Grid Resilience & Intelligence Platform (GRIP - GMLC Project #1.5.01)

Oct 22, 2019

Agenda

9-9:05am: Brief Introduction to GRIP (Mayank Malik, SLAC)

9:05-9:20am: Anticipation Use Case Overview (Alyona Ivanova, SLAC)

9:20-9:45am: Absorption Use Case Overview (Paul Hines, Packetized)

9:45-9:55am: GRIP Platform Implementation (Mayank Malik, SLAC)

9:55-10am: Q&A + Discussion/Feedback

GRIP Objectives & Approach

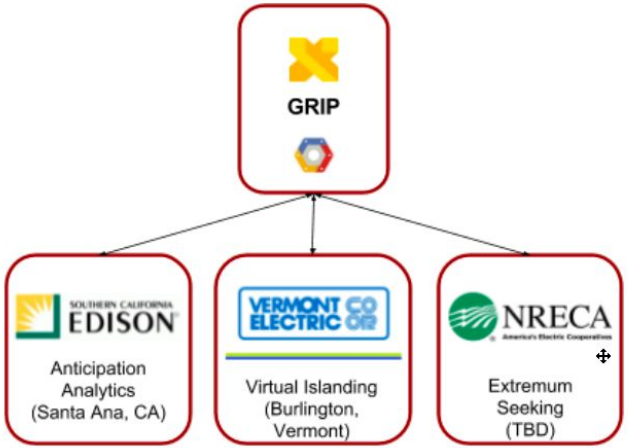
- Develop and deploy software tools to help utilities **anticipate**, **absorb** and **recover** from extreme events.
- Use artificial intelligence and machine learning for distribution grid resilience
  - Predictive analytics
  - Image recognition
  - Apply learning and problem solving capabilities for anticipation of grid events

Phased approach to research

✓ Machine learning and artificial intelligence from different data sources to anticipate grid events

✓ Validate controls for distributed energy resources for absorbing grid events

✓ Reduce recovery time by managing distributed energy resources in the case of limited communications



GRIP Value Proposition

- Extreme weather events threat to electric power systems and utility customers
- Existing utility tools do not support planning for and recovering from extreme events
- Vendors tools do not consider all available data to manage system impacts from hardware failure, damage, and replacement process during extreme events
- Platform development is driven by industry needs validated by our TAG members

GRIP Innovation and Impact

- GRIP applies artificial intelligence and machine learning to grid resilience
- National impact with unified deployment platform and advanced analytic tools
- Facilitates streamlining use of ML/AI applications for distribution resources
- Final deliverable: open-source commercially available product.
    - Phase 1: Anticipation (Completed)
    - Phase 2: Absorption (In-progress)
    - Phase 3: Recovery (Future Work)

Anticipation (2018)

Alyona Ivanova

Staff Engineer
Grid Integration Systems and Mobility (GISMo)
SLAC National Accelerator Laboratory (SLAC)

Anticipation Objectives

- Determine use-cases for resilience
  - Asset and protective device location and mapping
  - Predicting vulnerabilities to extreme weather conditions
  - Switch re-configuration
  - Secondary voltage optimization with DERs
  - Vegetation management
  - Optimized work plans considering budget hardening options
- Develop a new platform based on pre-existing Google tools
- Use previously DOE funded projects (VADER, OMF) as basis for GRIP
- Test and validate anticipation solution with data and models provided by National Rural Electric Cooperative Association (NRECA)

GRIP Implementation

Developing a platform for our three demonstrations

- Implemented functional wireframe version for demonstration of Anticipation
- Will review designs for future implementation

Designed for cloud deployment

- Cloud focused on Google Cloud Platform
- Flexibility data management

Production Infrastructure and Process

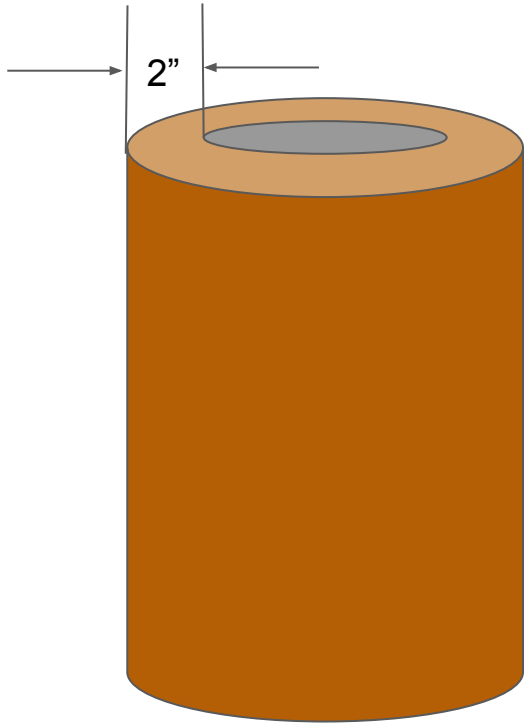
- Industry standard architecture
- Unit and functional testing infrastructure
- Agile development process
- Managed code on github

Core GRIP Simulation Analysis

- GridLAB-D implementation incorporates vulnerability analysis
- Analytical pole and line vulnerability model using weather data
  - Calculation of pole vulnerability index, electrical fault propagation and restoration time
  - Wind stress simulation represents worst case scenario
- Support for arbitrary vulnerability simulations
  - User ability to specify the electrical system model
- Calculations of stresses that lead to pole failures account for
  - Cables tension
  - Pole-mounted equipment
  - Pole tilt angle
  - Wind and ice loading

Internal pole degradation model

- Applicable to wood poles only
- Propagation of internal core degradation to outer edges
- Degradation defined by minimum shell thickness
  - End-of-life thickness: 2”
- Characterized by the difference between the outer core and inner core moment calculations
- Accounts for pole base failures



Planned Enhancements to Pole Vulnerability Model

- Planned enhancements to the pole vulnerability model
  - Add effect of changing wind direction
  - Add ice build-up model and line loading effects
  - Extend taxonomy of impacts of vegetation on lines, poles, and equipment
- Pole degradation
  - Pole top failures due to equipment, weather and animal impacts

IEEE Standard test models

IEEE 123

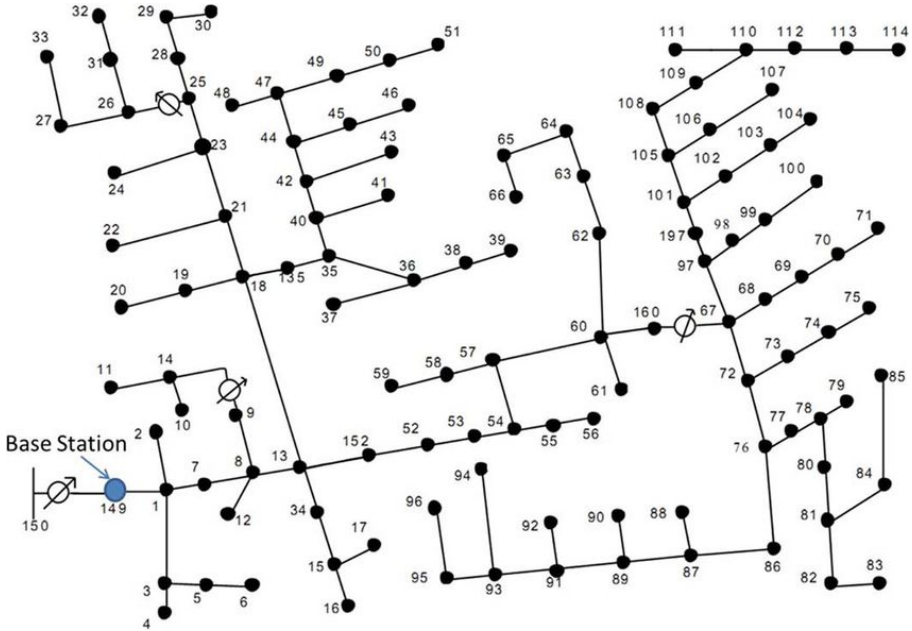


Image obtained from DOI: 10.1109/TSG.2013.2288868

IEEE 8500

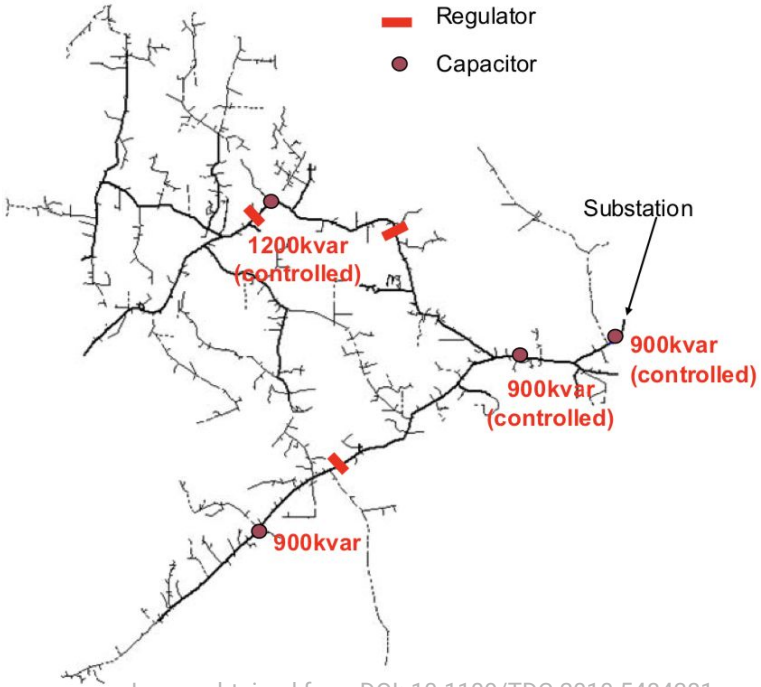
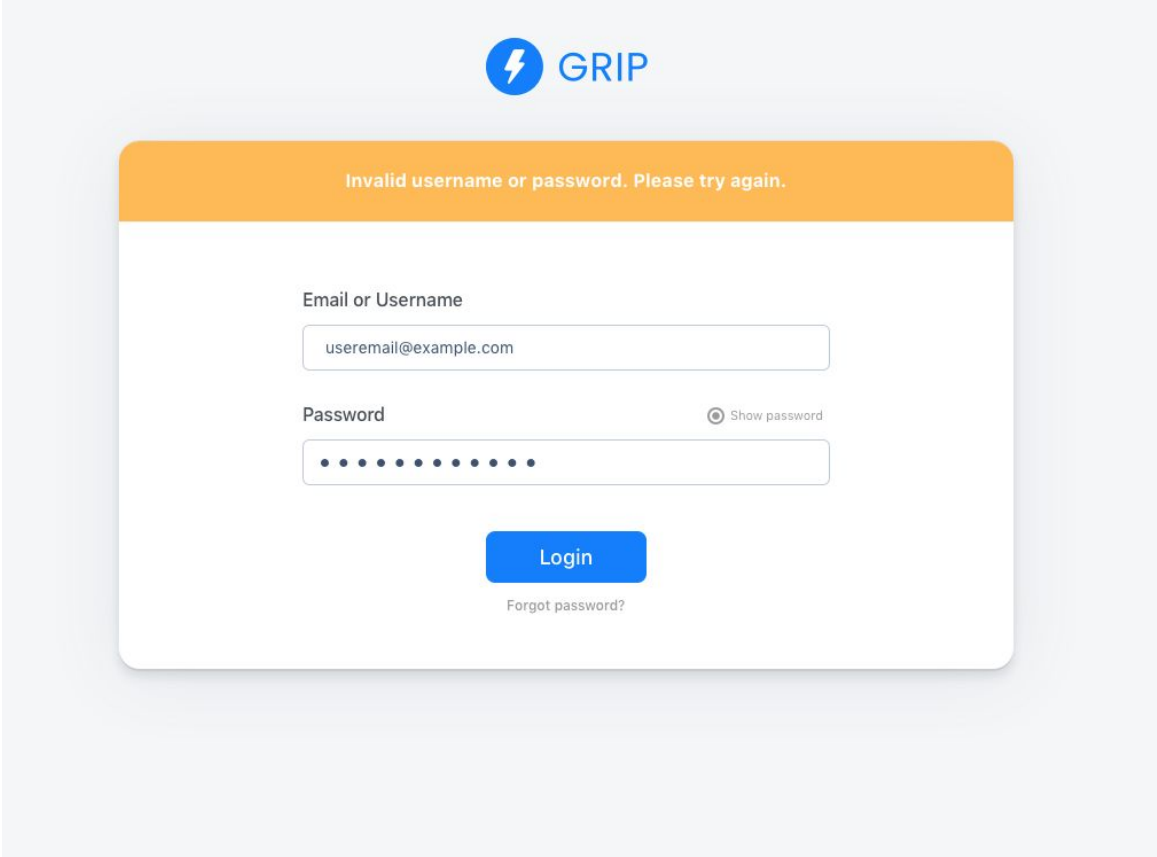
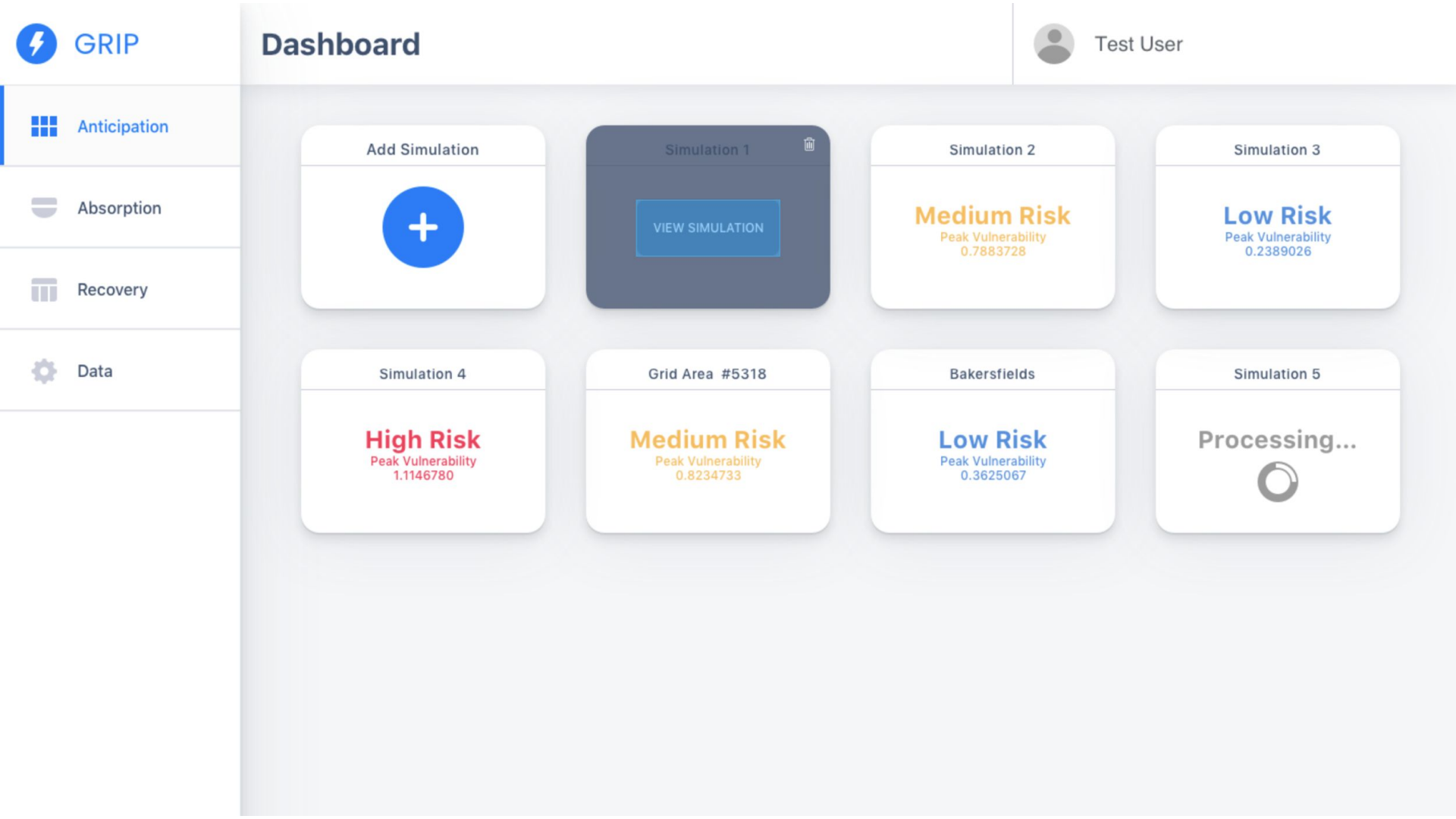


Image obtained from DOI: 10.1109/TDC.2010.5484381

GRIP Further Design




GRIP
Dashboard
Test User
Anticipation
Absorption
Recovery
Data
Add Simulation
Simulation 1
VIEW SIMULATION
Simulation 2
Medium Risk
Peak Vulnerability
0.7883728
Simulation 3
Low Risk
Peak Vulnerability
0.2389026
Simulation 4
High Risk
Peak Vulnerability
1.1146780
Grid Area #5318
Medium Risk
Peak Vulnerability
0.8234733
Bakersfields
Low Risk
Peak Vulnerability
0.3625067
Simulation 5
Processing...

GRIP

Simulation 1

Test User

- Anticipation
- Absorption
- Recovery
- Data

Graph

Network Source: Network_example_name

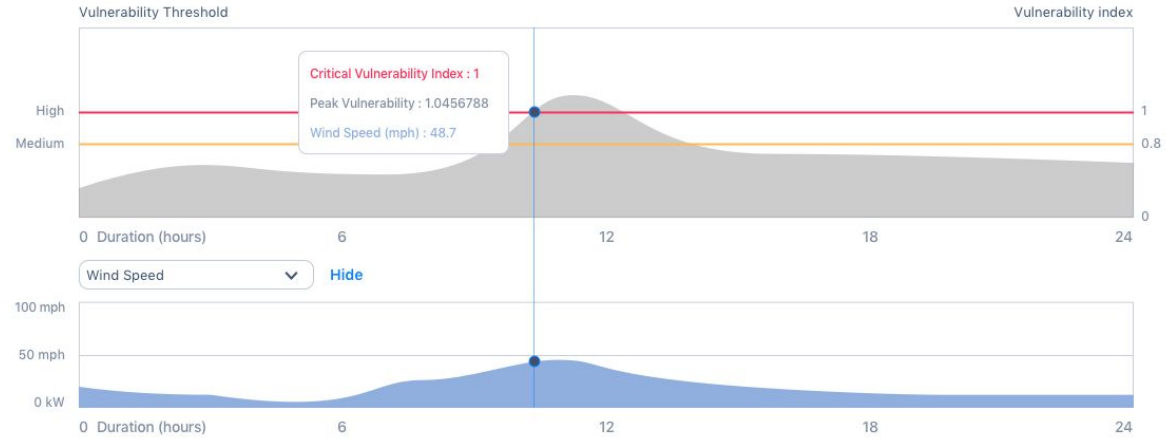
Weather Source: Southern California 12 2018

Duration(hrs): 24

Interval (secs): 300

Completed 00:03:20

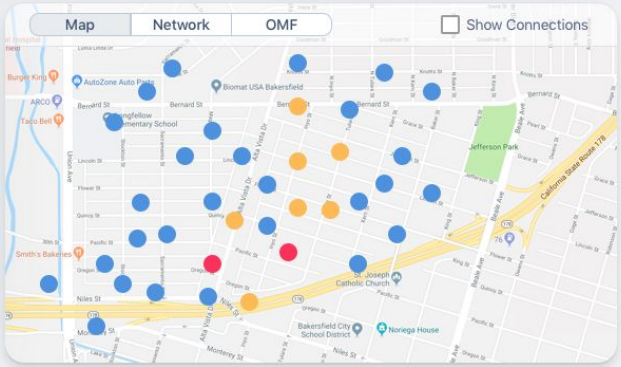
Re-Run Model



Asset List

Full report →

Name	Type	Vulnerability	Peak Power
Line	Pole	0.2345728	-
Node 2	Pole	0.2343682	-
Node 3	Pole	0.4672939	-
Node 4	Pole	0.4789442	-
Node 12	Pole	0.8022221	-
Node 13	Pole	1.0494033	-
Node 234	Pole	0.5623556	-
Line8to10	Overhead_line	0.5623556	-



GRIP

Simulation 1 > **node 2**

Test User

- Anticipation
- Absorption
- Recovery
- Data

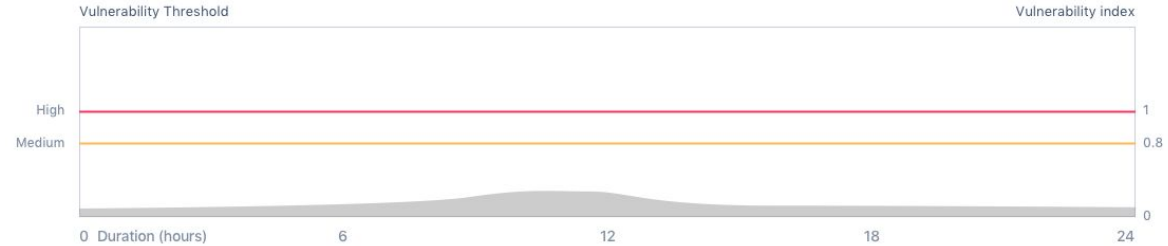
Graph

Network Source: Network_example_name

Weather Source: Southern California 12 2018

Duration(hrs): 24

Interval (secs): 300



Wind Speed ▾ Hide

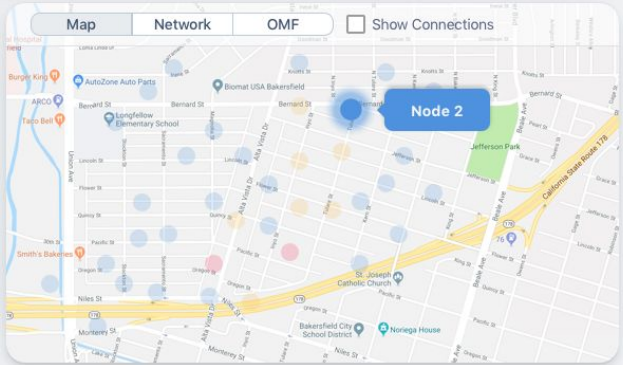
Asset Properties

All →

Name	Value
Area	+0 sf
Class	Pole
Height	+0 ft
Latitude	35.385283
Longitude	-118.999517
Tilt Angel	+0 rad
Tilt Direction	+0 deg
Type	Wood

Asset Connections

Name	Type
line2to3	line
line3to4	line
line5to7	line
sw3to62	-
sw5to78	-
sw12to21	-



GRIP

Simulation 1

Test User

- Anticipation
- Absorption
- Recovery
- Data

Graph

Network Source: Network_example_name

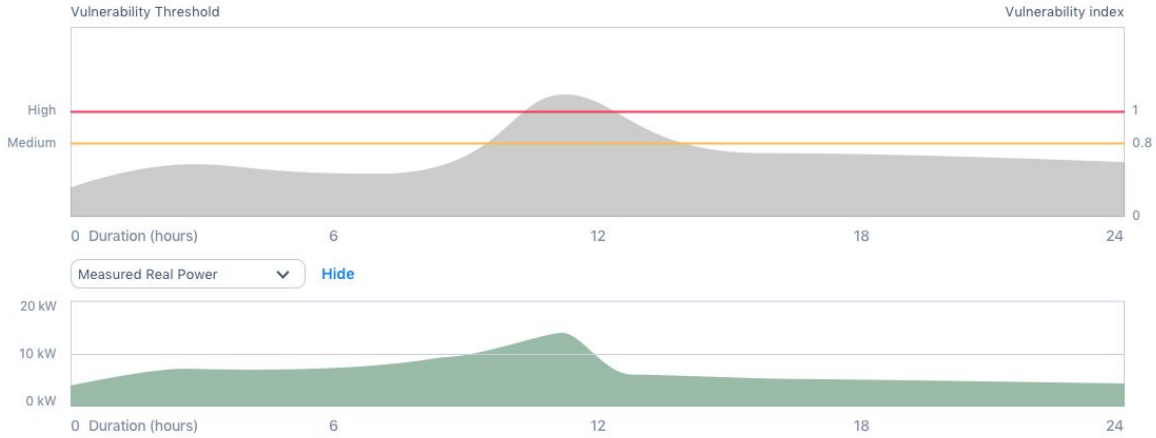
Weather Source: Southern California 12 2018

Duration(hrs): 24

Interval (secs): 300

Completed 00:03:20

Re-Run Model



Asset List

Full report →

Name	Type	Vulnerability	Peak Power
Line	Pole	0.2345728	-
Node 2	Pole	0.2343682	-
Node 3	Pole	0.4672939	-
Node 4	Pole	0.4789442	-
Node 12	Pole	0.8022221	-
Node 13	Pole	1.0494033	-
Node 234	Pole	0.5623556	-
Line8to10	Overhead_line	0.5623556	-

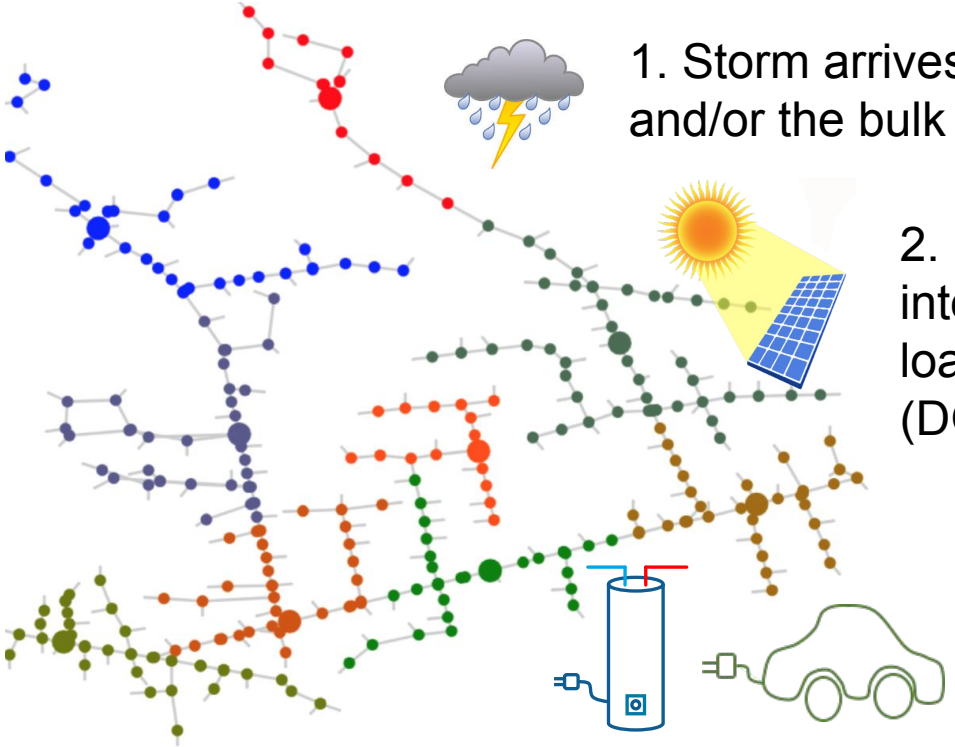
Absorption (2019)

Paul Hines
Co-founder and CEO
Packetized Energy

ABSORPTION / VIRTUAL ISLANDING

PACKETIZED ENERGY

ABSORPTION: GRACEFUL DEGRADATION FOR RESILIENCE



1. Storm arrives, damaging distribution circuits and/or the bulk grid

2. Dynamically reconfigure the network into **Virtual Islands** to serve as much load as possible from existing resources (DG, batteries)

3. Use flexible DERs (e.g., water heaters, distributed batteries, EV chargers) to help balance supply and demand within virtual islands.

VIRTUAL ISLANDING SEQUENCE

Step 1. Fault occurs

Step 2. Fault isolation

Step 3. Reconfiguration (Virtual Islanding)

Step 4. Load balancing

RECONFIGURATION METHOD

After faults are isolated, choose islands to:

- Serve as much load as possible
- Ensure that each island has as much reserves/flexibility as possible
- Minimize the number of switching events
- Ensure that line flows are within limits
- Ensure that after switching events are complete, the circuit remains radial

MATH:

$$\text{Maximize} \quad \sum_{d}\sum V_d P_d + \alpha\left(R + \sum_{i\in D}\Delta P_{d,i}\right) - \beta\sum_{m\in M}|u_m[1] - u_m[0]| - \gamma\sum_{d\in D} u_d$$

s.t.

$$P_{g,n} - P_{d,n} - P_{b,n} = \sum_{m\in M_n} P_{ft,m}, \forall n \in N \tag{6}$$

$$(P_{g,n} + \Delta P_{g,n}) - (P_{d,n} + \Delta P_{d,n}) - (P_{b,n} + \Delta P_{b,n}) = \sum_{m\in M_n}(P_{ft,m} + \Delta P_{ft,m}), \forall n \in N \tag{7}$$

$$-\overline{P_{ft,m}} * u_m \le P_{ft,m} \le \overline{P_{ft,m}} * u_m \tag{8}$$

$$-\overline{P_{ft,m}} * u_m \le P_{ft,m} + \Delta P_{ft,m} \le \overline{P_{ft,m}} * u_m \tag{9}$$

$$0 \le P_{g,i} \le \overline{P_{g,i}}, \forall i \in G \tag{10}$$

$$0 \le (P_{g,i} + \Delta P_{g,i}) \le \overline{P_{g,i}}, \forall i \in G \tag{11}$$

$$0 \le P_{d,i} \le P_{d,i}[0], \forall i \in D \tag{12}$$

$$0 \le \Delta P_{d,i}, \forall i \in D \tag{13}$$

$$-\overline{P_{b,i}} \le P_{b,i} \le \overline{P_{b,i}}, \forall n \in N \tag{14}$$

$$-\overline{P_{b,i}} \le P_{b,i} + \Delta P_{b,i} \le \overline{P_{b,i}}, \forall n \in N \tag{15}$$

$$\sum_{m\in L_k} u_m \le |L_k| - 1, \forall k \in \text{LOOPS} \tag{16}$$

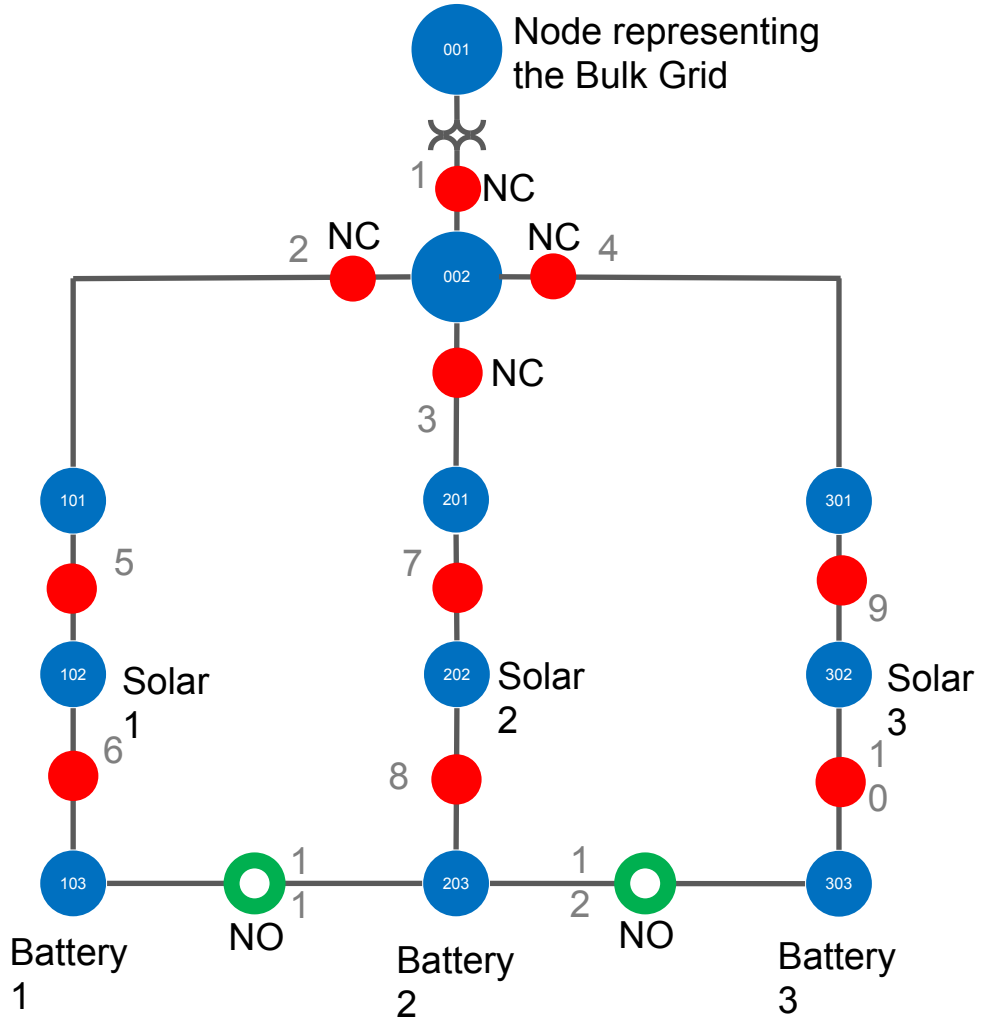
$$R \le \Delta P_{d,n} - M u_d, \forall n \in N \tag{17}$$

$$u_{d,i} \in \{0,1\}, \forall i \in D, u_{m,j} \in \{0,1\}, \forall j \in M \tag{18}$$

VIRTUAL ISLANDING TEST CASE

Legend

- Switch or circuit breaker/recloser that is closed (hot)
- Switch or circuit breaker/recloser that is open (not hot)
- xyz — Distribution circuit node (or collection of nodes) with (eg) hundreds of customers.
- Fault location



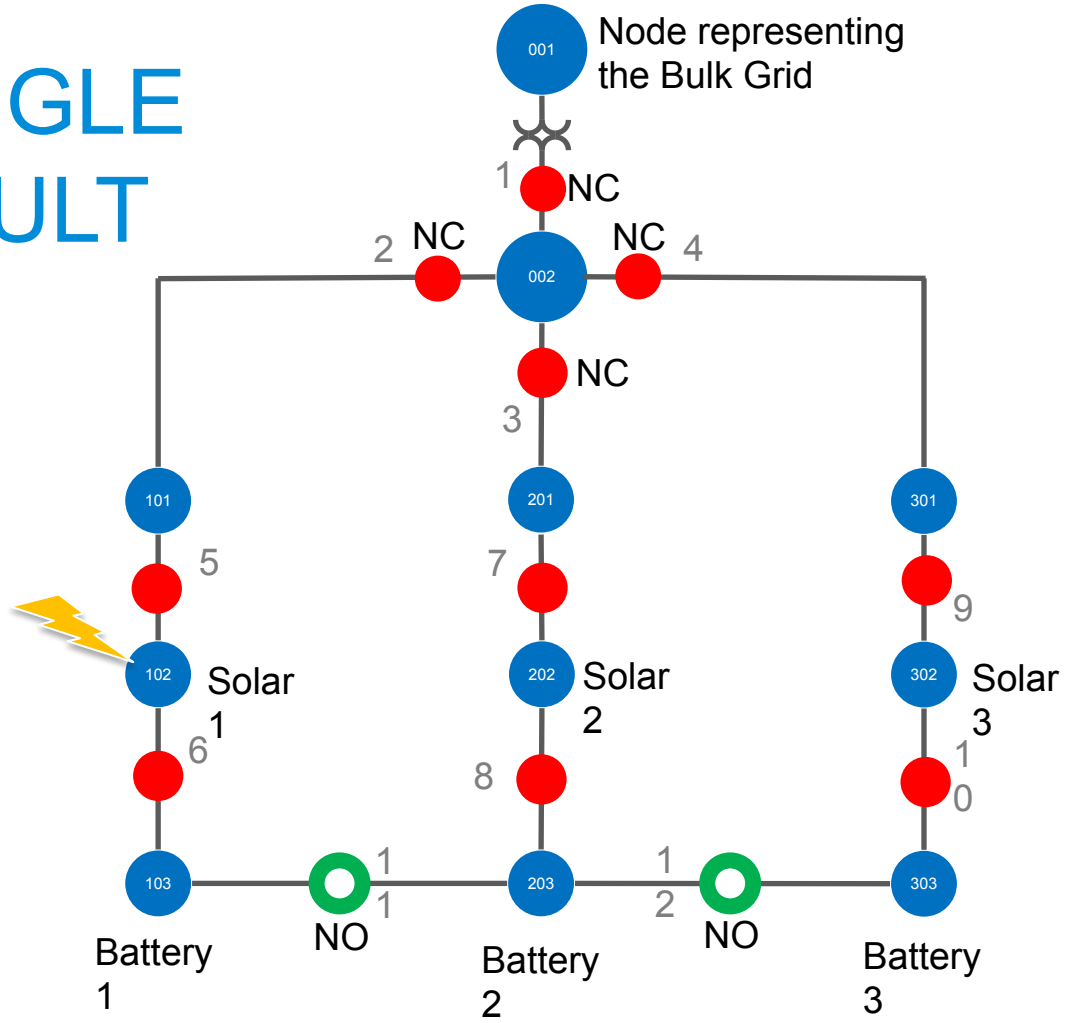
CASE 1: SINGLE FEEDER FAULT

25

CASE 1: SINGLE FEEDER FAULT

Legend

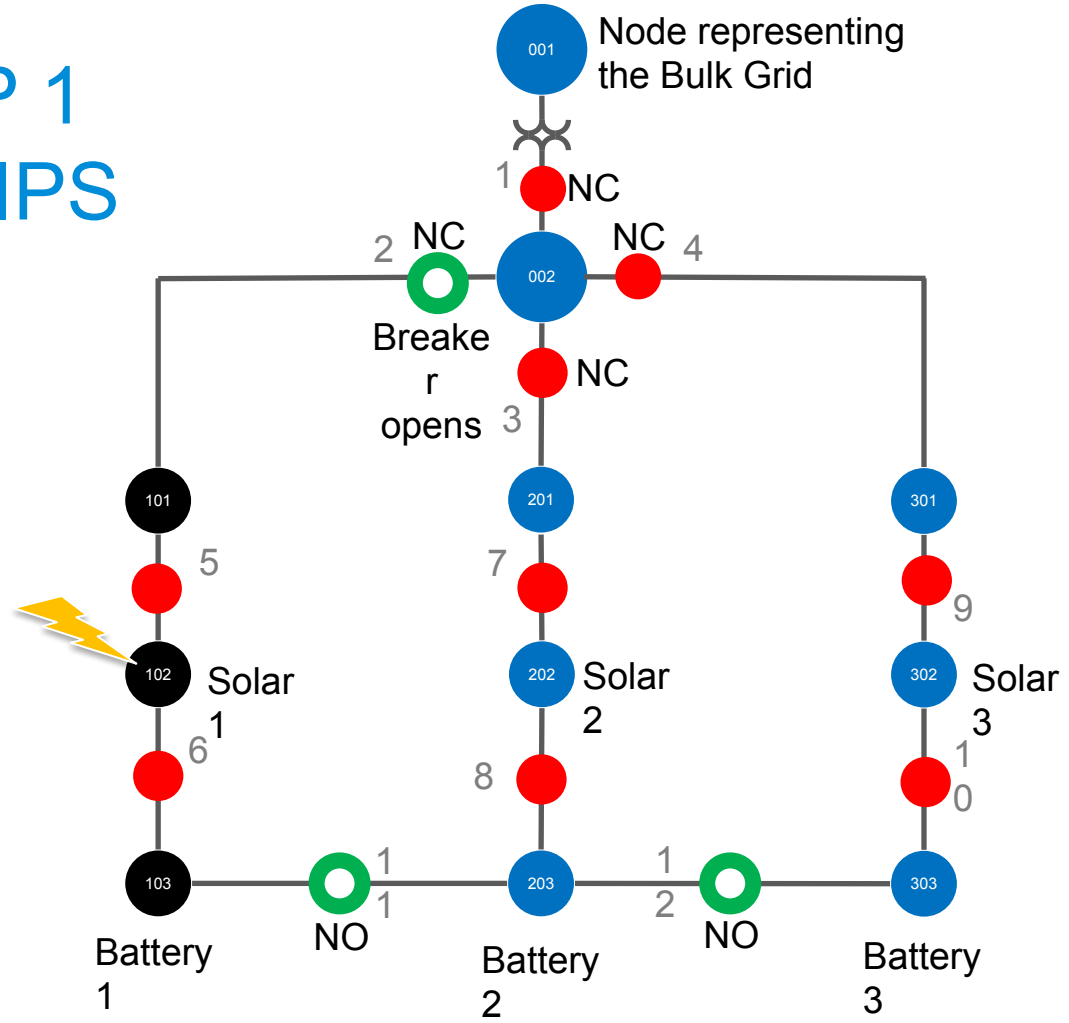
- Switch or circuit breaker/recloser that is closed (hot)
- Switch or circuit breaker/recloser that is open (not hot)
- xyz — Distribution circuit node (or collection of nodes) with (eg) hundreds of customers.
- Fault location



CASE 1: STEP 1 BREAKER TRIPS

Legend

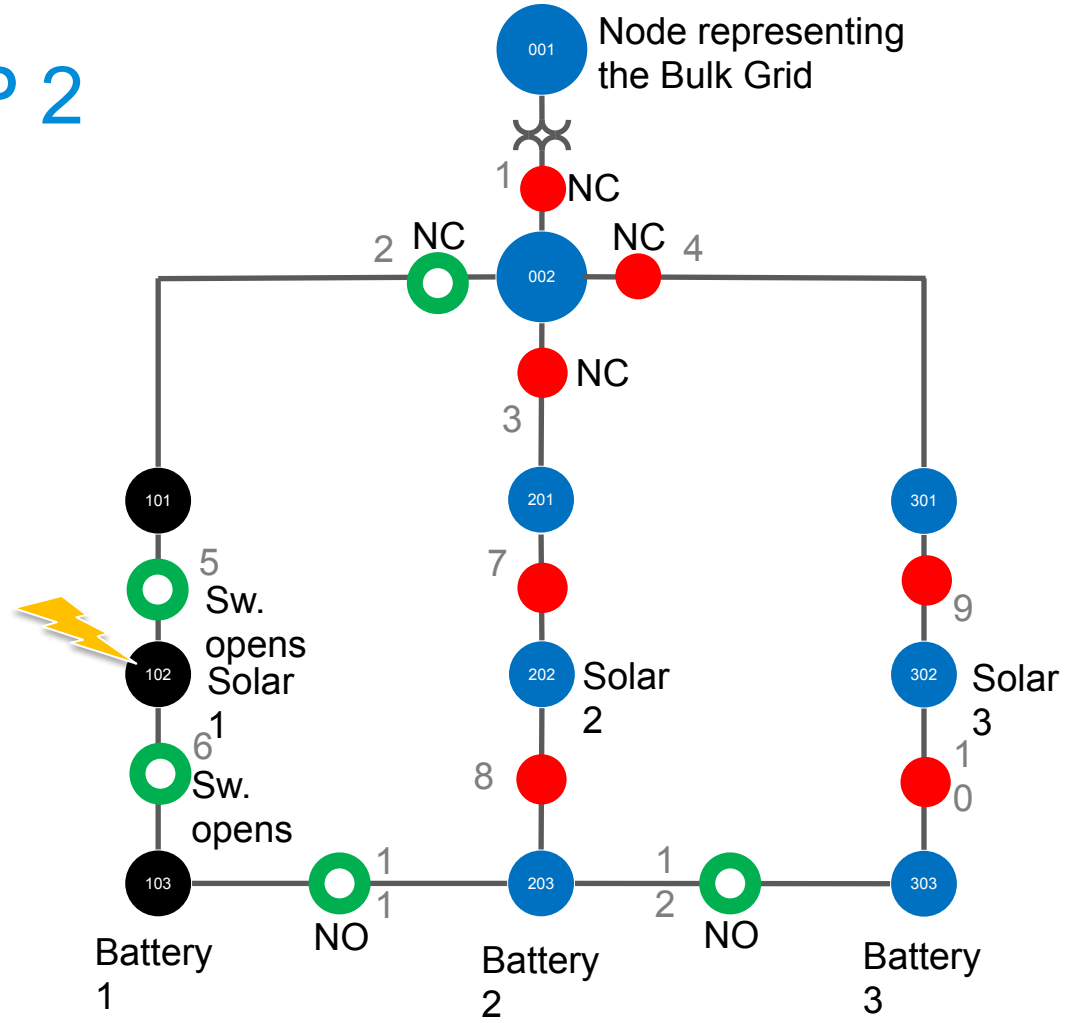
- Switch or circuit breaker/recloser that is closed (hot)
- Switch or circuit breaker/recloser that is open (not hot)
- xyz — Distribution circuit node (or collection of nodes) with (eg) hundreds of customers.
- Fault location



CASE 1: STEP 2 FAULT ISOLATION

Legend

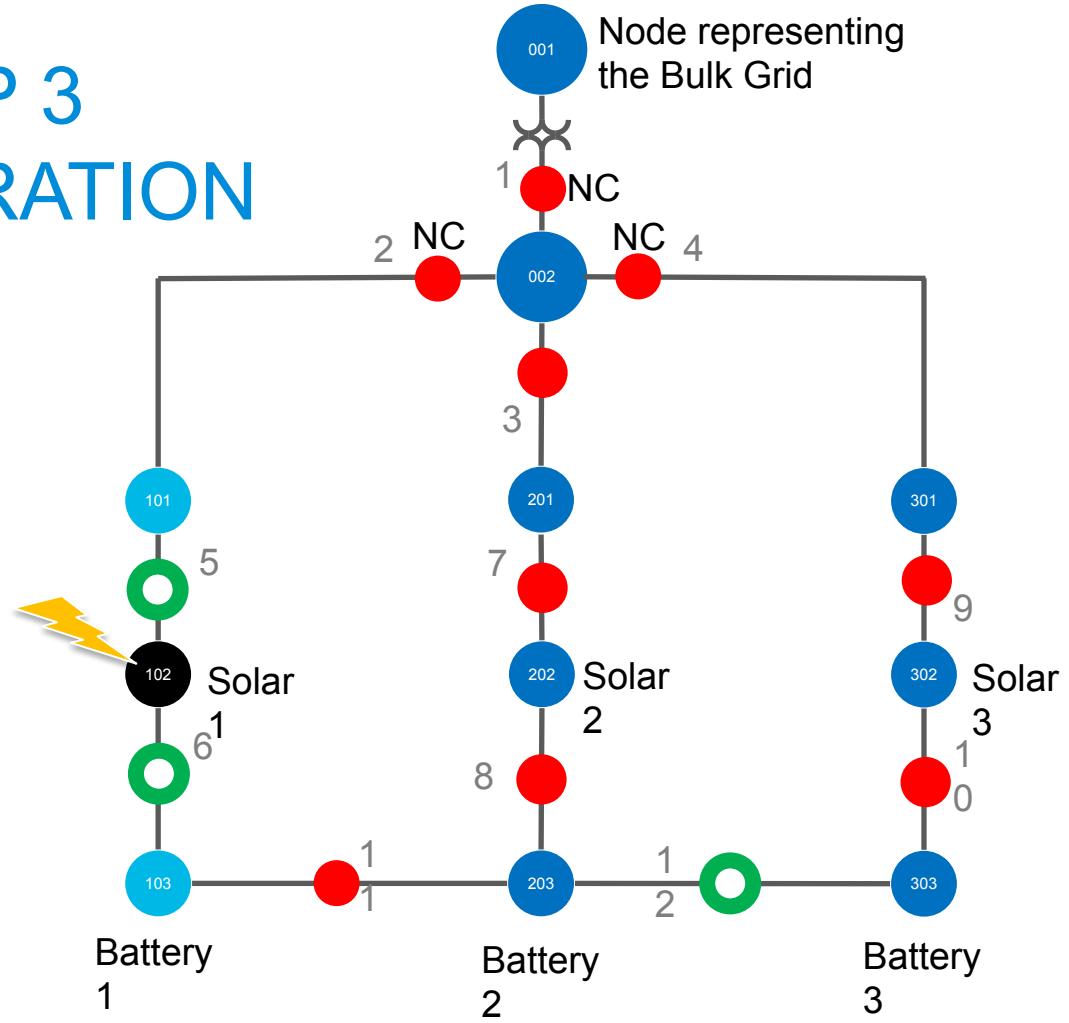
- Switch or circuit breaker/recloser that is closed (hot)
- Switch or circuit breaker/recloser that is open (not hot)
- xyz — Distribution circuit node (or collection of nodes) with (eg) hundreds of customers.
- Fault location



CASE 1: STEP 3 RECONFIGURATION

Legend

- Switch or circuit breaker/recloser that is closed (hot)
- Switch or circuit breaker/recloser that is open (not hot)
- xyz — Distribution circuit node (or collection of nodes) with (eg) hundreds of customers.
- Fault location



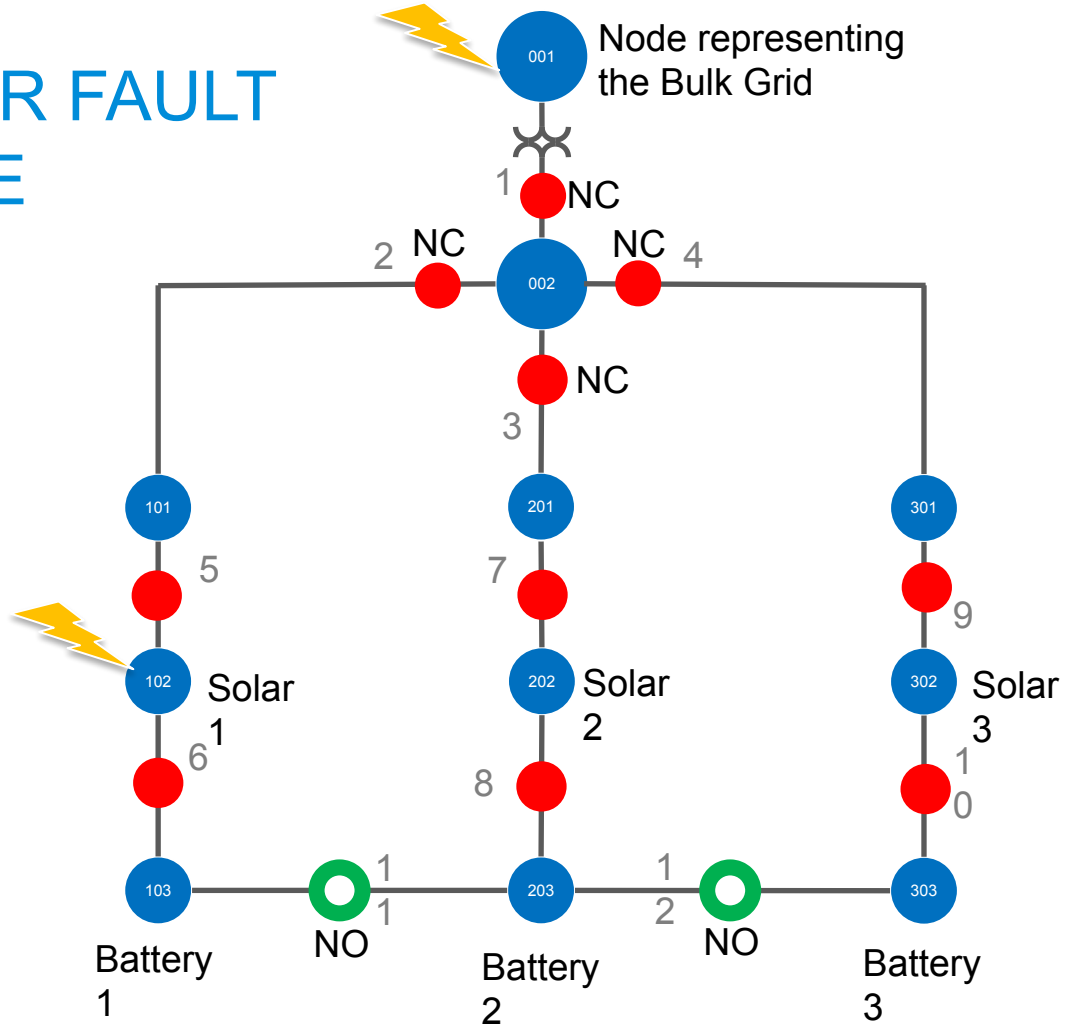
CASE 1: FEEDER FAULT + BULK GRID FAILURE

30

CASE 2: FEEDER FAULT & GRID OUTAGE

Legend

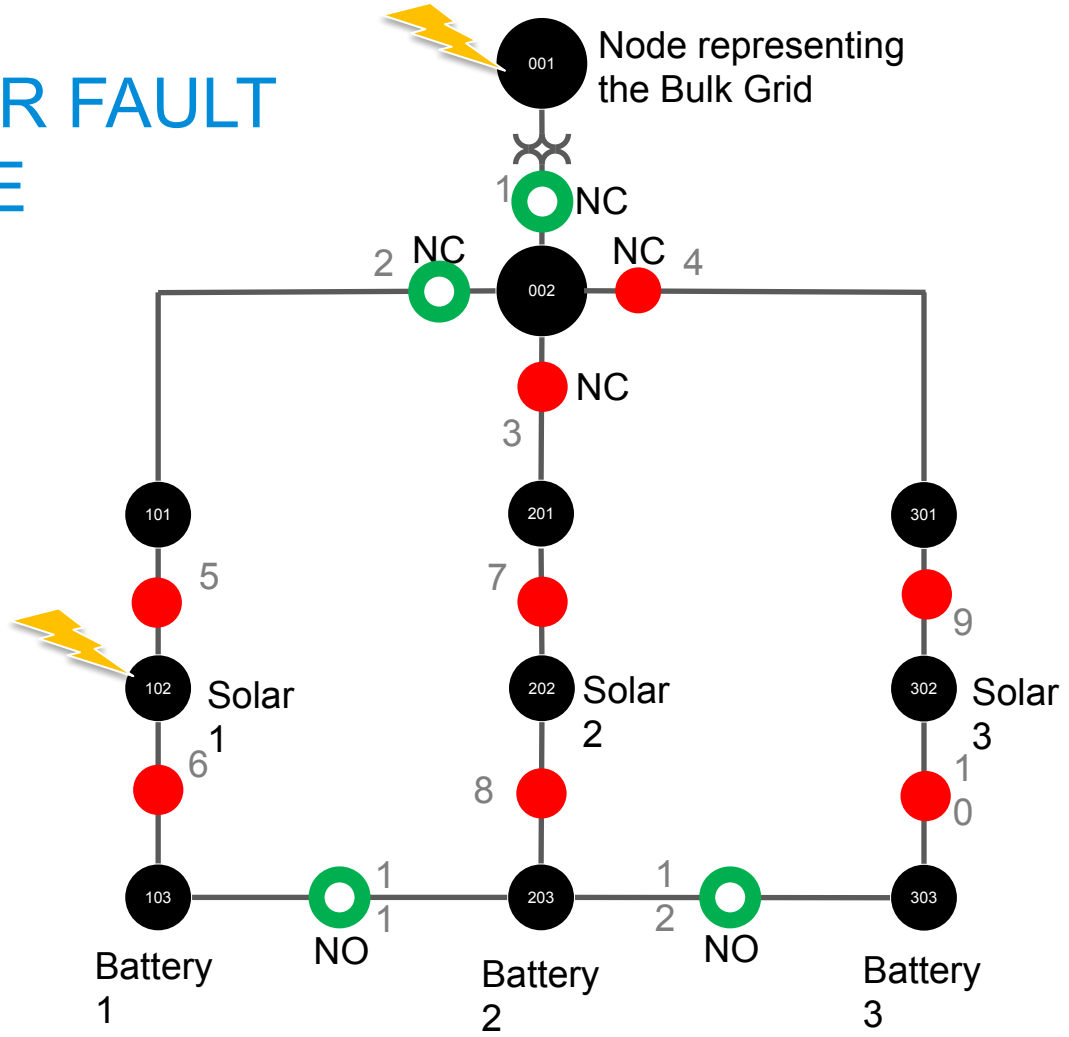
- Switch or circuit breaker/recloser that is closed (hot)
- Switch or circuit breaker/recloser that is open (not hot)
- xyz — Distribution circuit node (or collection of nodes) with (eg) hundreds of customers.
- Fault location



CASE 2: FEEDER FAULT & GRID OUTAGE

Legend

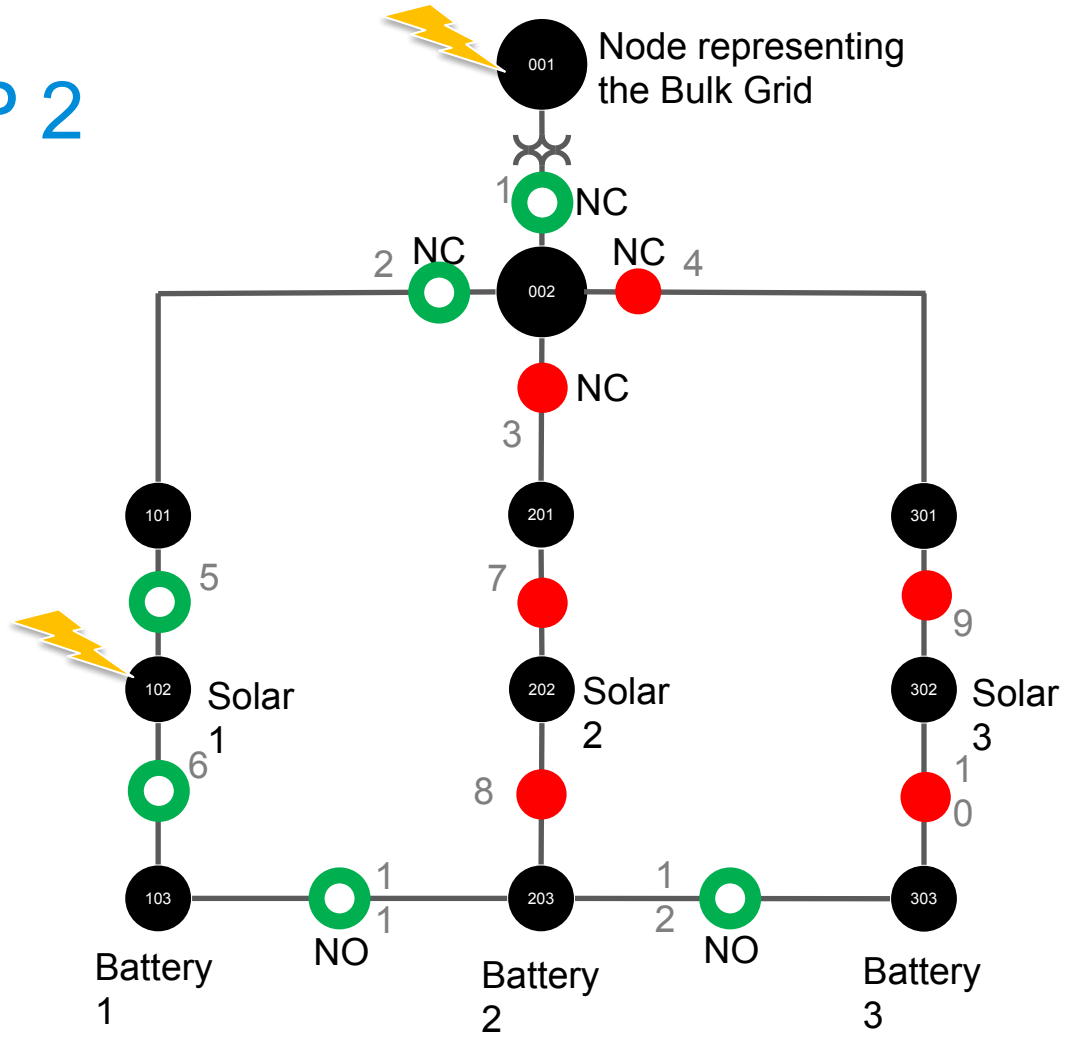
- Switch or circuit breaker/recloser that is closed (hot)
- Switch or circuit breaker/recloser that is open (not hot)
- xyz — Distribution circuit node (or collection of nodes) with (eg) hundreds of customers.
- Fault location



CASE 2: STEP 2 FAULT ISOLATION

Legend

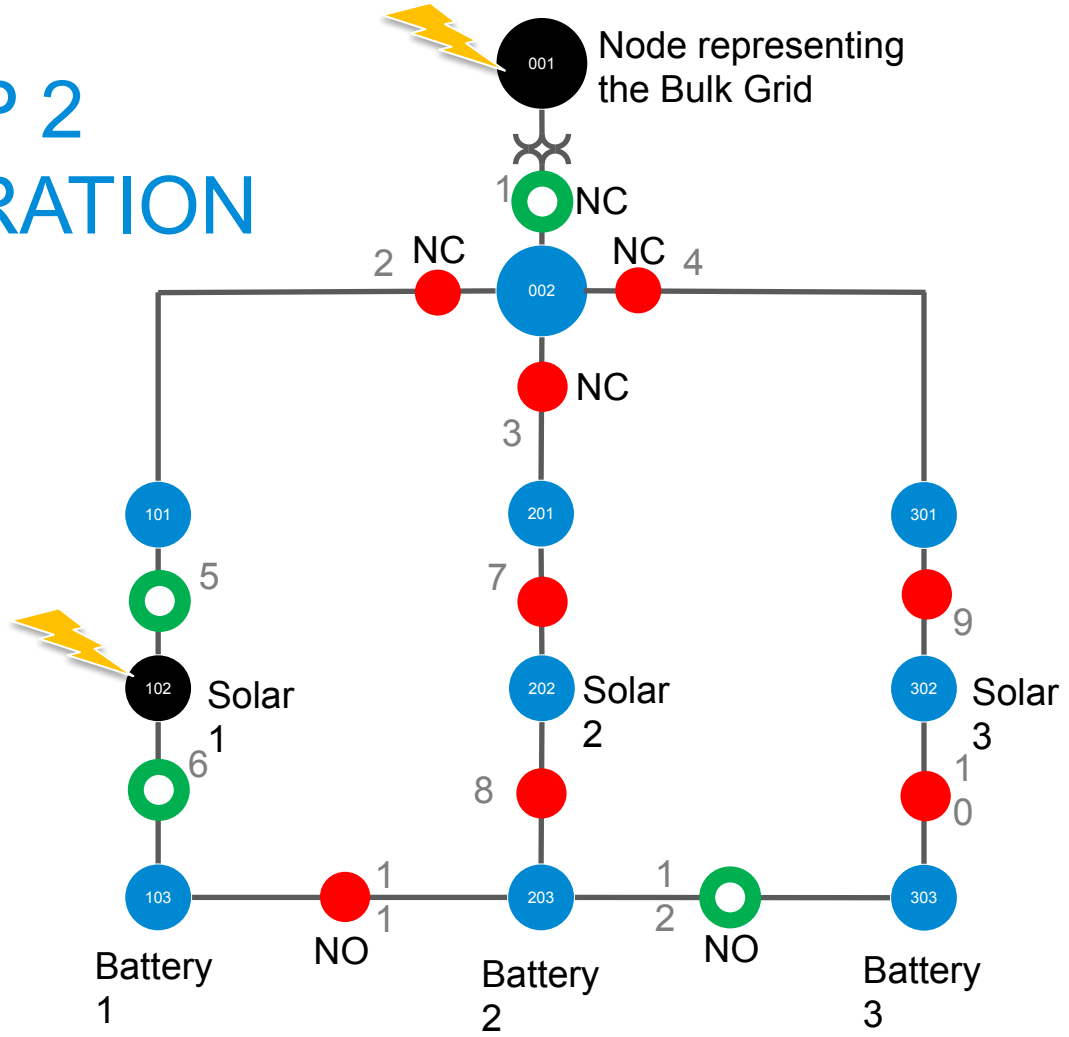
- Switch or circuit breaker/recloser that is closed (hot)
- Switch or circuit breaker/recloser that is open (not hot)
- xyz — Distribution circuit node (or collection of nodes) with (eg) hundreds of customers.
- Fault location



CASE 2: STEP 2 RECONFIGURATION

Legend

- Switch or circuit breaker/recloser that is closed (hot)
- Switch or circuit breaker/recloser that is open (not hot)
- xyz — Distribution circuit node (or collection of nodes) with (eg) hundreds of customers.
- Fault location



POWER BALANCING AFTER RECONFIGURATION

35

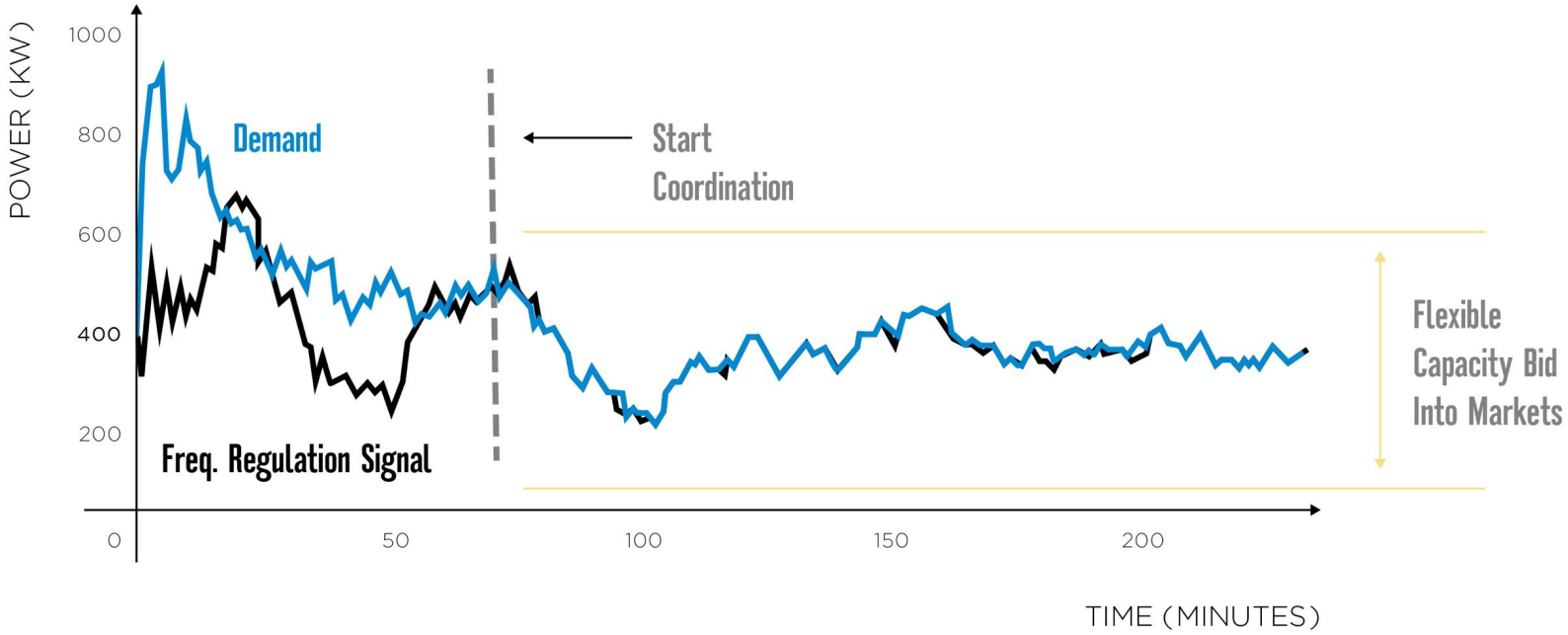
AFTER RECONFIGURATION

Each node uses local communications and/or local frequency measurements to locally balance supply and demand

The primary objectives are to:

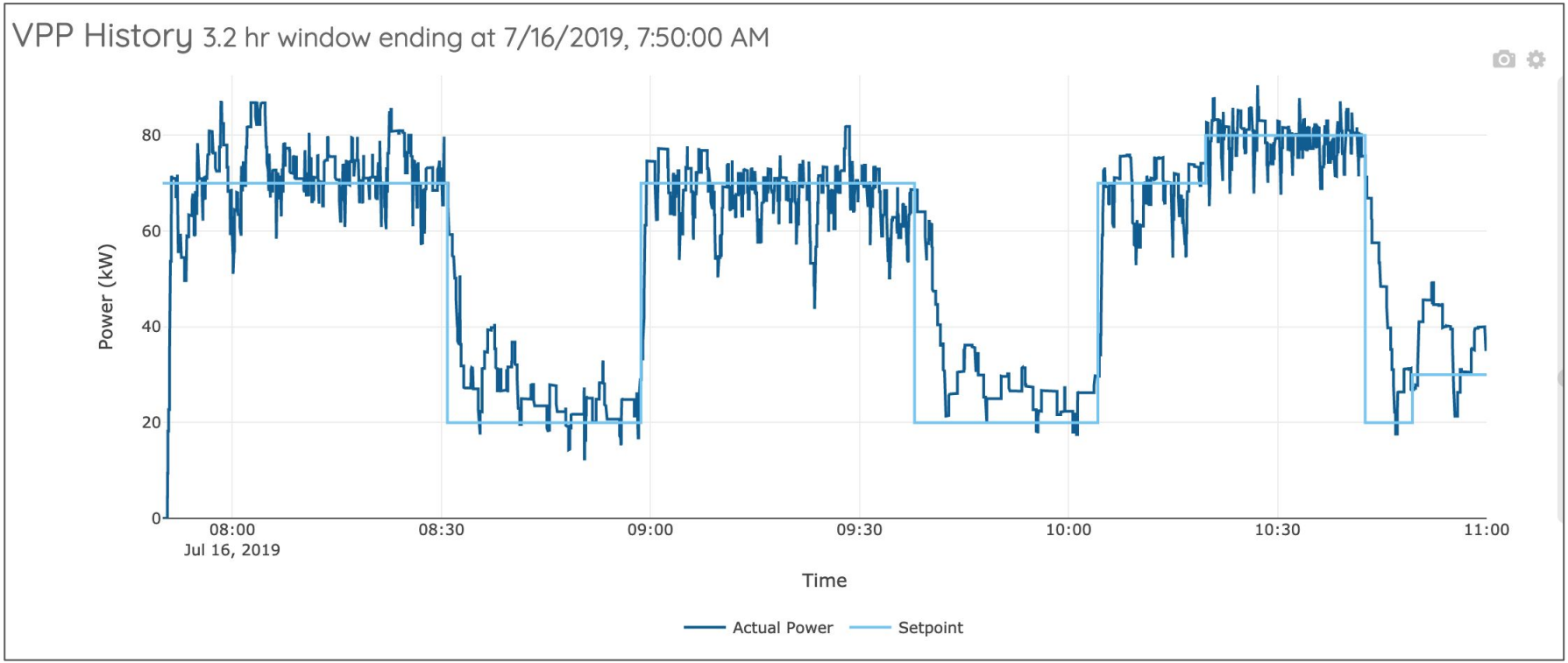
- preserve the energy storage, given supply (PV) and demand
- ensure that at every moment frequency is stable at 60 Hz

POWER BALANCING EXAMPLE



300 SIMULATED WATER HEATERS

REAL-WORLD ABSORPTION RESULTS FROM ~150 DEVICES



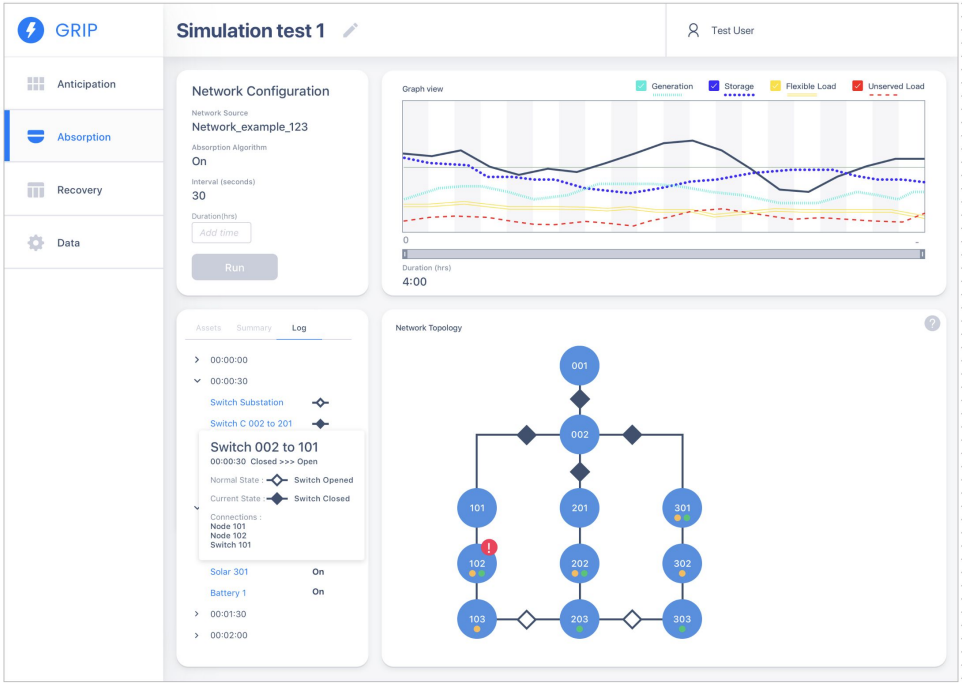
EXPECTED OUTCOMES

39

EXPECTED OUTCOMES

GRIP Absorption report will explain the technology pathway needed to use GRIP/Absorption to increase resilience for their customers

GRIP Absorption software will allow utilities to try absorption with their circuits

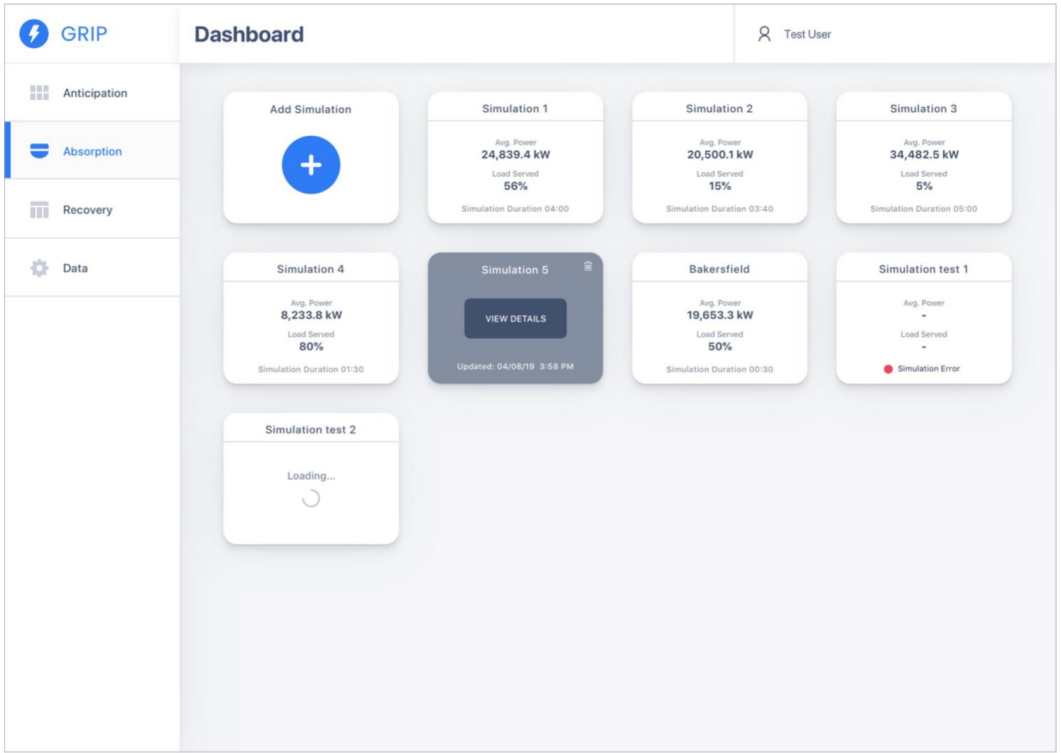


GRIP - Absorption Design

Dashboard

Key Features:

- View previous and active Absorption simulations
- Overview of key metrics and outcomes
- Management and link out to simulation details

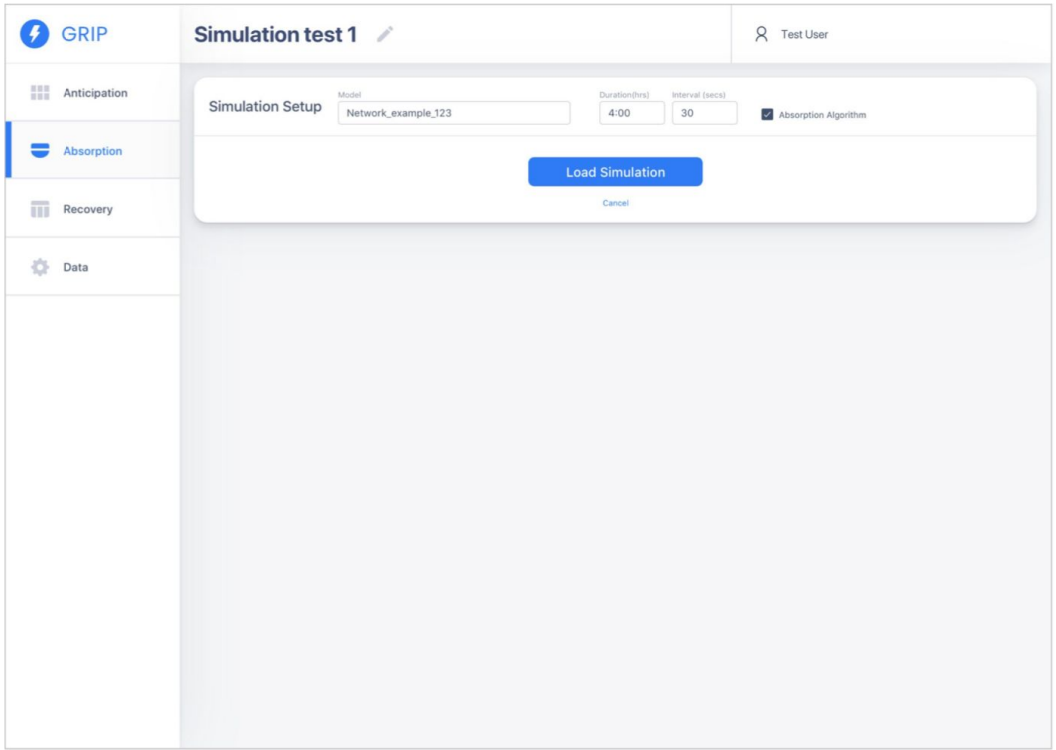


GRIP - Absorption Design

Absorption Setup

Key Features:

- GLM model support
- Specification of simulation duration
- Toggle Absorption algorithm

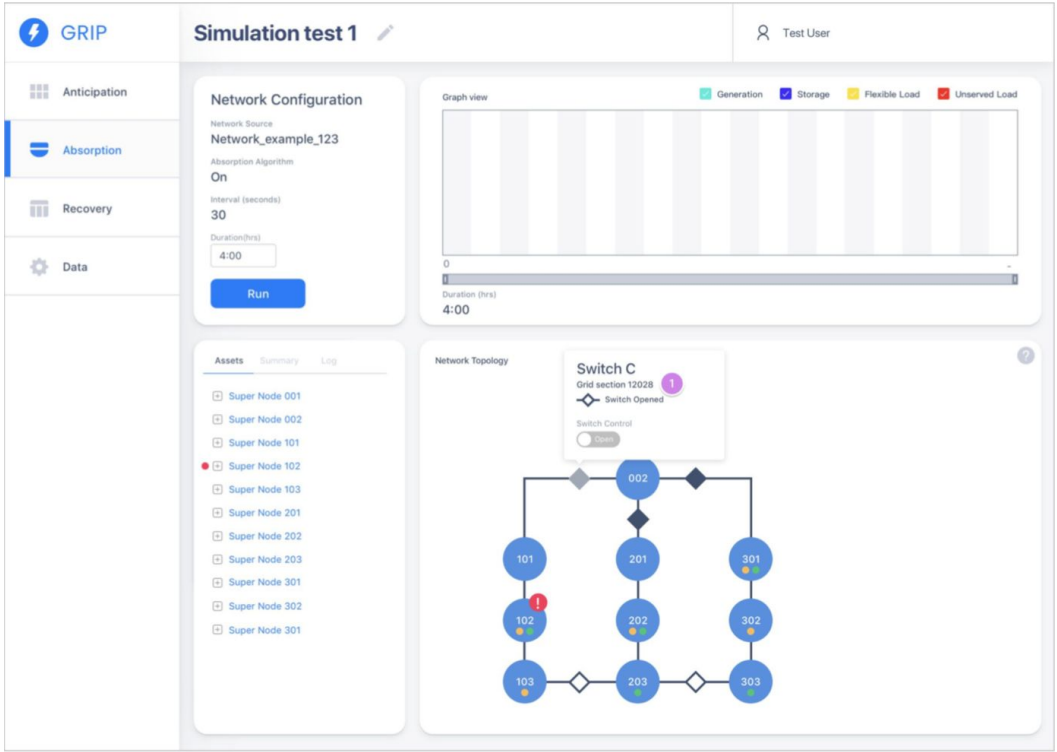


GRIP - Absorption Design

Simulation Details

Key Features:

- Pause/Restart simulation
- Graphical representation of Network Topology
- Tree representation of Asset Hierarchy

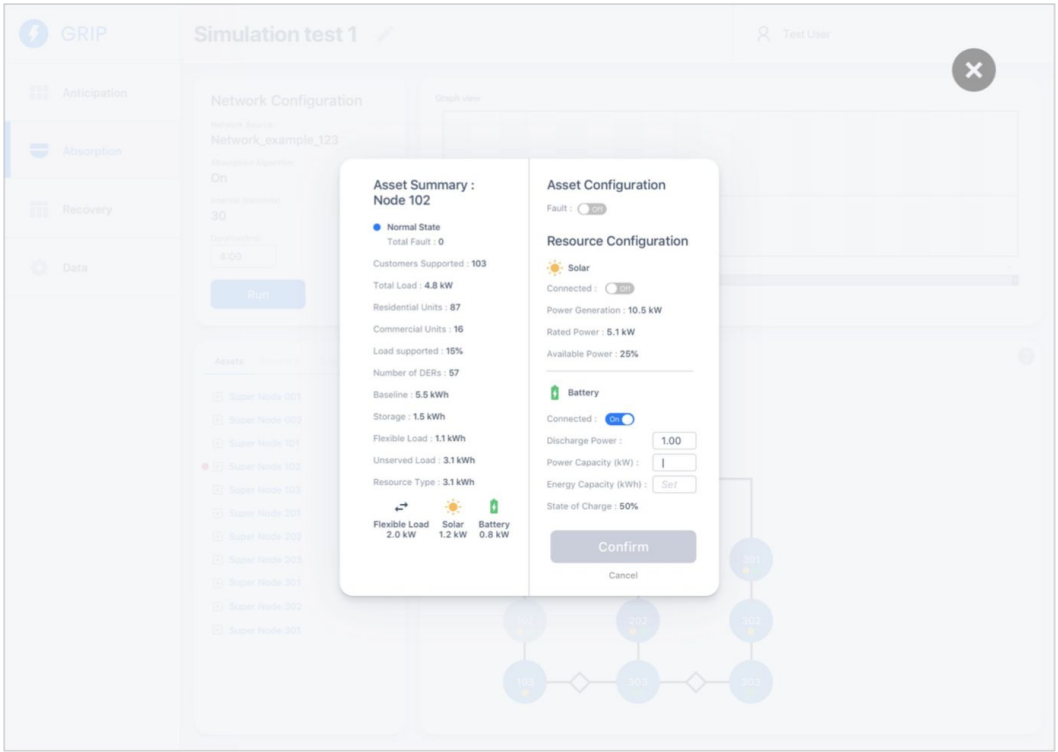


GRIP - Absorption Design

Asset Editor

Key Features:

- Toggle Manual Fault
- Live edit Solar/Battery properties
- Overview of key Asset properties

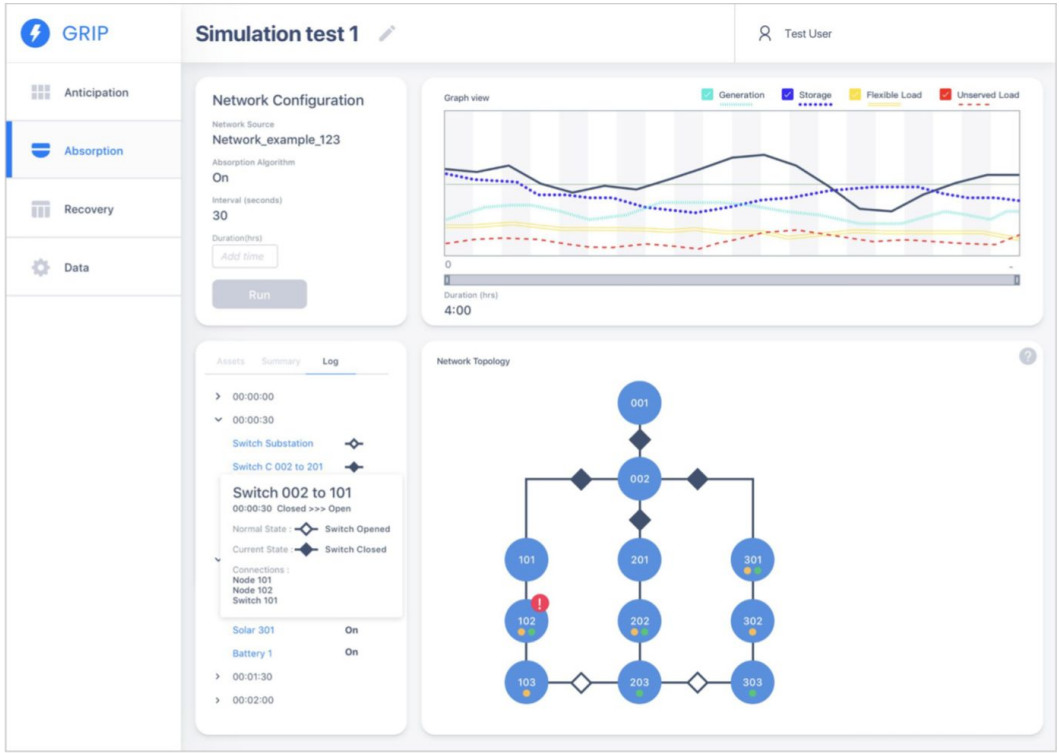


GRIP - Absorption Design

Simulation Results

Key Features:

- Time Series capture of Grid Metrics
- Summary of key Simulation results
- Detailed Log of Grid Events and associated Assets



GRIP Platform Implementation

Mayank Malik
Chief Data Officer
Grid Integration Systems and Mobility (GISMo)
SLAC National Accelerator Laboratory (SLAC)

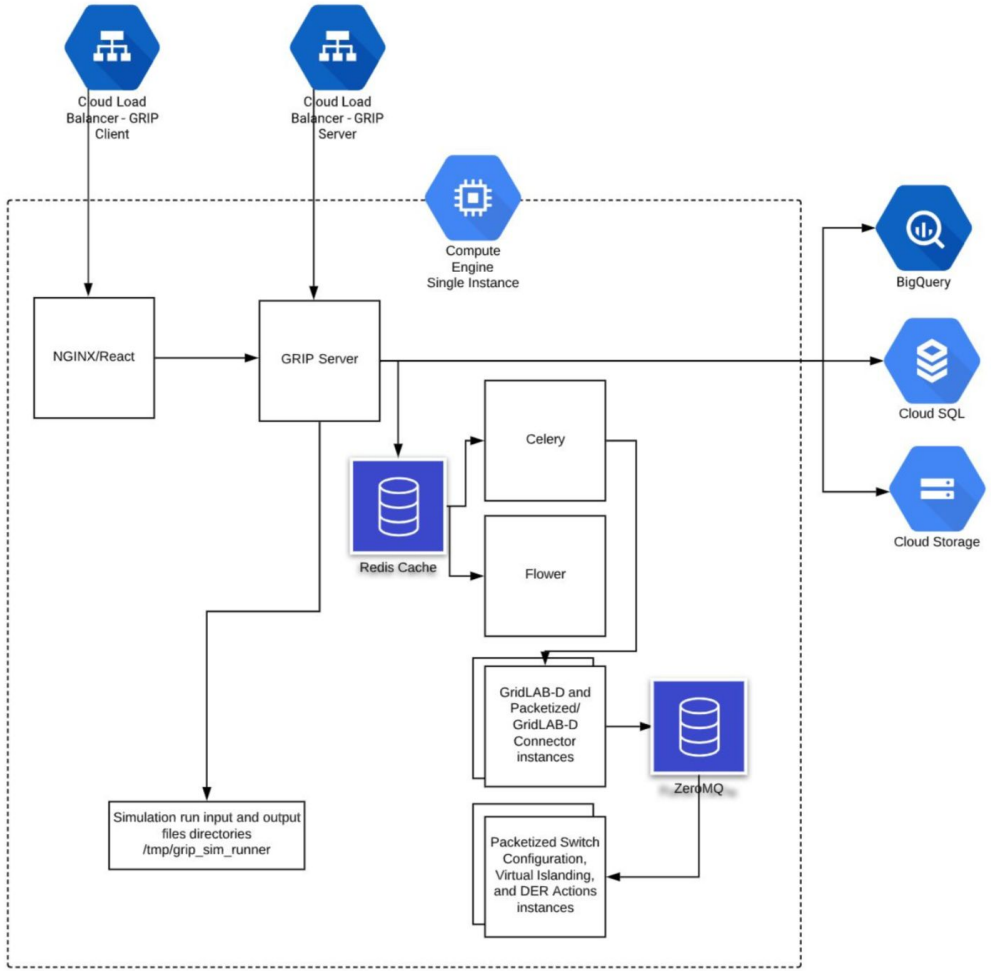
GRIP Platform Implementation

Physical Architecture

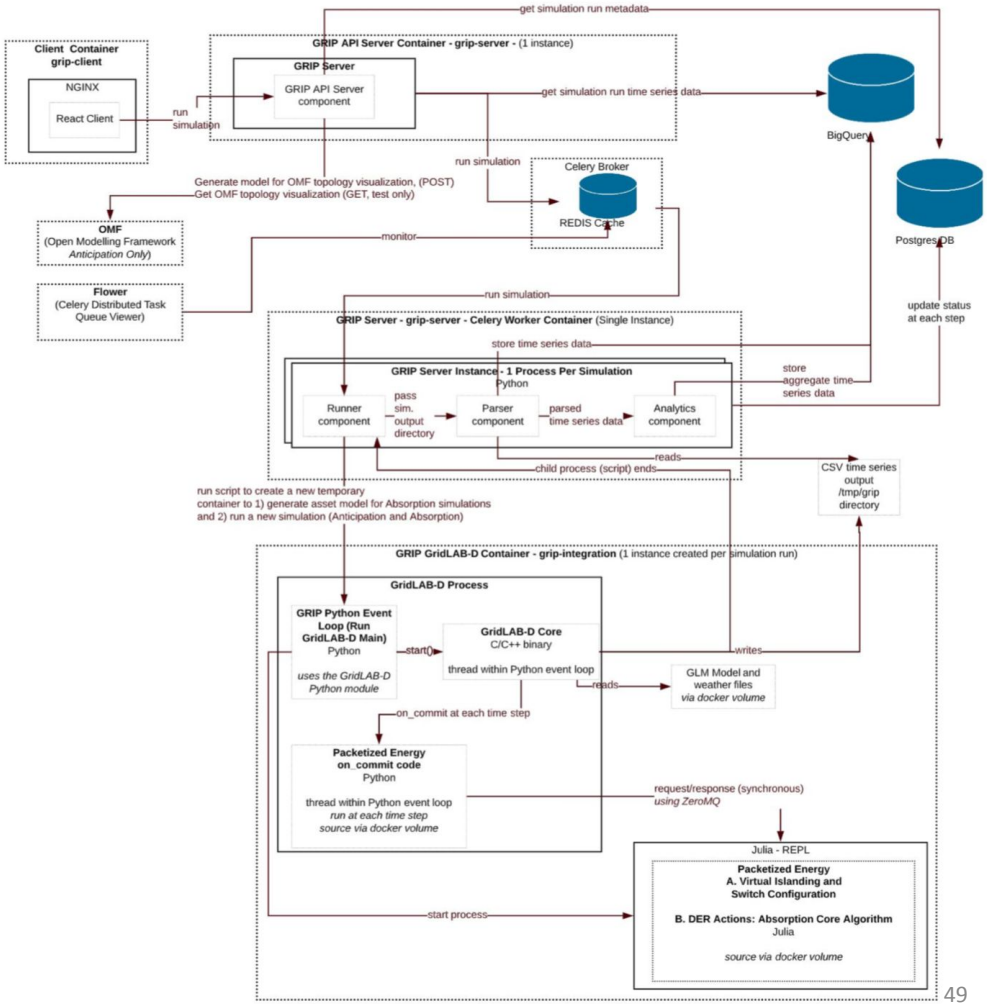
Component Architecture

GRIP Database Model

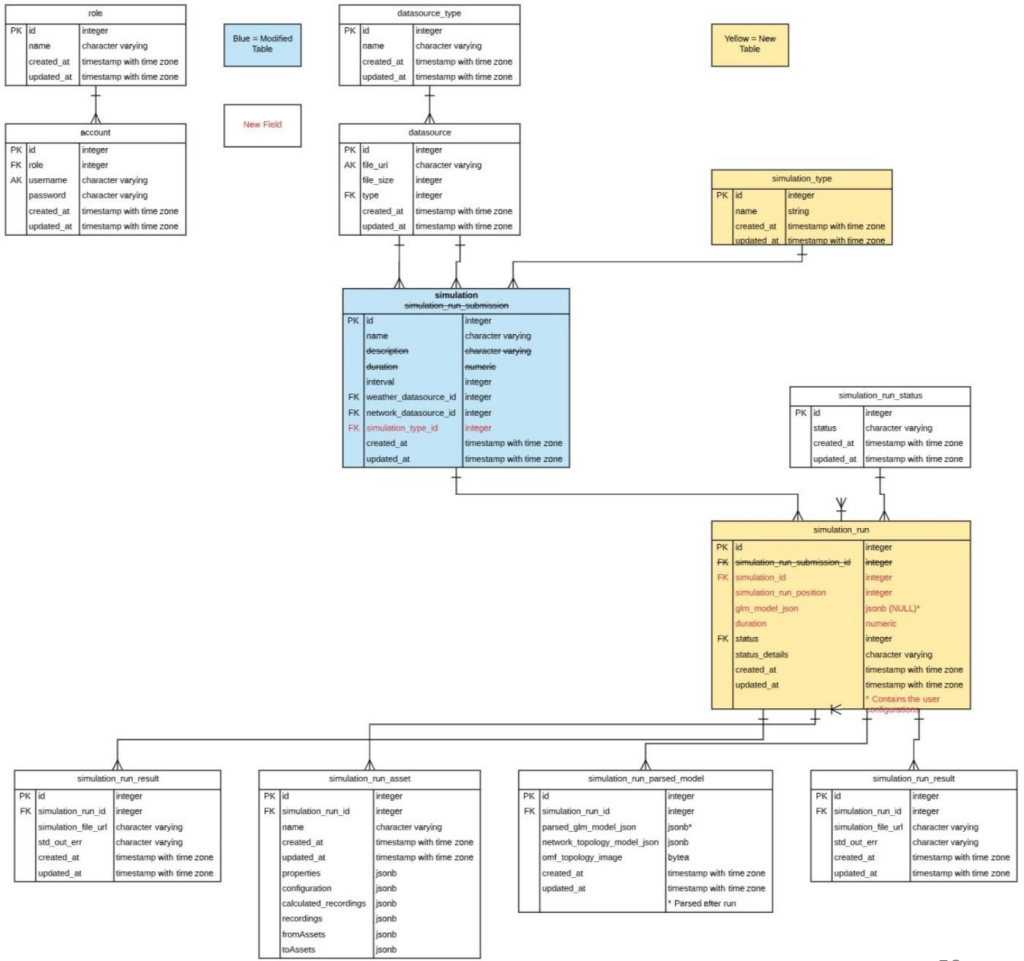
GRIP Physical Architecture



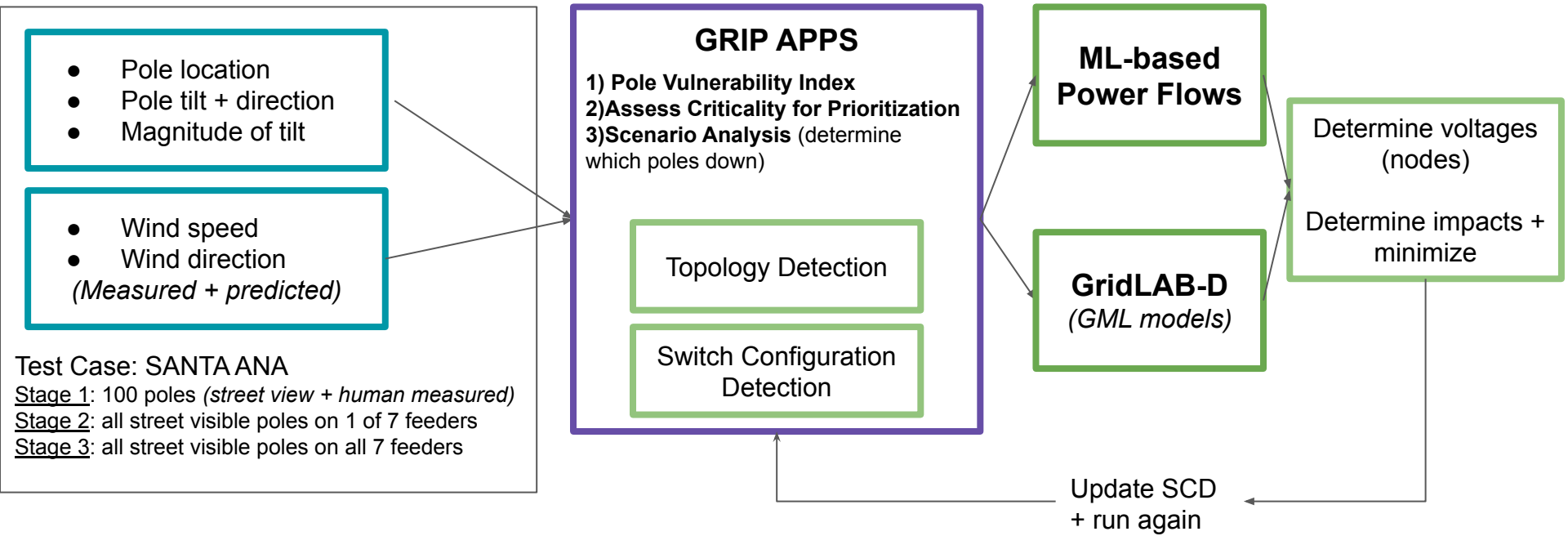
GRIP Component Architecture



GRIP Database Model

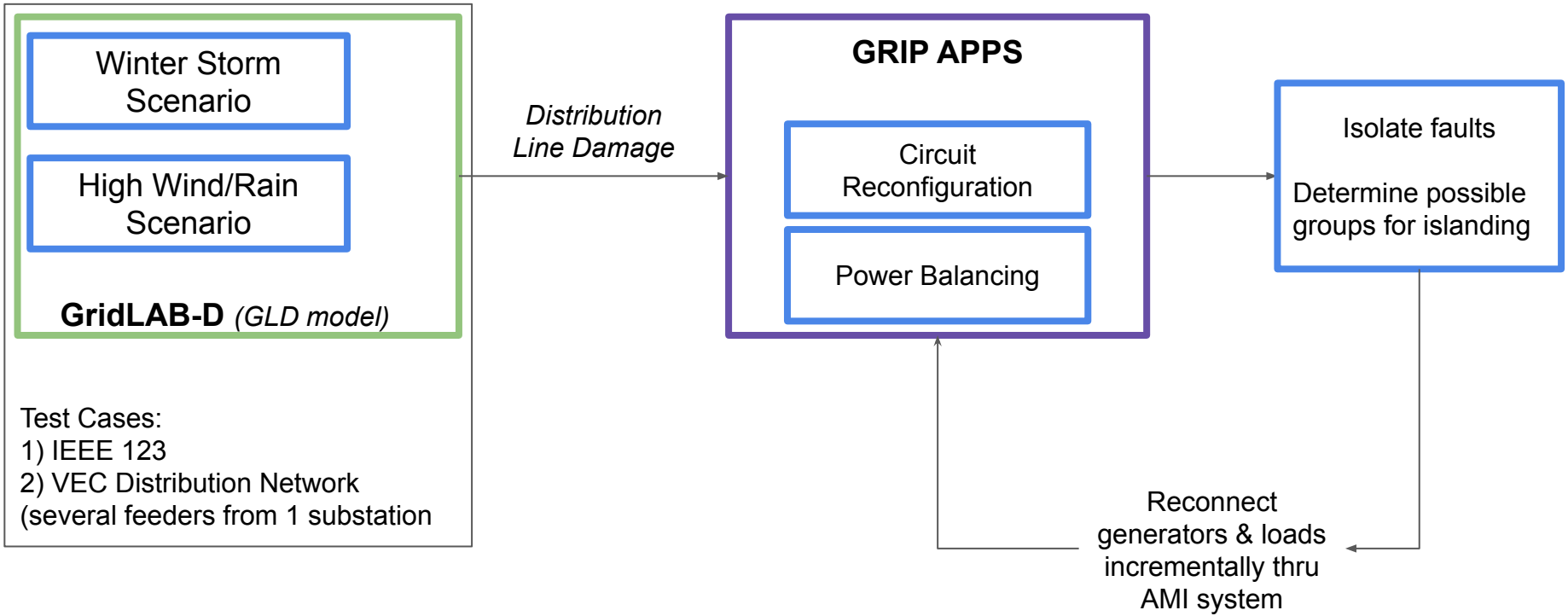


Quick recap



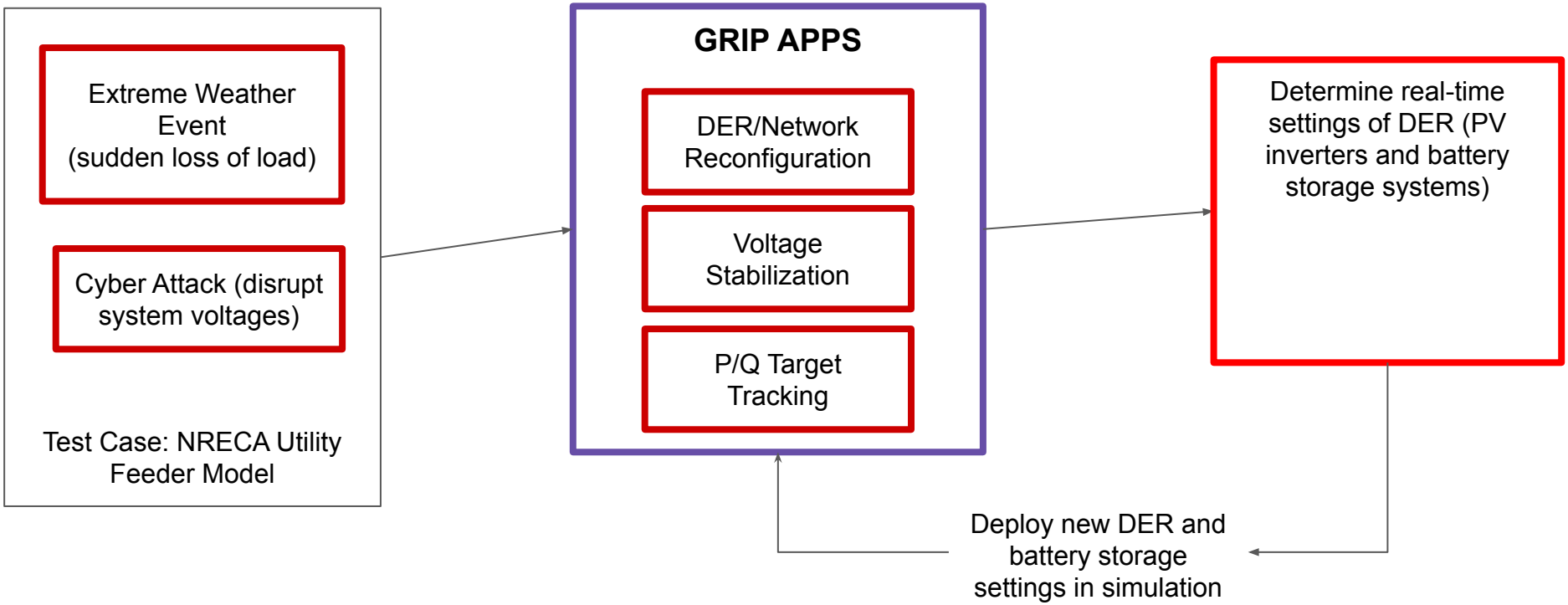
Anticipation: Analytics

Absorption: Virtual Islanding



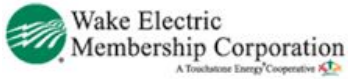
What’s Next?

Recovery: Extremum Seeking



Acknowledgements

GRIP Technical Advisory Group Members



Q&A

Contacts:

Mayank Malik, mmalik@slac.stanford.edu
Alyona Ivanova, aivanova@slac.stanford.edu
Paul Hines, paul@packetizedenergy.com