# Integrating Polysun into a Test Bench for Prosumer Hardware

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### Abstract

New hardware such as batteries, energy management systems and inverters need to be tested and the correct function needs to be verified before companies install the hardware in the consumer homes. For this the Prosumer-Lab test bench was created. It contains a wide range of emulation hardware enabling Hardware in the Loop (HIL) testing and development of system components for prosumer-households. System components used in smart buildings can be compared regarding increase in self-consumption, economic efficiency or influence on grid stability. The integration of the simulation software Polysun expands the Prosumer-Lab portfolio by including sophisticated simulation models as well as weather and temperature profiles for systems with renewable energies. Polysun is integrated into the Prosumer-Lab test bench via a custom controller programmed in Java and is used to simulate the building and the building infrastructure such as heat pumps.

*Keywords: Prosumer, energy management system (EMS), Polysun, self-consumption, HIL, smart building*

## 1. Introduction

The expansion of renewable energies, photovoltaics in particular, is increasingly driven by private households. The next step will be so called Prosumers, which actively participate in the energy market. As a result, new operational concepts for household devices controlled by smart algorithms are emerging.

The Prosumer-Lab test bench aims to enable testing of solutions for a better integration of renewable energies into smart homes, while simultaneously maintaining stability and power quality of the domestic and distribution grid. Therefor it emulates a prosumer-household.

These tests are done with the hardware in the loop (HIL) method. That means that the object under test is physically present and real current flows, but other components of the house are simulated. This combination of emulation hardware and simulation enables testing, optimization and development of system components. Currently, the Prosumer-Lab is mainly used to test and compare different energy management systems (EMS), namely the SolarLog (Solare Datensysteme GmbH), the SolarWatt (SOLARWATT GmbH) and the SmartFox (DAfi GmbH) EMS.

Within the Prosumer-Lab a wide range of different devices and emulators are available to enable testing of smart control algorithms in distinct household setups. Thereby different states or situations of a household, which would otherwise be difficult to reproduce, can be realistically simulated with previously created profiles (consumption, weather, temperature profiles, etc.). The test bench uses a combination of emulation and simulation to recreate the electrical energy flows of a household with photovoltaics, heat pump and battery storage to the grid connection point with real voltages and currents. This is necessary to develop, compare and test system components such as energy management systems, inverters or battery storage under controlled conditions. Thanks to its modular design, the test platform is suitable for testing all types of energy management systems and system components for private households such as batteries, inverters, etc.

## 2. Method

### 2.1 Overview

To simulate a prosumer household as realistically as possible, emulations and simulations are combined in the test bench. The power grid and the accumulated household consumption are each mapped on an emulation device with an output of up to 50 kVA. Several photovoltaic emulators can model different roof orientations of the system with up to eight times 5 kWp.

For the operation of this physical emulation of the system, realistic profiles are required, which are generated partly by long-term measured values, partly by simulations. In addition, simulations are used within the test bench to depict components or profiles that are difficult to integrate. Validity and accuracy of HIL-simulations for private households depends upon the integration of highly realistic simulations of thermal and electrical profiles.

For that, Polysun (Vela Solaris AG) is used in the Prosumer-Lab as simulation software. It offers a wide range of sophisticated simulation models for systems regarding renewable energies that are commercially available – such as heat pump systems, photovoltaics or solar thermal systems.

The integration of Polysun extends the test bench with a complex building simulation, which takes into account thermal mass, insulation and heat losses of the building. In addition, heat pumps or battery storage systems can be simulated via Polysun. Calculation models for hot water storage tanks and hot water load profiles are also integrated.

The top-level control of the Prosumer-Lab is called the scenario manager, which is programmed in Java. Fig. 1 presents the integration of different applications required within the test bench by the scenario manager. Through a web interface it provides access to the Prosumer-Lab test bench for different research groups. This way different test scenarios can be implemented or started on the test bench. The scenario manger provides basically a hub for different smaller applications that each deal with individual tasks. They communicate with a REST-Interface. For example, the communication with Polysun, the integration of CSV-profiles or the communication with the energy readers are all realized as individual applications. The hardware-connector programmed in java and python connects to the test bench via the dSPACE MicroLabBox. The scenario manager also deals with logging all measurement values to a database. It was decided to use SQLite as format for all logging, since it is very performant and enables the logging of all kinds of data into a single file. In this way all the results including the test configuration from a test can be stored in a single file, which makes it very easy to archive the results.
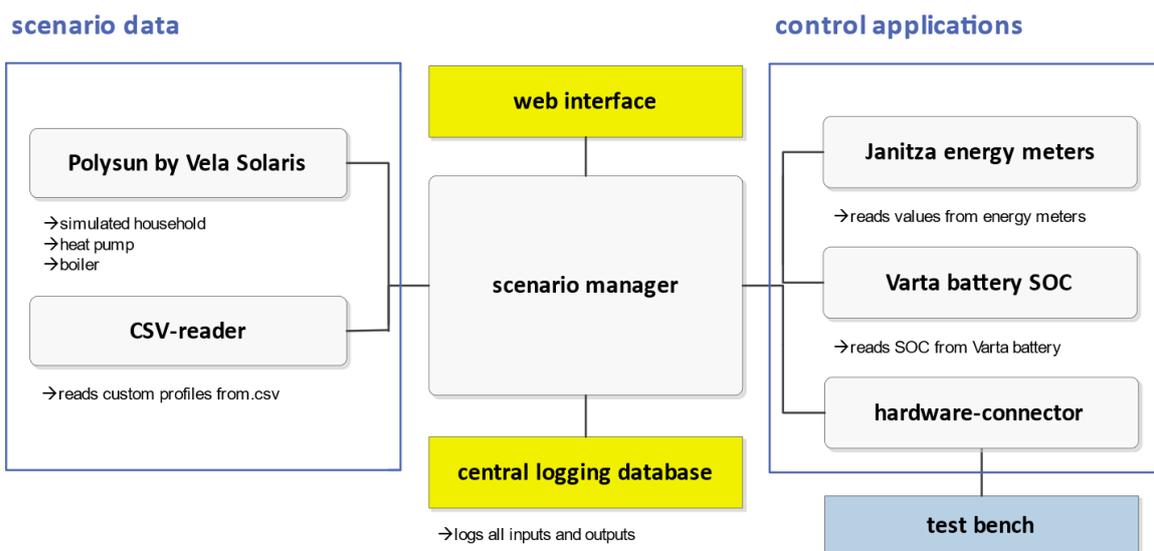


**scenario data**

**Polysun by Vela Solaris**
→simulated household
→heat pump
→boiler

**CSV-reader**
→reads custom profiles from.csv

**web interface**

**scenario manager**

**central logging database**
→logs all inputs and outputs

**control applications**

**Janitza energy meters**
→reads values from energy meters

**Varta battery SOC**
→reads SOC from Varta battery

**hardware-connector**

**test bench**

Fig. 1: The scenario manager as the top-level control integrates various applications into the Prosumer-Lab test bench.

## 2.2 Control of the simulated heat pump through the EMS

The connection from the scenario manager to Polysun is done with a custom controller in Polysun, which connects to the scenario manager with the mentioned REST interface. It replaces the built-in heat pump controller in Polysun with a custom controller. Polysun starts the simulation at the beginning of the year and then runs in accelerated mode, where days are simulated in seconds, until the day that should be tested in the ProsumerLab. Then the custom controller switches Polysun to real time mode where one simulated second is one real second. The custom controller starts talking to the scenario manager and acquires for example the current state of the EMS signal from the scenario manager every second and then controls the target temperature for the two DHW storages and subsequently the switching of the simulated heat pump based on that target value. The simulated heat pump then generates a simulated power consumption, which is fed into the load emulator and leads to real current flowing.

The plugin which integrates Polysun into the Prosumer-Lab can have as many input and output channels as needed. It can be easily extended to different controller strategies. New input channels can be defined in the configuration file so that any needed value can be extracted from Polysun and be sent to the scenario manager.
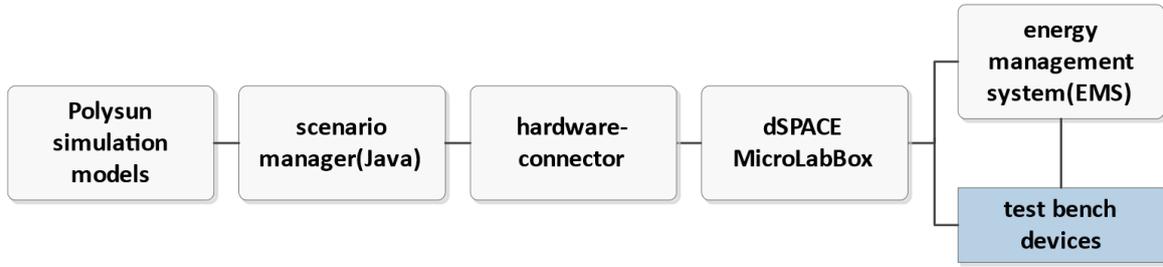
**Fig. 2: Integration of Polysun to the Prosumer-Lab HIL test bench. The device under test is an energy management system which communicates with other test bench devices and the scenario manager.**

As shown in Fig. 2 the scenario manager connects to the internal control unit of the test bench – a dSPACE MicroLabBox – and supplies it with target values to be set for the different devices.

The MicroLabBox is a programmable real-time system with various interfaces, such as analogue and digital I/O, RS232/RS485 and Ethernet. It is therefore very well suited as a central control unit for the test bench hardware. Control algorithms are programmed on the MicroLabBox in Matlab Simulink. It has an ASAM XIL API model access port (MAPort) through which the scenario manager can access the MicroLabBox application using a Python script. This allows the system to be started and stopped remotely. During operation, the scenario manager transfers setpoints for the various devices of the test bench via the access port and reads out actual values. The Prosumer-Lab operates with an update frequency of 1 Hz. The control and regulation of the test bench devices via the MicroLabBox, however, operates at a much higher resolution of up to 10 kHz to generate for example the wave forms of the grid emulator in real-time. This makes it possible to emulate all kinds of grid conditions and evaluate how the devices deal with them.

The device under test (DUT), in this case an EMS, receives all the required inputs – either directly from the test bench devices or through a simulation – and feeds back its operating commands for the devices available in the prosumer-household.

In order to integrate one of the EMS into the test bench a seperate heat pump consumption measurement was required. This could be solved by programming an S0-signal on the MLB and emulating it via optocouplers.

## 2.3 Representative testing scenarios

The profiles, calculation and target values required for a test are predefined in scenarios. A scenario defines all load and production profiles and lasts, for example, 24 hours for a typical test day. This information comes directly from applications, simulations, measurements and calculations to obtain realistic test conditions. The development and comparison of systems are based on identical profiles or conditions over an entire test series.

Four main scenarios were developed for testing and comparing EMS, each of which corresponds to a representative day of one of the four seasons. Each of these scenarios is tested with a different hardware setup of the test bench, testing either control of single or a combination of multiple devices by the EMS.

**Table 1: General description for the scenarios used for comparing control of the simulated Polysun heat pump with and without EMS.**

| | Parameters |
| --- | --- |
| **PV installed** | PV-emulators, 5.4 kWp, orientation: south, 45° elevation |
| **PV inverter** | SMA Sunny Tripower 7000 |
| **Heat pump** | Polysun: air-fluid HP (10 kW, COP at A2/W35: 3.1) |
| **Boiler** | Polysun: 3.5 kW |
| **Thermal loads** | Polysun: indoor temperature development with given min/max-values |
| | Polysun: 200 liters/day warm water at 50°C |
| **Household** | Bern; single-family house; family, 4 persons |
| **Irradiance data** | MeteoSwiss, Koppingen, Switzerland, 2015 |
| **Outside temp. data** | MeteoSwiss, Koppingen, Switzerland, 2015 |

Table 1 shows the general description of the main scenarios for one specific kind of household. It lists the components which will be simulated through Polysun. The irradiance data used for the PV-emulators is based on MeteoSwiss

measurement data in a resolution of 10 minutes. A software called LoadProfileGenerator (Pflugradt, 2015) creates target values for emulating the consumption of the household based on behavior simulation. The target values for the PV-emulators as well as the ones extracted from the LoadProfileGenerator are read into the scenario manager via the CSV-reader.

**Project PROSUMERLAB V1 - System diagram VITOCAL 200-S: with electric heater and standard HP/heater controller (Reference)**

Average volume withdrawal: 200 l/day

Temperature: 50 °C

Building: Swiss Minergie standard, renovated SFD
Heated/air-conditioned living area: 149.8 m²
Length of building : 10.7 m
Width of building: 7 m
Number of floors: 2
Heating setpoint temperature - day: 21 °C

plugin

Heat pump: Modulating heat pump 10 kW

Number of electricity consumption profiles: 1
Consumption profile 1: Prosumerlab Scenario 10
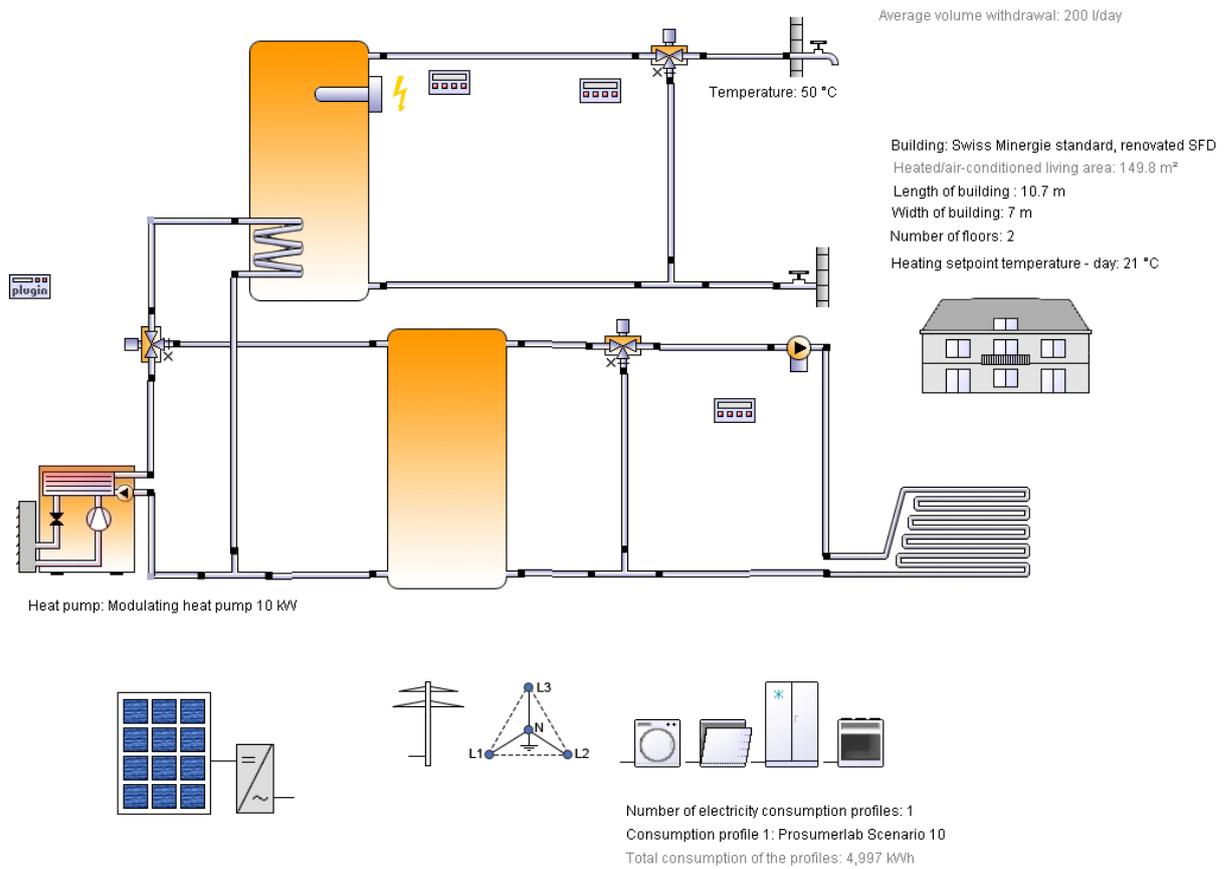Total consumption of the profiles: 4,997 kWh

**Fig. 3: Configuration of Polysun used for in the Prosumer-Lab test bench for the main scenarios.**

Fig. 3 shows the configuration done in Polysun which is used in the main scenarios, corresponding to the description in Table 1.

## 3. Results

In order to compare the increase in own consumption of the various energy management systems, the same main test scenario with data from a typical day of the year was carried out for all EMS. A representative day was selected for each season in order to highlight the clear seasonal differences - for example, 20 October 2015 with the corresponding power flows, i.e. the production of the photovoltaic system and the consumption of the household (Fig. 4). This scenario can be used any number of times to test different EMS.
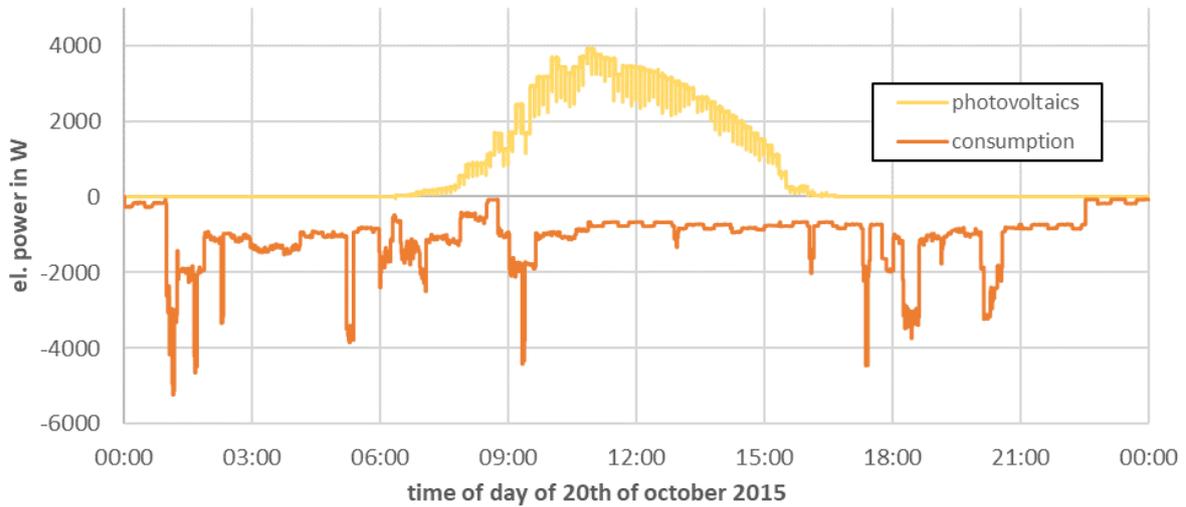
**Fig. 4: Power flows of a representative 4-person household in Switzerland on 20 October 2015, divided into production by photovoltaics and accumulated consumption.**

As a reference for quantifying the EMS performance, the scenario is run through once without an EMS connected. Subsequently, the control of the heat pump simulated in Polysun can be examined. In this test scenario no battery was used.

Fig. 5 shows the power consumption of the heat pump with different operating characteristics. The operation of the heat pump without control and with control by two different EMS is compared.
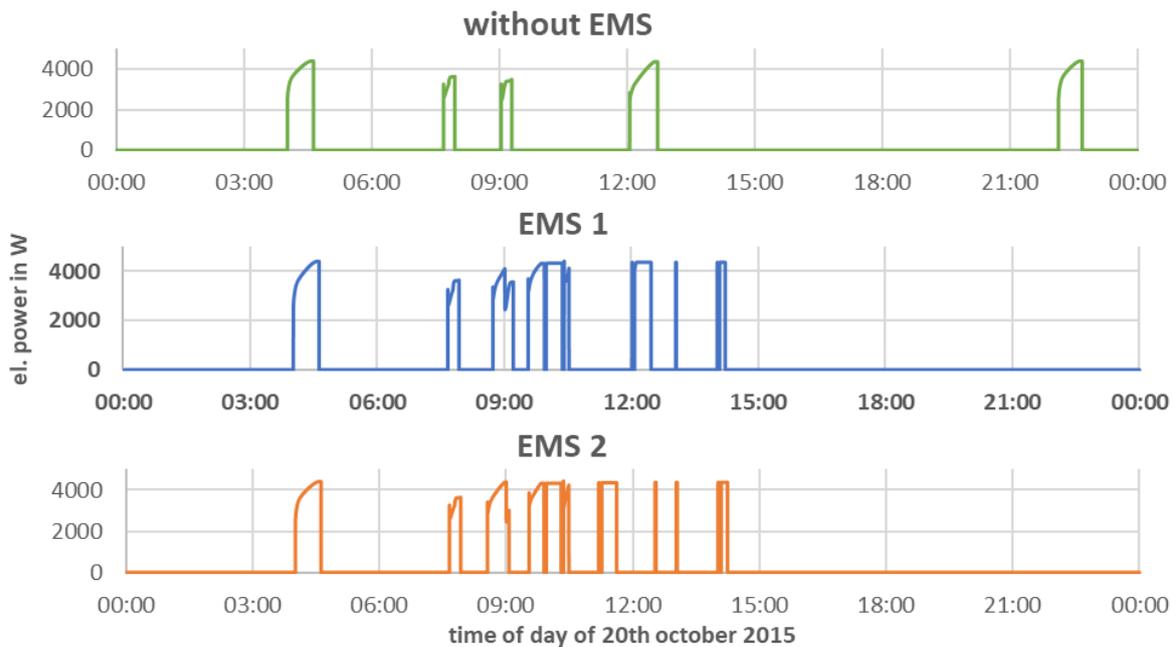


**Fig. 5: Comparison of power consumption of the heat pump during operation without control and when controlled by two different EMS.**

Without the EMS, the main parameter influencing the switching behaviour of the heat pump is the internal temperature of the water storage tank. When controlling the heat pump with an EMS, the excess power of the household due to a high production of photovoltaics as well as setting of the configuration parameters for the EMS are further factors. The control signal of the EMS can switch between a default and a raised target temperature for the DHW cylinders. Based on the actual temperature and its target value the heat pump can switch on or off. This means the EMS does not control the heat pump directly but controls it via setting the desired temperature value of the DHW cylinders.

As can be seen in Fig. 5, the energy management systems increase the use of the excess power produced during the day by photovoltaics for the operation of the heat pump. Since the temperature of the DHW cylinder cools down only slowly, there is no need to switch on the heat pump again at night. This increases the amount of own

consumption of electricity by the user. The target temperature in the DHW cylinder is also raised temporarily.

The EMS examined have a very similar switching behavior of the heat pump in order to increase own consumption. However, they have several configuration parameters that can be set by the user which can greatly affect their behavior. This example shows the importance of a systematic investigation of the EMS for understanding the functionalities. The final results of this research project will be published in a final report in mid-2019.

## 4. Conclusion

Testing system components for Prosumer-households such as energy management systems (EMS) requires realistic and reproducible electrical and thermal testing conditions. The setup of a complete thermal system in the test bench could be avoided by integrating thermal simulations. The application of a custom controller successfully integrated Polysun into the Prosumer-Lab test bench, whereby a significant development effort for specially developed simulations could be saved. Electrical profiles for the emulation devices of the test bench are based on measurements and behavior simulation and are integrated into the top-level control as well. During testing, Polysun simulations run in real-time and influence setting of the target values for the test bench devices. First EMS test results indicate similar switching behavior of the heat pump to increase own consumption. Therefore, a systematic investigation of the EMS is necessary to understanding functionalities.

## 5. References

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