WHEN ALGORITHMS CONTROL PV CONSUMPTION

When households not only consume electricity but also produce it, they become pro-sumers. The growing number of prosumers leads to new issues in electricity supply. The Bern University of Applied Sciences has set up the ‹Prosumer Lab› in Biel in order to be able to research these issues. Researchers at the *Centre Suisse d'Électronique et de Microtechnique SA* (CSEM) have now used this laboratory to investigate energy management systems that can increase the amount of photovoltaic (PV) electricity used for own consumption. The results: energy managers' contribution to increasing own energy consumption should not be overestimated. Also, the systems must be configured correctly to avoid undesirable effects.

Different battery types such as the DC-coupled batteries in the photo are available as hardware in the Prosumer Lab. They are connected via an inverter, which is being adjusted here by Yoann Moullet, an assistant in the Prosumer Lab. Photo: Bern University of Applied Sciences

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After rapid expansion in recent years, Switzerland now has over 84,000 PV systems. Many owners use solar power to cover part of their own needs. Farmers also produce - in addition to heat - their own electricity when they gasify liquid manure and organic waste in agricultural biogas plants. The examples show a trend towards decentralized production. The term ‹prosumer› has been established to describe this paradigm shift: prosumers not only consume electricity that they purchase from outside sources but they also produce electricity that they consume themselves or make available to other consumers via the general grid.

Prosumer as an Object of Research

With decentralization, the power supply changes. In the past, the electricity grid was designed to distribute the electricity produced in large hydroelectric and nuclear power plants to households. Today, electricity flows from decentralized power stations into the grid. The operators of distribution grids are faced with the question of whether they can cope with the burdens of decentralized electricity feed-in and whether grid stability will be maintained even if decentralized production continues to expand. This challenge also affects the company BKW Energie AG, which supplies electricity to approximately one million people in the canton of Berne and neighboring cantons.

Against this backdrop, a team of scientists at the Bern University of Applied Sciences (BFH), supported by BKW, has set up a laboratory to investigate these questions in a practical way. The Prosumer Lab is part of the Energy Storage Research Center (ESReC), which BFH and CSEM operate in Biel. The laboratory makes it possible to realistically replicate the power

ONE-FAMILY HOUSE RECONSTRUCTED IN THE LABORATORY

To investigate the electrical systems of prosumers and their interaction with the surrounding power grid, it is ideally necessary to have a single-family house in which all settings for electricity production and consumption can be controlled as much as possible. This is the only way to investigate all conceivable operating conditions as they occur in reality.

The Prosumer Lab in Biel uses various components to simulate the electrical system of a detached house: an emulator makes it possible to simulate all the electrical loads of a household (from the heat pump to the oven and shaver to the mobile phone charger). In addition, there are eight other emulators, each with an output of 5 kW, that can simulate the fluctuating electricity production of a PV system, and another emulator stands for the electricity grid connection to the house (three-phase, with variable frequency and amplitude up to 50 kVA). The replica home in the Prosumer Lab also currently includes four battery storage units. The hardware components are controlled via a real-time system programmed with MATLAB/Simulink. Thermal parameters such as room temperature, hot water demand or thermal storage losses are simulated with the Polysun planning software.
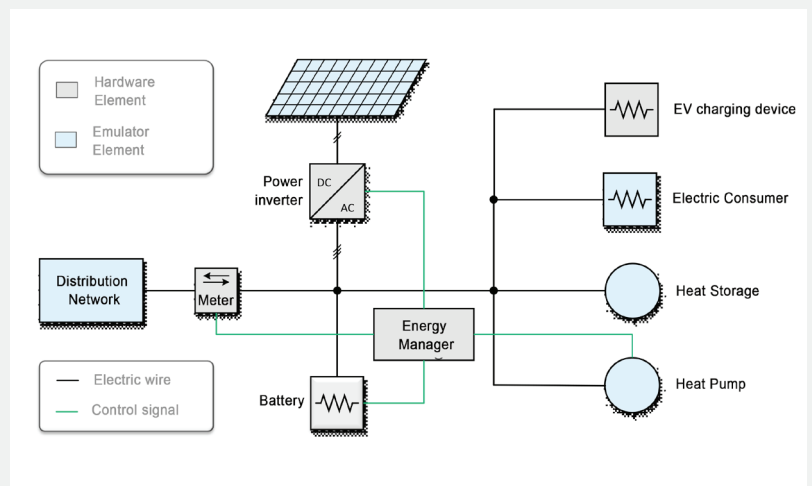
The Prosumer Lab consists of solid hardware components. Emulators are devices that generate real electricity flows. In this way they differ from simulations, which only estimate electricity flows mathematically. BV

↗ The Prosumer-Lab is located in the Switzerland Innovation Park building (a five-minute walk from the Biel railway station). For guided tours, groups interested in the technical details should contact Steffen Wienands (steffen.wienands@bfh.ch).

supply of a detached house (see text box p. 2). «Here, BFH researchers and scientists from other institutions can study the electricity flows in a detached house and the interactions with the distribution network,» says BFH scientist Steffen Wienands.

A Test of Three Energy Management Systems

The laboratory went into operation in mid-2018. One year later, the first results of a study on energy management systems has become available. Such energy managers offer the possibility of recording and evaluating energy flows over time, but also of influencing them. Several commercial providers have brought such systems onto the market in recent years with the promise that single-family home owners could also use them to increase their own consumption of the PV electricity they produce and thus save money, as the feed-in of PV electricity to the grid is relatively poorly compensated in many places. In order to increase own consumption, energy management systems switch on electrical loads such as a heat pump via a smart grid ready signal (see text box at the bottom) at times when PV electricity is generated. Thus, the heat pump is operated when the PV system produces more electricity than is needed in the rest of the household. The

The black box in the Prosumer Lab contains the three energy management systems, the performance of which BFH researcher Steffen Wienands and his colleagues have investigated within the framework of a current project. Photo: B. Vogel

heat pump can be operated flexibly because the hot water provided for heating and domestic hot water is temporarily stored in a boiler.

CSEM researchers examined three common energy management systems in the Prosumer Lab. The effect on own con-

CONTROL WITH SMART GRID READY SIGNAL

For an energy management system to optimally supply a heat pump with PV electricity, it would have to be informed about its operating status at all times. Such interfaces are not yet available on the market. Instead, heat pumps have thus far been controlled relatively rudimentarily with a so-called Smart Grid Ready signal (SG Ready signal for short). The SG-Ready signal can „demand" four operating states from the heat pump:

Signal 1: The heat pump runs as it would without the SG-Ready signal: If the water temperature falls below the lower threshold value, the heat pump starts; if the water temperature reaches the upper threshold value, the heat pump switches off.

Signal 2: The heat pump is instructed by the SG-Ready signal not to draw electricity for a period of two hours (e.g. to relieve the heavily used power grid during lunchtime).

Signal 3: The heat pump is instructed to draw electricity if this is possible.

Signal 4: The heat pump is obliged to draw electricity.

The SG Ready signals 3 and 4 can be used to start the heat pump when there is a lot of PV electricity. How these control commands are actually implemented by the heat pumps, however, is handled differently by each of the manufacturers, according to CSEM researcher Andreas Hutter. "It was often unclear how the heat pumps we investigated reacted to SG-Ready signals 3 and 4. One manufacturer increases the threshold values for heating and domestic hot water by 5 degrees for SG-Ready signal 3 and by 10 degrees for SG-Ready signal 4 in order to create scope for additional energy consumption. This is a sensible approach, because in a 500 l tank you can store 2 kWh of electrical energy with an additional 10 degrees (assumption COP of 3). But we found out that the manufacturers cannot guarantee that SG-Ready-Signal 4 will always absorb energy as it actually should." BV
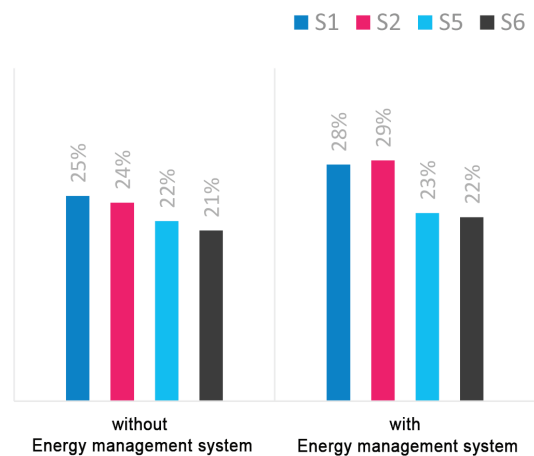
sumption was sobering: In typical system configurations, the rate of own consumption rose by only one to five percentage points, depending on the type of household (see chart on the right). Despite the use of energy managers, on average hardly more than a quarter (25.5%) of the PV electricity produced in the course of the year could be used directly for operating the heat pump. Only when the household was supplemented with a 10 kWh battery storage unit did the own consumption rate rise noticeably to an average of 44%.

"Own consumption could be further increased - using the same battery storage - if the energy management systems were equipped with improved algorithms (e.g. by including weather and consumption forecasts)," says Dr. Andreas Hutter, Head of the Energy Systems Group at the CSEM PV Center. Higher own consumption would also be possible if interfaces were available on the market for more efficient communication with the heat pump, with which the output of the heat pump could be continuously adapted to the available excess PV output, says Hutter. Another way is to install larger hot water storage tanks, which can store more of the PV electricity in the form of heat.

Own consumption of solar power

■ S1 ■ S2 ■ S5 ■ S6

The energy management systems investigated increase the own consumption of solar power in a poorly insulated single-family house by one percentage point (scenarios S5 and S6) to a maximum of five percentage points in well-insulated houses (scenarios S1 and S2). S1 and S5: the house is inhabited by a family of four. S2 and S6: the house is occupied by two working adults. The graph shows the results for one energy management system; the difference in values of other appliances studied is insignificant. Graphic: CSEM/reworked by B. Vogel
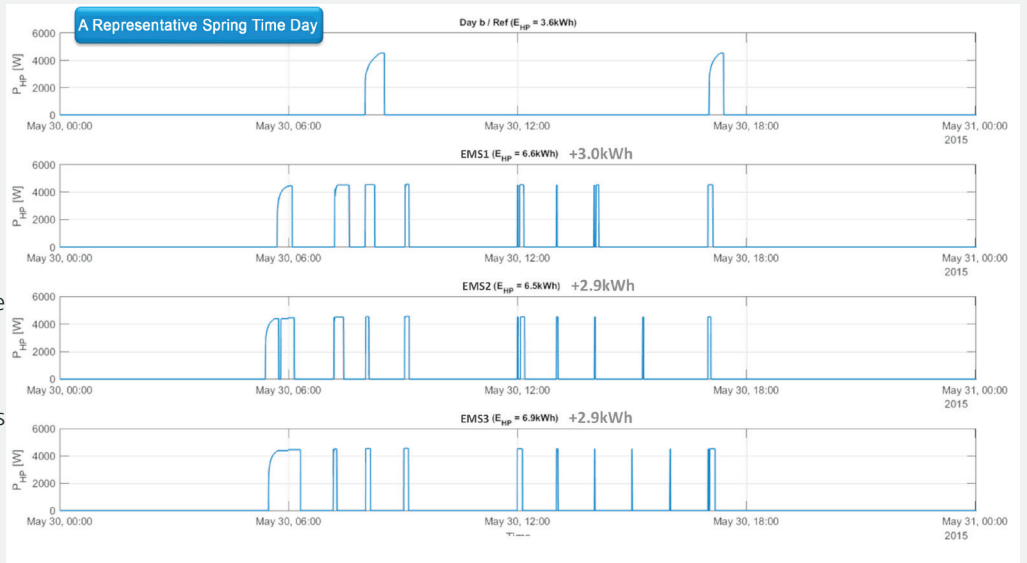
Configure Energy Managers Correctly

In the Prosumer Lab, scientists have also simulated the electricity flows when using energy management systems. As was expected, this showed that increased own consumption of PV electricity goes hand in hand with reduced grid feed-in. But will grid consumption also be reduced accordingly with higher own consumption? Not necessarily, as the researchers were able to show. On the contrary, in an unfavorable case,

grid consumption even increases noticeably. The reason: the electricity from the PV system (e.g. typically 2 kW in winter) does not fully cover the heat pump's requirements (typically 3 kW); grid electricity must therefore also be purchased to operate the heat pump. If only little PV electricity is available, a relatively large amount of electricity from the grid must be used. "This undesirable effect occurs when the energy mana-
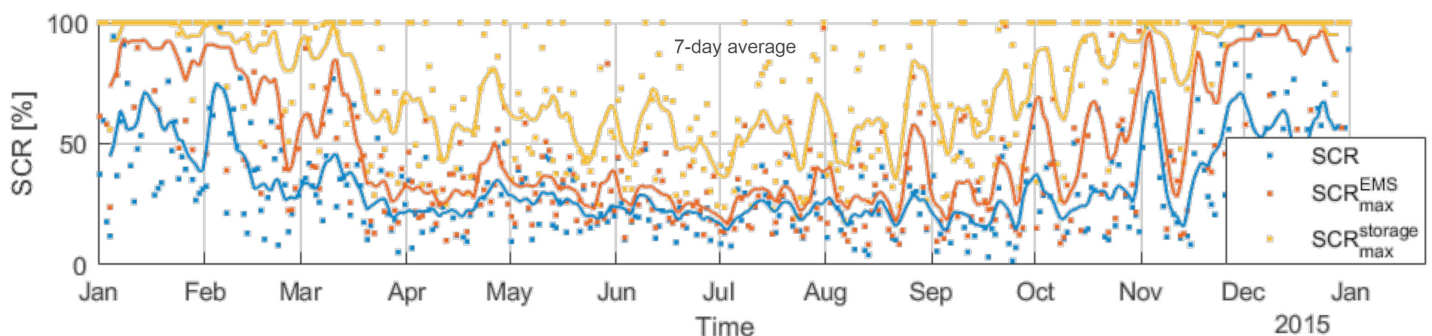
The graph shows the own consumption rate (SCR) for a single-family house with a PV system (scenario S1). The curves illustrate the mean value over the past seven days. The blue curve shows the own consumption rate without an energy management system. The red curve shows the theoretical maximum own-consumption rate to be achieved (with 24-hour balancing) using an optimum energy management system, whereby an optimum control algorithm under ideal conditions should be able to operate the heat pump whenever the sun is shining. The yellow curve shows the corresponding maximum own-consumption rate that can be achieved with an optimally controlled energy management system and a battery, assuming that an infinitely large storage capacity is available. Graphic: CSEM

The graph shows the run times of the heat pump of a single-family house on a spring day, first without using an energy management system (top graph), then using one of the three energy management systems tested (second, third and fourth graph), whereby the configuration of the energy management systems was deliberately poor (very low switch-on level). Without an energy management system, the heat pump runs once early in the morning and once late in the afternoon. The energy management systems start the heat pump in the early morning as soon as the sun shines and PV electricity is available. They switch the the heat pump on in the afternoon, but only for a short time. The reason: the temperature in the hot water tank drops slightly due to heat losses; the energy managers interpret this as a signal to heat it up again. However, because the temperature is only slightly below its target, the heat pump runs for only a very short time. This is the result of a deliberately badly chosen configuration (very short switch-on time of the heat pump). Graphic: CSEM

gers are poorly configured, which often happens in reality," says Andreas Hutter.

Such unfavorable effects can be avoided if the switch-on level of the energy manager is set high enough. In other words, the heat pump should only operate with PV electricity if sufficient PV electricity is available to cover a large part of the demand. In addition, the heat pump must be set accordingly to ensure that it is not switched on for only short running times. "Energy managers help us to determine whether heat pumps are properly configured," says Hutter.

Not Yet Profitable

The study by CSEM researchers in the BFH's Prosumer Lab also allows conclusions to be drawn about the economic viability of the energy managers currently available. Since these

The graph illustrates how the control of the heat pump shown in the figure at the top affects electricity consumption: without using an energy management system (top), 13.3 kWh of PV electricity are used for own consumption (Esc = Energy own consumption), a further 20.3 kWh are fed into the grid (Einj = Energy injected). In order to supply the household with electricity, 7.7 kWh must also be drawn from the electricity grid (Eext = external energy). If the three energy management systems examined (second, third and fourth curves) are used in a deliberately unfavorable configuration, own consumption is increased by 1.3 kWh (Esc; gray number) over the day and the grid feed-in (Einj; green number) is reduced accordingly. Electricity purchased from the power grid is not constant, as one might expect, but increases relatively starkly (Eext; red number). The reason for this effect is that the switch-on value selected by the energy manager is too low. Graphic: CSEM
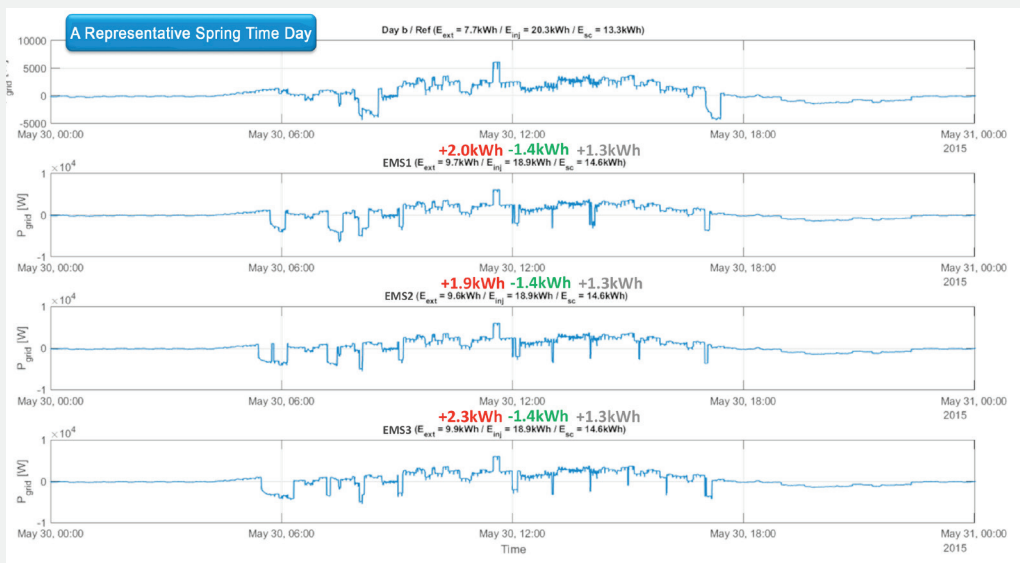
systems increase own consumption, they help to save money since in many places a kilowatt-hour fed into the grid earns less than one must pay for a kilowatt-hour drawn from the grid. The researchers have calculated how high the financial advantage is for four household types and three locations, namely Koppigen (compensation for fed-in electricity as high as the price of purchased electricity), Bern (average feed-in compensation of 10 cents/kWh) and Eggiwil (low feed-in compensation of 4 cents/kWh). In Bern and Eggiwil, where the use of energy managers should be worthwhile, a maximum of 48 Fr. can be saved per year, but considerably less in most scenarios. With acquisition costs of 1000 Fr. and more, energy managers for the pure increase of own energy consumption are not profitable today, according to the researchers.

If a battery (capacity 10 kWh) is used in addition to the energy management system, up to 400 Fr. per year would be saved in the best case- depending on the scenario and location. But even this is hardly worth it for homeowners today: taking battery costs into account - around 7,000 Fr. including transport and installation costs - the payback periods are significantly longer than the guaranteed service life of the battery (typically 3,000-5,000 cycles, i.e. 8 to 14 years with daily charge/discharge cycles). The conclusion: By using an energy manager and a battery, the degree of self-sufficiency can be significantly increased. However, by the time it becomes financially viable to use such a system in the home, battery costs would have to be halved to about 300 Fr/kWh.

↗ Information on the **Energy Storage Research Center** (ESReC) of BFH and CSEM at: www.esrec.swiss. Information on the **BFH Energy Storage Center** at: www.bfh.ch/energy.

↗ Information on **CSEM** at: www.csem.ch

↗ For **information** on the project, please contact Dr Men Wirz (men.wirz[at]bfe.admin.ch), responsible for the SFOE's pilot and demonstration program.

↗ Further **technical papers** on research, pilot, demonstration and flagship projects in the field of networks can be found at www.bfe.admin.ch/ec-strom.

PILOT, DEMONSTRATION AND FLAGSHIP PROJECTS

The Swiss Federal Office of Energy (SFOE) provided financial support for the investigation of energy management systems in the Prosumer Lab described in the main text. The project is one of the pilot and demonstration projects with which the SFOE promotes the development of economical and rational energy technologies and the use of renewable energies. The SFOE supports pilot, demonstration and flagship projects with 40% of the non-amortizable, chargeable costs. Applications can be submitted at any time.

↗ **Information**:
www.bfe.admin.ch/pilotdemonstration