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Internet of Things for Smart Buildings
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Project 9: MPC and deep learning

We present a building with an energy system that consists of a solar panel for energy generation, a battery to store energy locally and a connection to the grid (see Fig. 1). It is possible to buy or sell electricity via the grid.

The states that describe the system depicted in Fig. 1 are $x^T = [T_\mathrm{r}, E_\mathrm{bat}]$, where T_r is the room temperature and E_bat is the energy stored in the battery. The available control inputs are $u^T = [P_\mathrm{hvac}, P_\mathrm{bat}, P_\mathrm{grid}]$, where P_hvac is the power needed for the HVAC, P_bat the power delivered by or charged to the battery and P_grid the power sold or bought from the grid., If $P_\mathrm{grid} < 0$ energy is sold to the grid and if $P_\mathrm{grid} \geq 0$ energy is bought. For $P_\mathrm{hvac} < 0$ the building is cooled whereas for $P_\mathrm{hvac} \geq 0$ the building is heated. If $P_\mathrm{bat} \geq 0$ energy stored in the battery is used to power the HVAC, if $P_\mathrm{bat} < 0$ the battery is being charged.

The external disturbances acting on the building are $d = [d_\mathrm{T}, d_\mathrm{sr}, d_\mathrm{int}]$, where d_T is the external temperature, d_sr is the solar radiation and d_int are the internal gains.

The system can be described by a linear dynamic system

$$x_{k+1} = Ax_k + Bu_k + Ed_k, \tag{1}$$

where

$$A = \begin{bmatrix} 0.8511 & 0 \\ 0 & 1 \end{bmatrix},$$
$$B = \begin{bmatrix} 0.0035 & 0 & 0 \\ 0 & -5 & 0 \end{bmatrix}, E = 10^{-3} \begin{bmatrix} 22.217 & 1.7912 & 42.212 \\ 0 & 0 & 0 \end{bmatrix}.$$

The goal of the energy management system is to fulfill several constraints that are described in the following. The state constraints are given by

$$20.0 \leq T_\mathrm{r} \leq 23.0°\mathrm{C}, \tag{2}$$

which gives a band of comfortable room temperatures and

$$0.0 \leq SoC \leq 200000, \tag{3}$$

where SoC is the state of charge of the battery. You can choose arbitrary values for the capacity of the battery.

The following mixed constraints ensure fulfilling the legal requirements and the energy balances. Regardless of weather conditions, the power required by the HVAC for cooling or heating should be provided by the energy stored in the battery, the power currently generated by the solar panels P_PV and the power bought from the grid:

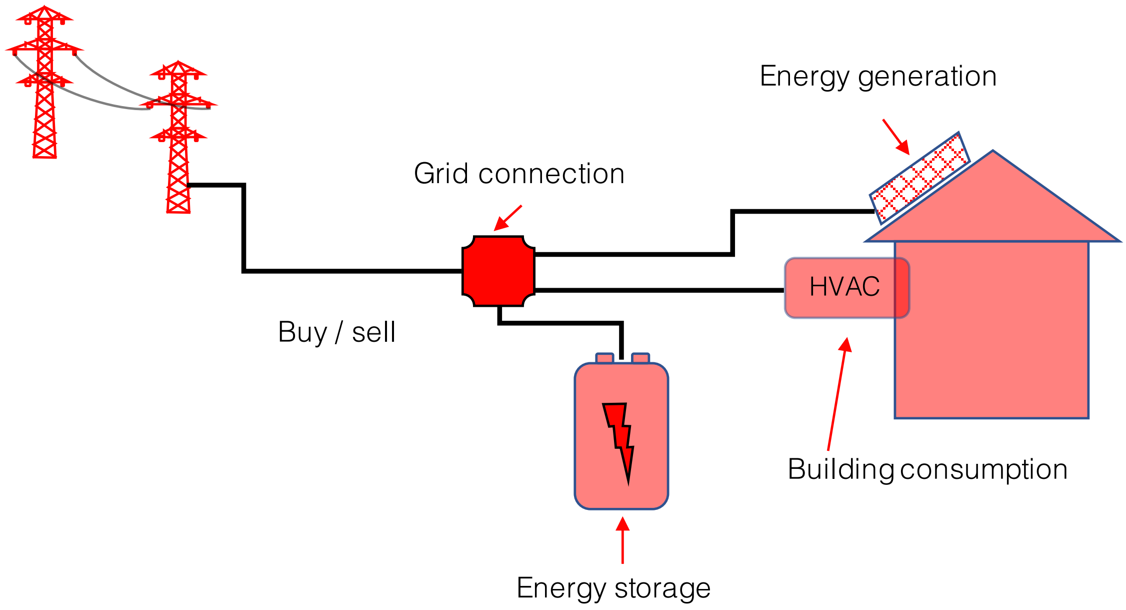

Figure 1: A simplified energy management system.

$$|P_{\text{hvac}}| \leq P_{\text{bat}} + P_{\text{grid}} + P_{\text{PV}}, \tag{4}$$

where $P_{\text{PV}} = 0.5\frac{1}{m^2} \cdot d_{\text{sr}}$, meaning that we assume that 50% of the solar radiation can be converted to electrical energy.

The *economic* control goal is to maximize the energy sold to the grid. Additionally, we assume that it is desired to have a desired energy level in battery to ensure flexibility, which is modeled by a small tracking term. The resulting QP that should be solved at each sampling time of the MPC can be written as:

$$\begin{aligned}
&\underset{(x,u)}{\text{minimize}} && \sum_{k=0}^{N-1} (P_{\text{grid}}^k + \gamma(E_{\text{bat}}^k - E_{\text{bat}}^{\text{ref}})^2) && \text{(5a)}\\
&\text{subject to} && x_{\text{lb}} \leq x_k \leq x_{\text{ub}}, && \text{(5b)}\\
& && u_{\text{lb}} \leq u_k \leq u_{\text{ub}}, && \text{(5c)}\\
& && m_{\text{lb}} \leq Du_k + Gd_k \leq m_{\text{ub}}, && \text{(5d)}\\
& && x_{k+1} = Ax_k + Bu_k + Ed_k, && \text{(5e)}
\end{aligned}$$

where N is the prediction horizon, γ is a penalty parameter, and x_{lb}, x_{ub}, u_{lb}, u_{ub}, m_{lb} and m_{ub} are the lower and upper bounds of the states, inputs and mixed constraints. Use any feasible state as initial condition for the system. The mixed constraints explained above can be defined by the matrices:

$$D = \begin{bmatrix} -1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 0 \end{bmatrix}, G = \begin{bmatrix} 0 & 0.5 & 0 \\ 0 & 0.5 & 0 \end{bmatrix}.$$

The input constraints are given by

$$u_{\mathrm{lb}} = \begin{bmatrix} -1000 \\ -500 \\ -500 \end{bmatrix}, \quad u_{\mathrm{ub}} = \begin{bmatrix} 1000 \\ 500 \\ 500 \end{bmatrix}.$$

The mixed constraints bounds are given by

$$m_{\mathrm{lb}} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}, \quad m_{\mathrm{ub}} = \begin{bmatrix} \infty \\ \infty \end{bmatrix}.$$

Tasks

1. Implement an MPC controller for the system.
2. Learn the MPC controller (run many closed-loop simulations with different initial values for training data).
3. Learn the model (e.g. make a grid of the inputs and simulate the system for training data).
4. Make a CasADi formulation of the learned model und run various simulations with the learned model as optimization model and the given model as simulation model.
5. Learn a controller from the data generated in the previous point.

Reasonable trajectories for the external disturbances will be provided.