Geophysical Research Abstracts
Vol. 14, EGU2012-318, 2012
EGU General Assembly 2012

First and second order semi-Markov chains for wind speed modeling

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The increasing interest in renewable energy leads scientific research to find a better way to recover most of the available energy. Particularly, the maximum energy recoverable from wind is equal to 59.3% of that available (Betz law) at a specific pitch angle and when the ratio between the wind speed in output and in input is equal to 1/3. The pitch angle is the angle formed between the airfoil of the blade of the wind turbine and the wind direction. Old turbine and a lot of that actually marketed, in fact, have always the same invariant geometry of the airfoil. This causes that wind turbines will work with an efficiency that is lower than 59.3%. New generation wind turbines, instead, have a system to variate the pitch angle by rotating the blades. This system able the wind turbines to recover, at different wind speed, always the maximum energy, working in Betz limit at different speed ratios. A powerful system control of the pitch angle allows the wind turbine to recover better the energy in transient regime. A good stochastic model for wind speed is then needed to help both the optimization of turbine design and to assist the system control to predict the value of the wind speed to positioning the blades quickly and correctly. The possibility to have synthetic data of wind speed is a powerful instrument to assist designer to verify the structures of the wind turbines or to estimate the energy recoverable from a specific site. To generate synthetic data, Markov chains of first or higher order are often used [1,2,3]. In particular in [3] is presented a comparison between a first-order Markov chain and a second-order Markov chain. A similar work, but only for the first-order Markov chain, is conduced by [2], presenting the probability transition matrix and comparing the energy spectral density and autocorrelation of real and synthetic wind speed data. A tentative to modeling and to join speed and direction of wind is presented in [1], by using two models, first-order Markov chain with different number of states, and Weibull distribution.

All this model use Markov chains to generate synthetic wind speed time series but the search for a better model is still open. Approaching this issue, we applied new models which are generalization of Markov models. More precisely we applied semi-Markov models to generate synthetic wind speed time series.

Semi-Markov processes (SMP) are a wide class of stochastic processes which generalize at the same time both Markov chains and renewal processes. Their main advantage is that of using whatever type of waiting time distribution for modeling the time to have a transition from one state to another one. This major flexibility has a price to pay: availability of data to estimate the parameters of the model which are more numerous. Data availability is not an issue in wind speed studies, therefore, semi-Markov models can be used in a statistical efficient way.

In this work we present three different semi-Markov chain models: the first one is a first-order SMP where the transition probabilities from two speed states (at time T_n and T_{n-1}) depend on the initial state (the state at T_{n-1}), final state (the state at T_{n}) and on the waiting time (given by t=T_{n}-T_{n-1}), the second model is a second order SMP where we consider the transition probabilities as depending also on the state the wind speed was before the initial state (which is the state at T_{n-2}) and the last one is still a second order SMP where the transition probabilities depends on the three states at T_{n-2},T_{n-1} and T_{n} and on the waiting times t_1=T_{n-1}-T_{n-2} and t_2=T_{n}-T_{n-1}.

The three models are used to generate synthetic time series for wind speed by means of Monte Carlo simulations and the time lagged autocorrelation is used to compare statistical properties of the proposed models with those of real data and also with a time series generated though a simple Markov chain.

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