EFFECT OF THE FLUCTUATIONS OF PV PRODUCTION AND ELECTRICITY DEMAND ON THE PV ELECTRICITY SELF-CONSUMPTION

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ABSTRACT: The electricity self-consumption level of a family household is determined both experimentally and by modelling. The effect of rapid fluctuation in PV production and electricity demand, and especially the effect of the temporal resolution of their measurements, are studied. For accurate determination of the self-consumption level, temporal resolution of at least 30 s for the load profile and at least 10 min for the PV production measurements are suggested. The effect of temporal resolution becomes negligible when a local electricity storage system is added.
Keywords: Small Grid-connected PV Systems, storage, gird integration

1 INTRODUCTION

In several European countries, feed-in tariffs for electricity produced from photovoltaic (PV) systems are now below the retail price of electricity. This is a major incentive for PV system owners to increasing the share of self-consumption and to add storage capacity [1,2]. Calculation of such self-consumption level is usually performed using standard load profile curves and PV production forecasts. However, electricity demand in a household exhibits quite rapid fluctuations and sharp peaks that can easily exceed the PV generated power. When using standard load profiles with temporal resolutions of 15 minutes or more, such fluctuations and peaks are not present (see example in Fig. 1). Even though PV generation exhibits a smoother behaviour, fluctuation are also observed as in the case of Fig. 1. Thus, self-consumption of generated PV power is expected to be overestimated. Such effect has already been described in [3,4] based on simulation and measurements of load profile curves.

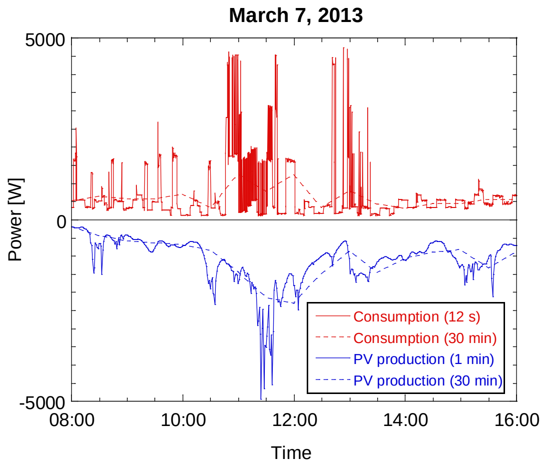

Figure 1: Load profile (upper part of the graph) measured with a time resolution of 12 s in a family house near Neuchâtel and estimated PV production (lower part) of a 5 kW system in Neuchâtel deduced from the performance of a single PV module measured at 1 min interval on March 7, 2013.

In this paper we present the effect of the temporal resolution of the measurement of both the load profile and the PV generated power on the self-consumption level of a typical family Swiss household. Such effect is analysed with measured load profile (with temporal resolution of 6 seconds and extrapolated to resolutions of up to 1 hour) as well as with PV performance system (of various sizes) determined with a temporal resolution of 1 minutes (and extrapolated to resolution of up to 1 hour). Effect of the temporal resolution for a PV system with local electricity storage is also simulated.

2 EXPERIMENTAL

2.1 Load curve and PV production measurements

Load curves were measured in several households in the Neuchâtel area (Switzerland). These load curves were determined using commercial systems with current clamps on the 3 phase grid feed lines, assuming constant voltage. The precision of the system was compared to a calibrated house energy meter and to current/voltage meters and was found to better than +/- 10%. The data were acquired with a temporal resolution of 6 or 12 s (the acquired power data being an average over that time period).

For PV production determination, the actual PV performance of a single PV module (thin-film silicon micromorph tandem) mounted outdoor in Neuchâtel was monitored at a 1 minute interval. The maximum power of the module was used as relative performance of a larger PV system. For such system a production of 1000 kWh/kW was assumed. In order to complement missing data (less than 10% of the data for the overall measurement campaign) due to monitoring problems, those missing data were replace by simulation of a PV system using PVSyst [5] and/or PV-Lib Toolbox [6] and irradiance data for Neuchâtel, as given by the Swiss Federal Office for Meteorology, with a temporal resolution of 10 minutes.

All calculations done in the work, if not indicated otherwise, are based on data sets obtained from September 1, 2012 to August 31, 2013.

2.2 Simulations

A simple model of a PV system with electrical storage was designed. It assumed that the electrical storage (battery) is connected on the AC side and that the storage roundtrip efficiency is assumed constant at 85%. This means that 15% of the energy stored cannot be retrieved and is lost. The model only considers an effective and fixed storage capacity. The variables of the model are the load profile and PV production curve as a function of time, the battery effective capacity and an optional feed-in limit, i.e. a maximum power limit to the electricity injected into the grid by the system. Note, however, that such a limit does not at all affect the self-consumption value as the latter is independent of the feed-in energy. The outputs of the model are the time dependent power and energy values of the fluxes between the various elements (PV system, electrical storage, local load and grid) and self-consumption value over the time period considered.

3 RESULTS AND DISCUSSION

The example of Fig. 2 shows the effects on the self-consumption level of the temporal resolution of the measurement of the load profile (for a fixed 1 minute resolution for the PV power determination) and of the determination of the PV generated power (for a fixed 1 minute temporal resolution for the load profile). The plot was here calculated for the load profile of a family house with 5 people, a total yearly consumption of 4.9 MWh and a simulated 5 kW PV system, without storage.

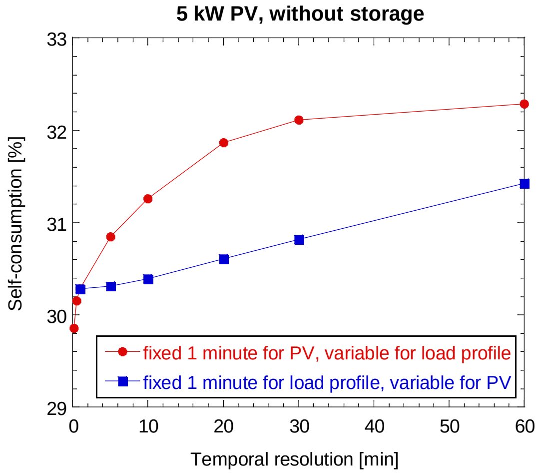

Figure 2: Effect of the measurement temporal resolution on the self-consumption level for a 5 kW PV system for a household with a 4.9 MWh yearly consumption: Circles represent the effect of temporal resolution of the load profile measurement (PV performance is recorded at 1 min intervals) while squares represent the effect of temporal resolution of the PV performance (load profile recorded at 1 min intervals).

One can observe that the impact of poor temporal resolution in the measurements is more critical in the case of the load profile determination than in the case of PV production. This can be easily understood as sharp and short peaks are much more frequent in the load profile than in the PV production profile. From the case study of Fig. 2, one can conclude that a minimal temporal resolution of 1 minute for load profiles and 10 minutes for the PV production curves are acceptable (which lead to less than 3% error). The magnitude of this effect of temporal resolution is similar to the one deduced in [4].

When 5 kWh battery storage is added to the system, the dependence on the temporal resolution seen in Fig. 2 disappears almost completely, as demonstrated in Fig. 3. This observation differs from the ones of [3], however, possibly due to the fact that the latter was obtained from measurements in a household over a single day. IN our case study, the self-consumption level is increased from roughly 30% to 54%, and the values exhibit almost no dependency on the temporal resolution of the load profile or PV production profile (at least for reasonably high temporal resolution values).

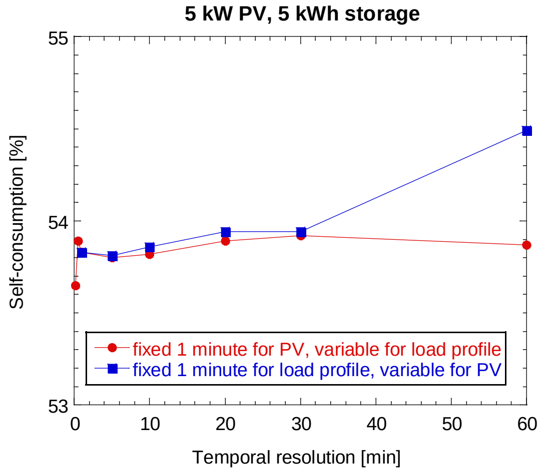

Figure 3: Effect of the measurement temporal resolution on the self-consumption level for a 5 kW PV system for a household with a 4.9 MWh yearly consumption and a 5 kWh effective storage: Circles represent the effect of temporal resolution of the load profile measurement (PV performance is recorded at 1 min intervals) while squares represent the effect of temporal resolution of the PV performance (load profile recorded at 1 min intervals).

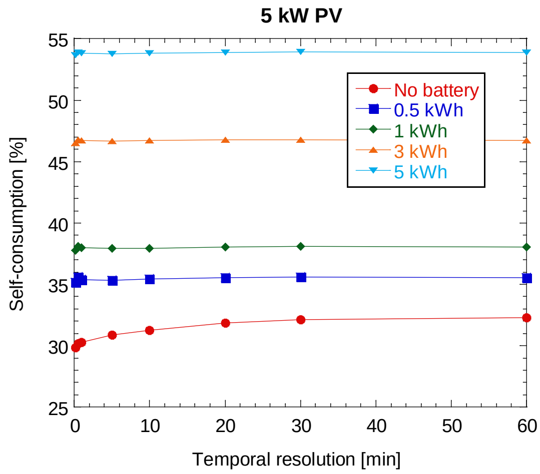

Figure 4: Effect of the temporal resolution of the load profile measurement on the self-consumption level for a 5 kW PV system for a household with a 4.9 MWh yearly consumption and various effective storage capacity.

The stochastic short variations in PV production and especially in the consumption are smoothed out by the introduction of battery storage. As long as the battery is in an intermediate state of charge, it can absorb production or consumption peaks and no excess PV energy is lost (for the self-consumption). As observed in Fig. 4, even a very small storage capacity is able to remove the effect of sharp peaks in the consumption than led to the underestimation of the self-consumption seen in Fig. 2. However, the battery can only play this role of buffer if it can supply the necessary power needed to cover the consumption peaks. It therefore should not be completely empty. Such a condition is met (for most days in the year) throughout the year as consumption peaks mostly take place during cooking times or after lunches at times when charging of the battery has already started.

As expected, battery size plays an important role on the self-consumption level which rises to more than 55% for a 5 kWh battery (in our case-study). Note, however, that this improvement is not linear with the battery size and that additional gains in self-consumption require bigger additional battery capacity.

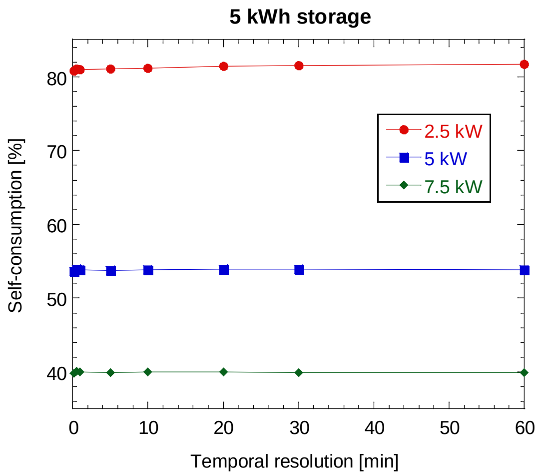

Figure 5: Effect of the temporal resolution of the load profile measurement on the self-consumption level for various PV system sizes (2.5- 7.5 kW) for a household with a 4.9 MWh yearly consumption.

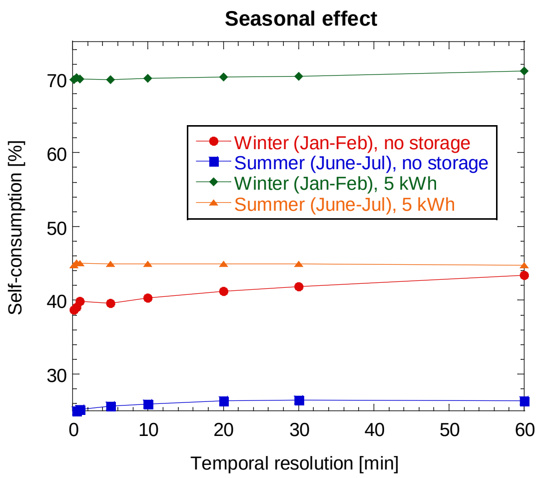

Figure 6: Effect of the temporal resolution of the load profile measurement on the self-consumption level as a function of season (deduced for a one month consumption and PV production data) and presence of a storage system (5 kWh effective) for a household with a 4.9 MWh yearly consumption.

As seen in Fig. 5, the performance of a battery to remove the effect of temporal resolution on the self-consumption is also not affected significantly by the size of the PV system. Nevertheless, a small variation starts to be seen at large value of the self-consumption. The effect originates in the fact that the PV systems is now too small to start charging the battery and some consumption peaks occur when the battery is still empty. Similarly to the observation of Fig. 4, larger battery capacity, compared to PV system power, leads to better self-consumption level. Evaluation of self-consumption using other measured load profiles (of different households) led to similar results.

The effect of PV power to battery capacity ratio on the self-consumption is also seen in the seasonal variation of the latter. Effects of the temporal resolution are seen when no storage is present (for both summer and winter times) and in winter time with storage when self-consumption is high (see Fig. 6). The important seasonal variations of the self-consumption level are similar to the one of Fig. 5, a change of the effective PV power compared to the consumption power. Similar seasonal effects have also been observed in another study [7].

6 CONCLUSIONS

Self-consumption level is an important figure for the optimization of PV systems installed in households. Using load profiles with a poor temporal resolution may lead to an underestimation of the self-consumption level. For a case study comprising real load data measured in a family household and PV production data measured with high temporal resolution (down to 6 s for the load profile and 1 min for the PV production), the self-consumption is overestimated by 8% (relative) when the load profile temporal resolution is 30 min or more. The value of the self-consumption is found to be less sensitive to poor time resolution in the PV measurement. For accurate evaluation, temporal resolution of at least 30 s for the load profile and at least 10 min for the PV production are suggested.

In case a battery storage system is added for local storage, the effect of poor temporal resolution almost vanishes leading to almost negligible effect in case of high self-consumption. This may happen in winter time when PV production is low or in case of small PV systems with respect to household consumption (PV systems covering less than 50% of the household yearly energy demand).

ACKNOWLEDGMENTS

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