VII.C.1 Optimal Stationary Fuel Cell Integration and Control (Energy Dispatch Controller)

Genevieve Saur
National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401-3305
Phone: (303) 275-3783
Email: genevieve.saur@nrel.gov

DOE Manager: Jason Marcinkoski
Phone: (202) 586-7466
Email: Jason.Marcinkoski@ee.doe.gov

Subcontractors:
- Washington State University, Pullman, WA
- University of Colorado Boulder, Boulder, CO

Project Start Date: June 2016
Project End Date: May 2019

Overall Objectives

Create an open source tool set to foster growth in fuel cell integrated buildings with emphasis on optimal dispatch control.

- Objective 1: Energy Dispatch Controller (EDC) – Implement an open source tool for optimized dispatch of building components, to be used in building management systems in communicating and transacting with a fuel cell integrated building system and the grid.
- Objective 2: System Planning Tool – Implement a planning tool for optimal component selection and sizing for distributed energy systems and smart building components, using location-specific energy markets, building energy modeling, and chosen dispatch control strategy.

Fiscal Year (FY) 2017 Objectives

- Initial formulation of the EDC optimization using model predictive control.
- Develop initial graphical user interface screens to provide interface for testing and feedback.
- Create interface for providing building specification and design.
- Create a functioning co-simulation environment for testing EDC.

Technical Barriers

This project addresses the following technical barriers from the Grid Modernization Initiative Multi-Year Program Plan.

- 4.2.3 Utilizing open standards and middleware software approaches to enable integration of energy management systems, distribution management systems, and building management systems. [1]
- 4.3.3 Develop efficient linear, mixed-integer, and nonlinear mixed-integer optimization solution techniques customized for stochastic power system models, novel bounding schemes to use in branch and bound, and structure exploiting algorithms. Demonstrate the cost-benefit achieved by these techniques relative to existing ones. [1]

Contribution to Achievement of DOE Technology Validation Milestones

This project provides program-specific support from the Fuel Cell Technologies Office to DOE's Grid Modernization Initiative. There are no specific milestones set for this multi-program effort [1], but this project provides support that aligns fuel cell integration and grid modernization efforts. Beneficial impacts include:

- Enhanced energy management and added benefits of an integrated building system.
- Expansion of grid supportive features of buildings as distributed energy resources.
- Support for fuel cell market development.

FY 2017 Accomplishments

- Completed initial formulation of the optimization for building controls and demonstrated the EDC optimization framework with a number of simplified cases to show how varying inputs would drive different behaviors for controlling building components.
- Developed and coded initial modules of the graphical user interface with several reviews and improvements.
- Collected foundational material on combined heat and power (CHP) design for inclusion as an option in the building design module.
- Initiated evaluation of building load forecasting for the uncontrollable loads for use as an input to the EDC optimization. Evaluating four different methods for load

forecasting: corrected naïve, autoregressive integrated moving average, neural network, and surface fit.

- Developing a co-simulation environment using EnergyPlus [2] in order to evaluate the EDC with a feedback loop using simulated buildings.

✧ ✧ ✧ ✧ ✧

INTRODUCTION

Current building control strategies can rely on arbitrary assignment of value to assets and be simplistic, needing prior analysis for set control strategies. This project is creating open source tools for dynamic building energy management: an energy dispatch controller capable of supervisory control, and a planning tool for component sizing of distributed generation and storage components using simulated dispatch. The controllable components within a building can be equipment such as fuel cell, chiller, or water heater, or the thermal mass of the building envelope as controlled through the temperature. Constraints to the energy management can be thermal comfort or required operations of specific equipment.

The project aims to modernize building energy management by holistically integrating control of building elements for optimal operation, including maximizing benefit of distributed generation and storage. The project also aids grid modernization by characterizing the potential of buildings to participate in ancillary grid services and positioning building operators to participate in ancillary grid service markets as they are available.

APPROACH

The project is using a cross-functional approach with team members who have expertise in fuel cells, power systems, commercial buildings, and building communication networks, leveraging prior knowledge with tools and research from the different areas to create a novel controller and planning tool.

The EDC optimization utilizes a model predictive control strategy. This approach allows forecasting of building loads and operation, which facilitates participations in grid ancillary service markets. The planning tool then uses simulated optimal dispatch to size added components into the system.

RESULTS

The first year of the project involved initial formulations of the EDC and foundational work on the different modules needed to run the tool (Figure 1). A graphical user interface has been developed to aid visualization of the different modules. Common methods of integrating CHP were catalogued and described, in order to portray current methods of integration and to have a basis for providing novel designs that may offer additional benefits. Initial evaluation of several load forecasting methods was also performed; insights gained will be used as input to the EDC.

The model predictive control strategy for building dispatch control allows prediction of the building operation, which facilitates participation in ancillary grid services. The forecast provides knowledge of expected capacity for providing services at different times. Factors such as current temperature, equipment states, utility costs, weather prediction, and load forecasting are used as inputs. The EDC optimization then determines an optimal operation over the next 24-hour period and implements set-points for the next one hour. The optimization runs again each hour over a rolling 24-hour period. Variation between scheduled and actual operation occur due to building feedback and variability in actual building loads versus the forecast.

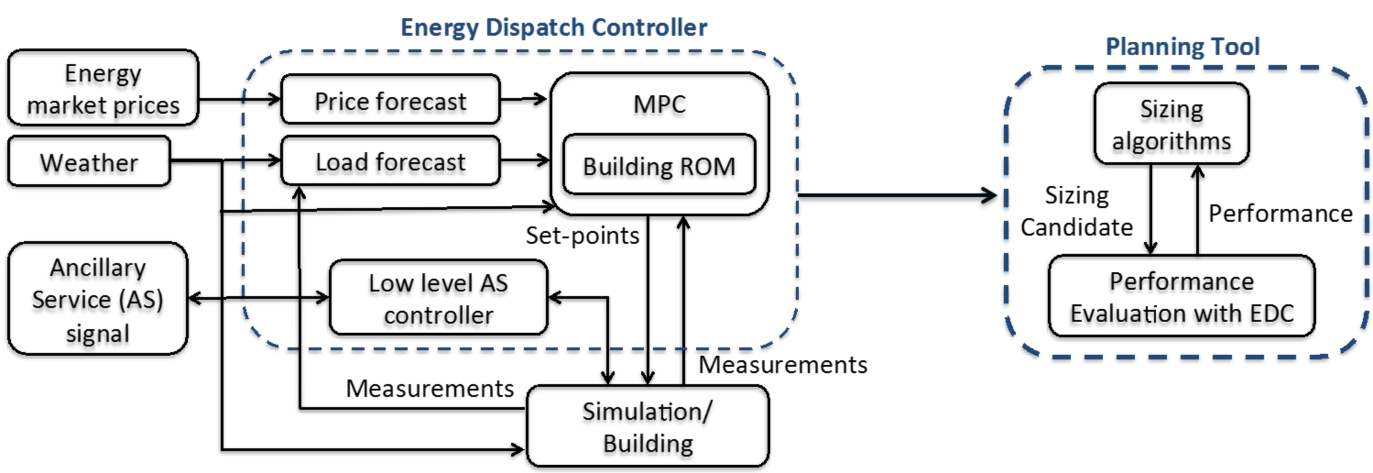

FIGURE 1. EDC and planning tool modules and flow

The EDC takes into account the cost of providing energy to the buildings as well as payment for any potential grid services. Using load and operation prediction, distributed generation and storage can be dispatched in optimal ways. Several simplified demonstration cases were done to show how different inputs would influence the controller and change operation. Figure 2 is a case in which cooling is required and the electricity price will increase during peak hours. One can see from the figure that the temperature of the building is allowed to increase in small increments up to near the thermal comfort constraint in order to minimize the cooling requirements. Additionally, the battery is charged during times of low electricity price and discharged during high electricity cost in order to reduce electricity costs. Figure 3 shows a heating case in which the fuel cell provides excess heat. One can see that to reduce the heating load, the building temperature is allowed to incrementally decrease. The fuel cell exceeds the heating demand, but during times of low natural gas cost it is still economic to provide only electricity. When there are high natural gas prices, it is not

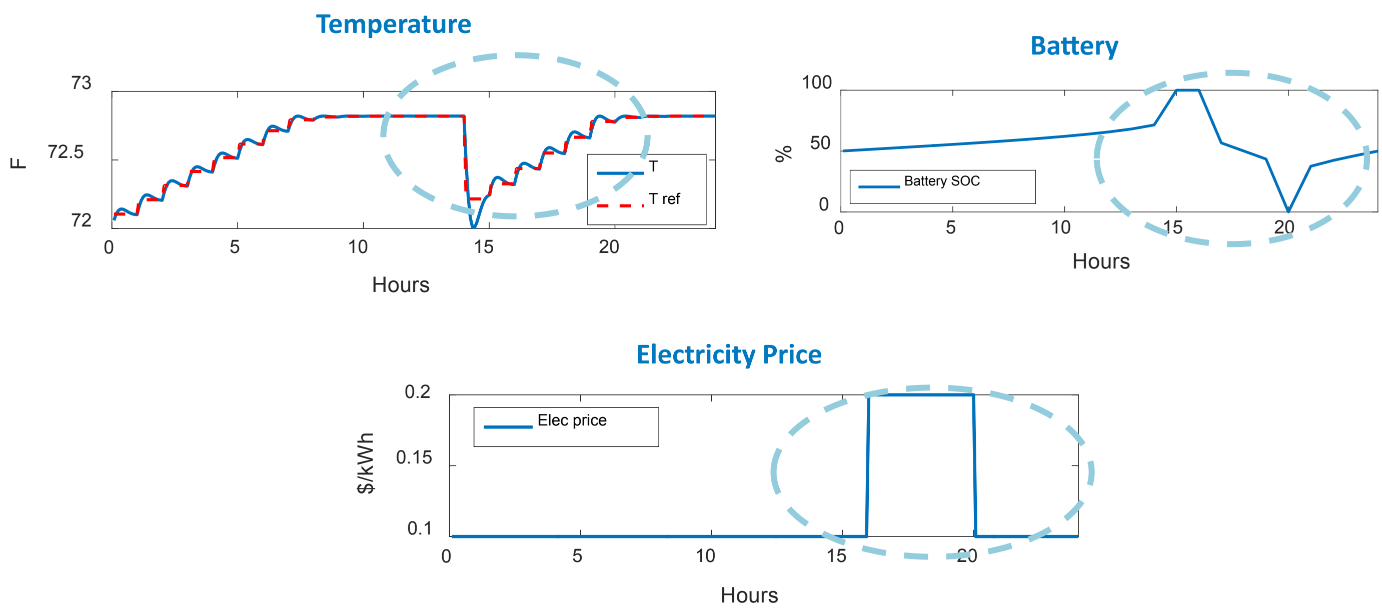

FIGURE 2. EDC demonstration results, cooling case

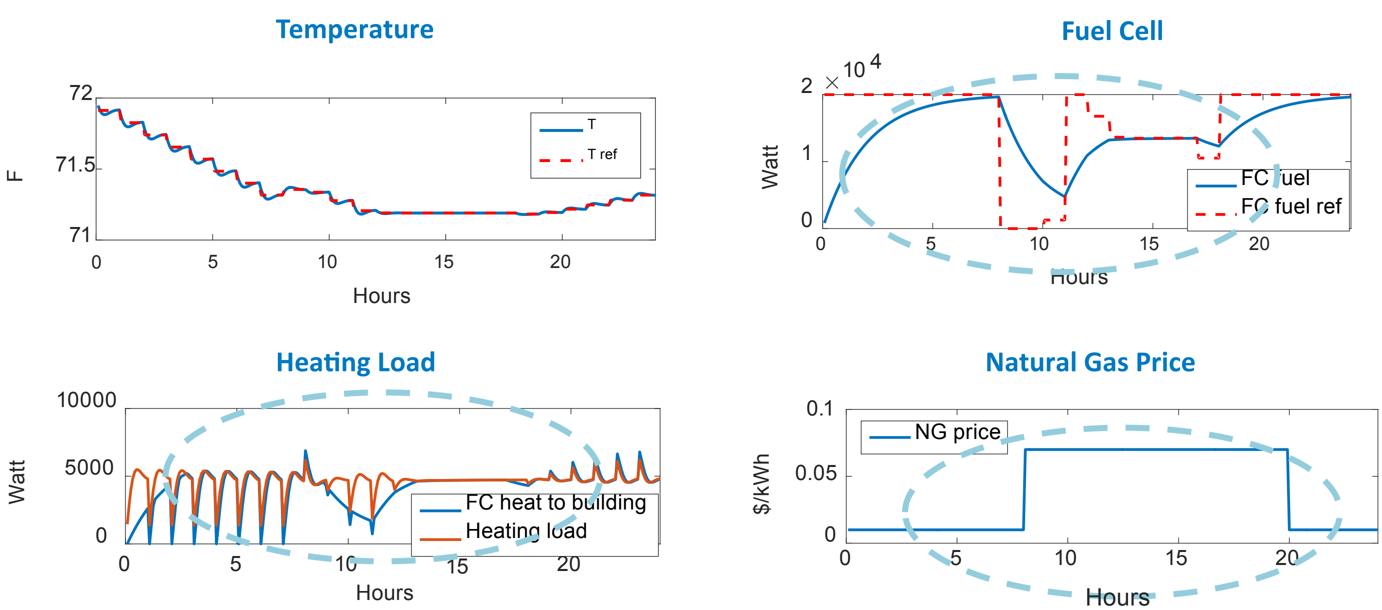

FIGURE 3. EDC demonstration results, excess heat

economic for the fuel cell to generate only electricity so the fuel cell operates at part load as determined by the thermal demand.

Load forecasting is an important module for the EDC. Several methods for forecasting uncontrollable loads have been identified and are being evaluated:

- Corrected Naïve: A simple exponential smoothing using a single calibration constant.
- ARIMA: Autoregressive integrated moving average with multiple calibration points.
- Neural Network: Trained by previous week's data and compatible with machine learning.
- Surface Fit: Best guess from historical data, e.g., time and weather.

Figure 4 shows the four test methods compared to test data. Initial evaluations suggest that a combination of methods may be best as determined by the quantity and type of historical data available.

Building design work has been ongoing. This includes researching current common methods for CHP integration and developing a design framework which can accommodate both current and novel CHP designs. The building design framework is required for specifying the building and its components and for developing reduced order model representations which will be used in the EDC optimization.

A co-simulation environment is being set-up using EnergyPlus. This will allow the EDC to run against a building simulation which will provide a feedback loop to which the EDC can react to. The EDC and the EnergyPlus simulation are currently running separately and the project team is working towards a functioning co-simulation environment by the end of FY 2017.

CONCLUSIONS AND UPCOMING ACTIVITIES

The first year of this project has been instrumental in laying the foundational groundwork for creating a suite of novel tools for building energy management and component sizing. The initial formulation of the EDC has been completed and testing has been started. The testing and evaluation of the EDC in co-simulation will be used for iterative improvements to the methods and implementation of the approach.

Second year activities include:

- Continued and more extensive testing of the EDC in co-simulation.
- Evaluation of the commercial solver, Gurobi, versus open source solvers (ultimate goal).
- Evaluation and refinement of forecasting modules for both load forecasting and ancillary service pricing.
- Continued development and refinement of the building design framework, which will be used to specify CHP designs. This will also be used for the extraction of reduced order models that will be used in the EDC.
- Continued development of the graphical user interface to meet the needs of building operators and testing environments.
- Development work on a communications backbone for allowing communication between the EDC and building equipment, providing the EDC supervisory control.
- Development of the component sizing optimization algorithms for use in the planning tool.

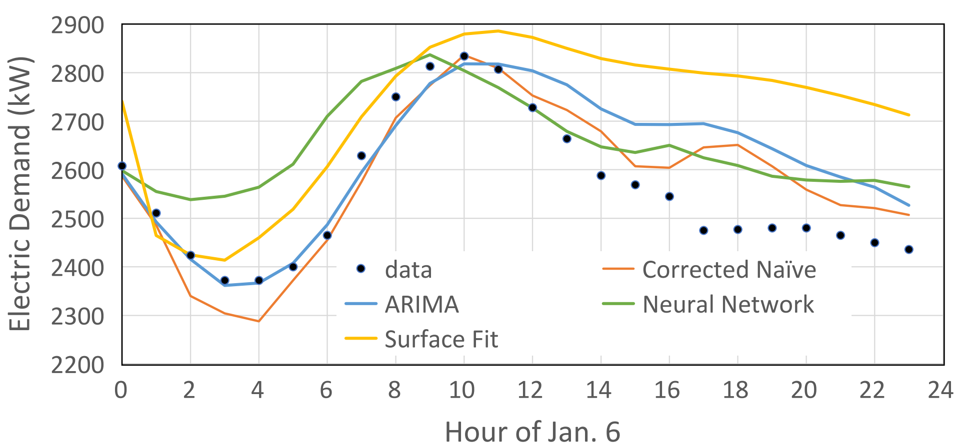

FIGURE 4. Comparison of four load forecasting methods

FY 2017 PUBLICATIONS/PRESENTATIONS

- Genevieve Saur, "Optimal Stationary Fuel Cell Integration and Control," presented at the 2017 DOE Annual Merit Review and Peer Evaluation Meeting, Washington, D.C., June 2017.
- Genevieve Saur, Zhiwen Ma, Annabelle Pratt, Yashen Lin, Bill Livingood, Luigi Gentile Polese, Brian Ball, Jereme Haack, Dustin McLarty, "NREL Energy Dispatch Controller Project: Stakeholders Review," presented for identified stakeholders in a webinar, Golden, CO, June 2017.
- Genevieve Saur, Zhiwen Ma, Annabelle Pratt, Yashen Lin, Dustin McLarty, William Livingood, Luigi Gentile Polese, Brian Ball, Jereme Haack, Gregor Henze, "Optimal Stationary Fuel Cell Integration and Control (Energy Dispatch Controller)," presented as a poster at the 2017 DOE Grid Modernization Initiative Peer Review, Washington, D.C., April 2017.
- Genevieve Saur, "NREL Energy Dispatch Controller Project: GUI Review for Stakeholders," presented for identified stakeholders in a webinar, Golden, CO, December 2016.

REFERENCES

1. Grid Modernization Initiative Multi-Year Program Plan, November 2015, https://energy.gov/sites/prod/files/2016/01/f28/Grid%20Modernization%20Multi-Year%20Program%20Plan.pdf

2. EnergyPlus is a whole building energy simulation program that engineers, architects, and researchers use to model both energy consumption—for heating, cooling, ventilation, lighting and plug and process loads—and water use in buildings. https://energyplus.net/