Renewable Energy 68 (2014) 326–336

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Analysis of the short-term overproduction capability of variable speed wind turbines

Anca D. Hansen [a,*], Müfit Altin [a], Ioannis D. Margaris [b], Florin Iov [c], Germán C. Tarnowski [d]

[a] Technical University of Denmark, Department of Wind Energy, Denmark
[b] National Technical University of Athens, Greece
[c] Aalborg University, Department of Energy Technology, Denmark
[d] National University of Misiones, Centre for Energy Studies for Development, Argentina

ARTICLE INFO

Article history:
Received 7 June 2013
Accepted 6 February 2014
Available online 4 March 2014

Keywords:
Active power
Overproduction
Inertial response
Variable speed wind turbine
Standard model

ABSTRACT

Emphasis in this article is on variable speed wind turbines (VSWTs) capability to provide short-term overproduction and better understanding of VSWTs' mechanical and electrical limits to deliver such support. VSWTs' short-term overproduction capability is of primary concern for the transmission system operators (TSOs) in the process of restoring critical situations during large frequency excursions in power systems with high wind power penetration.

This study is conducted on a simplified generic model for VSWTs with full scale power converter (Type IV), which includes several adjustments and extensions of the Type IV standard wind turbine model proposed by the IEC Committee in IEC 61400-27-1. This modified standard model is able to account for dynamic features relevant for integrating active power ancillary services in wind power plants, such as frequency support capabilities.

The performance of VSWTs during short-term overproduction is assessed and discussed by means of simulations for different wind speed levels, overproduction percentages and durations. The results show that the capability of VSWTs providing short-term overproduction to the grid strongly depends on the initial pre-overproduction conditions.

1. Introduction

High wind power penetration levels into power systems have posed serious concerns regarding security of supply. They have led to a growing interest in the wind turbines' potential to provide the ancillary services delivered by conventional generations up to now [1,2]. Even though wind turbines do not inherently provide these services, they can stipulate them through suitable additional control actions. In particular, the impact of large amounts of wind power on the power system frequency stability is of primary concern for TSOs [3,4].

Frequency stability is a challenging technical issue, which has initiated both an intensification of the research on VSWTs' frequency support capability and a continuous revision by TSOs of the grid requirements for large wind farms [5]. The frequency support terminology includes both the inertial response and the primary frequency control [6]. The inertial response of a wind turbine (WT) refers to the short-term additional active power contribution that can be temporarily released by a WT equipped with an appropriate control, by exploiting the stored kinetic energy in the rotating mass of the turbine. This action is also called short-term overproduction [7] and it is activated during grid frequency excursions until the primary frequency control reserve of the power system is released [8] or some operational limit in the VSWT is reached during this action.

A comprehensive state of the art review, regarding the frequency response capability of wind turbines, is conducted in [4]. According to [4], TSOs in some countries, i.e. Germany, Spain, Canada and United Kingdom recognize the importance of the wind power inertial response for the system reliability, and stipulate therefore that wind power must provide frequency support and spinning reserve, as conventional power stations do. The TSOs of Ireland and Denmark are in different stages of implementing inertial response requirements in their operations. Recent studies [9]

* Corresponding author.
E-mail address: anca@dtu.dk (A.D. Hansen).

http://dx.doi.org/10.1016/j.renene.2014.02.012

made in the UK have led to the conclusion that "inertia should be provided by ancillary services market and not by a Grid Code requirement (either as an obligation or as a capability)".

Several studies regarding the inertial response contribution from VSWTs [10–12] have as goal to enhance their capability to actively support the power system. However, as indicated in [7,13], it is important to assess both the capability of VSWTs of injecting short-term additional active power into the grid and its limiting factors (i.e. rotational speed, stress in the mechanical and electrical components). Nevertheless, further studies for a better understanding and extensive quantification of the wind turbines capability to provide short-term active power overproduction are still necessary in order to enhance the reliability of modern wind turbines' frequency support capabilities. This capability, as is limiting the frequency excursions, might be especially beneficial in power systems with reduced inertia, i.e. in non-interconnected power systems, island power systems [14] or in power systems with weak interconnections and high wind power penetration.

The objective of this article is to analyze and quantify the capability of providing short-term active power overproduction by VSWTs. The article does not focus on the impact of this capability on a power system frequency profile, as this has been addressed in many relevant publications [6,12–14], over the years. Rather, focus is on explaining features of VSWTs capability to provide short-term overproduction and on a better understanding of the WT limitations to deliver such support.

The WT model used in this study has as starting point the generic approach proposed by the IEC Committee in Part 1 of IEC 61400-27 [15] for VSWTs. Nevertheless it is extended to include the dynamic features relevant for active power and grid frequency control capability studies. The IEC standard models [15] are not directly suitable for the type of study presented in this article, as their range of applicability focuses on the short-term stability of the power system.

The article is organized as follows. Section 2 briefly presents the WT modeling. Section 3 focuses on the behavior of the proposed WT model during short-term overproduction. Simulation and analysis results, illustrating the short-term overproduction capability of VSWT, are described in Section 4. The main parameters characteristic for the turbine behavior during overproduction operation are assessed and analyzed for different wind speed and overproduction conditions. Finally, conclusive remarks are reported.

2. Model description and characteristics

A simulation model for a VSWT with full scale power converter is illustrated in Fig. 1.

The model aims to reflect the dynamics caused by changing the active power references of the WT. In addition to the IEC standard Type IV model [15], this model includes information on the aerodynamical behavior of the rotor and on wind speed variability, as this is of high relevance whenever study of new control functionalities, like short-term active power overproduction, inertial response and primary frequency control are in focus [16].

As illustrated in Fig. 1, the model mainly consists of an aerodynamic model, a mechanical model, a pitch control model and models of the generator system and the electrical control system. The coupling between the aerodynamic and mechanical model contains information about WT's limitations to provide short-term active power overproduction.

A simplified aerodynamic model, based on a two-dimensional aerodynamic torque coefficient $Cq(\theta, \lambda)$ table, is used to illustrate the effect of the speed and pitch angle changes on the aerodynamic power. A 2-mass mechanical model is used in order to reflect the torsional shaft oscillations whenever there is a sudden torque imbalance in the mechanical system [17]. The block diagrams of the pitch control and the active power control are illustrated in Fig. 2. The pitch control system is realized by a PI controller with anti-reset windup, using a servo-mechanism model with limitations on both the pitch angle and its rate of change, while the active power controller uses the error signal between the measured power and the power reference as input.

Even though the control, illustrated in Fig. 1, both includes active and reactive power controllers, the attention in this investigation is only on the active power control loop. A frequency control block could be also implemented, as suggested in [6], but how or why the overproduction decision is taken is out of the scope of this study.

Besides component and control blocks, the WT model also contains blocks for wind speed, available power, maximum power point tracking (MPPT) and selection mode. A constant wind speed model is considered. This investigation, as is focusing on wind

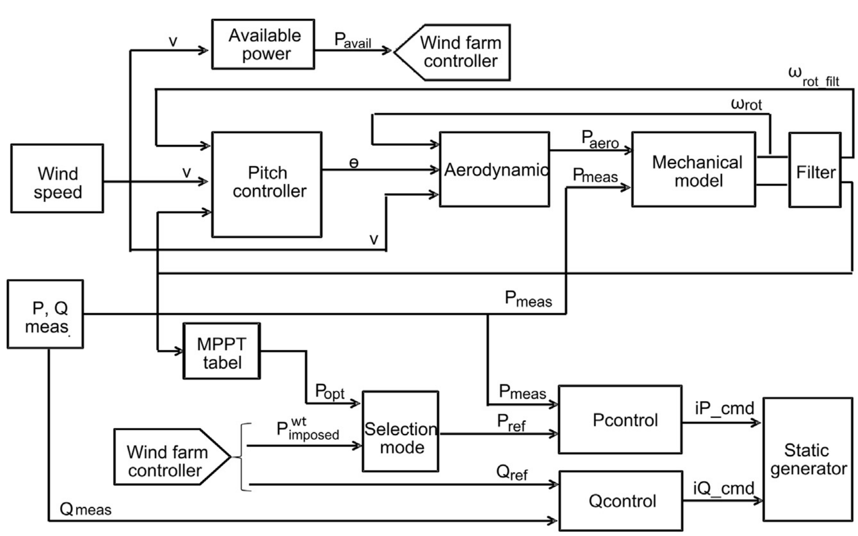

Fig. 1. Type IV wind turbine model structure.