FREQUENCY REGULATION AT A WIND FARM EMPLOYING TIME-VARYING INERTIA AND DROOP CONTROLS

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ABSTRACT

One of the major and more challenging problems that is going to affect the future electricity system is the one relate to the frequency stability and support from generating units. In traditional power networks Frequency support were transiently provided by the rotating mass of the generator (directly connected to the grid) while the steady state contribution to frequency is provided by a droop control primary regulation. With the massive diffusion of under-converter generation the system is facing and increasing of the overall installed capacity, and a reduction of the percentage of ”inertial responding” generators and of generator actively participating in frequency regulation. This situation negatively affects the system frequency response and may increase the risk of generation outages and blackouts. The aim of the present paper is that of analyzing the possible contribution of variable speed wind generating units in frequency support, by means of the definition of dedicated control strategies to be implemented at power electronic level. Then, the paper also proposes the integration of inertial and droop frequency controller in order to define a control strategy capable of emulating the frequency response behavior of a traditional generating unit. The performances and limits of the proposed controller is evaluated by means of dedicated simulations.

Key-Words: - *Frequency controller, frequency stability, power system, protection scheme, wind turbine generator*

1. INTRODUCTION

The frequency control is being traditionally performed by conventional synchronous generators in almost all power systems [1]. Traditionally, wind farms have not contributed to system frequency support. However, as the global penetration of wind power into the power system increases, the grid code requirements are gradually becoming more demanding. Apart from the well-known fault-ride through capability for wind farms, the frequency stability support is also becoming an important aspect of grid codes around the world. From this point of view, the increasing penetration of renewable generation sources have introduces new problems and issue in guaranteeing specific power quality issues [2]-.[3], but also some improvements from a flexibility point of view, thanks to the employment of power electronic devices [4]. Among these, the massive integration of wind power is expected to be part of the power system and therefore some countries have started to establish new grid codes relevant to wind farms. Several transmission system operators have discussed the inclusion of frequency response in grid code. During a system frequency disturbance (SFD) the generation/demand power balance is lost, the system frequency will change at a rate initially determined by the total system inertia [5]. However, future power systems will increase the installed power capacity (MVA) but the effective system inertial response will stay the same nowadays [5, 6]. The result is deeper frequency excursions of system disturbances. Many modern wind turbines (WT) have the ability to control active power output in response to grid frequency in ways that are important to overall grid performance and security.

Several publications relate the main aspects and considerations about modeling [7] and simulation [8] of the inertial response of wind turbine generators (WTGs) and some of them provide general ideas about possible impacts on power systems and their effects on transient underfrequency response [9]-[10]. This situation negatively affects the system frequency response. The aim of this paper is to evaluate the integration of inertial and droop frequency control provided by variable speed wind generators. In this paper, time domain simulations are used to evaluate the system frequency response (SFR) provided by evaluating the inertial frequency support provided by a variable speed wind generator. The main contributions of this paper are: (i) to highlight the positive contribution of hidden inertia controller under different load variation conditions; (ii) to practically identify there is a possible point out that high values of the synthetic inertia parameter, may stall the wind turbine negatively affecting the power system and (iii) to evaluate the possible integration of the hidden inertia and droop controller in order to obtain an effective frequency support in all the phases of the perturbation

2. LITERATURE SURVEY

2.1 Comparison of the Response of Doubly Fed and Fixed-speed Induction Generator Wind Turbines to Changes in Network Frequency

Synchronous and fixed-speed induction generators release the kinetic energy of their rotating mass when the power system frequency is reduced. In the case of doubly fed induction generator (DFIG)-based wind turbines, their control system operates to apply a restraining torque to the rotor according to a predetermined curve with respect to the rotor speed. This control system is not based on the power system frequency and there is negligible contribution to the inertia of the power system. A DFIG control system was modified to introduce inertia response to the DFIG wind turbine. Simulations were used to show that with the proposed control system, the DFIG wind turbine can supply considerably greater kinetic energy than a fixed-speed wind turbine

2.2 Frequency control and wind turbine technologies

Increasing levels of wind generation has resulted in an urgent need for the assessment of their impact on frequency control of power systems. Whereas increased system inertia is intrinsically linked to the addition of synchronous generation to power systems, due to differing electromechanical characteristics, this inherent link is not present in wind turbine generators. Regardless of wind turbine technology, the displacement of conventional generation with wind will result in increased rates of change of system frequency. The magnitude of the frequency excursion following a loss of generation may also increase. Amendment of reserve policies or modification of wind turbine inertial response characteristics may be necessary to facilitate increased levels of wind generation. This is particularly true in small isolated power systems.

2.3Dynamic contribution of DFIG-based wind plants to system frequency disturbances

The paper investigates contribution of doubly fed induction generator (DFIG) to system frequency responses. Impact of different governor settings and system inertia are investigated. Three distinct cases are simulated in order to illustrate the influence of DFIG penetration on frequency regulation. Provision of inertial response by DFIG through artificial speed coupling is also presented. The effects of the inertial response on the machine behavior and its significance for frequency regulation are discussed. The influence of converter current limits and auxiliary loop parameters on the inertial response are illustrated and a novel control algorithm is developed for extracting maximum energy from the turbine in a stable manner. The results of the study are illustrated on the example of an isolated power system consisting of a diesel generator and a DFIG.

3.POWER SYSTEM FREQUENCY RESPONSE

The system frequency (*f*) is related to the rotational speed of the rotor of all synchronous machines directly connected to the grid. Any variation of the electric demand or power generation will produce changes in the system frequency. For this reason, the frequency is an electrical variable that must be controlled second by second by second using controllers to preserve the instantaneous balance between system demand and total generation. An active power change, at any point of the network, is propagated throughout the whole power system by a change in the electric frequency. Consequently, the system frequency is the useful index to detect system generation and load unbalance. For a better understand of the described frequency phenomena, let us consider an electric power system accounting for *N* synchronous generators. For the generic i^{th} synchronous machine, it is possible defining the following relation between the individual incremental mismatch power and individual the frequency (f_i):

$$\frac{2H_i}{f_0}\frac{df_i}{dt} = p_{mech,i} - p_{elec,i} = \Delta p_i \qquad (1)$$

where $p_{mech,i}$ is the p.u mechanical power of prime mover, $p_{elec,i}$ the p.u electrical power, Δp_i is the load/generation imbalance, in p.u , H_i is the inertia constant in seconds, f_i is the frequency in Hz and f_0 is the rated frequency.

Assuming a strong coupling between the generation units, it is possible obtaining a relation similar to (1) but extended for the entire power system.

$$\frac{2H_T}{f_0}\frac{df_{COI}}{dt} = p_{mech,T} - p_{elec,T} = \Delta p_T \qquad (2)$$

where $P_{mech,T}$, $P_{eelec,T}$, and S_T are respectively the algebraic sum of the individual synchronous machine electric power, mechanical power, and rating capacity, while the total system frequency inertia

(*HT*) and the frequency of the centre of inertia (*fCOI*) can be written as:

$$H_T = \left(\sum_{i=1}^{N} S_{N,i}\right)^{-1} \sum_{i=1}^{N} H_i S_{N,i} \qquad (3)$$

$$f_{COI} = \left(\sum_{i=1}^{N} H_i\right)^{-1} \sum_{i=1}^{N} H_i f_i \qquad (4)$$

Examining (2) and (3), it is clear that the system frequency dynamic strongly depends on the overall value of the system inertia (*HT*). Increasing the number of generators connected to the grid using power converter increases the total installed capacity (*ST*) but the inertial contribution of those generators is zero because the power converter interface hides the inertial contribution of its generation. Enabling the inertial response of power converter-based generators requires proper controllers for that purpose. Therefore, installing fully rated power converter generation units produces a reduction of the total system inertia that can lead to a quick and dangerous drop of system frequency adversely affecting the frequency stability of the electric power system. On this aspect, WTGs can play an important role providing the support of *frequency response* (FR). A WTG has the inertia of their rotating parts such as blades, gearbox, generator, etc. The overall value of wind turbine moment of inertia is up to 500 kilogram-square metres (kg.m2) and it represents a relevant amount of kinetic energy stored in rotating components of the WTG. Using appropriate control strategies at converter level, it is possible to extract the kinetic energy of the WTG and uses it to support the FR of the power system.

4. DROOP CONTROL STRATEGY

If the two previously described control strategies aim at supporting the initial frequency response of the system, the droop control strategy is designed with the aim of providing support to the frequency in a longer time. This is in accordance to the to the classical control strategy of the conventional power plant where the droop approach allows sharing the load variation among the generators to achieve and acceptable steady state frequency until secondary control will not act. The governor control refers to control actions that are done locally (at the power plant level) based on the set-points for frequency and power. The steady-state properties of the governor controller are defined by the *permanent droop*, which is defined as the change in frequency, normalized to the nominal frequency (f_0), divided by the change in power output, normalized to a given power base, (P_{base})

$$\rho = \frac{\Delta f\left[p.u\right]}{\Delta P\left[p.u\right]}$$

The inverse of the droop is R and it is referred to as

$$R = \frac{1}{\rho} = \frac{\Delta P\left[p.u\right]}{\Delta f\left[p.u\right]}$$

The *droop controller* is described by a steady-state frequency characteristic as shown in Fig. It produces an active power change that is proportional to the frequency deviation.

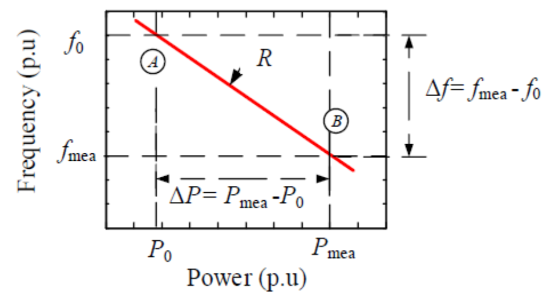

Fig. 1. Frequency droop characteristic.

Frequency droop controller can be included in a control loop in modern WTs based on generators electronically controller and/or electronically The droop control in WTG emulates the similar frequency droop characteristic to the synchronous generators.

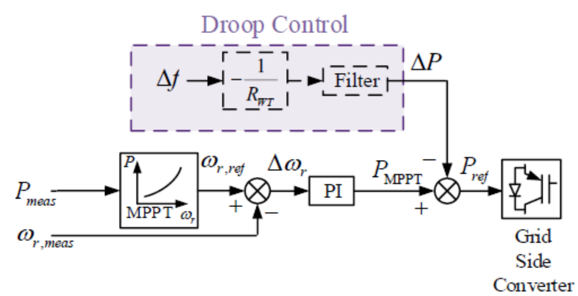

Fig. 2. A representative block diagram of a Frequency Droop Control for full converter rated VSWT .However, the power increase during a sudden drop in system frequency must be obtained from the kinetic energy of the rotation parts of WTG, it causes a decrease in rotational speed due to the *Maximum Power Point Tracking* (MPPT) operation. The support of steady-state frequency requires extra steady state power to reduce the frequency deviation; this extra power is provided in the long term from the prime-mover in classical generation units.

5. SIMULATION RESULTS

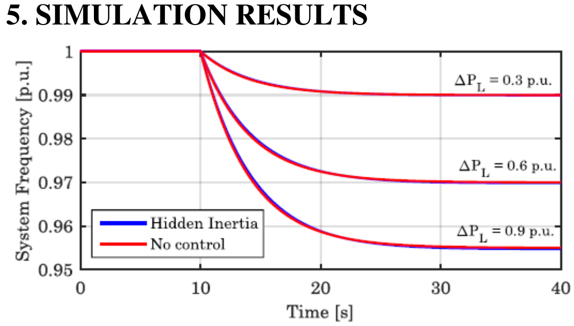

Fig. 3. System frequency dynamic response during system frequency disturbance considering three different power imbalances

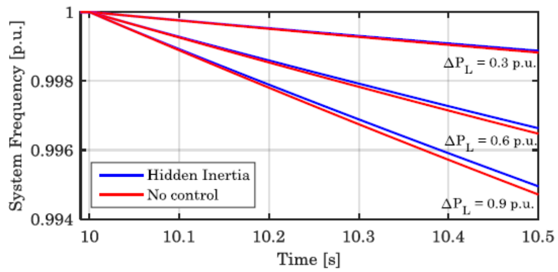

Fig. 4. Details at the very beginning (0.50 sec) of the system frequency response.

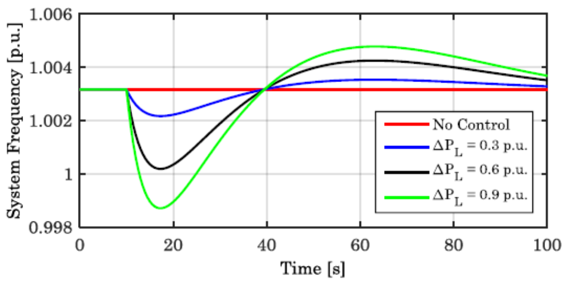

Fig. 5. Rotor speed response during system frequency disturbance. Inertia controller gain adjusted at H_{syn} = 28.0 sec.

6. CONCLUSION

The aim of this paper is that of describing the possible impact of variable speed wind generating unit on frequency support. As well known, under converter generation contribution in frequency support is null, due to the frequency decoupling between the generator and the grid. For this reason it is necessary to design and implement some frequency support control logic to be integrated with the conventional power converter unit control system of the wind generator. With this purpose, the main control strategy used to emulate an inertial behaviour of under converter generators where detailed, namely hidden inertia controller a fast power reserve emulation. These two strategies allows a fast active power contribution, and the fast power reserve emulation controller provides a smoother response depending on the slope included in the controller (P_{syn}/H_{syn}). The last proposed control strategy for frequency support is the droop control concept. This provides a contribution in a longer time frame similar to those provided by frequency control system for traditional power plants.

REFERENCES

[1] J. Ekanayake and N. Jenkins, "Comparison of the Response of Doubly Fed and Fixed-speed Induction Generator Wind Turbines to Changes in Network Frequency," IEEE Transactions on Energy Conversion, vol. 19, no. 4, pp. 800-802, 2004

[2] G. Lalor, A. Mullane and M. O'Malley, "Frequency control and wind turbine technologies," IEEE Transactions on Power Systems, vol. 20, no. 4, pp. 1905-1913, Dec. 2004

[3] M. Kayikci and J. V. Milanovic, "Dynamic contribution of DFIG-based wind plants to system frequency disturbances," IEEE Transactions on Power Systems, vol. 24, no. 2, pp. 859-867, May 2006.

[4] J. Morren, J. Pierik and S. W. H. D. Haan, "Inertia Response of Variable Speed Wind Turbines," Electric Power Systems Research, vol. 76, no. 11, pp. 980-987, 2006.

[5] J. Morren, S. Haan, W. L. Kling and J. A. Ferreira, "Wind turbines emulating inertia and supporting primary frequency control," IEEE Transactions on Power Systems, vol. 21, no. 1, pp. 433-434, Feb. 2006

[6] G. Ramtharan, J. B. Ekanayake and N. Jenkins, "Frequency support from doubly fed induction generator wind turbines," IET Renewable Power Generation, vol. 1, no. 1, pp. 3-9, Mar. 2007

[7] I. D. Margaris, S. A. Papathanassiou, N. D. Hatziargyriou, A. D. Hansen and P. Sorensen, "Frequency Control in Autonomous Power Systems with High Wind Power Penetration," IEEE Transactions on Sustainable Energy, vol. 3, no. 2, pp. 189-199, 2012

[8] J. F. Conroy and R. Watson, "Frequency response capability of full converter wind turbine generator in comparison to conventional

generation," IEEE Transactions on Power Systems, vol. 23, no. 2, pp. 189-199, May 2008