# Mitigation, Rapid Restoration Strategies, and Best Practices – with Case Studies

**Presented by Nichole Hanus, Berkeley Lab**

**Resilience Training for States**

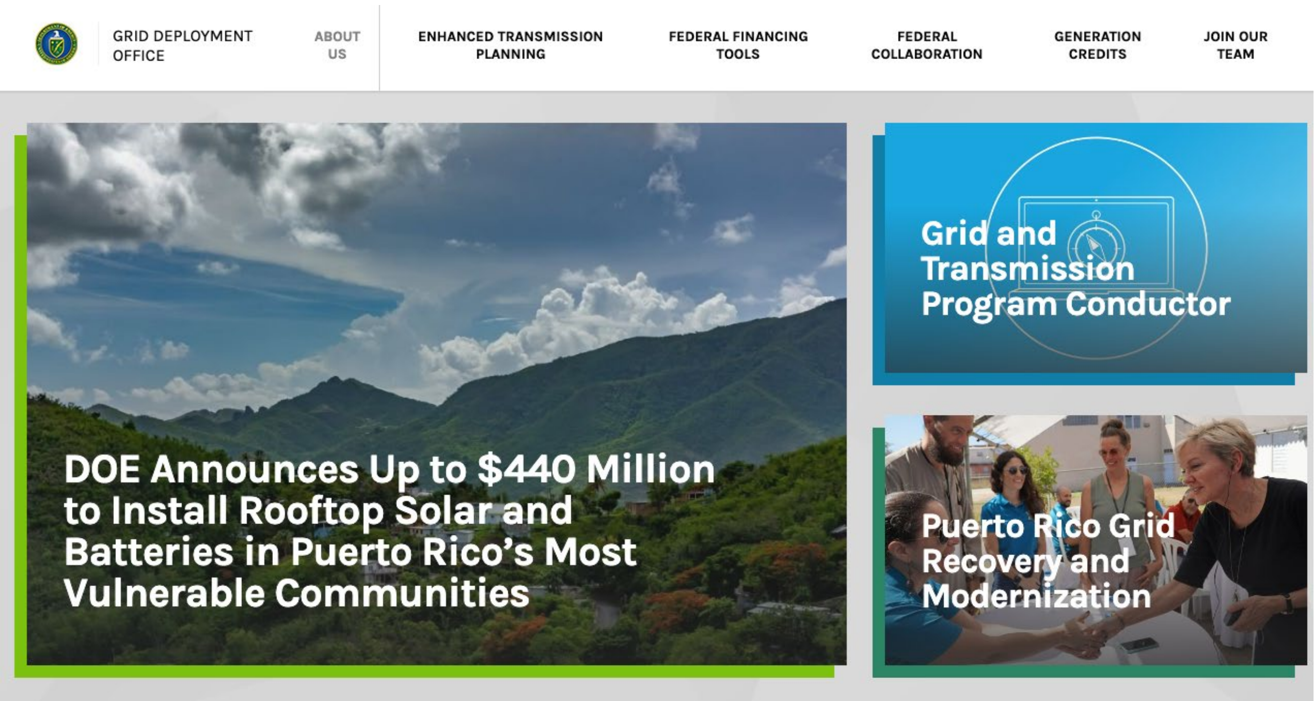
November 30, 2023

# Today's agenda

- Resources from the U.S. Department of Energy's Grid Deployment Office
- Overview of identified grid resilience strategies
- Three case studies of mitigation strategies implemented in various U.S. jurisdictions

# Resources from GDO

- ***The Grid Deployment Office (GDO)*** provides guidance to State Energy Offices, regulators, utilities, and other electricity investment decision-makers on ***grid resilience best practices***
- ***FORTHCOMING*** – Early 2024 Resources:
  - **3 Resilience Prioritization Case Studies**
    - NY Con Ed – East 13th St. Substation Hardening
    - FL Duke Energy – Undergrounding Lines
    - CA SDG&E – Borrego Springs Microgrid
  - **10 Resilience Strategy Fact Sheets**
    - Undergrounding
    - Pole Investments
    - Wires Investments
    - Vegetation Management
    - Monitoring and Controls
    - Adaptive Protection Technologies
    - Distributed Energy Resources (DERs)
    - Weatherization Technologies
    - Fire-resistant/prevention Technologies
    - Advanced Modeling Technologies
- GDO is developing the case studies and fact sheets to provide ***timely guidance*** on how to take advantage of funding available through the ***Infrastructure Investment and Jobs Act (IIJA)***




[1] Source: https://www.energy.gov/gdo/grid-deployment-office

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# Overview of Resilience Strategies

# General Pros/Cons/Costs of Resilience Strategies

| Strategy | Description | Pros | Cons | Costs |
|---|---|---|---|---|
| **Vegetation Management** | Ground-to-sky clearing on a regular cycle, hazard-tree programs, targeted maintenance | Prevents initial outages and reduces restoration times against:<br>• High winds<br>• Severe rain<br>• Ice | • Subject to utility rights-of-way to affected areas<br>• May have aesthetic impacts, causing community resistance | Vegetation management is less costly than other measures (such as undergrounding) and can be quite cost-effective overall |
| **Hardening** | Undergrounding, substation and generation hardening, utility pole investments, and wires investments | This broad list of strategies improves performance against:<br>• Extreme weather conditions<br>• Flooding<br>• Wildfire<br>• Vehicle and animal interference | Disadvantages vary across these strategies, but generally include higher capital and maintenance costs than traditional infrastructure | Costs vary across strategies by a wide margin |
| **Customer-focused Strategies** | Distributed energy resources (e.g., storage, demand flexibility, microgrids) and making buildings more resilient | DERs can be flexibly harnessed to support the grid by:<br>• Reducing peak demand and alleviating stress on the transmission and distribution systems<br>• Providing voltage and frequency support<br>• Cutting costs for both grid operators and energy<br>• Increasing consumer resilience | • Larger-scale DERs are considerably more expensive than individual backup generators, which are already mature and widely adopted in the market<br>• DERs that rely on variable energy sources are susceptible to weather conditions | Costs of DERs can be high and vary based on system size, location, configurations, and complexity |
| **Redundancy and Back-up** | Includes transmission-, distribution-, and customer-level strategies | Prevents initial outages and reduces restoration time across threats to utility-scale generation and distribution | Can be a time-intensive strategy requiring planning and coordination across multiple parties | Costs will depend on the existing redundancy and back-up in place at the generator or by individual customers |
| **Grid Modernization Technologies** | Advanced Distribution Management System (ADMS); Fault Location, Isolation, and Service Restoration (FLISR); Distributed Energy Resource Management System (DERMS) | Prevent outages and reduces system average restoration times against these hazards by automatically reconfiguring grid operations | Primary disadvantage is wide-scale investment for grid sensors, systems integration, and communication infrastructure, including advanced metering infrastructure | Wide range of costs, primarily due to differences in the scope of what is included in each utility plan or program |

# Vegetation Management

- **Tree pruning:** Cutting back tree growth to maintain clearances from utility transmission and distribution overhead lines
- **Tree removal:** Taking out damaged, unhealthy, or dead trees in proximity to utility lines
- **Vegetation control:** Removal of flammable brush and suppression of hazardous brush growth
- **Integrated vegetation management:** "promoting desirable, stable, low-growing plant communities that will resist invasion by tall-growing tree species through the use of appropriate, environmentally-sound, and cost-effective control methods" [2]

**Cost Range:** $3,000 – 12,000 / mile [3-7]


[8] Source: EPRI



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# Hardening

## 1. Undergrounding

[8] Source: EPRI

## 2. Pole Investments

## 3. Wire Investments

# 1. Undergrounding

**Advantages:**

- The key advantage of underground transmission and distribution lines is reduced vulnerability to disruption from extreme weather and wildfires
- Larsen (2016) found that a 10% increase in a system's underground line miles was correlated with a 14% reduction in annual interruption durations across the U.S. [9]

**Disadvantages:**

- Underground repairs generally take longer because of access difficulties
- Underground lines also have generally shorter lifetimes than overhead
- Depending on location, underground transmission and distribution lines may be at risk from flooding, including due to sea level rise

**Cost Range:**

- Transmission: $6 – 100M / Mile [10]
- Distribution: $0.2M – 6M / Mile [10-12]

[8] Source: EPRI

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# 2. Utility Pole Investments

- Two general types of pole-related measures for improving transmission and distribution reliability and resiliency:
  - inspection and maintenance of installed wood poles
  - conversion of wood poles to non-wood material
- Inspection and maintenance:
  - decayed but can be serviced and remain in use
  - decayed to the point of requiring replacement

**Disadvantages:**

- Wood poles are easier to climb than non-wood poles and are less conductive than steel and ductile iron poles, which are safer for line-workers.
- Additionally, concrete and ductile iron poles are heavier than wood poles, making them difficult to transport.

**Cost Range:**

- Transmission: ~$37,000 / Mile (inspection and repair) [13, 14]
- Distribution: $500 – 10,000 / Pole (inspection and repair) [15, 16]

[17] Source: Wikipedia



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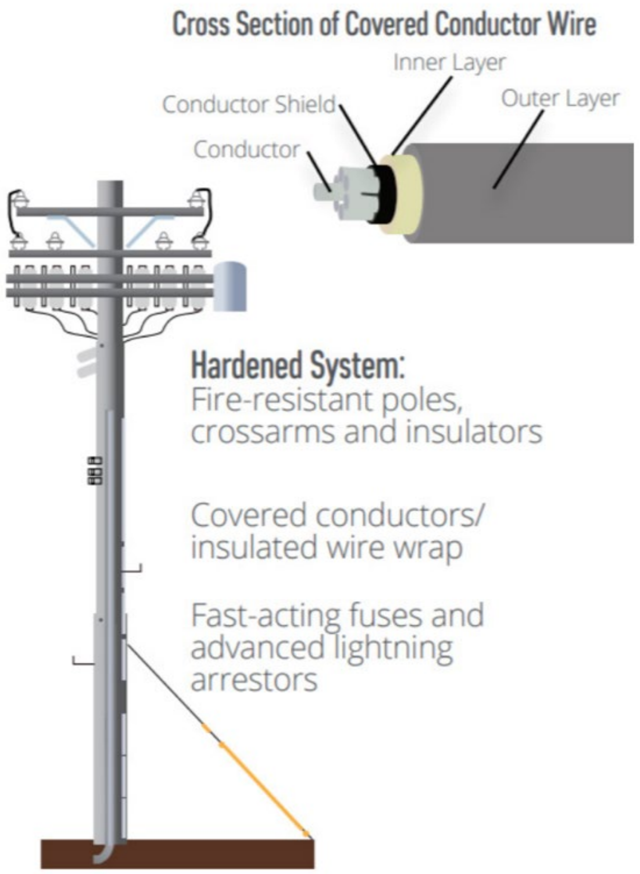
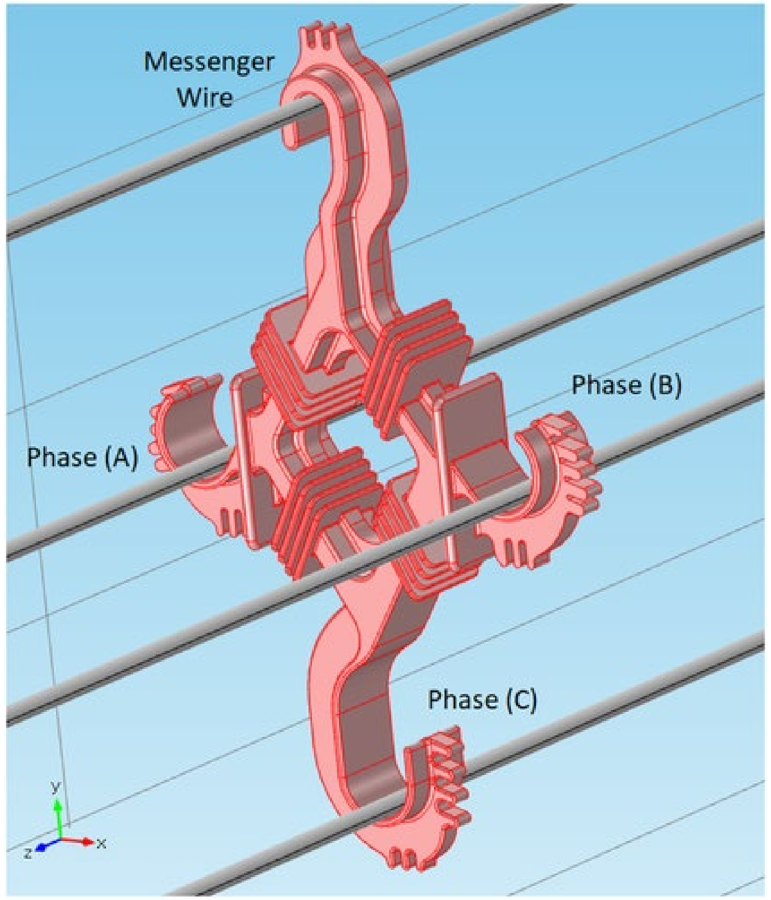
# 3. Utility Wire Investments

- Relocation/replacement or reconductoring of power lines with low-sag, advanced conductors, covered conductors, spacer cables, guy wires
  - **Covered Conductors:** Equipped with an external polymer sheath to prevent accidental contact with other conductors and grounded objects
  - **Spacer Cables**: Type of overhead power line construction that employs non-shielded, non-tensioned, insulated conductors arranged in a compact triangular configuration
- **Line Management and Inspections**: Infrared assessments, corona scanning, and high-definition imagery acquisition can detect defects and abnormalities that may not be visible during mandatory inspections
- **Disadvantages**: Wire insulation is costly (much more than vegetation management) and is less effective than undergrounding

**Cost Range:** $200k - 1,430k / Mile [18-20]




[21] Source: Edison Electric Institute




[22] Source: Stefenon, et al. (2022)



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# Customer-focused Strategies

[8] Source: EPRI

- DERs encompass a diverse array of small-scale, modular, and decentralized energy technologies that can be employed individually or in combination to deliver power and energy services in close proximity to end-users.
- Customer-focused strategies include:
  - Microgrids / community resilience hubs
  - Solar PV
  - Solar + storage
  - Electric vehicles (EVs) w/ bidirectional charging
  - Smart thermostats
  - Energy efficiency

**Cost Ranges:**

- Microgrids / resilience hubs: $1-6M / MW [23, 24]
- Solar: $3-5 / W [25]
- Solar + Storage: $4-7 / W [25]
- EVs w/ bidirectional charging: $30-70k / vehicle (not including chargers) [26]
- Smart thermostats: $80-300 / thermostat [27]
- Energy efficiency: Varies by approach [28]

# Energy Efficient and Grid-Interactive Buildings

| | During ***Normal*** Grid/Fuel Supply Operations | During Grid/Fuel Supply ***Outage*** |
|---|---|---|
| Energy Efficiency | • Reduced disruptions from demand spikes<br>• Lower costs for total energy required<br>• Greater comfort, higher indoor air quality | • Increases passive survivability – the ability of buildings to maintain habitable conditions in the event of a heating/cooling system loss [29] |
| Energy Efficiency with Onsite Generation + Storage | • Cost savings from reduced demand charges and sale of excess power<br>• Support renewable energy target/goals<br>• Reduced disruptions due to demand spikes<br>• Provision of other grid services | • Continuity of energy services |

[30] Table adapted from DOE's Better Buildings Resilience Website

# Redundancy and Backup

**Strategies for transmission include:** [31]

- If in an open, flood-prone location, move to higher ground and/or a more secure building (e.g., control room)
- Assure adequate fuel availability/storage
- Increase quantity and security of local fuel storage/supply
- Shock-mount for vibration protection
- Pre-stage replacement equipment

**Strategies for distribution and customers include:** [31]

- Portable or pad-mounted generator w/ adequate fuel
- Resilient PV + storage
- Grouping end-users (e.g., islanding) and ensuring local fossil generation has adequate fuel source (or resilient PV + storage)


[32] Source: Foremost

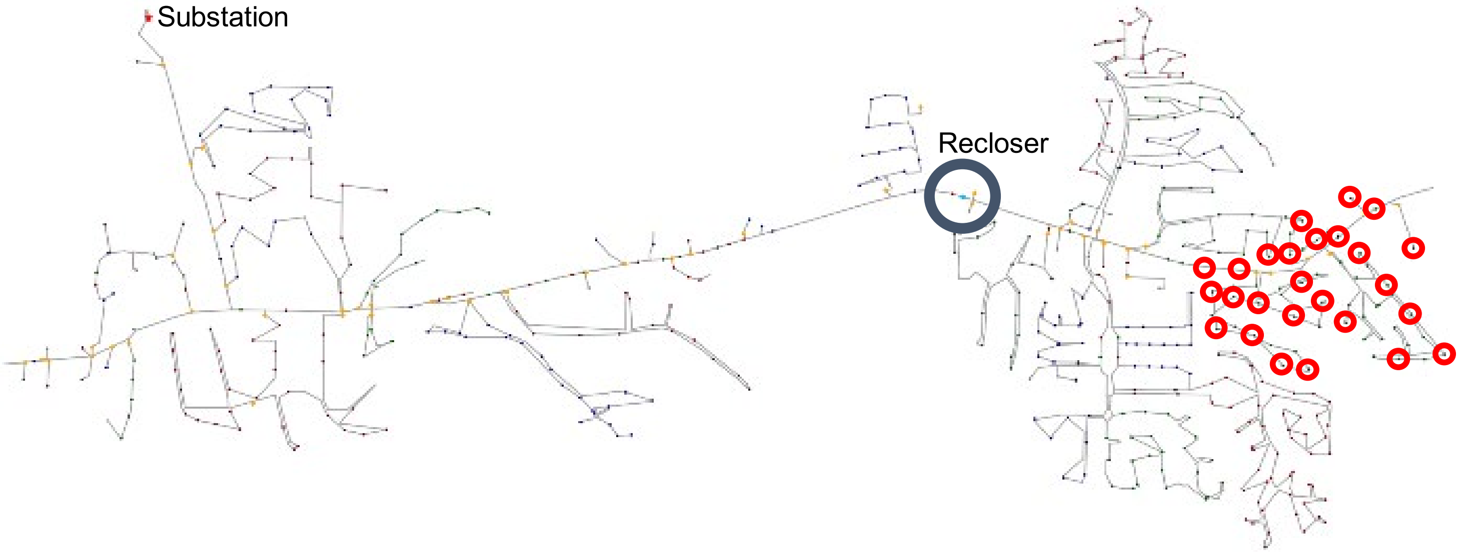
# Grid Modernization Technologies

- **Advanced Distribution Management System (ADMS):** Enterprise software platform that enables utility engineers, field crews, and operations personnel to better monitor, control and optimize distribution grids

- **Fault Location, Isolation, and Service Restoration (FLISR):** Grid sensors and software that integrate with ADMS to quickly locate and isolate faults on the grid and automatically restore power to as many customers as possible

- **Distributed Energy Resource Management System (DERMS):** Enterprise software that monitors and controls DERs and optimizes of dispatch based on grid needs

[8] Source: EPRI




**Cost Ranges:**
- ADMS and/or DERMs: $10.7 - 20.9 / customer [33, 34]
- Comprehensive plans: ~$200 / customer [35, 36]

# Resilience Strategy Case Studies

# Florida Power & Light: Grid Hardening

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# Florida Power & Light's Modified Storm Protection Plan [37]

- Following extreme weather events in Florida (e.g., Hurricane Matthew (2016) and Irma (2017)), the state began requiring utilities to file Storm Protection Plans (SPPs) detailing the utility's 10-year transmission and distribution needs

- Must file a report at least every 3 years

- The scope of the plans should include all transmission and distribution facilities: poles, fixtures, towers, overhead conductors, substations, land and land rights, underground materials, etc.

Docket No. 20220051
FPL's 2023-2032 Storm Protection Plan
Modified Exhibit MJ-1, Page 1 of 51

FPL.

**Florida Power & Light Company**

**Modified**

**Storm Protection Plan**

**2023-2032**

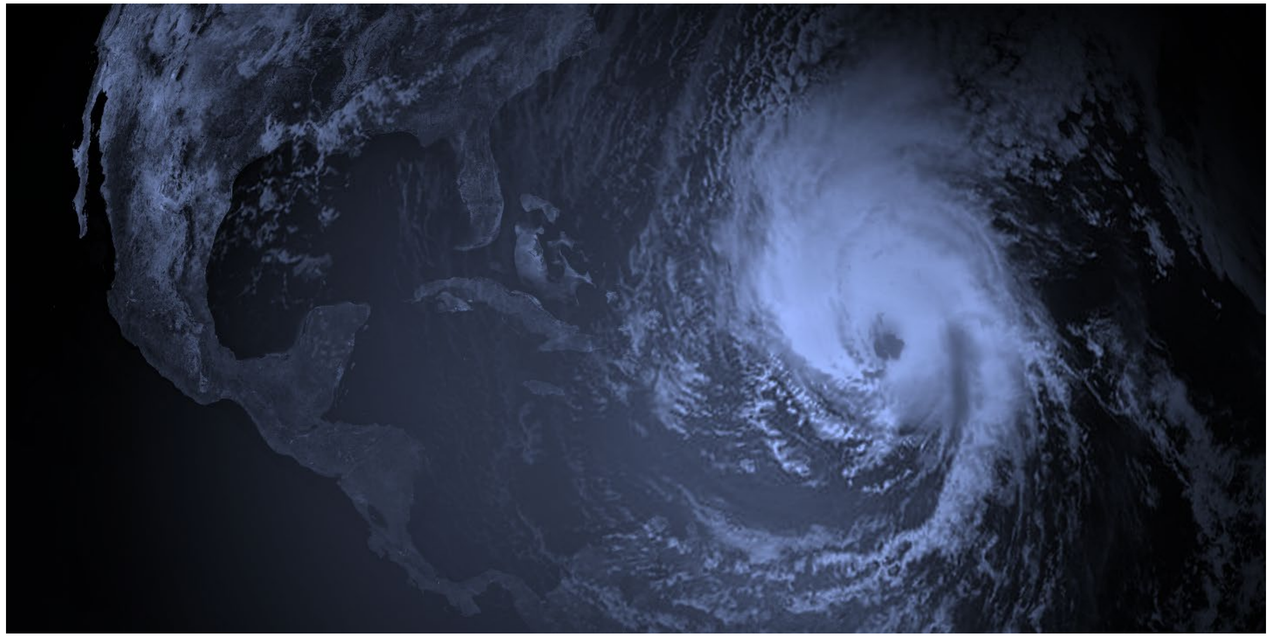
**(Rule 25-6.030, F.A.C.)**

**Docket No. 20220051-EI**

**November 14, 2022**

# FPL's Hardening Strategies

- The 2023 SPP is largely a continuation of programs approved in the 2020 SPP:
  - Distribution Inspection Program
  - Transmission Inspection Program
  - Distribution Feeder Hardening Program
  - Distribution Lateral Hardening Program
  - Transmission Hardening Program
  - Distribution Vegetation Management Program
  - Transmission Vegetation Management Program
  - Substation Storm Surge/Flood Mitigation Program



[8] Source: EPRI



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# Distribution and Transmission Inspection Programs

- **Distribution Inspection Program:**
  - Commission requires IOUs to implement an eight-year pole inspection cycle for all distribution poles
  - FPL utilizes a contractor to inspect 1/8 of poles annually:
    - Must meet National Electrical Safety Code's (NESC) standards
    - Visual inspections for above-ground
    - Wood poles: 18" underground inspection – "Shell Boring"
    - Chromium Copper Arsenate (CCA) (wood preservative) poles are only excavated if > 28 yrs old
- **Transmission Inspection Program:**
  - Commission requires IOUs to implement a six-year inspection cycle for all transmissions structures
  - All of FPL's transmission structures (e.g., substations) are visually inspected annually
  - Climbing/bucket truck inspections are performed on wooden structures every six years; steel structures every 10 years

Improvements ***before inspection programs*** (Hurricane Wilma – 2005) and ***after inspection programs*** (Hurricane Irma - 2017) for distribution and transmission systems, respectively:

| | Hurricane Wilma | Hurricane Irma |
|---|---|---|
| Hurricane Strength (Category) | 3 | 4 |
| Customer Outages (Millions) | 3.2 | 4.4 |
| Distribution Poles Replaced | >12,400 | <2,900[13] |
| Total Days to Restore | 18 | 10 |
| Average Days to Restore | 5.4 | 2.1 |

[37] Source: FPL

| Transmission Facilities | Hurricane Wilma | Hurricane Irma | Improvement |
|---|---|---|---|
| Line Section Outages | 345 | 215 | 38% |
| Substation Outages | 241 | 92 | 62% |
| Structures Failed | 100 | 5 | 95% |

[37] Source: FPL

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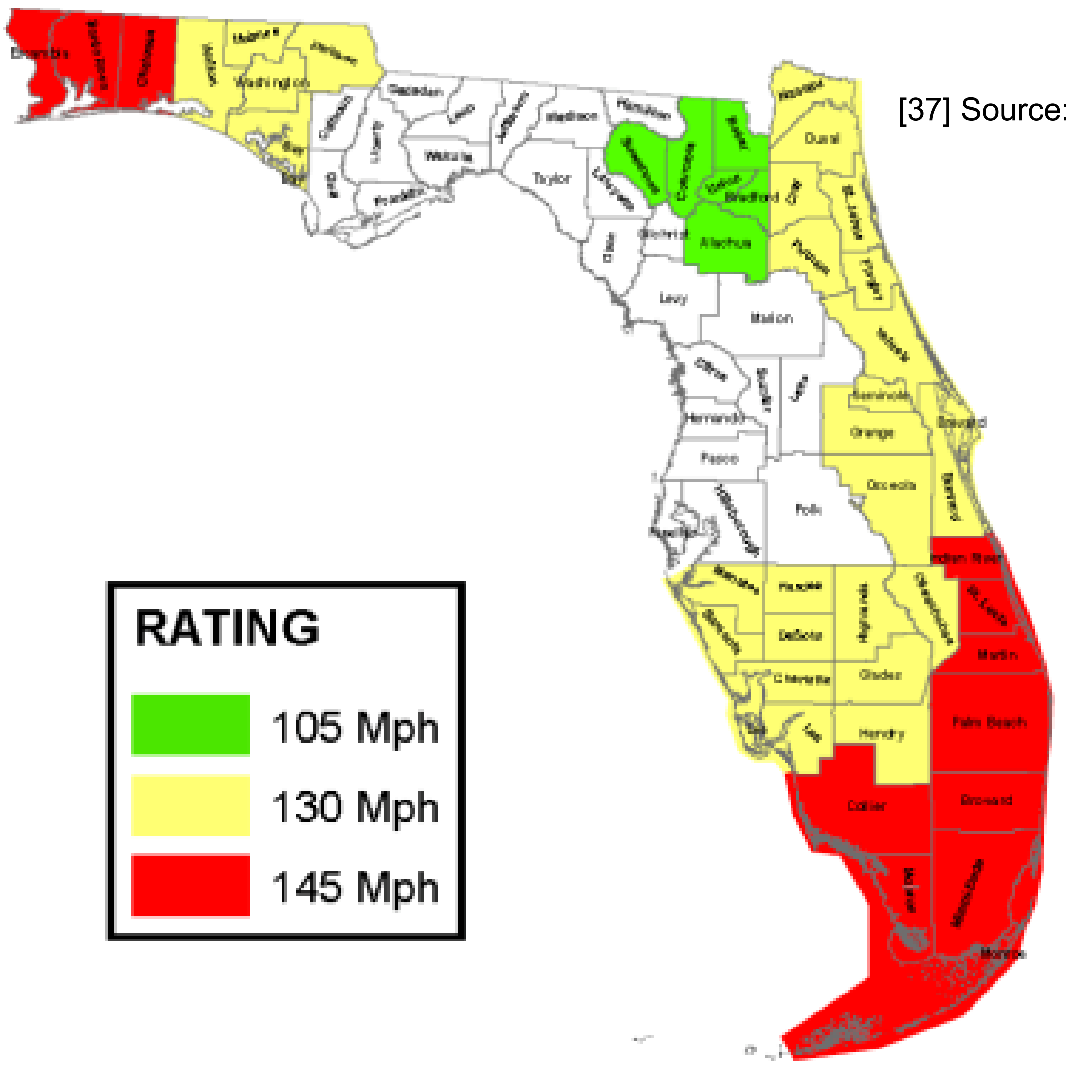
# Distribution Feeder and Lateral Hardening Programs

- **Distribution Feeder Hardening Program:**
  - After Hurricane Wilma, FPL realized that “wind only” threats were the driver for downed distribution poles
  - They apply NESC’s “extreme wind loading” (EWL) criteria to ***harden existing*** distribution feeders and critical poles and for the ***design of new*** poles
  - FPL’s design toolkit: storm guying, equipment relocation, intermediate pole, upgrading pole class, and undergrounding facilities

- **Distribution Lateral Hardening Program:**
  - This is a continuation of the 2020 SPP undergrounding pilot; the 2023 SPP targets overhead laterals impacted by recent storms and prioritizes them for undergrounding
  - Lessons learned from undergrounding pilots:
    - Place underground lines in public or rights-of-way to reduce easement approvals
    - Utilize directional boring
    - Utilize Ground Penetrating Radar
    - Initiate community meetings for education and to address concerns

**FPL Extreme Wind Regions**




[37] Source: FPL

# Transmission Hardening Programs

- A transmission-related outage can affect tens of thousands of customers compared to a distribution-related outage, which can affect several thousands of customers
- Transmission outages can also lead to cascading failures
- During the 2004 and 2005 storms, FPL's transmission infrastructure experienced significantly less damage than distribution facilities
- The focus of transmission hardening in FPL is to convert all wood transmission structures (~70%) with steel or concrete structures

Improvements from ***before transmission hardening program*** (Hurricane Wilma – 2005) and ***after transmission hardening program*** (Hurricane Irma - 2017) for distribution and transmission systems, respectively:

| | Hurricane Wilma | Hurricane Irma |
|---|---|---|
| % Line Section Outages | 37% | 17% |
| Transmission Structure Failures | 100 | 5<br>(all non-hardened) |
| Transmission Substations De-energized | 241 | 92 |
| Days to Restore Substation Outages | 5 | 1 |

[37] Source: FPL

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# Consumer Energy's
# Grid Modernization Investments



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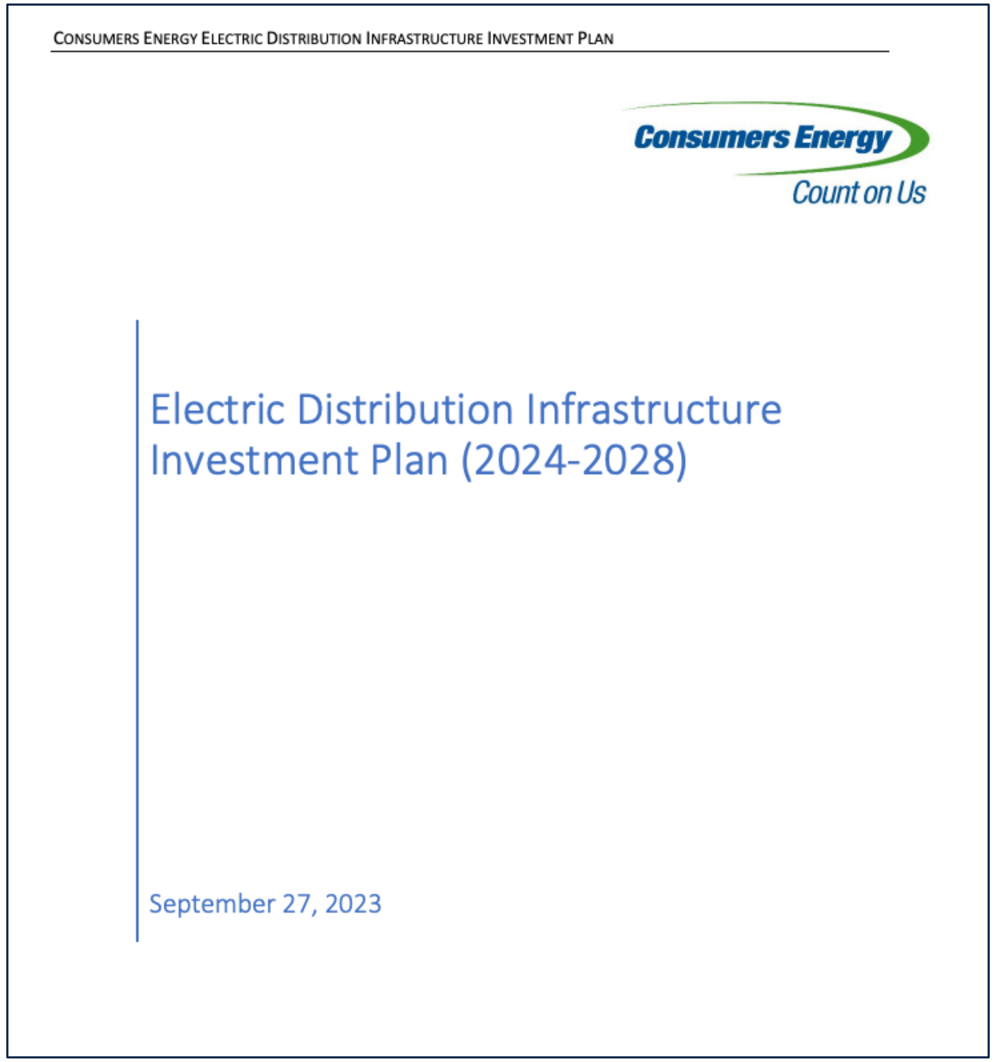
# Consumer Energy's Electric Distribution Infrastructure Investment Plan (EDIIP) [38]

- Since 2017, the Michigan Public Service Commission (PSC) has required regulated utilities to develop distribution investment plans every two years, with a five-year planning horizon

- Consumers Energy delivered its first Electric Distribution Infrastructure Investment Plan (EDIIP) in 2018 and filed its most recent plan in September 2023

- The utility developed a Grid Modernization Roadmap and prioritized deploying devices on the grid to enable automated response to improve reliability and resilience


CONSUMERS ENERGY ELECTRIC DISTRIBUTION INFRASTRUCTURE INVESTMENT PLAN

Consumers Energy
Count on Us

Electric Distribution Infrastructure Investment Plan (2024-2028)

September 27, 2023



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# Consumer Energy’s Grid Mod Strategies

## Isolated Technologies Limit Benefits

**Line Sensors**

- Quickly locate faults to restore power
- ~11,000 installed sensors by 2024

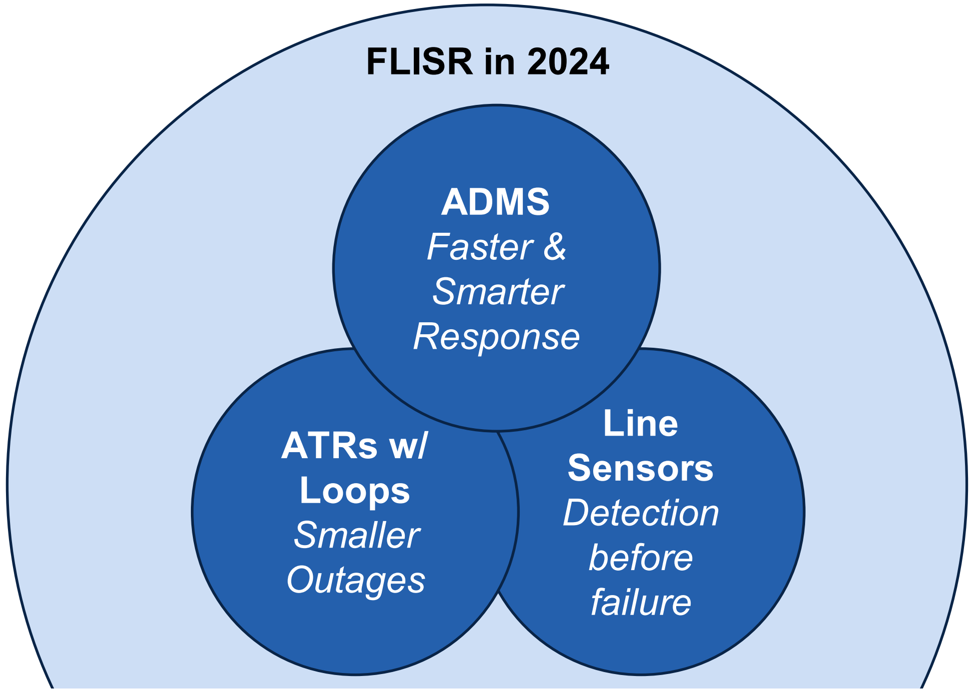
**Automatic Transfer Reclosers (ATRs) w/ Loops**

- Remotely restore customers
- ~235 loops installed by 2025

**ADMS**

- Manage outages through real-time data
- Operate the system safely and efficiently

## Integrated Technologies Amplify Performance




[38] Adapted from: Consumers Energy

| ADMS Enhancement | 2023 Capital | 2024 Capital | 2025 Capital | SAIDI Savings (excluding MEDs) |
|---|---|---|---|---|
| OMS Electra incl Live Wire Down | $800k | $900k | $0 | 5 minutes |
| Field Mapping Application | $0 | $1,600k | $0 | 4 minutes |
| DMS complete FLISR and SOM | | | | |
| Outage Applications Integration | $250k | $250k | $0 | 4 minutes |
| AMI Automation Use Case | $150k | $0 | $0 | 2 minutes |
| **Total** | **$1,200k** | **$2,750k** | **$0** | **15 minutes** |

# National Grid's Grid Modernization Investments



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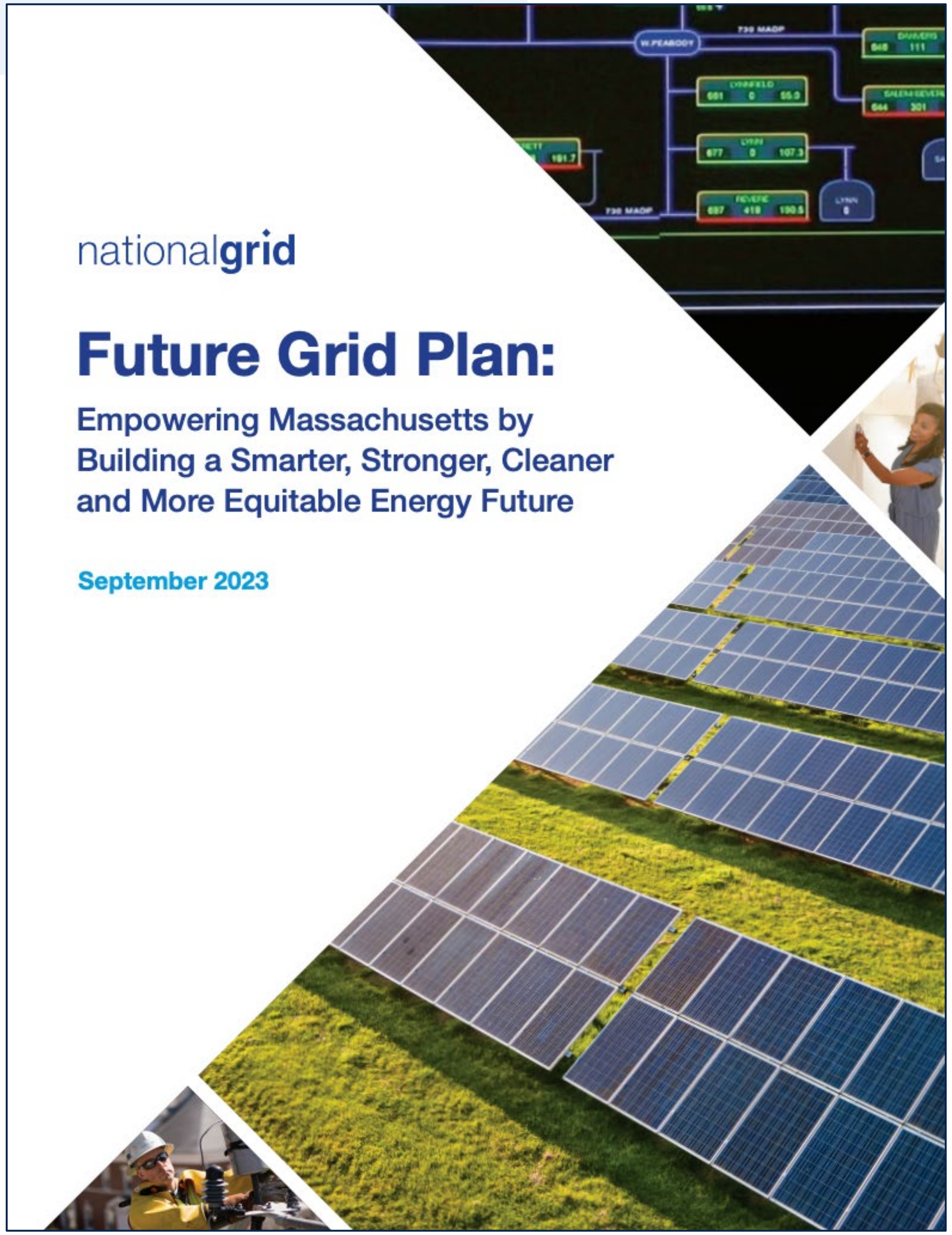
# National Grid's Future Grid Plan [39]

- Massachusetts' **"2022 Climate Act"** sets statewide 2050 goals that require the grid to connect "at least twice the amount of energy storage, 10 times the amount of renewable energy, 75 times the number of EVs, and 100 times the number of heat pumps than we see today"

- The Act also directed each of the state's electric distribution companies to file an **Electric Sector Modernization Plan** detailing distribution and transmission upgrades for a 5- and 10-year horizon, as well as out to 2050

- National Grid's plan is designed to address the needs outlined in Section 53 of the 2022 Climate Act – proposing investments that will enable a resilient clean energy future



# National Grid's Grid Mod Strategies

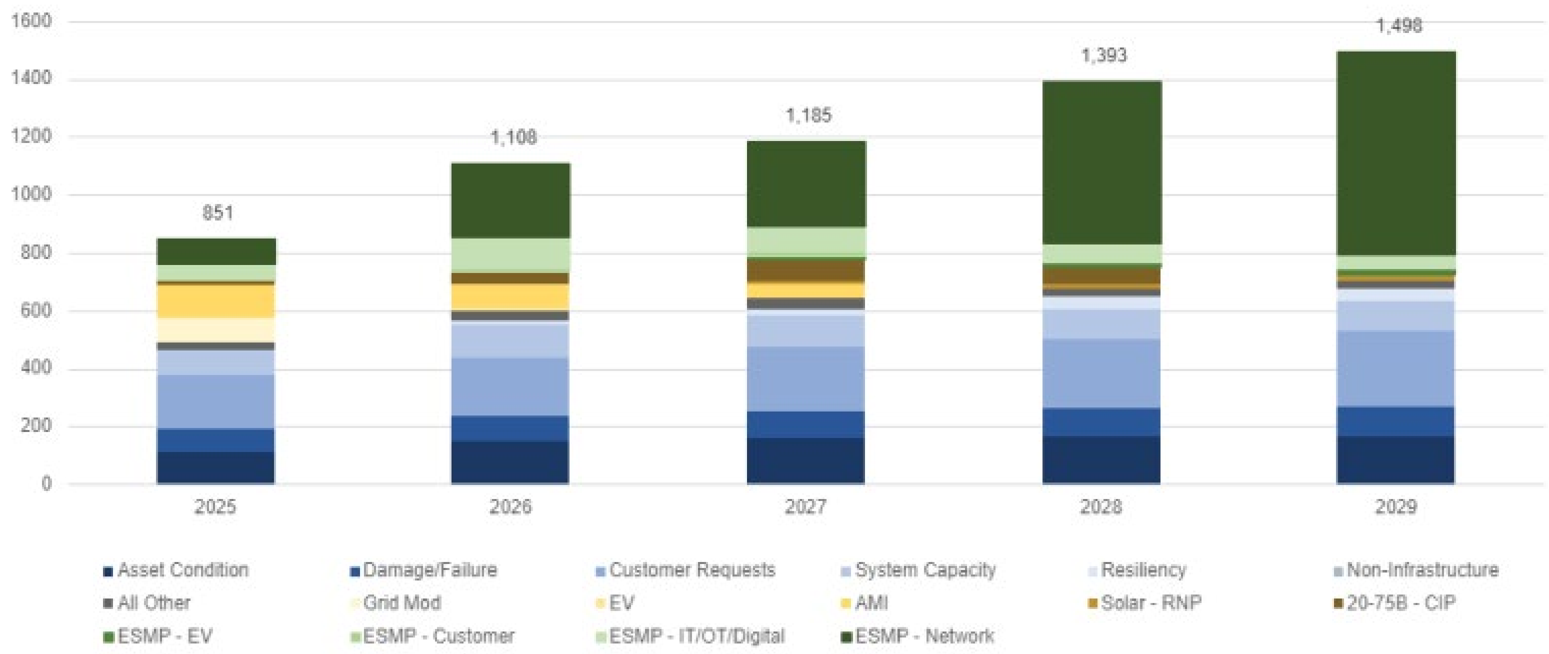
The Plan calls for leveraging existing and future IT technology – ADMS and DERMS – to better enable and optimize smart devices, EVs, and demand response

| | Scale Existing | Deliver In-Flight | Deploy New (via ESMP or related filing) |
|---|---|---|---|
| **Customer Programs** | • EE<br>• System Peak DR (curtailment, ESS, controllable thermostats, EVs)<br>• Off-peak managed EV charging | • ARI for solar (flexible connections pilot) | • Targeted EE<br>• Targeted DR<br>• TVR<br>• Virtual Power Plant (VPP)<br>• Flexibility Market<br>• Scale flexible connections for EVs and ESS |
| **Enabling Technology** | | • AMI<br>• ADMS<br>• DERMs (pre-authorized) | • DERMs (expanded features)<br>• Supporting data, security, and communications |

[39] Source: National Grid

The utility is expecting to make $2B in incremental investment over 2025-2029 to meet customer needs and build a network that supports the state's 2050 goals

Exhibit 7.1: 2025-2029 Capital Investments ($M)



# Contact

https://www.energy.gov/gdo/grid-deployment-office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# Thank you

# References in Presentation [1/2]


1. Energy.gov. “Grid Deployment Office.” Available at: https://www.energy.gov/gdo/grid-deployment-office
2. Hauer, R. J., and R. H. Miller. (2021). *Utilities & Vegetation Management in North America: Results from a 2019 Utility Forestry Census of Tree Activities & Operations.* Special Publication 21-1. College of Natural Resources, University of Wisconsin – Stevens Point.
3. Brown, R. E. (2009). *Cost-Benefit Analysis of the Deployment of Utility Infrastructure Upgrades and Storm Hardening Plans – Final Report*. Prepared by Quanta Technology for Public Utility Commission of Texas, Project No. 36375, March 4.
4. Burlingame, M., and P. Walton. (2013). *NARUC and MDPSC Cost-Benefit Analysis of Various Electric Reliability Improvement Projects from the End Users’ Perspective – Analysis Summary*. Study prepared for the National Association of Regulatory Utility Commissioners and Maryland Public Service Commission.
5. Northern States Power Company, dba Xcel Energy. (2021). *Integrated Distribution Plan 2022-2031.* Submitted in Docket No. E002/M-21-694, Minnesota Public Utilities Commission, November 1.
6. Duke Energy Florida. (2022). *Storm Protection Plan*. Submitted in Docket 2022-0050 to Florida Public Service Commission, November 15.
7. Florida Power & Light Company. (2022). *Florida Power & Light Company 2023-2032 Storm Protection Plan*. Submitted in Docket 2022-0051-EI to the Florida Public Service Commission, April 11. Available at: https://www.floridapsc.com/library/filings/2022/02358-2022/02358-2022.pdf
8. Short, T. (2023). *Practice for Resilient Distribution Systems*. EPRI. Resilience Training for Southeast Public Service Commission of South Carolina. Available at: https://eta-publications.lbl.gov/sites/default/files/tom_short_-_epri_-_practices_for_resilient_distribution_systems_final.pdf
9. Larsen, P. (2016). *Severe Weather, Power Outages, and a Decision to Improve Electric Utility Reliability*. Ph.D. dissertation, Stanford University.
10. California Public Utilities Commission (CPUC). (2021). *CPUC Undergrounding Programs Description*. Available at: https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/infrastructure/electric-reliability/undergrounding-program-description
11. Virginia Electric and Power Company (VEPC). (2023). *Strategic Underground Program Annual Report*. Submitted to the Virginia State Corporation Commission in Case No. PUE-2016-00136, March 31.
12. Wisconsin Public Service Corporation (WPSC). (2021). *WPS earns national awards for expectational reliability, service to customers*. Available at: https://news.wisconsinpublicservice.com/wps-earns-national-awards-for-exceptional-reliability-service-to-customers/
13. Smith, S. T. A Cost-Benefit Analysis of Creosote-Treated Wood vs. Non-Treated Wood Materials. *Creosote Council* Available at: https://creosotecouncil.org/cost-benefit-analysis/.
14. DTE Energy Michigan. 2021. DTE Electric Company – 2021 Distribution Grid Plan Final Report. Submitted to the Michigan Public Service Commission in Case No. U-20147, September 30.
15. Northern States Power Company, d. b. a. Xcel Energy. 2021. Integrated Distribution Plan 2022-2031. Submitted to the Minnesota Public Utilities Commission in Docket No. E002/M-21-694, Nov. 1.
16. Teoh, Y. E., Alipour, A. & Cancelli, A. (2019). “Probabilistic performance assessment of power distribution infrastructure under wind events.” *Eng. Struct.* 197, 109199
17. Utility pole. (2023). Wikipedia. Available at: https://en.wikipedia.org/wiki/Utility_pole
18. Southern California Edison (SCE). (2020). *Southern California Edison 2020-2022 Wildfire Mitigation Plan*. Available at: https://www.sce.com/sites/default/files/AEM/Wildfire%20Mitigation%20Plan/SCE's%202020-2022%20Wildfire%20Mitigation%20Plan%20-%20Revision%2003.pdf
19. Pacific Gas & Electric (PG&E). (2023). *Alternate Proposed Decision of Commissioner John Reynolds. Decision on Test Year 2023 General Rate Case for Pacific Gas and Electric Company*. Available at: https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M520/K114/520114360.PDF

# References in Presentation [2/2]


20. California Wildfire Safety Advisory Board. (2023). *2023-2025 WMP Joint IOU Covered Conductor Working Group Report*. Available at: https://efiling.energysafety.ca.gov/eFiling/Getfile.aspx?fileid=53548&shareable=true
21. Edison Electric Institute (EEI). (2020). *Investing in Transmission to Enhance the Reliability and Resilience of the Energy Grid*. Available at: https://www.eei.org/-/media/Project/EEI/Documents/Issues-and-Policy/Value-of-Transmission---Resilience.pdf?la=en&hash=A30775D58C3C7C0885A4F94DEF5A2E69FAD5772C#:~:text=As%20demonstrated%2C%20transmission%20system%20investments,if%20the%20transmission%20system%20fails.
22. Stefenon, S. F., Seman, L. O., Pavan, B. A., Ovejero, R. G., & Leithardt, V. R. Q. (2022). "Optimal design of electrical power distribution grid spacers using finite element method." *IET Generation, Transmission & Distribution*, 16(9), 1865-1876.
23. Illinois Commerce Commission. (2018). *ICC Approves Bronzeville Community Microgrid, Nation's Most Advanced*. Available at: https://www.icc.illinois.gov/downloads/public/ComEd%20Bronzeville%20Microgrid%20Project%20Press%20Release.pdf
24. City of Austin, TX. (2021). *Response to Climate Resilience Resolution 20210408-028*. Available at: https://services.austintexas.gov/edims/pio/document.cfm?id=365374
25. Barbose, G., Darghouth, N., O'Shaughnessy, E., & Forrester, S. (2023). "Tracking the Sun: Pricing and Design Trends for Distributed Photovoltaic Systems in the United States 2023 Edition." Lawrence Berkeley National Laboratory. Available at: https://emp.lbl.gov/sites/default/files/5_tracking_the_sun_2023_report.pdf
26. Avery, D. (2023). *Bidirectional Charging and EVs: How Does it Work and Which Cars Have It?* CNET. Available at: https://www.cnet.com/roadshow/news/bidirectional-charging-and-evs-how-does-it-work-and-which-cars-have-it/
27. CNET staff. (2023). *Best Smart Thermostats for November 2023*. CNET. Available at: https://www.cnet.com/home/energy-and-utilities/best-smart-thermostats/
28. Frick, N. M., Carvallo, J. P., & Schwartz, L. (2021). "Quantifying grid reliability and resilience impacts of energy efficiency: Examples and opportunities." Lawrence Berkeley National Laboratory. Available at: https://eta-publications.lbl.gov/sites/default/files/ee_reliability_resilience_2022_11_10.pdf
29. Franconi, E, E Hotchkiss, T Hong, M Reiner et al. (2023). "Enhancing Resilience in Buildings through Energy Efficiency." Richland, WA: Pacific Northwest National Laboratory. PNNL-32737, Rev 1. Available at: https://www.energycodes.gov/sites/default/files/2023-07/Efficiency_for_Building_Resilience_PNNL-32727_Rev1.pdf
30. U.S. Department of Energy Better Buildings. *Resilience*. Available at: https://betterbuildingssolutioncenter.energy.gov/resilience/about
31. Bohman, A. D. (2023). *Investing in Power System Resilience: A mixed methods approach to assessing the tradeoffs of resilience strategies*. Ph.D. dissertation, Carnegie Mellon University. Available at: doi:https://doi.org/10.1184/R1/21913629.v1
32. Foremost. *Above Ground Stationary Utility Tanks*. Available at: https://foremost.ca/fuelstoragetanks/products/above-ground-stationary-utility-tanks/
33. Consumers Energy. (2021). *Electric Distribution Infrastructure Investment Plan (2021-25).* Available at: https://mi-psc.my.site.com/sfc/servlet.shepherd/version/download/068t000000NiZGDAA3
34. Unitil Massachusetts. (2023). *Electric Sector Modernization Plan.* Available at: https://www.mass.gov/doc/gmacesmp-draftunitil/download
35. Duke Energy Florida. (2022). *Storm Protection Plan.* Available at: https://www.floridapsc.com/library/filings/2022/11327-2022/11327-2022.pdf
36. National Grid Massachusetts. (2023). *Future Grid Plan: Empowering Massachusetts by Building a Smarter, Stronger, Cleaner and More Equitable Energy Future.* Available at: https://www.mass.gov/doc/gmacesmp-draftnational-grid/download
37. Florida Power & Light Company. (2022). *Modified Storm Protection Plan 2023-2032.* Available at: https://www.floridapsc.com/library/filings/2022/11240-2022/11240-2022.pdf
38. Consumers Energy. (2023). *Electric Distribution Infrastructure Investment Plan (2024-28).* Available at: https://www.consumersenergy.com/-/media/CE/Documents/company/electric-generation/ediip-report.pdf
39. National Grid. (2023). *Future Grid Plan: Empowering Massachusetts by Building a Smarter, Stronger, Cleaner and More Equitable Energy Future.* Available at: https://www.mass.gov/doc/gmacesmp-draftnational-grid/download

# Additional References


- California Department of Water Resources (2019). Climate Change Vulnerability Assessment. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/All-Programs/Climate-Change-Program/Climate-Action-Plan/Files/CAP-III-Vulnerability-Assessment.pdf
- Colorado PUC (2021). Decision Addressing Exceptions to Decision No. R21-0287 and Adopting Rules for Distribution System Planning. https://www.dora.state.co.us/pls/efi/EFI_Search_UI.Show_Decision?p_dec=28544&p_session_id=
- ConEd (2023). Con Edison Climate Change Vulnerability Study. https://www.coned.com/-/media/files/coned/documents/our-energy-future/our-energy-projects/climate-change-resiliency-plan/climate-change-vulnerability-study.pdf
- CT PURA (2022). PURA Investigation into Distribution System Planning of The Electric Distribution Companies – Resilience And Reliability Standards And Programs. https://www.dpuc.state.ct.us/2nddockcurr.nsf/8e6fc37a54110e3e852576190052b64d/4bcecc163d47d814852588af005bca09/$FILE/171203RE08-083122.pdf
- LPSC (2023). Final Proposed Rule - In re: Assessment of Louisiana's current electric utility infrastructure for resilience and hardening for future storm events. https://lpscpubvalence.lpsc.louisiana.gov/portal/PSC/ViewFile?fileId=DqqYBjMkjYI%3d
- LLNL (2023). Cyber and Physical Threats to the Grid. https://eta-publications.lbl.gov/sites/default/files/gdo_se_resilience_training_klauberllnl_final.pdf
- FPSC (2020). Rule: 25-6.030 – Storm Protection Plan. https://www.flrules.org/gateway/ruleno.asp?id=25-6.030&Section=0
- NARUC (2023). Critical Infrastructure, Cybersecurity and Resilience. https://www.naruc.org/cpi-1/critical-infrastructure-cybersecurity-and-resilience/cybersecurity/
- PG&E (2023). 2023-2025 Wildfire Mitigation Plan. https://www.pge.com/pge_global/common/pdfs/safety/emergency-preparedness/natural-disaster/wildfires/wildfire-mitigation-plan/2023-wildfire-mitigation-plan.pdf
- PUCT (2023). Transmission and Distribution System Resiliency Plans. https://interchange.puc.texas.gov/Documents/55250_11_1329924.PDF
- SCL (2015). Seattle City Light Climate Change Vulnerability Assessment and Adaptation Plan. https://www.seattle.gov/documents/Departments/CityLight/ClimateChangeAdaptationPlan.pdf




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