Grenze International Journal of Engineering and Technology, July 2015

Participation of Doubly Fed Induction Generator based Wind Turbines in Power System Primary Frequency Regulation

[1]Renuka T K and [2]Dr. Reji P
[1]Department of Electrical & Electronics Engineering, MES College of Engineering, Kuttippuram, Kerala State, India
[2]Department of Electrical & Electronics Engineering, Government Engineering College, Thrissur, Kerala State, India

***Abstract*—The increasing penetration of Doubly Fed Induction Generator (DFIG) based wind turbines in the power system will result in the reduction of total system inertia. This will require new methods to control the grid frequency. This paper proposes two control methods for primary frequency control namely speed delay recovery control and droop control. Small-perturbation, linear, dynamic, transfer function models are used for the simulation of primary frequency regulation services for single-area and two-area power systems with a mix of conventional and non-conventional DFIG-based wind generators. Variation in DFIG penetration levels on system frequency control performance has been examined**

***Keywords:* DFIG, Frequency regulation , Speed delay recovery, Droop control**

I. INTRODUCTION

Now a days the worldwide trend is to integrate more wind energy in to the power system. Modern wind farms are equipped with Variable Speed Wind Turbines (VSWT). The most frequently applied variable speed drive concept is the Doubly-Fed Induction Generator (DFIG) drive. The kinetic energy of wind turbines is stored in the rotating mass of their blades, but in the DFIG based turbines this energy will not contribute to the inertia of the grid as the rotational speed is decoupled from the grid frequency by a power electronic converter. This leads to a reduction of the total system inertia of wind integrated power system and hence the frequency change will be more during a load/generation mismatch.

Even though the penetration of wind turbines into the power grid has increased, the frequency regulation and AGC tasks are mainly under taken by conventional generation units. Modern wind turbines are equipped with maximum power point tracking facilities, so that they deliver maximum power output under all possible conditions. A sustained increase in power is not possible and therefore wind turbines cannot participate in 'secondary response' services which conventional plants are able to do. Although the steady-state active power delivered to the grid by a VSWT depends on the mechanical energy transferred from the wind, they can be modified to increase their output power almost instantaneously. Recently the grid codes are revised to ensure that wind turbines contribute to control of frequency. The electric power has to be transiently controlled by using the kinetic energy stored in the mechanical system.

Grenze ID: 01.GIJET.1.2.505

II. Comparison of the Frequency Response of DFIG based Wind Turbine and Conventional Generation Plants

In Synchronous generators based conventional generating plants, any decrease in power system frequency manifests as a change in the speed of stator-led rotating flux. Such speed changes are resisted by the rotating mass (generator rotor and the wind turbine rotor) leading to rotational energy transfer to the power system via the stator. Also the Synchronous generators, which have the spinning reserve, activate the primary control by supplying the active power proportional to the frequency deviation based on the droop characteristics. After the primary control, the system operator can successively activate secondary and tertiary controls to recover the frequency to the nominal value. Figure 1 shows the block diagram of conventional generator with frequency control.

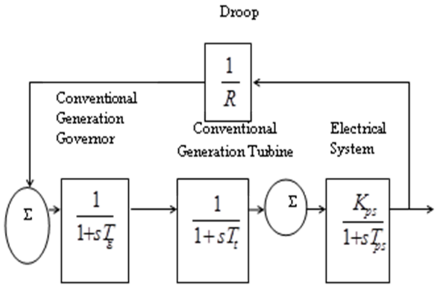

Fig.1. Block diagram of power system comprising a conventional generator with frequency control

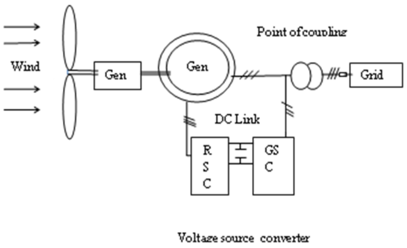

Fig. 2. Block diagram of DFIG

The stator of DFIG is directly connected to the grid whereas the rotor is connected via a power electronic converter to grid as shown in figure 2. Two way transfer of power is possible due to the converter system. The grid side converter provides a dc supply to the rotor side converter. When there is a reduction in wind speed, the rotor speed also drops and then the generator operates in a sub synchronous operating mode. In the sub synchronous mode the DFIG rotor absorbs power from the grid. During high wind speed, the DFIG wind turbine running at super synchronous speed will deliver power from the rotor through the converters to the network. Thus the rotational speed of the DFIG determines whether the power is delivered to the grid through the stator only or through the stator and rotor.

As the penetration of wind is expected to grow considerably in the coming decade, there will be a reduction in the total system inertia and greater rates of frequency change will be observed in various system contingencies (e.g. generating unit loss or sudden load variations). One of the solutions is to mimic the inherent inertial response of traditional synchronous generators; i.e., to add a control loop that helps to make the inertia of DFIG based turbine available to the grid.

III. DFIG Frequency Control

The Frequency variations can be controlled using two methods namely speed delay recovery control and droop control. The speed delay recovery module consists of DFIG mechanical inertia block together with speed regulator as shown in figure 3.The DFIG mechanical inertia block provides an output that is based on measured speed and reference speed (obtained from measured electrical power Pmeas).This output is sent to DFIG speed regulator which consists of PI controllers. Thus the speed delay recovery module provides a power set point to the wind turbine.

The droop control proposed is similar to the one usually used in the synchronous generators. The droop loop, which is characterized by a regulation R inject an active power which is proportional to the difference in nominal and measured frequency. The DFIG droop loop is shown in figure 4. This loop will be activated for a short duration that is only when there is a change in frequency. The filter ensures that the permanent frequency deviation has no effect in the control.

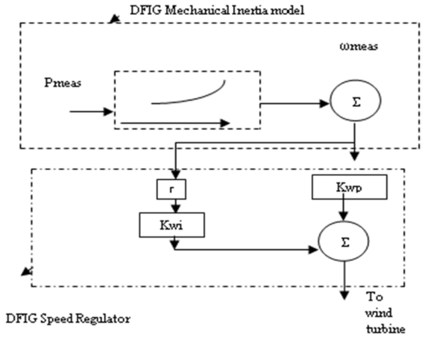

Fig 3. Speed Delay Recovery control of DFIG

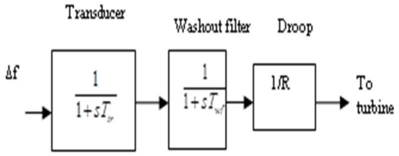

Fig. 4. Droop Loop Control of DFIG

IV. PRIMARY FREQUENCY REGULATION IN A SINGLE-AREA SYSTEM WITH DFIG-BASED WIND TURBINE

The block diagram of a power system comprising a conventional generator and a DFIG-based wind turbine with frequency control is shown in Figure 5. Here ΔP_d is the incremental active power demand, ΔP_w the incremental value of wind generation, ΔP_c the incremental value of conventional generation and Δf is the incremental frequency change.

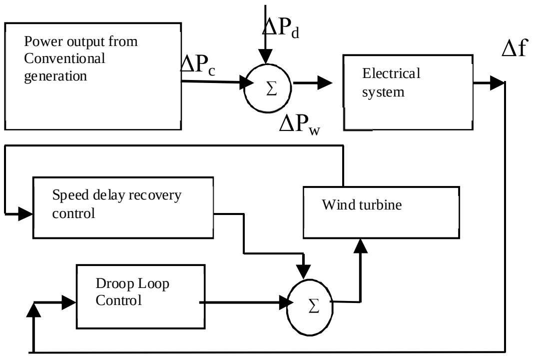

Fig.5. Block diagram of a power system comprising a Conventional generator and a DFIG-based wind turbine

Simulations are done for a 0.02 per unit load perturbation with and without DFIG wind turbine to examine its contribution in primary frequency regulation. Different plots for theses simulations are presented in Figure 6 to 9. It is assumed that DFIG-based wind turbines are in their optimal mechanical speed with the maximum power obtainable from the wind. The penetration level of wind power can be increased by changing some parameters, such as system inertia constant and permanent droop. An x % wind penetration means that the existing generator units are reduced by x %, i.e. an x% reduction in inertia and increase in permanent droop.

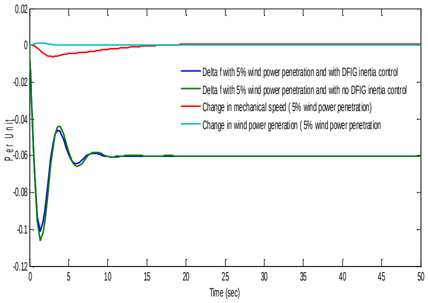

Fig. 6. Primary frequency regulation for 2% load change &5% wind power

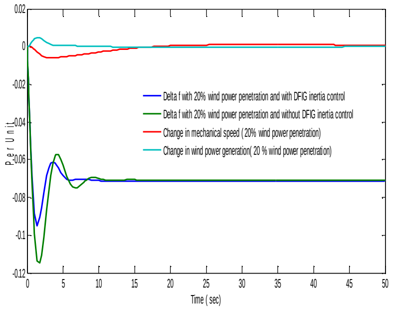

Fig. 7. Primary frequency regulation for 2% load change & 20% wind

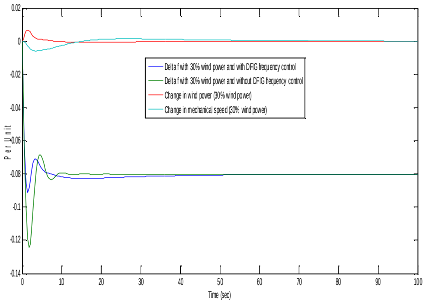

Fig. 8. Primary frequency regulation for 2% load change & 30% wind

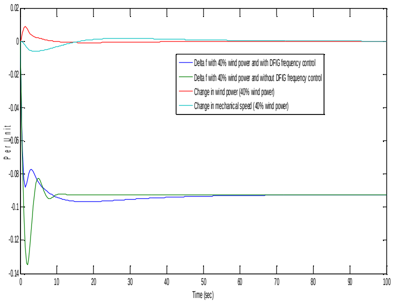

Fig. 9. Primary frequency regulation for 2% load change & 40% wind

Table1 shows the magnitudes of peak values and steady state error of frequency response curves for different levels of wind penetration. From the frequency response plots and Table1 it is clear that, following the disturbance the response is improved in terms of lower frequency excursion with DFIG participation. With 5 % penetration there is no significant improvement in frequency response compared to without-DFIG frequency control case. But as the penetration of wind energy increases from 5% to 40%, there is considerable improvement in lower peak values. When the load increases at t=0, the DFIG instantly releases its kinetic energy by reducing the mechanical speed, and hence increases its output to participate in primary frequency regulation. Thereafter DFIG output decreases because the speed is no longer at the optimal and power extracted from the wind is reduced. Then the DFIG speed controller will act and the optimal speed will be recovered so that the DFIG power output returns to its nominal value.

TABLE I: COMPARISON OF THE FREQUENCY RESPONSE FOR VARIOUS WIND LEVEL PENETRATION

Wind Penetration	Steady state error (pu)		Peak values(pu)	
	With DFIG Frequency control	Without DFIG Frequency control	With DFIG Frequency control	Without DFIG Frequency control
5%	-0.0602	-0.0601	-0.1012	-0.1059
10%	-0.0634	-0.06326	-0.0990	-.1085
15%	-0.06717	-0.06679	-0.0970	-0.1112
20%	-0.07114	-0.0707	-0.0949	-0.1148
25%	-0.07576	-0.07515	-0.09299	-0.1194
30%	-0.08102	-0.080172	-0.09111	-0.1241
40%	-0.094137	-0.09253	-0.08751	-0.13463

V. PRIMARY FREQUENCY REGULATION IN A TWO-AREA SYSTEM WITH DFIG-BASED WIND TURBINE

The dynamic performance of a two-area interconnected system can be analyzed using small-perturbation transfer-function model. During the simulations in both areas, it has been assumed that DFIG-based wind turbines are in their maximum power tracking mode and wind speed remain constant during the simulation.

Figures 13 to 16 show the power increment for tie-line power for 5% to 40% DFIG based wind power penetration contributing to frequency control and also without wind power generation contributing to frequency regulation.

It can be observed that with DFIG-based wind power penetration with frequency control, the increment in tie line power reduces with increase in wind penetration and the settling time also improves with increased penetration.

VI. CONCLUSION

This paper attempts to address the frequency regulation issues associated with the integration of DFIG based wind generation with conventional generation sources in the total energy supply mix of the power system. Small perturbation, transfer function models in state-space form are used for simulation of both single-area and two-area power systems with a mix of conventional generation and wind generation. In order to control frequency variations two methods namely speed delay recovery control and droop control methods are

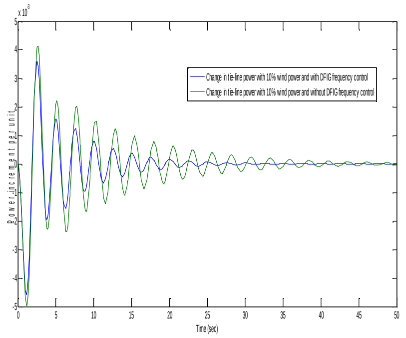

Fig. 13. Change in Tie line power for 2% load change with and without frequency regulation (10% wind power penetration)

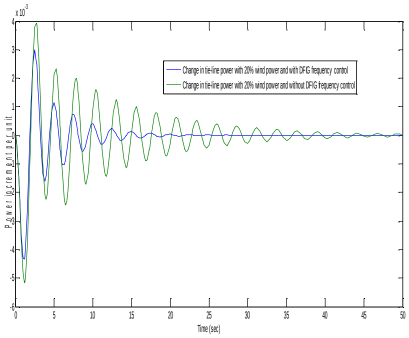

Fig. 14. Change in Tie line power for 2% load change with and without frequency regulation (20% wind power penetration)

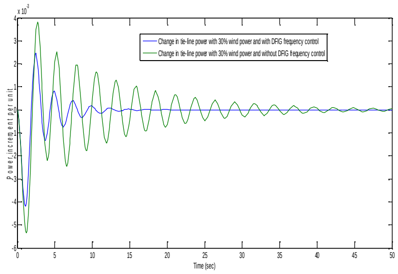

Fig. 15. Change in Tie line power for 2% load change with and without frequency regulation (30% wind power penetration)

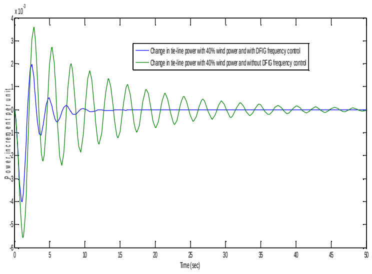

Fig. 14. Change in Tie line power for 2% load change with and without frequency regulation (40% wind power penetration)

proposed. As the penetration of wind energy increases there is considerable improvement in lower frequency peak excursion values. For two area system, with these controls, the increment in tie line power reduces with increase in wind penetration and the settling time also improves with increased penetration.

REFERENCES

[1] Erlich & M. Wilch. (2012). “Primary frequency control by wind turbines ", *3rd IEEE PES ISGT Europe, Berlin*, Germany, October 14 -17.

[2] Jalali, M. & Bhattacharya, K. (2013).“Frequency regulation and AGC in isolated systems with DFIG-based wind turbines”, *Power and Energy Society General meeting (PES)*, pp.1-5. Jalali M.and Bhattacharya K, “Frequency regulation and AGC in isolated systems with DFIG- based wind turbines”,*Power and Energy Society General meeting(PES)* 2013, pp.1-5.

[3] Johan Morren, , Sjoerd W. H. de Haan, , Wil L. Kling, , and J. A. Ferreira, “Wind Turbines Emulating Inertia and Supporting Primary Frequency Control”, *IEEE Transactions on Power Systems*, Vol. 21, No. 1, February 2006 .

[4] Michael Z. Bernard, T. H. Mohamed, Raheel Ali, Yasunori Mitani, Yaser Soliman Qudaih, “PI- MPC Frequency Control of Power System in the Presence of DFIG Wind Turbines”, *Scientific Research, Engineering*, 2013, 5, 43-50 .

[5] Sun HaiShun, Liu Ju, WEN JinYu, Cheng ShiJie, Luo Cheng & Yao LiangZhong, “Participation of large-scale wind power generation in power system frequency regulation”, *Chinese Science Bulletin*, Vol.58, December 2013