FACILITATING THE INTEGRATION OF WIND TURBINES INTO POWER NETWORKS WHILE MAINTAINING FREQUENCY STABILITY

Stewart WHYTE
National Grid – UK
stewart.whyte@uk.ngrid.com

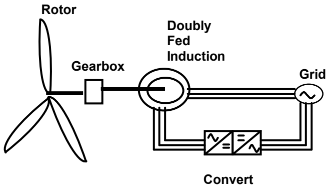
J.V. MILANOVIC
The University of Manchester – UK
Milanovic@manchester.ac.uk

ABSTRACT

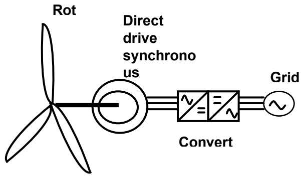
Frequency stability in large power networks has been traditionally maintained by the inertia of synchronous generators. However wind turbines that are coupled to the power system through a power electronics (PE) interface do not provide the inertia that is required to maintain frequency stability. This will have a material effect on the ability of the power system to manage incidents arising from the loss of a generator or sudden increase in demand. To facilitate the increased integration of wind turbines an inertial component needs to be synthetically supplied by the wind turbines to maintain the stability of the frequency. In this paper the impact of PE interfaced generation has been assessed on a simplified representation of the UK power system appropriate for determining the frequency stability. The test network used in simulations was validated for a significant number of recorded system incidents. The studies carried out established the sensitivity of frequency stability to changes in the power system's generation mix (increase of wind generation) and system conditions including frequency support provided by loads. It then assessed the impact of employing a synthetic inertia component associated with wind turbines and the contribution it makes to frequency stability in the network. The synthetic inertia controller was then designed to give different inertial outputs. Sensitivity of inertial response to controller parameters is clearly established. Finally it is demonstrated that by employing suitably tuned synthetic inertia controllers more wind turbines can be integrated into the system while maintaining required frequency stability of the power system.

INTRODUCTION

Frequency Control is managed by many elements on a power system: one of which is the inherent inertia of large machines rotating shafts that are electrically coupled to the power system. However in facilitating government targets for a reduction in CO_2 suppliers of electricity are changing the face of the electricity generating quite dramatically and are turning to wind turbines to provide energy to the system. The UK targets in practical terms require 37% of electricity to be produced from renewable sources by 2020 [1]. This changing generation background provides many challenges to the power system industry. One of these areas is frequency stability of the network following a large disturbance on the network. The majority of the wind turbines being connected are of the variable speed type where much of the mechanical mass of the wind turbine and in some instance all of it is situated behind the PEs and therefore not electrically coupled to the power system, as shown in figure 1.



a) Doubly Fed Induction Generator



b) Full Converter Wind Turbines

Figure 1 Schematics of PE interface connected Wind Turbines

The practical impact of this is that the inertial contribution of the wind power turbine will not be provided to the power system [2-5]. The effect of this increase in generation that has a much reduced, or even no inertia at all, will be that the system inertia (the cumulative effect of all the synchronous machines inertia) will also be reduced and the effect (bigger drop in frequency for smaller inertia) can be clearly seen in figure 2.

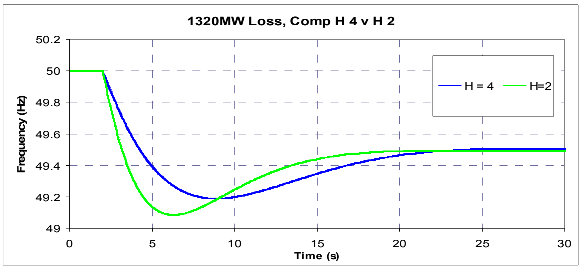


Figure 2 Effect of reducing the system inertia

With this impact in mind the manufacturers have been quick to show that the wind turbines can provide a synthetic inertia contribution [6, 7]. The inertial contribution is realised by not operating the wind turbine at the optimal rotor speed for that wind speed condition. The temporary over production is realised by increasing the converter active power set point. This creates an imbalance between the mechanical input and electrical output [8]. Any system operator looking at the issue of inertialess generation connecting to their system and the impact that this could have on the frequency stability of the power system should consider the synthetic inertia contribution of the wind turbines.

MODELLING OF THE TEST SYSTEM

A simple representation of the UK power system has been developed in this study that allows the focus of the power system studies to be on frequency stability. The two-bus test system developed for the study (in DigSILENT environment) is shown in Figure 3. It includes two large conventional plants, a load, a static generator that is used to represent the wind turbine and the largest loss infeed to the UK system connected to each bus. Total demand in the system is 25GW. All generators are lumped parameter models to represent that particular type of generation in that area.

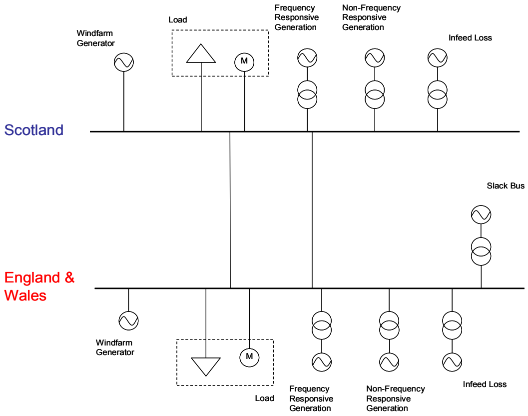


Figure 3 Simplified UK power system representation

These two types of large synchronous generators are modelled because one of the generators has to operate in a frequency response mode that is required by the UK Grid Code [9] and the other in a limited frequency sensitive mode. In frequency sensitive mode the generator should provide an energy contribution proportional to the frequency change on the grid. In limited frequency sensitive mode no change of active power is required until a set level. The UK Grid Code requires all plant (including wind turbines) to be capable of providing frequency response to the value of 10% of the active power capacity of the plant within 10s and sustained for 30 minutes [10]. (The past experience in the UK is that wind farms can provide frequency response [11]). The responses of these two types of generators following the simulated loss of the tripping generator (infeed loss) are shown in Figure 4 and 5.

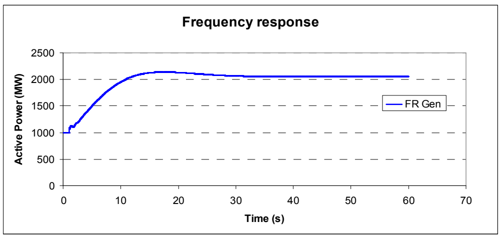


Figure 4 Output of Frequency response generation

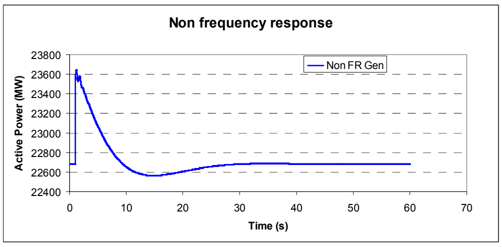


Figure 5 Output of Limited Frequency response generation

The wind farm (WF) generator is modeled using a static generator that is current controlled to allow an injection of active power into the network. This model provides an effective method for studying the output of the wind generators on the grid but does not account for the mechanical impact of providing the inertial contribution.

The load is modeled as part induction machines and part static frequency dependant loads, using a 2% per Hz relationship. The load provides a great deal of uncertainty in any model when considering its impact on system response. Therefore, the sensitivity of frequency stability to change in the make up of the load must be established.

The modeled test system is used to show the impact that inclusion of inertialess generation can have on the frequency stability. The UK transmission system operator has a licensed obligation to contain the frequency fall above 49.2Hz following the largest (currently 1320MW) infeed loss [12].

SIMULATION RESULTS

The results of simulations illustrate the sensitivity of the frequency control of the system to load make up and the amount of wind generation in the system following the largest infeed loss.

Three case studies of demand make up modeled by equivalent inertia constant of demand of 0s, 2.18s and 4s, were considered to establish the influence of demand on frequency response. (The inertia of 2.18s corresponds to a border line case when the system without wind generation just meets the required frequency response.) The results of simulations are shown in figure 6. It can be seen that the increase of the inertia of demand results in better frequency response of the system, i.e., the demand provides better frequency support.

To determine the effect of wind penetration on the frequency stability of the power system three case studies were considered, i.e., 0%, 40% and 70% wind penetration. The inertia of demand used in these cases was set to 2.18s. The results, shown in figure 7, demonstrate that as the penetration of wind generation increases the power system could not constrain the frequency nadir to the required limit (49.2Hz). The frequency dropped to about 49.1Hz for 40% penetration and to 48.9Hz for 70% penetration.

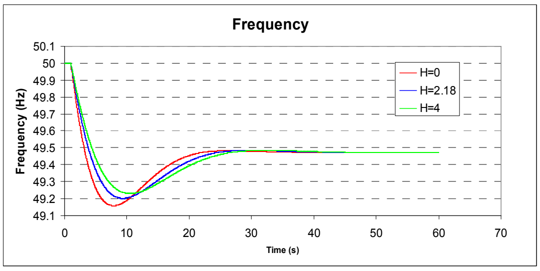


Figure 6 Frequency sensitivity to different load make up

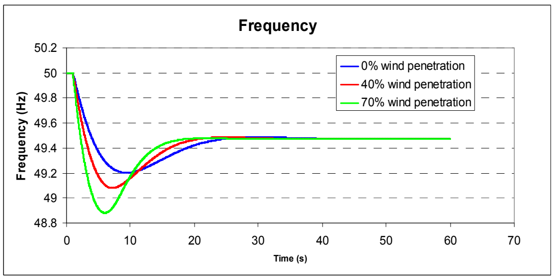


Figure 7 Frequency sensitivity to the penetration of wind

DESIGN OF CONTROLLER

Further penetration of wind is shown to have an impact on the ability of the power system to contain the frequency within the required limits. In order to address this issue one option is to consider the inertial contribution of the wind turbines as set out by the wind turbine manufacturers. There are other options available, e.g., constraining off wind, constraining the generators with the largest inertia constants, tripping load etc. These however are economically viable.

The simulation results shown in figure 8 and figure 9 are for 50% wind penetration on a 25GW system. In this instance the inertial contribution as outlined in [6] is employed. The results show that while the wind turbines output can be increased to provide some energy to help the frequency stability of the system it is important to coordinate this with the system frequency incident. Because of the system frequency drop we require most of the energy upfront and not at the frequency nadir. Therefore, it would seem sensible to control frequency using the rate of change of frequency (ROCOF), i.e., df/dt, which will be higher at the start of the event, as shown in figure 10.

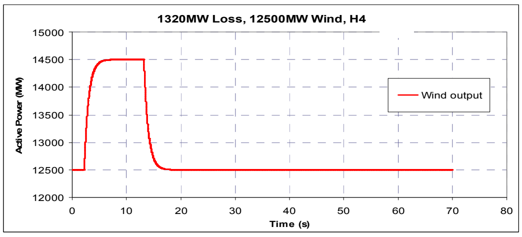


Figure 8 Simulation of manufacturer's response

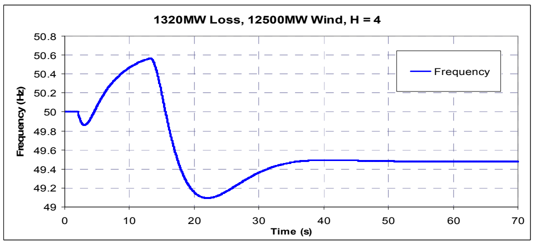


Figure 9 Impact of manufacturer's response on frequency

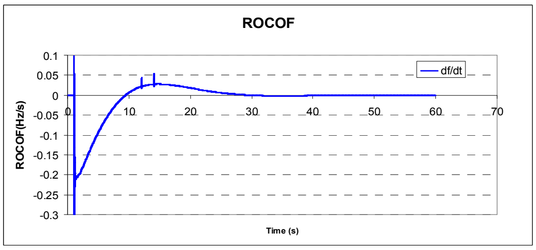


Figure 10 ROCOF example

Initially, the controller was designed to provide "on-shot control", i.e., depending on the df/dt caused by the loss of the infeed, or sudden increase in demand, the generators output would be regulated. After the initial energy contribution up front which is proportional to df/dt, the controller would reduce the energy volume over the period of 10s in accordance with required frequency response timescales specified in the UK Grid Code. However, discussion with manufacturers revealed that it would be extremely difficult to have this type of "variable/adaptive" control when providing the energy from the wind farm. It was therefore decided that the inertial controller should be fully based on df/dt controller. The block diagram of the controller is shown in figure 11.

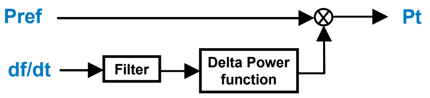


Figure 11 Wind farm inertial controller

The augmentation of power in the delta power function block is the inverse of the equation (1) given below:

$$df/dt = \frac{\Delta P}{2H} \qquad (1)$$

This means that the wind farm generator will increase its output as a result of a falling system frequency such providing extra power when it is required.

Three case studies were considered for different wind penetrations, as before. To determine the synthetic inertia control parameters the worst case scenario, i.e., 70% penetration of wind on a 25GW system is used. The sensitivity of frequency responses to the value of synthetic inertia is clearly shown in figure 13. The increase in synthetic inertia constants results in better frequency response. With the value of synthetic inertia above 4s the frequency response is within required limits of the Grid Code even for 70% penetration of wind.

The controller parameters: the delay in response to the start of the frequency event; the speed of the inertial contribution and the inertial energy contribution that should be provided during event can be easily adjusted if required.

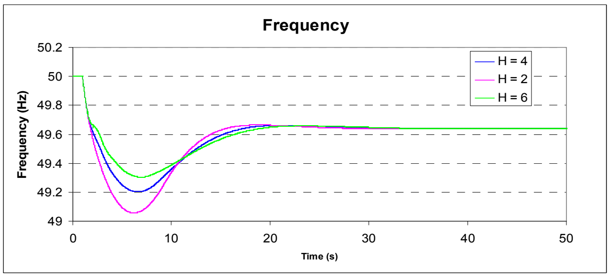


Figure 12 Frequency Sensitivity to changing Synthetic inertia controller's inertial contribution

As well as changing the overall energy contribution that the inertia controller should provide the effect of the timing of the provision of synthetic inertia is examined. Figure 13 shows that if the action of the controller is delayed beyond 1s, for this particular test system, the requirements of the Grid Code could not be met.

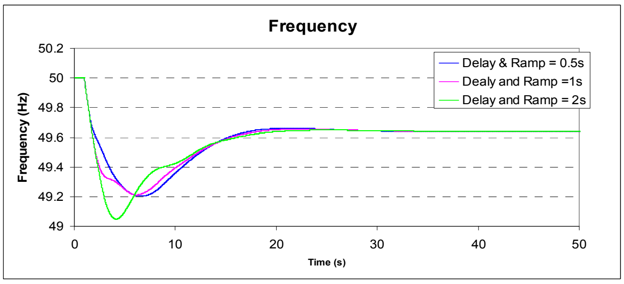


Figure 13 Frequency Sensitivity to changing Synthetic inertia controllers delay and ramp rate

The results of sensitivity of the frequency response to synthetic inertia controller parameters show that the synthetic inertia contribution of the wind turbines can have a positive impact on the frequency stability of the power system. Most importantly the results show that by employing synthetic inertia the frequency stability of the network can be maintained to the standards required. Detailed sensitivity studies are very important to determine the required speed of controller response, i.e., the speed of provision of required inertial contribution.

CONCLUSIONS

The consequence of a future integration of inertialess generation into power systems is that the frequency stability of the network may be affected. A possible solution to the lack of an inertial contribution form wind turbines is to design controllers for the wind turbines which would emulate synthetic inertia. One such controller is designed and its performance illustrated in this paper.

It is extremely important that the parameters of this controller are appropriate for the power system that it is connecting to. The network operator therefore, should specify the requirements for synthetic inertia controller in advance, following appropriate studies, in order to facilitate further increase in penetration of wind generation and to insure full compliance with corresponding Grid Code.

REFERENCES

[1] DECC, "Low Carbon Transition Plan"
[2] Gillian Lalor, Student Member, IEEE, Alan Mullane, Member, IEEE, and Mark O'Malley, Senior Member, "IEEE Frequency Control and Wind Turbine Technologies"
[3] Dynamic Frequency Control with Increasing Wind Generation, Gillian Lalor, Julia Ritchie, Shane Rourke, Damian Flynn and Mark J. O'Malley
[4] P Kuundur, "Power System Stability and Control"
[5] Alan Mullae, Member, IEEE and Mark O'Malley, Senior Member, IEEE, "The Inertial Response of Induction-Machine-Based Wind Turbines"
[6] Stephan Wachtel and Alfred Beekman, "Contribution of Wind Energy Converters with Inertial Emulation to frequency control and frequency stability in power systems"
[7] Nichalas Miller, Kara Clark, Roberto Delmerico and Mark Cardinal, "WindINERTIA: Inertial Response Option for A manufacturers Wind Turbine Generators"
[8] Germán Claudio Tarnowski, Philip Carne Kjær, Poul E. Sørensen and Jacob Østergaard, "Variable Speed Wind Turbines Capability for Temporary Over-Production"
[9] GB Grid Code, Issue 4 revision 2
[10] Helge Urdal and Jonathan Horne, "2GW of wind and rising fast – Grid Code compliance of large wind farms in the Great Britain Transmission system"
[11] Jonathan Horne MIET, "Wind Farms can provide Frequency Response – Experience of the Great Britain Transmission System Operator"
[12]National Electrical Transmission system Security and Quality of Supply Standards (NETSSQSS)