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Grid-Edge Energy Resources to Shape Resilient Community Microgrids

Building a Resilient Community Using Distributed Energy Resources Workshop

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Communities Need Resilience

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Pressing need to increase system resilience:

- Communities are asking for distributed clean energy solutions to realize community microgrids.
- Increased distributed energy resource (DER) penetration and improved grid-forming technologies.

Unsolved key challenges:

- Lack of methods to partition grids into community microgrids
- Inaccurate system models and limited communication networks during prolonged outages
- Need to maintain microgrid stability under various conditions
- Participation of behind-the-meter (BTM) DERs.

REORG: Resilience and Stability Oriented Cellular Grid Formation and Optimizations for Communities with Solar PVs and Mobile Energy Storage

SETO FOA 2243 Awarded Project, FY21–FY24

Our Solution

Organize the distribution system into community microgrids using dynamically reconfigurable cells:

- Resilient and stable cell-based microgrid operation
- Adapt to time-varying system conditions.

Project Overview

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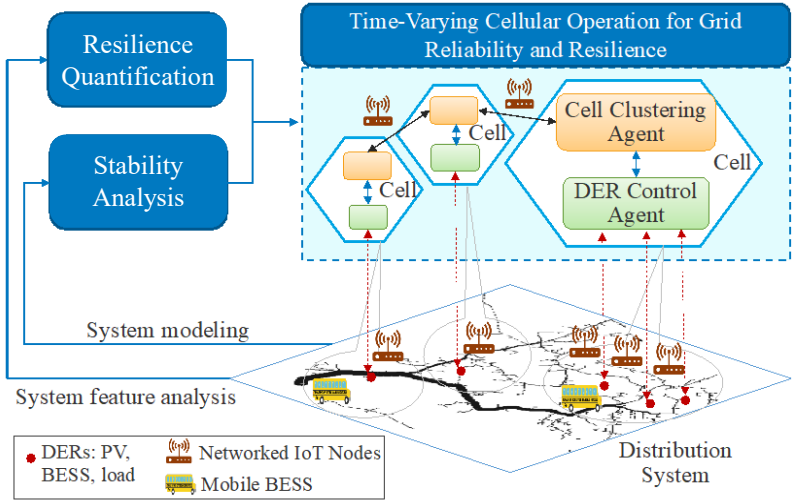
Objectives: Develop, validate, and demonstrate a cellular community microgrid formation and optimization approach to achieve resilient, stable, scalable operations for distribution feeders with photovoltaics (PV) and mobile battery energy storage systems (BESS).

Technical approach:



Outcomes:

- **Innovation:**
  - Resilient and stable cell microgrid organization scheme using machine learning and advanced stability designs
  - Distributed and adaptable cell management system realized using modern Internet of Things (IoT) platforms.
- **Impact:**
  - Solution that addresses an electric co-op's wildfire mitigation requirements
  - National scalable approach for operating multiple microgrids and to increase system-level resilience.

Team: NREL, Holy Cross Energy, Minsait ACS, Mississippi State University, National Rural Electric Cooperative Association

Technical Approach: Form Cells

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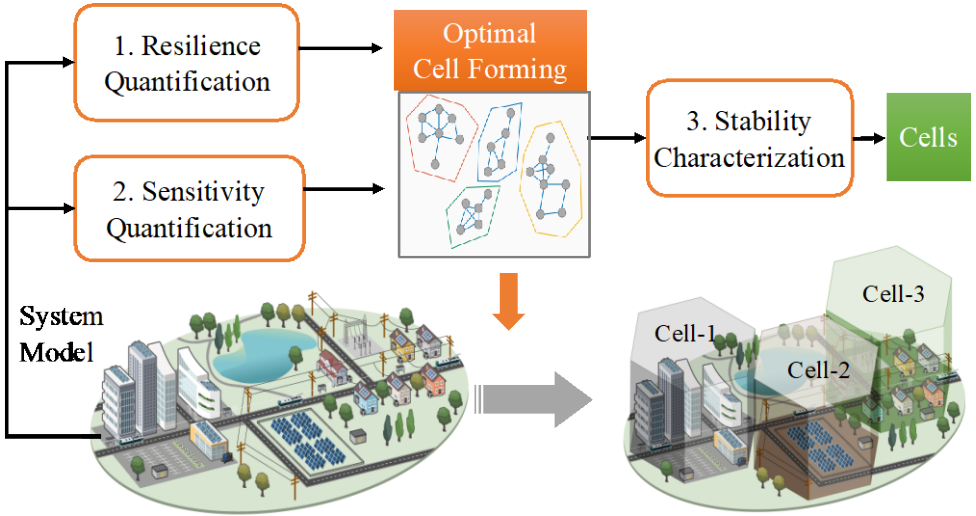
A ***cell*** is a group of interconnected PV, BESS, and buildings that comprise the smallest subset of the grid capable of operating independently using its own resources.

1. Resilience quantification to preliminary identify resilient cells
2. Sensitivity analysis to obtain "loosely connected" cells
3. Stability analysis to guarantee cell stability in islanded mode.



Each identified cell has integrated resilience over a desired threshold and can achieve stable operation when disconnected from the grid.

Technical Approach: Operate Cells Using Machine Learning

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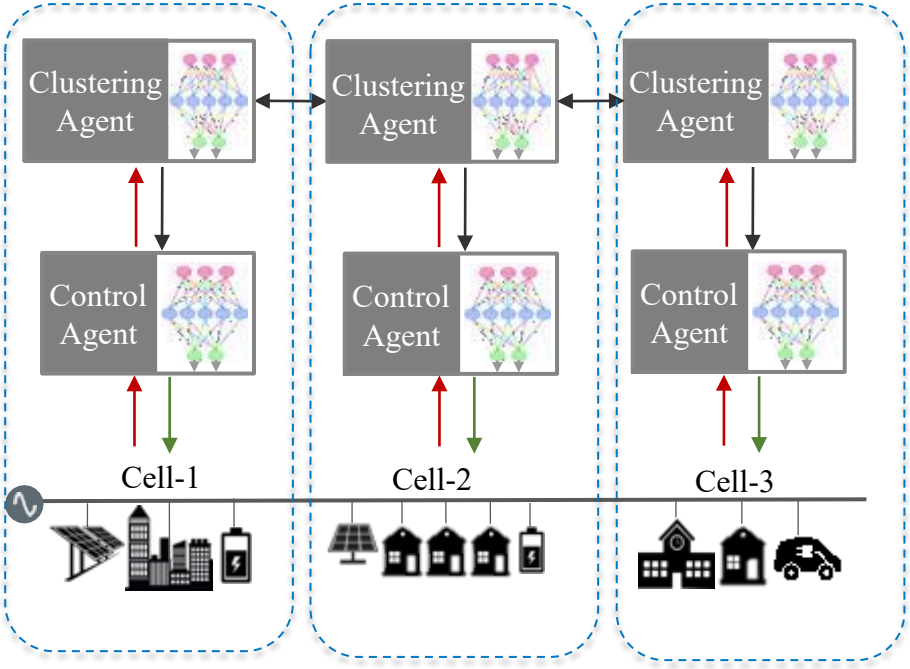

Use **multi-agent deep reinforcement learning** to design a two-level control strategy:

- **Cell control agent:**
  - Control DERs inside the cell.
- **Cell clustering agents**:
  - Coordinate with other cells for network reconfiguration and service restoration.

Use machine learning to reduce the reliance on accurate system model and massive communication.

Cell Normal Operation

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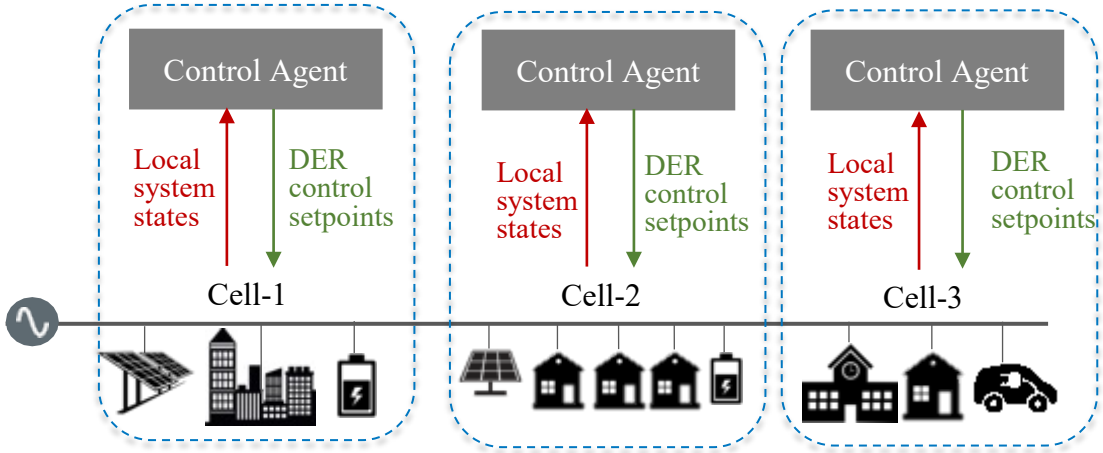
Cell control agents are ***only*** used to achieve **inter-cell communication-free** DER optimization to regulate distribution voltages and manage peak demand.



- Fast, real-time DER optimization
- Distributed and coordinated cell optimizations to manage >10,000 DERs
- No communication between cells to reduce the vulnerability to cyberattacks and communication loss.

Cell Microgrid Operation

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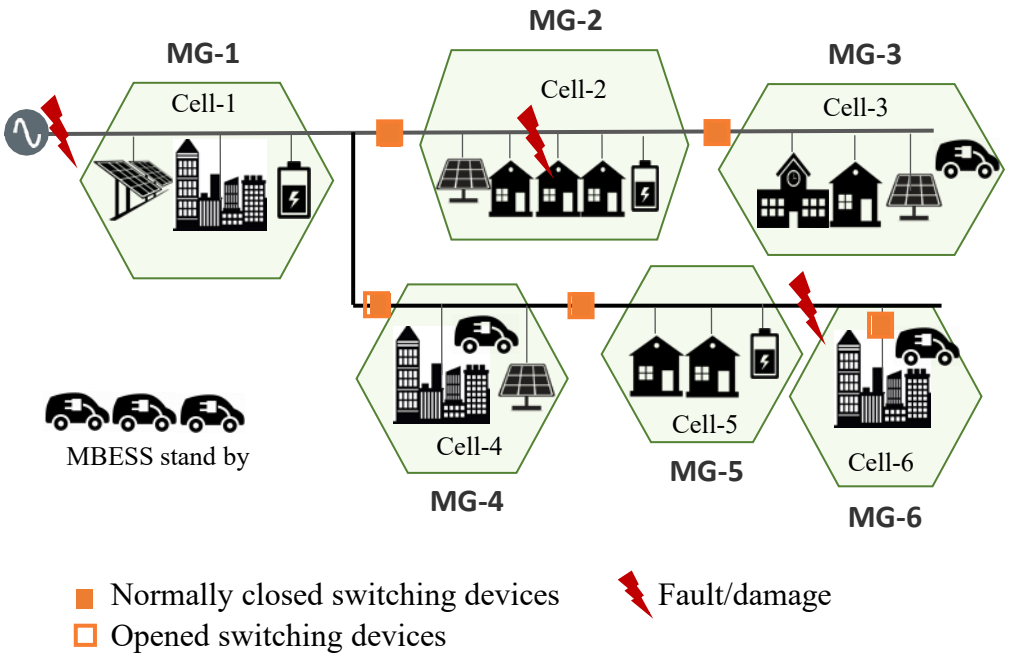
Use cells to form islanded community microgrids and quickly restore local services.



- Open switching devices to form cell-based microgrids
- Route available mobile BESS to optimal depots
- Each microgrid black starts by using inverter-based grid-forming resources.
- **Cell control agent**: Optimize the operations of PV, BESS, and other DERs within each microgrid to maximize local microgrid resilience.

Cell Microgrid Operation

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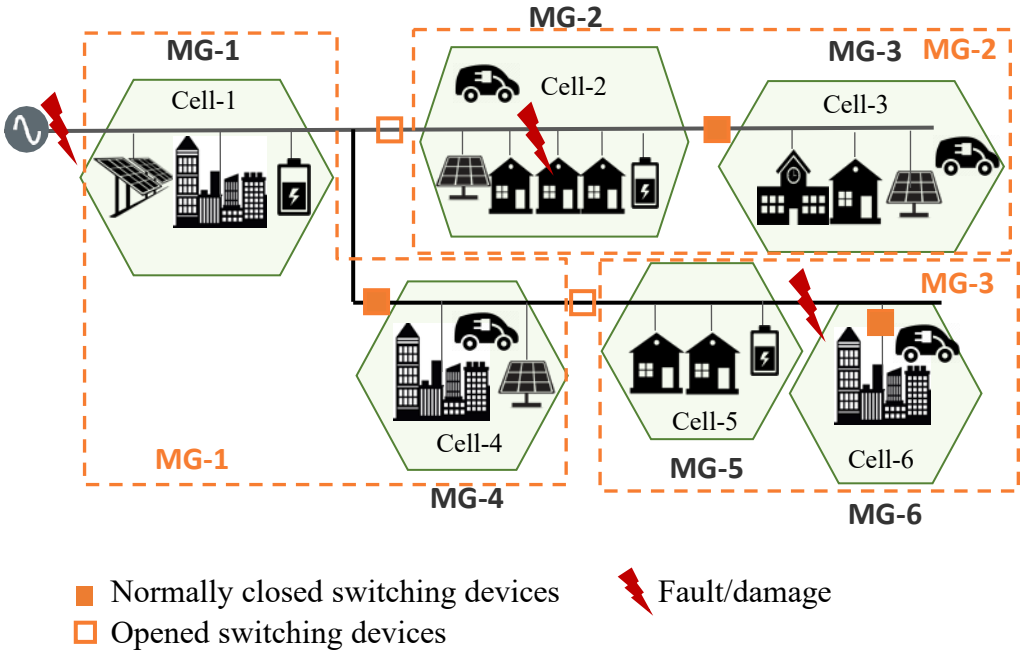
Resilience-driven cell clustering and organizing scheme to adapt to non-daylight hours and time-varying conditions in prolonged outages and to maximize entire system resilience.



- **Cell clustering agents** coordinate with each other to maximize system-level resilience by:
  - Closing switching devices
  - Rerouting mobile BESS
  - Solving reference signals that are sent to cell control agents.
- **Cell control agent**: Re-optimizing the operation of DERs within its own cell based on the reference signal

Distributed and Adaptable Cell Management System Using Minsait Software Platform

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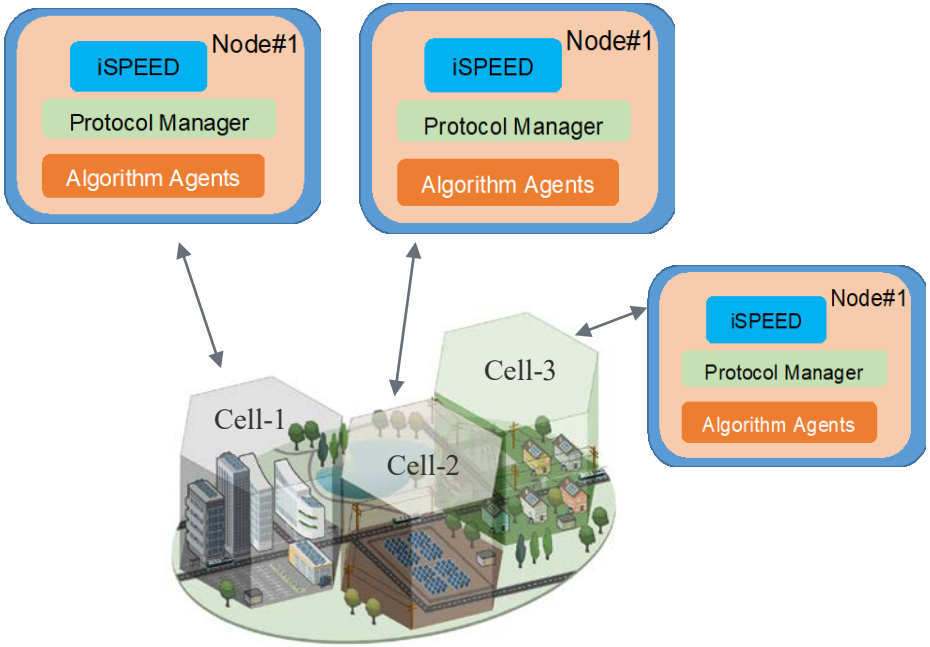
The dynamic nature of clustering cells and the distributed control require a software architecture able to act as a **distributed and adaptable cell management system**.



- Collect, process, and store data **locally** in every node.
- **Modular and highly reproduceable** node software architecture
- In coordination with:
  - Edge sensors and IoT devices
  - Utility metering infrastructure and system
  - Controllable switches, protection relays.

Testing and Demonstration

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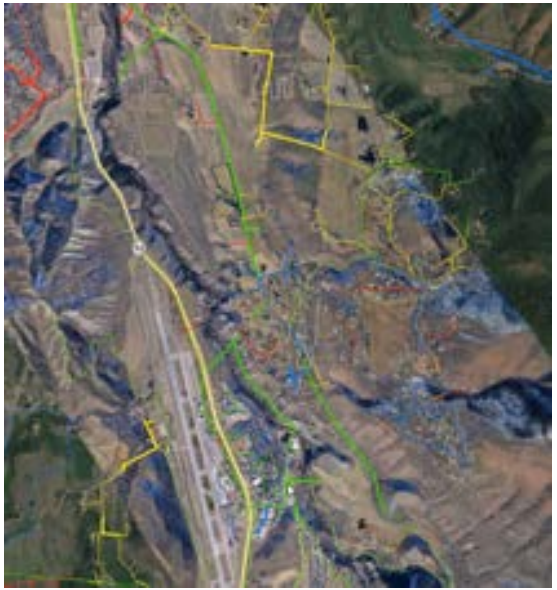
NREL's Energy Systems Integration Facility (ESIF) will be used to conduct **hardware-in-the loop experiments.**

Selected community with 100% PV penetration:

- 760 residential and 379 commercial customers, with 4.5 of MW peak demand and 400 kW of distributed PV
- A 5-MW PV power plant and more energy storage systems
- A couple of critical loads
- Multiple existing bus depots and park-and-ride lots to host mobile BESS.



Summary

A nationally scalable approach to operate multiple community microgrids and increase system-level resilience:

- **Integrate PV and BESS at 100% of peak load,** ensuring increased time to operate in islanded condition under prolonged outages.
- Provide **an immediate solution** to help a local electric co-op enhance its system resilience.
- **Create a distributed and secure microgrid management platform** that can be adopted by utilities and stakeholders to operate communities with >10,000 DERs.
- Encourage **field adoption of advanced solar technology** to enhance grid resilience.

AI-Driven Smart Community Control for Accelerating PV Adoption and Enhancing Grid Resilience

SETO Lab Call Project, FY19–FY21

Our Solution

A hierarchical control to enable the use of BTM DERs to improve grid resilience

Project Overview

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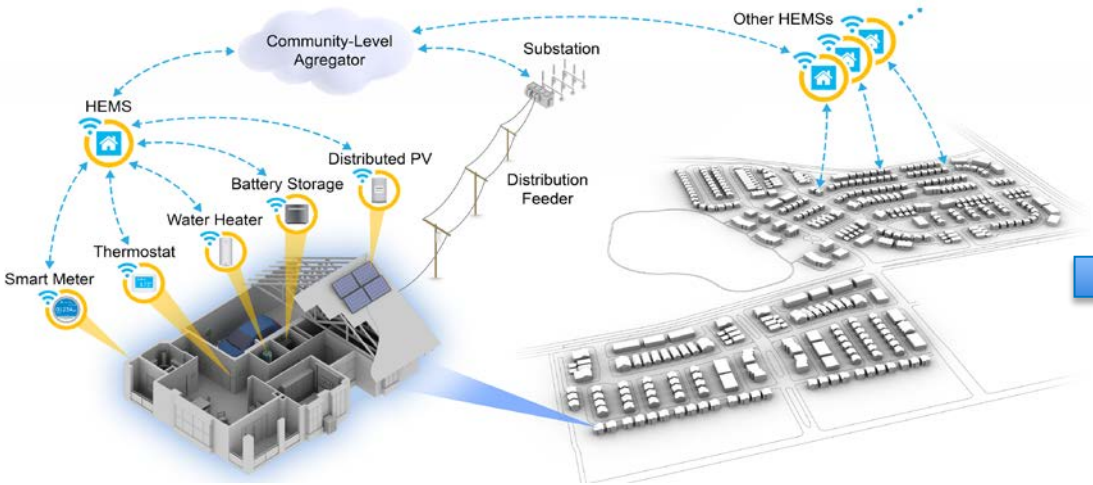
Objectives: Develop and demonstrate a community-scale solution to resolve adverse distribution grid impacts caused by high-penetration PV.

Team:
NREL, Thrive Home Builders, Fort Collins Utilities, Holy Cross Energy, A.O. Smith

Technical approach: **Artificial intelligence + Home energy management system (HEMS) + Aggregator**



PV self-consumption (reduce PV curtailment with flexible loads and batteries)

Grid reliability (reduce voltage violation; demand response; virtual power plant)

Grid resilience (100% critical load support for up to 5 days during emergencies)

Hierarchical Control System

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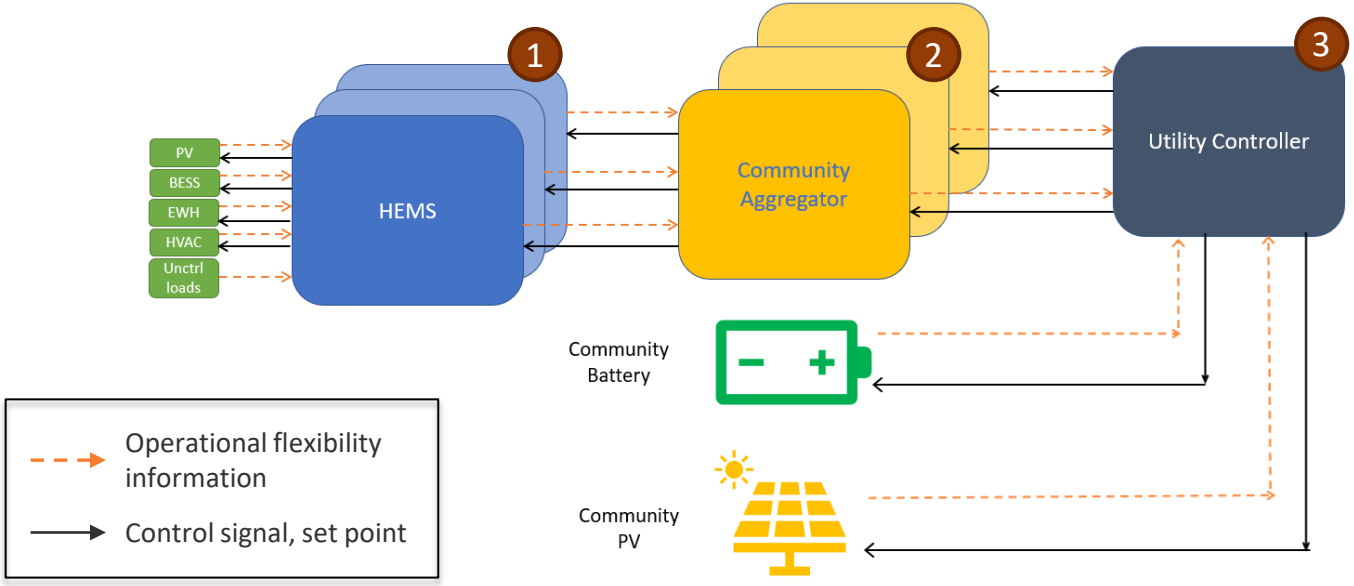
Directly control BTM DERs inside a home and satisfy occupant comfort.

Coordinate the operation of multiple HEMS and manage home node voltages.

Coordinate the operation of multiple aggregators and manage entire distribution voltages.



Co-Simulation Platform

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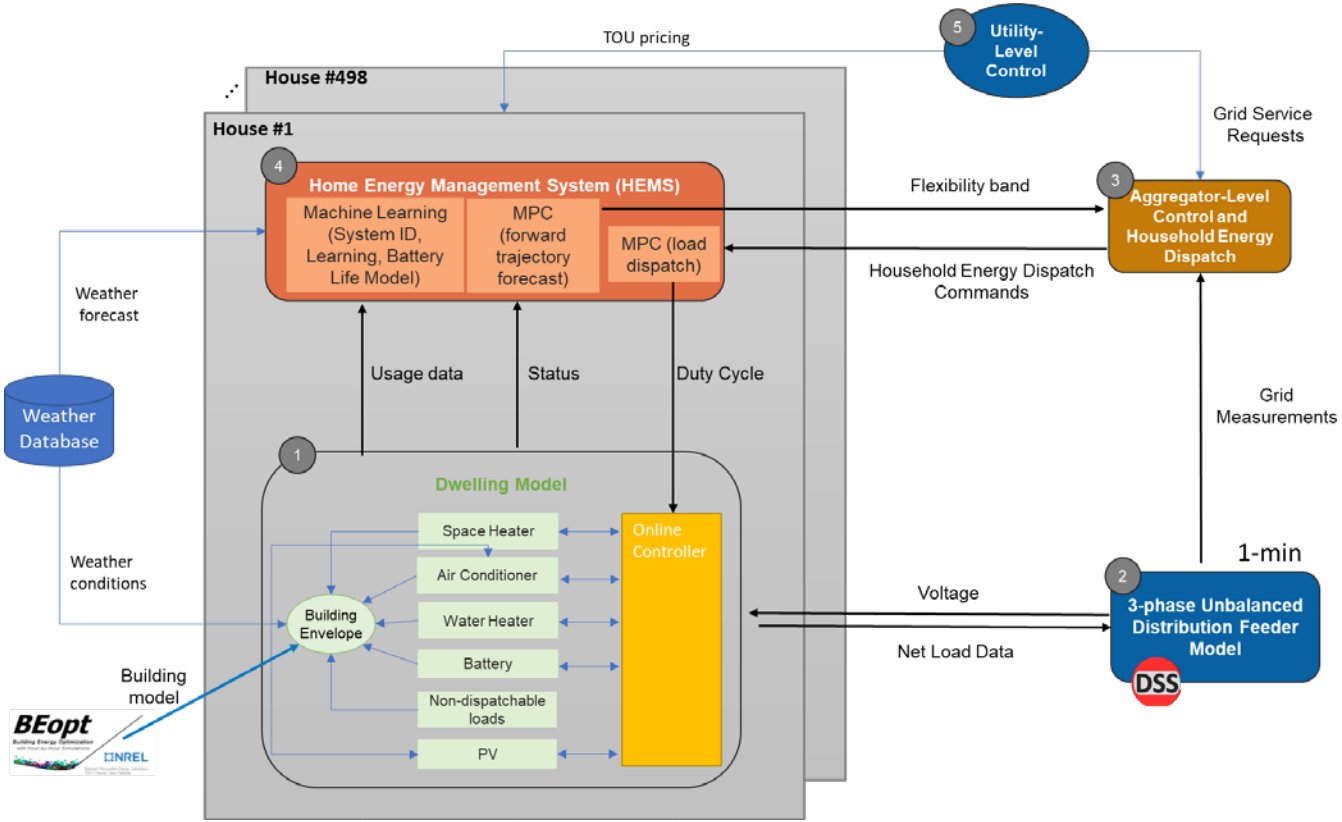

Critical Load Definition

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Scale of Criticality

Level	Consequence
1	No impact to minor annoyance
2	Annoyance, but alternatives exist
3	Annoyance, no alternatives exist
4	Major annoyance or monetary loss
5	Safety/health risk

Criticality of Loss of Service by End Use, Season, and Outage Duration

Load	Consequence of Loss of Service	Criticality					
		Winter Season		Shoulder Season		Summer Season	
		Short Outage	Long Outage	Short Outage	Long Outage	Short Outage	Long Outage
Misc. Loads: Communication	May miss evacuation orders/checking in on others/other key information during disaster	5	5	5	5	5	5
HVAC: Heating	Property damage (frozen pipes), occupant health/safety	4	5	1	2	1	1
HVAC: Cooling	Occupant health/safety	1	1	1	2	4	5
Appliance: Refrigerator	Loss of perishable food (can be temporarily stored outside in cold outage)	4	4	4	4	4	4
Appliance: Cooking	Must rely on shelf-stable, uncooked goods for sustenance	2	4	2	4	2	4
Lighting	Reduced lighting levels in certain areas of the home	2	4	2	4	2	4
Water Heating	Must bathe in cold water	1	3	1	2	1	2
HVAC: Dehumidification	Higher discomfort	1	1	1	1	2	2
Ventilation	Risk of buildup of indoor pollutants (VOCs, CO2, etc.)	2	2	1	2	2	2
Appliance: Clothes Washer	Must hand-wash clothes in cold water	1	2	1	2	1	2
Appliance: Clothes Dryer	Must line dry/drying rack	1	2	1	2	1	2
Ceiling Fan	Discomfort, inability to mitigate loss of AC	1	1	1	1	2	2
Appliance: Dishwasher	Must hand-wash dishes in cold water	1	1	1	1	1	1
Misc. Loads: Others	Possible loss of entertainment/work-from-home income	1	1	1	1	1	1

Resilient Operation

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- **Maximize the use of community DERs to support all critical loads and to minimize reliance on the utility grid.**

Uncoordinated operation by using HEMS only:

- Minimize energy exchange with the grid
- Maximize PV self-consumption while minimizing battery cycling
- Thermal comfort: relax comfort band of air temperature to 60°F–80°F.

Coordinated operation among three-layer controls:

- HEMS provide BTM DERs flexibility to aggregators, and community aggregators provide feasible, aggregated flexibility to utility control.
- Utility controller minimizes net power import from the utility grid.
- Aggregators follow utility control signals, and HEMS follow aggregator control signals as close as possible.

Key Takeaways

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- In the uncoordinated scenario, HEMS can help shift the controllable load and dispatch the home battery to reduce the net energy consumption of the home, but community voltages suffer from violations.
- In the coordinated control scenario:
  - 100% of the critical loads at each home were met.
  - The home gets preheated in winter and precooled in summer during the PV production period to self-consume PV energy and to reduce energy consumption during nighttime. Occupant comfort is almost always satisfied during resilient days.
  - The community can maintain resilient operation for 5 days in summer with high PV generation and the support of a 4-MWh/1-MW community battery.
  - Due to high heating load and low PV generation, the community can only maintain resilient operation for 4.5 days in winter with the support of a 32-MWh/8-MW community battery.
  - The entire community net power consumption is close to 0 during resilient days.
  - The community has better grid independency (defined as the capability of a community to support the electricity usage of its own loads using its own generation resources) performance.

Thank You

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Achieving Resilient Communities with DERs

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