Performance of Home Energy Management Systems: Insights from the Prosumer-Lab

Y. Stauffer, N. Koch, A. Hutter

The Prosumer-Lab aims at emulating the electric behavior of a building equipped with PV, batteries and a heat-pump in a controlled environment. It provides a test environment to precisely asses, with hardware in the loop, the impact of various energy management systems (EMS) on self-consumption of PV. In addition, control strategies involving different controllable elements can also be precisely benchmarked.

Prosumer-Lab allows to quantify under controlled conditions the impact of energy management systems (EMS) on the self-consumption ratio (SCR) of buildings equipped with PV and controllable electrical equipment. Since the internal time constants of the EMS affect the resulting SCR, tests have to run in real time. The full assessment therefore relies on a combination of live tests carried out on selected representative days coupled to one year simulations. Different hardware configurations (e.g., combination of controllable equipment) can be tested thanks to the modularity of the test bench to assess their impact on the SCR.

State-of-the-art commercial EMS are rule-based controller which are usually defined by the following parameters:

- Minimum turn-on power: the controllable system is turned on if the PV overproduction is above that value
- Turn-off power: the system is switched off if the overproduction drops below that value
- Minimum on time and off time of the controllable equipment.

To access these parameters, we defined a synthetic test profile. As shown on Figure 1, this profile consists in a constant (uncontrolled) load combined with linear ramps and step functions in PV power of variable length.

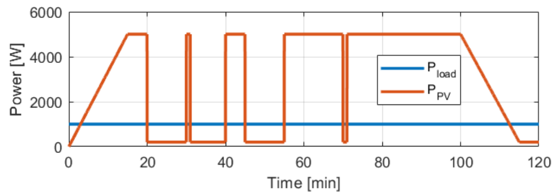

Figure 1: Synthetic test profile to access internal parameters of the EMS. Blue line: house electricity consumption; red line: PV production.

In addition, to evaluate the operation in realistic conditions, four representative simulation days were selected by clustering on weather data: one cold, sunny day; one cold, overcast day; one mid-season day with passing clouds; one warm, sunny day. These representative days thus cover periods of over and under production with specific consumption and production profiles to each seasonal meteorological condition in terms of temperature and sunshine.

Based on these two tests, the behavior of the studied EMS can be reproduced in a simulation program. Yearly simulations were run with the EMS output connected to a simulated smart-grid-ready heat pump. The internal controller of such a heat pump increases the set-point temperature of the domestic hot water and space heating water tanks if the EMS sends an activation signal. In addition, features such as storage in the thermal mass of the building, batteries and combinations of these features were tested.

Thermal storage only increases the SCR by 8 percentage points on average over the year, with the highest potential in winter due to space heating. Adding batteries can increase the SCR. With a large electric-vehicle battery (100 kWh), this increase can be of 34 percentage points on average over the year. Finally, combining elements further raises the SCR.

From an economic perspective, different price configurations were applied to buying and selling electricity. In the case of net metering (same price for buying and selling electricity), the grid effectively behaves as an infinite, perfect battery. As a result, increasing the SCR with a local, imperfect storage is not desirable as it raises the net electricity bill (Figure 2). On the contrary, when the feed-in tariff is much lower than the purchase price of electricity, increasing the SCR is beneficial.[1]

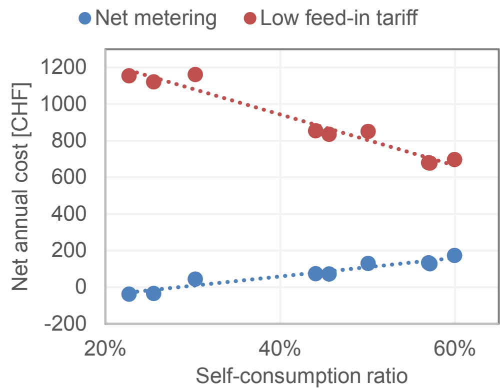

Figure 2: Net annual electricity bill as a function of self-consumption ratio and electricity price configuration. The different SCR values are obtained with different combinations of controllable equipment.

Work is now ongoing to:

- Implement and asses smarter control strategies such as model-predictive control
- Develop a more effective system sizing rule than the currently-applied 1 kW_p of PV and 1 kWh of battery for 1 MWh of annual electricity consumption
- Integrate capital expenditure, degradation and maintenance costs of equipment in the economic assessment of EMS.

This work is funded by the Swiss Federal Office of Energy under the grant n° SI/501431-01.

[1] Y. Stauffer, N. Koch, A. Hutter, N. D. Pflugradt, "Quantifying the potential of smart heat-pump control to increase the self-consumption of photovoltaic electricity in buildings," EuroSun 2018: 12th International conference on solar energy for buildings and industry, September 2018, Rapperswil, Switzerland.