THE SOL-ION SYSTEM: PROTOTYPE DEPLOYMENT IN FRENCH OVERSEAS AND SOUTHERN GERMAN FIELD TRIAL LOCATIONS AND LOGGED PARAMETERS FOR PV STORAGE SYSTEM AT HOME LOCATIONS

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ABSTRACT: Solar home systems combining PV and storage capacity through Lithium-Ion batteries have been developed within the French-German Sol-ion project. Deployment into a field trial with 25 installations in French Overseas, 20 installations in Southern Germany and several research institutes has commenced, allowing for the test of different operation modes, including back-up for grid failure, optimization of self-consumption and grid support. Details of the types of installations, the operation modes and parameters collected in the field trial are given including first samples of collected data.
Keywords: Implementation, Battery Storage and Control, Grid-connected PV Systems, Stand-alone PV Systems

1 INTRODUCTION

PV home installations are contributing to the increase of renewable energy content in the grid. Integrating the fluctuating source of PV-generated electricity into the grid is a challenge of balancing generation, load and storage. Combining storage capacity through Lithium-Ion batteries with the PV installation can help to achieve part of the required balancing between generation and load at the site of electricity generation [1-5]. Full balance leads to an off-grid system with independence from the grid.

As part of the French-German research Project Sol-Ion, prototypes of PV-Storage Systems have been developed with storage capacity of 8,8 to 13,2 kWh [6].

Important goals of the Sol-Ion Project are to demonstrate improvements for grid and user brought by the system in various cases and to also generate data that enables the creation of economic scenarios for the deployment of such systems. Thus the systems are operated in different modes, to gather data on the performance as it varies with load and generation conditions, the requirements put onto the battery in those modes, and the influence on grid parameters. The different modes include back-up for grid failure, optimization of self-consumption and grid support

2 OBJECTIVES OF THE FIELD TRIAL

The Sol-ion system has passed the development, lab-test and certification stage. By exposing about 50 samples of the system to a field trial, the next step in the product cycle towards general availability is taken.

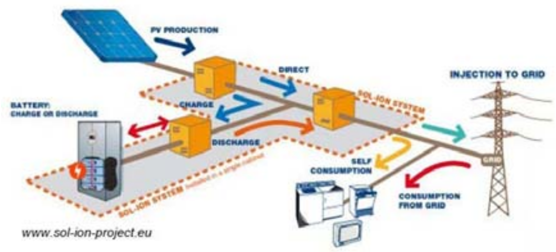
The objectives of the field trial are with technical, scientific and installation-related focus

- validate the operation over several months under various conditions of installation and load
- determine the performance of each component
- compare measurements with simulations
- improve the original model, which was used in the design of the system, to better describe the behavior.
- based on the improved model, fine-tune system performance through SW-changes, e.g. by adapting control-loop responses or interpretation of internal and external sensor data
- gain experience in installations procedures and handling
- evaluate customer response, expectations and acceptance.

3 FIELD TRIAL DESIGN

The Sol-ion system can be operated either connected to the Grid or stand-alone, as shown in Fig. 1. Transition between the two modes is done automatically, depending on the presence or absence of the grid.

(a) connected to the grid / optimize self-consumption



(b) stand-alone / back-up for grid failure

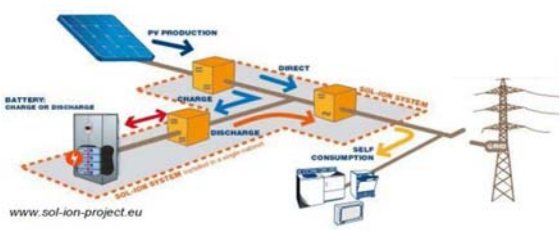


Figure 1: Sol-ion system with two DC/DC convertors towards PV generator and battery and one AC/DC convertor to connect to 235 V output line. The system is shown in two operation modes, connected to the grid and stand-alone.

To realize both operation modes, the Sol-ion system has two “line-out” terminals. The first single-phase output is designed for connection to any phase of the grid-connected power-bus bar of a home installation. Upon grid failure, this first output terminal will go into "listen" mode to detect re-appearance of the grid supply. During grid failure, Sol-Ion supplies power from the battery to a second terminal for back-up / stand-alone operation.

Sol-Ion supplies a low-voltage DC-signal to control a user-supplied power relays, for switch-over the house wiring from the grid connected power-bus bar to Sol-ion´s back-up terminals. Single-phase house wiring simplifies switch-over for the complete load of the house within the output power specifications of the Sol-ion system. For a three-phase connection of the house wiring to the grid, the customer typically has to choose, which of the three phases he wants to provide with back-up functionality and put all critical loads onto this one phase.

2.1 Optimized self-consumption

The field trial in Southern Germany with E.ON is used to test the mode "optimized self-consumption", since

- German feed-in tariffs provide an incentive to increase the level of self-consumption
- full stand-alone operation is difficult to implement given the three phase installations in Germany
- low solar-radiation levels during extended periods of the year impede stand-alone operation.

2.2 Stand-alone operation / back-up for grid failure

The field trial in Guadeloupe with Tenesol is used to test the mode "stand-alone operation / back-up for grid failure", since

- reliably high numbers of sun-shine hours throughout the year promise a high level of self-sufficiency
- grid outages or weak grids are more common in Guadeloupe
- single-phase house wiring make full back-up easy to implement in Guadeloupe.

2.3 Test with electronic loads

The tests at most research institutes are done with electronic loads and/or additional sensors to characterize the power flow and time characteristics at the external power terminals and selected internal measurement points of the Sol-ion system.

2.3 Measured parameters

Measured parameters include Power (active, reactive and apparent power, as well as the respective energy-flows), voltage levels, internal currents, battery parameters, line frequency, solar radiation, ambient temperature and system status parameters. Most values and parameters are sampled at 1 sec intervals.

3 FIELD TEST DETAILS

The first four installations went to the research institutes INES-CEA, Fraunhofer IWES and ZSW. All Sol-ion systems in those installations have battery packs of 4 modules with a total 8.8-kWh storage capacity.

The two installations at INES-CEA in France are operated each using a PV-generator composed of 3 strings of 11 panels (Photowatt PW 1400 / 150W) with a V_{OC} of 473 Volts delivering a nominal peak power of 4950 Wp. INES-CEA has collected load profiles of 88 households with a yearly consumption of 1.500 to 17.125 kWh/year. The loads are resistive and electronic loads, controlled via SW-interface to follow specified load profiles. Goals of the investigations at INES-CEA are

- validation of the different modes of operation on a yes/no basis
- evaluation of the performance of each mode in terms of efficiency and energy management accuracy
- evaluation of the impact of each component on the global performance of the system and
- comparison of the real data and simulated data for the improvement of the model.

The installation at Fraunhofer IWES will be operated initially using electronic mock-ups of PV-generator and loads. The goal of the investigations are the analysis of the system performance, comparison and improvement of the model, as well as the derivation of updated algorithms for the control of battery charging and feed-in ratios. Goal of the updates are improvements for the economics of the system performance depending on assumed and time-dependent feed-in and consumption tariffs.

Figure 2: The PV Generator of the Sol-Ion installation at ZSW Widderstall consists of 21 modules (Galaxy Energy GS245m) with nominal 5.145 Wp mounted on a double carport.

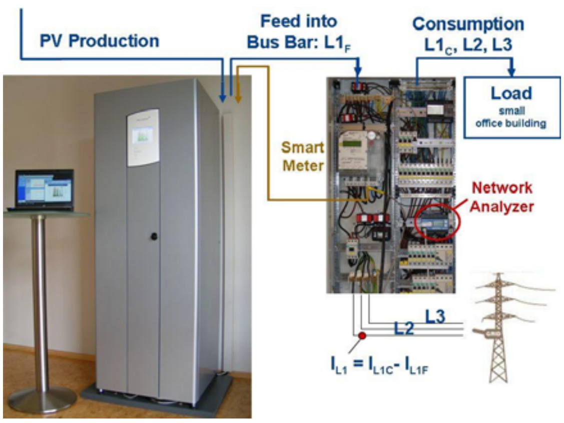


Figure 3: Sol-Ion Installation at ZSW-Widderstall, showing the Sol-Ion Cabinet and the connectivity to the fuse box and local load. The Sol-ion system feeds into L1 at the power bus bar of the small office building (Line $L1_F$). The sum of the consumption from the building is marked as Power $L1_C$+L2+L3. The Smart Meter measures the power flow towards the grid (L1+L2+L3). The additional Network Analyzer is mounted for field-trial purposes with sensors at line $L1_C$, $L1_F$, L2 and L3.

The installation at ZSW consists of a PV-generator with nominal peak power of 5145 Wp and V_{OC} of 787,5 Volts. The Sol-Ion System is placed at the entrance to the pavilion of the Solar Test Field. Appliances and Computers in the small office building, incl. kitchen and meeting room, serve as a load to the system. Fig. 3 shows the respective interconnection of the PV-generator, Sol-ion system and fuse box of the pavilion. The Sol-ion system is connected to the Smart Meter shown in Fig. 3 via RS485. The Smart Meter determines the power-flow at the interconnection point to the grid, i.e. the difference between total power consumed by the loads of the building and the feed-in from the Sol-ion system. The Sol-ion system retrieves this value once per second from the Smart Meter for feed-in control purposes.

The initial goals for the tests at ZSW are to verify data collection and transmission procedures for the many distributed field-test sites and then to investigate the long term stability of the systems operation.

Figure 4 shows two screen shots from the display of the Sol-ion system. The same display can be retrieved via the Web-Interface of the Sol-ion system. The top trace in Fig. 4 displays the PV power retrieved by the Sol-ion system from the PV generator, as well as the consumption of the load "$L1_c$+L2+L3". The consumption of the load is calculated by the Sol-ion system by subtracting its own "feed-in" power on line $L1_F$ from the total power measured by the Smart Meter

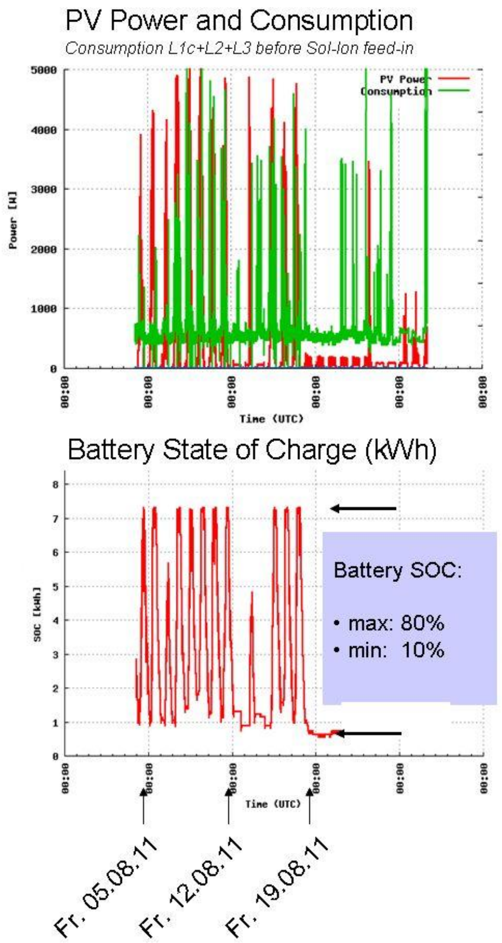


Figure 4: Two Screenshot from the Sol-ion system with trace of two weeks continuous operation from Aug 5^{th}, 2011 onwards.

Figure 5 shows an enlarged display of the PV power and consumption of the loads for Aug. 8^{th}, 2011, i.e. one of the days also recorded in Fig. 4. Also shown are the Output Power of the Sol-ion system at terminal $L1_F$ (Fig. 3) and the State of Charge (SOC) of the battery.

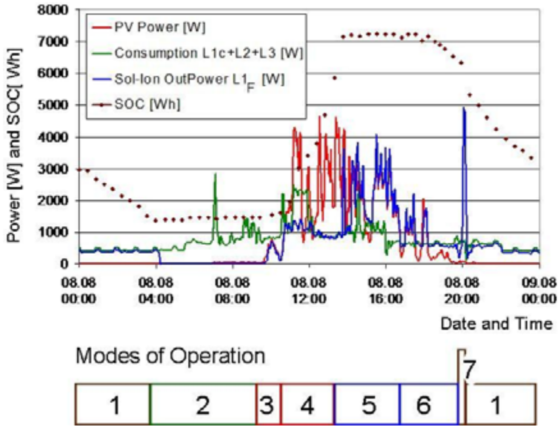


Figure 5: Plot of data recorded by the Sol-ion system at ZSW for Aug. 8^{th}, 2011. The traces are PV power as seen from the Sol-ion system at the interface to the PV-Generator, Sol-ion OutPower $L1_F$ as seen on the terminals of the Sol-ion system towards the home installation, consumption $L1_c$+L2+L3 of the home installation (without Sol-Ion input) and State of Charge (SOC) of the Li-battery. The modes of operation marked at the bottom of the graph are explained in Table 1

Table I: Modes of Operation

Mode	home installation powered by	feed into grid	battery status
1	battery	no	discharching
2	grid	no	at SOC_{min}
3	grid and PV	no	at SOC_{min}
4	PV	no	charging
5	PV	yes	at SOC_{max}
6	PV	no	discharging
7	battery	yes	discharging

It can be seen from Fig. 5, that the Sol-ion system does charge the battery at the earliest opportunity, when the PV-Power exceeds the local consumption, feeds-in additional energy into the grid, once the batteries are charged. Finally the batteries are discharged, as soon as the PV-Power falls below the local consumption.

The feed-in spike of Sol-Ion as seen in Fig. 5 from 20:00 hours onwards, exemplifies a feature of grid support. In this particular case the Sol-ion system is programmed to supports the grid (Mode 7) with configurable parameters of time interval, power-level and fraction of battery content to be used for grid support. The trace of Fig. 7 was taken with the setting of starting time 20.00 h (time of the "evening peak" in typical load profiles of networks and time without PV power), power level of 5000 W and delivering 10% of the batteries capacity into the grid. Other schemes of grid support, depending on tariffs, network operator request, frequency, etc. can be thought of.

4 CONCLUSION

The Sol-ion system has passed the development, lab-test and certification stage. Systems have been produced in small volume, deployed at research-partner locations during the last months and are now being shipped and installed in 45 private customer locations. First data of 2 weeks continuous operation during August 2011 at ZSW shows, that the Energy Management System of Sol-Ion follows through the required modes of operation correctly during each day. Collection and analysis of data from the complete field-trial base, comparison with simulations and improvements to models and system will follow during the upcoming months.

5 ACKNOWLEDGEMENT

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