Optimal Stationary Fuel Cell Integration and Control (Energy Dispatch Controller)

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- University of Colorado at Boulder, Boulder, CO

Project Start Date: June 1, 2016
Project End Date: March 20, 2020

Overall Objectives

Create an open-source tool set to foster growth in fuel-cell-integrated buildings with an 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 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) 2019 Objectives

- Develop methods for improving the building reduced-order model used for the optimization.
- Run closed-loop co-simulations of the dispatch controller optimization to analyze results.
- Integrate modules into a graphical user interface (GUI).
- 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 emergency management systems, distribution management systems, and building management systems.
- 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 Milestones

This project will contribute to achievement of the following DOE milestones from the Manufacturing R&D section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan [2]:

- 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 (PEMFC) MEA components leading to an automotive fuel cell stack that costs $20/kW. (4Q, 2020)

FY 2019 Accomplishments

- Tested two different implementations of the EDC.
    - National Renewable Energy Laboratory (NREL) EDC approach: focused on load

modifications and control of the air thermal mass of the building

- Washington State University Efficient Allocation of Grid Energy Resources including Storage (EAGERS) EDC approach: focused on equipment dispatch and use of the thermal mass of the hot and chilled water loops
- Continued closed-loop testing and validation activities
- Obtained results for a range of scenarios.

- Began design and integration of the planning tool for sizing building components; implemented several methods for discrete and continuous sizing with an initial GUI interface.
- Developed and revised several VOLTTRON [3] agents needed for a comprehensive communication platform; showed successful communication with five agents for initial proof of concept.
- Progressed to planning and setup for hardware-in-the-loop testing.

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.

This project aims to modernize building energy management by holistically integrating control of building elements for optimal operation, including maximizing the 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 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. 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 participations in grid ancillary service markets. The planning tool will then use simulated optimal dispatch to size added components into the system.

RESULTS

In the third and final year of project, we expanded the foundational work developed in the optimization formulations to begin co-simulation testing and validation. The collaborating team has developed two complimentary approaches to the energy management control optimization. Both approaches take advantage of model predictive control optimization but differ in implementation.

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 hour. The optimization runs again each hour over a rolling 24-hour period. Variation between scheduled and actual operation occurs due to building feedback and variability in actual building loads versus the forecast.

The NREL team has developed an approach that utilizes the thermal mass of air within the building and performs load control and modification through the use of air temperature set points. The WSU team has developed an approach which utilizes the thermal mass in the hot and chilled water loops. The two approaches demonstrate the inherent advantages to model predictive control while helping to characterize the benefit of different aspects of the building. The two approaches (NREL and WSU EAGERS) are currently separated in their implementation but are compatible as the benefits of each approach are explored.

The results include a subset of common scenarios run by both (Table 1). Each approach to building controls has strengths and weaknesses that should be investigated further, but the project shows proof of concept in understanding the benefits of model predictive control to building energy management and grid modernization.

Table 1. Scenarios Description ("-" means same as the base case)

Scenario	Location	Season	Building	Fuel Price	Model Mismatch	Perfect Forecast
1 (Base)	Baltimore	Winter	Office	Low electricity High natural gas	No	No
2	San Francisco	-	-	-	-	-
3	-	Summer	-	-	-	-
4	-	Fall	-	-	-	-
5	-	-	Hotel	-	-	-
6	-	-	-	High electricity Low natural gas	-	-
7	-	-	-	-	High	-

Cost savings from the NREL approach are shown in Table 2. These are in comparison to a default building operation strategy, where the zones are kept at a constant temperature (mean of the temperature bounds). With the exception of the San Francisco case we saw cost savings compared to the base case. The San Francisco case showed that additional reduced-order model calibration may be required in different climate regions. The proof-of-concept that model predictive control can provide benefit is shown, but more work is still needed.

Table 2. Cost Savings Compared to a Default Building Strategy Where Temperature is Held Constant at the Mean of the Comfort Bounds

Scenario	Total Savings ($)	Total Savings (%)	Electricity Savings ($)	Natural Gas Savings ($)
1 (Base)	717	10.2	1327	−602
2	−153	−2.1	666	−777
3	589	6.6	704	−103
4	445	6.4	772	−291
5	373	7.6	787	−411
6	2611	23.7	3080	−466
7	718	10.2	1331	−605
8	799	11.4	1263	−442

Several simulations were designed to isolate certain types of behavior to understand their impact and how the controller operates. Figure 1 shows a set of simulations from the NREL approach that removed additional battery and thermal storage. These cases showed 6.5%–7% cost savings and helped to display what part of the cost savings is due to fuel cell operation and load modifications rather than flexibility due to additional electrical and thermal storage.

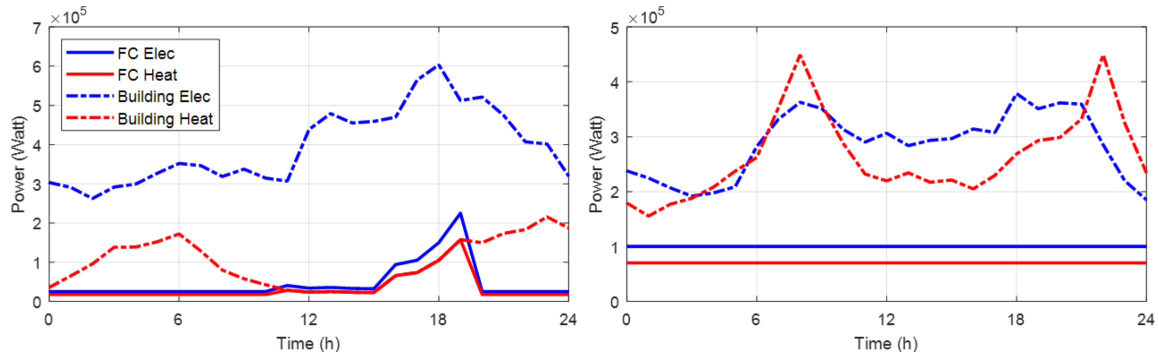

Figure 1. Fuel cell operation results in simulation with no additional battery or thermal storage (left: office; right: hotel)

The WSU EAGERS approach featured insights into the effect on building operation. Figure 2 shows the fuel cell operation for a large office in Baltimore. While the control of the fuel cell was highly dynamic, the utilization of the heat capacity of hot- and cold-water loops for storing energy improved the flexibility of operations.

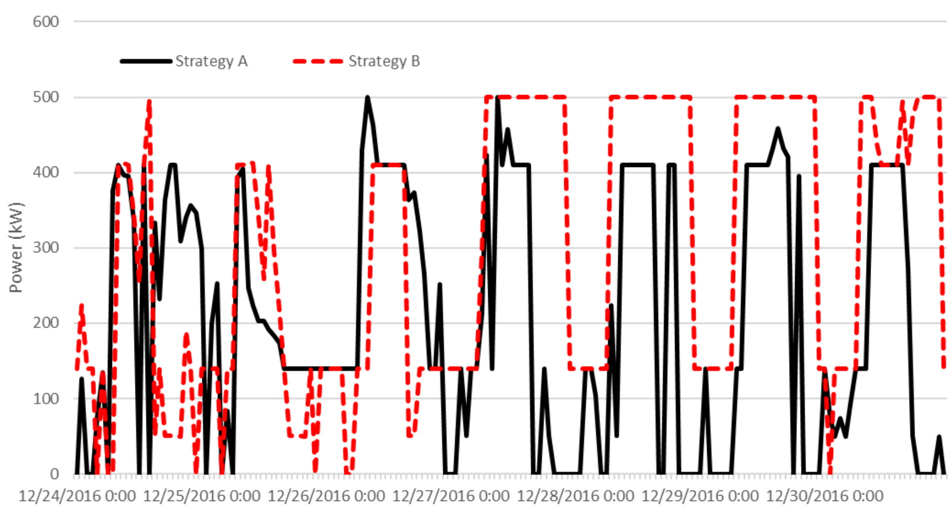

Figure 2. Fuel cell operation for the large office in Baltimore (WSU EAGERS approach)

CONCLUSIONS AND UPCOMING ACTIVITIES

In the third year and final year, the project has begun to demonstrate what the benefits are of the use of model predictive control in building controls. We have demonstrated that there are potential savings, but more analysis is needed to better understand where the savings come from, what factors can impact the benefits, operational impacts for the buildings and equipment, and potentials of merging approaches that include all aspects of the building thermal mass, air, and water loops.

A hardware-in-the-loop experiment is being set up to further understand the impacts of real hardware dynamics versus simulated results.

FY 2019 PUBLICATIONS/PRESENTATIONS

1. Genevieve Saur, "Optimal Stationary Fuel Cell Integration and Control (Energy Dispatch Controller)." Presented at the DOE Hydrogen and Fuel Cells Program 2019 Annual Merit Review and Peer Evaluation Meeting, Washington, D.C., April 29–May 1, 2019.

REFERENCES

1. U.S. Department of Energy, "Grid Modernization Multi-Year Program Plan," November 2015, https://energy.gov/sites/prod/files/2016/01/f28/Grid%20Modernization%20Multi-Year%20Program%20Plan.pdf.
2. U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Fuel Cell Technologies Office, "Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan," https://www.energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22.
3. Pacific Northwest National Laboratory, "Buildings-Grid Integration: VOLTTRON," last updated November 2018, https://bgintegration.pnnl.gov/volttron.asp.