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TEXAS
The University of Texas at Austin

MAKING THE ELECTRIC GRID RESILIENT TO EXTREME WEATHER EVENTS

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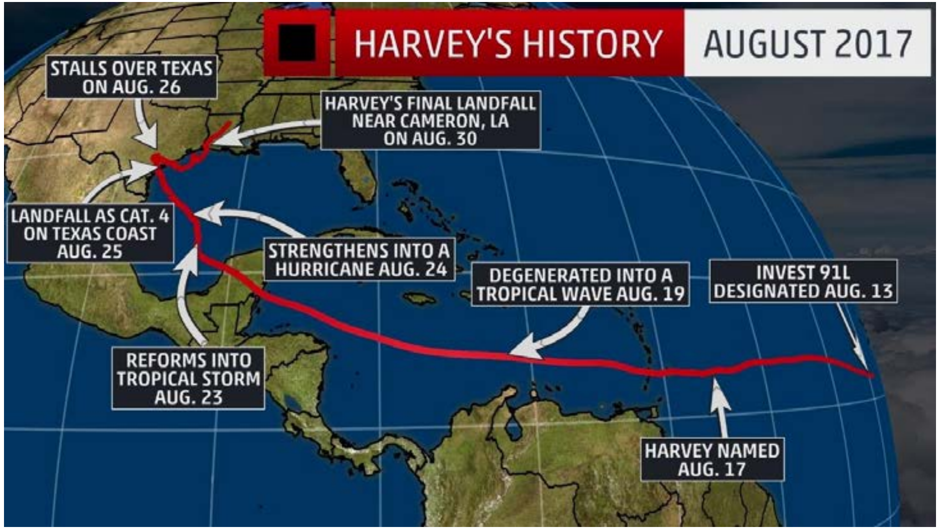
Making the Electric Grid Resilient

Objective: Develop a grid resilience planning and response model: flood projection, power grid, and optimization models.



Rockport, TX on August 25

Days - Weeks

Months – Multiple Hurricane Seasons

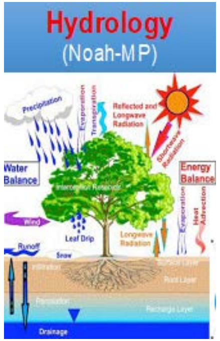
Years – Decades – Climate Change Projections

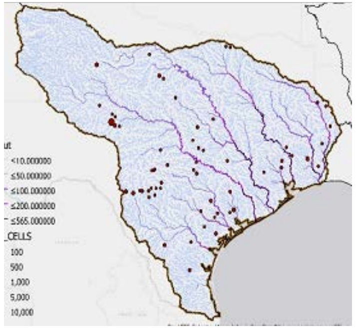
Inputs:

(1) real-time weather forecast

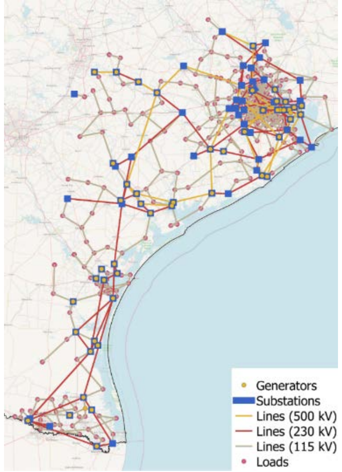
(2) model initialization parameters

Grid resilience planning approach





Hydrological Models



Electric Grid Models

Minimize

$$\sum_{i} f_i z_i + \sum_{s} p^s \left[\sum_{i,j,v,p} c_{ij}^{v} x_{ij}^{vps} + \sum_{j,k,v,p} c_{jk}^{v} x_{jk}^{vps} + \sum_{k,l,v} c_{kl}^{v} x_{kl}^{vs} \right]$$

Subject to

$$\sum_{k} \alpha^{0} x_{jk}^{0,C,s} = D_j^{C,s} \qquad \forall j \in J, s \in S$$

$$\sum_{v,k} \alpha^{v} x_{jk}^{v,N,s} = D_j^{N,s} \qquad \forall j \in J, s \in S$$

$$\sum_{j,v} \alpha^{v} x_{jk}^{vps} \le B_k^{p} \qquad \forall k \in K, p \in P, s \in S$$

$$\sum_{j,p} x_{ij}^{vps} \le q_i^{v} \qquad \forall i \in I, v \in V, s \in S$$

$$\sum_{i} x_{ij}^{vps} = \sum_{k} x_{jk}^{vps} \qquad \forall j \in J, v \in V, p \in P, s \in S$$

$$\sum_{j,p} x_{jk}^{vps} = \sum_{l} x_{kl}^{vs} \qquad \forall k \in K, v \in V, s \in S$$

$$\sum_{i,v\neq 0} q_i^{v} \le O_{max}$$

Optimization Models

Outputs:

Optimal preparedness decisions: mobile substations, grid hardening, etc.

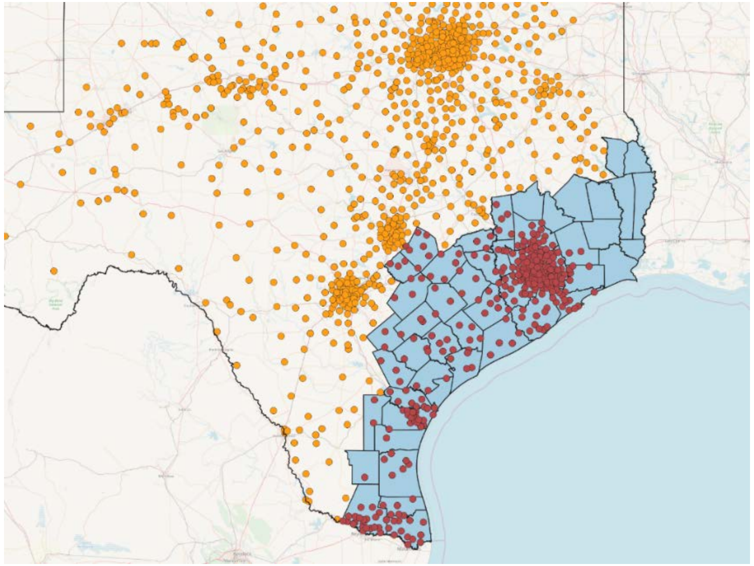
Grid Impact of Flooding

Objectives:

- Project time of substation outages
- Project MW of generation and load loss
- Project number of equipment loss: substations and lines

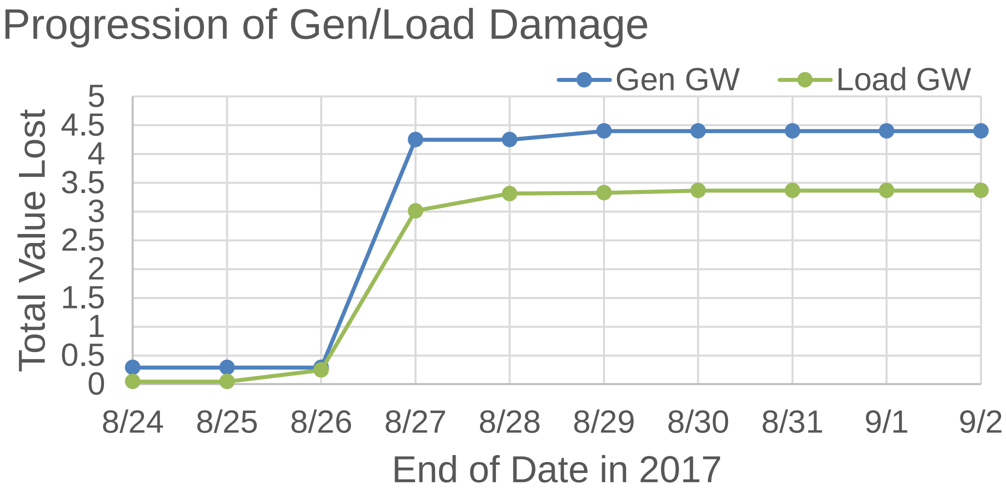
Electrical system:

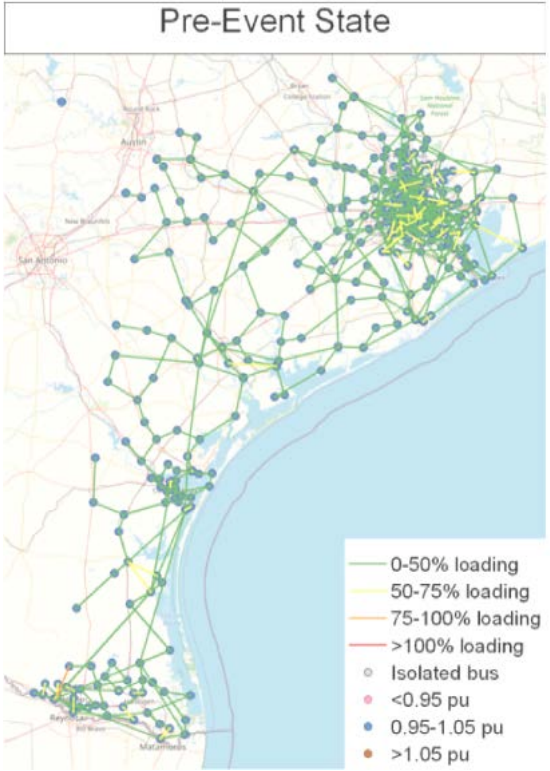
- Use a synthetic ERCOT grid (e.g., ACTIVSg2000), containing transmission lines, T&D substations, generators, and loads
- Map synthetic grid to real-world locations using HIFLD data, https://gii.dhs.gov/hifld/



Generation and Load Loss (10-day horizon)

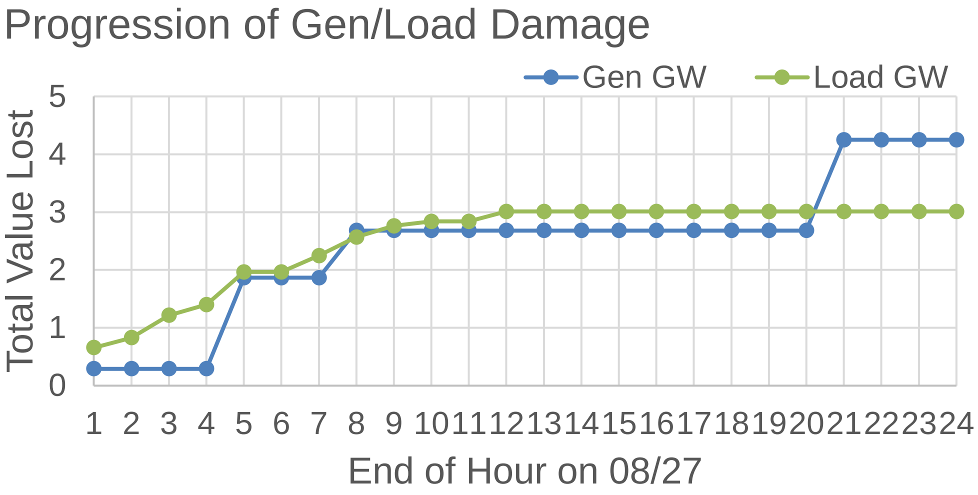
- Suppose peak load levels throughout network
- Most flood damage to electrical network has occurred by end of day August 27 (Day 4 of 10)
- Loading increases in branches still in service, undervoltage becomes more prevalent due to more radial topology

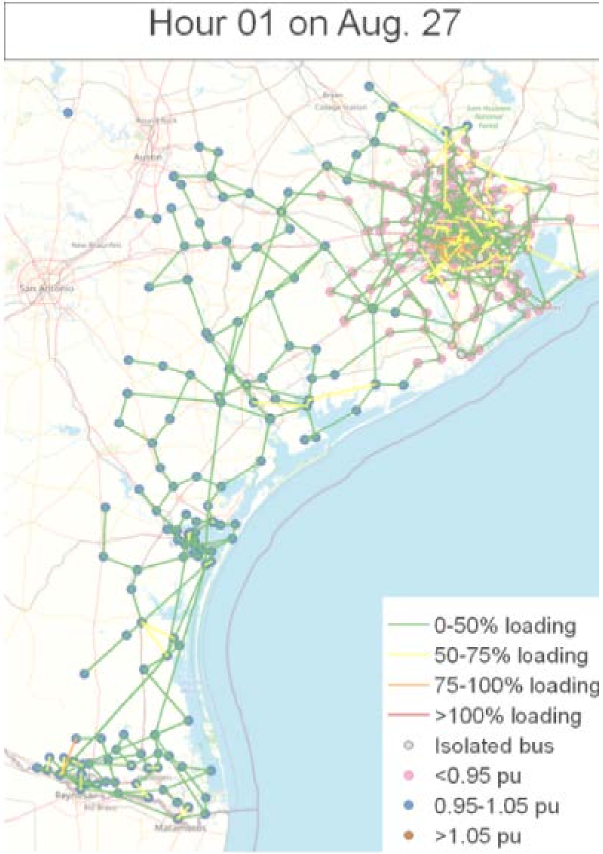




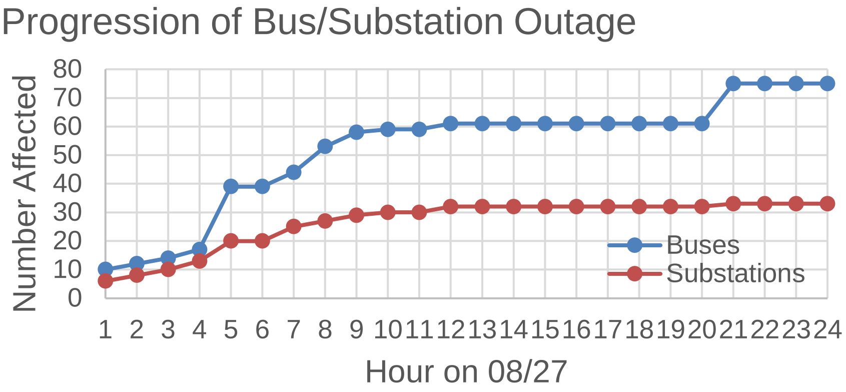
Generation and Load Loss (hourly on 8/27)

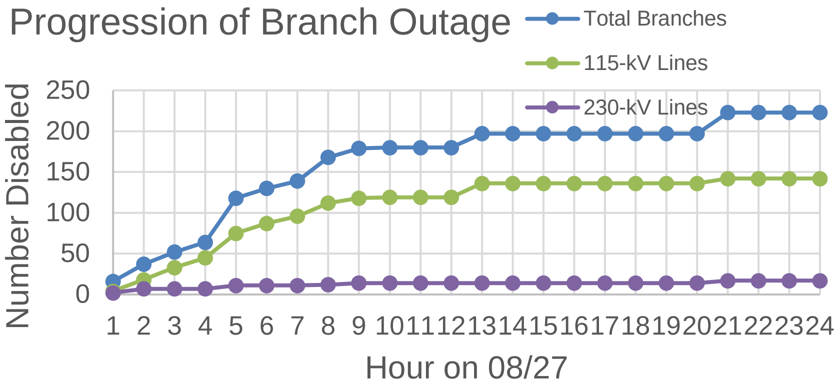
- Within August 27, most new loss of generation occurs in early morning and in evening
- New loss of load occurs more steadily over course of day
- Short-range NWM: hourly forecast of 18 hours ahead

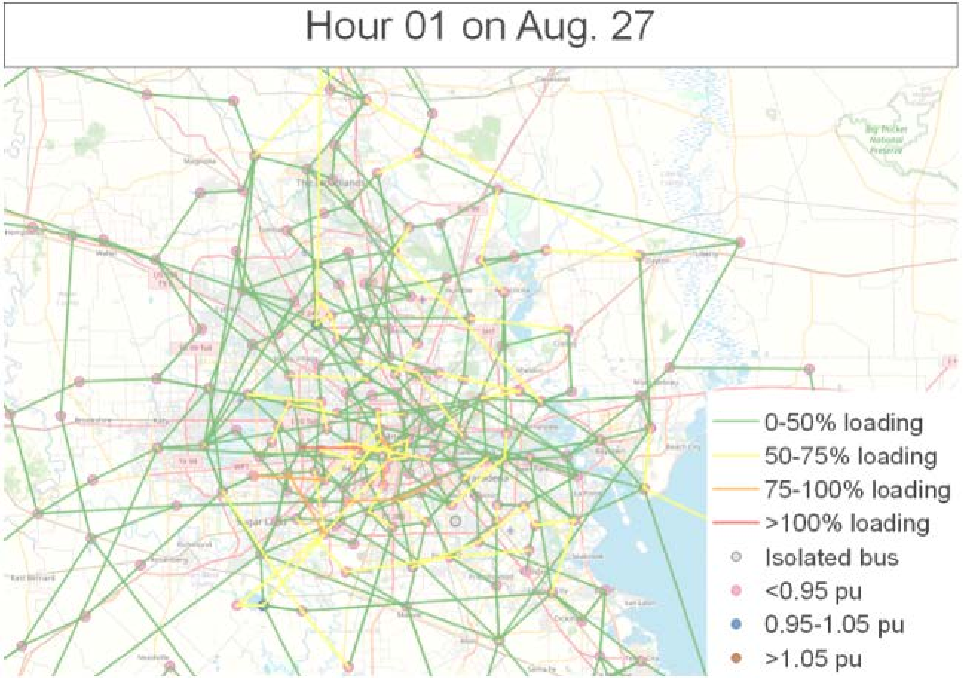




Substation and Line Loss (hourly on 8/27)


Progression of Bus/Substation Outage


Progression of Branch Outage


Hour 01 on Aug. 27

Mobile Resources for Grid Resilience

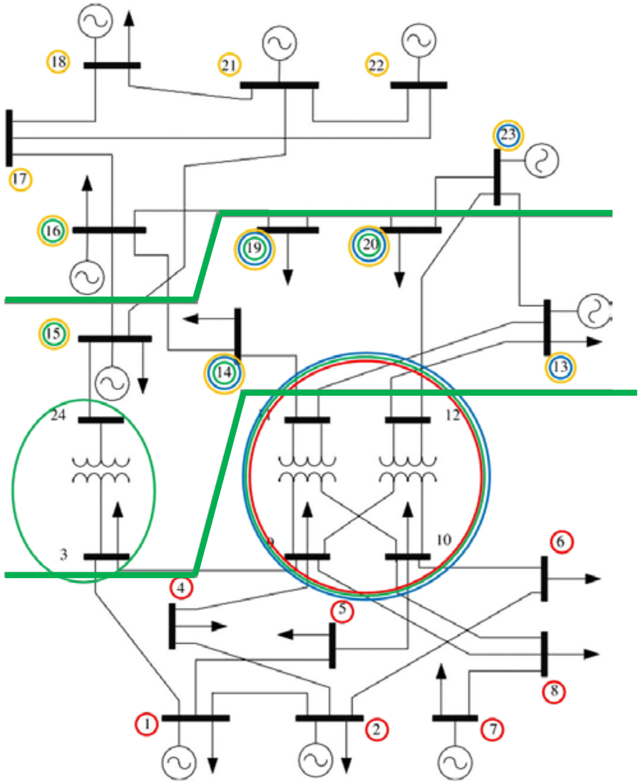
- Substations are flooded and out of service.
- Transmission lines are intact.
- Deploy mobile resources to restore substation functions or bypass the flooded substation.

T&D World, Sept. 15, 2017

http://mobileenergyinc.com/.

Sample formulation instance

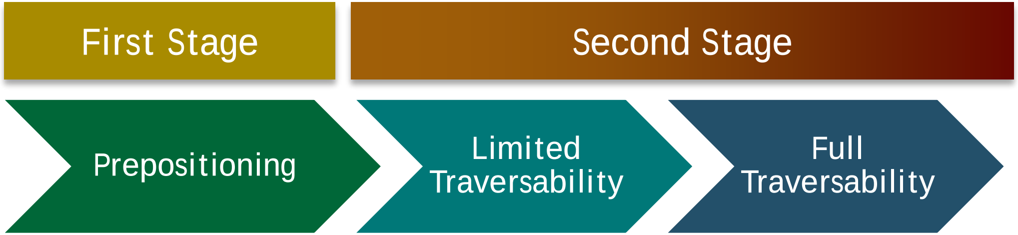
- IEEE 24-bus system: total real load of 2850 MW, generation of 3000 MW
- Mobile transformer specifications:
  - Generation step-up: 60 MVA at either 138/25 kV or 230/25 kV
  - Branch: 40 MVA at 230/138 kV
  - Primary distribution step-down: 20 MVA at either 138/12.47 kV or 230/12.47 kV
- Resources: 5 mobile transformers, 10 mobile breakers



Optimization formulation

Two-stage, scenario-based stochastic mixed-integer linear program (MILP)

- First stage: prepositioning of resources at depots
- Second stage:
  - deployment at substation sites reachable from depots during limited traversability,
  - deployment and repair at any site during full traversability



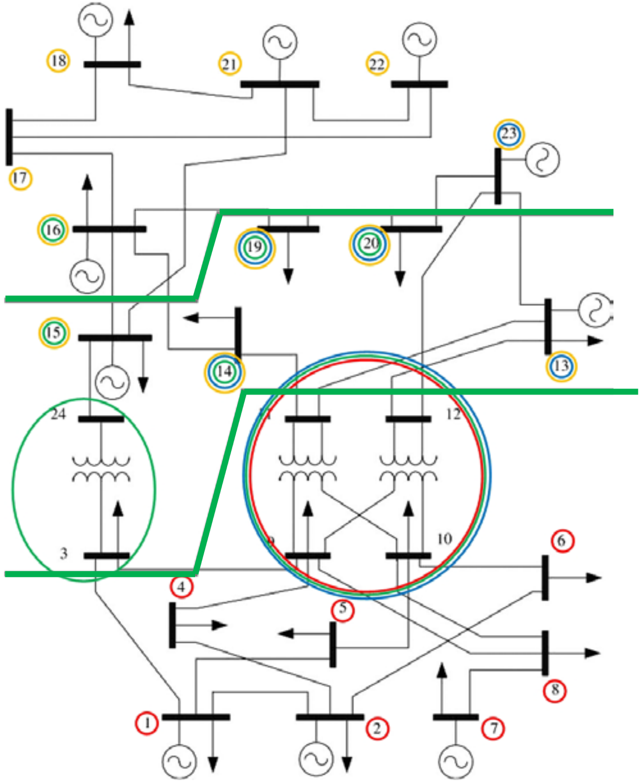
First Stage

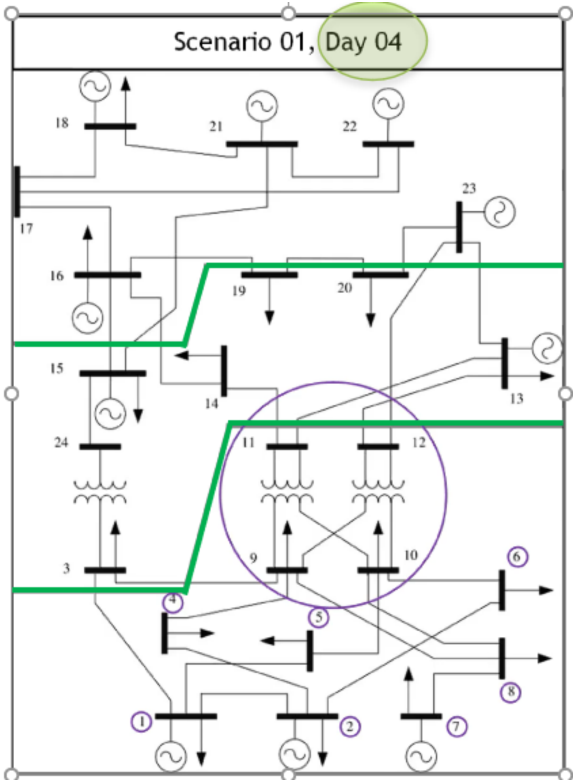
Second Stage

Prepositioning

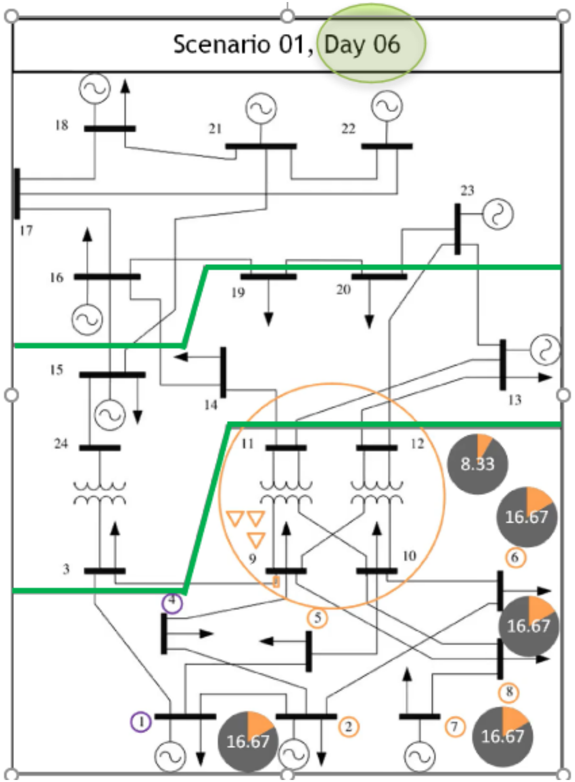
Limited Traversability

Full Traversability

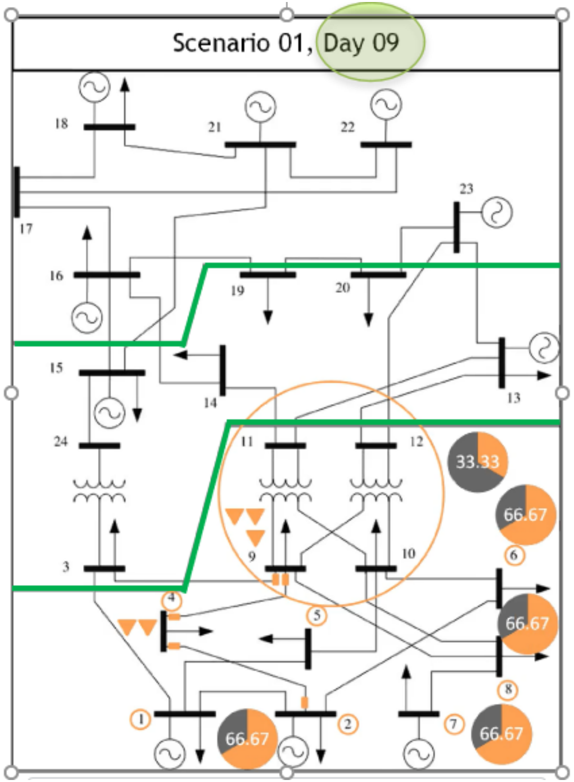




Substations in purple are flooded and not accessible

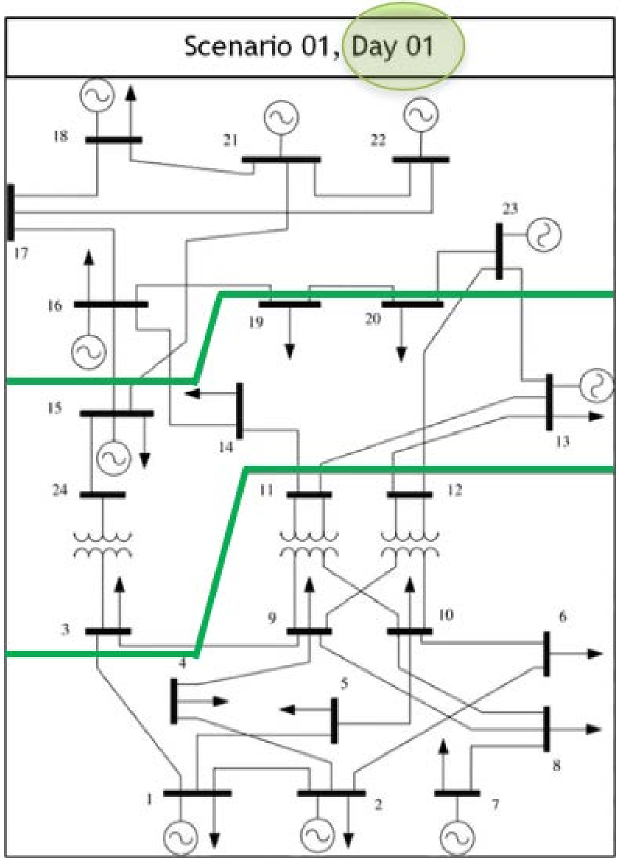


Substations in orange are flooded and but accessible. Mobile resc. are deployed.



Mobile resources are operational, restoration continues.

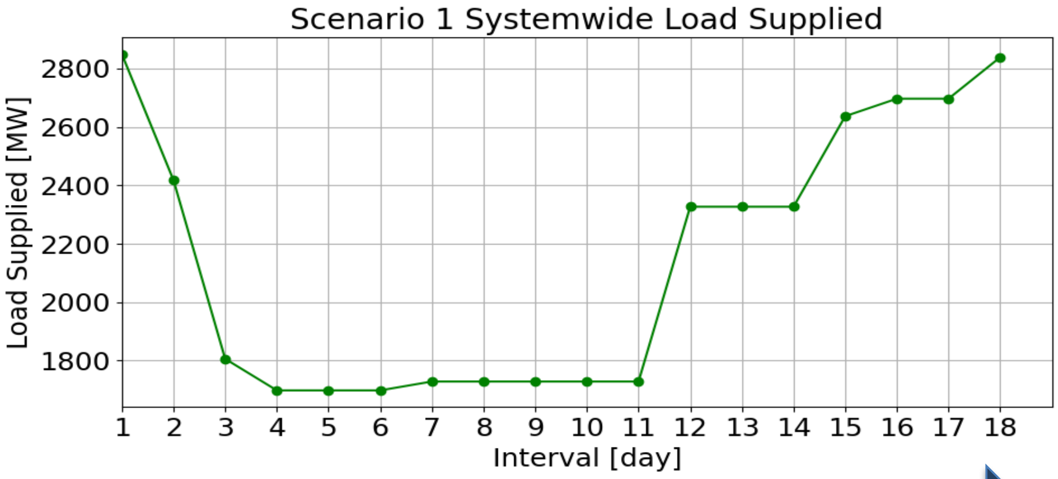
Sample formulation instance (Results)



Prepared resources:

Red Depot: five 138 kV breakers + five 138/12.47 kV xfmrs

Blue Depot: two 230 kV breakers



Limited

Full Traversability

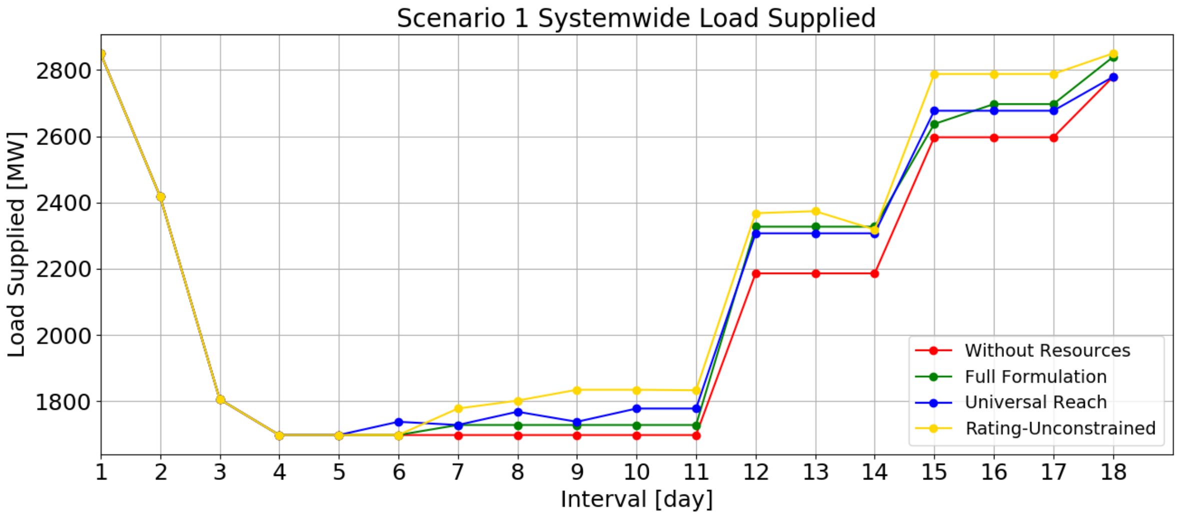
Effects of Resource Relaxation

Without Mobile Resources

Full Formulation: original experiment

Universal Reach: mobile resources at every depot can reach all substations during limited traversability period

Rating-Unconstrained: mobile resource deployments are not restricted by voltage ratings



With mobile resources, load supplied is about 100 MW more than the base case (without mobile resources)

Follow up:

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