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Fixed-Speed and Variable-Slip Wind Turbines Providing Spinning Reserves to the Grid

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Introduction

• By 2030, it is possible that up to 300 GW of wind power may be generated by wind power plants (according to the "20% Wind by 2030" study by the U.S. DOE)

• Wind turbine technology must move from merely generating power from wind to taking a role in supporting the bulk power system

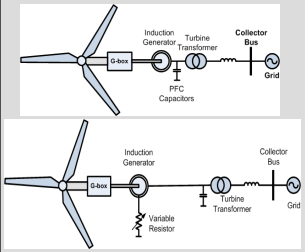
• Wind turbines should have the capability to provide inertial response and primary frequency (governor) response. Wind turbine generators with this capability can support the frequency stability of the grid

• Wind turbines should be able to generate less power than the available wind power and hold the rest in reserve, ready to be accessed as needed

• In this work, we explore several ways to control wind turbine output to enable reserve-holding capability. The focus of this paper is on fixed-speed (also known as Type 1) and variable-slip (also known as Type 2) wind turbines

• The benefit of allowing these turbines to hold reserve power is enhanced grid stability at lower cost

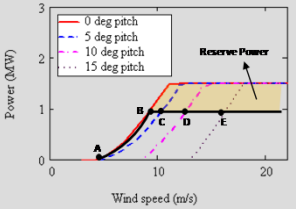
Type 1 and Type 2 Wind Turbines



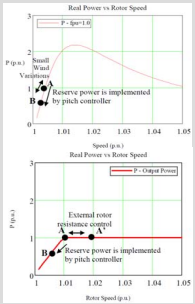
In Type 1 wind turbines, the power output is dictated by the characteristic of the induction generator. There is no power converter connected to the stator winding or the rotor winding. In Type 2 wind turbines, there is an external rotor resistance that can be used to control the output power; however, using the rotor resistance control may result in losses. In the approach proposed in this paper, the pitch controller is used to allocate part of the available aerodynamic power as reserve power and the turbine delivers the remainder to the power system grid

Pitch Control to Allow Reserve Holding

It is possible to operate wind turbines at different pitch angles (or scheduled pitch angles). This allows the WTG to set aside the reserve power to be called when needed—for example, when a large generator drops from the grid because of fault occurring in the transmission lines, the reserved power may be called to substitute the loss of generated power; thus, the power system frequency will not drop significantly. The operation follows the path ABCDE. The shaded area represents the reserve power available that can be retrieved. The disadvantage of this algorithm is that during productive winds, the output power has to be shed; thus, there is some productivity loss.



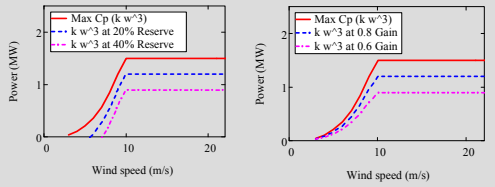
Power vs. Speed Characteristics



Top figure: Type 1 WTG
The normal operating point at rated wind speed is at Point A, where the output power is at 1.0 per unit. To allow power to be held in reserve, the wind turbine is operated with an output power set point lower than what is actually available, e.g., at high wind speeds, the pitch can be controlled to generate 80% of rated power although it is capable of generating 100% of rated power. The operating point moves from A to B.

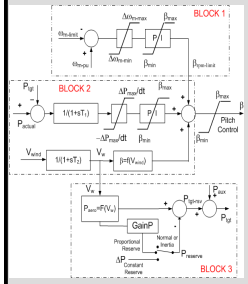
Bottom figure: Type 2 WTG
The external rotor resistance can be adjusted so that the output power stays constant. This is indicated by A and A'. Alhough the rotor resistance can be varied, in practice the pitch controller is used to control the speed to minimize the external rotor resistance because deployment of rotor resistance generates heat that must be dissipated. To allow power to be held in reserve, the wind turbine is operated with an output power set point lower than available power as in the Type 1 WTG. The operating point moves from A to B.

Two Different Reserve-Holding Methods



To set aside some reserve power, a constant value of reserve power (constant reserve) or a constant proportion of the available aerodynamic power (proportional reserve) may be selected. The figure on the left shows wind turbine power curves if the reserve power to be held is a constant value (20% and 40% of rated power); the figure on the right shows the power curves if the reserve power to be held is a constant percentage (20% and 40% of target power—i.e., maximum C_p operation).

Proposed Pitch Controller

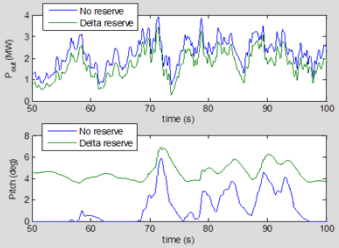


There are several groups of control blocks performing different functions. Block 1 computes the input to the pitch controller to limit the rotational speed at rated value when the wind speed is high to avoid a runaway condition. Block 2 computes the input to the pitch controller to limit the average output power of the wind turbine based on the target power P_{tgt}. The target power P_{tgt} varies with wind speed and the level of reserved power defined. In Block 3, the target power is computed to guide the pitch controller in adjusting the output power from the WTG. The input to Block 3 is the filtered wind speed that is translated to aerodynamic power using the power curve of the turbine via a lookup table. The output of the lookup table is the actual output of the turbine without accommodation for reserve power.

Dynamic Simulations

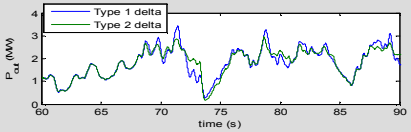
- *The performance of the proposed controller was investigated through dynamic simulations*
- *The induction generator is represented by typical fifth-order dynamic representation*
- *Dynamic models were developed in PSCAD/EMTDC*
- *Models tested using 150 s of real wind speed data*
- *In each case, the rated power of the wind turbine is 3 MW*

Reserve Power Implementation: Type 1



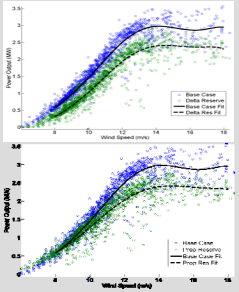
A constant reserve power is commanded (20% of rated power—i.e., 0.6 MW). The output power shows both the available wind power (blue line) and the output power with reserve power held (green line). The pitch angle is shown to vary at a slower rate than the wind speed variation. The pitch controller is slower than the power electronics controller when used to limit the output power; thus, only the average power is limited to the rated output power. As shown in the figure, there are times when the peak of the output power briefly exceeds the rated power (3 MW) of the wind turbine.

Reserve Power Implementation: Type 2



In this implementation, the rotor resistance is used to limit the generator output current to a constant value, according to the percentage of the reserve power to be held. For example, if the reserve power to be held is 20% of rated power, the output current will be limited to 80% of rated current by controlling the external rotor resistance. Note that the rotor resistance control is much faster than the pitch controller; thus, the current regulation can be accomplished very effectively.
The effect of fast control of external resistance control can be shown by comparing the output power fluctuations between Type 1 wind turbines and Type 2 wind turbines. In Type 2 wind turbines, the power output is practically clamped at the maximum output power of the wind turbine, which is equal to the rated power (3 MW); whereas in Type 1 wind turbines, the output power sometimes exceeds the rated value of 3 MW.

Output Power Comparison



The Type 2 WTG was simulated and the output was plotted against wind speed. This figure shows the output power comparison between the base case and the operation with reserved power. As expected, the actual output power was scattered. However, when we used the polynomial fitting of 7th order, the output power characteristic was similar to the one predicted in Figure 7. The scattered points can be accounted to the changes of the kinetic energy stored in the rotating mass (blades, generator, gearbox, etc.) because the rotational speed of the wind turbine changes with time.

Top figure: Base case vs. delta reserve power case, Type 2 WTG, $\Delta P_{reserve}$ = 20% of the rated power
Bottom figure: Base case vs. proportional reserve power case, Type 2 WTG, $\Delta P_{reserve}$ = 20% of the rated power

Conclusion

- *This paper describes the reserve power implementation in a wind power plant for Type 1 and Type 2 wind turbines*
- *We chose Type 1 and Type 2 wind turbines because they are still available on the market and because the reserve power is more difficult to control with pitch control*
- *The power converters in Type 3 and Type 4 wind turbines make it easier to implement spinning reserves; however, as shown in this paper, spinning reserve power can be implemented successfully even with only the pitch controller*
- *When scaled up to the plant level, these capabilities can offer significant frequency support to the bulk power system grid and should be considered in a high-wind-penetration scenario*
- *The low cost of Type 1 and Type 2 wind turbines make them an attractive choice if they are able to provide grid support.*

References

1. S. Lindenberg, B. Smith, and K. O'Dell, "20% wind energy by 2030," Prepared by Energetics, Inc., for the National Renewable Energy Laboratory, Golden, CO, TP-550-41869, July 2008.
2. J. Eto, et al., "Use of frequency response metrics to access the planning and operating requirements for reliable integration of variable renewable generation," Ernest Orlando Lawrence Berkeley National Laboratory report, Berkeley, CA, LBNL-4142E, Dec. 2010.
3. P. W. Christensen and G. T. Tarnowski, "Inertia of wind power plants: State-of-the-art review year 2011," in Proc. 10th International Workshop on Large-Scale of Wind Power, Aarhus, Denmark, 2011.
4. L. Ruttlege and D. Flynn, "System-wide inertial response from fixed-speed and variable-speed wind turbines," in IEEE PESGM Proc., Detroit, MI, 2011, pp. 1–7.
5. N. W. Miller, K. Clark, and M. Shao, "Impact of frequency responsive wind plant controls on grid performance," in Proc. 9th International Workshop on Large-Scale Integration of Wind Power, Quebec, Canada, 2010.
6. N. W. Miller, M. Shao, and S. Venkataraman, "California ISO: Frequency response study," Final draft, Nov. 9, 2011. www.uwig.org/Report-FrequencyResponseStudy.pdf.
7. S. Sharma, S. H. Huang, and N. D. R. Sarma, "System inertial frequency response estimation and impact of renewable resources in ERCOT interconnection," in IEEE PESGM Proc., 2011, pp. 1–6.
8. L. Holdsworth, J. B. Ekanayake, and N. Jenkins, "Power system frequency response from fixed-speed and doubly-fed induction-generator-based wind turbines," Wind Energy, vol. 7, no. 1, pp. 21–35, 2004.
9. J. Morren, J. Pierik, and S. W. H. de Haan, "Inertial response of variable-speed wind turbines," Electric Power Systems Research, vol. 76, no. 11, pp. 980–987, 2006.
10. E. Muljadi, V. Gevorgian, M. Singh, and S. Santoso, "Understanding inertial and frequency response of wind power plants," IEEE PEMWA 2012 Proc., Denver, CO, 2012

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