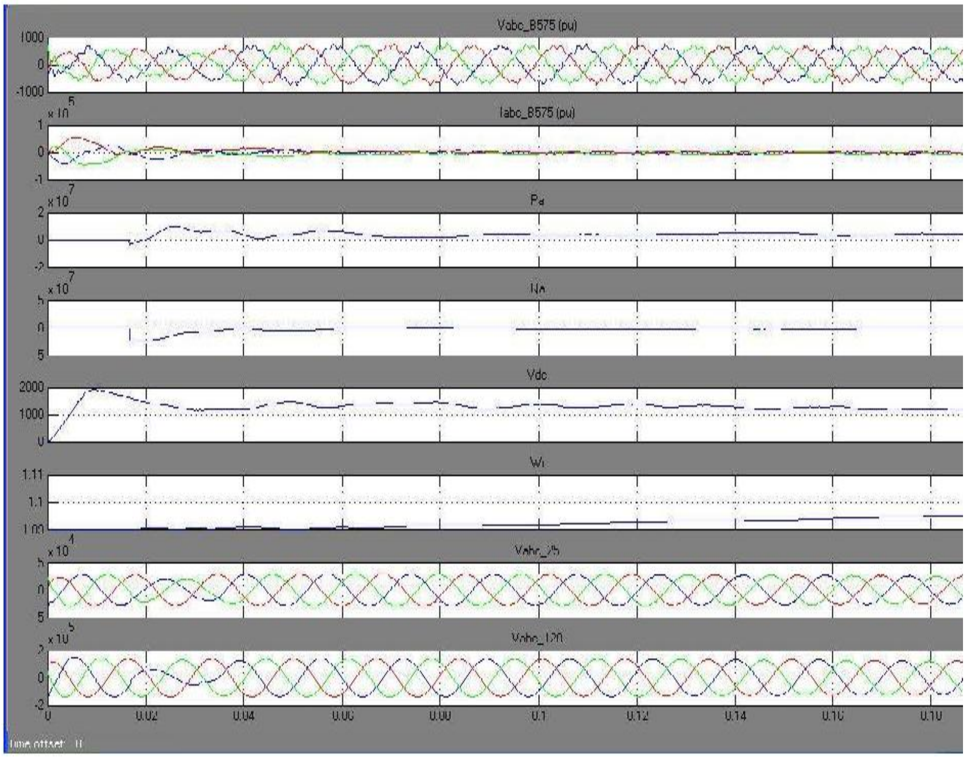

Fig. b Wind plant 1

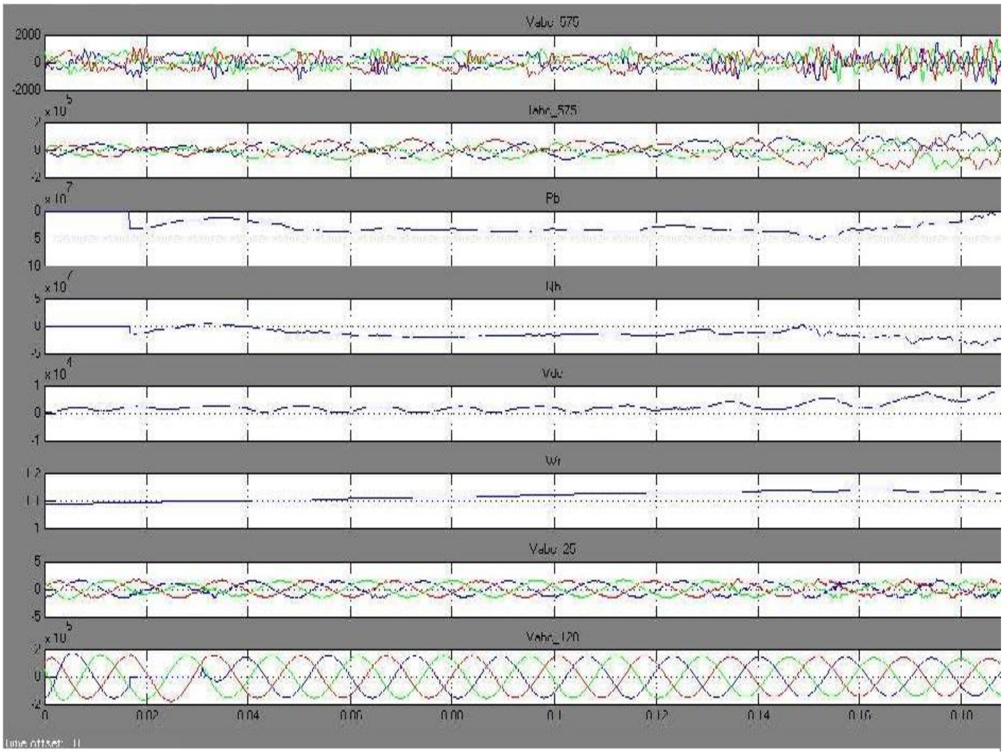

Fig. c Wind plant 2

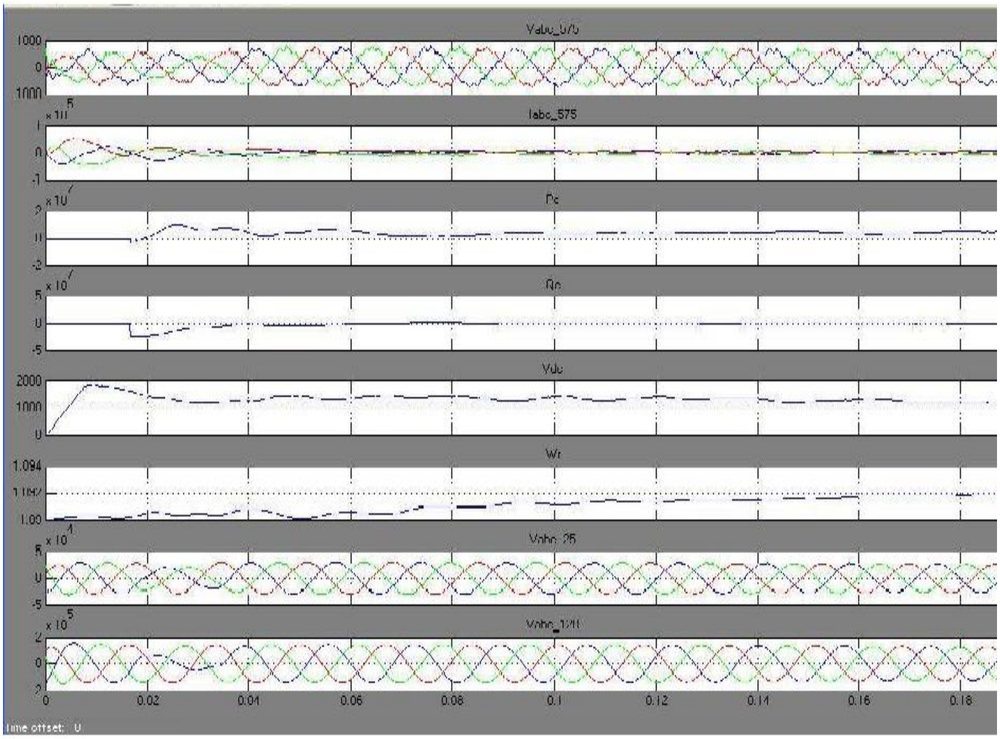

Fig. d Wind plant 3

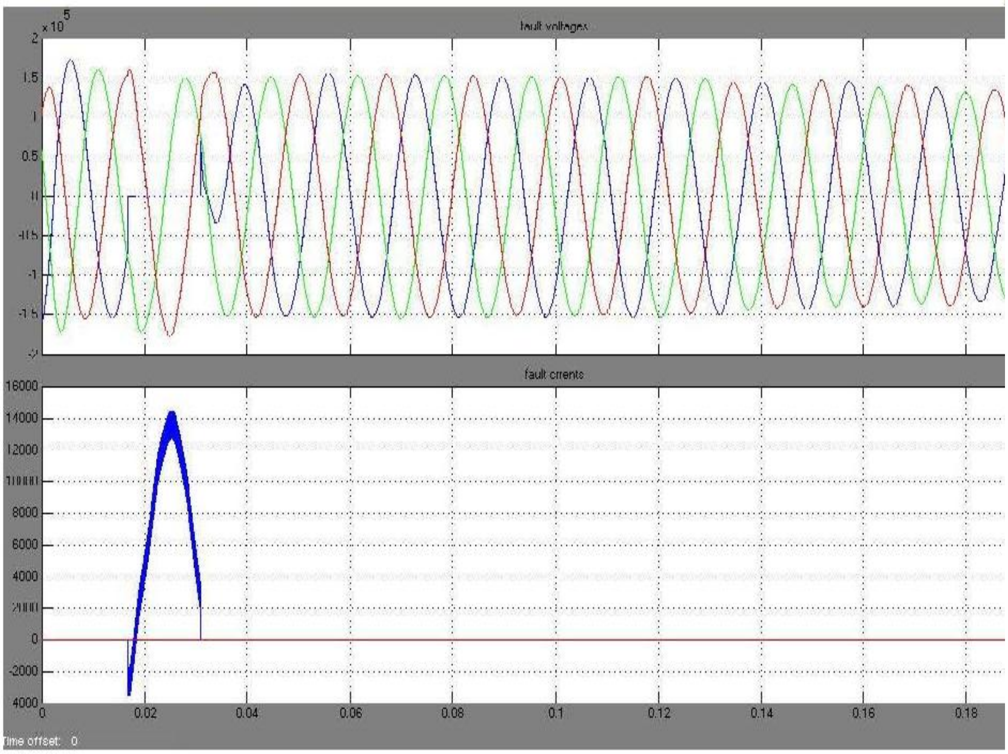

Fig. e Fault voltage & Fault current

The first waveform of Figures b, c, and d corresponds to 575 volt bus generated by DFIG. This voltage consists of harmonics which are clearly visible. Harmonics are first filtered and then stepped up to 25 KV and further stepped to 120 KV which are clearly seen in sixth and seventh waveform of Figures b, c, and d. Waveform third and fourth of Figures b, c, and d represent active and reactive power. Reactive power appears to be close to zero under varying wind speed as shown in waveform six. Zero reactive power implies unity power factor which indicates the effectiveness of pi controller. The Fifth waveform of Figures b, c, and d represents the DC link voltage within the reasonable limit for the varying wind speed. Overall we can infer that a good control strategy is developed, which is not only maintaining the desired active and reactive power, but also the DC link voltage within the limits under varying wind speed. The response for the wind plant 2 is a little more distorted due to L-G fault. The system regains the stability soon after clearance of fault which is shown in Figure e. The L-G fault on grid result in an increase of the current in the stator windings of DFIG. Because of the magnetic coupling between stator and rotor, this current will also flow in the rotor circuit and power converters. This can lead to damage of converters, which is one of the major drawbacks.

5. Conclusion

The modeling and control strategy is proved by maintaining the desired active power, reactive power and DC link voltage within the limits. Validation and good performance of the test system, consisting of thermal connected grid and DFIG based wind farms, are observed. The study can be further extended for all kinds of fault and design systems, for ride through of all kinds of faults.

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