Real-Time Optimization and Control of Next-Generation Distribution Infrastructure

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Network Optimized Distributed Energy Systems (NODES) Workshop and Demonstration

NREL, January 16, 2020
Project Summary

- Distribution feeders
- Microgrids
- Campuses, communities, community choice aggregations.
Project Summary

- Distributed, real-time, and network-cognizant operation
- Large-scale distributed energy resource (DER) coordination to acknowledge customer and operator objectives.
A real-time, distributed, and plug-and-play optimization platform that coordinates the operation of massive numbers of DERs to ensure voltage and power quality, to maximize social welfare, and to emulate virtual power plants.
Project Summary

Real-time optimization of a single cell in an autonomous energy system
Team

National Renewable Energy Laboratory:
- Andrey Bernstein (PI)
- Blake Lundstrom
- Pete Gotseff
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Southern California Edison:
- Vahid Salehi

University of Minnesota:
- Sairaj Dhople
- Swaroop Guggilam

Harvard University:
- Na Li
- Xin Chen

University of Colorado, Boulder:
- Emiliano Dall’Anese (original PI)
Technical Approach

Distribution feeder $f$

Transmission system

\[ \text{symbol} = \begin{align*}
\circ &= \text{sun}, \text{solar} \\
\bullet &= \text{battery} \\
\text{building} &= \text{building} \\
\text{electric car} &= \text{electric car}
\end{align*} \]
Technical Approach

- Respect electrical limits (e.g., voltage regulation)
- Maximize customers’ and utility/aggregator objectives

- Inertial response
- Primary frequency response
- Secondary frequency response
- Follow dispatch signals.
Technical Approach

Respect electrical limits (e.g., voltage regulation)

Maximize customers’ and utility/aggregator objectives

- Inertial response
- Primary frequency response
- Secondary frequency response
- Follow dispatch signals.
Inertial and Frequency Response

\[ \Delta P_0 = D_f \Delta \omega_f \]

Primary response
Inertial and Frequency Response

\[ \Delta P_0 = D_f \Delta \omega_f + M_f \Delta \omega_f \]

- Primary response
- Inertial response
Inertial and Frequency Response

\[ \Delta P_0 = D_f \Delta \omega_f + M_f \Delta \omega_f \]

Primary response

Inertial response
Inertial and Frequency Response

- Proposed approach (details follow in the presentation by Sairaj Dhople):
  - *Optimization model and algorithms* to compute coefficients
  - Ensure *given* aggregate response
  - Accommodate *fairness* or *economic indicators*. 
Technical Approach

- Maximize customers’ and utility/aggregator objectives
- Respect electrical limits (e.g., voltage regulation)
- Inertial response
- Primary frequency response
- Secondary frequency response
- Follow dispatch signals.
Real-Time Voltage Regulation and Dispatch Signals Following

Measurements $y^t = \{V^t, I^t, P_0^t\}$

Commands to DERs

Reserve provisioning
$\{r_n^{t+1}, \ldots, r_n^{t+T} \}$

Real-time module
$(P_n^t, Q_n^t) = C_n(P_n^{t-1}, Q_n^{t-1}, d_t^t)$
Real-Time Voltage Regulation and Dispatch Signals Following

Tracking + Cost minimization + Enforce limits

Measurements $y^t = \{V^t, P^t, P^t_0\}$

Real-time module
$\{P^t_n, Q^t_n\} = C_n(P^t_{n-1}, Q^t_{n-1}, d^t)$

Reserve provisioning
$\{r^t_n + 1, \ldots, r^t_n + T\}$

Commands to DERs

$P^t_0, M$

Set Point

Power Substation

Past Present Future

M Up M Down
Real-Time Voltage Regulation and Dispatch Signals Following

Reserve provisioning
\[ \{ r_{n}^{t+1}, \ldots, r_{n}^{t+T} \} \]

Real-time module
\[ (P_{n}^{t}, Q_{n}^{t}) = C_{n}(P_{n}^{t-1}, Q_{n}^{t-1}, d_{n}^{t}) \]

Commands to DERs

Reserve provisioning
\[ \{ r_{n}^{t+1}, \ldots, r_{n}^{t+T} \} \]

Real-time module
\[ d_{n}^{t} = D(y_{n}^{t}, P_{0, set}^{t}) \]

Measurements
\[ y_{n}^{t} = \{ V^{t}, I^{t}, P_{0}^{t} \} \]

Power Substation

Set Point

Past
Present
Future

M Up
M Down
Real-Time Voltage Regulation and Dispatch Signals Following

- Tracking
- Cost minimization
- Enforce limits

Trip planner (details in the presentation by Na Li)

Measurements $y^t = \{V^t, I^t, P_0^t\}$

Real-time module
$$\{P_n^t, Q_n^t\} = C_n (P_{n-1}^t, Q_{n-1}^t, d^t)$$

Reserve provisioning
$$\{r_{n+1}^t, \ldots, r_{n+T}^t\}$$

Commands to DERs

Power Substation

- Set Point
- Past
- Present
- Future

M Up
M Down
Real-Time Optimal Trajectories

\[ y(t) = H u(t) + D w(t) \]

Controllable power set points

Uncontrollable power set points

Voltages
Real-Time Optimal Trajectories

- **Continuous-time** optimal power flow (OPF)

\[
\begin{align*}
\min_{\{\mathbf{u}_i\}} & \quad c_0(\mathbf{y}(\mathbf{u}; t); t) + \sum_i c_i(\mathbf{u}_i; t) \\
\text{subject to} & \quad \mathbf{u}_i \in \mathcal{U}_i(t) \quad \forall i \\
& \quad g(\mathbf{u}, \mathbf{y}(\mathbf{u}; t); t) \leq 0
\end{align*}
\]

\[
\mathbf{y}(t) = \mathbf{H}\mathbf{u}(t) + \mathbf{D}\mathbf{w}(t)
\]
Real-Time Optimal Trajectories

- Continuous-time OPF

\[
\min_{\{u_i\}} c_0(y(u; t); t) + \sum_i c_i(u_i; t)
\]

subject to \( u_i \in U_i(t) \ \forall i \)

\( g(u, y(u; t); t) \leq 0 \)

\[
y(t) = H u(t) + D w(t)
\]
Real-Time Optimal Trajectories

- **Continuous-time OPF**

\[
\min_{\{u_i\}} c_0(y(u; t); t) + \sum_i c_i(u_i; t)
\]

subject to \( u_i \in \mathcal{U}_i(t) \ \forall \ i \)

\[
g(u, y(u; t); t) \leq 0
\]

- **Example:**

\[
\|y(u; t) - y^{\text{target}}(t)\|_2^2 - \nu \leq 0
\]

\[
y(t) = Hu(t) + Dw(t)
\]
Real-Time Optimal Trajectories

- Continuous-time OPF

\[
\min_{\{u_i\}} \quad c_0(y(u; t); t) + \sum_i c_i(u_i; t)
\]

subject to \( u_i \in \mathcal{U}_i(t) \ \forall \ i \)

\[
g(u, y(u; t); t) \leq 0
\]

\[
y(t) = Hu(t) + Dw(t)
\]
Batch Optimization

\[ \min_{\{u_i\}} \ c_0^{(k)}(y^{(k)}(u)) + \sum_i c_i^{(k)}(u_i) \]

subject to \[ u_i \in U_i^{(k)} \ \forall \ i \]

\[ g^{(k)}(u, y^{(k)}(u)) \leq 0 \]

- Series of time-invariant optimization problems: impractical in real time

\[ y(t) = Hu(t) + Dw(t) \]
Online algorithm to track optimal solutions (Dontchev et al. 2013; Simonetto-Leus 2014)

\[
\begin{align*}
\mathbf{u}^{(k+1)} &= \mathcal{C}(\mathbf{u}^{(k)}) \\
\mathbf{y}(t) &= \mathbf{H}\mathbf{u}(t) + \mathbf{D}\mathbf{w}(t)
\end{align*}
\]

\[
\begin{align*}
\min_{\{\mathbf{u}_i\}} c_0^{(k)}(\mathbf{y}^{(k)}(\mathbf{u})) + \sum_i c_i^{(k)}(\mathbf{u}_i) \\
\text{subject to } &\mathbf{u}_i \in \mathcal{U}_i^{(k)} \forall i \\
g^{(k)}(\mathbf{u}, \mathbf{y}^{(k)}(\mathbf{u})) &\leq 0
\end{align*}
\]
Feed-Forward Online Optimization

$$u^{(k+1)} = C(u^{(k)})$$

Subject to

$$y(t) = Hu(t) + Dw(t)$$

$$\min_{\{u_i\}} c_0^{(k)}(y^{(k)}(u)) + \sum_i c_i^{(k)}(u_i)$$

$$\text{subject to } u_i \in U_i^{(k)} \forall i$$

$$g^{(k)}(u, y^{(k)}(u)) \leq 0$$

- Feed-forward; time-scale separation; needs expression $y^{(k)}(u) = Hu + Dw^{(k)}$
Feedback Online Optimization

\[ u^{(k+1)}_i = C_i(u^{(k)}_i, \hat{y}^{(k)}) \]

subject to \( u_i \in \mathcal{U}_i^{(k)} \quad \forall \ i \)

\[ g^{(k)}(u, y^{(k)}(u)) \leq 0 \]

\[ \min_{\{u_i\}} c_0^{(k)}(y^{(k)}(u)) + \sum_i c_i^{(k)}(u_i) \]

\[ y(t) = H u(t) + D w(t) \]
Multiperiod optimization problem, rolling horizon, multicase

*Base case*: maximize customer/aggregator objectives

- Subject to: voltage constraint, hardware constraints.

*Reserve provisioning:*

- Headroom for power at substation
- Fair reserve provisioning participation.
(P1) \[
\min_{x, \bar{x}, \bar{z}, z, \bar{z}, \bar{y}, \text{p}_0, \text{r}, \bar{r}} \sum_{t=t_k}^{t_k+T} \sum_{i=1}^{N} C_{i,t}(x_{i,t}) + \sum_{t=t_k}^{t_k+T} U(r_t, \bar{r}_t)
\]

s.t.: \[x_i \in \mathcal{Y}_i^{(k)} \quad \forall \ i = 1, \ldots N\]
\[\bar{x}_i \in \mathcal{Y}_i^{(k)} \quad \forall \ i = 1, \ldots N\]
\[x_i \in \mathcal{Y}_i^{(k)} \quad \forall \ i = 1, \ldots N\]
\[r_{min} \leq \bar{r}_t, \quad r_{min} \leq r_t\]
\[\hat{p}_{0,t}(x) = P_{0,t} \quad \forall t = t_k, \ldots, t_k+T\]
\[\hat{p}_{0,t}(\bar{x}) = P_{0,t} - \bar{r}_t \quad \forall t = t_k, \ldots, t_k+T\]
\[\hat{p}_{0,t}(x) = P_{0,t} + r_t \quad \forall t = t_k, \ldots, t_k+T\]
\[v_{min} \leq |\tilde{v}(x)| \quad \forall t = t_k, \ldots, t_k+T\]
\[|\tilde{v}(\bar{x})| \leq v_{max} \quad \forall t = t_k, \ldots, t_k+T\]
Trip Planner

\[
(P1) \quad \min_{x, \overline{x}, \tilde{z}, \overline{z}, \bar{z}} \quad \sum_{t=t_k}^{t_{k+T}} \sum_{i=1}^{N} C_{i,t}(x_i,t) + \sum_{t=t_k}^{t_{k+T}} U(r_t, \overline{r}_t)
\]

s.t.: \quad x_i \in \mathcal{Y}_i^{(k)} \quad \forall \quad i = 1, \ldots N

\overline{x}_i \in \mathcal{Y}_i^{(k)} \quad \forall \quad i = 1, \ldots N

x_i \in \mathcal{Y}_i^{(k)} \quad \forall \quad i = 1, \ldots N

r_{\min} \leq \overline{r}_t, \quad r_{\max} \leq r_t

\tilde{p}_{0,t}(x) = P_{0,t} \quad \forall t = t_k, \ldots, t_{k+T}

\tilde{p}_{0,t}(\overline{x}) = P_{0,t} - \bar{r}_t \quad \forall t = t_k, \ldots, t_{k+T}

\tilde{p}_{0,t}(\overline{x}) = P_{0,t} + r_t \quad \forall t = t_k, \ldots, t_{k+T}

v_{\min} \mathbf{1} \leq |\tilde{v}(x)| \quad \forall t = t_k, \ldots, t_{k+T}

|\tilde{v}(\overline{x})| \leq v_{\max} \mathbf{1} \quad \forall t = t_k, \ldots, t_{k+T}

Cost function

Hardware constraints

Green and red trajectories

Power Substation

Set Point

Past

Present

Future
Validation and Demonstration

- **PHIL at NREL:**
  - Real feeder from SCE territory, ~7-MW peak load
  - Hundreds of DERs; at least 100 physical DERs at power.

- **CHIL at SCE:**
  - Substation model with multiple feeders: 50-MW peak, 350-GWh yearly energy
  - Hundreds of DERs.

- **Field deployments:**
  - Stone Edge Farm microgrid
  - Holy Cross Energy Basalt Vista Affordable Housing Project
Test case overview

- Feeder located in California, within SCE territory
- 366 single-phase points of connection
- Residential, commercial, and industrial customers
- Peak load of ~7 MW
- Mix of delta and wye connections
- Real load data
- Real irradiance data
- Summer/Peak day
- Winter/Min day
Considered DERs

- PV systems (string and microinverters), batteries, EVs, controllable load
- Total DER capacity:
  - PV: ~8.5 MW
  - Batt: ~1 MW
- Results in renewable energy penetration (annual energy basis) of ~51%
- Over 100 controlled powered devices (via PHIL)
- 10 additional CHIL devices
- Over 100 controlled simulated devices
PHIL & CHIL Setup Overview
## PHIL & CHIL Setup Overview

<table>
<thead>
<tr>
<th>Rack</th>
<th># Devices</th>
<th>Simulated Device</th>
<th>Physical Device</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHIL</td>
<td>50</td>
<td>(3) Batteries – 14/12, 23/35, 150/150 kW/kWh (2) PV – 100 and 1500 kW</td>
<td>BBB Microcontroller</td>
</tr>
<tr>
<td>PHIL-1</td>
<td>16</td>
<td>PV Inverters – 199 kW total Batt Inverters – 60.6 kW total Loads - varying</td>
<td>(1) 3 kW sPV, (1) 3 kW sPV, (12) 320 W uPV (1) 5 kW / 10 kWh Li-ion Batt (1) 12 kVA load bank with profile</td>
</tr>
<tr>
<td>PHIL-2</td>
<td>16</td>
<td>PV Inverters – 1000 kW total Batt Inverters – 237 kW total Loads - varying</td>
<td>(1) 5 kW sPV, (1) 3.8 kW sPV, (12) 320 W uPV (1) 5 kW / 10 kWh Li-ion Batt (1) 12 kVA load bank with profile</td>
</tr>
<tr>
<td>PHIL-3</td>
<td>16</td>
<td>PV Inverters – 481 kW total Batt Inverters – 114 kW total Loads - varying</td>
<td>(1) 5 kW sPV, (1) 3.8 kW sPV, (12) 320 W uPV (1) 5 kW / 10 kWh Li-ion Batt (1) 12 kVA load bank with profile</td>
</tr>
<tr>
<td>PHIL-4</td>
<td>16</td>
<td>PV Inverters – 185 kW total Batt Inverters – 47 kW total Loads - varying</td>
<td>(1) 3 kW sPV, (1) 5 kW sPV, (12) 320 W uPV (1) 5 kW / 10 kWh Li-ion Batt (1) 62 kVA load bank with profile</td>
</tr>
<tr>
<td>PHIL-5</td>
<td>15</td>
<td>PV Inverters – 791 kW total Loads - varying</td>
<td>(1) 3 kW sPV, (1) 5 kW sPV, (12) 320 W uPV (1) 62 kVA load bank with profile</td>
</tr>
<tr>
<td>PHIL-6</td>
<td>16</td>
<td>PV Inverters – 62 kW total Batt Inverters – 17 kW total Loads - varying</td>
<td>(1) 3 kW sPV, (1) 5 kW sPV, (12) 320 W uPV (1) 5 kW / 10 kWh Li-ion Batt (1) 62 kVA load bank with profile</td>
</tr>
<tr>
<td>PHIL-EVs</td>
<td>9</td>
<td>Parking Garage – 388 kW</td>
<td>(9) 5 kW Level 2 EVSE with EV</td>
</tr>
<tr>
<td>Total</td>
<td>104 + (10)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Test Case #1

- Max Load Day
  - Virtual Power Plant

Feeder Head Power (3-ph)

Solar Irradiance

2-3 PM
Virtual Power Plant

Total Substation Power

Active Power (MW)

Solar Irradiance

Solar Irradiance (W/m²)

14:00 14:10 14:20 14:30 14:40 14:50 15:00

14:00 14:10 14:20 14:30 14:40 14:50 15:00
Virtual Power Plant

Simulated PV Inverter Response (Controlled Case)

Avg. RMS Voltage at Bus (Controlled Case)
Virtual Power Plant

Simulated PV Inverter Response (Controlled Case)

Avg. RMS Voltage at Bus (Controlled Case)
Virtual Power Plant

Simulated PV Inverter Response (Controlled Case)

- PV85
- PV125
- PV86
- PV44
- PV9
- PV117
- PV23

Active Power (kW)

Substation A Set Point (kW)


0 20 40 60 80 100 120 140

-400 -200 0 200 400

arpae
CHANGING WHAT'S POSSIBLE
Virtual Power Plant

PHIL Injection at Bus

CHIL Injection at Bus

Parking Garage PHIL Injection
Virtual Power Plant

Rack #1 Power

Rack #2 Power

Rack #3 Power

Load Power
Virtual Power Plant

Rack #4 Power

Rack #5 Power

Rack #6 Power

Load Power

arpa e
CHANGING WHAT’S POSSIBLE
Virtual Power Plant

Rack #1-3 Power

Rack #4-6 Power

All Loads Power

EVSE Power

Substation A Set Point
Test Case #2

- Min Load Day
  - Frequency Response + Virtual Power Plant

![Graph of Feeder Head Power (3-ph)](image)

- Solar Irradiance

![Graph of Solar Irradiance](image)

10:30-11:30 AM
Frequency Response + Virtual Power Plant
Controller-Hardware-in-the-Loop at SCE

- CHIL experiments at SCE
- PowerFactory model with updates of 1-second in real-time simulation platforms
- Validate synthetic regulating reserve (voltage regulation and dispatch signal-following) algorithms
- Model properties:
  - ~1,500 single-phase points of interconnection representing approximately 2,000 customers (a mix of residential, commercial, and industrial customers)
  - ~500 controllable devices are included. Controllable devices are at both the residential and commercial/utility scales.
SCE Distribution System Model

- Peak load of ~49 MW and a minimum load of ~15 MW in 2015.
- Sub-A annual net energy delivered in 2015 was ~216 GWh
- To meet the 50% renewable penetration level, ~108 GWh should be provided by DERs.
- Based on NREL’s PVWatts® data, a 1-kW PV system in Santa Ana produces approximately 1,586 kWh annually.
- Sub-A requires at least 68 MW of distributed renewable sources.
## Existing and Added Fictitious DERs

<table>
<thead>
<tr>
<th>Feeder</th>
<th>Existing DER Count</th>
<th>Existing PV MW</th>
<th>Existing BESS MW</th>
<th>Fictitious PV Inst.</th>
<th>Fictitious PV MW</th>
<th>Fictitious BESS MW/MWh</th>
<th>Total DER Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fd-A_12KV</td>
<td>4</td>
<td>0.015</td>
<td>-</td>
<td>41</td>
<td>5.425</td>
<td>1 MW/6 MWh</td>
<td>46</td>
</tr>
<tr>
<td>Fd-B_12KV</td>
<td>4</td>
<td>0.725</td>
<td>-</td>
<td>123</td>
<td>10.085</td>
<td>1 MW/6 MWh</td>
<td>128</td>
</tr>
<tr>
<td>Fd-C_12KV</td>
<td>17</td>
<td>0.087</td>
<td>-</td>
<td>97</td>
<td>10.25</td>
<td>1 MW/6 MWh</td>
<td>115</td>
</tr>
<tr>
<td>Fd-D_12KV</td>
<td>7</td>
<td>0.968</td>
<td>-</td>
<td>52</td>
<td>9.29</td>
<td>1 MW/6 MWh</td>
<td>60</td>
</tr>
<tr>
<td>Fd-E_12KV</td>
<td>40</td>
<td>0.534</td>
<td>-</td>
<td>33</td>
<td>10.03</td>
<td>1 MW/6 MWh</td>
<td>74</td>
</tr>
<tr>
<td>Fd-F_12KV</td>
<td>4+3</td>
<td>0.676</td>
<td>-</td>
<td>30</td>
<td>10.1275</td>
<td>-</td>
<td>37</td>
</tr>
<tr>
<td>Fd-G_12KV</td>
<td>15</td>
<td>0.842</td>
<td>-</td>
<td>33</td>
<td>9.53</td>
<td>1 MW/6 MWh</td>
<td>49</td>
</tr>
<tr>
<td>All 4-kV feeders @ Sub-B</td>
<td>5.209</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total feeders</td>
<td>409</td>
<td>64.727</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Existing data redacted

<table>
<thead>
<tr>
<th>Total DERs</th>
<th>514</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total PV MW</td>
<td>68.786</td>
</tr>
<tr>
<td>Total BESS MW/MWh</td>
<td>9.5 /54</td>
</tr>
</tbody>
</table>
SCE’s CHIL Architecture

Power Factory Server (192.168.28.52)

- Network Model (Real-Time RMS Simulation)
- OPC Client
- Data Gateway
- OPC Server
- Control & Visualization
- OPC Client

Windows Docker Server (192.168.13.160)

- Data Concentrator
- (Provider by NREL)
- 500 DERs as Container Images
- (Provider by NREL)
- Local DER Optimization
- DSO Signals
- DERS Control P, Q
- Ratings & Network Para.
- (Provided by CalTech)

Linux Server (192.168.13.142)

- Central Optimization
- (Provided by CalTech)
- UDP Send
- DERS Control P, Q
- V, P, Q, SoC Meas.

- UDP Receive
- DERS Control P, Q
- V, P, Q, SoC Meas.
- DSO Signals
- DERS Control P, Q

- BeagleBone Boards (x10)

Local DER Optimization
192.168.28.190 to 192.168.28.199
Results of Optimization

Feeder-head active power (following the load & PV irradiance)

Overvoltage in most of the Buses

Optimization

Following the RMT set points

Mitigated overvoltage issues

After applying RMT controls
Distributed Energy Resource Real-Time Control

(Curtailing PV, controlling battery energy storage system [BESS] dispatch and reactive power contributions)
Stone Edge Farm Demonstration

- Stone Edge Farm Microgrid
- Extending more than 16 acres in Sonoma, CA
- ~20 assets:
  - PV systems, energy storage systems, hydrogen electrolyzer, gas turbine, controllable loads.
- In collaboration with Heila Technologies.
Stone Edge Farm Demonstration

- System configuration:

  \[ [P_{sp}, V_{min}, V_{max}] \]

  Central Control

  Read PCC Power

  Dual variables

  DER 1
  \[ [P_1, Q_1] \]

  DER 2
  \[ [P_2, Q_2] \]

  DER 3
  \[ [P_3, Q_3] \]

  ... DER 22
  \[ [P_{22}, Q_{22}] \]

  Solar

  Loads

  Network

  Meter

  Distribution Grid

  480V, 3-Φ
Stone Edge Farm Demonstration

- 24-hour point of common coupling power flow tracking:

- 24-hour point of common coupling power flow without control:
Stone Edge Farm Demonstration

- Voltage regulation

*Figure 11. Average line-neutral voltage at nodes in the microgrid*
Holy-Cross Energy Demonstration

Basalt Vista Affordable Housing Project

- Habitat for Humanity, Pitkin County, Basalt School District
- 27 homes for teachers and local workforces.
- Designed to ZNE building with *all electric* construction
- Adjacent to Basalt High School
- 4 selected for HCE’s field deployment

**Home Equipped with Controllable Loads**
- Rooftop solar
- Energy storage
- Mobility charging (EVSE)
- Comfort (Hot Water + HVAC)
Holy-Cross Energy Demonstration

Basalt Vista Case Study

Project Goal: Demonstrate the ability for a distribution utility to control and dispatch Distributed Energy Resources (DERs) to provide value to the grid as well as to the individual consumer.

- Microgrid controllers coupled with DER
  - Flexible
  - VPP at All Levels
    - Feeder, Community or Individual Buildings
- ADMS: Simple Management and Visibility of DER
- Studied High Penetration of DERs
- Interoperability of different “Systems”
- Resilient Soft Microgrid
Advanced Distribution Management System (ADMS)

Fully integrated:
- Supervisory Control And Data Acquisition (SCADA)
- Outage Management System (OMS)
- Distribution Energy Resource Management System (DERMS)

Enhanced Situational Awareness for:
- Load Flow and State Estimation
- Vehicle Location
- Switching Validation
- Outage and Restoration Information from AMI
- Also runs applications, including:
  - CVR – conservation voltage reduction
  - VVO – volt/var optimization
  - FLISR – fault location, isolation and service restoration

One easy-to-use graphical interface provided by Survalent (existing HCE partner)
Holy-Cross Energy Demonstration

3 Day Test at BV (Nov) – 4 homes
Holy-Cross Energy Demonstration

3 Day Test at BV
Peak Load Management
Power at Transformer set to 0 Watts throughput. System set to aggregated optimization. PV set to charge batteries than to grid. Option to curtail PV to create a true 0 Watts load profile.
Holy-Cross Energy Demonstration

Learnings from the Grid Edge

• Stay focused on the Big 3 – PV, EV, and BESS
  • Some members show willingness to allow utility control of DERs
  • Battery Storage may provide voltage and frequency support to a high penetration grid
  • Distributed resources can help manage overall cost of service for members
• DER will have a greater value if they work together in small groups to provide VPP and Microgrids
• Cost of capital can have a material impact on project viability
Holy-Cross Energy Demonstration

More Learnings

• Only need to control a subset of DER in a high penetration system
• Coordination & Computations is best left at the grid edge
• There is a need for multiple and redundant communication systems
List of Achievements

- More than 20 publications
- More than 20 presentations to conferences, universities, and industry
- Record of inventions, patent applications (one issued)

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<tr>
<th>Project name</th>
<th>Validation</th>
<th>Core functions</th>
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<tr>
<td>ARPA-E NODES</td>
<td>Lab demo: DERMS implemented in Beaglebone, SCE feeder (51% PV penetration)</td>
<td>Voltage regulation, VPP and frequency response</td>
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<td>Field demo: DERMS implemented in Heila Edge, Stone Edge Farm (100% DER penetration)</td>
<td>Voltage regulation and VPP</td>
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<td>Holy-Cross Energy High Impact Project</td>
<td>Lab demo: DERMS implemented in Heila Edge, HCE feeder (15.5% PV penetration)</td>
<td>Voltage regulation and Customer Bill Reduction</td>
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<tr>
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<td>Field demo: DERMS implemented in Heila Edge, HCE community (100% DER penetration)</td>
<td>Voltage regulation, VPP and Customer Bill Reduction</td>
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<td>SETO ENERGISE ECO-IDEA</td>
<td>Lab demo: DERMS implemented in PC, Xcel Energy feeders with 20,000 nodes (200% PV penetration)</td>
<td>Voltage regulation</td>
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<td>SETO ENERGISE GO-Solar</td>
<td>Lab demo: DERMS implemented in PC, HECO feeders with 2,500 nodes (50% PV penetration)</td>
<td>Voltage regulation</td>
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<td>SETO ENERGISE SolarExpert</td>
<td>Lab demo: DERMS implemented in PC, IEEE 8,500 node system (45.4% PV penetration)</td>
<td>Voltage regulation</td>
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<tr>
<td>LDRD Autonomous Energy Systems</td>
<td>Lab demo: DERMS implemented in PC, San Francisco bay area synthetic model, &gt; 100,000 nodes system (100% PV penetration)</td>
<td>Voltage regulation and VPP</td>
</tr>
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</table>
IPGroup sponsored participation to Energy I-Corps.

- Link: https://energy.gov/eere/technology-to-market/energy-i-corps.

- Activities: “Comprehensive training and each conduct at least 100 customer discovery interviews with industry. Once they have completed the training, participants have secured the necessary industry connections and insights to ready their energy technologies for the market, and gained an industry engagement framework to apply to future research and share with fellow researchers.”
Customer segments:

- Investor-owned utilities, cooperatives, and municipalities
- Microgrid operators
- Operators of soft microgrids.

Strategy:

- Licensing
- Startup.
Technology to Market Path and IAB

- **Grub funding** was obtained via participation from **IP-Group**.

- Techno-economic analysis performed under this funding.
Technology to Market Path and IAB

California Independent System Operator
  PJM
  GE Grid Solutions
  Emobtech
  Schneider Electric
  SIEMENS
  Centrica
  E.On
  SunPower
What’s Next Today?

- Project presentations (Sairaj Dhople and Na Li)
- Technology commercialization opportunities (Erin Beaumont)
- Invited talks (Sonja Glavaski and Michael McMaster)
- PHIL demonstration at NREL (Blake Lundstrom).

THANK YOU!

National Renewable Energy Laboratory
Southern California Edison
California Institute of Technology
University of Minnesota
Harvard University
University of Colorado, Boulder