DynaGrid:
Dynamic Microgrids for Large-Scale DER Integration and Electrification

Microgrid Program Peer Review, July 26–27, 2022

Andrey Bernstein, PI
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Objectives & Outcomes
Develop a framework for the dynamic formation and operation of networked microgrids to address major research challenges outlined in the Topic 4 concept paper and the overall Microgrid Program goals:
• Improve transmission-and-distribution (T&D) system real-time resilience.
• Integrate and efficiently leverage large amounts of renewables and distributed energy resources (DERs).
• Allow wide-scale electrification.
• Increase distributed and decentralized decision making.
• Improve equity and energy justice.

Technical Scope
Develop a multi-resolution (fractal) approach, which considers several layers of dynamic grid partitioning with different levels of detail:
• During normal operation, the optimal partition might change over time, e.g., because of the presence of large amounts of electric vehicles (EVs) or daily variations in solar photovoltaic (PV) generation that dynamically change the loading conditions in the network.
• During disruptions, a partition that is typically performing well for normal operation might be ineffective to continue to serve customers in both unaffected and heavily damaged parts of the network.

Innovation:
• Dynamic and multi-resolution formation of microgrids
• Distributed control and operation of networked microgrids
• Network of equitable microgrids for improved energy justice.

Funding Summary ($K)

<table>
<thead>
<tr>
<th></th>
<th>FY21 &amp; prior, authorized</th>
<th>FY22, authorized</th>
<th>FY23, requested</th>
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<tbody>
<tr>
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Develop a framework for the dynamic formation and operation of networked microgrids to **address major research challenges** outlined in the Topic 4 concept paper and the overall Microgrid Program goals:

- Improve T&D system real-time **resilience**.
- Integrate and efficiently leverage large amounts of **renewables and DERs**.
- Allow wide-scale **electrification**.
- Increase **distributed and decentralized decision making**.
- Improve **equity and energy justice**.
Overall Approach

Multi-resolution (fractal) approach, with several layers of dynamic grid partitioning:

- **Normal operation**: The optimal partition changes over time due to changing net load (e.g., EVs, solar); affected by energy justice metrics.
- **Disruptions**: The optimal partition contributes to increasing resilience and energy justice.

**Innovation**:  
- Dynamic and multi-resolution formation of microgrids  
- Distributed control and operation of networked microgrids  
- Network of equitable microgrids for improved energy justice.
Significance and Impact

- Addresses **industry needs** for scalable, flexible, and reconfigurable microgrid systems
- Improves system **reliability and resilience** by explicitly considering these aspects in dynamic microgrid formation methods
- Engagement with industry (DTE Energy, ComEd, PG&E)
  - Industry advisory board
  - Developing **demonstration plans** (DTE Energy).
- **Improves energy justice** by explicitly considering energy justice metrics in microgrid design (addressing EJ40)
- Release of **open-source software tools**
- **Publication** in high-impact peer-reviewed journals and/or conference proceedings.
Overall Project Plan

Use Case Development (UWM, NREL)*
Task 1: Develop use cases for normal operation and disruptions

Laboratory Evaluation (NREL)
Task 7: Laboratory evaluation

Technology Development (ALL)
Task 2: Definitions of partition optimality
Task 3: Offline algorithms for robust partitions, and co-simulation
Task 4: Online algorithms to compute partitions in real time
Task 5: Adaptive control algorithms, and co-optimization of boundaries and set points that maintain grid stability and protection
Task 6: Long-term planning of microgrid capabilities

Field Demonstration (LLNL)
Task 8: Field demonstration

IAB Engagement (ALL)
Task 9: IAB Engagement

*Main contributors are listed in parentheses.
Currently completing Q2 of the project

**Overall Project Plan**

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- Task 2: Definitions of partition optimality
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- Task 4: Online algorithms to compute partitions in real time
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NREL and UWM Approach and Progress

Andrey Bernstein and Line Roald
Illustrative Dynagrids

Clustering: No penalty on generation from G11, G12

30% serviced, 0.985 p.u.
G11 - 3 MW
G12 - 1 MW

30% serviced, 0.985 p.u.
G11 - 3 MW
G12 - 0.7 MW

30% serviced, 0.985 p.u.
G11 - 3 MW
G12 - 0.5 MW
Clustering: With penalty on generation from G11, G12

30% serviced, 0.985 p.u.
G11 - 3 MW, 0x
G12 - 3 MW, 0x

30% serviced, 0.985 p.u.
G11 - 3 MW, 40x
G12 - 3 MW, 60x
Clustering: With penalty on generation and varying voltage limits

Illustrative Dynagrids

50% serviced, **0.95 p.u.**
- G11 - 3 MW, 40x
- G12 - 3 MW, 60x

50% serviced, **0.985 p.u.**
- G11 - 3 MW, 40x
- G12 - 3 MW, 60x
Use Case Development (UWM, NREL)

Task 1: Develop use cases for normal operation and disruptions

Normal operation:
• Large-scale EV integration (NREL)
• Aggregators: Support of FERC Order 2222 (NREL)
• Energy justice: Correlation with demographic data (UWM, NREL).

Disruptions:
• Impact of large storms and hurricanes (NREL)
• Hot/cold weather snaps (NREL)
• Wildfires (UWM, NREL)
• Energy justice: Consideration of data on social vulnerability (UWM, NREL).
Use Case Development (UWM, NREL)
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Use Case: Natural Disasters

Example: Hurricane Dolly, TX, 2008

WIND Toolkit wind field at 100 m above ground

Path and synthetic TAMU 2,000-bus transmission grid. The size of the blue circles corresponds to the hurricane’s radii and their color intensity corresponds to the maximum wind speed.
Use Case: Natural Disasters

Approach:
• Simulate T&D system under disruptions.
• Use fragility curves to model equipment (substations, generators, lines) failure.
• Model “human-in-the-loop” during disruptions.
• Apply DynaGrid algorithms to reduce disaster effect.

Path and synthetic TAMU 2,000-bus transmission grid. The size of the blue circles corresponds to the hurricane’s radii and their color intensity corresponds to the maximum wind speed.
Considering Energy Justice

DynaGrid dynamically forms **optimal** microgrid partitions to **optimize** the operations of the electric grid during normal operation and emergency situations.

What does **optimal** mean?
- Most sustainable?
- Most affordable?
- Most reliable?

It doesn’t help to have reliable access to electricity if you cannot afford to use it!

It doesn’t help if the overall cost is low if you still experience outages!

More than 20% of U.S. households reported reducing or **foregoing food or medicine** to pay energy bills. (Source: EIA 2015 RECS Survey)

14.5% of U.S. households reported receiving a **disconnect or delivery stop** notice. (Source: EIA 2015 RECS Survey)
Examples of Inequities

Inequities arising from PV net metering:

- The installation of PV increases the need for grid updates, which get rolled into the per kWh grid charge.
- The higher fees will be disproportionately paid for by non-PV owners, who generally have lower income.

Project goal: Develop metrics and analysis methods to assess outcomes for different groups of customers.
Examples of Inequities

**Project goal:** Develop metrics and analysis methods to assess outcomes for different groups of customers.

If access to DER power is accounted for in post-disaster restoration, the optimal restoration strategy might shift toward reconnecting customers without DERs.

(Source: N. Rhodes and L. Roald, “The Role of Distributed Energy Resources in Distribution System Restoration,” Best paper award in Energy Track, HICSS 2022.)
Examples of Inequities

If utilities account for access to DER power in post-disaster restoration, the optimal restoration strategy prioritizes reconnection of customers without DERs.

(Source: N. Rhodes and L. Roald, “The Role of Distributed Energy Resources in Distribution System Restoration,” Best paper award in Energy Track, HICSS 2022.)

The ability to cope with outages causes inequities:
- “Critical loads”: hospitals, emergency responders
- How about food- and housing-insecure families who cannot afford to refill their fridge after an outage?
- How about the senior citizen who might die from heat-related health complications?

Project goal: Develop metrics and analysis methods to assess outcomes for different groups of customers.

Project goal: Understand how data on community vulnerability can best be integrated in decision-making tools for electric grid operation and investments.
Available Data Sources

Original data:

**Socioeconomic data:** American Community Survey (U.S. Census Bureau)

**Data on natural hazards:** National Risk Index (FEMA)

**Data on energy affordability:** Low-Income Energy Affordability Data (DOE)

**Medicare Electricity-Dependent Populations:** HHS emPOWER Map (DHHS)

Derivative risk metrics:

US Climate and Economic Justice Screening Tool (identifying underserved communities for Justice40 Initiative)

U.S. Census Bureau Community Resilience Estimates

CDC Social Vulnerability Index

Questions: How similar/different are those metrics? Which capture the most relevant information?
**Approach:** Correlate grid data with wildfire risk and demographic data to demonstrate how DynaGrid operation could mitigate wildfire ignitions from power equipment and promote social equity.

**Modeling:** Start with the optimal switching/load-shedding problem for microgrid operation (implemented in PowerModelsONM), then modify the objectives to minimize wildfire risk and maximize load delivery, with consideration of two social vulnerability aspects:

1. Vulnerability to power outages
2. Vulnerability to wildfire ignitions.

**Impact:** Promote awareness of energy justice and climate change-induced extreme weather events in the operation of future grids.
Main Achievements on Dynamic Reconfiguration

• Developed distribution system reconfiguration formulation that **has the ability to form islands** using the capability of grid-forming inverters

• Adapted three radiality formulations to ensure forest (collection of trees) structure instead of a single tree

• Analyzed the computational complexity of the three formulations and compared their relaxations tightness.
Define $\tilde{A}$ as follows:

$$
\tilde{A}_{\ell,k} = \begin{cases} 
+1, & k = n \\
-1, & k = m \\
0, & \text{otherwise}
\end{cases}, \forall \ell = (n, m).
$$

Then, partition the matrix $\tilde{A}$:

$$
\tilde{A} = \begin{bmatrix}
N_0 & N_g \\
A_{00} & A_{0g} \\
A_{10} & A
\end{bmatrix}
$$

**Theorem 1.** The network topology defined by the activating the lines in $L_1$ and operating the buses in $N_0$ as slack buses is a collection of trees where each node in $N_0$ is the root of a single tree if and only if:

- **C1** there exists a vector $f \in \mathbb{R}^{|L_1|}$ such that $A^T f = 1$,

- **C2** $\sum_{\ell \in L} y_\ell = (N + 1) - \sum_{n \in R_f} (1 - \gamma_n)$

**Constraints Reformulation** ($M := |N|$):

$$
-My \leq f \leq My
$$

$$
\tilde{a}_n f \leq 1 + M(1 - \gamma_n)
$$

$$
\tilde{a}_n f \geq 1 - M(1 - \gamma_n)
$$

$$
1^T y = (N + 1) - |R_f| + 1^T \gamma
$$

# cont. optimization variables = $|L|$

# binary optimization variables = $|L| + |R_f|$

# number of constraints = $2|L| + 2|N| + 1$
Theorem 1. Let the lines in $\mathcal{L}_1$ be the only energized lines, and let the buses in $\mathcal{N}_0$ operate as slack buses. The topology of the resulting reconfiguration is a collection of trees where each node in $\mathcal{N}_0$ is the root of a single tree if and only if:

1) there exist vectors $f^{(k)}, \bar{f}^{(k)} \in \mathbb{R}^{|\mathcal{L}_1|}$ such that

$$A^Tf^{(k)} + \bar{A}^T\bar{f}^{(k)} = e_k, \quad \forall k \in \mathcal{N}_g$$

2) $\sum_{t \in \mathcal{L}_1} y_t = (N + 1) - \sum_{n \in \mathcal{R}_f} (1 - \gamma_n)$

Constraints Reformulation ($M := |\mathcal{N}|$):

$$\lambda + \bar{\lambda} = y$$

$$0 \leq f^{(k)} \leq \lambda$$

$$0 \leq \bar{f}^{(k)} \leq \bar{\lambda}$$

$$\tilde{a}_n(f^{(n)} - \bar{f}^{(n)}) \leq 1 + M(1 - \gamma_n)$$

$$\tilde{a}_n(f^{(n)} - \bar{f}^{(n)}) \geq 1 - M(1 - \gamma_n)$$

$$\tilde{a}_n(f^{(k)} - \bar{f}^{(k)}) \leq M(1 - \gamma_n) \quad \forall n \neq k$$

$$\tilde{a}_n(f^{(k)} - \bar{f}^{(k)}) \geq -M(1 - \gamma_n) \quad \forall n \neq k$$

$$1^Ty = (N + 1) - |\mathcal{R}_f| + 1^T\gamma$$

$$\bar{\mathbf{A}} := -\mathbf{A}$$

$$\tilde{\mathbf{A}} := \begin{bmatrix} \mathbf{A}_{00} & \mathbf{A}_{0g} \\ \mathbf{A}_{10} & \mathbf{A} \end{bmatrix}$$
Cut-Set Constraints for Radiality

Define: \( \Gamma(N_x) := \{(u, v) : (u \in N_x, v \notin N_x) \text{ or } (u \notin N_x, v \in N_x)\} \)

Then, \( \sum_{\ell \in \Gamma(N_x)} y_\ell \geq 1 - \sum_{n \in N_x} (1 - \gamma_n) \quad \forall N_x \subseteq N \)

represents a reformulation of the desired radiality constraints.

Constraint generation approach:

- **STEP 1**: Formulate the reconfiguration problem with only: \(1^T y = (N + 1) - |\mathcal{R}_f| + 1^T \gamma\)
- **STEP 2**: Solve the reconfiguration problem.
- **STEP 3**: If the solution is radial, exit.
- **STEP 4**: Identify sets \(N_x\) where the constraint above is not satisfied.
- **STEP 5**: Add the corresponding constraints to the reconfiguration problem formulation, and go to **STEP 2**.

# cont. optimization variables = 0

# binary optimization variables = \(|\mathcal{L}| + |\mathcal{R}_f|\)

# number of constraints = \(\sim 2|N|\)
The LP relaxation of the cut-set formulation and the directed multi-commodity flow formulation are equivalent, i.e., a feasible solution for the LP relaxation of the cut-set formulation is feasible for the directed multi-commodity flow formulation and vice versa.

The LP relaxation of the cut-set formulation is tighter than the LP relaxation of the single-commodity flow formulation, i.e., there are feasible solutions for the LP relaxation of the single-commodity flow formulation that are not feasible for the LP relaxation of the cut-set formulation.

This makes the directed multi-commodity flow more advantageous because it does not include an exponential number of constraints.
136-bus Brazilian distribution feeder:

- The total load in the system is 18.31 MW.
- The total renewable energy available is almost 4.5 MW.
- The original system configuration results in a power loss of 320.17 KW.
- The minimum voltage magnitude in the system is 0.9307.

<table>
<thead>
<tr>
<th>Bus</th>
<th>Available Power (KW)</th>
</tr>
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<tbody>
<tr>
<td>18</td>
<td>17.22</td>
</tr>
<tr>
<td>25</td>
<td>219.37</td>
</tr>
<tr>
<td>27</td>
<td>190.78</td>
</tr>
<tr>
<td>29</td>
<td>382.76</td>
</tr>
<tr>
<td>46</td>
<td>397.60</td>
</tr>
<tr>
<td>68</td>
<td>93.44</td>
</tr>
<tr>
<td>78</td>
<td>244.88</td>
</tr>
<tr>
<td>87</td>
<td>222.79</td>
</tr>
<tr>
<td>134</td>
<td>323.16</td>
</tr>
<tr>
<td>137</td>
<td>354.68</td>
</tr>
<tr>
<td>157</td>
<td>377.34</td>
</tr>
<tr>
<td>159</td>
<td>138.01</td>
</tr>
<tr>
<td>160</td>
<td>339.85</td>
</tr>
<tr>
<td>209</td>
<td>327.54</td>
</tr>
<tr>
<td>210</td>
<td>81.31</td>
</tr>
<tr>
<td>218</td>
<td>59.50</td>
</tr>
<tr>
<td>219</td>
<td>249.18</td>
</tr>
<tr>
<td>220</td>
<td>479.87</td>
</tr>
<tr>
<td>Total</td>
<td>4499.28</td>
</tr>
</tbody>
</table>
## Optimization Results

Computational time with varying number of switchable lines (in seconds).

<table>
<thead>
<tr>
<th>#L_S</th>
<th>SCF</th>
<th>DMCF</th>
<th>Cut-Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.343</td>
<td>1.906</td>
<td>0.080</td>
</tr>
<tr>
<td>20</td>
<td>0.531</td>
<td>7.387</td>
<td>0.295</td>
</tr>
<tr>
<td>30</td>
<td>7.047</td>
<td>75.212</td>
<td>16.489</td>
</tr>
<tr>
<td>40</td>
<td>28.772</td>
<td>321.314</td>
<td>104.999</td>
</tr>
</tbody>
</table>

\[ c(V, p, \tilde{p}, q, \tilde{q}) = \max_n v_n - \min_n v_n \]

Cost and actual minimum voltage with varying numbers of switchable lines.

<table>
<thead>
<tr>
<th>#L_S</th>
<th>Cost</th>
<th>( \min_n v_n )</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.082</td>
<td>0.957</td>
</tr>
<tr>
<td>20</td>
<td>0.076</td>
<td>0.960</td>
</tr>
<tr>
<td>30</td>
<td>0.074</td>
<td>0.961</td>
</tr>
<tr>
<td>40</td>
<td>0.062</td>
<td>0.977</td>
</tr>
</tbody>
</table>

- The cut-set formulation is faster when only one problem is solved.
- The initial relaxation has the same gap in DMCF and SCF.
- All formulations here identify solutions with 1 root node except for \#L_S=40.
We consider the case when all lines are switchable, i.e., $L_S=156$.

<table>
<thead>
<tr>
<th></th>
<th>SCF</th>
<th>DMCF</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIP GAP</td>
<td>50.7%</td>
<td>4.28%</td>
</tr>
<tr>
<td>Cost</td>
<td>0.057</td>
<td>0.035</td>
</tr>
<tr>
<td>$\min_n v_n$</td>
<td>0.971</td>
<td>0.981</td>
</tr>
<tr>
<td>Partitions</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

- The stopping time is 4 hours.
- The cut-set formulation does not find a radial solution after 4 hours.
- Again, the initial relaxation has the same gap in DMCF and SCF.
- The DMCF identifies a better solution after 4 hours.
Next Steps

• The project team will integrate the developed formulations in the test cases such as wildfires.

• Study the analytical properties of the formulations and compare with the tightest known radially formulation (multi-cut formulations).

• Study the scalability of the proposed formulation by introducing distributed optimization algorithms.
LANL Approach and Progress

David Fobes
LANL Approach

- Build on high-fidelity physics-based resilient network operations methodologies (DOE/GMLC/CSDERMS, DOE/OE/RONM)
  - include physical/engineering constraints, e.g., power flow, load priority, resilience score, reserved capacity, etc.
- Generate sets of **offline-computed robust partitions** into Online-DynaGrid, providing base configurations for real-time operations to
  - improve performance
  - provide some minimum resilience guarantees
- Optimize power flows of neighboring partitions to enable dynamic partitioning with improved stability
- Estimate resilience and optimality of Online-DynaGrid-generated partitions by
  - comparing to offline-generated robust partitions
  - running sets of scenarios to evaluate performance against various contingencies
• Key Capabilities leveraged
  – PowerModelsDistribution
    • Core phase unbalanced power flow formulations for distribution feeders
    • DOE/GMLC/CSDERMS
  – PowerModelsProtection
    • Fault analysis in transmission and distribution networks
    • DOE/OE/RONM
  – PowerModelsONM
    • Microgrid operations optimization (mixed-integer problems)
    • DOE/OE/RONM
Problem: MIP
Formulation: LinDist3Flow
(Branch Flow)

variable_block_indicator binary
variable_inverter_indicator binary
variable_mc_bus_voltage
variable_mc_branch_power
variable_mc_switch_power
variable_mc_transformer_power
variable_mc_generator_power
variable_mc_storage_power
variable_mc_load_power
variable_switch_state binary
variable_mc_transformer_tap
variable_mc_capcontrol

constraint_grid_forming_inverter_per_cc mixed-integer
for i in bus
  constraint_mc_inverter_theta_ref(i)
constraint_mc_bus_voltage_block mixed-integer
for i in gen
  constraint_mc_generator_power_block(i)

for i in load
  constraint_mc_load_power(i)
for i in bus
  constraint_mc_power_balance_shed_block(i) mixed-integer
for i in storage
  constraint_storage_state(i)
  constraint_storage_complementarity_mi_block(i)
  constraint_mc_storage_block(i)
  constraint_mc_storage_losses_block(i)
  constraint_mc_storage_thermal_limit(i)
  constraint_mc_storage_phase_unbalance_grid_following(i) mixed-integer
for i in branch
  constraint_mc_power_losses(i)
  constraint_mc_model_voltage_magnitude_difference(i)
  constraint_mc_model_voltage_angle_difference(i)
  constraint_mc_ampacity_from(i)
  constraint_mc_ampacity_to(i)
constraint_radial_topology mixed-integer
constraint_isolate_block mixed-integer
for i in switch
  constraint_mc_switch_state_open_close(i) mixed-integer
  constraint_mc_switch_ampacity(i)
for i in branch
  constraint_mc_transformer_power_block(i)
objective_min_shed_load_block mixed-integer
Innovation: “Block” Formulation

By exploiting the structure of distribution feeders, we partition the base problem into "load blocks", i.e., sections that can be segregated via switching actions, to reduce the variable space considerably, allowing the problem to scale to significantly larger networks.

Iowa 240 Example

Traditional
Binary Variables: 22,785
Solve time: 22s

Blocks
Binary Variables: 1137
Solve time: 4s
Challenge: “Robust” vs “Optimal” Partitions

• “Optimal” in the traditional sense of power flow could consist of a narrow definition of demand, voltages, powers, etc.

• Robust to what?
  – fluctuations in demand
  – fluctuations in generation (Solar PV)
  – contingencies

• Strategies
  – constrained resources
  – objective tuning
  – parallel generation of optimal topologies given contingency sets
  – convex restriction of power flow
Evaluating Optimality: Phase unbalanced relaxations

- Few well-studied proposals for phase unbalanced power flow relaxations
  - Second-Order Cone
  - Semidefinite Programming
  - Quadratic Cone

- Recovering feasible points from relaxations are challenging

A Venn Diagram of the Solutions Sets for Various AC Power Flow Relaxations (not to scale)
LLNL Approach and Progress

Vaibhav Donde
LLNL: DynaGrid project highlights for Year 1

Dec 2021
- Funds received $215k

March 2022
- Discussions with DTE & NREL
- DTE/LLNL/NREL NDA in place
- DTE IT approvals
- CYME models
- IEEE 123 bus system GridLab-D modeling
- Design of Site 300 Energy Assurance project at LLNL
- 65% Design by PMO
- Initial single lines and concepts

June 2022
- FY22
- Permits for FY24 construction

Sept 2022
- DTE models, Site 300 models

Utility/industry engagement and use cases
- Modeling, simulation, co-simulation
- Site 300 setup for demo prep
• DTE has substantial interest in the project and has invested time/effort
  – Advanced microgrid concepts and implementation using DTE feeders
  – DTE’s tiered strategy: from DER only to DynaGrid, ModSim-HIL-field, over 5 years
• Weekly calls with DTE management, engineers and leadership
• LLNL/NREL/DTE NDA in place
  – CYME Models will be shared for two prototyped feeders
  – Urban and rural feeder
  – Microgrids with changing boundaries per DER availability
  – DTE circuits will be used for DynaGrid modeling/simulation
• White paper is developed by DTE, LLNL, NREL, LANL, Univ of Michigan-Dearborn, EPRI
• LLNL presented DynaGrid concepts to DTE’s Engineering All Hands (June 2022)
Toy Model to simulate the dynamic-boundary behavior

- Modeled in GridLab-D
- Two microgrids with different configurations of DER resources.
  - Area 1: battery
  - Area 2: solar + battery
- Three modes of power system operations:
  - Main grid
  - One microgrid (Area 1 + 2)
  - Two microgrids (Area 1&2)
- Potential Test Scenarios:
  - Installation capacity/number of DER
  - Different time (in a day/seasons)
  - Locations of DER devices
- Utilize DER models, Site 300 specific model
- Grid/communication HELICS co-simulation characterizing comms between the microgrids and controller
LLNL: Next Steps

• Obtain CYME models from DTE, translate, and use for modeling in GridLab-D
• Create sample communication model for interacting microgrids and co-simulate in HELICS, using GridLab-D and ns-3
• Work on the use cases with DynaGrid team and DTE Energy
• Create Site 300 microgrid models in GridLab-D for simulation
• Plan for Site 300 demo
  – Keep PI/PM posted on Site 300 Energy Resilience project design and timeline
  – Dependence of DynaGrid demo on GMLC CleanStart DERMS setup progress
SNL Approach and Progress

Matthew Reno
SNL: DynaGrid Protection

- **Objective:** Develop protection schemes that work for fractal grid of the future with hierarchical-distributed control of dynamically formed microgrids
  - Dynamic formation and operation of networked microgrids with flexible boundaries requires protection that can work across different ownership models, communication boundaries, and architectures.
  - As opposed to the adaptive protection framework for RONM, this will provide protection without universal communication/knowledge/control of the system
- **Technical Approach:** Protection and Dynamic Reconfiguration With Only Local Measurements
  - Develop undervoltage-supervised overcurrent (UVOC) protection function to detect and isolate faults
  - Design protection to work in grid-connection, islanded, and 100% inverter based systems, so the system is protected in any state (although without centralized communication the system may not be coordinated)
  - Defaults to robust partitions established in Task 3, with time delays to protect against other faults
  - Provide resynchronization protection and protection during self-healing
Proposed UVOC protection:

- Provides protection for microgrids in any configuration (each building block is protected) with dynamic boundaries and networking systems
- Does not require communication, which ensures cybersecurity, protected systems during resilience events with loss of communication, and interoperability between microgrids that might have different communication protocols
- Provides low-cost protection solution self-assembly of ad-hoc microgrids
- Does not require generation to have large fault currents to be protected
SNL Progress

- Developed coordinated under-voltage protection system to detect and isolate faults as the power electronics go into current-limiting mode leading to voltage collapse.
- Developed UVOC for self-healing restoration and networking of islanded systems
- Developed unintentional loop detection function to make sure each system and microgrid is still operated radially
- Implemented each of the above in PSCAD using an example system with grid-forming DER and no communication between microgrids or protective relays

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Date</th>
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<tbody>
<tr>
<td><strong>Year 1</strong></td>
<td></td>
</tr>
<tr>
<td>Simulation models of faults and self-healing architecture developed based on use cases established with the IAB (Task 1)</td>
<td>6 months</td>
</tr>
<tr>
<td>Develop undervoltage-supervised overcurrent UVOC protection function to detect and isolate faults (Task 5)</td>
<td>12 months</td>
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</tbody>
</table>
Engagement with DTE and Next Steps
DTE Collaboration and Demonstration

• Discussed different options for demonstration

• DTE is committed to demonstrating networked microgrids in the next 5 years.

• Two main options for the demonstration site:
  • **Rural, sparse community**, with long feeders and multiple microgrids
  • **Underserved neighborhood**, more compact, with less opportunity for dynamic boundaries.

• In the process of obtaining models for simulation and hardware-in-the-loop validation.
## Next Steps

<table>
<thead>
<tr>
<th>Year 1 Milestones</th>
<th>Date</th>
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<tbody>
<tr>
<td>Feedback obtained from IAB on realistic use cases and a potential list of use cases developed (Task 1; NREL, UWM)</td>
<td>3 months</td>
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<tr>
<td>Determined three concrete use case scenarios under normal operations as well as disruptions and identified appropriate data sources (Task 1; UWM, NREL)</td>
<td>6 months</td>
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<tr>
<td>Simulation models of faults and self-healing architecture developed based on use cases established with the IAB (Task 1; SNL)</td>
<td>6 months</td>
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<tr>
<td>Models of field demonstration microgrids developed with HELICS (Task 3; LLNL)</td>
<td>6 months</td>
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<tr>
<td>Constraints and formal definitions for optimal partitions under normal and emergency conditions developed (Task 2; NREL, LANL)</td>
<td>9 months</td>
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<tr>
<td>Implementation of algorithms for offline robust partitioning, made available as open-source software library (Task 3; LANL, NREL)</td>
<td>12 months</td>
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<tr>
<td>Models and algorithms for long-term optimal planning given a small number of planning scenarios focused on normal operation developed (Task 6; UWM)</td>
<td>12 months</td>
</tr>
<tr>
<td>Develop undervoltage-supervised overcurrent UVOC protection function to detect and isolate faults (Task 5; SNL)</td>
<td>12 months</td>
</tr>
<tr>
<td>Initial simulation validation and testing complete for field demonstration (Task 3; LLNL)</td>
<td>12 months</td>
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<tr>
<td>Go/No-Go: Initial algorithms for robust partitioning developed and evaluated on a selected use case.</td>
<td>12 months</td>
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</tbody>
</table>
Thank you