A residential microgrid Operational Planning & Sizing

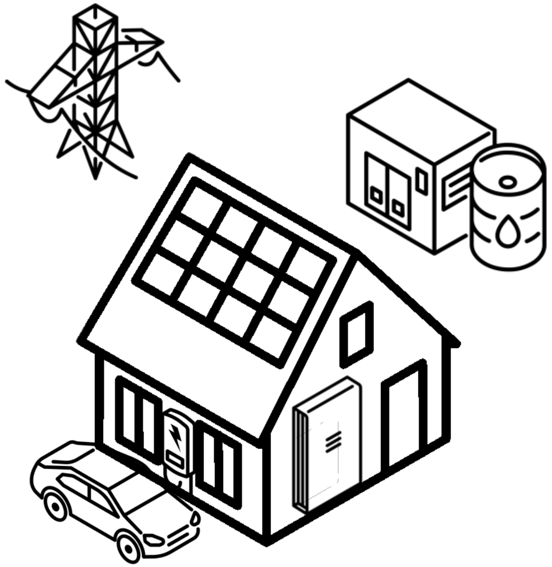
Bertrand Cornélusse, Thomas Stegen, Clément Moureau

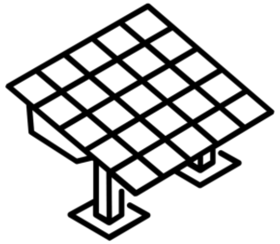
2 April 2025

I. Case study

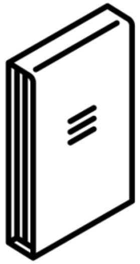
Introduction to the physical problem

Representation of the house

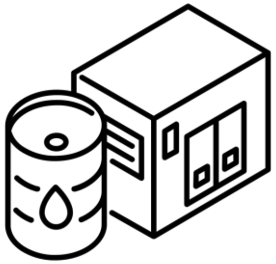




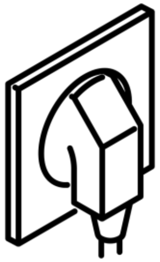
Photovoltaic panels are the main energy source



Battery storage system can be used as a slack

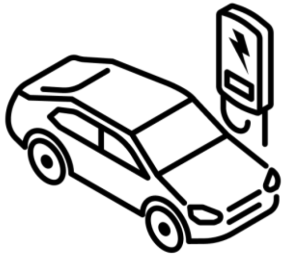


A diesel genset can also provide energy if needed



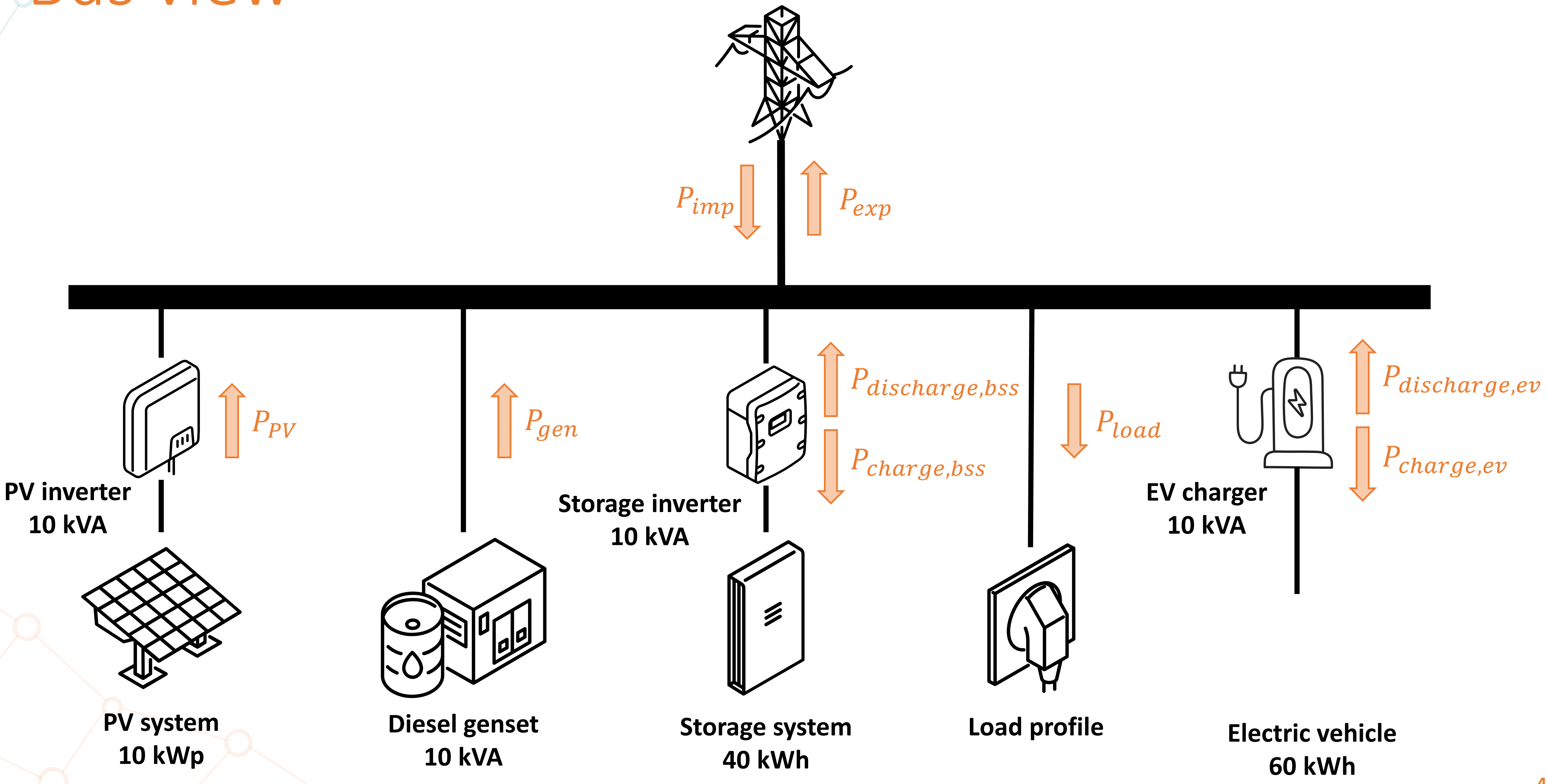
Load is fixed and should be always satisfied

The system can exchange with the grid at a given price



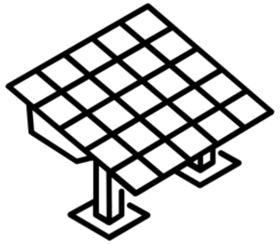
Electric vehicle connects, then should be charged

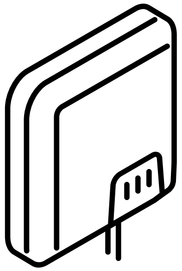
Bus view



P_{imp}
P_{exp}
P_{PV}
PV inverter
10 kVA
P_{gen}
$P_{discharge,bss}$
$P_{charge,bss}$
Storage inverter
10 kVA
P_{load}
$P_{discharge,ev}$
$P_{charge,ev}$
EV charger
10 kVA
PV system
10 kWp
Diesel genset
10 kVA
Storage system
40 kWh
Load profile
Electric vehicle
60 kWh

Power generation



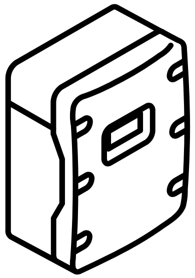


- Main source of energy
- Power profile for MPPs
  - $P_{pv,max}$
- Connected via inverter
- “Free energy”

- Inverter connected to the PV panels
- Rated capacity defines the maximum power output
  - $P_{pv,nom}$

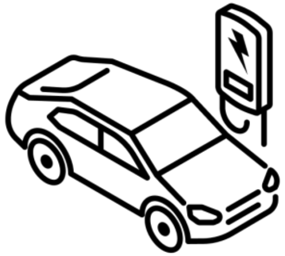
Energy storage

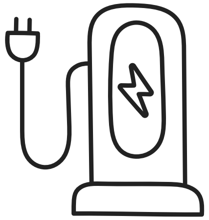
- Should mitigate imbalance
- Fixed capacity
  - C_{bss}
- Constant charging efficiency
  - eff_{bss}
- Bounded SOCs
  - $[SOC_{min\ bss},\ SOC_{max\ bss}]$



- Inverter connected to the batteries
- Limits the power output
  - $P_{bss\ nom}$

Electric vehicle

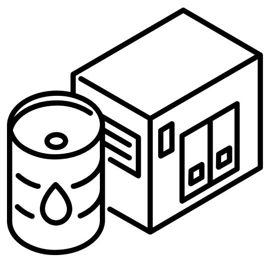




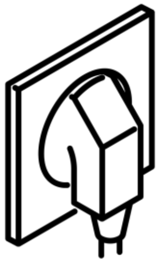
- Not always connected
  - $EV_{connection}$ (binary)
- EV usage is provided with 3 vectors
  - $SOC_{ev,i}$ $\mathrm{t_{arr}}, \mathrm{t_{dep}}$
- Should be charged when leaving
  - $SOC_{ev\ target}$
- Fixed capacity and efficiency
  - C_{ev}, eff_{ev}
- Bounded SOCs
  - $[SOC_{min\ ev},\ SOC_{max\ ev}]$

- Charger connected to the electric vehicle
- Limited charging power
  - $P_{ev\ nom}$

Controllable generation and fixed load



- Contingency usage
- Maximum/minimum power
  - $P_{max,gen}$
- Fuel costs when used
- Avoid repetitive on-off switches
- Power output should maximize efficiency



- Represents plugged-in appliances
- Defined by a profile
  - P_{load}
- Should always be satisfied

Objectives of the controller

This is what a good controller should achieve, in decreasing order of priority

Ensure feasibility: Power/energy bounds, demand satisfaction,…

Approach optimality: final cost, asset management, genset operation,…

Improve reliability: robustness, more realistic model of appliances,…

II. Operational Planning

Description of the first part of the homework

Objective

Using perfect forecast and given equipment sizes, define the complete optimal power profile of all assets at once.

➔ In practice, this step would be done daily, this is called day-ahead operational planning.

➔ In this work, we will consider all available data at once to re-use the same code for the second part of the assignment (Sizing of the microgrid).

Python set-up

- Very similar to the previous homework, but now you take decisions for multiple time steps → vector variables.
- Some constraints must be enforced for each time-step
- The vehicle is now potentially connecting and disconnecting multiple times → needs to be handled properly.

Code diagram

Parameters

```
delta_t,SOC_i_bss, SOC_min_bss, SOC_max_bss, eff_bss
P_nom_ev, eff_ev, SOC_min_ev, SOC_max_ev, SOC_target_ev
C_ev, PI_gen, PI_imp, PI_exp
```

Result object

- P_load, P_pv_max (MPP ratio)
- EV profile
  - t_arr, t_dep
  - SOC_ev_i
- Asset sizes

- Power setpoints and SOCs:
  - P_pv
  - P_bss — SOC_bss
  - P_ev — SOC_ev
  - P_imp
  - Pexp
  - P_gen

create_model()

solve_model()

save_results()

check_res()
print_res()
plot_res()

Model object

- Contains all physical constraints of the microgrid
- Minimizes costs as objective function
- Takes decision for power set points

Utils function

- Post processes the result object to ensure simulation results are:
  1. Feasible
  2. Optimal
  3. Looking nice and smooth

How to access data in the Results object

This object is very similar to the one from the last assignment, only more complete.

Inputs

- res.P_load[t] = Load power at time t
- res.P_pv_max[t] = Max available PV power at time t
- res.EV_connected[t] = EV connected at time t

- res.t_arr[c] = Time at which the EV is connected for the c-th connection
- res.t_dep[c] = Time at which the EV is disconnected for the c-th connection
- res.SOC_i_ev[c] = Arrival SOC of the EV connected at time t_arr[c]

Outputs

- res.P_pv [t] : Power of the PV system [kW]
- res.P_gen [t] : Power of the generator [kW]
- res.P_bss [t] : Power of the battery [kW]
- res.P_ev[t]: Power of the EV [kW]
- res.P_imp [t] : Power of the battery [kW]
- res.P_exp[t]: Power of the EV [kW]
- res.SOC_bss[t]: Energy in the battery [kWh]
- res.SOC_ev[t]: Energy in the EV [kW]
- res. objective: Value of the objective function

Differences with last assignment

- Grid connection
- Time-step is now 15 minutes
- You handle time-series up to one year in one solve
- No power minimum for the generator
- EV can connect and disconnect multiple times
- Each DC asset is connected through an inverter with nominal power

Pay attention to solving time

- The decision horizon will go until 1 year so the running time will grow drastically

- You should keep a linear formulation in order for the solution to be tractable then

- Avoid non-convexity at all costs:
  - $\cancel{P_{charge} P_{discharge} = 0}$

- Use of binary variables is also unwanted and you can avoid them

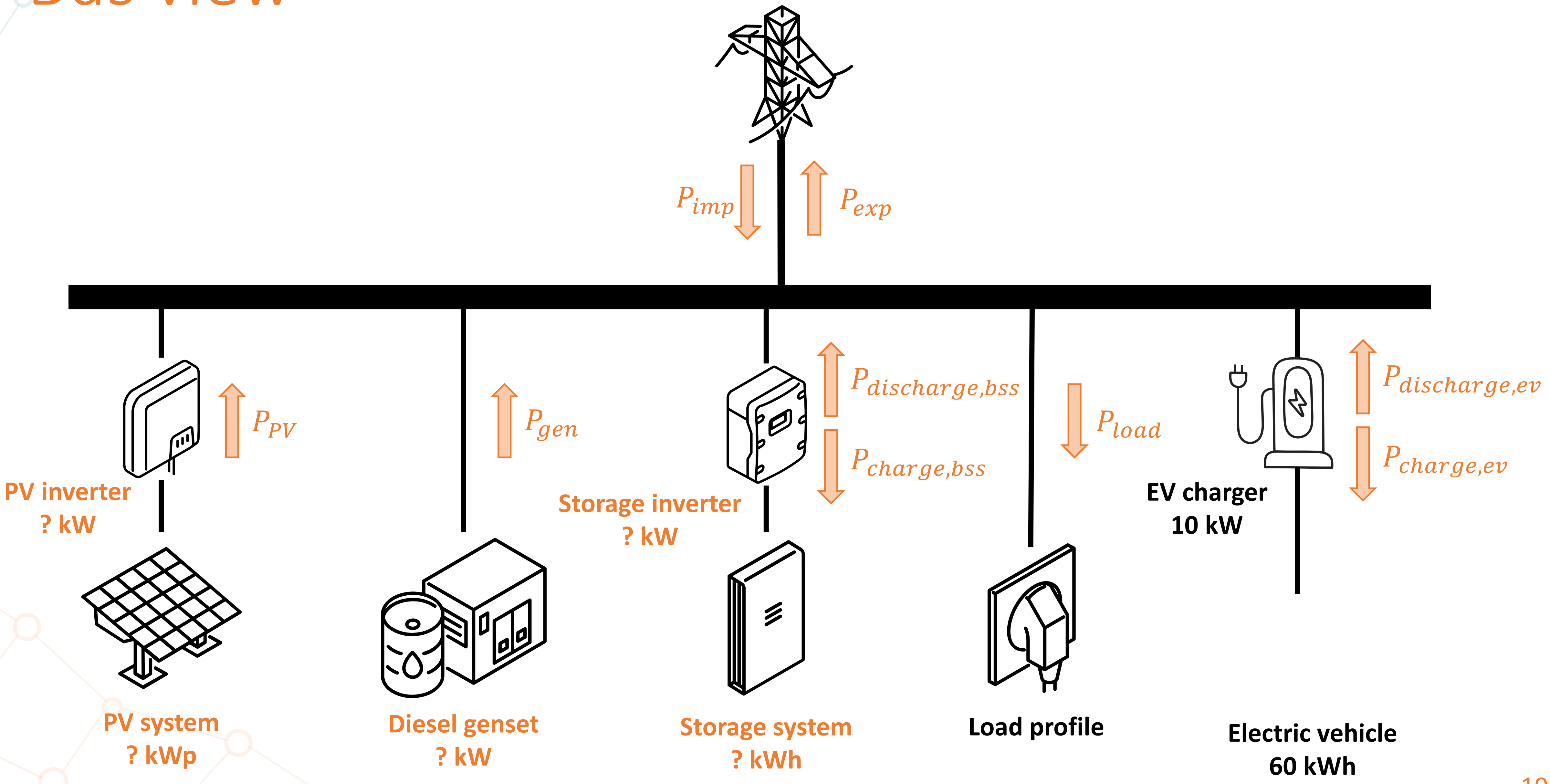
Guidelines for operational planning

1. Solve the operational planning problem using a linear programming formulation. Optimize the usage of each device to minimize OPEX.
2. Compute the yearly system costs and present some results.
3. What are the key parameters? How could they totally change the optimal results?
4. Show the dependency between the PV size and the operational costs is nonlinear. Explain why.
5. Plot the monthly costs, self-consumption, self-sufficiency, BSS, PV, inverter usage, and any other relevant result.
6. What are the strong assumptions made when solving this problem? Discuss.

III. Sizing

Description of the second part of the homework

Bus view



P_{imp}
P_{exp}
P_{PV}
PV inverter
? kW
P_{gen}
$P_{discharge,bss}$
$P_{charge,bss}$
Storage inverter
? kW
P_{load}
$P_{discharge,ev}$
$P_{charge,ev}$
EV charger
10 kW
PV system
? kWp
Diesel genset
? kW
Storage system
? kWh
Load profile
Electric vehicle
60 kWh

Main changes from the last part

- **Asset sizes are now variables** and not parameters
- Parameters of the model now include investment horizon and investment prices for each technology
- CAPEX should be included in the objective function
- If relevant, you should also add constraints and variables to the model

Guidelines for sizing – Part 1

1. Reformulate the optimization problem of the previous section as a sizing problem. Additional constraints could be required, and the objective function must be adapted to include scaled CAPEX.

2. Compute the optimal sizing considering only January.

3. Apply the same procedure for June instead of January and finally for the whole year. Compare and comment the sizing results you obtain in each case.

4. Show the usage and price of each investment in the yearly case. Discuss the savings they create individually and how they interact.

Guidelines for sizing – Part 2

5. Size the microgrid over the entire year considering varying export tariffs (from 0 to any value you may find interesting). How do these influence your results? Explain. What happens when the import cost gradually decreases?

6. Describe the impact of simultaneous increase of load and kilometers per year on the results. How would a change in these parameters affect the results?

7. Discuss the results and show how the asset sizes are linked. For example, what can you say about the PV inverter size compared to the installed PV capacity?

IV. Report

Report guidelines

1. **Maximum 8 pages**

2. Pay attention to the graphs and results you present

3. Be concise, focus on your decisions and results, not on the case study
    - Try to present the result in the most adequate possible way
    - Use graphs to show dependencies
    - Use tables to summarize and compare results