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Scientific Measuring and Evaluation Program for Photovoltaic Battery Systems(WMEP PV-Speicher)

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Abstract

Grid parity of residential photovoltaic (PV) power generation and retail electricity prices makes 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 from the beginning. This paper outlines the most important terms and conditions of the market incentive program, the methodology of the monitoring program and presents first results of the current market situation of government-funded PV Battery Systems in Germany.

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Keywords: PV Battery Systems; self-consumption; grid integration; market incentive programm; kfw funding; decentralized storage

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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 2014, a production of 35.2 TWh of solar power covered more than 6.9 % of the German net power consumption; at the beginning of the year 2015, about 1.4 million photovoltaic power plants with an accumulated nominal power of more than 38.5 GW were installed [1, 2]. 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 [3, 4 and 5]. 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 [6, 7]. In order to promote the use of PV Battery Systems and examine their grid-relieving potentials under realistic operation conditions, the German Federal Government issued a market incentive program accompanied by a scientific evaluation program. This paper gives an overview over the terms and conditions of the market incentive program (II), the methodology of the monitoring program (III) and presents first results on the current market situation of PV Battery Systems in Germany (IV).

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 that came into effect on May 1st, 2013. 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 of 30 % of the eligible cost[†]. 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:

- For each PV power generator only one PV Battery System can be subsidized.
- The maximum size of the corresponding PV power generator may not exceed 30 kW of nominal power.
- The maximum feed-in power of the corresponding PV power generator has to be limited to 60 % of its nominal power at the network connection point.
- Batteries must be shipped with a manufacturer's warranty of at least 7 years to be eligible for grants. If a battery system fails within the guarantee period, the retailer is obliged to repay the batteries' current value using straight-line depreciation.
- 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 [6], [7] and [8]). However, the impact of larger numbers of decentralized PV Battery Systems

[†] Details of the funding and the exact calculation methods regarding the eligible cost can be found at the official website of the KfW bank [9].

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 consists of three phases:

3.1. Basic Monitoring

All funding recipients have to register with the monitoring program as part of their funding requirements. The data can be provided online using the website *www.speichermonitoring.de*. During the registration process, technical data of the solar power generators, the battery systems and the respective households is collected. The gathered technical core data includes:

- Retail price, date of installation and nominal power of the PV power generator
- Retail price and date of installation of the Battery System
- Architecture of the PV Battery System (*1- or 3-phase connection*, *DC or AC coupling*)
- Battery type (*lead-acid*, *lithium-ion*, *other*)
- Installed and / or usable energy capacity of the battery
- Number of residents, annual electricity consumption and electricity price of the household (*all indications optional*)

By analyzing this core data, statistical statements regarding 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 can be made.

3.2. Standard Monitoring

From mid-2014 to the end of the monitoring program in 2016, up to 2,000 of the registered households are requested to provide their operating data on a monthly basis. Depending on availability, the gathered information includes power meter data like

- Power generation of the photovoltaic system (kWh per month)
- Electricity consumption of the household (kWh per month)
- Grid feed-in (kWh per month)
- Battery system efficiency

as well as statements on the system operation (fault reports, down time, maintenance, repair and overhaul).

The operation data will then be automatically processed analyzed and provided to the participating users on a private area of the program website. Thus users can compare their systems' performance to other PV Battery Systems in Germany or in their postal code area. Analysis of this operational data will lead to a better understanding of overall system efficiencies, the achievable increase in self-consumption and the number of full cycle equivalents seen by the battery; thus an economic analysis of the monitored systems can be made.

3.3. Full Scale Monitoring

From the beginning of 2015 onwards, up to 20 households with funded PV Battery Systems will be equipped with comprehensive high-precision measuring instruments. Depending on the system specifications, more than 60 different values will be measured for each household at every second. Among these are: 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.

All measured values are continuously transmitted to an FTP server where they are processed and fed into an online database. Participants will obtain direct access to the measured data of their systems via the program website. The comprehensive measuring data from the full scale monitoring will allow advanced analysis of PV Battery Systems in the field: Among other points of interest, grid-relieving effects of the systems or potentials for future bi-directional grid services can be quantified.

4. First results of the Monitoring Program

The following chapter presents a schematic evaluation of the data gathered within the scope of the Basic Monitoring from September 1st 2014 until today. 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. Restrictions of the first analysis

The results of the Basic Monitoring presented in this paper illustrate a preliminary analysis of the ongoing monitoring program. There are two major limitations to the validity of the evaluation that need to be considered when interpreting the results:

- Not all funded PV Battery Systems that have been installed to date (more than 9,500 as of March 31st, 2015, according to the KfW banking group [10]) have also been registered for the monitoring program yet, as the registration is not obligatory until the disbursement request for the grant is being filed with the bank. This process is typically initiated about six to nine months after purchasing the system.
- Because the technical data of the PV Battery Systems is manually entered into a web interface including free text fields, incorrect or mixed up entries can occur. Steps are taken to continuously clean up the database through autonomous algorithms and / or manual reviewing through experts. For this first analysis however, unless specified otherwise, only data that showed none or low anomalies was considered (see validity conditions in Table 1 and Table 2).

Table 1. Technical validity Conditions of the first analysis

Value	**Validity Condition**
Stated installed capacity	Larger than 2 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)

Table 2. Furthervalidity Conditions

If the stated installed capacity was smaller than the stated usable capacity, the entries were interpreted as faulty and swapped manually.	A total of 54 participants of the monitoring program stated battery technologies other than lead-acid or lithium-ion. However, all of these entries could be detected to be incorrect and manually corrected.
Retrofitted systems: If the storage system was retrofitted to an existing PV generator, the storage system price incl. battery needs to be at least 70 % of the overall price to avoid possible typing errors.	***Joint installations:*** If the storage system was installed together with a PV generator, the storage system price incl. battery needs to be less than 80 % of the overall system price (consisting of PV generator, PV power inverter, storage system and assembly) to avoid possible typing errors

4.2. Technical analysis of the registered PV Battery Systems

In Figure 1 (left), the distribution of three major technical system properties of the registered PV Battery Systems is displayed. While only few battery systems are retrofitted to existing PV generators (*installation type*), the market is fairlyevenly distributed concerning battery technology (with an increasing surplus of lithium-ion batteries) and system design (with an increasing surplus of AC-coupled systems).

To point out the differences in system dimensioning of lead-acid and lithium-ion batteries, Fig. 1 (right) displays the average battery sizes of the registered PV Battery Systems according to the battery technology used. First, it can be seen that lead-acid batteries on average feature usable capacities of about 7.5 kWh whereas lithium-ion based systems are smaller designed, featuring average usable capacities of about 5.5 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 more than 13.5 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 of less than 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 standards to maximize the lifetime of stationary battery systems, as presented in [12, 13 and 14] for lead-acid batteries or in [15, 16] for lithium-ion batteries.

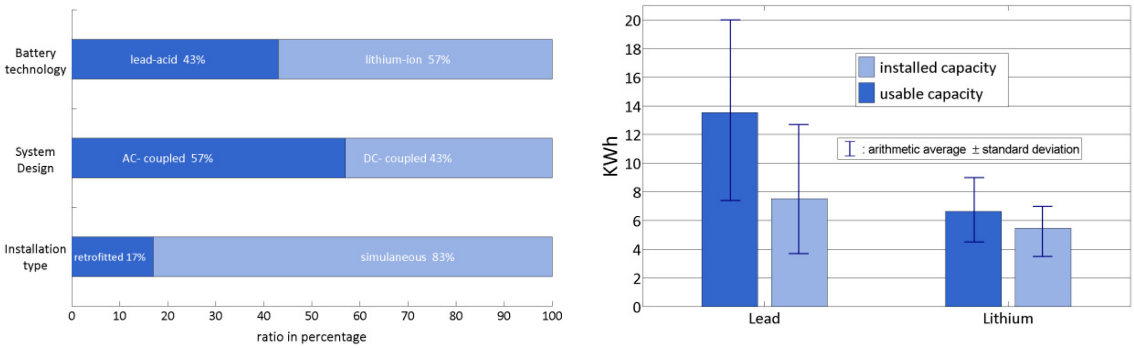

Fig. 1. (left) Overview about typical system configurations of the registered PV Battery Systems
(right) Average installed and usable capacity of the registered PV Battery Systems

4.3. Price analysis of the registered PV Battery Systems

In **Fehler! Verweisquelle konnte nicht gefunden werden.**, 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. First, it can be seen, that PV Battery Systems using lithium-ion batteries today in average have a 75 % higher retail price based on their usable capacity than similarly sized lead-acid battery systems. The long-term price for a stored kilowatt-hour, however, cannot be conclusively assessed by the retail price of the storage system alone, as it also strongly depends on the lifetime and the efficiencies of the PV Battery System. Accompanied by higher investment costs, the typical lifetime of lithium-ion based PV Battery Systems is expected to be significantly higher than the lifetime of comparable lead-acid battery systems. Many retailers of stationary lithium-ion battery systems advertise lifetimes of more than 5,000 equivalent full cycles or 10-15 years of service life ([17, 18, 19 and 20]) while lead-acid battery systems usually are declared to last up to 3,000 cycles at 50 % depth-of-discharge or 7-10 years of service life ([17, 21, 22]). However, as product quality and guarantee agreements vary significantly not only for different battery technologies but also depending on the chosen manufacturers and retailers, no final evaluation on the life cycle costs can be made today‡.Figure 2 also reveals a continuous decrease in system prices since the beginning of the market incentive program in May 2013. Compared to the first half-year of 2014, price reductions of 18% (storage systems utilizing lithium-ion batteries) resp. 12%(storage systems utilizing lead-acid batteries) can be observed today.It should be noted though, that parts of the pictured (average)price reductioncanbe traced back to the factthat increasing amounts of AC-coupled systems and/or single-phase systemsenterthe market.These systemsboth featurefewer components and are usually cheaper than comparable DC coupled systems or systems featuring a tri-phase grid connection, thus lowering the average market price.

However, if the decrease of system prices will persist over the next years, a reduction of today's retail prices by 50 percent can be expected between the years 2019 and 2020for both pictured battery technologies.

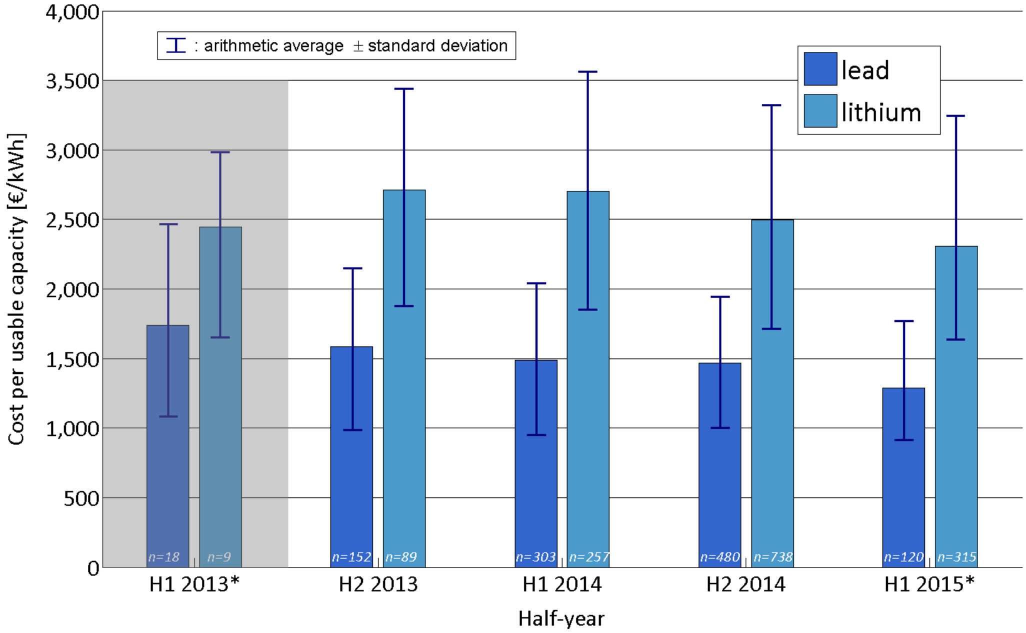

Fig. 2. Evolution of the average net system prices of the registered PV Battery Systems (storage system incl. battery, without assembly) per usable kilowatt-hour. The grey-shaded area indicates insufficient data for the first half-year of 2014.

4.4. Attitude towards PV Battery Systems

The registration process for the Basic Monitoring includes a short survey of yes-no questions considering the motivation of acquiring a PV Battery System and the experiences made while purchasing it. In Fig. 3, the participants' main motivations of acquiring a PV Battery System are displayed for the first and second half of the ongoing monitoring program. Remarkably, the results for both periods of time (stated by different participants at different times) 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 few people 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

‡While some lithium-ion battery based storage systems advertise lifetimes of 20-25 years [20, 23] or 15.000 equivalent full cycles [54], some retailers of lead-acid batteries provide cell replacements at reduced rates when the battery reaches its end of life [24].

System. This clear division into two categories as well as the parity of the results for both periods of time indicatethat today especially ‘soft factors’ are predominant reasons to invest into residential solar storage systems.

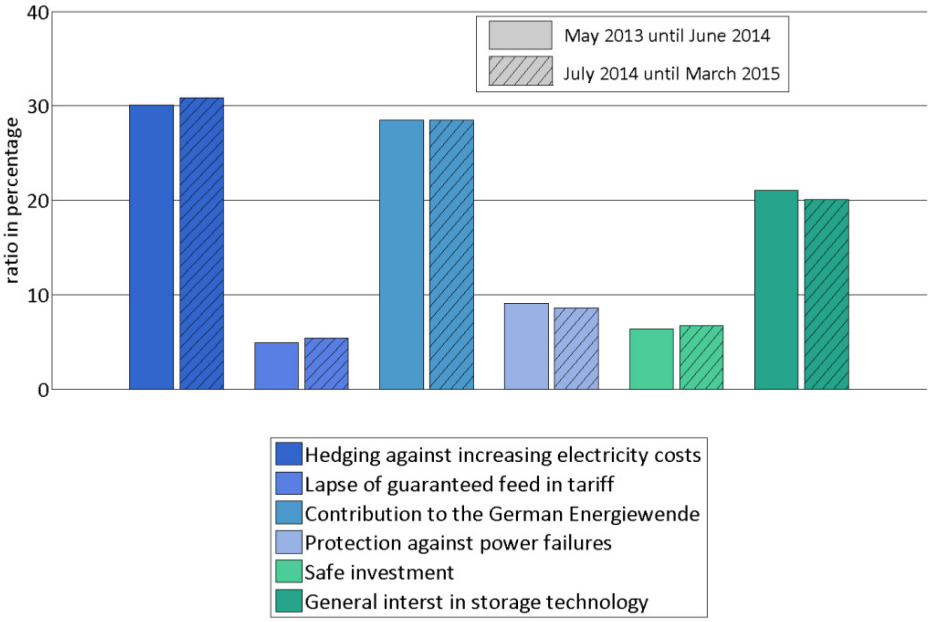

Fig. 3. Main purchase motives of the registered buyers of PV Battery Systems

5. Summary and Outlook

The Scientific Measuring and Evaluation Program for Photovoltaic Battery Systems started its monitoring activities on September 1st, 2014. A steadily growing database of comprehensive information on PV Battery Systems has been established and a first analysis of the market data was carried out. Additionally to a supervision of the market development, the established database continuously pools real term operating experiences like system efficiencies, breakdown statistics and potentials for bi-directional grid services which will be evaluated in future works. The first annual report of the monitoring program will be published at the end ofJune 2015. It will provide further and more detailed information on the Basic Monitoring, including reviews about the market penetration of different manufacturers of PV Battery systems, a more detailed analysis of price development and also feature first results of the monitoring of the operating data.

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