Co-funded by the Horizon 2020 programme
of the European Union

Description of the Ballen2016 Data Set

Jan Jantzen, jj@energiakademiet.dk

3 Sep 2019

Samso Energy Academy, www.energiakademiet.dk

SMILE, https://www.h2020smile.eu/

Abstract. The data set *Ballen2016* concerns mainly electrical supply and demand on the Ballen marina, Samso, Denmark. The data set spans the year 2016 divided into time steps of one hour. The purpose is to simulate the operation of a smart energy system. For example, to use the data to develop a scheduling algorithm, which utilizes the available solar energy maximally. The energy system involves a photovoltaic plant (60 kWp), a battery energy storage system (237 kWh), and the demand from the marina including visiting boats (105 000 kWh/year). The system is connected to the public electricity supply. A baseline simulation indicates that 90% of the energy from the photovoltaic plant is consumed internally (self-consumption); the rest is sold to the grid. Without the battery, the self-consumption would be 48%. The battery thus increases the supply of free, solar energy by 42%.

Introduction

The Ballen marina installed in 2019 a large battery and a photovoltaic (PV) plant in order to implement a *smart energy* system. On the supply side, the battery stores energy for use after sunset. On the demand side, some of the electrical loads on the marina can be deferred in time. For example, the onshore wastewater pump could be operated during the night, because the wastewater is held in a large tank. Furthermore, since heat pumps link electricity with heat, the system is not just a *smart grid* system, but a smart *energy* system. The demonstrator is specified in overall terms in a report, which is a deliverable of the SMILE project (1).

If the project is a success, the system can be replicated in other marinas, for example among the 266 members of the association of marinas in Denmark (2). Such a system may even become relevant for households or *smart houses*, because the prices on PV panels and batteries are falling.

Figure 1 shows the components of the smart energy system marked on an aerial photograph. The battery energy storage system (BESS) is inside the so-called Warehouse. The photovoltaic panels are in three sites within the marina, namely: the roofs of The Warehouse and a service building taken together; the outer side of a board fence; and the two roof faces of the harbour master’s office. The board fence is a barrier facing southeast against the sea, and the PV panels are mounted vertically on the seaward side.

The technical goal is to exploit the available solar energy as much as possible (maximize *self-supply*). A related goal is to cover as much as possible of the marina's demand by solar energy (maximize *self-sufficiency*). On the nontechnical side, the goal is to attract more sailors to the marina and ultimately to increase Samsø's population.

Foto: Styrelsen for Dataforsyning og Effektivisering

Figure 1. Overview of the Ballen marina with its smart energy components.

Data Description

The data concern 2016. The smart energy components were installed in 2019, and new data will be collected during the following years in order to update the picture. The data are collected in a spreadsheet (Excel, Ballen2016_hourly.xlsx). The paragraphs below explain the data column-by-column.

Marina [kWh/h]

The electricity consumption of the marina (onshore + offshore) was measured from May 2016 until mid-2017. The measurements were collected by the distribution network operator on a 15-minute basis. There is one public meter, which connects the marina to the public grid. Figure 2 shows a large peak in the summer period, when many boats visit the marina. The rest of the year the load is moderate. On the one hand, this is an advantage, because the PV panels start their highest production in May. During December, January, and February the production is about one tenth of the May production. On the other hand, the demand peak is so large that the PV panels and the battery are unable to cover the demand. The remainder must come from the grid.

The measurements (kWh per sample period) have been resampled into hourly values. The year 2016 was a leap year, so there are in total 8784 rows of data (366 days × 24 hours/day). The raw data did not cover 2016 exactly, so the values lying in the first part of 2017 were folded back into the first part of 2016 until 1 May 2016. Therefore, the data from 1 January to 1 May 2016 do not correspond correctly to weekends and holidays. The switch from summer time to winter time, and vice versa, has been eliminated by deletion and interpolation, respectively, to make the time axis consistent.

PV 4kW [kWh/h]

The measurements are from 2016, and they come from a PV plant 3 kilometres from the Ballen marina. The size of that plant is 4 kWp. The raw measurements in kWh per sample period were resampled to hourly samples. The time series form a profile over the year, but the production is smaller than the actual PV production on the marina (60 kWp). For simulation purposes the values must be scaled to fit the annual production of the marina PV plant (56 000 kWh/year).

Sauna [kWh/h]

The sauna in the service building was not measured directly but filtered out from the marina consumption. When resampled to hourly samples, the sauna is on for one sample, typically. The filter detected every abrupt upward change followed by an abrupt downward change (using Matlab). The sauna’s nominal power is 15 kW. It is controlled by a thermostat, and the energy consumption for one hour is estimated at 12 kWh/h.

Outdoor [deg C]

The outdoor temperature may be relevant for estimating heat consumption. The outdoor temperature was measured 10 kilometres from the Ballen marina in 2016 (Sensorist). The raw 15-minute measurements are averaged over every hour.

Elspot [EUR/kWh, DKK/kWh]

The price of electricity follows the spot price on the Nord Pool electricity market. The prices are hourly prices on the so-called DK1 market, which is the western part of Denmark. The electricity selling price for the marina is the same as the spot market price. The buying price is higher, as it includes trading fees and taxes. The buying price is the spot price plus taxes and fees. Taxes and fees are estimated at 0.525 DKK/kWh or 0.07 EUR/kWh.

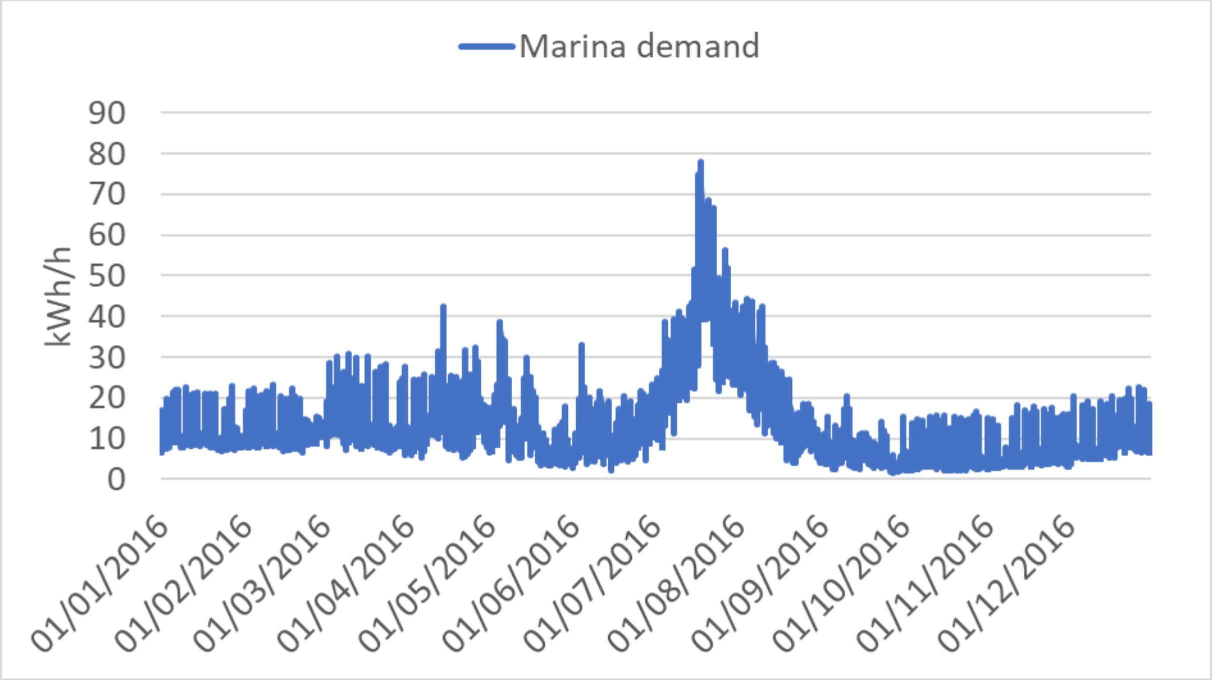

Figure 2. The electricity consumption of the marina, onshore + offshore.

Baseline Simulation

The following pseudocode shows the simplest possible strategy for controlling the battery.

```
IF PV power ≥ demand THEN
    IF battery is not full THEN charge battery ELSE sell to grid;
ELSE
    IF battery is not empty THEN discharge battery ELSE buy from grid.
```

Selling to the grid is to be avoided, because the selling price is low, and it is better to use the solar energy to maximize the self-supply. Buying from the grid is unavoidable, because the PV production is too small to cover the annual demand.

Using the data set and the simple load-matching algorithm above, a baseline simulation is included in a separate file (Excel, Ballen2016_sim.xlsx). As a result, Table 1 shows that the PV plant is exploited to 90% of its annual production. Thus, the battery improves the self-supply of solar energy by 41%. The marina is only 48% self-sufficient (renewable energy share) owing to its large consumption compared to the size of the PV production.

Figure 3 explains why and when the PV plant, battery, and load are out of balance. During the peak season, all available self-supply is fully consumed, because the consumption is high. However, on both sides of the summer peak, the battery saturates with PV production. At those times it is necessary to sell the overflow to the grid. Over the whole year, there is trade with the grid, and the system is far from being autonomous.

Table 1. Simulated key performance indicators.

Mode	Self-supply	Self-sufficiency
With battery	90%	48%
Without battery	49%	26%

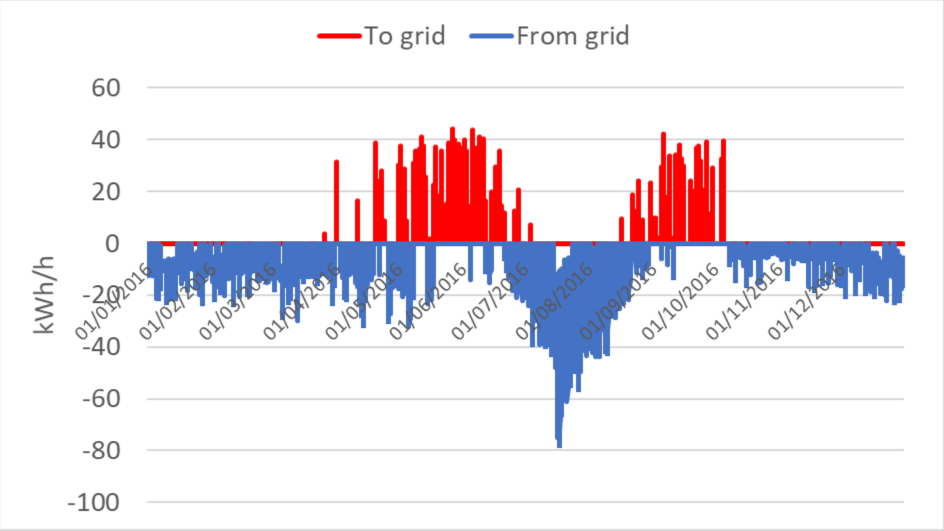

Figure 3. Export and import when using the battery as a buffer.

Smart Scheduler

The load profile (Figure 2) has a large peak during the summer, larger than the battery plus the PV production can fulfil. In order to smooth out peak consumption, some loads can be deferred. For example, the heat pumps can preheat or precool rooms, the floor heating in the service building can shut off during peak hours, the sauna heater can preheat the room at times when the battery can afford it, and the wastewater pump can start during the night. The loads are specified in a separate document, which also suggests some heuristic control rules (3).

It may be possible to affect the demand. The boats access up to 340 connection points, and a tariff could make electricity more expensive during peak hours and less expensive during the dark hours. This could help to smooth out the demand from the boats.

Conclusion

The data set is a call for scheduling algorithms. A scheduling algorithm could calculate the best timing to turn flexible loads on or off, by means of *linear programming*, for instance. The objective is to maximize the self-supply or to minimize the daily operational cost.

However, the baseline simulation shows that the improvement can be at most 10%, theoretically (from 90% self-supply up to 100%). This may seem to be a small improvement, but every percentage counts when an alternative investment in bonds may yield less than one percent.

Acknowledgement

This work has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731249 (SMILE, Smart Islands Energy System).

References

1. Jantzen J, Bak-Jensen B. Specifications and Data Report for the Samsø Demonstrator: Deliverable D3.1 [Internet]. SMILE; 2017. Available from: https://www.h2020smile.eu
2. Larsen T. Ballen marina tests intelligent power grid. Havnemagasinet Flid og Fakta [Internet]. 2019; Available from: https://www.h2020smile.eu/wp-content/uploads/2019/05/Larsen2019.pdf
3. Jantzen J. Requirements Specification: Deliverable D3.4 [Internet]. SMILE; 2019. Available from: https://www.h2020smile.eu