On the use of Markov chain models for the analysis of wind power time-series

Vitor V. Lopes[1], Teresa Scholz[1], Ana Estanqueiro[2], Augusto Q. Novais[1]
[1]Energy Systems Modeling and Optimization Unit
[2]Ocean, Wind and Solar Energy Systems Unit
LNEG, National Laboratory for Energy and Geology
Estrada do Paço do Lumiar, 22, 1649-038, Lisboa, Portugal
vitor.lopes@lneg.pt

Abstract—**Wind energy is becoming a top contributor to the renewable energy mix, which raises potential reliability issues for the grid due to the fluctuating and intermittent nature of its source. This paper explores the use of Markov chain models for the analysis of wind power time-series. The proposed Markov chain model is based on a 2yr dataset collected from a wind turbine located in Portugal. The wind speed, direction and power variables are used to define the states and the transition matrix is determined using a maximum likelihood estimator based on multi-step transition data. The Markov chain model is analyzed by comparing the theoretically derived properties with their empirically determined analogues. Results show that the proposed model is capable of describing the observed statistics, such as wind speed and power probability density as well as the persistence statistics. It is demonstrated how the application of the Markov chain model can be used for the short-term prediction of wind power.**

Keywords-component: Discrete Markov chain models, wind power, variability, persistence

I. Introduction

The EC European Parliament objective to achieve 20% of the consumed energy from the renewable energy sector by 2020, introduced a major challenge to the planning and operation of power systems. Wind energy is becoming a top contributor to the renewable energy mix, which raises potential reliability issues for the grid due to the fluctuating and intermittent nature of its sources. Thus, the understanding of wind speed characteristics and its impact upon the power production is an important task, as shown by the extensive literature addressing wind speed forecast [1] and wind power prediction [2]. Generally speaking, the existent modeling approaches can be classified into: physical, statistical, or a combination of both.

Among the different statistical approaches, Markov chain models are a frequent choice in the published literature and the dominant trend over the years has been the increase on the number of states to improve their performance [3]. The main applications for the Markov models are: a) the short term wind power prediction; and, b) the simulation of wind speed data, however with some limitations in capturing the long term characteristics of the autocorrelation function [4].

This paper addresses the development of a Markov chain model for a wind power turbine using a 2-year historical dataset collected by the device data logger. The main goal is to assess whether Markov chain models can be used to capture statistics commonly used for wind power characterization, such as production level persistence, by comparing the statistics computed from the transition matrix with the ones obtained directly from the data. Moreover, the power prediction capabilities of the model are discussed along with the analysis of the impact of different wind speed uncertainty levels.

The paper first proposes a joint discretization of the wind speed, direction and power variables for the state definition. Then, it presents a multi-step maximum likelihood estimator for the determination of the Markov chain transition matrix. Finally, the results are shown and discussed.

II. Modeling the wind power time-series

A. Wind power data

In this study, the data was obtained from a wind power turbine from a wind park located at the Pinhal Interior region in Portugal. The time-series comprises a two year period (2009/10) of historical data obtained from the turbine data logger, with a 10 minute sampling rate. The wind speed and direction information is collected from the anemometer placed in the wind turbine hub. Due to confidentiality, wind power and speed data values are reported as a fraction of their corresponding maxima.

B. Discrete Markov chain model

A discrete finite Markov process $\{X_k \in S, k \geq 0\}$ is a stochastic process on a discrete finite state space $S = \{s_1, ..., s_n\}$, $n \in \mathbb{N}$ that is characterized by the following property: the probability of a state at any step of the process only depends on the previous state [5]. The Markov property is expressed mathematically by

$$\Pr\{X_{k+1} = s_j \mid X_k = s_i \wedge X_l \in S \quad \forall l = 0, ..., k-1\} = \Pr\{X_{k+1} = s_j \mid X_k = s_i\} = p_{ij}(k). \tag{1}$$