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Photovoltaic energy rating data sets for Europe

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Abstract

We present a study of possible climatic data sets that can be used to perform energy rating calculations on photovoltaic (PV) modules in Europe. We selected five geographic locations across Europe to cover the range of climatic conditions present. In order to assess the validity and significance of such climatic data sets we performed a detailed analysis of the sensitivity of the calculated energy rating to the variability of the input parameters. These are the transmission of the front glass based on the angle of incidence of the irradiance, the spectral response measurement of the PV module, coefficients for calculating module temperature from ambient temperature, and measured power matrices as function of module temperature and irradiance. We found that the calculated energy rating is not sensitive to the first three, but mainly varies due to difference in measured power matrices. This is in particular true for the module performance at low irradiance, and therefore shows a more pronounced difference in climates where such low irradiance conditions occur more frequently, such as in the northern parts of Europe. Nevertheless, the variability found is still less than those between geographic locations. We propose a selection of four energy rating data sets, which differ between them by more than the uncertainty and represent the main climates present across Europe.

Keywords: Photovoltaics; Energy rating; Sensitivity analysis; Power matrix

1. Introduction

It is well known that the power output of photovoltaic (PV) modules is not simply proportional to the light intensity at the surface of the modules (King et al., 1998, 2004; Kenny et al., 2003; Huld et al., 2008; Schweiger and Herrmann, 2015) and hence cannot be predicted accurately only from the nominal power of the modules as measured under Standard Test Conditions (STC) (IEC Central Office, 2009). For a number of years there have been studies and discussions about ways to provide PV module buyers with more information about the performance of PV modules under realistic conditions, and how this varies between module types and under different climatic conditions. As part of this work, the International Electrotechnical Commission (IEC) has been preparing the standard IEC-61853 prescribing how to perform measurements and simulations of PV modules that will make it possible to calculate an *energy rating* for the modules. Part 1 of IEC-61853 (IEC Central Office, 2011) has already been published, and at the time of writing Part 2 is at the final stage before approval. Together, these two parts of IEC-61853 describe the measurements needed for the energy rating procedure. Parts 3 and 4 are still at an early stage.

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These parts describe the calculation methods for the energy rating and provide standard data sets of climatic quantities needed for the calculations.

The effects influencing PV performance that are taken into account in the present version of IEC-61853 are the following:

- Increased surface reflectivity at shallow angles of incidence, also known as the Angle-of-incidence effect (AOI).
- The PV module spectral response and the influence of variations in the solar spectrum.
- Dependence of module temperature on local climatic conditions (irradiance, ambient temperature and wind speed).
- PV power as a function of in-plane irradiance and module temperature.

The energy rating of a PV module is commonly expressed as the *Module Performance Ratio* (MPR). This is the ratio of the energy produced by the module over a time period (typically one year) to the energy that would have been produced if the module had always worked at the efficiency measured under Standard Test Conditions (STC). It is given by:

$$\mathrm{MPR}_{\mathrm{year}} = \frac{E_{\mathrm{year}}/H_{\mathrm{year}}}{P_{\mathrm{STC}}/G_{\mathrm{STC}}} = \frac{G_{\mathrm{STC}} \cdot E_{\mathrm{year}}}{P_{\mathrm{STC}} \cdot H_{\mathrm{year}}} \tag{1}$$

where

$\mathrm{MPR}_{\mathrm{year}}$ [dimensionless] is the module performance ratio over the time period, here chosen as one year;

G_{STC} [W/m^2] is the irradiance at STC (i.e. 1000 W/m^2);

P_{STC} [W] is the PV module's maximum power at STC;

E_{year} [kW h] is the total energy produced by the PV module during the time period, here chosen as one year;

H_{year} [kW h/m^2] is the total irradiation during the time period, here chosen as one year.

Given the measurement results for a PV module it is then possible to apply models for PV performance with time series of climatic data to produce the yearly annual MPR. One important question in this regard is then how many climatic data sets will be necessary to give a good representation of the performance of a given PV module type for conditions occurring in reality.

One attempt to answer this question was given in Huld et al. (2013). However, the method used did not consider the full range of effects being considered in IEC 61853. Furthermore, there was no consideration of what effect uncertainty in the module measurements will have on the energy rating values (see for example Dirnberger et al. (2015a) for a discussion of energy rating uncertainty). The aim of the present paper is to update the methodology in Huld et al. (2013) to take these two aspects into account.

The structure of the paper is as follows: Section 2 gives an overview of the energy rating methodology. Section 3 describes the mathematical models and the climatic data used to estimate the energy rating of PV modules. The PV module measurements used for this study are described in Section 4. The calculation results are presented and discussed in Section 5, including the uncertainty analysis and the mapping of module performance results over Europe. Finally, Section 6 contains the conclusions.

2. Energy rating methodology

2.1. Energy rating versus yield prediction

The subject of energy rating for PV modules is often misunderstood. It will therefore be useful to distinguish between *Yield Prediction* and *Energy Rating*:

Yield Prediction is an estimate of how much energy a particular PV installation will produce over a period of time. This depends on knowledge of the PV module characteristics but also on the details of the installation, such as the inclination and orientation of the modules, whether the site is affected by shadows, etc. The climatic data used to make a yield prediction should be data for a location as close as possible to the location of the installation and should cover a multi-year period to average out the naturally occurring year-to-year variability in the overall estimate. The Yield prediction is given in units of energy over a time period, say, kW h/year.

Energy Rating is a way to present the productivity of a PV module type in a certain type of climate. This depends on the PV module characteristics but is independent of the details of the installation. It is typically expressed as the annual average module performance ratio (MPR), a dimensionless number. Essentially it rates the module in terms of its maximum power at STC. The latter is normally used as a parameter for selling the PV module and determines the price.

2.2. Methodology

For each of these two performance evaluations a procedure is followed in order to calculate a parameter that can be finally used as comparison metric between for example effects of different climates on the performance of the same module's technology (i.e. the same type of PV active material) or variations in performance of different PV technologies at the same location.

For the Energy Rating approach, the overall procedure can be summarized as follows:

Measurements. A series of measurements is made on the PV module to determine its electrical performance under different operating conditions. For instance its maximum power should be measured at different irradiance levels and different module's temperatures. The set of