Minimizing storage needs for large scale photovoltaics in the urban environment

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A R T I C L E   I N F O

Keywords:
Aggregated demand
community BIPV
Net load variance
Electricity storage

A B S T R A C T

The rising popularity of PV has prompted the creation of urban community solar projects. This study evaluates the combined effect of aggregating demand, photovoltaic generation and electricity storage, on-site consumption of PV and its impact on the grid. Data sets with real aggregated electricity demand from grid distribution transformers were used and the PV potential of building façades and rooftops was estimated. The amount of PV in each orientation in the façades and rooftops was optimized maximizing self-sufficiency and minimizing net load variance. Two storage management strategies were investigated: one for maximizing self-consumption and the other to reduce net load variance. We show that the aggregation of the demand and PV potential from different building surfaces in the urban context translates into a better demand-supply match, thereby minimizing storage needs. Higher storage capacities with proper management strategy are needed for mitigation of unmanageable net load variance and consequent costs for the grid operator.

1. Introduction

In 2015, almost 54% of the world’s population was living in cities and the average electricity consumption was higher than 3.1 MW h/person/year (The World Bank, 2017). Cities have become hot spots for electricity demand, which has to date been mostly covered by fossil fuel combustion in utility scale power plants. However, this form of supply directly contributes to global warming and should be avoided by an energy source that could be commissioned locally, with use of local resources and owned by the users. It has gradually been acknowledged that solar photovoltaic (PV) energy is the fittest candidate to tackle this challenge. Decreasing prices, market availability and technological improvements in terms of building integration are the main reasons for the emerging interest in urban PV where both rooftop and façade integration have become more popular (Biyik et al., 2017).

The commissioning of building integrated PV (BIPV) installations contribute to bringing buildings one step closer to the Net Zero Energy Buildings (NZEB) concept (Karlessi et al., 2017). Since a perfect demand-supply match is difficult to accomplish, the grid still serves as a sink for surplus PV production and a backup for periods of insufficient PV generation. Although it depends on the particular legal framework (Comello and Reichelstein, 2017), from the point of view of the end-user this, in general, means a high valorisation of the self-consumed electricity and a penalty for the exported electricity. Hence it is important that a PV system configuration allows for the maximization of self-consumption (Luthander et al., 2015). On the other hand, from the perspective of the grid operator, high PV penetration could be a technical challenge associated with voltage and frequency regulation (Obi and Bass, 2016) and demand/feed-in ramping rates, i.e. net load variance, (Grueneich, 2015) - the rates of change in the power that is required from the grid to satisfy abrupt increase/decrease in load demand, or the rapid increase in prosumer exports to the grid. Hence, there seem to be mutual excluding interests for prosumers and grid, which may ultimately set a limit for maximum feed-in power from households (Golden and Paulos, 2015), although this curtailment would entail a loss of production and, consequently, loss of revenue for the prosumer.

Although PV could – in principle – be installed according to a larger plan that ensures that the resulting solar electricity generation matches the demand profile of the PV host buildings, this is a challenging task to realize because the consumer behavior cannot be trivially inferred. Actual household consumption profiles are complex, featuring high variability and many spikes, which are difficult to grasp and model in a fully reliable way (Gouveia and Seixas, 2016; Grandjean et al., 2012). Yet, as one aggregates different profiles, the result is a smoother profile whose shape will match better the PV generation profile shape. When complemented with storage technologies and management strategies, the resulting overall system might be able to control the net load.
Electricity storage is still an unprofitable option for many users, except in very particular conditions or applications (Weniger et al., 2014; Naumann et al., 2015; Merei et al., 2016; Cucchiella et al., 2016; Camilo et al., 2017; Vieira et al., 2017). On the other hand, the effect of aggregation of electricity storage has only been discussed in few publications. For instance, Santos et al. (2014) assess the relevance of having distributed electricity storage capacity at the residential level, side by side with the consumption and generation devices. It is demonstrated that storage could be essential for the grid management for higher penetrations of PV generation in the residential sector by reducing the annual maximum power flow values. However, the effect of storage is strongly influenced by its sizing and operating strategy. In (Parra et al., 2017) the performance, economic benefits and optimum battery capacities for community electricity storage systems were quantified as a function of the size of the community. The optimization algorithm features demand load shifting strategies based on PV and load forecasts. It is shown that optimum storage capacity should ensure fully discharge during the peak period.

This study explores the combined effect of aggregating building demand, photovoltaic generation and storage on the self-consumption of PV and its impact on the grid. In particular, its main goal is to evaluate to what extent the building integration of PV alone avoids costs of extra storage while remaining profitable for users and innocuous for the grid. For this purpose, real aggregated electricity demand data from grid distribution transformers was employed; the amount of PV installed in each orientation in the façades and rooftops was optimized through a genetic algorithm aiming for the minimization of net load variance and maximization of self-sufficiency; and two storage management strategies were employed, one for maximizing the prosumer profit and the other to reduce net load variance.

Section 2 provides a detailed explanation of the Methods employed, followed by Results, Discussion and Conclusion in Sections 3–5.
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