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Monitoring and assessment of PV generation based on a combination of smart metering and thermographic measurement

C. Stegner[a,*], M. Dalsass[a], P. Luchscheider[a], C.J. Brabec[a,b]

[a] ZAE Bayern, Renewable Energies, Unterkotzauer Weg 25, 95028 Hof, Germany
[b] FAU Erlangen-Nürnberg, i-MEET, Martensstraße 7, 91058 Erlangen, Germany

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ABSTRACT

Electrical solar power generation has a very decentral character which is posing significant challenges to monitoring and assessment due to the high number of considered systems. At the same time, with the advent of smart metering, huge amounts of data are becoming available and demand for automated approaches that are robust enough to deal with measuring gaps and noise. We propose and introduce a combined method consisting of a fitting algorithm, which works with the high temporal resolution of the smart meter data used (15 s), and an infrared thermography measurement. The results are region-specific irradiance characteristics, precise description of individual skylines for single systems derived from calculations, indication of abnormalities that should be compared with the abnormalities identified in thermal images and identification of reasons for underperformance.

1. Introduction

A considerable share of renewable energy sources will be connected to the distribution grid in the future. Photovoltaic (PV) in Germany is a good example—in 2014 a total power of 22.6 GW was installed on the low-voltage (LV) level (Schmutzer et al., 2015). Most of these small scale systems are rooftop installations. Every LV subnet forms a natural unit with a clearly defined connection point to the next level, inherent dependencies based on physical load flows and ambient parameters that can be assumed as constant within the system boundaries. Examples for such ambient parameters are air temperature, wind velocity, humidity and cloud effects because they affect the module temperature and are also relevant for PV performance apart from the irradiance. A high number of systems constitutes a challenge regarding measurement and surveillance. Even if smart meters are already existent, communication costs for data transfer can be the bottleneck when metering every system and data gaps are very common due to communication or meter failure. On the other hand, algorithms that can work with high amounts of input data, which can cope with measuring gaps and can give instant feedback on performance (or deviations), could become a valuable tool for the plant operators as well as for the distribution system operator (DSO). The plant operator is interested in assessing the performance of his system while the DSO needs to have precise figures of current power generation in such a LV subnet in order to fulfil his network services. Established methods for monitoring PV systems include satellite based observation, but for example in the case of Drews et al. (2007) the drawbacks are the low spatial resolution of at least 1 km and the fact that even high energy yield deviations of 17% can only be detected with restrictions. A more common approach among grid operators and commercial operators or aggregators of bigger PV plants is the upscaling algorithm based on measurement of reference systems as analysed in Saint-Drenan et al. (2016). However the authors state that due to the higher characteristics variety among small PV plants—a factor that they identify as one of the two major sources of inaccuracy—the suitability of the method might be limited for LV networks. An example of a PV monitoring system that is also aimed at owners of small rooftop plants is the *Sunnyportal*[1] by the inverter manufacturer *SMA*. It displays live performance data in high temporal resolution and archives measurement in form of 15 min average values. In this paper smart meters are used for measurements mainly because of two reasons. Smart meters might become state of the art, for example will they be mandatory for certain users in Germany starting in 2017, and their capability of precise and dynamic metering is available without major, additional effort. Furthermore, if the PV plant is

* Corresponding author.
E-mail addresses: christoph.stegner@zae-bayern.de (C. Stegner), manuel.dalsass@zae-bayern.de (M. Dalsass), philipp.luchscheider@zae-bayern.de (P. Luchscheider), christoph.brabec@fau.de (C.J. Brabec).
URL: http://www.zae-bayern.de (C. Stegner).

[1] https://www.sunnyportal.com.

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metered separately, the advantage of measuring generated power over for example irradiance is that all the factors for non standard conditions that otherwise would have to be considered in form of a more complex PV model are already included.

We propose a surveillance strategy based on two tools. In the first instance, an algorithm calculates effective irradiance values based on smart meter data of PV systems, which in turn allow for the simulation of theoretical power values for each PV generator within the system. Energy measurements over longer periods, which are almost always available and already implemented in PV systems, can then be compared with the simulation results to assess the performance of the system. If data collection is quick enough, a near-realtime calculation of the PV generation in the LV subnet can be achieved. In the second instance, systems with remarkable deviations can be analyzed using infrared (IR) thermography—a contactless, non-destructive, and fast assessment tool for the quality evaluation of PV modules under operating conditions. In this context, thermal abnormalities in IR images of PV modules often indicate irregularities. Hot spots or hot areas, for example, are probably caused by defects in the PV module (Molenbroek et al., 1991; Herrmann et al., 1997; Wohlgemuth and Herrmann, 2005; Buerhop et al., 2012). For the quick generation of aerial infrared (aIR) thermographic recordings of PV modules which are difficult to access, remote-controlled unmanned aerial vehicles (UAV) can be used nowadays.

2. Data

The data acquisition was conducted within the *Smart Grid Solar* research project. *Epplas*, which is a village-like district of the city of Hof in Bavaria, Germany, qualified for a smart meter roll-out because of its high presence of rooftop PV systems. The single low voltage network of Epplas comprises 19 households, which generate roughly three times the electrical energy demand per year by means of 13 PV systems summing up to a total installed generator power of 290 kW_p. The exact annual figures for Epplas were 88.7 MWh consumption and 267.6 MWh generation in 2015. Like in most rural LV grids in Germany Kerber (2011) the structure in Epplas is radial.

2.1. Smart meter infrastructure

The used smart meter model is *EMH LZQJ-XC* which measures active energy with accuracy class B according to *EN 50470*, i. e. 1%. This accuracy however applies to the function as energy meter, which means integrating active power over time. For our 15 s data, which consists of instantaneously measured active power values, there is no indication of accuracy. *Raspberry PI* micro PCs were used to format, buffer and encrypt data as well as to gather measurements from multiple smart meters in one household for combined transmission in order to reduce data traffic and communication costs. A GSM-module sends the data to a central database. This dependency on the mobile network plus the high temporal resolution of the measured data (15 s) made it necessary to buffer data locally. The micro PCs were supplied with 32 GB SD memory cards for that reason.

2.2. Details on PV systems

We will use the term *PV system* for a set-up which is measured by one smart meter. The system can consist of several *PV generators*, each with a single orientation, i. e. azimuth and tilt angle of the modules. In Epplas, there are six single-oriented systems and seven mixed set-ups with up to four PV generators. Power ratings and orientations are summarized in Table 1, where for example ID 3.2 stands for the second generator of the third system. Not only is the number of PV systems high in Epplas, but also the variety in orientations. Note that there are also PV generators that face towards north-eastern and north-western directions.

Table 1
Detailed PV generator information, azimuth of 0° is north, tilt angle of 0° is horizontal.

ID_{gen}	Azimuth/°	Tilt angle/°	P_{STC}/kW_p
1.1	172	40	23.8
1.2	161	17.5	30.6
2.1	145	12.5	2.1
2.2	235	42.5	8.6
3.1	174	25	9.5
3.2	180	30	5.1
3.3	175	30	10.1
4.1	180	40	30.2
5.1	178	45	7.4
6.1	191.5	30	7.5
7.1	183	40	16.7
8.1	126	40	3.6
8.2	51.5	40	26.1
9.1	231.5	40	28.6
10.1	231.5	40	8.6
10.2	126	40	8.6
10.3	137.5	40	5.7
10.4	216	40	5.7
11.1	317.5	35	12.6
11.2	306	40	14.0
11.3	126	40	3.6
12.1	144.5	35	14.4
13.1	137.5	40	3.8
13.2	227.5	40	3.0

2.3. Aerial infrared thermography

For the generation of aIR thermographic recordings, we use the remote-controlled octocopter *Davinci Copters ScaraBot X8*, which is equipped with two lightweight cameras, the IR camera *Optris PI450* (uncertainty of ± 2 °C) and the RGB camera *GoPro Hero3+* (see Fig. 2). The measurement flights were conducted manually.

In order to ensure a minimal geometrical resolution of a single solar cell in the aIR images of 5 × 5 pixels as recommended in Bundesverband für Angewandte Thermografie e.V. (2016) as well as an observation angle of the cameras towards the glass surface of the PV modules smaller than 30° as recommended in ZAE Bayern e.V. (2007), the flight path and the observation angle of the cameras were adjusted individually for each PV generator. In this context, the given geometrical resolution of the IR camera of 382 × 288 pixels determines the maximum measuring distance between the PV modules and the drone measurement system. According to the individual PV generator setups, the measurement distances ranged between 10 m and 25 m.

The aIR measurements were performed on May 10th, 2016, a sunny and almost cloudless day with fairly high solar irradiance values of greater than 600 W/m^2.

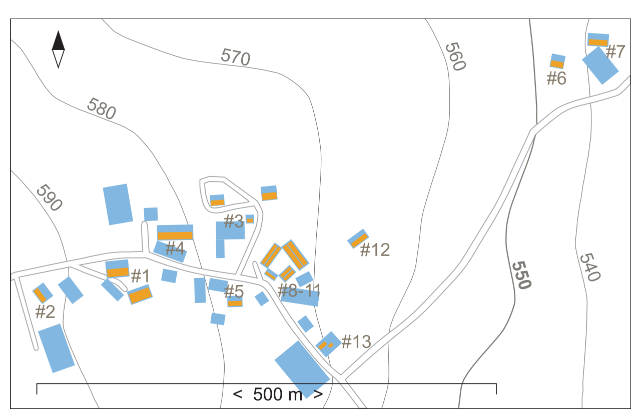

Fig. 1. Map of Epplas with locations of houses, PV systems, main roads and contour lines. (Illustration based on https://opentopomap.org and https://www.google.de/maps.)