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 at Boulder, Boulder, CO

Project Start Date: June 1, 2016
Project End Date: September 30, 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 dispatch and load-control tool for building management that can communicate and transact with a fuel-cell-integrated building system and with the grid for optimized dispatch of building components.
- Objective 2: System planning tool—Implement a planning tool for optimal component selection and sizing based on optimal resource control for distributed energy systems and smart building components using location-specific energy markets, building energy modeling, and chosen dispatch control strategy.

Fiscal Year (FY) 2018 Objectives

- Improve and refine optimization for the EDC optimization.
- Develop methods for improving the building reduced order model (ROM) used for the optimization.
- Begin closed-loop testing and validation of modules in co-simulation with EnergyPlus.
- Create optimizations and start integration of the planning tool for building component sizing.
- Build and refine communications agents for implementation of VOLTTRON communication framework.

Technical Barriers

This project addresses the following technical barriers from the Grid Modernization Initiative Multi-Year Program Plan [1]:

- 4.2.3: Utilizing open standards and middleware software approaches to enable integration of EMS, DMS, and BMS.
- 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.

Contribution to Achievement of DOE Technology Validation Milestones

This project will contribute to achievement of the following DOE milestones from the Technology Validation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan[1]:

- Milestone 1.5: Demonstrate processes for highly uniform continuous lamination of membrane electrode assembly (MEA) components. (4Q, 2019)
- Milestone 1.6: Develop fabrication and assembly processes for polymer electrolyte membrane fuel cell MEA components leading to an automotive fuel cell stack that costs $20/kW. (4Q, 2020)

[1] https://www.energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22

FY 2018 Accomplishments

- Testing and validation of EDC was begun in co-simulation. Some promising results were used to demonstrate the dispatch controller techniques at a high-performance building conference.
    - Closed-loop testing and validation activities were ongoing using an EnergyPlus simulation for feedback.
    - Improvements were made to the optimization formulation using results from co-simulation testing.
    - Developed significant improvements to the ROM. Validation testing with first- and second-order ROMs were evaluated for accuracy and speed.
    - Fuel cell start-up/shut down functionality introduced.
- Design and integration of the planning tool for sizing building components was begun. Several methods for discrete and continuous sizing were implemented with an initial graphical user interface.
- Developed and revised several VOLTTRON agents needed for a comprehensive communication platform. Showed successful communication with five agents for initial proof-of-concept.

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 will create open-source tools for dynamic building energy management, an EDC 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 a 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 will also aid grid modernization by characterizing the potential of buildings to participate in ancillary grid services and positioning building operators to participate in ancillary grid services 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. We are leveraging prior knowledge with tools and research from the different areas to create a novel controller and planning tool.

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

RESULTS

In the second year of the project we have taken the foundational work on optimization formulations from the first year and begun testing, validation, refinement, and integration. Using closed-loop simulation with EnergyPlus [2] we have begun testing of different modules of the optimization. This has led to improvements in the EDC optimization formulation, the building ROMs, and co-simulation environment. Work also has begun on the development of the planning tool, which integrates the functionality of the EDC to evaluate building component sizing. Development of a comprehensive communications framework resulted in the development and refinement of several VOLTTRON agents and demonstrated successful communication between agents.

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; it takes in inputs such as current temperature, equipment states, utility costs, weather prediction, and load forecasting. 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.

The initial dispatch controller optimization formulation was improved to include allowance of fuel cell startup and shutdown during optimization. This required moving to mixed integer linear programming for the algorithm formulation. The fuel cell model also was improved to include the ability to reject heat into the hot-water loop for additional combined heat and power applications.

Testing and validation work using a co-simulation environment (Figure 1) supported improvement in several areas of the project. Using EnergyPlus for the closed-loop simulation we moved from simpler single-zone reference building models to multi-zone models of both a large office building and a large hotel. In testing we identified significant ROM mismatches (Figure 2), which led to a collaborative effort in ROM development between NREL, Washington State University, and Pacific Northwest National Laboratory. The ROM is needed by the dispatch controller to forecast the building load, generation, and storage and to optimize their operation. A ROM mismatch causes non-optimal solutions, but a perfect ROM is impossible due to the uncertainties of the elements that go into it (Figure 3). However, there are methods for reducing the impact of error through improvements to the ROM and forecasting.

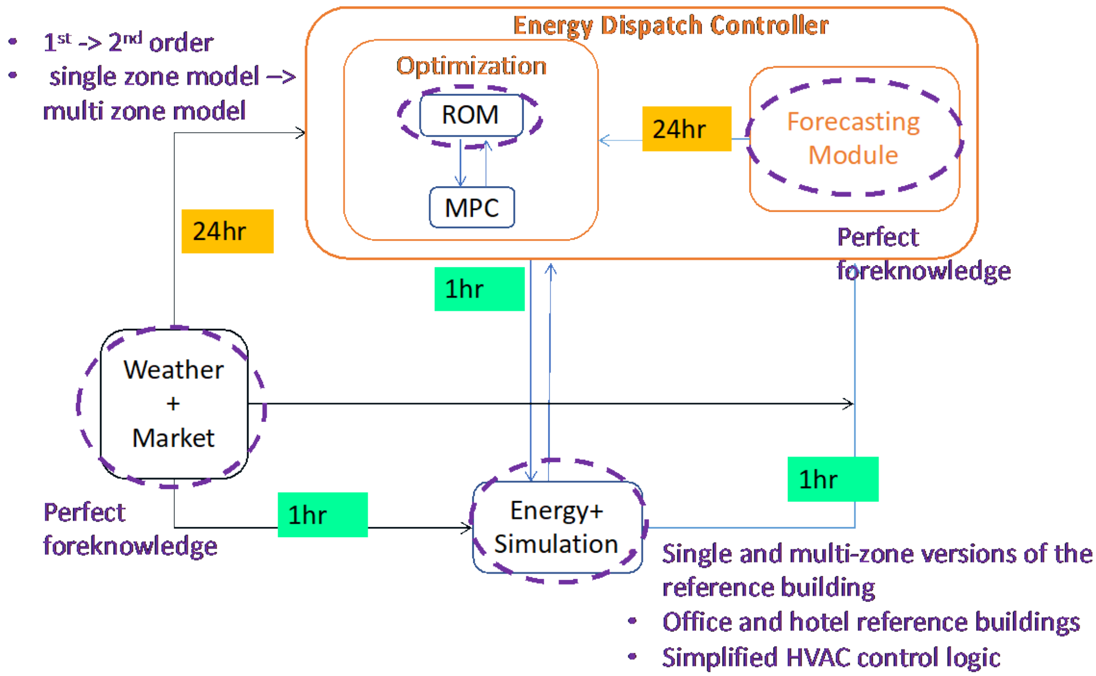

Figure 1. Co-simulation environment

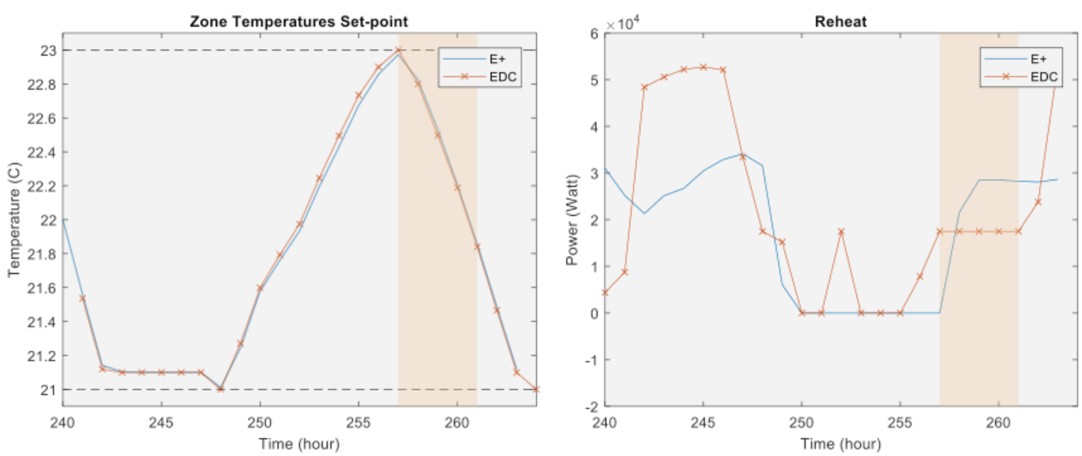

Figure 2. Example of ROM mismatch: temperature tracks well but power for reheat does not

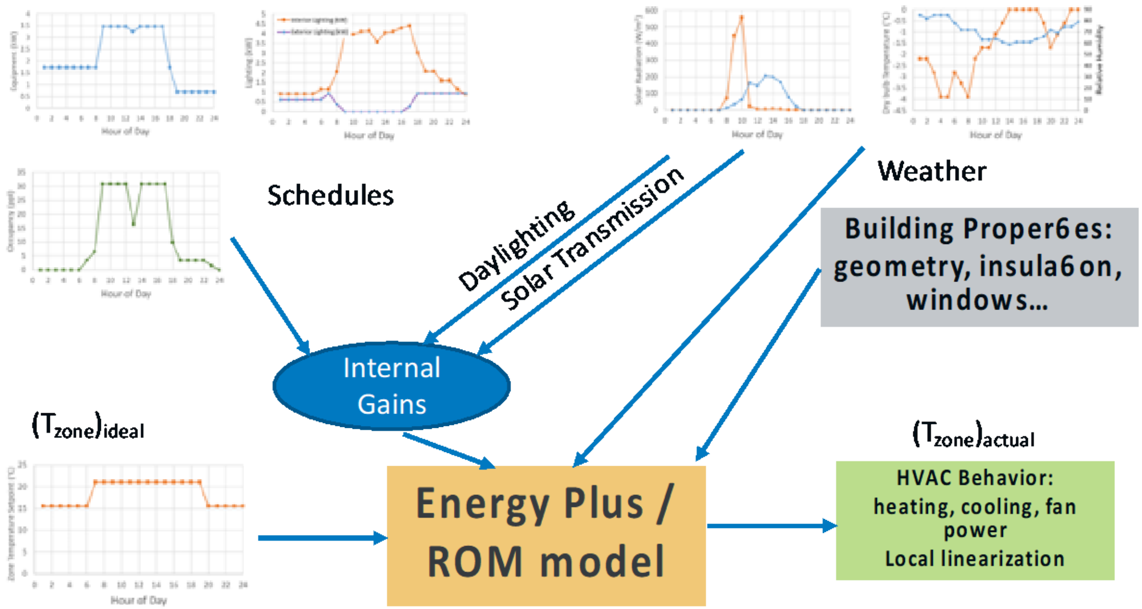

Figure 3. Elements that go into ROM development

Multiple iterations of ROM improvement were accomplished. Some of the outcomes included moving from a first-order ROM to a second-order with local linearization. The time-step selection was shown to be an important factor due to the difference in response time between wall zones (slow response rate) and air zones (fast response rate). It was shown that undesirable temperature oscillations could occur when the time steps were too short, but not enough information was captured about the changes if the time step was too large. The team developed methods for reducing undesirable effects in the ROM.

Some preliminary results were completed for the single-zone office building, which showed the operation of different modules and promising prospects for use of the dispatch controller with a fuel cell-integrated building. Several scenarios were developed to test various aspects of the optimization. Table 1 has results for a low-gas-cost scenario, which shows a significant cost improvement for the FC- and EDC-operated building. However, there is still work to be done to quantify the benefit that the fuel cell has with and without optimized control to isolate the source of the improvement. We also need to validate with the multi-zone building models and improved ROM.

Table 1. Preliminary Results for a Single-Zone Office Building Running with the EDC and Fuel Cell, Low-Gas-Cost Scenario

Low NG cost scenario	Total cost	Electricity cost	Natural gas cost	Ancillary services payment
EDC	398	81	321	5
EDC, no FC	**733**	**611**	**127**	**5**
No EDC, no FC, 1 set-point	747	594	153	
No EDC, no FC, 2 set-points	**691**	**572**	**119**	

A comprehensive communication bus that can simplify integration with a building is being developed with Pacific Northwest National Laboratory using VOLTTRON [3]. Required agents were identified and developed. In several cases previous work was adapted and expanded to serve the needs of the project, including identifying gaps in the OpenADR agent for serving non-demand-response grid ancillary services, revising a weather agent to use a non-subscription-based weather forecast, and evaluating others for their use in the project. A communications network was set up to demonstrate the agents functioning together.

Initial formulations for a planning tool that can optimally size several building components given the expected optimal operation of the building were developed. The building components for on-site generation and storage included fuel cells, batteries, and thermal storage. Methods for discrete and continuous sizing were implemented. This was coupled with a graphical user interface that will be expanded to include inputs and visualizations for the EDC.

CONCLUSIONS AND UPCOMING ACTIVITIES

The second year of the project built upon the foundational work of the first year to include initial testing and validation. The framework for a suite of novel tools for building energy management and component sizing is functioning though additional work is needed to integrate all the modules into one complete package.

Third and final year activities include the following.

- Settle upon a formulation for the optimization and ROM that can be thoroughly evaluated and quantify benefits for building operations as well as grid services.
- Develop a package of test scenarios that can adequately map how the controller performs. These scenarios may include spark spread (difference between electricity and natural gas prices), geography, building types, combined heat and power opportunities, and grid service environments.
- Integrate the planning tool sizing to demonstrate the combined benefit of optimal component sizing and building operation.

- Complete hardware-in-the-loop testing to validate co-simulation results.
- Complete a transition to python to facilitate graphical user interface development and use of open-source solvers in the optimization problems.

FY 2018 PUBLICATIONS/PRESENTATIONS

1. Y. Lin, D. McLarty, A. Pratt, B. Ball, G. Henze, and G. Saur. "Optimal Dispatch Controller for Fuel Cell Integrated Building." 5th International High Performance Buildings Conference at Purdue, West Lafayette, Indiana, July 9–12, 2018.
2. Genevieve Saur. "Optimal Stationary Fuel Cell Integration and Control (Energy Dispatch Controller)." Presented at the DOE Hydrogen and Fuel Cells Program 2018 Annual Merit Review and Peer Evaluation Meeting, Washington, D.C., June 13–15, 2018.
3. Genevieve Saur, Annabelle Pratt, Yashen Lin, Dustin McLarty, Zhiwen Ma, Brian Ball, Jereme Haack, Venkatesh Chinde, Nathaniel Jones, and Haley Mikeska. "Optimal Stationary Fuel Cell Integration and Control (Energy Dispatch Controller) (GMLC0252)." Presented at the U.S. Department of Energy's Grid Modernization Initiative Second Peer Review, Washington, D.C., September 4–7, 2018.

REFERENCES

1. Grid Modernization Initiative Multi-Year Program Plan, 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/.
3. VOLTTRON is a real-time, scalable platform for transactive energy control and other applications. https://bgintegration.pnnl.gov/volttron.asp.