

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)

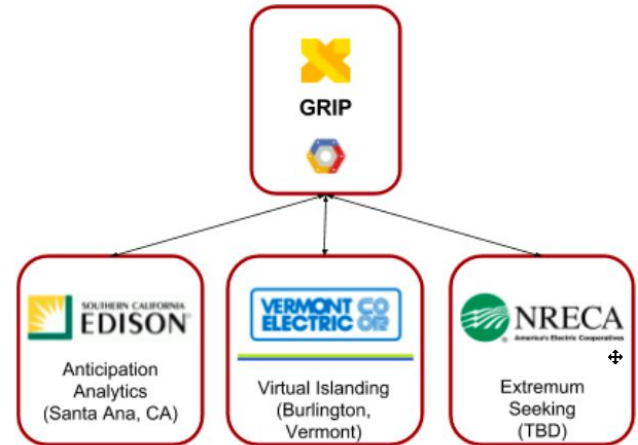
9:55-10am: Q&A + Discussion/Feedback

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

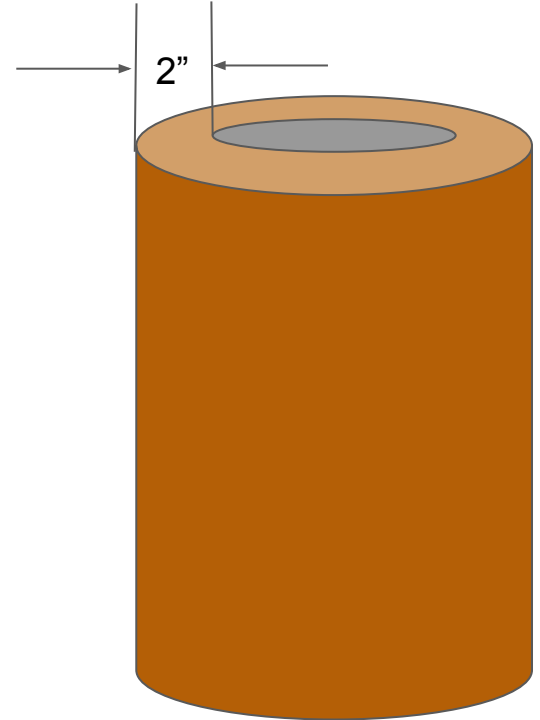
- Industry standard architecture
- Unit and functional testing infrastructure
- Agile development process
- Managed code on github

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

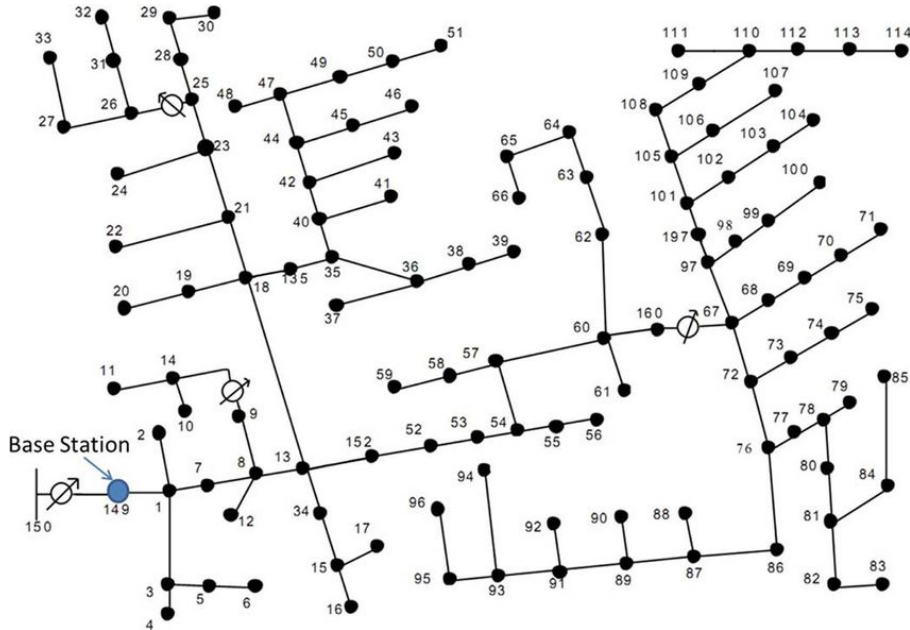


Image obtained from DOI: 10.1109/TSG.2013.2288868

IEEE 8500

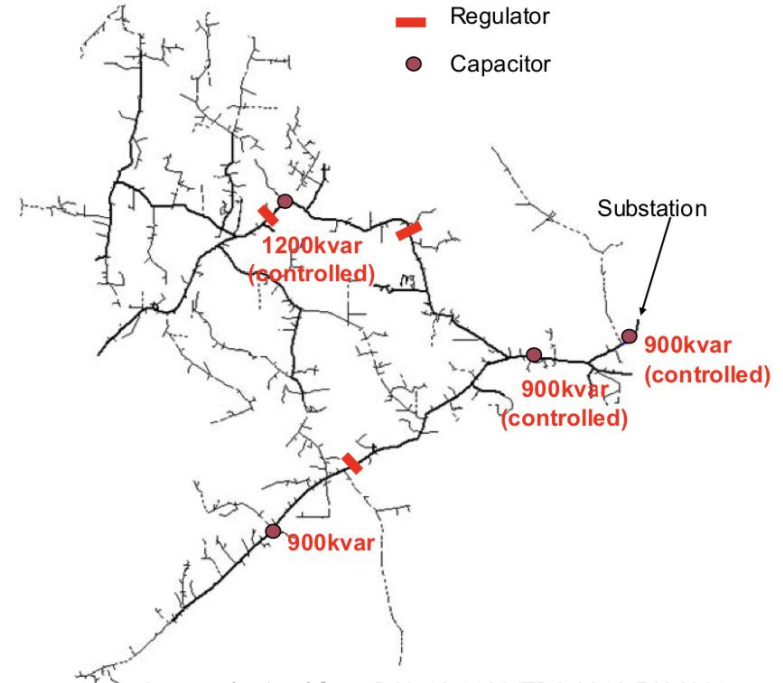
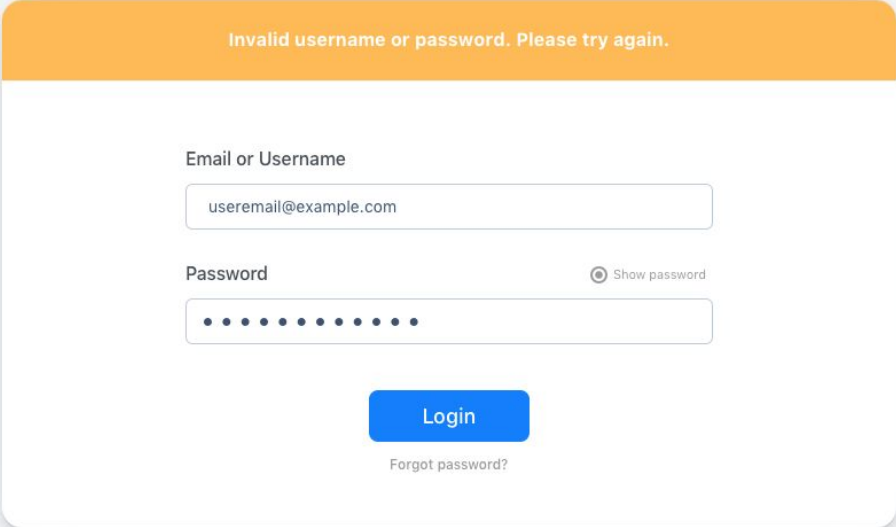


Image obtained from DOI: 10.1109/TDC.2010.5484381

GRIP Further Design



The image shows a login form for a service called GRIP. At the top center is the GRIP logo, which consists of a blue circle containing a white lightning bolt icon, followed by the text "GRIP" in a blue, sans-serif font. Below the logo is a white rounded rectangle representing the login form. At the top of this form is an orange horizontal bar with the text "Invalid username or password. Please try again." in white. Below the bar are two input fields. The first is labeled "Email or Username" and contains the text "useremail@example.com". The second is labeled "Password" and contains ten black dots. To the right of the password field is a "Show password" toggle, which is currently turned off (indicated by a small circle to the left of the text). Below the password field is a blue "Login" button. At the bottom of the form is a link that says "Forgot password?".



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

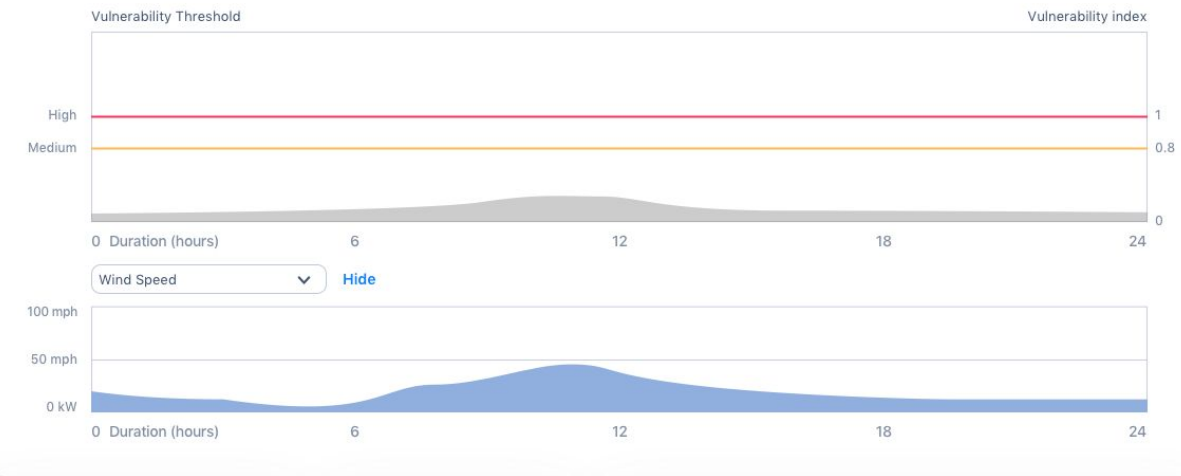
Simulation 5

Processing...



Graph

Network Source: Weather Source: Duration (hrs): Interval (secs):

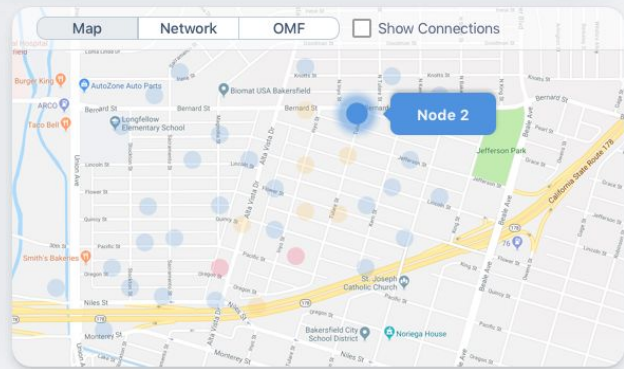


Asset Properties [All →](#)

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	-

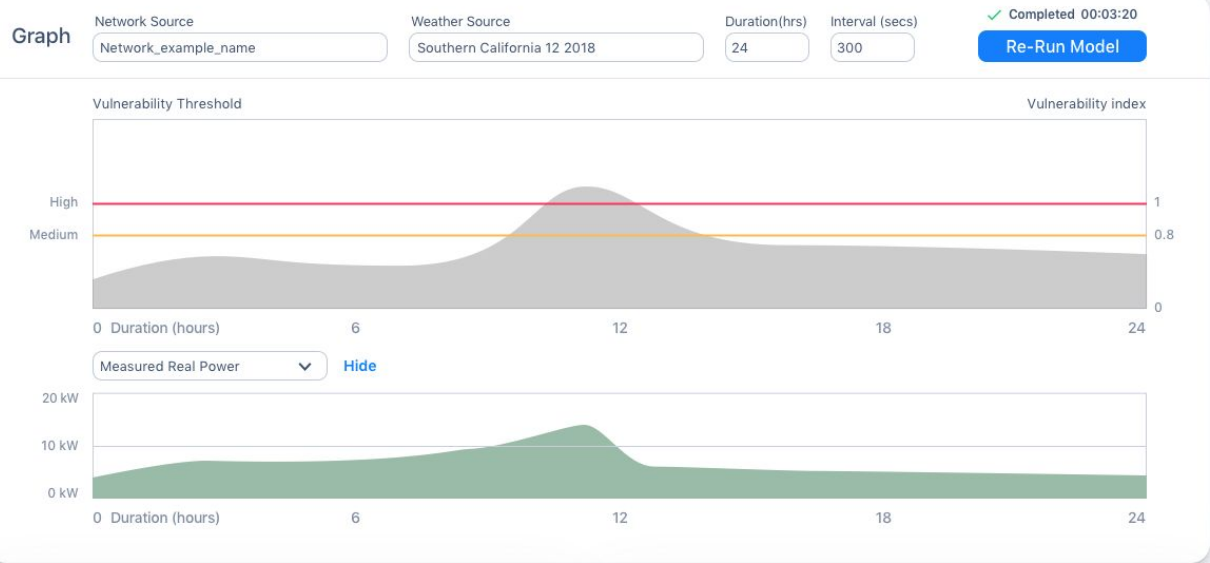


Anticipation

Absorption

Recovery

Data



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

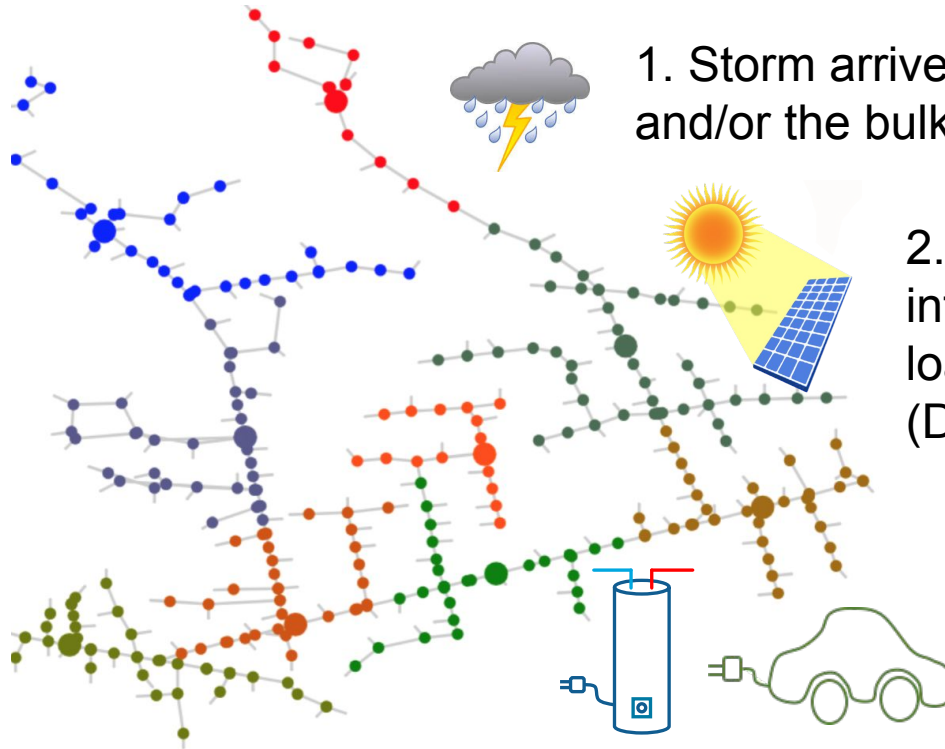
Co-founder and CEO
Packetized Energy



ABSORPTION / VIRTUAL ISLANDING



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:

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

$$\text{s.t.} \quad P_{g,n} - P_{d,n} - P_{b,n} = \sum_{m \in M_n} P_{ft,m}, \forall n \in N \quad (6)$$

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

$$- \overline{P_{ft,m}} * u_m \leq P_{ft,m} \leq \overline{P_{ft,m}} * u_m \quad (8)$$

$$- \overline{P_{ft,m}} * u_m \leq P_{ft,m} + \Delta P_{ft,m} \leq \overline{P_{ft,m}} * u_m \quad (9)$$

$$0 \leq P_{g,i} \leq \overline{P_{g,i}}, \forall i \in G \quad (10)$$

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

$$0 \leq P_{d,i} \leq P_{d,i}[0], \forall i \in D \quad (12)$$

$$0 \leq \Delta P_{d,i}, \forall i \in D \quad (13)$$

$$- \overline{P_{b,i}} \leq P_{b,i} \leq \overline{P_{b,i}}, \forall n \in N \quad (14)$$

$$- \overline{P_{b,i}} \leq P_{b,i} + \Delta P_{b,i} \leq \overline{P_{b,i}}, \forall n \in N \quad (15)$$




$$\sum_{m \in L_k} u_m \leq |L_k| - 1, \forall k \in \text{LOOPS} \quad (16)$$

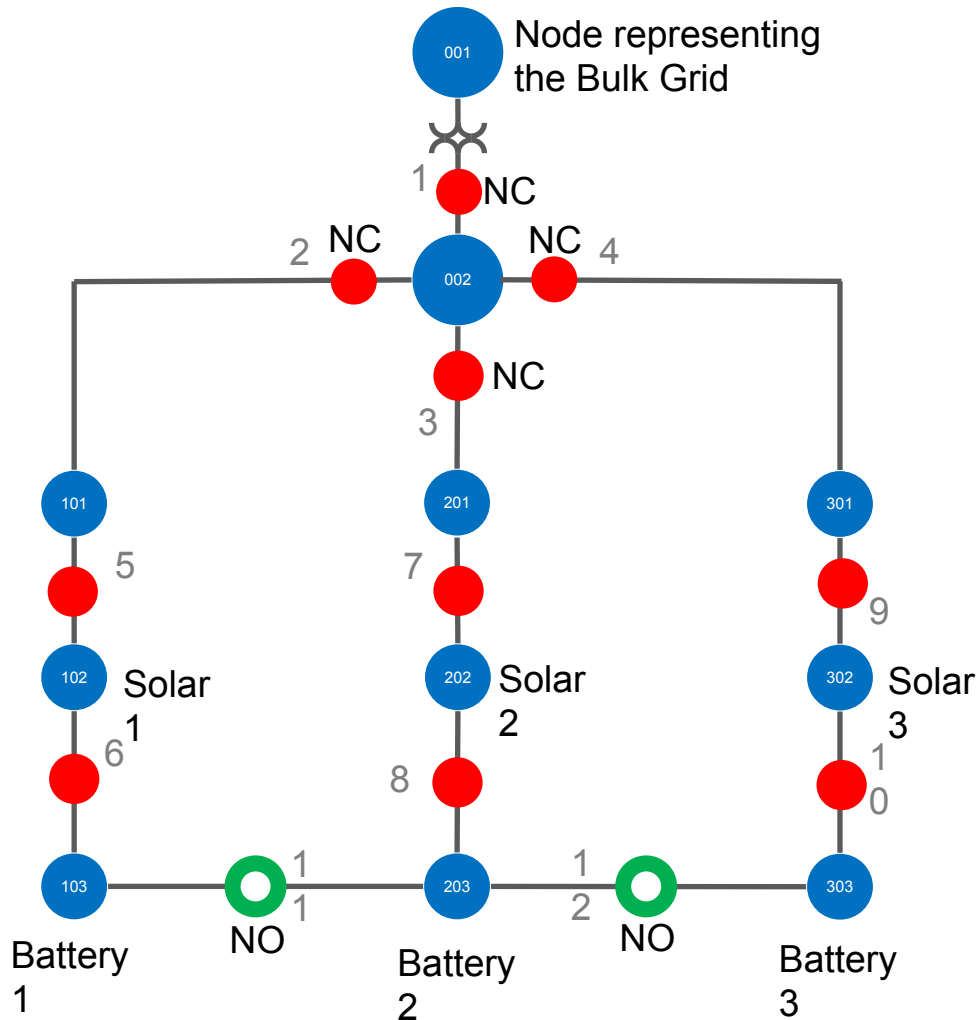
$$R \leq \Delta P_{d,n} - M u_d, \forall n \in N \quad (17)$$

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

VIRTUAL ISLANDING TEST CASE

Legend


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





CASE 1: SINGLE FEEDER FAULT

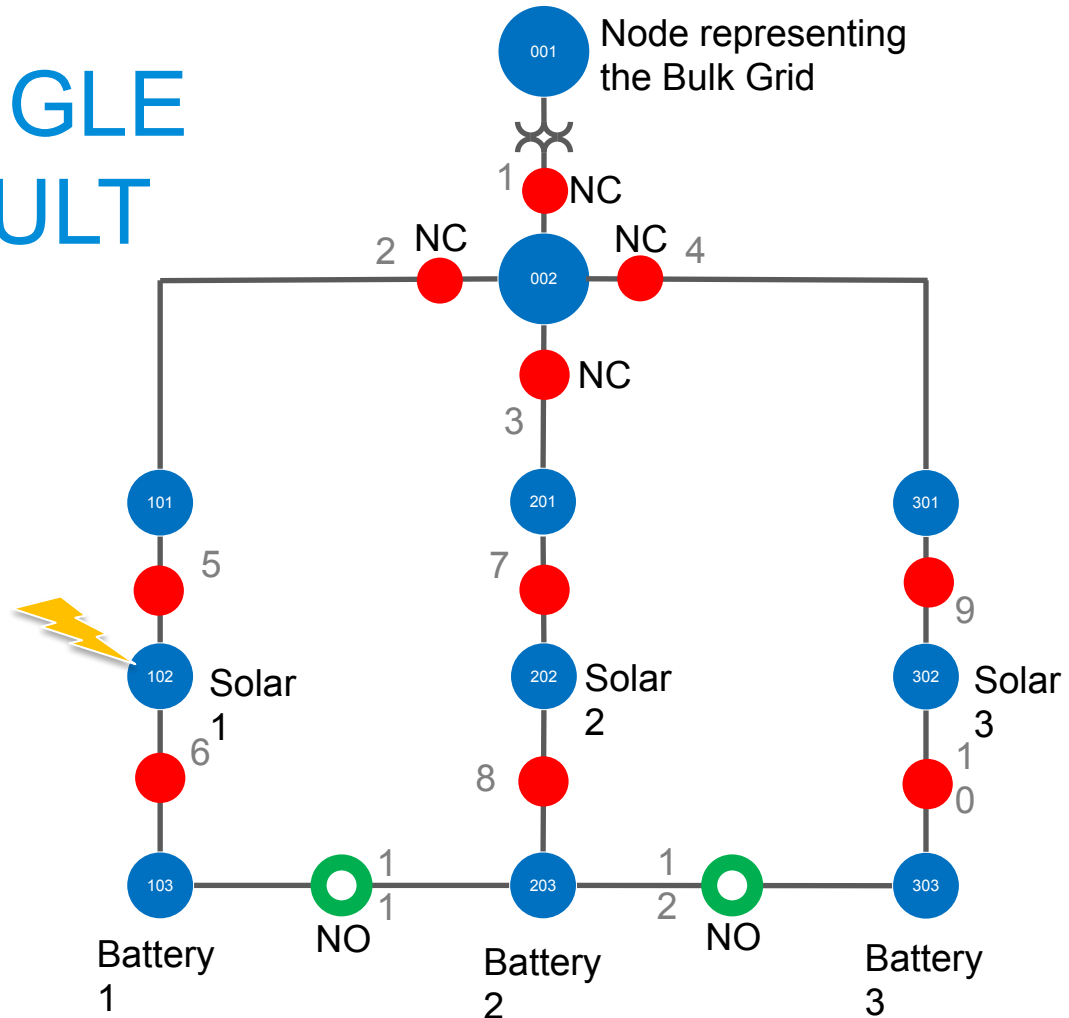
CASE 1: SINGLE FEEDER FAULT

Legend

 Switch or circuit breaker/recloser that is closed (hot)


 Switch or circuit breaker/recloser that is open (not hot)


 Distribution circuit node (or collection of nodes) with (eg) hundreds of customers. Fault location





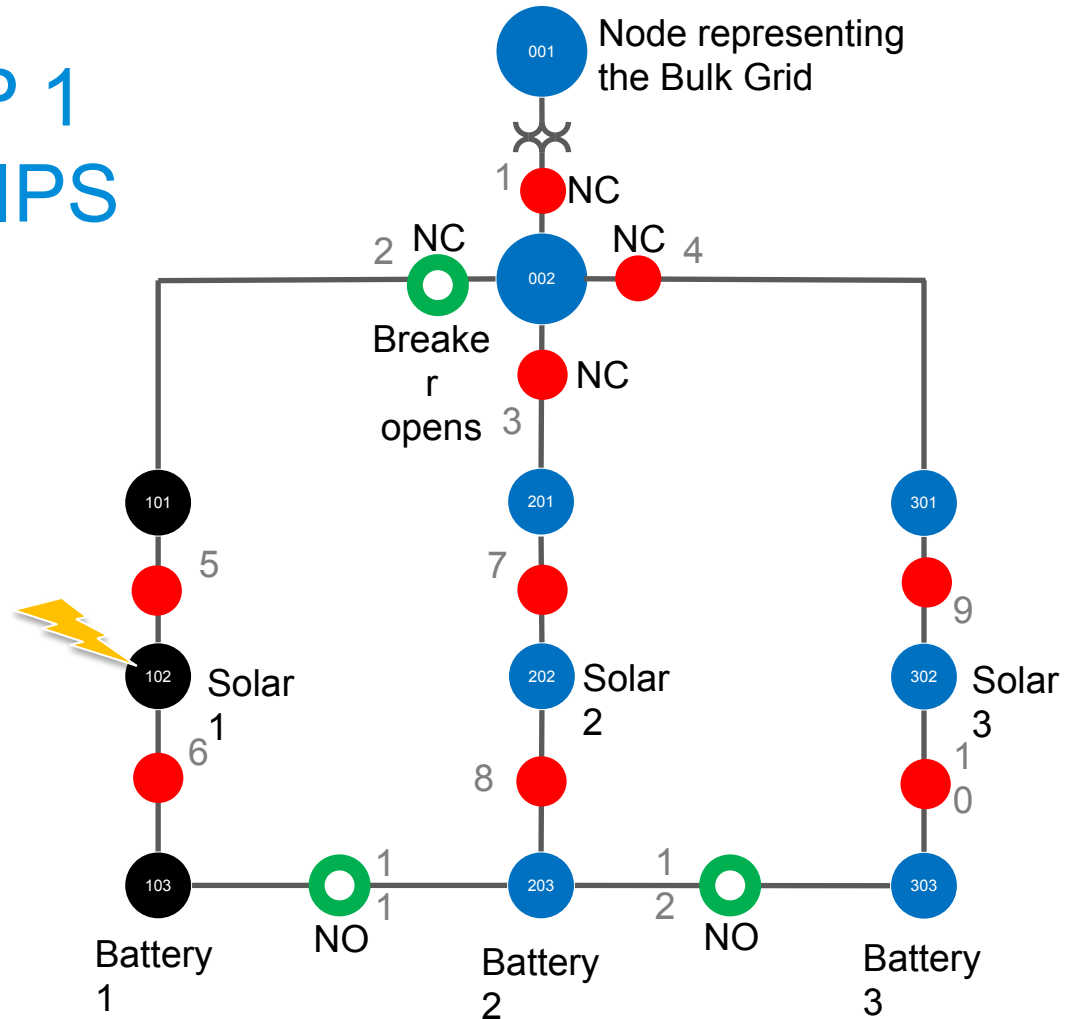
CASE 1: STEP 1 BREAKER TRIPS

Legend

 Switch or circuit breaker/recloser that is closed (hot)


 Switch or circuit breaker/recloser that is open (not hot)


 Distribution circuit node (or collection of nodes) with (eg) hundreds of customers.
 Fault location





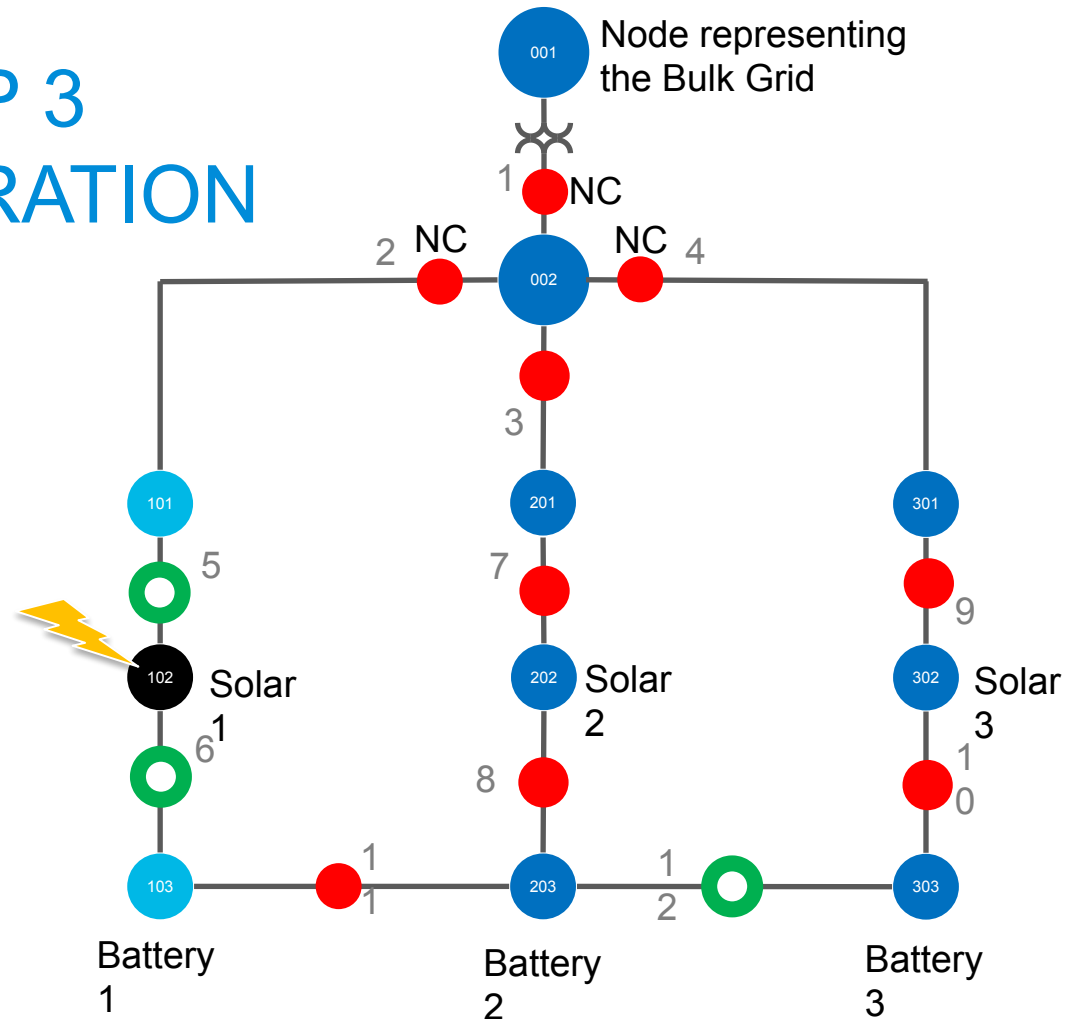
CASE 1: STEP 3 RECONFIGURATION

Legend

 Switch or circuit breaker/recloser that is closed (hot)

 Switch or circuit breaker/recloser that is open (not hot)





 Distribution circuit node (or collection of nodes) with (eg) hundreds of customers.
 Fault location

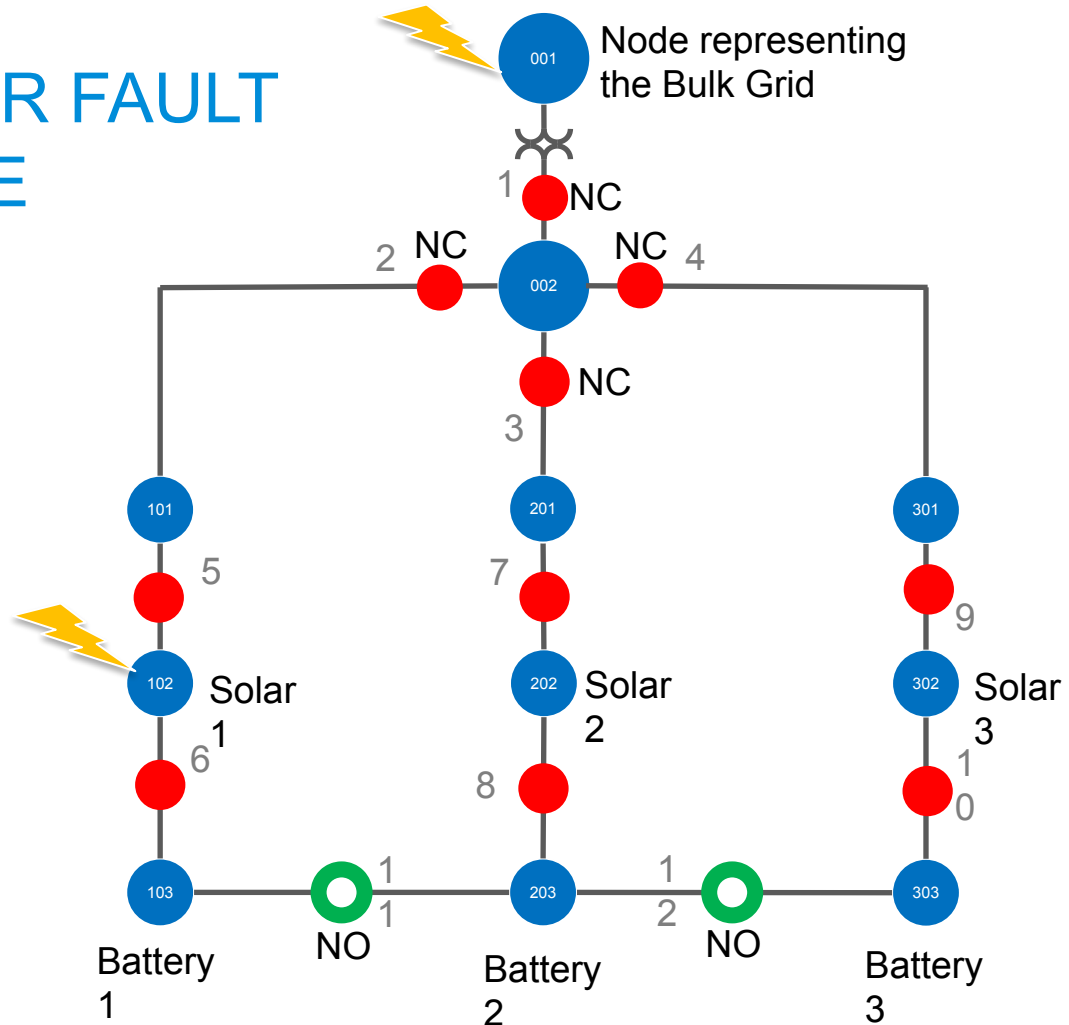


CASE 1: FEEDER FAULT + BULK GRID FAILURE

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)
-  Distribution circuit node (or collection of nodes) with (eg) hundreds of customers. Fault location
-  Fault location




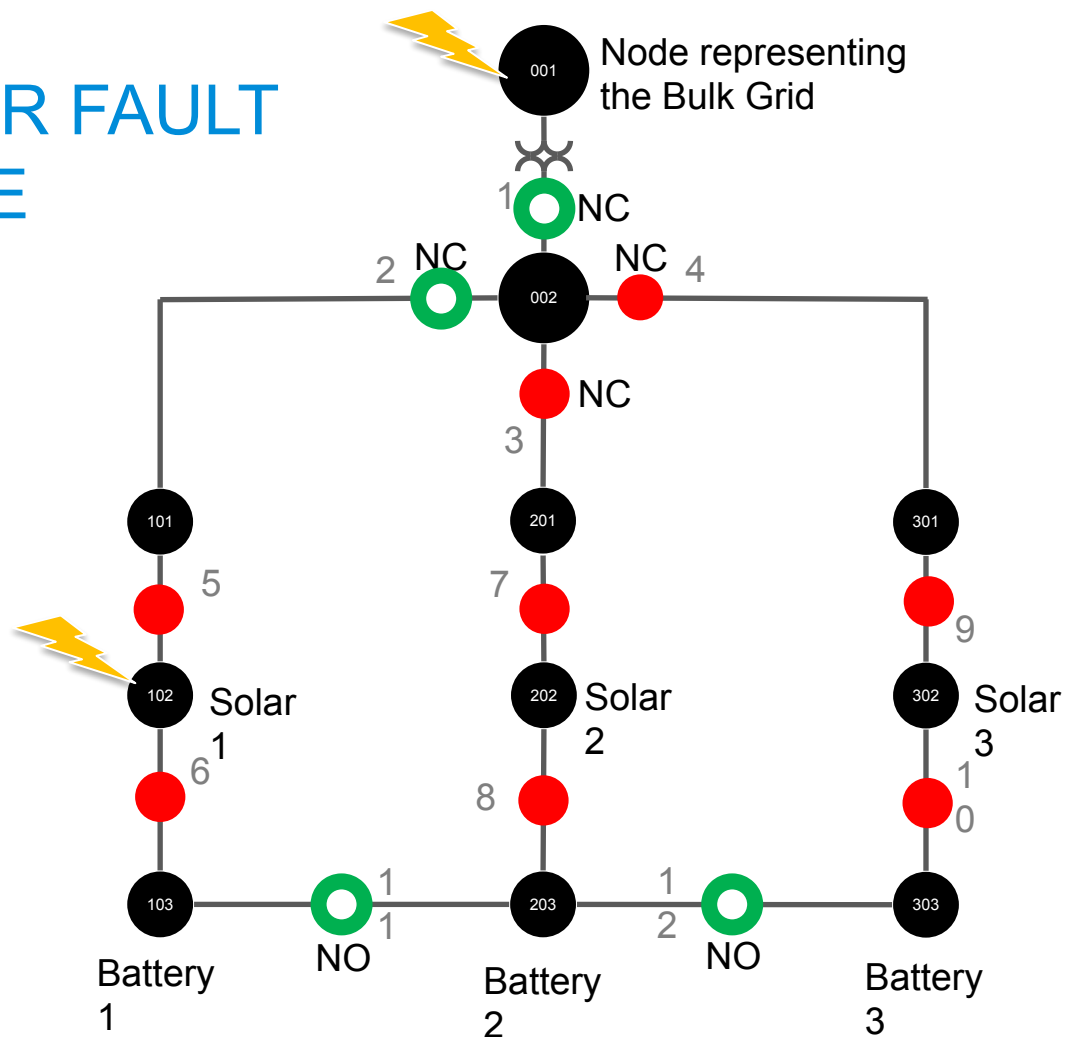
CASE 2: FEEDER FAULT & GRID OUTAGE

Legend

 Switch or circuit breaker/recloser that is closed (hot)





 Switch or circuit breaker/recloser that is open (not hot)

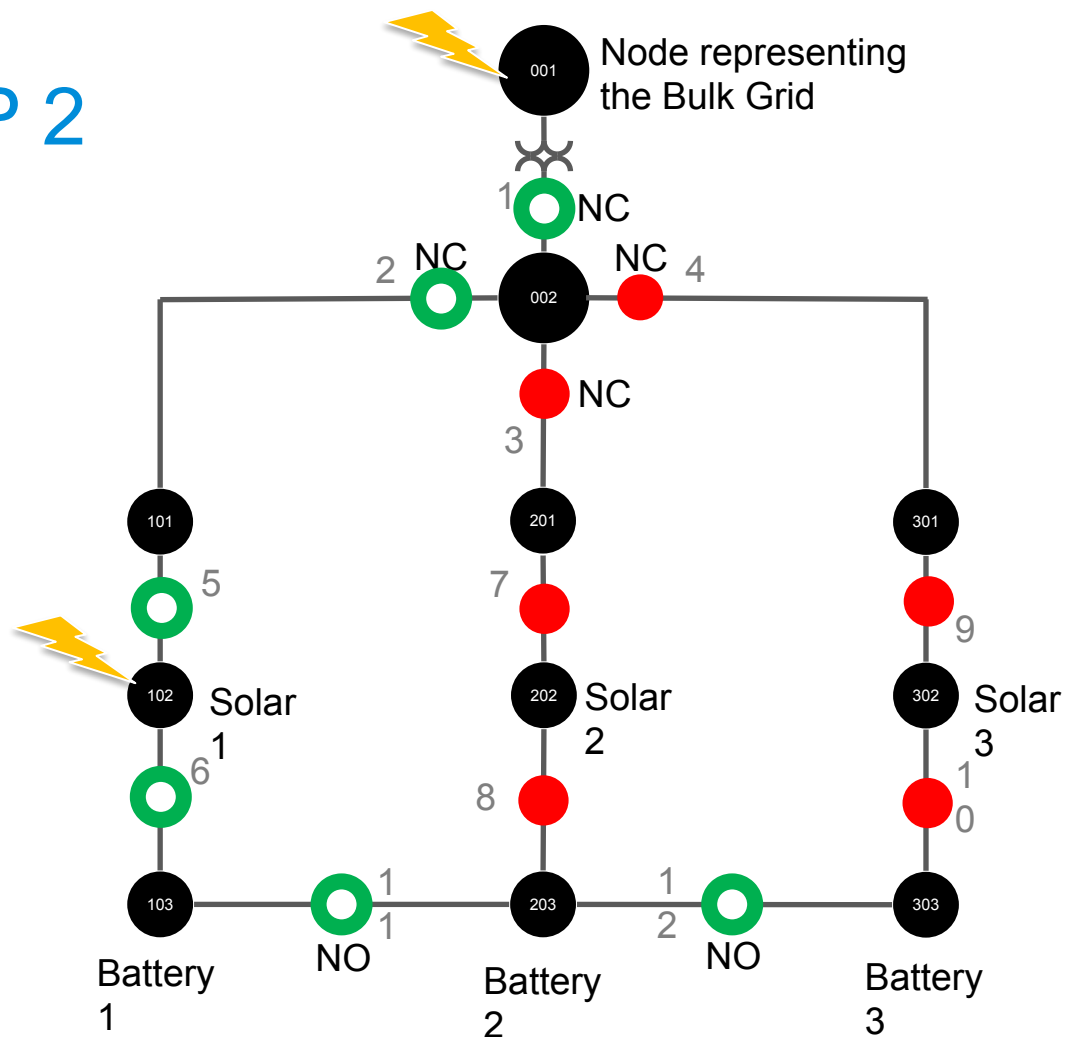
 Distribution circuit node (or collection of nodes) with (eg) hundreds of customers. Fault location



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)
-  Distribution circuit node (or collection of nodes) with (eg) hundreds of customers. Fault location
-  Fault location





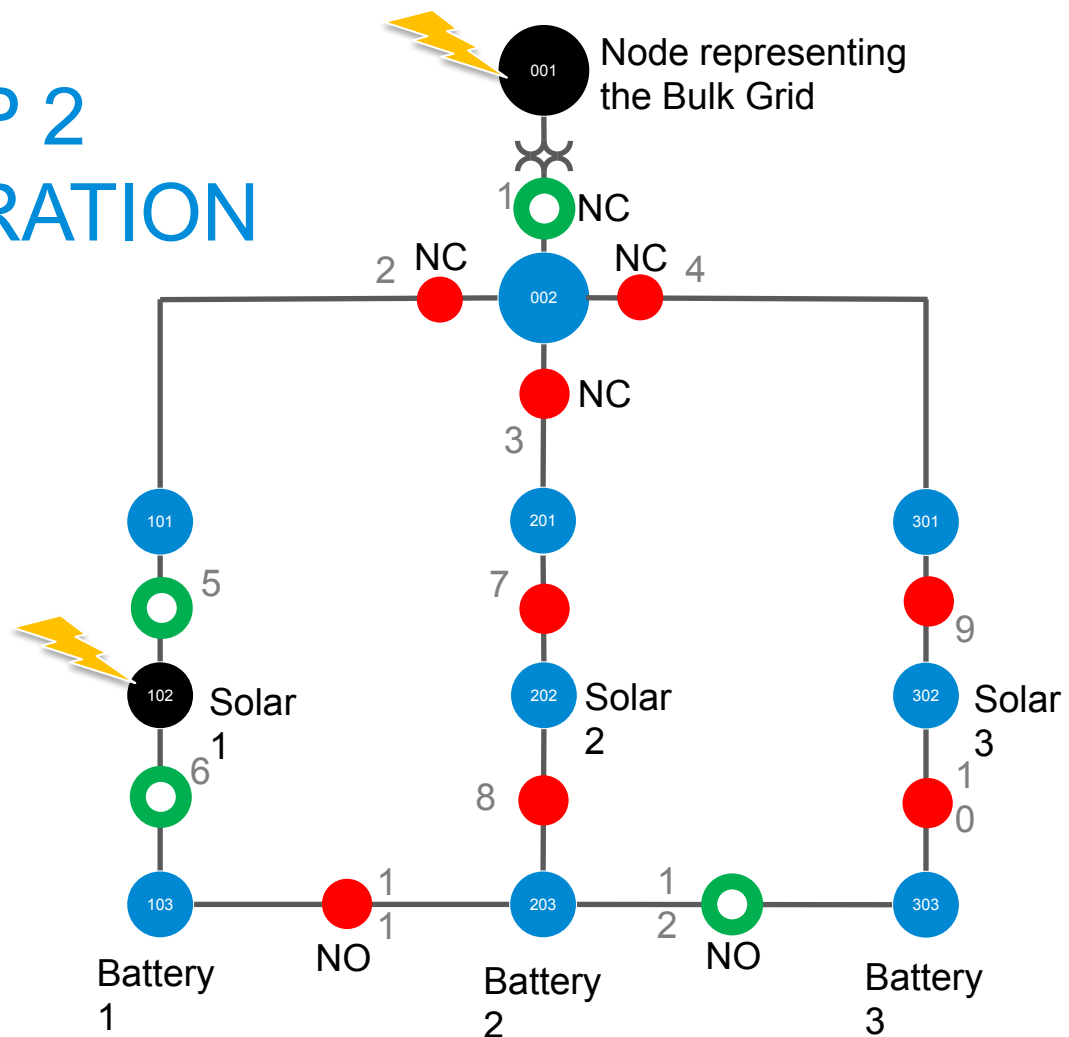
CASE 2: STEP 2 RECONFIGURATION

Legend

 Switch or circuit breaker/recloser that is closed (hot)

 Switch or circuit breaker/recloser that is open (not hot)

 Distribution circuit node (or collection of nodes) with (eg) hundreds of customers.
 Fault location



POWER BALANCING AFTER RECONFIGURATION

AFTER RECONFIGURATION

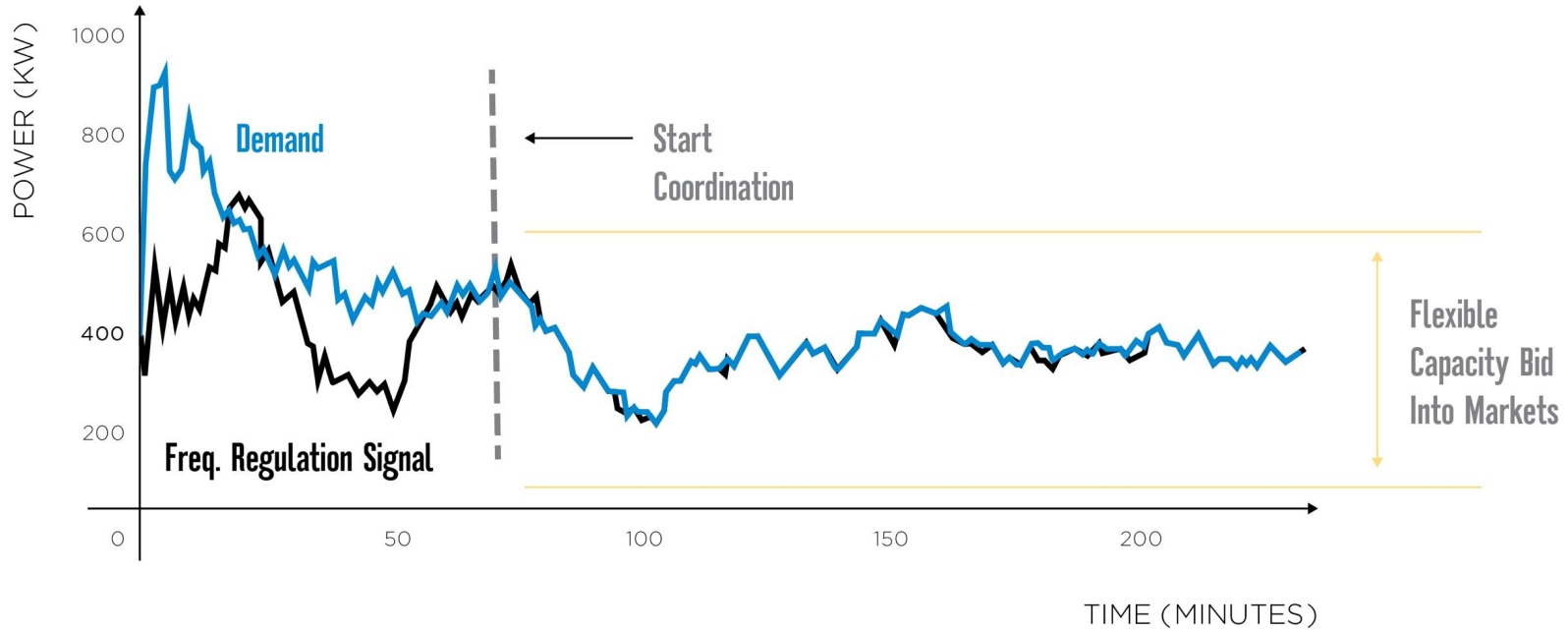
Each node uses local communications and/or local frequency measurements to locally balance supply and demand

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



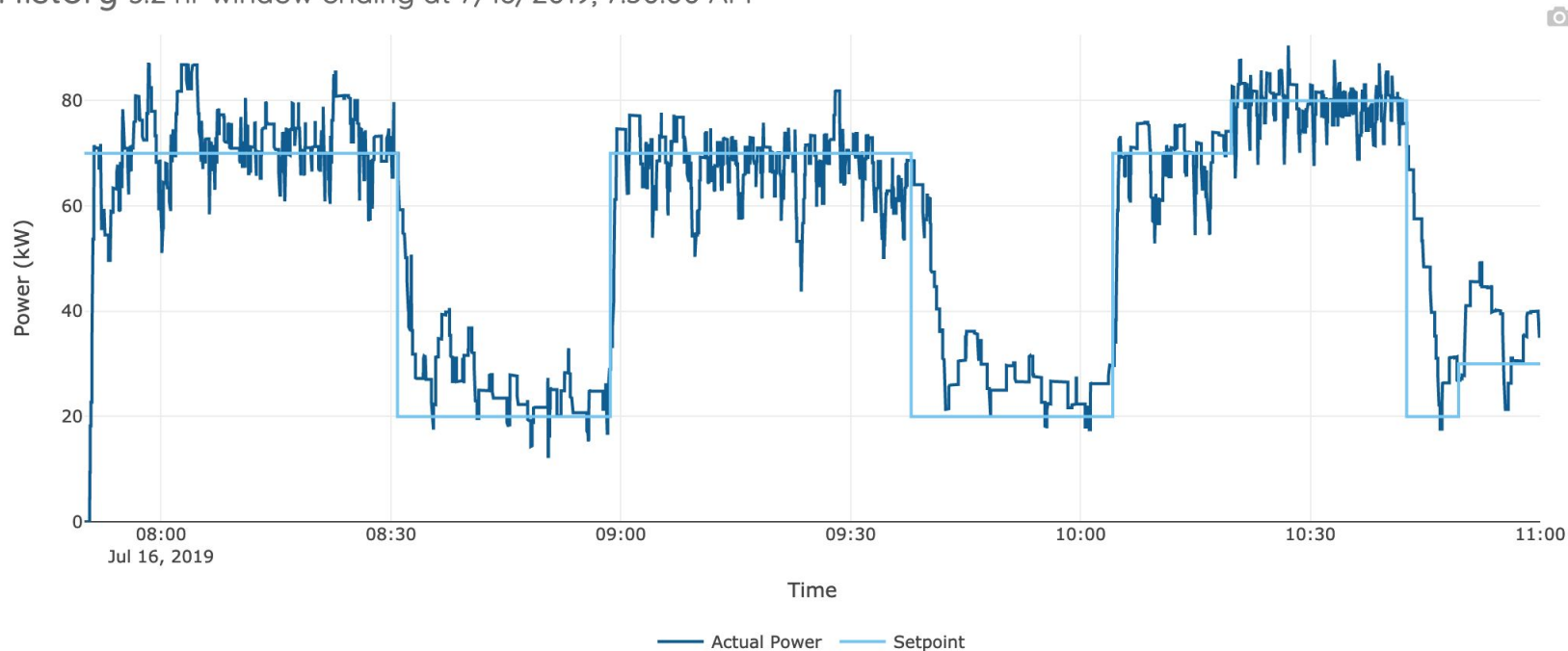
POWER BALANCING EXAMPLE



300 SIMULATED WATER HEATERS

REAL-WORLD ABSORPTION RESULTS FROM ~150 DEVICES

VPP History 3.2 hr window ending at 7/16/2019, 7:50:00 AM

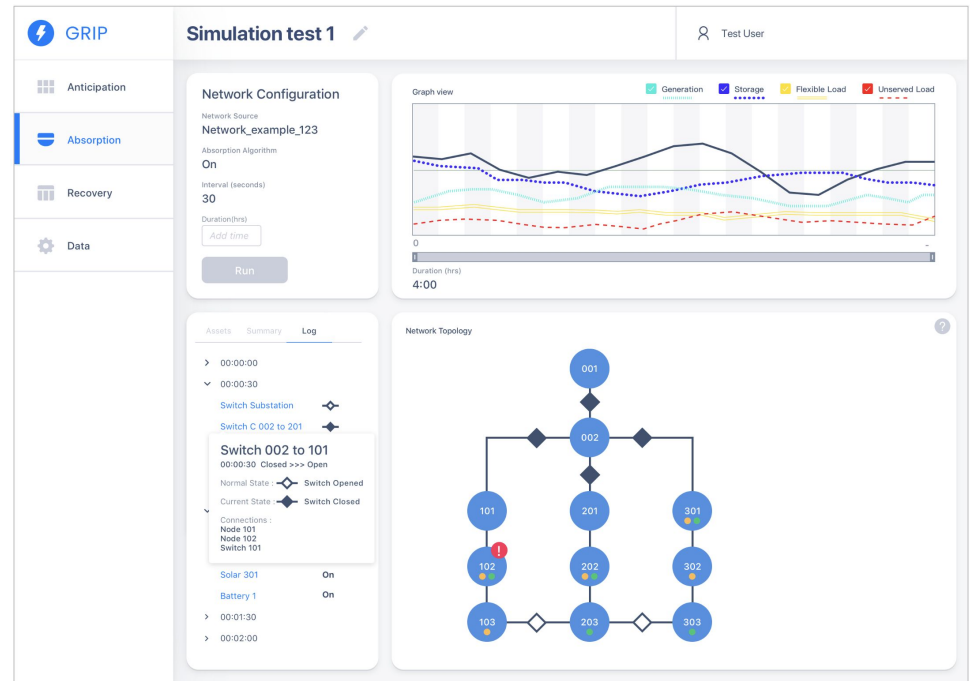


EXPECTED OUTCOMES

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

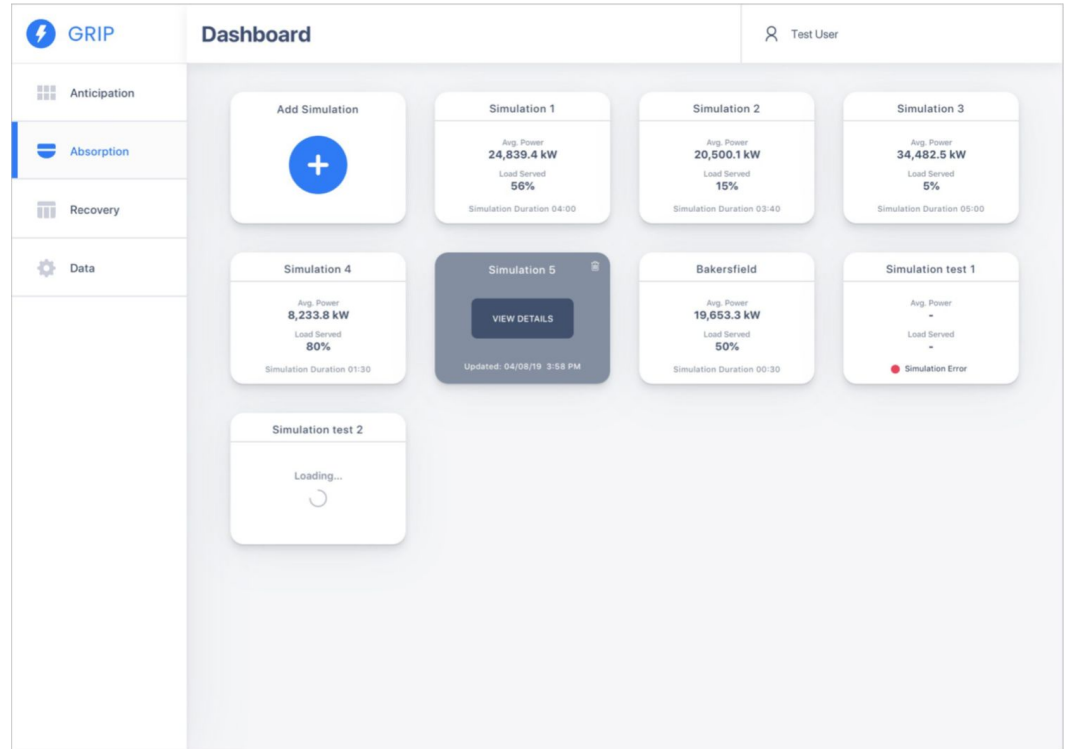


GRIP - Absorption Design

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

The screenshot displays the GRIP web interface. On the left is a navigation sidebar with icons for 'Anticipation', 'Absorption' (highlighted), 'Recovery', and 'Data'. The main content area is titled 'Simulation test 1' and shows a 'Simulation Setup' form. The form includes a 'Model' field with the value 'Network_example_123', a 'Duration(hrs)' field with '4:00', an 'Interval (secs)' field with '30', and a checked checkbox for 'Absorption Algorithm'. Below the form is a blue 'Load Simulation' button and a smaller 'Cancel' button. The top right of the interface shows the user 'Test User'.

GRIP - Absorption Design

Simulation Details

Key Features:

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

The screenshot displays the GRIP simulation interface. The top navigation bar includes the GRIP logo, the simulation name "Simulation test 1", and the user name "Test User". A left sidebar contains navigation options: "Anticipation", "Absorption" (selected), "Recovery", and "Data".

The main content area is divided into three panels:

- Network Configuration:** Shows "Network Source: Network_example_123", "Absorption Algorithm: On", "Interval (seconds): 30", and "Duration (hrs): 4:00". A "Run" button is visible.
- Graph view:** A bar chart showing simulation progress over time. The x-axis is labeled "Duration (hrs)" and ranges from 0 to 4:00. A legend indicates: Generation (green), Storage (blue), Flexible Load (yellow), and Unreserved Load (red).
- Network Topology:** A diagram showing a network structure. A pop-up window for "Switch C" (Grid section 1202B) is open, showing "Switch Control" with a "Switch" button. The topology consists of a central node "002" connected to three columns of nodes: 101, 102, 103; 201, 202, 203; and 301, 302, 303. Node 102 has a red exclamation mark icon.

GRIP - Absorption Design

Asset Editor

Key Features:

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

The screenshot displays the GRIP simulation interface for 'Simulation test 1'. The main window shows 'Network Configuration' for 'Network_example_123'. A modal window titled 'Asset Summary : Node 102' is open, providing detailed information about the asset's state and configuration.

Asset Summary : Node 102

- Normal State
- Total Fault : 0
- Customers Supported : 103
- Total Load : 4.8 kW
- Residential Units : 87
- Commercial Units : 16
- Load supported : 15%
- Number of DERs : 57
- Baseline : 5.5 kWh
- Storage : 1.5 kWh
- Flexible Load : 1.1 kWh
- Unreserved Load : 3.1 kWh
- Resource Type : 3.1 kWh

Asset Configuration

- Fault :
- Resource Configuration**
- Solar**
Connected :
Power Generation : 10.5 kW
Rated Power : 5.1 kW
Available Power : 25%
- Battery**
Connected :
Discharge Power : 1.00
Power Capacity (kWh) : |
Energy Capacity (kWh) : Set
State of Charge : 50%

Summary

- Flexible Load : 2.0 kW
- Solar : 1.2 kW
- Battery : 0.8 kW

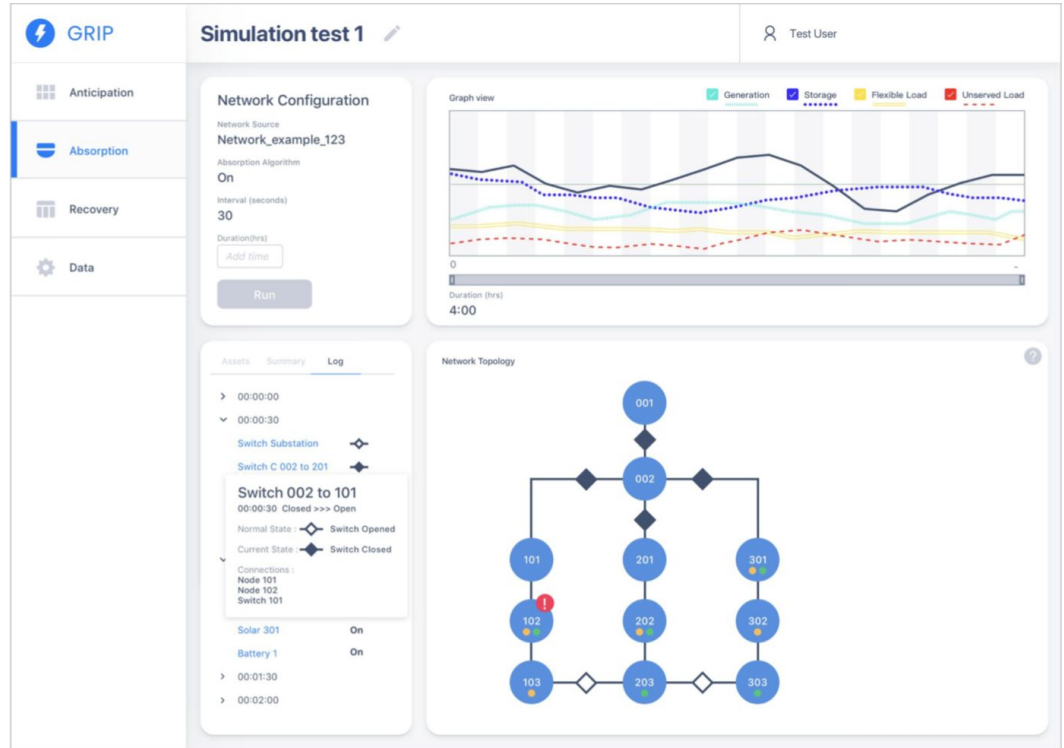
The modal window includes 'Confirm' and 'Cancel' buttons. The background interface shows a network diagram with nodes 101 through 104 and a 'Run' button.

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)

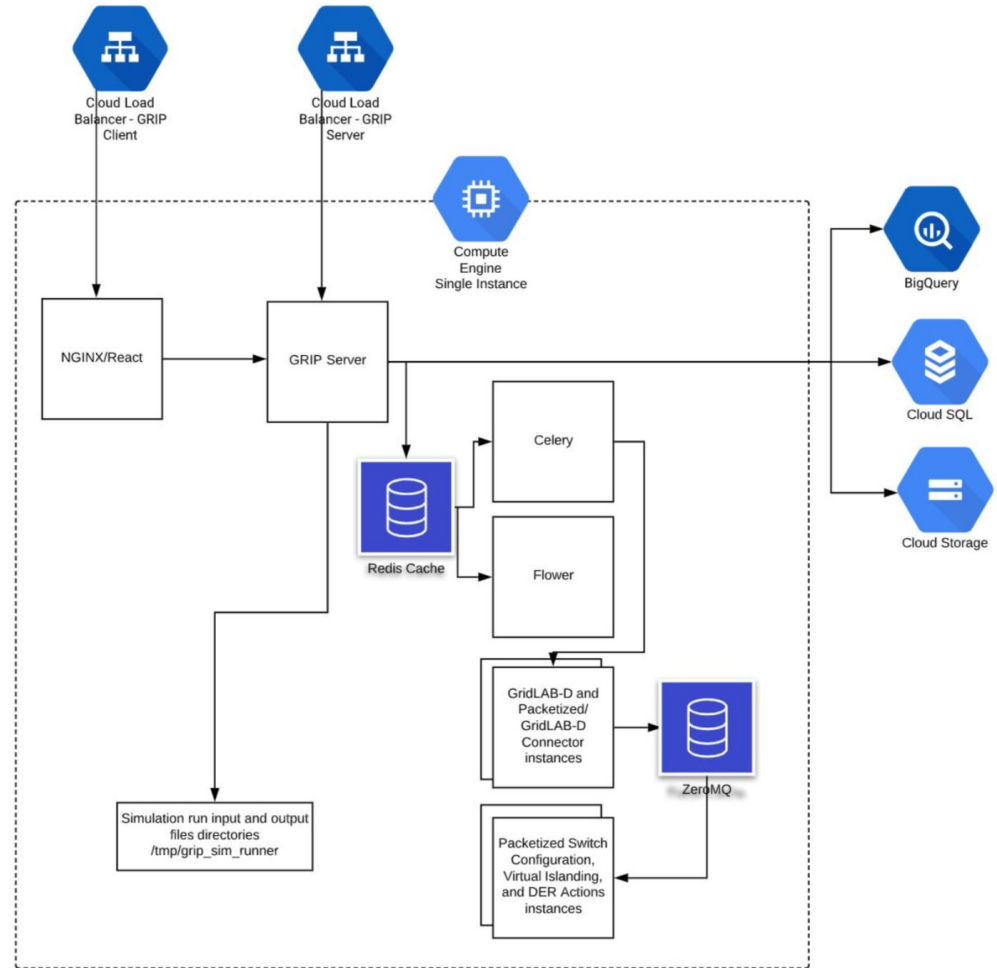
GRIP Platform Implementation

Physical Architecture

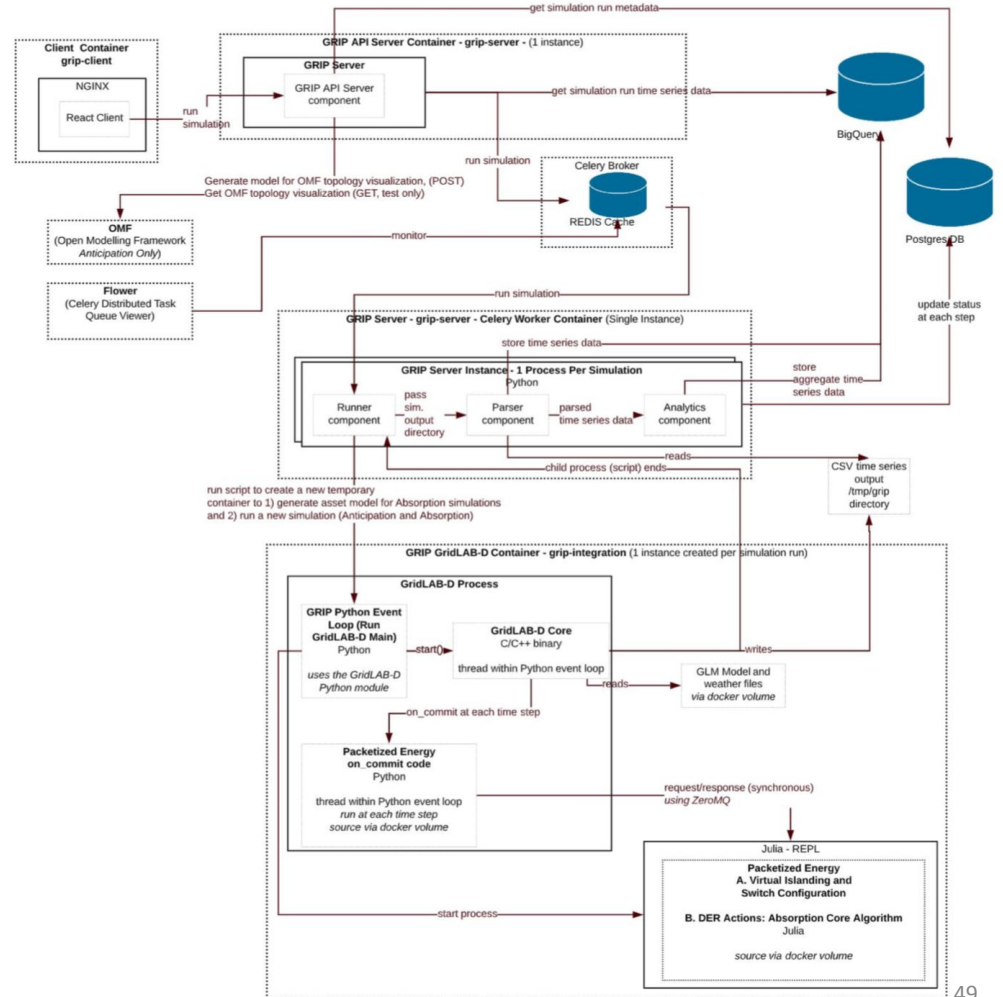
Component Architecture

GRIP Database Model

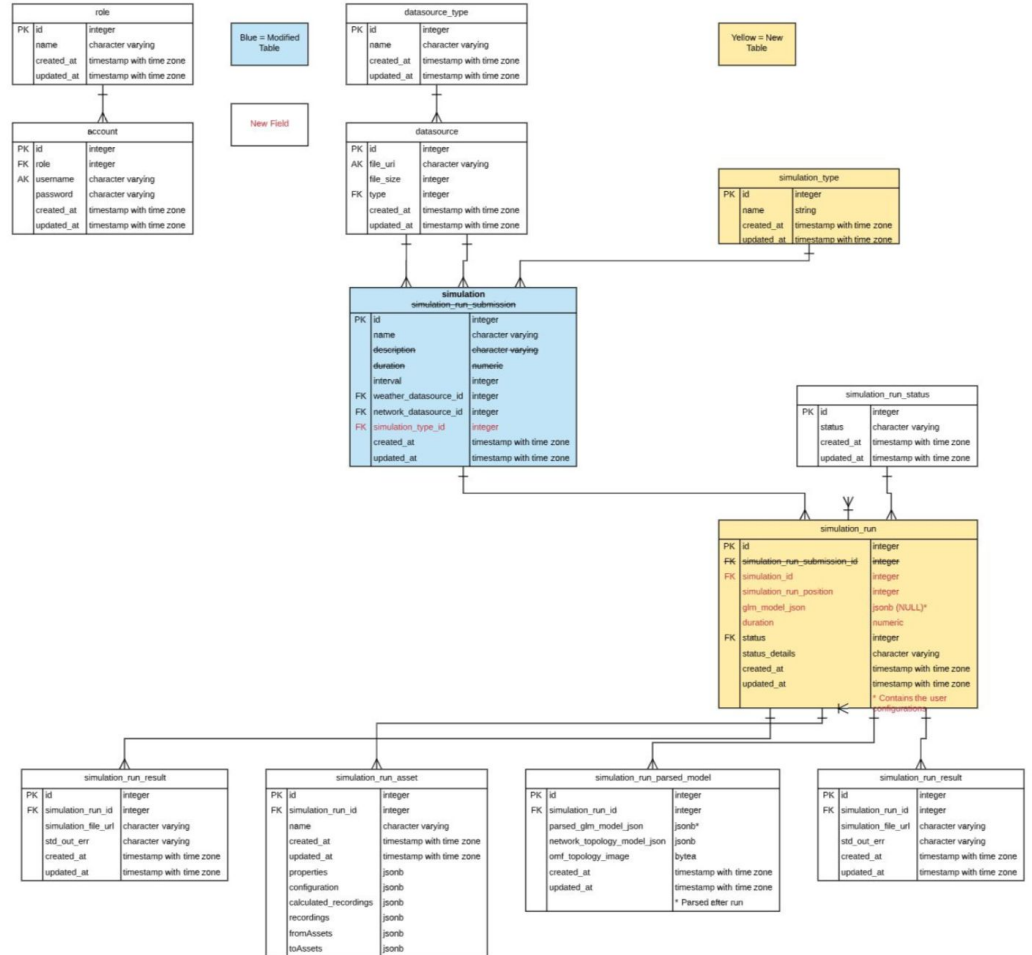
GRIP Physical Architecture



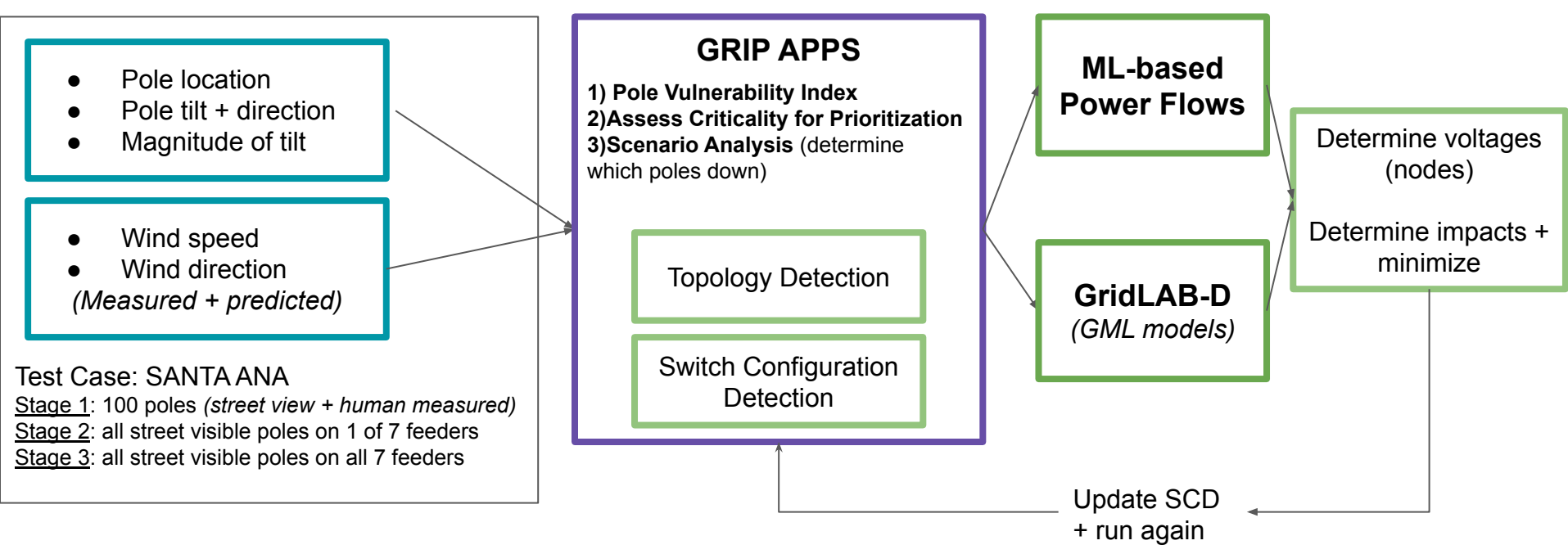
GRIP Component Architecture



GRIP Database Model

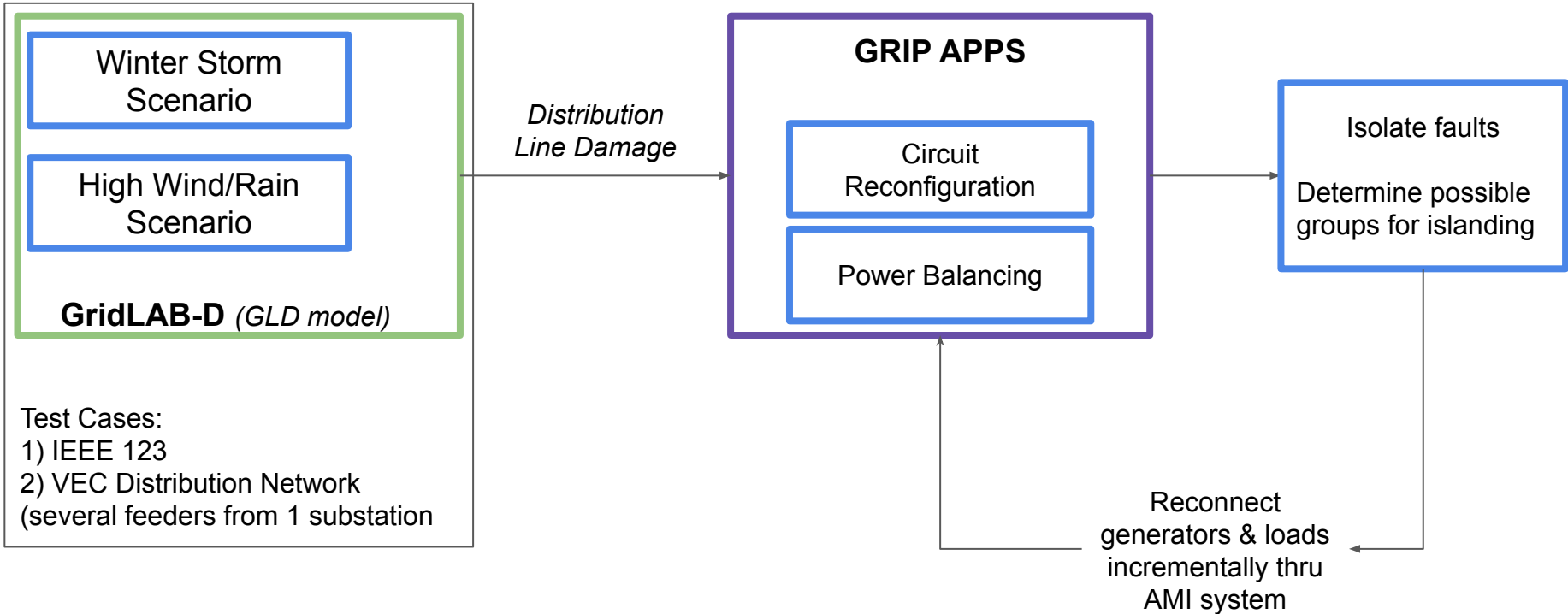


Quick recap



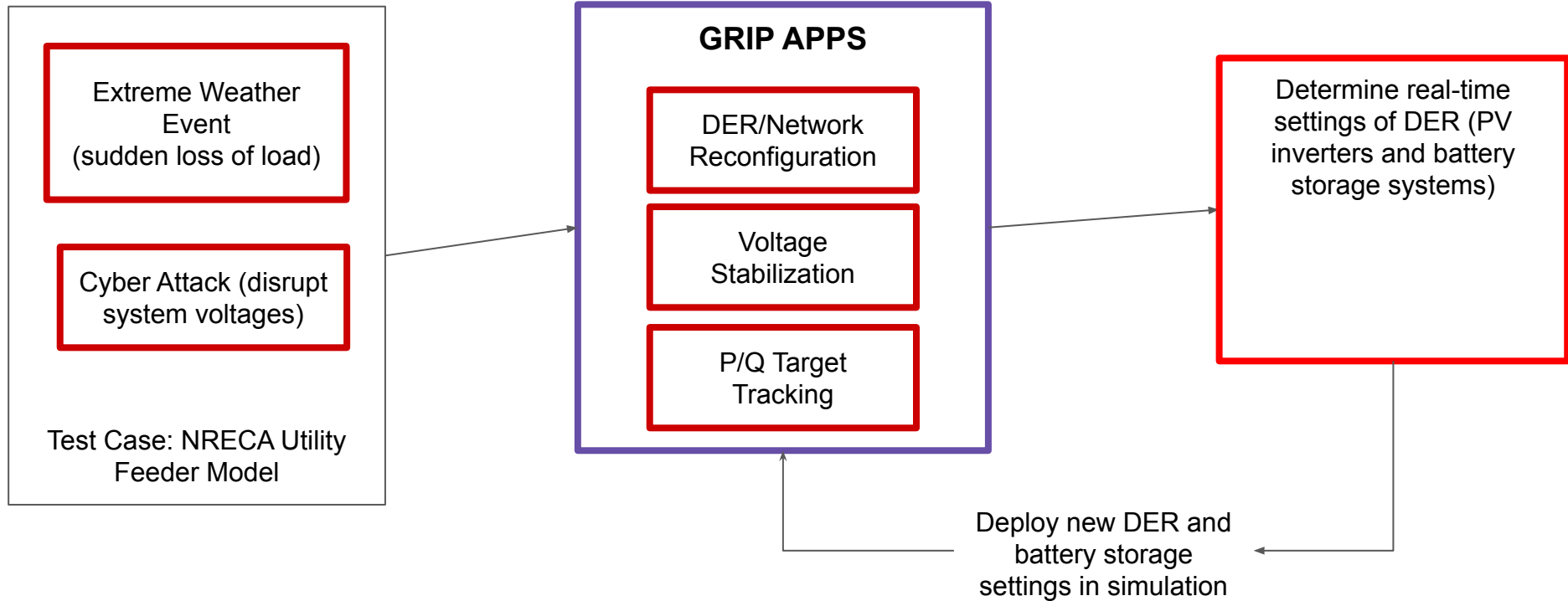
Anticipation: Analytics

Absorption: Virtual Islanding



What's Next?

Recovery: Extremum Seeking



Acknowledgements

GRIP Technical Advisory Group Members



Q&A

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