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Technical and economic impact of residential electricity storage at local and grid level for Portugal

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HIGHLIGHTS

- Residential energy storage simulation with real data of a complete year.
- Three different storage roles defined and simulated with management rules.
- Grid global impact assessed for residential storage massification.
- Storage can reduce cost to 35% of PV alone.
- The residential power flows with the grid can be reduced more than 20%.

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ABSTRACT

The development of the Smart Grids will enable a more interactive and intelligent behaviour of the houses that are connected to the grid. This modification of behaviour of the house must rely on a conjugation of technologies (on-site generation, demand-side management, demand response, etc.) but, in general, the literature mentions storage as the ultimate response to conjugate generation, demand and grid interaction. In this context, the impact of in-house energy storage capacity deserves to be properly analysed. This work focuses on the analysis of electricity storage inside the house and its influence on the grid interaction, ensuring the demand satisfaction. First the typical demand and generation profiles are analysed to characterise the need for storage. Different roles for the storage utilisation are analysed with the objective of optimising self-consumption and mitigating the peak power flows from and to the grid. For the given storage roles, the benefits are evaluated from a local and grid global perspective. The analysis is done using data from real profiles of demand and generation, as well as by simulating the existence of storage. The simulated storage capacity in this analysis has resulted in significant improvements in the residential energy management. Furthermore, the effect of the simulated storage capacity is strongly influenced by the sizing and operating strategy.

1. Introduction

The house of the future should progressively become a Nearly Zero Energy House (ZEH), and, to achieve it, the architecture and thermal optimisations are not enough, but also improvements in the electrical systems are needed. The presence of self-generation in the residential sector is growing and will certainly become an issue in terms of grid management and reliability. Additionally, the increasing amount of large scale generation from intermittent sources available on the grid is already posing difficulties for the grid management. In this context, the house should achieve a more interactive behaviour in the grid connection, in contrast to the typical passive situation. Since the local generation is highly variable and intermittent, with a different profile from the demand, and the local demand has limited flexibility, the distributed local storage will certainly be an important resource for the house to balance supply and demand. Without storage, the house uses only the grid to compensate the generation–consumption mismatch, causing an unnecessary additional power flow in the grid connection. At the same time, the cost of the storage technologies is decreasing, and soon is expected to become economically suitable for small applications. However, it is important to know how much storage capacity is needed and how it should be managed to optimise the expected benefits for the grid and for the customer.

The importance and the opportunity for storage in the electrical system is addressed in several publications [1–6], some of them

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suggesting distributed applications and particularly at residential level. A more specific evaluation of the use of energy storage in residential buildings has already been done from several perspectives. In [7] a perspective on the sizing of residential storage is given, considering the benefit of keeping the grid connection, resulting in some calculation rules for storage with two different objectives of covering most of the electricity needs or only the peaks. In [8], the evaluation of a residential reversible fuel cell Photovoltaic (PV) storage system found numerous advantages of having the system grid-connected instead of stand-alone, but in this case the management option is to use the grid to supply the residential consumption peaks. A different purpose for storage is exploited in [9] where a storage system is optimised to take advantage from time-of-use pricing to obtain cost savings, despite the system cost not being considered. Another strategy is presented in [10,11] by the combination of storage with demand side management for self-consumption enhancement. With a more generic solution approach it is proposed in [12] an algorithm that could take into account multiple scenarios, domestic technologies and house configurations. In [13], a technique for scheduling the management of a residential installation with PV and energy storage is proposed that assumes a predefined energy price evolution trough the day and on the references prices defined by the customer. Another potentially profitable PV storage system is proposed in [14], considering the provision of ancillary systems to the grid. In [15], the energy storage is used in a residential distribution feeder to shave the peak demand and the impact of PV installations at the house level is also analysed. In a global perspective of the grid, the storage importance is revealed in [16] where the fraction of variable generation curtailed is clearly reduced with storage capacity increase. The study in [17] also shows how the particular residential storage could attenuate the peak injection of electricity into the grid that could lead to negative impacts in high residential PV penetrations. An economic assessment of a residential storage system with incentives is provided in [18] by quantifying the dependence of the internal rate of return on the battery costs. In [19], the economical optimal sizing of PV and battery system is determined as a function of the remuneration policy. An approach to house energy management including PV and storage together with the charging load of PHEV is presented in [20] where the impact of different tariffs is also analysed. In [21] the authors have concluded completely against the financial and environmental benefit of using lead acid batteries to time-shift the demand in PV houses with the current feed-in tariff.

The present work addresses the residential storage option with the aim of demonstrating the importance of defining concrete objectives for the storage management. The remainder of the paper is structured as follows. In Section 2 an analysis of the residential profiles is made. Section 3 is focused on the sizing aspects of the storage capacity for general typical profiles of demand and generation. In Section 4 the global impact on the grid is evaluated considering penetration of PV and storage systems. Section 5 presents the economic assessment of the storage use. Finally, Section 6 summarises the paper, emphasising its main conclusions.

2. Residential profiles analysis

The role of energy storage in residential buildings is mainly influenced by the profiles of the local generation and demand, that the storage system will help to match, and so the first step of such assessment is to analyse them. The research work about residential storage found in the literature is made for particular examples of houses. In most of the cases the data used are from a unique residential site and for a small time period, like one day [14,22,13,9,20], one week [23], or for a large time interval like one year or more [24]. In other cases the data from a set of houses are used for an entire year [7,25,21]. In two of these, the houses in the set are analysed each one independently and compared among them. In two situations the data are from different metered houses and in the other is from a model that simulates different types of houses. In a similar manner, the generation data are from isolated systems metered or simulated.

The results presented in the related work for the relationship between demand and generation profiles are usually biased by the ratio between total generation and total demand. In order to perform an analysis independent from this ratio, the absolute values of demand and generation were not considered, the values relatively to the annual total being used. In this way, the assessment was focused on the relative intensity variation through time and the simulations can be performed considering any desired ratio of total demand/generation. So, all the values of demand, generation, and storage capacity are given relatively to the annual demand daily mean (AD). The data used in this assessment were provided by the Portuguese mainland transmission system operator (REN). For the demand, the load profile provided to give the residential consumption with 15 min resolution, when the customer meter does not give readings with that resolution, was used [26]. This profile represents a generic profile for the residential sector in the entire country. Since this profile is used relatively to the average daily demand, the total annual demand does not affect the analysis performed, and so the results are independent from variations in the house size, typology or income. Since the impact from generation is fully dependent on the considered generation profile, this work was done for the situation of residential generation based on Photovoltaic (PV) technology. The reason for this is that PV is the most common and suitable generation type for residential application. The PV generation profile used is based on all the PV systems that are connected to the grid in the whole system [27].

In order to analyse the cyclic profile of the demand, a histogram of the demand for every 15 min interval of a day period was built. The resulting graph for the entire year demand is shown in Fig. 1. It is visible in the graph a significant coincidence around the same demand value at the same time of the day. In fact there is, for most of the day periods, a single frequency peak and the adjacent hills. This reveals the daily cyclic profile of the demand since, when considering a day period, the distribution of the demand is very similar for the entire year. This is mainly found in the late night and early morning period, while during the day the demand is more dispersed and especially in the late afternoon and evening the frequency peak is lower and the dispersion higher. It is also remarkable that there is a peak in demand happening in a small

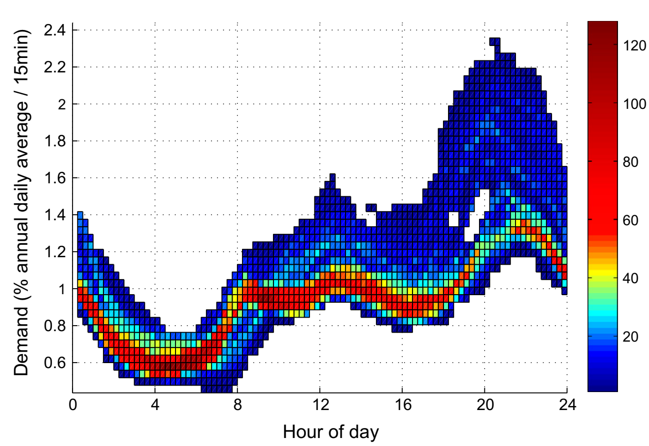

Fig. 1. Demand distribution for the entire year counting the number of days with given demand in each 15 min period.