Optimal Co-Design of Integrated Thermal-Electrical Networks and Control Systems for Grid-interactive Efficient District (GED) Energy Systems

DE-EE0009139

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06/09/2022

Acknowledgement

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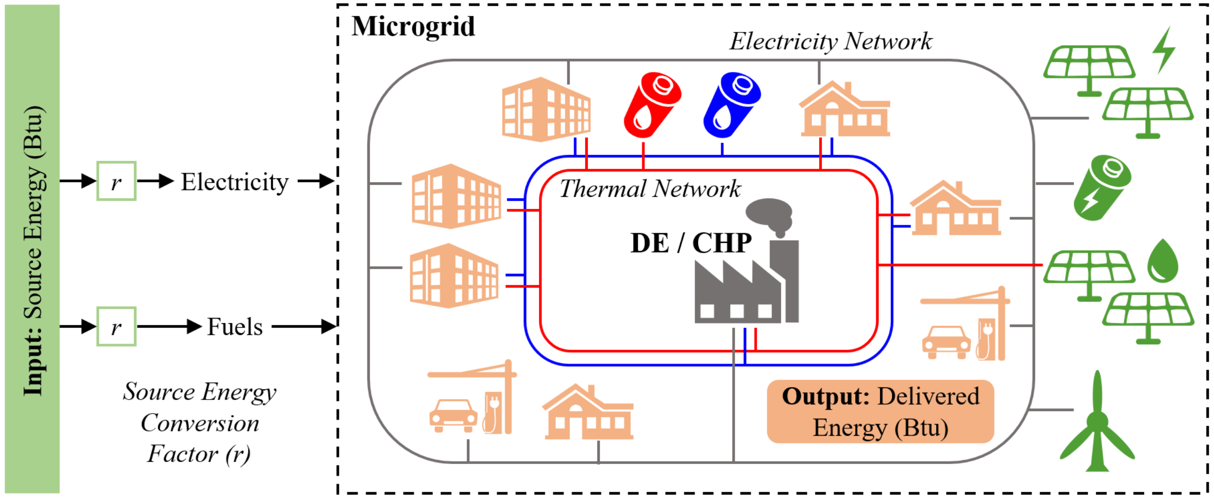
Amzur Technologies: Raymond Kaiser

Outline

- Project Objectives
- Introduction of URBANopt and Modelica
- Project Scope
- Project Progress
- Plan for the Next Step

Project Objectives

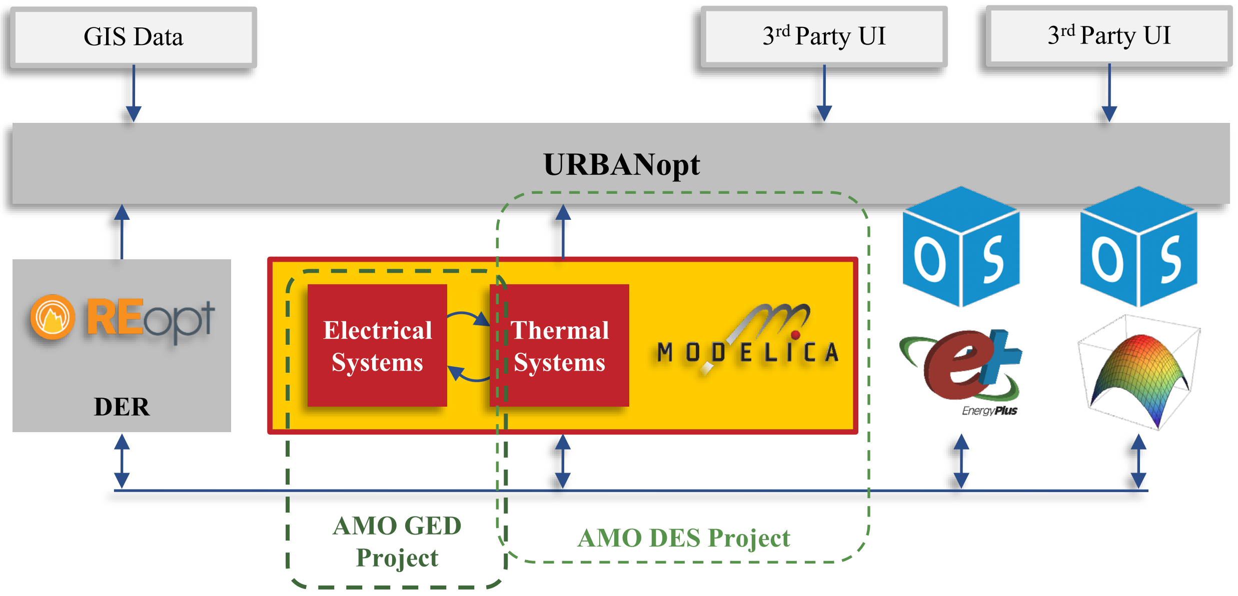
To create a holistic *open-source modeling platform* for the optimal design and retrofit of the GED energy systems and microgrids via integrating thermal and electrical systems along with their integrated control.



We aim to

- achieve a **25% total system energy efficiency** improvement compared to current state-of-the-art district energy and microgrid systems
- increase **the number of continuous operational hours by at least 25%** to increase the resilience of the district energy system.

Project Scope

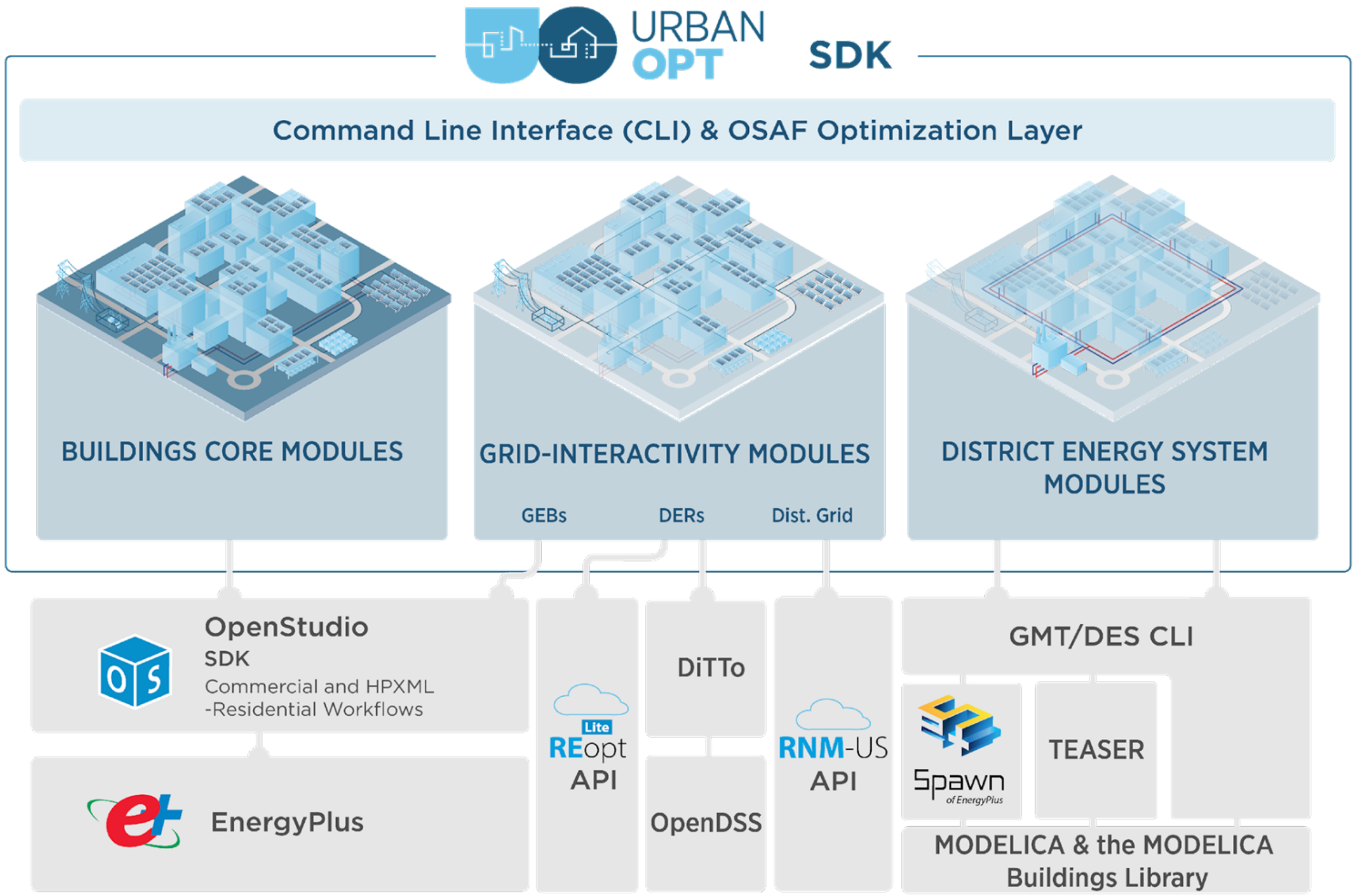


Budget Period 1 (2020.10~2022.9): Develop the Alpha version of the Optimal Co-Design Platform.

Budget Period 2 (2022.10~2023.9): Develop a Beta version of the Optimal Co-Design Platform.

Budget Period 3 (2023.10~2024.9): Demonstrate the performance targets at two distinct sites, publicly release the final version of the modelling platform, finalize the commercialization plan, and identify partners for commercialization.

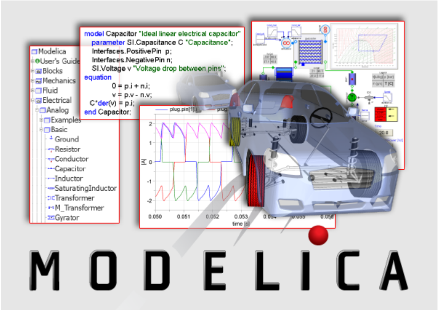
URBANopt Advanced Analytics Platform



Website: https://www.nrel.gov/buildings/urbanopt.html

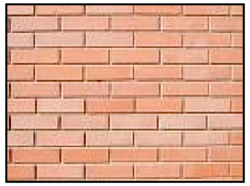
Equation-Based Modeling with Modelica

Modelica: Equation-based, object-oriented, multi-domain modeling language for dynamic systems
- Developed since 1996
- three free standard libraries with 2100+ models
- 100+ free & commercial libraries

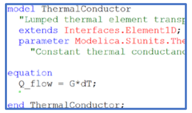


Separation of Concerns

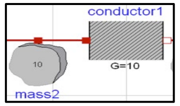
Modeling
(by Human)



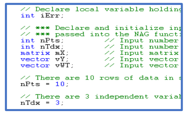
Modeling



Equations



Diagrams

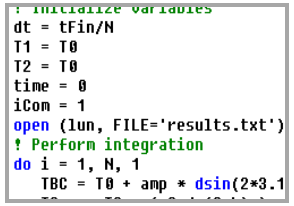


Algorithms

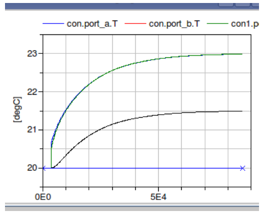
Acausal & Transparent Models

Code Generation, Computing & Optimization
(by Computer)

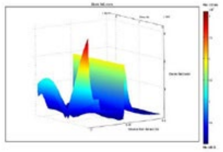
Code Generation



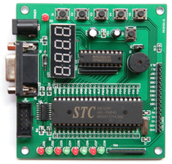
Procedural Code



Simulation



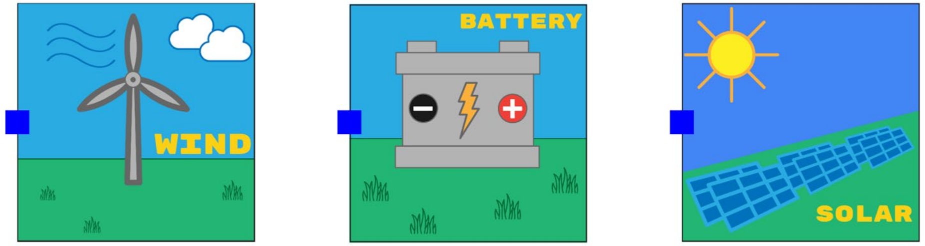
Optimization



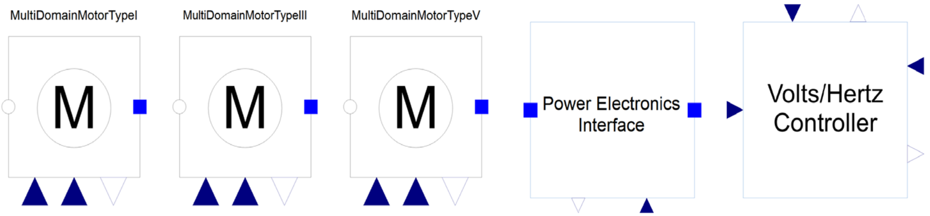
Embedded Computing

Modelica Models for Microgrid

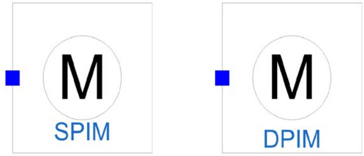
Components Implemented in OpenIPSL Library



Implementation of renewable sources and battery energy storage

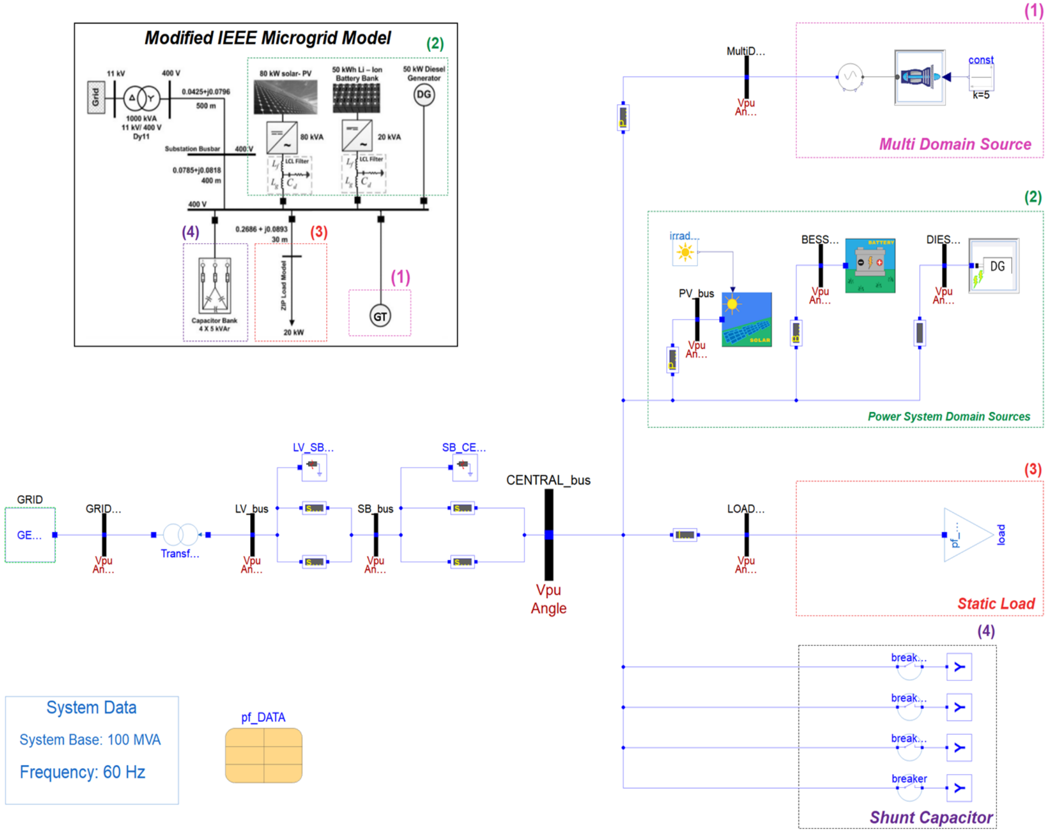


Implementation of multi-domain three phase induction motors and variable speed drive control



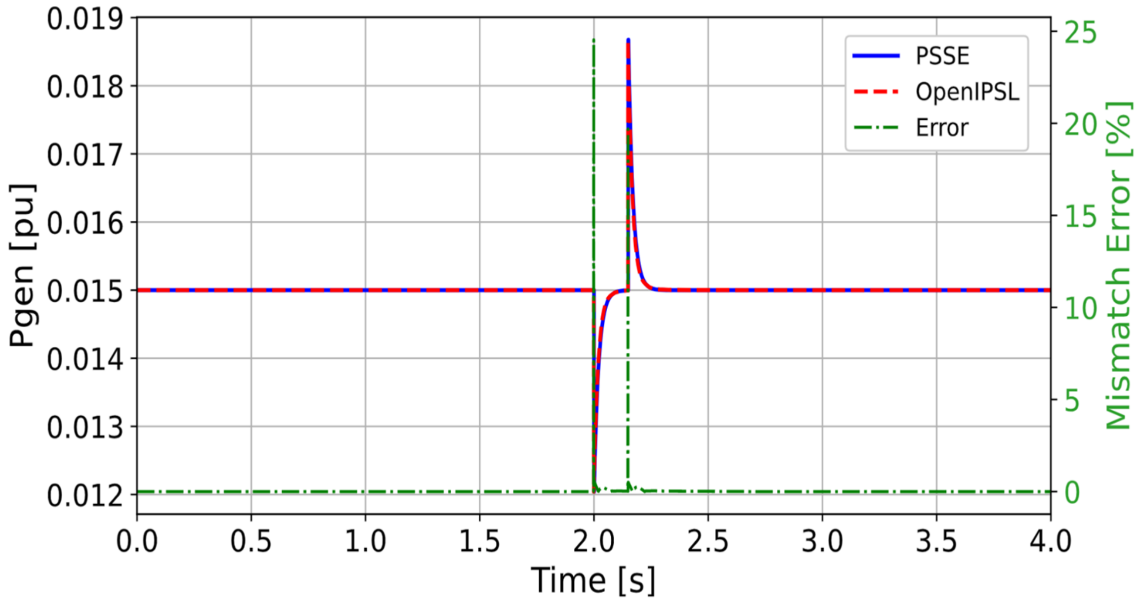
Implementation of single & double phase motors for AC unit

System Examples: Microgrid

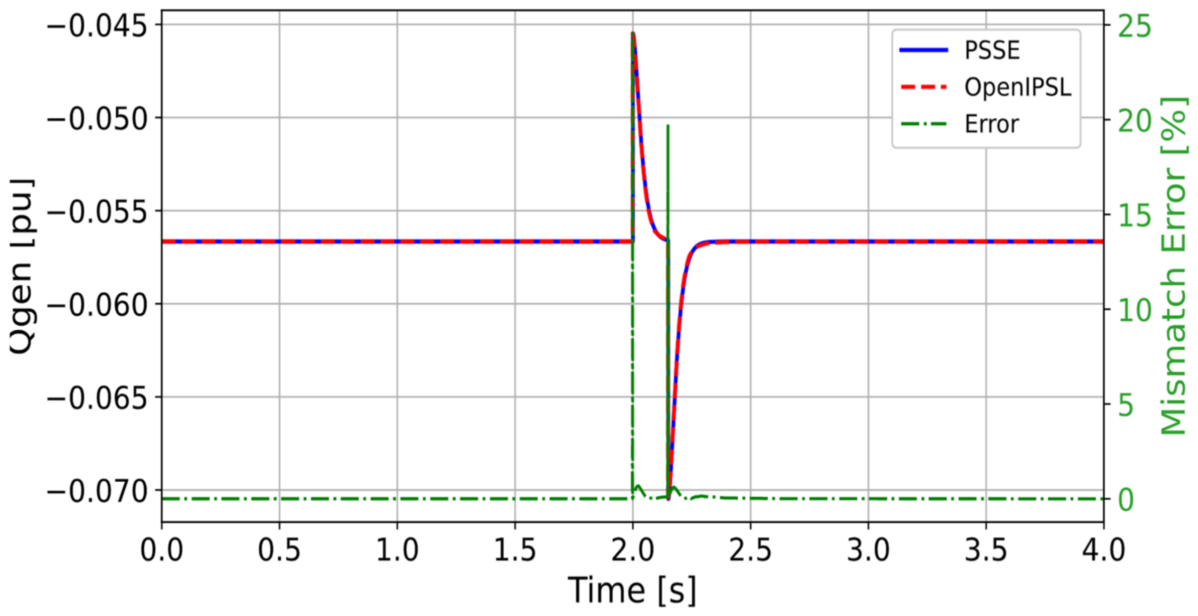


Alpha Version of the IEEE Microgrid model for stability studies

Case Study: Validation of Microgrid Model



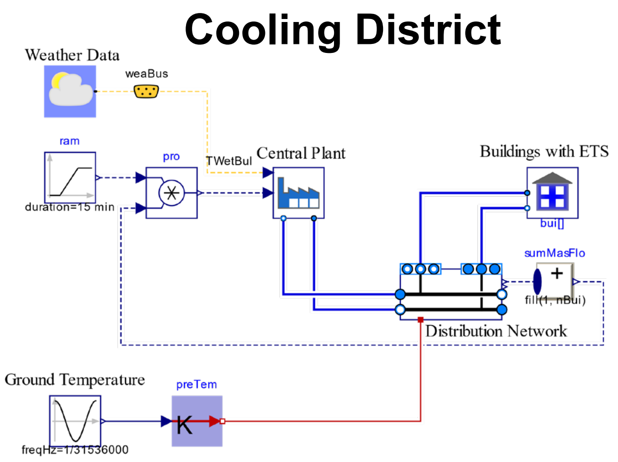
Validation results for Active Power Injection of OpenIPSL PV model against PSSE

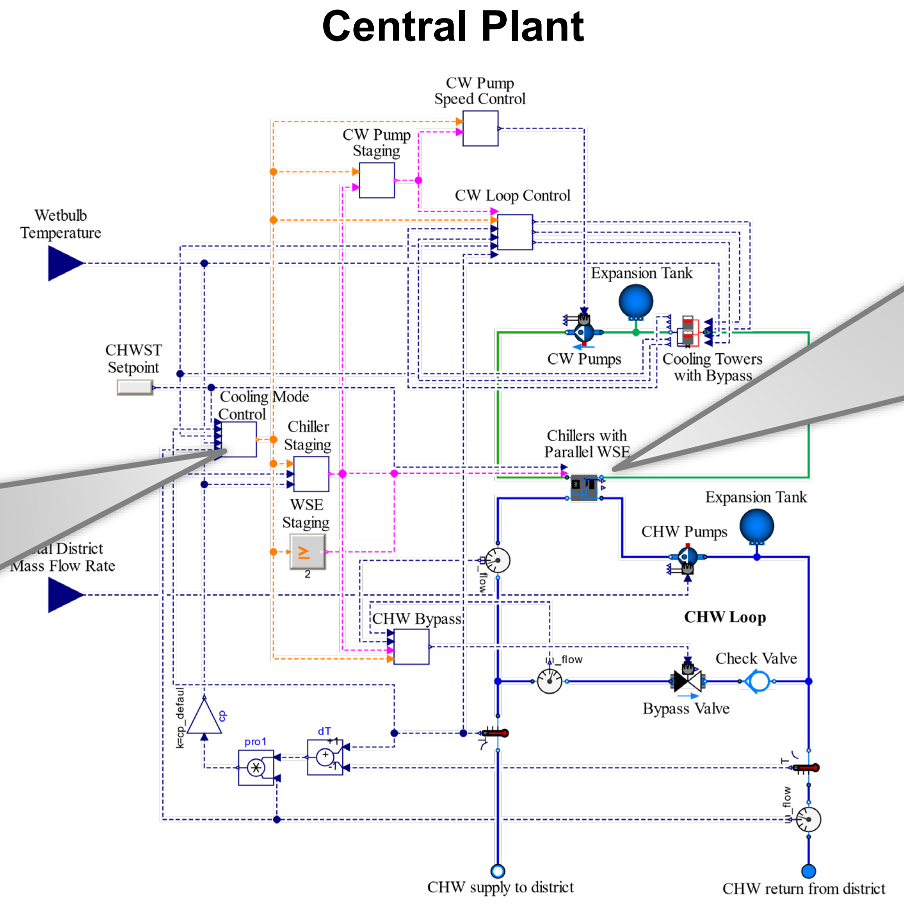


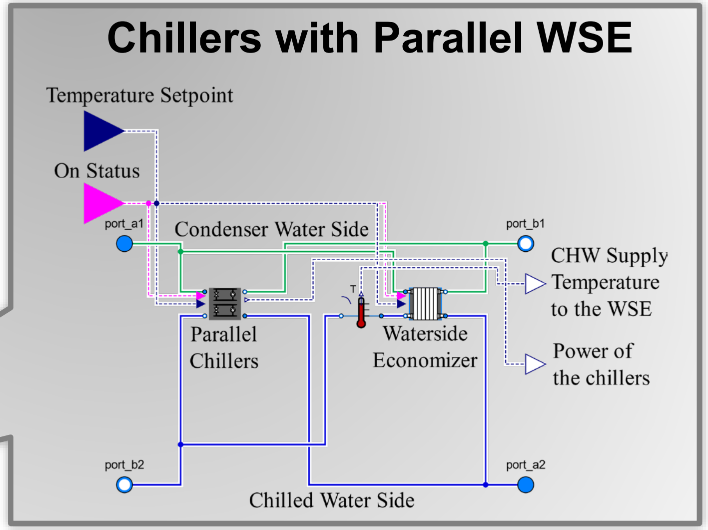
Validation results for Reactive Power Injection of OpenIPSL PV model against PSSE

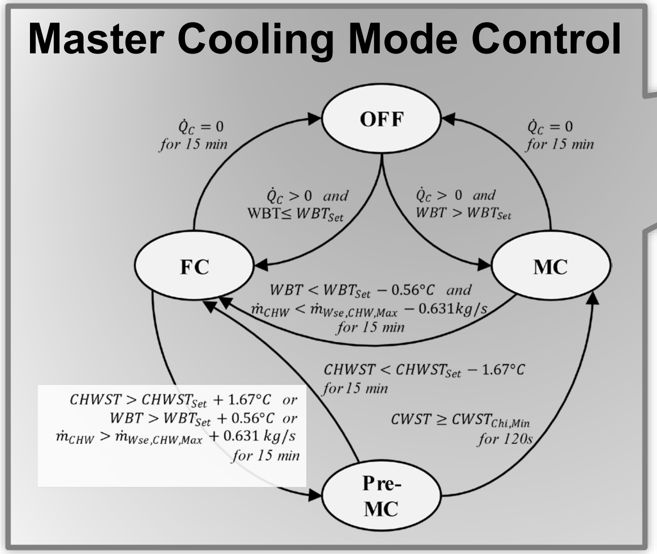
F. Fachini, L. Vanfretti, M. de Castro, T. Bogodorova and G. Laere, "Modeling and Validation of Renewable Energy Sources in the OpenIPSL Modelica Library," *IECON 2021 – 47th Annual Conference of the IEEE Industrial Electronics Society*, 2021, pp. 1-6.

District Cooling Systems









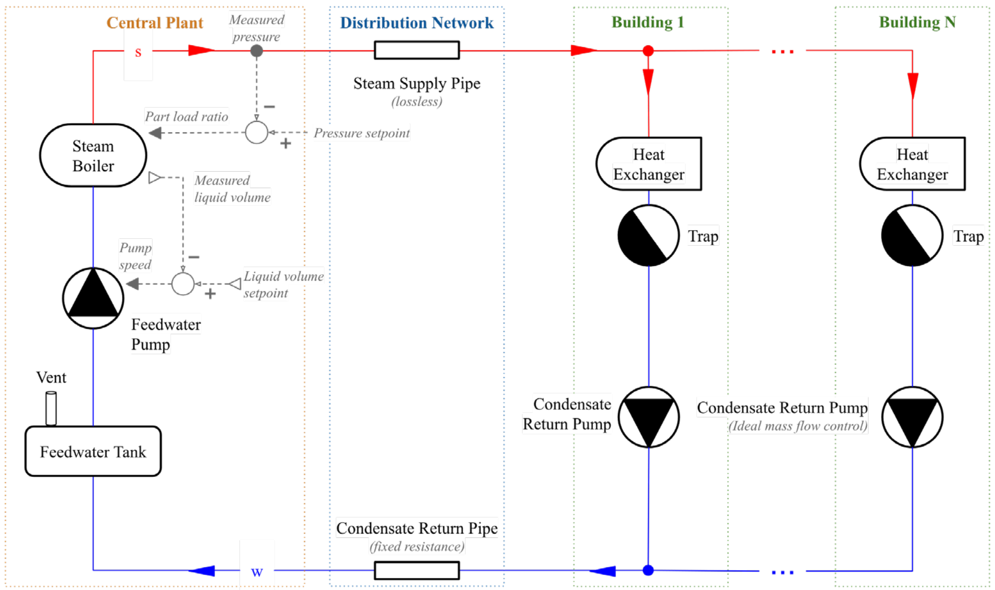
Model-based control optimization leads to:

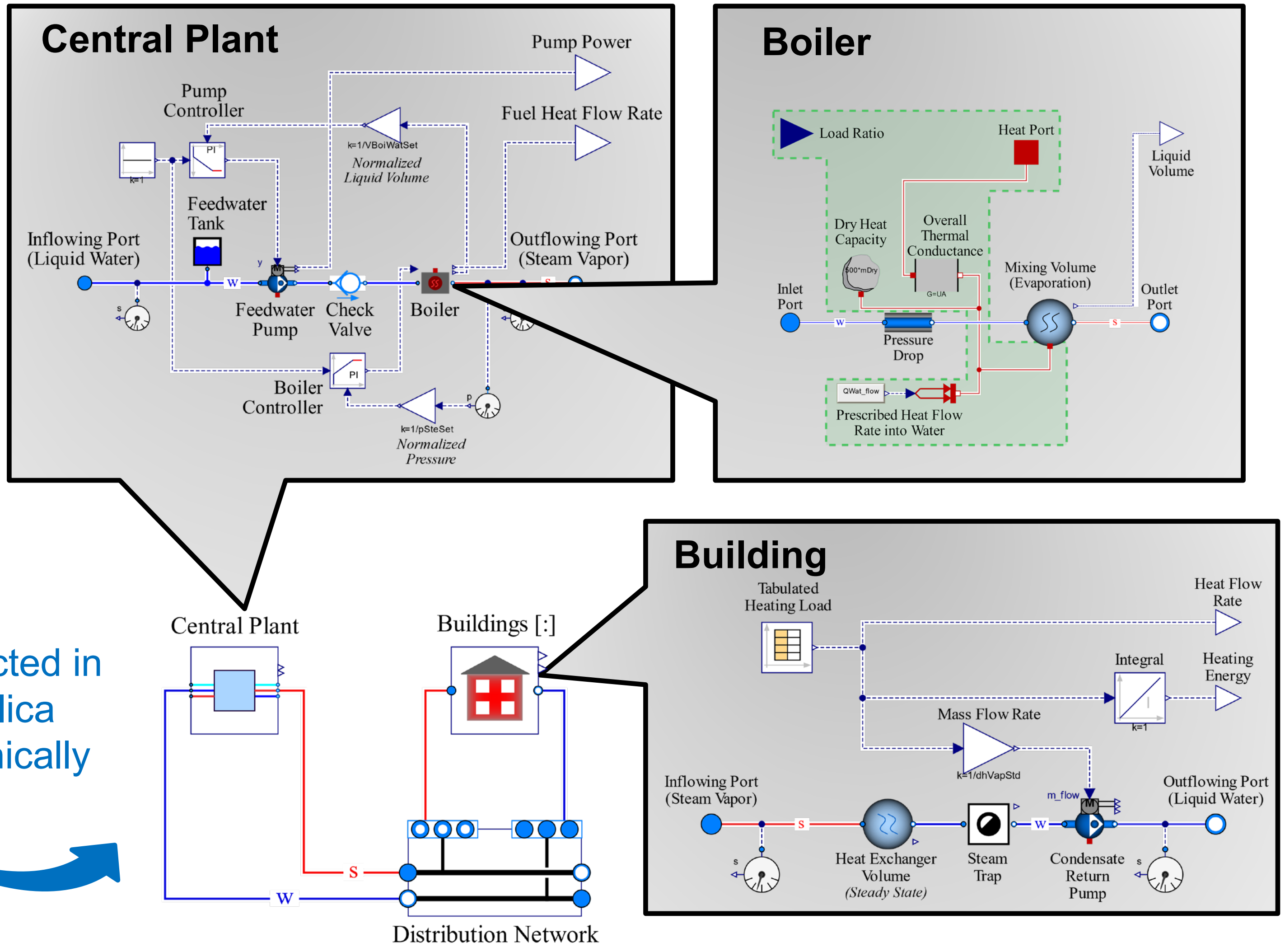
- 15.3% reduction in Energy
- 8.9% reduction in Cost
- 15.0% reduction in CO_2 emission

K. Hinkelman, J. Wang, W. Zuo, A. Gautier, M. Wetter, C. Fan, N. Long. 2022. "Modelica-Based Modeling and Simulation of District Cooling Systems: A Case Study." Applied Energy, 311, pp.118654.

District Heating Systems

System Schematic





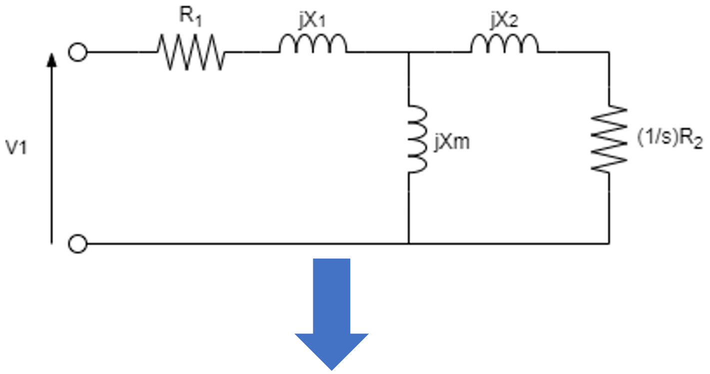
Constructed in Modelica hierarchically

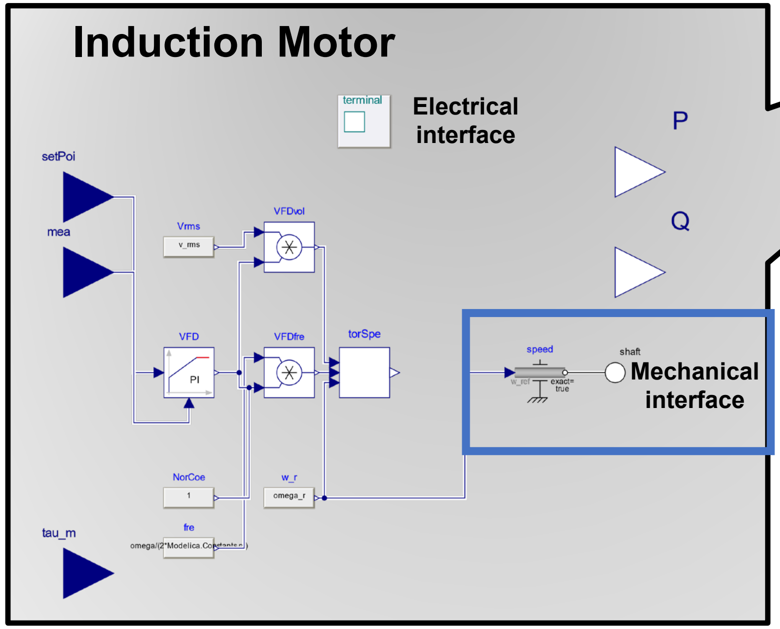
A new approach to model district heating system can reduce computing time for a network with 180 buildings **from 33 hours to 1.3 hours with a relative error <0.079%**

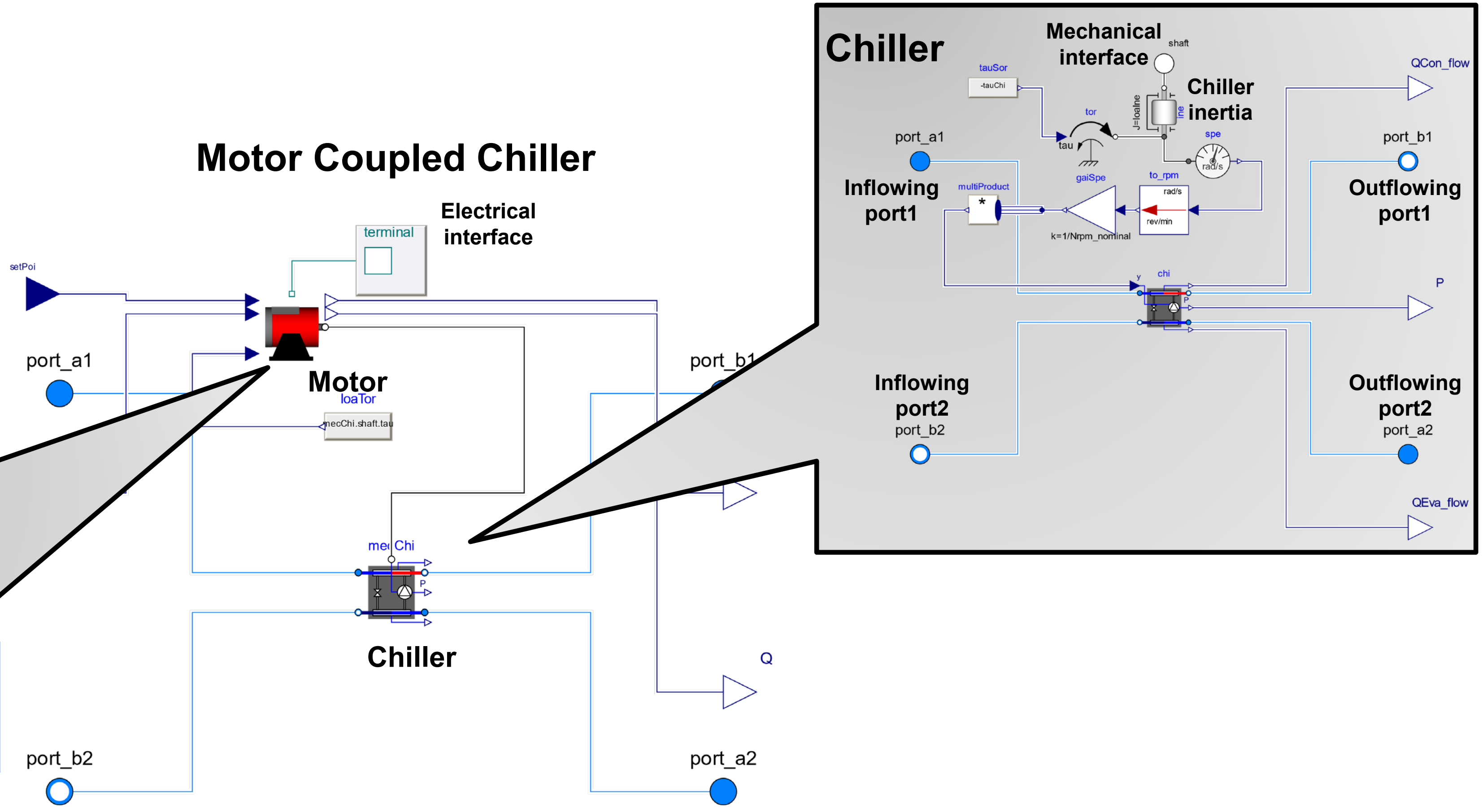
K. Hinkelman, S. Anbarasu, M. Wetter, A. Gautier, W. Zuo, 2022. “A Fast and Accurate Modeling Approach for Water and Steam Thermodynamics with Practical Applications in District Heating System Simulation.” *Energy*.

Integration of Electric-Thermofluid System

Induction Motor Equivalent Circuit



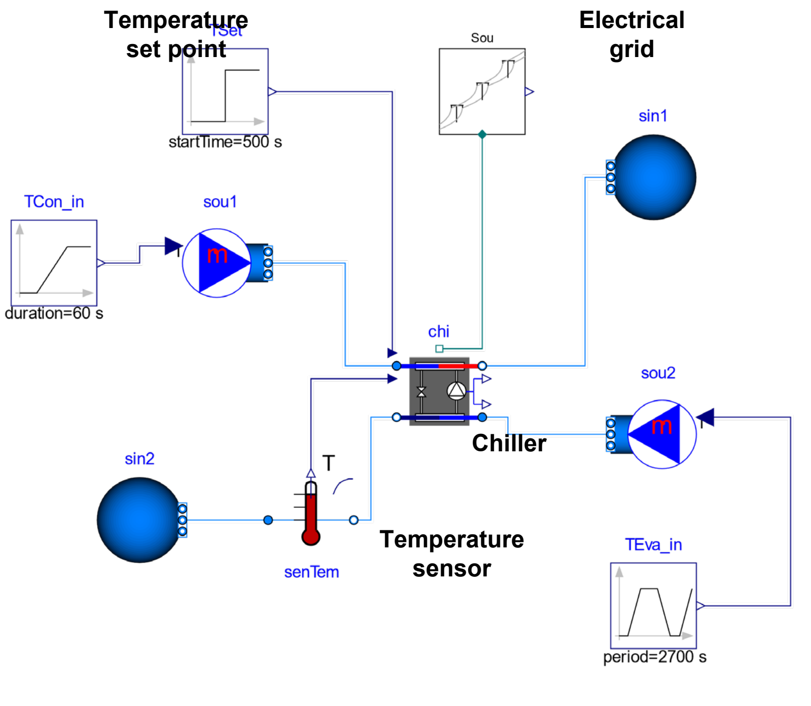




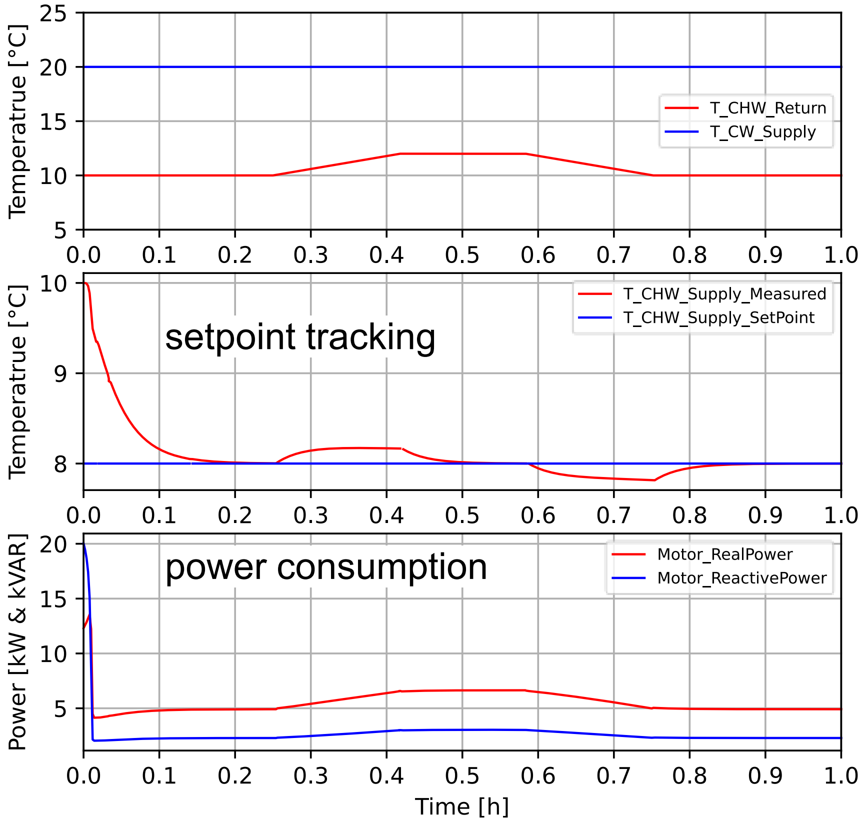
An implementation to couple electric and thermofluid systems, which constructs the model in Modelica hierarchically.

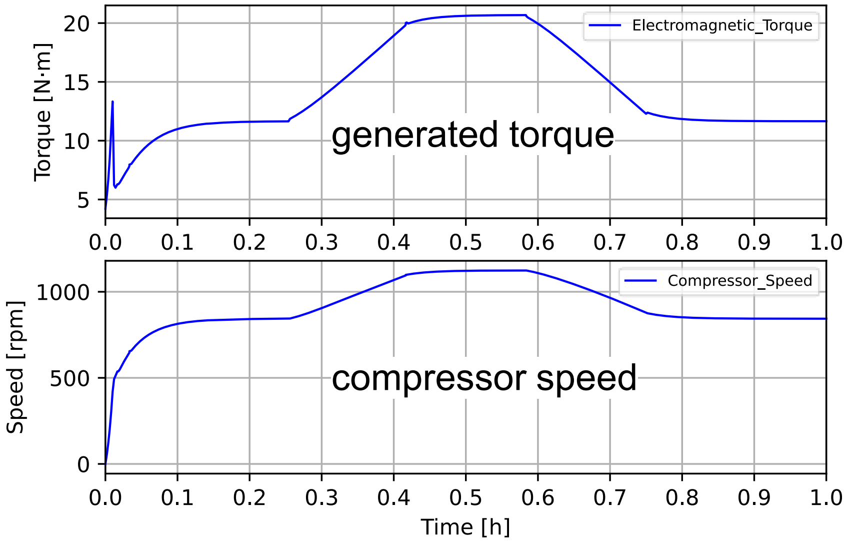
Case Study

This case study shows a motor coupled chiller used to track the chilled water supply temperature set point (8 °C), when the chilled water return temperature changes.



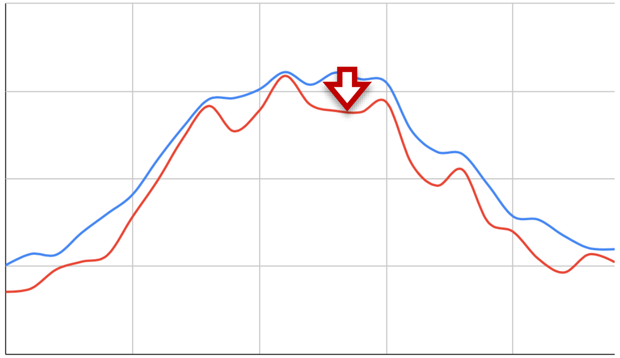
System Schematic



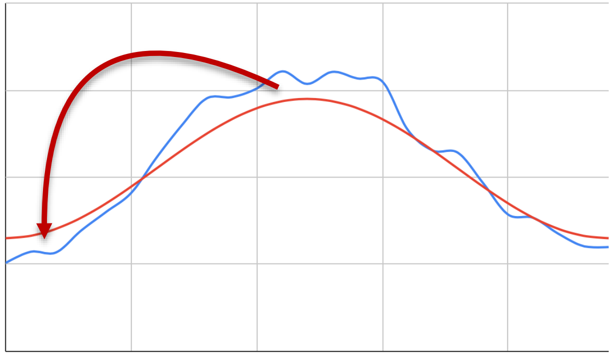


Optimization

We will create a multi pronged approach to improving efficiency throughout the electrical network



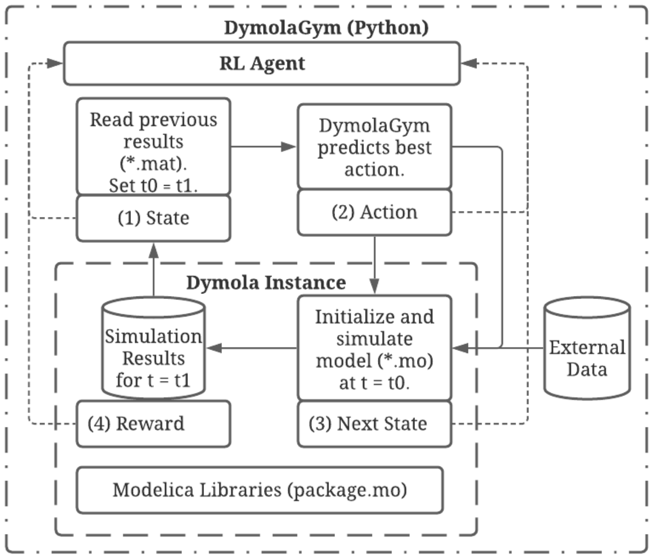
(a) Load reduction where possible



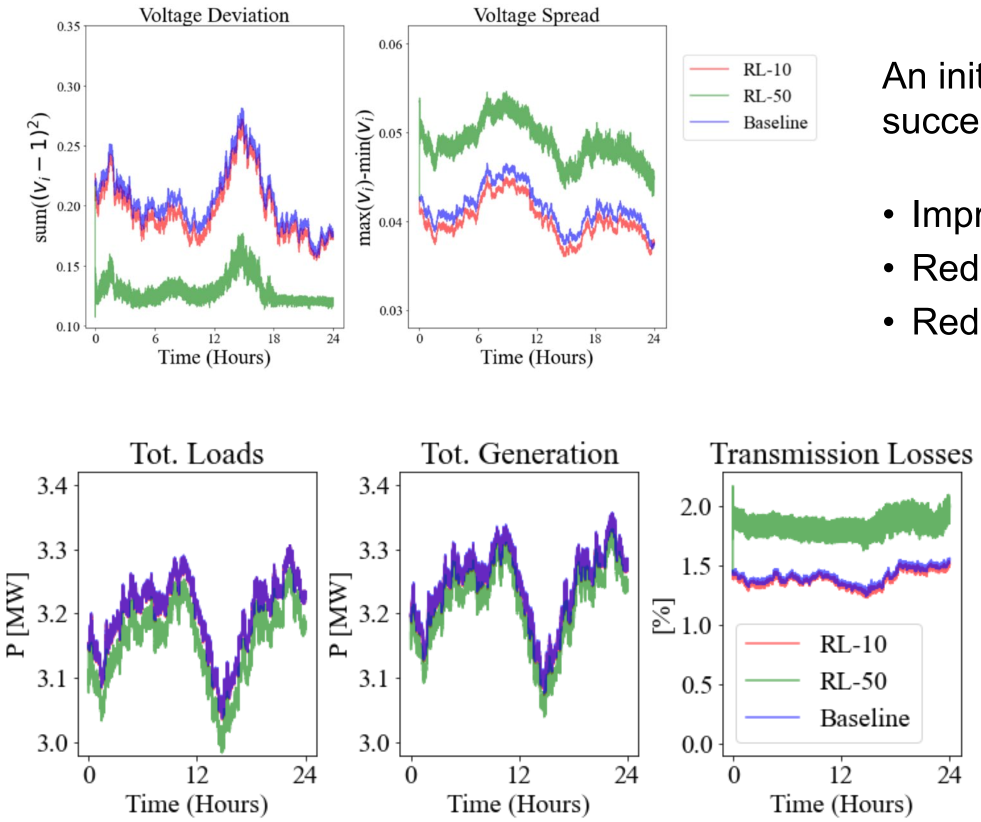
(b) Peak shaving to reduce stress on generation

	(Thermal) Demand response	Generator setpoint optimization	Battery energy storage
Reduce consumption (Fig. a)	X		
Peak shaving and shaping	X		X
Reduce line losses		X	X

Optimization: Reinforcement Learning



DymolaGym allows for rapid prototyping of reinforcement learning environments using Modelica based models



An initial case study showed success with:

- Improved voltage regulation
- Reduced line losses
- Reduced overall generation

A. Pigott, K. Baker, S. Dorado-Rojas, L. Vanfretti. “Dymola-Enabled Reinforcement Learning for Real-time Generator Set-point Optimization.” IEEE ISGT, 2022.

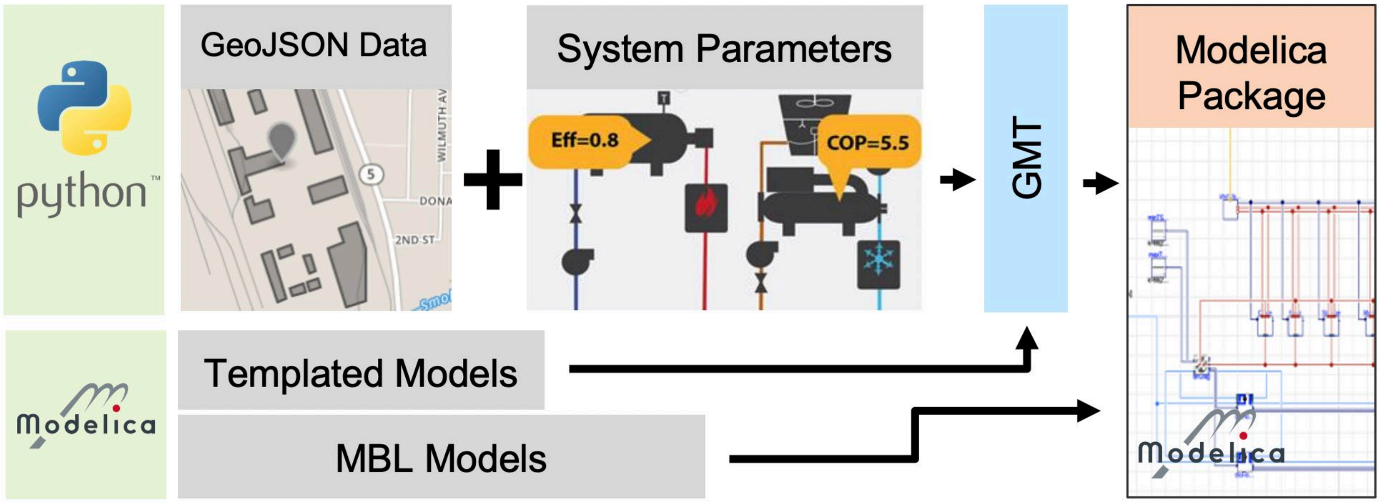
URBANopt SDK to Modelica

URBANopt Software Development Kit (SDK) integrates multiple analysis tools including OpenStudio, OpenDSS, REopt, and the GeoJSON to Modelica Translator.

The GeoJSON to Modelica Translator currently handles two levels of model construction.

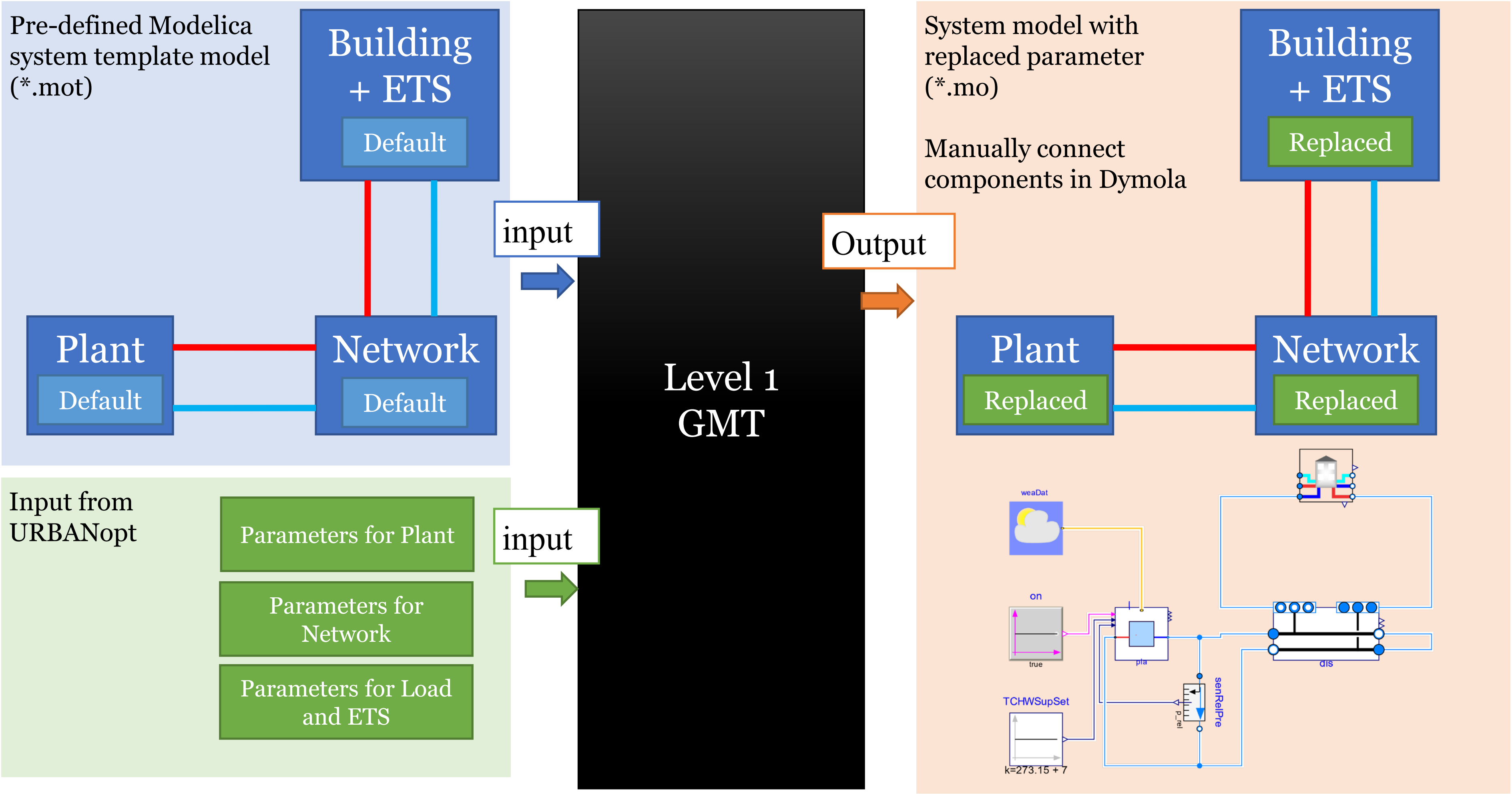
Level 1: The focus of this project. Enables string substitution into Modelica files to create simulatable models.

Level 3: Dynamically generates couplings. Currently only works for 4G and 5G systems. Loads are dynamically created and connected and include Spawn, TEASER, and time series data. Time series data can be sourced from URBANopt SDK's OpenStudio simulations.



URBANopt to Modelica

Based on the inputs from URBANopt, GeoJSON to Modelica Translator (GMT) replaces some default design and sizing parameters in existing Modelica system template models.



Demonstration via Case Studies

Using the University of Colorado Boulder and University of Texas at Austin Campuses to demonstrate that the proposed platform can achieve

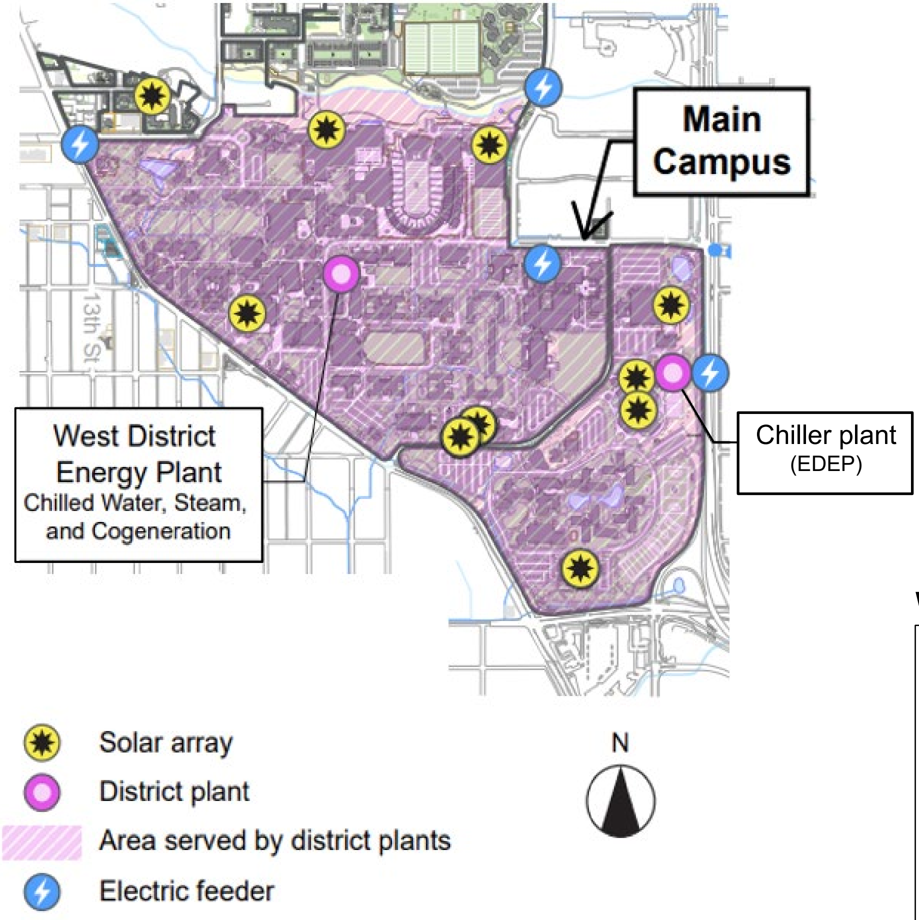
- 25% total system energy efficiency improvement from source energy to delivered energy

- 25% increase in the number of continuous operational hours in a simulation environment

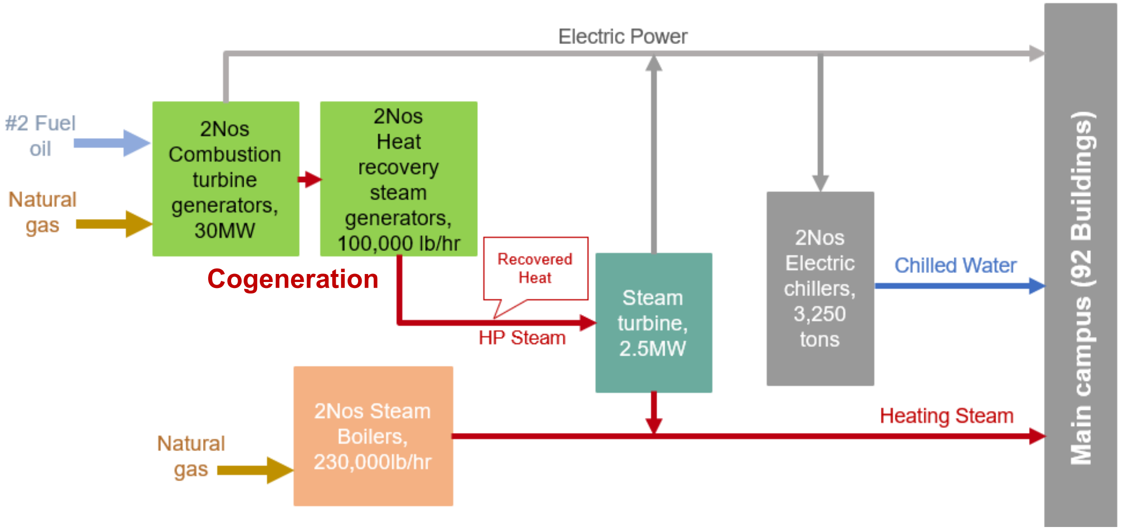
Timeline

- Phase 1: Data collection
- Phase 2: Develop and calibrate models
- Phase 3: Demonstration

Case Study: University of Colorado Boulder



2.26 MW



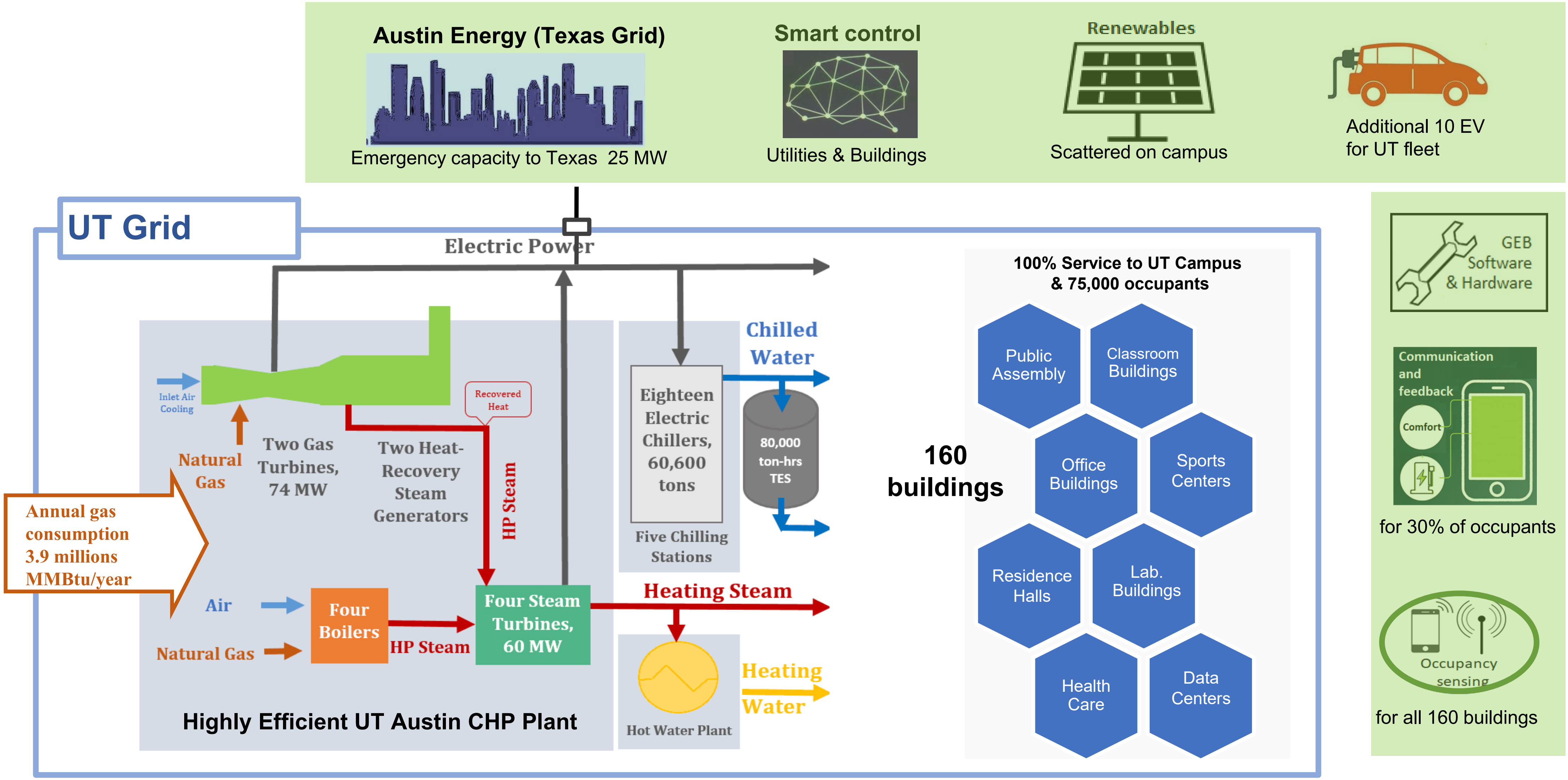
West district energy plant

	Dual fuel combustion turbines	Extraction condensing turbine	Variable flow chillers	Dual fuel boilers	Heat recovery steam generators
No	2	1	2	2	2
Capacity	15 MW	2.5 MW	1625 Ton	130,000lbs/hr	50,000 lb/hr

Buildings demand

Number of buildings	Steam demand	Chilled water demand	Electricity demand
92	160,000 lb/hr	3,000 tons	20-25 MW (summer peak)

Case Study: University of Texas Austin



Outreach and Engagements

- Formed a Technical Advisory Group with major stakeholders

- Interviewed NREL software developers regarding commercialization success factors.

- Open Source Release
  - URBANopt Release GMT 0.2.3 Release https://github.com/urbanopt/geojson-modelica-translator
  - Modelica Buildings Library targeted release of V9.0 in summer 2022 https://simulationresearch.lbl.gov/modelica/index.html
  - Modelica OpenIPSL library release https://github.com/ALSETLab/MicroGrid_MultiDomain/tree/MicroGrid-MultiDomain

- Publications: Two (2) journal papers and three (3) conference papers

- Project Website: https://sites.psu.edu/sbslab/research/city/grid-interactive-efficient-district-energy-system/

Plan for the Next Step

Budget Period 1 (Now to 9/22): Complete the release of Alpha Version.

Budget Period 2 (2022.10~2023.9): Develop a Beta version of the Optimal Co-Design Platform.

Budget Period 3 (2023.10~2024.9): Demonstrate the performance targets at two distinct sites, publicly release the final version of the modelling platform, finalize the commercialization plan, and identify partners for commercialization.

Thank you!

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