Modeling real-time balancing power demands in wind power systems using stochastic differential equations

Magnus Olsson*, Magnus Perninge, Lennart Söder

Royal Institute of Technology (KTH), Electric Power Systems, Teknikringen 33, 10044 Stockholm, Sweden

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ABSTRACT

The inclusion of wind power into power systems has a significant impact on the demand for real-time balancing power due to the stochastic nature of wind power production. The overall aim of this paper is to present probabilistic models of the impact of large-scale integration of wind power on the continuous demand in MW for real-time balancing power. This is important not only for system operators, but also for producers and consumers since they in most systems through various market solutions provide balancing power.

Since there can occur situations where the wind power variations cancel out other types of deviations in the system, models on an hourly basis are not sufficient. Therefore the developed model is in continuous time and is based on stochastic differential equations (SDE). The model can be used within an analytical framework or in Monte Carlo simulations.

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1. Algebraic symbols

Variables in continuous time are denoted with the time argument with parenthesis, as e.g. \( P(t) \), while discrete time is indicated with subscripts, as e.g. \( P_k \). Stochastic variables are in uppercase Latin letters, e.g. \( P_k \). Realizations or historical data of the same are in lowercase letters, as e.g. \( p_k \). The indicator function \( I_A \in \{0, 1\} \) take the value \( I_A = 1 \) if the logical expression \( A \) is true, otherwise \( I_A = 0 \). Below follows a list of the variables and most important parameters. Additional parameters are defined on first occasion.

- \( D(t) \) demand for balancing power [MW]
- \( P(t) \) base production [MW]
- \( L(t) \) base load [MW]
- \( Q(t) \) controllable production [MW]
- \( W(t) \) uncontrollable production [MW]
- \( N(t) \) net base load [MW]
- \( \mu(t) \) mean function of \( L(t) \)
- \( \alpha, \sigma \) parameters of \( X(t) \)
- \( o_0(t) \) deterministic part of \( W(t) \)
- \( U(t) \) stochastic process in \( W(t) \)
- \( \pi(t) \) deterministic part of \( Q(t) \)
- \( Y(t) \) stochastic process in \( Q(t) \)
- \( r_k(t_k) \) segments of \( \pi(t) \)
- \( \beta \) parameter in \( Y(t) \)
- \( Z(t) \) stochastic jump process in \( Y(t) \)
- \( (T_n, V_n) \) stochastic pairs defining \( Z(t) \)

2. Introduction

This paper addresses the problem of balance management in power systems. The aim is to describe a new probabilistic model of the time continuous balancing demand in MW in a system with large amounts of wind power. This model can, e.g. be used to estimate energy demands for primary, secondary and tertiary control. In addition to be useful within an analytical framework, the presented model can be applied in Monte Carlo simulations. Performing such analyses and simulations is of great importance not only for system operators, but also for producers (and possibly consumers) since they in most systems provide balancing power through various market solutions. The presented model provides a tool for calculation and simulation of the demand for frequency control and required ramp rates.

Probabilistic load or production models are usually based on an hourly time resolution as in, e.g. [1] and [2]. However, to be able to perform precise estimations of the impact of new power sources into the power system on the continuous need for balancing power, models using an hourly time resolution are not sufficient. This is due to the fact that the production may vary significantly during the hour, as e.g. in the case of wind power.

* Corresponding author.

E-mail addresses: magnus.olsson@ee.kth.se (M. Olsson), magnus.perninge@ee.kth.se (M. Perninge), lennart.soder@ee.kth.se (L. Söder).