Fig. 8. System frequency dynamic response during system frequency disturbance considering three different power imbalances (ΔP_L), $H_{syn} = 0.25H_{WTG}$.

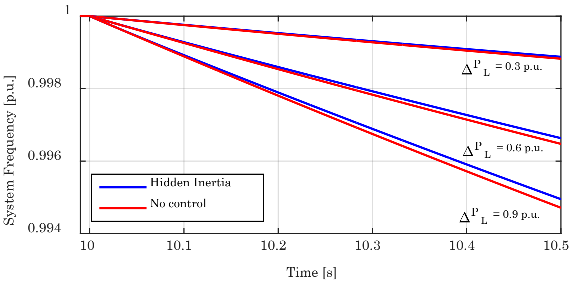

Fig. 9. Details at the very beginning (0.50 sec) of the system frequency response.

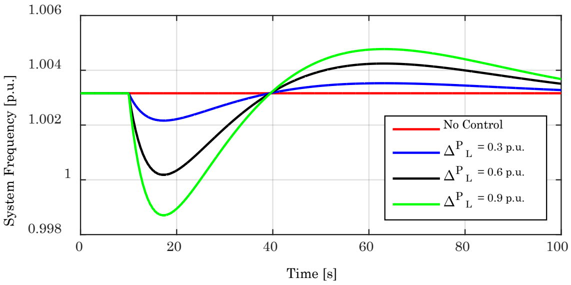

Fig. 10. Rotor speed response during system frequency disturbance. Inertia controller gain adjusted at $H_{syn} = 28.0$ sec.

It should be noticed, the implementation of this kind of frequency support strategy has to be properly designed since as high value of the synthetic inertia may lead to a problem in the wind turbine dynamic. In Fig. 10 and 11 show the system frequency response and generator rotor speed in case of inertial controller gain adjusted to three times the wind generator inertia ($H_{syn} = 3H_{WTG}$) and system frequency disturbance of 0.90 pu

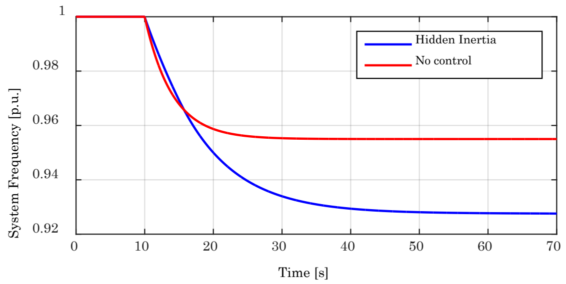

Fig. 11. System frequency response: System frequency disturbance $\Delta P_L = 0.90$ pu and inertia controller gain $H_{syn} = 3H_{WTG}$.

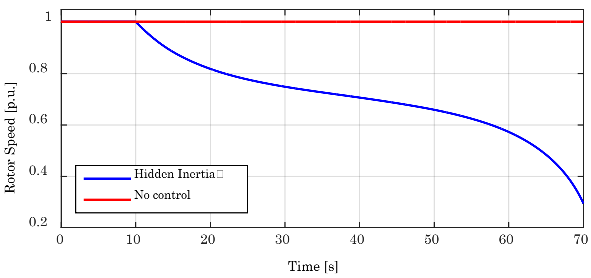

Fig. 12. Rotor speed response: $\Delta P_L = 0.90$ pu and inertia controller gain $H_{syn} = 3H_{WTG}$.

Fig. 12 shows a clear condition where the wind turbine generator stalls by means of a drift of the rotor speed and the consequent shut down of the WTG. This is a very critical condition for frequency stability since it produces a further system frequency disturbance by losing wind turbine generation and decreasing in frequency. Analysing the mathematical rule of the synthetic inertia controller (5), it is possible to notice that its contribution does not provide a change in the possible steady-state equilibrium point of the power system, since the additional term is proportional to the time derivative of frequency. This suggest that the frequency instability problem is not related to the feasibility of the system equilibrium point but is probably related to the interaction between the WTG controller and the synthetic inertia one.

The limit value of the synthetic inertia controller gains for the stable operation of the system vary in accordance with the amplitude of the frequency disturbance. In this paper, the limit values of stable conditions are obtained by means of dedicated simulations, Table 1 shows the results for the three-power imbalance conditions used in the previous simulations.

Table 1: Hidden Inertia limits for stable operation.

Load variation ΔP_L (pu)	**Synthetic inertia limit $H_{syn,max}$ (sec)**
0.30	$5H_{WTG}$
0.60	$3H_{WTG}$
0.90	$2H_{WTG}$

6 Conclusion

The aim of the present paper is to evaluate the inertial frequency support provided by variable speed wind generators. With this purpose, the main control strategy used to emulate an inertial behaviour of under converter generators where detailed, namely hidden inertia controller. It allows a fast active power contribution, fast power reserve emulation controller, that provides a smoother response depending on the slope included in the controller (P_{syn}/H_{syn}) and finally the droop control concept, that provides a contribution in a longer time frame similar to those provided by frequency control system for traditional power plants. The effect of this family of the control system has been evaluated considering the hidden inertia controller in a simplified wind turbine and network model implemented in Matlab/Simulink. The simulation highlighted the positive impact of the proposed controller on the system frequency in different load conditions highlighting the positive contribution of Hidden Inertia Controller under different load variation conditions. In this sensitivity analysis, it was also possible to point out that high values of the synthetic inertia parameter, may destabilize the power system causing the stall of the WTG. Future works will concern the possibility to study the nature of this unstable behaviour of the Hidden Inertia controller in order to provide some criteria for the optimal and secure design of this controller. Moreover, it will be necessary to evaluate the possible integration of the synthetic inertial controller and the droop ones in order to achieve a more effective effect of a wind generator in the support of frequency beyond the first instants of the transient.

References:

[1] F. Gonzalez-Longatt, "Frequency Control and Inertial Response Schemes for the Future Power Networks," in *Large Scale Renewable Power Generation*, J. Hossain and A. Mahmud, Eds., ed: Springer Singapore, 2014, pp. 193-231.

[2] F. Gonzalez-Longatt, "Impact of emulated inertia from wind power on under-frequency protection schemes of future power systems," *Journal of Modern Power Systems and Clean Energy,* pp. 1-8, 2015/08/12 2015.

[3] F. Gonzalez-Longatt, E. Chikuni, W. Stemmet, and K. Folly, "Effects of the synthetic inertia from wind power on the total system inertia after a frequency disturbance," in *Power Engineering Society Conference and Exposition in Africa (PowerAfrica), 2012 IEEE*, 2012, pp. 1-7.

[4] S. Yuan-Zhang, Z. Zhao-Sui, L. Guo-jie, and L. Jin, "Review on frequency control of power systems with wind power penetration," in *Power System Technology (POWERCON), 2010 International Conference on*, 2010, pp. 1-8.

[5] J. Ekanayake and N. Jenkins, "Comparison of the response of doubly fed and fixed-speed induction generator wind turbines to changes in network frequency," *Energy Conversion, IEEE Transactions on,* vol. 19, pp. 800-802, 2004.

[6] R. Doherty, A. Mullane, G. Nolan, D. J. Burke, A. Bryson, and M. O'Malley, "An Assessment of the Impact of Wind Generation on System Frequency Control," *Power Systems, IEEE Transactions on,* vol. 25, pp. 452-460, 2010.

[7] I. Erlich, W. Winter, and A. Dittrich, "Advanced grid requirements for the integration of wind turbines into the German transmission system," in *Power Engineering Society General Meeting, 2006. IEEE,* 2006, p. 7 pp.

[8] F. M. Gonzalez-Longatt, "Impact of emulated inertia from wind power on under-frequency protection schemes of future power systems," *Journal of Modern Power Systems and Clean Energy,* pp. 1-8, 2015/08/12 2015.

[9] G. Lalor, A. Mullane, and M. O'Malley, "Frequency control and wind turbine technologies," *Power Systems, IEEE Transactions on,* vol. 20, pp. 1905-1913, 2005.

[10] F. M. Gonzalez-Longatt, "Activation schemes of synthetic inertia controller for full converter wind turbine generators," in *PowerTech, 2015 IEEE Eindhoven*, 2015, pp. 1-5.

[11] N. Miller, K. Clark, and R. Walling, "WindINERTIA: Controlled Inertial Response from GE Wind Turbine Generators," presented at the 45th Annual Minnesota Power Systems Conference, Minneapolis, Minnesota, 2009.

[12] S. Wachtel and A. Beekmann, "Contribution of Wind Energy Converters with Inertia Emulation to Frequency Control and Frequency Stability in Power Systems," presented at the 8th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Farms, Bremen, Germany, 2009.

[13] F. Gonzalez-Longatt and J. M. Roldan, "Effects of dc voltage control strategies of voltage response on multi-terminal HVDC following a disturbance," in *Universities Power Engineering Conference (UPEC), 2012 47th International*, 2012, pp. 1-6.

[14] J. Morren, S. W. H. De Haan, W. L. Kling, and J. A. Ferreira, "Wind turbines emulating inertia and supporting primary frequency control," *Power Systems, IEEE Transactions on,* vol. 21, pp. 433-434, 2006.

[15] K. Ping-Kwan, L. Pei, H. Banakar, and B. T. Ooi, "Kinetic Energy of Wind-Turbine Generators for System Frequency Support," *Power Systems, IEEE Transactions on,* vol. 24, pp. 279-287, 2009.

[16] A. Teninge, C. Jecu, D. Roye, S. Bacha, J. Duval, and R. Belhomme, "Contribution to frequency control through wind turbine inertial energy storage," *Renewable Power Generation, IET,* vol. 3, pp. 358-370, 2009.

[17] N. R. Ullah, T. Thiringer, and D. Karlsson, "Temporary Primary Frequency Control Support by Variable Speed Wind Turbines— Potential and Applications," *Power Systems, IEEE Transactions on,* vol. 23, pp. 601-612, 2008.

[18] Y. Jeong and C. S. o. M. D. o. Engineering, *Comparison and Testing of Active Power Control Strategies for Grid-connected Wind Turbines*: Colorado School of Mines, 2011.

[19] J. Duval and B. Meyer, "Frequency behavior of grid with high penetration rate of wind generation," in *PowerTech, 2009 IEEE Bucharest*, 2009, pp. 1-6.

[20] F. M. Gonzalez-Longatt, "Activation schemes of synthetic inertia controller on full converter wind turbine (type 4)," in *Power & Energy Society General Meeting, 2015 IEEE*, 2015, pp. 1-5.

[21] O. Anaya-Lara, *Wind energy generation : modelling and control*. Oxford: Wiley, 2009.

[22] T. Ackermann, *Wind power in power systems*. Chichester: John Wiley & Sons, 2005.