LiLoTrack—Short-term Forecasting and Storage for Optimal Management of PV Electricity

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This project combines energy and power management in relation to photovoltaic (PV) systems on timescales which range from sub-second to one day. The whole system is best suited for mid-sized buildings; the components which have been developed in the project can also add value to most commercial or utility-scale: full-sky image analysis and machine learning for short- and medium-term forecasting, and control of ramp rates with storage for grid integration.

Reduced costs of photovoltaic (PV) systems across the world make it increasingly attractive for households and companies to use their own production rather than purchase electricity from the grid. Maximizing this self-consumption of PV electricity requires managing the energy flows between generation, loads, and storage over at least one day. On the other hand, the challenges in terms of grid integration of PV are related to the instant power exchanged with the grid in terms of absolute values and variations. Managing these challenges therefore requires a very responsive control loop operating on a second timescale.

In this project an integrated management system is being developed with its three components: observation, forecasting, and action. A demonstrator has been installed in one of CSEM's regional centers in Alpnach. Its power chain includes a set of PV modules on single-axis trackers, module-level DC/DC converters with maximum-power-point tracking (MPPT), short-term storage in the form of supercapacitors, and a programmable inverter. Figure 1 shows the central electrical components of the demonstrator.

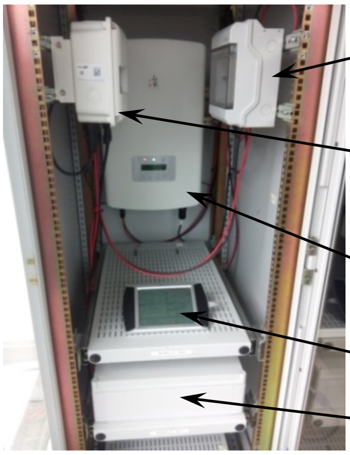

Figure 1: Power and energy management cabinet as installed in the demonstrator.

Performing lifecycle tests on the storage components is desirable to determine the effects of this application on their lifetime, and to integrate this knowledge in the optimal control system. Existing standards have been developed for very different applications such as electric vehicles. New current profiles have been developed in this project to reflect the specificities of our application (Figure 2). A representative set of battery technologies is currently under test with these new profiles.

The energy management system is implemented in a pocket computer running a lightweight Linux distribution (Raspberry Pi). Commercial components (consumer-grade weather station, DC/DC converters, and power meters) generally provide data with a time resolution between one and fifteen minutes and use proprietary protocols. To monitor the state of the system, custom interfaces have therefore been implemented in the energy management platform to aggregate information from these components.

In addition, a 360º fisheye camera captures full-sky images. These images are analyzed in real time to estimate the current and near-future levels of irradiance. The most challenging situation is when passing clouds cross an otherwise clear sky. This situation represents about 40% of the days in Neuchâtel. It is handled by using pattern recognition techniques to identify clear areas. Cloud motion direction is estimated by comparing subsequent images.

A self-training algorithm was developed to predict energy consumption over 24 h with a 15 min resolution. It is based on support vector regression (SVR) and takes as input information such as occupancy, outdoor temperature, solar radiation, and actual energy consumption. The algorithm continuously adapts its forecasting model to follow seasonal changes and weekly/daily patterns. The algorithm was validated on synthetic and real data with a correlation coefficient between 0.6-0.95, depending on the pattern of energy consumption.

As the PV modules individually operate at their maximum power point and the load is a constraint, possible actions from the control system are charging or discharging the storage elements, adjusting the position of the single-axis trackers, or modifying the operating point of the inverter. Due to the time resolution of most available data to the energy management system, charging and discharging of the storage elements for management of rapid power fluctuations are separately triggered based on the DC voltage. This control has been programmed in the power converters themselves. In the laboratory integration of the components prior to their installation on site, a reduction in ramp rates from 4200 W/s to 15 W/s was demonstrated.

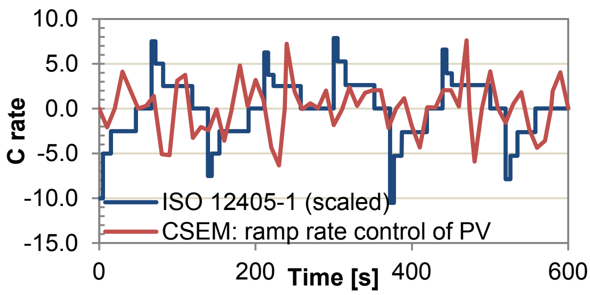

Figure 2: Current profiles for cycle life test on batteries derived from automotive standards (ISO 12405-1, scaled down for single cells) and developed by CSEM for ramp-rate control of PV.