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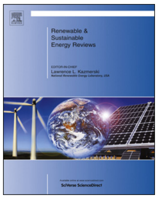

Assessing wind speed simulation methods

Andrés Feijóo *, Daniel Villanueva

Departamento de Enxeñería Eléctrica, Universidade de Vigo, EEI, Campus de Lagoas, 36310 Vigo, Spain

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ABSTRACT

In this paper simulation methods of wind speed series at different locations are reviewed. Over the last few decades wind farms (WF) have increasingly been introduced into electric power systems (EPS) in many countries. The strong relationship between wind speed and the power generated by a wind energy converter (WEC) has led researchers to reflect on the need to develop adequate models for simulating wind speed data. In recent years some proposals to meet this need have been published in the literature, and this paper aims to gather and discuss them.

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* Corresponding author. Tel.: +34 986 812055.
E-mail addresses: afeijoo@uvigo.es (A. Feijóo), dvillanueva@uvigo.es (D. Villanueva).

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1. Introduction

Integration of wind power into EPS needs to be carried out with knowledge of the behaviour of such an energy source. The possibility of fitting its cumulative behaviour to given distributions in order to make statistical analysis easier has been an issue over the years [1,2].

One of the main concerns facing those who manage wind energy in EPS is the difficulty of controlling power obtained from such a variable resource. The impossibility of storing wind directly as a primary resource together with the difficulty of predicting its behaviour has created a need to develop adequate procedures for correct simulation. It must be said that prediction tools based on meteorological models have improved over recent years and in some markets, such as the Spanish one, part of the wind energy being injected in the system is commercialised daily in the electricity pool. This is possible thanks to such models, as they provide some guarantee as to the amount that can be injected [3].

In the early years of wind energy development, some companies, particularly transmission system operators (TSO), saw the concept of simultaneousness as an interesting question that needed an answer. It is a concept that has been generally applied to loads. Conventionally, it is considered that a power flow can be run for a given area under the assumption that only a given percentage of the total load is being applied, and not the whole bulk of the installed capacity. According to this, a figure below 100% of total load amount is called the simultaneousness of the load. The question begging an answer is whether a similar concept can be defined for wind generation.

In the case of loads, thousands of recorded operation hours allow operators to establish certain rules that result in that figure called simultaneousness. For conventional power stations (nuclear, coal, hydro), the possibility of programming them on the basis of the availability of their primary resources allows stakeholders to limit the degree of uncertainty in the calculations.

This is not the case for wind energy, due to its variable behaviour. The way the wind behaves can determine different decisions in an EPS. Thus, the knowledge of what kind of wind speed distribution is to be handled is important and, when there are several WFs in a given network, which is the general case, the correlation between their wind speeds is also important. For instance, in a probabilistic load flow analysis, changes in these variables (distributions, correlations) can determine different solutions.

There has been a steady flow of research and literature dealing with this topic over recent years, and the goal of this paper is to review that body of work and add to the discussion.

The rest of the paper is devoted to discussing different issues involved in the simulation of wind speed series. In Section 2 the most used continuous statistical distributions for the description of wind speed cumulative behaviour are reviewed. In Section 3 the important concept of correlation is introduced and several methods that have been used in the literature for inducing correlation in uncorrelated series of data are explained. In Section 4 the introduction of autocorrelation in the simulation is explained. Section 5 is about Markov processes and their relationship with autocorrelation and chronological features. Finally, after very brief comments in Section 6 about other possible methods, Section 7 adds conclusions and some more discussion.

2. Wind speed distributions

The main feature of wind speed is its variability. Disregarding the fact that wind speed at a given location in particular can be constant over long periods of time, it has been generally confirmed that wind speed is a very variable resource at any place. This variability can be observed in time and in space. Wind speed is variable at a given location over time, but it can also be very different at two different locations simultaneously.

Wind speed can be considered as a vector, i.e. a pair of numbers, one of them corresponding to its mean value for a fixed period of time, and the other one indicating a direction. In this paper the direction of wind speed will not be considered, and the discussion will be only about mean values. There are interesting works in the literature where the direction of wind has been considered when modelling it stochastically [4].

There seems to be general agreement on the fact that wind speed in a given location can be cumulatively represented by means of a Weibull distribution [5,6]. Saying cumulatively means that a typical probability density function (PDF) for a given period of time can be established.

Wind speed can be considered as a continuous function depending on time. However, the number of wind speed values stored by any meteorological station can only be finite, due to the existence of a sampling period, which means these values can be interpreted as a discrete function. The Weibull distribution is described by means of a continuous function of time, so when it is used as a wind speed distribution it must be understood at best as a good approximation to the previously considered discrete function. Finally, when simulations are required for any process needing those values, a new discrete function will be generated, the simulated discrete function, whose values will probably be extracted from the continuous function that has been obtained from the discrete values stored. It is a complex process.

The goal of the simulations is to obtain series satisfying some statistical constraints, depending on those observed in the original series. Generally, these statistical values are given in the form of a PDF, or at least given in terms of the mean, variance and correlations between series. Occasionally, autocorrelations are also considered, especially when chronological features are required.

2.1. Weibull and Rayleigh distributions

The PDF of the Weibull distribution, f, has been widely described in the literature, and can be expressed as a function of three parameters, i.e. origin (γ), scale (C) and shape (k), although in the case of wind speed distributions, given that the minimum value of wind speed is 0, the origin parameter, γ, equals 0, and this is why the following 2-parameter expression (C, k) stands for it:

$$f(v_w)=\begin{cases}0 & v_w<0\\ \frac{k}{C}\left(\frac{v_w}{C}\right)^{k-1}\exp\left(-\left(\frac{v_w}{C}\right)^{k}\right) & v_w\geq 0\end{cases} \tag{1}$$

where v_w is the wind speed absolute value and *exp* represents the exponential function.

Parameters C and k are connected with the mean, μ_{v_w}, and with the variance, $\sigma^2_{v_w}$, of the distribution by means of the Gamma function [7], $\mu_{v_w}=C\Gamma\left(1+\frac{1}{k}\right)$, and $\sigma^2_{v_w}=C^2\left(\Gamma\left(1+\frac{2}{k}\right)-\left(\Gamma\left(1+\frac{1}{k}\right)\right)^2\right)$, and $\Gamma(p)=\int_0^\infty e^{-x}x^{p-1}dx$.

In addition, a simplified version of the Weibull distribution has been accepted as an alternative PDF for wind speed series, i.e. the Rayleigh distribution. A Weibull distribution is said to be a Rayleigh one when parameter k equals 2. The expression of the Rayleigh PDF function does not need to be written, because it consists of substituting k in (1) by 2. An advantage of this distribution is that it can be completely determined by its mean value, and this feature can be very useful in locations where no large sets of data are available, and where only an estimate of the average wind speed is known. If the Rayleigh distribution is assumed, then the mean and the variance can be expressed as $\mu_{v_w}=C\frac{\sqrt{\pi}}{2}$ and $\sigma^2_{v_w}=C^2\left(1-\frac{\pi}{4}\right)$.