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Use of weather forecast for increasing the self-consumption rate of home solar systems: An Italian case study

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HIGHLIGHTS

- Focus on using deferrable loads to improve self-consumption rate of PV home systems.
- Two different weather forecast services are used for GHI information.
- An optimization tool based on a determinist and a stochastic approach is developed.
- Weather forecast uncertainty reduces the achievable self-consumption rate by 0.5–5%.
- Stochastic approach is preferred in the case of high percentage of deferrable load.

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ABSTRACT

With the aim of increasing the self-consumption rate of grid-connected Photovoltaic (PV) home systems, two main options can be implemented: the inclusion of an energy storage system, in particular a battery bank, and the adoption of a Demand Side Management (DSM) strategy. However, both the reshaping of the load consumption curve with the displacement of deferrable loads and the optimal management of the battery bank require estimation of the daily PV generation profile. The assessment of the on-site energy production can be carried out based on weather forecast data. However, the latter are characterized by uncertainty, which may affect the achievable self-consumption rate.

This work investigates the influence of weather forecast errors on the performance of home PV systems equipped with a battery bank and characterized by a certain share of deferrable loads. Two different weather forecast services are considered, referring to the annual meteorological conditions occurring in Rome, and energy consumption data for 150 different households are analysed. The self-consumption rate is maximized by solving a suitable optimization problem, while different combinations of relative battery capacity, PV-to-load ratio and share of deferrable loads are considered. Two different approaches—deterministic and stochastic—are adopted and compared with an ideal approach where the PV generation profile is perfectly forecasted. The results show that the adoption of the deterministic approach leads to a reduction in the achievable self-consumption rate in the range of 0.5–4.5% compared to the ideal approach. The adoption of a stochastic approach further reduces the deviations from the ideal case, especially in the case of consumption profiles with a high share of deferrable loads. Finally, a preliminary economic analysis proves that the use of a battery bank is not yet a cost-effective solution and a price reduction of the current battery prices is therefore required.

1. Introduction

After coal, Renewable Energy Sources (RESs) are the second-largest contributor to global electricity production, accounting for 22.6% of world generation in 2014 [1].

Solar Photovoltaic (PV) is one of the main renewable technologies and is experiencing very high annual growth rates in terms of installed capacity, which increased from 38 GW in 2010 [2] to 176 GW in 2014 [1] in OECD countries. A particular rise in the PV capacity has occurred in Italy, where the installed PV capacity achieved 18.9 GW at the end of 2015 [3], allowing Italy to become the third largest producer of PV electricity (25.2 TWh) in OECD countries, after Germany (38.4 TWh) and Japan (36 TWh) [4]. Still referring to the Italian situation, about 91% of PV systems have a peak power lower than 20 kW, corresponding to about 20% of the overall Italian PV capacity [3]. Therefore, an increasing number of PV owners use the produced electricity directly to

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Nomenclature

Symbols

A	area [m^2]
BCR	benefit-cost ratio
DLR	deferrable loads ratio
E	energy [kWh]
GI	global irradiance [kW/m^2]
I	investment cost [€]
L	lifetime [year]
P	power output [kW]
R_B	relative battery size
R_{PV}	PV-to-load ratio
SCR	self-consumption rate
SSR	self-sufficiency rate
T	temperature [°C]
c	specific cost [€/kWh]
f^{PV}	derating factor
i	interest rate
n^{PV}	number of installed PV sub-arrays
ΔSCR	mean deviation of the self-consumption rate
Δt	time step [h]
η	efficiency

Subscript (index)

t, T	time index and set
l, L	load profile index and set

Superscript

B	battery
BC	battery charging phase
BD	battery discharging phase
DIR	directly consumed
DL	deferrable loads
INV	inverter
NDL	non-deferrable loads
PUR	purchasing
SEL	selling
TL	total load

Acronyms

D	deterministic approach
DSM	demand side management
GHI	global horizontal irradiance
MAE	mean absolute error
MBE	mean bias error
MILP	mixed integer linear programming
NWP	numerical weather prediction
PV	photovoltaic
RES	renewable energy source
RMSE	root mean square error
S	stochastic approach
SOC	state of charge
WFS	weather forecast service

supply a share of their own consumption (the so-called prosumers). The interest in self-consumption of PV electricity is particularly noticeable for these prosumers, due to the economic advantages coming from the reduction in the amount of electricity purchased from the grid as well as the support policies introduced in several countries with net-metering schemes [5].

The improvement of the self-consumption in residential PV systems is mainly achieved by considering two options: the introduction of an energy storage system and the adoption of a Demand Side Management (DSM) strategy. These two methods have been well studied in the literature, as reported in an extensive review concerning self-consumption of PV electricity in buildings by Luthander et al. [6]. Among the alternative storage systems, battery storage (intended as both stationary systems and electric vehicles) is the most mature technology and the most suitable option for short-term energy storage [7]. Hoppmann et al. [8] demonstrated that given an economically rational household, investments in lead-acid battery storage are already profitable for some small residential PV systems. The achievable self-consumption in PV/battery systems depends on several relevant factors, such as system design, location, and number of buildings involved. For instance, Merei et al. [9] analysed the self-consumption and degree of self-sufficiency in commercial buildings for several sizes of PV plant and battery bank. In [10], the self-consumption of residential PV power in a community of several single-family houses was evaluated by considering different battery capacities. In [11], the best configuration in terms of minimization of the energy cost for a given self-sufficiency rate was investigated by varying the PV power output and the storage capacity. In addition, an analysis on the effect on the grid was carried out. Linssen et al. [12] highlighted the major impact of the chosen load profile on the congruence between electricity demand and PV generation and hence on the share of self-consumption. Therefore, they recommended the use of realistic load profiles for modelling, system design, and battery selection instead of aggregated profiles (e.g. standard load profiles). For this reason, recent papers analysed the level of self-consumption for a large number of different household consumption profiles. For instance, Quoilin et al. [13] built up a database of load profiles from monitoring data. The authors stated that the self-consumption rate largely varies between households and, therefore, the level of self-consumption cannot be predicted in a deterministic way. This fact was proved by Nyholm et al. [14], who investigated the optimal sizing of battery and PV modules by using real household energy consumption data from 2104 Swedish dwellings. The results highlighted an important dispersion in the achievable self-consumption rate although a common trend was observed.

The demand-side management includes several techniques for reshaping the pattern and magnitude of end-use electricity consumption. The load shifting, which represents the reallocation of the load demand from periods with high energy deficit toward periods with surplus PV production, is the most common and well-studied DSM strategy [15]. The adoption of this DSM technique in households is of remarkable importance as PV systems are often applied at this scale and the increasing electrification of heating and cooling loads in households provides greater flexibility [16]. However, as highlighted by Widén [17], the DSM capacity to increase self-sufficiency is currently limited by the low consumer engagement, the existence of a large number of low power loads, and the difficulties associated with the automation of such loads. The combination of DSM with battery storage is an interesting solution for optimizing the PV energy utilization and for further increasing the self-consumption. Castillo-Cagigal et al. [18,19] analysed the benefits of the inclusion of energy storage and DSM in a household equipped with a 5.5 kW_p grid-connected PV system. The authors proved the benefits in terms of increased self-consumption, decreased energy losses, reduction of storage size, and increased possibilities for electricity management. Femia et al. [20] investigated the self-consumption rate of PV residential applications equipped with energy storage and using a load management strategy, demonstrating that a synergic use of the load-shifting minimizes the energy exchanged with the grid. In [21], the authors confirmed that the improvements in self-consumption