Solving Optimal Scheduling Problem with Switching Models of an Electrical-Thermal System

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Outline

- System description
- Optimal scheduling problem
- Some issues and ideas

System description

Micro-scale trigeneration lab at Institute for Energy System Technologies (Offenburg):

System description

System diagram:

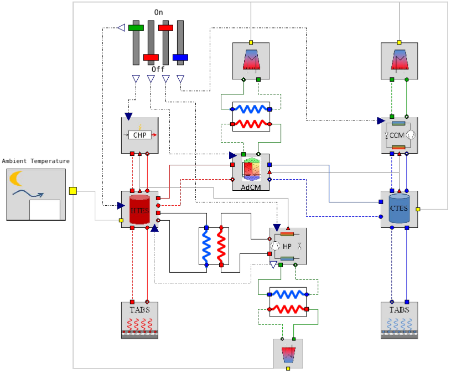
+ CHP: Combined Heat-Power generation

+ HTES: Hot Thermal Energy Storage

+ AdCM: Adsorption Chilling Machine

+ HP+CCM=RevHP: Reversible Heat Pump

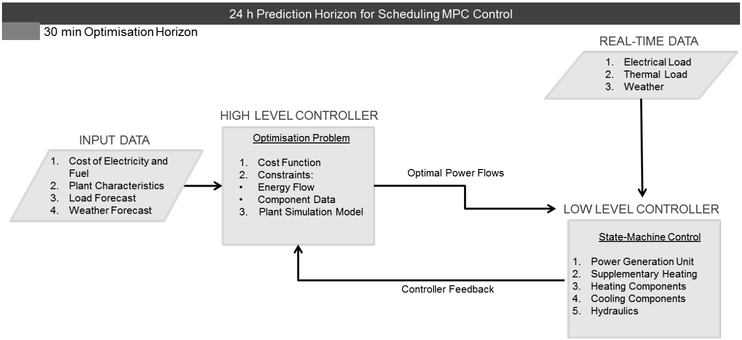
+ CTES: Cold Thermal Energy Storage



Summer: HP, Hot Load off
Winter: AdCM, CCM, Cold Load off

Control setting

- Use MPC over a horizon of 24h, optimize economic benefits
- Control inputs: turning each component ON/OFF
- Lower level controllers take care of local tracking



System model

Components have dynamical or have static models. DAE model:

$$\frac{dx}{dt} = f(x, z, u) \tag{1}$$

$$0 = g(x, z) \tag{2}$$

with $x(\cdot)$ contains **temperature** of layers in the tanks, $z(\cdot)$ includes **flow rates** (between components, and between layers inside the tanks)

- Differential part comes from energy balance equations for layers:
  $$\frac{d\text{Energy}}{dt} = m * c_p * \frac{d\text{Temperature}}{dt} = \text{heat in} - \text{heat out}$$
- Algebraic part comes from mass balance equations (and static models): $\sum(\text{flows into layer}_i) = \sum(\text{flows away layer}_i)$

MPC-fashion optimal scheduling problem

Solve a mixed-integer problem at every step (T=15 minutes):

$$\min_{x(\cdot),z(\cdot),u(\cdot)} \quad \int_0^{NT} \Big(\big[a u_2(t) + b u_3(t) + c u_4(t) - d u_1(t) \big] p_e(t) + f u_1(t) p_f \Big) dt$$

$$\text{s.t.} \quad \dot{x}(t) = f(x(t), z(t), u(t)), \quad t \in [0, NT]$$

$$0 = g(x(t), z(t))$$

$$x_{\text{min}} \leq x \leq x_{\text{max}}, \quad z_{\text{min}} \leq z \leq z_{\text{max}}$$

$$u(t) \in \{0, 1\}$$

$$u(t) \text{ invariant in every step } [kT, (k+1)T], k = 0, \cdots, N-1$$

u_1 is CHP ON/OFF, u_2 is AdCM ON/OFF, u_3 is HP ON/OFF, u_4 is CCM ON/OFF.

Issues

- Modelling each layer of the tank: determine the direction of flow?

  Current strategy of Parantapa: use an **if-else** structure

  Adrian's suggestion: put additional binary variables to represent this if-else structure

  Idea to make the model smooth: introduce $q_{\text{up to down}}$ and $q_{\text{down to up}}$ for each layer in the tanks, add complementarity constraints:

  $q_{\text{up to down}}(t).q_{\text{down to up}}(t) = 0$

Trial solution: when there are only CHP, HTES and Hot Load, $T = 1h, N = 6$, solving the multiple shooting problem with solver Bonmin in Casadi takes 20 minutes.

Issues

- There are some constraints on control inputs: some components cannot be both ON together

  Winter mode: {only CHP on, only RevHP_hot on, all off}. Summer mode: 6 options.

Ideas needed: how to exploit this property?

Note: we still need integrators to simulate the dynamical parts of the model.

Summary

- A system combined of electrical and thermal components
- Modelling still needs to be improved (CHP will be identified with a dynamics)
- Optimal scheduling problem with MPC fashion:
  - All control inputs are binary variables
  - At every step, there are only few modes to choose

Thanks for your attention!