

Dynamic contribution of DFIG based wind energy penetration in interconnected system for improved load frequency control

Anirudh K^{1*}, K R M Vijaya Chandrakala¹

¹ Department of Electrical and Electronics Engineering Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham India.

*anirudhjayaaprakash24@gmail.com

Abstract

Frequency unbalance occurs when wind electric generators are connected with the grid since their power output depends with the wind flow and thus it reduces system inertia. Since renewable interaction in near future will be higher, it is important to control frequency even if wind electric machines are connected to the grid. This paper presents an analysis on a single area load frequency control (LFC) comprising of a thermal plant integrated with the doubly fed induction generators (DFIG). DFIG wind generators help to meet the load immediately before the action of the governor of thermal plant thus retaining the system in operating frequency level. But, to retain the system back to the normal frequency the addition of secondary controller is emphasized. Therefore, in this work for fine tuning of frequency is carried out using secondary controller namely, Proportional Integral (PI) controller. The PI controller fine tunes the frequency retaining the system back to normal frequency. The whole analysis is performed with 2% load variation and is simulated under MATLAB/SIMULINK and results are validated using performance index.

Keywords: Thermal Power Plant, Double Fed Induction Generator (DFIG), Load Frequency Control (LFC), PI controller, Frequency Regulation.

1. Introduction

The next era focuses towards usage of renewable energy with the conventional system to support on meeting high demand variation. And this high demand may lead the conventional system to perform either generator scheduling or load management.

But consumers require reliable power supply. Rising energy demand and the need of reduction in the amount of greenhouse gases paved the way for the inclusion of renewable energy sources into the grid. Among renewable energy sources, in the near future wind usage will be the most important intruding technologies [1]. The developed kinetic energy in the blades of the wind generator helps to meet the change in demand instantly before the action of the governor of the conventional system.

Thus, it would relieve the usage of high potential conventional sources [2]. Power system consists of interconnected system sup-

port mainly hydro, wind, thermal, solar etc. so focus into the cleaner sources.

High wind energy penetration into the electric network will account for frequency vulnerability to oscillations, since the wind units do not change the amount of production irrespective of frequency. And, high penetration based wind units suffer severe if being working in isolated areas.

And, wind integration operation becomes more challenging under deregulated power system operation [3-4]. Therefore, the support of DFIG with the conventional system due to its ability to balance the system under high load variation would result the usage of cleaner source support.

Therefore, in the analysis along with thermal power plant DFIG based wind electric machine is connected for a unit step load change of 2%. On subjection to load variations, DFIG supports the system through immediate release of kinetic energy stored in the rotating parts before governor of the thermal power plant operates.

Therefore, DFIG helps to maintain the frequency variations within the limits and attain secured operation of a power system. Here, modified pitch control is suggested in the work.

But, the system has to be retained to normal rated frequency for which the secondary controller action is preferred. The secondary controllers used for Automatic generation control are proportional and integral control (PI), proportional-integral-derivative control (PID), optimal controller, and the fuzzy logic controller [5-7].

The dynamic contribution of DFIG in frequency control is analyzed with the support of PI controller acting along with the thermal power plant on subjection of 2% load variation. The fine tuning of frequency is met which would result the system to operate at nominal rated frequency. The objective of this paper is to analyze the LFC problem of a single area system comprising of thermal power plant with DFIG based wind turbine [8-9]. As a secondary controller, PI controller in thermal power plant with the DFIG helps to retain the frequency variations to nominal value. For the analysis the whole system is simulated using MATLAB/SIMULINK platform and the frequency responses is analyzed [10-11]. Sections 2 introduces the aspect of DFIG with conventional system and the variable speed wind turbine used for frequency control. Section 3 describes the mathematical modelling of thermal power plant with DFIG interconnection. Section 4 highlights the results and discussions. Section 5 concludes the work.

2. Variable speed wind turbines for frequency control

Turbine of fixed speed spins always at the same speed irrespective of wind speed whereas variable speed wind turbine's rotor speed varies in proportional with speed of the wind. Thus the fixed speed turbine has to be prevented from supplying their maximum power such that some power can be stored as reserve power for future injection which can lead to frequency control. So it is indeed require variable speed wind turbine for regulation of frequency. The mostly used controls for VSWT are pitch control, inertial control and speed control.

2.1. Pitch Control of DFIG

It is very much similar to the synchronous machine governor control. The controller checks the output power in a pitch controlled wind system which operates on hydraulics. The pitch control of the blade is varied according to the speed of the wind so that it covers larger surface area and optimum power output from it is generated. It should be noticed that an optimum rotational speed has to maintain rotational during de-loading via pitching irrespective of wind speeds.

Nowadays, the wind turbines commercially available can produce optimal power with 14-15m/s of wind speed. The pitch mechanism makes wind flow around the blade smooth. Two types of pitch controls are Active pitch control design and Passive or Stall pitch control design. Figure 1. shows the modified pitch control used in DFIG.

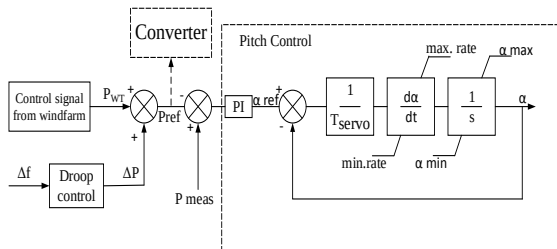


Fig. 1: Modified pitch control used in DFIG

2.2. Speed Control of DFIG

Wind turbine speed is made to adjust according the turbine output. Kinetic energy stored is made to transfer from or into the

grid. Figure 4 shows the variation of max power available with the wind speed. For a particular wind speed, the optimum power can be generated. However, wind turbine is made to operate along 95% curve, thus generating power less than maximum. So there will be some reserve available for primary frequency regulation. So the active power generation will be increased by this reference curve as frequency decreases when load change is made as shown in Figure 2.

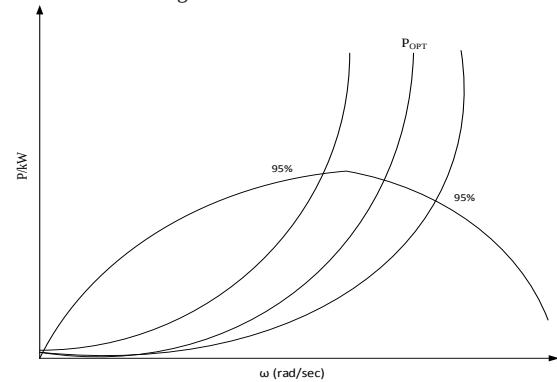


Fig. 2: P vs. ω curve of DFIG

3. Mathematical modelling of thermal power plant with DFIG interconnection

3.1. Thermal Power Plant

Figure 3. shows the linearized mathematical model of a thermal plant. speed governor, turbine and generator load models are depicted by the time constant values T_{sg} , T_t and T_{ps} . Typically, the time constant values of speed governor T_{sg} lies in the range of 0.01 to 0.1sec and that of turbine T_t lies in the range of 0.2 to 2.5 sec. The power system is related with the frequency changes since it increments or decrements the power input according to the frequency on subjection to load variation [10, 11].

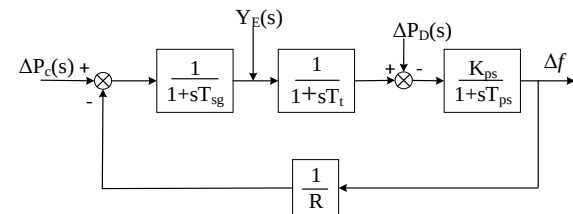


Fig. 3: Mathematical model of thermal power system

3.2. Thermal Power Plant Interconnected with DFIG

To compensate for the frequency dip in the grid when thermal energy systems are connected, DFIG is made to interconnect with the grid. When DFIG is interconnected with the thermal area for a load change of 2 percent, the active power injected to grid increases in an instant which in-turn increases the frequency and thus reduces the gap of regulation. Figure 4 and Figure 5 shows the DFIG interconnected with thermal power system and detailed modeling of DFIG [4-6,10,11].

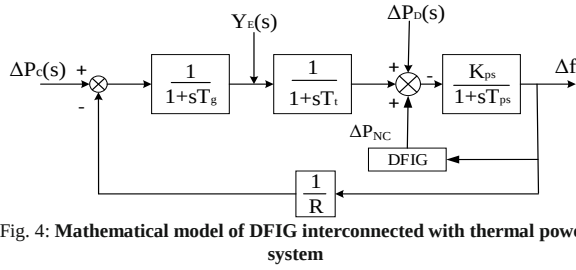


Fig. 4: Mathematical model of DFIG interconnected with thermal power system

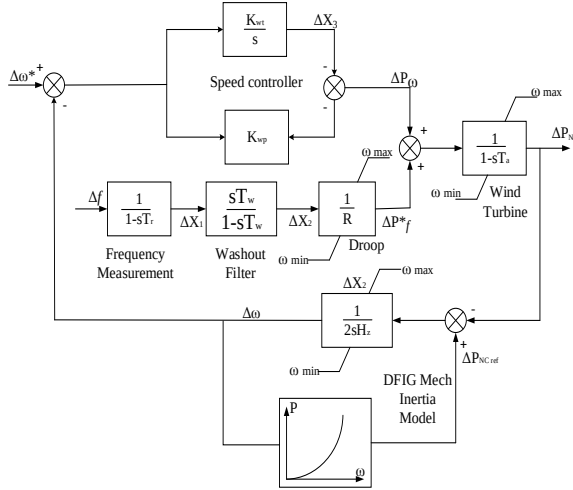


Fig. 5: DFIG-based wind turbine frequency change control

3.3. Thermal power plant interconnected with DFIG and PI controller

The use of PI control with DFIG supports in fine tuning of the frequency which in turn regulates and make it under the limit. Also the integral square error value obtained from this is also vulnerable as compared to thermal with and without DFIG. Figure 6, highlights PI controller in thermal power plant with DFIG.

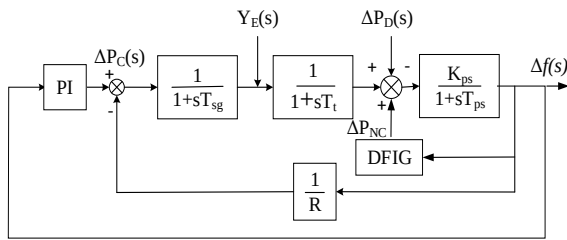


Fig. 6: PI controller with DFIG and Thermal power system

The DFIG injects electrical power depending upon optimum power extraction curve and frequency deviations on subjection to load variation. Through which the active power is induced by DFIG immediately following the frequency variation due to load change thus helps in maintaining the frequency within the limits. DFIG helps to follow the load with the frequency tracking thus retaining the system in stable operation. Through the optimized parameters of DFIG controller the frequency responses are addressed in this work. The advancement in control of DFIG machines has led for participation along with the conventional generators to balance the load thus regulating the frequency within the limits. Here ΔP_f^* is taken which is rate of change of frequency with deviation and acts as a power set point. Another power set point ΔP_w^* is taken based on electric power and speed measured taken from the controller. Both set points added to form the active

power ΔP_{NC} , which is injected by the wind turbine as referred in (1), (2) and (3);

$$\Delta P_f^* = -K_{df} \frac{df}{dt} - K_{pf} \Delta f \quad (1)$$

$$\Delta P_\omega^* = -K_{wp} \omega^* - \omega + K_{wi} \int \omega^* - \omega dt \quad (2)$$

$$\Delta P_{NC} = \Delta P_f^* + \Delta P_\omega^* \quad (3)$$

Where; K_{wp} and K_{wi} are PI controller constants which helps the thermal generators to provide required active power in order to regulate frequency deviations. The DFIG contribution to system inertia is shown in (4) and (5):

$$\frac{2H}{f} \frac{d\Delta f}{dt} = \Delta P_f - D\Delta f \quad (4)$$

$$= \Delta P_g + \Delta P_{NC} - \Delta P - \Delta P_D - D\Delta f \quad (5)$$

Equation (5) is the swing equation and it provides the details about the DFIG contribution towards system inertia. It contains an additional power setting reference based on the frequency change using a washout filter having time constant T_w which mostly relies on primary regulation performance in a transient.

$$\Delta P_f^* = \frac{1}{R} \Delta X_2 \quad (6)$$

The DFIG respond to frequency changes by using their kinetic energy stored in the rotating part, but cannot act during permanent system frequency deviation period. So for this reason, the term ΔX_2 used in (6) which is the output of washout filter as shown in Figure 1. The controller acts accordingly to the frequency deviations and provides a fast response of active power injection control.

4. Simulation results and discussions

LFC regulates or maintain the frequency under limits and to control the power flow variations even if more systems are connected with the network. The simulations were conducted for a thermal area system. When DFIG is connected to this system, it contributes to frequency regulation by giving inertial control. PI control is used for fine tuning of system such that the frequency is maintained under limits.

Figure 3 represents the response of conventional thermal plant of the area. When DFIG is allowed or made to connect, the peak values of system are reduced and are much lower compared to those without DFIG. In initial intervals of system disturbances, the DFIG supports the system frequency through kinetic energy release stored in its rotating body.

This is done by decreasing the speed momentarily. The droop regulation "R" based on the negation between the measured and the optimal frequency of the system is used to produce a change in real power injection by the wind turbine. The energy needed is obtained from the kinetic energy of the rotating masses, which in turn leads to variations in rotor speed. Since DFIG acts very fast to disturbances, its action delays the responses of conventional generators.

Let the load ΔP_D be simultaneously applied to the control area. Figure 7 shows the power generated into the system with thermal alone, thermal with DFIG and thermal, DFIG with PI controller. Figure 8 represents the response of the generation of thermal area system with and without the DFIG participating in frequency change with a load change of 2 percent.

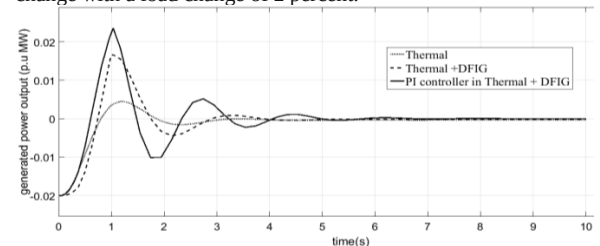


Fig. 7: Generated power output of the system (p.u. MW)

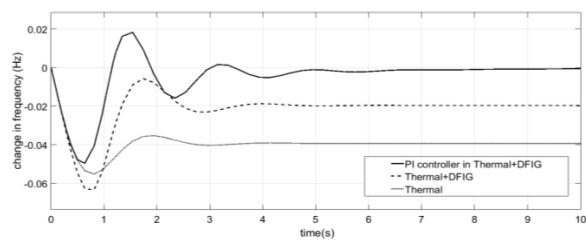


Fig. 8: Change in frequency variation in the system

It is observed that the change in frequency value goes down for a thermal system which is not tolerable. But the addition of DFIG supports the conventional system maintaining the system frequency within the limits on subjection to 2% load variation, which is within the tolerance level.

Secondary PI controller in the governor of the thermal plant helps to fine tune the frequency thus making the system frequency back to nominal value. Figure 9 shows the active power injection into the grid by the DFIG in p.u. MW and Figure 10 validates the integral square error of the change in frequency been improved with PI controller in thermal power plant and DFIG.

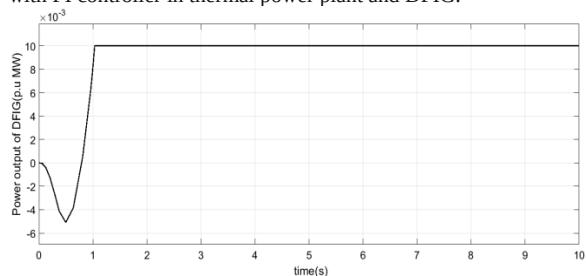


Fig. 9: Power output of the DFIG (p.u.MW)

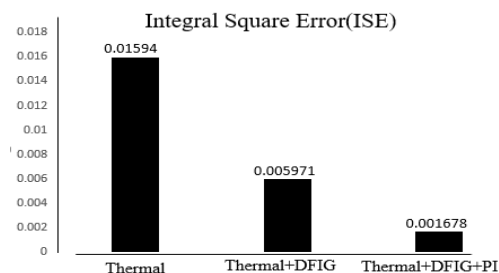


Fig. 10: Bar chart of the performance index (ISE)

The results indicate that frequency response have very much smaller variations when DFIG is connected to the system to perform frequency control. Therefore, from the above figures it reflects that the frequency variation on subjection to high load variation can be controlled by suitable pitch controlled DFIG in support with thermal power plant and secondary controller.

5. Conclusion

This paper focusses towards the DFIG wind energy system contribution towards load frequency control. Since DFIG's have significant amount of kinetic energy stored in their rotating masses, thus the release of it can provide fast frequency improvement under high load variations. The system considered is DFIG interconnected with the thermal power plant subjected to 2% load variation. During which the DFIG limits the system frequency through release of kinetic energy at a faster pace before the speed governor of the thermal power plant comes into action. Further the system frequency is fine-tuned using appropriate PI controller in the governor of the thermal plant acting along with DFIG. The results are

validated using the performance index namely Integral Square Error method.

Appendix

Description	Parameter	Value
Equivalent wind turbine inertia	H_e	1.5 pu.MW.
Gain of the power system	K_p	50 Hz/pu
DFIG integral gain	K_{wi}	0.1
DFIG Proportional speed controller gain	K_{wp}	1.23
Regulation droop	R	3
DFIG Turbine time constant	T_a	0.2s
Thermal power plant governor time Constant	T_h	0.1s
Transducer time constant	T_r	15s
DFIG Washout filter time constant	T_w	6s

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