Electric system reliability and resilience: Discussion with the SEAB members July 26, 2022

- Granger Morgan, Carnegie Mellon University
- Anjan Bose, Washington State University
- Sue Tierney, Analysis Group

In our remarks today we will briefly:

- Summarize two National Academies' reports we helped to write.
- Identify strategies to increase electric-system resilience, noting limitations as to how well they will work.
- Note the challenges for better modeling/simulation tools for grid planning and operations in light of increasing uncertainties about the grid of the future.
- Talk about the urgent need for new policies, regulations, and strategies to maintain grid reliability and resiliency.

Two National Academies' studies on the grid

2017
https://www.nap.edu/24836

2021
https://www.nap.edu/25968

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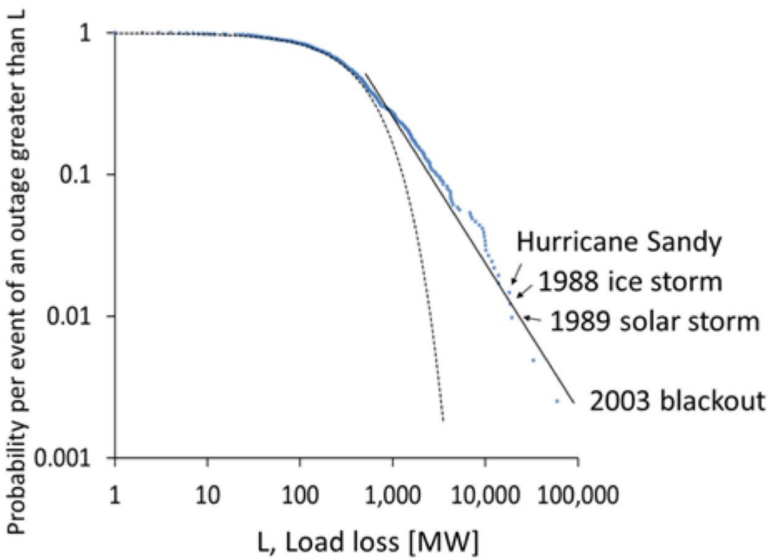
About the 2017 Study

Congressional request to DOE for the Academies to organize a study to identify technologies, policies, and organizational strategies to increase the resilience and reliability of the U.S. electricity system.

Our focus was wide-area outages of long duration (not the more common short-term outages).



Large, long-term outages occur more often that one might think.

Most visible reminder: Puerto Rico (after Maria)

60 days: 40% power restored
120 days: ~60% restored
180 days: ~90% restored

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Resilience ≠ Reliability

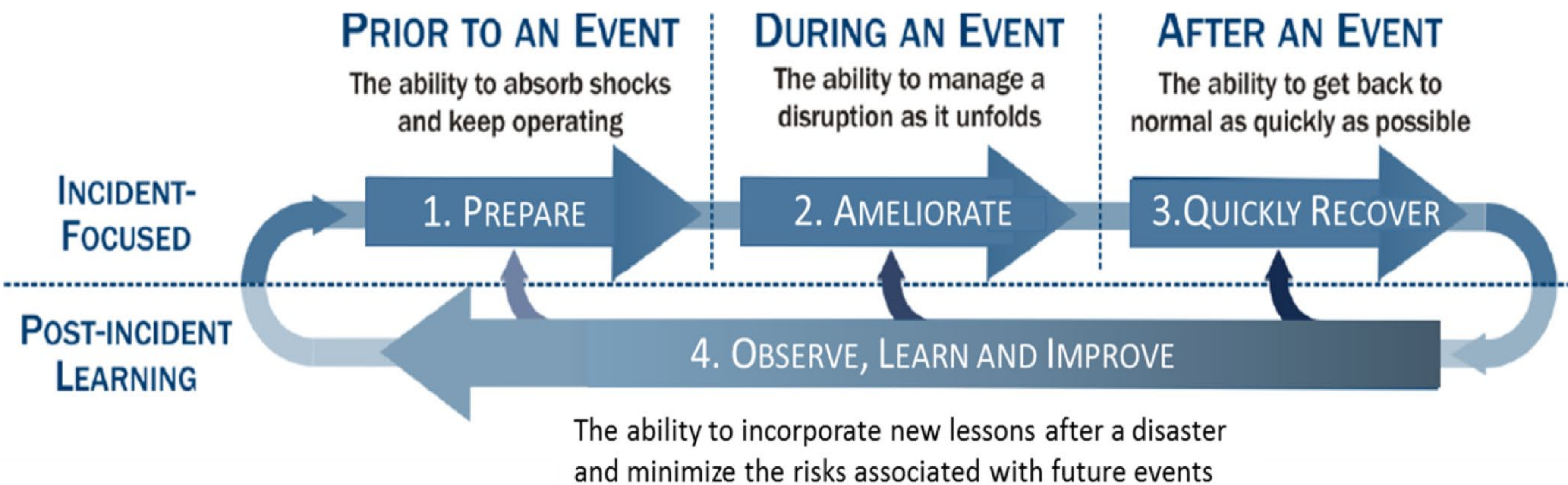
Random House Dictionary definition of resilience:

> "the power or ability to return to the original form, position, etc. after being bent, compressed, or stretched . . . [the] ability to recover from illness, depression, adversity, or the like . . . [to] spring back, rebound."

A resilient system:

- Minimizes the likelihood of large-area, long-duration outages
- Acknowledges that large outages can occur and prepares for them
- Minimizes their impact while they are occurring
- Is able to restore service quickly
- Learns from the experience to improve future performance.

The Committee’s framing of Grid Resilience



The NASEM report addresses these various elements of the cycle and identifies strategies to address them.

Framework motivated by Flynn, *Foreign Affairs* (2008)

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Many causes of grid failure

- Human induced
  - Physical attack
  - Cyber attack
  - Operat(or/ion) error(s)
- Natural events
  - Drought and associated water shortage
  - Earthquake
  - Flood/storm surge
  - Hurricane
  - Ice storm
  - Pandemic
  - Regional storms and tornados
  - Space weather
  - Tsunami
  - Volcanic events
  - Wild fire

Different causes require different preparation and have different consequences

A few images can make this idea more real:

Images sources: NYT, NOAA, CBC, NWS, Thinglink, NCAR, teara.govt.nz

Examples of strategies for reducing harmful consequences from loss of grid power

Greater attention to assuring the reliably of existing back-up, especially in context of a long duration large area grid outage.

More work on advanced preparations for the use of non-traditional sources of back up.

Make it possible for those with roof top PV to obtain power during outages, and to use hybrid and fuel cell vehicles for distributed backup power

Images from CAT; fslwfuels; Abley (1998), Geentech Media, GM.

Turning now to the 2021 National Academies' Report

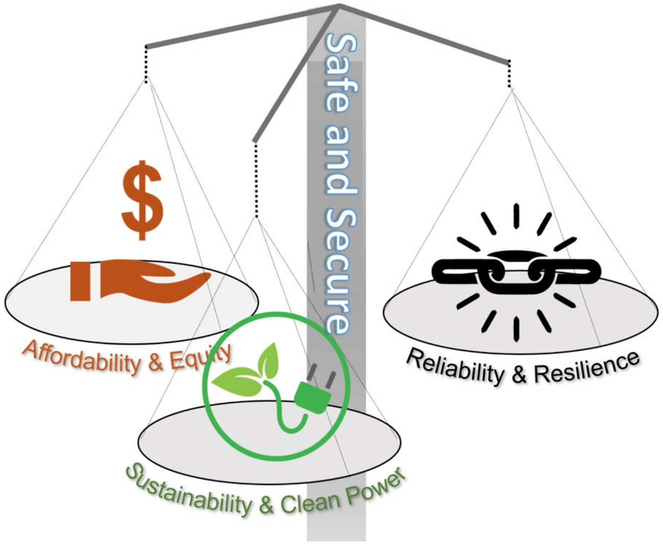
Congressional request to DOE for the Academies to "conduct an evaluation of the expected medium- and long-term evolution of the grid. This evaluation shall focus on developments that include the emergency of ***new technologies, planning and operating techniques, grid architecture, and business models***."

We ***do not*** say how the grid ***will*** evolve.

We ***do*** lay out ways it ***might*** evolve.

We identify the core value of the grid: *continued safe and secure operations* Around this central pillar, other attributes should also be balanced:

- affordability and equity
- sustainability and clean power
- reliability and resilience



2021 Future of Power Report

Our report discusses: *drivers of change; legal and regulatory issues; the problem of persistent under investment in electric power innovation; technologies and tools to enable arrange of future power systems; and issues related to creating a more secure and resilient power system.*

We discuss five major needs and make 41 specific recommendations.

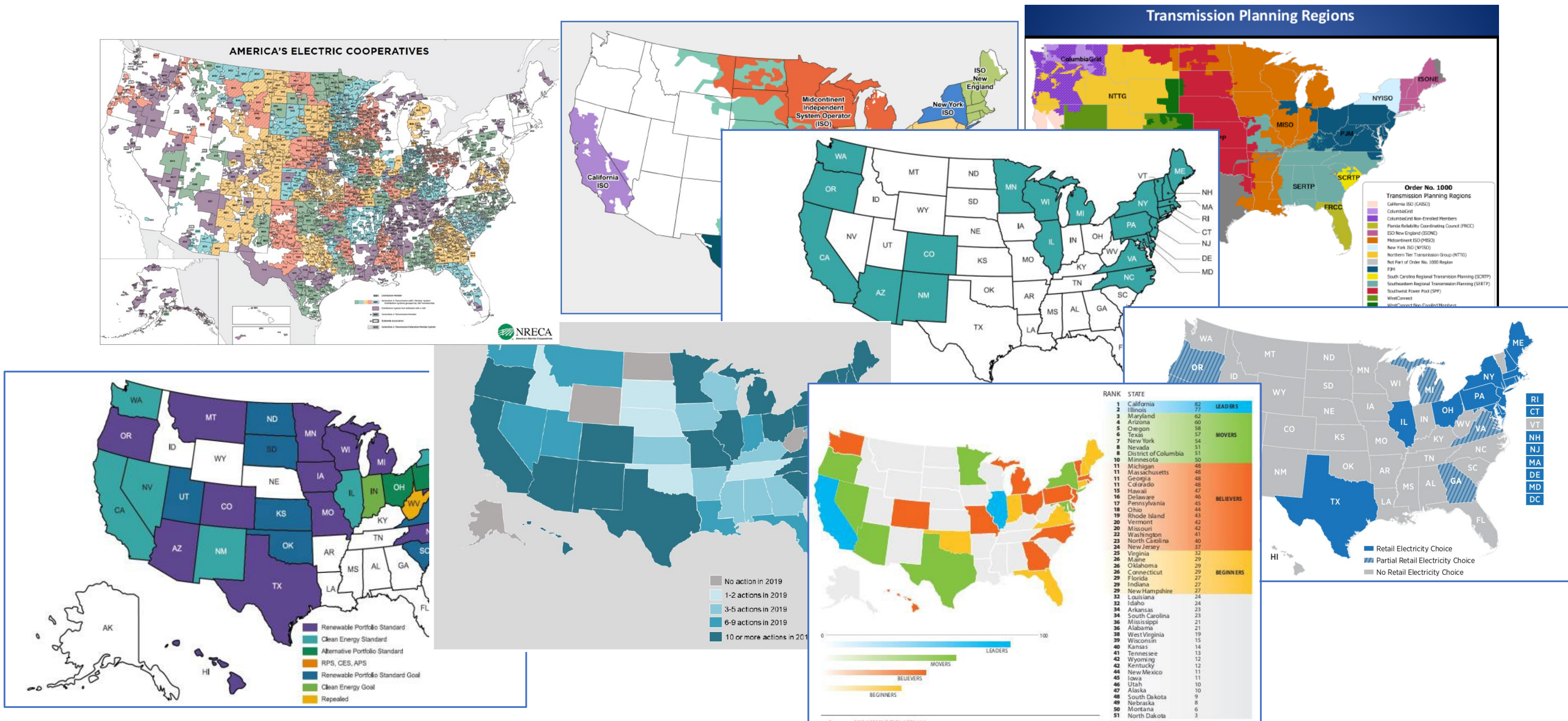
Our focus today will be on:

- Policy recommendations relating reliability and resilience (Sue)
- Tools for planning and operating for a reliable and resilient grid (Anjan)

Each of us will also share some of his/her own insights about these issues.

Turning to Sue on Policy…

Mapping “the” electric system



Some policy-related findings from the 2021 report

- The jurisdictional lines between federal v. state regulation in the electric industry have shown signs of increasing tension in recent years, as the industry undergoes significant technological, economic and social change.
- The generation segment is evolving rapidly and will likely continue to do so.
- Transmission planning and expansion have not kept up with the operational and regional delivery needs anticipated in the future electric system.
- Local utility distribution systems are greatly affected by changes at the grid edge, and state regulatory policies and incentives, combined with traditional utility business models, can either enable or frustrate innovation.
- Policy innovation at both the transmission and distribution system levels is critical to enable the vibrant changes needed to assure a low-carbon, reliable, resilient, and accessible power system for the future.

Some policy-related recommendations from the 2021 report

Congress and the states should support the evolution of planning for and siting of regional transmission facilities in the U.S., with changes in federal law to:

- Establish a **National Transmission Policy**
- Direct FERC to expand on the policy bases for **regional transmission planning**
- Give FERC responsibility to designate new **National Interest Electric Transmission Corridors** and to approve interstate transmission lines in them
- Direct DOE to provide **funds** to states, communities, tribes to enable **meaningful participation in regional transmission planning and siting**.

Note: Infrastructure Investment & Jobs Act:
- Retained and expanded/clarified DOE's NIETC authority
- Clarified FERC authority to issue a permit when a state has denied one in a DOE-designated NIETC context.

Note: FERC's 2022 NOPR on transmission

Additional policy-related recommendations from the 2021 report

- "State regulators... should *accelerate* their investigations into what **changes in industry structure, security, rate design and other pricing approaches, and market design** are needed to align with significant deployment of DER and to address equity issues in energy access and deployment of clean energy technologies."
- A new federal task force should be formed to identify whether any new legislative authority is needed so that the electric industry/regulators can **understand in a timely manner why a significant physical and/or cyber disruption occurred**.
- Congress should authorize FERC to designate a central entity to establish/enforce standards for the **reliability of the nation's natural gas delivery system**.
- Congress should provide federal funding (e.g., loans, grants) to encourage publicly owned utilities (e.g., municipal electric utilities, cooperatives, tribal utility authorities) to **invest in grid modernization**.

Note: Infrastructure Investment & Jobs Act:
- $3b for smart grid investment and $5b to fund resilience

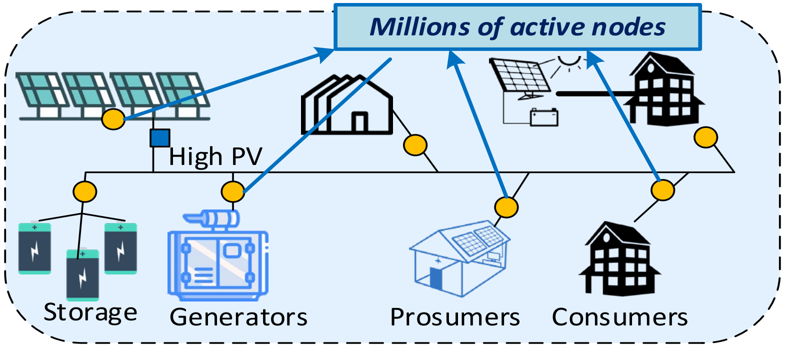
Continuing challenges regulation of the grid – for reliability and resilience

- There is a lot of clear authority for some specific issues – but not in terms of directing/guiding/regulating how the many pieces of the increasingly integrated bulk power system/local grids fit together
  - Resilience standards are lacking
  - Consistent reliability standards do not exist relating to fuel delivery, local distribution operations/cyber
  - Generation-related planning remains highly fragmented and disconnected from transmission planning

Turning now to Anjan on Technology and Tools…

Technology and tools

- Technology innovation is the *Foundation* of a robust electric grid.
- Key technologies Include:
  - Clean generation
  - Short and long-term energy storage
  - Power electronics, inverters, DC transmission, EVs, microgrids,
  - Advanced grid protection, control, communications, automation and simulation



Grid of the future

Some findings re: technology and tools in the 2021 report

Clean Generation and Commercialization (5.1, 5.2)

- Government and Industry collaborate to develop, fund and de-risk new and critical technologies essential to the future grid (including generation, storage, and distributed energy technologies with no emissions).

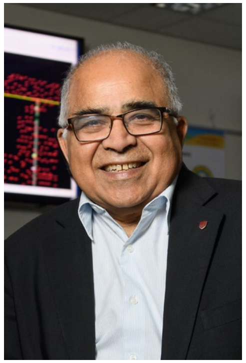
Communication, Automation, and Simulation (5.3-5.8)

- Develop ICT *secure and reliable* technologies to support enhanced participation from grid connected devices to enable a flexible grid.
- Develop technologies to enable a high-level of automation and resilient system.
- Develop advanced *inter-compatible* simulation tools that can analyze the evolving grid architectures.
- Explore the use of large field experiments for new grid architectures.

Develop Workforce of the Future (5.9, 5.10)

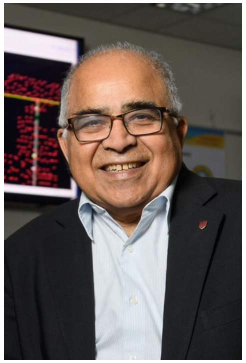
- Fund training and retraining of the current and future workforce.

Reliability metrics/calculations



- **Generation adequacy**
  - One day in 10 years (0.9997) Loss of Load Probability (LOLP)
    - Analytic calculation using probability distributions
    - Monte Carlo simulations using probability distributions
  - Old rule of thumb – 15% reserve over max demand
- **Transmission Reliability**
  - Withstand single contingency (N-1 criterion)
    - Power network simulations
    - Probabilistic methods don’t work
- **Planning vs Real Time Operation**
  - Use worst contingency for operation

Resiliency (for extreme weather)



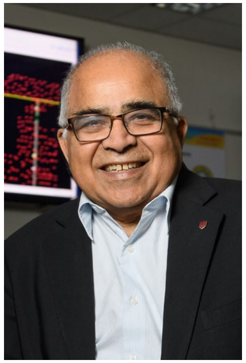
As Granger noted…

- Resiliency is the ability to recover from outages after an extreme weather (or other) event
- Reliability is the measure of avoiding outages
- Resiliency depends on severity of weather event and restoration readiness

Additionally:

- All utilities have restoration plans and practice drills
- As of now, there are no standard metrics or calculations for resiliency
- Resiliency depends more on the characteristics of the distribution system than the bulk power system

Challenges due to grid transformation



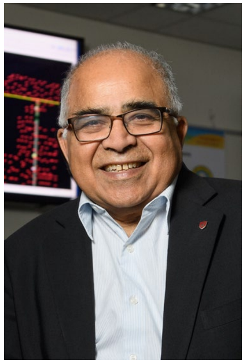
Generation Adequacy

- Availability characteristics of distributed generation less known (larger variance results in need for more reserve)
- More generators necessitates more Monte Carlo simulations

Network Reliability

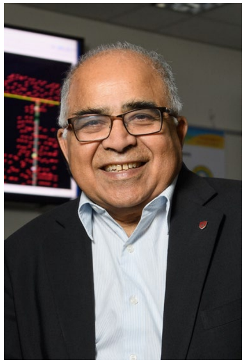
- Generation contingencies have to be redefined
- Distribution-feeder contingencies must be added to N-1 lists
- Distribution system must be simulated for contingencies
- Standard models needed for new equipment (inverters, batteries, etc.)

Challenges for resiliency



- Extreme weather events are expected to increase
- Standards for restoration planning will be helpful
  - For pre-storm preparation
  - During storm
  - After storm restoration
- Some resiliency metrics for designing/planning of distribution feeders will be helpful

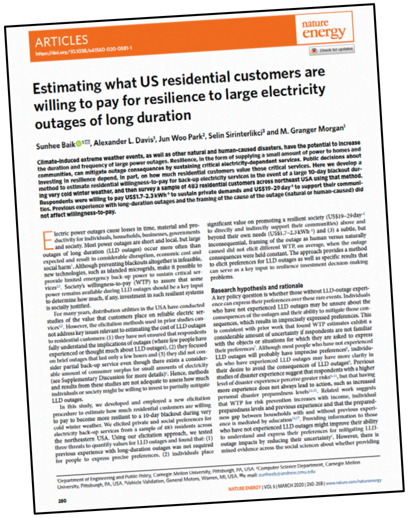
Standards = more important than math



- The analytical techniques, models and solution algorithms will require R&D and need to evolve
- More important: the adoption of standardized metrics so that everyone in an interconnection uses compatible metrics
- Also important: the standardization of the best models and analytical techniques so that the results obtained from them are compatible across the interconnection
- The bulk power system and the distribution system can no longer be analyzed separately as their impact on each other keeps growing

Now back to Granger…

Insights from 3 CMU studies …


ARTICLES

nature energy

Estimating what US residential customers are willing to pay for resilience to large electricity outages of long duration

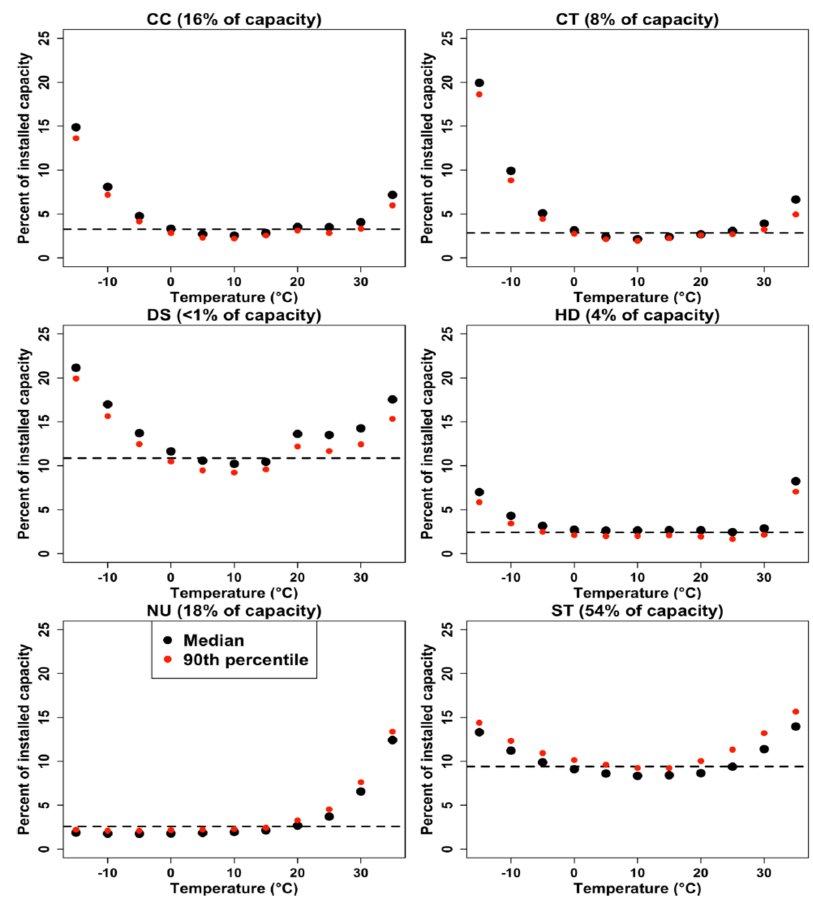
Sunhee Baik, Alexander L. Davis, Jun Woo Park, Selin Sirinterlikci and M. Granger Morgan

Recent PhD graduate Sunhee Baik (now at LBNL) For a large 10-day blackout during very cold winter weather…: ”a sample of 483 residential customers… were willing to pay US$1.7–2.3/kWh to sustain private demands and US$19–29/day to support their communities.”

Prof. Jay Apt and several of his recent PhD students have done extensive work on generation reliability – focusing especially on natural gas and on temperature extremes.

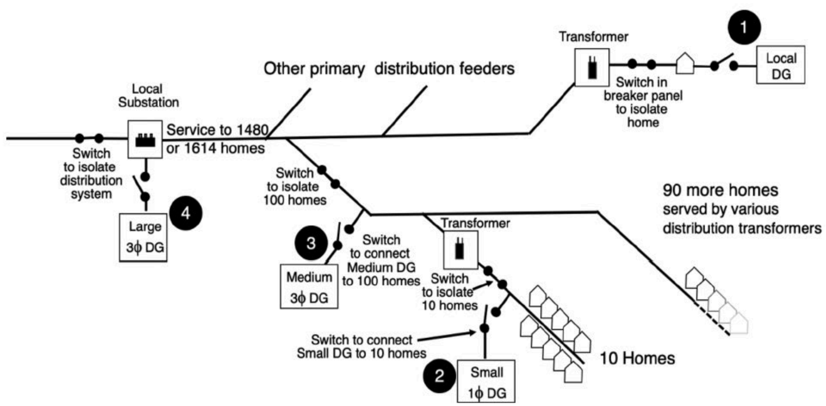
Here is one example based on 23 years of data for 1845 generators in PJM.
The results show that by contrast to the usual assumption, outages are correlated.

Source: Murphy, S., Sowell, F., & Apt, J. (2019). A time-dependent model of generator failures and recoveries captures correlated events and quantifies temperature dependence. *Applied Energy*, *253*, 113513.



Insights from 3 CMU studies…

PhD student Angelena Bohman (who will join DOE when she graduates at the end of the year) has been working on a variety of issues related to increasing the resilience of the power system.



Risk Analysis, Vol. 42, No. 3, 2022

DOI: 10.1111/risa.13765

Individual and Collective Strategies to Limit the Impacts of Large Power Outages of Long Duration

Angelena D. Bohman[1,*] Ahmed Abdulla[2] and M. Granger Morgan[1]

As modern society becomes ever more dependent on the availability of electric power, the costs that could arise from individual and social vulnerability to large outages of long duration (LLD-outages) increases. During such an outage, even a small amount of power would be very valuable. This article compares individual and collective strategies for providing limited amounts of electric power to residential customers in a hypothetical New England community during a large electric power outage of long duration. We develop estimates of the emergency load required for survival and assess the cost of strategies to address outages that last 5, 10, and 20 days in either winter or summer. We find that the cost of collective solutions could be as much as 10 to 40 times less than individual solutions (less than $2 per month per home). However, collective solutions would require community-wide coordination, and if local distribution system lines are destroyed, only individual back-up systems could provide contingency power until those lines are repaired. Costs might be reduced if more robust distributed generation were employed that could be operated continuously with the ability to sell power back to the grid. Our cost-effectiveness analysis only assesses what *could* be done, developing estimates of preparedness cost. A decision about what *should* be done would require additional input from a range of stakeholders as well as some form of analytical deliberative process.

KEY WORDS: Blackouts; distributed energy resources; electric power resilience; grid transformation; power outages

1. INTRODUCTION

Most disruptions in electric power service are limited in scope and duration. These are also the ones utilities track most carefully and report in standard measures of reliability such as the System Average Interruption Duration Index (SAIDI) and the System Average Interruption Frequency Index (SAIFI). However, large electric power outages of long duration (LLD-outages), which are defined as "blackouts that extend over multiple service areas or states and last several days or longer," are possible and do occur (National Academies [NASEM], 2017). The potential causes of LLD-outages are myriad and extend beyond natural hazards such as major storms, floods, and earthquakes, to include cyber or physical sabotage, operator error, and instabilities that can cascade across the continent-spanning high voltage power transmission system. Such outages incur large costs: vulnerable people die; food spoils; water, sewage or energy services fail; pipes freeze; economic output diminishes; and emergency services struggle (NASEM, 2017).

For example, in 1998 an ice storm collapsed 770 high voltage transmission towers and 26,000 distribution poles, destroyed 4,000 pole-top transformers, and left 5.2-million customers across southern

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Working with LBNL she had built a summary and completed a literature review of strategies to improve resilience.

If in the open move into a secure building
If in a flood-prone location move to higher ground & flood monitors
Shock-mount for vibration protection
Maintain portable replacement substations
Pre-stage equipment

Perform regular vegetation management
Increase pole inspection and replacement cycle
Convert conventional wood poles to steel, reinforced concrete, and possibly shorter
Underground lines (including flood-proofing)
Sensors/controller to monitor/assess status
Increase number of dead-end structures
Higher strength and/or quick disconnect wires
Use wind dampeners
Pre-stage replacement equipment

Transmission level

Central generation

HV substations

HV transmission

DERs

Distribution and customer level

DG & storage in distribution

Distribution circuits

DG & storage at customers

If in a flood-prone location move to higher ground
Assure adequate fuel availability/storage
Prestaging replacement equipment
IF conventional generator
If in the open, move into a secure building
Increase quantity and security of local fuel storage/supply
Shock-mount for vibration protection
IF PV
Lower profile and hardening: flush and pole mounted racking options.
Storm covers
IF Wind
Use more resilient tower structures
Use down-wind geometry

Perform regular vegetation management
Increase pole inspection and replacement cycle
Convert wood poles to steel or reinforced concrete
Underground AC circuits
Use sensors/controller to monitor/assess status
Shorten span between poles or shorter poles
Higher strength and/or quick disconnect wires
Use wind dampeners

Individual end user
Portable or pad-mounted generator w/adequate fuel
Resilient PV with local storage

People, Planning and Organization
Maintain:
An up-to-date emergency preparedness plan (who does what, when)
A pre-identified list of critical loads for load-shedding and restoration priority
Pre-standing arrangements with local governments, and with other utilities for augmented emergency crews.

Groups of end users
μ-gird or distribution smart switches that allow intentional islanding with:
Local fossil generation w/ adequate fuel source
Resilient PV with local storage

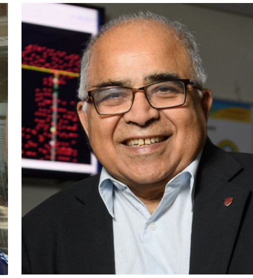
Some summary thoughts:

Although we can identify strategies to enhance resilience, no one knows how effective each will be in the face of the various threats that climate change and extreme events present to the grid.

Unlike short term reliability, there is no adequate metric for resilience.

The only way we know how to assess resilience is through simulation studies. For the most part such studies have not been done. They should be a focus of work undertaken in the coming years by the DOE Office of Electricity.

Some summary thoughts:



While good electric-system reliability data are available, similar not exist for natural gas. Our recent NASEM study recommended that such reporting should be required. (Rec. 3.2)

Modeling and tools to support grid expansion planning will have limited value until existing authorities are expanded (and/or new authorities are established) so as to assure coherent, system-wide planning for both generation and transmission.

This issue will become even more challenging as distributed resources continue to grow.

DOE should give serious thought to what it might do, in coordination with its federal partners, to assure that the needed expansion of authority occurs.