Optimal parameterization of a PV and a battery system add-on for a consumer

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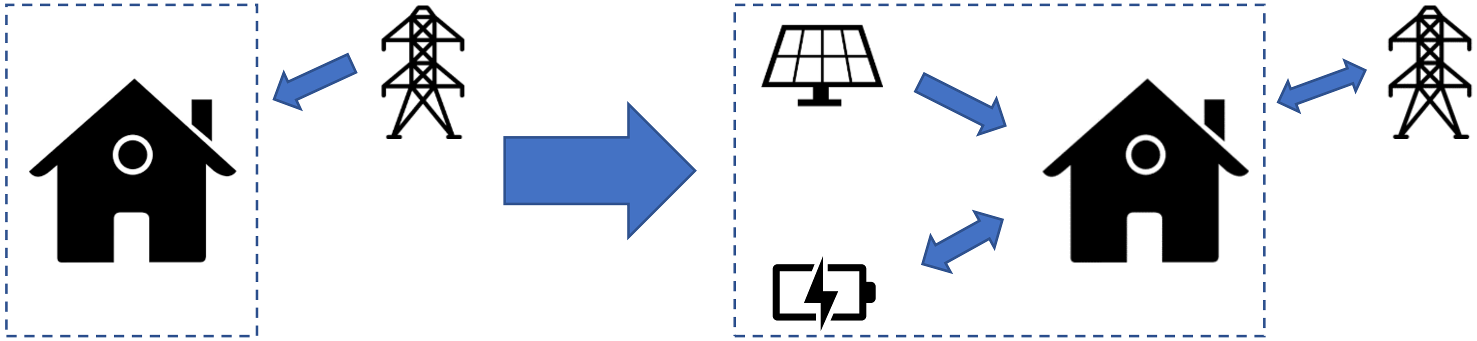

$E_{demand} = E_{grid}$

$E_{demand} - E_{PV} + E_{bat} = E_{grid}$

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- Photovoltaic (PV) systems
  - widespread renewable energy systems (RES)
- Battery energy storage systems (BESS)
  - enhance grid stability
  - increase penetration of RES
- PV + BESS together
  - significantly reducing the electricity bill for the consumer
  - prices of feed-in energy are considerably low compared to the prices of energy coming from utility grid

- What is the optimal size of PV + BESS?
  - peak power of the PV system, $P_{PV,peak}$
  - energy capacity of the BESS, $E_{bat,max}$
  - maximum power of the BESS power converter, $P_{PC,max}$
- Optimality guaranteed by solving linear programming (LP) problem:

$$Minimize\ f^T x$$
$$s.t.\ A_{eq} x = b_{eq},$$
$$A_{ineq} x \leq b_{ineq},$$
$$lb \leq x \leq ub$$

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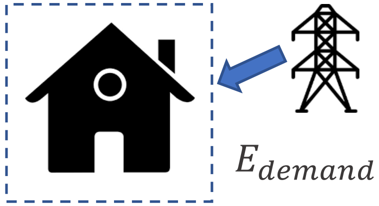
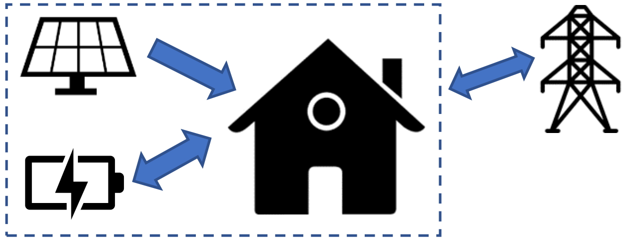
- Inputs:
  - measured electrical energy consumption of the consumer, $E_{demand}(k)$
  - possible PV energy production, $E_{PV}(k)$ → obtained from a nearby site or a web service
  - parameters and prices
- Before the add-on:



$$E_{demand}(k) = E_{grid}(k)$$

- After the add-on:



$$E_{demand}(k) = E_{grid}(k) - E_{ch}(k) + E_{dch}(k) + \alpha_{PV} E_{PV}(k)$$

- Optimization vector x contains:
  - Energy charging the battery, $E_{ch}(k)$
  - Energy discharging the battery, $E_{dch}(k)$
  - Energy taken from the grid, $E_{grid,pos}(k)$
  - Incurred peak power, $P_{grid,peak}(l)$
  - SoC of the battery system at time 0, $SoC(0)$
  - Capacity of the BESS, $E_{bat,max}$
  - Power rating of the BESS power converter, $P_{PC,max}$
  - Scaling coefficient for the peak power of the PV system, α_{PV}
  - Additional auxiliary variables for calculation of peak power if the billing formula is non-linear
- LP also returns optimal charging/discharging sequence of the BESS → optimal control

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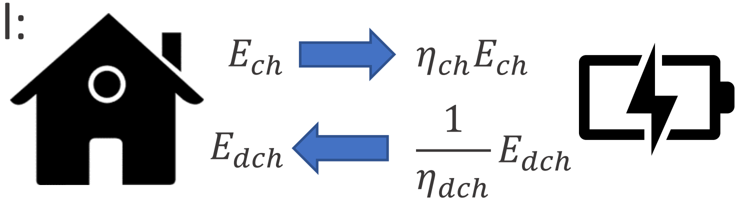
- α_{PV} is the scaling factor of the PV system:

$$\alpha_{PV} = \frac{P_{PV,peak}}{P_{PV,peak,nearby}}$$

- BESS model:



- State of charge of the battery:

$$SoC(k) = SoC(0) + \sum_{i=0}^{k-1} \eta_{ch}E_{ch}(i) - \sum_{i=0}^{k-1} \frac{1}{\eta_{dch}}E_{dch}(i)$$

- **Constraint** → ensure repeatability of the calculated sequence:

$$SoC(0) = SoC(N)$$

- **Constraint** → counteract simultaneous charging and discharging of the battery:

$$E_{ch}(k) + E_{dch}(k) \le P_{PC,max}T_S$$

- **Constraint** → ensure economical viability of the investment:

$$J_{en,no\ inv} - J_{en,yes\ inv} \ge \frac{J_{inv}}{n_{payoff}} + J_{ym}$$

$J_{en,no\ inv}$: cost of energy without investment; $J_{en,yes\ inv}$: cost of energy with investment; J_{inv}: cost of the investment; n_{payoff}: payoff period in years; J_{ym}: cost of yearly maintenance

- Yearly maintenance: $J_{ym} = J_{deg,bat} + J_{deg,PC} + J_{deg,PV}$
  - $J_{deg,bat} = \frac{c_{bat}}{2n_{cyc}DoD}\sum_{i=0}^{N-1}\left(\eta_{ch}E_{ch}(i) + \frac{E_{dch}(i)}{\eta_{dch}}\right)$
  - $J_{deg,PC} = \frac{c_{PC}}{n_{PC}}P_{PC,max}$
  - $J_{deg,PV} = \frac{c_{PV}}{n_{PV}}\alpha_{PV}P_{PV,peak,nearby}$

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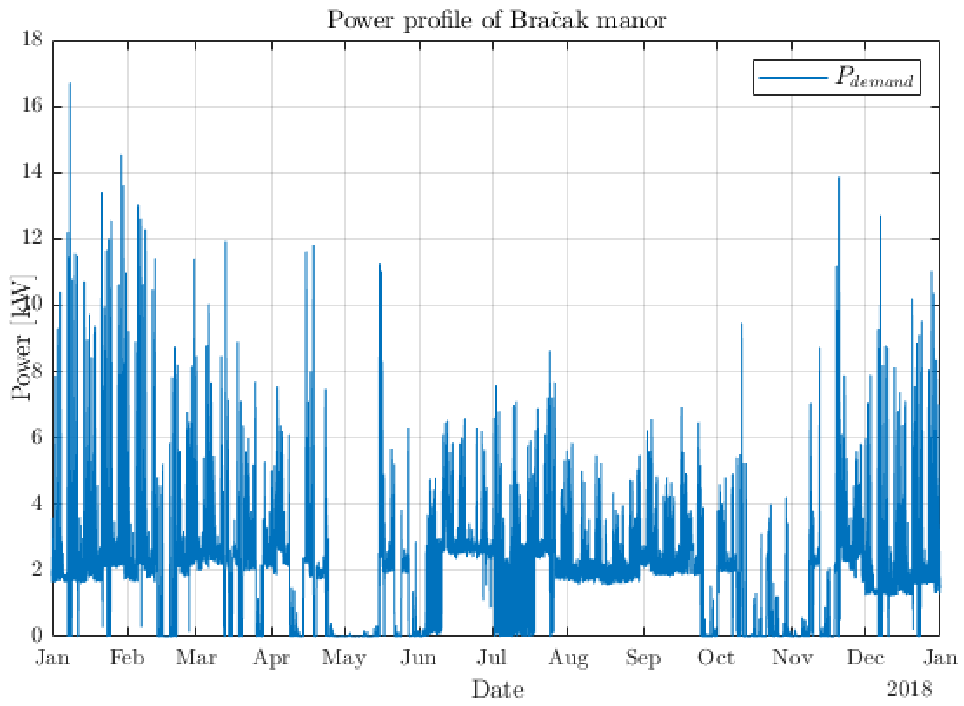
- Other **constraints**:
  - $0 \leq E_{ch}(k) \leq P_{PC,max} T_s$
  - $0 \leq E_{dch}(k) \leq P_{PC,max} T_s$
  - $(1 - DoD) E_{bat,max} \leq SoC(k) \leq E_{bat,max}$
  - $0 \leq \alpha_{PV} \leq \alpha_{PV,max}$ → due to physical restrictions
  - $0 \leq P_{PC,max}$
  - additional constraints for peak power billing
- Different **cost functions** for different consumer requirements:
  1. overall energy taken from the grid
  2. price of the overall energy taken from the grid
  3. total spending (price of the overall energy taken from the grid + price of the investment yearly scaled + price of the yearly maintenance)

- Experimental results for Bračak manor
  - Energy metered in 2018
  - Sampling time $T_s = 15$ min
  - PV production profile from UNIZGFER in 2018



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Optimal sizes using cost function 1 (minimal energy exchange)

Payoff period in years (n_payoff)	12	15	20
Battery capacity (E_bat_max) [kWh]	0	1.90	5.23
Power converter power (P_pc_max) [kW]	0	0.42	1.15
PV system peak power (P_pv) [kWp]	1.30	7.00	7.00

Optimal sizes using cost function 2 (minimal price of the energy)

Payoff period in years (n_payoff)	12	15	20
Battery capacity (E_bat_max) [kWh]	0	1.71	5.65
Power converter power (P_pc_max) [kW]	0	1.07	2.57
PV system peak power (P_pv) [kWp]	1.30	7.00	7.00

Optimal sizes using cost function 3 (minimal total spending)

Payoff period in years (n_payoff)	12	15	20
Battery capacity (E_bat_max) [kWh]	0	0	0
Power converter power (P_pc_max) [kW]	0	0	0
PV system peak power (P_pv) [kWp]	0.52	7.00	7.00

- Calculations performed using Matlab© and CPLEX®

- LP problem is too big to solve on regular computer → E_{ch} and E_{dch} can change every hour rather than every 15 min
- Future work:
  - introduce feed-in prices → more accuracy
  - software module for optimal on-line control of BESS based on this procedure
  - making the procedure simpler to compute

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https://www.interreg-central.eu/Store4HUC