Sustainable Energy Technologies and Assessments 27 (2018) 180–191

Contents lists available at ScienceDirect

Sustainable Energy Technologies and Assessments

journal homepage: www.elsevier.com/locate/seta

Original article

Statistical approach for improved wind speed forecasting for wind power production

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ARTICLE INFO

Keywords:
Wind
Power
Forecast
Correction
Error reduction
Electricity

ABSTRACT

As wind energy converter (WEC) become an important part of electricity systems, the limitations of wind power forecasting have become a matter of ever greater concern. While electricity grid load forecasting is well established and successful, forecasting wind speeds at wind fields, or more directly WEC power output, has room for improvement. This research uses four months of hourly wind speed data from 36 WECs in Nova Scotia, Canada to find corrections for wind forecasts generated conventionally from a nested Weather Research and Forecasting atmospheric model. Site-specific corrections are categorized by forecast conditions (wind speed and direction) and used for two new forecast techniques. The first technique is a statistically based correction for improved wind speed forecasting. By building a "correction topography" (correction as a function of forecast conditions) on ¾ of the available data, absolute wind speed forecast errors in the remaining ¼ of the data are shown to be reduced by 20–25% for forecast lead times out to 24 h. This is a standalone technique of value to wind field operators and utilities concerned with integrating wind energy. The second technique is interpolating correction topographies and instantaneous forecast errors. By interpolating errors of surrounding known sites, similar error reduction was found to be possible at distances 10s of kilometers from known sites.

Introduction

The need for better forecasting

System operators are grappling with the challenges of integrating ever larger quantities of non-dispatchable renewable electricity generation into the electrical grid. Regulations in Nova Scotia, Canada require the utility to provide an aggressively increasing fraction of electricity from renewable sources, culminating (presently) with 40% renewable energy by year 2020 [1,2]. The majority of renewable electricity at these milestone years is expected to come from wind energy converters (WECs). Previous research on WEC integration indicates that levels of penetration above 20–30% of installed capacity can significantly affect costs associated with maintaining grid stability [3–6], and WEC capacity is, as a consequence, often limited to some fraction of the minimum expected demand experienced throughout the year [7,8]. When political will favors exceeding such limits, it presents a resource management and optimization problem to electricity grid operators [9,10].

Whether the chosen solution is energy storage [11–16], strategic wind farm siting for resource dissimilarity [17], backup conventional generation, or curtailment of WECs [18–20], electricity grid operators benefit from whatever degree of knowledge of future grid conditions is available [21,22]. Knowledge of upcoming wind speeds and power outputs inform optimal generation/storage operating strategy, and the more accurately and precisely the upcoming conditions are known, the more effectively and productively such resources can be dispatched.

With respect to load forecasting, utilities and grid system operators customarily have day-ahead and hour-ahead load forecasts that have been developed with experience based on general conditions (workday, holiday, etc., recent observations) and weather forecast aspects that will influence electricity consumption (ambient temperature, solar insolation, wind speed) [23]. These load forecasts have been refined with decades of experience managing generation, transmission, and distribution networks, as well as the application of advanced research techniques such neural networks [24] and wavelet transforms [25], and are quite good with errors of only a few percent even in day-ahead (up to ~36 h lead time) forecasts [26,27].

With respect to wind and other non-dispatchable generation however, electricity generation forecasts are less well developed, though their importance is widely recognized and an area of active research [28–31]. This is primarily due to three factors. The first is the relative rapidity with which wind speeds can change, which makes the desired precision and temporal resolution greater. The second is the

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https://doi.org/10.1016/j.seta.2018.04.010
Received 21 September 2017; Received in revised form 19 January 2018; Accepted 16 April 2018
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comparative novelty of the need for such forecasts; they were largely unnecessary when renewable energy generation capacity constituted only a few percent of any given network and could thus be easily incorporated into existing control strategies [14,32,33]. The last is the high level of sensitivity of WEC power production as a function of wind speed, which for much of the spectrum of useful wind speeds is a cubic relationship due to the combination of more air passing through the rotor (a factor of velocity) and that air having higher kinetic energy (a factor of velocity squared) [34–36].

The combined outcome of these factors is that WEC electricity production forecasts, even in well-understood systems, can carry significant errors. Thus, there exists a need for research and development of wind speed and WEC power forecasting on i) regional spatial scales and ii) time scales appropriate to the operation (determined by the characteristics of available dispatchable generating resources) of electric grid systems.

Internal constraints correction methods

With few exceptions, weather forecast products derive from one of just a few global atmospheric models through a model nesting approach. In Canada, weather forecast generally rely on the North American Model (NAM), prepared every six hours by the American National Centers for Environmental Prediction (NCEP) using the Global Forecast System (GFS) values as boundary conditions [37,38]. Regional forecasts are generally developed through dynamical downscaling, such that the continental or synoptic atmospheric weather model provides boundary conditions, and sometimes internal reference points, to a smaller mesoscale or regional model that uses more precise information about an area of particular interest. Downscaling alone, however, may not deliver the degree of forecast improvements desired, unless internal constraints methods are also employed [39,40]. In addition, computation time of large, complex models imparts latency, meaning that forecasts are based on observations that may be many hours old.

When observations are available from quasi-real time sources such as satellite observations, radial Doppler winds [41,42], radar reflectivities [43] or wind profiles from vertically pointing Ultra High Frequency/Very High Frequency (UHF/VHF) radars [44], they may be used to find and reduce field errors in the model for further forecast improvements. Three differentiable techniques for correcting model errors with measured values may be used for improving operational mesoscale forecast models: three-dimensional variational, which establishes an error field but does not account for time-varying observations; four-dimensional variational, which does account for time-varying observations [45] and nudging [44]. Nudging, which may be the most successful of the interior constraint methods [46], aims to develop an accurate and precise initial condition for a regional climate model, which is then driven into the future via boundary conditions determined by a large-scale atmospheric model. Propagation of the regional climate model is thus periodically adjusted during model evolution by near real-time data taken by sensors within the region [47].

Internal constraints techniques are being developed for a variety of environmental model applications including renewable energy generation [48]. In the context of wind forecasts to inform renewable energy generation within Canada, this technique could be especially valuable due to latencies associated with running the NAM forward in time. NAM forecasts are delivered every 6 h, but by the time the forecast is delivered, roughly two hours has passed since the model initialization. As a consequence, at the end of each 6-h cycle, wind predictions for just one hour in the future are based on observations that are as much as 8 h old.

Objective

The goal of this research is the development of a tool to provide low-computation time WEC power forecasts to wind field operators and utilities with greater accuracy than is available from existing numerical weather forecasting products. The efficiency of the developed technique avoids the computational overhead and associated forecast latency of many competing techniques [48], by relying on statistical, rather than physics- or neural-network based adjustments.

Previous statistical techniques were pioneered in the 1980s in which forecast wind conditions were statistically mapped to local conditions [49]. In the 1990s both numerical (physics based) and statistical forecast corrections schemes were shown to improve mesoscale numerical weather forecasts [50], however in such cases detailed knowledge of the physical environment was necessary. The objective of the research reported in this paper is to extend these simple 'look-up-table' correction models using a computationally inexpensive and robust technique.

In the present paper, two investigative tasks in aid of the development of a forecast adjustment product are presented. First this research will seek statistically significant trends in forecast errors as a function of forecast weather conditions. Secondly, this paper will evaluate the feasibility of interpolating wind speed corrections to new locations, to provide improved forecasting for locations that do not have a forecast history. The intent of this paper is to develop and demonstrate a wind forecast correction method that is easy to create using measured WEC data, and can be applied to standard commercial forecast products to improve the forecast accuracy for electricity grid system operators.

Data and methods

The success of such an undertaking is naturally dependent on the quality and quantity of data upon which it is based. The data requirements for this project are i) wind speed and direction measurements from existing wind field sites around the region, and ii) contemporaneous wind speed and direction forecasts.

Data sources

For this research, *in-situ* wind speed measurements came from wind speed monitoring equipment located on the nacelles of WECs. Data from thirty-six (36) WECs, listed in Table 1, at seven wind fields around the province of Nova Scotia, Canada (see Fig. 1) were provided by the industrial research partners that own and operate the sites. All wind turbines are either General Electric or Enercon units ranging in nameplate capacity from 800 to 2300 kW, and all were manufactured and installed after year 2009. At each of the seven sites, only one type of turbine (manufacturer and model) is in use.

It should be noted that wind speeds across the nacelle of an operating WEC will be lower than wind speeds measured in the free stream of air at a distance from the equipment. However, WEC manufacturers have attempted to correct for this in their measurement systems. While this correction accuracy remains a concern, turbine manufacturers have a great interest in improving the accuracy and correcting any bias in such measurements, and efforts to further 'reverse-engineer' a yet more accurate free stream velocity from reported nacelle measurements were not undertaken.

The benchmark forecast weather conditions for these sites were likewise provided by an industrial research partner as a forecast product customized to the locations of the centroid of each wind field and to the elevations of the WEC nacelles (73 or 80 m, depending on model). The centroid was used, because these forecasts are produced on a 4 km grid, with the result that more specific siting or turbine-specific forecasting was not consistent with current practices. They were produced using a conventional nested model approach consisting of NAM-based boundary conditions informing a regional 4 km grid scale WRF atmospheric model [51]. Forecasts were produced every six hours, and provide conditions at each hour out to 72 h 'lead time' from delivery.

Both measured and modeled wind conditions were available for the 7 windfields for roughly two months' duration, from late October 2016 through December 2016, thus giving approximately 2000 hourly data

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