QUANTA TECHNOLOGY

Resiliency of Electric Power Systems

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Don Hall, PE

April 9, 2020

COVID-19 Update

Stay Safe

Stay Healthy

Stay Connected

https://www.cdc.gov/coronavirus/2019-ncov/index.html

Upcoming Webinars

Time	APRIL 16, 2020 11:00 AM-12:00 PM	APRIL 23, 2020 11:00 AM-12:00 PM	APRIL 30, 2020 11:00 AM-12:00 PM
Topic	VALUE OF DER, SESSION #1	STATE OF THE ART ON 100% RENEWABLE SYSTEMS	DERMS VS. MICROGRID CONTROLS- BATTLE OF BUSINESS OPERATION
Speakers	DR. RALPH MASIELLO, DR. ELLI NTAKOU, DR. KHASH MAHANI, DR. FARNAZ FARZAN	DR. HISHAM OTHMAN & RAHUL ANILKUMAR	DR. FARID KATIRAEI, DR. CHAD ABBEY, & SHADI CHUANGPISHIT

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Introductions

- **Dr. Julio Romero Aguero**
  - Vice President, Strategy & Business Innovation & Executive Advisor
  - Areas of expertise include technology strategy, innovation, emerging technologies, distribution systems, reliability and resiliency, Smart Grid, and DER integration
  - 25 years of experience working with electric utilities and regulatory boards. Developed solutions for electric utilities in the USA, Canada, Latin America, The Caribbean and Asia

- **Don Hall, PE**
  - Executive Advisor, Distribution & Asset Management
  - Areas of expertise include T&D business/strategic planning, asset strategy & planning, engineering, field operations and testing, system operations, reliability and resiliency
  - 35+ years of experience working with electric utilities and technology vendors. Provided services to over 50 utilities worldwide. Licensed PE in DC, DE, and MD

Agenda

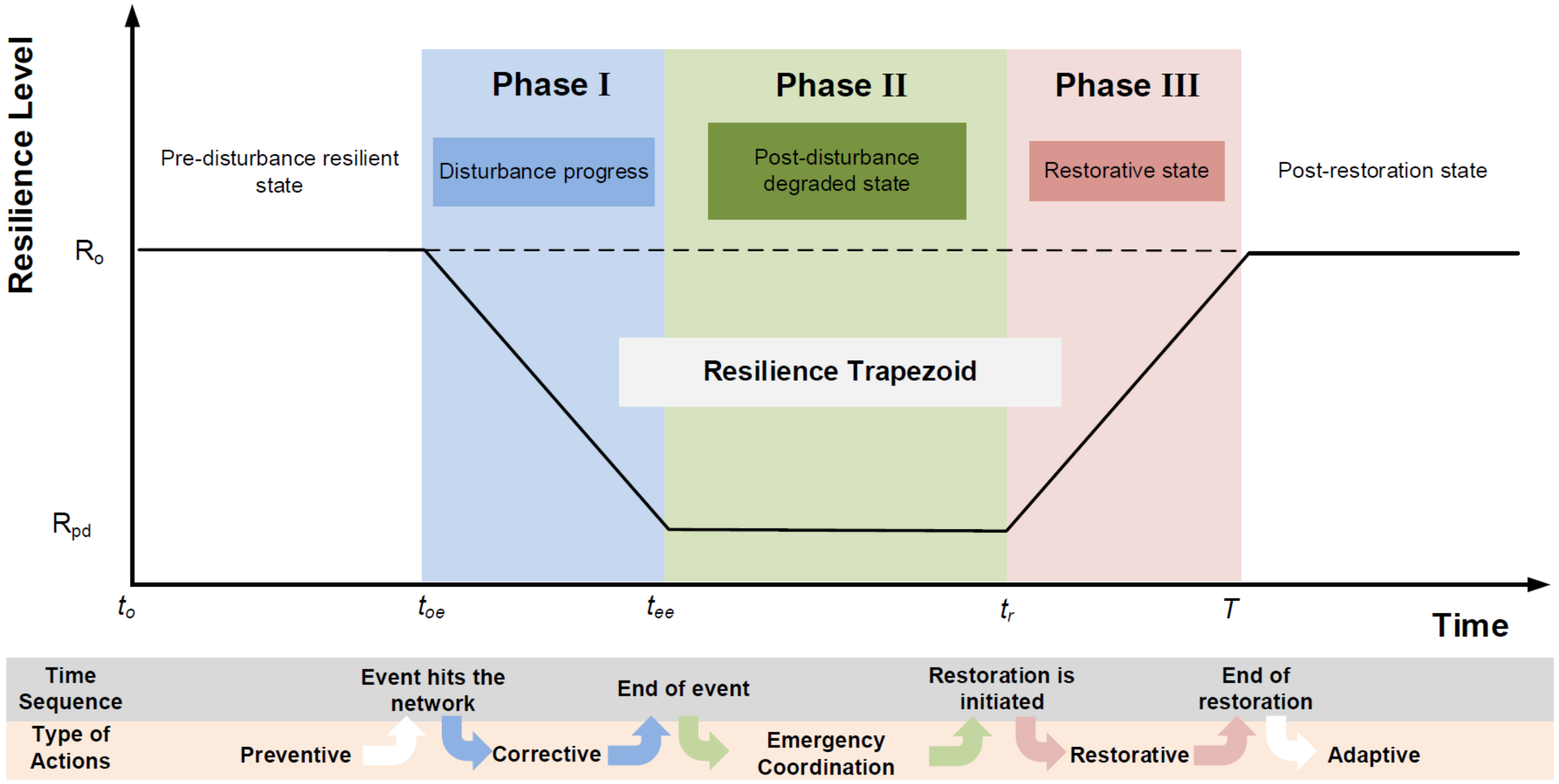
- Introductions
- Definitions
- Scope
- Metrics
- Evaluation
- Solutions
- Trends and Challenges
- Conclusions

Definitions (1)

- Definition of resilience (or resiliency), as per IEEE Technical Report PES-TR65 and FERC Docket No. AD18-7-000 (Jan. 8, 2018):
  - "The ability to withstand and reduce the magnitude and/or duration of disruptive events, which includes the capability to anticipate, absorb, adapt to, and/or rapidly recover from such an event."

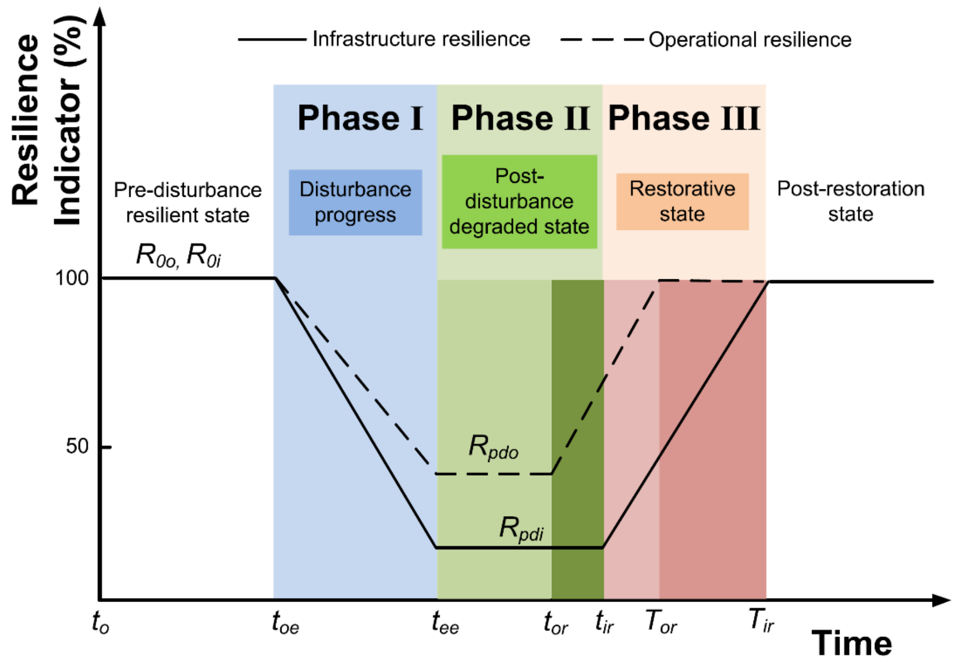
- Differences between reliability and resiliency
  - Resiliency encompasses all hazards and events, including high-impact low-probability (HILP) events that are commonly excluded from reliability calculations
  - Resiliency quantifies not only the final state of the system (like reliability), but also transition times among the states. Thus, it requires a more detailed characterization of the preparation process prior to any events occurring, the operational process during the event, and the response process after the event
  - Resiliency aims to capture both the effects on the customer (like reliability), effects on the grid operators and staff, and effects on the infrastructure itself (possibly on two or more time horizons)

Definitions (2)

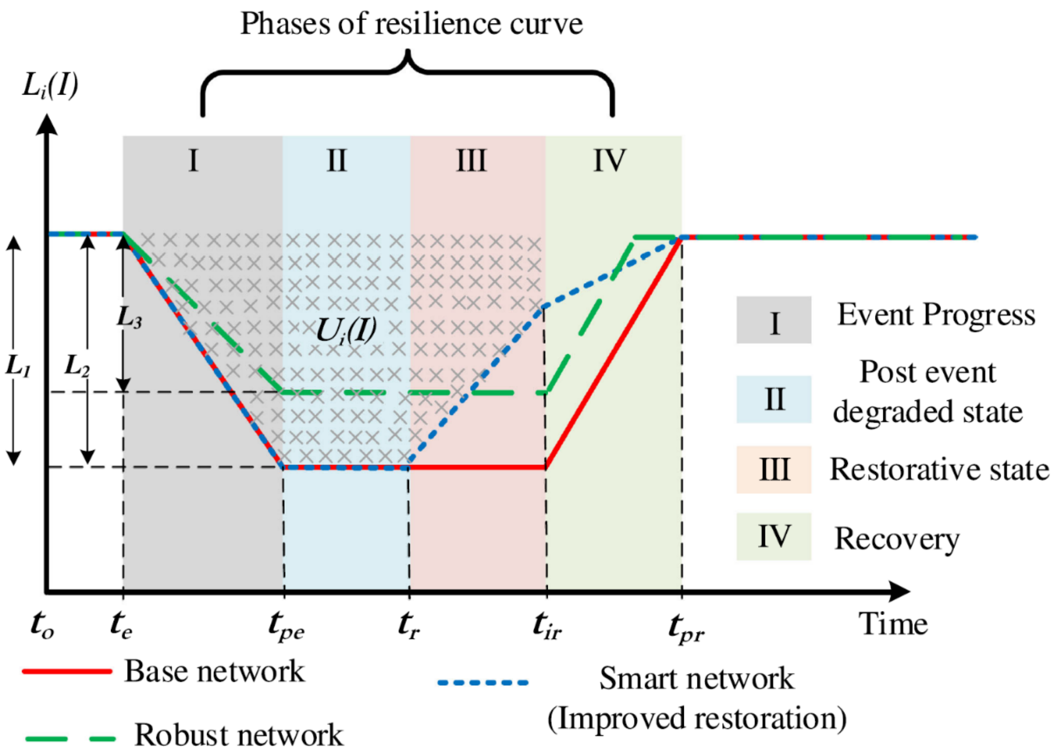


Source: The Definition and Quantification of Resilience, Technical Report PES-TR65
http://grouper.ieee.org/groups/transformers/subcommittees/distr/C57.167/F18-Definition&QuantificationOfResilience.pdf

Definitions (3)



Source: M. Panteli et. al, "Metrics and Quantification of Operational and Infrastructure Resilience in Power Systems", IEEE Transactions on Power Systems
https://ieeexplore.ieee.org/document/7842605



Source: S. Poudel et. al, "Risk-Based Probabilistic Quantification of Power Distribution System Operational Resilience", IEEE Systems Journal, Early Access
https://ieeexplore.ieee.org/document/8848458

Growing Interest in Resiliency – Evolving Threats Impacting Power Systems

Cyber Security

- NERC CIP 002-011 and CIP 013 (Supply Chain, July '20)

Physical Vulnerability

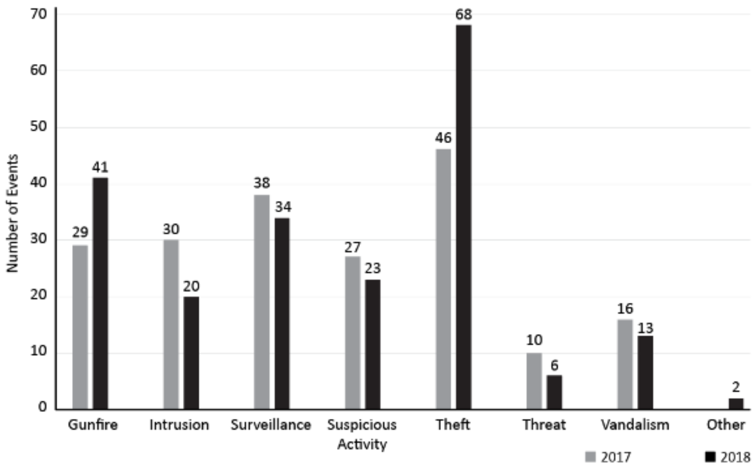
- NERC CIP 014 - Physical Security
- Substation and System - Critical substations

Geomagnetic Disturbance (GMD)

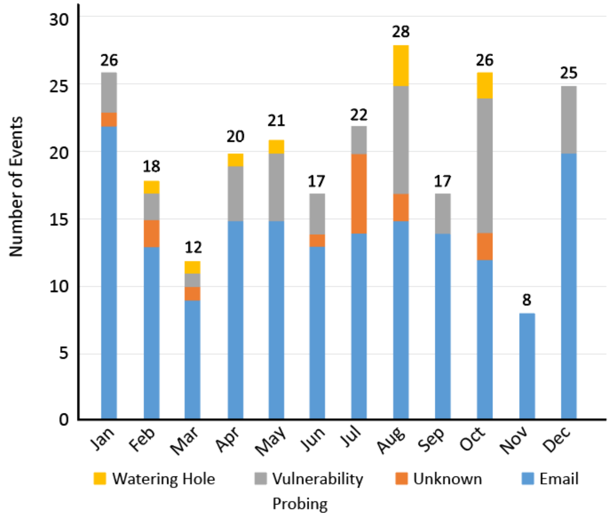
High-altitude Electromagnetic Pulse (HEMP)

Prevention – Detection – Mitigation - Recovery

Physical Security



Cyber Security



Source: NERC

FERC Resiliency Order 2018

- Ensuring resiliency requires
  - Determine which risks (events) to the grid to protect against
  - Identify the steps, if any, needed to ensure those risks are addressed
- Examples of high-impact, low frequency disruptive events
  - Fuel supply interruptions
  - Extreme weather events
  - HEMP attack/GMD

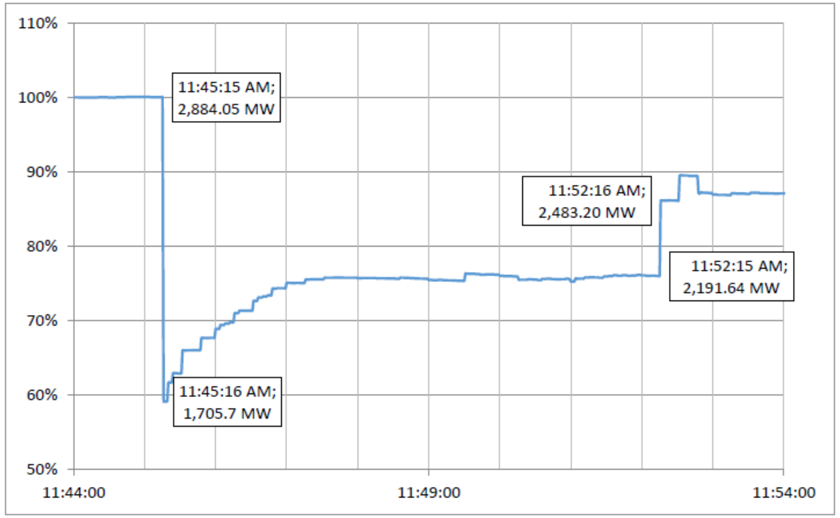
Resilience Targets

- Fast changing environment requires continuous and adaptive response to various risks/events (e.g. cyber risks, DER integration)
- Important not to lose sights of priorities to invest time and funds (fire risk vs. HEMP risk)
- Metrics and industry standards
  - System dependent - e.g. hurricane vs. snow-storm risks
  - Measure base and future states to define metrics - Data analytics
  - Resilience may conflict with reliability metrics – Reclosing improves SAIDI but creates fire risks
- Focus on solutions to improve current state:
  - DER, energy storage, microgrids
  - Advanced monitoring, control, & protection
  - Tools, processes, and training
  - Etc.

Growing Interest in Resiliency – Evolving Power System: Renewable Integration

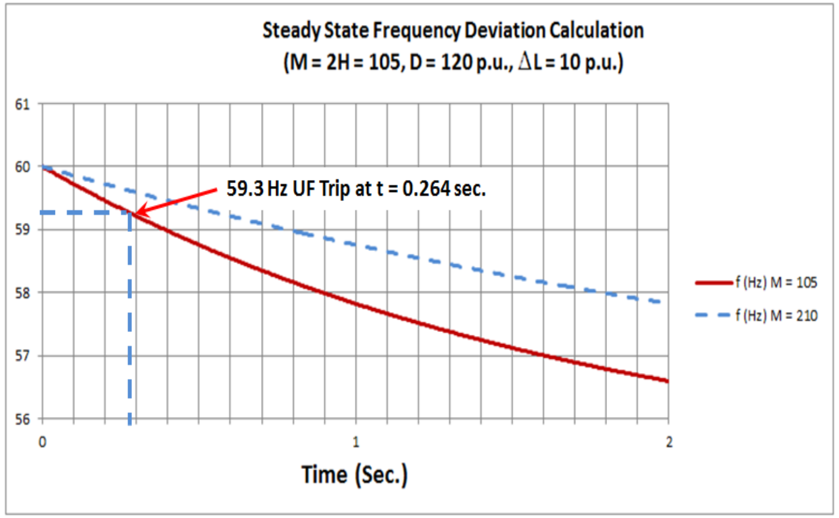
Inverter Based Resources (IBR) → Less Inertia → Things Happen Faster! + Low Fault Currents

Southern California Solar Resource Loss, Aug. 2016



- Address inverter ride-through settings and calculations of voltages and frequency
- Re-evaluate NERC PRC-024-2 – inverters should not trip instantaneously

Frequency Decay for Loss of 1,000 MW

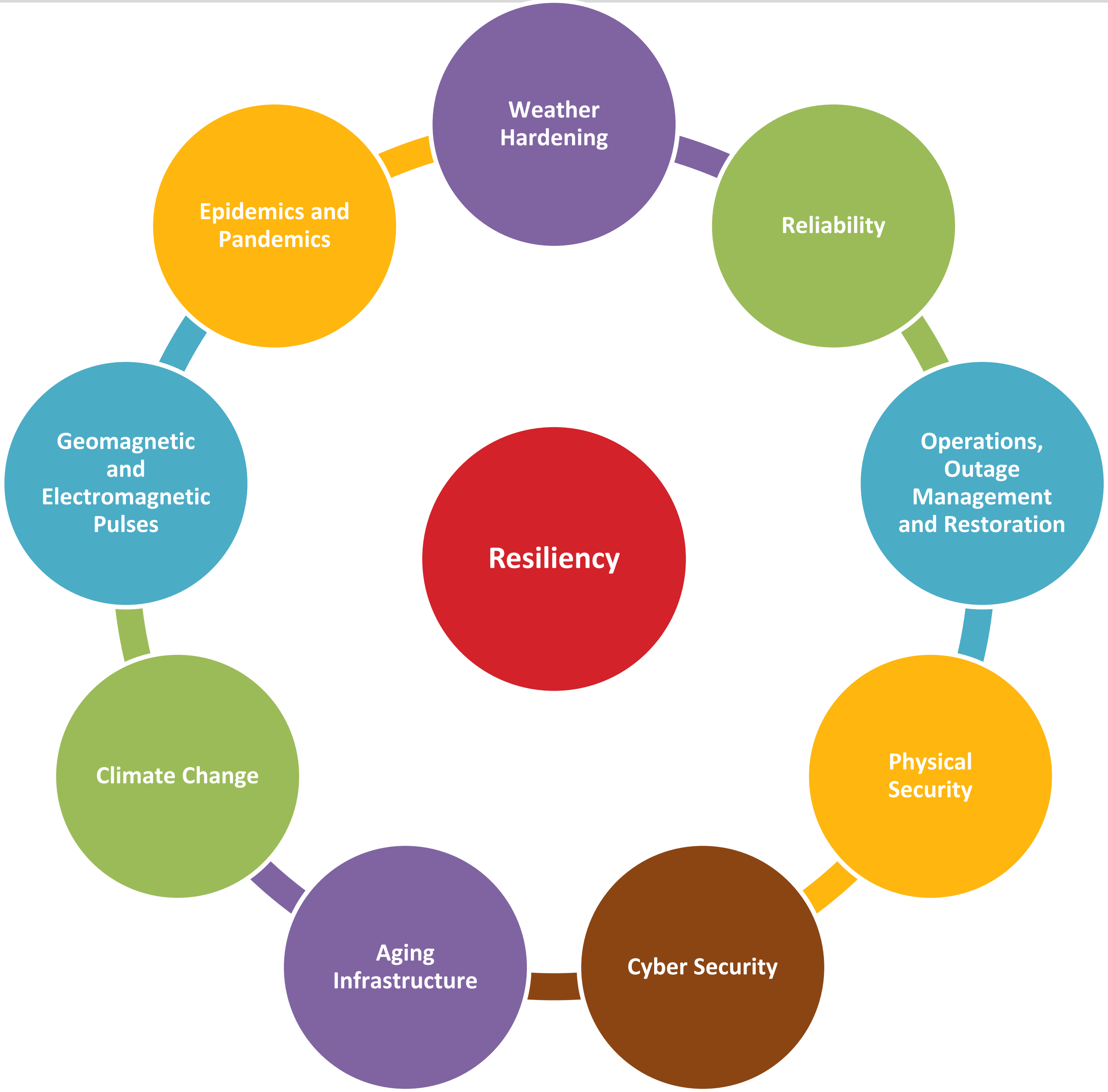


- Inverter-Based Resources can provide reserve margins if recognized in the marketplace
- IEEE Std. 1547-2018 defines reliability services, e.g. frequency response, ramping and voltage support

- T&D planning & operations require accurate modeling
- Monitoring & control of smart inverters to mitigate impact and enhance the DER benefits => **Grid Management System**
- Increased visibility needs – Synchronized Measurements
- Low fault currents & dynamic system changes requiring adaptive protection

Source: IEEE/NERC report on Impact of Inverter Based Generation on Bulk Power System Dynamics and Short-Circuit Performance

Resiliency Scope

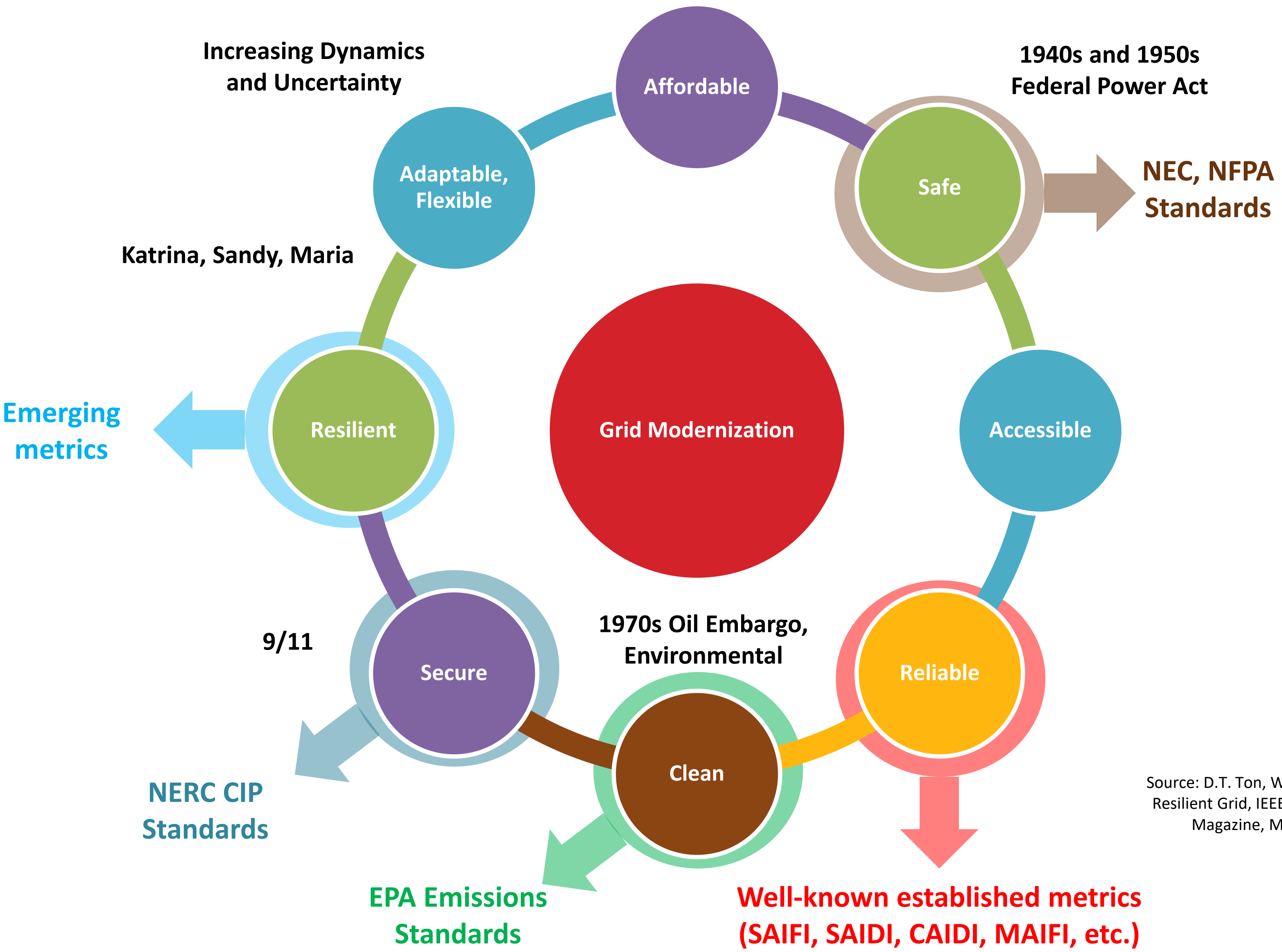


Key Elements Impacting T&D Resiliency

Natural Hazards		Direct Intentional Threats		Other Threats, Hazards, and Vulnerabilities	
	Ice, snow, and extreme cold weather		Physical attacks		Geomagnetic and electromagnetic pulses
	Thunderstorms, tornadoes, and hurricane-force winds		Cyber attacks		Aging infrastructure
	Storm surge, flooding, and increased precipitation		---		Capacity constraints
	Increasing temperature and extreme hot weather		---		Workforce turnover and loss of institutional knowledge
	Earthquakes		---		Human error
	---		---		Dependencies and supply chain interruptions

Source: Front-Line Resilience Perspectives: The Electric Grid, Argonne National Laboratory
https://www.energy.gov/sites/prod/files/2017/01/f34/Front-Line%20Resilience%20Perspectives%20The%20Electric%20Grid.pdf

Resiliency Metrics and Evaluation



Source: D.T. Ton, W-T.P. Wang, A More Resilient Grid, IEEE Power and Energy Magazine, May/June 2015

Resiliency Metrics

- Resiliency evaluation methods and metrics are key areas of research, however, there is no widely accepted industry standard in this area yet
- While reliability metrics have been standardized and widely adopted, metrics for quantifying resilience have not – many entities are involved in the topic including USDHS, USDOE, National Labs, FERC, NERC, NARUC,IEEE PES, EPRI, academia, consultants, and individuals
- For example, DOE sponsored Grid Modernization Laboratory Consortium (GMLC) is conducting a project to "select, describe, and define metrics for the purpose of monitoring and tracking system properties of the electric infrastructure as it evolves over time". Topic areas include:
  - Reliability
  - Sustainability
  - **Resilience**
  - Affordability
  - Flexibility
  - Security

Source: https://gmlc.doe.gov/sites/default/files/resources/GMLC1%201_Reference_Manual_2%201_final_2017_06_01_v4_wPNNLNo_1.pdf

Metrics Trade-Offs

- In an ideal world, resilience metrics would have simple data requirements, be easy to calculate, provide useful information that is easily understood, and provide a backward looking & forward looking perspectives
- This is not an ideal world – selection of resilience metrics involves trade-offs

Metric Trade-Offs

Simpler vs. More Complex	
The simplest metrics require less data that are easy to obtain, and the process for integrating the data into metrics is fairly straightforward (e.g., simple arithmetic).	More complex metrics may require larger amounts of data that may be challenging to obtain. The process for integrating the data may require technical expertise, such as numerical modeling.
Retrospective vs. Forward-Looking	
Retrospective metrics typically measure the resilience of the system to previous events. They may be used to determine if previous performance was (un)satisfactory.	Forward-looking metrics typically measure the resilience of the system to future or hypothesized disruptions. These metrics are commonly used to inform planning and investment activities.
Targeted vs. Broadly Informative	
Targeted resilience metrics may provide limited information on a single, or limited number of topics (e.g., single threat).	Broadly informative metrics may be able to provide information that is useful across a variety of analysis topics (e.g., investment, planning, operational response).
Less Consistent vs. More Consistent	
Repeated application of resilience metrics with little consistency can be a challenge. If the metric results tend to change from analyst-to-analyst or do not enable comparative analysis, stakeholders may lose confidence in the metrics.	Consistent metrics enable reproducibility and comparison. Consistency builds confidence and leads to widespread usage of the metrics.

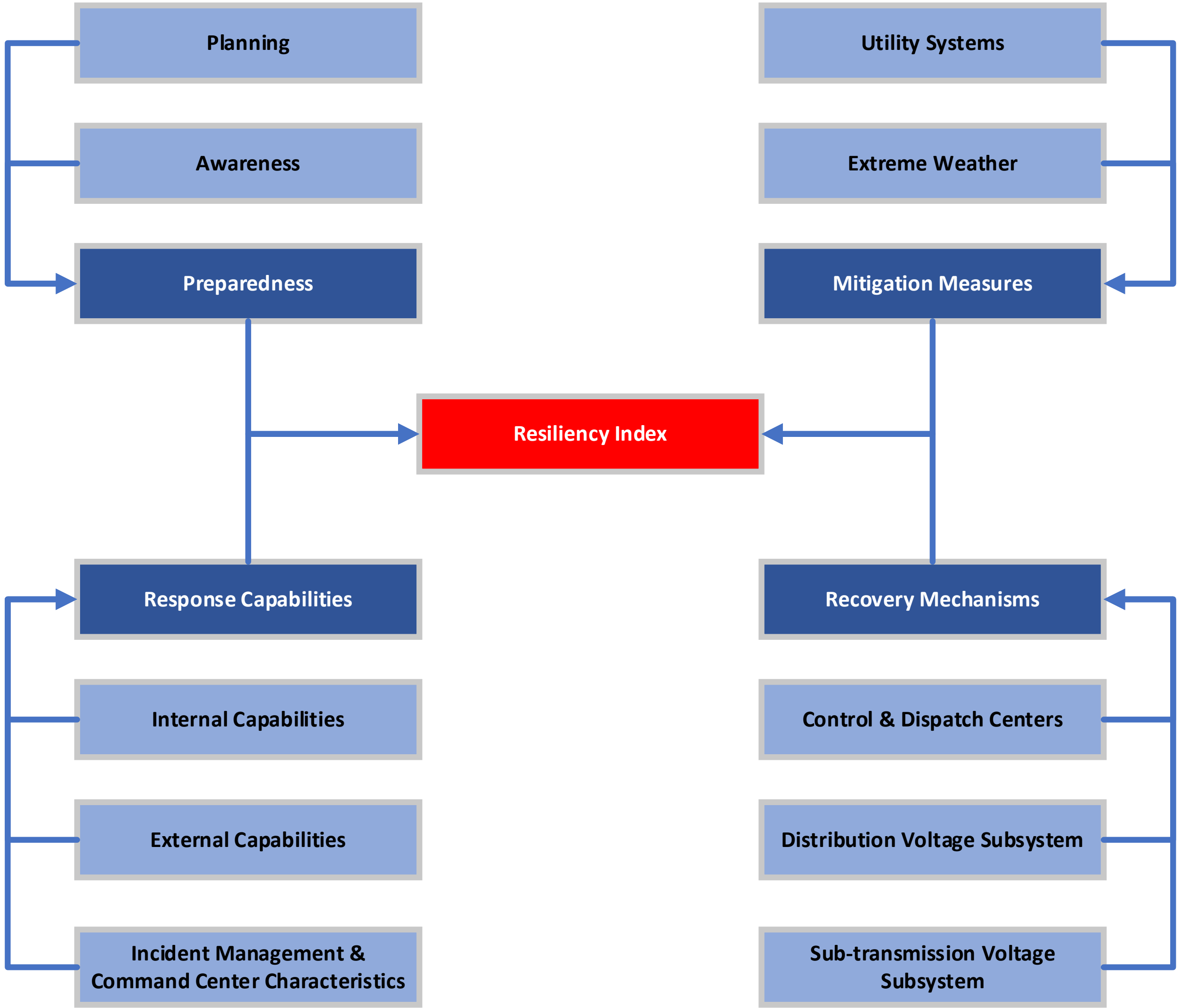
Source: https://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/2017/171493.pdf

Resiliency Metrics

- **Multi-Criteria Decision Analysis (MCDA)-based metrics** try to answer the question: “what is the current state of resilience of the electric system, and what are the options to enhance its resilience over time?”
  - MCDA metrics provide a baseline understanding of current resilience, facilitate consideration of enhancement options, and include categories such as robustness, resourcefulness, adaptiveness or recoverability
- **Performance-based metrics** generally try to answer the question: “how would an investment impact the resilience of the electric system?”
  - Performance-based metrics are used to provide a quantitative describe of how the grid has been impacted or compromised by a specific disruption (e.g., a natural disaster). The required data can be collected from historical events, subject matter estimates, or computational infrastructure models
  - MCDA metrics are recommended for benefit-cost and planning analysis
- Researchers are currently investigating the combination of both types of metrics
  - The MCDA approach may be used first to provide a high-level characterization of the resilience of the electric system, moreover, it allows comparing resilience enhancement options
  - Then, the performance-based approach may incorporate the outputs of the MCDA approach to do a detailed evaluation of the resilience of the electric system, including economic and regional variables

Source: Grid Modernization: Metrics Analysis (GMLC1.1) – Resilience Reference Document Volume 2, Mar 2019

Multi-Criteria Decision Analysis (MCDA) Metrics



Source: Grid Modernization: Metrics Analysis (GMLC1.1) – Resilience Reference Document Volume 2, Mar 2019

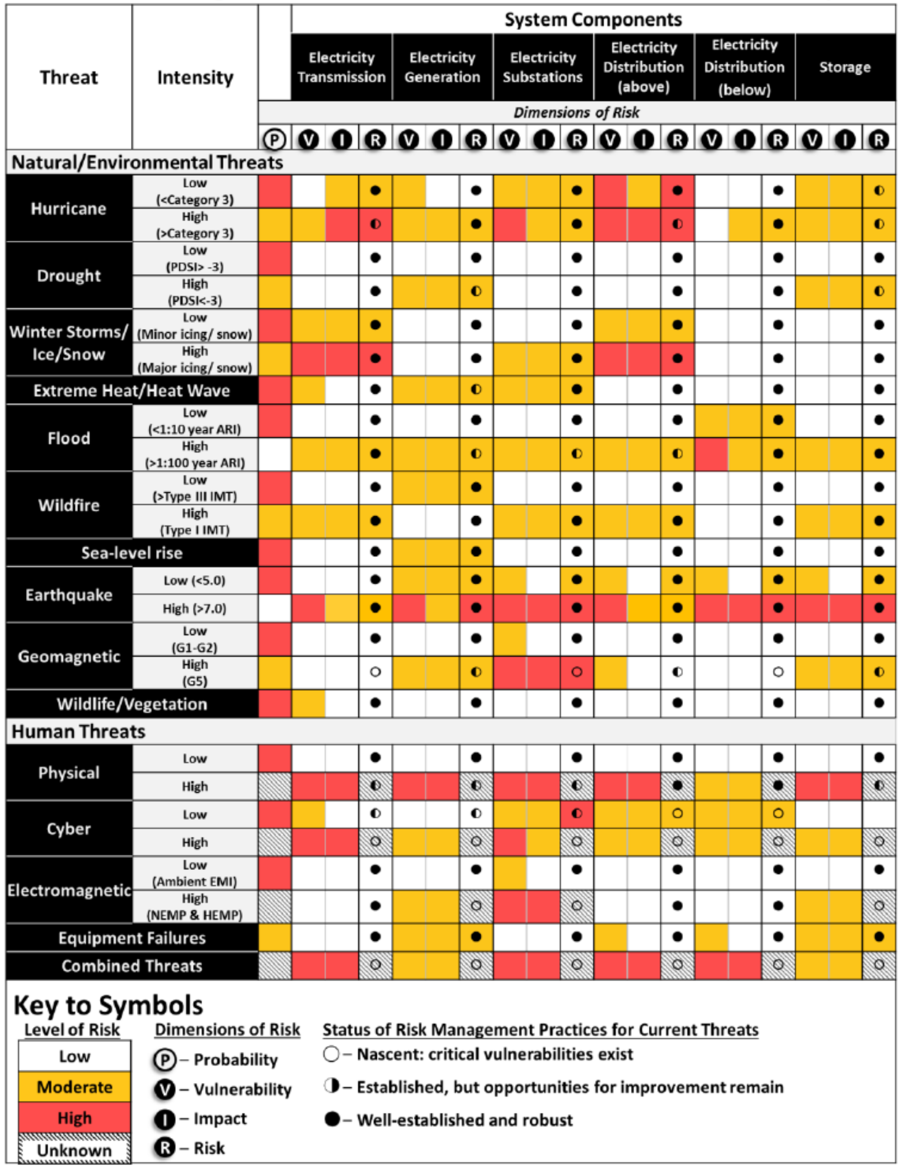
Consequence-Based Metrics

(GMLC) Metrics for consideration in grid resilience metric development

Impact	Consequence Category	Resilience Metrics
Direct	Electric Service	Cumulative customer-hours of outages Cumulative customer energy demand not served Average number (or percentage) of customers experiencing an outage during a specified time period
	Critical Electrical Service	Cumulative critical customer-hours of outages Critical customer energy demand not served Average number (or percentage) of critical loads that experience an outage
	Restoration	Time to recovery Cost of recovery
	Monetary	Loss of utility revenue Cost of grid damages (e.g., repair or replace lines, transformers) Cost of recovery Avoided outage cost
Indirect	Community Function	Critical services without power (e.g., hospitals, fire stations, police stations)
	Monetary	Loss of assets and perishables Business interruption costs Impact on Gross Municipal Product (GMP) or Gross Regional Product (GRP)
	Other critical assets	Key production facilities without power Key military facilities without power

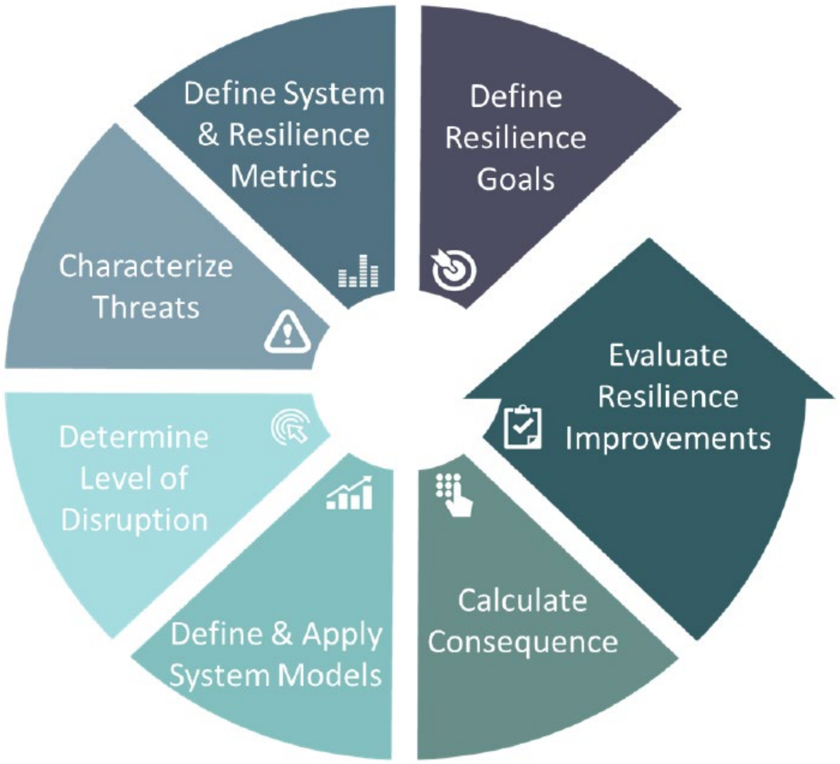
Source: https://gmlc.doe.gov/sites/default/files/resources/GMLC1%201_Reference_Manual_2%201_final_2017_06_01_v4_wPNNLNo_1.pdf

Resiliency Evaluation



Source: https://energy.gov/epsa/downloads/resilience-us-electricity-system-multi-hazard-perspective

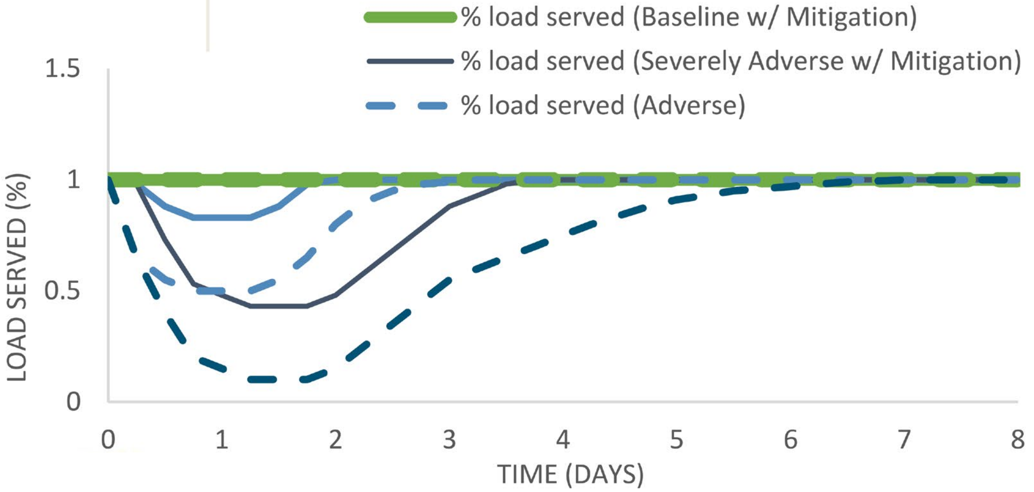
Performance-Based Spiral

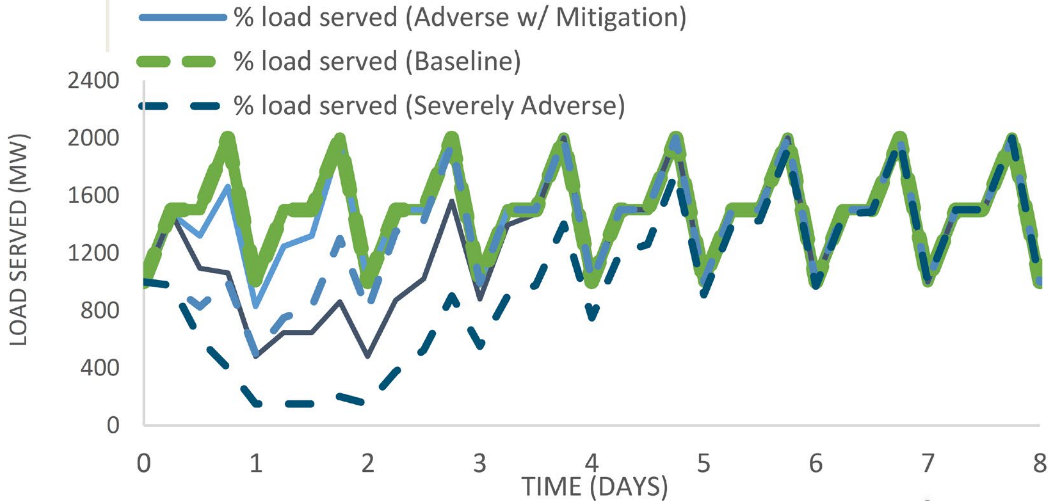


Source: https://energy.gov/sites/prod/files/2015/09/f26/EnergyResilienceReport_(Final)_SAND2015-18019.pdf

Resiliency Evaluation – Consequence-Based Metrics

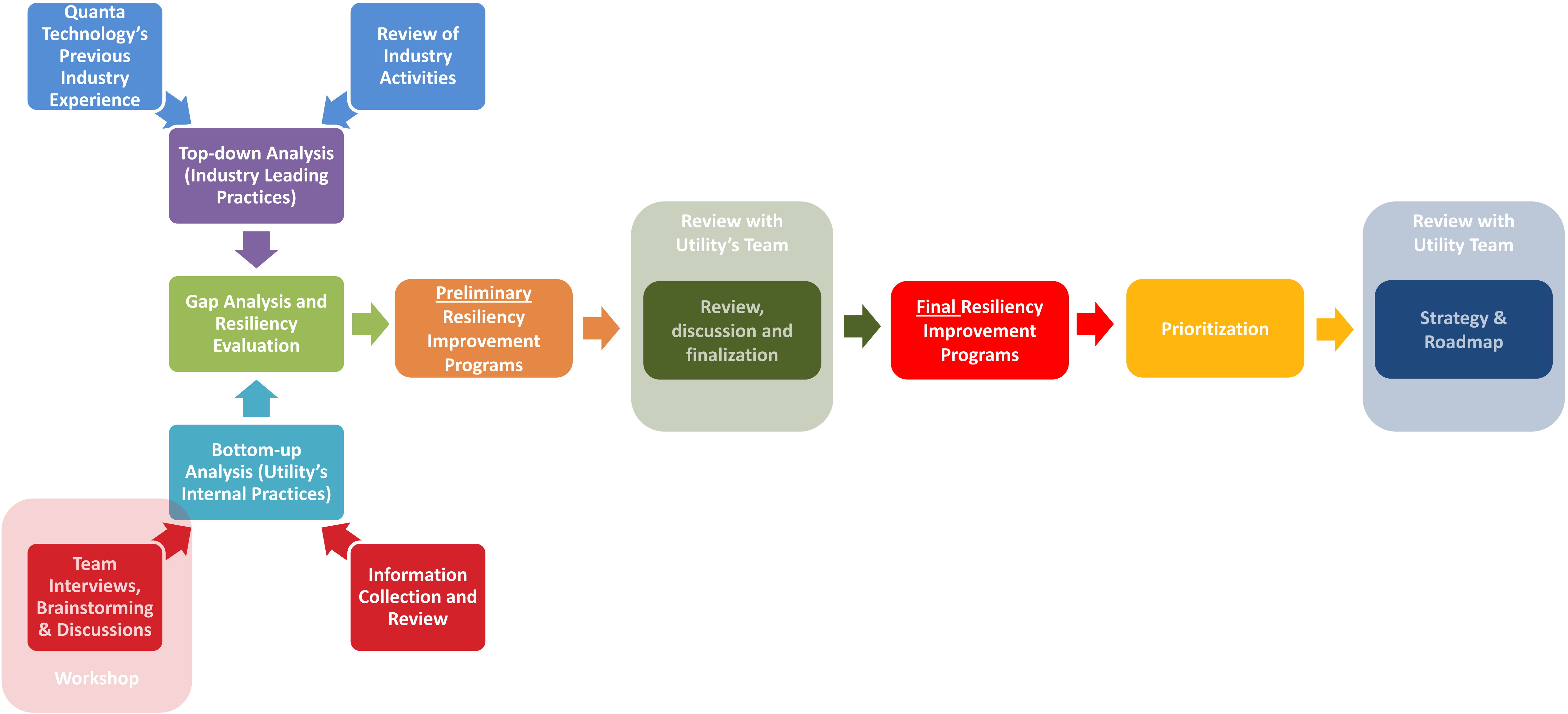
SCENARIO	METRICS					METRICS WITH MITIGATIONS				
						20% of poles upgraded and installation of hardened microgrid for selected critical loads				
Severity and Disruption	Component Performance *Distribution assets damaged*	System Performance *Load not served*	Critical Service *Critical load not served*	Economic *Repair and recovery costs*	Social *Burden to access services*	Component Performance *Distribution assets damaged*	System Performance *Load not served*	Critical Service *Critical load not served*	Economic *Repair and recovery costs*	Social *Burden to access services*
Baseline	0%	0 MWh	0 MWh	$0	0 hours	0%	0 MWh	0 MWh	0 dollars	0 hours
Adverse *100-year flood level* *75 mph windspeed*	5%	31,800 MWh	636 MWh	$15 million	4 million hours	1%	7,170 MWh	143 MWh	$3 million	1 million hours
Severely Adverse	25%	96,390 MWh	1,928 MWh	$50 million	12 million hours	12.5%	42,420 MWh	848 MWh	$20 million	4 million hours





Source: M.B. DeMenno et. el, From Financial Systemic Risk to Grid Resilience: Applying Stress Testing to Electric Utilities, 2020 IEEE PES Innovative Smart Grid Technologies Conference (ISGT), Washington, DC., Feb. 2020

Resiliency Evaluation and Improvement Roadmap



Resiliency Improvement – Solutions

Resiliency

Weather Hardening and Climate Change Preparedness
- Upgrade infrastructure/assets for wind, ice, snow and flood protection (e.g., installing tree wire, aerial bundled and spacer cable, upgrading crossarms and poles, installing submersible equipment, etc.)
- Vegetation management
- Targeted undergrounding
- Review/update overhead and underground infrastructure design

Reliability, Outage Management and Restoration
- Enhanced line inspection programs
- High reliability/resiliency distribution system design (primary loop, primary and secondary selective, etc.)
- Digital/mobile workforce management
- Advanced inspection and damage assessment

Physical and Cyber Security
- Redundant infrastructure (e.g., backup control center, backup infrastructure to supply critical customers, etc.)
- Distribution and DER physical and cyber security standards
- Reinforced buildings and fences
- Shield assets from outside attacks
- Gas insulated and underground substations

Aging Infrastructure Replacement
- Underground cable replacement
- Protective, switching and volt-VAR equipment replacement
- Pole inspection and replacement

Logistics, Staffing and Processes
- Spare equipment (e.g., PPE, distribution poles, wires, cables, switches, and distribution transformers)
- Mobile transformers and generators
- Mutual assistance agreements, contractors/service provider agreements and onboarding, staff augmentation, etc.
- System and business recovery/remediation plans and processes (e.g., blackstart, contingency plans, storm restoration, safety, etc.)

Electromagnetic and Geomagnetic Pulses
- Shielding of T&D control centers, mitigation of radiated threats at substations, mitigation of conducted threats at protection and control equipment

DER Integration
- Distributed generation, energy storage, and microgrids
- Advanced DER monitoring and control
- Hosting capacity management and optimization

Advanced Analytics
- Data collection, processing, storage and analysis
- System modeling, simulation and analysis
- Resiliency analytics
- Performance analytics
- Asset health analytics

Real-Time Monitoring and Control
- Management and monitoring systems (Advanced Distribution Management Systems – ADMS, Outage Management Systems – OMS, Network Monitoring Systems – NMS, etc.)
- DER and Demand Response Management Systems (DERMS and DRMS)
- Microprocessor-based controllers (voltage regulators, load tap changers, and capacitor banks)

Optimized Distribution System Capacity
- New substations, feeders, line extensions, and feeder ties
- Reconductoring and rephasing
- Phase balancing
- Distribution class series and shunt FACTS devices for power flow control

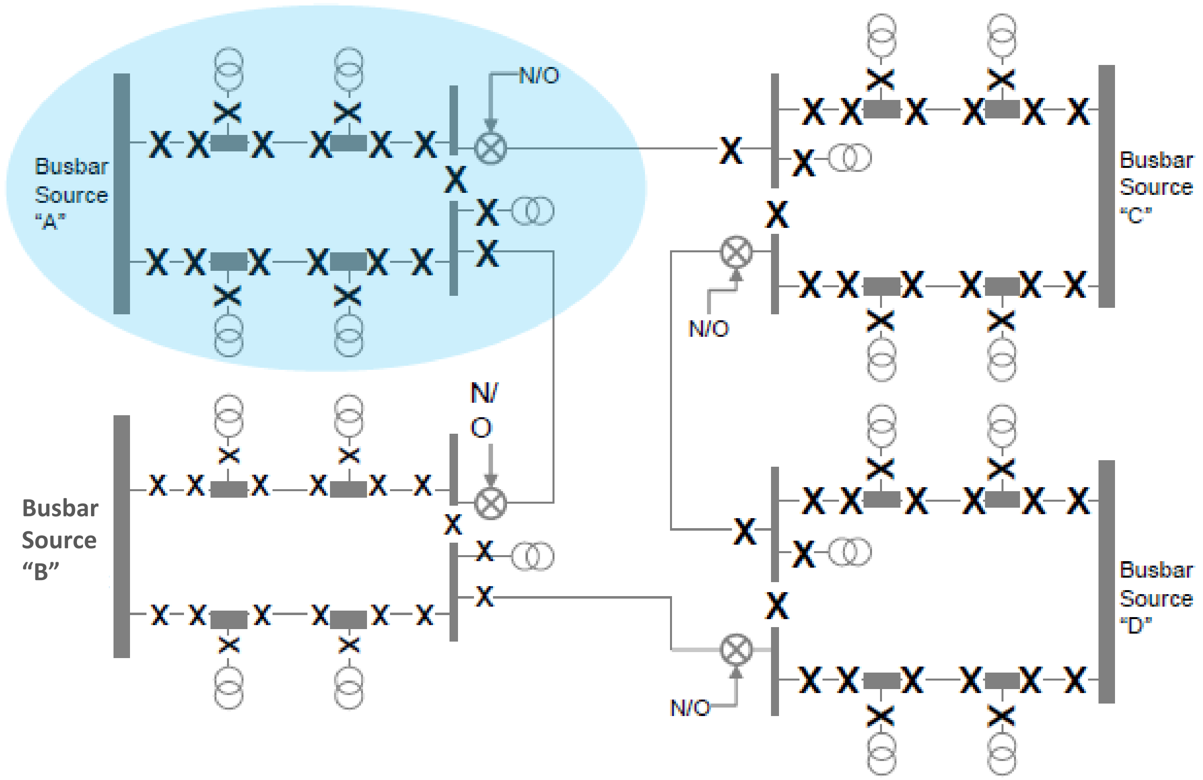
Distribution Automation
- Smart protective and switching devices (e.g., smart reclosers/switches, self-resetting interrupters, etc.)
- Advanced reclosing (single-phase reclosing, pulse reclosing, etc.)
- Fault Location, Isolation and Service Restoration (FLISR)
- Substation automation

Advanced Protection and Control
- Substation and feeder protective devices
- Bidirectional network protectors
- Adaptive protection and control of overcurrent protection devices

Sensors and Intelligent Devices
- Smart Meters and Advanced Metering Infrastructure (AMI)
- Sensors and advanced meters (voltage, current, power flow, temperature, irradiance, wind speed, fault circuit indicators, PMUs, power quality meters, etc.)
- Power electronics-based volt-VAR control devices (e.g., low-voltage SVCs)

Telecom and IT Infrastructure
- Remote/virtual operations
- Backup IT systems
- Substation, feeder and last-mile telecommunications infrastructure

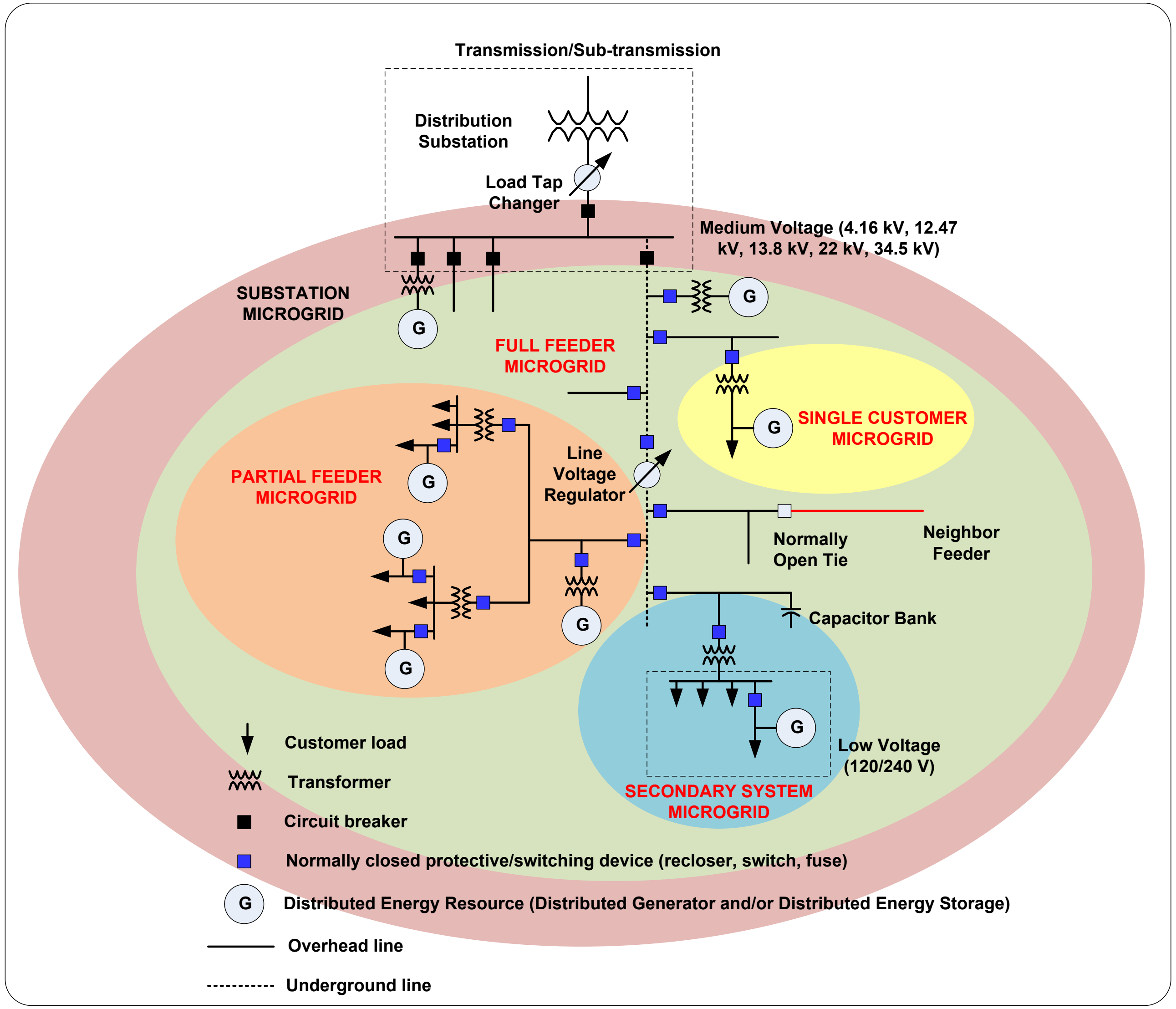
Solutions – High Reliability/Resiliency Distribution



Source: Chan S.C., Yeung K.T., A Model of Dual Distribution Voltage in a Developed Cosmopolitan City, CICED 2008

- **<u>Example: 22 kV closed ring system (Hong Kong):</u>**
  - Two feeders from same zone substation busbar without any open point in between
  - No interruption to customers occurs during single cable faults in the 22 kV simple ring (faulty section isolated in 100 mS)
  - Each ring interconnected to 2 closed rings from different zone substations busbars by a radial feeder with normally open points
  - Typically 4 simple closed rings are interconnected in the form of a feeder group
  - Load of single ring can be fully backed up by neighbor closed rings, this system can achieve better SAIFI than 11 kV open ring

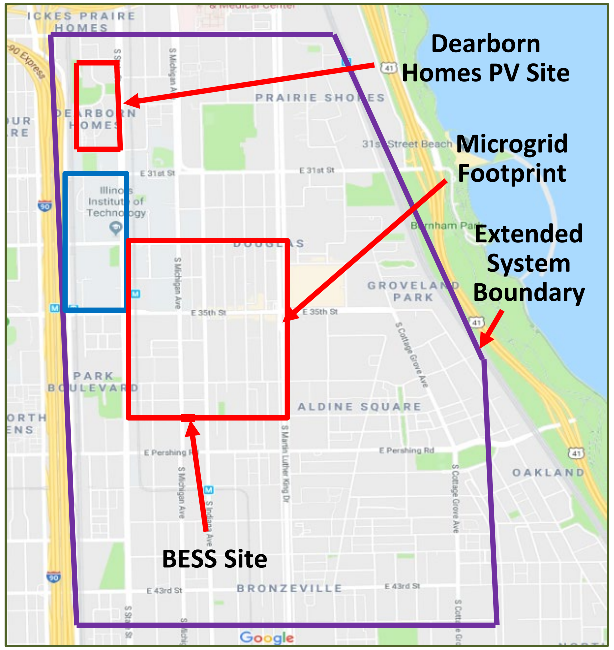
Solutions – Microgrids

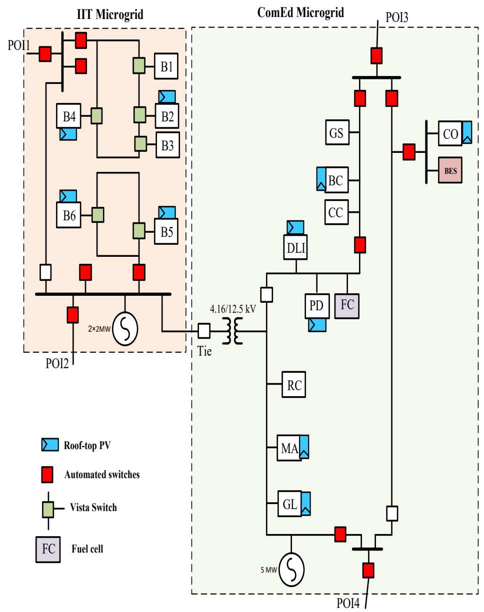


Source: J. Romero Aguero, A. Khodaei, R. Masiello, The Utility and Grid of the Future, IEEE Power and Energy Magazine, Sep/Oct 2016

Example: Bronzeville Microgrid

- Adjacent to IIT campus microgrid to form a cluster microgrid
- 7 MW load, mix generation: PV ≈ 1 MW, BESS = 500 kW/2 MWh, CHP + Diesel + Fuel Cell= 7 MW)
- Selected as one of the DOE funded projects for microgrid controller design and testing
- Using loop scheme with supply from two substations and automated fault detection, clearing and fast restoration
- Two separate islands or connected together

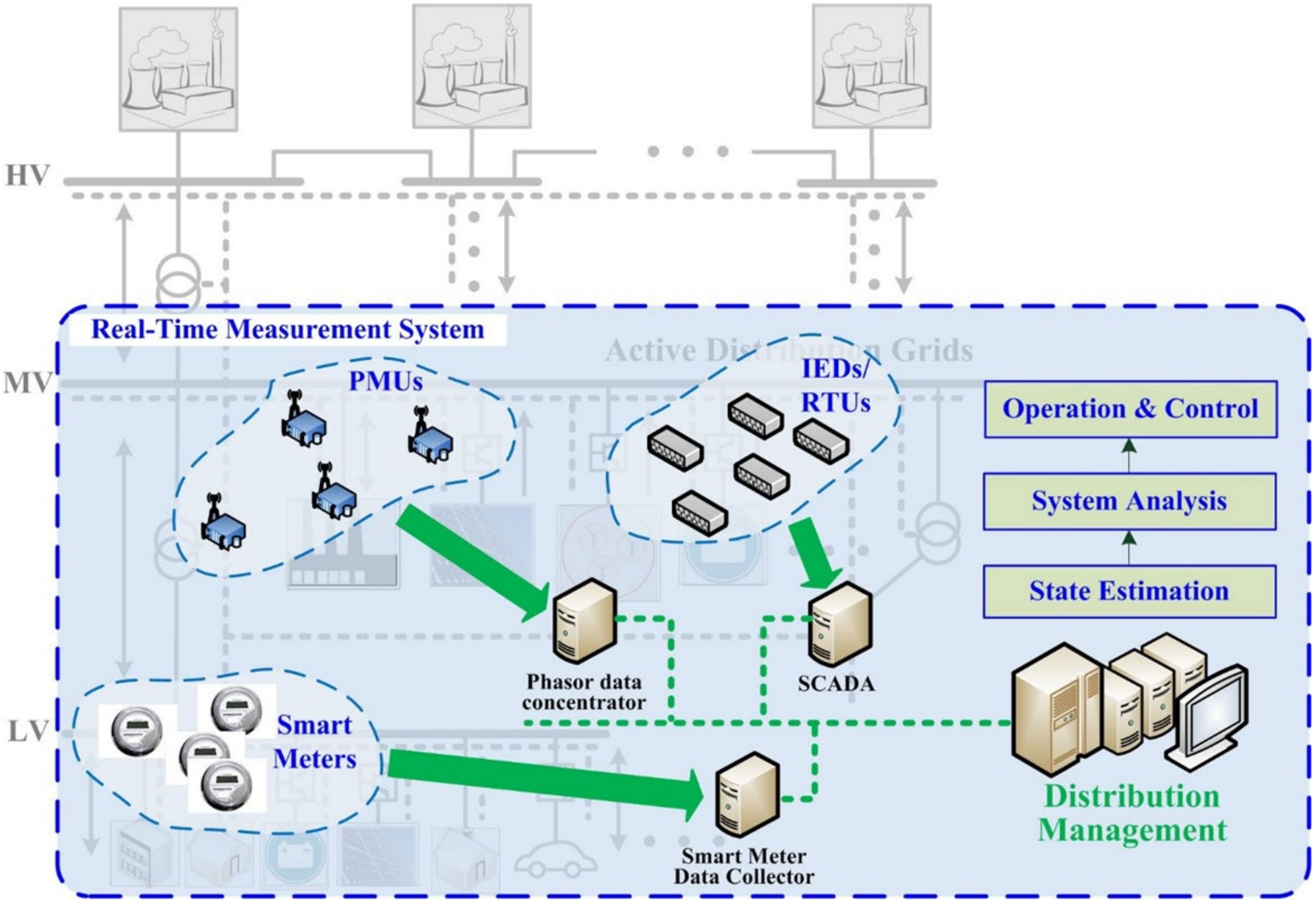




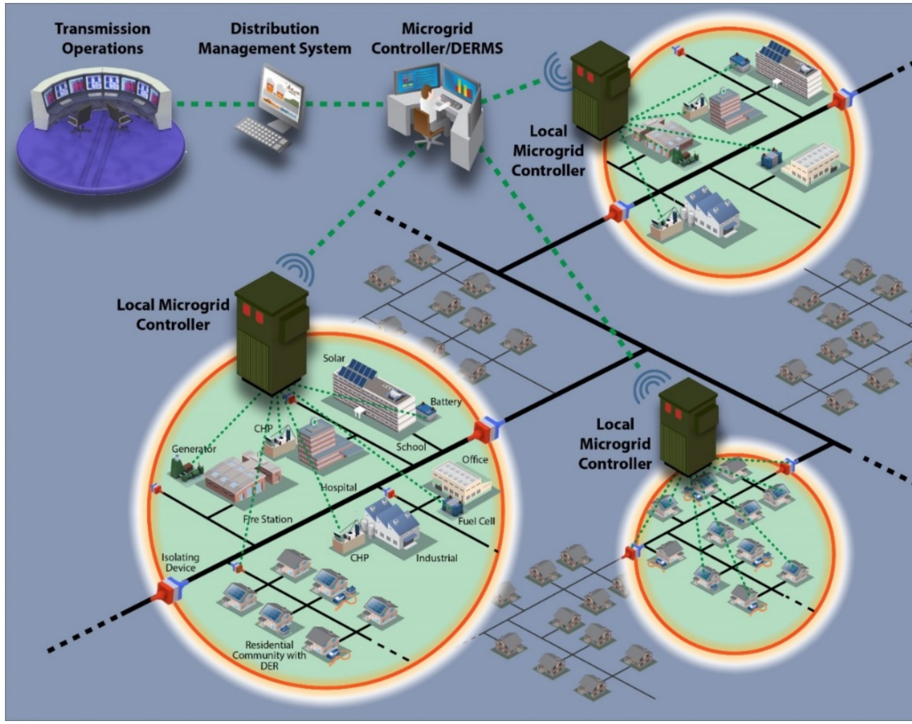
Source: ComEd

Aggregating 17 roof-top PV systems

Solutions – Real-Time Distribution Operations



Source: RTWH Aachen

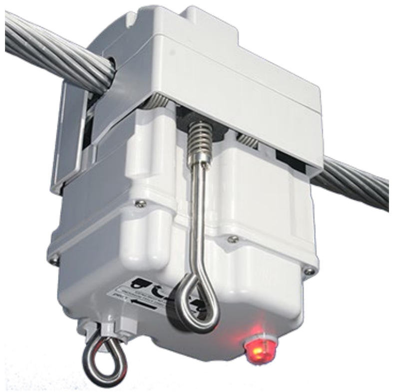


Source: EPRI

Solutions – Real-Time Distribution Operations

Solutions – Sensors and Grid Edge IEDs/Switchgear

ConnectDER: behind-the-meter DER monitoring device



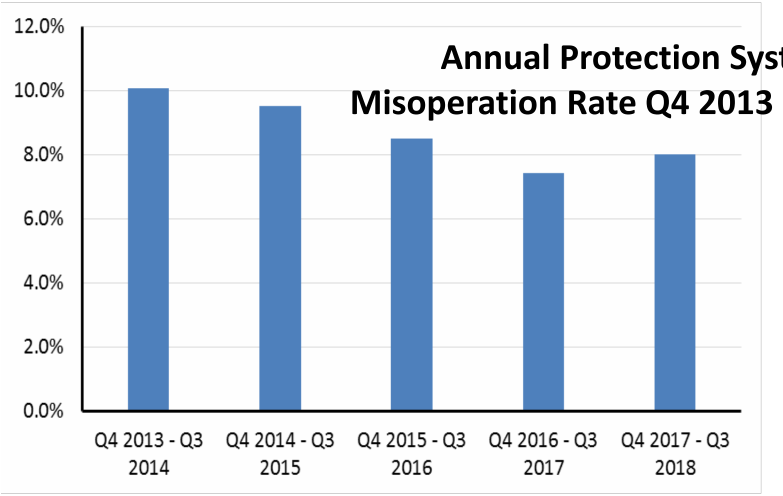
MM3: advanced line sensor and Fault Circuit Indicator (FCI)

VacuFuse: grid edge (service transformer) self-resetting interrupter

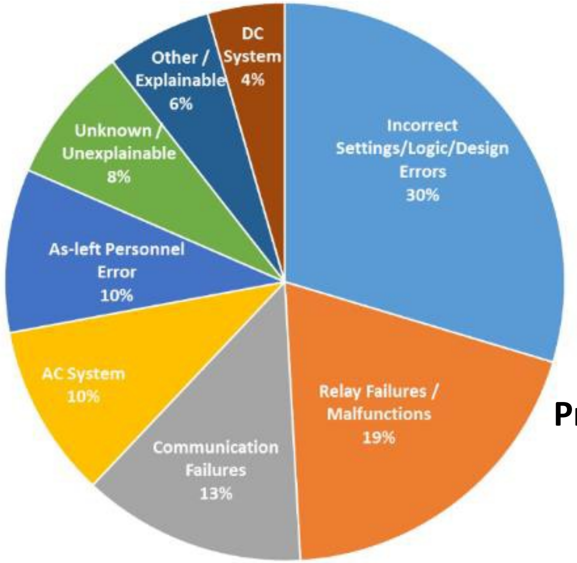
micro-PMU: Phasor Measurement Unit (PMU) for distribution applications

Solutions – Advanced Protection and Automation

Increasing Complexity of Protection and Control Systems



Source: NERC

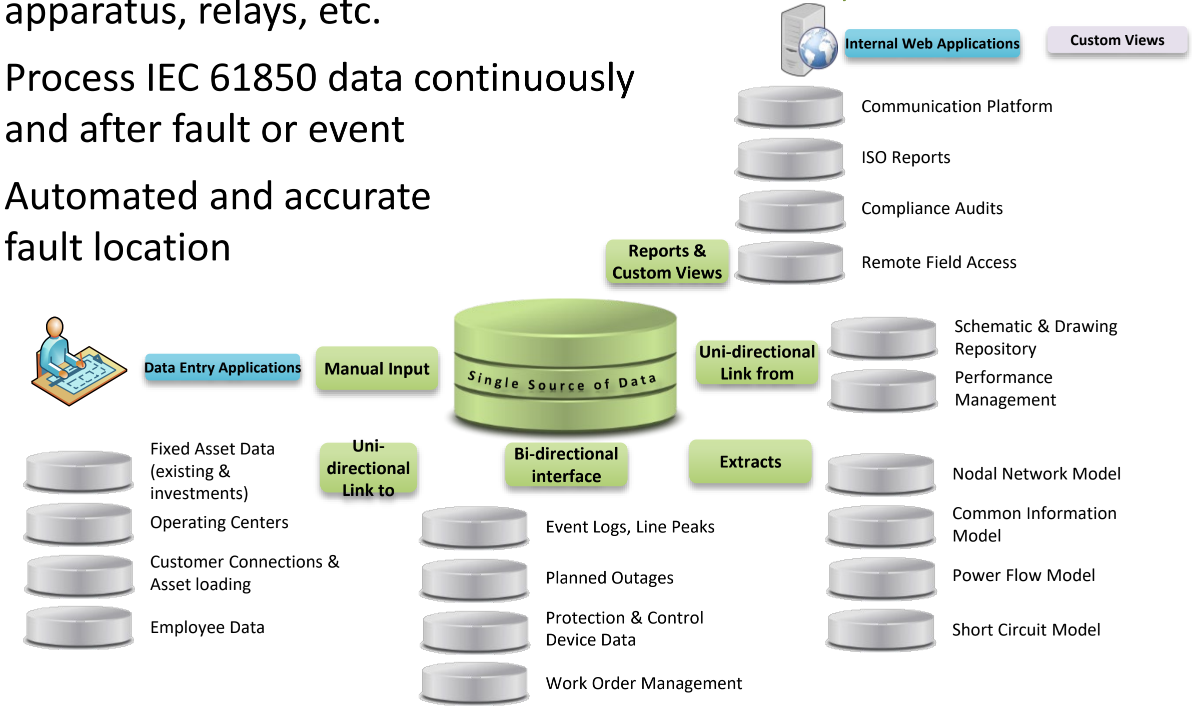


Protection Misoperations by Cause Code (4Q 2013 - 3Q 2018)

Solutions through Automation

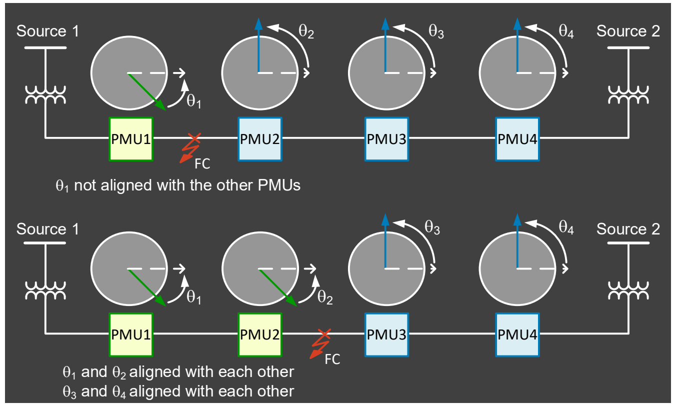
- Automation of NERC PRC/CIP compliance and reporting
- Give fast, clear information and decision guidance to engineers
- Assess mis-operations and correct relay margins
- Improve life cycle asset replacement strategy: report failed or malfunctioning apparatus, relays, etc.
- Process IEC 61850 data continuously and after fault or event
- Automated and accurate fault location

Achieve Single Source of Data and eliminate redundant manual entry/calculations

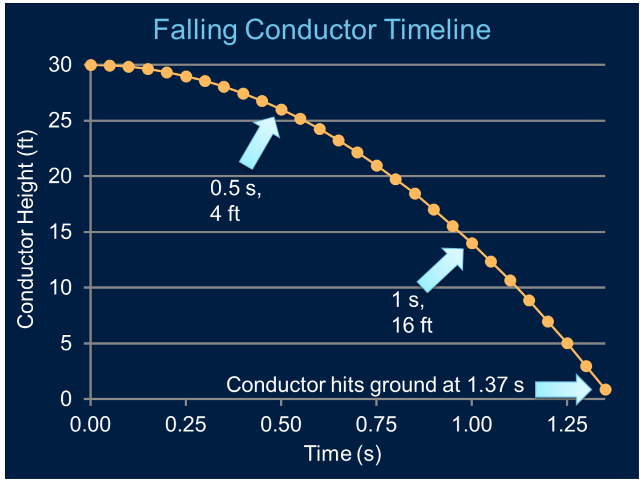


Example: Technologies to Reduce Wildfire Safety Risks

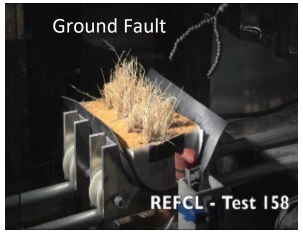
Falling conductor protection using distribution PMUs and wireless WAN to detect a line break before it hits the ground

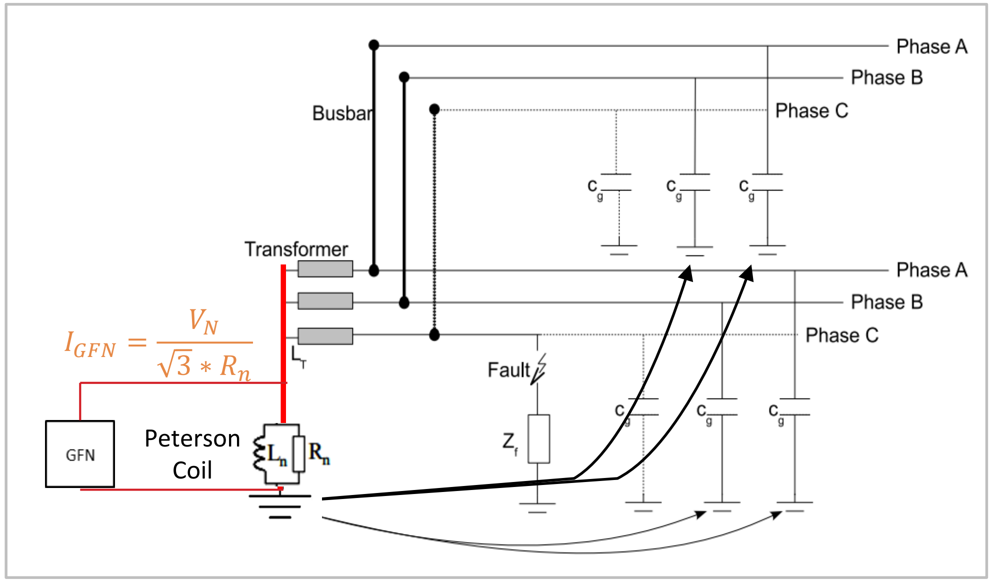


Source: SDG&E



Rapid earth fault current limiter to address fire risks due to arcing

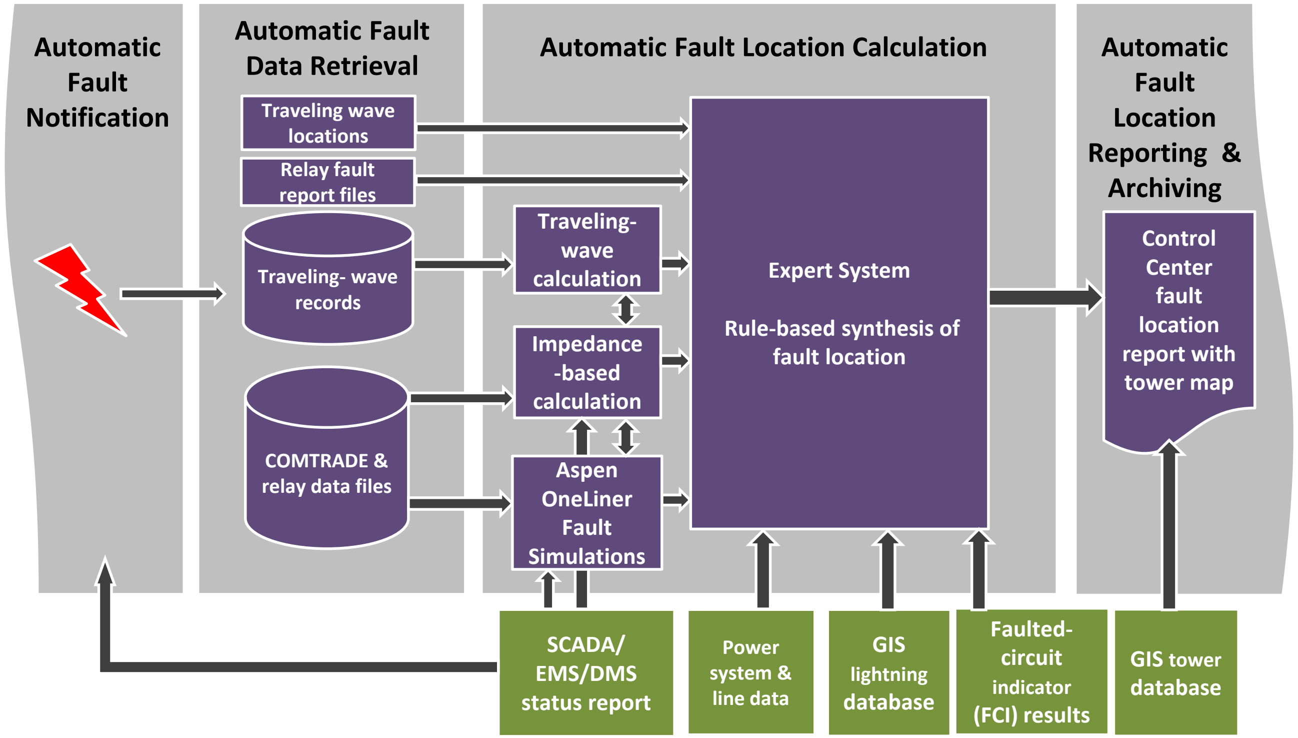




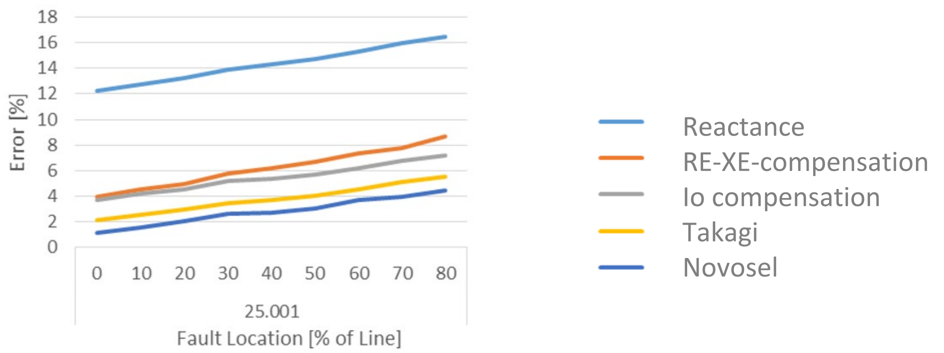
Typical fault current values: 0–50 mA (after 80 ms)

- Higher voltages on healthy phases and protection challenges
- Circuit to remain energized for seconds to facilitate faulted circuit detection
- Reclosing to be de-activated for all types of faults
- Circuit will remain de-energized until either data determines faulted section or entire circuit patrolled

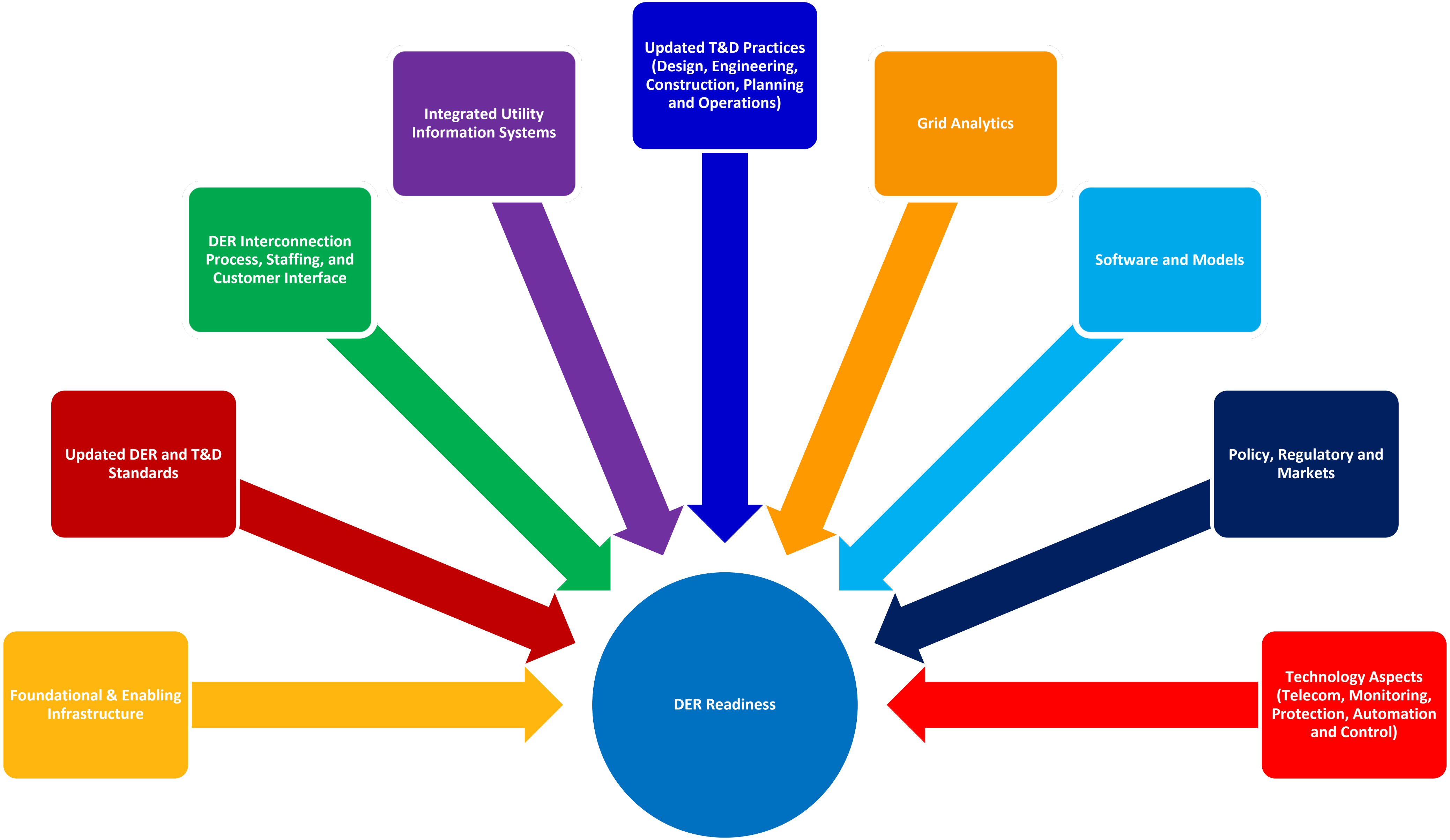
Example: Automated Fault Location System



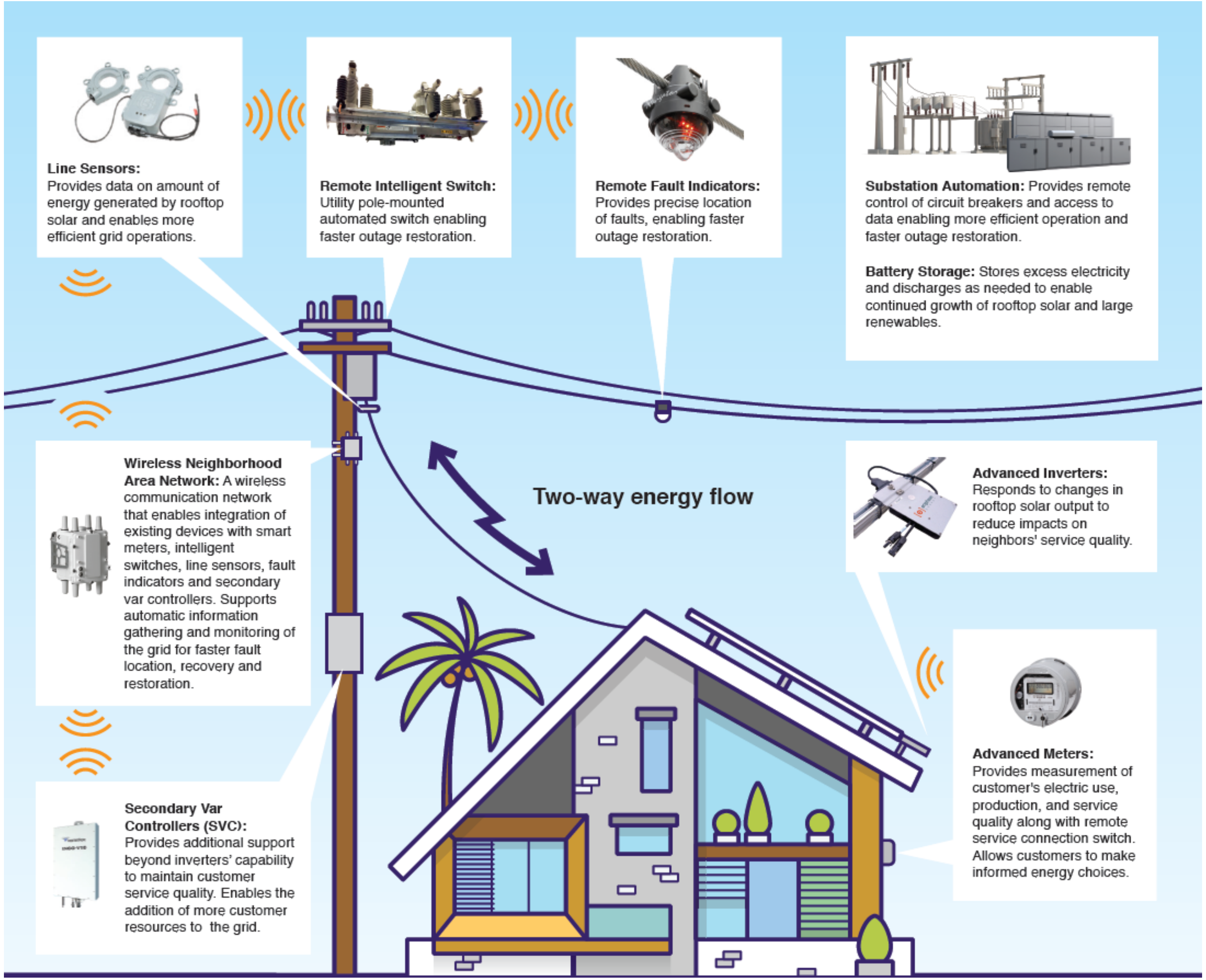
- Quick and Automatic
- With map location identifying the most probable tower and error estimate
- With best accuracy



Solutions – DER Readiness: Ability to Effectively and Seamlessly Host and Manage DER

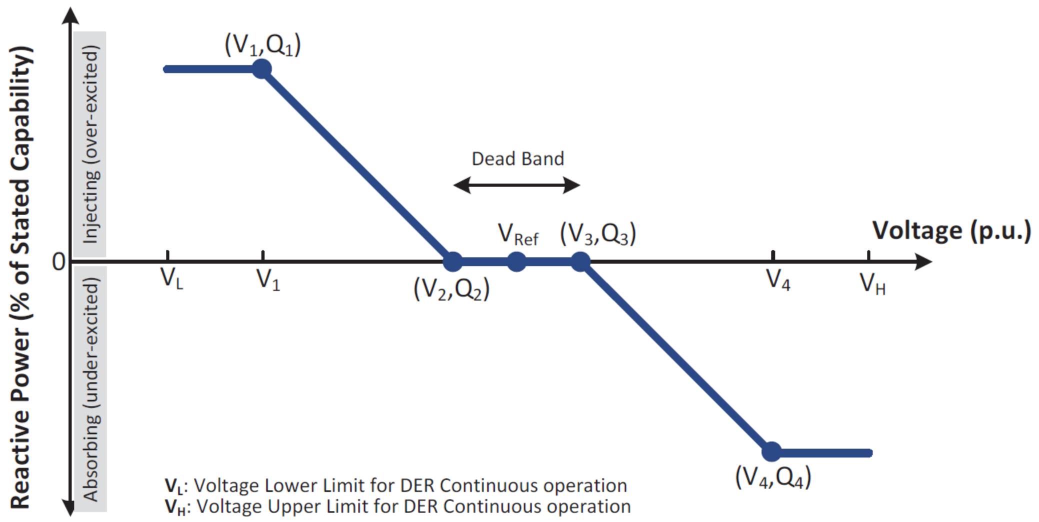


Solutions – Grid Edge Awareness and Control

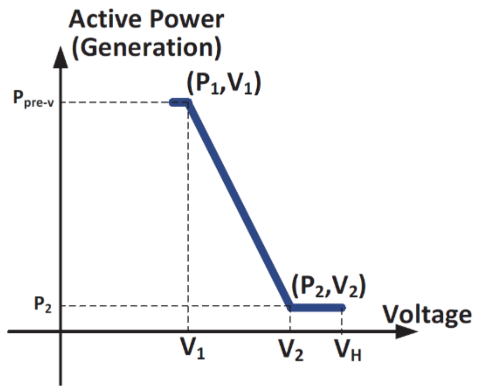


Source: M. Asano, Grid Modernization Applications in a High DER Environment, 2018 IEEE PES T&D Conference and Exposition, Denver CO

Solutions – Smart Inverters



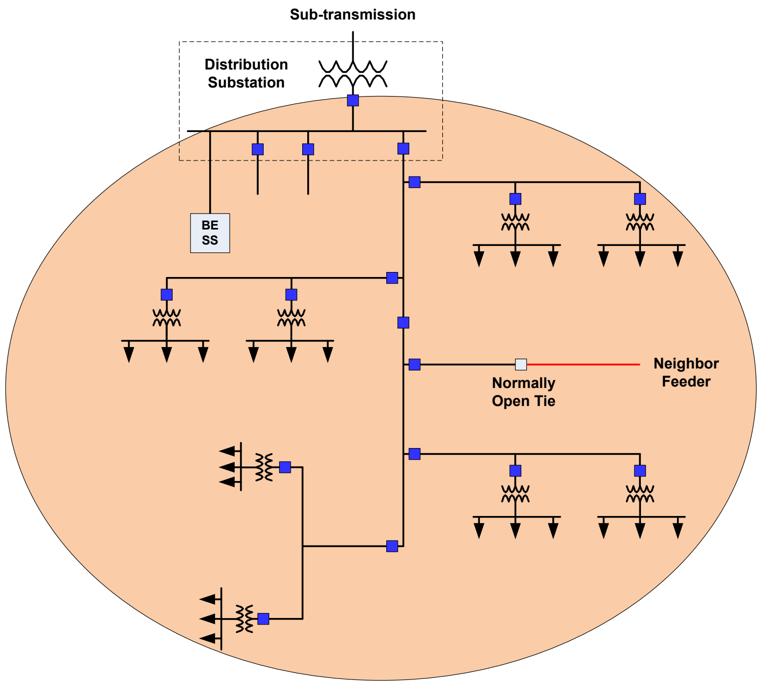
Volt-VAR Function
(Voltage Control)
IEEE 1547

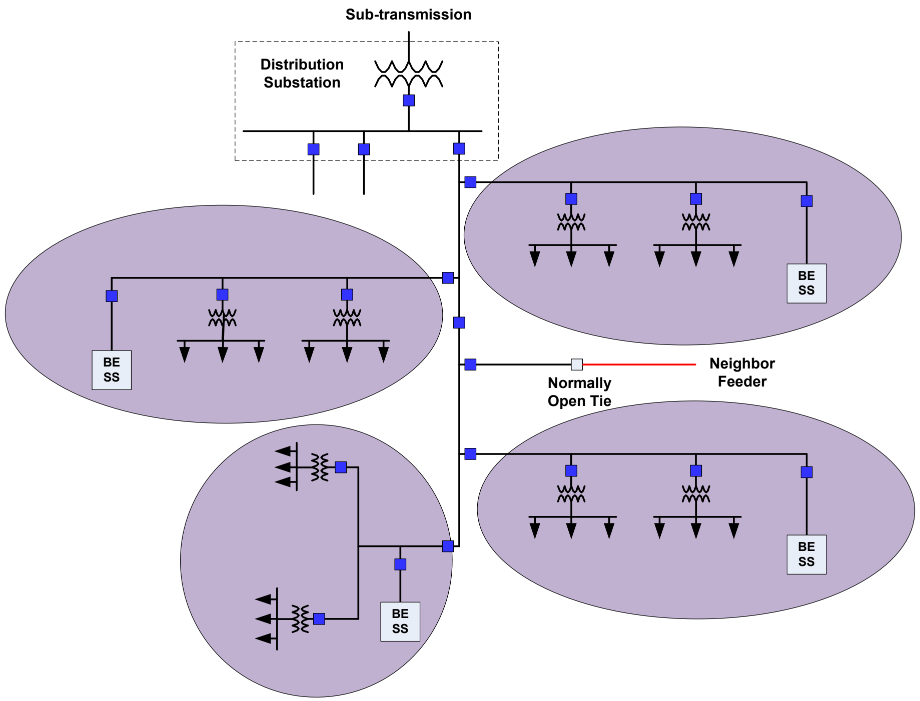


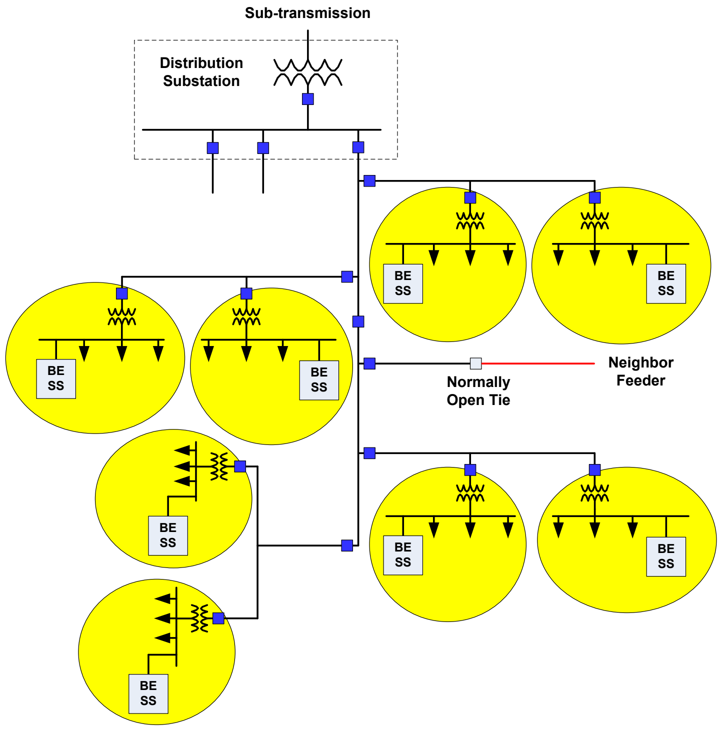
Volt-Watt Function
(Output Curtailment)
IEEE 1547

Source: 1547-2018 - IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces

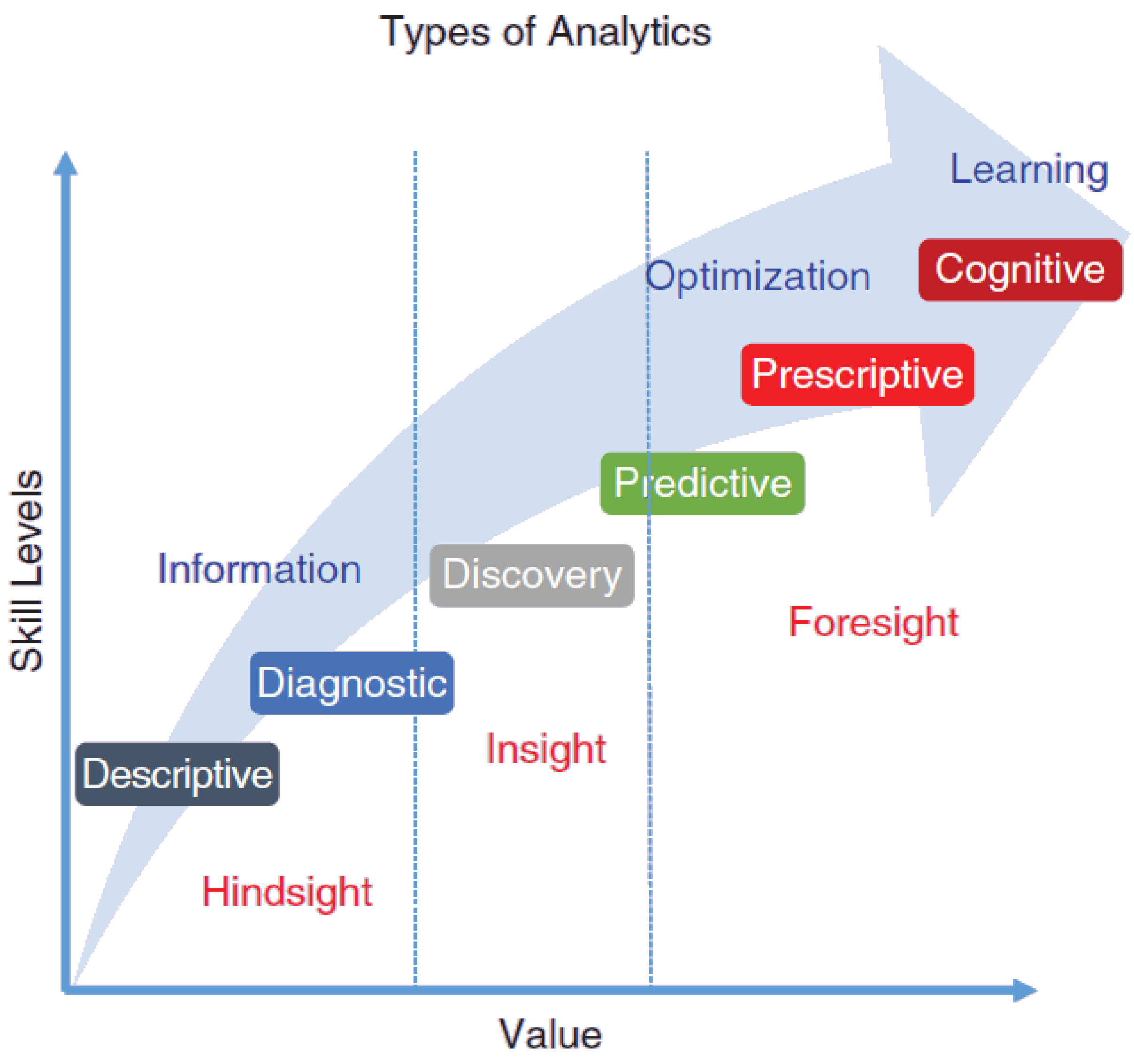
Solutions – Distributed Energy Storage







Solutions – Big Data Grid Analytics



Source: J. Romero Aguero et. al, Managing the New Grid: Delivering Sustainable Electrical Energy, IEEE Power and Energy Magazine, Jul/Aug 2019

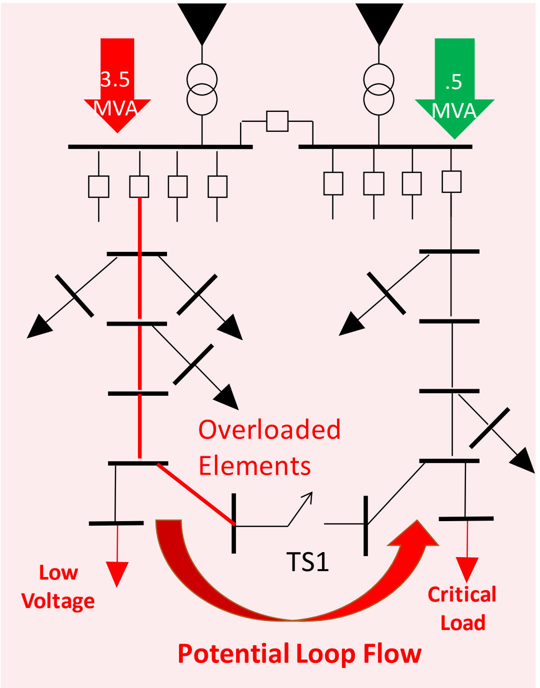
Grid Analytics

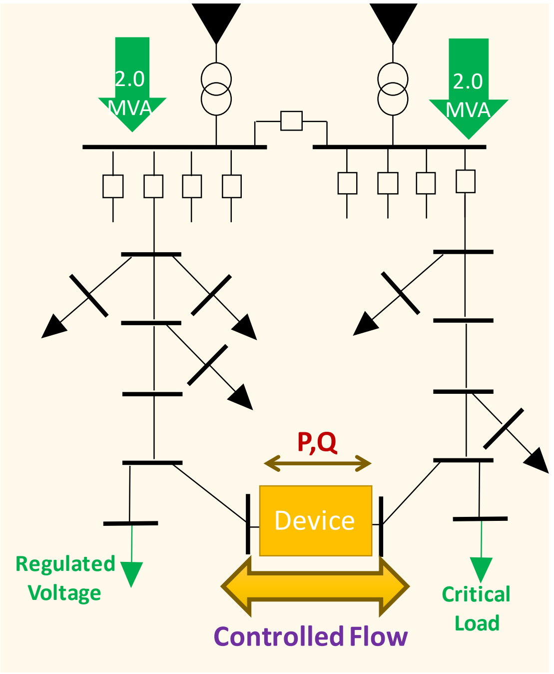
- **Descriptive analytics:** describe past performance of distribution grid by analyzing historical data, e.g., use service interruption records to calculate reliability indices (SAIFI, CAIDI, SAIDI, etc.)
- **Diagnostic analytics:** diagnose root-cause of distribution system performance, e.g., to identify the root-cause of service interruptions and equipment outages
- **Discovery analytics:** provide additional insights about distribution grid performance to identify unknown issues, particularly in areas of the grid that traditionally have had limited real-time visibility and awareness, e.g., assess grid edge performance
- **Predictive analytics:** estimate expected distribution grid performance based on historical and real-time data, e.g., estimate potential equipment overloads that might occur as a consequence of extreme weather patterns
- **Prescriptive analytics:** use historical and real time data along with system analysis capabilities to provide recommendations regarding preventive measures that would allow to preclude or minimize performance disruptions, e.g., advice on most resilient system configuration to withstand major weather events.
- **Cognitive Analytics:** Use computational intelligence technologies inspired by human learning (e.g., artificial intelligence techniques such as machine learning, deep learning, etc.) to collect, process, analyze, and manage qualitative (e.g., natural language) and quantitative data from diverse sources. Cognitive analytics may be used to develop adaptive self-learning solutions whose accuracy improves over time.

Solutions – FACTS Devices

- Flexible AC Transmission Systems (FACTS) devices are advanced static power electronics-based series and/or shunt equipment used to provide fast, dynamic and continuous control of voltages and/or power flows in transmission systems and increase power transfer capability, stability and controllability of the grid
- FACTS applications in transmission systems is an established and mature area, while applications in distribution are still emerging and generally targeted to custom power and DER integration use cases (e.g., volt-Var control in wind and PV farms).
- Most popular distribution technologies are SVCs and STATCOMs (e.g., D-VAR by American Superconductor). Technology has been deployed by utilities such as Alliant Energy https://www.tdworld.com/digital-innovations/volt-var/article/20971388/alliant-energy-chooses-dvar-vvo-for-distribution-grid-voltage-optimization-project

Example of application of UPFC for power flow and voltage control



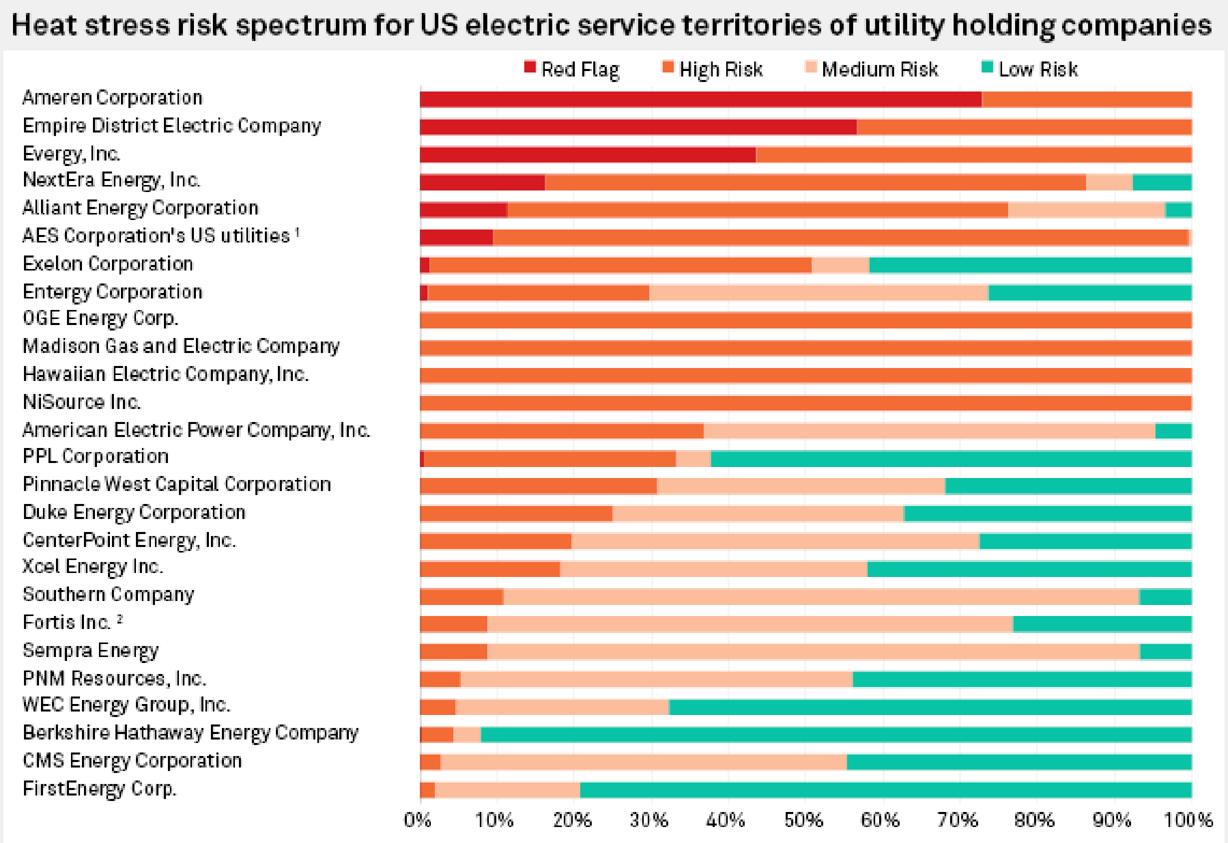


Power flow distribution **before** UPFC

Power flow distribution **after** UPFC

Source: A. Ingram, J. Schatz, C.J. Murray, H.A. Al Hassan, The Transformer-less Unified Power Flow Controller (TUPF) for Power Flow Control at Normally-Open Primary Ties, CIGRE US National Committee 2018 Grid of the Future Symposium

Climate Change Impacts – Risks

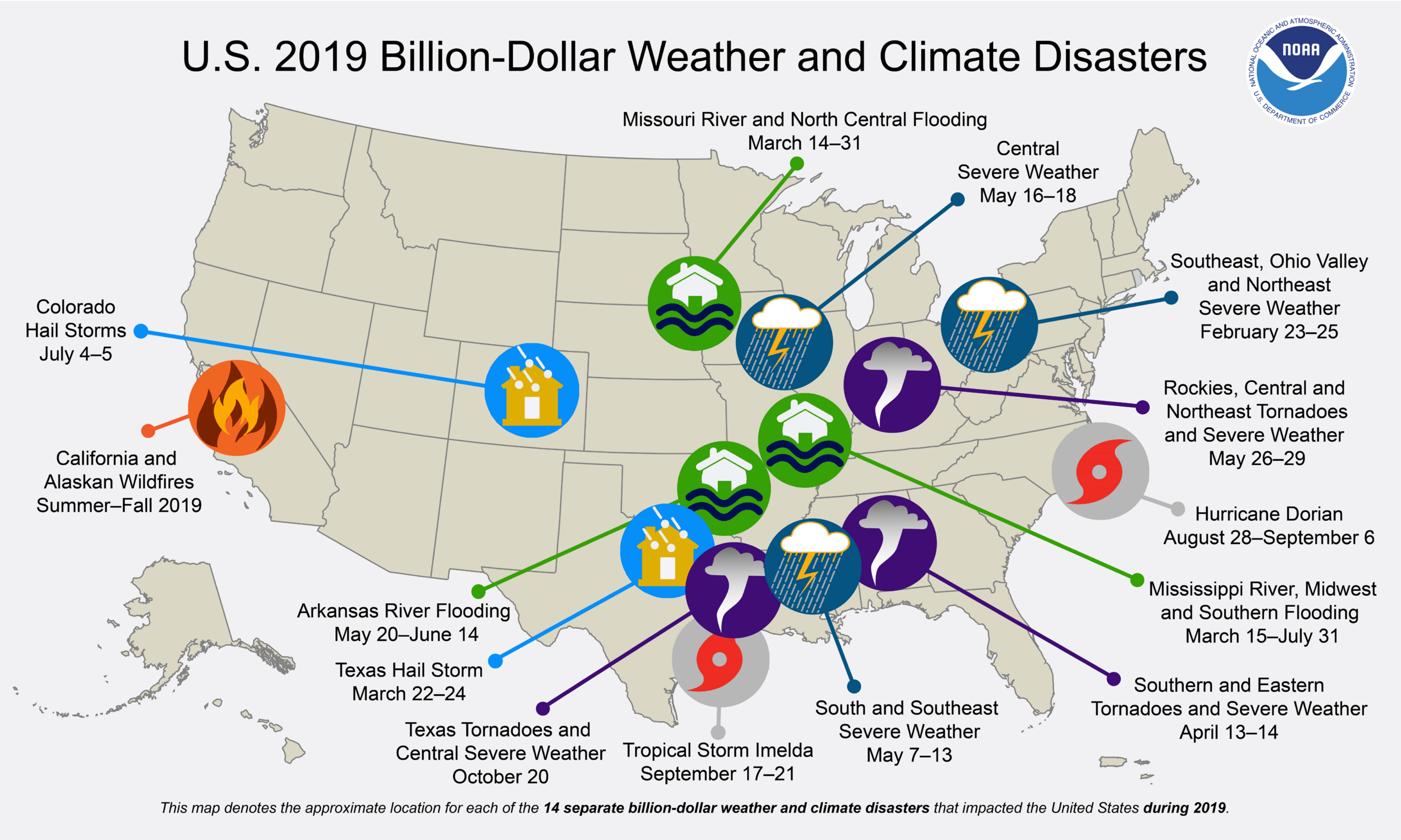


Data effective Jan. 16, 2020.
[1] AES Corp.'s U.S. utilities consist of AES Corp. U.S. subsidiaries DPL Inc. and IPALCO Enterprises Inc.
[2] Fortis Inc. consists of U.S. subsidiaries UNS Energy Corp. and Central Hudson Gas & Electric Corp.
Risk of increased heat stress is for the period of 2030 to 2040 in relation to the historical period of 1975 through 2005.
Excludes holding companies with regulated U.S. service territories facing only limited or no risk of heat stress.
Sources: Four Twenty Seven; Moody's Investors Service; S&P Global Market Intelligence

- Water stress risk:
  - According to Moody's 11 utilities (red flag risk) have a combined $31 billion in exposed rate base with a 22-year average depreciation life (Edison International, Xcel Energy Inc., Sempra Energy, Fortis Inc., Berkshire Hathaway Energy, Black Hills Corp., Pinnacle West Capital Corp., Exelon, IDACORP Inc., American Electric Power Co. Inc. and Alliant)
  - About two-thirds of U.S. utilities are at high risk or red-flag risk of intense rain and flooding risk in their service territories. Parts of the Midwest, Southeast and Pacific Northwest are projected to face the sharpest increases
  - Utilities facing red-flag risk represent almost $21 billion in rate base with a 23-year average depreciation life (AEP, AES' U.S. utilities, PPL Corp., FirstEnergy Corp., Duke Energy Corp., Avangrid Inc. and Dominion Energy Inc.)
- Hurricanes:
  - Projected to continue to put critical infrastructure at risk along the East Coast and the Gulf of Mexico
  - Six utilities serving regions with red flag hurricane risk represent over $55 billion in rate base with a 20-year average depreciation life (NextEra, Dominion, Duke, Entergy, Cleco Corp. and Southern Co.)

Source: https://www.spglobal.com/marketintelligence/en/news-insights/trending/0kcLHVuEeuleWrC_VaxHIw2

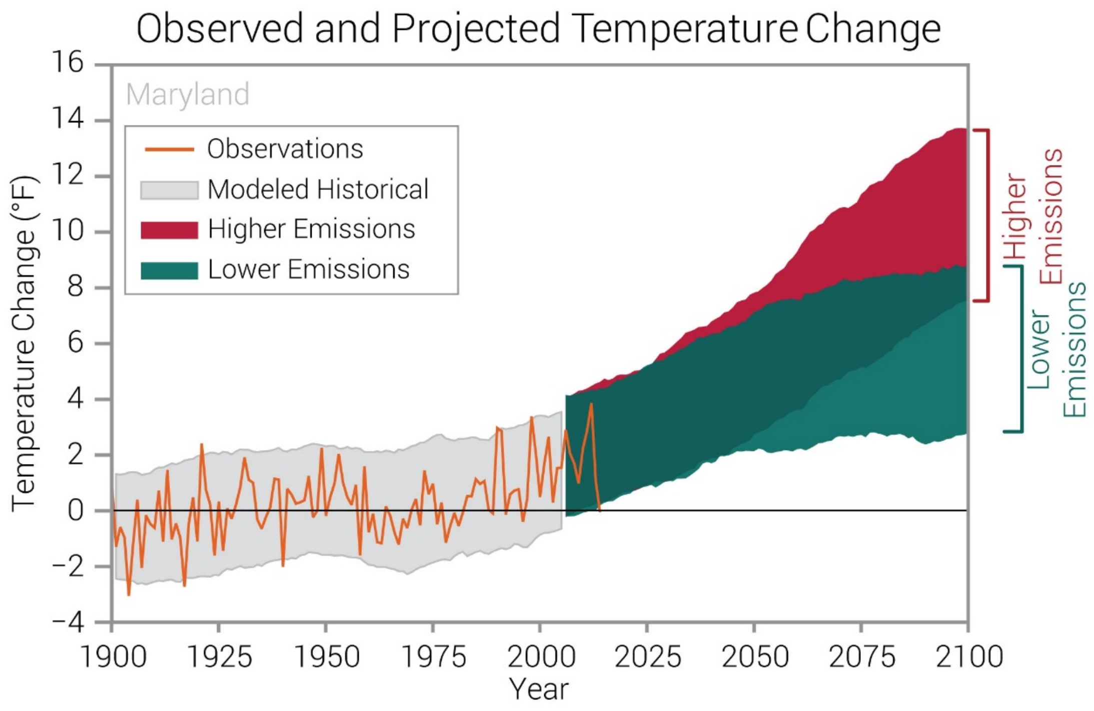
Climate Change Impacts



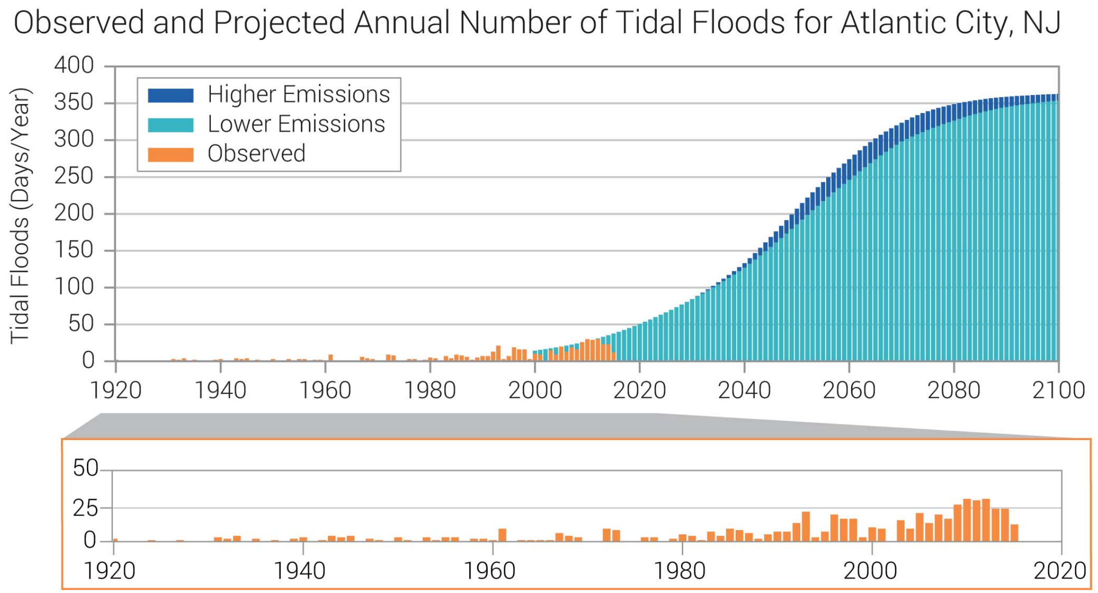
"2019 is the fifth consecutive year (2015-2019) in which 10 or more billion-dollar weather and climate disaster events have impacted the United States. Over the last 40 years (1980-2019), the years with 10 or more separate billion-dollar disaster events include 1998, 2008, 2011-2012, and 2015-2019". Source: NOAA National Centers for Environmental Information

Source: NOAA

Example of Climate Change Impacts

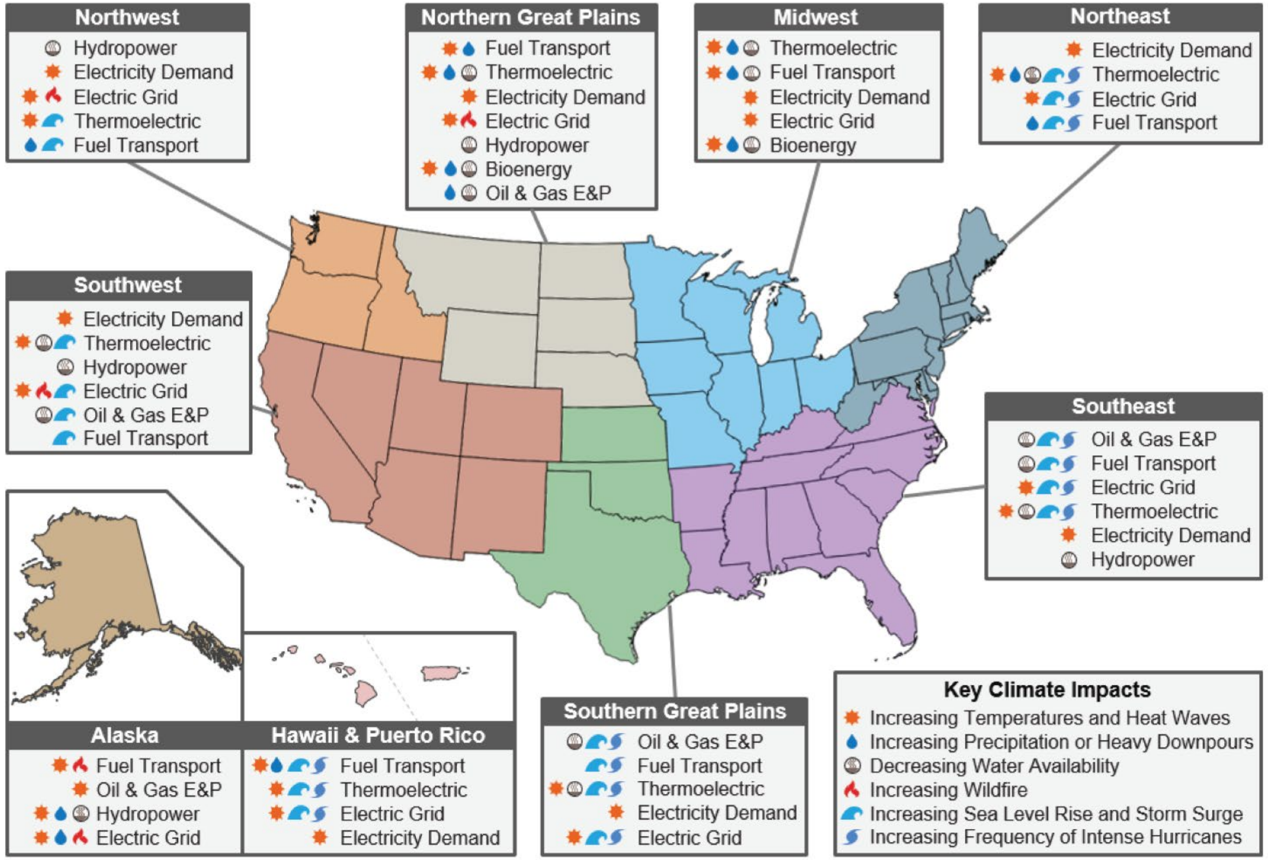


Source: U.S. Climate Resilience Toolkit
https://statesummaries.ncics.org/chapter/md/

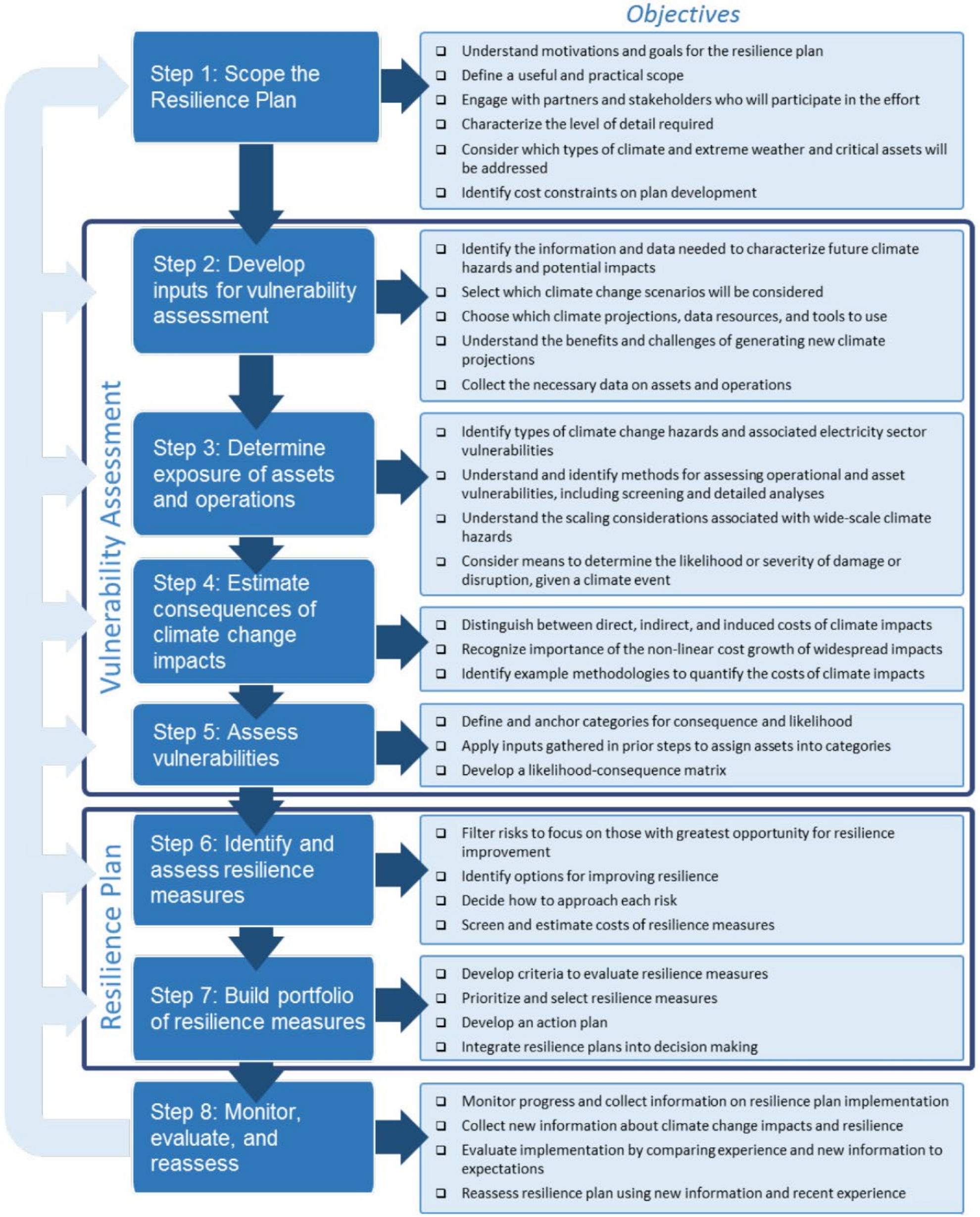


Source: U.S. Climate Resilience Toolkit
https://statesummaries.ncics.org/chapter/nj/

General Approach for Climate Resilience Solutions



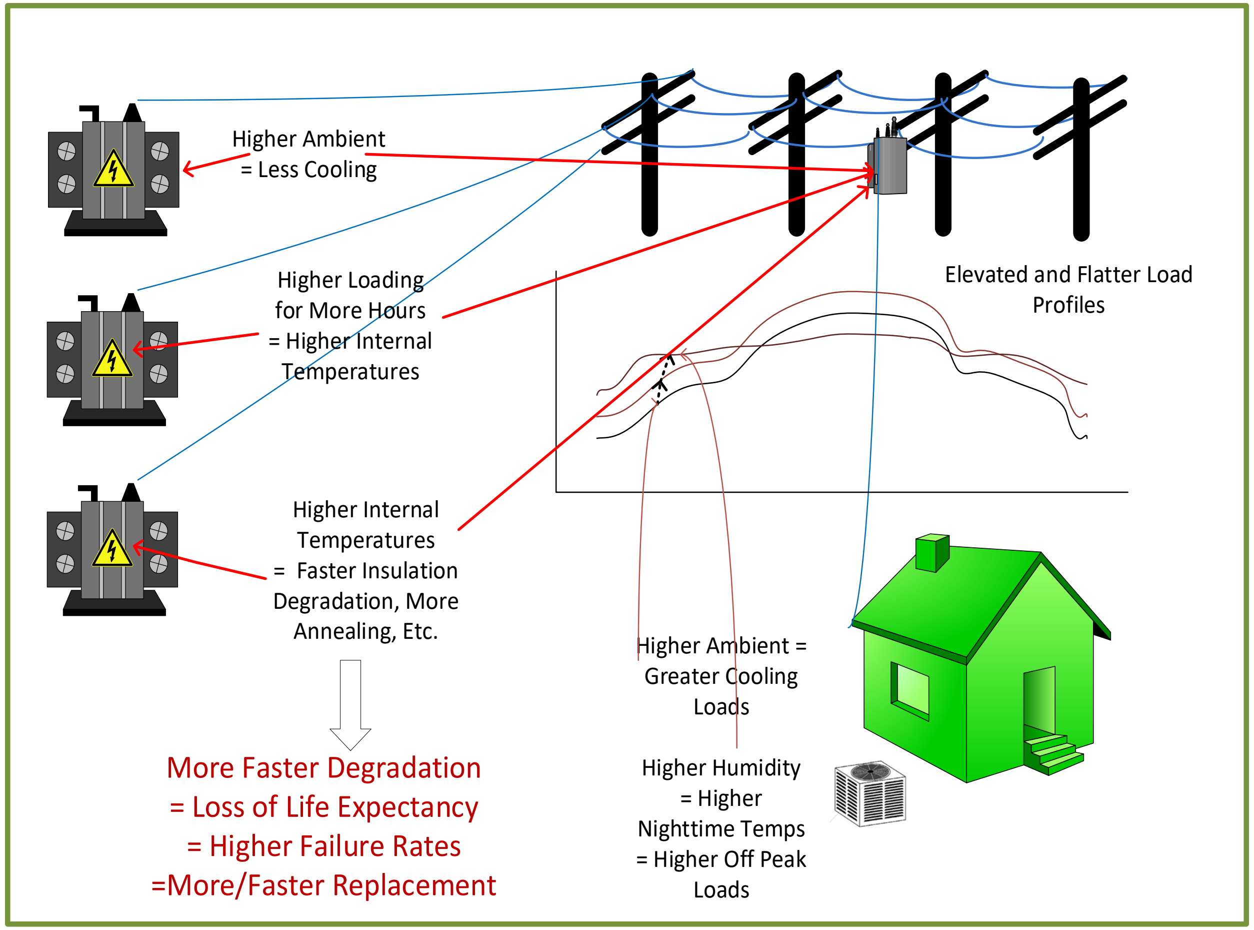
Source: Climate Change and the U.S. Energy Sector: Regional Vulnerabilities and Resilience Solutions https://www.energy.gov/policy/downloads/climate-change-and-us-energy-sector-regional-vulnerabilities-and-resilience



Source: Climate Change and the U.S. Energy Sector: Guide for Climate Change Resilience Planning

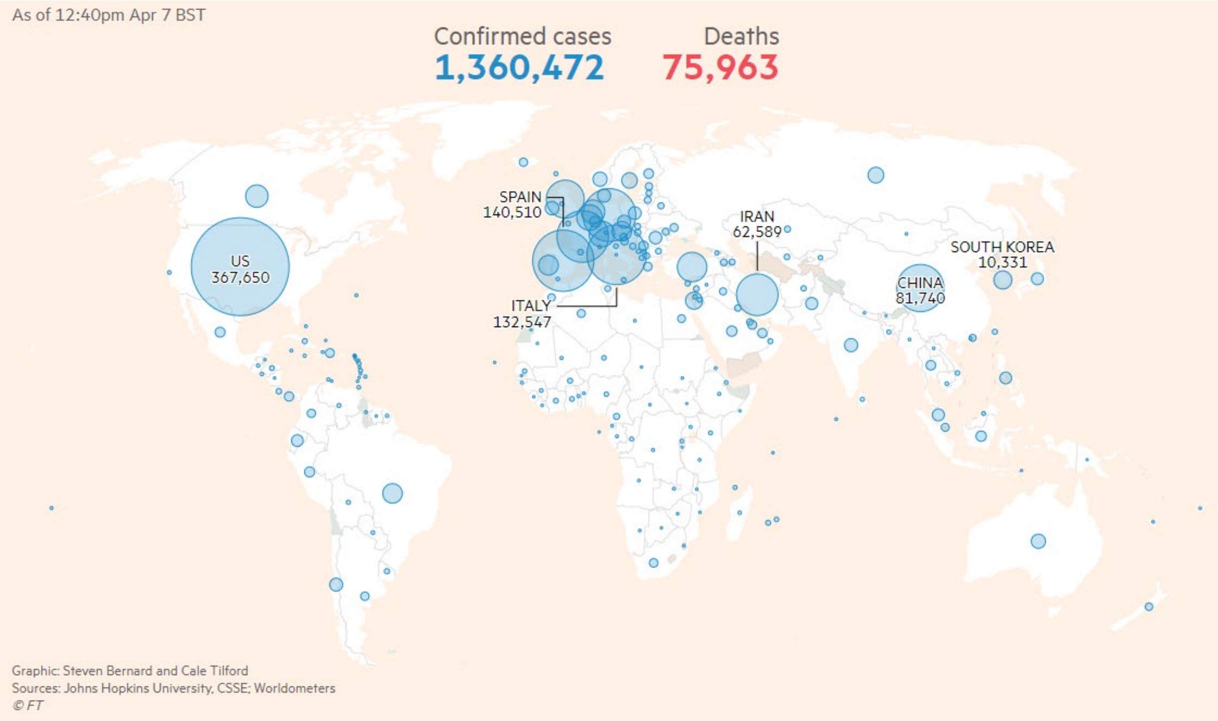
Climate Change and Asset Risk Management

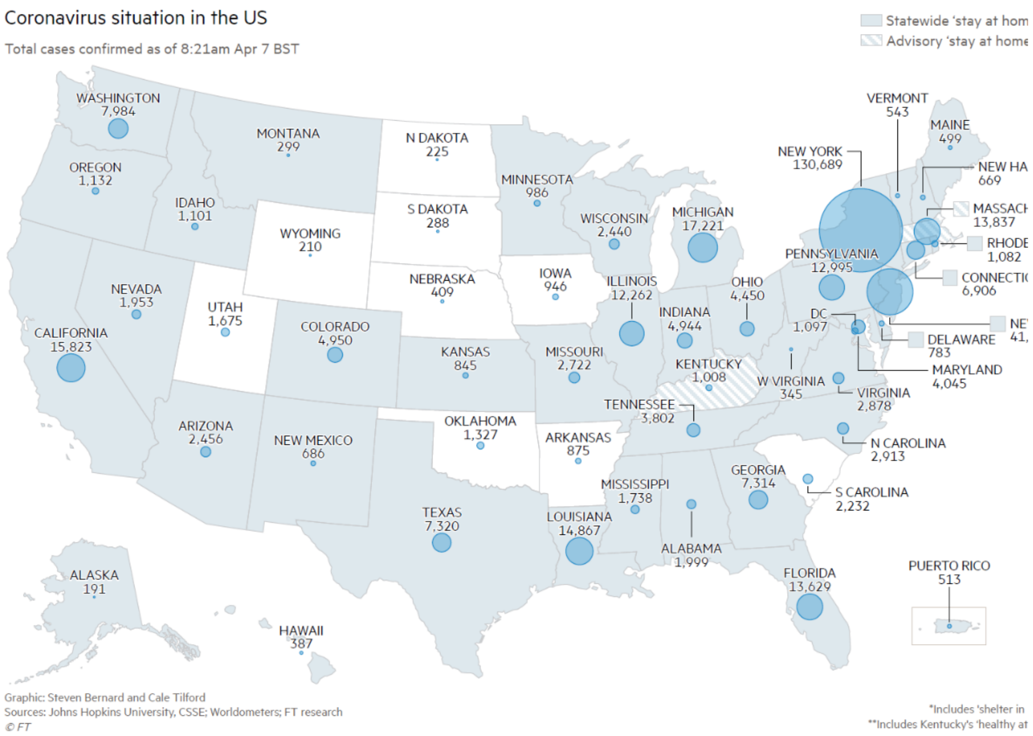
- A temperature rise of 2-4 degree Celsius could increase peak load by 5% and impact overall asset loading – loss-of-life (e.g. power and service transformers)
- Higher humidity means evening temperatures stay higher longer
- More severe weather could cause reliability issues and higher costs to maintain reliability (SAIDI/SAIFI)
- Sea level rise and severe weather mean flooding of facilities



Quantifying this Risk

Covid-19 Situation – World and US





Source: Financial Times https://www.ft.com/coronavirus-latest

How may covid-19 affect the electric power industry? (1)

Operations

- Limited resource availability and supply chain disruptions
- Sequestering control center staff
- Cautions put in place for field operations to assure social distancing (e.g. one person in basket, drone/helicopter inspections)
- Criticality of electric infrastructure
  - Electrical industry showing ability to respond fast
  - Importance of hurricane/tornado/storm/wildfire season preparedness
- Growing importance of reliability and resiliency at customer level
  - System wide average indices will not be sufficient anymore
  - Residential reliability increasingly important (growth of work from home)

Business

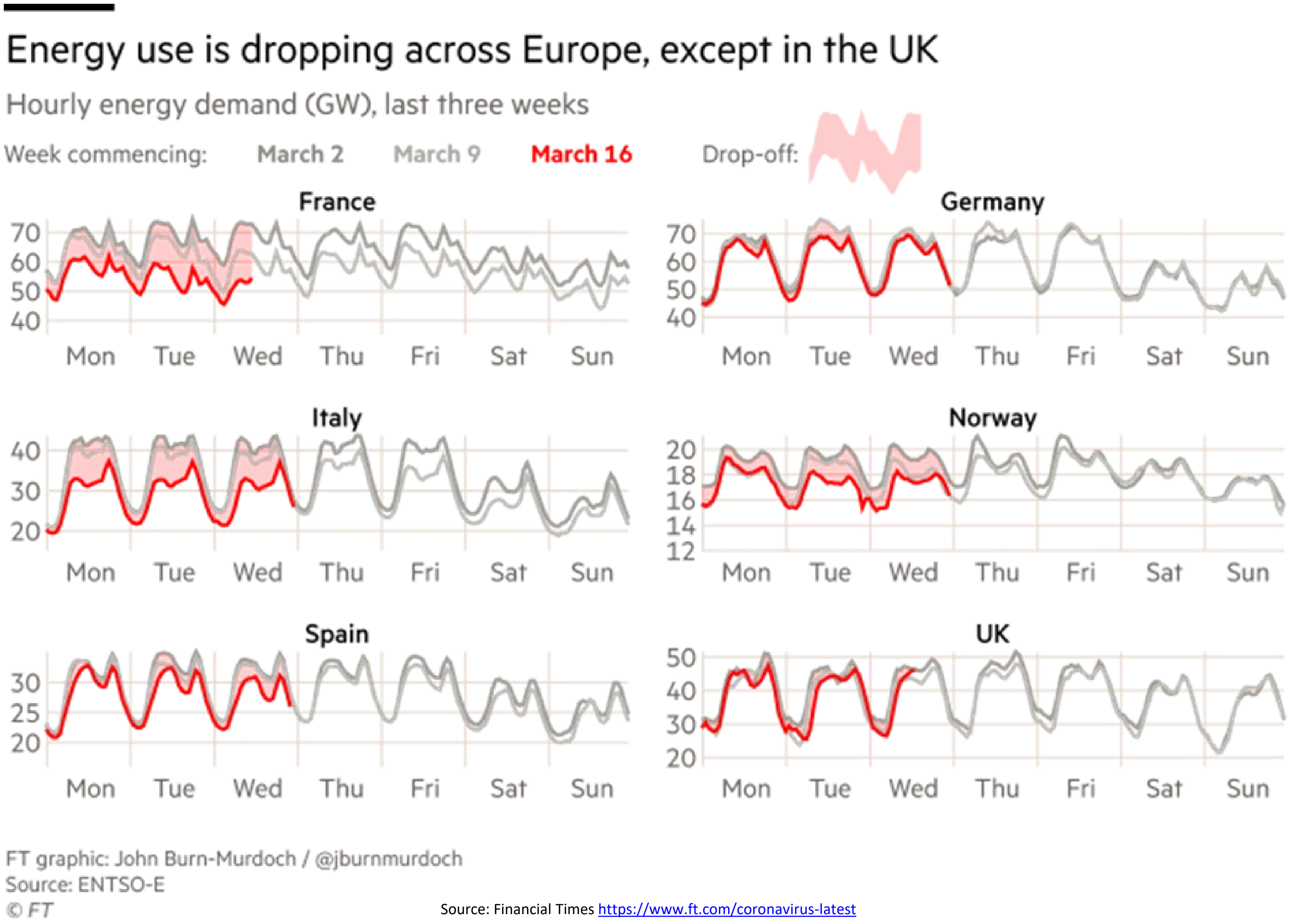
- Reduction of energy consumption/peak demand and modification of consumptions patterns and load curves
  - Revenue decrease for utilities operating under volumetric rates
  - Potential reduction of some capacity investment needs (e.g., substation transformer upgrades) for all utilities
  - Residential end users working from home (e.g., AC loads may increase in the South in late Spring and Summer), potential peak shifts and overloads of grid edge assets (e.g., service transformers)
- Increase in customers requiring assistance with bills
- Impact on discretionary spending and priorities
  - Justified if improving reliability/resiliency, etc.
  - Emerging technologies, renewables, energy storage, electrification
- Focus on core competencies and foundational infrastructure (“back to basics”)

Impacts may vary by region

How may covid-19 affect the electric power industry? (2)

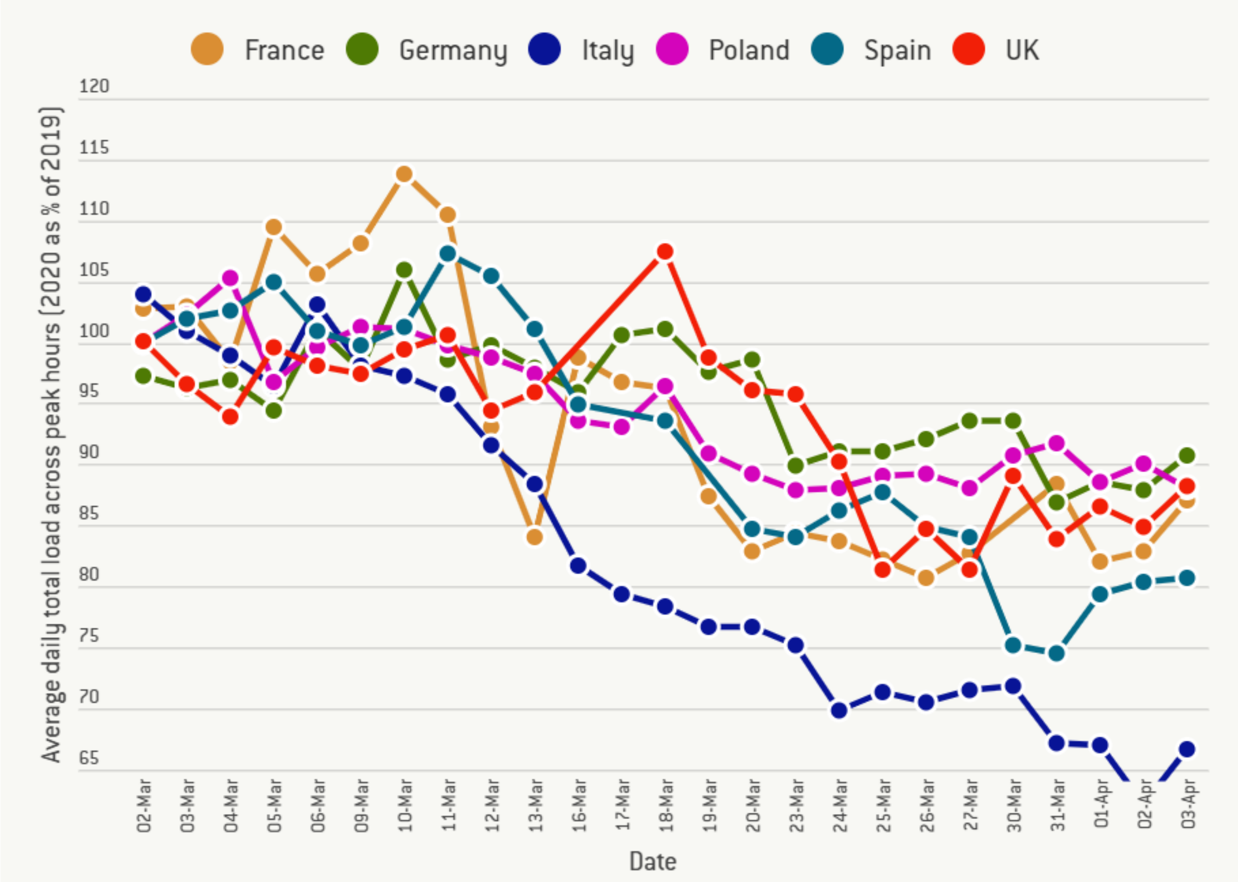
- Potential new/renewed areas of interest for the industry
  - Maintaining/improving reliability/resiliency (including behind-the-meter DER technologies to improve residential performance)
  - Updated resiliency criteria to account for impacts of pandemics and based on actual data
  - Weather hardening to prepare for hurricane/tornado/wildfire/storm season
  - Grid edge awareness
  - High reliability/resiliency service for critical customers such as health care facilities
  - Online/remote staff augmentation
- Some of these changes may become permanent
  - For instance, growing importance of residential reliability/resiliency and grid edge awareness as more remote work likely to be allowed after crisis, this may impact load curves, peak demands, and asset utilization
- Industry is increasingly critical, investments will continue being necessary:
  - Impact likely to consist of investment shift toward keeping the lights on (e.g., maintaining/improving reliability and resiliency, grid modernization, efficiency improvement, etc.)
- Potential future demand scenarios are uncertain and may include load increase in some jurisdictions (e.g., C&I customers addressing backlog, etc.)
  - Load forecasting is particularly challenging given that there is no modern precedent to a health crisis of this magnitude

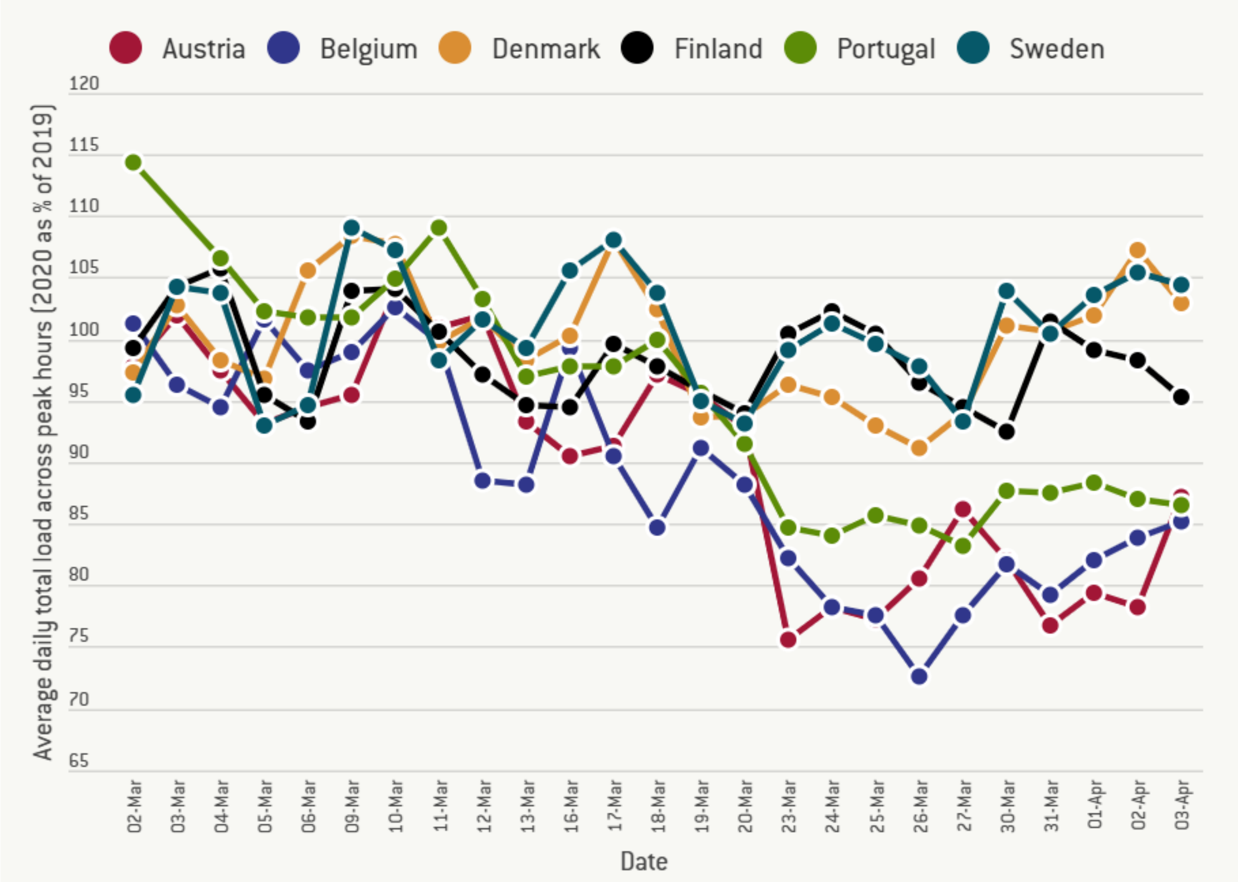
Impacts on Peak Demand – Europe



Source: Financial Times https://www.ft.com/coronavirus-latest

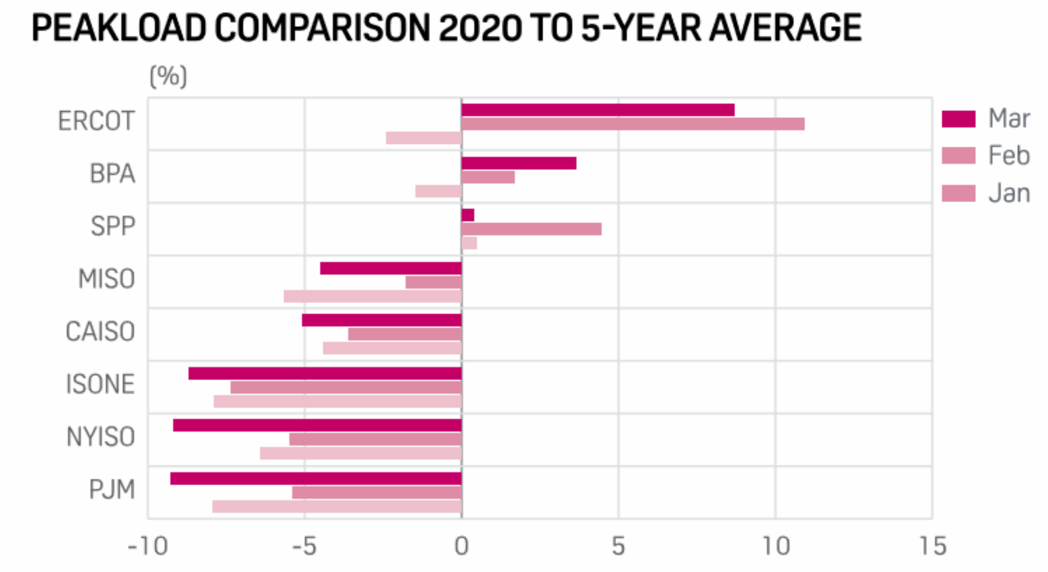
Impacts on Peak Demand – Europe



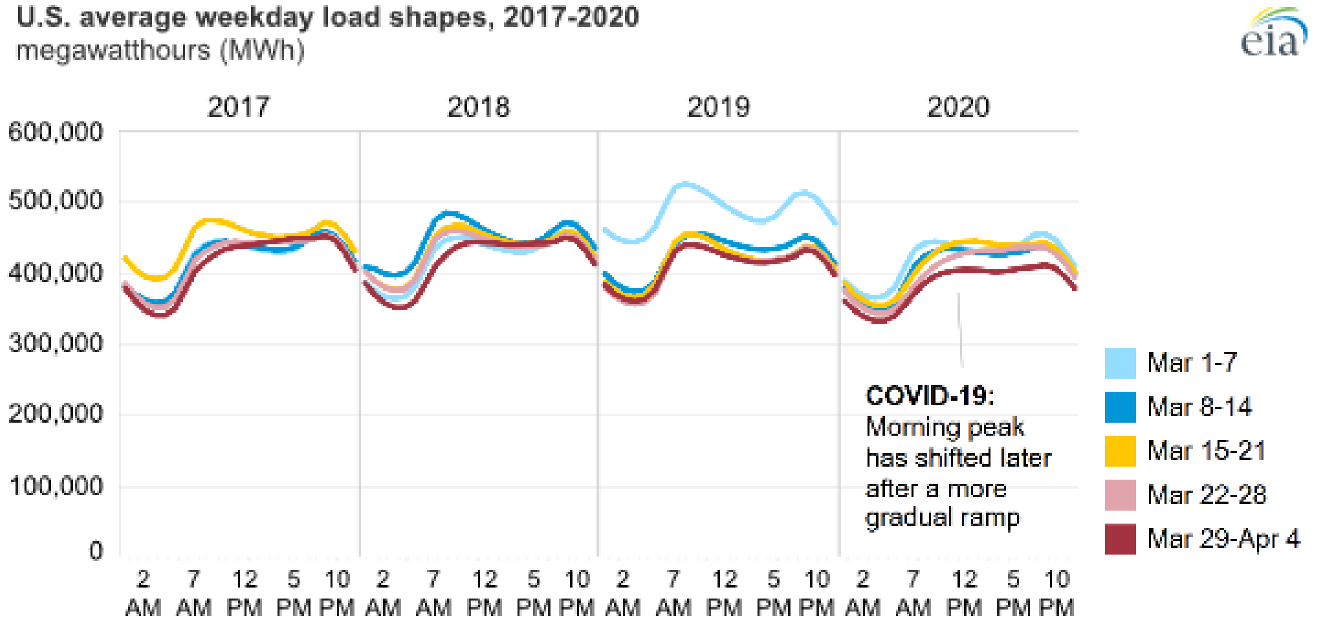


Source: https://www.bruegel.org/2020/03/covid-19-crisis-electricity-demand-as-a-real-time-indicator/

Impacts on Peak Demand and Load Shapes – U.S. (1)

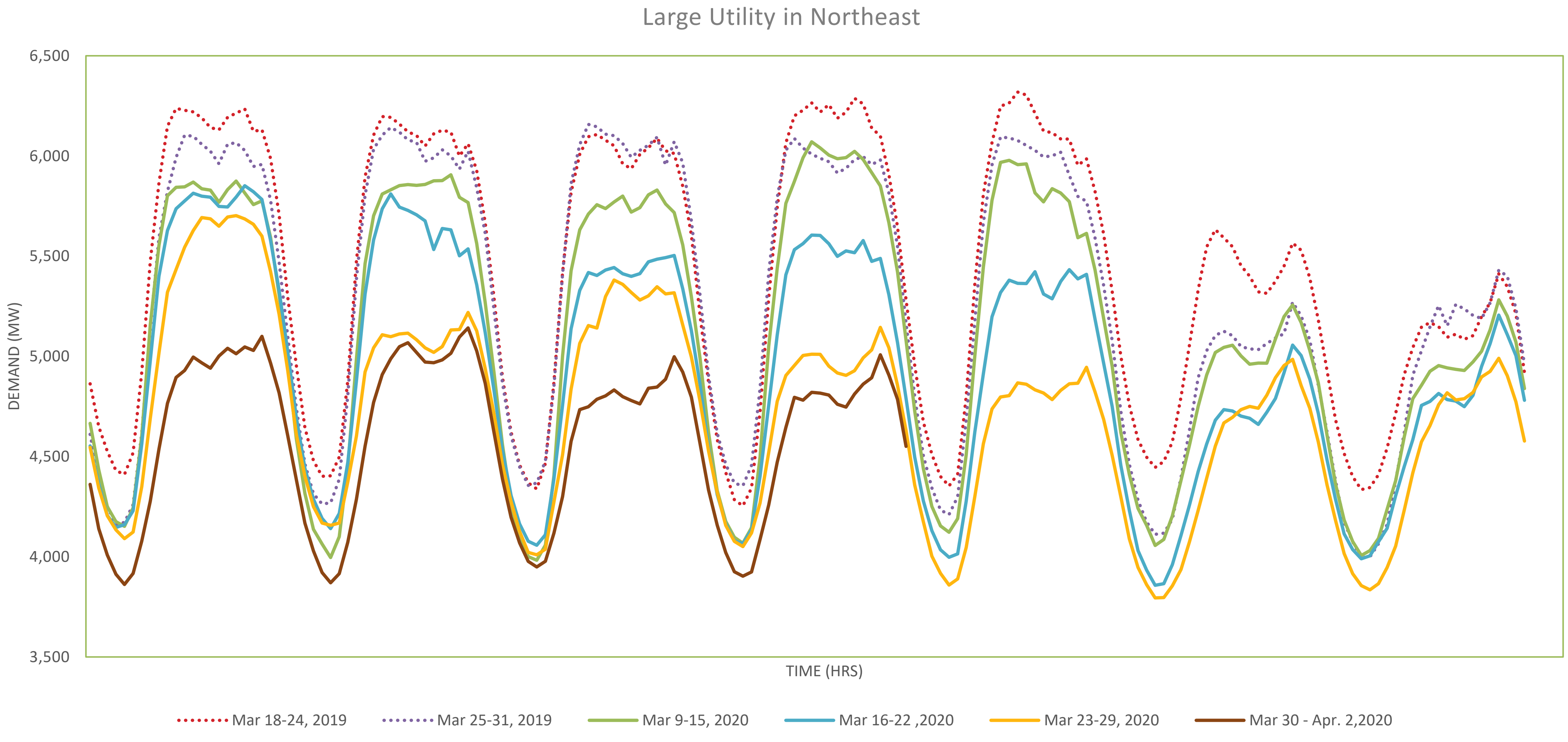


Source: https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/040120-factbox-power-demand-prices-begin-to-slip-as-coronavirus-stay-home-orders-spread



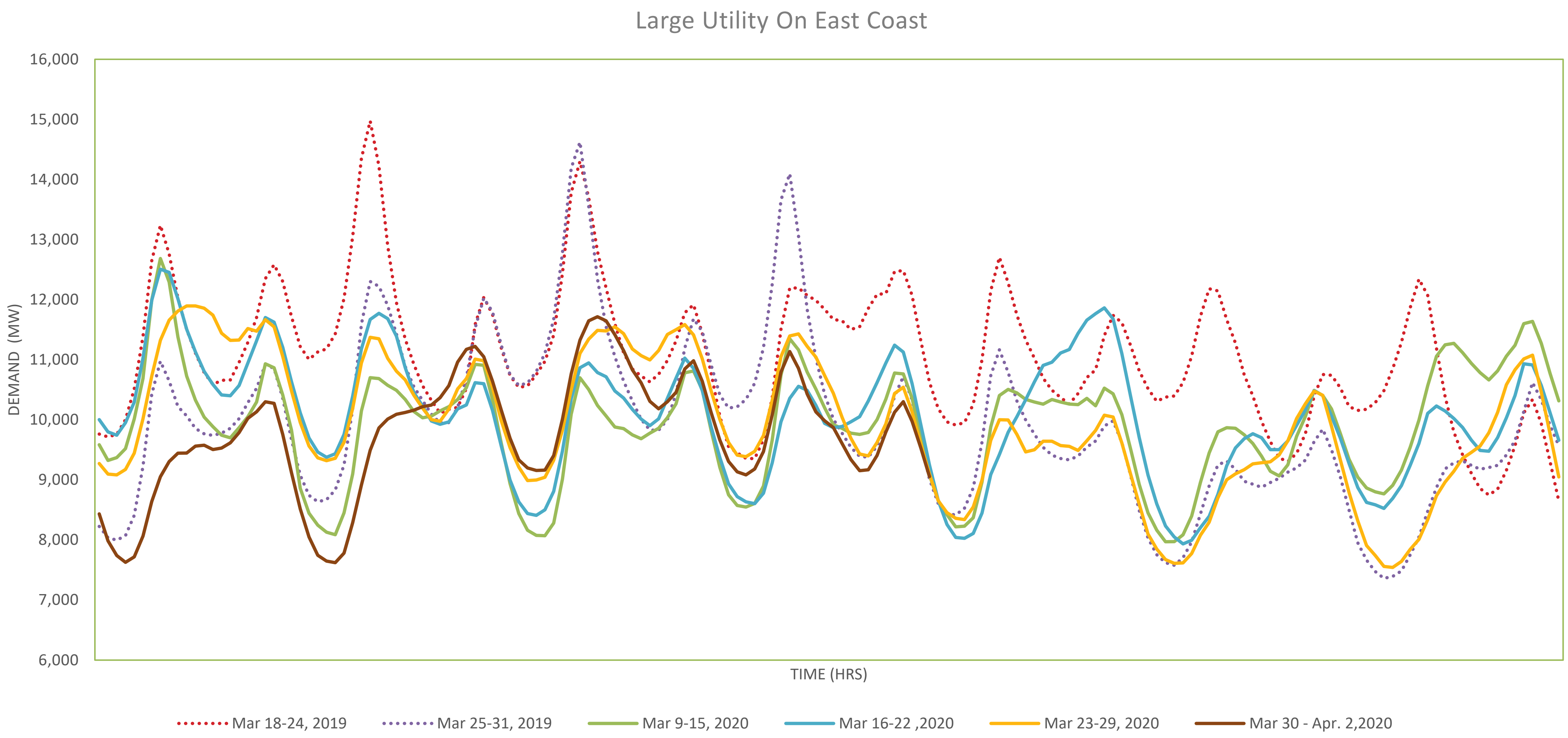
Source: https://www.eia.gov/todayinenergy/detail.php?id=43295#

Impacts on Peak Demand – U.S. (2)



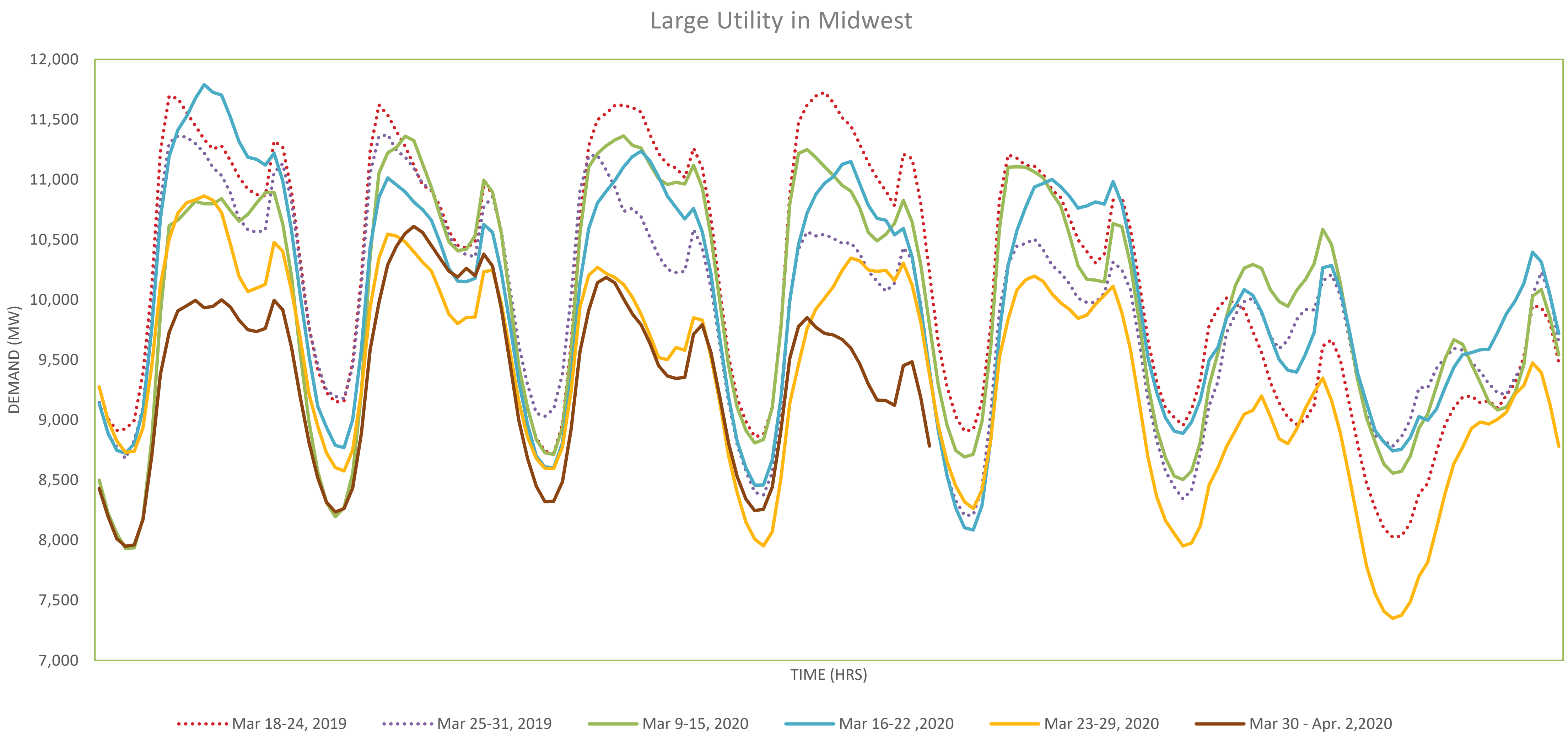
Source: NYISO

Impacts on Peak Demand – U.S. (3)



Source: PJM

Impacts on Peak Demand – U.S. (4)



Source: PJM

Conclusions

- The concept of resiliency is complex and requires a detailed characterization of the preparation, operational, and response processes related to an event
- Resiliency evaluation methods and metrics are key areas of research, however, there is no widely accepted industry standard in this area yet
- Development of a Resiliency Evaluation and Improvement Roadmap is recommended to guide an organization in improving resiliency and ensure all functions are moving in the same coordinated direction
- Resiliency improvement solutions are multifaceted and span hardware, software, human, and new technology resources
- In addition to climate change, recent environmental phenomena that must be considered include pandemics

Q&A

Upcoming Webinars

Time	APRIL 16, 2020 11:00 AM-12:00 PM	APRIL 23, 2020 11:00 AM-12:00 PM	APRIL 30, 2020 11:00 AM-12:00 PM
Topic	VALUE OF DER, SESSION #1	STATE OF THE ART ON 100% RENEWABLE SYSTEMS	DERMS VS. MICROGRID CONTROLS- BATTLE OF BUSINESS OPERATION
Speakers	DR. RALPH MASIELLO, DR. ELLI NTAKOU, DR. KHASH MAHANI, DR. FARNAZ FARZAN	DR. HISHAM OTHMAN & RAHUL ANILKUMAR	DR. FARID KATIRAEI, DR. CHAD ABBEY, & SHADI CHUANGPISHIT

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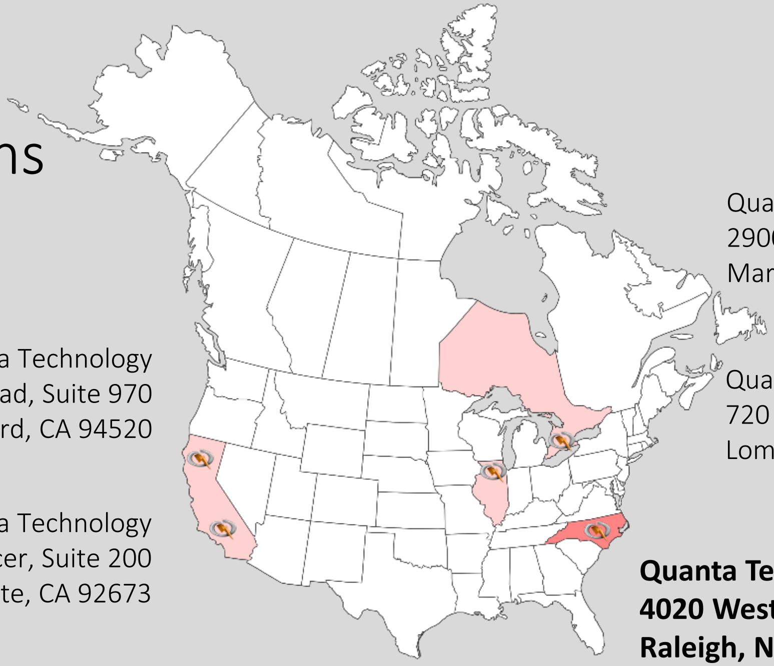
Thank you!

Office Locations



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