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 deterministic 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.

ARTICLE INFO

Keywords:
Solar photovoltaic
Self-consumption
Energy storage
Battery bank
Demand side management
Photovoltaic power forecast

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
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 storage and electric vehicles) is the most mature technology and 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, in- stalling 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 several single-family houses by considering different household consumption patterns. 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 kWp 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. Femía 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 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].

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