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Influence of time resolution in the estimation of self-consumption and self-sufficiency of photovoltaic facilities

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HIGHLIGHTS

- The performance of a real PV self-consumption facility is analysed.
- Self-consumption and self-sufficiency were estimated for several time resolutions.
- The PV facility size corresponding to a ZEB has been proposed as benchmark.
- The differences in self-consumption are 9% when using hourly data or 10 s data.

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ABSTRACT

The main objective of this paper is to analyze and evaluate the impact of time resolution when estimating self-consumption and self-sufficiency in grid-connected photovoltaic facilities. The consumption data were obtained from a photovoltaic facility installed in Malaga (Spain). They were extrapolated to analyze other PV facility sizes for the same location. The size of the PV installation that generates an annual energy equal to the annual consumption has been estimated. This size has been used as benchmark size in order to generalize the results. The different time resolutions analyzed to estimate self-sufficiency and self-consumption parameters range from 10 s to one year. These different time aggregation levels are related to the different net-metering regulations. The results show that using hourly data overestimates these parameters compared to the results at smaller time resolutions; when hourly data are used instead of 10 s data, the differences between these parameters are around 9%. This may be due to the fact that this, and higher, time resolution does not take steady state voltages and power flows into account. Thus, increasing the time resolution can cause relevant information loss. Moreover, the results are also useful for analyzing different net metering systems by means of the self-consumption and self-sufficiency metrics. Self-consumption and self-sufficiency for the facility benchmark size range from 48% to 98% depending on the time resolution.

1. Introduction

The presence of photovoltaic solar systems has increased in recent years due to their drop in price. Improving manufacturing process modules has also contributed to this growth. According to data published by the International Energy Agency, [1], a total of 75 GWp of photovoltaic was installed around the world in 2016, while the total installed photovoltaic in 2015 was 50 GWp, and a cumulative total installed capacity of 300 GWp in 2016.

This growth in installed power is also reflected in self-consumption facilities. A self-consumption PV facility is an installation connected to the system of the owner or to the grid, for own consumption (on-site) while money is received for the non-consumed electricity which is injected into the grid in some countries. This type of PV facility has attained grid parity in several countries; that is, these facilities can generate electricity at a levelized cost that is less than or equal to the price of purchasing power from the mains [2].

Some countries incentivize self-consumption and in some cases the remuneration is even higher if a rate of self-consumption over a certain percentage was achieved. Several proposals based on demand-response smart grid technologies have been developed for industrial facilities, such as the one presented in [3]. In the case of home energy consumption, the characteristics of different demand responses that take into account the dynamic pricing tariffs are investigated using a

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computational approach in [4]. The more that is known about the actual daily profile of energy consumption, the better the guide-lines that can be established to adjust consumption to production of self-consumption photovoltaic systems. Regarding the issue of this adjustment, the impact of time resolution in the estimation of self-consumption and self-sufficiency in grid-connected photovoltaic facilities has been analyzed in several papers. Having sufficient data is important in order to estimate these parameters accurately, especially for facilities in countries where there is no net-metering system.

The demand for electricity in an individual house can change rapidly (in seconds) and is highly random when considering short-periods of time as it depends on the activities of its occupants; for this reason, some authors proposes the use of one-minute time resolution data, such as in [5] where an integrated model to generate synthetic electricity demand data at one-minute time resolution is presented. Wright and Firth, [6], affirm that using data periods longer than a minute underestimate the proportions of electricity export and import as a considerable information is hidden when high-frequency variations of loads are used; they conclude that logging at one or two minutes time interval is necessary to capture the fine detail of load patterns. Widen et al. [7] analyze the impact of time averaging on data series of domestic demand and output of PV in a simulated low-voltage grid and they conclude that it has a significant impact on individual households but smaller on aggregated demand. Bucher et al., [8] analyze the effects of averaging data by changing the temporal resolution; they propose one-minute time resolution for achieving a realistic representation of maximum power, maximum voltage or energy flows and smaller time resolution for evaluating transient currents and voltages.

The effect of time resolution on the estimated cost-saving delivered by 5 kWh of residential storage is analyzed in [9]; the authors found that using a 30-min time resolution underestimates the cost-saving by 17% on average compared to the results obtained at a 1-min time resolution. Five-minute resolution is recommended for modelling, system design and battery selection in [10]. .

As regards other tasks, such as optimizing planning distributed generation data at an hourly resolution are sufficient if the full range of stochastic fluctuations cannot be taken into account [11]. Hourly data are also used for a system that integrates solar photovoltaic, Stirling engine CHP and battery storage [12].

Nyholm et al. [13] use hourly data for estimating self-consumption and self-sufficiency for a PV facility with battery installed in Sweden. Quoilin et al. [14] analyze self-consumption with or without battery using a time resolution of 15 min. They found that self-sufficiency varies between 30 to 35% for the data from different countries.

From an economic point of view, the time resolution used for analyzing the performance of self-consumption facilities is related to the net-metering regulation. Net-metering is a system where the PV facility is connected to the public-utility power grid and PV surplus power is transferred onto the grid. This allows customers to offset the cost of power drawn from the public-utility grid for a certain period of time. The net-metering is related to the billing period, depending on the price of surplus energy [15]. Each country's regulations affect the profitability of photovoltaic facilities. It is increasingly common for countries to allow some type of net metering system such as Denmark, Finland and the Netherlands ([16]). Depending on the net metering system allowed the facility will be able to supply all the consumption or only a limited percentage for the house. When there is no compensation system in place, the percentages of self-consumption for several European countries range from 29 to 43% for an average PV system size of around 3.5 kWp with an annual demand of around 3500 kWh, [17]. In Germany, self-consumption varies between 38 and 42% compared to 29 and 34% in Spain. The estimations have been performed using hourly values.

The main objective of this paper is to analyze the impact of time resolution on the estimation of self-sufficiency and self-consumption for grid-connected photovoltaic facilities. Although the analysis is exploratory in nature, the conclusions on the effects of time resolution are important for research that use hourly data to simulate and design these facilities. They are also useful to evaluate these facilities from an economic point of view when some type of net-metering is allowed.

Moreover, we propose a size of photovoltaic facility as benchmark facility size. This benchmark size corresponds to a size in which energy produced by the photovoltaic system is equal to consumption for a year. In this case, the house can be classified as a zero energy building (ZEB), concept used in all fields of building construction in Europe. A ZEB is defined as a building able to generate as much energy as it consumes over a selected time frame. Self-consumption and self-sufficiency have been estimated for different sizes of PV facilities related to this facility size.

The rest of the paper is organized as follows. The materials and methods used are presented in Section 2; moreover, in that section, the architecture of the developed monitoring system is briefly presented. Section 3 describes the self-consumption photovoltaic facility in which data were recorded. The results obtained are presented and discussed in Section 4. Finally, Section 5 summarizes the conclusions and provides an outline for future work.

2. Materials and methods

The performance of photovoltaic self-consumption systems will be evaluated based on metrics related to the energy exchange with the grid, the fraction of load covered by the photovoltaic system and the fraction of photovoltaic production that is instantly consumed.

Sartori et al. [18] propose several concepts and parameters for their use in zero energy buildings that are useful for photovoltaic self-consumption facilities. In particular, they propose the following terms, all specified by each energy provider in (kWh/year) or (kWh/m^2):

- *imported energy* for energy flowing from the grids to building;
- *exported energy* for the energy flowing from buildings to the grids;
- *load* for the building's energy demand;
- *generation* for the building's energy generation.

Different metrics have also been proposed to evaluate the grid interaction of local electricity production. In [19] the use of metrics related to the load matching and grid interaction is proposed. These metrics are used to evaluate five different buildings: two for a photovoltaic system, two for photovoltaic and thermal heat pump system and one using micro wood pellets. The metrics proposed are the annual load cover factor and annual supply cover factor and the loss of load probability, which represents the percentage of time during which local production cannot cover the load.

Other parameters aim to investigate the usage of the grid connection according to its design capacity, such as the peak power generation, peak power load or capacity factor as in [19]. The load cover factor was previously described in [18] and it represents the percentage of the electrical demand covered by on-site electricity generation; it is similar to the self-sufficiency defined in [20]. The supply cover factor, also known as self-consumption is the percentage of the on-site generation that is used by the building; it is similar to the self-consumption factor defined in [21], but in this case the factor ranges from 0 to 1 and it includes the photovoltaic electricity supplied to the loads by the storage system as the evaluated systems includes batteries.

Klein et al. [22] propose two dimensionless metrics for the grid support of shiftable electricity consumers or producers. These metrics are the absolute and relative Grid Support Coefficients. These metrics express whether consumers and producers operate during favorable or unfavorable times with respect to availability of electricity in the public grid (stock electricity price, residual load, cumulative energy consumption or fraction of wind and PV in the electricity mix). The operation of the present-day installations is analyzed using these new metrics.