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Joint modelling of wind power and hydro inflow for power system scheduling

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Abstract

This paper concerns the joint modelling of wind power and hydro inflow for long-term power system scheduling. We propose a vector autoregressive model applied to deseasonalized series to describe the joint generating mechanism of wind and inflow. The model was applied to daily and weekly bivariate time series comprising wind and inflow from seven regions in Norway. We found evidence of both lagged and contemporaneous dependencies between wind and inflow, in particular, our results indicate that wind is useful in forecasting inflow, but not the other way around. The forecasting performance of the proposed VAR models was compared to that of independent AR models, as well as the persistence forecasts. Our results show that the VAR model was able to provide better forecasts than the AR models and the persistence forecast, for both the daily and weekly time series.

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1. Introduction

Integration of high shares of wind generation in hydro dominated power systems, such as Norway, can substantially alter the conditions for long-term generation scheduling. For example, consider the case of wind and hydropower facilities owned by the same producer and located within the same transmission constrained area. In such cases the long-term hydropower scheduling should be coordinated with the variable and uncertain wind production in order to avoid or minimize energy losses (in the form of spillage or wind curtailment)[1]. In turn, the question of how to model the stochastic wind and inflow processes in long-term scheduling models come forward. This work concerns the joint modelling of wind power and hydro inflow for power system scheduling.

The number of forecasting methods proposed for wind power and inflow separately are numerous. More than three decades ago Brown et al.[2] proposed to use autoregressive time series models in wind speed and wind power forecasting. Since then, a great number of studies concerning wind speed and/or power predictions have emerged in the literature. We refer to the reviews by Giebel et al.[3] and Jung and Broadwater[4] for a comprehensive coverage of the various approaches to wind power forecasting. With regards to inflow forecasting we mention the extensive

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forecasting study conducted in [5], which compared 10 different time series models applied to 30 monthly river flows. A stochastic inflow model which has been implemented in hydro scheduling models currently used by several hydropower producers in Norway is described in Gjelsvik et al.[6].

Several authors have studied the correlations and complementary characteristics of wind and hydro, e.g. [7,8], however, there are few studies on joint modelling of the two stochastic processes. Souto et al.[9] presented a high-dimensional multivariate time series model for forecasting and simulation of monthly wind and hydro inflow in the Brazilian power system. It is, however, hard to judge the quality of the proposed model based on this study, since a benchmark is not included.

The present work was highly motivated by the need for a proper stochastic representation of wind and inflow in scheduling models based on the Stochastic Dual Dynamic Programming (SDDP) algorithm [10]. Helseth et al.[11] presented an SDDP-based scheduling model that treated wind power as a stochastic variable. The stochastic wind-energy model employed suffer from some weaknesses, as the authors clearly point out, in that it assumes wind and inflow are independent and that it ignores possible autocorrelations.

We propose to first properly deseasonalize wind and inflow series individually, and then use a vector autoregressive (VAR) model to describe the dynamics and inter-dependence structure of wind and inflow. The advantage of a VAR model is first of all its flexible and simple structure which makes it ideal for forecasting and simulation [12], which in turn makes it practically useful in power system applications. For example, such a model can be used internally to generate scenarios for wind and inflow in stochastic scheduling models based on the SDDP algorithm. Secondly, VAR models also allows for easy interpretation of the individual and joint dynamics of wind and inflow, which in it self may contribute to insight relevant for a range of applications, such as wind integration studies, transmission planning and power system analysis.

The methodology is applied to daily and weekly wind and inflow series from seven regions covering Norway. Our primary concern is the VAR models' ability to forecast future values of wind and inflow. We evaluate the models' step-ahead forecasting performance out-of-sample by considering both deterministic (point) and probabilistic (distributional) forecasts. As a benchmark to judge whether the model is successful or not, we use the persistence forecast for comparison. Furthermore, to assess whether there is any gain in joint modelling, as opposed to modelling wind and inflow as two independent processes, we also include individual AR-models for comparison. To numerically measure the performance and rank the competing forecast methods we use the Energy Score [13].

The remainder of this paper is structured as follows. Section 2 describes the data used in this study and summarizes the exploratory data analysis. The deseasonalization method and the (vector) autoregressiv models are described in Section 3. Section 4 presents the results and finally, Section 5 ends this paper with a conclusion.

2. Data and exploratory analysis

2.1. Wind and inflow data

The wind data series used in this work are based on NCEP Reanalysis data [14] provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their web site at http://www.esrl.noaa.gov/psd/. The Reanalysis data set contains wind speeds from 1948-today with a temporal resolution of six hours and a spatial resolution of 2.5 degrees in both longitude and latitude. For the purpose of this study, it is important to use time series of sufficient length in order to properly capture seasonal effects and the potential dependence structure. Alternative data series with finer spatial resolution are typically only available for a few years (¡10 years), and are therefore not considered here. A two-dimensional linear interpolation has been applied to get wind speeds at seven selected sites in Norway, see Figure 1. Hourly wind speed values were derived by linear interpolation of the 6-hourly values and then converted to normalized wind power using a regional power curve developed in the TradeWind project [15]. The data processing was carried out by SINTEF Energy Research and the hourly wind power series were made available to the authors upon request.

Inflow data were provided by the Norwegian Water Resources and Energy Directorate, available on their web site at http://www.nve.no/no/Vann-og-vassdrag/Data-databaser/Historiske-vannforingsdata-til-produksjonsplanlegging-/. The complete data set contains average daily inflow [m^3/s] from the period 1958-2013 for 82 sites, which is used to describe the inflow to the Norwegian hydropower system. Seven inflow series are chosen for this study based on their proximity to the selected wind coordinates (Figure 1). The inflow series are 'Karpelv' (Region 1), 'Skogsfjordvatn'