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Analysis of wind power productions by means of an analog model

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ABSTRACT

The purpose of this work is to evaluate the performance of an analog model on day-ahead forecasting of wind power production over large European regions based in Ireland, Denmark and Germany. To do this, several data sets have been used: sea level pressure field over the North Atlantic and wind power outputs from individual wind farms and from wind farm clusters. The analog method uses Principal Component Analysis to reduce the dimensionality of the large-scale atmospheric database. Then, the analog method is based on the finding in the historic sea level pressure database, a principal component subset of large-scale atmospheric patterns that are the most similar to a large-scale atmospheric pattern used as input. Similar atmospheric situations to a particular atmospheric situation to be modeled have been determined and from them, different wind power outputs have been estimated. Several deterministic and probabilistic results are shown. Results of bias, spatial correlations and root mean squared errors between the estimated and observational wind power outputs are displayed. Concerning wind farm data set, the analog method improves both climatology and persistence in the Danish test case. The probabilistic results are shown by means of Brier Skill Scores and reliability diagrams. Danish test case shows pretty good BSS results with underestimation of the observational wind power frequencies in the reliability diagrams. For aggregated data sets, the model performing improves climatology in both Danish and German test cases, showing the latter better results than the former. A comparison between the two Danish databases, wind farm and aggregated data, gives as result higher BSSs for aggregated data than for the wind farm data set in high wind power outputs. The process used in this work to estimate wind power productions based on finding analogs in a previously reduced large-scale atmospheric data has proven to be a good technique to analyze the effect of the regional wind climate contribution to the daily wind output prediction.

1. Introduction

Wind energy has been, during the last decades, one of the fastest growing energy technologies. In some European countries as Spain, Ireland, Germany or Denmark, wind power is extensively used. Advances in this source of energy give noticeable benefits as results. Many efforts are lead to using high potential wind energy resources. Forecasting, modeling and wind data assimilation for safe large-scale wind power integration are the objectives of several studies and research projects (Bermejo et al., 2011; Trombe et al., 2012; Girard et al., 2013). Within the European Project *SafeWind*, the atmospheric circulation patterns, particularly those dealing with risky meteorological situations related to extreme wind events have been analyzed, since they are especially important

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for wind energy applications (Kariniotakis, 2010; Martín et al., 2011a,b; Pascual et al., 2013).

The improvement of wind power forecasts by means of dynamic modeling has been progressing along the development of limited area models or ensemble prediction systems, among other methodologies (Hamill et al., 2000; Du and Tracton, 2001; Tastu et al., 2011; Bossavy et al., 2012; Petroliagis and Pinson, 2012; Pinson and Hagedorn, 2012). However, these methodologies have the disadvantage of bearing high computational costs. In order to overcome this problem, the so-called analog method in a framework of temporal prediction can be used (Lorenz, 1969). The basic principle of the analog methodology is the assumption that in the atmosphere similar synoptic conditions are linked with similar local weather behaviors. Therefore, a forecasting of the local weather can be constructed searching for similar synoptic conditions to a particular one in a historic database. The methodology compares a synoptic pattern to analyze with the patterns stored in the historic database; those patterns that maximize the similarity between them are selected and associated with their respective local effects to make a statistical forecasting. This methodology has been implemented in the climatic anomaly predictions (Zorita and von Storch, 1999; Wilby and Wigley, 1997). In the short-range meteorological forecast, the analog methodology has been also applied producing both deterministic and probabilistic weather predictions (Barnett and Preinsendorfer, 1978; Dool van den, 1994). Van den Dool (1989) applied this methodology to obtain 500-hPa geopotential height forecasts from a historic database and within them, he found analogs of a present analysis using the 12-hour later analysis to every analog as a plausible forecast. Zorita and Von Storch (1999) tested the methodology for daily and monthly winter rainfall over Iberia demonstrating that their analog method can be used to any distributed variables since it is non-parametric; Klausner et al. (2009) validated the methodology for near-surface wind speed forecasting, obtaining better results against persistence and climatological forecasts and Panziera et al. (2011) used an analog approach based on radar observations for forecasting short-range orographic rainfall and obtaining better results against persistence for 1 h lead time and against results of a limited area NWP forecast for 4 h lead times. Hamill and Whitaker (2007) used the analog methodology in a Numerical Weather Prediction (NWP) ensemble in order to obtain probabilistic precipitation forecasts; Messner and Mayr (2011) evaluated the skill of different analog strategies applied to NWP ensembles; a wind power prediction system, calibrated by means of an analog ensemble Kalman filter and Quantile Regression, is used for enhancing the value of wind energy (Mahoney et al., 2012) and Monache et al. (2011, 2013) applied this methodology to generate a wind speed and temperature ensemble based on past observational data using a NWP to find the analogs. Pascual et al. (2012) and Valero et al. (2014) applied the analog methodology to obtain probabilistic daily wind gust and wind speed forecasts, finding better results against persistence and climatological forecasts.

Pascual et al. (2012) developed the downscaling model ANPAF (ANalog PAttern Finder) for diagnosing large-scale atmospheric circulation patterns and subsequently estimating extreme wind probabilities in Spain using observational wind data. Thus, a set of atmospheric circulation pattern estimations of mean wind and gust fields in Spain are obtained by means of the analog methodology. Following their procedure, the present study investigates the capabilities of this method to predict wind power production over large areas. This methodology can be directly applied to wind power output data instead of applying it to wind speed data and then modeling the power output of a wind turbine according to a determined mathematical expression (Bwea, 2005; Brayshawa et al., 2011). Any transformation of wind speed in power output results on more complexity not only because non-lineal processes are involved in the procedure but also because the conversion depends mainly on own technical characteristics of involved turbines. Thus, to this study, three test cases from the *Safewind* database are evaluated consisting in wind power clusters from Ireland, Germany and Denmark. While the general circulation patterns dominating the wind climate of the three areas are the same (main driver of the analog method) the regional topographic and climatic characteristics of the three cases are different. Hence, the impact of the regional wind climate contribution to the daily wind power prediction will be evaluated. The study is of interest for transmission system operators and wind power utilities with important shares of wind energy over large European areas. This is especially relevant in the context of a pan-European transmission network where balancing of the electric system needs to be done over various countries with large shares of renewable energies. It is true that for wind power prediction industry, precise wind power forecasts are currently made nowcasting, for lead time of minutes, hours,…; however, accurate predictions of the day-ahead wind power production as well as the probability of extreme winds are keys for a safe and efficient management of the transmission system and in this sense, ANPAF model can be useful.

The main difference against most of the abovementioned works lies in the procedure to obtain the analogs. While other works use NWP prediction data sets, the ANPAF model starts by applying Principal Component Analysis (PCA) to the atmospheric circulation field to reduce the dimensionality of the large-scale atmospheric data (Joliffe, 1986; Preisendorfer, 1998). Multivariate techniques have been successfully used by the authors in other studies to gain a better insight into the seasonal relationships between the large-scale circulation anomalies and the fluctuations of some regional variables, in order to highlight the influence of several low-frequency North Atlantic teleconnection patterns on the variability of the regional variables in the Western Mediterranean area (Valero et al., 2004, 2009; Martín et al., 2004, 2006; Morata et al., 2006, 2008; Sotillo et al., 2006). Once the large-scale atmospheric statistical modes have been obtained, the constructed analog method is applied. In the process of any analog model, a weighting function that considers the similitude between any given situation and the past situations is needed. To take into account a similitude measurement, several strategies can be considered which are limited to a greater or lesser degree of the computing capacity (Cofiño, 2004; Sordo, 2006; Zhu et al., 2011; Grenier et al., 2012). In Pascual et al. (2012) several distance functions based on the principal component scores were analyzed and finally proposed. These distance functions are used to find the most similar atmospheric situations to a given atmospheric situation used as input in the analog model.