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Regional forecasts and smoothing effect of photovoltaic power generation in Japan: An approach with principal component analysis

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ABSTRACT

Regional forecasts of power generated by photovoltaic systems have an important role helping power utilities to manage grids with a high level of penetration of such systems. The objective of this study is to propose a method to obtain one-day ahead hourly regional forecasts of photovoltaic power when regional information is available. The method is based on the use of principal component analysis, support vector regression and weather forecast data. One-day ahead regional forecasts of photovoltaic power were done for 4 of the main regions of Japan for 1 year, 2009, using hourly power generation data of 453 photovoltaic systems. The performance of the method was characterized comparing the results it yielded with the ones provides by a persistence approach and by an approach that do not employ the principal component analysis. Moreover, the expected smoothing effect on the error achieved when the regional forecasts are based on forecasts for each photovoltaic system is presented, constituting an additional reference to evaluate the proposed method. The results show that the method performed well; its regional forecasts had a normalized annual root mean square error of 0.07 kWh/kW_{rated} in the worst case, and the persistence approach was outperformed by at least 51% regarding the same error. The use of principal component proved to be a simple and particularly effective approach, decreasing the bias of the forecasts in all regions, and causing a reduction of the normalized root mean square error from 20.2% to 57.8% depending on the region. The proposed method also yielded results within the same level of forecasts which benefitted from the smoothing effect; the former presented a maximum variation of 10.2% of the normalized root mean square error of the latter in the worst case.

1. Introduction

In Japan, after the Fukushima nuclear disaster in 2011, all attentions are turned to renewable energy systems as means to provide an important share of the power consumed in the country. In this scenario and with a new feed-in tariff plan, the number of new installations of photovoltaic, PV, systems is surging [1]. Thus, power utilities are already looking for ways to manage and integrate the typically unstable power generated by PV systems in their grids while keeping the balance of demand and supply of power unaffected. Regional forecasts of PV power will have an important role in this task as they provide information ahead of time regarding potential variations of the regional power supply.

As the attractiveness of PV systems increases, and so their penetration in grids around the world, the relevance of the PV power forecasts methods becomes global. Due to this fact, the development of PV power forecast methods has been receiving strong attention from the scientific and academic communities around the world. These forecast methods can be classified according to several categories such as the forecast horizon, temporal and spatial resolution, the use or not of solar irradiance forecasts as an intermediary step, etc. Furthermore, the methods can also be categorized according to the type of solar energy technology, PV or solar thermal for example, for which it is desired to know the energy output.

Regarding the forecast horizon, there are methods applied for forecasts of a few seconds or minutes ahead of time (known as

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nowcasting). In this case the boundary between forecast and estimation is less clear. Such forecasts are often based on satellite estimations of solar irradiance and techniques to correct for inherent distortions from such estimations. Examples of such methods can be found in studies such as the one from Takenaka et al. [2] or in Hammer et al. [3]. Short-term forecast methods can also be based on the time-series characteristics of ground measurements such as the sunshine hour, and autoregressive techniques. An example of such approach was proposed by Paulescu et al. [4]. Often in these studies solar irradiance is forecasted first and from it conversion models, which account for installation conditions of a solar energy system, are used to obtain the resulting power generation. However, PV power can also be directly forecasted, as showed in Takahashi et al. [7]. In this study the authors used a hybrid approach based on generalized radial basic function networks, the PV panel temperature and past power generation, as well as their variances at different time scales to forecast PV power 30 min ahead of time. For longer forecast horizons, instead using satellite data and ground measurements, methods based on weather forecast prediction usually gives better results as showed by Lorenz et al. [5] and Bacher et al. [6].

With respect to the temporal and spatial resolutions, forecasts can be done for every minute, 15 or 30 min, for every hour, or even for a whole day according to the application. Nowcasting and short-term forecasts of solar energy are important in places where intra-day energy market trading are allowed and for fine tuning of power systems loads by power utilities. In places where intra-day market trading does not happen, forecasts of solar energy one day or more ahead of time are more important. In this case, several methods to provide one-day-ahead forecasts of solar irradiance and for single PV power system were developed. For example, Yona et al. [8] used radial basis function and a feed-forward neural network with past measured and forecasted temperature, atmospheric pressure, air relative humidity and cloud amount to forecast hourly solar irradiance, and from it obtained the corresponding PV power generation. Cao and Cao [9] used wavelet analysis and neural networks to obtain one day ahead daily forecasts of solar irradiance. Bacher et al. [6] evaluated autoregressive models, measured solar power and forecasts of solar irradiance to forecast solar power generation of 21 PV systems in Denmark, up to 36 h ahead of time. Mellit and Trieste [10] proposed a multilayer perceptron neural network to forecast solar irradiance 24 h ahead of time using as input mean daily values of measured solar irradiance and air temperature. For 1 day ahead of time forecasts and single locations or single PV systems, besides autoregressive models and neural networks, newer machine learning algorithms such as support vector machines were also evaluated using forecasts of air temperature, air relative humidity and cloudiness to forecast PV power generation [11]. One advantage of this approach is that it can be used when solar irradiance forecasts are not available.

In spite of the availability of forecast methods, they are usually applied and validate for single locations or single PV systems. Only recently methods to forecast regional PV power have been receiving more attention with the publication of a few studies. For example, Shi et al. [12] did a preliminary evaluation of a method to forecast regional PV power in China. This method used 4 support vector machine based models. Each model was applied for a different kind of weather. The models used as input past PV power, maximum and minimum daily temperatures and next day forecasts of temperature. The output was 1 day ahead of time regional PV power generation forecast with a 15 min resolution. In Germany, an advanced forecast system for regional photovoltaic power is already under heavy development [13–15]. This system uses weather forecasts of solar irradiance from the European Centre for Medium-Range Weather Forecast, ECMWF, and it post-process them to obtain hourly horizontal solar irradiance forecasts according to the location of the PV systems. The forecast of horizontal solar irradiance is them converted to the equivalent that reaches the PV modules according to their installation characteristics. After that, forecasts of power generation for single PV systems are obtained. Regional forecasts can then be obtained applying this procedure to all systems installed in a region or via an up-scaling procedure. In Canada a similar forecast system was developed by Pelland et al. [16]. In this case, the forecasted global horizontal solar irradiance, provided by a meteorological agency, is post-processed using a Kalman filter and space averaging to remove bias. The solar irradiance on the tilted plane of the PV panels is calculated and converted to PV power using appropriate models. The system was tested for 3 PV systems but due to its characteristics it can be extended to regional forecasts.

In Japan, the electricity market is divided in 10 regulated companies, each with exclusive rights over the power grids of a predefined area. However, to improve competition in the sector, a plan to deregulate the electricity market until 2020 is being prepared by the government [17]. Thus, it is not clear yet how the power grids management will be affected. Furthermore, due to privacy issues, it is unknown if detailed information regarding installed residential PV systems, which is usually required in the regional PV power forecast methods previously developed, will be available to utilities to use, and how this information should be managed.

Under these conditions, assessments regarding the level of accuracy that can be obtained for regional forecasts of PV power without using detailed information about the installed PV systems can provide important information for the decision makers. Ideally, in a scenario of high penetration, the lower the forecast error of the power generation of PV systems, less reserve power is required from the power utilities to keep the stability of the power grids. Moreover, forecasts of PV power with lower error allow for a more efficient scheduling of conventional power systems, yielding meaningful savings. These two factors help to explain why accurate forecasts of regional PV power are important to increase the penetration of PV systems. Additionally, an analysis of forecast errors in different regions has also the merit of contributing to generate a basis to compare methods to forecast regional PV power and to evaluate their improvements.

Therefore, the objective of this study is to present an approach to obtain one-day ahead regional forecasts of photovoltaic power using local weather forecast data, support vector regression and principal component analysis. The regional forecast of photovoltaic power is directly forecasted from basic weather forecast data, without using solar irradiance, measured or forecasted. Furthermore, the only information used about the individual PV systems installed in a region is their approximate latitude and longitude, avoiding potential privacy concerns.

The accuracy of the method was assessed, making hourly regional forecasts for 1 year in 4 of the main regions of Japan. In total, 453 installed and operating PV systems in the regions of Kanto, Chubu, Kansai and Kyushu were included in the analysis. Moreover, typical error values for the forecasts and the characteristic smoothing effect in different parts of Japan are presented. Finally, a comparison with a naïve method based on persistence is done to evaluate the accuracy of the proposed method.

2. Data used in the regional forecasts

Two kinds of data are necessary for the application of the forecast methods. Measured regional PV power generation used in the training and configuration of the forecast methods, and the data used as input information for the forecasts.