Dynamic Modeling, Control, and Optimization of Micro-CHP Systems

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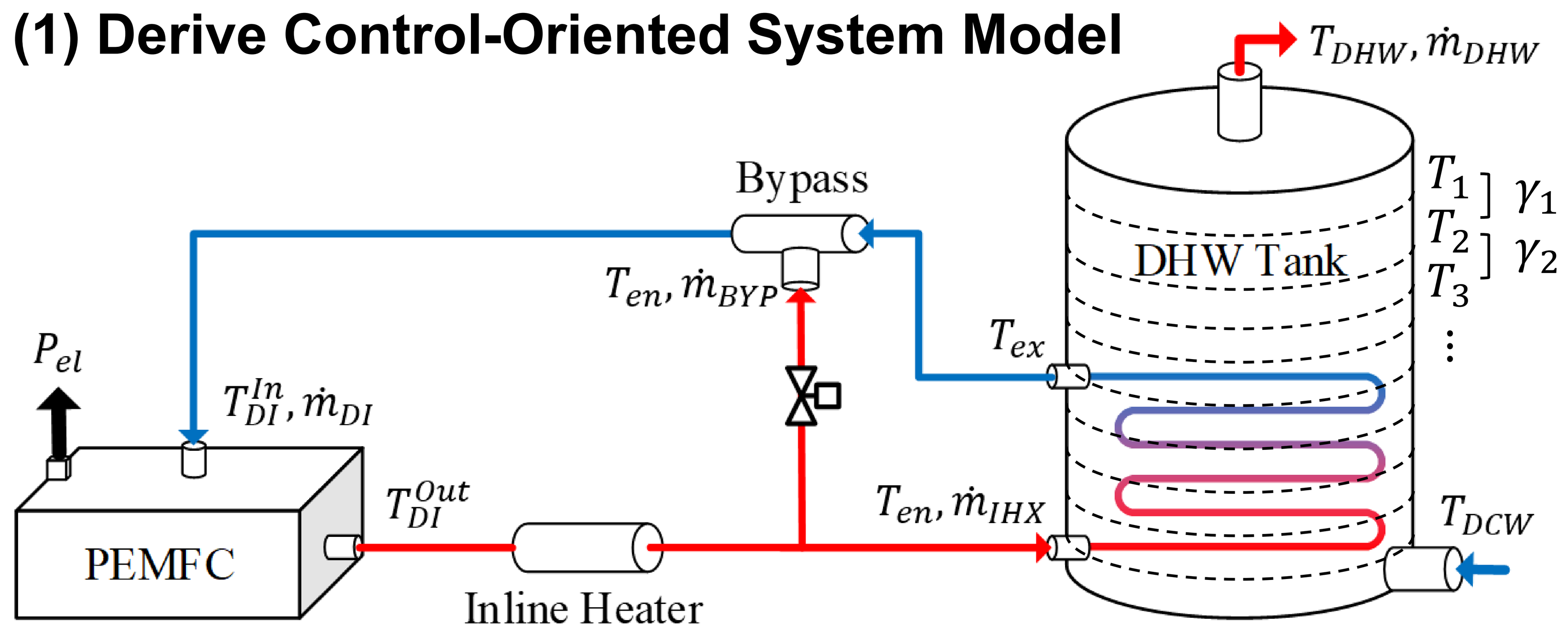
Problem Statement

- Distributed energy resources (DER) have the potential to increase **robustness to blackouts** and **increase overall efficiency** of electricity generation and distribution
- Micro-CHP (Combined Heat and Power) systems are DERs that combine controllable (non-renewable) electricity generation with waste heat recovery methods
- However, the operation of micro-CHP systems is limited by their **synchronous generation** of heat and power while tasked with meeting **asynchronous loads**
  - Current control methods only aim to meet a single load and often operate in a state of full on or off (e.g. thermostat control)

Research Objective:
Develop optimal control strategies for micro-CHP systems to improve demand response and economic viability

Approach

(1) Derive Control-Oriented System Model



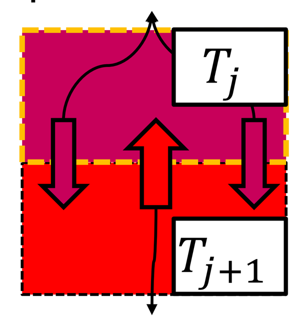
Hybrid switched system model used to capture nonlinear temperature inversion dynamics within Domestic Hot Water (DHW) Tank

$$x[k+1] = A_\sigma x[k] + B_\sigma u[k] + W_\sigma v[k] + f_\sigma$$

$$\sigma(\gamma): \mathbb{R}^{n-1} \rightarrow [1, \cdots, m]$$

$$\gamma_j = \begin{cases} 1 & \text{if } T_{j+1} > T_j \\ 0 & \text{otherwise} \end{cases}$$

Displaced cool water



Rising warm water

(2) Controller Design for Demand Response

Model Predictive Control (MPC) used to track a prescribed electricity demand while maintaining a desired domestic hot water (DHW) supply temperature

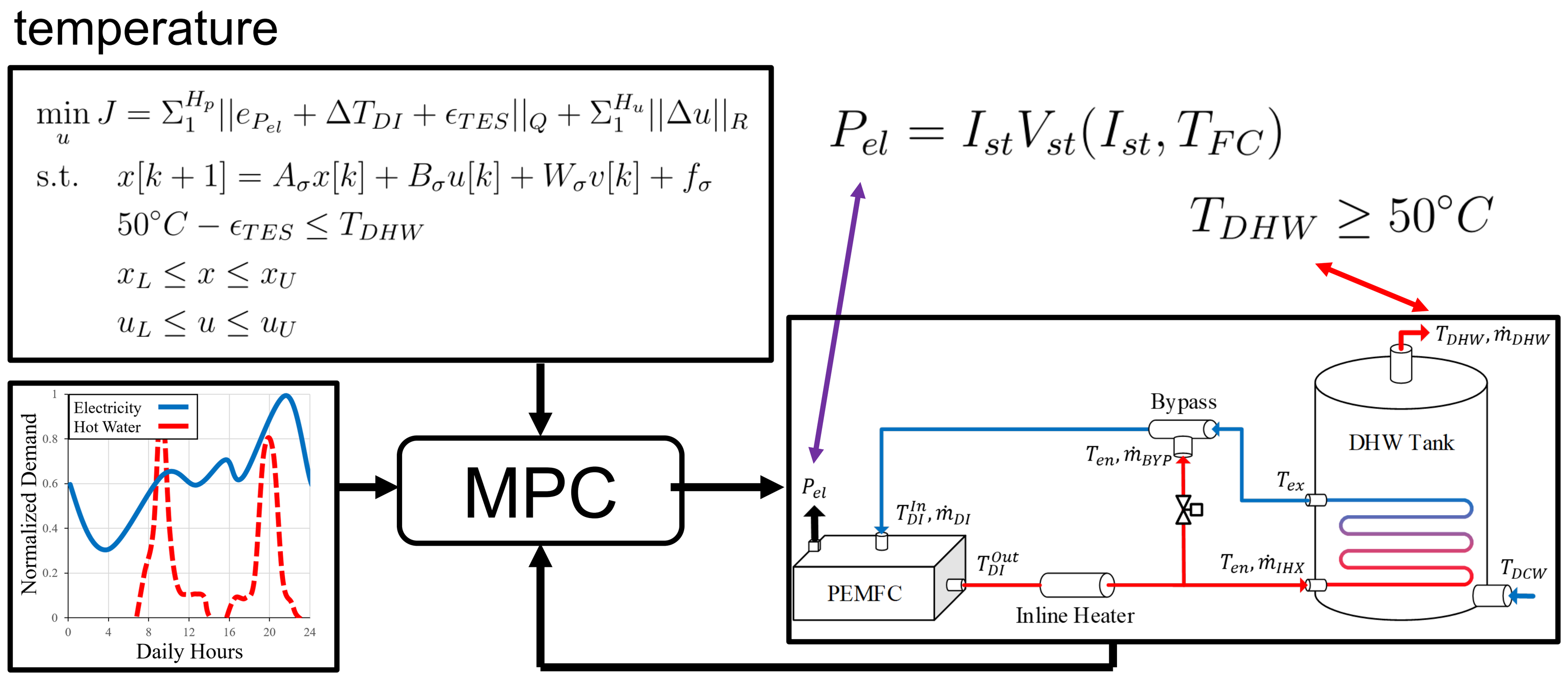
$$\min_u J = \Sigma_1^{H_p} ||e_{P_{el}} + \Delta T_{DI} + \epsilon_{TES}||_Q + \Sigma_1^{H_u} ||\Delta u||_R$$

$$\text{s.t.} \quad x[k+1] = A_\sigma x[k] + B_\sigma u[k] + W_\sigma v[k] + f_\sigma$$

$$50°C - \epsilon_{TES} \leq T_{DHW}$$

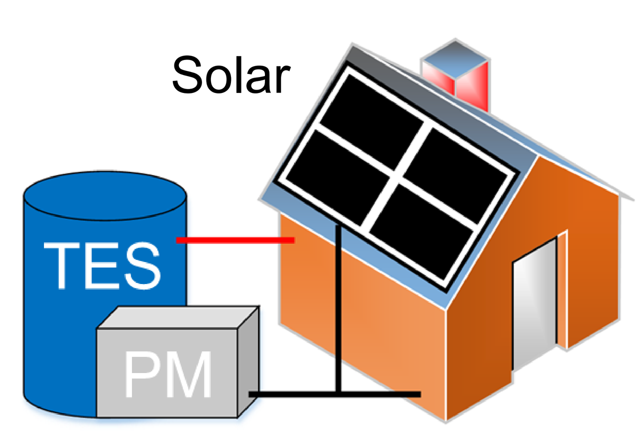
$$x_L \leq x \leq x_U$$

$$u_L \leq u \leq u_U$$



(3) Field Testing of Real-Time Control in DC-House

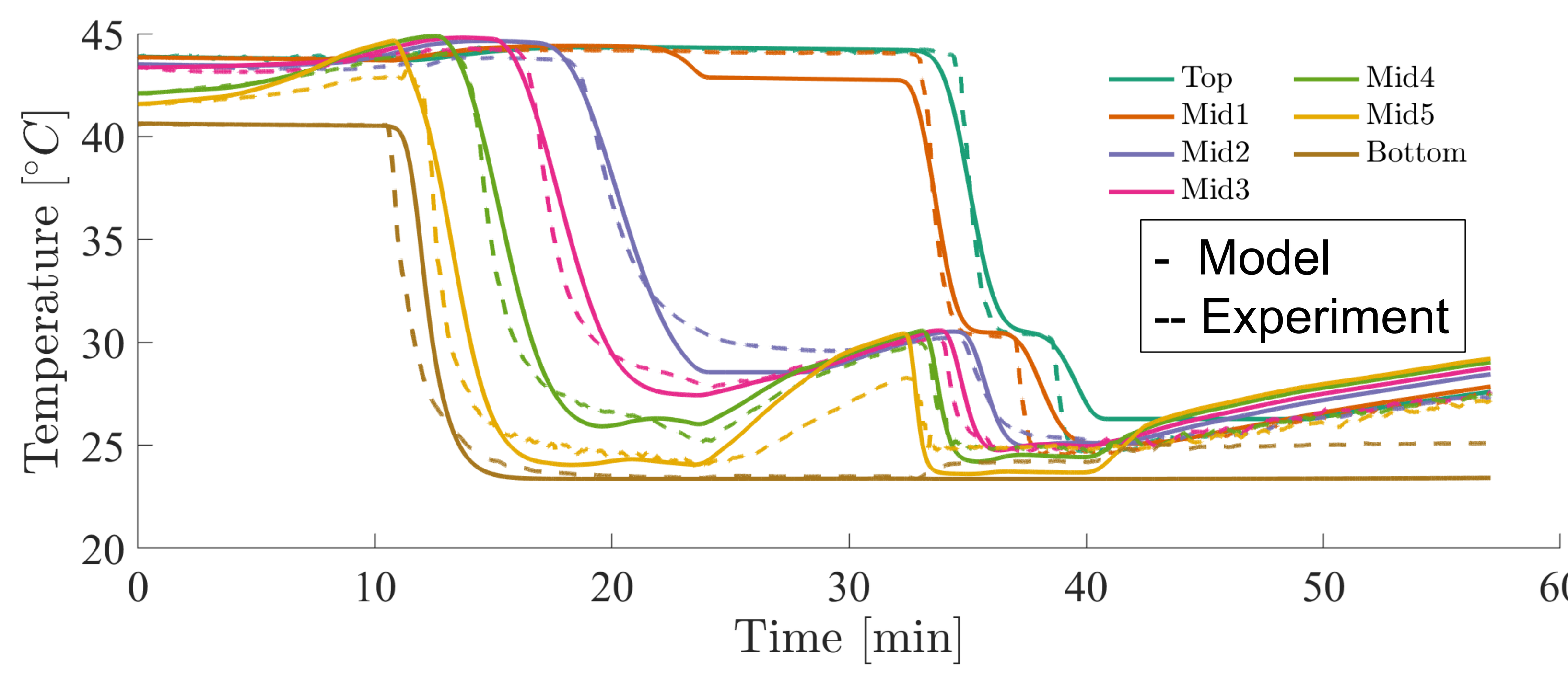
Integrate experimental testbed with DC nano-grid and additional electricity sources (e.g. solar PV) for real-time testing of optimal control strategies in a residential setting



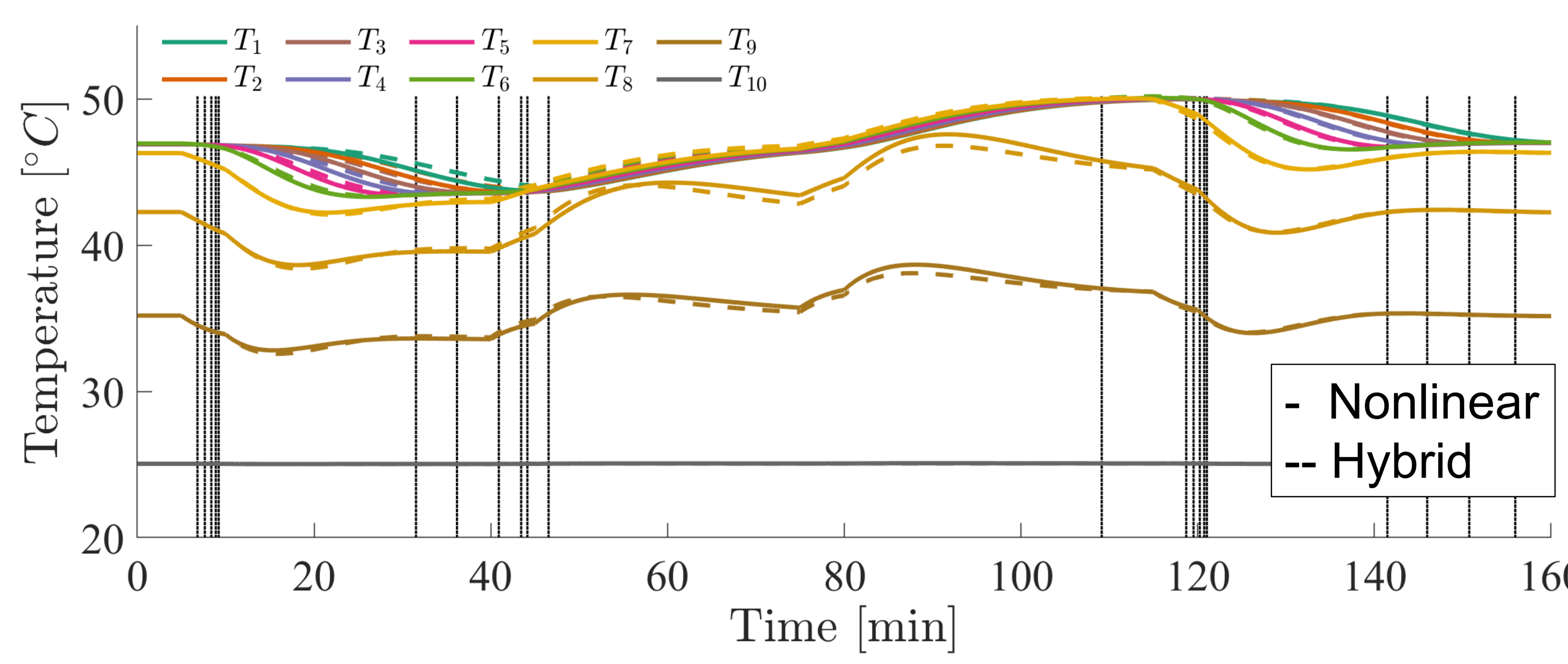
PURDUE MECHANICAL ENGINEERING

Results

Validation of System Models



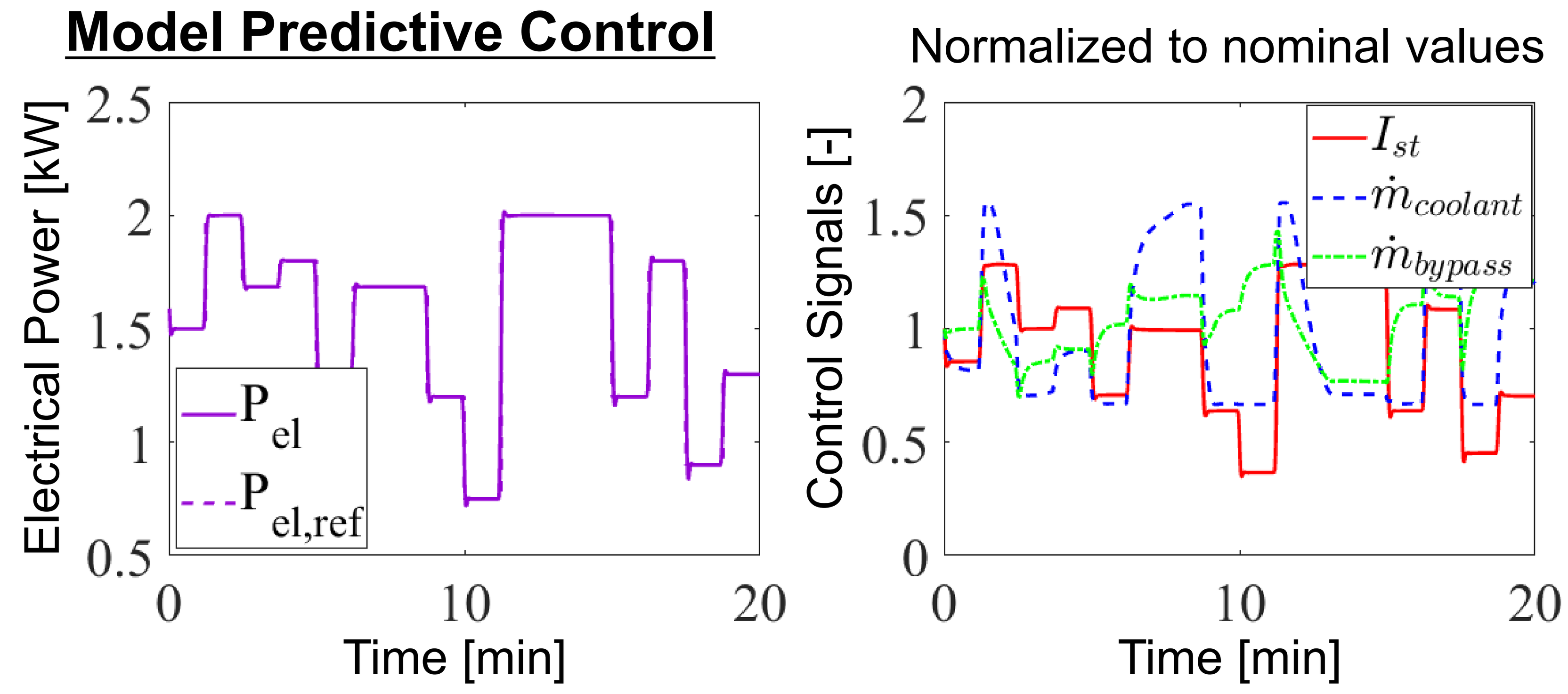
Nonlinear simulation model validated against experimental platform.



Hybrid switched linear model approximates nonlinear dynamics

Model Predictive Control

Normalized to nominal values



The controller is able to regulate the fuel cell temperature and current to track a prescribed electrical power demand

Future Work

1. Develop tools to estimate reach sets of hybrid systems with complex state-dependent switching
2. Increase complexity of system by considering control of micro-CHP when coupled with additional electricity sources and sinks

Potential Impact of Research

- The optimal control strategies developed in this research may increase the economic viability of micro-CHP systems
- Generalization of the validated modeling and control methodologies could be translated to other complex thermal systems

Acknowledgements

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[2] A. Nash et al., "Dynamic modeling of a sensible thermal energy storage tank with an immersed coil heat exchanger under three operation modes," Applied Energy 2017

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