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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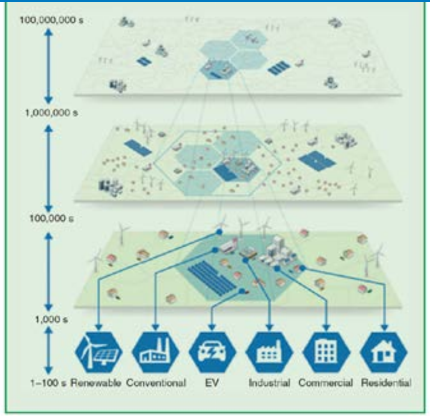
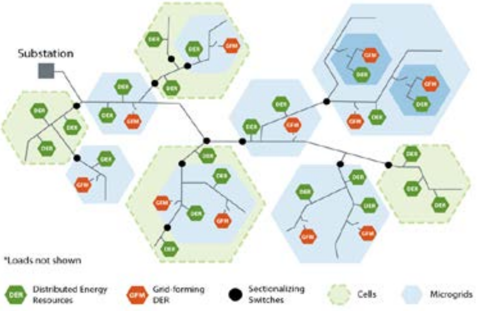
DynaGrid

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.**





Left: Hierarchical-distributed grid structure
Above: Dynamic microgrids

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.

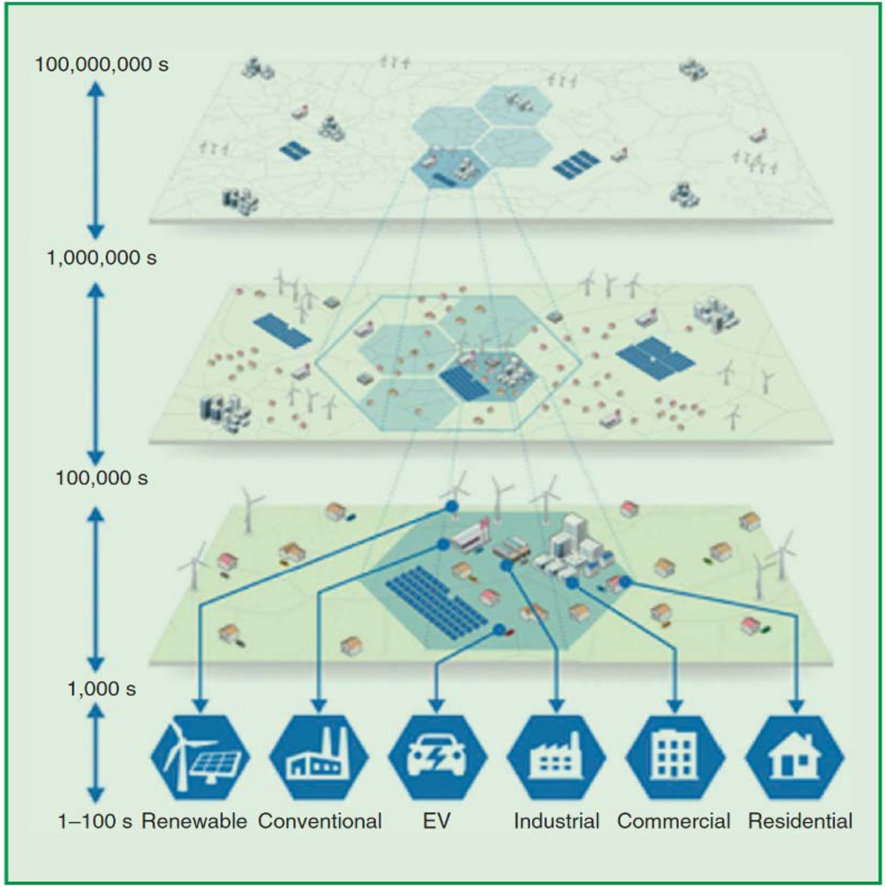
Innovation:

- 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)

FY21 & prior, authorized	FY22, authorized	FY23, requested
	$1.2M	$1.2M

Project Purpose



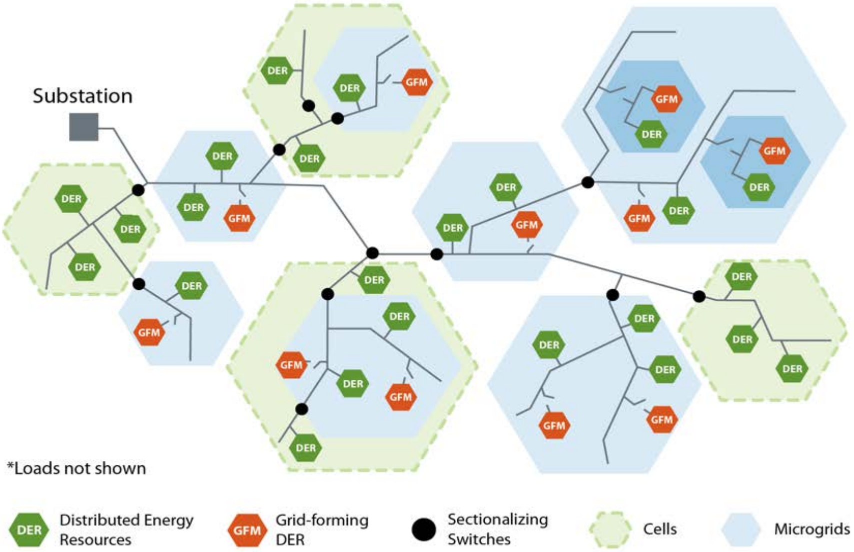
Develop a framework for the dynamic formation and operation of networked microgrids to **address major research challenges outlined in the Topic 4 concept paper and the overall Microgrid Program goals**:

- 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.



*Loads not shown

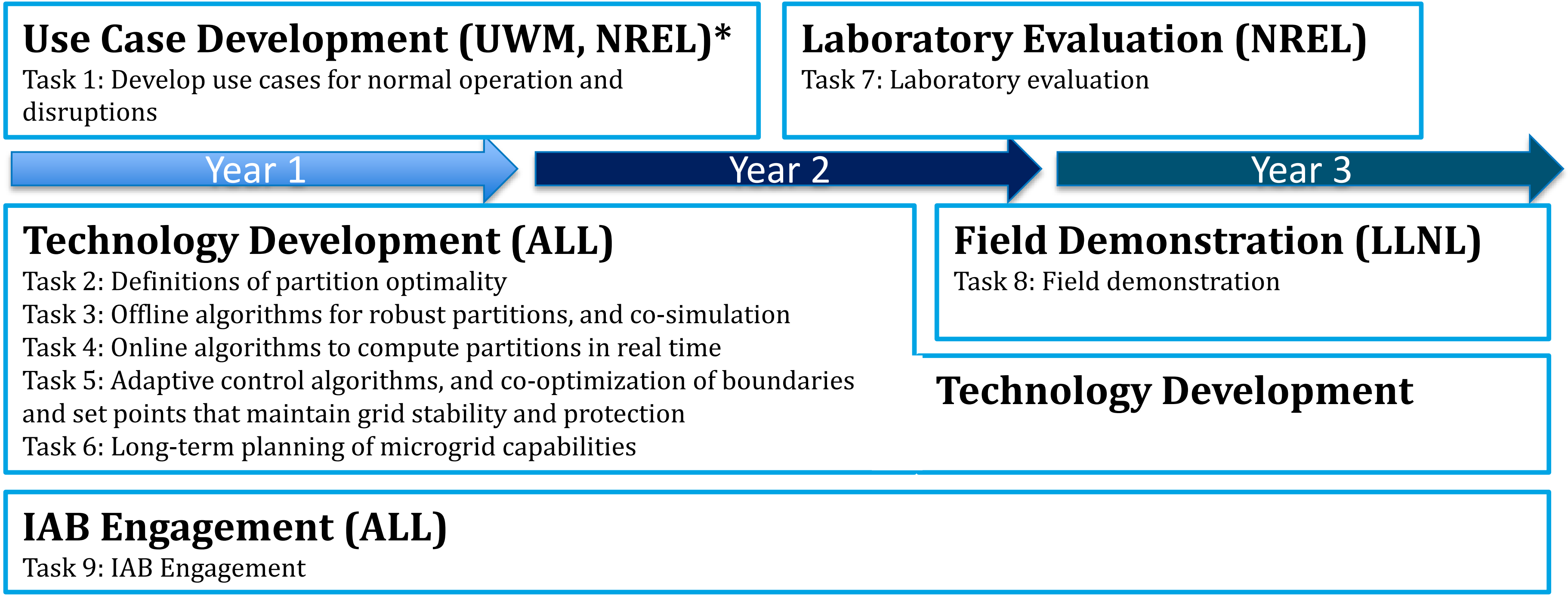
Innovation:

- 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

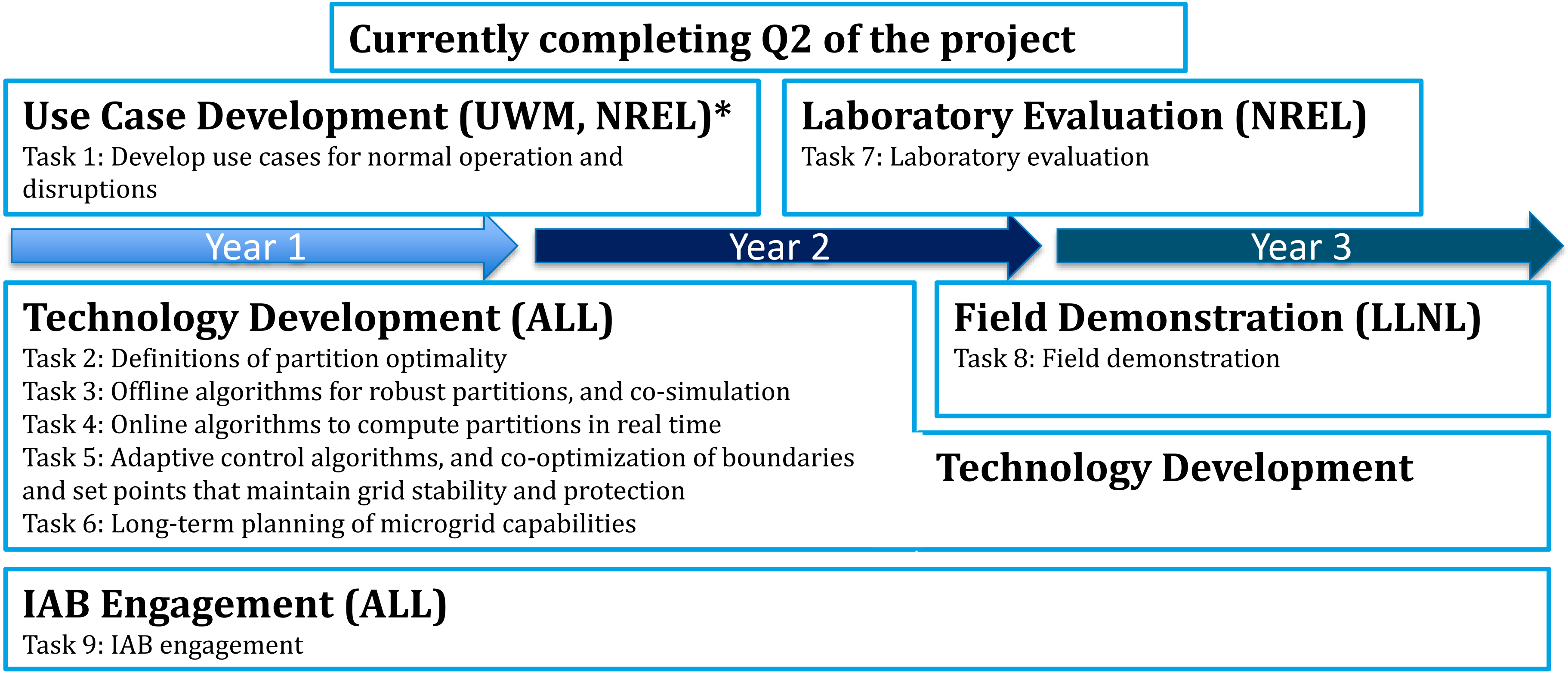
Technology Development

IAB Engagement (ALL)

Task 9: IAB Engagement

*Main contributors are listed in parentheses.

Overall Project Plan



Currently completing Q2 of the project

Use Case Development (UWM, NREL)*

Task 1: Develop use cases for normal operation and disruptions

Laboratory Evaluation (NREL)

Task 7: Laboratory evaluation

Year 1

Year 2

Year 3

Technology Development (ALL)

Task 2: Definitions of partition optimality
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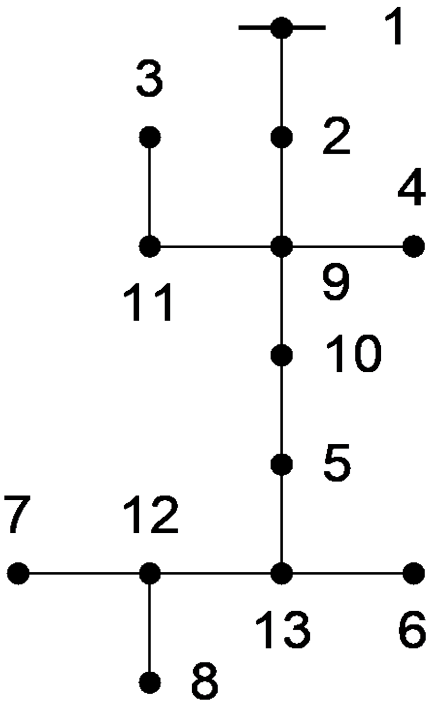
NREL and UWM Approach and Progress

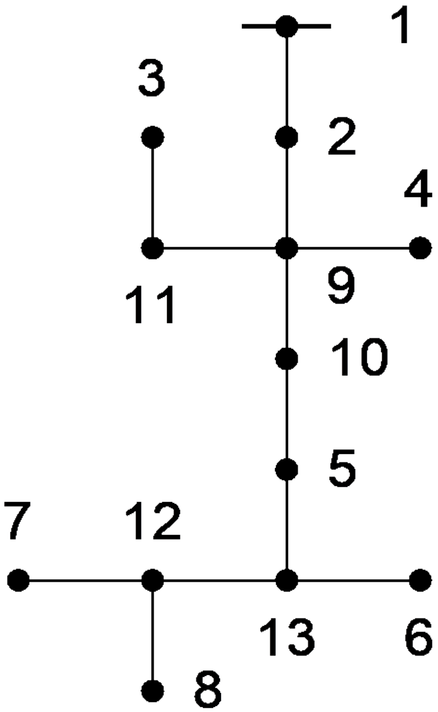
Andrey Bernstein and Line Roald

Illustrative Dynagrids

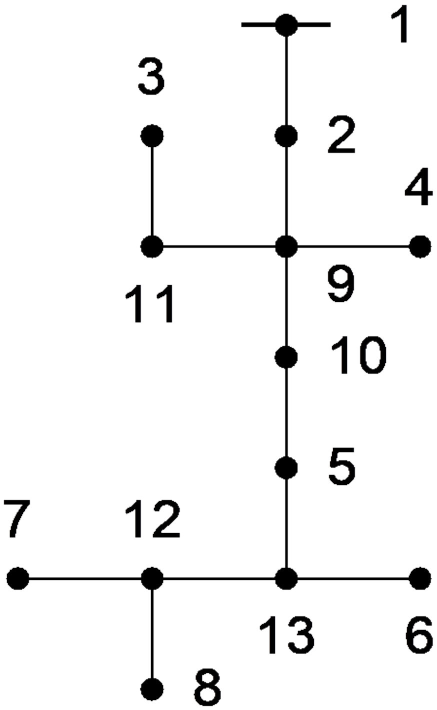
Clustering: No penalty on generation from G11, G12



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



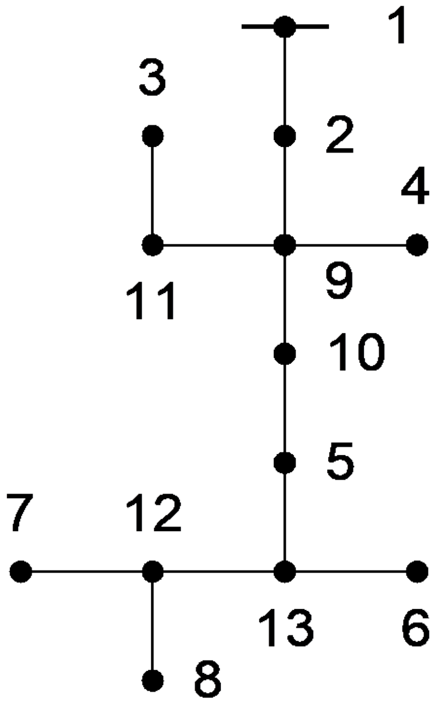
30% serviced, 0.985 p.u.
G11 - 3 MW
G12 - ***0.7 MW***



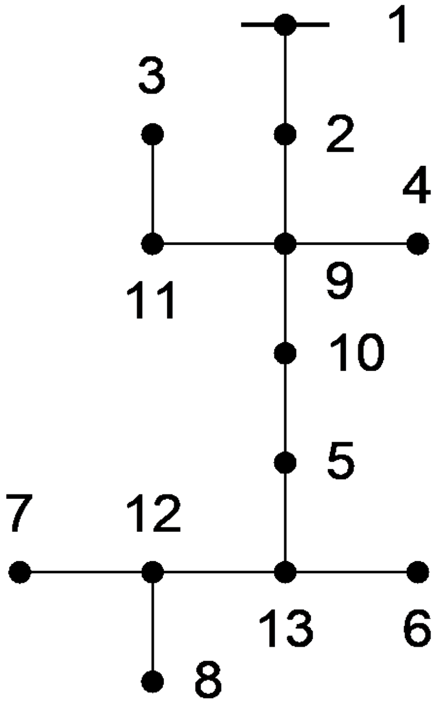
30% serviced, 0.985 p.u.
G11 - 3 MW
G12 - ***0.5 MW***

Illustrative Dynagrids

Clustering: With penalty on generation from G11, G12



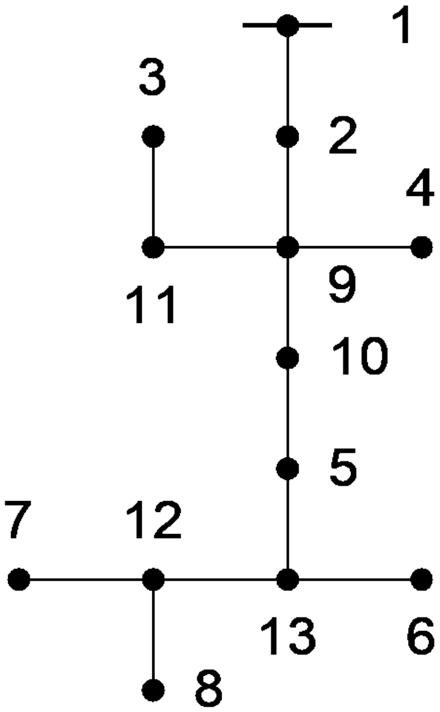
30% serviced, 0.985 p.u.
G11 - 3 MW, ***0x***
G12 - 3 MW, ***0x***



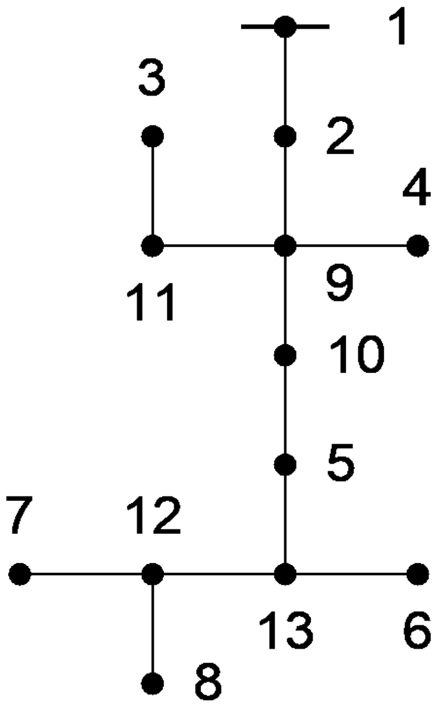
30% serviced, 0.985 p.u.
G11 - 3 MW, ***40x***
G12 - 3 MW, ***60x***

Illustrative Dynagrids

Clustering: With penalty on generation and varying voltage limits



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

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

Use Case Development (UWM, NREL)
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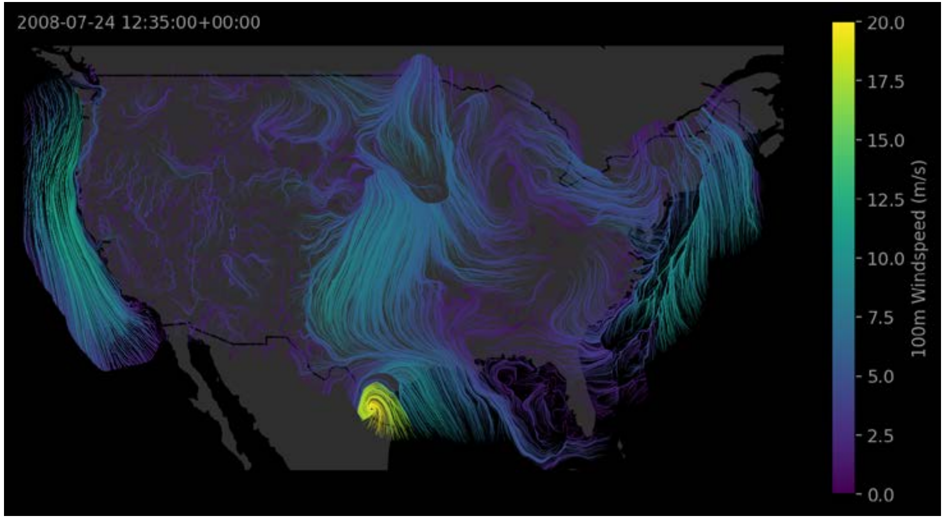
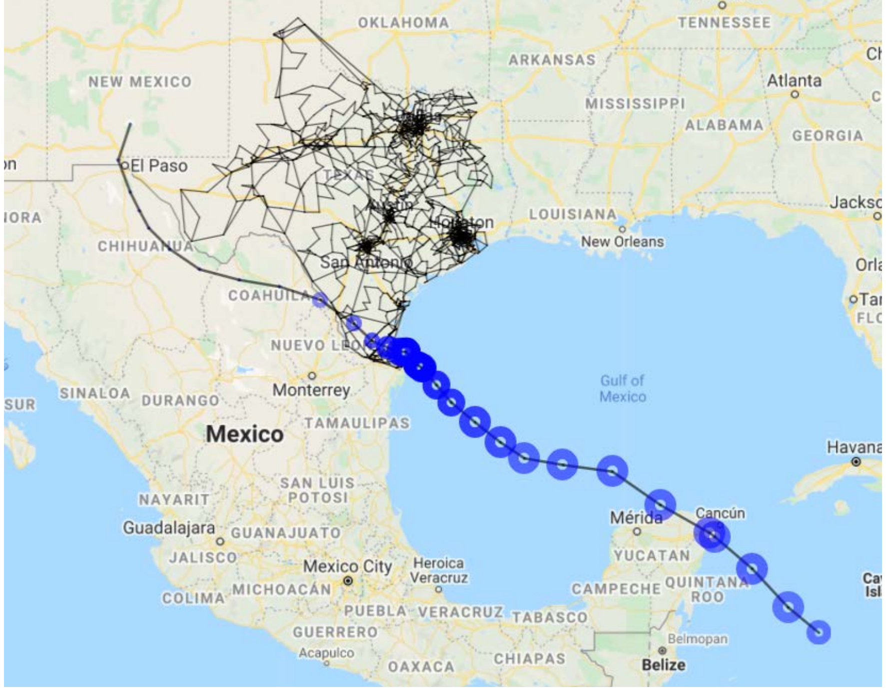
Use Case: Natural Disasters

Example: Hurricane Dolly, TX, 2008



WIND Toolkit wind field at 100 m above ground

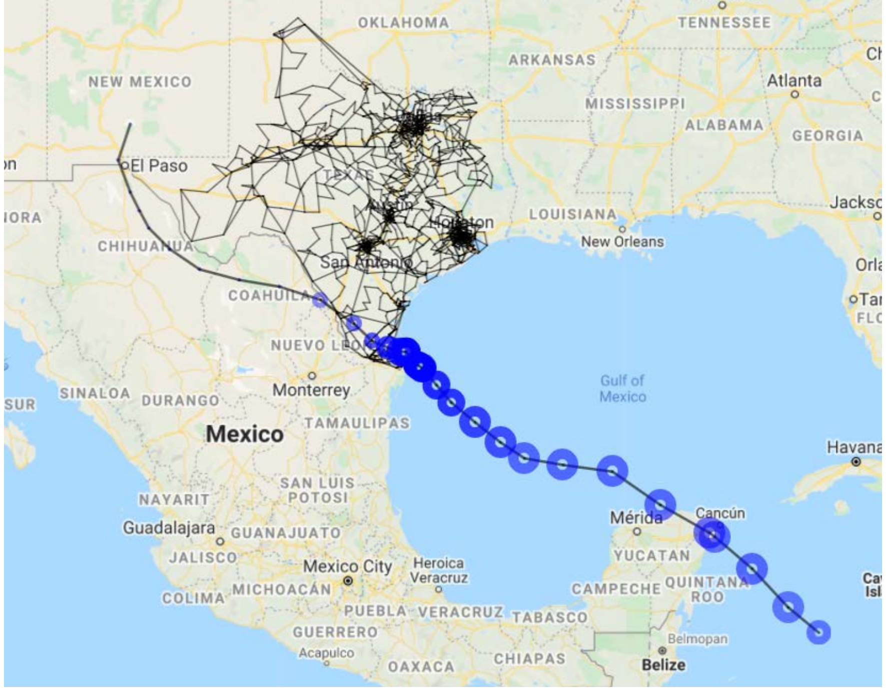


Path and synthetic TAMU 2,000-bus transmission grid. The size of the blue circles corresponds to the hurricane's radii and their color intensity corresponds to the maximum wind speed...

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

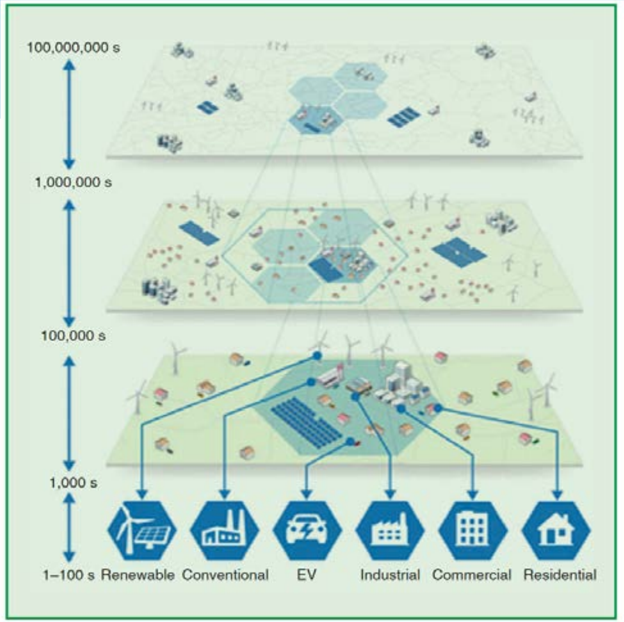
DynaGrid dynamically forms **optimal** microgrid partitions to **optimize** the operations of the electric grid during normal operation and emergency situations.

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

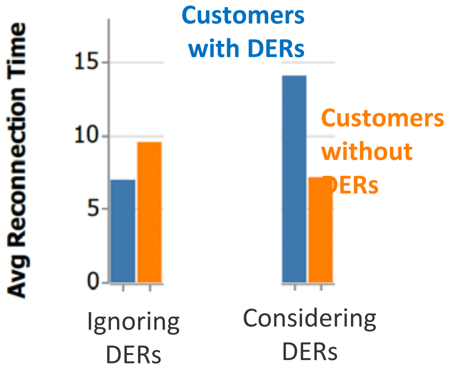
Inequities arising from PV net metering:

- The installation of PV increases the need for grid updates, which get rolled into the per kWh grid charge.
- The higher fees will be disproportionally 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*.

Photo from Wikipedia

Examples of Inequities

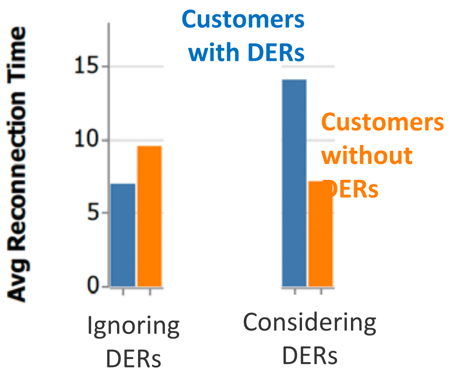


If access to DER power is accounted for in post-disaster restoration, the optimal restoration strategy might shift toward reconnecting customers without DERs.

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

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

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.)

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

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: Understand how *data on community vulnerability* can best be integrated in decision-making tools for electric grid operation and investments.

Available Data Sources

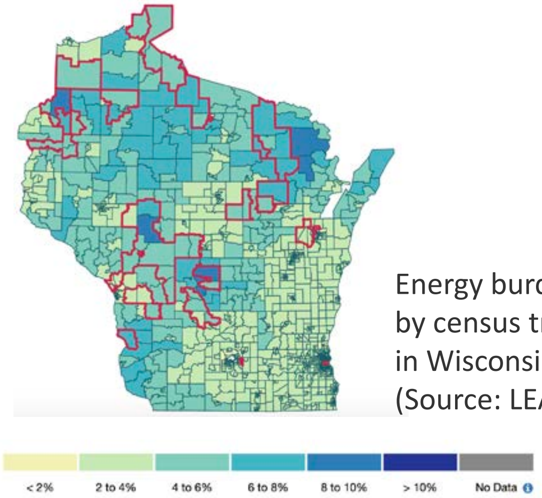
Original data:

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)



Energy burden by census tract in Wisconsin (Source: LEAD)

Derivative risk metrics:

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

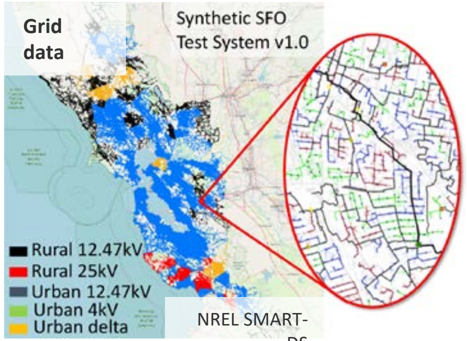
U.S. Census Bureau Community Resilience Estimates

CDC Social Vulnerability Index

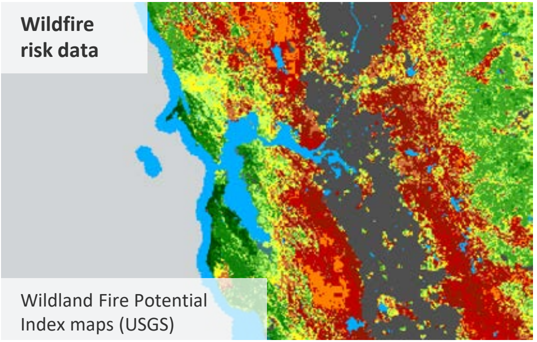
Questions: How similar/different are those metrics? Which capture the most relevant information?

Use Case: Wildfire Risk and Energy Justice

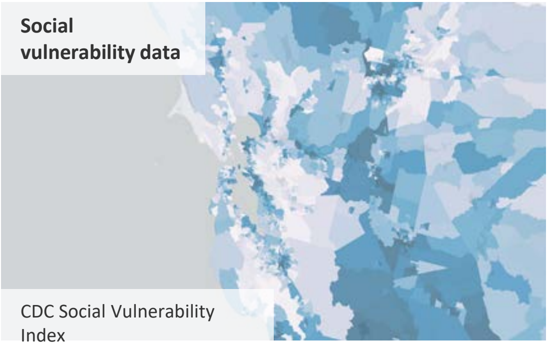
Approach: Correlate grid data with wildfire risk and demographic data to demonstrate how DynaGrid operation could mitigate wildfire ignitions from power equipment and promote social equity.


Grid data

NREL SMART-DS


Wildfire risk data

Wildland Fire Potential Index maps (USGS)


Social vulnerability data

CDC Social Vulnerability Index

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.

Single-Commodity Flow Radiality Constraint

Define $\widetilde{\mathbf{A}}$ as follows:

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

Then, partition the matrix : $\widetilde{\mathbf{A}}$

$$\widetilde{\mathbf{A}} := \begin{array}{cc} \mathcal{N}_0 & \mathcal{N}_g & \\ \left[\begin{array}{c} \mathbf{A}_{00} \\ \mathbf{A}_{10} \end{array}\right. & \left.\begin{array}{c} \mathbf{A}_{0g} \\ \mathbf{A} \end{array}\right] & \begin{array}{c} \mathcal{L}_0 \\ \mathcal{L}_1 \end{array} \end{array}$$

Theorem 1. *The network topology defined by the activating the lines in $\mathcal{L}_1$ and operating the buses in $\mathcal{N}_0$ as slack buses is a collection of trees where each node in $\mathcal{N}_0$ is the root of a single tree if and only if:*

C1) there exists a vector $\mathbf{f} \in \mathbb{R}^{|\mathcal{L}_1|}$ such that

$$\mathbf{A}^T\mathbf{f} = \mathbf{1},$$

C2) $\sum_{\ell \in \mathcal{L}} y_\ell = (N+1) - \sum_{n \in \mathcal{R}_f} (1-\gamma_n)$

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

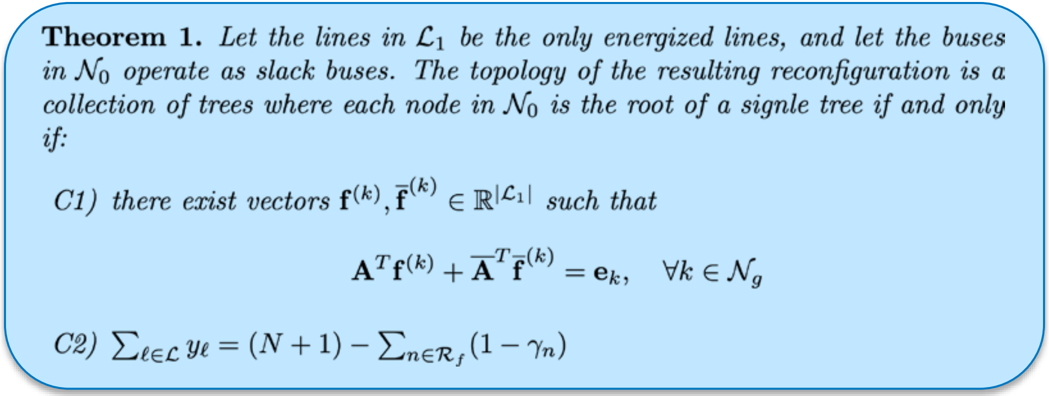
$$-M\mathbf{y} \leq f \leq M\mathbf{y}$$
$$\tilde{a}_n \mathbf{f} \leq 1 + M(1-\gamma_n)$$
$$\tilde{a}_n \mathbf{f} \geq 1 - M(1-\gamma_n)$$
$$\mathbf{1}^T\mathbf{y} = (N+1) - |\mathcal{R}_f| + \mathbf{1}^T\boldsymbol{\gamma}$$

cont. optimization variables = $|\mathcal{L}|$

binary optimization variables = $|\mathcal{L}| + |\mathcal{R}_f|$

number of constraints = $2|\mathcal{L}| + 2|\mathcal{N}| + 1$

Directed Multi-Commodity Flow Radiality Constraint



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 signle tree if and only if:*

C1) there exist vectors $\mathbf{f}^{(k)}, \overline{\mathbf{f}}^{(k)} \in \mathbb{R}^{|\mathcal{L}_1|}$ such that

$$\mathbf{A}^T\mathbf{f}^{(k)} + \overline{\mathbf{A}}^T\overline{\mathbf{f}}^{(k)} = \mathbf{e}_k, \quad \forall k \in \mathcal{N}_g$$

C2) $\sum_{\ell\in\mathcal{L}} y_\ell = (N+1) - \sum_{n\in\mathcal{R}_f}(1-\gamma_n)$

$$\widetilde{\mathbf{A}} := \begin{array}{cc} \mathcal{N}_0 & \mathcal{N}_g & \\ \left[\begin{array}{c} \mathbf{A}_{00} \\ \mathbf{A}_{10} \end{array}\right. & \left.\begin{array}{c} \mathbf{A}_{0g} \\ \mathbf{A} \end{array}\right] & \begin{array}{c} \mathcal{L}_0 \\ \mathcal{L}_1 \end{array} \end{array}$$

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

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

$$\boldsymbol{\lambda} + \overline{\boldsymbol{\lambda}} = \mathbf{y}$$
$$\mathbf{0} \le \mathbf{f}^{(k)} \le \boldsymbol{\lambda}$$
$$\mathbf{0} \le \overline{\mathbf{f}}^{(k)} \le \overline{\boldsymbol{\lambda}}$$
$$\tilde{a}_n(\mathbf{f}^{(n)} - \overline{\mathbf{f}}^{(n)}) \le 1 + M(1-\gamma_n)$$
$$\tilde{a}_n(\mathbf{f}^{(n)} - \overline{\mathbf{f}}^{(n)}) \ge 1 - M(1-\gamma_n)$$
$$\tilde{a}_n(\mathbf{f}^{(k)} - \overline{\mathbf{f}}^{(k)}) \le M(1-\gamma_n) \qquad \forall n \ne k$$
$$\tilde{a}_n(\mathbf{f}^{(k)} - \overline{\mathbf{f}}^{(k)}) \ge -M(1-\gamma_n) \qquad \forall n \ne k$$
$$\mathbf{1}^T\mathbf{y} = (N+1) - |\mathcal{R}_f| + \mathbf{1}^T\boldsymbol{\gamma}$$

cont. optimization variables = $2|\mathcal{L}||\mathcal{N}|$

binary optimization variables = $3|\mathcal{L}| + |\mathcal{R}_f|$

number of constraints = $5|\mathcal{L}| + 2|\mathcal{N}|^2 + 1$

Cut-Set Constraints for Radiality

Define: $\mathbf{\Gamma}(\mathcal{N}_x) := \{(u,v) : (u \in \mathcal{N}_x, v \notin \mathcal{N}_x) \text{ or } (u \notin \mathcal{N}_x, v \in \mathcal{N}_x)\}$

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

represents a reformulation of the desired radiality constraints.

Constraint generation approach:

- STEP 1: Formulate the reconfiguration problem with only: $\mathbf{1}^T \mathbf{y} = (N+1) - |\mathcal{R}_f| + \mathbf{1}^T \gamma$
- STEP 2: Solve the reconfiguration problem.
- STEP 3: If the solution is radial, exit.
- STEP 4: Identify sets $\mathcal{N}_x$ 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 = $\sim 2^{|\mathcal{N}|}$

LP Relaxation Tightness

- 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.

Medium-Size Distribution Feeder Example

- 136-bus Brazilian distribution feeder:

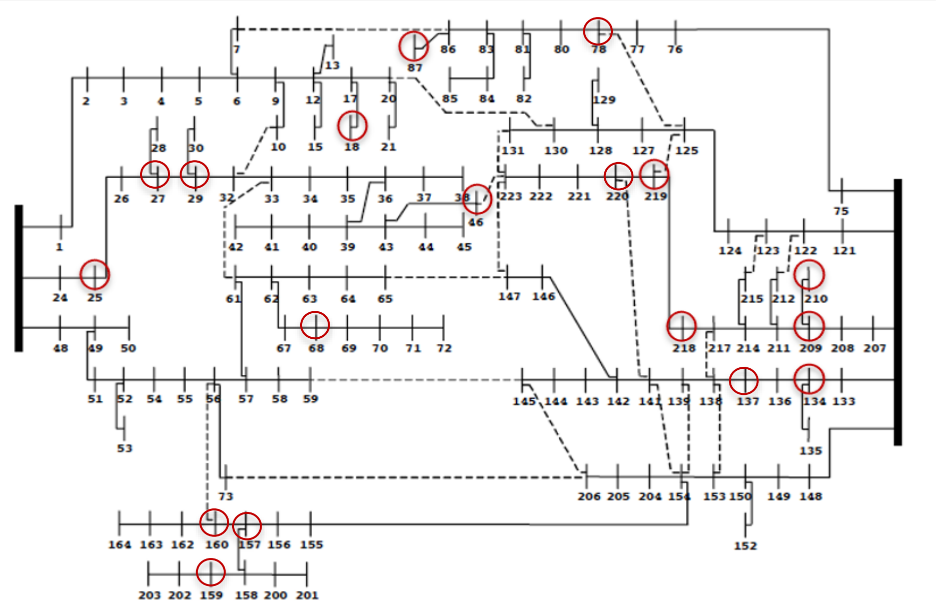


TABLE III: Available power from inverters and their locations.

Bus	Available Power (KW)
18	17.22
25	219.37
27	190.78
29	382.76
46	397.60
68	93.44
78	244.88
87	222.79
134	323.16
137	354.68
157	377.34
159	138.01
160	339.85
209	327.54
210	81.31
218	59.50
219	249.18
220	479.87
Total	4499.28

- 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.

Optimization Results

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

#L_s	**SCF**	**DMCF**	**Cut-Set**
10	0.343	1.906	**0.080**
20	0.531	7.387	**0.295**
30	**7.047**	75.212	16.489
40	**28.772**	321.314	104.999

- 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

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

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

#L_s	**Cost**	$\min_n v_n$
10	0.082	0.957
20	0.076	0.960
30	0.074	0.961
40	0.062	0.977

Optimization Results Cont.

We consider the case when all lines are switchable, i.e., L_s=156.

Solution of different radiality constraint formulations

	SCF	DMCF
MIP GAP	50.7%	4.28%
Cost	0.057	0.035
$\min_n v_n$	0.971	0.981
Partitions	2	2

- 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

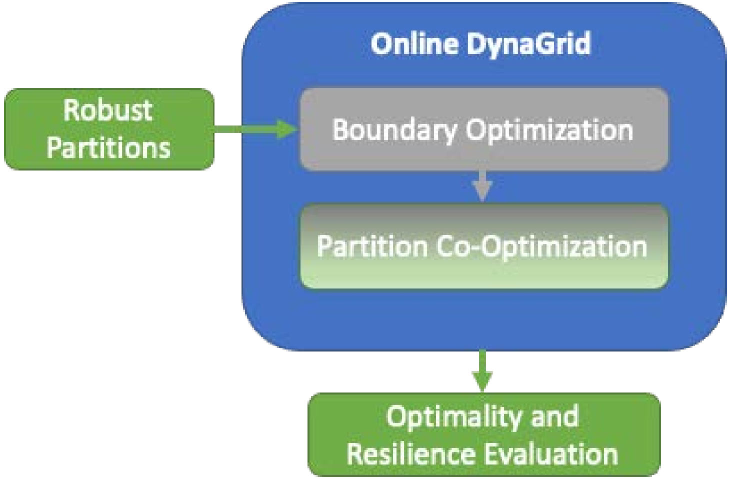
- The project team will integrate the developed formulations in the test cases such as wildfires.
- Study the analytical properties of the formulations and compare with the tightest known radiality formulation (multi-cut formulations).
- Study the scalability of the proposed formulation by introducing 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



Online DynaGrid

Robust Partitions

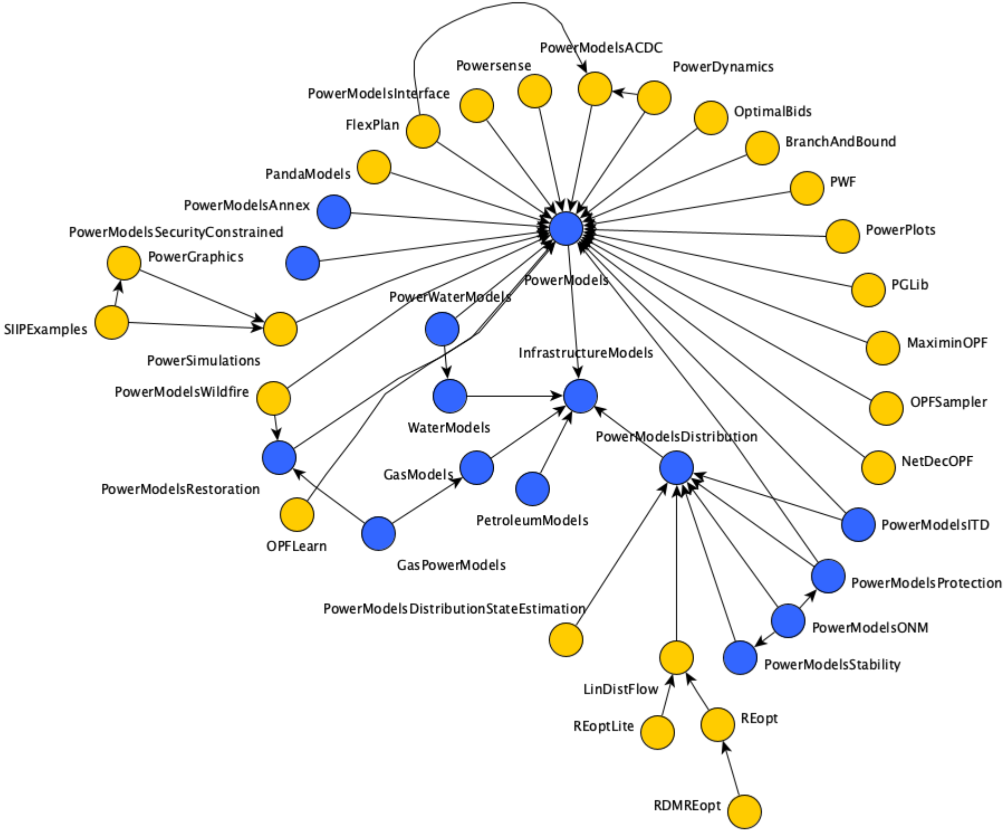
Boundary Optimization

Partition Co-Optimization

Optimality and Resilience Evaluation

InfrastructureModels Ecosystem

- 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



Current Progress: Optimal Partition Formulation

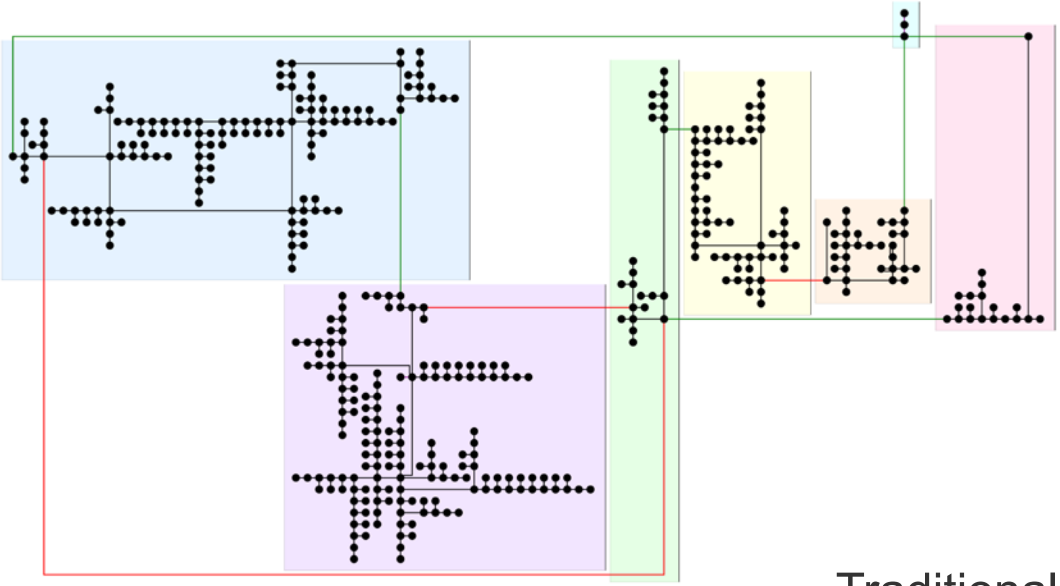
Problem: MIP

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               mixed-integer
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)           mixed-integer

constraint_mc_bus_voltage_block                 mixed-integer

for i in gen
  constraint_mc_generator_power_block(i)          mixed-integer
```

```
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)           mixed-integer
  constraint_mc_storage_block(i)                           mixed-integer
  constraint_mc_storage_losses_block(i)                    mixed-integer
  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_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 transformer
  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

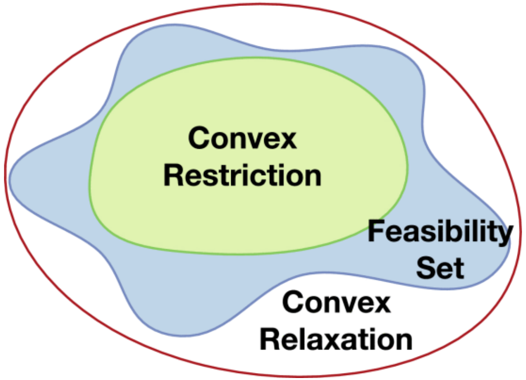
Blocks
Binary Variables: 1137
Solve time: 4s

Challenge: “Robust” vs “Optimal” Partitions

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

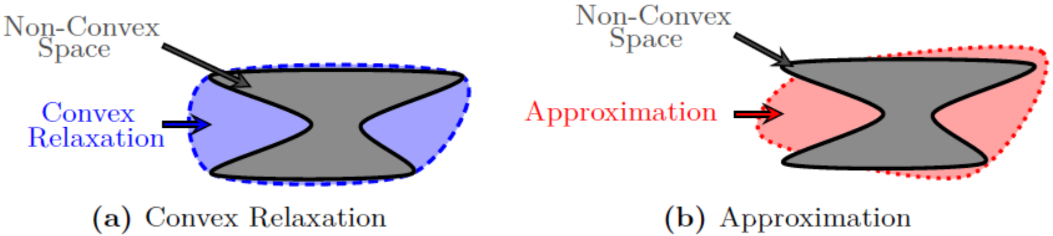
- Robust to what?
  - fluctuations in demand
  - fluctuations in generation (Solar PV)
  - contingencies

- Strategies
  - constrained resources
  - objective tuning
  - parallel generation of optimal topologies given contingency sets
  - convex **restriction** of power flow

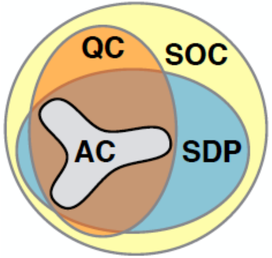


Evaluating Optimality: Phase unbalanced relaxations

- 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) Convex Relaxation (b) Approximation

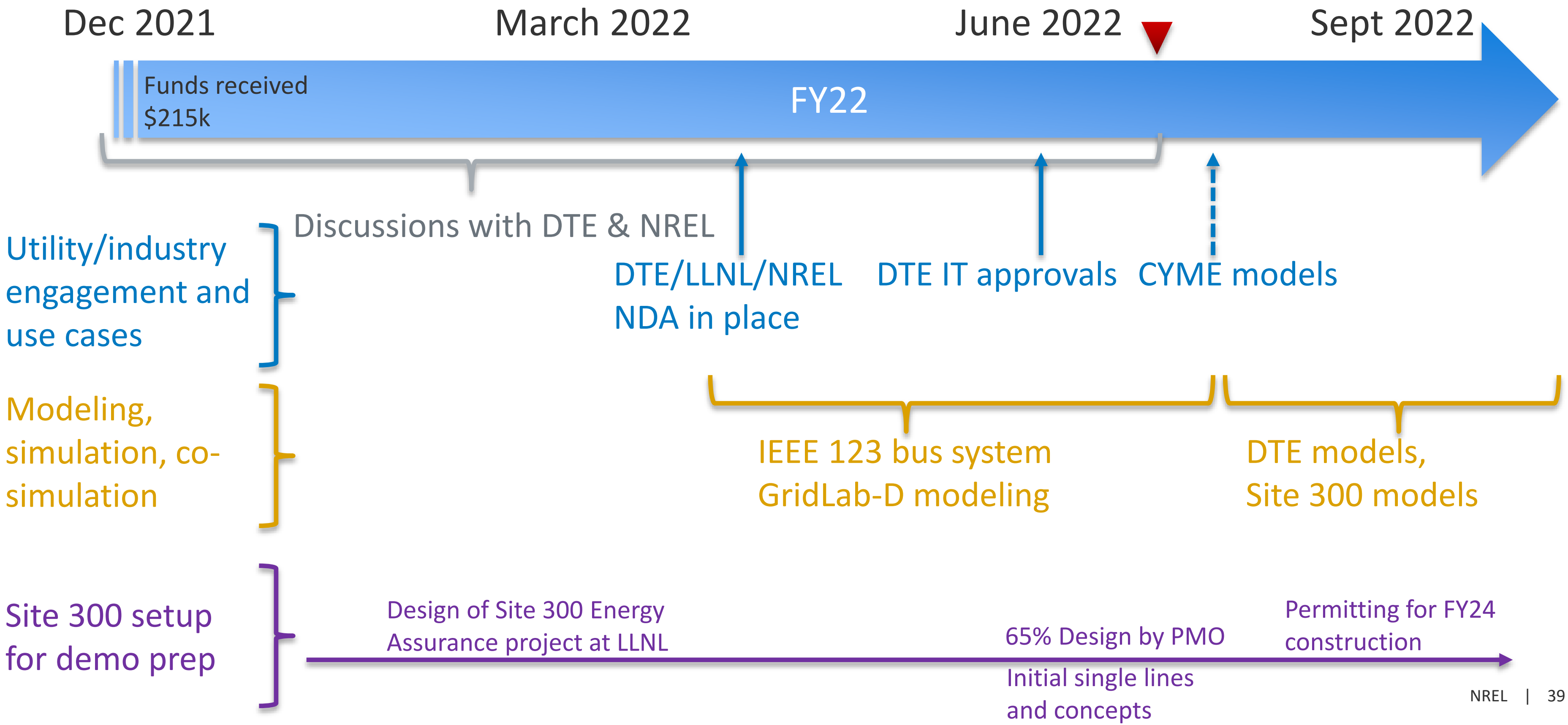


A Venn Diagram of the Solutions Sets for Various AC Power Flow Relaxations (not to scale)

LLNL Approach and Progress

Vaibhav Donde

LLNL: DynaGrid project highlights for Year 1



Dec 2021

March 2022

June 2022

Sept 2022

Funds received
$215k

FY22

Discussions with DTE & NREL

Utility/industry engagement and use cases

DTE/LLNL/NREL
NDA in place

DTE IT approvals

CYME models

Modeling, simulation, co-simulation

IEEE 123 bus system
GridLab-D modeling

DTE models,
Site 300 models

Site 300 setup for demo prep

Design of Site 300 Energy
Assurance project at LLNL

65% Design by PMO

Initial single lines
and concepts

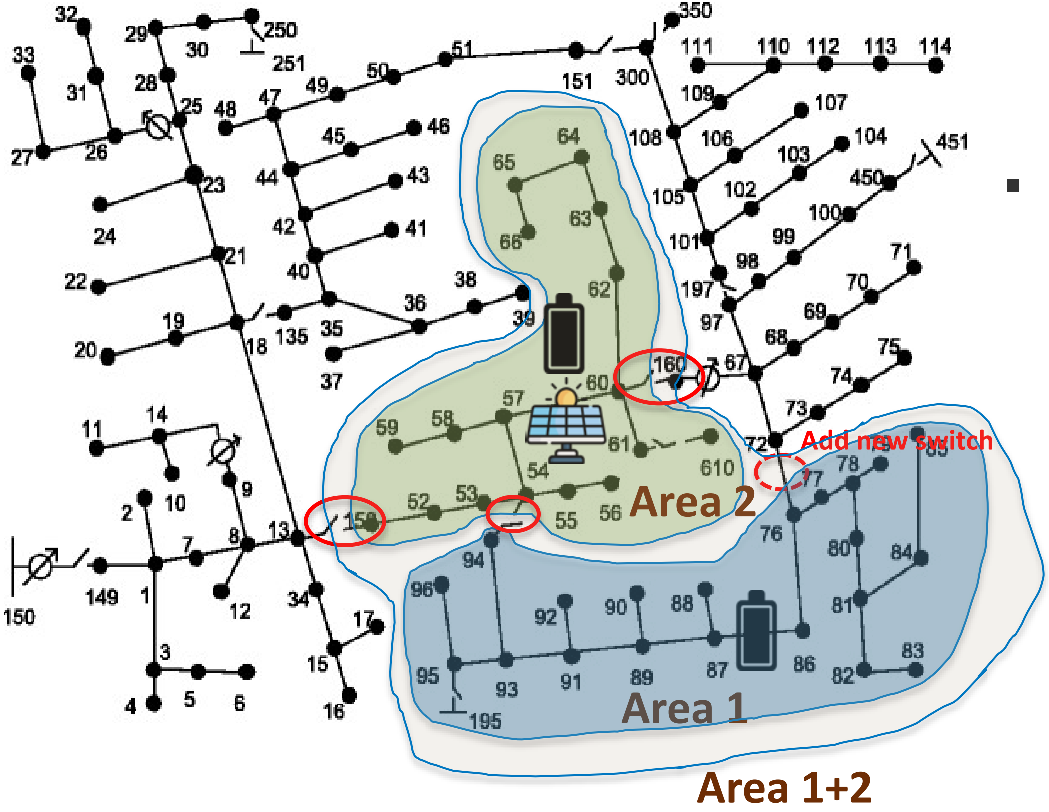
Permitting for FY24
construction

LLNL: Utility Engagement with DTE Energy

- 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
  - Micrograds 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

IEEE 123-node test feeder



- 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

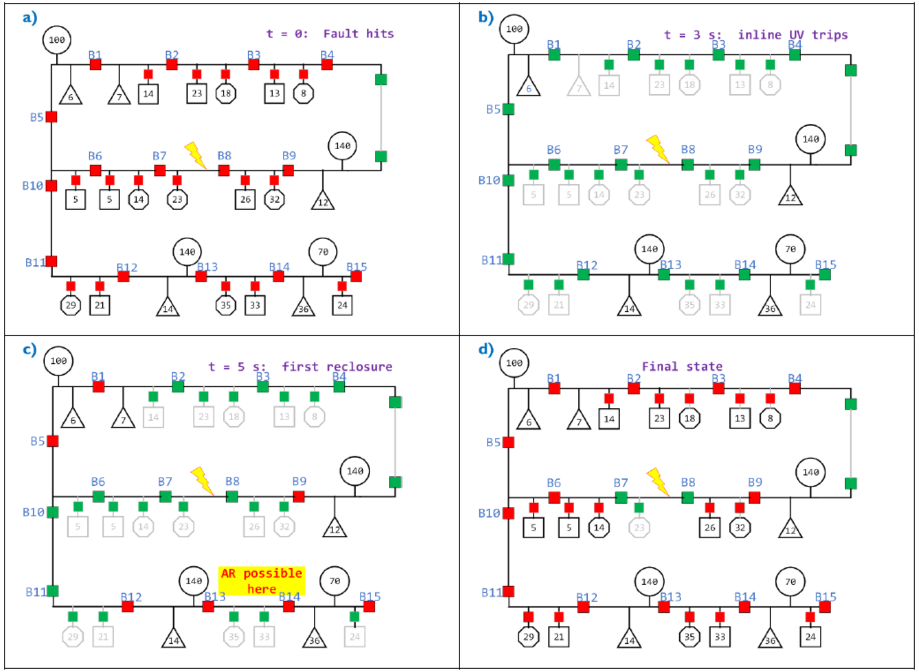
SNL: DynaGrid Protection

- **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

SNL: Outcomes and Impact

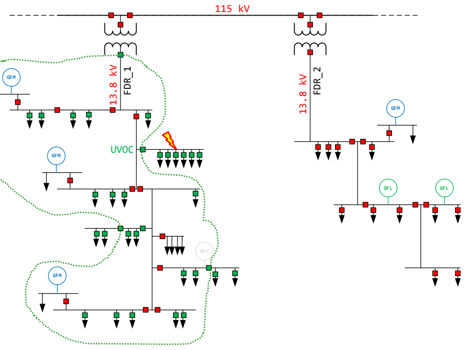
Proposed UVOC protection:

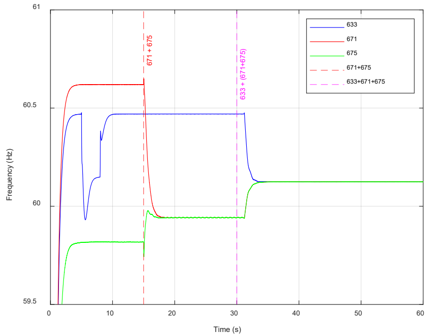
- Provides protection for microgrids in any configuration (each building block is protected) with dynamic boundaries and networking systems
- Does not require communication, which ensures cybersecurity, protected systems during resilience events with loss of communication, and interoperability between 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





Milestone	Date
Year 1	
Simulation models of faults and self-healing architecture developed based on use cases established with the IAB (Task 1)	6 months
Develop undervoltage-supervised overcurrent UVOC protection function to detect and isolate faults (Task 5)	12 months

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

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

Thank you

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