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Wind speed and energy forecasting at different time scales: A nonparametric approach

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HIGHLIGHTS

- We model wind speed by an indexed semi-Markov (ISMC) process.
- We use ISMC to forecast next values of wind speed.
- We use the forecasted wind speed to forecast the energy produced by a wind turbine.

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ABSTRACT

The prediction of wind speed is one of the most important aspects when dealing with renewable energy. In this paper we show a new nonparametric model, based on semi-Markov chains, to predict wind speed and the energy produced by a commercial blade. Particularly, we use an indexed semi-Markov model, that reproduces accurately the statistical behavior of wind speed. The model is used to forecast future wind speed and the energy produced through a 10 kW Aircon wind turbine. We forecast one step ahead and for different time scales. In order to check the main features of the model we show, as indicator of goodness, the root mean square error between real data and predicted ones. We compare our forecasting results with those of a persistence model and of an autoregressive model.

1. Introduction

The variations of wind speed, in a certain site, are strictly related to the economic aspects of a wind farm, such as maintenance operations, especially in the off shore farms, pitch angle control on new wind turbines and evaluation of a new site. Many researchers are working proposing new stochastic models that can allow the prediction of wind speed, minutes, hours or days ahead. Many of these models are based on neural networks [1], autoregressive models [2,3], Markov chains [4–8], hybrid models where the previous mentioned models are combined [9–12] and other models [13–17]. Often, these models are either focused on specific time scale forecasting, or synthetic time series generation. Instead, our model can be used both for time series generation and for forecasting at different time scales. Physical models based on Navier–Stokes equation are also used to model wind speed, we decided to follow a stochastic approach in our work.

The approach we propose here is based on indexed semi-Markov chain (ISMC) model that was introduced by the same authors in Ref. [18] and applied to the generation of synthetic wind speed time series. In Ref. [18] we showed that our model

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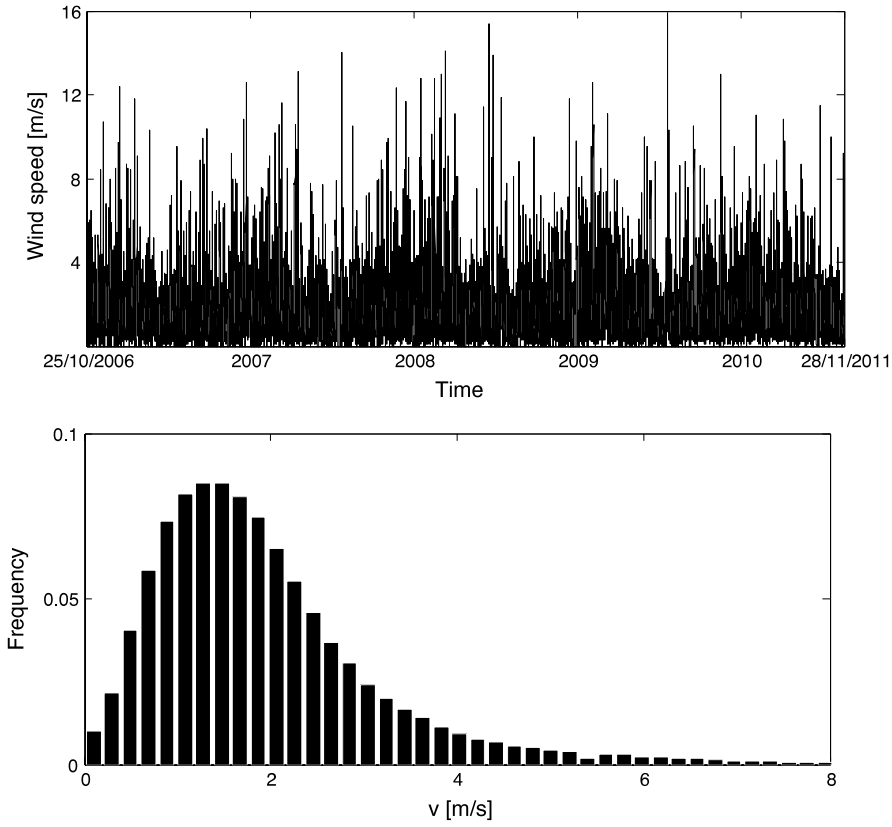

Fig. 1. Database and its probability density distribution.

is able to reproduce correctly the statistical behavior of wind speed. The ISMC model that we present here is a nonparametric model because it does not require any assumption on the form of the distribution function of wind speed. In this work we use the same model, slightly modified by adding a daily deterministic component, to forecast future values of wind speed.

Results of our model are compared with a simple persistence model (where the forecasted next step value of wind speed is simply given by the previous value) and with a more realistic Autoregressive Model optimized by using a Box–Jenkins procedure [19]. It is shown that our model performs better than a simple persistence model and an autoregressive model, by comparing the root mean square errors. The ISMC model is able to forecast wind speed at different time scale without losing the goodness of forecasting. We apply the model also to forecast the energy produced by a commercial wind turbine.

The paper is organized as follows. First of all, in Section 2, we describe the database used for the analysis. In Section 3, we present the model and its validation. Then, in Section 4, we present results of the wind speed and energy forecasting through indicators of goodness and comparison with the persistence model and with an autoregressive model. Finally in Section 5, we present some concluding remarks.

2. Database

The database used for the analysis in this work is freely available from www.lsi-lastem.it/meteo/page/dwnldata.aspx and is composed of more than 230 000 data of wind speed collected in every 10 min. The weather station of L.S.I.—Lastem is situated in Italy at N 45 28′ 14, 9″–E 9 22′ 19, 9″ and at 107 m of altitude. The station uses a combined speed–direction anemometer at 22 m above the ground. It has a measurement range that goes from 0 to 60 m/s, a threshold of 0,38 m/s and a resolution of 0,05 m/s. The database and its empirical probability density function are represented in Fig. 1. We discretized wind speed into 8 states (see Table 1) chosen to cover all the wind speed distribution. Table 1 shows the wind speed states with their related wind speed values.

In order to analyze the behavior at different time scales, we resampled the data at different sampling frequencies: namely 30 min, 1 h and 2 h.

3. Model

3.1. The indexed semi-Markov chain model

The general formulation of the ISMC as developed in Refs. [20–22,18] is here discussed informally.