Beneficial Integration of Solar PV, Energy Storage, Load Management, and Solar Forecasting

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Electric Power Research Institute (EPRI)

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Presentation Outline

• Project Team
• Objective and Key Research Components
• Budget Period 1 Highlights
  • System and Local Controller Strategies
  • Solar Forecasting
  • Load Management
• Demonstration Sites
• Next Steps
• Conclusion
# EPRI SHINES Project Team

<table>
<thead>
<tr>
<th>Utility Partners</th>
<th>University Partners</th>
<th>Industry Partners</th>
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</thead>
<tbody>
<tr>
<td>• FirstEnergy*</td>
<td>• Case Western Reserve University (CWRU)</td>
<td>• Eaton</td>
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<td>• NYP A*</td>
<td>• City University of NY (CUNY), Queens College</td>
<td>• GE (Alstom Grid)</td>
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<td>• ConED*</td>
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<td>• Clean Power Research</td>
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<td>• Southern Co*</td>
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<td>• PowerHub</td>
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<td>• Gulf Power*</td>
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<td>• LG Chem</td>
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<td>• LADWP†</td>
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<td>• Smart Inverter vendors</td>
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<td>• AECC†</td>
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<td>• AEP†</td>
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<td>• Duke†</td>
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<td>• SMUD†</td>
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<tr>
<td>• Gas Natural SDG†</td>
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*DOE proposal team member
†Supplemental Project Participants

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**EPRI**

- Integration of DER (P174)
- Energy Storage and DG (P94)
- End-Use EE and DR (P170)
- Information and Com Tech (P161)
- System Studies
- Economic Analysis

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Objective

*Beneficial Integration* of solar photovoltaic generation, energy storage, load management, and advanced forecasting technique, with electric power delivery network through optimal control strategies at a minimized cost.
End-to-End Integration

- **Local controller** coordinates DER devices to satisfy local objectives while responding to operational requests received from system controller.

- **System controller** sends setpoints to local controllers and distribution system controllable equipment based on service and reliability needs identified.
Key Research Components

- **End-to-end integrated system** through two-level **optimized control architecture**
- **Controllable Distributed Energy Resources** combining energy storage, and load management with solar PV
- **Improved predictability of solar PV generation** through high resolution solar forecasting
- **Reduced lifetime cost of solar plus storage system** through reliably integrated smart inverters
- **Interoperable and scalable solution** with open standards and communication protocols
- **Identifying power system level benefits** through distribution feeder modeling and impact studies
Budget Period 1 (Feb 1, 2016 ~ Jul 31, 2017) Tasks

Task 1.1: Project management and planning

Task 1.2: Create functional requirements and performance metrics for the control architecture and components

Task 1.3: Develop optimal control strategies for local and system controllers

Task 1.4: Improvement of PV and ES smart inverters

Task 1.5: Enhance solar forecasting resolution and interfaces

Task 1.6: Calculate host site and distribution feeder PV hosting capacity without proposed SHINES solution

Task 1.7: Demonstration site preparation – PV system

Task 1.8: Develop economic assessment methodology to assess the impact of proposed control architecture
Approach – Two-Level Control Strategy

**System Controller**
- System objective

**Local Controller**
- Local objective

**Available Dear Capability**
- Real & Reactive Power Setpoints

**Integrated DER**
- System Controller
  - Control commands (P, Q)
  - Price Signals
- Local Controller
  - Local Control Strategy
  - Cost minimization

**Execution Approach**

**Solution Design**
- Control architecture
- Functional requirements
- Performance metrics

**Systems Design & Implementation**
- Local & system controllers
- Smart inverter design & development
- Improved solar forecasting module

**Site Demonstrations**
- Site preparations
- PV & ESS Commission
- Data collection

**Performance Assessment & Impact Analysis**
- Solution technical performance
- Impact on PV hosting capacity
- Cost & benefit analysis

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Local Controller Functional Blocks

**System Controller**
- Forecasted POC voltage
- System requests
- Energy services available (fast, slow timeframes)

**Local Controller**
- Forecasted irradiance forecast
- Irradiance forecasting module
- Other inputs:
  - Electricity prices
  - Comfort preferences
- “Slow” Time Horizon Module
  - Scheduling algorithm regularly solving the local optimization problem
- Uncontrollable load consumption forecasting module
- “Fast” Time Horizon Module
  - Monitors fast changes (PV, loads..) and modifies optimal setpoints accordingly
- Measurements processing module
- Com Interface

**Resource availability assessment module**
- Measurements processing module
- Actual control setpoints

**Information exchanged between**
- Measurements
- Input data
- Information exchanged between controllers

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System Controller Functional Blocks

- **Data Repositories**
  - Circuit Models including System Parameter limits (OpenDSS, IDMS GridLab-D)
  - Solar PV generation (forecast)
  - Load Forecast
  - SCADA measurements (past, current)
  - Availability of aggregated DERs

- **Power Flow Solver**
  - Voltages
  - Other outputs

- **Trajectory Module**
  - Com Interface
  - Set-points
  - Cap banks, LTCs, etc.

- **System Controller**
  - Com Interface
  - Feeder topology
  - SCADA measurements
  - Distribution Feeders

- **Local Controller**
  - Information between controllers
  - Input data
  - Measurements

- **External Inputs**
  - Solar irradiance & PV generation forecasting module
  - SCADA measurements
  - Availability of aggregated DERs

- **Outputs**
  - Real and reactive power setpoints/trajectories
## Functional Requirements Local and System Controllers

<table>
<thead>
<tr>
<th>Req ID</th>
<th>Requirement</th>
<th>SC Functional Module</th>
</tr>
</thead>
<tbody>
<tr>
<td>R.SC.1*</td>
<td>SC shall receive SCADA measurements in real time.</td>
<td>Com Interface</td>
</tr>
<tr>
<td>R.SC.2</td>
<td>SC may receive PV output forecasts in real time.</td>
<td>Com Interface</td>
</tr>
<tr>
<td>R.SC.3</td>
<td>SC shall store information on relevant distribution circuit models (including capacitor banks, LTCs and other controllable devices).</td>
<td>Data repositories</td>
</tr>
<tr>
<td>R.SC.4</td>
<td>SC shall store information on past and current circuit conditions (i.e. voltages, power demand, etc.)</td>
<td>Data repositories</td>
</tr>
<tr>
<td>R.SC.5</td>
<td>SC shall store information on availability of local DER resources received from local controllers.</td>
<td>Data repositories</td>
</tr>
<tr>
<td>R.SC.6</td>
<td>SC may receive and store information on past and current solar irradiance and solar PV power output from the local controllers to apply corrections to the forecasted solar data.</td>
<td>Data repositories</td>
</tr>
<tr>
<td>R.SC.7</td>
<td>SC shall compute power flow for any given set of circuit conditions and return key output variables including voltages for the relevant feeder(s).</td>
<td>Power flow solver</td>
</tr>
</tbody>
</table>

*R.SC = Requirement for System Controller

<table>
<thead>
<tr>
<th>Req ID</th>
<th>Requirement</th>
<th>LC Functional Module(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R.LC.1*</td>
<td>LC shall receive real and reactive power setpoints from the SC.</td>
<td>Com Interface</td>
</tr>
<tr>
<td>R.LC.2</td>
<td>LC shall adjust the local DER schedules based on real and reactive power setpoints received from the SC.</td>
<td>Dynamic resource allocation; Reactive control loop</td>
</tr>
<tr>
<td>R.LC.3</td>
<td>LC shall compute availability of aggregated real and reactive power from local DER.</td>
<td>Resource availability assessment</td>
</tr>
<tr>
<td>R.LC.4</td>
<td>LC shall send updates to the system controller on availability of aggregated DERs.</td>
<td>Com Interface</td>
</tr>
<tr>
<td>R.LC.5</td>
<td>LC shall operate local DER systems to optimize local objective(s).</td>
<td>Dynamic resource allocation; Reactive control loop</td>
</tr>
</tbody>
</table>

*R.LC = Requirement for Local Controller
Local Controller Requirement: Enable PV Ramp Control Using Storage and Load Management

Max ramp rate: +78% of PV capacity/min

Max ramp rate: 10% of PV capacity/min

SHINES integrated solution
Local Controller Requirement: Enable PV Ramp Control Using Storage and Load Management

- PV
- PV+ES+LM (10% of PV capacity/min)

Charging/
Load increase

Discharging/
Load reduction
System Level Benefit of PV Generation Ramp Rate Control

- 3433 buses
- 5 capacitors
- 9 LTC
- 4 PV systems

- Maximum PV ramp rates observed in solar profile assumed (% of installed capacity/min):
  - UP: +87.2%
  - DOWN: -93.7%
Impact of PV Ramp Rate Limiting on Tap Changing

① The number of transformer tap operations increases with the increase of installed PV capacity.

② When PV capacity is large enough to impact tap operation, limiting PV ramp rate through integrated DER control reduces the number of tap operations required which extends equipment life.
Interaction between System and Local Controllers

Step 1: LC provides set of feasible trajectories to SC for real and reactive power

Feasibility space for PV+ES+LM passed to System controller

PV forecast

Initial self-commitment complying with ramp rate maximum

System Controller

Available DER resources

Local Controller
Interaction between System and Local Controllers

Step 2: SC assigns operating range for real and reactive power trajectories to LC

Feasibility space for PV+ES+LM

PV forecast

Initial self-commitment complying with ramp rate maximum

Operating range assigned to Local controller
(may be time-specific as shown in this illustrative example)
Interaction between System and Local Controllers

Step 3: LC is free to dispatch DER resources within operating range assigned by SC

Feasibility space for PV+ES+LM

PV+ES+LM dispatched by local controller to comply with operating range
Interaction between System and Local Controllers

Feasibility space for PV+ES+LM

Operating range

PV+ES+LM dispatched by local controller to comply with operating range assigned

Use of LM to decrease number of ES cycles

Charging/Load increase

Discharging/Load reduction

ES

LM
Advanced Solar Forecasting

- One-min temporal, 1-km spatial resolution, 30-min ahead, and
- Thirty-min temporal, 1-km spatial resolution, 7-day ahead solar forecasting

![Graph showing solar forecasting](image-url)
Improving the Accuracy of Near-Term Solar Forecasting

• Getting ready to use the higher resolution Images from GOES-R
• Accuracy of forecasted data will be evaluated against field measured data
Load Management – Pool Pump

Pentair Pump with CTA2045 DR Controller

Baseline Operation

Load Shed

Load Up

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Identifying System Level Benefits – Feeder PV Hosting Capacity

- Can this integrated DER solution increase feeder PV hosting capacity without requiring expensive infrastructure upgrade?
Demonstration Sites

Case Western Reserve University (CWRU) / Mandel School of Applied Social Science (MSASS) Cleveland, OH

City University of New York (CUNY), Queens College/The Summit, 64-80 Kissena Blvd, Flushing, NY

SCS/GP Residential Demo Site Pensacola, FL
# Demonstration Sites

<table>
<thead>
<tr>
<th></th>
<th>Commercial Site#1</th>
<th>Commercial Site#2</th>
<th>Residential site#1</th>
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</thead>
<tbody>
<tr>
<td><strong>Owner</strong></td>
<td>CWRU</td>
<td>Queens College/CUNY</td>
<td>Individual home owners</td>
</tr>
<tr>
<td><strong>Utility</strong></td>
<td>FirstEnergy/MCCo</td>
<td>NYP/ConED</td>
<td>Southern Co/Gulf Power</td>
</tr>
<tr>
<td><strong>PV</strong></td>
<td>50kW</td>
<td>50 - 60kW</td>
<td>Two; each 5kW</td>
</tr>
<tr>
<td><strong>Energy Storage</strong></td>
<td>50kW/200kWh</td>
<td>100kW/200kWh</td>
<td>14kW/40kWh</td>
</tr>
<tr>
<td><strong>Solar Forecasting</strong></td>
<td>CPR</td>
<td>CPR</td>
<td>CPR</td>
</tr>
<tr>
<td><strong>Smart Inverter</strong></td>
<td>Eaton AC-coupled hybrid Inverter</td>
<td>Dynapower DC coupled hybrid inverter</td>
<td>PV Smart Inverter - SMA, PowerHub SiC-based 4-quadrant DESS</td>
</tr>
<tr>
<td><strong>Battery</strong></td>
<td>LG Chem, SuperCap</td>
<td>LG Chem</td>
<td>Saft</td>
</tr>
<tr>
<td><strong>Local Controller</strong></td>
<td>Eaton</td>
<td>TBD – BEMS will be considered</td>
<td>TBD – HEMS will be considered</td>
</tr>
<tr>
<td><strong>System Controller</strong></td>
<td>GE (Alstom)</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td><strong>Data Monitoring and Analysis</strong></td>
<td>CWRU, EPRI</td>
<td>Queens College, EPRI</td>
<td>Home Owners, EPRI</td>
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Budget Period 2 & 3 Key Tasks

Budget Period 2 (Aug 1, 2017 ~ Jul 31, 2018)
• Verification of controllers’ optimization algorithms and implementation in commercial platform
• On-site commissioning of PV, ES, and controllable loads
• GOES-R satellite image based improved near-term solar forecasting
• Economic analysis

Budget Period 3 (Aug 1, 2018 ~ Jul 31, 2019)
• Feeder level PV hosting capacity improvement through integrated DER with local and system level controllers
• Demonstration of the integrated DER solution, data collection, and performance analysis
• Final economic analysis
Lessons Learned

• Contract negotiation, especially IP issues can be complicated and time consuming
  • Diverse type of stakeholders: non-for profit tax exempt, non-for profit universities, for-profit large business, for-profit small business

• Change in business model
  • GE purchased Alstom Grid
  • PowerHub’s business priority changed to EV charging

• Potential snow loading concerns, identified through structural analysis, required demo site change at CWRU

• Energy storage system (ESS) cost can vary widely and interconnection permitting for Li-Ion based battery system can be a challenge at certain jurisdictions
Relevance to Solar Challenge

- Making the grid ready for seamless integration of solar plus storage to support customer choice
  - while optimizing the electric system: technically and economically
- Making solar plus storage more operationally integrated
  - in a cost competitive manner
- Improving the value proposition of solar plus storage and other distributed energy resources
  - extending benefits beyond customer premises
Together...Shaping the Future of Electricity

Contacts:
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