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The Impact of Control Strategies on the Performance and Profitability of Li-Ion Home Storage Systems

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Abstract

An increase in electricity prices along with a decrease in the price of storage systems has led to rapid expansion of the PV-battery home storage system market in Germany. In order to be economically viable PV-storage systems must fulfill certain performance criteria, and in this context the system control strategy has a large impact on the overall system performance. In a nutshell, the control software should regulate the system in such a way as to maximize the self-supply ratio as well as the battery lifetime. An intelligent control strategy also has added benefits for the grid operator.

At KIT 20 commercially available PV-battery systems have been analyzed with respect to specific performance criteria: of those the following were used to quantify the level of intelligence of the storage system control software: (a) whether the software contains a predictive module at all, and if so whether it depends on external weather data; (b) the success of delayed charging in reducing the time spent at high stage of charge (SOC) levels and (c) whether prediction errors lead to the battery not being fully charged so that the user's self-sufficiency is unnecessarily reduced. Since the different effects are not independent the goal is to quantify the effects on system performance and profitability in each case. This shows the effect of software on the overall economics of energy storage systems and complements other studies based on simulation or those that look at different aspects like cell aging in an isolated context.

Roughly one quarter of the systems tested have an intelligent algorithm that controls the battery charging in such a way as to minimize calendar aging. In addition, differences of up to two years in battery lifetime are shown using voltage measurements with realistic household profiles and measured PV data. In this way, the present work outlines how control software can influence the performance and in particular the calendar aging of PV storage systems.

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1. Introduction

Efficient and economic energy storage technologies are key elements for a sustainable future energy supply, indeed, attractive and economical applications can be established if persistent and cost-efficient storage systems for electrical energy can be provided.

Since electricity prices in Germany have increased over the last few years [1] and storage prices are starting to decline, the economics will soon become attractive for small German household applications. It can already be seen that more and more PV home storage systems have been installed during the last years [2].

There are several critically important aspects affecting the performance and as a consequence the commercial viability: the system design and dimensioning, the level of development of the system control software and the calendar and cycle life of the battery and electronic components.

The system control strategies as well as the efficiency of different components have a large impact on the overall system performance. For this reason, 20 commercially available PV-battery systems with a usable storage capacity of between 2 and 8 kWh are currently being analyzed with respect to different performance criteria. The present work focuses on the system control strategy and its effect on system performance.

The control software should regulate the system in such a way as to maximize the self-supply ratio. The underlying algorithms must also ensure the longest possible operational lifespan of the battery; in particular the various electrochemical processes that take place during the normal operation of a lithium-ion battery must be taken into account. For this reason a vital component of the software is its ability to predict both the energy needs of the customer as well as the energy supplied by the PV-array, throughout the day. In essence one needs to be able to predict the load as well as the available power, to deduce how the system should best be regulated in order to increase profitability.

One concrete example of this is that excess energy should not be stored in the battery right at the start of the day, but rather only after midday, since lithium-ion batteries age faster when their state of charge (SOC) is high [3].This requires serious brainpower in the control system, since one has to decide in advance when and with what power the battery should be charged or discharged in order to simultaneously maximize self-supply and ensure a long battery life.

The main aim of this work was to find out how well-developed the system control software is, how good the performance of commercially available systems already are and which future developments are still necessary in this area.

2. Methodology

2.1. Input data

To find out whether the commercial home storage systems possess any sort of intelligent and/or predictive charging/discharging algorithm, they are tested within a hardware-in-the-loop environment similar to that described in [4]. The test setup, including all points of measurement is described in [5]. The measurements are done for typical reference days with measured solar PV data from KIT with a time resolution of one second and load curves for single-family households that can be generated based on the VDI 4655 reference profiles [6]. The tests were performed with an annual electricity demand of between 3500 and 4200 kWh, which corresponds to between 2 and 5 inhabitants per household. The resulting household load profiles have a time resolution of one minute. The PV data comes from the 1 MW PV plant at KIT north campus, located at 49.1° N, 8.44° E, which corresponds to climate zone TRY12 in the VDI 4655 classification system.

By testing all 10 different reference days of the VDI 4655 and using the corresponding frequency of each day within climate zone TRY12, the results can be extrapolated to the whole year.

In addition, tests were performed using the same PV data from summer and load data of one household from one summer week of measurements at 1 Hz, from the project "ADRES-CONCEPT" [7].