Solar Energy 147 (2017) 257–276

Contents lists available at ScienceDirect

Solar Energy

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

A probabilistic approach to the estimation of regional photovoltaic power production

Y.M. Saint-Drenan [a,b,*], G.H. Good [a], M. Braun [a,c]

[a] Fraunhofer Institute for Wind Energy and Energy System Technology, Koenigstor 59, 34119 Kassel, Germany
[b] MINES ParisTech, PSL Research University, O.I.E. – Centre for Observation, Impacts, Energy, CS 10207, 06904 Sophia Antipolis CEDEX, France
[c] University of Kassel, Wilhelmshöher Allee 71 – 73, 34121 Kassel, Germany

ARTICLE INFO

Article history:
Received 19 September 2016
Received in revised form 10 February 2017
Accepted 4 March 2017

Keywords:
Photovoltaic
Forecast
Regional model

ABSTRACT

Forecasting the total photovoltaic (PV) power generated in the control areas of the transmission system operators (TSO) is an important step in the integration of the large amounts of PV energy into the German electricity supply system. A standard approach for evaluating the regional PV power generation from weather forecast consists in upscaling the forecast of a limited set of reference plants to the complete area. Previous studies shown that this method can lead to large errors when the set of reference plants has different characteristics or weather conditions than the set of unknown plants. In this paper, an alternative to the upscaling approach is proposed. In this method, called a probabilistic regional PV model, an average PV model with a very limited number of inputs (two module orientation angles) is used to calculate the power generation of the most frequent module orientation angles. The resulting power values are finally weighted according to their probability of occurrence to estimate the actual power generation. The implementation of this model thus only requires information on the location and peak capacity of the plant installed in a region and no PV plant measurement is necessary. The proposed method has been evaluated against the estimate of the total power generation provided by the German TSOs, which shows that an RMSE ranging from 4.2 to 4.9% can be obtained with this method using on IFS meteorological forecast. The regional power forecasted with the probabilistic approach was also compared to the day-ahead forecast disseminated by the TSO. This analysis shows that the forecast evaluated with the proposed approach has an RMSE less than 0.5% higher than the reference forecasts. This is considered a promising result given that the forecast evaluated with the probabilistic model is based on one single weather model and that – at the exception of the model calibration - no statistical post-processing method is used to optimize its performance.

1. Introduction

Over the last years, Germany has witnessed a rapid development of its photovoltaic (PV) capacity. In the beginning of 2016, more than 1.5 million PV plants with a total installed capacity of 36.66 GW_p were connected to the German grid. With Germany having an energy demand varying between 35 and 75 GW (Consumption data, 2015) and a minute reserve power (tertiary control reserve) of −5.5 and +7 GW (Bundesnetzagentur für Elektrizität, 2014), the accurate consideration of the PV power generation is thus crucial for the secure and economical operation of the power system.

For the integration of the large amount of PV power into the electricity supply system, the transmission system operators must assess and forecast the total PV power generated in their control areas. Since only a limited number of power measurements are available, an exact determination of the total power generated by the PV plants installed in a region is not possible. The actual value of the power generated by the numerous PV plants installed in a control area must instead be estimated using the limited information available for each PV plant (peak capacity, location, time of installation). This estimate, which is referred to in this paper as an estimate of the regional PV power generation, is very important, as it is used for the grid monitoring and as a basis for the PV power forecast.

The upscaling algorithm is currently the standard approach in Germany for estimating the regional PV power generation. The principle of the upscaling method is to assess the normalized power generation of any PV plant installed in a region by a spatial

* Corresponding author at: MINES ParisTech, PSL Research University, Centre for Observation, Impacts, Energy, CS 10207 – 06904 Sophia Antipolis Cedex, France.
E-mail address: yves-marie.saint-drenan@iwes.fraunhofer.de (Y.M. Saint-Drenan).

http://dx.doi.org/10.1016/j.solener.2017.03.007
0038-092X/

interpolation of the normalized power of a set of reference plants. This approach has been described by e.g. Lorenz and Heinemann and Schierenbeck et al. (2010). Saint-Drenan et al. conducted a detailed analysis of the sources of error of the upscaling method in Saint-Drenan et al. (2016), which shows that the uncertainty of this method results mainly from two issues:

– The spotty acquisition of the irradiation field by a limited number of point measurements, and,
– Differences between the characteristics of the reference and uncharacterized PV plants.

A methodology was proposed by Shaker et al. to identify the most adapted set of reference plants by a mixture of k-means clustering and PCA and to derive an estimate of the total PV power generation based on measurements from this set of reference plants using linear regression (Shaker et al., 2015) or fuzzy-logic operators (Shaker et al., 2016). A prerequisite for the implementation of this approach is however that power measurements of all plants installed in the considered region are available over a training time period of at least 4 months. This requirement makes the implementation of this method difficult when the availability of PV power measurements is limited.

An alternative approach to the upscaling method and its modified versions (Shaker et al., 2015, 2016) with the aim of mitigating the two issues mentioned above without the need for PV power measurements is proposed in A Probabilistic Approach (2015). This method, called probabilistic approach, is based on two main ideas. Firstly, given that meteorological data is available region-wide (e.g. from NWP model or satellite derived irradiation), the irradiation and temperature of each PV plant installed in the considered region can be considered explicitly instead of interpolating data from a set of reference plants. Secondly, values derived from the statistical analysis of numerous PV plants are used as the parameters of a PV plant model, rather than considering only the parameters of the set of reference plants. The probabilistic approach thus avoids the first issue of the upscaling method by efficiently using the meteorological data available for the power estimation of each plant installed in the considered region. The problem of representativeness of the set of reference plants is also mitigated by the probabilistic approach by using statistical values for the model parameters.

A first validation of this approach is proposed in A Probabilistic Approach (2015), where the results of the upscaling and probabilistic approaches are compared for several hundreds of PV plants located in Southern Germany. This analysis shows that the performance of the probabilistic approach is slightly better than that of the upscaling approach when the number of reference plants is high, and that the probabilistic approach outperforms the upscaling method when the number of reference plants is low. It however fails to clarify to what extent the results can be generalized for different regions, and especially for the control areas of the transmission system operators (TSOs), for which regional PV forecast are needed by grid operators. One major goal of this paper is thus to evaluate and analyse the performances of the probabilistic approach at TSO level, which is highly relevant for the grid integration of PV electricity.

In contrast to the work presented in A Probabilistic Approach (2015), where power measurements of several hundreds of PV plant has been used to validate the probabilistic approach, assessing the performances of this method on control areas raises the problem of choosing the true value of the total power generated. Indeed, as previously mentioned, only a limited subset of the plants is measured and the access to these measurements is very difficult for most stakeholders. As a result, it is impossible to get the actual value of the aggregated power generation on that regional scale and the only possibility is to use a best guess, which has a given uncertainty. It was therefore decided to assess the performances of the proposed approach against TSO estimates of the PV power generation, which can be considered as the best estimate of this regional power generation. These values are evaluated by upscaling power measurements from numerous PV power plants installed in their control area.

The use of TSO estimates raises a number of questions related to the relevance of the validation presented in this paper. Since the reference power values are estimated by an upscaling method, it is questionable to which extend it is relevant to propose an alternative approach to the upscaling? To answer this first question, it is important to note that the power measurements used by the German TSOs are - to date - not available to any forecast provider. It is thus not possible to use the same information than the TSO for forecasting purposes. A forecast provider has thus to develop its forecast approach independently from the TSO by e.g. collecting its own power measurements. The access to power measurements being in Germany extremely difficult, this prerequisite can noticeably limit the number of companies being able to propose a forecast product. The methodology proposed in this paper being implementable without power measurements, its validation may be highly relevant to stakeholders interested by PV power forecast but without access to measurements. A second question may be what is the value of the validation proposed in this paper since the actual aggregated power generation is not known and an estimate is used as true value? In a rigorous scientific context, the relevance of a comparison of the output of the proposed method with the TSO estimates is unclear since the actual value is unknown and both estimates have a given uncertainty. However, the chosen validation reflects the situation faced by forecast providers during the evaluation of their model output: the performances of a PV power prediction are assessed by TSO using their estimates. Though the validation proposed in this paper is of limited relevance from a scientific perspective, it is nevertheless pertinent in an industrial context.

This paper is structured in three main parts. The first part describes the motivations and the principle of the probabilistic approach already introduced in A Probabilistic Approach (2015) (Section 2). The difference between the TSO estimates and the output of the probabilistic approach are analysed in the second part (Section 3). The results are finally summarized and discussed in the concluding part of this paper (Section 4).

2. Approach

2.1. Motivation

The motivation for the development of the probabilistic approach is to design a method mitigating the two problems identified in the upscaling method: The uncertainty resulting from the acquisition of the meteorological information by a coarse network of reference plants and the lack of representativeness of the set of reference plants.

The mitigation of these two problems by the probabilistic approach is based on two main ideas, (a) the efficient use of available meteorological data and (b) the use of statistical information on the PV plant parameter for the calculation of the PV power.

(a) Efficient use of available meteorological data

As previously mentioned, one issue with the upscaling method is that the meteorological fields are only assessed by a limited number of points (set of reference PV plants). This approach is justified when an estimate is made from power measurements but when a NWP-based power forecast is made this approach is subop-