Analysis of Funded PV Battery Systems in Germany: Prices, Design Choices and Purchase Motivation

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ABSTRACT

Grid parity of residential photovoltaic (PV) power generation and retail electricity prices make self-consumption of solar power increasingly interesting for private households. Residential PV Battery Systems provide the opportunity to store solar energy that is not locally consumed during the day and make it available for self-consumption in the evening, thus cutting the electricity bill. Moreover, decentralized stationary battery systems are a promising technology to deal with grid problems that can arise due to high local penetration of solar power generation. Because relatively high system costs for small stationary battery systems still pose an obstacle for a broad market launch, the German Federal Government has issued a market incentive program to stimulate the market and boost technology development of PV Battery Systems. In order to additionally gain a better understanding of the technology under realistic operating conditions, an accompanying scientific monitoring program has been established. This paper outlines the most important terms and conditions of the market incentive program, the methodology of the monitoring program and presents current results of the market situation of government-funded PV Battery Systems in Germany. Note, that this paper is a short version update to an existing paper published by Kairies et al. in *Energy Procedia Volume 73* [1].

Keywords: PV Battery Systems; grid integration; market incentive programm; KfW funding; decentralized storage

1 INTRODUCTION

As part of its internationally much-noticed transition towards renewable energies (*Energiewende*), Germany faces an increasing penetration of PV power generation in its electricity grid: In 2016, a production of 38.2 TWh of solar power covered more than 6.4 % of the German net power consumption [2]; in early 2017 more than 1.58 million photovoltaic power plants with an accumulated nominal power of ca. 41.2 GW were installed [3]. Since 80 % of the German PV power generation and feed-in occurs decentralized in the low voltage distribution grids, significant challenges for the local electrical equipment can arise as large numbers of individual PV systems add up to considerable power levels. This can lead to regional problems with respect to the voltage stability or overburden the local electrical equipment such as power cables or medium voltage transformers [4, 5 and 6]. PV Battery Systems can reduce the described problems by absorbing the peak solar power generation that is produced during noon time and make it available for local self-consumption in the evening, thus relieving the low voltage distribution grids [7, 8]. In order to promote the use of PV Battery Systems and examine their grid-relieving potentials under realistic operation conditions, the German Federal Ministry for Economic Affairs and Energy issued a market incentive program accompanied by a scientific evaluation program.

2 THE MARKET INCENTIVE PROGRAM

The German Federal Government and the state-owned KfW banking group issued a market incentive program for PV Battery Systems in the year 2013. Due to its huge success, the funding program was re-launched in 2016 for another three years till 2018. The program aims towards an accelerated market introduction of PV Battery Systems that increase self-consumption and act grid-relieving at the same time. The funding is intended to stimulate the market, thus promoting technology development and bring down retail prices for small stationary battery systems in the long term. For this purpose, the KfW banking group provides loans for PV Battery Systems at reduced rates with an additional repayment grant. This grant is – starting from 25 % at the beginning of 2016 – decreased by 3 percentage points every six months, which leads to a current rate of 19 % of the eligible costs in May 2017. To ensure an expedient development of the technology and a grid-relieving operation of the subsidized devices, the funding is subject to several requirements. The most important technical requirements include a fixed maximum feed-in power of 50 % of the corresponding PV power generator and a battery warranty of at least 10 years. Furthermore, all funding recipients need to register with a scientific monitoring program and provide the technical data of their PV Battery System. Both, the amount of funding and the funding requirements are laid down in guidelines which are continuously amended, taking account of the current state of market developments [9].

3 THE MONITORING PROGRAM

Several studies have shown a positive influence of PV Battery Systems on low voltage grids by using computer simulations (including [7], [8] and [10]). However, the impact of larger numbers of decentralized PV Battery Systems in the field today can only be estimated. To gain a profound understanding of their effects under real term conditions, the market incentive program is supervised by a monitoring program funded by the Federal Ministry for Economic Affairs and Energy (BMWi) from the start. The monitoring program gathers several kinds of data:

- **Core data** like the number and type of battery systems, their dimensioning and average retail prices as well as the geographical distribution of PV Battery Systems in Germany
- **Electricity meter data** like the PV System's monthly power generation, electricity consumption of the household (kWh per month), grid feed-in (kWh per month) or the battery system efficiency
- **High-resolution measuring data** like irradiation, power generation of the PV power generator, three-phase currents and voltages of the household and the PV Battery System, battery temperature and state of charge, power line frequency and harmonics, grid feed-in power, self-consumption, et cetera.

This data is used to track market developments, to evaluate system performances and to provide acquired knowledge to the interested public.

4 RESULTS OF THE MONITORING PROGRAM

The following chapter presents an evaluation of the core data gathered from the program's beginning in 2013 until April 2017. After an introduction of the analysis' marginal conditions in Chapter 4.1, the results of the analysis are presented in sections 4.2 to 4.4.

4.1 Data Cleansing

The results of the core data presented in this paper illustrate an analysis of the ongoing monitoring program. The technical data of the PV Battery Systems is manually entered into a web interface including free text fields; as a result, incorrect or mixed up entries can occur. To consider these circumstances, autonomous algorithms are developed and additionally manual reviewing through experts is done to improve quality of the data base. Table 1 shows an extract of validity conditions, which are defined within the scope of data-cleansing.

Table 1: Technical validity conditions for the shown analysis.

Value	**Validity Condition**
Stated installed capacity	Larger than 1 kWh, smaller than 100 kWh
Stated usable capacity	Larger than 1 kWh, smaller than 50 kWh
Stated battery technology	Lead-Acid or Lithium Ion
Storage system price incl. battery	Larger than 2,000 €, smaller than 30,000 € (incl. VAT)

4.2 Technical analysis of the registered PV Battery Systems

In Figure 1 (left), the distributions of three major technical system properties (battery technology, system design and installation type) of the registered PV Battery Systems depending on three different evaluation criteria (number of systems, installed capacity, used capacity) are shown. The installation type is dominated by simultaneous installations with more than 80 % for all three criteria. More than half of the installed systems are AC-coupled systems with shares around 60 %. While the first two system properties are similar throughout the different evaluation criteria there is a higher variation concerning the ratio of the battery technology. The spread of 15 percentage points between the lead share regarding the criteria number of systems and the installed capacity can be explained by the differences in system dimensioning of lead-acid and lithium-ion batteries. Figure 1 (right) displays these differences showing the average battery sizes of the registered PV Battery Systems according to the battery technology used. First of all, it can be seen that lead-acid batteries on average feature usable capacities of about 8.8 kWh whereas lithium-ion based systems are smaller designed, featuring average usable capacities of about 6 kWh. The installed capacities that are needed to make these usable capacities available differ even more significantly. Lead-acid batteries usually utilize only 50-60 % of their installed capacity, leading to average installed capacities of ca. 16 kWh to obtain reasonable lifetimes. Most lithium-ion batteries on the other hand are able to utilize 80-100 % of their installed capacity. Thus on average installed capacities around 6.7 kWh can be observed for lithium-ion systems. This typical dimensioning seen in the PV Battery System market complies directly with well-recognized studies on battery aging and international

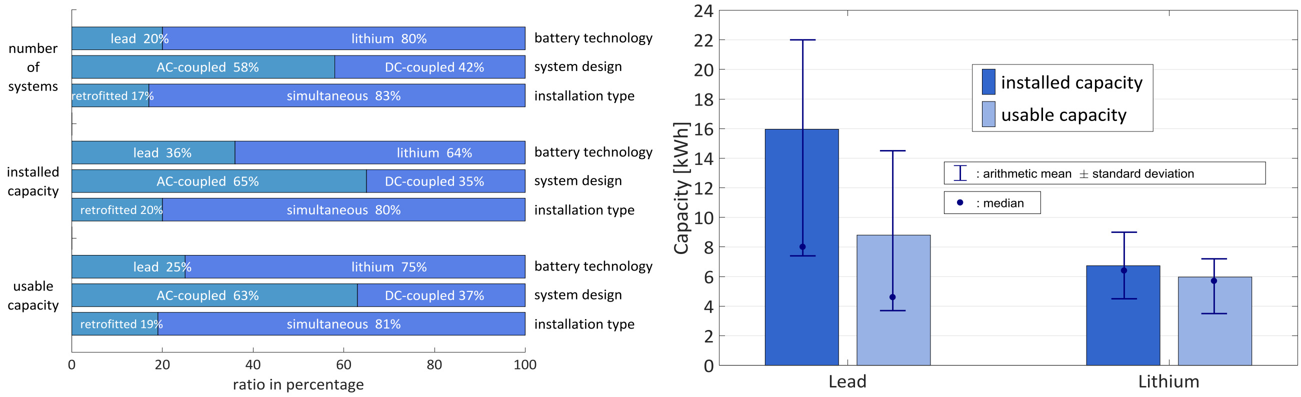

Figure 1. Overview about typical system configurations (left) and average installed and usable capacity of the registered PV Battery Systems (right).

standards to maximize the lifetime of stationary battery systems, as presented in [11, 12 and 13] for lead-acid batteries or in [14, 15] for lithium-ion batteries.

4.3 Price analysis of the registered PV Battery Systems

In Figure 2 (left) the development of the retail prices (incl. VAT) of PV Battery Systems with different battery technologies, related to one kilowatt-hour of usable capacity, is pictured. It has to be noted that the prices for the first half of 2013 and for the first half of 2017 are considered to be less sufficient than the others due to the relatively small number of datasets. It can be seen, that there is a continuous decrease in system prices since the beginning of the market incentive program in May 2013. While the average lead prices decreased from around 1,400 €/kWh in the end of 2013 to 1,200 €/kWh in the end of 2016 by ca. 14.3 %, the average lithium prices fell by 41.6 % from the end of 2013 (2,640 €/kWh) till the end of 2016 down to ca. 1,540 €/kWh. The first 96 registered lithium systems in the beginning of 2017 indicate that this course continues. Reasons for the observed price decreases can be found, among others, in decreasing battery costs and a larger production scales. It should be noted though, that parts of the pictured (average) price reduction can be traced back to the fact that increasing amounts of AC-coupled systems and/or single-phase systems enter the market. These systems both feature fewer components and are usually cheaper than comparable DC coupled systems or systems featuring a tri-phase grid connection, thus lowering the average market price.

4.4 Attitude towards PV Battery Systems

The registration process for funded systems includes a short survey of questions considering the motivation of acquiring a PV Battery System and the experiences made while purchasing it. In Figure 2 (right), the participants' main motivations of acquiring a PV Battery System are displayed for the registered systems clustered by the kind of installation. Remarkably, the results for both installation types are almost identical: The three main reasons to invest in a PV Battery System today are hedging against increasing electricity costs, contribution to the German *Energiewende* and a general interest in storage technology. On the other hand, only a few of the participants pointed out that a discontinuation of their guaranteed feed in tariff, the use as a safe investment or a protection against power failures were valid reasons to invest into a PV Battery System. This clear division into two categories as well as the parity of the results for both installation types indicate that today especially 'soft factors' are predominant reasons to invest into residential solar storage system.

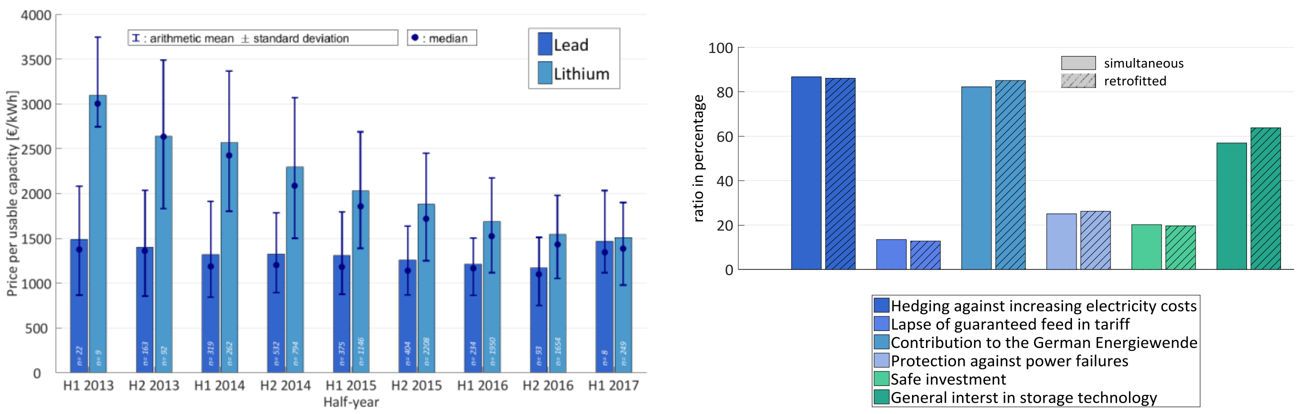

Figure 2. Evolution of the average net system prices of the registered storage systems without assembly prices (left) and main purchase motives (right).

SUMMARY AND OUTLOOK

The Scientific Measuring and Evaluation Program for Photovoltaic Battery Systems ("Speichermonitoring") started its monitoring activities in September 2014. A steadily growing database of comprehensive information regarding PV Battery Systems allows continuous in-depth analysis of the German market for decentralized storage systems. Additionally, high-resolution measurements (T=1s) of 20 privately operated storage systems in Germany are conducted since 2015. This data is used, among others, to evaluate the real-life operating behaviour, system efficiencies and potentials for bi-directional grid services. Results are regularly published on conferences, in journals and on the project website www.speichermonitoring.de. The next annual report of the monitoring program will be published at the beginning of July 2017. It will provide further and more detailed information regarding the technology- and market development of PV Battery Systems in Germany and also feature results of the monitoring of the operating data.

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