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Short-term prediction of wind energy production

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Abstract

This paper describes a statistical forecasting system for the short-term prediction (up to 48 h ahead) of the wind energy production of a wind farm. The main feature of the proposed prediction system is its adaptability. The need for an adaptive prediction system is twofold. First, it has to deal with highly nonlinear relationships between the variables involved. Second, the prediction system would generate predictions for alternative wind farms, as it is made by the system operator for efficient network integration. This flexibility is attained through (i) the use of alternative models based on different assumptions about the variables involved; (ii) the adaptive estimation of their parameters using different recursive techniques; and (iii) using an on-line adaptive forecast combination scheme to obtain the final prediction. The described procedure is currently implemented in SIPREÓLICO, a wind energy prediction tool that is part of the on-line management of the Spanish Peninsular system operation.

Keywords: Adaptive estimation; Dynamic models; Forecast combination; Kalman filter; Nonparametric regression; Recursive least squares; Wind energy

1. Introduction

Wind energy has been, in the last decade, the fastest growing energy technology. In some countries as Germany, Denmark, and Spain, wind power is widely used. In the case of Spain, more than 4% of its electricity comes from this source of energy. However, in spite of the noticeable benefits of wind energy, this level of installed capacity can have unwanted consequences. The reason for this is that wind energy cannot be scheduled and, therefore, there will always be uncertainty about the final production. As a consequence, the uncertainty caused by the connection of many utilities to the grid can decrease the efficiency of the network system operation. Accordingly, both utilities and the system operator need accurate on-line forecasts of the wind power production. In a liberalized electricity market, such a forecasting ability will help enhance the position of wind energy compared to other forms of energy.

This article describes a statistical forecasting system for wind energy prediction based on the adaptive combination of alternative dynamic models. The main feature of the forecasting system is its flexibil-

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ity. This flexibility is needed for two main reasons. First, it has to deal with highly nonlinear relationships between the variables involved. Second, the prediction system would generate predictions for alternative wind farms of different characteristics, as it is made by the system operator for efficient network integration.

For a given wind farm, the input variables are the meteorological predictions of wind (velocity and direction) for the next 48 h and past values of output power. The forecasting system has then to supply, on an hourly basis, the predicted output power up to 48 h ahead. The prediction system needs to operate on-line. Therefore, once some preliminary off-line identification of the models is made using data from selected sites, the system needs to be flexible enough to adapt to (a) unforeseen changing relationships between the variables involved and (b) alternative wind farms with minimal or no calibration. This on-line flexibility also requires recursive estimation procedures that must be performed in reasonable time. For instance, the Spanish system operator needs to calculate hourly predictions for more than 200 wind farms. There is, therefore, little time for doing the calculations for each wind farm.

From a statistical point of view, wind energy data has some interesting features: (i) the relationship between the velocity of the wind and the generated power is highly nonlinear and, therefore, candidate predictors have the risk of only being reliable within certain ranges of data; and (ii) for a given velocity, this relationship is time-varying because it depends on other variables such as wind direction, local air density, local temperature variations, local effects of clouds and rain, and so forth. Since some of these variables are difficult to foresee or even measure, they might not be appropriately included in a model. Fig. 1 shows some typical situations with wind energy data that help illustrate these features. In this figure, both graphs (a) and (b) show 200 consecutive hourly data points of velocity of wind (hourly average) and generated power at a certain wind farm in Spain. The first 100 points are marked with a circle (○), whereas the last 100 points are marked with a plus symbol (+). It can be seen in these pictures that a model estimated by using the first 100 points (period 1) will produce a poor performance when applied to the next 100 points (period 2) if no adaptation is allowed.

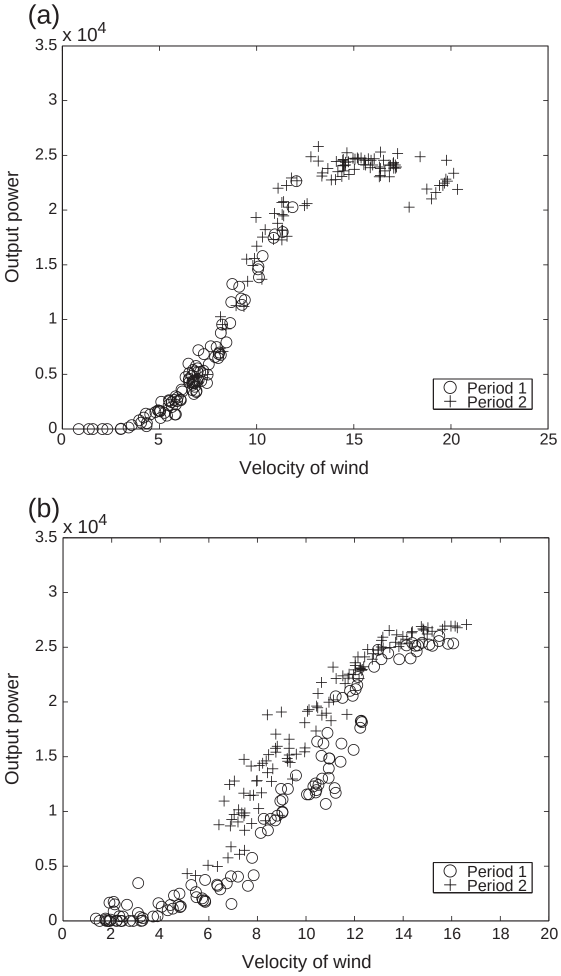

Fig. 1. Hourly average wind speed and generated power in a wind farm in Spain. In each picture, periods 1 and 2 are consecutive.

In Fig. 1(a), due to stronger winds in period 2, the wind park has reached the rated capacity. In this situation, the output power of the rotor of the wind turbine is maintained at an approximately constant level, or should even be reduced in order to avoid damages. These changes in the relationship between speed and power are regulated by a control system that might not be the same across all windmills. Besides, this control technology is constantly evolving (see, for instance, Ackerman & Söder, 2002). Therefore, such behaviour should be learned from data. The changes observed in Fig. 1(b) can be pro-