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Constructing probabilistic scenarios for wide-area solar power generation

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ABSTRACT

Optimizing thermal generation commitments and dispatch in the presence of high penetrations of renewable resources such as solar energy requires a characterization of their stochastic properties. In this paper, we describe novel methods designed to create day-ahead, wide-area probabilistic solar power scenarios based only on historical forecasts and associated observations of solar power production. Each scenario represents a possible trajectory for solar power in next-day operations with an associated probability computed by algorithms that use historical forecast errors. Scenarios are created by segmentation of historic data, fitting non-parametric error distributions using epi-splines, and then computing specific quantiles from these distributions. Additionally, we address the challenge of establishing an upper bound on solar power output. Our specific application driver is for use in stochastic variants of core power systems operations optimization problems, e.g., unit commitment and economic dispatch. These problems require as input a range of possible future realizations of renewables production. However, the utility of such probabilistic scenarios extends to other contexts, e.g., operator and trader situational awareness. We compare the performance of our approach to a recently proposed method based on quantile regression, and demonstrate that our method performs comparably to this approach in terms of two widely used methods for assessing the quality of probabilistic scenarios: the Energy score and the Variogram score.

1. Introduction

Optimizing thermal generation commitments and dispatch in the presence of high penetrations of renewable energy sources such as solar ultimately requires inputs that characterize their stochastic properties. For wide-area wind power, methods have been described that characterize forecast errors so that probabilistic *scenarios* can be created (Pinson et al., 2009; Pinson and Girard, 2012; Sari et al., 2016; Staid et al., 2017). Each such scenario specifies a distinct forecasted wind power trajectory (e.g., 24 hourly values) with an associated probability. Such probabilistic scenarios can be used, optionally in conjunction with probabilistic load scenarios (Feng et al., 2013, 2015), as input to stochastic optimization of thermal generation commitment and dispatch problems, e.g., (Barth et al., 2006; Papavasiliou and Oren, 2013; Cheung et al., 2015). Independent of stochastic commitment and dispatch, probabilistic scenarios can also be used by system operators for situational awareness, to assess potential reliability issues.

In this paper, we describe a novel method to create day-ahead, wide-area, utility-scale probabilistic solar power scenarios, using historic forecasts and associated observations. While we focus here on day-ahead power systems operations, our methodology is generic and can be applied to shorter (e.g., hours ahead) time scales, assuming relevant historical data is available. Following (Staid et al., 2017; Feng et al., 2015; Rios et al., 2015) we propose computation of a forecast error distribution for solar power that is appropriate for hourly forecasts for the next day. Constructing probabilistic solar power scenarios presents some unique challenges, particularly with respect to establishing a non-trivial and time-varying upper bound on power output. For high levels of forecasted solar power, it is important to avoid creating scenarios that are not physically possible, even if an error distribution might extend to those power levels. In contrast, determining an upper bound for wind power is straightforward, with many balancing authorities (BAs) and independent system operators (ISOs) publishing an installed wind capacity quantity for their territory which is appropriate for this

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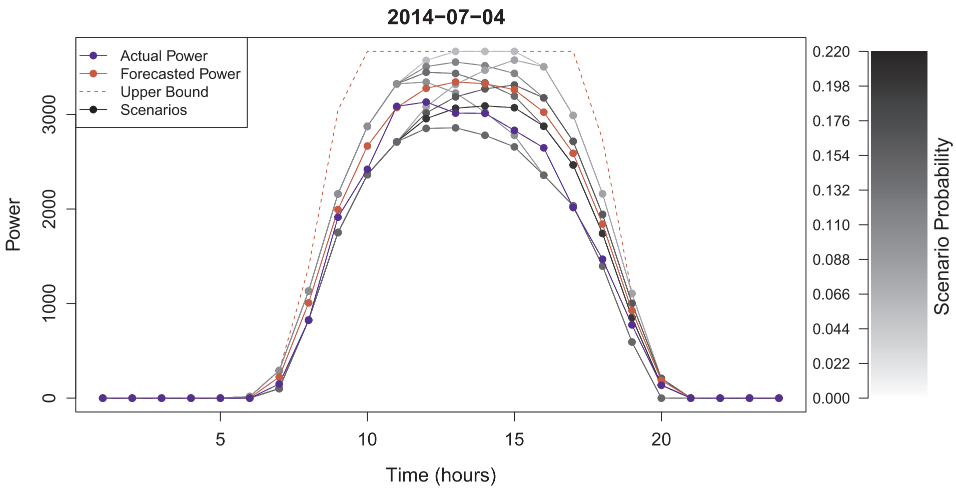

Fig. 1. Probabilistic solar power scenarios for the northern region of the California Independent System Operator (CAISO), for July 4, 2014. Darker shading represents a higher probability of occurrence for the corresponding scenario. The graphic further reports forecasted and actual power reported by CAISO, in addition to our computed upper bound.

purpose. For solar power we are not aware of any corresponding published methods due to the difficulty associated with calculating such a time-varying bound at utility scale. Upper bounds on utility scale solar power output depend on the time of day, day of year, solar plant locations, and even the mix of solar generation tracking technologies used, e.g., single-axis and fixed tilt. We include the effects of these factors in a simplified manner in the estimation of an upper bound from historical data.

Our probabilistic solar power scenario creation methodology is implemented in the Prescient software tool, co-developed by Sandia National Laboratories and the University of California Davis. Prescient is a software package for the analysis of stochastic versions of power systems operations problems (commitment and dispatch), in the context of high penetrations of renewables. The software can be obtained by contacting the authors. The raw scenarios used for the computational experiments in this paper are available at https://github.com/jwatsonnm/prescient-scenarios. As an illustrative example of the output of our methodology, we show a set of probabilistic solar power scenarios for the northern region of the California Independent System Operator (CAISO) in Fig. 1; this set is specifically for July 4, 2014.

The remainder of this paper is organized as follows. After placing our work in the context of relevant solar energy literature in Section 2, we provide details of our upper bound estimation method in Section 3. We then continue with a description of methods for computing forecast error distributions in Section 4. This section also includes description of how the error distributions are used to create well-calibrated sets of solar scenarios of interest for stochastic power systems operations planning, i.e., a combination of extreme high and low power output scenarios in addition to more likely scenarios. We describe how to create solar power scenarios from these error distributions in Section 5. In Section 6, we describe methods for attaching probability estimates to the generated scenarios. In Section 7, we perform computational experiments comparing the probabilistic solar power scenarios resulting from our method to those obtained using a state-of-the-art method based on quantile regression. Our results indicate that our scenarios perform comparably to scenarios resulting from the quantile regression approach, when performance is quantified using two widely used metrics for assessing the quality of probabilistic scenario sets: the Energy score and the Variogram score. Finally, we conclude in Section 8 with a summary of our contributions and directions for further research. Section Appendix A provides details of the copulas we use to compute scenario probabilities. Additional computational experiments are detailed in Appendix B, including a description of the resulting scenario sets created using publicly available data from CAISO.

2. Relevant literature

There is a large body of literature on generating high-accuracy solar power forecasts, describing many proposed and deployed methods for doing so (Inman et al., 2013). Significant work has been reported on short-term solar power forecasting, e.g., see (Bacher et al., 2009; Pedro and Coimbra, 2012). These methods generally focus on generating a single “point” forecast (trajectory) of projected solar power output. Marquez and Coimbra consider methods for forecasting hourly medium-term irradiance, which leads to point solar power forecasts following application of a transformation (Marquez and Coimbra, 2011). Chen et al. take a different approach, employing neural networks to directly create a 24-h point forecast of solar power (Chen et al., 2011).

Additionally, there is a growing focus on generating probabilistic forecasts instead of point (also referred to as deterministic) forecasts. Probabilistic forecasts provide additional value to end-users, as they characterize the potential variability in generated solar power. Consequently, the use of probabilistic forecasts generally results in improved operational decisions due to the availability and utilization of the additional information concerning production uncertainty (Buizza, 2008; Zhu et al., 2002). The methods that we present here for probabilistic scenario construction could build upon the existence of probabilistic forecasts, but probabilistic scenarios fill a distinctly different role in operational decision-making for power systems. Specifically, we aim to provide probabilistic scenarios for solar power production for use in stochastic variants of core power systems operations optimization problems, e.g, unit commitment and economic dispatch (Cheung et al., 2015). These stochastic operations problems require as input a range of possible future realizations of renewables production, with associated probability, and minimize expected cost while maintaining operational feasibility across the full set of probabilistic scenarios.

Probabilistic forecasting methods for solar power cover a wide range of methods. Grantham et al. consider point solar power forecasts and impose non-parametric distributions around these forecasts, based on a characterization of historical forecast errors (Grantham et al., 2016). David et al. present a method for probabilistic solar power forecasting using a combination of ARMA and GARCH time series models (David et al., 2016). Liu et al., Zamo et al., and Sperati et al. all propose new methods for generating probabilistic solar forecasts (Liu et al., 2016; Zamo et al., 2014; Sperati et al., 2016). Liu et al. and Sperati et al. model forecast uncertainty using ensembles created by perturbing initial conditions in a meteorological (i.e., numerical weather prediction (NWP)) model. Zamo et al. introduce a number of quantile regression models that make use of an ensemble NWP model. Scolari et al. present a method for calculating prediction intervals on very short time scales (Scolari et al., 2016). Although similar in