PHOTOVOLTAIC SELF-CONSUMPTION IN GERMANY
USING LITHIUM-ION STORAGE TO INCREASE SELF-CONSUMED PHOTOVOLTAIC ENERGY

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ABSTRACT: The new German Renewable Energy Sources Act (EEG) for the year 2009 provides a new tariff option: self-consumption (EEG §33,2). By economically favouring the local consumption of PV energy, the EEG incentivises the owners of PV systems to either shift their consumption to the time of production by load management or use storage options. Massive deployment of such energy management approaches may reduce the impact of PV energy in the grid and thus pave the way for a further rise of the number of installations.
For maximizing locally consumed PV energy, a storage system based on lithium-ion batteries is developed in the French-German project Sol-ion. Fraunhofer IWES, INES, ISEA and ZSW developed models to analyse the energy flows in residential PV-battery systems installed in Germany and in France. The models are used to calculate the increase of PV self-consumption. Energy flow simulations show that PV battery systems as developed in the Sol-ion project increase the local consumption of PV energy at the point of common coupling without constraining the user in his consumption habits. Target battery costs were calculated in an economical assessment. The installation of a Sol-ion system will become economically interesting with specific battery costs below 350 €/kWh as expected by the manufacturers in the medium term. The integration of additional functionalities (e.g. backup power and grid support) can improve the benefit of the Sol-ion system significantly.
Keywords: PV-battery system, lithium-ion battery, self-consumption, EEG 2009, economical assessment

1 INTRODUCTION

Since 1st January 2009 the German Renewable Energy Sources Act (EEG) is in force. This amendment contains the first legal incentive to integrate photovoltaic (PV) energy into a energy-management for optimizing the energy flows at the point of common coupling of the household. The EEG guarantees a special tariff for PV plant operators, when the “installation operator himself or a third party is using the electricity himself in the immediate vicinity of the installation” (official translation of [1, §33(2)]). In the Sol-ion project, PV-battery-systems with lithium-ion storage devices are developed and tested to offer a feed-in management which optimizes the energy flow at the point of common coupling.

In Germany this management is used to improve the synchronization of PV feed-in and load demand to maximize the amount of PV energy with claim to the special reimbursement tariff for self consumption in ‘immediate vicinity of the installation’. This energy is henceforth referenced to as local PV consumption or self consumed PV energy.

The use of Sol-ion feed-in optimization influences the power flows at the grid coupling points of households in dependency of storage capacity, PV generation and load consumption. In this study, dynamic energy flow simulations are used to calculate the increase of self-consumption for installations in Germany.

In a second step the results of these energy flow simulations will be used in an economical assessment of the PV battery system. A sensitivity analysis determines the boundary conditions of greatest relevance to the profitability of the Sol-ion system and quantifies their influence on the results.

2 MODELLING ASSUMPTIONS

The installation of PV or PV-battery-systems influences the energy flows at the point of common coupling of the household. To calculate these effects a model was developed to represent the time-dependant behaviour of load demand, PV modules, battery cells and power electronic components.

2.1 Sol-ion system

In the Franco-German research project “Sol-ion” industrial partners (Voltwerk Electronics, Saft, Tenesol and E.ON Bayern) and research organisations (INES, ISEA, Fraunhofer IWES and ZSW) are developing and testing integrated PV-battery-systems using lithium-ion storage technologies. The system’s layout is outlined in Figure 1.

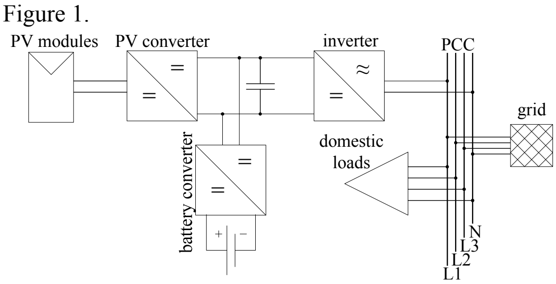

Figure 1: Layout of Sol-ion system

The Sol-ion system is based on the following sizing of components. It allows a single phase connection.

- PV modules: nominal power 5 kWp
- Inverter: nominal power 4.6 kW
- Battery: lithium-ion technology, variable number of blocks, each 2.3 kWh nominal capacity

2.2 Models of Sol-ion System Components

The system model is modularly designed. It consists of individual components models for the converters (including PV converter, battery converter and inverter), for the battery and for the PV modules.

2.2.1 Converter Models

For parameterising the efficiency curve of the power converters it is assumed, that the losses are separated into:

- constant losses due to self consumption (p_{self}),
- voltage losses (v_{loss}), proportional to normalized power throughput, and
- ohmic losses (r_{loss}), proportional to square of normalized power throughput

The total losses of the converter are given by the sum of all three contributions, with the normalized power throughput defined as the ratio between power at the converter output (P_{out}) and nominal power (P_N).

$$P_{losses} = p_{self} + v_{loss} \cdot \frac{P_{out}}{P_N} + r_{loss} \cdot \left(\frac{P_{out}}{P_N} \right)^2 \tag{1}$$

This approach was presented in [2] for inverters. It is applied to the parameterization of the DC converters in analogy. The comparison of this approach with measured efficiency curves validates the applicability of this approach.

The parameters can be identified by using the losses characteristics of the components. They are independent from the input power. In case of the PV-converter and the battery converter, the losses characteristics depend on the voltage level in the PV link and in the battery link. This voltage dependency is integrated into the models by defining three sets of parameters for different voltage levels. Each set parameterizes one efficiency curve for one specified voltage level. In case of voltages, which deviate from the specified levels, the efficiency is calculated by linearly interpolating between the curves. A single set of parameters is sufficient for the parameterization of the inverter efficiency, because the DC-link is controlled to have constant voltage and the AC voltage is defined by the grid to be 230V.

The maximum conversion efficiency over PV-converter and inverter is assumed to be 97.4% and the full conversion chain including the battery-converter in both directions is assumed to be 91.3%.

2.2.2 Electrical Battery Model

For simulating the battery losses, battery potential and the State of Charge (SOC) an equivalent circuit diagram is used. It represents the behaviour of one lithium-ion cell manufactured by SAFT [3] with a rated capacity of 45 Ah and a nominal potential of 3.6 V. For simulating the behaviour of one ore more battery blocks, the calculation is done for one cell and the resulting voltage is multiplied with the number of cells in series.

The equivalent circuit diagram consists of one voltage source, four resistances and three capacitors (Figure 2). The voltage source specifies the open circuit voltage (U_{OC}). The resistance R_{con} represents the electronic conductivity of the current collectors, the active materials and the electrolyte. A parallel combination of the ohmic charge transfer resistance R_{ct} and the double layer capacitor C_{dl} represent the transition of the charge carriers at the electrode interface. Diffusion effects (index dif) caused by the concentration gradients of the charge carrier within the electrolyte, the passivation film (index sei) at the negative electrode [4] and the active materials (index act) can also be described by RC elements. The combination of these resistances and capacitors is referenced to as battery impedance (Z_{bat}).

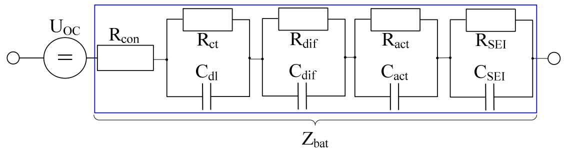

Figure 2: Equivalent circuit diagram of one battery cell

All parameters of the model vary with the SOC of the cell. U_{OC} drops approximately linear with the SOC. The behaviour of the other parameters is non-linear. All parameters depend on the cell temperature. For higher temperatures, the cell efficiency improves because the impedance decreases. Both, SOC and temperature dependency are considered in the developed battery model.

2.2.3 Battery Ageing Model

Apart from the electric behaviour of the battery, its lifetime is a very important parameter of the system. The ageing process affects the performance of the battery in two ways. It leads to:

- an increase of the real part of the battery impedance
- a reduction of the available battery capacity

Both effects of the ageing are assumed to be correlated linearly. The lifetime of a battery is defined as the period of time in which the capacity is reduced to 80% of the initial capacity and the internal resistance is increased by the factor 2. At this date the State of Health (SOH), which is the fraction of allowable performance degradation remaining before the end of lifetime, has been reduced from 1 to 0. The remaining storage capacity (Q_c) and the increased internal resistance (R) can be calculated in dependency of the SOH and their initial values with index 0.

$$Q_C = Q_{c,0}\left(1 - 0.2 \cdot \left(1 - SOH\right)\right) \tag{3}$$

$$R = R_0 \cdot \left(2 - SOH\right) \tag{4}$$

The ageing of the battery can be separated into the calendrical influence (a_{cal}) and the influence of the number of charge/discharge cycles (a_{cyc}). This study uses the approach of adding both contributions to evaluate the SOH.

$$SOH = 1 - \left(a_{cal} + a_{cycl}\right) \tag{5}$$

The calendrical ageing process is caused by a loss of active material and is influenced by the cell temperature T and by the potential difference between the electrodes U_{OC}. According to the Arrhenius law the degradation speed doubles for 10 to 15 K increase of temperature. The influence of the potential also follows an exponential relation [5]. Both effects are summarized by equation (6).

The parameters $a_{cal,0}$, b and c are defined in dependency of a reference potential U_0 and a reference temperature T_0.

$$a_{cal} = a_{cal,0} \cdot e^{\frac{U-U_0}{b}} \cdot e^{\frac{T-T_0}{c}} \quad (6)$$

The cycling of a battery leads to a growth of the SEI-film and morphological changes in the electrodes. This results in an increased resistance and in a reduced storage capacity Q_c. The impact of one cycle i depends on the Depth of Discharge of this cycle (DOD_i). The fitting of an analytical function to measured data offers a polynomial relation with the parameters d_2 and d_4.

$$a_{cycl,i} = d_2 \cdot DOD_i^2 + d_4 \cdot DOD_i^4 \quad (7)$$

The total ageing caused by cycling a_{cycl} is then calculated by adding all single cycle ageing amounts.

The increase of the real part of the battery impedance further modifies the efficiency of the battery during operation. This efficiency is defined by the ratio between the energy, which can be taken from the battery in the discharging process ($E_{discharge}$), and the energy, which is needed to recharge the battery (E_{charge}) to the initial state of charge. It depends on the SOC, on the cell temperature and on the power of charging and discharging.

$$\eta_{bat} = \frac{E_{discharge}}{E_{charge}} \quad (8)$$

According to the modelling assumptions, a fresh lithium-ion battery offers an efficiency of 97.4 % for one cycle between 20% and 80% SOC, charged and discharged with a current of Q_c/2h in an environment of 25°C. Having reached the SOH = 0, the real part of the impedance of the battery has doubled. In accordance to this, the losses of the battery are also approximately twice as high as for a new battery and the efficiency is assumed to be reduced to 94.1 %.

To enable a deployment of the lithium-ion batteries over 20 years, the active SOC range is constantly limited to 60% of the initial battery capacity. By applying this measure, high voltages and high DODs can be prevented and the ageing is slowed sufficiently to ensure that a replacement of the battery within the operation time is not necessary.

2.2.4 PV Model

This simulation uses an empirical PV model. It describes the efficiency of the PV module at the Maximum Power Point (MPP) as a function of the irradiation and the cell temperature [6].

$$\eta_{MPP} = \left(a_1 + a_2 G_{tilt} + a_3 \ln G_{tilt}\right)\left(1 + \alpha\left(T - 25°C\right)\right) \quad (10)$$

The temperature coefficient α can be specified with the data sheet of modules and integrates the reduction of efficiency for cell temperatures above 25°C. The parameters a_1, a_2 and a_3 parameterise the efficiency curve at Standard Testing Conditions (STC: irr.: 1000W/m², temp.: 25°C, AM: 1.5). Measurements of solar irradiation, cell temperature and PV yield of a monocrystalline silicon solar module at Fraunhofer IWES in 2008 were used for parameterisation. For STC the module efficiency is 12.7%.

2.3 Input Profiles

The described model needs three types of input profiles: irradiation, PV module temperature and load profiles. Exemplary profiles are shown in Figure 3.

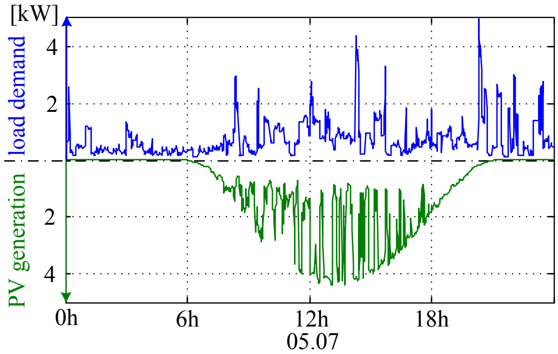

Figure 3: Exemplary profiles of load demand and PV generation on a summer day

2.3.1 Irradiation Profile

The irradiation profile was measured in 1995 in Kassel with a silicon diode on a tilted surface. 1 minute average values are applied in this study. The cell temperature T_{cell} is estimated based on the ambient temperature T_{amb}, the module heating coefficient $k_{temp,mod}$ and the irradiation on the tilted surface G_{tilted} as shown in equation (11). The ambient temperature profile was provided by the DWD for the site of Kassel in an hourly resolution.

$$T_{cell} = T_{amb} + \frac{k_{temp,mod}}{1000W/m^2} \cdot G_{tilted} \quad (11)$$

2.3.2 Load Profile

The load profiles are based on the broad statistical basis of the VDEW standard profiles for domestic loads in Germany, but also use high resolution measurement data, taken at a four persons household near Kassel. The VDEW profiles describe the statistical load demand of an adequately big number of households [7]. In five steps this VDEW profile is varied to get an assumed load profile of one household.

1) In a first step the population is distinguished into user types, e.g. children, employed adults or pensioners. Assessments about the habits are used to define the activity rate profile of a specific user group. The standard load profile is weighted with the activity rate to get a user specific standard load profile.

2) The standard consumption profile of a household is calculated as the sum of the user specific standard load profiles of its inhabitants. Three consumer types are distinguished:

- family (two children going to school, one employed and one partly employed adult)
- couple (two fully employed adults,)
- couple of pensioners

3) The profile is further scaled to reach a specified annual consumption. In the base scenario this consumption is assumed to be 5.5 MWh/a.

4) In the next step the profile is stochastically varied for disaggregation. The profile now represents the load demand of a household, including the habits of its inhabitants and typical fluctuations caused by switching of loads in a temporal resolution of 15 minutes.

5) To reach a higher temporal resolution, the 15-minutes-intervals of the synthetic load profile are then substituted with 15-minutes measurement sequences with a similar average load demand and a temporal resolution of 1 minute.

This approach offers scalable high resolution load profiles, which are adaptable to different consumer types and offer at the same time a good representativity and typical load fluctuations.

3 INCOME AND COSTS OF SOL-ION

The Sol-ion system is based on a conventional PV system using some additional components to increase the economic yield from the generated PV energy. This study concentrates on the **additional income** of a Sol-ion system and compares them to the **additional costs** with the aim of quantifying the profitability of the installation of storage devices at grid connected PV power plants.

3.1 Additional Income of the Sol-ion system

Figure 4 gives the possible energy flows in the Sol-ion system. If PV energy is used in immediate vicinity of the installation, the most recent amendment of the EEG reduces the reimbursement for direct feed-in c_{reimb} of 43.01 c€/kWh (E_{reimb}) to a reimbursement for local consumption $c_{PVlocal}$ of 25.01 c€/kWh ($E_{PVlocal}$) for installations in 2009 [1, §33(2)]. The difference between these tariffs can be interpreted as lost reimbursement or as costs for local PV consumption. For installations completed in 2009, these costs amount to 18 c€/kWh and have to be compared with the electricity price without VAT (value added tax), which has to be paid to the energy supplier. According to the German Federal Statistical Office the average electricity price c_{grid} in 2009 without VAT is approximately 19.45 c€/kWh (E_{grid}) for private households [8]. The owner of a PV installation can save $c_{grid} - c_{reimb} + c_{PVlocal}$ = 1.45 c€/kWh, when he locally consumes the self generated PV energy. The employment of this tariff for a 5 kWp PV power plant with an annual energy generation of approx. 5 MWh installed in 2009 saves electricity costs of up to 73 €/a if all generated energy is consumed locally. Due to the expected annual increase of electricity costs c_{grid} the span between these electricity costs and the costs for local PV consumption will increase for later operation years. In the fifth year of operation the saved electricity costs amount to 5.66 c€/kWh and 283 €/a, if an annual increase of electricity prices of 4% is assumed and all generated energy is consumed locally.

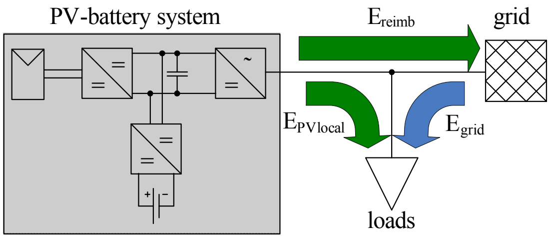

Figure 4: Energy flows in the Sol-ion system

Not only the annual increase of electricity prices but also the degression of the reimbursement tariffs leads to an increase of the profit margin. The EEG defines degression rates of 8% in 2010 and 9% onwards and appoints an increase or decrease of these degression rates by one percentage point in case of extraordinary low or extraordinary high installation rates [1, §20 (2a)]. This means that the owner of an installation completed in 2012 can reduce his electricity costs from c_{grid} = 21.88 c€/kWh (assuming an annual increase of the electricity price of 4%) to 13.27-14.17 c€/kWh and thus save 7.71-8.61 c€/kWh in the year of installation.

3.2 Additional Costs of the Sol-ion system

The additional installation costs of the Sol-ion system are caused by:

- an additional battery-DC-converter
- the lithium-ion battery blocks
- an Energy Management System (EMS)

According to actual estimations, the additional installation costs of a Sol-ion system without batteries are assumed to be 950-1950 €. The costs for the battery blocks are assumed to be proportional to the nominal capacity of the blocks. This nominal capacity is defined as the product of the average capacity and the nominal voltage, as defined on the data sheet. The usable energy depends on the charging current and on the cell temperature and can differ from the nominal capacity.

From the manufacturers point of view, specific lithium-ion battery costs can be less than 320 €/kWh within few years [9]. A study of the Japanese Ministry for Economy, Trade and Industry comes to similar results and defines target specific battery costs of 30,000 Yen/kWh ≈ 200 €/kWh for the year 2015 [10].

To make the results of this study independent from the costs predictions and their risks, the authors developed an approach of calculating target battery costs, which have to be reached to make the installation of lithium-ion batteries in residential PV power plants economically interesting.

Additional operational costs of Sol-ion are occasioned by additional energetic losses in the battery and the battery DC converter. Additional maintenance costs are assumed to be 3-6 %/a of the additional installation costs of the system without batteries.

4 BUSINESS CASE: MAXIMIZING PV SELF CONSUMPTION

In Germany the EEG provides an economic benefit for self consumed PV energy. To increase this benefit, Sol-ion system uses batteries and an EMS.

4.1 Energy Management Strategy

The major objective of the energy management is to compensate as much of the load as possible by synchronously injecting PV energy at the same Point of Common Coupling (PCC). In case of PV surplus the additional energy is stored in the battery cells (Figure 5). If load demand exceeds the energy provided by the PV installation, the battery will be discharged. This functionality is limited by the storage capacity. In the afternoon, when the battery is fully charged, the PV energy has to be injected directly into the grid. This energy is lost for local consumption. Late at night the battery is fully discharged and the consumed electricity is provided by the public grid.

The economically most interesting part of the energy flows through the PCC is the additional local PV consumption, i.e. the PV energy that can be locally consumed in addition due to the usage of storage capacity.

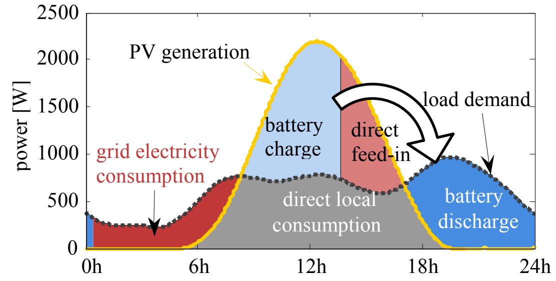

Figure 5: Energy management strategy for the German business case

4.2 Results of the Energy Flow Simulation

As shown in Figure 5, the PV energy of a Sol-ion system can be separated into three parts of whom the direct local consumption is not influenced by the installed battery capacity. An increase of the number of installed battery blocks leads to an increase of the additional local consumption. The simulation results (Figure 6) show that the relation between the cumulated additional self consumed PV energy over 20 years and the number of installed battery blocks follows an exponential equation, as given for the analysed example.

$$E_{add\ local} = 46MWh/20a \cdot \left(1 - \exp\left(-\frac{num_{blocks}}{5.06}\right)\right) \quad (12)$$

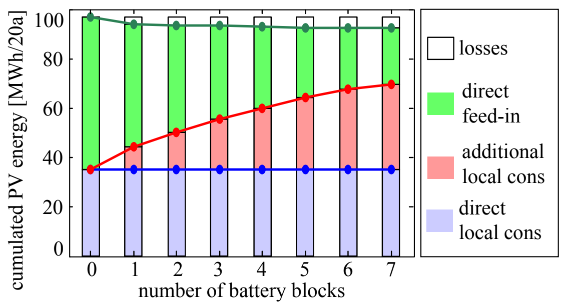

Figure 6: Usage of PV energy in dependency of the number of installed battery blocks for the base scenario (family, consumption: 5.5 MWh/a, 5 kWp PV, 40% ageing reserve)

Due to the losses in the battery and in the additional battery-converter, the total PV energy is reduced. The losses increase with the number of battery blocks and vary between 2.4 MWh and 4.2 MWh. The results of this energy flow simulation are used in the next section for the economic assessment.

4.3 Economic Assessment of the Sol-ion system

Revenues and costs of the Sol-ion system can be divided into four categories (compare Figure 4):

1. reduced reimbursements for direct feed-in Δc_{reimb}
2. reduced electricity costs for grid electricity consumption Δc_{grid}
3. increased reimbursements for local consumption of PV-energy $\Delta c_{PVlocal}$
4. additional costs for installation and maintenance c_{inst}

Before considering the influence of varying boundary conditions, the simulation results of the base scenario are presented. The base scenario considers an installation in 2012, an annual increase of electricity prices of 4%, reimbursements for PV energy of 32.77 c€/kWh for direct feed-in of PV energy and 19.05 c€/kWh for self consumed PV energy, a constant annual consumption of 5.5 MWh and the load demand profile of a family. Only 60% of the installed battery capacity is used for cycling.

Based on these assumptions, Figure 7 shows the cumulated cash-flow of a Sol-ion system using 5 battery blocks with specific costs of 350 €/kWh and an installation in the year 2014. In this case the break even is reached between the 15th and the 20th year, depending on the installation and maintenance costs.

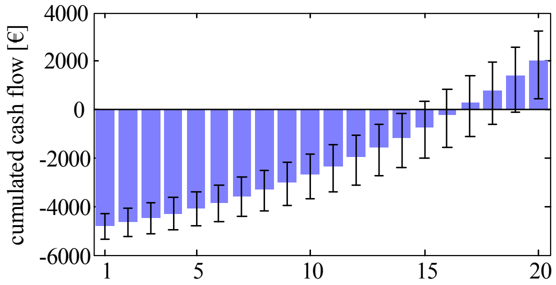

Figure 7: Exemplary 20 year course of the cumulated cash-flow with 5 battery blocks, assumed specific battery investment costs of 350 €/kWh, and an installation in the year 2014

To provide a better comparability of the results, further evaluations of the investment use the Internal Rate of Return (IRR). It is defined as the interest rate, which leads to a net present value of 0€ and is a measure to quantify the profitability.

$$\sum_{t=0}^{19} \frac{\Delta c_{grid} + \Delta c_{reimb} + \Delta c_{PVlocal} + c_{inst}}{(1+IRR)^t} \overset{!}{=} 0\,€ \qquad (13)$$

The investment in a Sol-ion system is economically reasonable as soon as the IRR of the additional components exceeds the rate of return of other investment opportunities. In this case the additional costs for Sol-ion are completely compensated by the additional income of Sol-ion within 20 years of system lifetime without leaving an additional profit.

The economic assessment of the investment in a Sol-ion system in the base scenario is shown in Figure 8 with variable numbers of battery blocks. The lines represent the results for average investment and maintenance costs of the Sol-ion system. The variation of the results of a system with 5 battery blocks due to the range of investment and maintenance costs is indicated by the grey area.

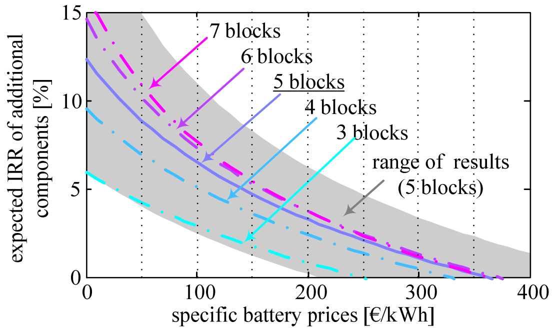

Figure 8: Expected IRR of the investment in the additional components of Sol-ion system with variable numbers of battery blocks

Assuming the base scenario and average costs for installation and maintenance, specific battery investment costs below 350 €/kWh should be envisaged to compensate the additional costs for installation by the additional income of a Sol-ion system. These specific battery costs are in the range of cost reductions, which is expected by the manufacturers as presented in [9] and [10]. A further reduction of the battery costs or of the costs of battery converter and EMS in the course of increasing installation rates leads to an increase of the IRR.

5 SENSITIVITY ANALYSIS

The performance of the system and thus the yield in form of the additional local PV consumption is not only influenced by the quantity of installed battery blocks but also by a number of further boundary conditions. Among these the following ones are assumed to have the greatest influence and are thus considered more detailed.

1. Influence factors on the energy flow simulation:
   - development of the annual load consumption
   - consumer type
   - position of the ageing reserve
2. Influence factors on the economic assessment:
   - year of installation
   - variation of the degression of the reimbursement according to the EEG §20
   - development of electricity prices

5.1 Sensitivity Analysis on the Energy Flow Simulation

To assess the influence of changed boundary conditions various scenarios are defined, which are assumed to cover the probable range of variations.

1. Development of the annual load consumption
   a. increase by 2%/a
   b. decrease by 2%/a
2. Influence of the inhabitants
   a. family
   b. couple of fully employed adults
   c. couple of pensioners
3. Position of the ageing reserve
   a. battery cycling between 10% and 70% SOC
   b. battery cycling between 20% and 80% SOC
   c. battery cycling between 30% and 90% SOC

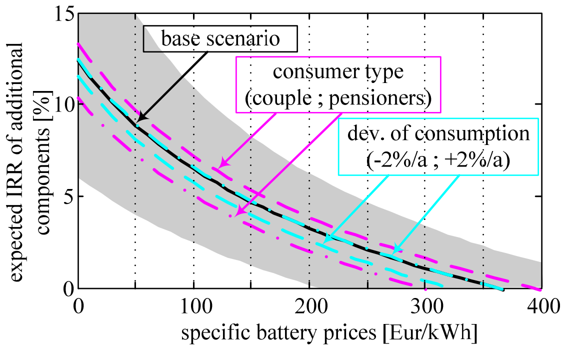

Figure 9: Influence of the type of the load profile and of the development of load demand on the expected IRR

The evaluation of the impact of the variation of annual load consumption, of the consumption scenarios and of the position of the ageing reserve on the additional local PV consumption shows that they do not influence the results of the energy flow simulation considerably. The total variation of the additional local PV consumption is less than 100 kWh in 20 years and thus below 0.5% of the result of the base scenario. The impact on the IRR is also small as shown in Figure 9.

5.2 Sensitivity Analysis on the Economic Assessment

Three economic boundary conditions were identified to have the greatest influence on the expected IRR of Sol-ion. Their influence on the presented result is analysed in the following scenarios:

1. Year of installation
   a. installation in 2010
   b. installation in 2014 (assuming the continuation of the EEG 2009)
2. Development of electricity prices
   a. increase of 3%/a
   b. increase of 5%/a
3. Variation of the degression rate
   a. reduction of the degression by one percentage point per year
   b. increase of the degression by one percentage point per year

The comparison is done for a Sol-ion system with five battery blocks. The results are presented in Figure 10. They show that the economic boundary conditions, with the exception of the variation of the EEG degression, have a much stronger impact on the results than the influencing factors of the energy flow simulation. Especially the development of the electricity prices is an important aspect for the assessment of the economic risks of the installation of a Sol-ion system because they cannot be precisely predicted. It should be mentioned that the base scenario leads to net electricity prices of 48 c€/kWh at the end of the system life time with an annual increase of 4%.

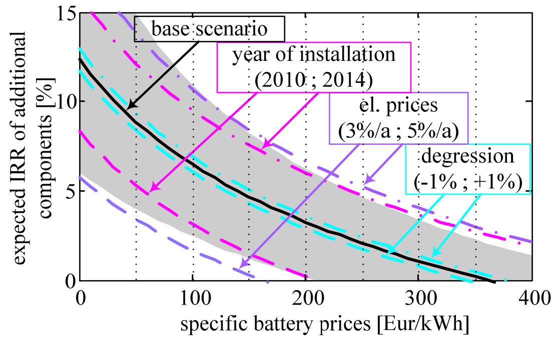

Figure 10: Influence of year of installation, variation of the degression rate of the reimbursement and of the development of electricity prices on the expected IRR

6 CONCLUSION

PV-battery systems based on lithium-ion technology, as developed in the French-German Sol-ion project, offer a promising possibility of optimizing the energy flows at the point of common coupling without constraining the user in his consumption habits. The installation of five battery blocks with a capacity of 2.3 kWh each, allows increasing the amount of self consumed PV energy by 82% of the self consumed PV energy of a conventional system without batteries.

The presented system model offers a detailed and modular representation of the Sol-ion system. It proved to be applicable for a wide range of different boundary conditions. The energy flow simulations further showed a clear robustness towards probable variations of the influencing factor including annual load consumption, consumer habits and the position of the ageing reserve.

The results of the economical assessment quantify the dependence of the expected internal rate of return (IRR) on the battery costs. A considerable influence of economic influence factors was identified, especially of the year of installation and the increase of electricity prices. It is shown that by a reduction of specific battery prices below 350 €/kWh, as expected by the manufacturers according to [9, 10], the investment in a Sol-ion can become economically interesting. A faster increase of electricity prices than considered in the given calculations will increase the expected IRR significantly. Additional functionalities implemented in the So-ion system can improve the economics.

In addition to the maximisation of the local consumption, the Sol-ion system can also be used to provide further functionalities. These include the optimization of energy flows in situations of time-variable electricity prices, temporally limiting the injection and thus reducing the maximum loading of grid components and supporting grid operation [11], or backup power. First calculations showed that the Sol-ion system can be used to feed the loads in case of grid failure. The costs of this backup functionality are expected to be lower than the costs of comparable stand-alone backup solutions.

All of these additional functionalities can improve the economics of an investment in a Sol-ion system. They are studied in the next project period.

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