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Analysis of a photovoltaic self-consumption facility with different net metering schemes

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Abstract

A methodology for analyzing the performance of a photovoltaic self-consumption facility is proposed. It is based on the possibility of doing net metering for different time intervals. The used data were recorded for a photovoltaic facility installed in a detached house in Malaga (Spain). The peak power of the installation is 3kW. The monthly values of consumption and photovoltaic production and the energy balances of the system for 2015 have been estimated. The net metering schemes checked range from instantaneous to annual. In the firs case, no compensation between energy injected into the grid and the energy imported from the grid is allowed, while in the last case (annual values) the incentive scheme allows compensating generation and consumption for a year. The obtained results show that depending on the net-metering scheme the self-consumption ranges from 34% to 71% while the self-sufficiency ranges from 49% to 100%. In all cases, the annual energy fed into the grid is greater that the imported from the grid.

Keywords: Self-consumption; photovoltaic; net metering

1. Introduction

Renewable energies are called to play an increasingly important role in the current energy mix. Deficiencies and imbalances in the energy system have led the European Commission to develop policy aimed at achieving a reduction in energy consumption and at increasing the use of renewable energies [1].

According to data included in the Report 2015 published by the International Energy Agency [2], in 2015 settled in the world a total of 50GW of photovoltaic, reaching a cumulative total installed capacity of 230GW. There has been a significant growth due, firstly, to technological maturity of these systems and, secondly, to the significant drop in prices. In addition, policies that have been implemented in recent years in different countries have also contributed significantly to this growth.

In this context, the significant increase in the number of photovoltaic installations connected to the electricity grid poses a number of challenges. In the case of large installations, it is necessary to know in advance the energy they will produce to ensure their successful integration into the grid. In the case of small installations, it is important to achieve an optimization of self-consumption to improve profitability and to reduce energy exchanges with the grid.

In the photovoltaic market, these facilities performed in houses or buildings built in the city are increasingly taking importance. Therein, electricity demand is covered by photovoltaic production whenever possible. In addition, this production surplus is fed into the grid. In recent years, thanks to the growth of this type of facility, has begun to speak of self-sufficient dwellings and zero energy houses. A house or a building zero energy (known as ZEB, Zero Energy Building) is a concept used in buildings with an energy balance between generation and consumption near zero energy or even zero or positive in a year typical [3], [4]. The massive development of such housing could mitigate economic and environmental, such as CO_2 emissions and dependence on fossil energy sources problems.

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Photovoltaic technology can play a leading role to achieve the objective of ZEB as it is one of the best-positioned technologies to increase energy self-sufficiency of housing. It should also be also taking account that at the present time, for this technology, grid parity in the residential segment is a reality in many enclaves in the world, [5]. That is why the PV self-consumption has become in recent years the main tool to promote distributed generation and thus to contribute to reduction to stress the electrical distribution lines [6]. As a result, there is growing interest in generating energy through photovoltaic systems within the internal networks of consumption, to reduce the electricity bill (what is known as self-consumption facilities).

The vast majority of photovoltaic systems inject energy into the power grid regardless of any other factor as local consumption profiles and generation, cost, energy efficiency, etc., [7]. In self-consumption photovoltaic systems a gap between consumption and photovoltaic production, which makes much of the energy produced is injected into the power grid. It would be desirable that, as far as possible, this energy was used to meet the demands of the home itself. Nevertheless it should be also considered the regulation applicable to the installation that depends on the country. Basically, in some countries it is possible to do net-metering compensation between grid consumption and energy injected into the grid by photovoltaic installation. The net-metering scheme corresponds to an incentive scheme that allows compensating production and consumption during a larger time frame.

It is important to have demand management systems that allow adapting the power demand profile to the power generated by the photovoltaic or to have the possibility of using storing systems such as batteries to store the surplus energy locally for its use when necessary.

In photovoltaic systems without batteries consumption, the only variable that can act to improve the efficiency of these systems are profiles of energy demand of homes in which they are installed. Therefore, in recent years has begun to use the concept of management of demand (in English, demand side management, DSM) or active demand management, which aims to improve the energy system of housing "intervening "consumption, [8], [9]. Basically, it is "shifting" power demands loads housing to coincide with photovoltaic production. This load management can be done manually or automatically, [10], [11], and [12]. Energy management of consumption based on consumption profiles in photovoltaic systems can help make these energy systems more efficient and profitable, [9], [12]-[14]. Although they have already made some proposals in this direction, there is still further research in this field to achieve solutions that are implementable in real systems, [6]. In this case, it is also necessary to know the regulation mainly with respect to the possibility of doing net metering and to know for which timeframe it is possible to do it.

In photovoltaic systems with batteries, it is also possible to reduce the exchange with the grid both adapting consumption to production and using the batteries to store the surplus photovoltaic power when consumption are lower that production.

The goal of this paper is to analyze the different ways to optimize the performance of a self-consumption facility installed in Malaga (Spain). On the one hand, it is analyzed the impact of different net-metering schemes. On the other hand, it is analyzed the use of batteries in such as system; in this case, several sizes of battery will be used.

The rest of the paper is organized as follows. The following section it is described the methodology proposed including the definition of the parameters used to evaluate self-consumption facilities. The self-consumption facility and data used are described in Section 3. Results obtained are presented in Section 4. Finally, the conclusions are summarized in the last section.

2. Methodology

Different parameters related to the energy exchange with the power grid have been used to evaluate photovoltaic self-consumption facilities. For instance, I.Sartorio et al. [15] propose several concepts and parameters that can be useful to evaluate photovoltaic self-consumption facilities such as the followings: delivered energy, used for estimating the energy flowing from the grids to building; exported energy, for the energy flowing from buildings to the power grid; load for the building’s energy demand; and generation, for the building's energy generation.

Other parameters aim at investigating the usage of the grid connection under consideration of its design capacity, such as the peak power generation, peak power load or capacity factor, [16]. The load cover factor was previously described in [15] and it represents the percentage of the electrical demand covered by on-site electricity generation; it is similar to the self-sufficiency de- fined in [6]. 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 [17], 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.

In [18] the use two new metrics for the grid support of electricity consumers or producers, which express whether they operate during favorable or unfavorable times, is proposed. The operation of the present-day installations is analyzed using these new metrics.

Taking into account all these proposals, in this paper the following parameters will be used to evaluate and analyze the performance of photovoltaic self-consumption facilities:

- Power/energy generated by the photovoltaic facility.
- Power/energy exported to the grid
- Power/energy imported from the grid
- Power/energy consumption
- Percentage of self-consumption: it is the percentage of the self-consumed relative to the total photovoltaic production.
- Percentage of self-sufficiency: it is the percentage of self-consumed energy relative to the total consumption.

The expressions proposed to estimate the different analysis parameters depend on the interval of integration. The expressions used to estimate these analysis parameters are described below.

The photovoltaic self-consumed power:

$$P_{PV,selfc} = \begin{Bmatrix} C & if\ C < P_{PV} \\ P_{PV} & otherwise \end{Bmatrix} \quad (W) \tag{1}$$

where C is the power consumption and P_{PV} is power generated by the photovoltaic system.

The photovoltaic daily self-consumed energy is estimated using the expression:

$$E_{d,PV,selfc} = \sum_{i=1}^{n} \frac{P^i_{PV,selfc}}{n} \qquad (Wh) \tag{2}$$

where i denotes instantaneous value and n is the number of measurements recorded each hour.

The photovoltaic power exported to the grid is estimated using the expression:

$$P_{PV,e} = \begin{Bmatrix} P_{PV} - C & if\ P_{PV} - C > 0 \\ 0 & otherwise \end{Bmatrix} \quad (W) \tag{3}$$

The photovoltaic daily energy exported to the grid is estimated using the expression:

$$E_{d,PV,e} = \sum_{i=1}^{n} \frac{P^i_{PV,e}}{n} \qquad (Wh) \tag{4}$$

The power imported from the grid is estimated using the expression:

$$P_i = \begin{Bmatrix} 0 & if\ P_{PV} - C > 0 \\ C - P_{PV} & otherwise \end{Bmatrix} \quad (W) \tag{5}$$

The daily energy imported from the grid is estimated using the expression:

$$E_{d,i} = \sum_{i=1}^{n} \frac{P_i^i}{n} \qquad (Wh) \tag{6}$$

The percentage of self-consumption and the percentage of self-sufficiency for a period *t* are estimated using the expressions:

$$self - consumption = \frac{E_{t,PV,selfc}}{E_{t,PV}} * 100 \qquad (\%) \tag{7}$$

$$self - sufficiency = \frac{E_{t,PV,selfc}}{C_t} * 100 \qquad (\%) \tag{8}$$

where $E_{t,PV,selfc}$ is the total energy self-consumed, $E_{t,PV}$ is the total photovoltaic energy generated and C_t is the total consumption, all of them for a period *t*.

Several scenarios of net metering have been analyzed. The net-metering scheme corresponds to an incentive scheme that allows compensating production and consumption during a larger time frame. Specifically, intervals that range from 1 second (instantaneous balance) to 1 year have been checked. In each case, the computable exchange with the grid is estimated as the difference between the energy generated and the energy consumed for the considered time period.

3. Facility and Data Description

The data used for this study were obtained from a photovoltaic system installed in a detached house in Malaga (Spain) (Latitude: 36.82, Longitude:-4.53). Fig. 1 shows the modules of the installation. This facility is connected to the grid. The system was designed to totally meet the electricity needs of housing unit.

Fig. 1. View of the photovoltaic installation.

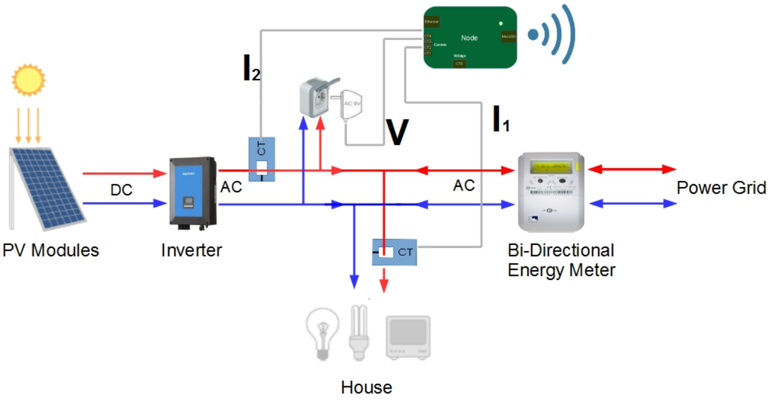

Fig. 2. Sensors installation scheme.

The technical characteristics of the photovoltaic installations are the following: 12 photovoltaic modules of 250Wp connected in series and one solar inverter of 3.0kW. Modules are oriented in line with the orientation of the house (10 °West) and at an inclination of 20 °from the horizontal. Data were obtained using a low cost monitoring system based on Arduino and EmonCMS. The scheme of the monitoring system is shown in Fig. 2.

Data used for the analysis and evaluations of the different net metering scenarios were recorded from January 2015 to December 2015. Monitoring system records the following measurements: voltage and current of photovoltaic generator and consumption current.

Fig. 3 shows the values of the monthly average of horizontal solar global radiation and outdoor temperature for Malaga for the same period. The mean daily solar radiation received ranges from 2.5 kWh/m^2 for winter to 7.8 kWh/m^2 for summer. The temperature ranges from 12.6 °C in winter to 28.5 °C in summer.

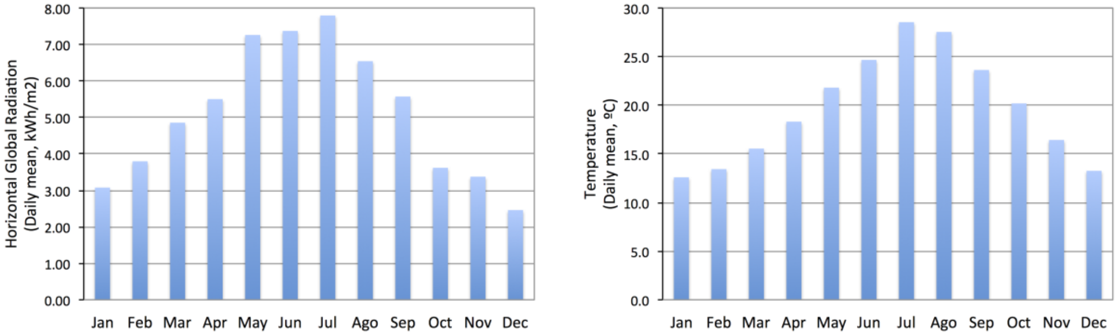

Fig. 3. Monthly mean values of horizontal solar global radiation and temperature for Malaga in 2015.

4. Results

The values of daily energy generated by the photovoltaic installation, daily energy imported from and exported to the grid (supposing instantaneous net metering), self-sufficiency and self-consumption have been estimated using expression proposed in Section 2. The monthly estimated values of all these daily parameters are summarized in Table 1.

Table 1. Mean values of daily estimated parameters. ($\overline{X}$ means monthly average)

Month	Daily C	$E_{d,PV}$	$E_{d,PV,self}$	$E_{d,PV,e}$	$E_{d,i}$	Self-cons	Self-suff
	kWh	kWh	kWh	kWh	kWh	%	%
Jan	14.53	10.90	4.17	6.73	10.36	38.3	28.7
Feb	12.86	12.35	4.58	7.78	8.28	37.1	35.6
Mar	8.31	14.19	4.14	10.05	4.17	29.2	49.8
Apr	8.80	14.55	4.45	10.10	4.34	30.6	50.6
May	8.75	17.72	6.35	11.37	2.40	35.8	72.6
Jun	7.68	17.38	5.51	11.87	2.17	31.7	71.7
Jul	10.15	17.55	6.54	11.01	3.62	37.3	64.4
Aug	13.45	15.76	7.34	8.42	6.11	46.6	54.6
Sep	10.64	14.43	6.35	8.08	4.29	44.0	59.7
Oct	7.15	11.23	3.04	8.19	4.11	27.1	42.5
Nov	5.43	12.27	2.11	10.16	3.31	17.2	39.0
Dec	10.35	8.68	3.68	5.00	6.67	42.4	35.6
Year	9.9	13.9	4.9	9.1	5.0	34.2	49.7

The annual mean yield of the photovoltaic system has been 4.6 kWh/kWp, that is, the system has generated more energy that the energy consumed from the grid. The yearly mean value of the self-sufficiency has been 49.7 % and the self-consumption has reached a value of 43.2%.

The maximum production of photovoltaic system is happening for summer due to the inclination of photovoltaic modules; these months the self-sufficiency reached values higher than 70%. In winter months these values are less than 30%.

The obtained results also show an important exchange with the power grid since more than half of photovoltaic energy generated has been injected into the grid while the grid has covered approximately half of consumption. This means that for the profitability of these systems the possibility of a net-metering scheme for medium and long term is essential, that is, the period in which the consumed energy can be compensated with the injected energy.

Different net metering schemes have been analyzed ranging from instantaneous net metering to 1 year net metering. Table 2 summarizes the obtained results for each scheme.

For each net metering scenario the second column shows the calculated energy injected to the grid and the third one the energy consumed from the grid taking into account the interval used to compensate energy injected with energy consumed from the grid.

Table 2. Grid injection and consumption for different net-metering schemes

Net-metering scheme	Computable grid injection (kWh)	Computable Grid consumption (kWh)
Instantaneously	3329	1841
15 minutes	3263	1775
1 hour	3200	1711
1 day	2042	553
1 month	1691	203
1 year	1489	0

As it can be observed, greater are the period of net metering lower are the values of energy consumed from the grid that should be paid to the power supplier. In the case of using annual net metering, the energy consumed from the grid is equal to 0 and this incentive scheme allows compensating production and consumption during a year. This value increases as the timeframe decrease but in any cases the total energy injected to the grid is greater that the consumed from the grid.

These results suggest that depending on the regulation of each country, the necessity of adapting demand to production can be more o less critical. In the worst case, when it is not possible to compensate any generated energy (instantaneous balances), the percentages of self-consumption and self-sufficiency only can be improved by using some type of demand management. In the best case, the grid acts as storage system for the photovoltaic facility.

5. Conclusions

A photovoltaic self-consumption facility has been analyzed. The monthly values of consumption and photovoltaic production and the energy balances of the system for 2015 have been estimated. The analysis of the system has been done using several parameters such as the percentage of self-consumption and the percentage of self-sufficiency. Once the analysis of the performance of the installation is made, the detailed analysis of different net metering schemes has been developed.

The obtained results show that depending on the net-metering scheme the self-consumption ranges from 34% to 71% while the self-sufficiency ranges from 49% to 100%. The annual energy fed into the grid is in all cases greater that the imported from the grid. The profitability of these type of installations will strongly depends on the regulation of each country; that is, on the one hand depends on the possibility of doing net metering for long time periods and, on the other hand, on the conditions of sale of the energy fed into the grid.

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