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ScienceDirect

Solar Energy 98 (2013) 255–264

SOLAR ENERGY

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Estimating climatological variability of solar energy production

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Received 13 February 2013; received in revised form 4 October 2013; accepted 7 October 2013
Available online 6 November 2013

Communicated by: Associate Editor Jan Kleissl

Abstract

A method is presented for estimating the climatological variability of yearly and monthly photovoltaic power production per 1 kWp of installed power. This quantity is computed for a specified portfolio of sources on the basis of historical data. Its climatological variability is derived from a simulation of 33 years of power production with hourly time step. Underlying meteorological variables are taken from the MERRA reanalysis for the years 1979–2011. Since the MERRA reanalysis is not a traditional data source for photovoltaic power modelling, various comparisons to available and more frequently used data sources are included. The method of estimation has the advantage of wide applicability due to the global coverage of the meteorological data.

Keywords: MERRA; Reanalysis; Numerical weather prediction; Photovoltaic power production

1. Introduction

The estimation of the power production potential of photovoltaic sources is one of the typical tasks solved by any current or potential shareholder of a solar power plant. A typical source of information is the map of expected annual power production which can be available both freely or on a commercial basis in many forms and with a number of additional services. Well known sources of such data in the European context are services such as SoDa (using HelioClim database Blanc et al., 2011), PVGIS (Šúri et al., 2007; Huld et al., 2012), or METEONORM (Remund and Kunz, 1997). Widely used solar databases are based mainly on satellite retrievals from various observing systems (among the most popular are METEOSAT in EUROPE, GOES in USA, and GMS in Japan), sometimes supplemented by information from ground measurements. The desired outcome can be specified as the estimate of yearly photovoltaic production per 1 kWp of installed power (YPP) for any given geographical location for a typical meteorological year.

The increasing penetration of photovoltaic power production brings new challenges not only for investors and owners of PV plants but also for transmission and distribution systems operators, electricity market participants, government authorities and policy makers. The long-term estimation of photovoltaic power production is important for the planning of electrical grid development, management of cash flow, development of strategies for supply–demand balancing, design and deployment of various financial tools – both commercial (e.g. electricity futures on electricity market) or governmental (e.g. state subsidies). For shorter trading horizons and for the purposes of transmission network operation, an estimate of monthly PV production per 1 kWp of installed power (MPP) is informative.

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0038-092X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.solener.2013.10.007

These emerging requirements will be better met if traditional YPP (MPP) estimates are supplemented with a quantification of uncertainty. There are many different types of uncertainty connected to photovoltaic power production modelling – uncertainties due to coarse spatial resolution of underlying meteorological data, uncertainties due to errors in satellite retrievals, uncertainties arising from errors of numerical weather prediction models, etc. Our specific goal is to study the *interannual variability of normalized yearly and monthly power production*, caused by varying meteorological conditions. This variability will be called climatological hereafter and will be estimated on the basis of climatological data. Analysis of the impact of climate change is not our goal, although we have to adjust our analysis for a long term trend.

In this study we present a method of calculating YPP (MPP) variability for a given portfolio of photovoltaic sources. The calculations are based on a statistical model which uses the MERRA (Modern-Era Retrospective analysis for Research and Applications, details follow) reanalysis as the source of meteorological data. The statistical model was trained on historical power production data of the given portfolio. The model was subsequently used to simulate hourly power production of the given portfolio for 33 years of the MERRA reanalysis for the years 1979–2011. The resulting database of virtual power production can be used for the study of possible fluctuations of power production due to meteorological conditions.

2. Photovoltaic production database

To illustrate and test our method we have used a portfolio of power sources and their respective measurements. The portfolio contains over 400 photovoltaic power sources. The installed power of individual sources ranges from 0.5 to 38 MWp with a total of about 700 MWp. The geographical extent of the area where the sources are located is approximately 50,000 km^2 (covering more than half the Czech Republic, see Fig. 1). Choosing this type of portfolio we present a typical situation where the interannual variability of power production is important not

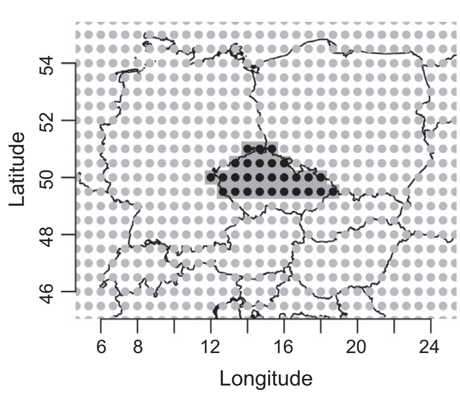

Fig. 1. Central Europe with country borders overlaid by the MERRA grid. The marked grid cells contain the portfolio used for modelling.

only for individual power source owners but also for larger scale policy making and planning by both distribution and transmission system operators.

The size of the portfolio makes it possible to capture the climatological variability by a statistical model. Various factors affecting the power production (e.g. maintenance breaks, snow-cover) cannot be neglected for the estimation of annual power production and they are better statistically modelled for a large portfolio than for individual power sources.

While the interannual variability can be expected to differ at different locations, the geographical extent of this particular portfolio is small enough to neglect these effects and to talk about the variability of annual production of the whole portfolio.

The time period of the measurements lasts from the beginning of 2011 until the end of October 2012. During the "solar boom" in the Czech Republic in 2009–2010 a large number of new power sources were added. Within the first four months of 2011 many stations still had spinup effects or statistically longer maintenance breaks before going to a full operational regime; therefore we opted to use a floating year from 1 May 2011 to 31 April 2012 for the estimation of parameters of the statistical model. The rest of the data (1 May 2012 to 31 October 2012) was used for out-of-sample testing.

3. Satellite measurements of solar radiation and the MERRA reanalysis of atmospheric conditions

MERRA (Modern-Era Retrospective analysis for Research and Applications) is a global reanalysis product produced in NASA (Rienecker et al., 2011). As stated, for example, in that paper, "reanalyses combine model fields with observations distributed irregularly in space and time into a spatially complete gridded meteorological dataset, with an unchanging model and analysis system spanning the historical data record."

The MERRA reanalysis covers the time interval starting from 1979 and is continually updated until the present day, similar to ERA INTERIM reanalyses from ECMWF. Specific emphasis in MERRA is given to simulation of the hydrological cycle for the use in climatological research. As an important consequence of this fact the reanalysis contains a complete budget of energy exchanges.

The main bulk of the assimilated data comes from satellite observations. Other types of data include surface and sounding data, similarly to other widely used global reanalyses such as ERA INTERIM, or NCEP/NCAR Reanalysis. MERRA uses the state-of-the-art assimilation method of the GEOS-5 (Goddard Earth Observing System) with the method of incremental analysis updating (Bloom et al., 1996), which is used in order to remove inhomogeneity at the restart of the 6 h forecast cycle.

The resulting meteorological fields of MERRA are produced with a 1 h frequency compared to the 3 or 6 h output frequency of other common global reanalyses. Combined