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Electricity storage for grid-connected household dwellings with PV panels

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Abstract

Classically electricity storage for PV panels is mostly designed for stand-alone applications. In contrast, we focus in this article on houses connected to the grid with a small-scale storage to store a part of the solar power for postponed consumption within the day or the next days. In this way the house owner becomes less dependent on the grid and does only pay for the net shortage of his energy production. Local storage solutions pave the way for many new applications like omitting over-voltage of the line and bridging periods of power-line black-out. Since 2009 using self-consumption of PV energy is publicly encouraged in Germany, which can be realised by electric storage.

This paper develops methods to determine the optimal storage size for grid-connected dwellings with PV panels. From measurements in houses we were able to establish calculation rules for sizing the storage. Two situations for electricity storage are covered: – the storage system is an optimum to cover most of the electricity needs; – it is an optimum for covering the peak power need of a dwelling.

After these calculation rules a second step is needed to determine the size of the real battery. The article treats the aspects that should be taken into consideration before buying a specific battery like lead–acid and lithium-ion batteries.

Keywords: Electric energy storage; Solar system; Batteries; Lead–acid battery; Lithium-ion battery; Smart grid

1. Introduction

Since the industrial age, we produced power and other products in ever bigger constructions. Concerning power production, this trend is turning. In the post-industrial age, our society strives to live more autarkic, causing that people take actions to get grip on their own living situation. A beautiful example of this tendency is PV installations. The house owner becomes less dependent on the electric utility companies and is proud to fulfil part of his own energy need. The balance between solar energy production and household electricity consumption is still obtained with the help of the electricity grid. An overproduction in the day is sent into the grid and a demand in the evening is drawn from the electricity network. The grid is used as a virtual storage. A next step could be to store the produced electric energy during the day for delayed consumption in the night or the day after. In this way the house owner becomes yet less dependent on the grid and does only pay for the net shortage of his energy production.

A logical counter argument is that storage is expensive. However, a second trend in our society is a fast increasing market share of hybrid cars. This has several advantages: a massive increase in batteries will take place in the future resulting in lower prices and an additional market for used batteries will appear. Batteries of which capacity have dropped will be replaced in hybrid cars or these cars are abandoned. Many of these batteries can still be used for domestic applications, where storage place is less critical

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(Les conclusions du groupe de travail sur les infrastructures de recharge pour les véhicules électriques ou hybrides rechargeables, 2009). These two effects will make it possible that future households will start to install batteries to back-up their energy supply system.

Local storage solutions pave the way for many new applications. Examples are: (i) over-voltage of the line due to too many injecting inverters on the grid is omitted by storage; (ii) periods of power-line black-out can be bridged provided that the house is allowed to work in island mode (Braun and Stetz, 2008). Other new business cases can be identified: households that store their produced energy may allow their electricity provider to switch them off during periods of peak demand. In return they may receive a discount or a payment. Moreover, the new realm of possibilities are so-called smart grid applications (Hammons, 2008; Clastres et al., 2010). A house can interactively work with the grid and trade with the power markets. Peak reduction and demand response can be established more thoroughly than without storage (Ibrahim et al., 2008; Jossen et al., 2004; Denholm and Margolis, 2007; Chicco and Mancarella, 2009). A dwelling can even start to trade on energy markets on arbitrary moments.

Since 2009 using domestic storage for self-consumption of PV energy is encouraged in Germany. Traditionally, German owners of PV panels obtain a remuneration of 0.43 €/kWh for feeding their electricity into the grid. However, to encourage direct consumption, the owners of PV panels (up to 30 kW) receive also an allowance of 0.25 €/kWh for the directly consumed electricity. (Auswirkungen des Direktverbrauchs von Strom aus Photovoltaikanlagen, 2009). In this way it becomes more attractive to store the PV power than sending it into the grid and buying electricity back later.

Classically the storage for PV panels is mostly designed for stand-alone applications (Jossen, 1994). This means that an amount of energy must be stored to fill at least the production gap of several days of very clouded weather. In practice this is between 3 and 20 days (Jossen, 1994; Markvart and Castañer, 2003; Häberlin, 2007; Diaf et al., 2007). The daily cycle of charge and discharge is therefore only a small variation on the total storage capacity, typically between 2% and 30%.

In contrast, we focus in this article on small-scale storage to store a part of the solar power of one day for postponed consumption within the day or the next days. If the dwelling is grid-connected a storage system should not necessarily cope with a long period of low solar energy production, as the grid is available as a back-up. Hence the sizing criteria can be different from autonomous systems. We study storage for dwellings in connection with the grid, establishing new sizing methods. All calculations are based on real measurements during a year in seven houses in Belgium with PV-panels.

We start this article with a characterisation of the solar production and household consumption in the next section. In Section 3 we study why a storage system is bound to an effective maximum size. In Section 4 several ways of dimensioning storage systems are studied. In this section calculation rules are derived based on correlations with measurement data such as panel surface and dependence on the electricity grid. In Section 5 generalised calculation rules are developed for the case that solar panels cover the electricity (peak) demand. In Section 6 the repercussions for several battery systems are discussed. In Section 7 the total system integration is discussed.

Two situations for electricity storage are covered:

– the storage system is an optimum to cover most of the electricity needs;
– it is an optimum for covering the peak power need of a dwelling.

2. Production and consumption

This section gives an introduction in production and consumption profiles for households with PV panels. This is necessary to understand the impact of small-scale battery systems and the way they can be dimensioned.

A typical solar energy production profile during a day is shown in Fig. 1. The figure also includes the simultaneous consumption of that dwelling. It is clear that consumption and production do not take place at the same moment. An intra-day storage can offer a solution.

Two important design criteria for storage systems are power need, both for charge and discharge current, and storage capacity. This paragraph studies the power need and responsiveness. The storage must be able to absorb the full power of the PV panel, as the consumption can be sometimes almost zero, according to Fig. 1. The solar power change happens on seconds scale. Fig. 1 shows that the PV power can suddenly drop and be at full power again several seconds later. The household draws sometimes high power during short periods due to e.g. water cookers or espresso machines. The power that flows into the storage

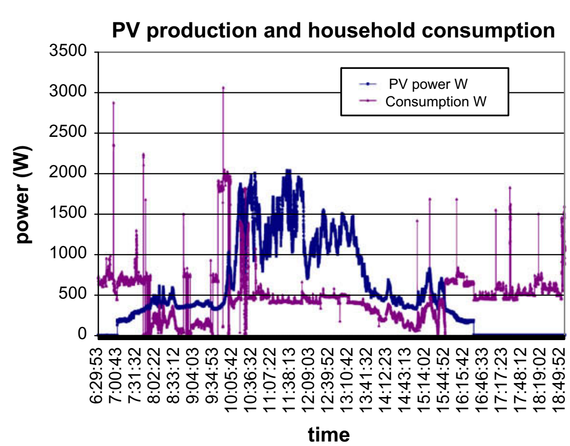

Fig. 1. A production profile of solar panels on a day in October and the consumption profile of the household on the same day.