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Resilience Webinar 2: Resilience Modeling Necessities, Capabilities and Benefits

Vishvas Chalishazar, Xiaoyuan Fan,

Sarah Davis, Marcelo Elizondo,

Juan Carlos Bedoya, Scott Mix and Emily Barrett

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Support and funding for this work provided by:
U.S. Department of State
Bureau of Energy Resources
Power Sector Program

Project background

- The U.S. Department of State, Bureau of Energy Resources, Power Sector Program (PSP), provides technical and regulatory support to the Central American regional electricity market.

- Under the PSP, Pacific Northwest National Laboratory delivers technical and analytic support to Ente Operador Regional (EOR, the Central American regional system operator).

Webinar 2 – May 19th
List of Presentations and Topics Covered

1. Standards for Resilience and Pre-event Preparedness, Exercises and Drills
   - NERC standards for resilience, IEEE 693 standards for substation equipment
   - Pre-event preparedness for Florida Power and Light, Hurricanes Harvey and Sandy
   - Mutual Aid Programs
2. Real-time operations through extreme events
   - Grid Resilience Evaluation and Emerging Dynamic Trend Adaptation
   - Situational Awareness and overview of the NE-ISO tools → Modeling Requirements and Grand Challenges
3. Dynamic system modeling for resilience – Tools and Analyses
   - Dynamic Contingency Analysis Tool → Dynamic simulations during hurricanes to evaluate system instabilities.
4. Central America Specific Considerations and Recommendations
   - Reliability and Resiliency Findings from Email Interviews
   - Recommendations for Planning and Operations
   - Modeling Extreme Events
   - Considerations for Preparation and Response

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Standards for Resilience and Pre-Event Preparedness Exercises and Drills

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North American Standards to Enhance Resilience

NERC EOP standards – Emergency Preparedness and Operations (*)

- EOP-005-3: System Restoration from Blackstart Resources
  - Ensure plans, Facilities, and personnel are prepared to enable System restoration from Blackstart Resources to ensure reliability is maintained during restoration and priority is placed on restoring the Interconnection.
  - Functional Entities: Transmission Operators - Generator Operators - Transmission Owners identified in the Transmission Operators restoration plan - Distribution Providers identified in the Transmission Operators restoration plan.
- EOP-006-3: System Restoration Coordination
  - Ensure plans are established and personnel are prepared to enable effective coordination of the System restoration process to ensure reliability is maintained during restoration and priority is placed on restoring the Interconnection.
  - Functional Entities: Reliability Coordinators
- EOP-008-2: Loss of Control Center Functionality
  - Ensure continued reliable operations of the Bulk Electric System (BES) in the event that a control center becomes inoperable.
  - Functional Entities: Reliability Coordinator - Transmission Operator - Balancing Authority
- EOP-011-1: Emergency Operations
  - To address the effects of operating Emergencies by ensuring each Transmission Operator and Balancing Authority has developed Operating Plan(s) to mitigate operating Emergencies, and that those plans are coordinated within a Reliability Coordinator Area.
- EOP-010-1: Geomagnetic Disturbance Operations
  - To mitigate the effects of geomagnetic disturbance (GMD) events by implementing Operating Plans, Processes, and Procedures
  - Functional Entities: Reliability Coordinator and Transmission Operator with an Area that includes a power transformer with a high side wye-grounded winding with terminal voltage > 200 kV

(*) https://www.nerc.com/pa/stand/Pages/ReliabilityStandardsUnitedStates.aspx?jurisdiction=United%20States

North American Standards to Enhance Resilience

NERC PER standards – Personnel Performance, Training, and Qualifications (*)

- PER-003-2: Operating Personnel Credentials
  - To ensure that System Operators performing the reliability-related tasks of the Reliability Coordinator, Balancing Authority and Transmission Operator are certified through the NERC System Operator Certification Program when filling a Realtime operating position responsible for control of the Bulk Electric System.
  - Functional Entities: Reliability Coordinator - Transmission Operator - Balancing Authority

- PER-005-2: Operations Personnel Training
  - To ensure that personnel performing or supporting Real-time operations on the Bulk Electric System are trained using a systematic approach.
  - Functional Entities: Reliability Coordinator - Transmission Operator - Transmission Owner - Balancing Authority - Generator Operator

- PER-006-1: Specific Training for Personnel
  - To ensure that personnel are trained on specific topics essential to reliability to perform or support Real-time operations of the Bulk Electric System.
  - Functional Entities: Plant personnel who are responsible for the Real-time control of a generator and receive Operating Instruction(s) from the Generator Operator's Reliability Coordinator, Balancing Authority, Transmission Operator, or centrally located dispatch center

(*) https://www.nerc.com/pa/stand/Pages/ReliabilityStandardsUnitedStates.aspx?jurisdiction=United%20States

IEEE Recommended Practice for Seismic Design of Substations – IEEE Std 693

- Seismic criteria for qualification of electrical substation equipment
  - ✓Seismic qualification objectives, approaches and methods
  - ✓Shake table testing, response spectra, damping with respect to seismic qualification methods
  - ✓Influence of support structures on seismic response of the equipment
- Design for site conditions and installation considerations
  - ✓Equipment assembly
  - ✓Anchorage
  - ✓Site response local topography, near-field effects, and subduction zone earthquakes
  - ✓Foundation analysis
  - ✓Seismic protective systems
  - ✓Suspended equipment
  - ✓Interaction between substation equipment
  - ✓Short circuit, wind and ice loads → No need to consider for seismic design

Ref: "IEEE Recommended Practice for Seismic Design of Substations," in *IEEE Std 693-2018 (Revision of IEEE Std 693-2005)* , vol., no., pp.1-220, 10 April 2019, doi: 10.1109/IEEESTD.2019.8686442.

IEEE Recommended Practice for Seismic Design of Substations – IEEE Std 693

- Operational considerations for seismic events
  - ✓Station Service
    - Verification of anchorages to foundations
    - Safe distances of equipment from trees, branches, light poles and other non-critical items
  - ✓Spare parts
    - *Locations of facilities for spares storage*
    - *Storage rack precautions*
  - ✓Telecommunication equipment
    - *Flexible anchorage details of communication equipment racks*
    - *Communication cable trays without friction clips*
    - *Communication equipment circuit board with positive restraints to prevent them from vibrating loose*
  - ✓Emergency power systems
    - Station and other batteries
    - Emergency generating systems

Ref: "IEEE Recommended Practice for Seismic Design of Substations," in *IEEE Std 693-2018 (Revision of IEEE Std 693-2005)* , vol., no., pp.1-220, 10 April 2019, doi: 10.1109/IEEESTD.2019.8686442.

Pre-Event Preparedness

- Common shortcomings of storm response [1]:
  - Failure to account for people, system, and process changes (staff retirements, system upgrades, etc.)
  - Inadequate stakeholder awareness & involvement
  - Limited preparation before storm seasons
  - Insufficient time allocated to knowledge development
  - Lack of role-based training and simulation
  - Lack of comprehensive Storm Response Plan

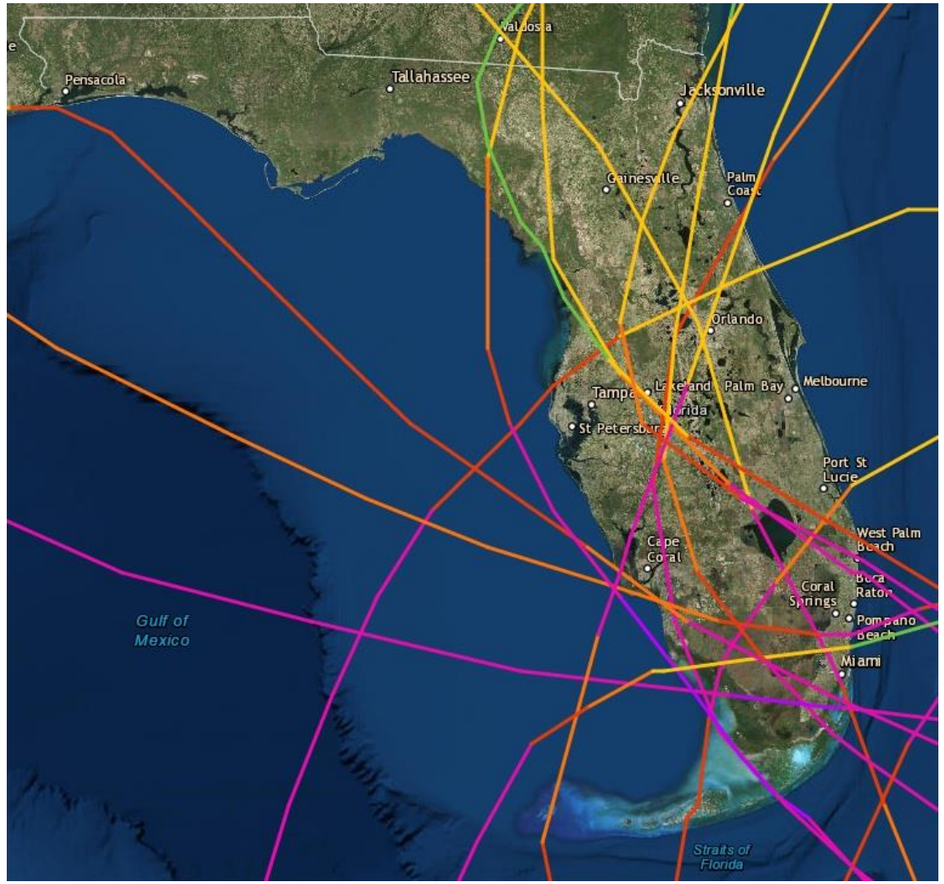
Storm Response Planning Checklist [1]

Strategy	Action
Resources – changes	Assign resources to roles. Review retirement eligibility and succession planning for key roles
System changes	Review critical IT system changes, schedules and role-based impact. Adjust schedules to minimize the impact top storm season
Process changes	Evaluate planned organizational changes, system changes, and corrective actions from previous post incident critiques and the related role-based process revisions
Event Profiling	Create evaluation criteria data sheets and gather or evaluate against rolling ten-year data. Hint: Make this a component of every event debrief – create a dashboard
Event Segmenting	Segment results into low, medium, and high impact events. Incorporate even debrief comments for evaluation
Stakeholder report out	Summarize findings and recommended planning for corrective actions
Gap resolution	Budget, assign, and manage corrective actions to closure
Storm Response Level	Update level criteria based on data and debriefing observations.
Updates	Look critically at lead time and geography related decisions and actions.
Create preparation timeline	Create the off season timeline and response group definition revisions from previous year success and failures. Create call out schedule for the upcoming season. Best and most experienced leading this effort
Review foundational training	Identify revision requirements. Revise, schedule, and deliver
Review role-based training	Identify revision requirements. Revise, schedule, and deliver
Review small group simulations	Identify revision requirements. Create new simulation scripts, schedule and evaluate small group simulations
Determine Multi-site drill scenario and timeline	Establish drill objectives by role. Identify key inputs and expected responses. Identify controllers/evaluators. Schedule training for controller/evaluator roles
Stress Test systems	Ensure system can respond to high volume events when loaded with data and users
Create backup plans	Identify manual processes for critical system failures

[1] https://electricenergyonline.com/energy/magazine/841/article/Strategies-for-Successful-Storm-Response-and-Management.htm

Florida Power & Light – Annual Preparedness Exercises

- Integrated transmission & distribution system with 645 substations, 10 million people
- Four-day simulated hurricane to practice storm response
- Annual training prepares company personnel and system operators to [1]:
  - Track outages
  - Assess damage
  - Communicate with customers & employees
  - Work with contractors & suppliers to restore service
- DTN/Meteorlogix mixVision Weather Sentry Online *Utilities Edition* [1]
  - Meteorological localized forecast information
  - Storm tracking & radar
  - What areas will be hit most severely
  - Supports strategic repair crew placement ahead of storm

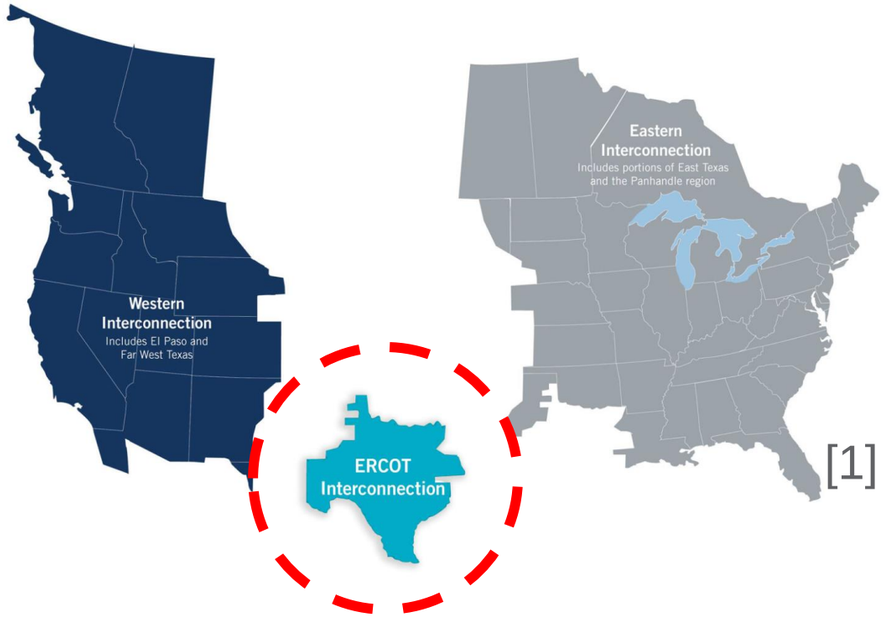


Historical Category 4 Hurricanes over Florida, USA [2]

[1] https://electricenergyonline.com/energy/magazine/422/article/Storm-and-Hurricane-Preparedness-Florida-Power-Lights-Efforts-to-Stay-One-Step-Ahead-of-Mother-Nature.htm
[2] https://www.news-press.com/story/weather/hurricane/2016/10/05/florida-hurricane-tropical-storm-magnet-for-a-century/91597860/

ERCOT – Hurricane Harvey Operational Response

- System Operations actions taken prior to landfall of Hurricane [1]:
  - Canceled as many planned outages as possible
  - Activated internal Disaster Management Team
    - ✓ Ensures operations are not impacted during storm event
  - Provided operation notices to Market Participants in advance of hurricane



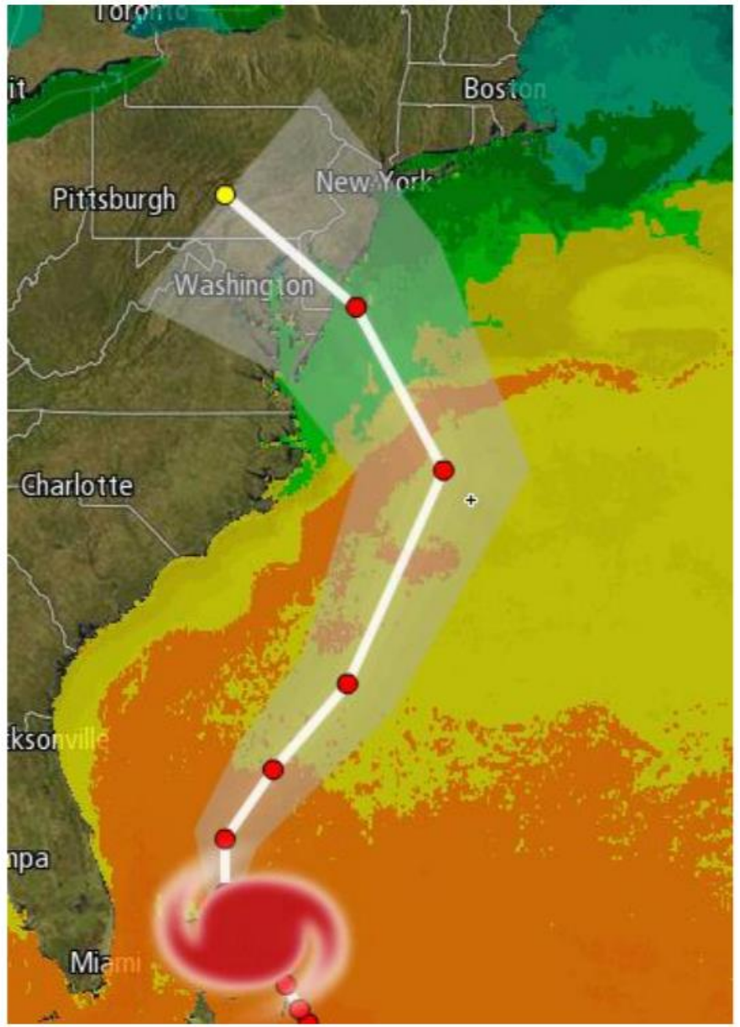
[1]

[2]

[1] http://www.ercot.com/help/harvey
[2] https://www.epa.gov/sites/production/files/2018-06/documents/hurricane_harvey_the_state_and_federal_response_tceq_0.pdf

NYISO & ISO-NE – Hurricane Sandy Preparation

- Storm Preparations [1]:
  - Communication with neighbors
  - Helicopters staged inland for aerial patrols
  - Sandbags & barriers deployed to substations
  - Substation inspections performed & manned
  - Pre-positioning labor, equipment, and materials for restoration
  - Service vendors contacted
  - Additional field resources & staffing scheduled
  - All transmission & generation returned to service
  - Status of Special Protection Schemes & RAS
  - Dynamic re-ratings of transmission facilities implemented



[1] https://www.nerc.com/pa/rrm/ea/Oct2012HurricanSandyEvntAnlyssRprtDL/Hurricane_Sandy_EAR_20140312_Final.pdf

North America Collaboration Groups to Enhance Resilience – Mutual Aid Programs

Electricity Subsector Coordinating Council (ESCC) (*)(**)

- Formed in response to recommendations from the National Infrastructure Advisory Council (NIAC)
- Provides high-level forum for *utility executives* and *federal* decision makers to engage and maintain open communication channels in preparation for large-scale outages, reduce risks of cyber and physical attacks
- NERC - Electricity Information Sharing and Analysis Center (E-ISAC) example
  - Disseminates information and alerts to electric industry and government representatives
  - Conducts training exercises
  - Maintains the Cyber Risk Information Sharing Program - covers nearly 80% percent of operators of the BES.
- NERC – Spare Equipment Working Group example
  - Maintain database of system components available (typically large transformer equipment) for participating utilities. See NERC. 2011- Special Report: Spare Equipment Database System. Atlanta

(*) https://www.electricitysubsector.org/

(**) NIAC (National Infrastructure Advisory Council). 2010. A Framework for Establishing Critical Infrastructure Resilience Goals: Final Report and Recommendations by the Council. https://www.dhs.gov/xlibrary/assets/niac/niac-a-framework-for-establishing-critical-infrastructureresilience-goals-2010-10-19.pdf.

North America Collaboration Groups to Enhance Resilience – Mutual Aid Programs

Electricity Subsector Coordinating Council (ESCC) (*)

- The Edison Electric Institute's (EEI) example(**):
  - Spare Transformer Exchange Program (STEP) and the Grid Assurance
  - STEP represents a coordinated approach to increasing the electric power industry's inventory of spare transformers
  - STEP streamlines the process of transferring those transformers to affected companies in the event of a transmission outage caused by a terrorist attack
  - Each participating energy company is required to maintain and, if necessary, acquire a specific number of transformers.
  - STEP requires each participating company to sell its spare transformers to any other participating company that suffers a "triggering event," (act of terrorism that disables substations and results in the declared state of emergency by the POTUS)

- Parfomak review (2014) (*)
  - Prepared a review of the issue of spare transformers for the Congressional Research Service.
  - Shows of developed efforts in spare transformers equipment
  - Highlights the needs of the remaining collaborative work to be done

(*) NIAC (National Infrastructure Advisory Council). 2010. A Framework for Establishing Critical Infrastructure Resilience Goals: Final Report and Recommendations by the Council. https://www.dhs.gov/xlibrary/assets/niac/niac-a-framework-for-establishing-critical-infrastructureresilience-goals-2010-10-19.pdf.

(**) https://www.eei.org/issuesandpolicy/transmission/Pages/sparetransformers.aspx#:~:text=STEP%20requires%20each%20participating%20company,President%20of%20the%20United%20States.

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Real Time Operations Through Extreme Events

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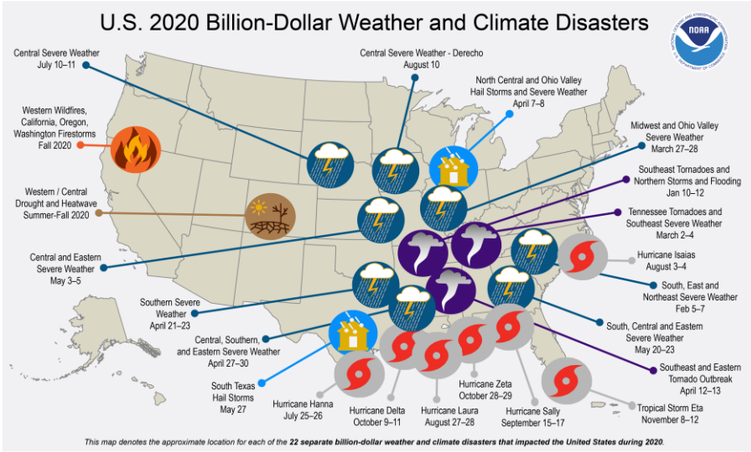
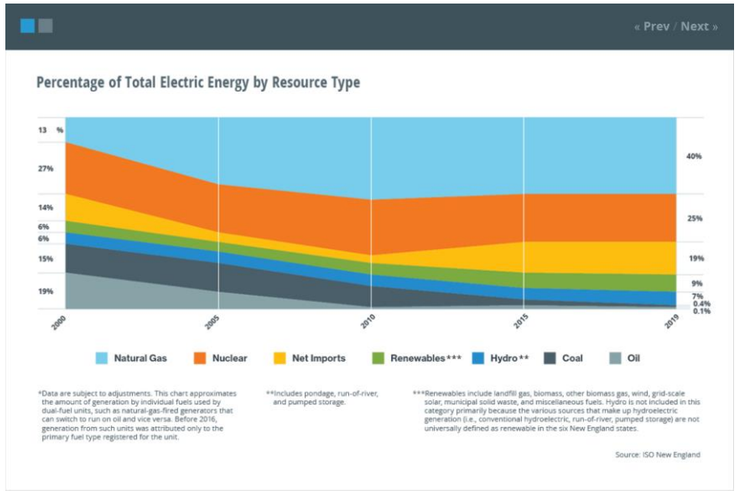
Grid Resilience Evaluation and Emerging Dynamic Trend Adaptation

- High-impact low-probability disruptive events by weather/disaster hazards
  - **Low-probability is NOT zero probability!**
  - Hurricane/Flooding/Wildfire/Earthquake impact evaluation
  - Near-term grid hardening prioritization
  - Automated evaluation for disaster mitigation evaluation
- Microgrid Assessment & Community Burden Evaluation
- Aggressive Renewable Integration & Delayed Transmission Upgrade
  - Risk quantification and intelligence filtering for Integrated Resource Planning (IRP)
- DER Aggregation Evaluation (FERC 2222)



Urgent need for Grid Resilience Evaluation. (Credits: NOAA)



Resource Mix Trend, 2000 to present. (Credits: ISO-NE)

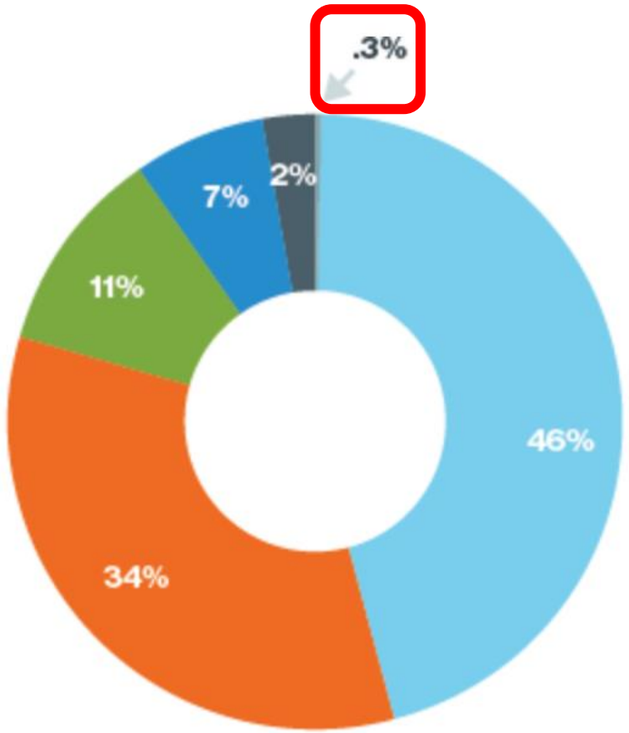
Grid Resilience Evaluation and Emerging Dynamic Trend Adaptation

Oil Generation is High During Extreme Winter Cold

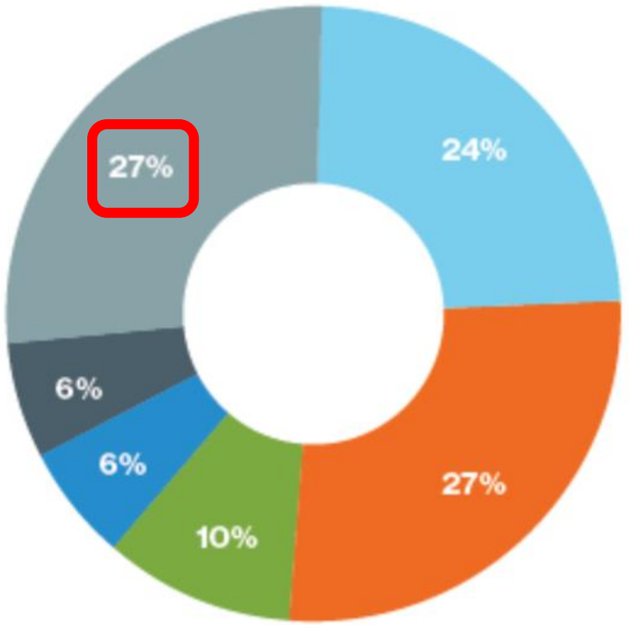
Oil generation was 27% of the regional fuel mix during the cold spell of winter of 2017/2018 compared with 0.3% for most of the month of December.

- Natural Gas
- Nuclear
- Renewables
- Hydro
- Coal
- Oil

DER?



Average Fuel Mix for Most of December 2017 (Dec. 1–26, 2017)



Average Fuel Mix for Extreme Cold Spell (Dec. 26, 2017 to Jan. 9, 2018)

- DER Aggregation Evaluation (FERC 2222)

Resource Mix Trend, 2000 to present. (Credits: ISO-NE)

Situational Awareness of the Weather Impact on ISO-NE Grid Operation

- ISO-NE has been developing an Online Weather Look-ahead Study (OWLS) tool, which calculates the outage probabilities of bulk power system equipment and network contingencies for forecasted weather events.
- The OWLS tool is a promising effort in development, and the operational benefit is still being explored through continuous online evaluation.
- The OWLS tool enhances the grid operators' situational awareness, and additional features such as high-risk contingency screening and cascading failure prevention can be further developed and evaluated.

Overview of ISO-NE OWLS Tool

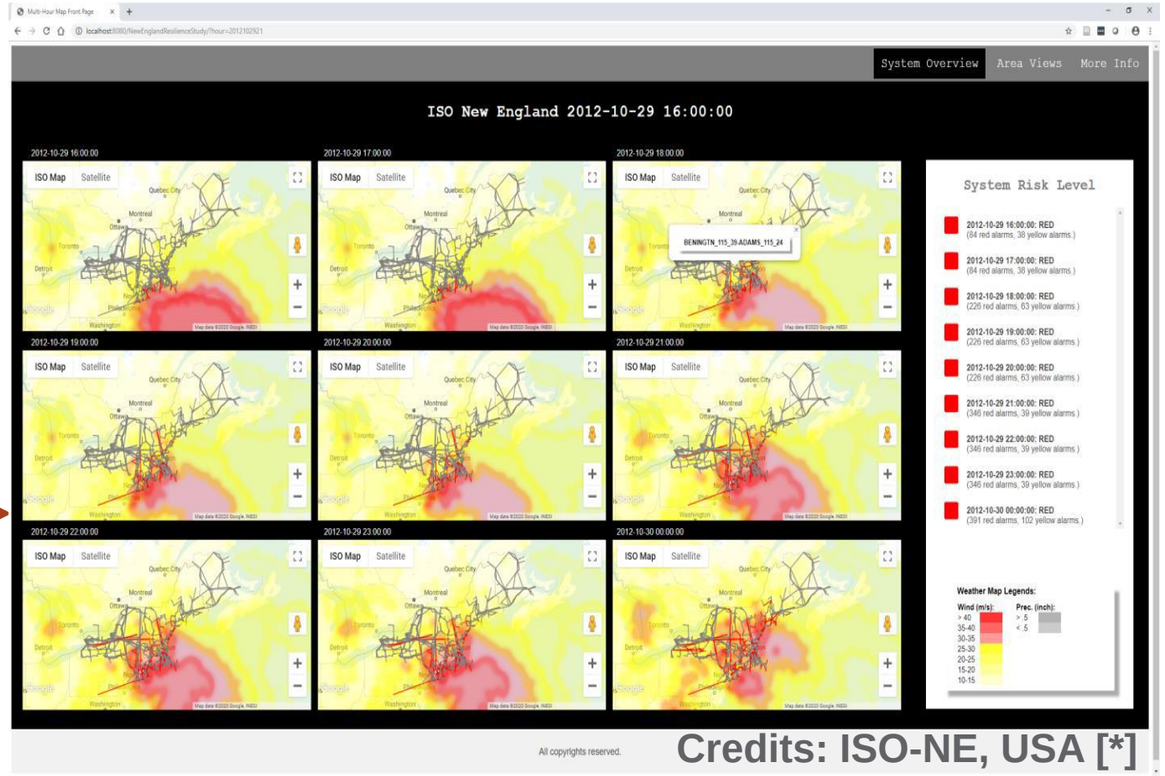
EMS CSV Files

NOAA data GRIB2 files

Look-Ahead Outage Risk Estimation Study (Python)

Web Displays and Operator Query (Java EE, Google Map)

Contingency risks for downstream operation planning studies

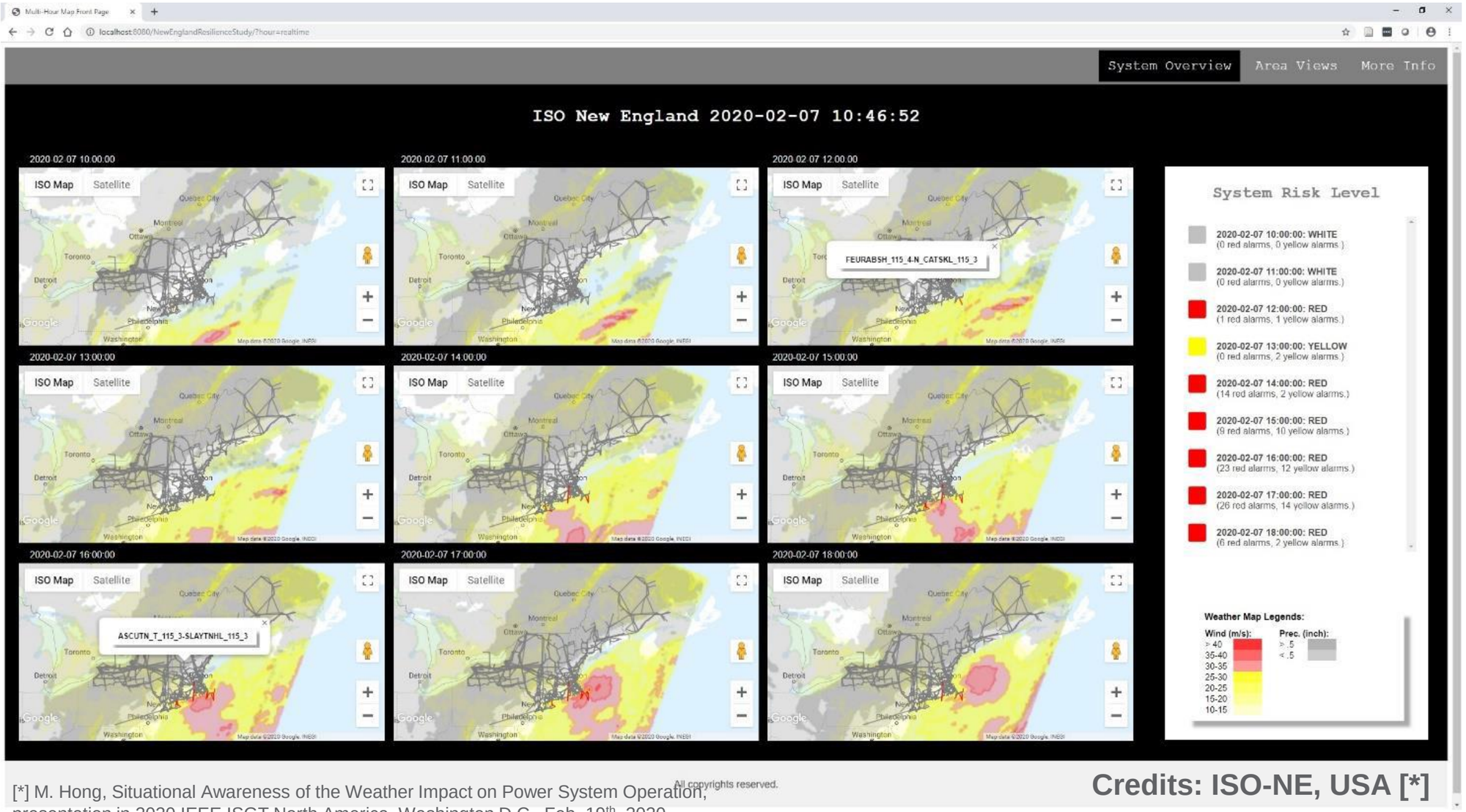


Credits: ISO-NE, USA [*]

- Runs Outage Risk Estimation each hour
- Integrated view of Grid and weather dynamic
- Report on system risk and colored alert levels
- Flexible query schemes

[*] M. Hong, Situational Awareness of the Weather Impact on Power System Operation, presentation in 2020 IEEE ISGT North America, Washington D.C., Feb. 19th, 2020.

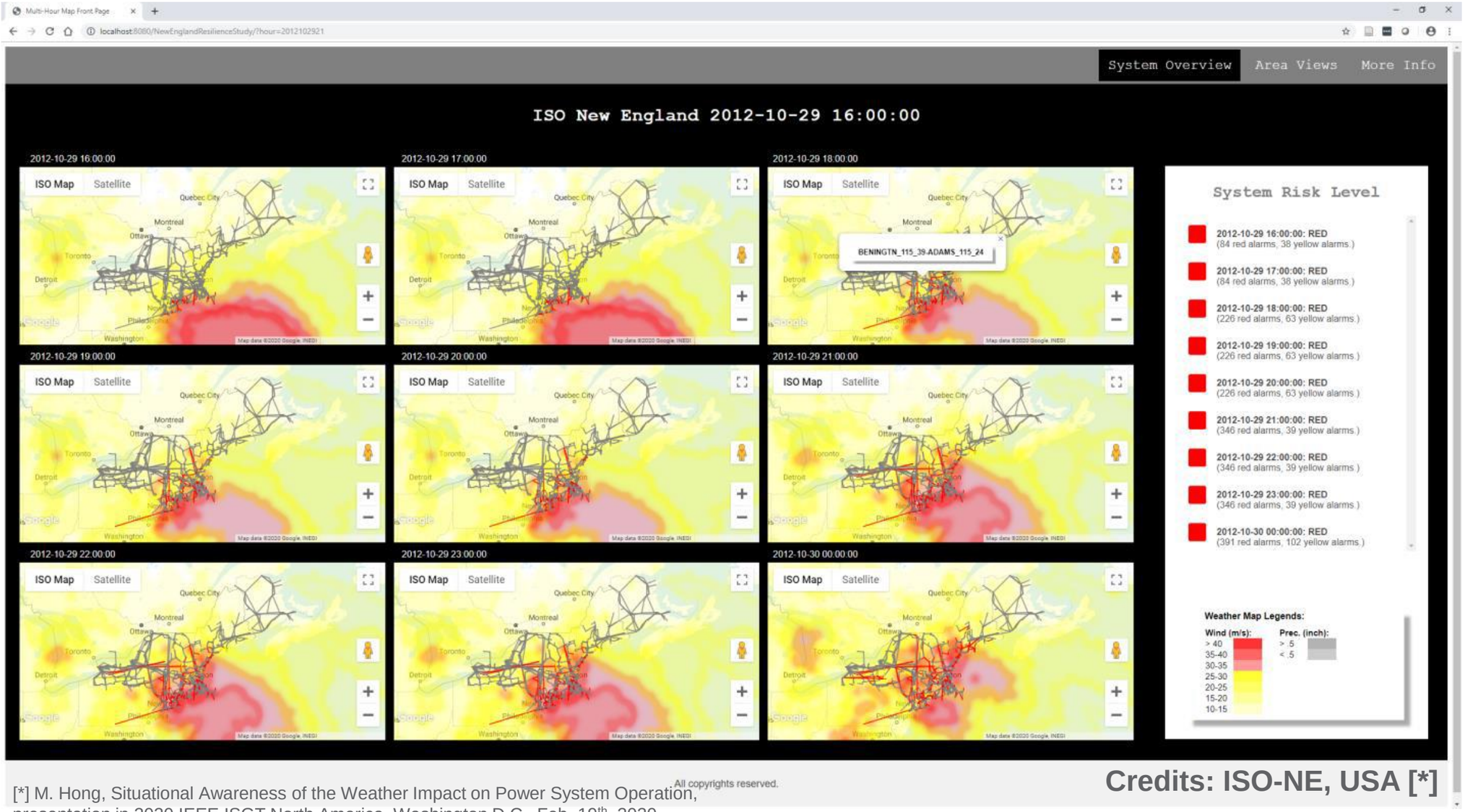
Example of OWLS tool during online evaluation



Credits: ISO-NE, USA [*]

[*] M. Hong, Situational Awareness of the Weather Impact on Power System Operation, presentation in 2020 IEEE ISGT North America, Washington D.C., Feb. 19th, 2020.

Historical Events Review (Hurricane Sandy, 2012)



Credits: ISO-NE, USA [*]

[*] M. Hong, Situational Awareness of the Weather Impact on Power System Operation, presentation in 2020 IEEE ISGT North America, Washington D.C., Feb. 19th, 2020.

Google Map aerial view of a power plant

Credits: ISO-NE, USA [*]

[*] M. Hong, X. Luo, S. Maslennikov, the late E. Litvinov, “Enhancement of Operational Resilience with the Online Weather Look-ahead Study”, 2021 IEEE PES General Meeting, to appear.

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Dynamic System Modeling for Resilience – Research Space

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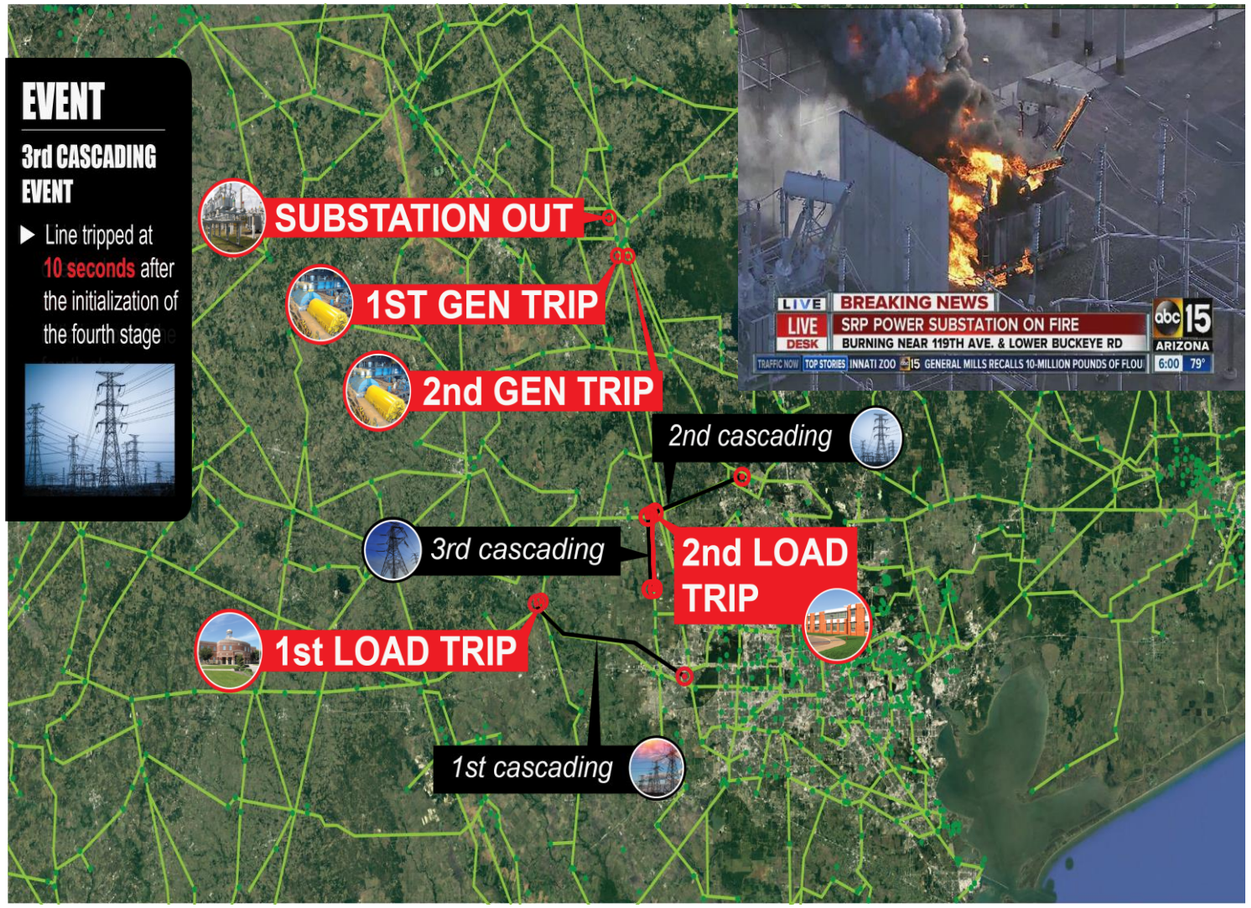
Dynamic Contingency Analysis Tool (DCAT)

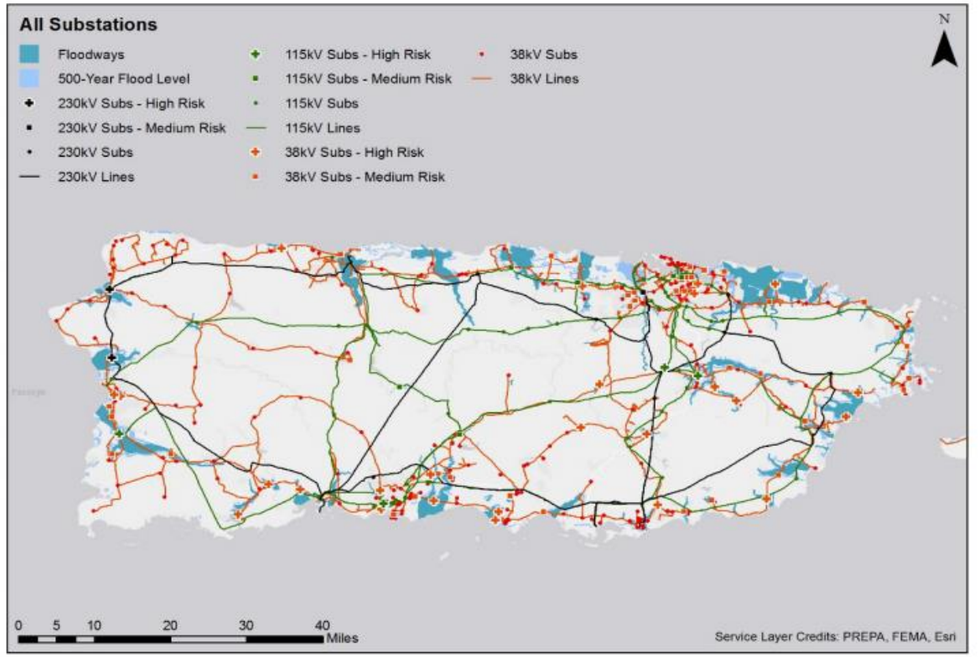
- **DCAT significantly improves how we prepare and plan for extreme events**
  - More realistic modeling enables effective decisions
  - Faster computing technology
  - Automatic simulations
- Prepare for extreme events
  - Improved assessment of cascading outage impacts
- Plan for the future
  - Provide necessary information to identify grid enhancements



DCAT simulates finer details of cascading events

Case Study: Hurricane Maria

NOAA (National Oceanic and Atmospheric Administration)

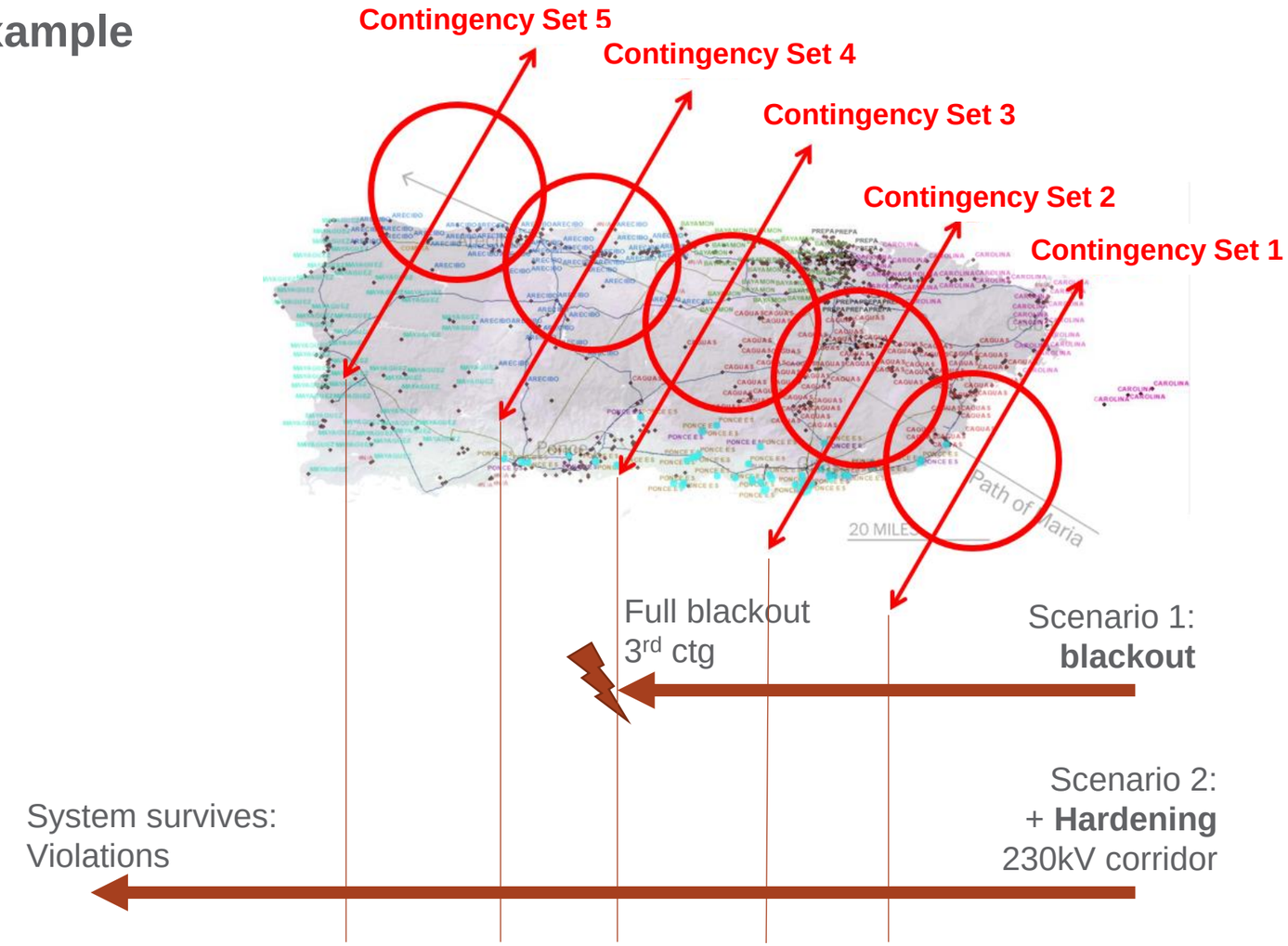


Source: “Build Back Better: Reimagining and Strengthening the Power Grid of Puerto Rico,” December 2017

DCAT Application to Puerto Rico

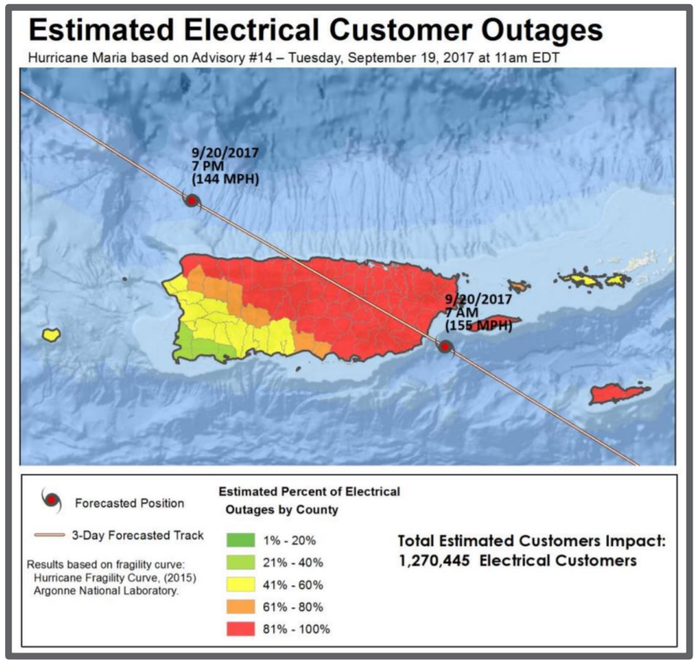
- Develop tool to improve resiliency planning and operation for hurricanes
- Generate, simulate & process large number of scenarios:
  - 78,000+ contingencies on component failure analysis
  - Hurricane scenarios – time sequence of contingencies
- Derive recommendations:
  - Priority transmission assets
  - Transmission hardening
  - Protection coordination
  - Voltage support
  - Preventive operational actions
  - High solar scenarios

Example



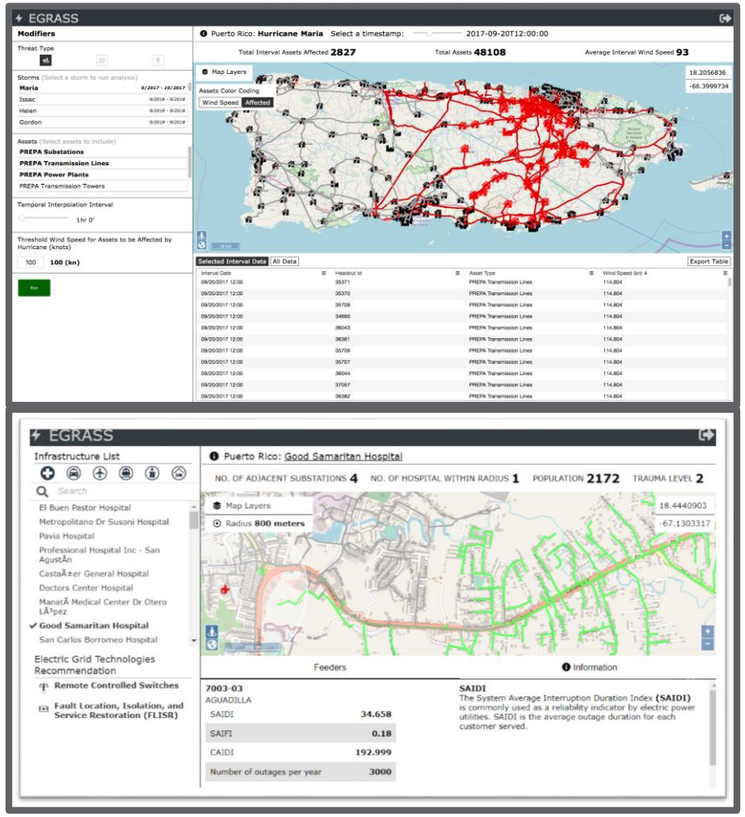
Framework Combines Three Tools

HEADOUT
Hurricane Electrical Assessment Damage Outage Tool



Argonne National Laboratory

EGRASS
Electrical Grid Resilience and Assessment Tool



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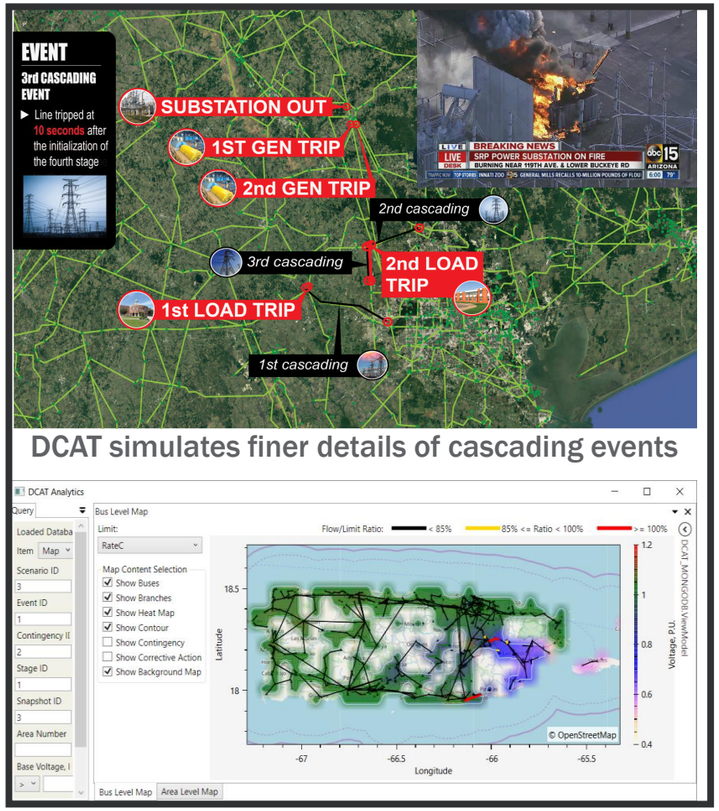
DCAT
Dynamic Contingency Analysis Tool



DCAT simulates finer details of cascading events

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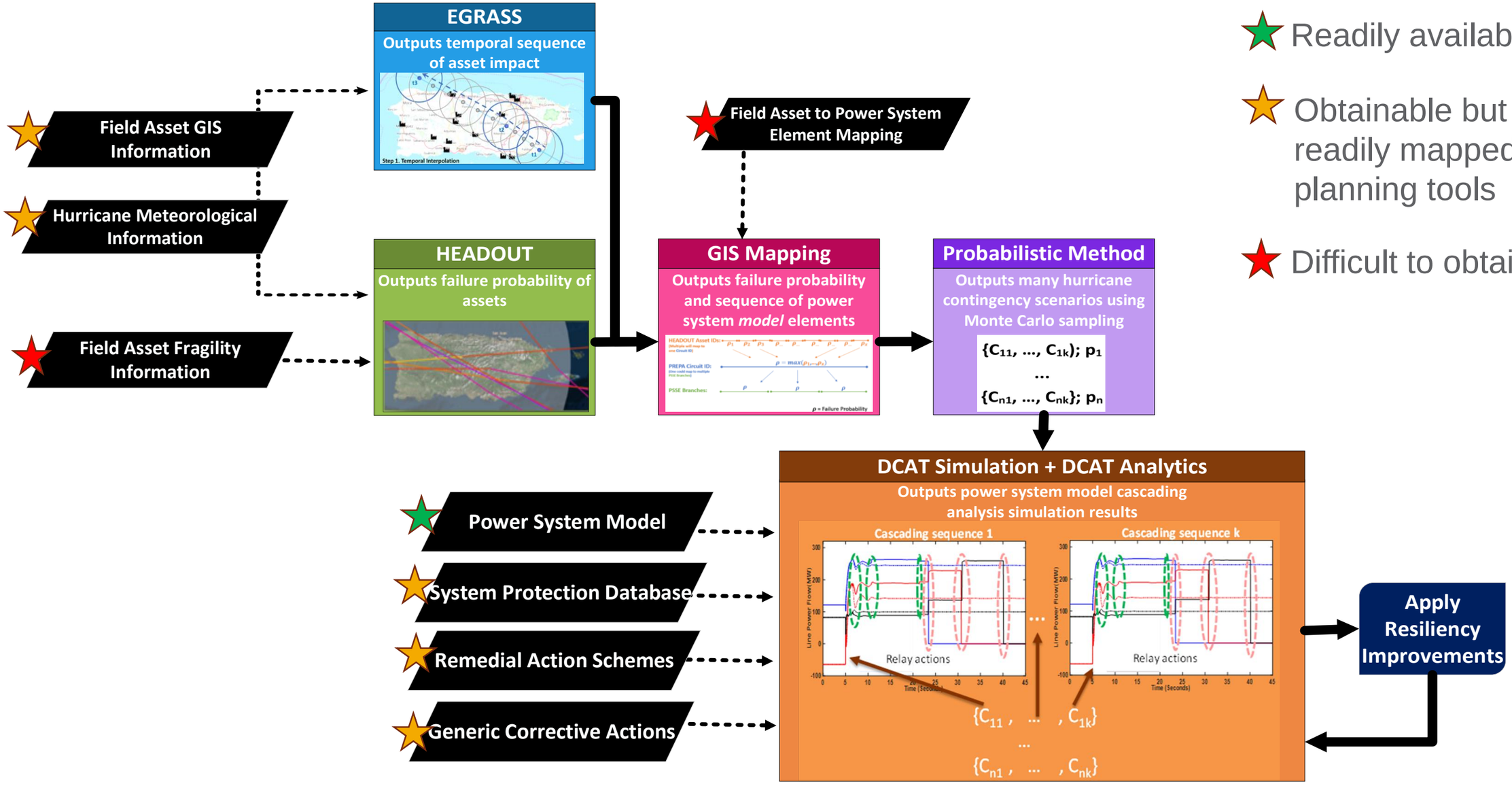
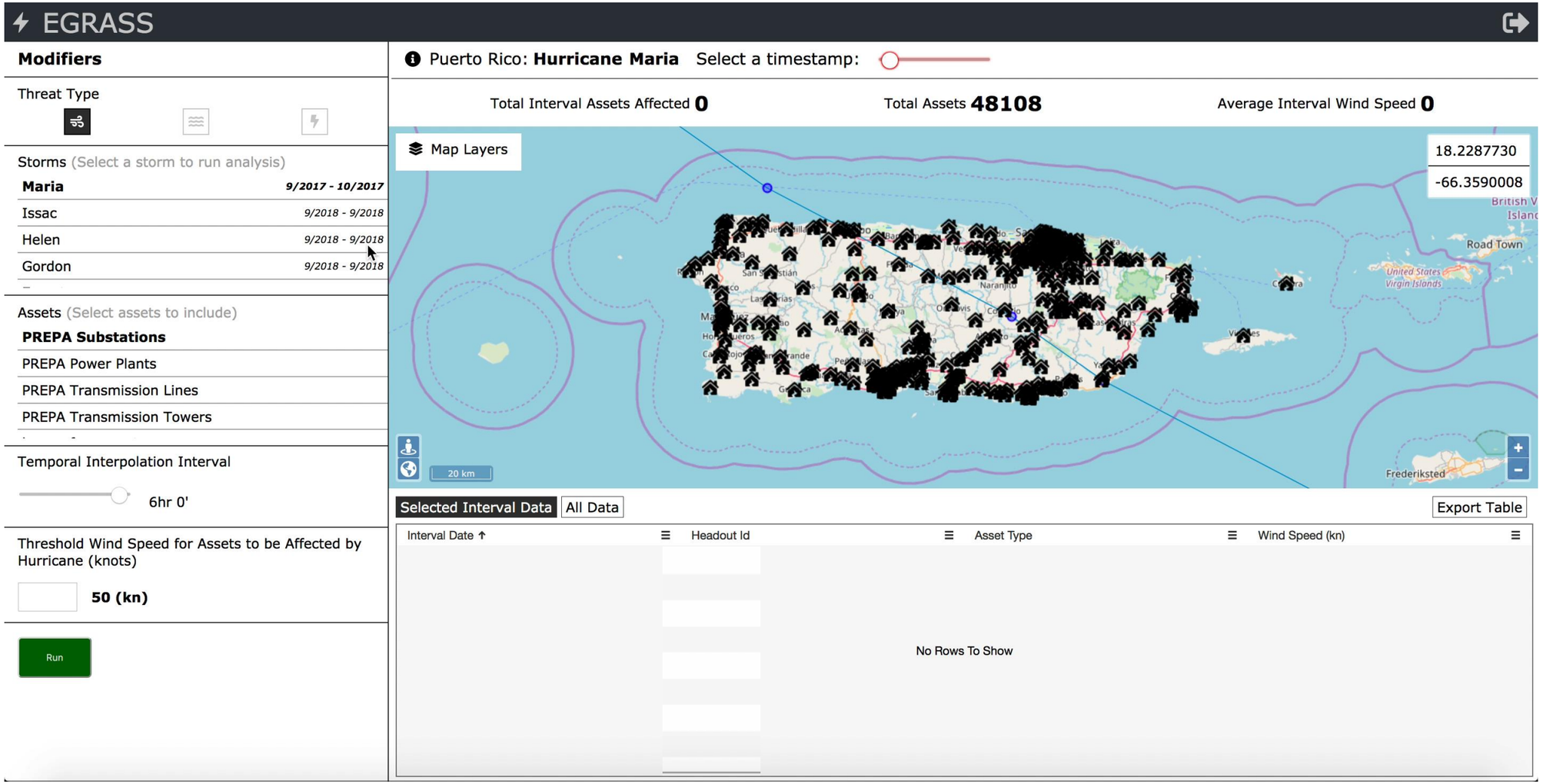
Data Requirements



- Readily available
- Obtainable but not readily mapped to planning tools
- Difficult to obtain

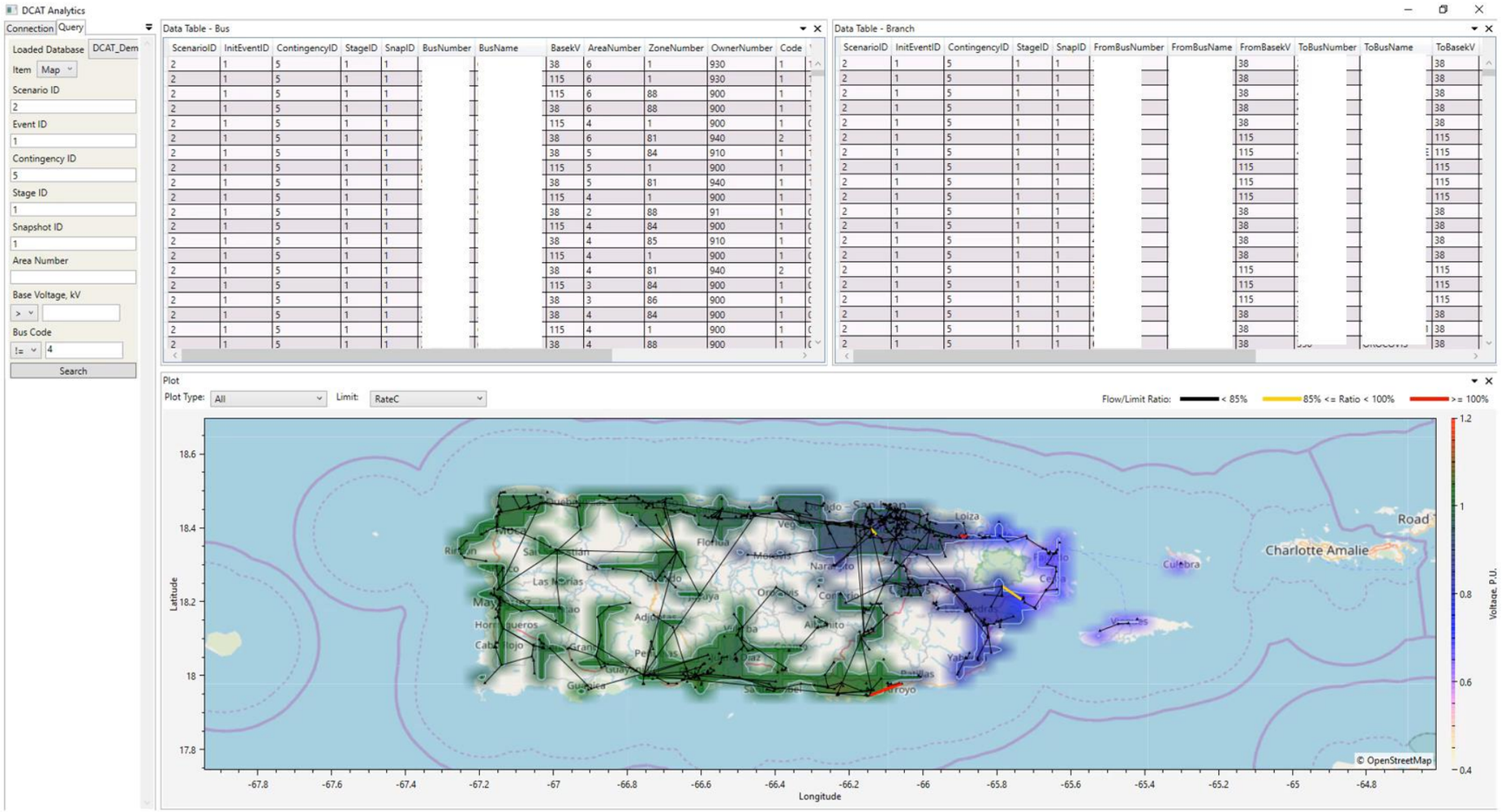
Simulation Demonstration



Video →

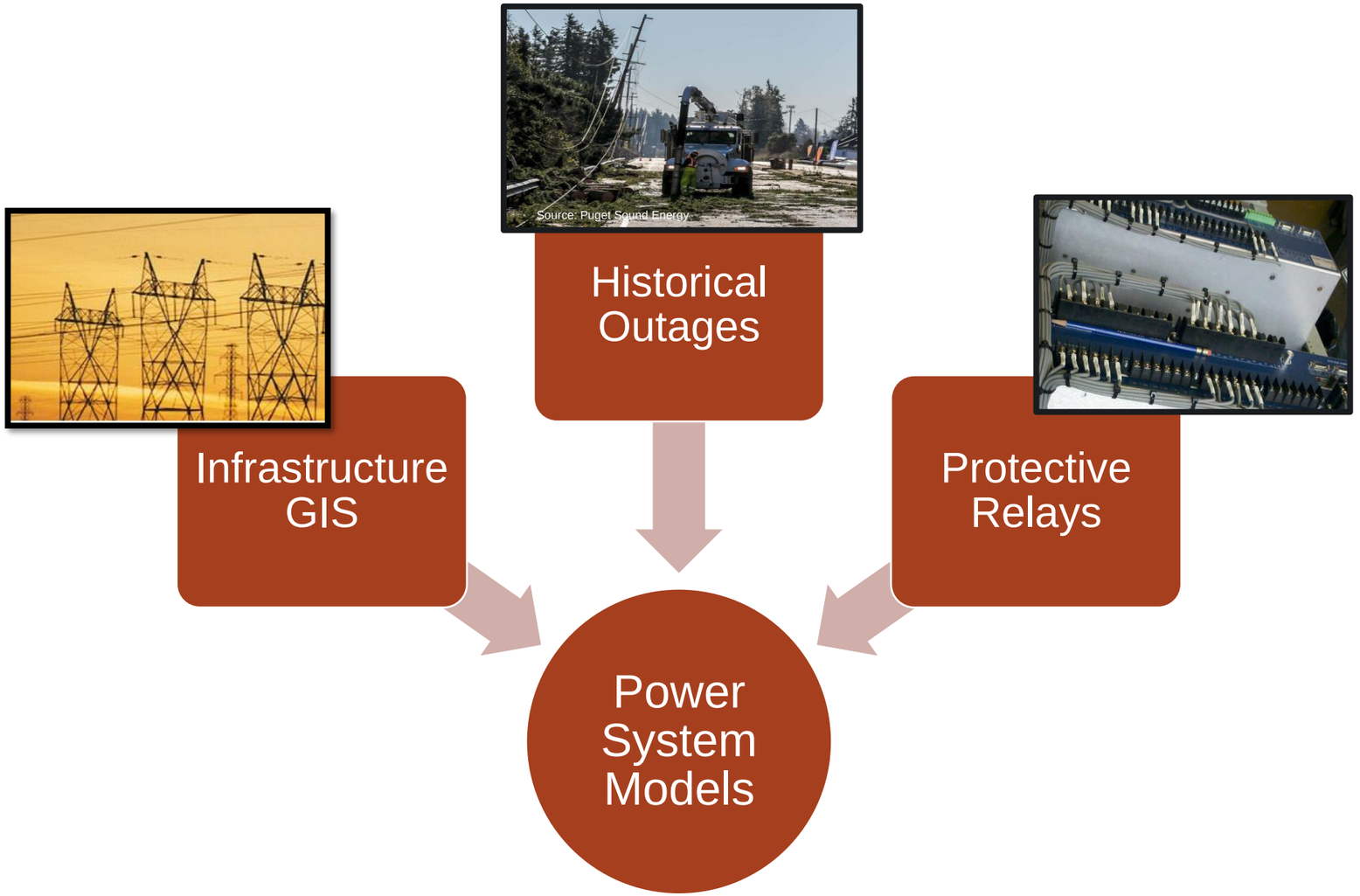
Simulation Demonstration

DCAT analytics – GUI (map)



Video →

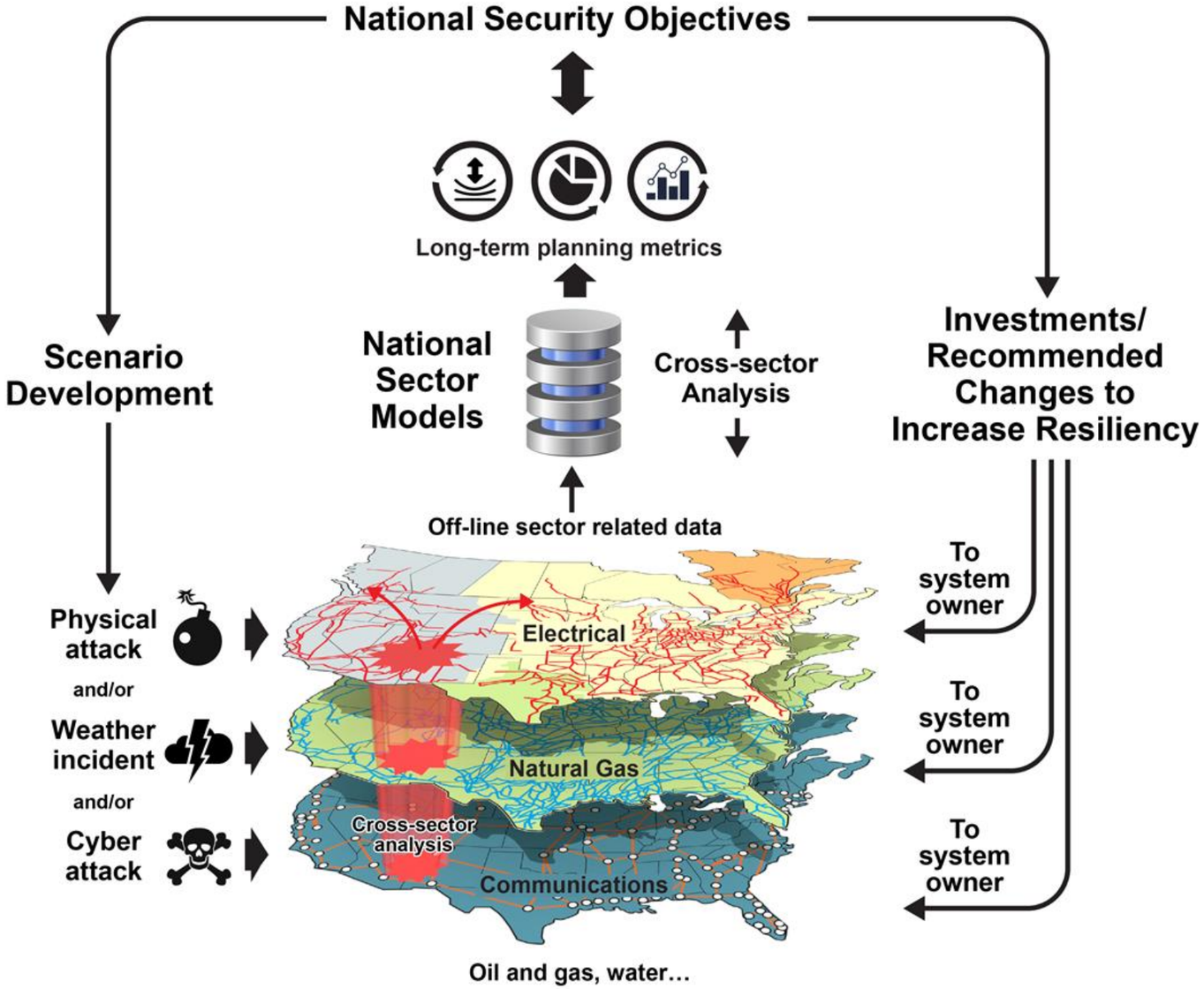
Lessons Learned: Improved Data Synchronization is Needed for Accurate Resiliency Planning Analytics



Davis S.H., M.A. Elizondo, X. Fan, S.F. Newman, E.L. Barrett, X. Ke, and B. Vyakaranam, et al. 2020. "Data Requirements for Application of Risk-Based Dynamic Contingency Analysis to Evaluate Hurricane Impact to Electrical Infrastructure in Puerto Rico." In *2020 Next Generation Network Paper Competition*. PNNL-SA-154443.

Resiliency Planning Tools on a Larger Scale

North American Energy Resilience Model (NAERM)



Additional Resources:

1) https://www.energy.gov/sites/prod/files/2020/05/f75/Bindewald-Yuan_NAERM-EAC-May2020.pdf
2) https://www.energy.gov/sites/prod/files/2019/07/f65/NAERM_Report_public_version_072219_508.pdf

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Ideas for Applications to Central America

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Reliability and Resiliency Findings from Email Interviews

Reliability and Resiliency

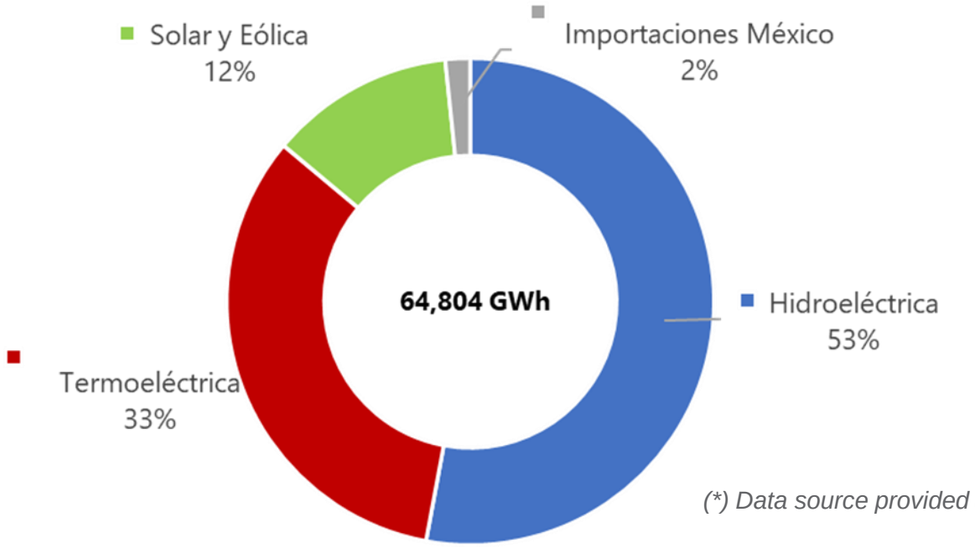
- Most of OS/OM have implemented reliability Key Performance Indicators (KPI). (*Not implemented resilience KPI*)
  - Time of service
  - Frequency of interruptions
  - AGC margins compliance
- Most of these KPI are not compulsory
- Some nations have not implemented reliability KPIs
- Some nations experience more operation issues that affect their own and neighboring power systems
- Causes of most common outages are:
  - Lighting and weather events
  - Defective components
  - Oscillations
  - Operational and human errors

Reliability and Resiliency Findings from Email Interviews

Planning for Reliability and Resilience

- Most of OS/OM do not plan considering resilience concepts. However, it is considered:
  - Niño phenomena (*Corredor seco: Pacific coast south Mexico to Costa Rica*)
  - Design for category III hurricane impact
  - Contingencies N-1, N-1-1, and N-2 for particular operation scenarios.
- Fuel supply chain: Some OS/OM observe the following subjects”
  - Back-up plans for *bunker* imports, taking up to 8 weeks.
  - Weekly planning for thermal units
  - Cost included in planning studies

Projected Regional Electricity Generation Dispatch - 2025 (*)



(*) Data source provided by EOR

Generation Matrix

- High speed wind seasons (Dec-Mar) in several nations of the region
- Some countries have identified maximum limits for VER penetration
- Identified slightly high PV production during dry seasons
- Niño phenomena highly impact system operation

Reliability and Resiliency Findings from Email Interviews

Power System Recovery and Operators Training

- All OS/OM have implemented recovery procedures after massive outage, independently of the source of the blackout – EOR implements real-time regional coordination for collaboration among control areas to restore the system
  - Recovery oriented to fast recovery of critical areas
  - Identification of critical loads (Distribution system operators)
  - Procedures to identify affected areas
  - Designed recovery strategies
  - Communication and coordination with regional transmission operators and distribution operators
- All OS/OM exhibit different training programs
  - Most of the OS/OM include annual training programs and drill activities
  - Durations are variable – 3 hrs. or 40 hrs.
  - Some OS/OM have training program that include generator/transmission system operators – Prepare seven months in advance
  - SCADA simulation environments to recreate past events
- No coordination *procedures to share resources* among local and regional operators

Reliability and Resiliency Findings from Email Interviews

Control Centers

- Not all OS/OM have implemented back-up control centers
  - Implemented back-up CC hot/hot configurations
  - Implemented temporal back-up centers during COVID period
  - Back-up centers infrastructure located in high-risk areas
  - Remote controlled substations

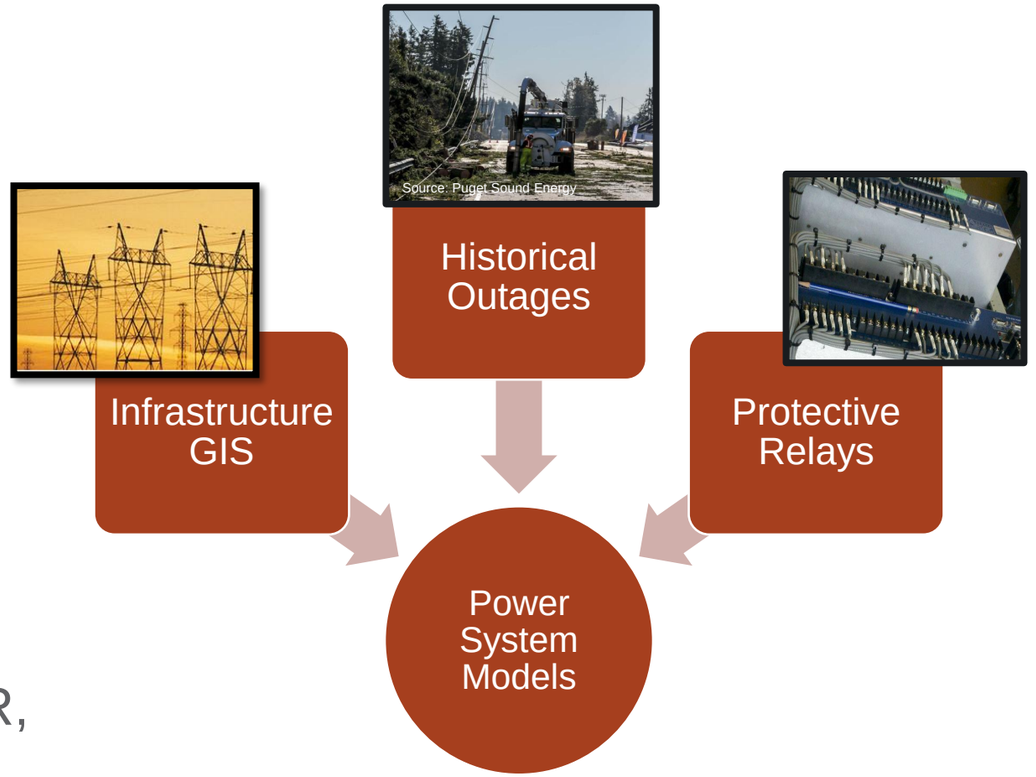
- Several OS/OM are certified with ISO and other standard compliance
  - ISO 9000 for almost all the OS/OM
  - ISO 14000 (Environmental management) – One OS/OM
  - ISO 27000 (Information Security Management Systems) – One OS/OM
  - ISO 45000 (Occupational health and safety) – One OS/OM
  - WECC and NERC standards – (Baja California CENACE Mx)

Considerations for Planning and Operation

- Consider implementing compulsory reliability KPI
- Quality assurance and certifications could help to improve operation procedures in those OS/OM that are not certified yet
- Develop the required infrastructure to operate back-up control centers considering safe and secure conditions
- Given the high impact of Niño and Niña phenomena and frequent hurricanes and earthquakes threats, it is recommended to conduct regional resilience studies considering extreme conditions:
  - Specialized production cost modeling studies
  - Infrastructure fragility like the earthquake performance-based studies
  - Cascading failure analysis

Modeling Extreme Events for Regional Resilience Studies

- Gather and coordinate information beyond traditional power system planning
  - Gather infrastructure fragility information for hurricanes and earthquakes
  - Maintain record of damaged infrastructure
  - Link and maintain power system models with geographic location of infrastructure
  - Enhance power system planning datasets and models with protective relay information
  - Coordinate data sharing among OS/OMs, EOR, and with Mexico and Belize if applicable



- EOR and OS/OMs should consider implementing coordinated resilience modeling practices
  - Cascading failure modeling of natural disasters
  - Modeling of extreme conditions such as extended droughts

Considerations for Preparation and Response

- Consider implementing mutual aid institution like Edison Electric Institute
  - Coordinated restoration effort
  - Sharing of restoration workers and specialized equipment
  - Regional electricity market (MER) member OS/OMs and EOR may be able to identify the efforts needed for establishing mutual aid institution in the Central American regional system
  - Mexico and Belize may consider participating in mutual aid programs with EOR and OS/OMs
- Standardize resilience training programs for OS/OM including regional transmission and generator operators (NERC standards PER-003-2, PER-005-2, and PER-006-1)

Upcoming Webinars

Remedial Action Scheme Design, Coordination and Modeling - April 14th and 21st, 2021

Resilience and Extreme Event Planning – May 12th and 19th, 2021

Transfer Capability and Coordinated Stability Studies – June 9th and 16th, 2021

Renewable Integration – July 14th, 2021

Final Session – August 18th, 2021

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Thank you!

Questions?

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