

Cooperative Optimization-Based Operation of Coupled Energy Systems



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Introduction

Model Predictive Control (MPC) is a promising supervisory-control scheme for **energy systems**. By considering forecasts of weather, demand or prices, MPC can compute **optimal, predictive operation schedules**. This enables operation of heat pumps or biomass boilers at higher efficiencies, reducing costs and emissions.

Multi-owner energy systems - coordination without centralization:

Many energy systems involve subsystems owned and operated by **different parties**. Although joint, coordinated operation could unlock substantial energy saving potential, a **central MPC architecture is not feasible in practice**: it would require owners giving up private operational data or even control of their own assets.

Instead, each subsystem requires an individual MPC controller that preserves **data privacy** and **local decision-making authority**. The controllers must nevertheless be **coordinated**, especially regarding the energy exchanged via networks or couplings. Without coordination and consensus, the controllers may contradict themselves, possibly leading to unmet demand or even overheating.

The challenge is therefore to coordinate independently operated energy systems such that exchanged energy is agreed upon without compromising privacy or local control.

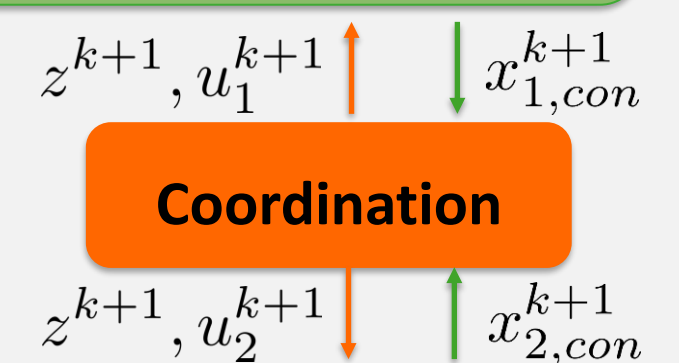
Approach: Distributed Optimization

The Alternating Direction Method of Multipliers (ADMM) is a distributed optimization algorithm suitable for enforcing consensus on multiple subproblems. It has convergence guarantees for convex problems and provides **data privacy**. Each controller only sends the values of the variables involved in the coupling for consensus $x_{i,con}^{k+1}$. A **coordination layer** computes the ADMM variables, which iteratively force the subproblems to consensus. The diagram shows the ADMM architecture for two subsystems.

$$x_i = \begin{bmatrix} x_{i,con} \\ x_{i,pri} \end{bmatrix}$$

$$\begin{aligned} z^{k+1} &= \bar{x}_{con}^{k+1} \\ u_i^{k+1} &= u_i^k + (x_{i,con}^{k+1} - z^{k+1}) \end{aligned}$$

$$\min_{x_1} f_1(x_1) + \frac{\rho}{2} \|x_{1,con} - z^k + u_1^k\|_2^2$$

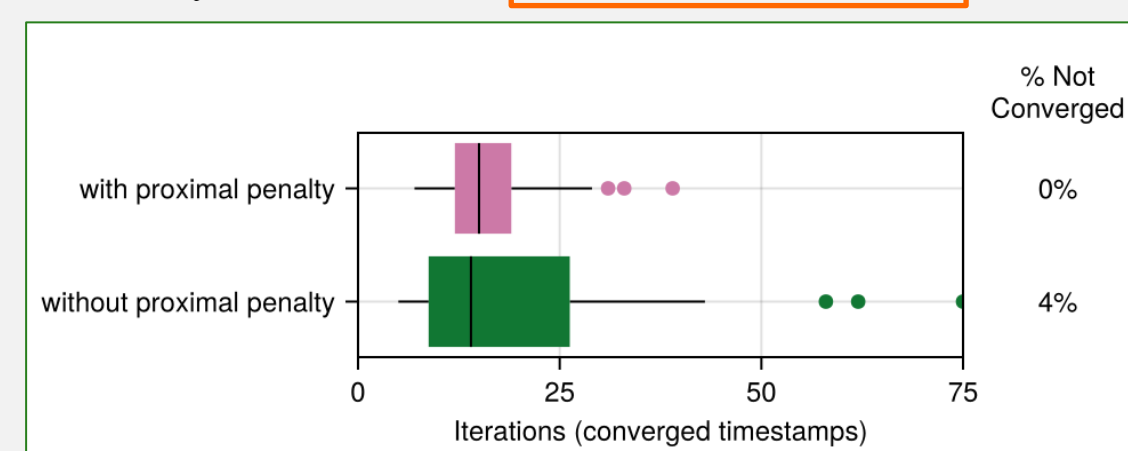


$$\min_{x_2} f_2(x_2) + \frac{\rho}{2} \|x_{2,con} - z^k + u_2^k\|_2^2$$

Issues & Measures

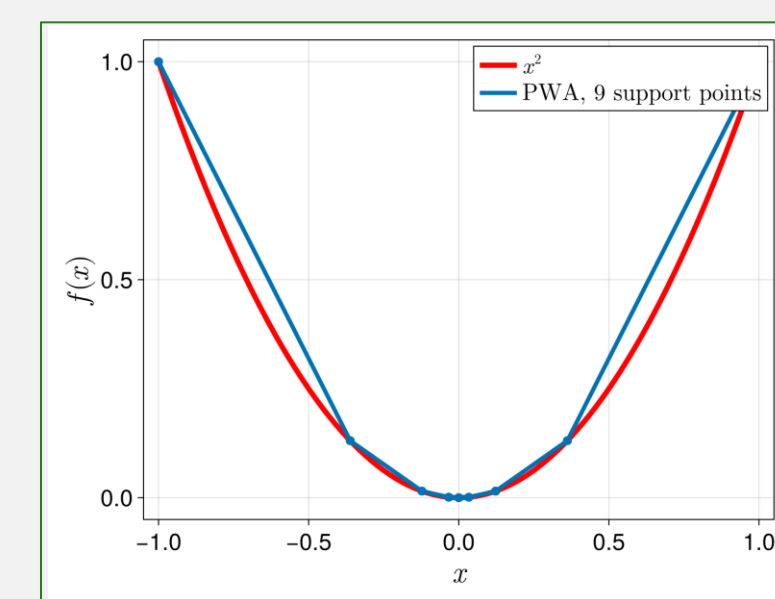
The optimization problems for energy systems with unit commitment are typically written in a **MILP** formulation. However, ADMM has **no convergence guarantees** for this problem class. Nevertheless, convergence must be reached. A **proximal penalty term** significantly improves the reliability:

$$\operatorname{argmin}_{x_i} f_i(x_i) + \frac{\sigma}{2} \|x_i - x_i^k\|_2^2$$



The MILP subproblems obtained by splitting the overall problem become MIQP due to the **quadratic augmented term** introduced for ADMM. For such large problems, **open-source MIQP solvers** are not sufficient.

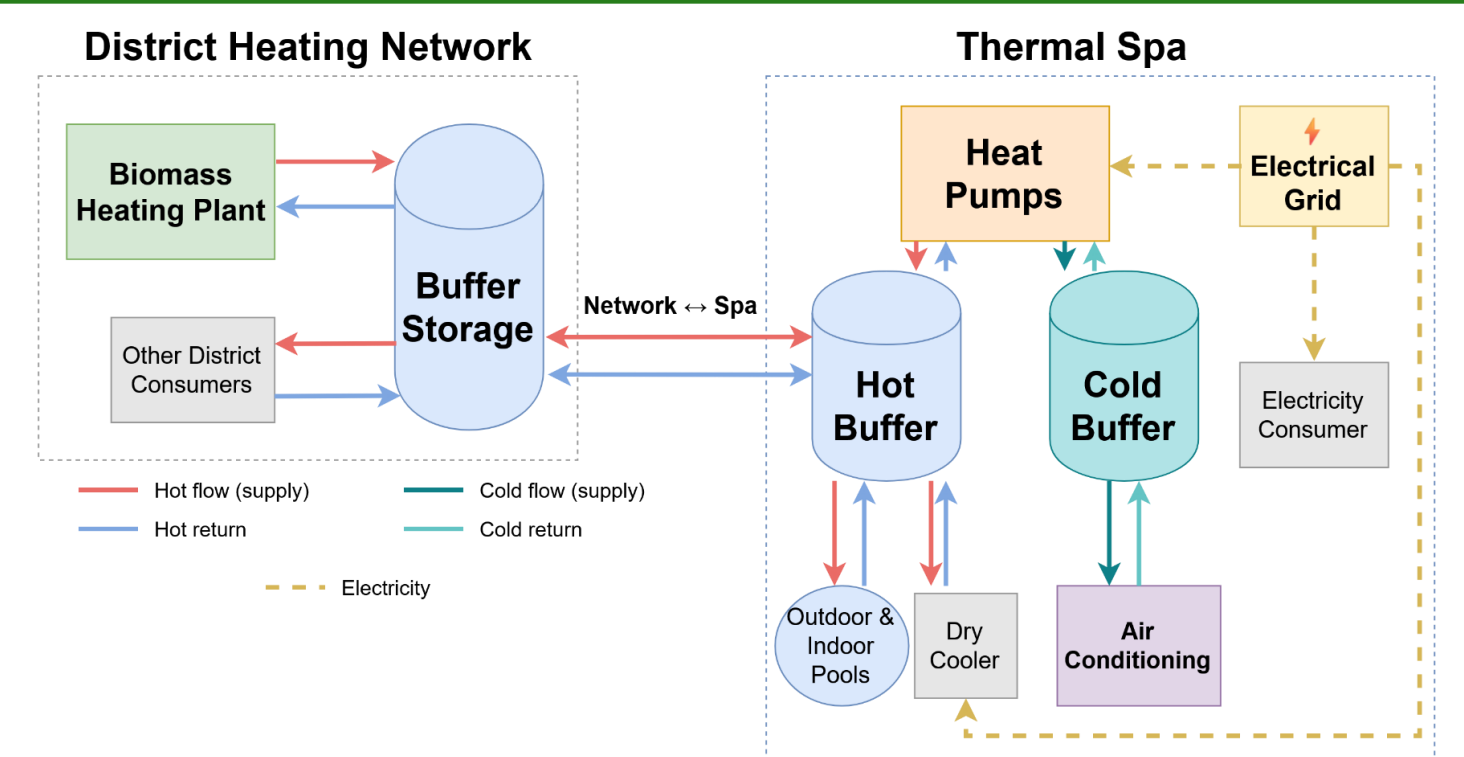
A **PWA-Approximation** of all quadratic terms mitigates this:



Case Study

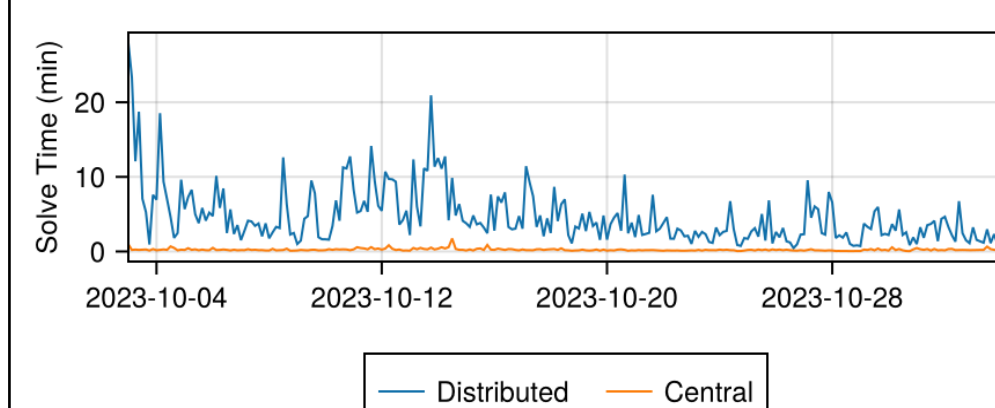
We consider an energy system of a **thermal spa** coupled to a **district heating network**, shown in the schematic on the right hand side. It is a typical **multi-owner energy system** requiring coordinated controllers: the two sites are operated by two parties and are located several kilometres apart but coupled bidirectionally to enable heat exchange.

This coupling unlocks new flexibilities for saving costs and emissions - the two controllers must be coordinated to tap into this potential.

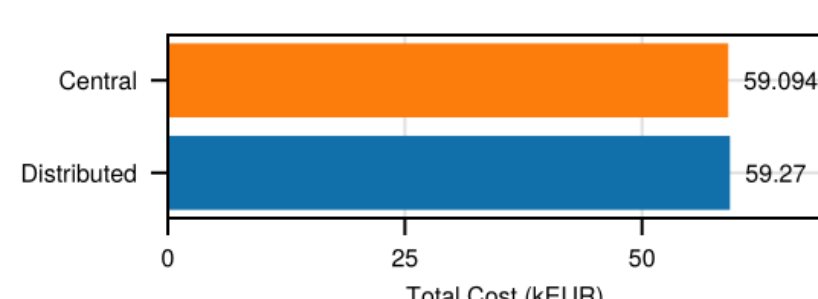


Results

The distributed problem takes significantly longer to solve than the central MPC, but it still **maintains real-time capabilities**.



Simulation of both central and distributed MPC operating the plant yields a **cost difference** of **+0.3%** for a duration of one month:



Conclusions

- Achieved **reliable convergence** of ADMM with MILP problems for cooperative MPC.
- Shows real-time capability in simulation for a **thermal spa and district heating network** case study.
- Reaches the **same costs** as a benchmark central MPC for a simulation period of one month.

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