HSLU Hochschule Luzern

Technik & Architektur
Competence Center Thermal Energy Systems and Process Engineering
Research Group Energy Integration and Optimization

Master's Thesis – Master of Science in Engineering, Energy and Environment

Model Predictive Control of an Industrial Heat Pump–Thermal Energy Storage System Using Data-Driven Pattern Recognition for Demand Forecasting

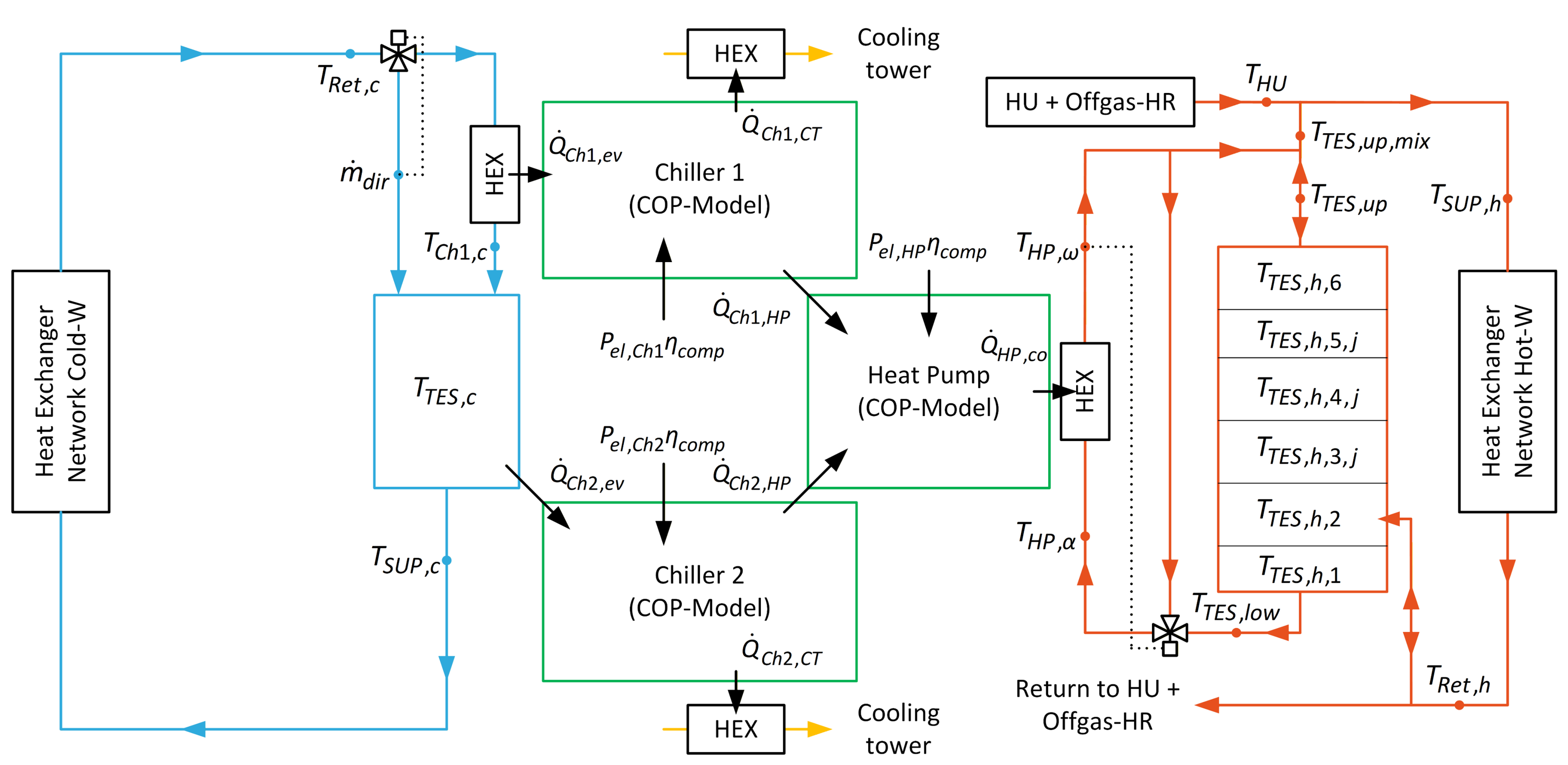

Figure 1: Simulation model topology with chillers, HP, cold- and hot network

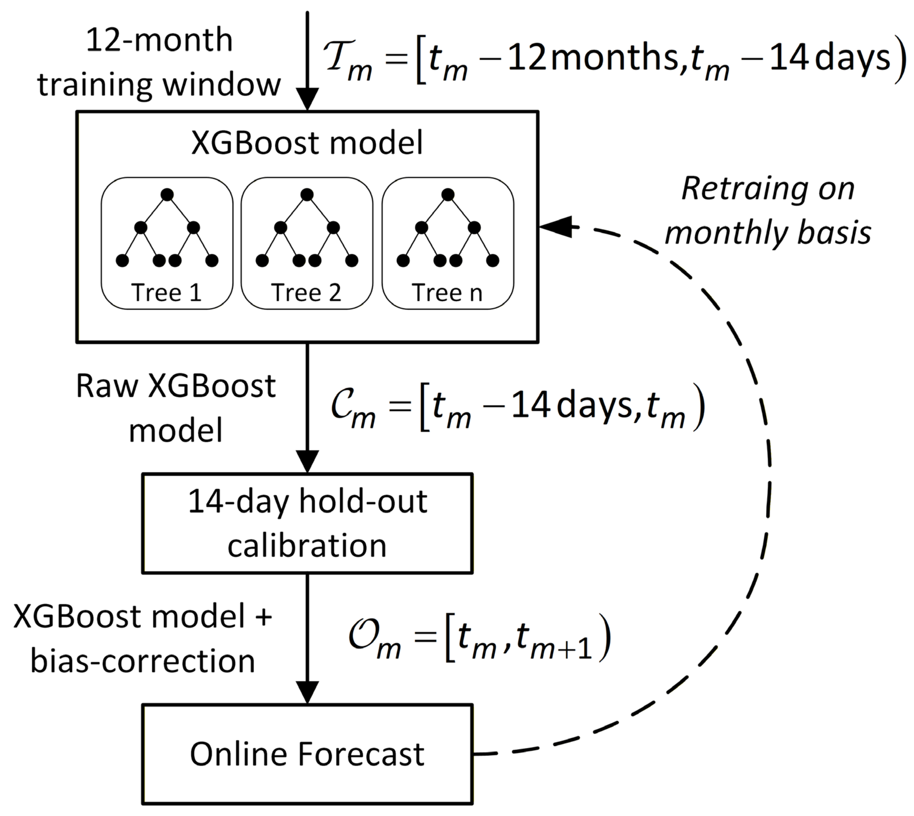

Figure 3: Data-driven demand forecast algorithm with XGBoost model

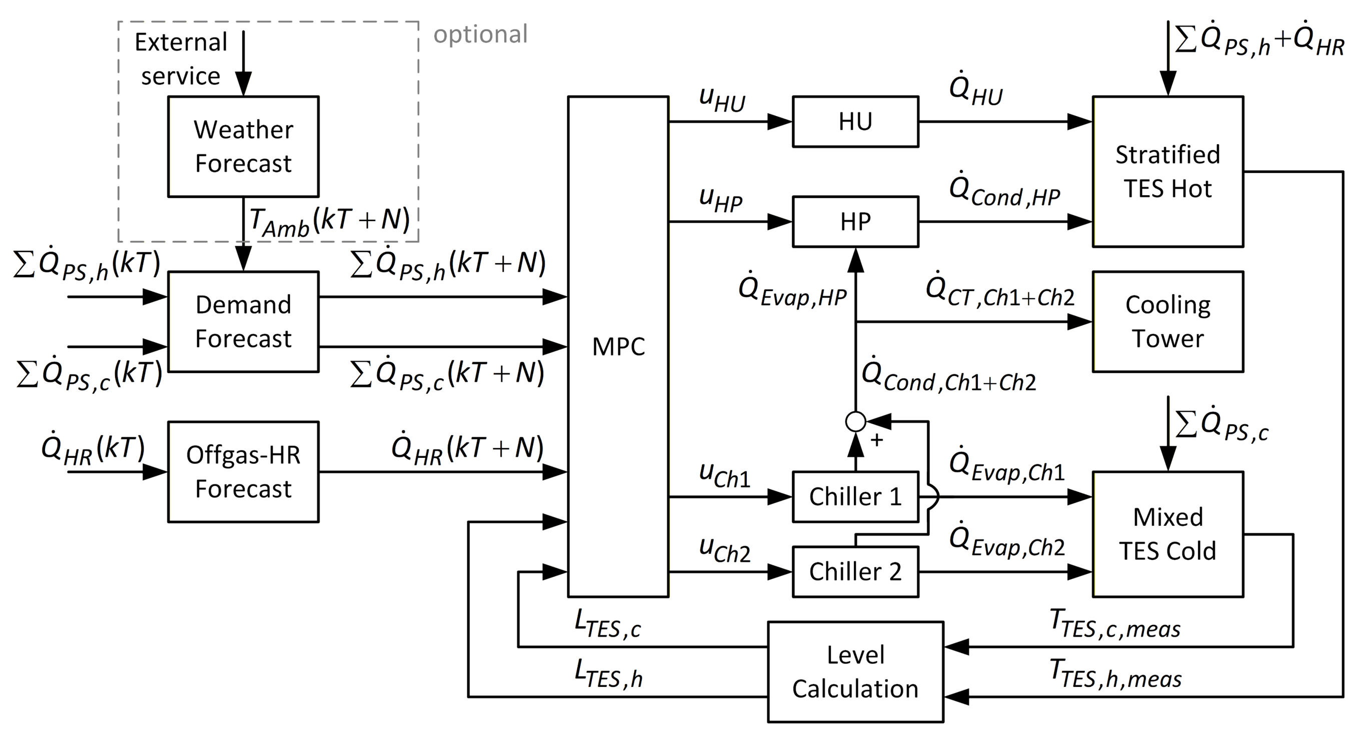

Figure 2: Schematic overview of high-level MPC control concept

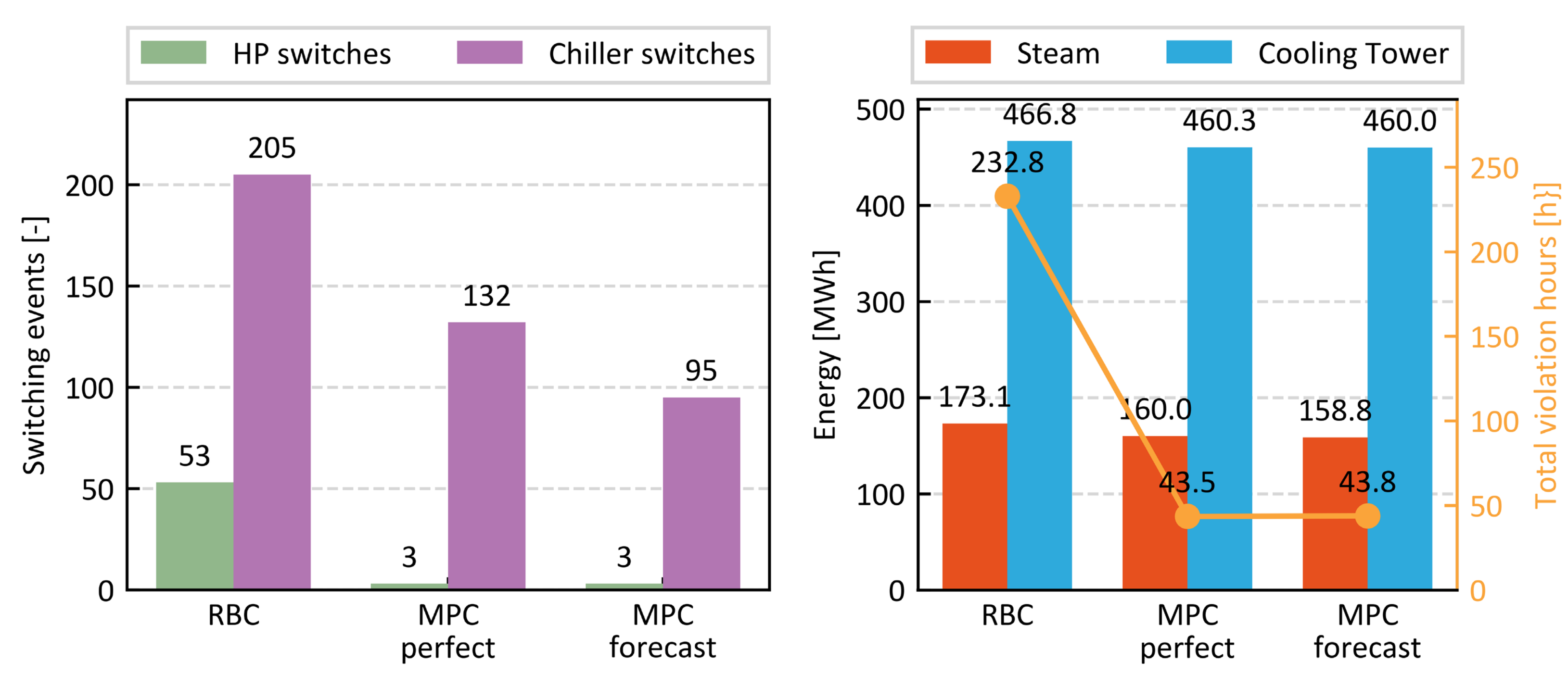

Figure 4: Combined results of RBC compared to MPC control strategy for representative summer, transition and winter weeks

Background and Motivation

Switzerland's process heat demand accounts for approximately 13% (25 TWh) of the final energy demand. This demand is today mostly supplied by fossil fuels (70%). Heat Pumps (HP) are a key technology to decarbonization.

The integration of HPs in industrial applications is often complicated by the non-continuous availability of waste heat sources and heat sinks. Thermal energy storage (TES) on both the hot and cold sides can temporally decouple heating demand, cooling demand, and HP operation, thereby increasing operational flexibility and improving the utilization of intermittent waste heat.

Although HP–TES systems, demand forecasting and model predictive control (MPC) have been investigated separately, their combined application to real industrial energy systems with coupled hot and cold-water networks remains less commonly addressed. Existing studies often rely on simplified demand profiles.

Task and Procedure

The objective of this thesis is to develop and evaluate a simulation-based control framework for a real industrial HP-TES-system with coupled hot- and cold-water networks. The framework (*Python, C++*) combines a validated simulation model, data-driven demand forecasting, and an MPC strategy. The proposed MPC strategy is compared with an existing high-level rule-based control (RBC) strategy using real industrial operation data.

Results and Recommendations

The developed and validated simulation model achieved an accuracy within 5% of the measured data for representative summer, transition, and winter weeks.

The proposed MPC strategy with a 1-hour prediction horizon reduced temperature violations and decreased the ON/OFF cycling frequency of both chillers and HP. During the transition and winter periods, the steam demand was decreased by 8%, while the electricity demand increased by 3% using more waste heat from chillers.

The forecast algorithms achieved a maximum energy error below 6%, providing a reliable basis for data-driven demand forecasting.

Future work should implement and validate the forecast methods and MPC strategy under industrial operating conditions.

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