Home Battery System: Homeowner-Centric Automation for Cybersecure Energy Efficiency and Demand Response
2017 Building Technologies Office Peer Review

Dane Christensen
dane.christensen@nrel.gov
National Renewable Energy Laboratory
Project Summary

Timeline:
Start date: May, 2016
Planned end date: March, 2018

Key Milestones
1. Go/No Go: Demonstrate automated, self-learned control of simulated loads.
   Cybersecurity Risk Assessment approved.
   09/20/2016 – Go Received
2. Demonstrate improved efficiency, resource predictions, and laboratory readiness for use case demonstrations. 6/20/2017

Budget:
Total Project to Date: $2.4M thru FY17
• DOE: $500k
• Cost Share: $1,900k ($1M BPA, $900k Bosch)

Total Project: $3.1M
• DOE: $750k
• Cost Share: $2,400k ($1.25M BPA, $1.15M Bosch)

Key Partners:
• Bonneville Power Administration
• Robert Bosch, N.A.
• Colorado State University

Project Outcome:
Residential automation solution delivers “win-win” for homeowners, utilities, and energy service aggregators.
Increase residential energy efficiency (goal: 5% savings, or ~1 Quad) & demand response participation (goal: 2kW+ firm resource per home), by easing consumer adoption of integrated solutions, towards enabling >10% active devices to provide flexibility by 2035.

⇒ Targets goals in BTO/ET MYPP, DOE Grid Modernization MYPP, and BPA Innovation Roadmaps
**Purpose and Objectives**

**Problem Statement:** Emerging residential technologies confuse homeowners with complexity and lack of interoperability. Integrated energy management is lacking among novel products. Demand Response appears to require homeowner discomfort, but homes drive utilities’ peak demand.

<table>
<thead>
<tr>
<th>Target Market/Audience</th>
<th>Homeowners</th>
<th>Leading Builders</th>
<th>Utilities</th>
<th>Grid Service Aggregators</th>
<th>Manufacturers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Market Barriers (Today)</strong></td>
<td>Confusion, frustration, high cost</td>
<td>Lack of proven, easy-to-integrate solutions. Utilities push back against rooftop PV</td>
<td>Limited residential DR participation via direct load management</td>
<td>No devices in homes to control, or high cost to retrofit</td>
<td>Connectivity features sell. Energy opportunities don’t</td>
</tr>
<tr>
<td><strong>Solution (Tomorrow)</strong></td>
<td>Simple &amp; secure automation acts on owner’s behalf. Low costs, good comfort, highly sustainable</td>
<td>Smart, green homes increase profit margins, improve HERS scores and reduce sales time. Controls streamline PV permitting</td>
<td>Ample reliable DR resource available through aggregators. Flexible load responds to signals. More PV. Increased profit</td>
<td>Strong business opportunity &amp; growing markets. Easier access to secure, firm resources.</td>
<td>Additional customer value from connected equipment increases sales &amp; transforms appliance markets. PV &amp; batteries take off</td>
</tr>
</tbody>
</table>
Purpose and Objectives

**Impact of Project:** Effectively meet homeowner comfort/budget and power-sector demand response needs with a low-cost, simple-to-use, cybersecure, and interoperable solution.

**Near-term outcomes:** Demonstration that win-win solutions can be cost-effective through emerging technological advancements

**Intermediate outcomes:** Connected equipment has increased value, speeding adoption of efficient tech and reducing net distributed resource costs

**Long-term outcomes:** No-pain demand response technology enables massive energy savings and increased infrastructure reliability

Graphic courtesy of Robert Bosch
Contributes directly to addressing residential-sector opportunities across most of BTO’s ET Sensors & Controls MYPP/Logic Model
Approach

Key Issues currently being addressed:

a) Interoperability with a variety of connected appliances
b) Lack of existing whole-home automation products
c) Poor Internet-of-Things cybersecurity
d) Lack of prior research on complex homeowner decision processes
e) Lack of techno-economic opportunity assessment for home energy management and stationary battery storage.

Distinctive Characteristics: Highly-predictive (72%+ at initialization) preference elicitation method identified, 12% uncertainty in resource availability at 12-hour look-ahead, and minimum 5% energy savings demonstrated in simulation.
Progress and Accomplishments: User Preferences

- 3 methods evaluated; 1,000 respondents each
- Follow-up survey, 250 each, to assess predictiveness

<table>
<thead>
<tr>
<th>Method</th>
<th>Percent Correctly Predicted</th>
<th>Average Usability Score (scale of 1-7)</th>
<th>Average Completion Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHP</td>
<td>49.0%</td>
<td>2.48</td>
<td>9.0</td>
</tr>
<tr>
<td>DCM</td>
<td>68.0%</td>
<td>2.57</td>
<td>5.7</td>
</tr>
<tr>
<td>SMARTER</td>
<td>72.2%</td>
<td>2.53</td>
<td>5.5</td>
</tr>
</tbody>
</table>

SMARTER selected as the method for foresee

\[ U_i = \beta_{i,m} M + \beta_{i,c} C + \beta_{i,d} D + \beta_{i,l} L + \beta_{i,s} S_l + \beta_{i,t} A_t^2 + \beta_{i,tn} I_{A_t<0} A_t^2 + \epsilon_i \]

- Money
- Dishes
- Shower Length
- Asym. Term

Money

\[ \text{Money} \]

Dishes

\[ \text{Dishes} \]

Shower Length

\[ \text{Shower Length} \]

Asym. Term

\[ \text{Asym. Term} \]
Progress and Accomplishments: Architecture

Human control drivers
- User Preferences
- Statistical Learning

Utility or Aggregator
- DR events
- load forecast
- weights
- patterns

Multi-Criterion Decision Making & Model-Predictive Control

Environmental control drivers
- Weather Service
- System Identification
  - weather data
  - models

Battery Storage
PV Inverter
HVAC
Water Heater
Dish Washer
Clothes Dryer
Unctrl Loads & Sensors

Human control drivers:
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- Statistical Learning

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- Utility or Aggregator
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RBSA House 14285
Seattle, WA
**Heating**: electric forced air furnace (22 kW)
Results:
- RMSE = 0.73°F
- $R^2 = 0.95$

RBSA House 11775
Tenino, WA
**Cooling**: heat pump
Results:
- RMSE = 0.37°F
- $R^2 = 0.98$
Progress and Accomplishments: Whole-Home Control

Current performance metrics: (in Pacific Northwest homes studied)
- Minimum energy savings, in any simulated home-day: 1.9kWh
- Maximum DR prediction error in simulated homes: 11%
- Average cost savings/home/day: $0.37 (or $130/yr)
- Average DR resource: 1.6 kW
Progress and Accomplishments: Cybersecurity

Home Battery System Risk Analysis

ESCRYPT – Embedded Security by ETAS, Inc.

Version: 1.0
Date: October 2, 2018
Status: Final
Author(s): ESCRYPT – Embedded Security by ETAS, Inc.
File: Home Battery System Risk Analysis.pdf
Pages: 24
Addresses: Bonnville Power Administration

Cybersecurity Implementation Plan

ESCRYPT – Embedded Security by ETAS, Inc.

Version: 1.0
Date: October 2, 2018
Status: Final
Author(s): ESCRYPT – Embedded Security by ETAS, Inc.
File: Cybersecurity Implementation Plan.pdf
Pages: 35
Addresses: Bonnville Power Administration

Cybersecurity Software Design and Specification

ESCRYPT – Embedded Security by ETAS, Inc.

Version: 1.0
Date: October 2, 2018
Status: Final
Author(s): ESCRYPT – Embedded Security by ETAS, Inc.
Pages: 41
Addresses: Bonnville Power Administration

Home Battery System Security Test Plan

ESCRYPT – Embedded Security by ETAS, Inc.

Version: 1.0
Date: October 2, 2018
Status: Final
Author(s): ESCRYPT – Embedded Security by ETAS, Inc.
Pages: 25
Addresses: Bonnville Power Administration

Home Battery System CIP Compliance

ESCRYPT – Embedded Security by ETAS, Inc.

Version: 1.0
Date: October 2, 2018
Status: Final
Author(s): ESCRYPT – Embedded Security by ETAS, Inc.
File: Home Battery System CIP Compliance.pdf
Pages: 25
Addresses: Bonnville Power Administration
Progress and Accomplishments

Accomplishments: Successfully meeting all milestones and deliverables, on budget and on time after delayed start.

Passed Go/No Go milestone: Demonstrated prototype control platform, operating simulated homes with <20% error in look-ahead prediction of demand response resource, delivered with energy savings (at least 2kWh/home/day) and no negative comfort impacts

Market Impact: Pre-market innovative technology in development; no market impact to date.
1. Engaging with industry to disseminate technical lessons learned
2. Three publications; seven additional publications in preparation – disseminating lessons learned
3. Three commercialization opportunities being pursued
Awards/Recognition

- Bosch/ESCRYPT devoted DistribuTECH booth to highlight this collaborative project
- Copyright & Trademark approved by DOE, in support of future commercialization
- Continued strong support from Bonneville Power Administration (primary funder) and Robert Bosch (industry partner; substantial in-kind participation)

“The Bonneville Power Administration sees great potential in this Technology Innovation project with NREL in its ability to reduce energy use and peak demand through automated management of residential end loads. […] The future of energy will rely on technologies which can help us manage grid issues […] without noticeable changes within the home while maintaining customer satisfaction. This project is a great example of the creativity and success that BPA strives to support when funding Technology Innovation projects.”

— Stephanie Vasquez, BPA

“Bosch is excited about its involvement in this highly innovative project with NREL and Bonneville Power Administration. One of the benefits to both residential homeowners and the power industry is the potential to dramatically reduce peak demand energy usage while also lowering consumers’ energy bills. Technologies like those being developed for this project will play a valuable role in attaining a robust, low-cost, and resilient power system for the future. Bosch is dedicated to bringing energy-efficient products to market that are designed to improve quality of life.”

— Scott Averitt, Robert Bosch North America
Project Integration and Collaboration

Project Integration: Tight collaboration with Bosch on co-development of the full cybersecure controller and connected home solution. Presentation and publication of results at industry conferences, journals. Engaging with other interested manufacturers for future collaborations.

Partners, Subcontractors, and Collaborators:
- Bonneville Power Administration – funder; Ryan Fedie & Kari Nordquist. Providing strategic and project direction. $1.25M participation, cash
- Bosch/ESCRYPT – partner; Scott Averitt. Developing cybersecurity layer, providing connected home appliances and battery, advising on controller hardware. $1.15M participation, in-kind
- Colorado State University – subcontractor; Sid Suryanarayanan & Pat Aloise-Young. Expertise in behavioral studies and multi-criterion decision making
Project Integration and Collaboration

External Communications:


➢ Six additional papers in development
Next Major Milestone **Planned for 6/20/2017**
The project team will demonstrate components of the Home Battery Solution to prove that the Home Battery System hardware/control system integration is ready to proceed to laboratory performance and cybersecurity testing. This milestone is passed when NREL:

a) Achieves **10% error in look-ahead predicted energy and resource availability in simple example cases**, and

b) The home battery system is **integrated with at least five connected appliances in NREL’s ESIF Systems Performance Laboratory** with control capabilities which enable testing against realistic, complex use cases.

This progress milestone demonstrates the continued viability of the project’s control methodology and substantial progress toward the ultimate goal of demonstrating 90% confidence in delivering demand response and energy efficiency under scenarios representative of real-world use cases (TRL 6+).
REFERENCE SLIDES
## Project Budget

### Budget History

<table>
<thead>
<tr>
<th></th>
<th>FY 2016 (past – started May 2016)</th>
<th>FY 2017 (current)</th>
<th>FY 2018 (planned – ends March 2018)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE</td>
<td>$250k</td>
<td>$250k</td>
<td>$250k</td>
</tr>
<tr>
<td>Cost-share</td>
<td>$950k</td>
<td>$950k</td>
<td>$500k</td>
</tr>
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### Total Project: $3.1M
- DOE: $750k
- Cost Share: $2,400k ($1.25M BPA, $1.15M Bosch)

### FY17 Spending, to date:
- DOE: $127k ($309k budget incl. carryover)
- Cost share: $272k BPA ($500k budget), $120k Bosch ($300k budget)

### Apparent variance: Artificial
- High October accrual identified in November & being incrementally corrected over time (BPA funds)

### Financial Summary: FY17 to date

- Combined BPA and DOE funds spending & working according to plan. 57% of total budget spent.
Project Plan and Schedule

Planned start date: 10/1/2015
Actual start date: 5/1/2016
  • Delayed due to contracting
  • Increased spending & met Year 1
  Go/No Go Milestone on time
Project end date: 3/31/2018

Current Work
  • Finalizing software on embedded platform
  • Integrating equipment into laboratory
  • Developing cybersecurity layer
Next major milestone: laboratory readiness demonstration 6/20/2017