Grid Modernization and Power Distribution Systems

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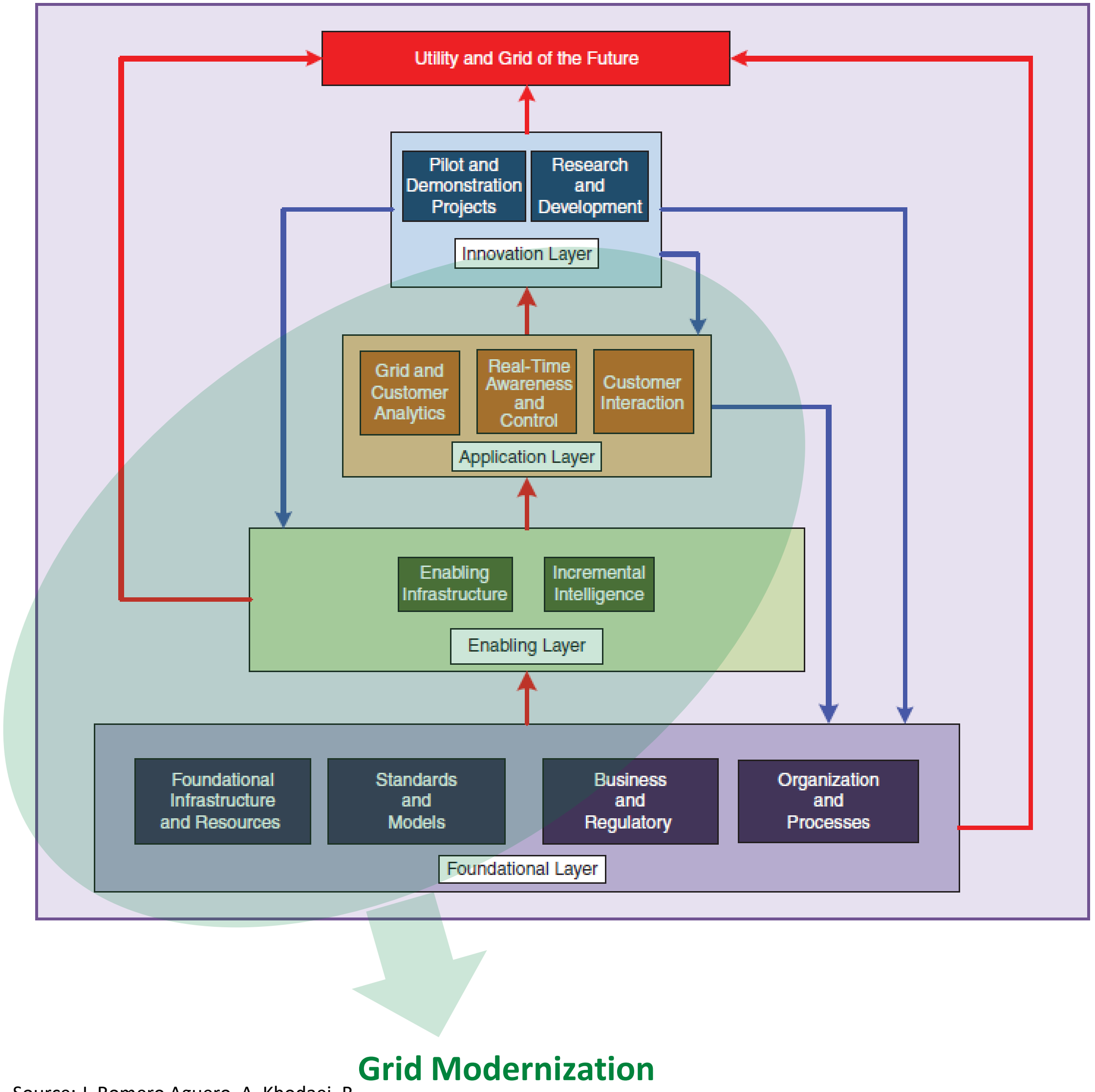
Utility and Grid of the Future

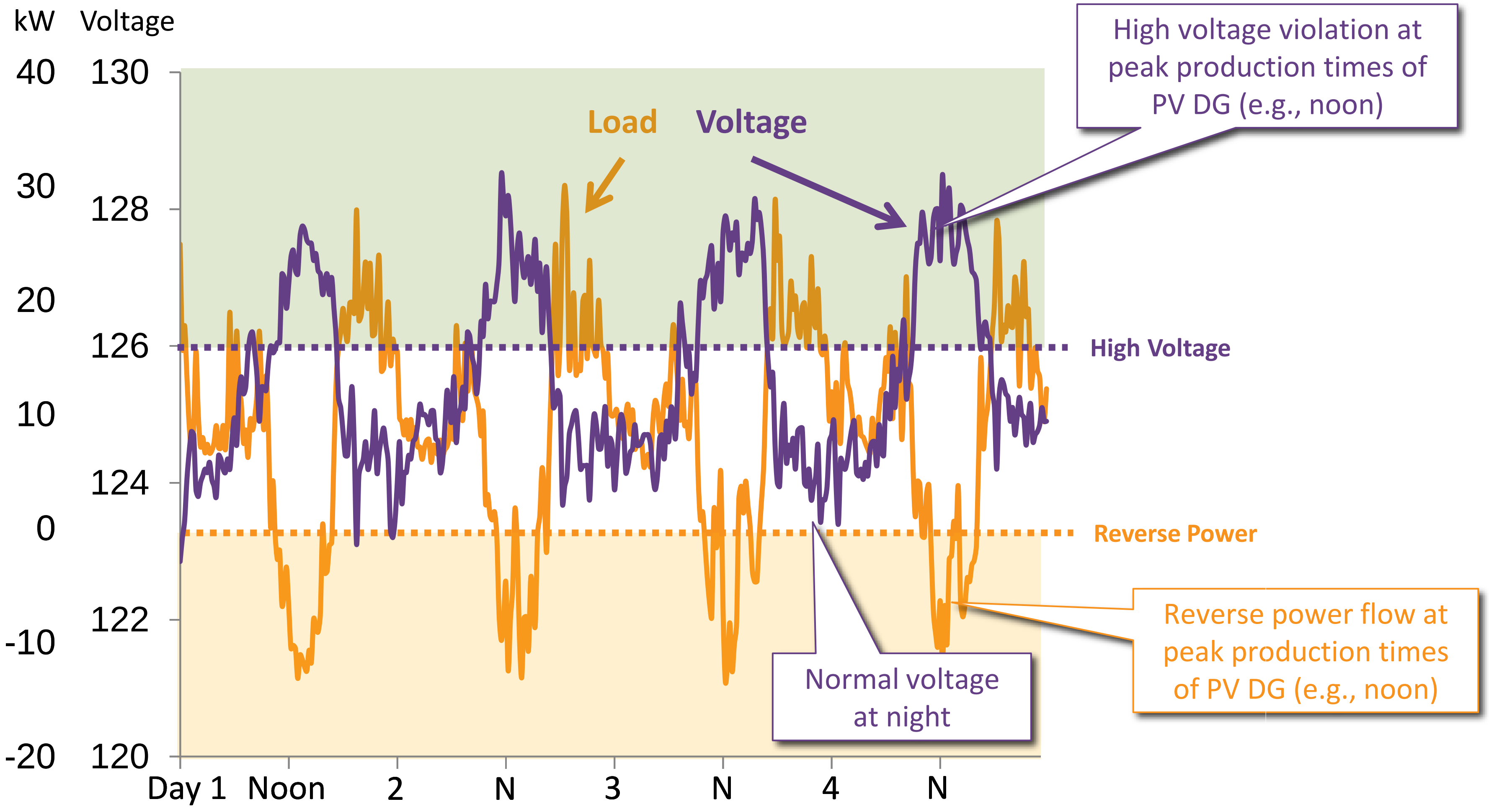


Source: J. Romero Aguero, A. Khodaei, R. Masiello, The Utility and Grid of the Future: Challenges, Needs, and Trends, IEEE Power and Energy Magazine, Sep/Oct 2016

- The terms "Smart Grid," "Grid of the Future," and "Grid Modernization" emphasize the need to build an intelligent grid that can be monitored and controlled in real time to allow for providing a reliable, safe, and secure service and empower customers to actively participate and benefit from greater and more diverse market opportunities and services.
- The Utility of the Future has a broader connotation and encompasses the evolution of all aspects of the utility industry to adapt to our new and dynamic customer-centric reality. This includes business and engineering processes, regulation, policies, rate design, asset ownership, service diversification, and relationships with customers.
- A Utility & Grid of the Future framework can consist of four layers:
  - Foundational layer: comprises the most essential components of an electric utility on top of which all remaining layers are built.
  - Enabling layer: consists of incremental intelligent infrastructure required to enable smart functionalities and increased grid and utility system intelligence
  - Application layer: includes software applications required to optimize the operation, maintenance, and planning of the grid and improve the overall efficiency of utility processes and customer experience
  - Innovation layer: focuses on identifying and evaluating the next wave of technology and business solutions

Need for Grid Modernization – Secondary Distribution Systems

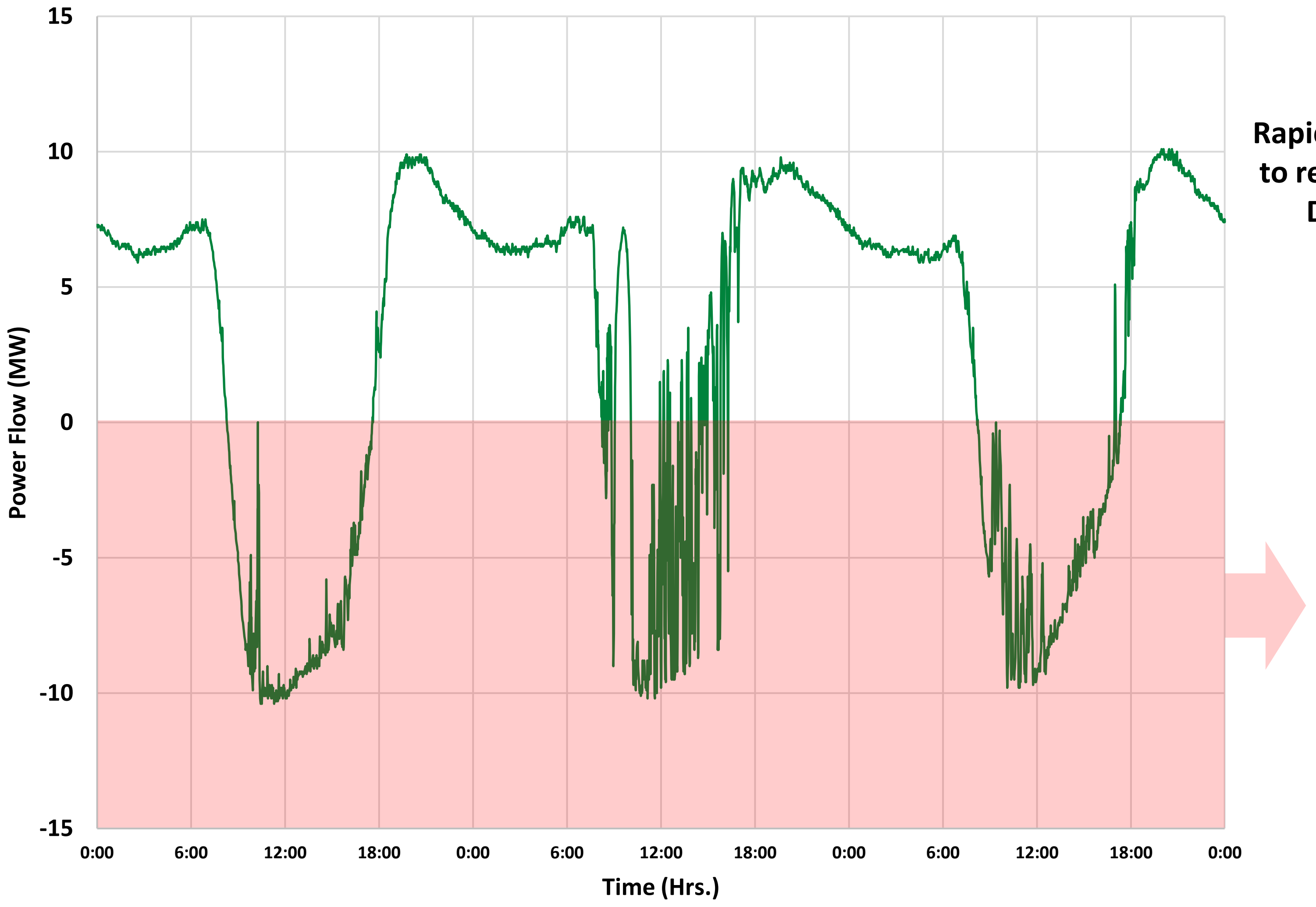
Overvoltage at service transformer due to reverse power flow caused by residential PV DG in Hawaiian Electric (HECO)'s distribution system



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

Need for Grid Modernization – Primary Distribution Systems

Reverse power flow and power flow fluctuations on real distribution substation in Virginia, USA

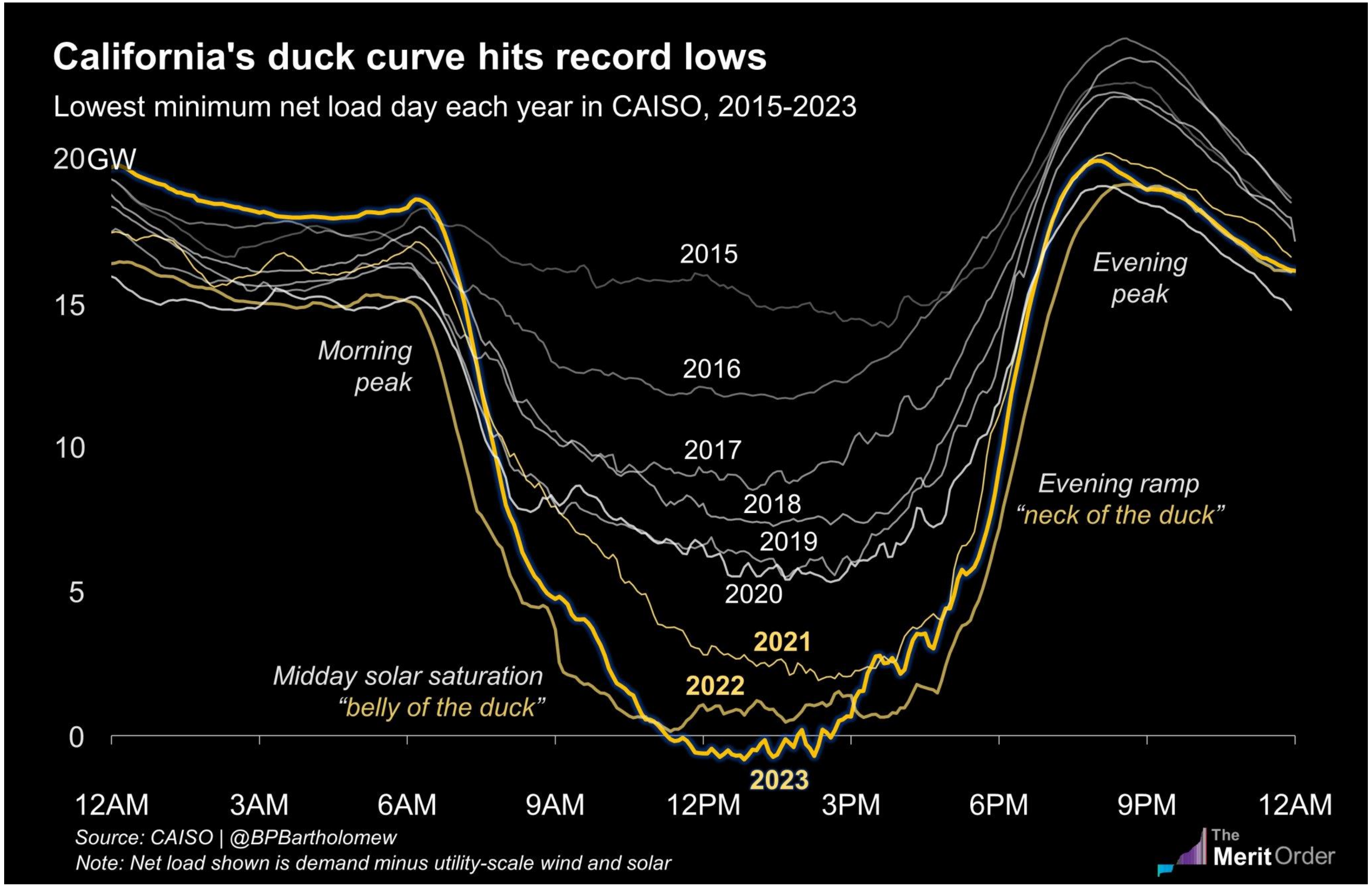


Rapid transition from forward to reverse power flow due to DER output variability

Reverse power flow through substation transformer

Source: Dominion Energy

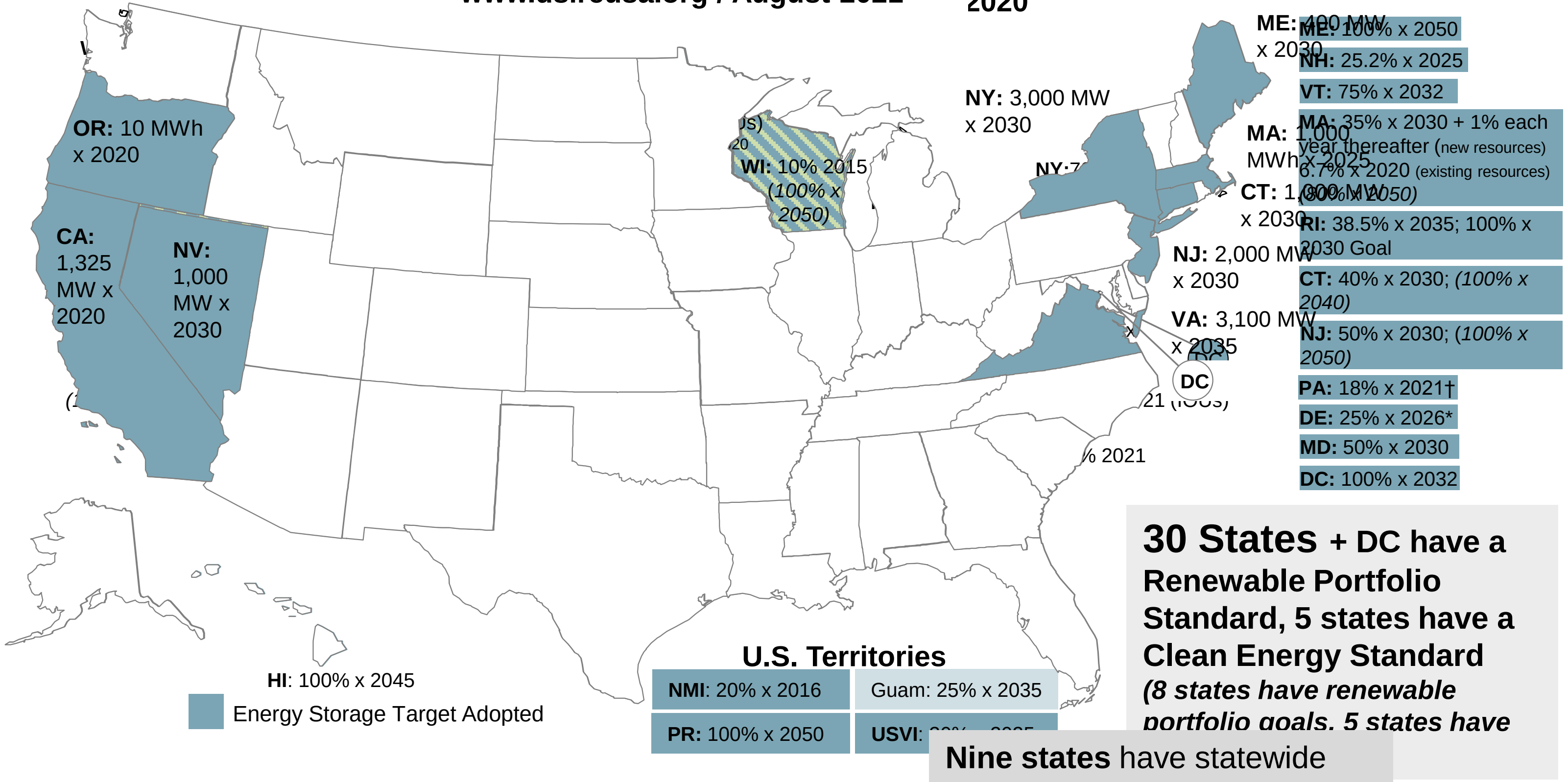
Need for Grid Modernization – Bulk Power System



Renewable/Clean Energy Standards & Energy Storage Targets

- Even outside of state mandates, 24 utility parent companies have adopted voluntary carbon-reduction targets, with 20 aiming for 100%. The administration's goal to reach 100% clean electricity by 2035 is another key driver.

- As the power sector approaches 80% to 85% clean electricity in the coming years, progress could slow unless new technologies, such as **long-duration energy storage and green hydrogen**, have been commercialized.



30 States + DC have a Renewable Portfolio Standard, 5 states have a Clean Energy Standard
(8 states have renewable portfolio goals, 5 states have

Nine states have statewide targets for energy storage deployment.

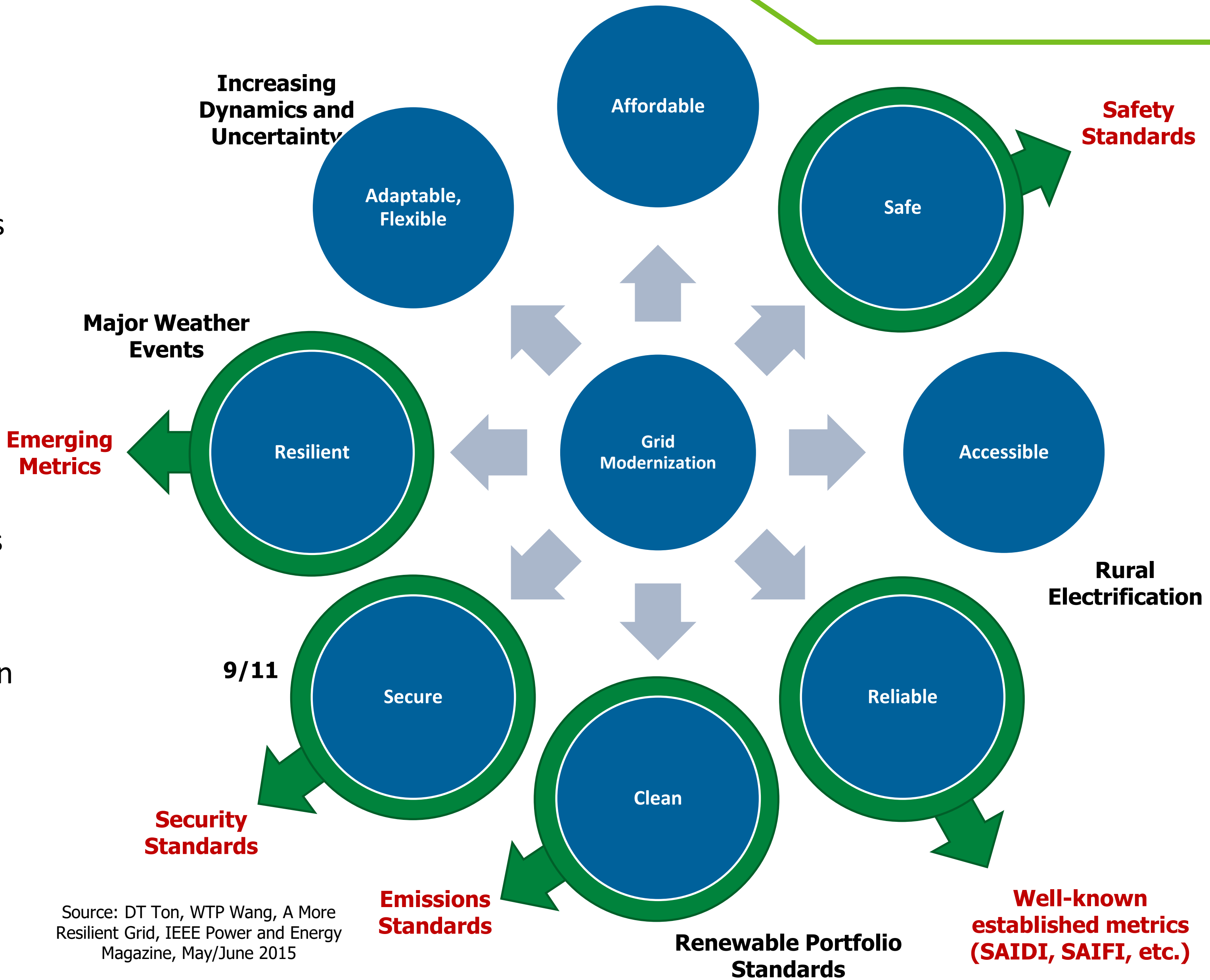
Renewable portfolio standard | *Clean energy standard*
Renewable portfolio goal | *Clean energy goal*

* Extra ... ables
† Includes non-renewable alternative resources

Source: DSIRE

What is Grid Modernization?

- Grid Modernization enables key capabilities and features required for a modern and future grid, including:
  - Greater **RESILIENCE** to hazards of all types
  - Improved **RELIABILITY** for everyday operations
  - Enhanced **SECURITY** from an increasing and evolving number of threats
  - Additional long-term **AFFORDABILITY** to maintain economic prosperity
  - Superior **FLEXIBILITY** to respond to variability and uncertainty of conditions at one or more timescales, including a range of energy futures
  - Increased **SUSTAINABILITY** through energy-efficient and renewable resources
- Grid modernization solutions include investments in **advanced technologies** (monitoring, protection, automation, control, enterprise systems and software solutions), **foundational infrastructure** (hardening and aging infrastructure) and **processes** (advanced planning)



Source: DT Ton, WTP Wang, A More Resilient Grid, IEEE Power and Energy Magazine, May/June 2015

Grid Modernization Industry Activities

Source: Strategy &

- Grid modernization is a global trend and there has been significant and increasing activity in this area in the U.S.
- Key drivers of grid modernization are enabling increasing monitoring, protection, automation and control capabilities, to improve reliability, resilience and efficiency, and supporting the integration of renewable resources (e.g., DER) and electrification

Utility Name	Distribution Infrastructure Hardening & Resilience	Advanced Grid Technologies	Transmission Infrastructure Hardening & Resilience	AMI	DER
Ameren Illinois	X	X		X	
Commonwealth Edison (Exelon)	X	X		X	
Consumers Energy	X	X	X		X
DTE Energy	X	X		X	X
Duke Energy Indiana	X	X	X		
First Energy Ohio	X		X		
Northern States Power Company (Xcel)		X			X
Ohio Power Company	X				X
Vectren South	X	X	X		X
Central Maine Power (AVANGRID)		X		X	
Eversource Energy		X			X
National Grid		X		X	X
PECO (Exelon)	X				X
PSE&G	X	X	X		
Duke Energy Carolinas	X	X	X	X	X
Entergy Arkansas				X	
Pepco (Exelon)	X				
Austin Energy		X		X	X
Hawaiian Electric		X		X	X
Public Service Company of Colorado (Xcel)		X		X	
Southern California Edison	X	X			X
Total	**13**	**16**	**6**	**10**	**12**

Source: S. Sergici, Grid Modernization: Policy, Market Trends, and Directions Forward, 4th Annual Grid Modernization Forum, May. 2019

Grid Modernization Roadmap

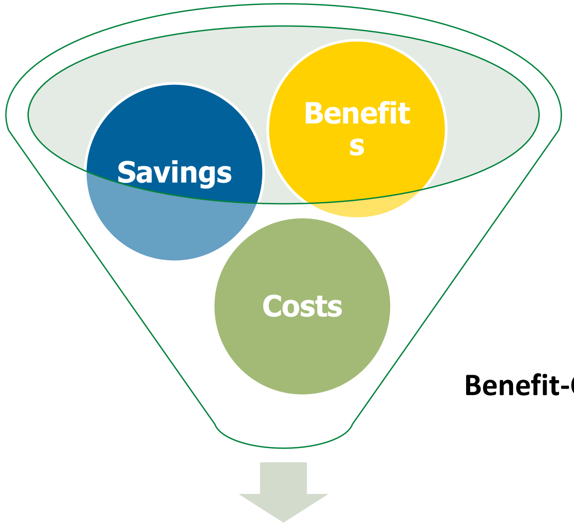
What are the key steps to a grid modernization roadmap?

- A Grid modernization roadmap allows implementing these requirements and capabilities in a practical manner based on the utility's goals and vision
- Steps to developing a grid modernization roadmap:
  - Identify key components of utility's vision and goals
  - Develop preliminary list of key programs considered to reach utility's goals
  - Benchmark existing utility practices and preliminary list of programs against industry trends and best practices
  - Conduct benefit-cost analysis to help prioritize programs
  - Develop a final list of prioritized programs for grid modernization
  - Identify "foundational" programs required for subsequent programs to align implementation schedule
  - Create grid modernization roadmap

Program prioritization and scheduling

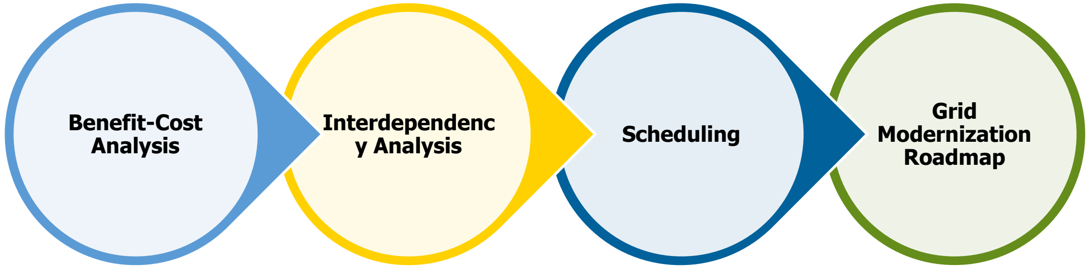
- Each program is evaluated in terms of:
  - **Benefits—**Benefits from implementing the program
  - **Capital costs—**Initial, fixed, one-time investment required to implement program
  - **O&M costs (annual)—**Recurring costs, including operations, maintenance, licenses, etc.
  - **Anticipated savings—**Expected savings derived from program implementation, either one-time or recurrent
  - **Assumptions—**Relevant assumptions used to calculate costs (e.g., unit costs, customer base, etc.)
- Benefit-cost ratios and interdependencies are analyzed to prioritize and schedule program implementation (e.g., foundational programs are implemented first)
- Results are used to develop grid modernization roadmap

Program Prioritization and Scheduling

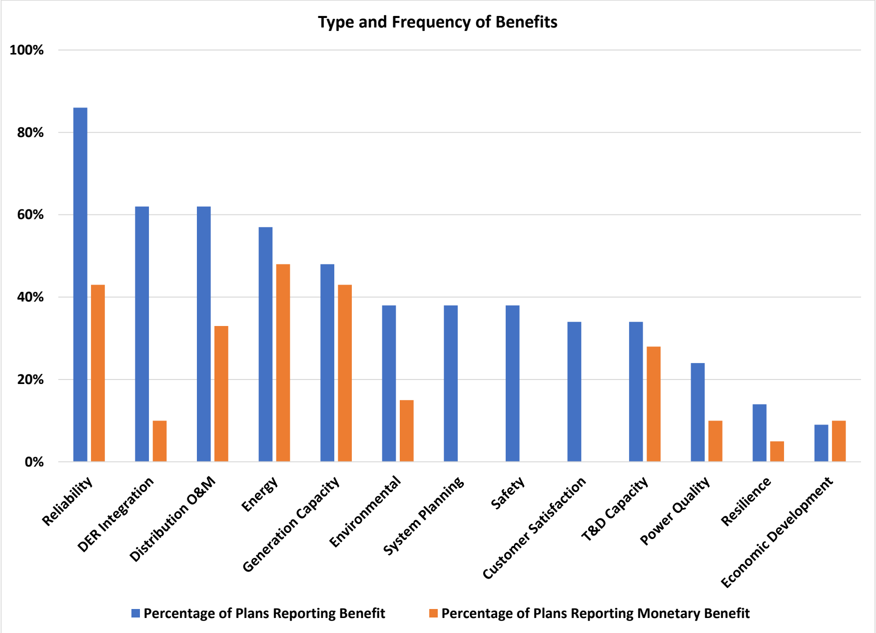


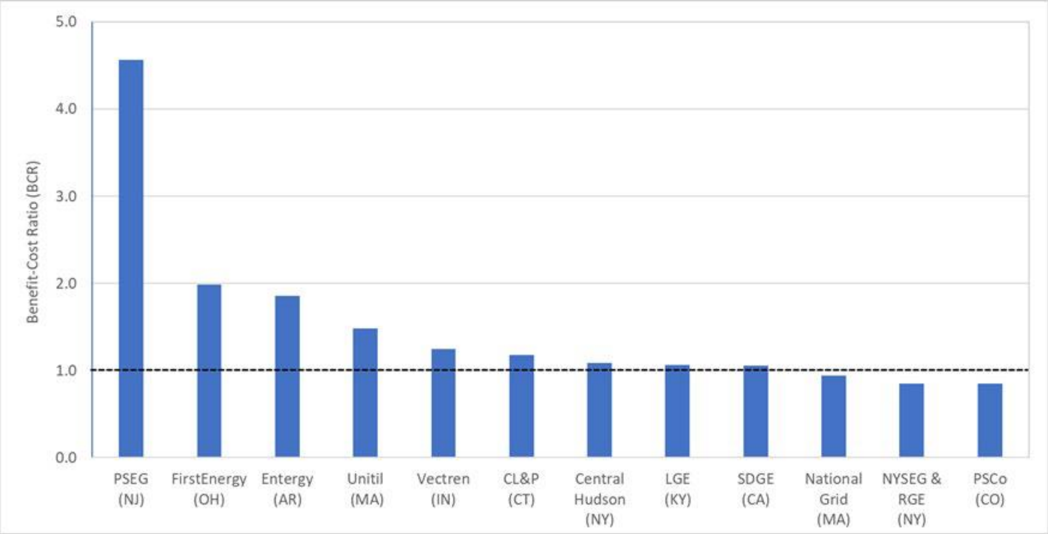
Benefit-Cost Analysis

Grid Modernization Roadmap



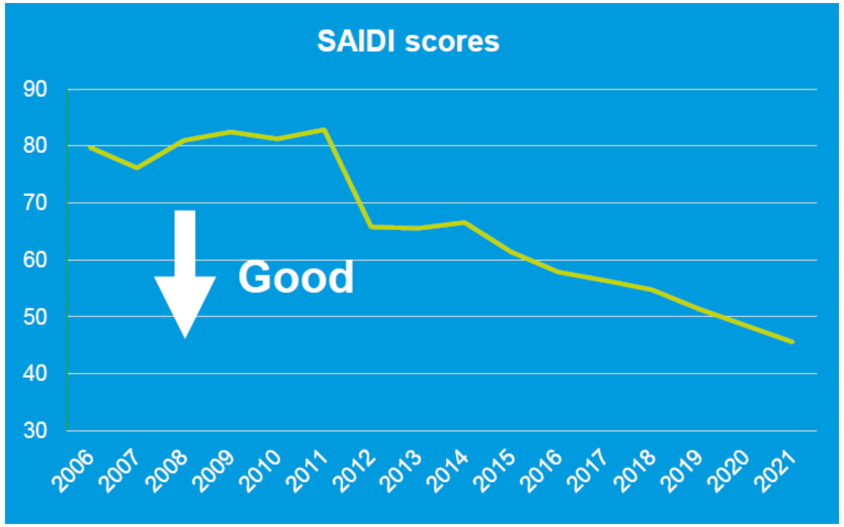
Examples of Benefits and Benefit/Cost Ratios Reported by Recent Studies





Source: T. Woolf et. al, Benefit-Cost Analysis for Utility-Facing Grid Modernization Investments: Trends, Challenges, and Considerations, Feb. 2021

Benefits of Grid Mod Programs

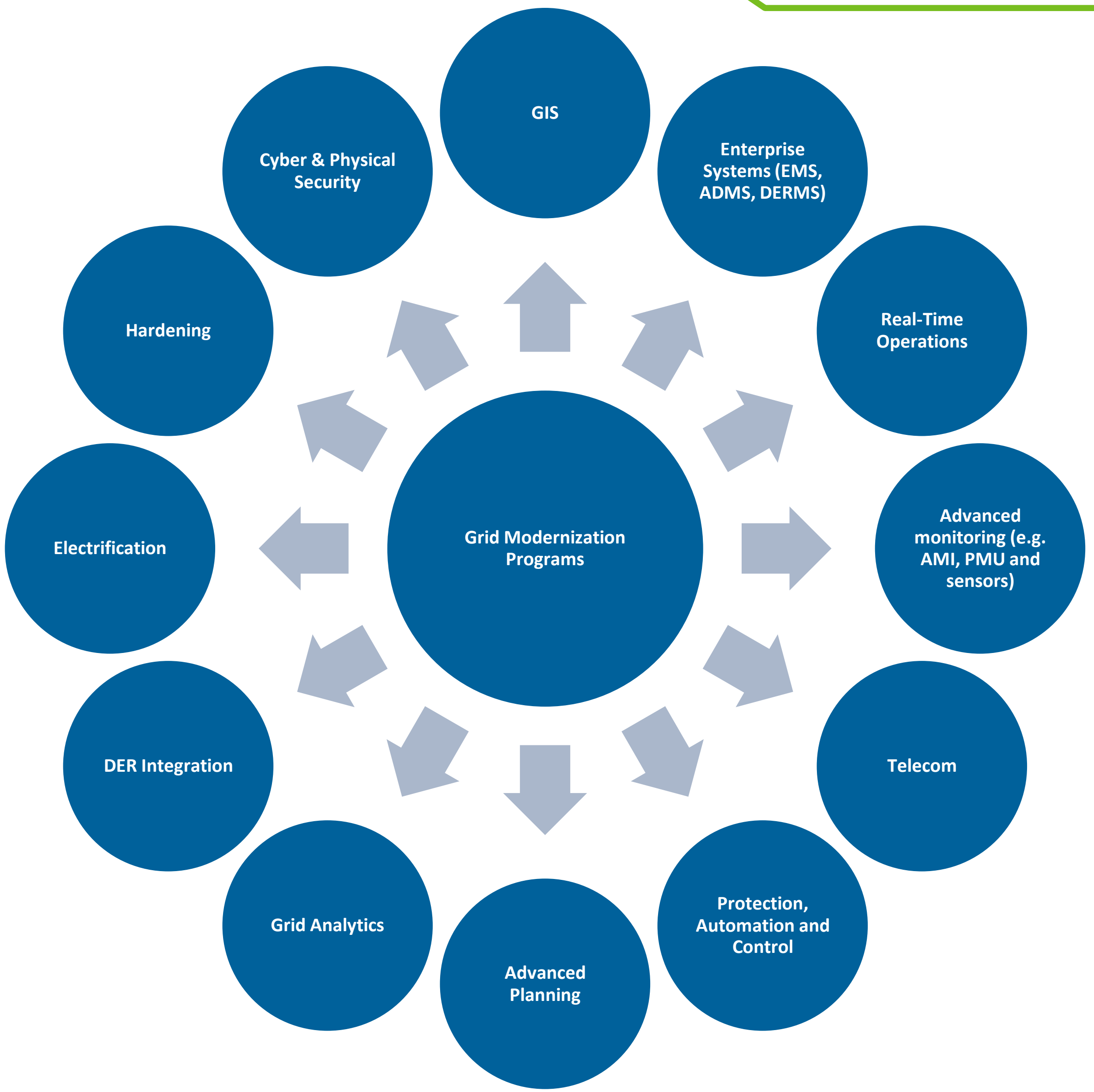


	Hurricane Wilma (2005)	Hurricane Irma (2017)
Saffir-Simpson Scale	Category 3	Category 4
Fla. landfall max sustained winds	120 mph	130 mph
Cyclone Damage Potential Index	2.8	4.3
Customers affected	3.2 million (75%)	4.4 million (~90%)
Poles damaged	12,400	2,900
Transmission structures failed	100	5
Substations de-energized	241	92
Substations restored	5 days	1 day
50% of customers restored	5 days	1 day
100% of customers restored	**18 days**	**10 days**
Average customer outage	**5.4 days**	**2.1 days**

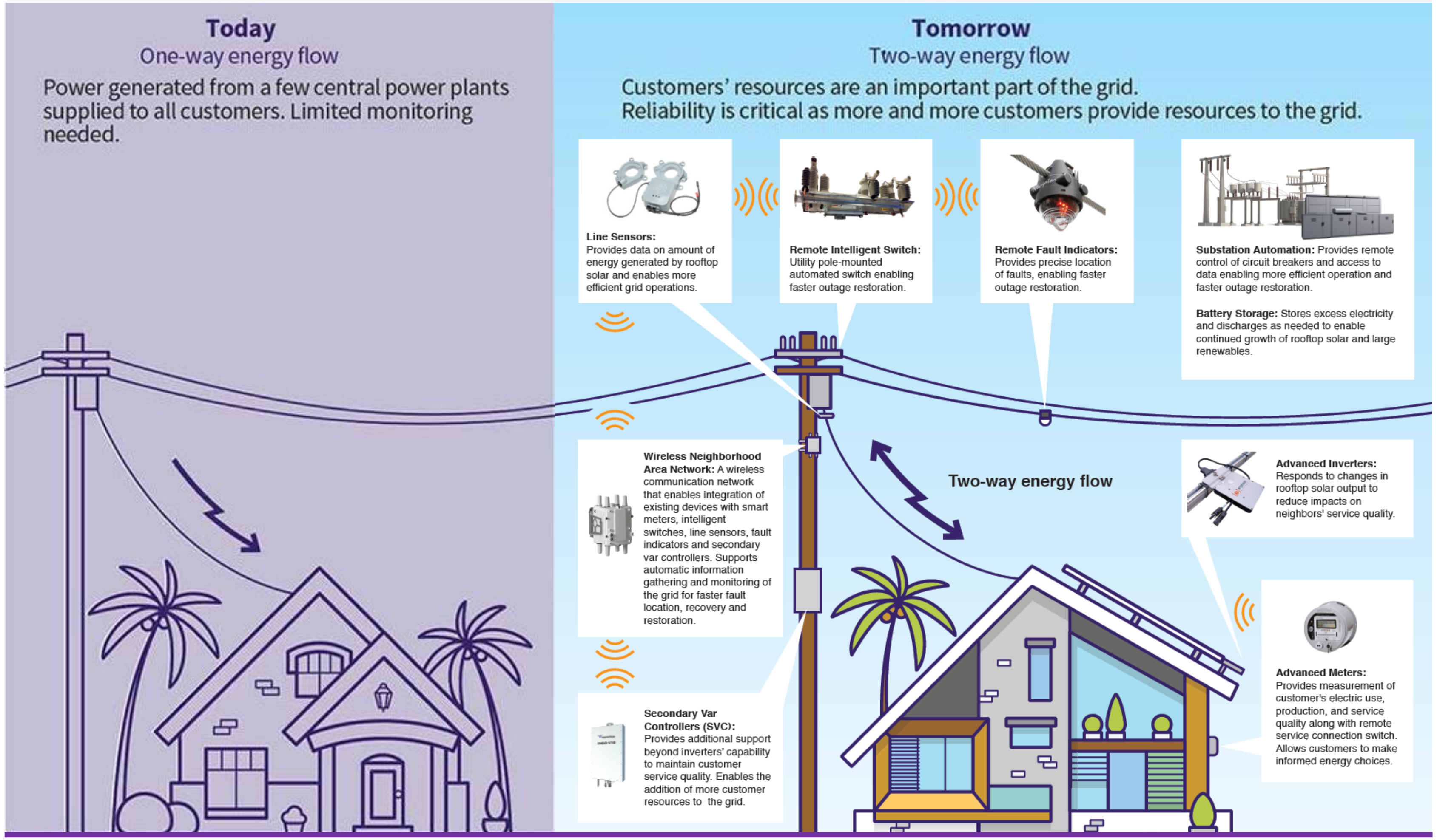
Source: Florida Power and Light

Examples of Grid Mod Programs

- Programs are defined initiatives to realize a modern grid
  - Includes all initiatives to reach utility and societal goals
    - Includes foundational areas such as telecommunications, GIS, etc.
    - Includes advanced technology areas such as grid analytics
    - Includes processes such as advanced planning
- To prioritize programs, they are evaluated in terms of:
  - Cost to implement
  - Benefits to utility and society
- Foundational programs are those required for implementation of other programs, such as:
  - AMI smart meters for outage management
  - Telecommunications systems for real-time monitoring and control

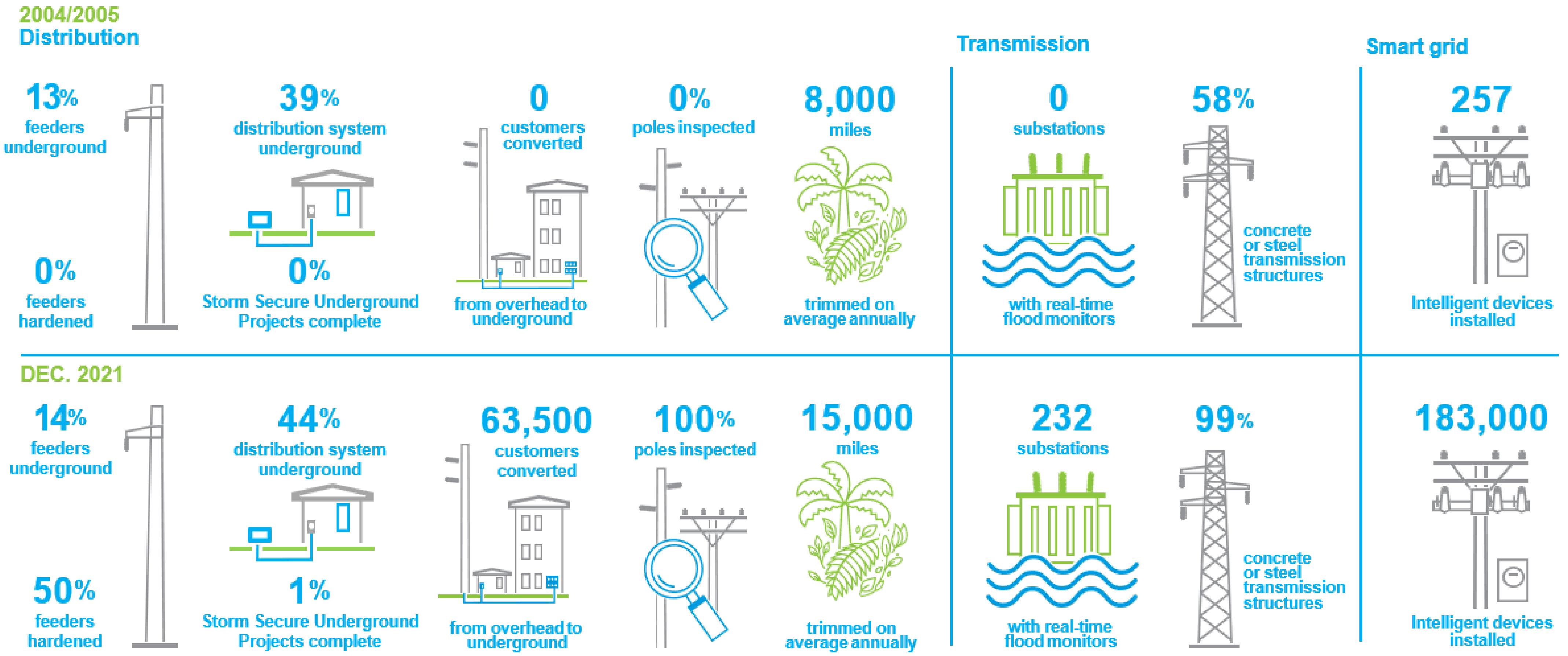


Examples of Grid Mod Programs



Source: Hawaiian Electric

Examples of Grid Mod Programs



Source: Florida Power and Light

Grid Mod Programs – Resilience Improvement

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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/strategic 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 and supply to critical cust., 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
- Non-Wires Alternatives (NWA) and value of DER
- Hosting capacity management and optimization

Asset Management

- Real-time asset monitoring and condition assessment/prioritization
- Predictive/prescriptive asset health assessment via advanced analytics
- Optimal asset upgrade/replacement strategy
- ISO Certification

Advanced Modeling, Planning & Analytics

- Data collection, processing, storage and analysis
- Advanced T&D system modeling, simulation, planning and analysis
- Resiliency analytics
- Performance analytics
- Asset health analytics

Real-Time Operations

- 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, capacitor banks)

Optimized 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

Advanced Automation & Control

- 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

- 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, Gas and IT Critical Infrastructure

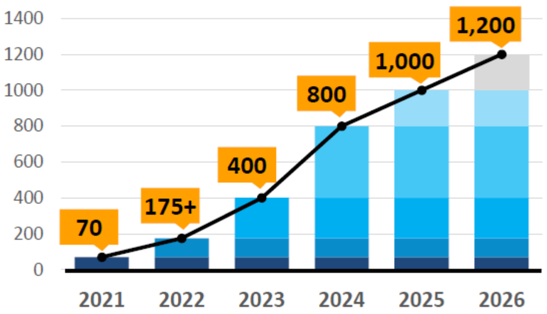
- Remote/virtual operations
- Backup IT systems (Network Operations Center – NOC, Security Operations Center – SOC)
- Substation, feeder and last-mile telecommunications infrastructure

Maintenance

- Advanced inspection techniques (e.g., LIDAR)
- Predictive/prescriptive maintenance via advanced analytics
- Efficiency improvement via digital/mobile workforce solutions

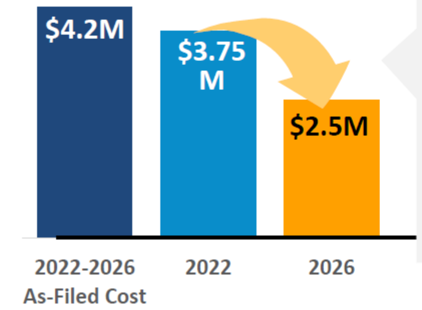
Grid Mod Programs – Undergrounding

Approximate Target Miles Per Year



Approximate Cost Per Mile

(Unescalated $)



- **Optimize** design and construction standards
- **Bundle** work strategically
- **Deploy** new technology and equipment

Source: PG&E

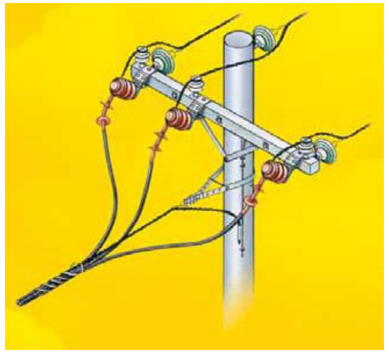
- Undergrounding overhead lines is a solution that is increasingly being used by electric utilities to improve resilience and reliability and address existing and new challenges driven by climate change, such as wildfires and more frequent and severe storms
- Strategic or selective undergrounding is the most popular approach and consists of targeting only selected areas of T&D lines (e.g., primary taps), this is the approach used by Florida IOUs
- Some utilities have decided to target significant parts of their service territory. For instance, PG&E plans to underground about 10,000 miles of power lines in high fire risk areas. This commitment represents the largest effort in the U.S. to underground power lines as a wildfire risk mitigation measure. Dominion Energy and Wisconsin Public Service have undergrounded 1,800 and 2,000 miles of overhead lines, respectively.
- Other alternatives to undergrounding include using covered overhead conductor (tree wire and spacer cable) and Aerial Bundled Cable (ABC)
- In general, overhead systems are less costly to install and easier to maintain than underground systems since problems are generally easier to find and repair. However, underground systems are less susceptible to damage from storms, vegetation, and other environmental disturbances

Targeted Underground Projects

	2018	2019	2020	2021
DEF	12 ($3.7 m)	3 ($17.7 m)	205 ($29.4 m)	204 ($65.2 m)
FPL	0	33 ($76 m)	216 ($129 m)	350 ($212.5 m)
Gulf	0	0	0	8 ($5.2 m)
TECO	0	0	1 ($8 m)	520 ($79.5 m)

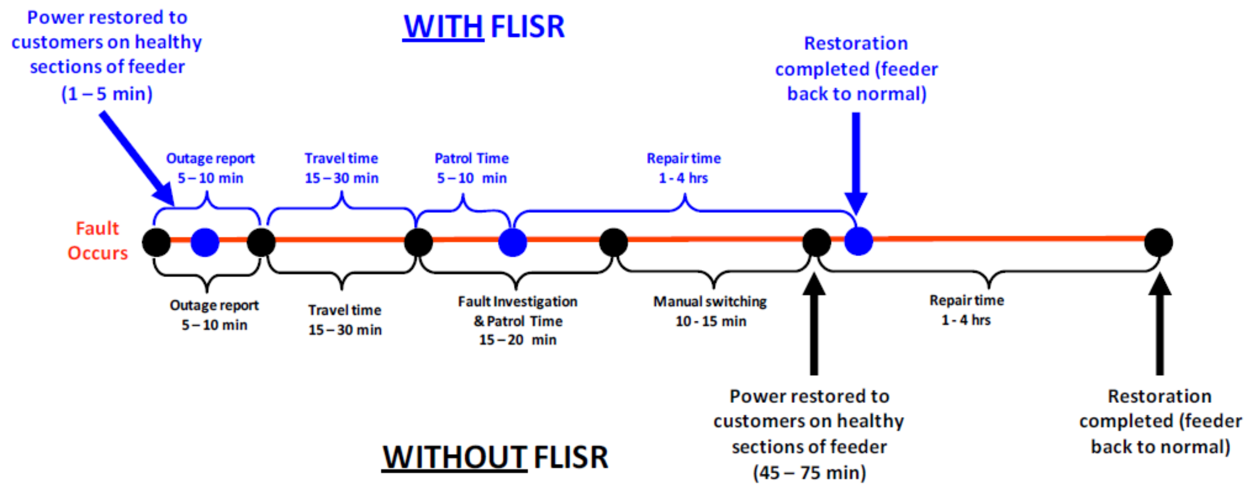
Source: FPSC

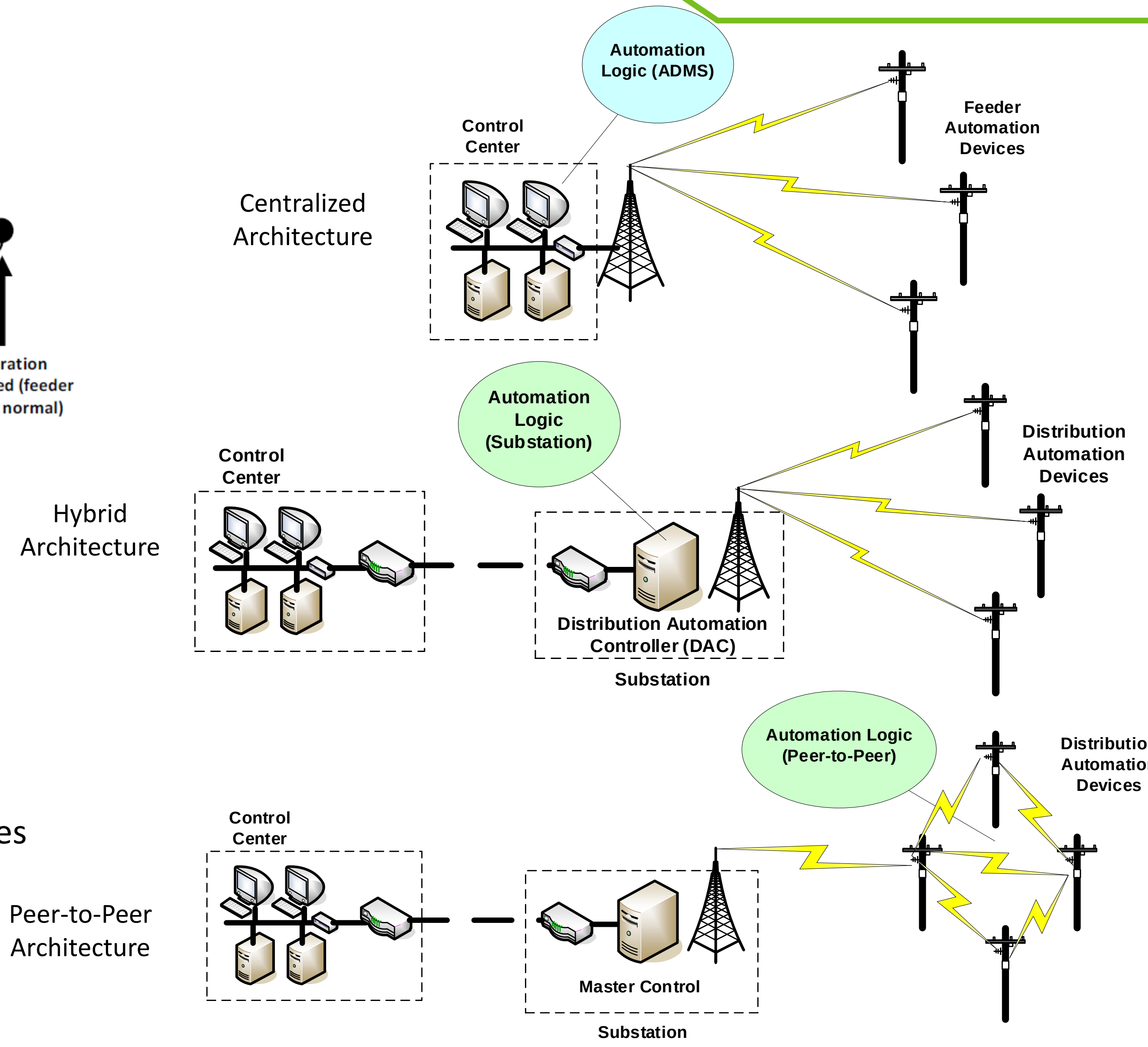


Source: Hendrix, Okonite and Olex (Nexans)

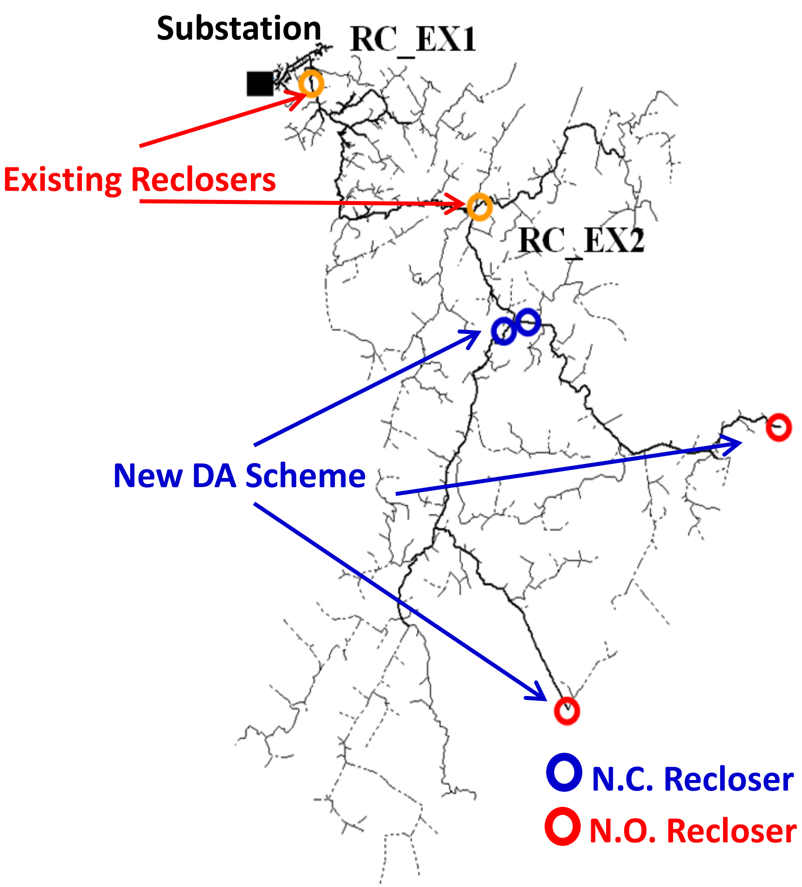
Grid Mod Programs – FLISR



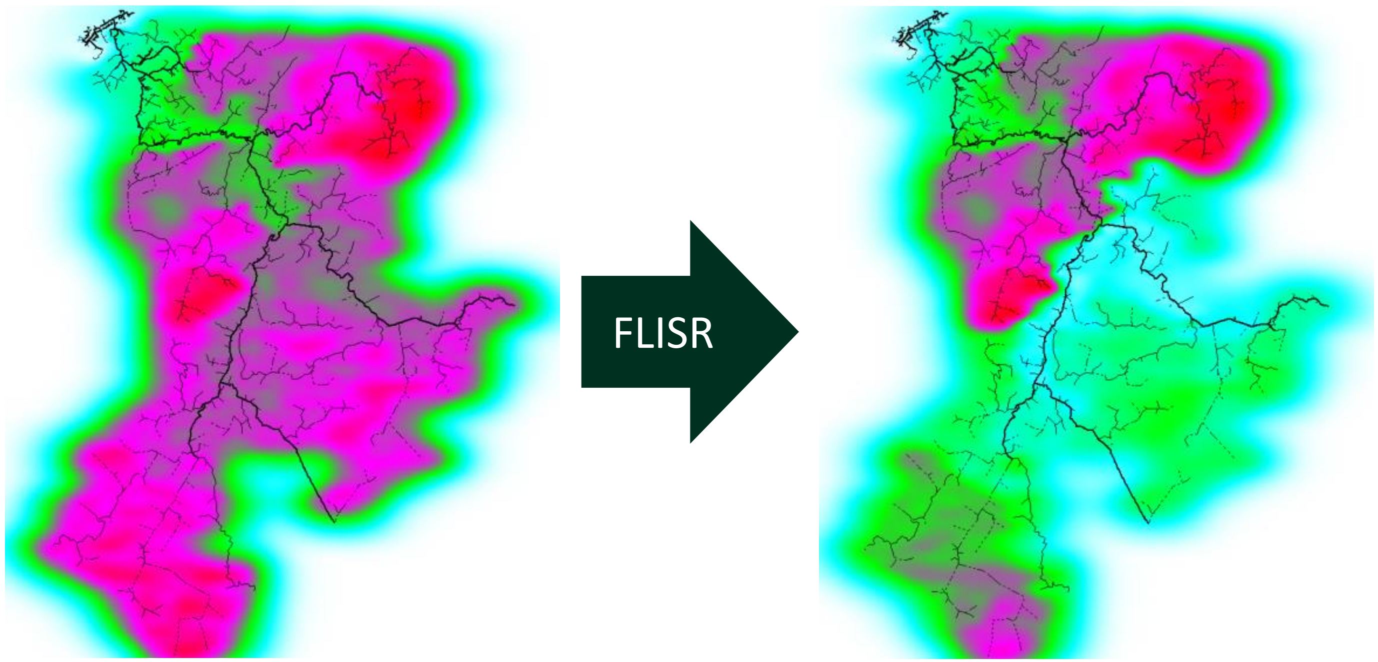


- **Fault Location, Isolation and Service Restoration (FLISR)** is a distribution automation application that consists of the coordinated operation of reclosers, switches, and sensors to automatically locate and isolate faults and restore service
- FLISR can be implemented via centralized (ADMS), hybrid (substation) and distributed (peer-to-peer) control architectures

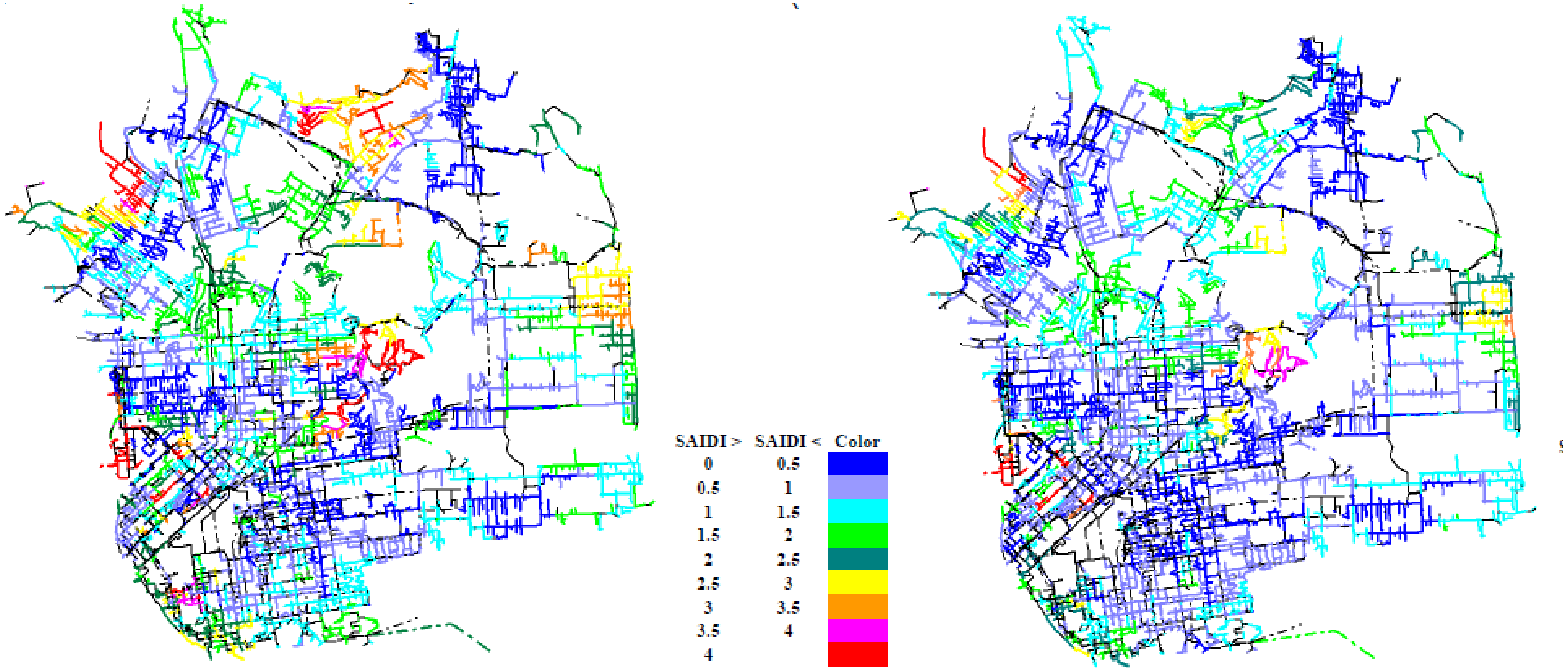
Grid Mod Programs – Feeder Reliability Improvement via FLISR



Spatial distribution of expected SAIDI (hr/cust-yr)



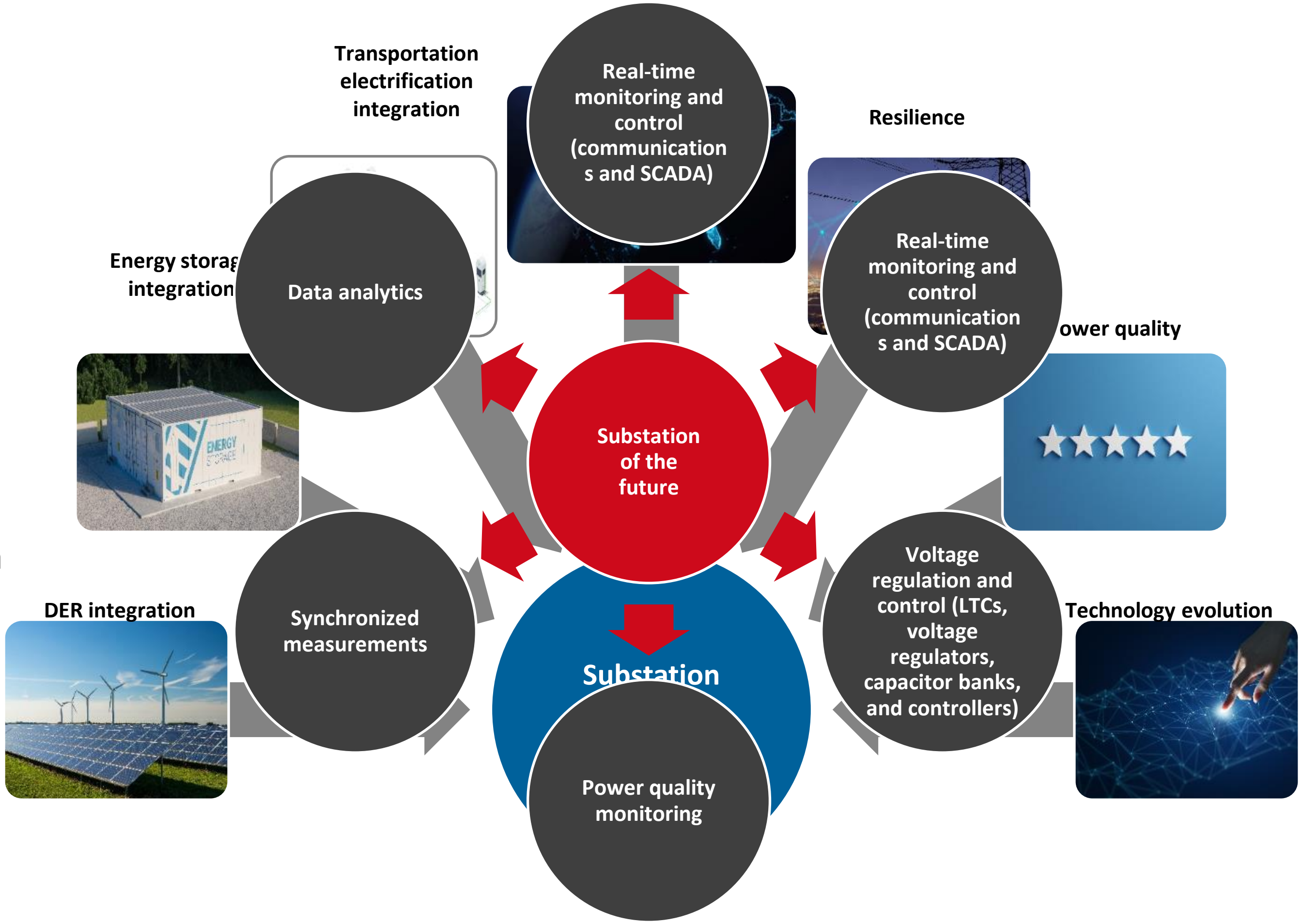
Example: Estimated reliability improvement (SAIDI reduction) due to implementation of distribution automation (FLISR) and other solutions in distribution system



SAIDI before **SAIDI after**

Grid Mod Solutions – Digital Substations

- DER, EVs, BESS and other technologies are being deployed on the grid in increasing numbers to meet state clean energy mandates.
- Utilities are faced with constant requirements for new or upgraded capital investments in lines, substations, including DER interconnections.
- Engineering and operations must meet these challenges in a timely manner.
- Digital substations can help expedite substation protection design, deployment, commissioning and maintenance.



Source: D. Hart, J. Romero Aguero, A. Paaso, Utilizing AMI for Last Mile Communications in Grid Modernization, PAC World, Dec. 2022

Grid Mod Solutions – Advanced Analytics

Inputs:

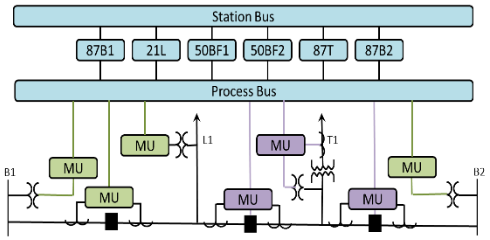
- IEDs (e.g., digital relays, digital reclosers, capacitor bank controllers)
- IEC 61850 network data
- Field sensors (e.g., FCIs, line sensors)
- Smart meters and AMI headend systems
- PQ meters
- SCADA data
- GIS data
- Lightning data
- LIDAR/satellite imagery
- System model (e.g., CAPE, ASPEN)
- Protection settings.

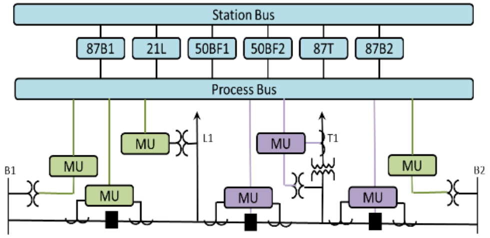


Analytics applications

Centralized data collection

Local data collection	Local data collection
IEC 61850 Substation	**IEC 61850 Substation**

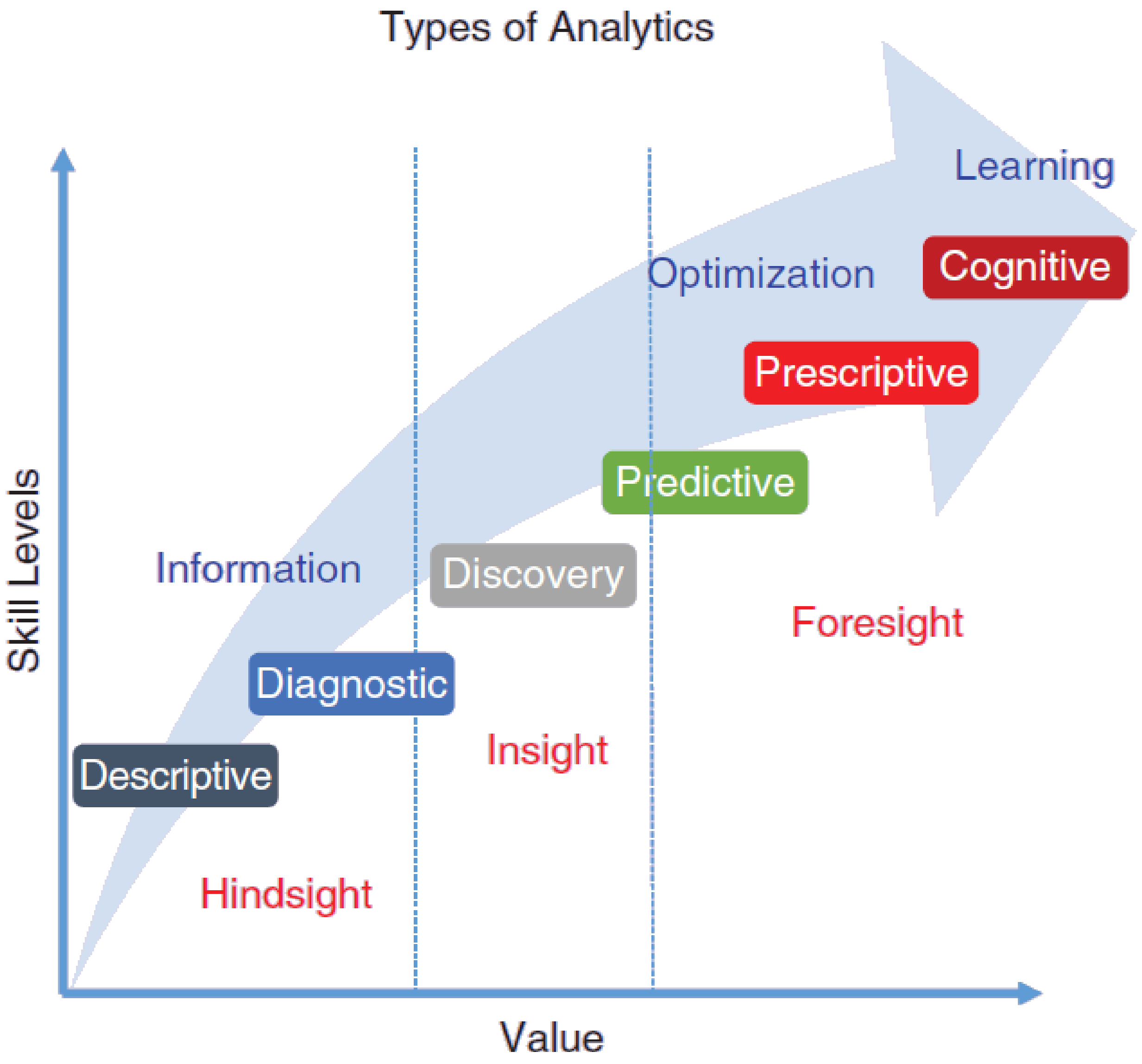




Outputs:

- Fault location
- Event analysis
- Model validation
- Settings validation
- Grid situational awareness
- Grid monitoring
- 61850 network monitoring
- Grid modeling (T&D)
- Compliance
- Asset monitoring
- Maintenance
- Reliability indices.

Grid Mod Solutions – Advanced 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.

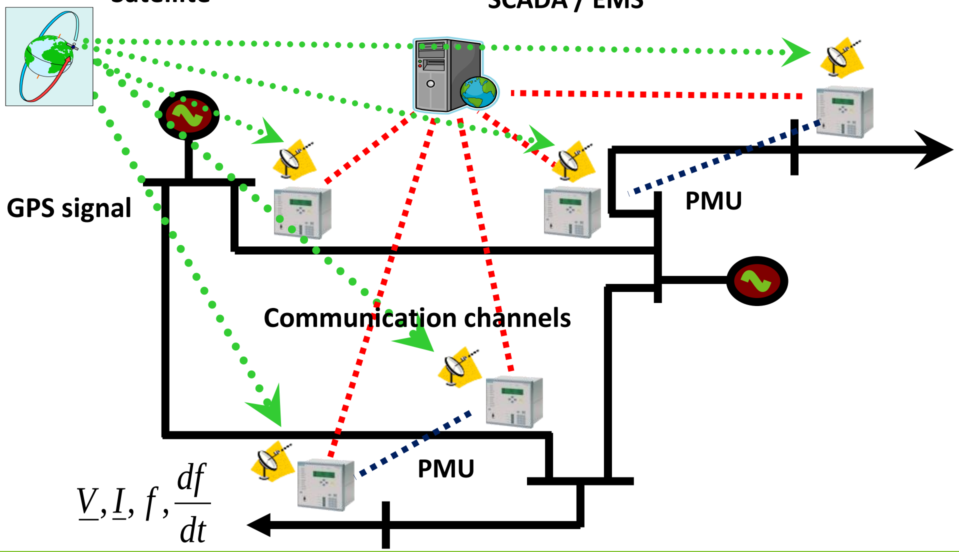
Grid Mod Solutions – HV Reclosers and PMUs

- HV sub-transmission recloser provides a way to improve system reliability and transmission grid resiliency by providing protection and isolation that was traditionally only available at the substation level

High-Voltage (72 kV) Sub-transmission Pole Top Recloser

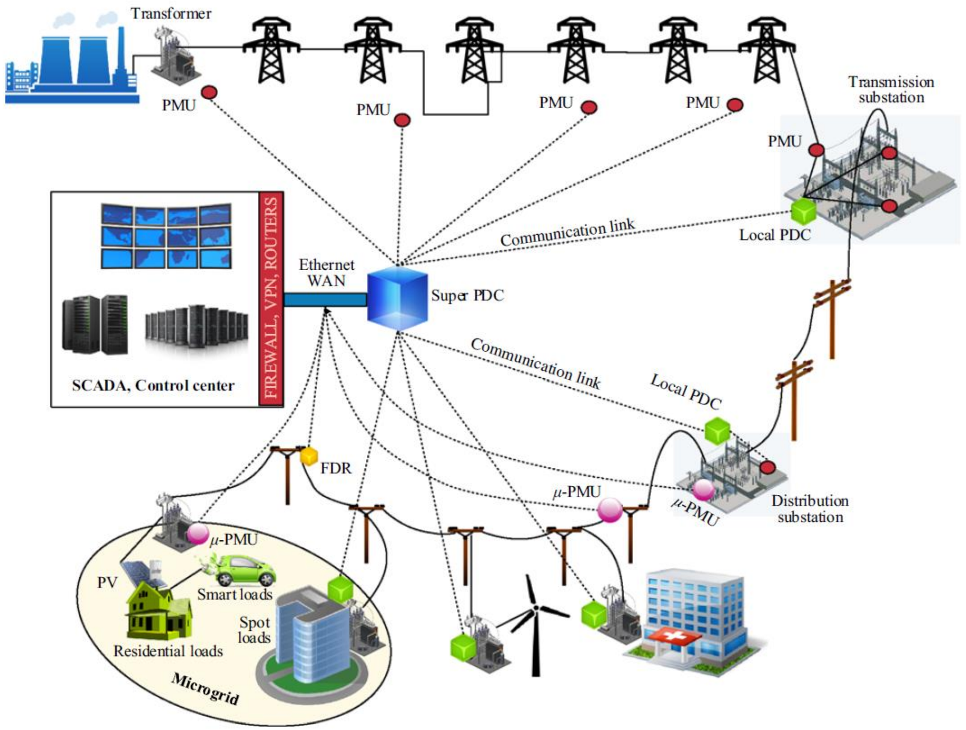
Source: G&W

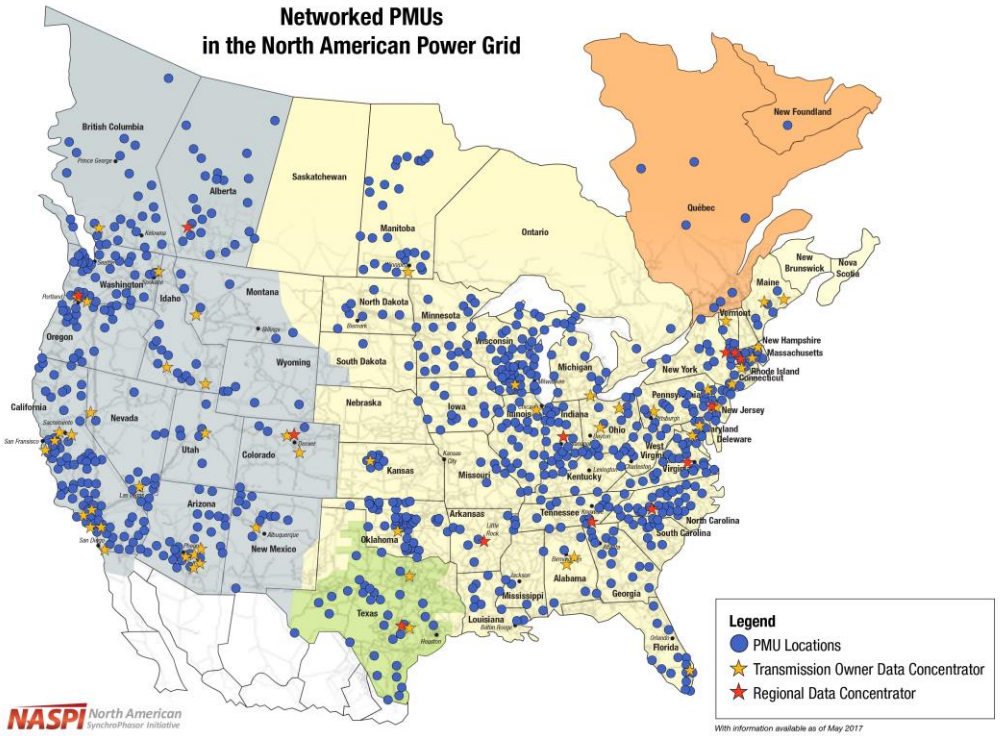
- Synchrophasors are precise grid measurements using GPS signals - available from phasor measurement units (PMUs)
- As PMU measurements are time-aligned to a common reference, they enable a precise and comprehensive real-time view of the utility network or entire interconnection
- PMU measurements are taken at high speed (e.g., 30 - 120 observations per second) compared to one every 4 seconds w/ conventional technology
- They allow evaluating grid stress more accurately, and can be used to trigger control actions to maintain reliability



Grid Mod Solutions – PMUs

- PMU deployment allows implementing Wide Area Monitoring, Protection, Automation and Control (WAMPAC), benefits include:
  - Data Analysis and Visualization
  - System Reliability: Outage Reduction, Blackout Prevention
  - System Operations, Modeling and Planning
  - Market Operations: Congestion Management & Locational Marginal Pricing





Source: NASPI

Grid Mod Solutions – Grid Edge Devices

ConnectDER: behind-the-meter DER monitoring device


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

UM3: advanced UG line sensor and Fault Circuit Indicator (FCI)


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


Combination (voltage and current) OH sensor


Optanode: distribution transformer monitoring device

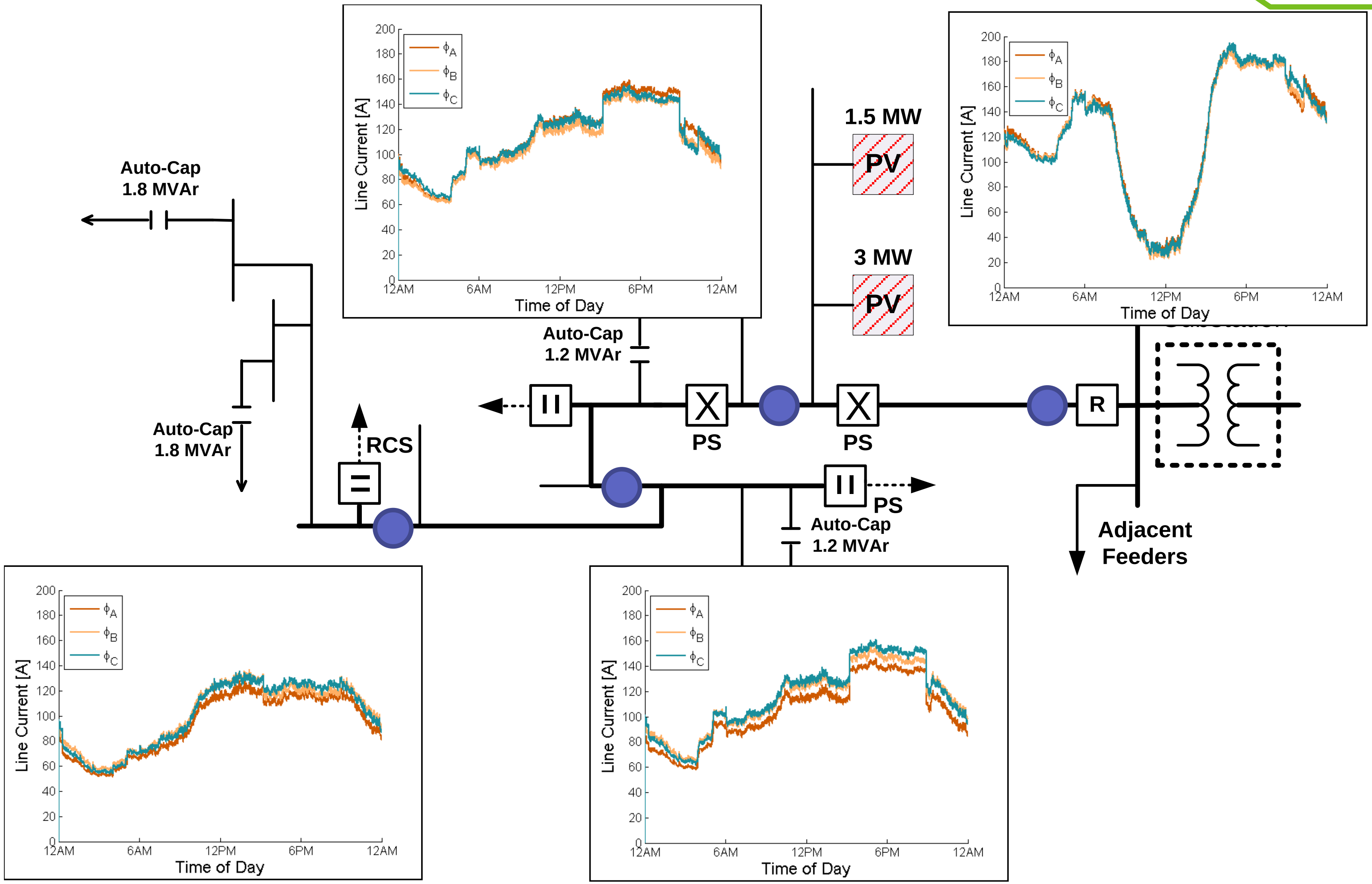

micro-PMU: Phasor Measurement Unit (PMU) for distribution applications

Power Quality Meter

Engo: low-voltage dynamic volt-Var control device

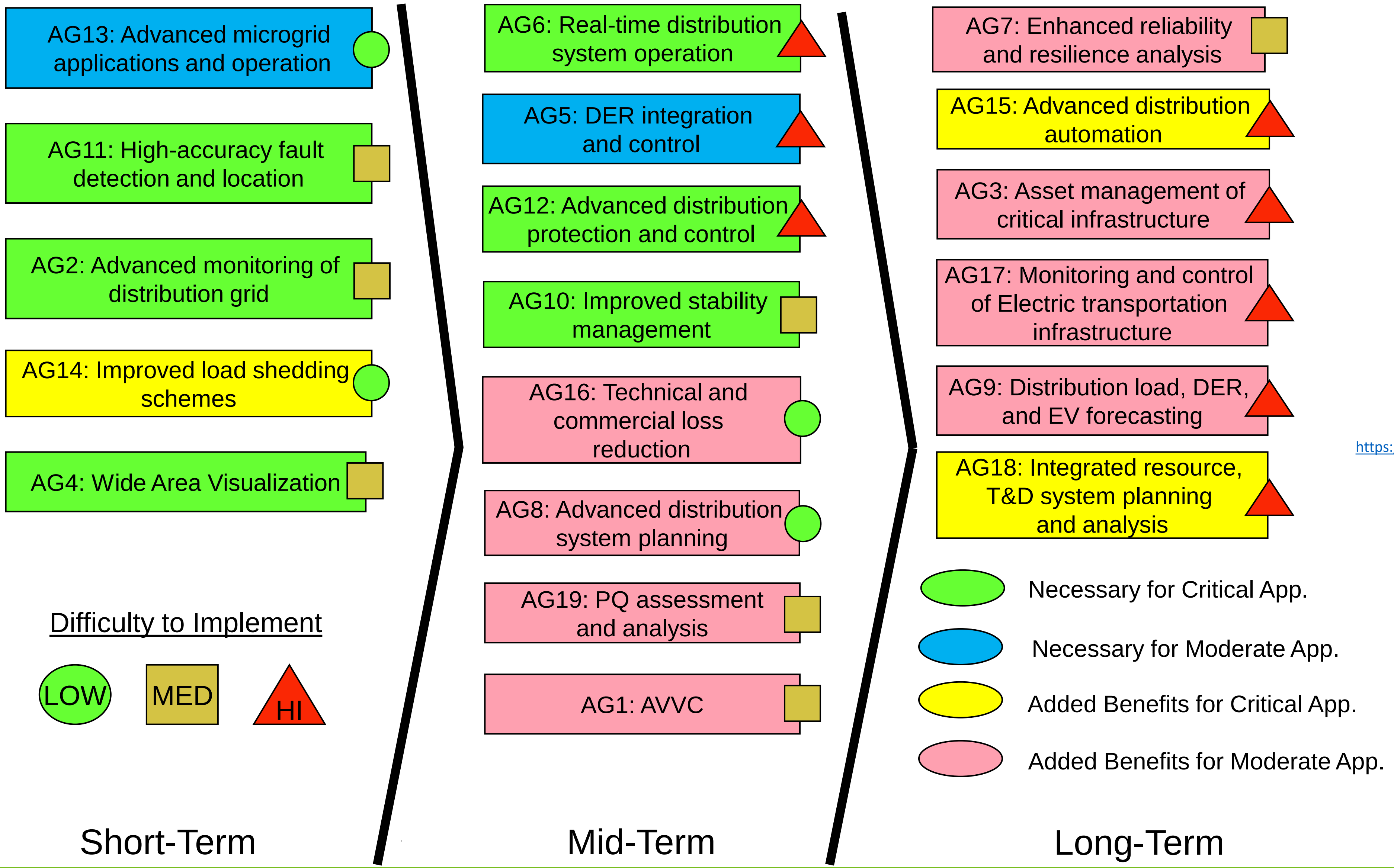
Combination (voltage and current) UG sensor

High Resolution Monitoring of PV-DG Using Distribution PMUs



Source: NREL and Quanta Technology

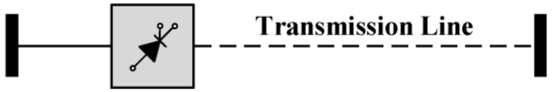
Synchronized Measurement Technologies Roadmap



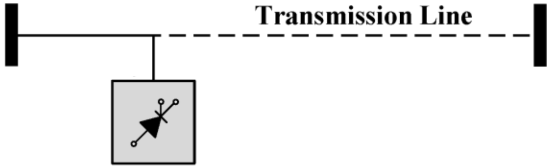
Source: Distribution Synchronized Measurements Roadmap
https://www.naspi.org/sites/default/files/reference_documents/distribution_synch_measurement_roadmap_20210927.pdf

Examples of Grid Modernization Solutions – FACTS Devices

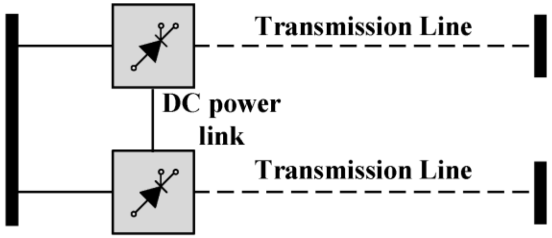
- Flexible Alternate Current Transmission Systems (FACTS) devices are power electronics-based solutions that allow controlling key electrical variables, including voltages, currents and power flows, of transmission lines. Applications of FACTS devices include increasing transmission system capability, controlling power flows and voltages, and improving system stability
- FACTS devices are classified as a) series, b) shunt, c) combined series-series, and d) combined series-shunt controllers. The most popular FACTS devices are series and shunt, and include Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), and Static Synchronous Series Compensator (SSSC)
- FACTS devices, particularly STATCOMs, are commonly used in the interconnection of large wind and solar farms to transmission and sub-transmission systems, and to increase transmission system capability to enable greater power flow between regions and address congestion issues



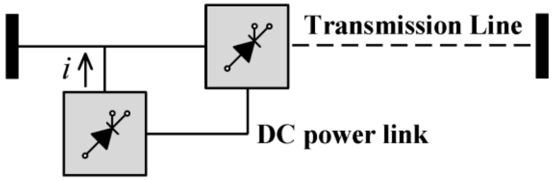
(a) Series Controller



(b) Shunt Controller



(c) Series-Series Controller

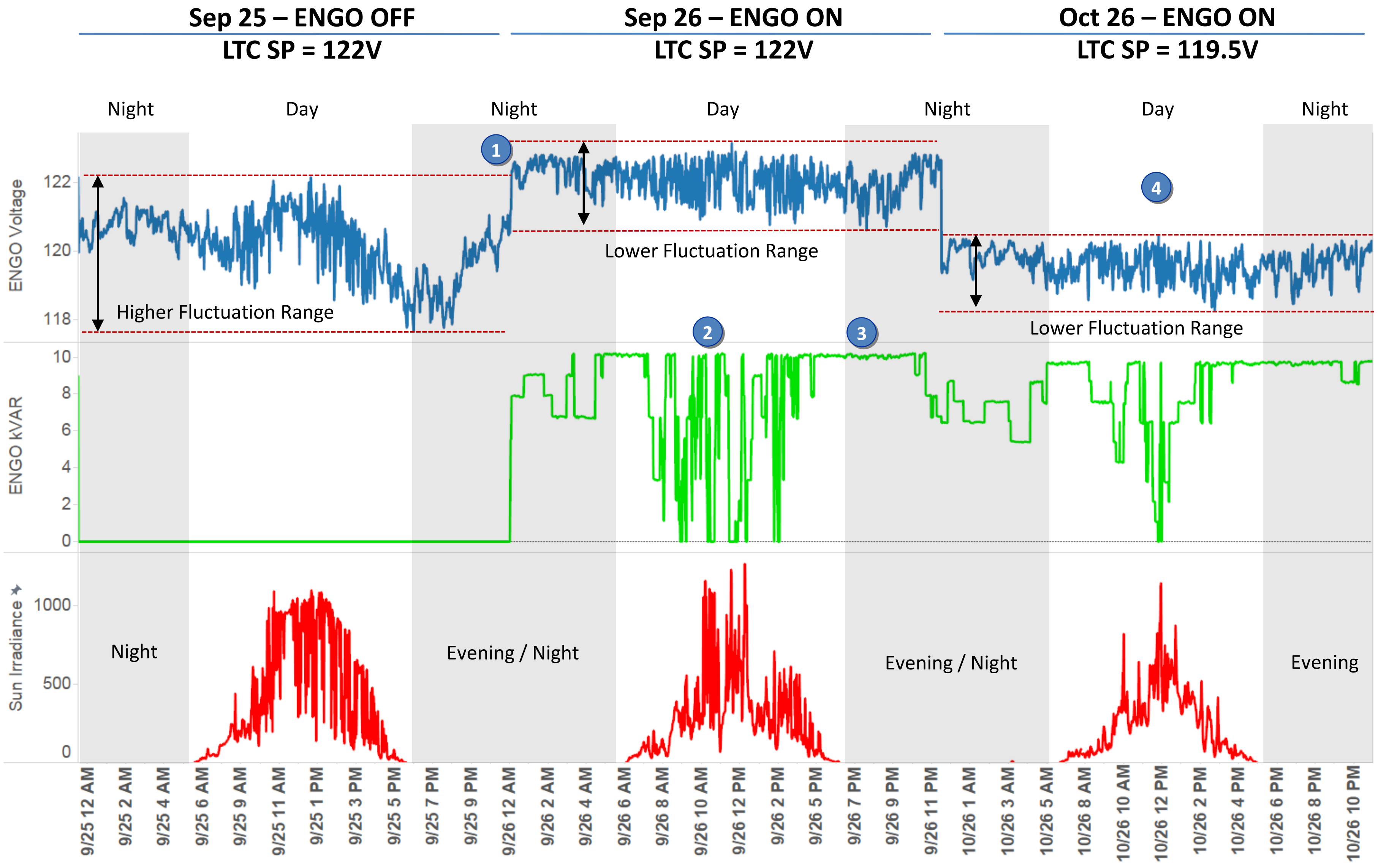


(d) Series-Shunt Controller

Static Synchronous Series Compensator (SSSC)

Source: Smart Wires

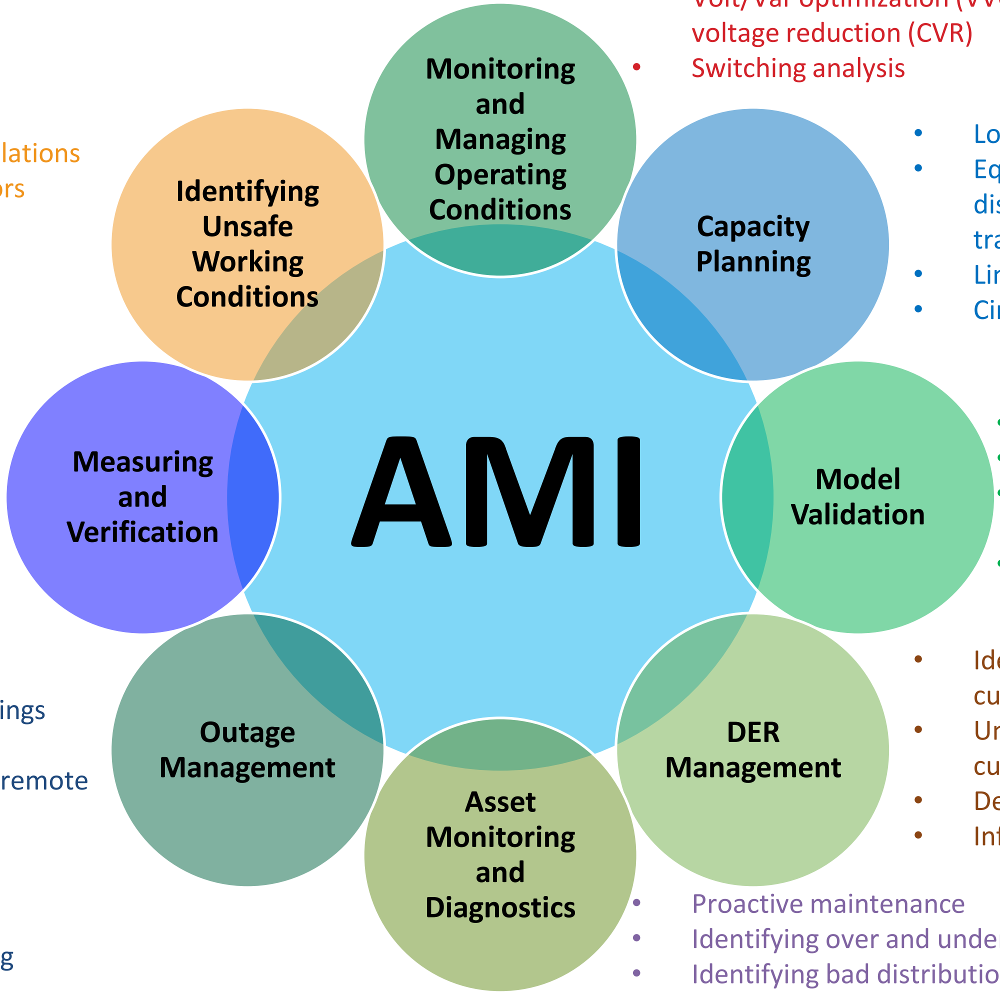
Grid Mod Solutions – Volt-Var Control at the Grid Edge



1. **Fluctuation Reduction:** ENGO voltage fluctuation range reduces when ENGO units are active
2. **Daytime Operations:** During the day time, ENGO units provide dynamic VAR support to compensate for PV generation volatility (e.g. cloud cover)
3. **Night Time Operations:** During the night time, ENGO units provide full kVAR support during peak-load times when PV generation is not available
4. **Tap Down LTC to Allow Extra PV Penetration:** ENGO provides voltage support to allow the LTC to tap down permanently which will allow extra PV penetration for the system.

Grid Mod Solutions – AMI (Beyond Meter Reading and Billing)

These benefits or use cases cannot be achieved by merely installing the network and meters. Many will require integration with ADMS or other software solutions that allow the data to be analyzed, visualized and paired with other data.



Monitoring and Managing Operating Conditions:
- Improved power quality
- Validation of voltage compliance
- Visualizing the data/Increased system visibility
- Volt/Var optimization (VVO) and conservation voltage reduction (CVR)
- Switching analysis

Capacity Planning:
- Load forecasting and projected growth
- Equipment investments and upgrades (e.g., distribution transformers, substation transformers, etc.)
- Line loss studies
- Circuit phase load balancing

Model Validation:
- Validation of primary circuit model
- GIS and network connectivity corrections
- Mater to transformer mapping/transformer load management
- Phase identification and mapping

DER Management:
- Identifying unregistered customer-owned systems
- Understanding the impacts of customer-owned systems
- Determining DER capacity
- Informing policy

Asset Monitoring and Diagnostics:
- Proactive maintenance
- Identifying over and underloaded transformers
- Identifying bad distribution voltage regulators and distribution capacitors
- Identifying hot sockets

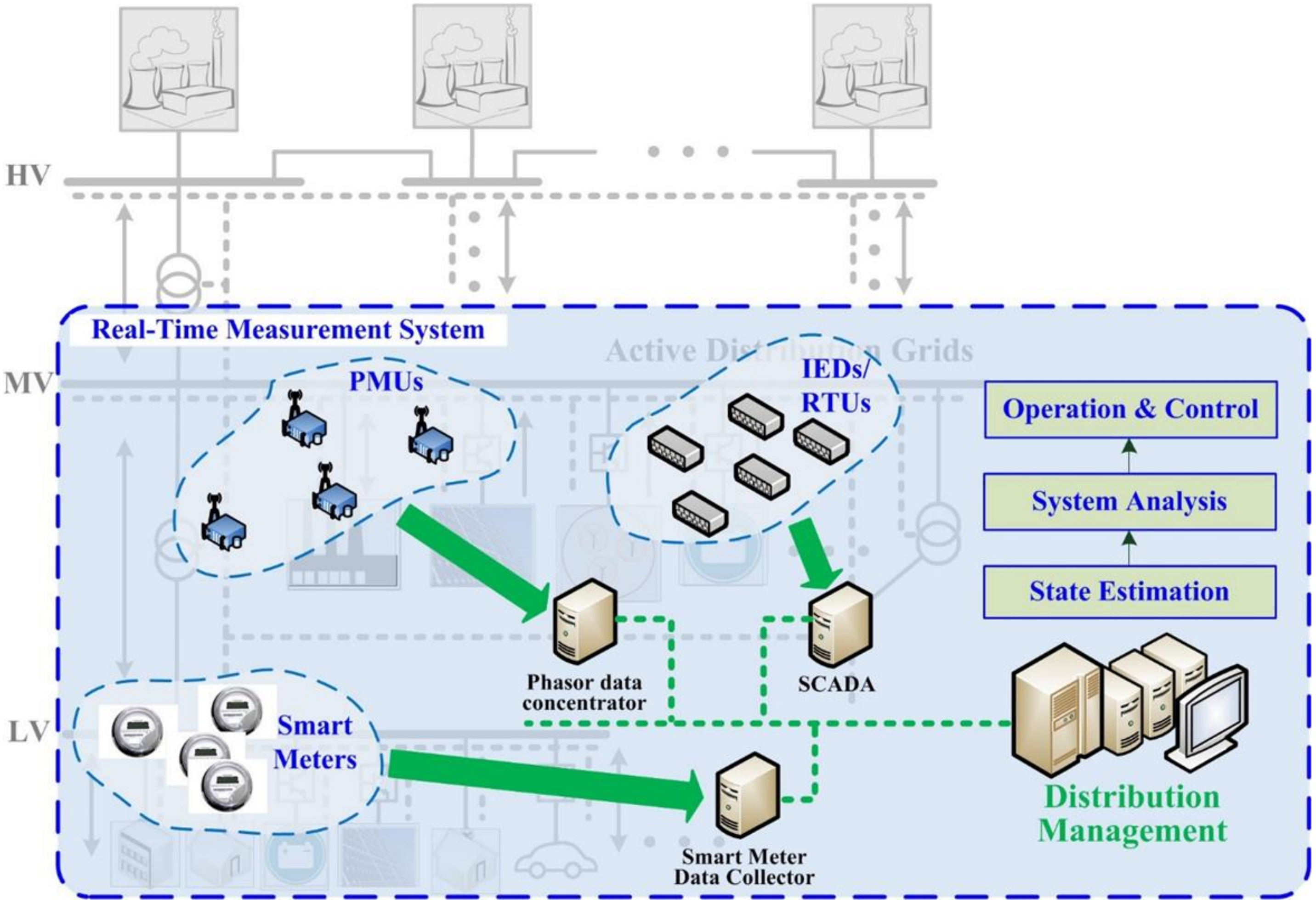
Outage Management:
- Verifying outages through meter pings
- Estimating restoration times
- Service order automation through remote connect/disconnect
- Identifying outage locations
- Determining cause of outage
- Customer communications
- Determine fire-caused outage using temperature data
- Identifying which phase of wires are down

Measuring and Verification:
- Reduce/eliminate estimated reads
- Revenue protection
- Reliability metrics
- Demand response verification/thermostat programs
- Demand response and load shifting for EV charging
- Enables new rate options (e.g., time of use and prepay)

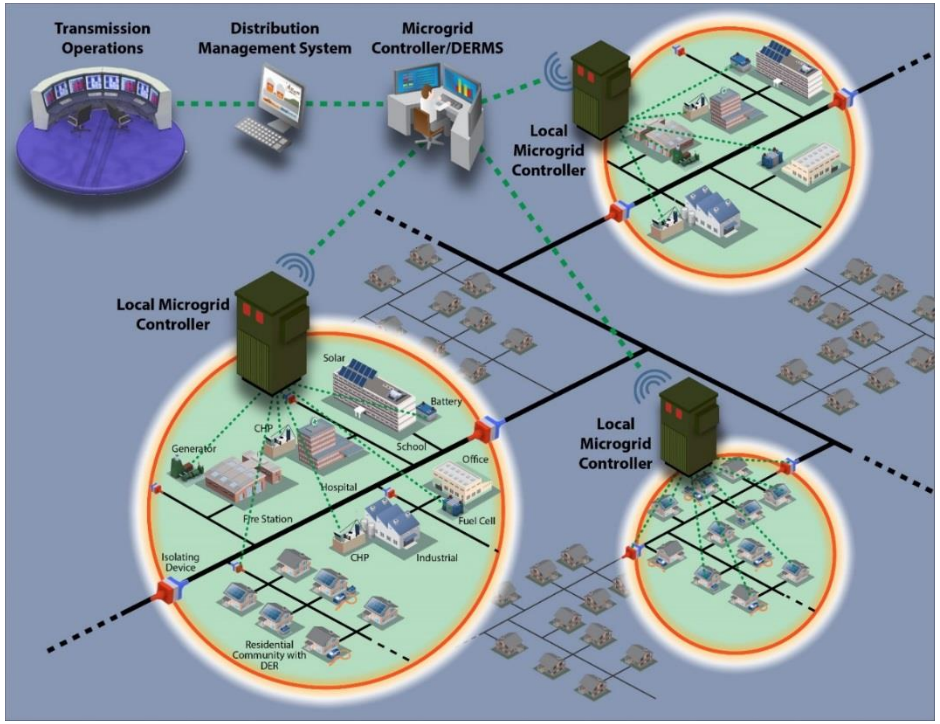
Identifying Unsafe Working Conditions:
- Identifying unregistered PV installations
- Identifying downed live conductors

Source: Voices of Experience, Leveraging AMI Networks and Data, U.S. DOE

Grid Mod Solutions – ADMS and Microgrids

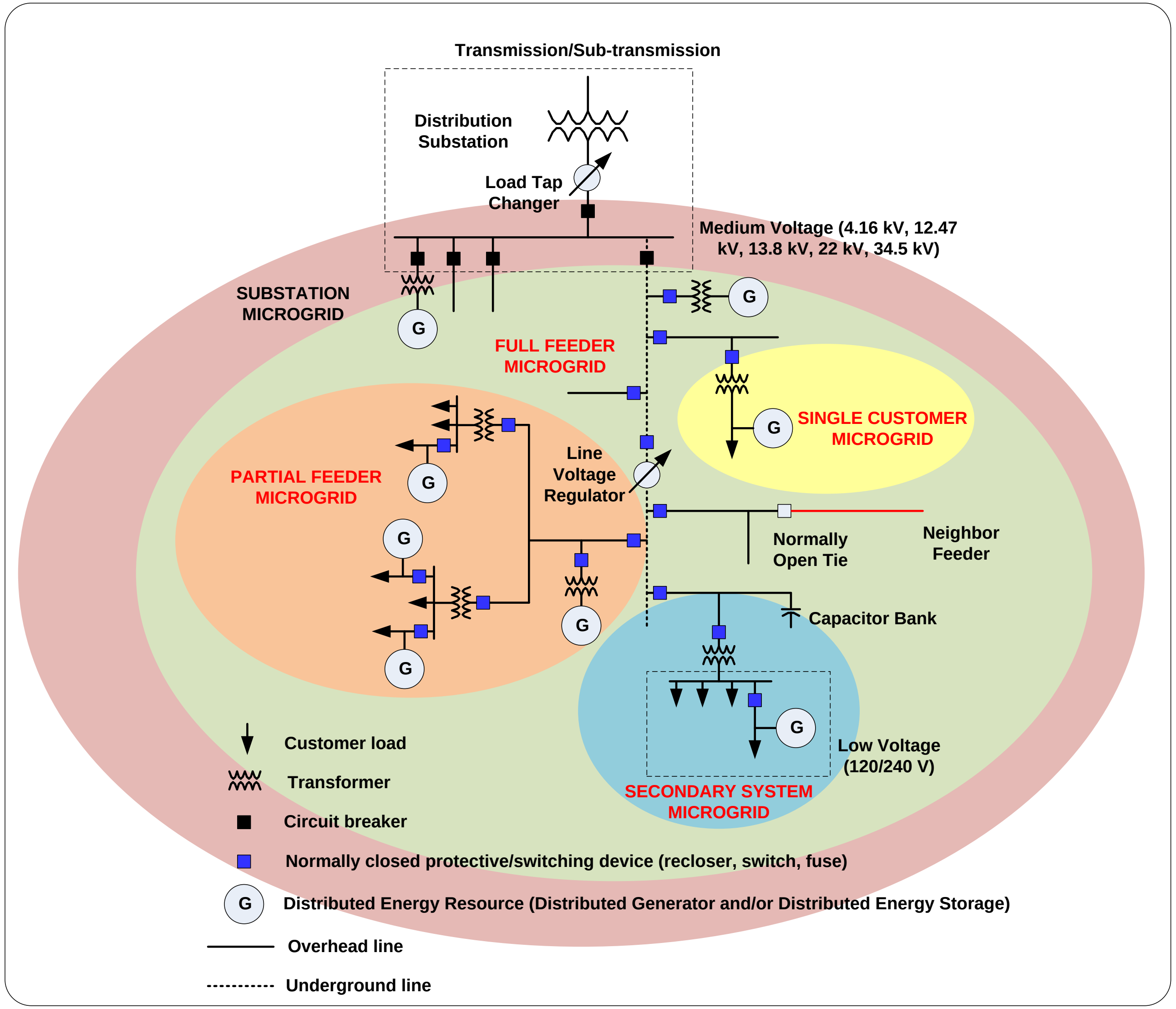


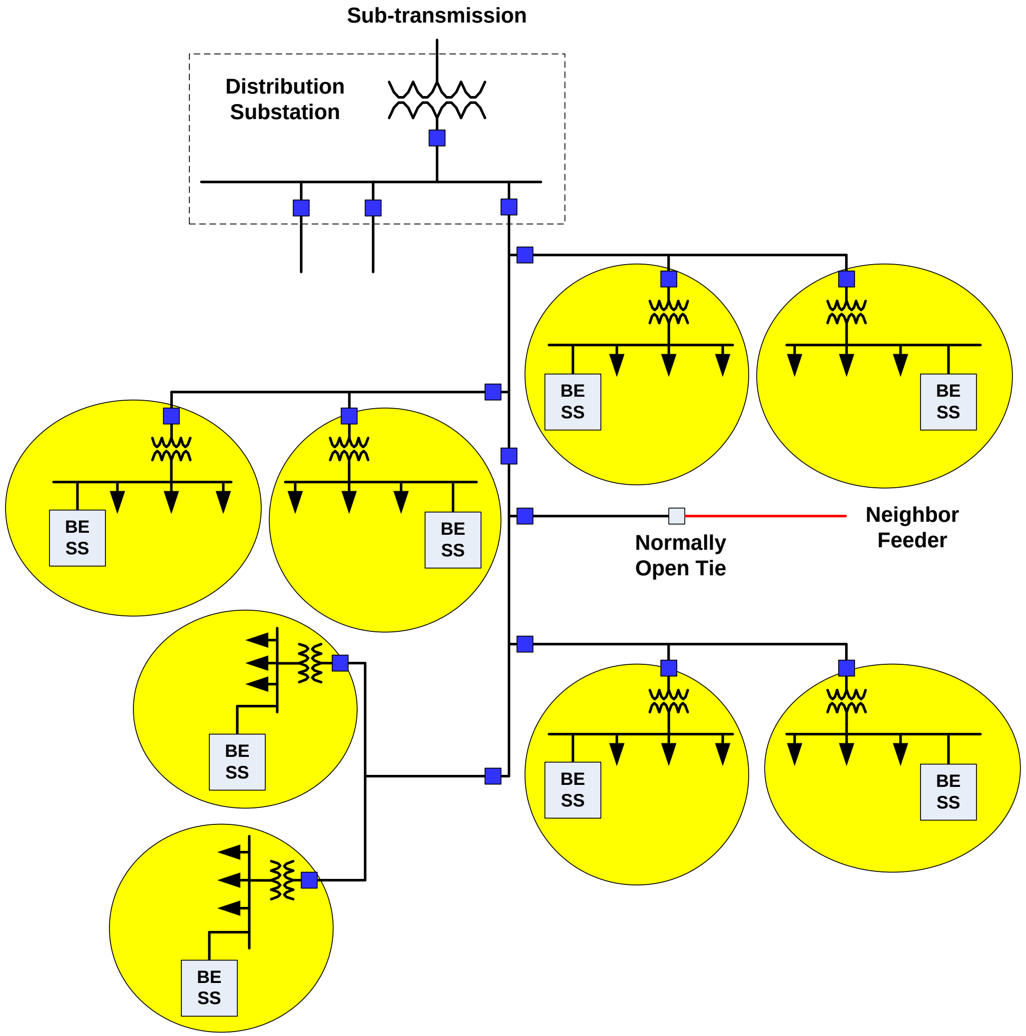
Source: RTWH Aachen



Source: EPRI

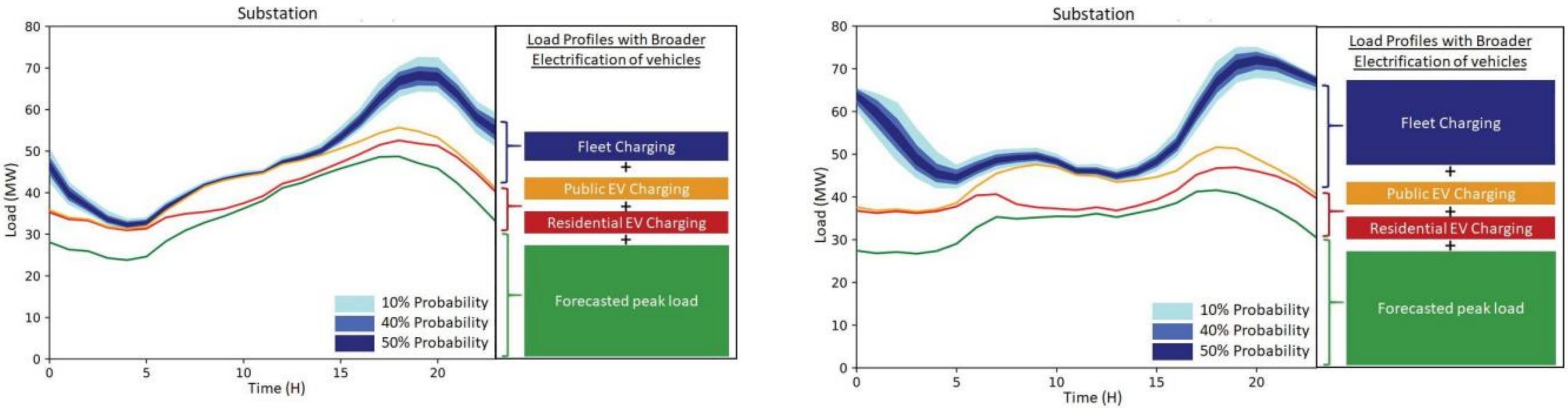
Hierarchical Microgrids & Distributed Energy Storage





Grid Mod Solutions – EV Adoption Planning

- Electric vehicles, particularly in fleets, can substantially increase power delivery system peak demand, create overloads and low-voltage violations, and trigger capital investments to increase capacity (e.g., upgrade substation transformers and distribution line conductors).



Forecasted impact of EV charging on daily substation load profile if 100% of vehicles are electric for summer (left) and winter (right) peaks

Source:
National Grid

Holistic Planning – From “Snapshot” to Performance Planning

Data & Grid Analytics

- Assess and calculate system performance using accurate, up-to-date, high resolution and abundant data at customer, service transformer and feeder level, and reduce reliance on assumptions and heuristics

Temporal & Spatial Analysis

- Move away from snapshot substation-level analyses (e.g., annual peaks, substation transformers and feeder mains) to time-series spatial analysis at feeder section and service transformer level (high resolution/granularity temporal/spatial analysis)

Holistic Planning

- Holistic approach that considers all distribution planning and engineering aspects together, rather than decoupled (capacity planning, reliability, protection, automation, volt-VAR control, asset management, DER, NWA, and microgrids

Planning & Operations Convergence

- DER proliferation is blurring the traditional boundaries between T&D systems, and between planning and operations of these systems, and leading to T&D planning and T&D operations convergence. This requires the development of new methodologies and new solutions

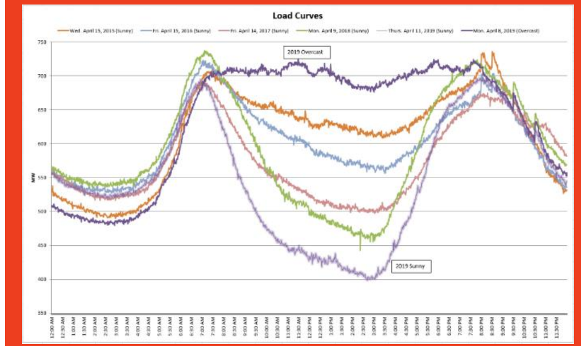
Coordinated Resource and T&D Planning

High Granularity/Resolution Spatial/Temporal Modeling, Simulation & Analysis

- Distribution Planning
- Integrated Resource Planning
- Transmission Planning

→ **GT&D Planning Convergence (e.g., "duck curve")**

Source: VELCO



Models and Software Solutions

Data & Analytics

Telecom & IT/OT

- Capacity Planning
- Load & DER Forecasting
- NWA & Microgrids
- Value of DER/Grid
- Reliability
- Resilience
- Operations
- Protection & Control
- Automation
- Volt-Var Control
- Asset Management

DER
Modern & Future End User & IoT

Transition from deterministic (snapshot) analyses based on annual peak demand of key assets (e.g., substation transformers) to multi-hour (time-series) probabilistic and spatial analysis of demand/production of granular assets (e.g., service transformers)

Integrated Distribution Planning (IDP)

Result is Holistic Investment Prioritization

GT&D Operations Convergence (e.g. DER voltage & frequency ride-through) ←

- Distribution Operations
- Generation & Renewable Resources Operations
- Transmission Operations

Source: NERC

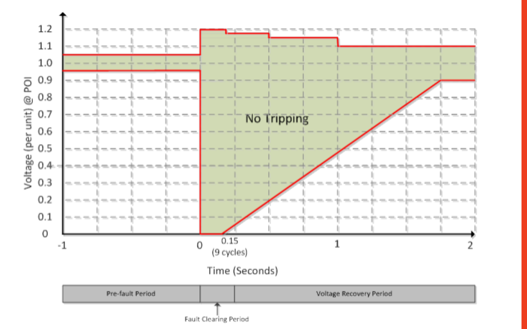
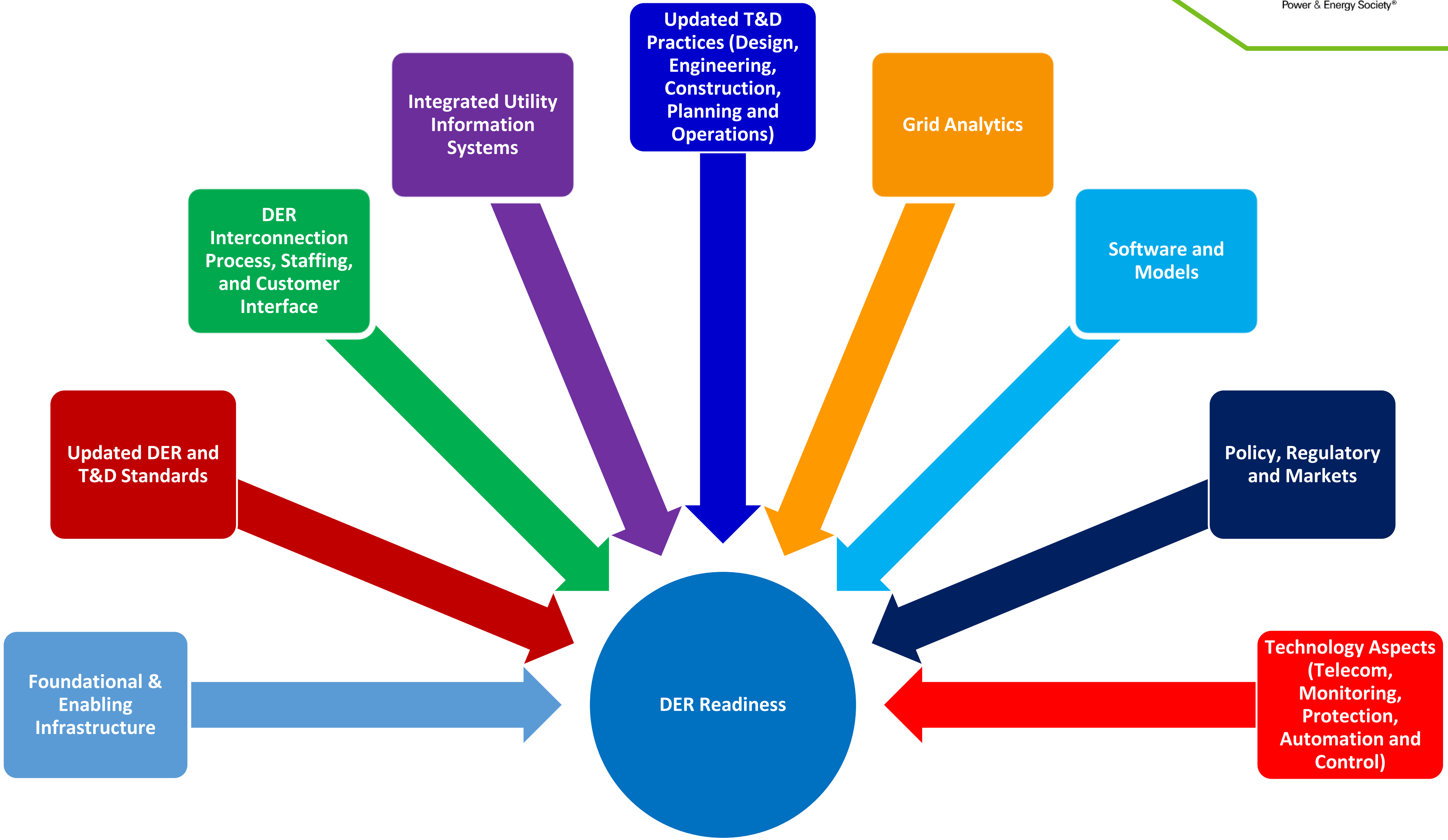


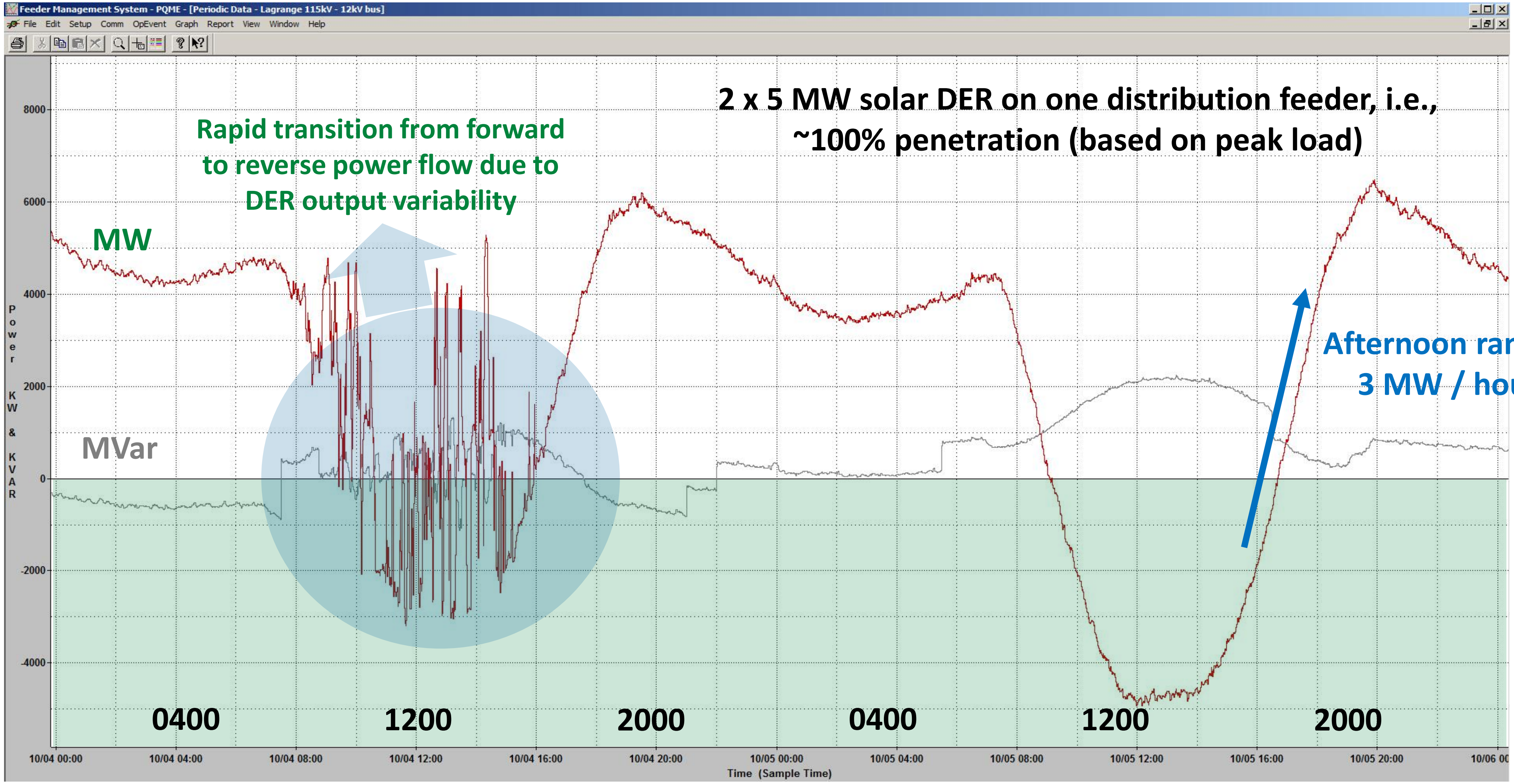
Figure 21: ERCOT Voltage Ride Through Profile [Source: ERCOT]

DER Readiness



Impacts of High Penetration of Utility-Scale PV DG

Duke Energy Progress, Lagrange 115 kV / 12 kV Substation near LaGrange, NC: October 4 & 5, 2014



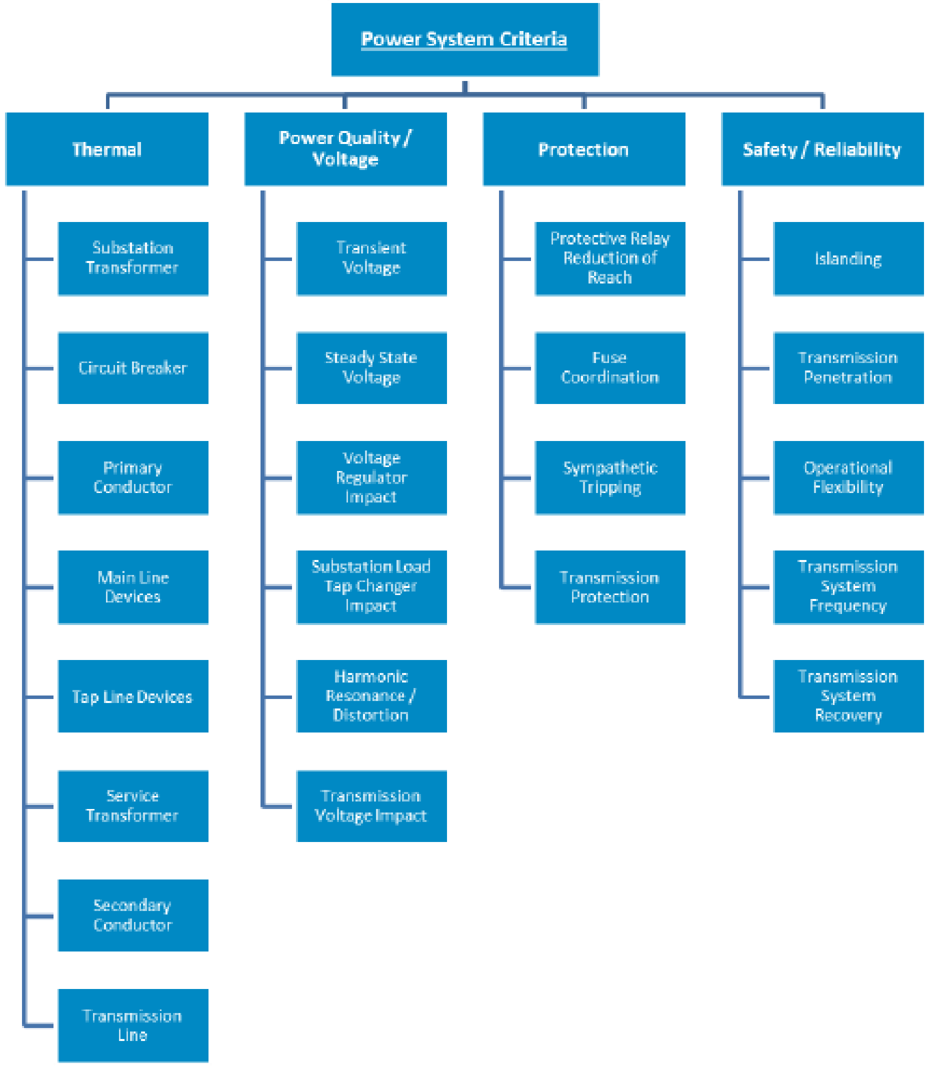
Reverse power flow through substation transformer into 115 kV transmission system

One-minute real & reactive power flow measured at substation bus, 48-hour period

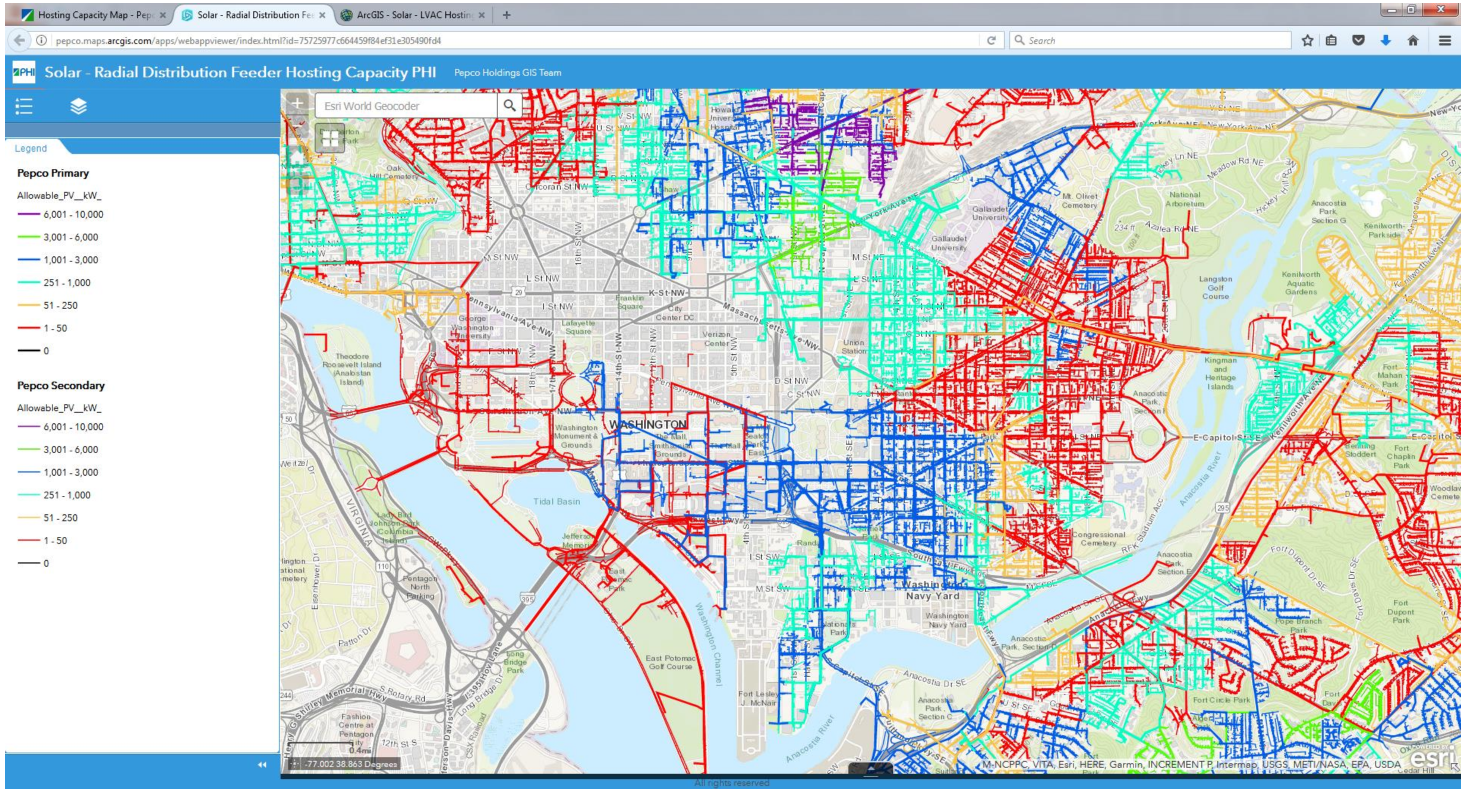
Source: J. Gajda, Creating sustainable and scalable interconnection requirements for high penetration of utility-scale DER on the distribution system, 2017 IEEE PES GM, Chicago, IL

Leading Practices – DER Hosting Capacity

DER Hosting Capacity Vision

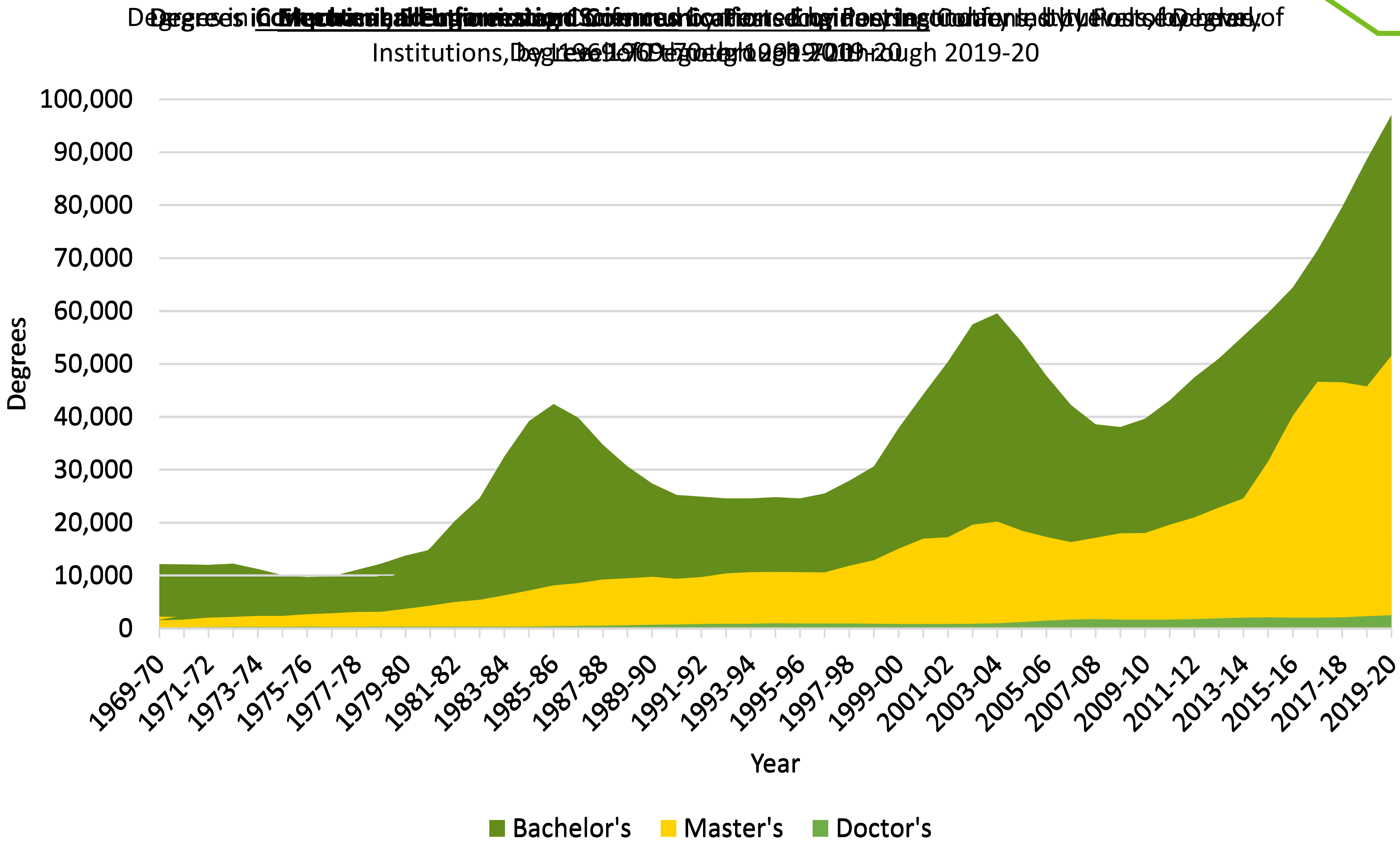


Source: http://www.cpuc.ca.gov/General.aspx?id=5071

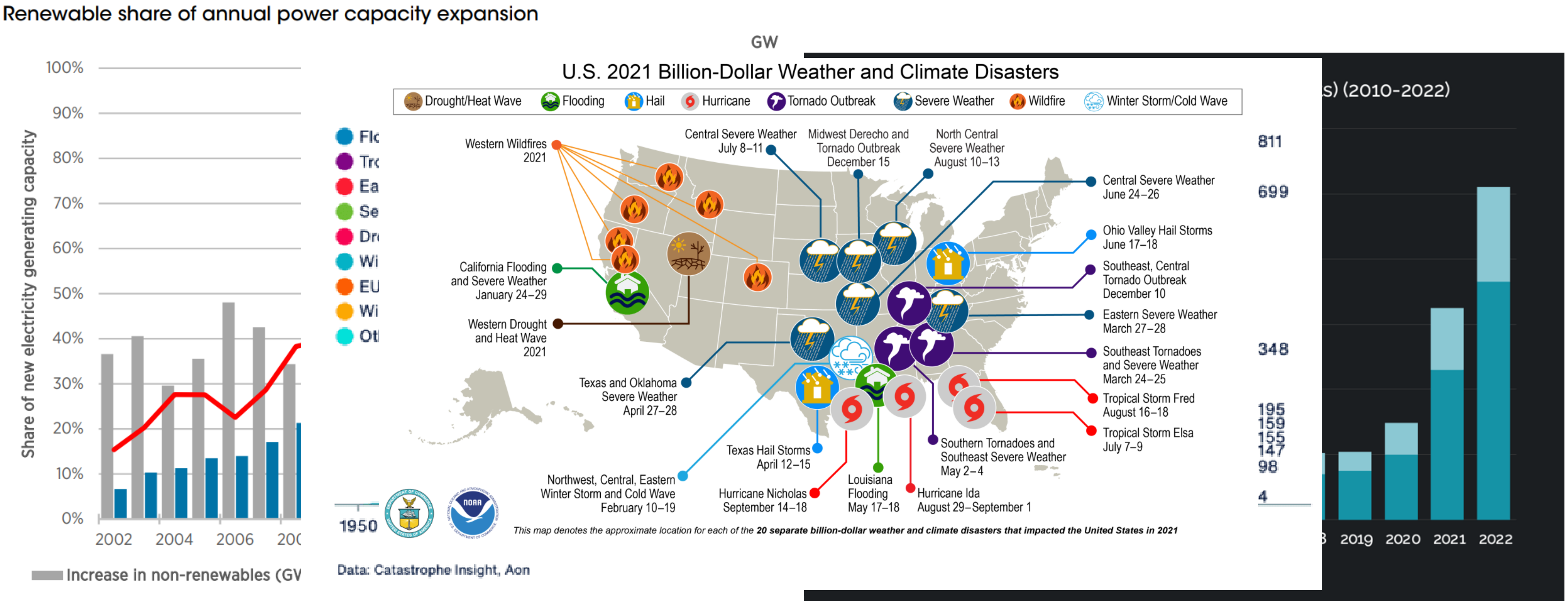


Source: https://www.pepco.com/SmartEnergy/MyGreenPowerConnection/Pages/HostingCapacityMap.aspx

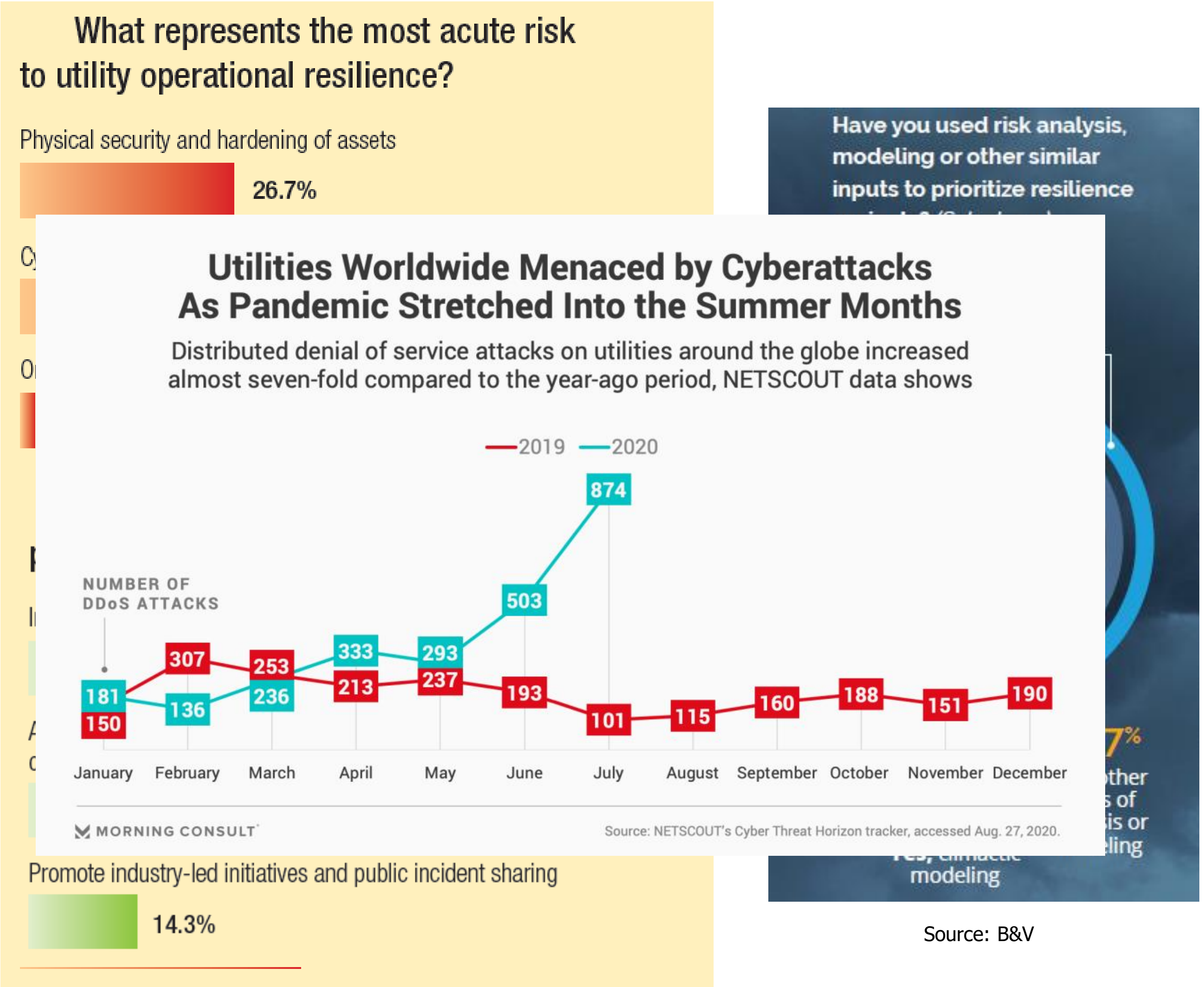
Workforce Challenges – U.S.



What we do is cool and vital for our global future!



What we do is cool and vital for our global future!



Source: Public Utilities Fortnightly/Guidehouse

Source: B&V

- According to recent results of an electric utility industry survey, **57% respondents use risk analysis to prioritize resilience investments**. Risk analysis focuses on what an asset or process is intended to do and identifies factors that stop it from performing as required. This information is used to inform measures to mitigate the factors degrading asset performance, helping identify the optimum balance between cost and risk.
- **About 20% respondents are using climatic modelling** to help them better understand and predict the events putting power infrastructure at risk.
- According to another industry survey of 250 executives, despite the growing frequency and severity of extreme weather events and fires, it is **cybersecurity**, rather than physical security and grid hardening, where utility industry survey participants see the greatest risk currently.

Why we do what we do?

- Engineering has been changing the world for millennia and the new rapidly emerging technologies are an opportunity for positive transformation that leaves no one behind.
- The world is still experiencing, on average, a shortage of engineers in all domains.
- Engineering is essential for economic advancement and for the implementation of new technologies and the application of science including for basic needs of food, health, housing, roads and transport, water, energy and management of the planet’s resources.
- Engineering is a vital profession in addressing basic human needs, in alleviating poverty, in promoting secure and sustainable development, in responding to emergency situations, in reconstructing infrastructure, in bridging the knowledge divide and in promoting intercultural cooperation.
- IEEE and PES can help accelerate career growth, ensure access to continuous education and prepare members to lead and address existing and future industry challenges driven by the energy transition
- **The future of PES and our industry relies on strong leadership, commitment, volunteering and innovative thinking from our leaders, volunteers and members!**

“Engineering is one of the keys to the sustainable development of our societies, and to activate its full potential, the world needs more engineers and more equality” – Audrey Azoulay, UNESCO Director-General

Conclusions and Recommendations

- Grid modernization allows utilities prepare the grid for the changes driven by the adoption of renewable energy and electrification and the impacts caused by more frequent and severe weather events. Grid modernization programs include deployment of advanced technologies and foundational infrastructure (e.g., hardening and aging infrastructure replacement) and implementation of enhanced processes. Grid modernization involves all components of power systems, including transmission, distribution and substations
- A key first step in transforming the grid for the energy transition is developing a grid modernization roadmap, which:
  - Enhances and strengthens grid planning, operations, and engineering activities
  - Identifies and prioritizes key infrastructure investments in support of the utility goals
  - Sets the foundation for transforming and preparing the utility for the future, according to industry leading practices, and outlines key initiatives
- Telecommunications, IT systems, big data analysis and AI will play a vital role to enable efficient and effective data collection, processing, storage, and analysis needed for real-time operations and high resolution/granularity spatial/temporal planning
- T&D modeling, simulation, analysis and planning capabilities should evolve to account and take advantage of these emerging trends and technologies, facilitate planning and operations activities, and ultimately further deliver value to end users

Further Reading

- Modernizing the grid: Challenges and opportunities for a sustainable future, JR Agüero, E Takayesu, D Novosel, R Masiello, IEEE Power and Energy Magazine 15 (3), 74-83
- The utility and grid of the future: Challenges, needs, and trends, JR Agüero, A Khodaei, R Masiello, IEEE Power and Energy Magazine 14 (5), 29-37
- Grid modernization, DER integration & utility business models-trends & challenges, JR Agüero, A Khodaei, IEEE Power and Energy Magazine 16 (2), 112-121
- Roadmaps for the utility of the future, JR Agüero, A Khodaei, The Electricity Journal 28 (10), 7-17
- Grid modernization: challenges and opportunities, JR Agüero, E Takayesu, D Novosel, R Masiello, The Electricity Journal 30 (4), 1-6
- Tools for success: Distribution System Planning in the Smart Grid Era, JR Aguero, IEEE Power and Energy Magazine 9 (5), 82-93
- Improving the reliability of power distribution systems through single-phase tripping, JR Agüero, J Wang, JJ Burke, IEEE PES T&D 2010, 1-7

Thank you!

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