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Stochastic modeling to represent wind power generation and demand in electric power system based on real data

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HIGHLIGHTS

- The Ornstein–Uhlenbeck process is used to model stochastic random perturbations.
- Multi-correlated model that represents windmills interactions.
- Validation technique for continuous unidimensional stochastic models.
- Short-time multidimensional wind generation forecasting model (hours).
- Medium-time one dimensional residential power demand forecasting hybrid model.

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ABSTRACT

A methodology to model two types of random perturbation that affect the operation of electric power systems (EPS) are presented. The first uncertainty is wind power generation and is represented by a one-dimensional and by a multidimensional continuous stochastic process. The second one is power demand, and is modeled by using an hybrid structure based on harmonic regression and the Ornstein–Uhlenbeck (O–U) process. The stochastic models are applied to a real Chilean case, using real data for parametric estimation and validation models.

1. Introduction

Dynamic and permanent regime studies that deal with electric power systems (EPS) are of vital importance to the electrical industry, because they make it possible to determine the adequate operating conditions for supplying the electric power required by society in an economic, reliable and safe manner. In this context, the most important approaches of the EPS studies are oriented at their planning and operation.

One of the main problems that concern planning and operation consists on keeping the system operating in a steady state, i.e., that the system does not lose its balance when it is subjected to perturbations that affect its behavior. The most frequent perturbations found in EPS are fault occurrence, load level variation, changes in the network topology, and the presence of random components caused by generation sources based on unconventional renewable energy.

In particular, wind generation and power demand will be the focus of this paper. Due to the stochastic nature governing these two types of disturbances, it is appropriate to consider statistical models to represent their behaviors and then, perform more realistically studies about their impact over the EPS [1].

Development of more precise and accurate models is of high importance for improving the results of their subsequent application [2–7]. For instance, paper [2] uses Kalman filtering in the context of short-term prediction wind speed, reflecting in turn into a better planning and usage of the power resource.

In [3], statistical regime-switching models are applied in order to modeling the fluctuations of offshore wind generation. The research is oriented to obtain models dedicated to enhance the existing control and energy management strategies at offshore wind parks.

Ref. [4] applied a Markov-switching model to perform point and interval forecasting of wind speed. It Emphasize that an accurate

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wind speed interval forecasting is beneficial to the robust optimization in wind farm operational planning.

A statistical and dynamical modeling are proposed in [5] for various classes of wind speed fluctuations distributions. A generated wind speed sequence in time is made solving the Langevin equation with different turbulence conditions. Ref. [6] uses Stochastic Differential Equations (SDE), based on Ornstein–Uhlenbeck (O–U) process, to develop methods to model wind speed.

Paper [7] presents models based on SDE and O–U process of wind power production, besides, base production and base consumption which can be used to evaluate the impact on power systems balancing. In addition, estimation methods for parameters are proposed and a case study is presented.

As can be seen, accurate wind speed and wind power simulations and forecasting have an important influence on studies and decision-making of EPS [8,9]. For this reason, a large number of techniques have been developed. Papers related to comparisons between different methods can be found in [10–14].

In [11] a comparison between time series and Artificial Neural Networks (ANN) models is presented by a long-therm prediction of production of wind power station in Mexico. Another comparison is made in [12], where Autoregressive – Moving Average (ARMA), 5 kinds of ANN and the Adaptive neuro fuzzy inference system (ANFIS) models are compare in different time horizons.

In [13], it is proposed a new method based on multiple architecture system (MAS).

Conversely, load uncertainty models can be found in [15–20], where they use continuous stochastic process in order to model the behavior of the loads for stability studies.

While continuous models are widely used for application to stability studies, other kinds of models are applied to modeling demand.

In [21–25], regression models to study residential energy demand are presented. Refs. [21,22] use multilinear regression with the aim of predicting future values of energy demand. On the other hand, logistic regression method is used in [23], where it is applied to analyse the domestic electric consumption types. In [24,25] harmonic regression is used taking advantage of their ability to describe processes with marked seasonality.

Time series analysis is also largely used in this context [26–30]. For example, in [29] residential demand is modeled and predicted with a Seasonal Autoregressive Integrated Moving Average with Exogenous Variables model (SARIMAX), considering as a data real residential demand measures.

The models and applications are vast, so in order to sum up all the techniques used to represent wind generation and power demand, Tables 1 and 2 classify the principal methods reviewed and expose their benefits and principal cases of application.

Classification of Table 1 is based on Refs. [31,32], and Table 2 maintains the structure classification but considering Ref. [33] as a guideline. It is important to say that Table 2 is focused on residential power demand because this type of load is the most commonly analysed.

As the literature shows, there is a wide variety of tools to study the impact of stochastic perturbation, as wind generation, and different approaches can be made. However the main purpose of this paper is to model stochastically in continuous time the behavior of wind farm power generation and the power demand due to residential consumption by means of a model that accounts for the random and self-sustained over time dynamics.

The novelty of the models proposed is the development of a multidimensional correlated model for a wind farm representation. The interesting thing in the equations obtained is the presence of a correlation matrix, which can provide potential

Table 1
Statistical methods to model and forecast wind speed and wind power generation.

Category	Subclass	Example	Advantage	Study focus
Conventional statistics	Recursive filter	Kalman filters	• Ability to provide the quality of the estimate • Relatively low complexity	• Used to predict the future wind speed. It is suitable for online forecasting of wind speed • Prediction to improve the planning and usage of power sources
	Stochastic process	Discrete time continuous state (Time series analysis: ARMA, ARIMA, ARIMA) Discrete time discrete space (Markov chains)	• Well established methodology • Well implemented estimation and validation techniques • Flexibility in assignment variables	• Long, medium and short term studies, where predicting future values are needed • Influence analysis of factors over wind power generation
		Continuous time continuous space (Brownian motion, O–U process, etc.)	• More general description for phenomena under study • Wider range of applicability of possible phenomena modeling	• Continuous time analysis, ideal for time depending studies, as analytic stability studies • Power wind impact studies
Artificial intelligence and new methods	Artificial neural networks	Feed-foreward Elman Radial Basis Function Multilayer perceptron	• More general than linear methods, which gives a major flexibility at the moment to fit a data series	• Accuracy improvement forecasting wind speed and wind power generation, applied to planning and control studies
	Fuzzy Logic Wavelets Entropy based training Spatial correlation		• Less condition about the data should be assumed, which is better in situations when the truly distribution is unknown or cannot be approximated easily	• Applied to non stationary wind speed prediction in wind power systems • Used where a system is difficult to model exactly
Hybrid methods	Mixtures of any method mentioned above	Adaptation neuro fuzzy inference system (ANFIS)	• Advanced ones and less error than others • Improvement of pure methods	• Depending on the hybrid mixture. In general used to improve the accuracy of forecasting methods • Short and medium term wind speed and wind power prediction