QUANTA TECHNOLOGY

Integration of Distributed Energy Resources & Electric Transportation in Distribution Systems

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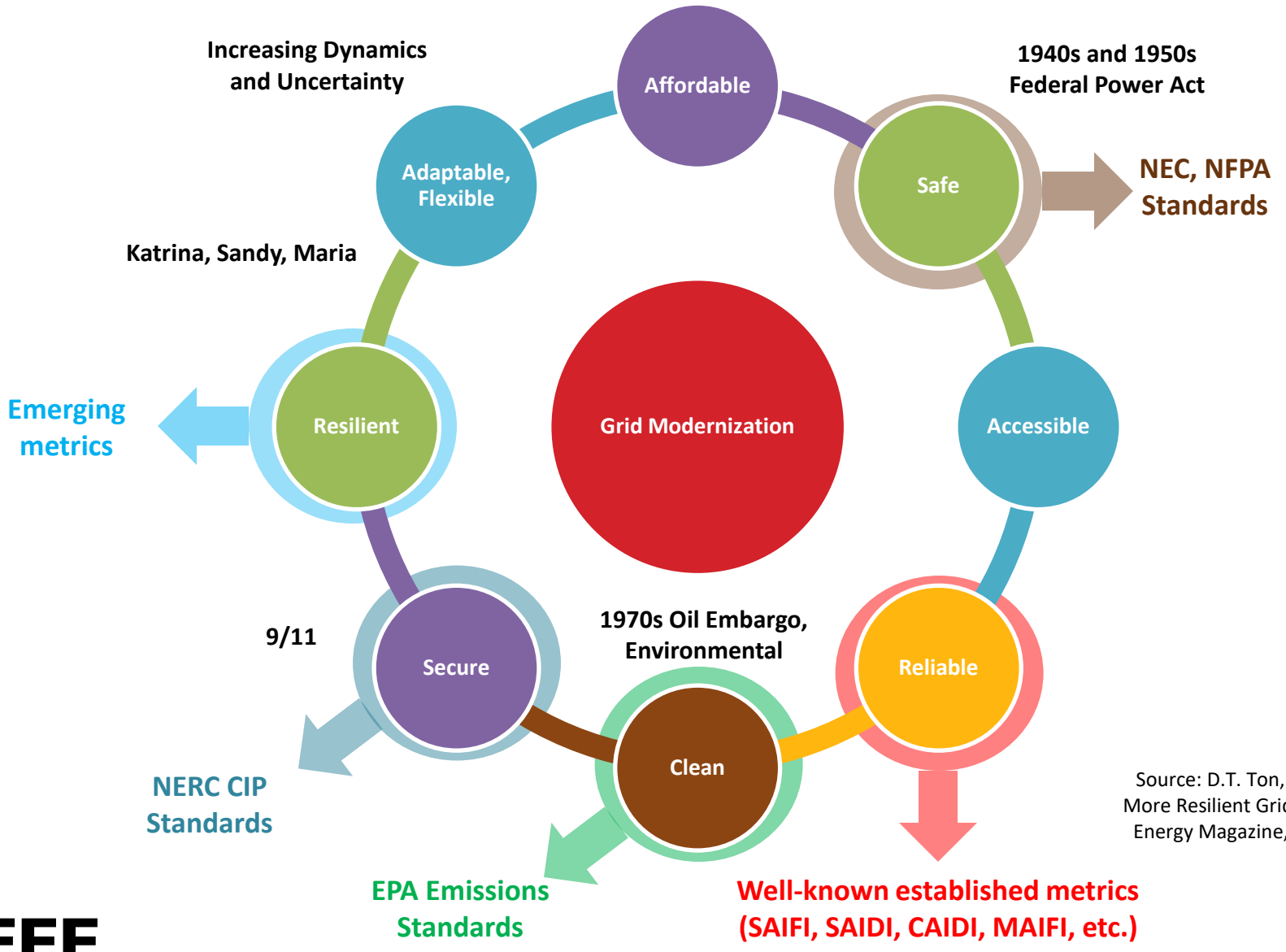
Key Attributes of Future Electricity System

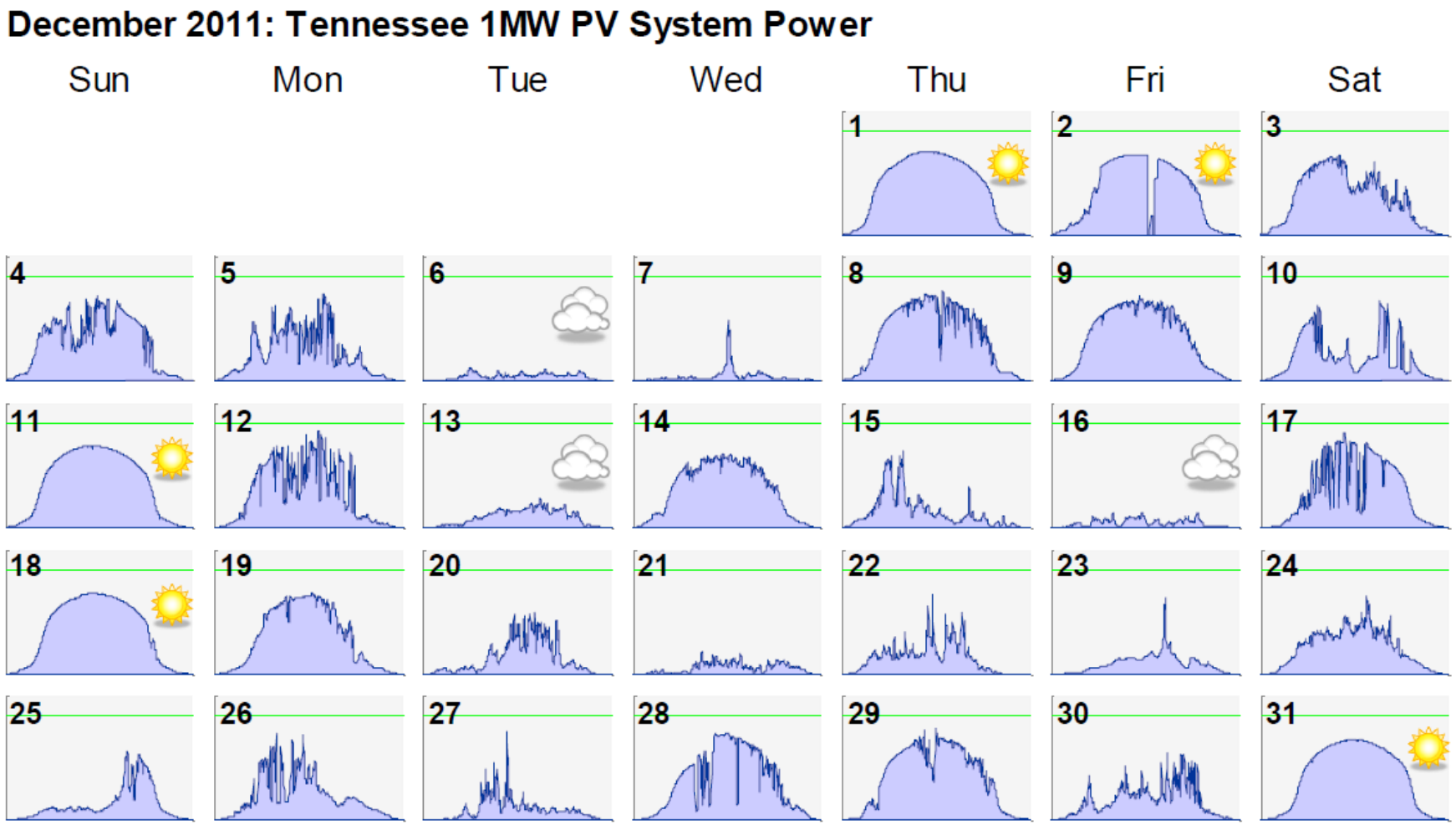


Source: D.T. Ton, W-T.P. Wang, A More Resilient Grid, IEEE Power and Energy Magazine, May/June 2015

DER Integration Challenges and Impacts

- Depending on size, type, technology, location, engineering practices, and penetration level DER may have various impacts and benefits on utility grids:
  - **Main concerns:** voltage increase and fluctuations, thermal rating violations, protection issues, load masking, wear and tear of circuit apparatus (tap changers and switches)
  - **Main benefits:** voltage support (especially toward the end of the feeders), peak shaving (potential for investment deferral), loss reduction, potential for intentional islanding (microgrid) to enhance reliability, emissions reduction (renewables)
- DER can change grid dynamics and daily utility operations and business practices:
  - Bidirectional power flows and feeder and substation back-feeding
  - Need for DER interconnection studies
  - More complex planning and operations, e.g., need for sophisticated load and generation forecasting

DER Integration Challenges



Calendar profiles are 1-minute averages derived from 1-sec data

Source: https://www.puco.ohio.gov/industry-information/industry-topics/powerforward/phase-2-exploring-technologies/presentations/tom-key/

DER Impacts – Background

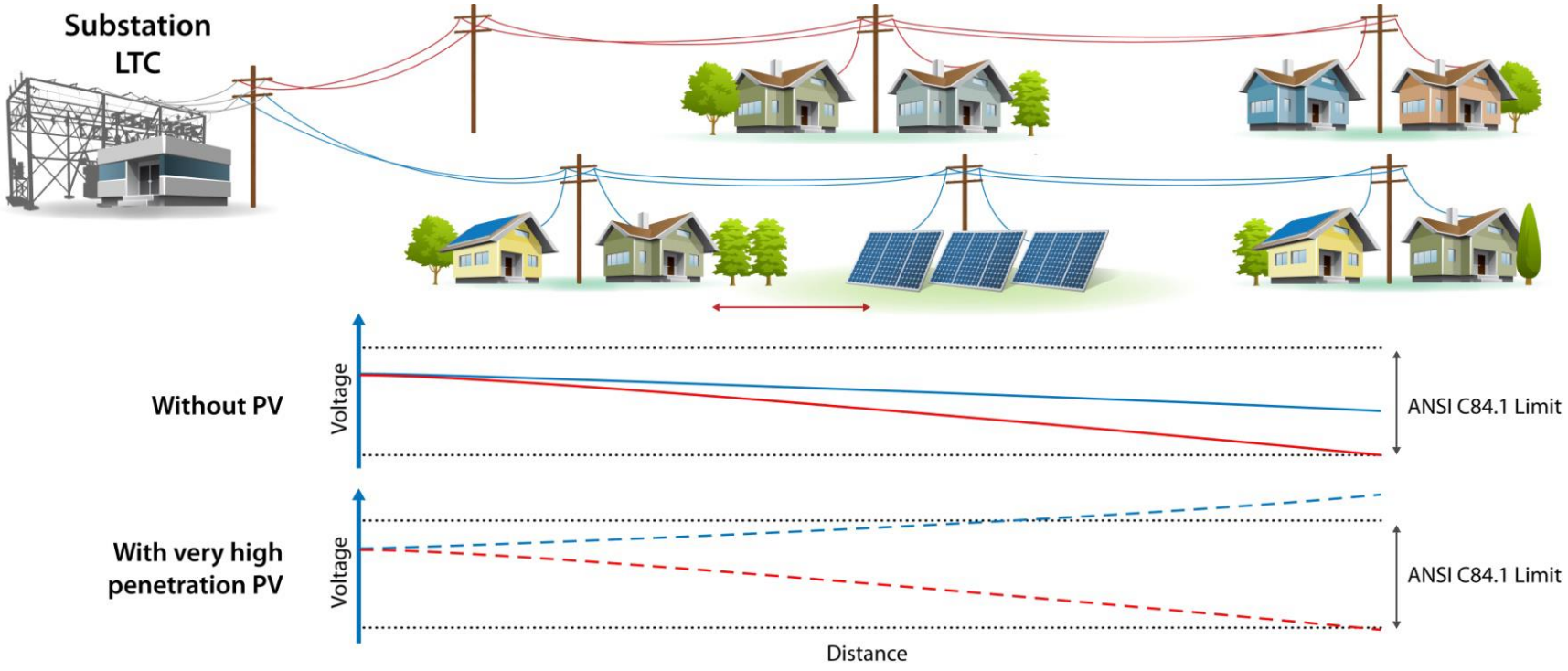
- DER interconnection may violate the basic assumption of unidirectional power flow and may perturb distribution system operations if required measures are not implemented
- DER has diverse **impacts** on distribution system planning and operations (e.g., solar **intermittency** due to cloud cover can have a significant impact on voltage variations)
- Impacts are not only of steady state but also of **dynamic** nature (e.g., Temporary Overvoltage TOV)
- This represents an important challenge for most planners, who are used to deal with steady state studies but not with **dynamic modeling and analysis**
- Impacts are not localized and grow as proliferation increases

DER impacts

- Potential impacts include:
  - Voltage increase
  - Voltage fluctuations
  - Reverse power flow
  - Interaction with LTC, switched capacitor banks and line voltage regulators
  - Reactive power fluctuations
  - Voltage and current unbalance (single-phase DG)
  - Equipment loading increase
  - Fault duty increase
  - Losses increase and power factor modification
  - Potential impacts on overcurrent and overvoltage protection systems, including Temporary Overvoltage (TOV), sympathetic tripping, reach modification
  - Total Harmonic Distortion (THD) increase

Examples of DER Impacts – Voltage Increase

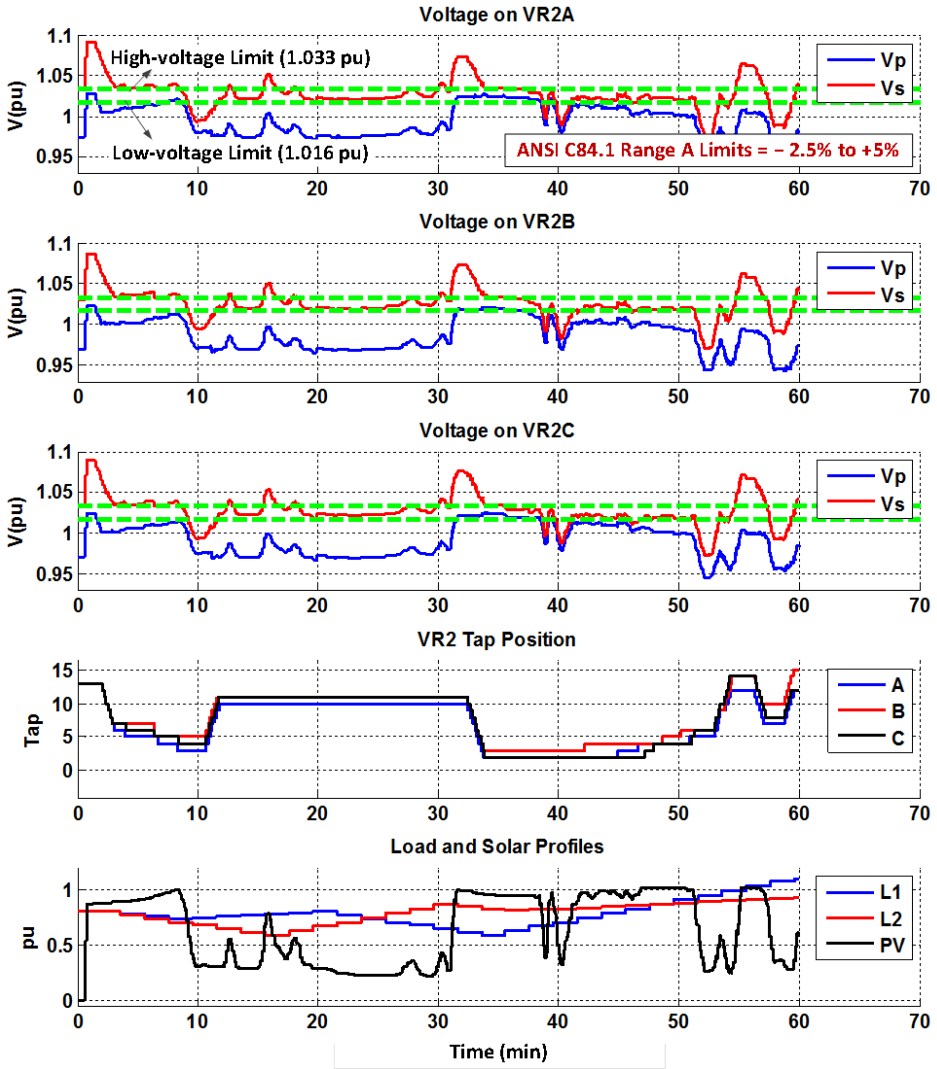
- DER interconnection generally leads to a voltage increase since it compensates the voltage drop caused by load current. However, reverse power flow caused by DG may lead to voltages outside allowable limits (e.g., ANSI 84.1) and interactions with voltage regulation and control equipment (LTCs, voltage regulators, capacitor banks)



Source: Results from the DOE-CPUC High Penetration Solar Forum http://energy.gov/eere/solar/downloads/results-doe-cpuc-high-penetration-solar-forum

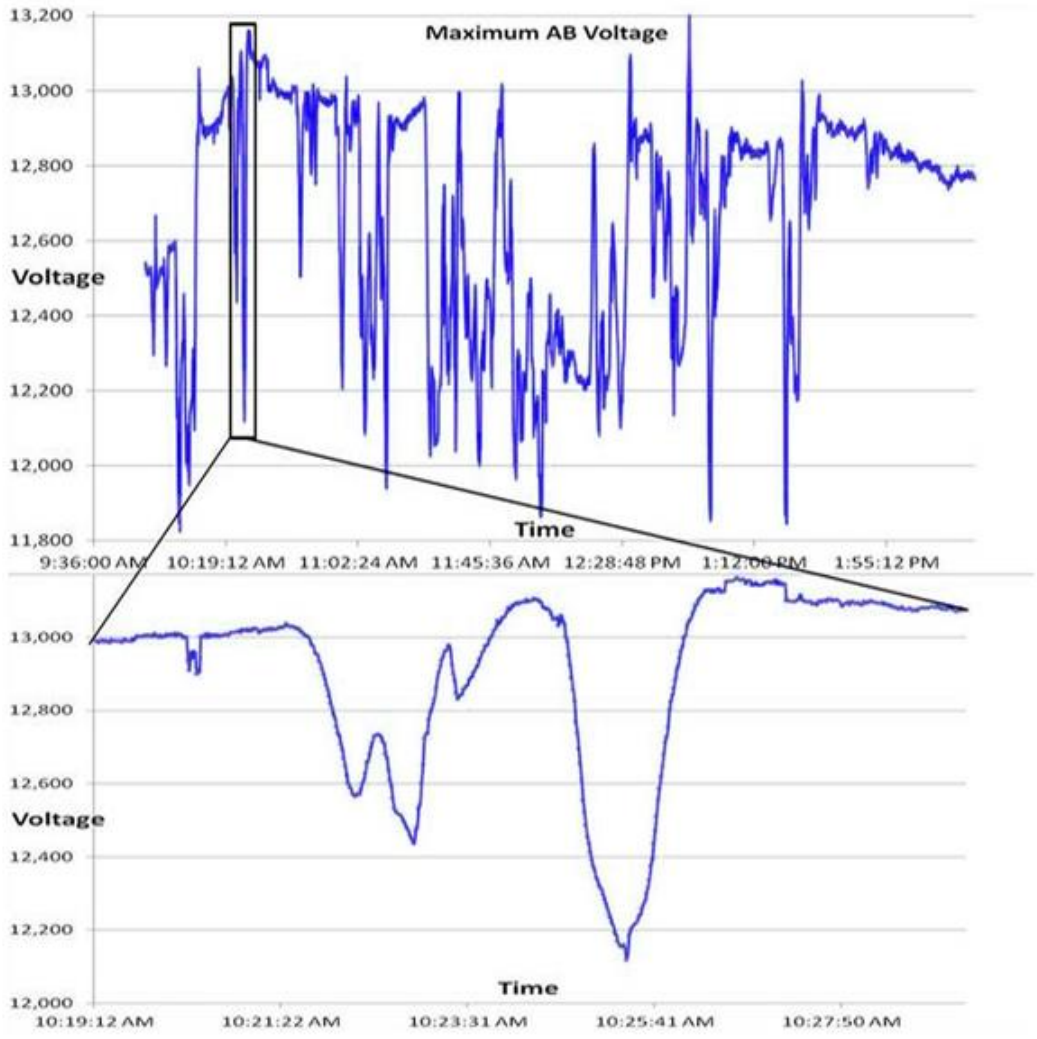
Examples of DER Impacts – Voltage Fluctuation (1)

- DER power fluctuations (e.g., from PV-DG) lead to voltage fluctuations on distribution systems
- Voltage fluctuations increase operation of voltage regulation and control equipment (Load Tap Changers – LTC, line voltage regulators, voltage/reactive power-controlled capacitor banks)
  - Voltage goes beyond permissible range
  - Equipment tries to re-adjust voltage
  - Frequent voltage changes increase number of operations of equipment
- Interactions can impact equipment lifecycle and increase dv/dt (flicker)



Source: https://www.powerelectronics.com/technologies/power-electronics-systems/article/21860668/solar-power-impacts-power-electronics-in-the-smart-grid

Examples of DER Impacts – Voltage Fluctuation (2)



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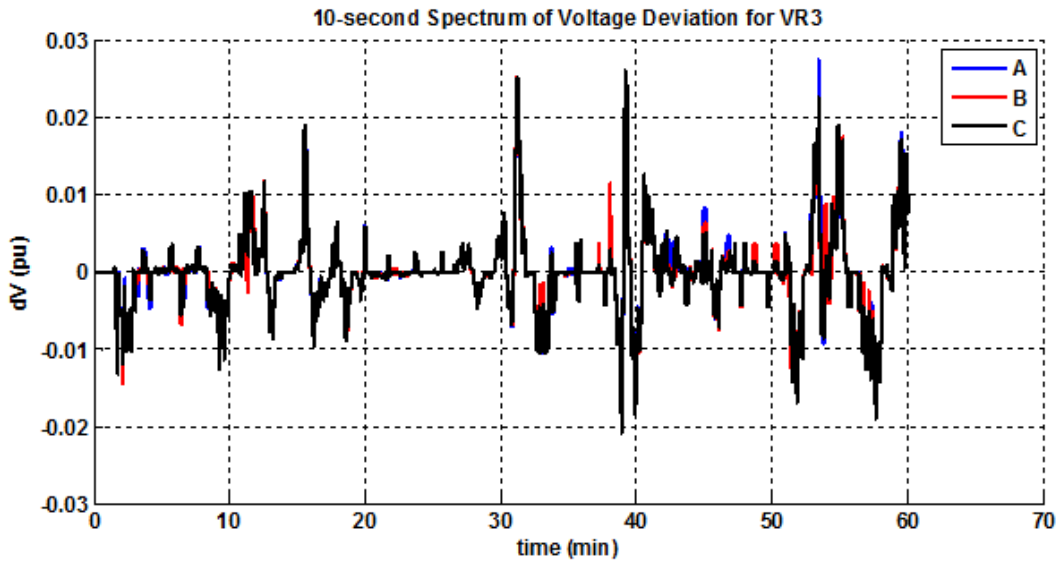
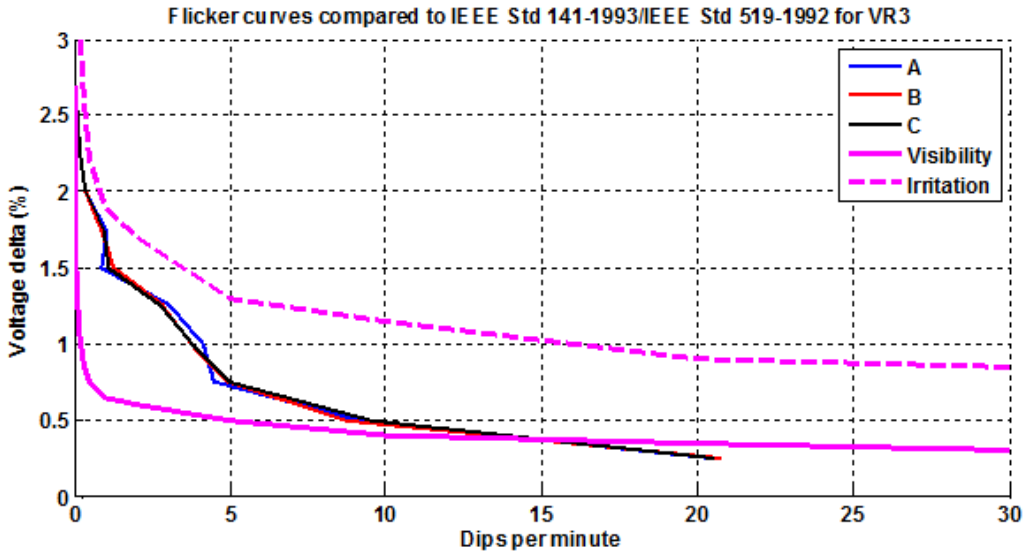
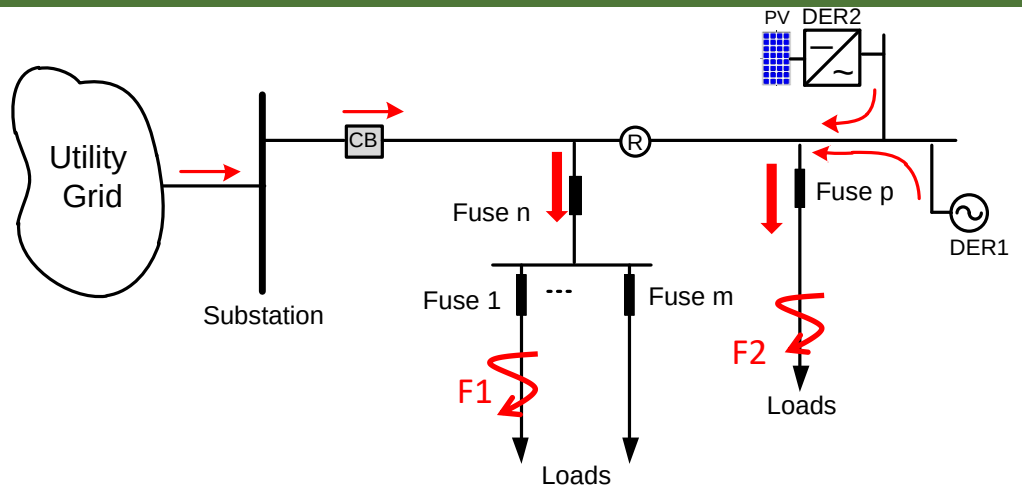
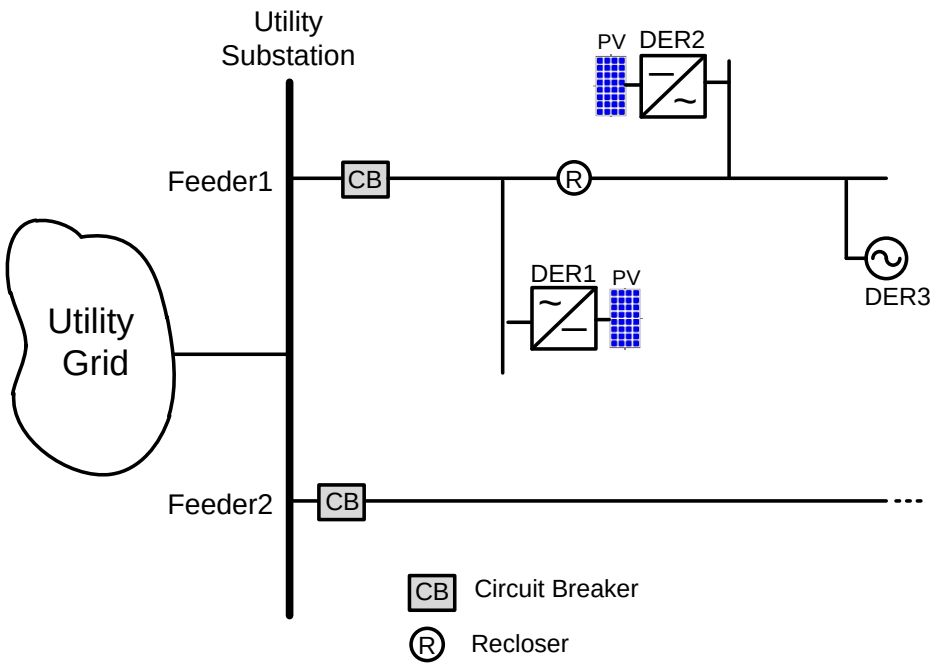




Examples of DER Impacts – Interaction with Protection Systems (1)

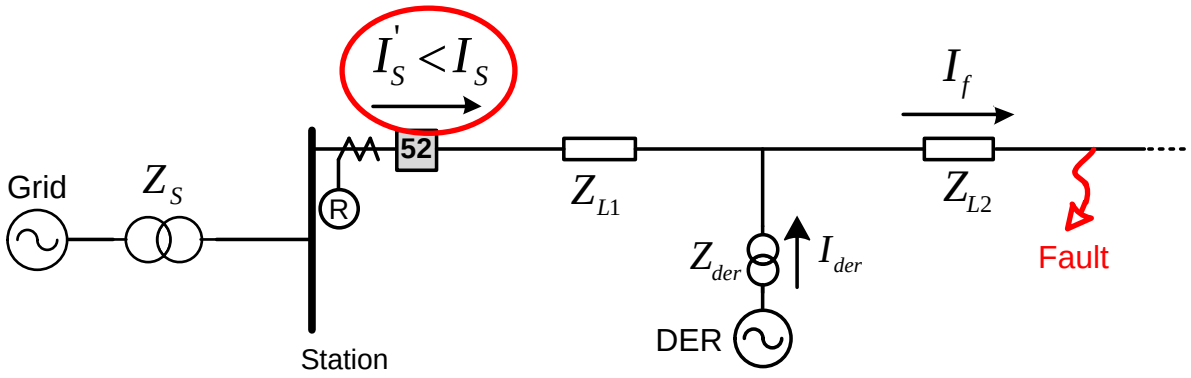
- Changes in fault current levels
  - Locally, DER fault current contribution may have an adverse impact on “fuse saving” overcurrent protection schemes used in distribution systems. During a temporary fault, DER fault current contribution may melt fuses before first fast trip operation of reclosers
  - Globally, there may be a decrease in fault current levels, because of power electronic-based DERs replacing synchronous machines
- Sympathetic tripping:
  - When DER penetration level on a feeder is high, faults on neighbor feeders may trip circuit breaker. This can be solved by using directional relays or selecting DER interconnection transformer configurations that limit fault current contribution





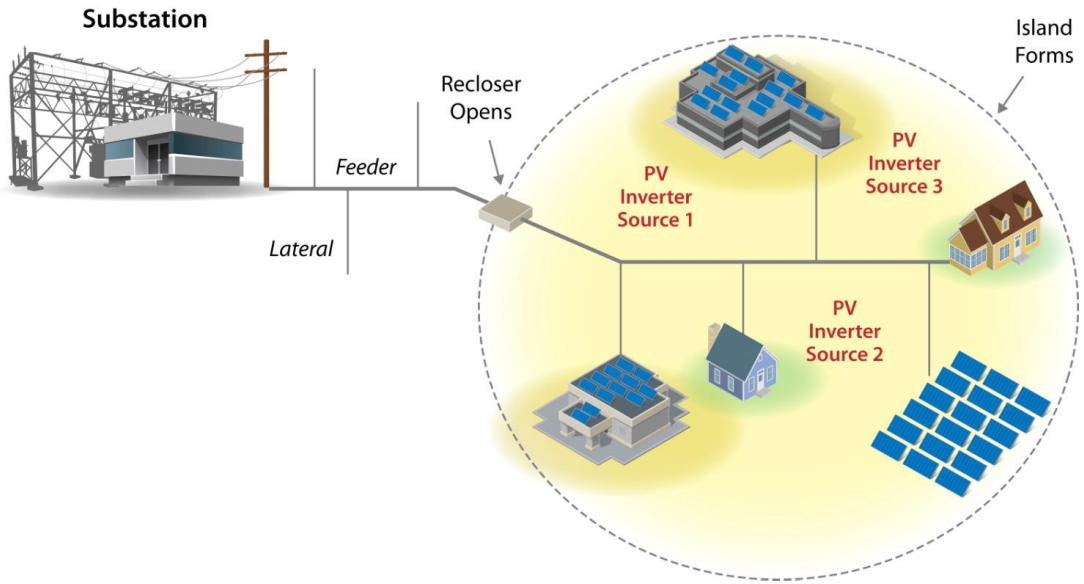
Examples of DER Impacts – Interaction with Protection Systems (2)

- Reach modification or “protection blinding” (overcurrent protection)
  - Overcurrent protection schemes are very sensitive during peak loading conditions (long reach), not too much additional current is required to trip protective devices, even faults located far from protective devices (low fault current) can be detected.
  - However, DER interconnection may modify the reach of overcurrent protection devices, and faults located far from protective devices may not draw enough fault current to be detected



Unintentional/Accidental Islanding

- Islanding is a situation were one or more DERs and part of the distribution system operate separated from the rest of the grid
- This generally represents an issue for utilities since it may lead to public and utility personnel safety hazards, damage to utility and customer equipment due to out-of-synchronism reconnection and temporary overvoltage (TOV)
- Selection of DER interconnection transformer configuration involves a trade-off between fault current contribution and TOV
- Anti-islanding protection is required, other alternatives involve using grounding transformers and Direct Transfer Trip (DTT)



Source: Results from the DOE-CPUC High Penetration Solar Forum
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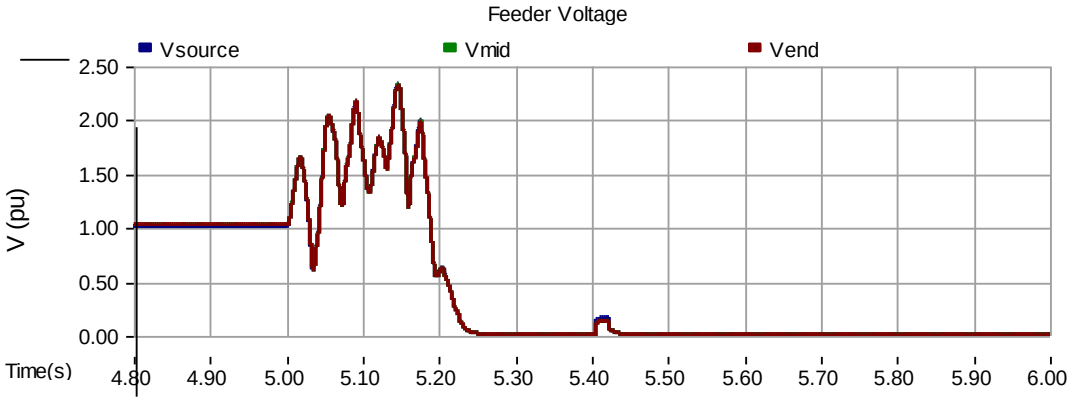


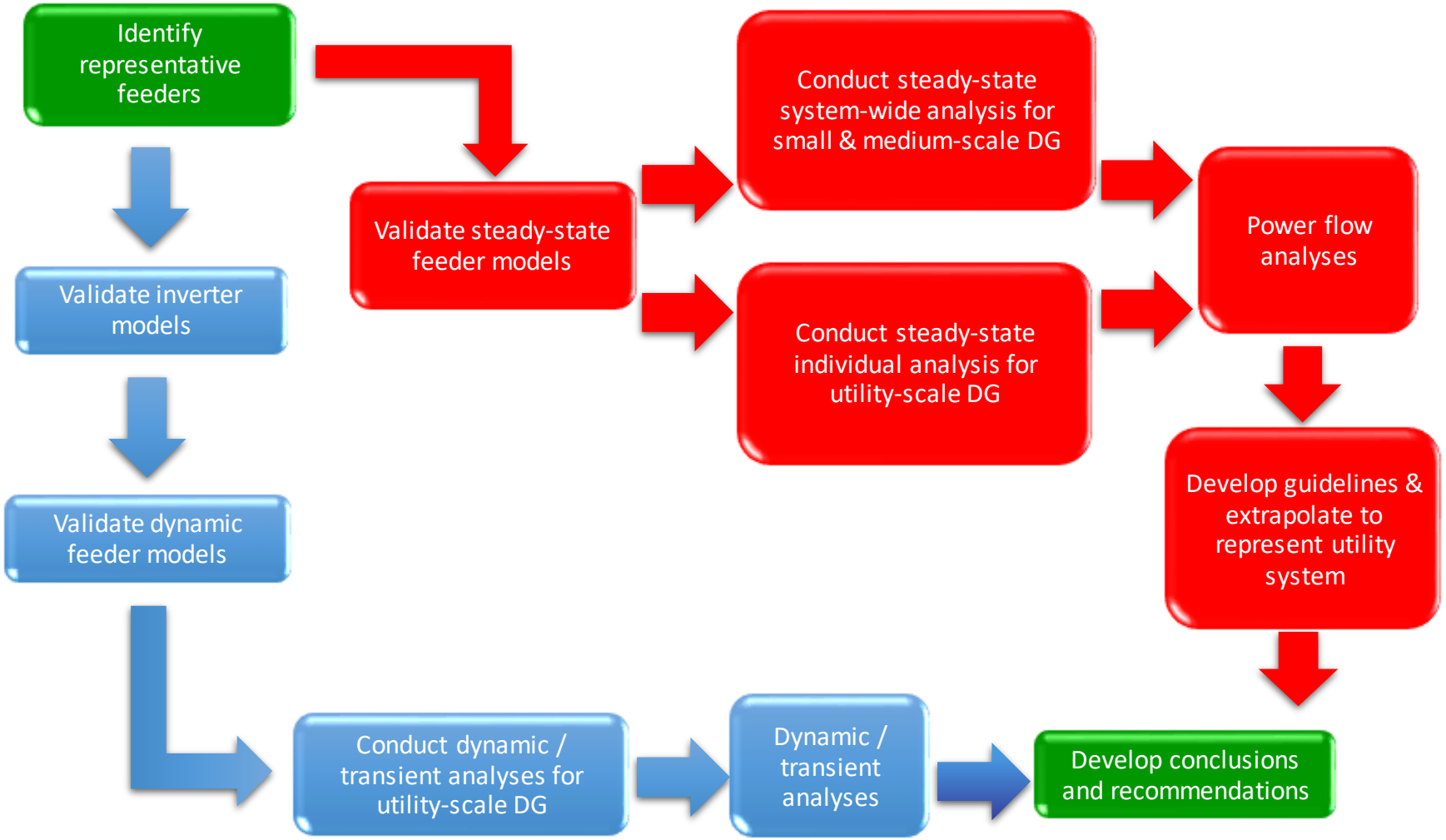
DER Impact/Interconnection Studies

- **Type of Studies**
  - Screening
  - Steady state analyses
  - Dynamic/transient analyses
  - Overcurrent and overvoltage protection
  - Special studies: harmonic, stability, etc.
  - Hardware-in-the-loop testing in laboratory setting (RTDS)
  - Advanced applications (energy storage, microgrids)
- **Typical Scope**
  - Identify local and/or system-wide impacts of DER on the power distribution grid
  - Develop guidelines regarding expected impacts as a function of DER penetration level
  - Determine potential mitigation measures for any problems discovered in the study
  - Development or update of DER interconnection standards

DER Simulations & Uncertainties

- Impacts and benefits can only be studied through simulations, it is necessary to use both steady state software (CYME, Synergi, SINCAL, Power Factory, etc.), and specialized simulation software such as PSCAD, EMTP, etc. to identify impacts and evaluate effectiveness of mitigation measures
- Different analysis are needed depending on DER type
  - Utility-scale DER (interconnection studies): utilities know where they will be installed (e.g., on industrial feeders, on rooftops of large warehouses, etc.), studies are more deterministic, and impacts are localized
  - Small and medium-scale DER (planning studies): they are being installed on residential and commercial feeders, studies are non-deterministic (need to study uncertainties and different penetration scenarios) and impacts are spread along the system. In order to model and handle uncertainties we need to perform thousands of simulations (statistical scenario modeling)

Example of Methodology for DER Impact Analysis

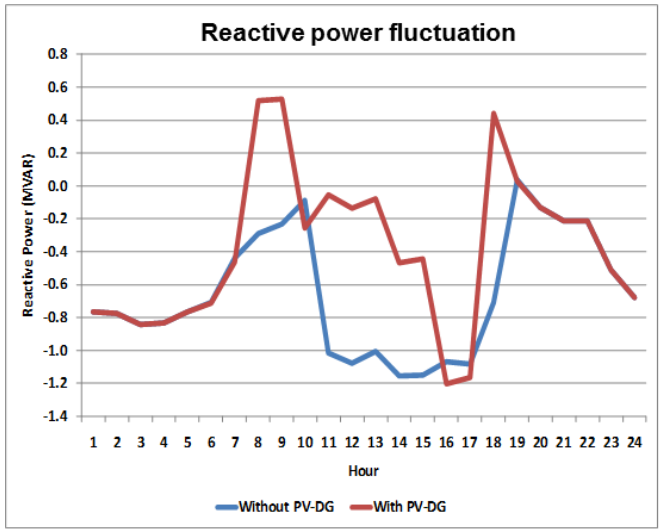


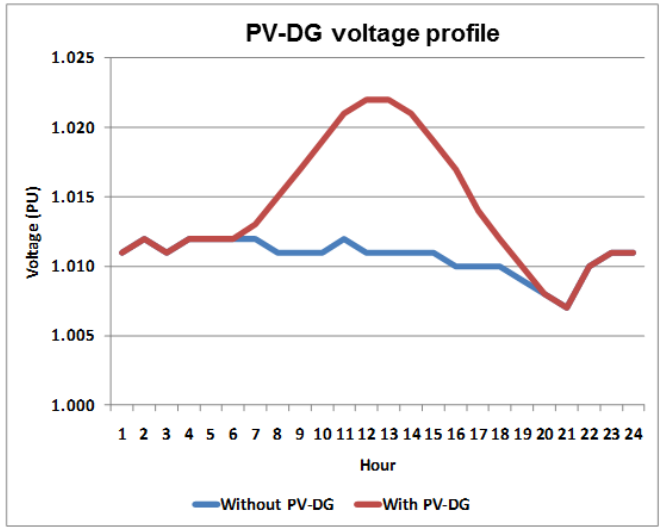
Steady State Analysis

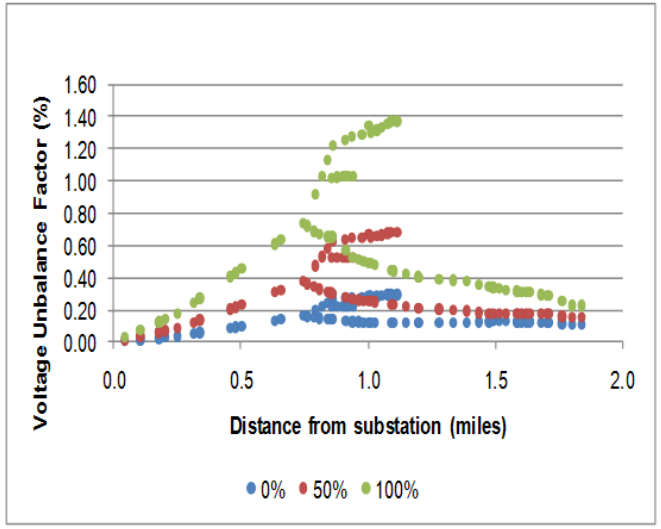
- **Analysis of different DER penetration scenarios**
- **Inputs**
  - Typical DER output profiles
  - DER capacity (kW, kWh)
  - Feeder models (distribution analysis software)
  - Hourly/minute feeder load curves and status of voltage control equipment (voltage regulators and capacitor banks) for scenarios of interest, e.g., annual peak and off-peak conditions

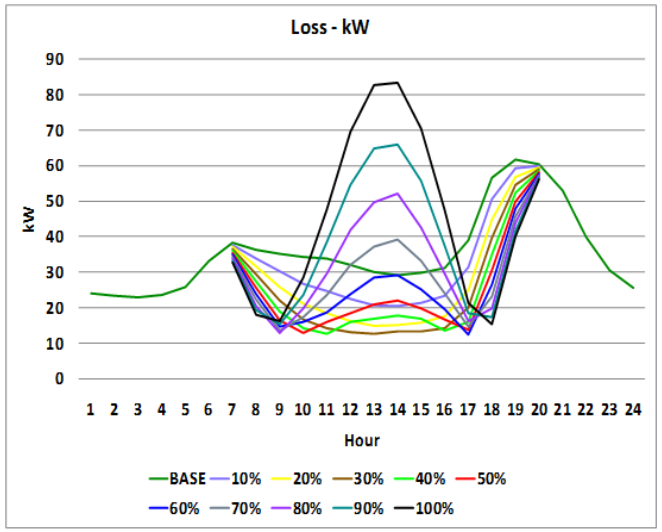
- **Multi-hour (time series) analysis of base case and DER cases**
  - Considers different feeder loading and DER output conditions/characteristics
  - Simulations can be conducted either for worst case scenarios (e.g., combination of minimum load and maximum DER output) or for 8760 hrs.
  - Results include all variables of interest:
    - Feeder voltages
    - Feeder loading
    - Active and reactive power flows
    - Status and number of operations of capacitor banks, LTCs and line voltage regulators
    - Power losses

Steady State Analyses – Results







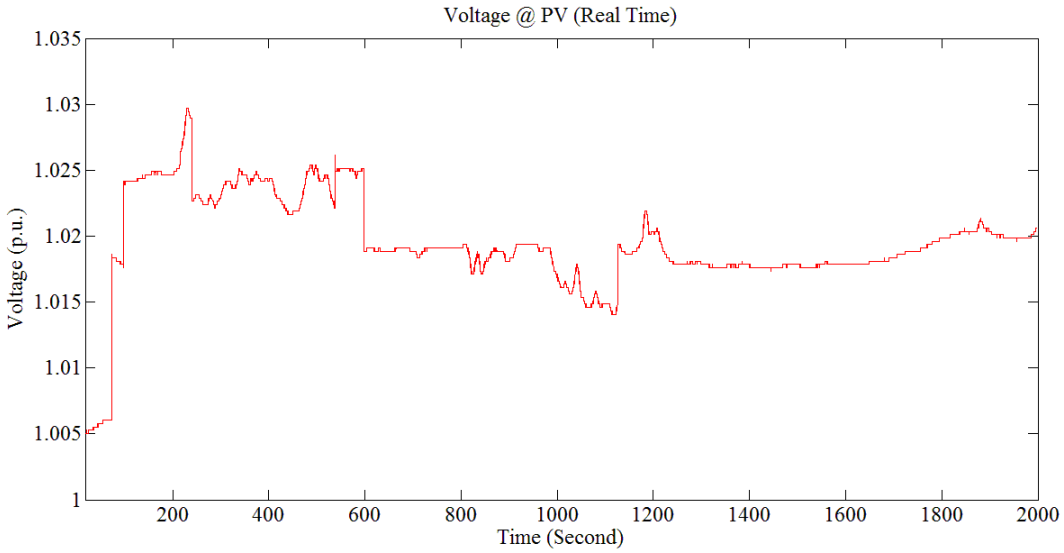


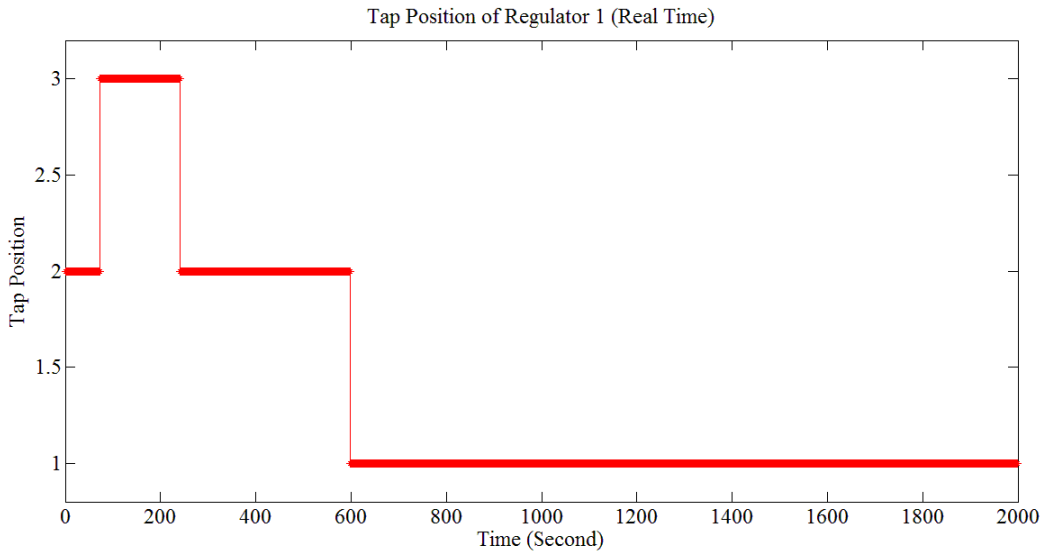
Dynamic Analysis

- **Justification**
  - Results from dynamic simulations are of critical importance for ensuring the reliable operation of feeders with utility scale DER
  - **Dynamic/transient impacts of DER cannot be identified using conventional distribution analysis software, more detailed modeling and simulations are necessary**
  - Dynamic and steady state studies are complementary. Dynamic analyses help define criteria and standard for integration and operation of DER in power distribution systems

- **Objectives**
  - Study impact of DER output variation (including intermittency) on distribution system
  - Study impact of distribution system transients and switching phenomena in DG units (including islanding)
  - Focuses on worst case scenarios (e.g., combination of minimum load and maximum DER output)
  - Results include all variables of interest:
    - Feeder voltages (including TOV)
    - Feeder loading
    - Active and reactive power flows
    - Status and number of operations of capacitor banks, LTCs and line voltage regulators

Dynamic Analysis – Results

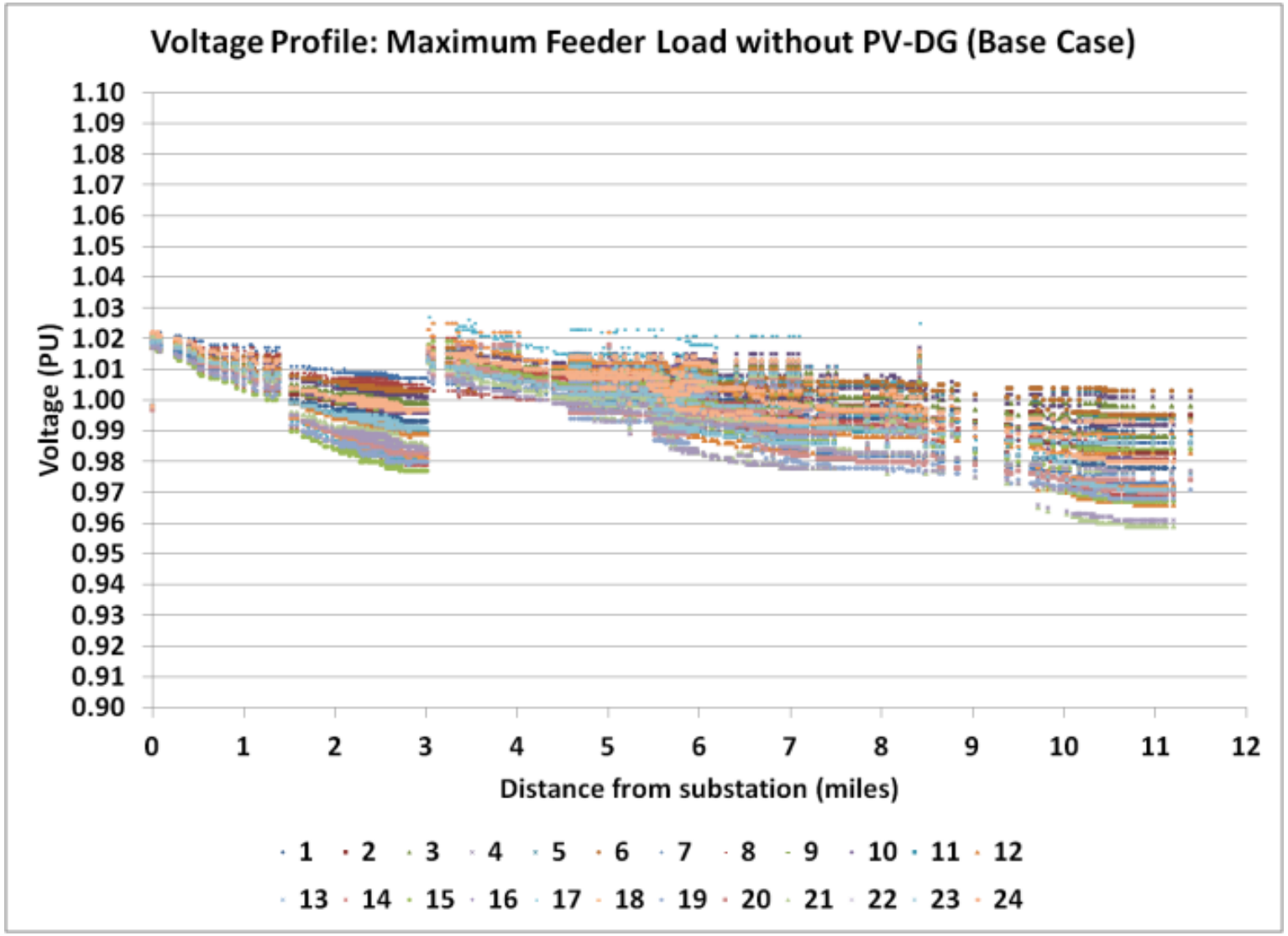




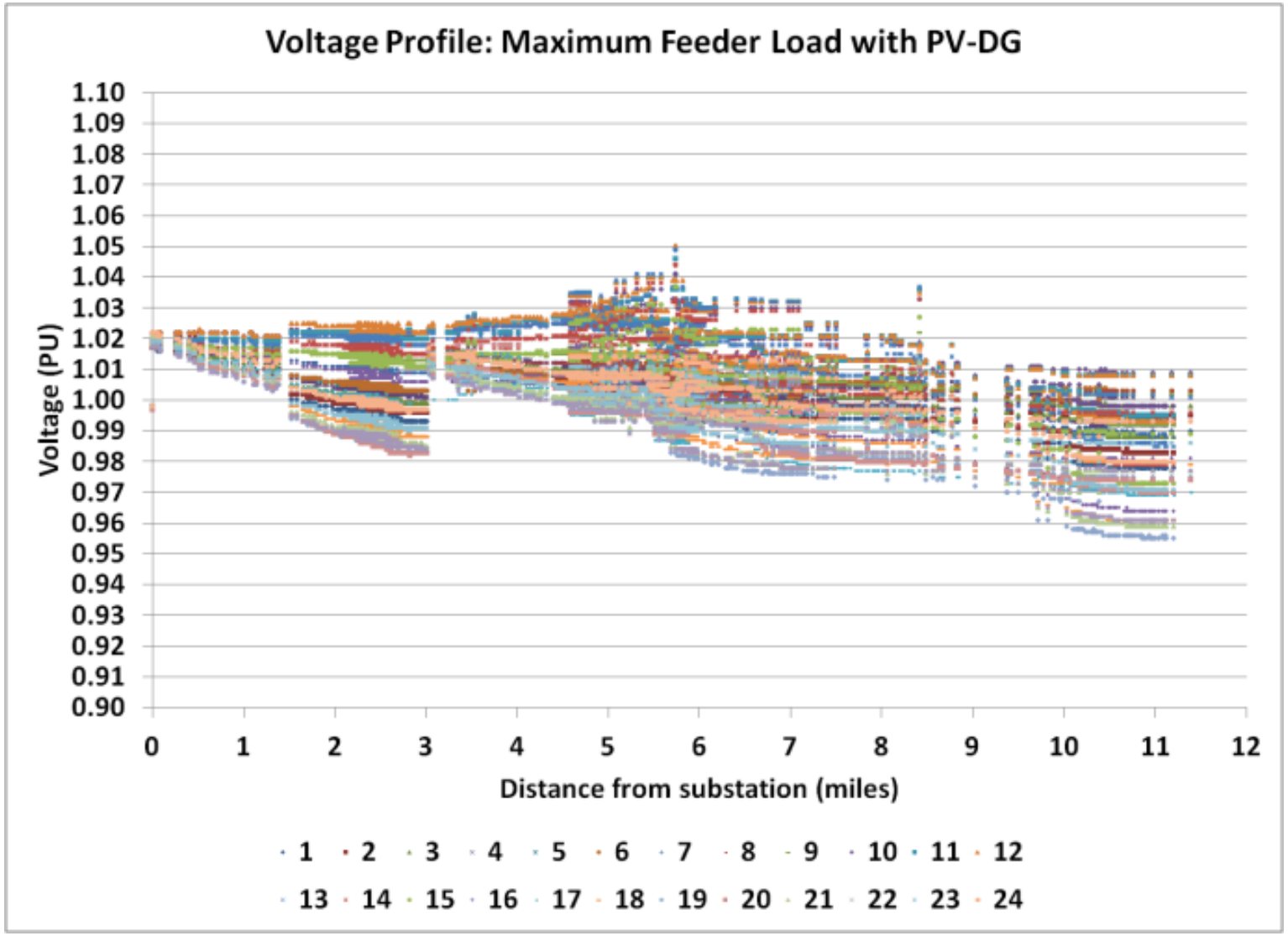
Mitigation Measures

- The objective of the mitigation measures is to reduce or minimize impacts caused by the interconnection of PV-DG to distribution systems
- Common mitigation measures include:
  - Operating PV-DG smart inverters to absorb reactive power
  - Modifying operation mode of line voltage regulators (e.g., to cogeneration or bidirectional modes)
  - Relocating capacitor banks and modifying settings of capacitor banks (e.g., switching off fixed capacitor banks and modifying switch off and switch on settings of voltage-controlled banks)
  - Modifying reference voltage of Load Tap Changers (LTCs) and compensating current offset on Line Drop Compensation (LDC) applications
  - Using express feeders for interconnection of large utility-scale PV-DG facilities
- More advanced mitigation measures may include:
  - Using Distributed Energy Storage (DES)
  - Using Static Synchronous Compensator (D-STATCOM)
  - Implementing a dynamic VAR compensation scheme via smart PV-DG inverters
  - Increasing express feeder design voltage (e.g., using 25 kV instead of 13.2 kV)

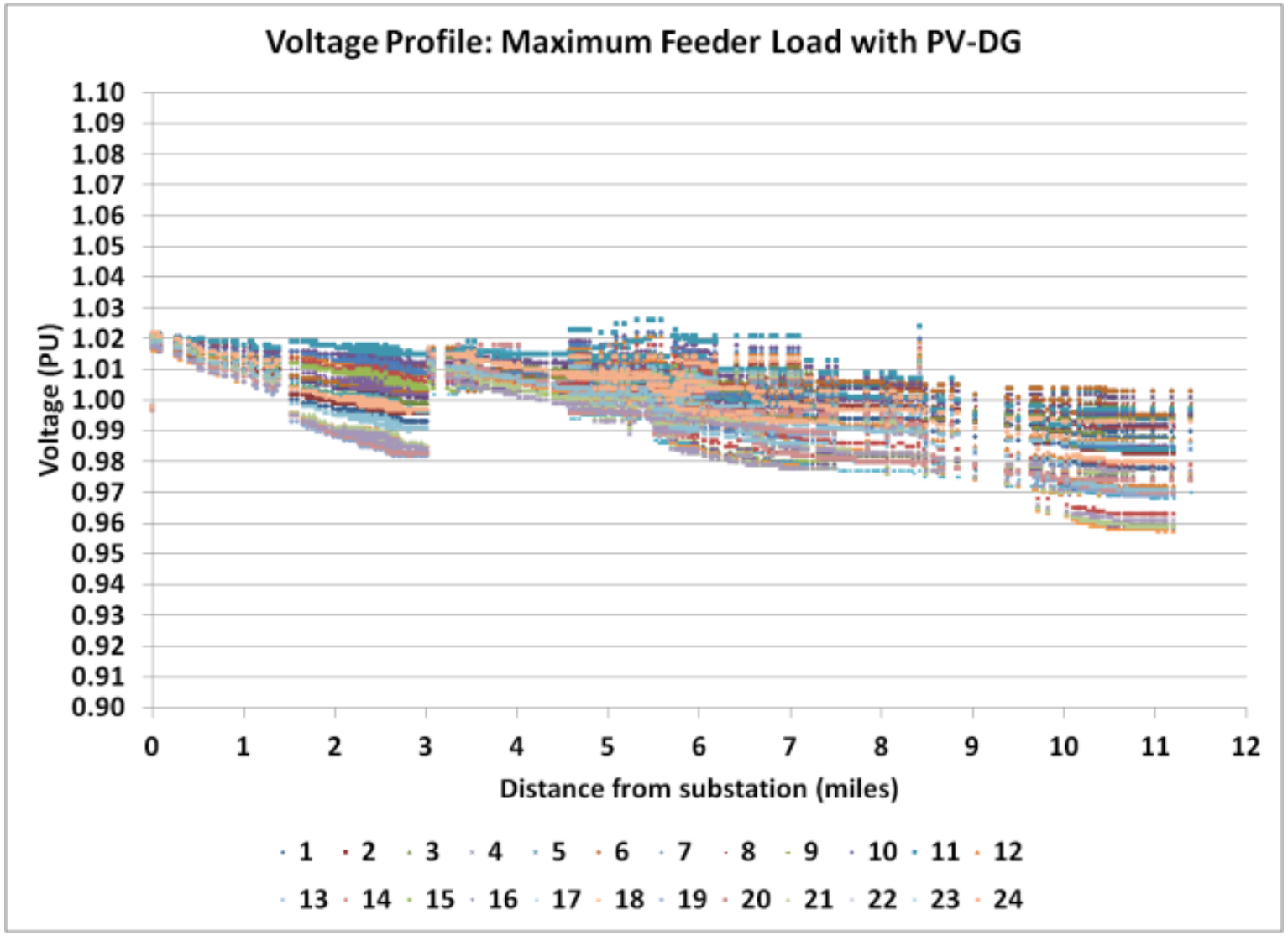
Mitigation measures (1)



Mitigation measures (2)

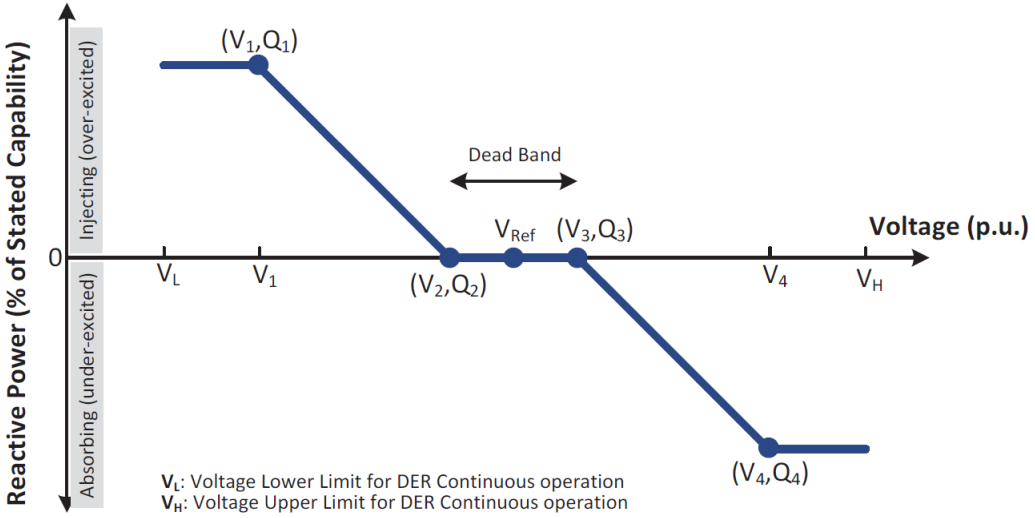


Mitigation measures (3)

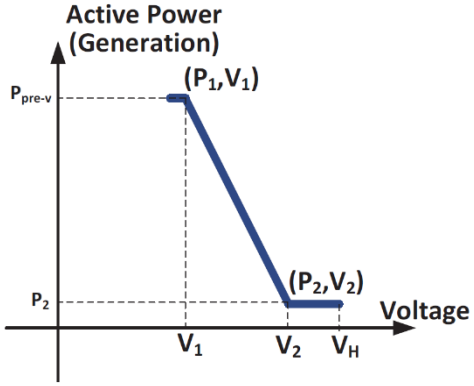


Examples of Advanced Inverter Functions in IEEE 1547-2018

Volt-VAR Function (Voltage Control)



Volt-Watt Function (Output Curtailment)

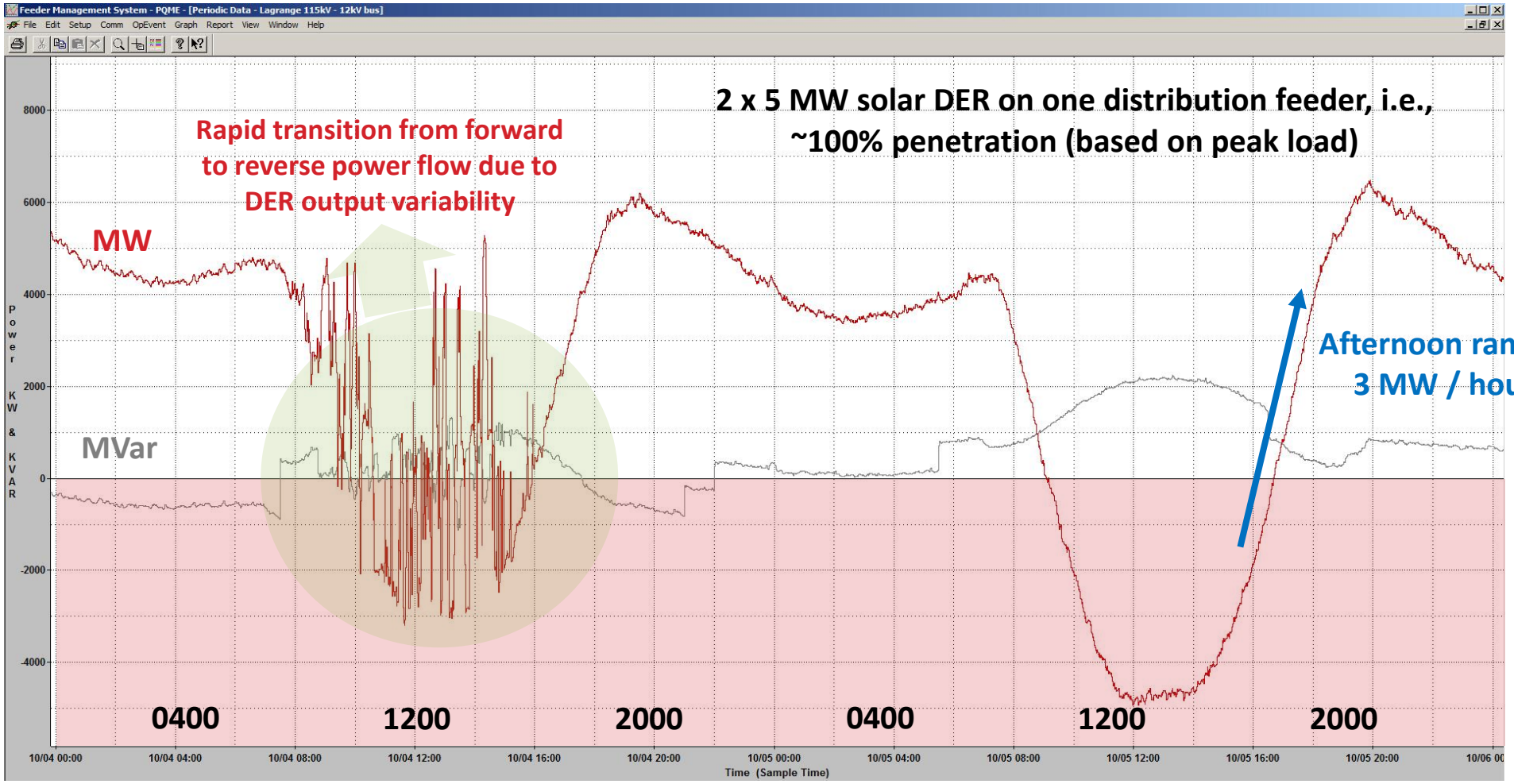


What is the industry doing? (1)

- DG proliferation is not a temporary trend, it is a business paradigm shift that is here to stay. Utilities are addressing this challenge from three perspectives
- **Short-term (focus on large DG plants):**
  - Utilities are conducting detailed DG integration studies for large DG plants with the objective of identifying impacts in the distribution system and proposing solutions to ensure seamless integration.
  - This approach is deterministic in nature (it is well-known where and when large DG plants will be interconnected)
  - It solves problems in the short-term but can be criticized as being equivalent to applying "patches" or short-term fixes to the system

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



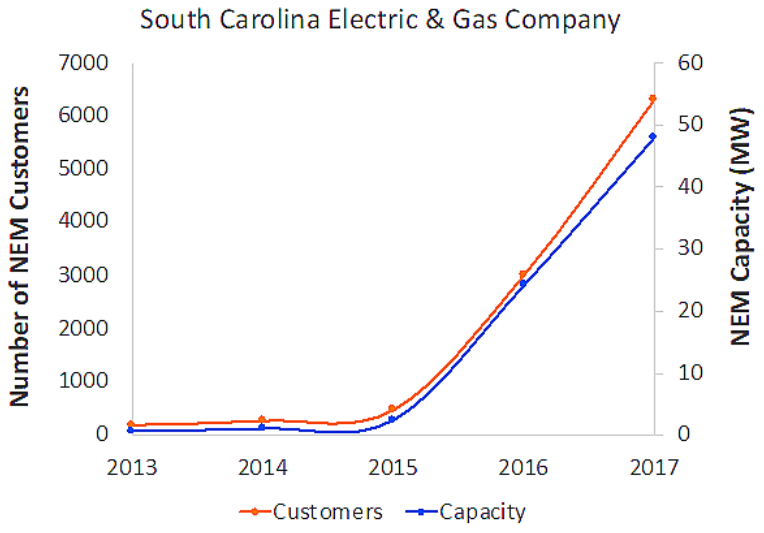
Reverse power flow through substation transformer into 115 kV system

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

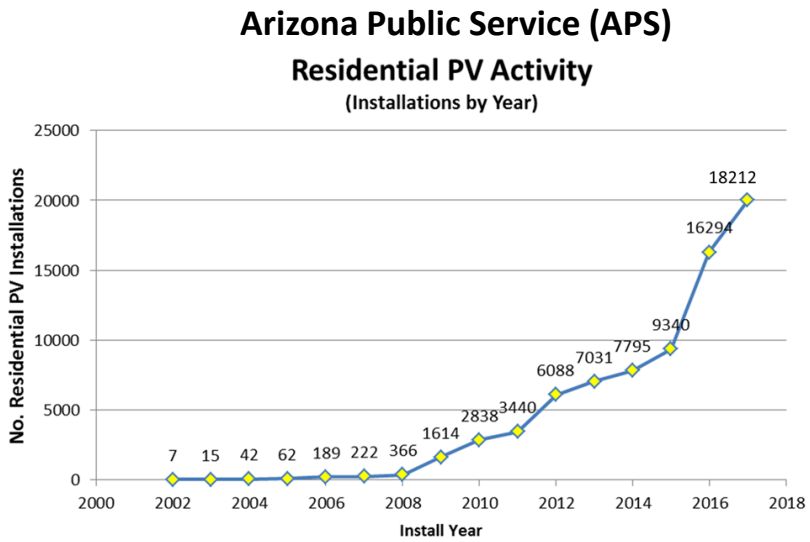
Source: J. Gajda, Creating sustainable and scalable interconnection requirements for high penetration of utility-scale DER on the distribution system, 2017 IEEE PES GM, Chicago, IL

What is the industry doing? (2)

- **Mid-term (focus on large and residential DG plants):**
  - Besides implementing short-term solutions, utilities are also analyzing a variety of proliferation scenarios for residential DG plants
  - This approach is stochastic, i.e., it is not known with certainty when and where residential DG plants will be interconnected
  - Although an individual residential DG plant may not impact the distribution system, the cumulative effect of hundreds or thousands of residential DG plants will certainly affect distribution system planning and operations
  - This allows utilities estimate maximum limits of DG proliferation, identify system upgrades, and plan respective implementation with enough anticipation to account for lead times (e.g., build new feeders and substations)

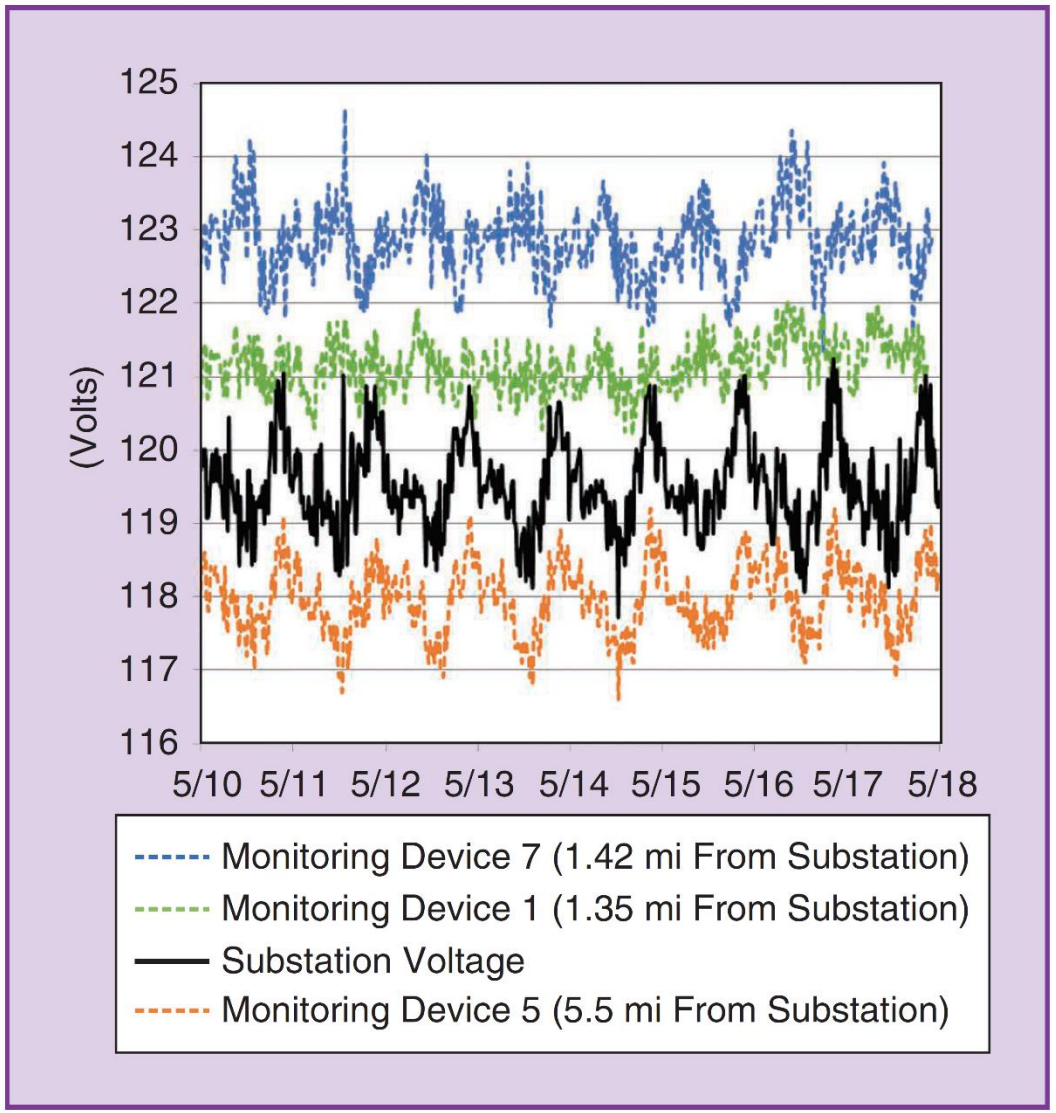


Source: SCE&G

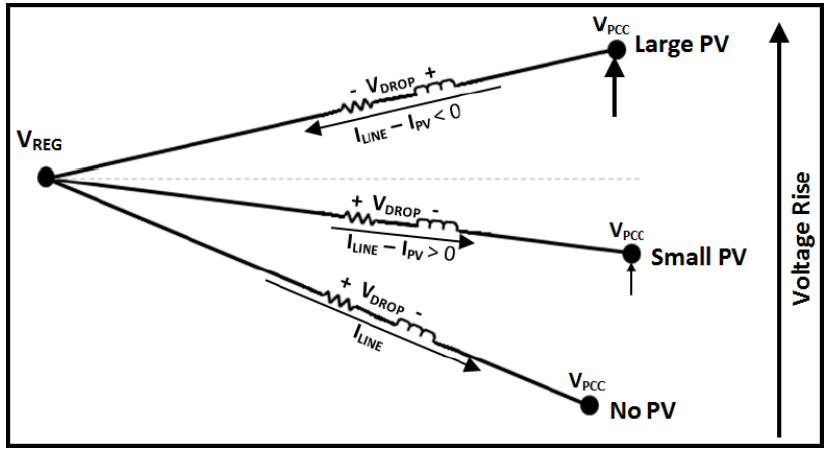


Source: APS

Impacts of High Penetration of Behind-the-Meter and Utility-Scale PV DG



Source: M. Asano, Hawai'i's Grid Architecture for High Renewables, IEEE Power and Energy Magazine, Volume 17, Issue 5, Sept.-Oct.-2019

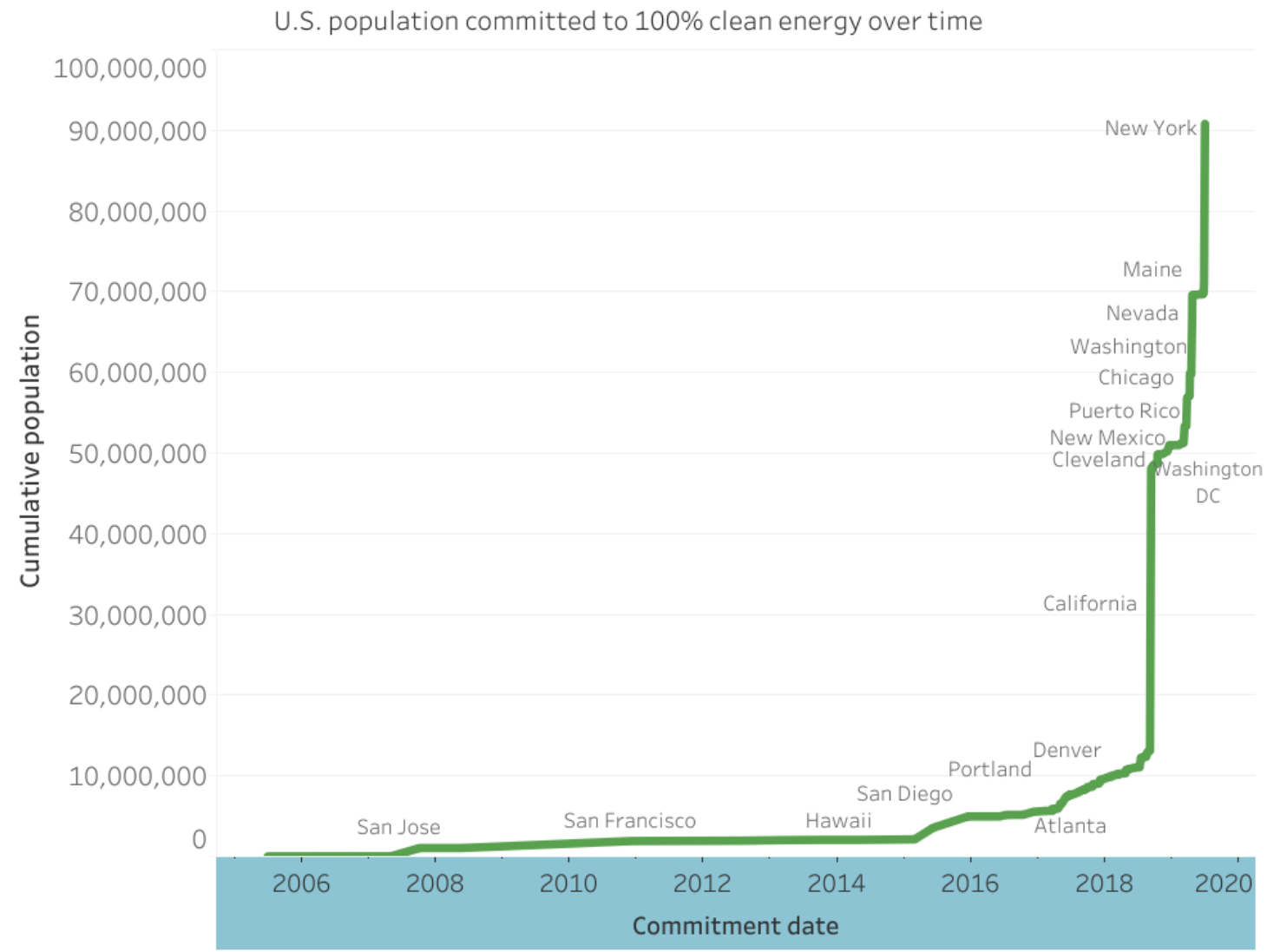


Source: https://www.esig.energy/wiki-main-page/time-series-power-flow-analysis-for-distribution-connected-pv-generation/

What is the industry doing? (3)

- **Long-term (focus on business processes, infrastructure and information systems):**
  - Utilities are updating applicable business processes and practices (e.g., engineering standards, annual planning cycle, load forecasting) to consider DG integration as an intrinsic component of their regular activities
  - Utilities are upgrading distribution assets, information technology, communications, and enterprise system infrastructures to gather and process the data required to operate modern distribution systems with large penetration levels of DG (e.g., sensor, DA and PMU deployment)
  - Utilities are exploring new concepts to fully take advantage of the potential benefits of DG proliferation (e.g., microgrids)
  - Utilities are participating in industry activities to share experiences, and are training their engineers to analyze, plan and operate modern and future distribution systems

U.S. Population Living in States or Cities Committed to 100% Clean Energy

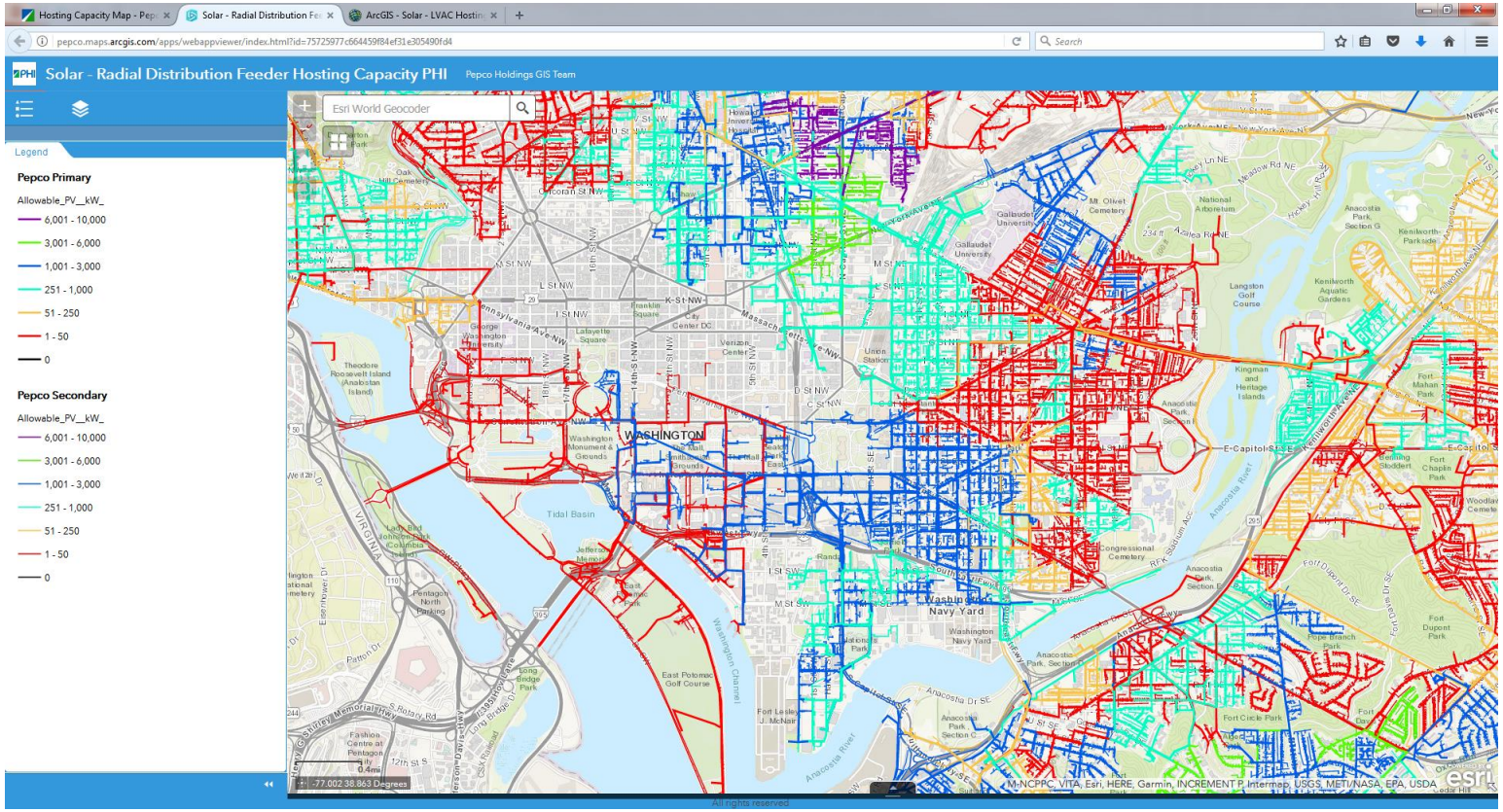


Data sourced using 2016 census. Incremental population for 100% states is reduced by the cities previously committed to 100% clean energy in those states, so as not to double count.

Source: https://www.sierraclub.org/articles/2019/08/100-clean-energy-movement-keeps-moving-forward

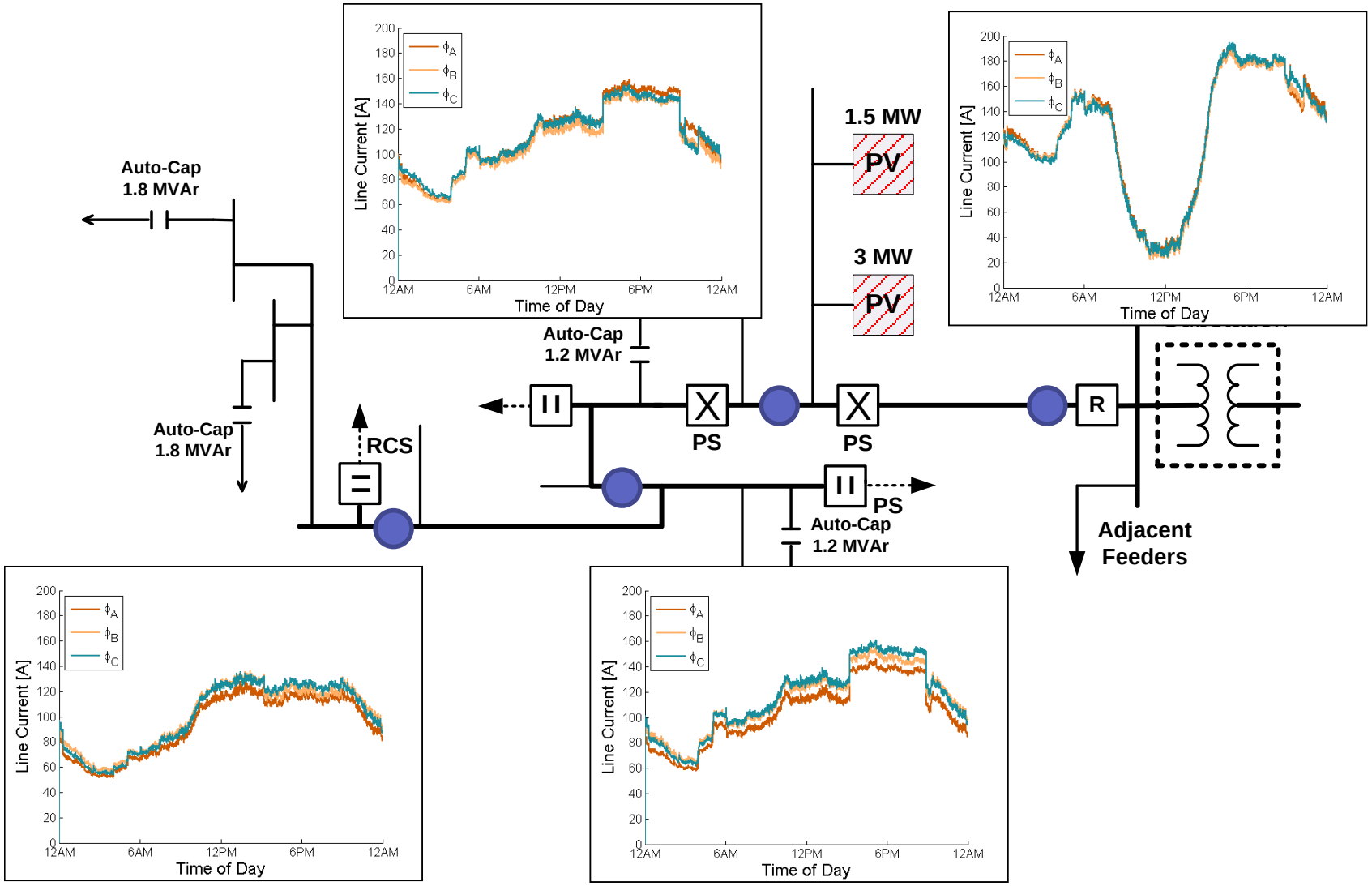
Examples of Leading Industry Practices

- DER Interconnection Process
- Smart Inverter Standards
- DER Monitoring and Control
- DER Management Systems (DERMS)
- Grid Analytics
- Advanced Distribution Planning
- DER Hosting Capacity
- Spatial Load and DER Forecasting
- Time Series Analyses (8760 hr.)
- Value of DER
- Non-Wires Alternatives (NWA)
- Microgrids



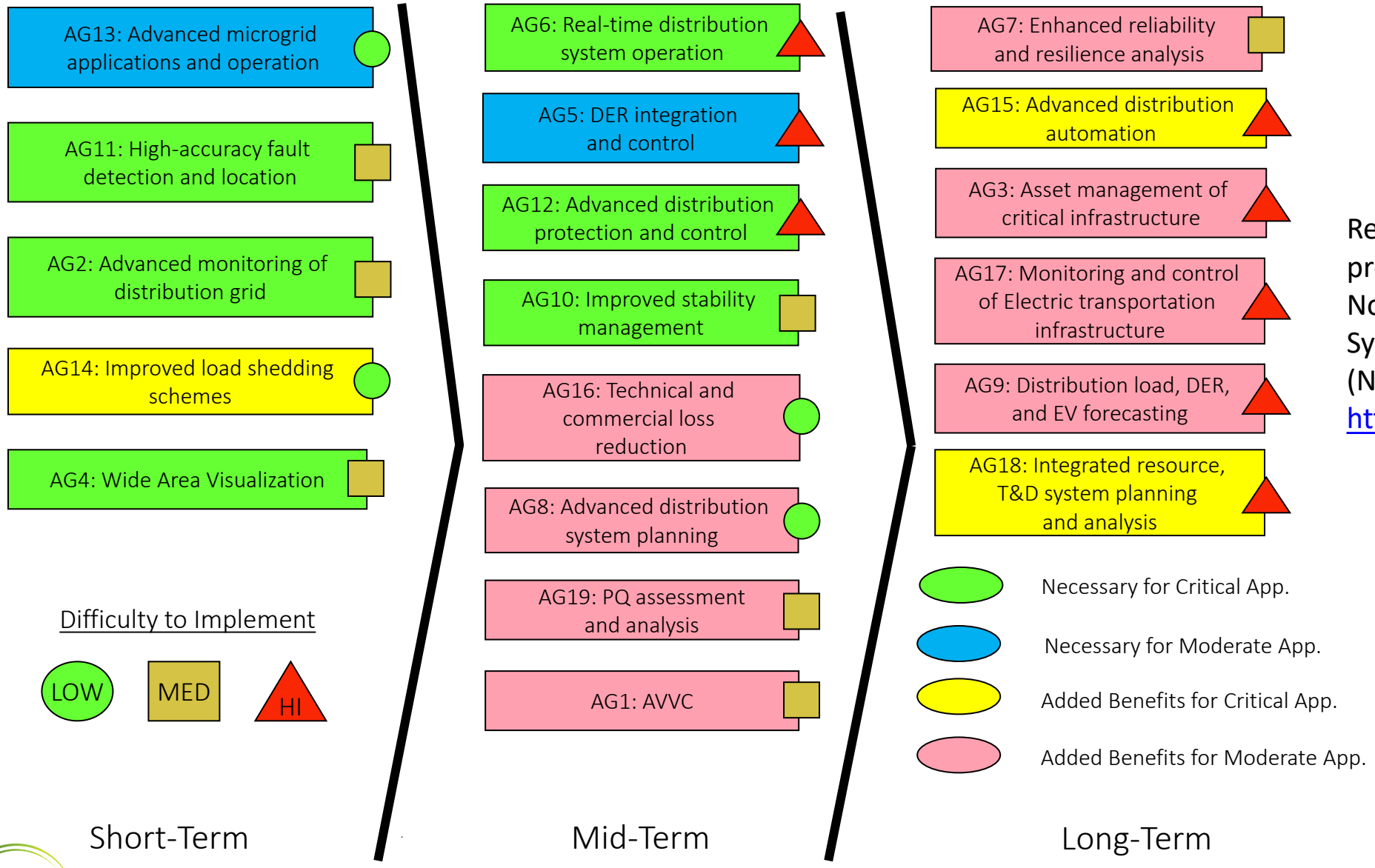
Source: https://www.pepco.com/SmartEnergy/MyGreenPowerConnection/Pages/HostingCapacityMap.aspx

High Resolution PV Monitoring



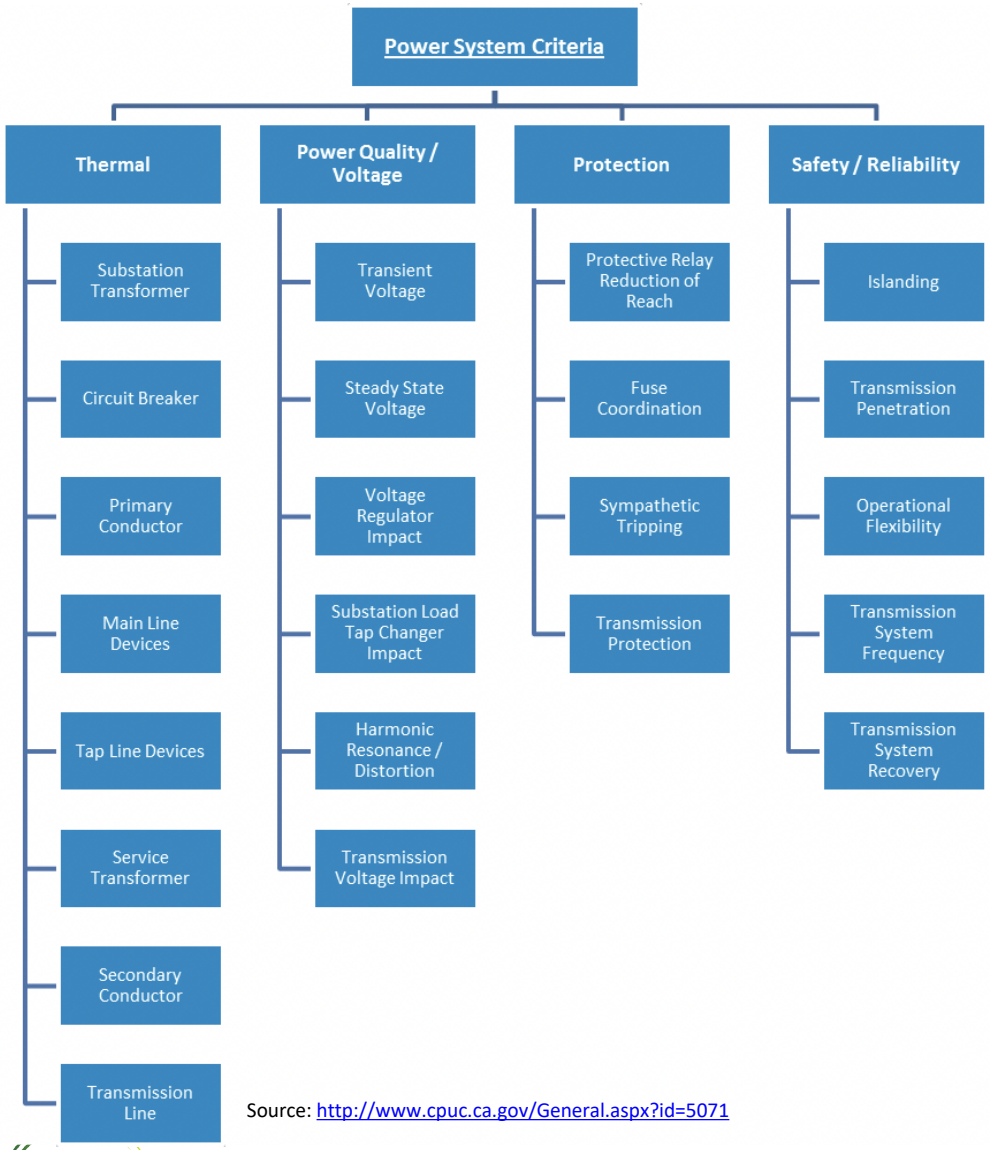
Source: NREL

Distribution Synchronized Measurement Technologies – Industry Application Roadmap

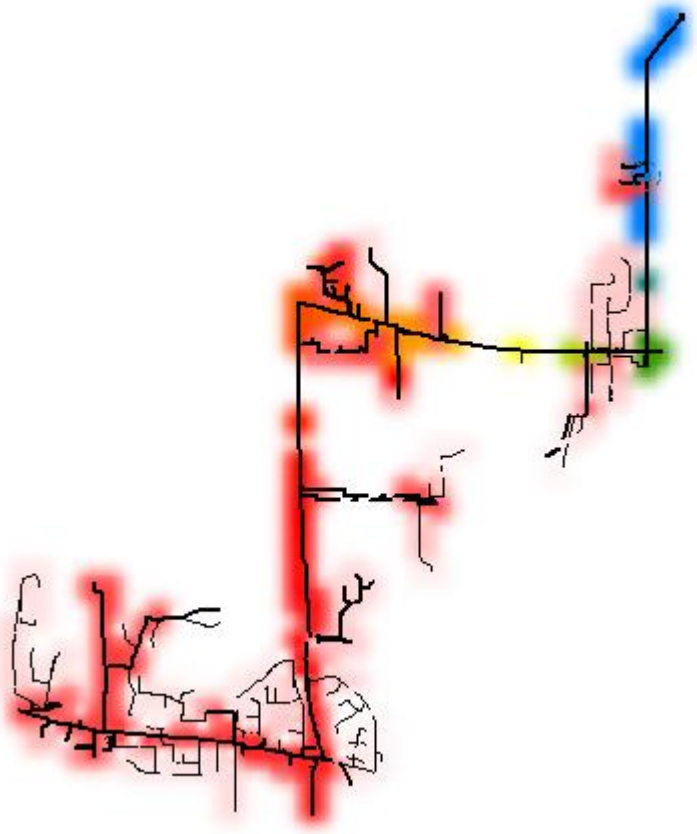


Report and companion presentation available at North American Synchrophasor Initiative (NASPI) website: https://naspi.org/node/934

Hosting Capacity Analysis



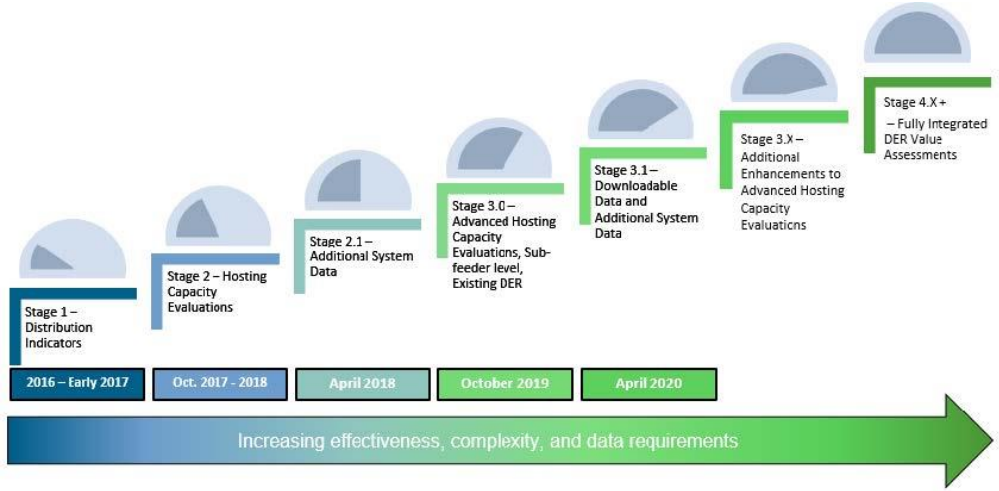
Source: http://www.cpuc.ca.gov/General.aspx?id=5071



Hosting Capacity <1000 kW
1000 kW<Hosting Capacity<2000 kW
2000 kW<Hosting Capacity<5000 kW
5000 kW<Hosting Capacity<10000 kW

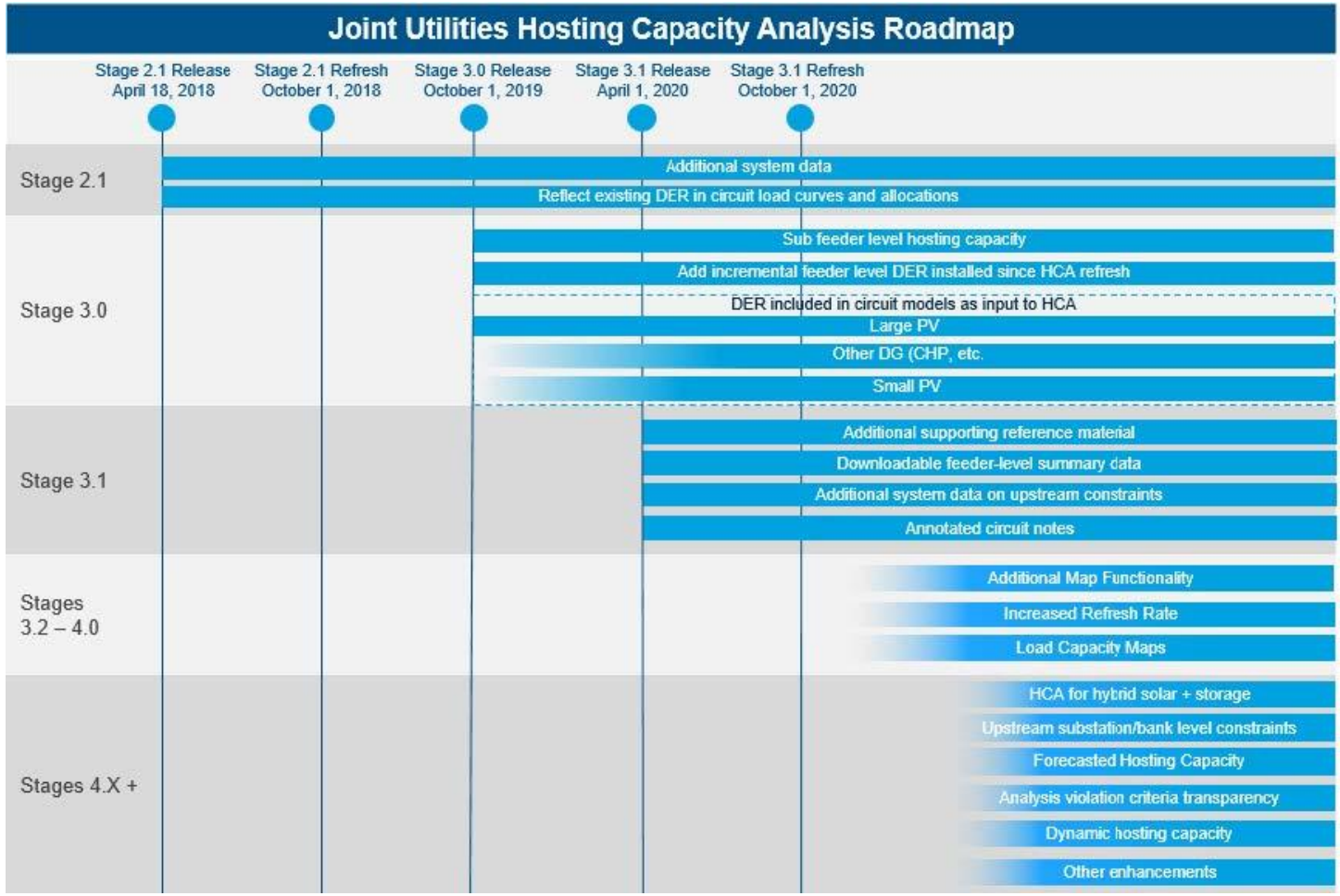
- Hosting capacity components of interest vary by utility
- Trade-off between several factors:
  - Data and model availability (e.g., load data, AMI, Synergi model, etc.)
  - Expected accuracy (e.g., data integrity, issues, spatial and temporal resolution, etc.)
  - Complexity (e.g., data and result requirements, etc.)
  - Cost (e.g., system size, level of effort, etc.)
- Most utilities evaluate hosting capacity based on thermal limits of lines and equipment and steady state voltage limits
- Results are published and updated periodically (e.g., annually biannually, monthly)

Example: DSIP Hosting Capacity Roadmap (New York)



New York Joint Utilities roadmap includes important improvements to hosting capacity analysis:

- Load capacity maps
- Hosting capacity analysis for hybrid solar + energy storage
- Calculating dynamic hosting capacity



Source: ConEd 2020 DSIP

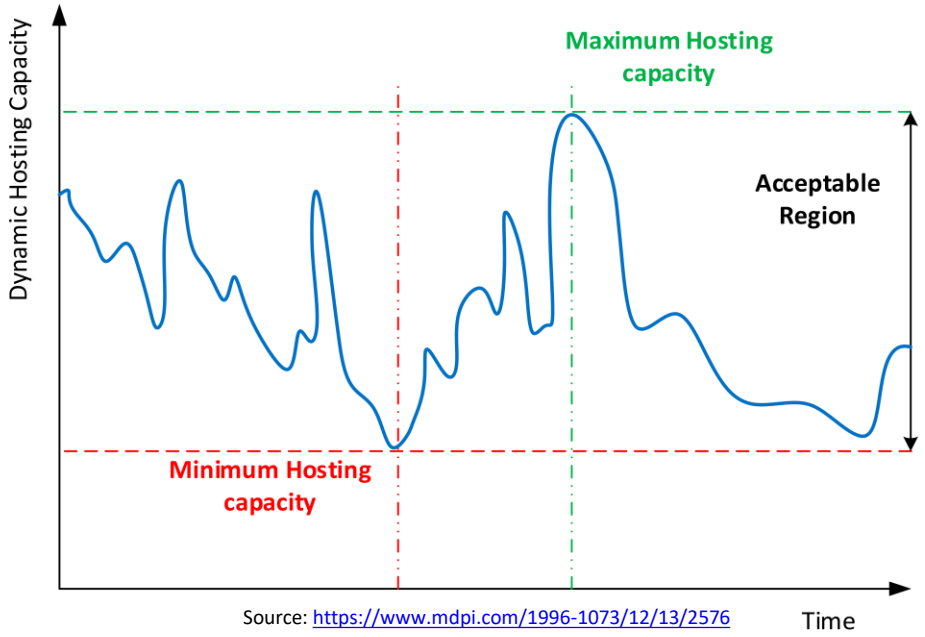
Dynamic Hosting Capacity

- Snapshot Hosting Capacity
  - Traditional firm interconnection approach
  - Fit and forget
  - Analysis uses worst-case static snapshots
  - Conservative limits on the changes in device operations by using proxies for solar variability
  - Example: Hosting capacity maps, such as those used in California

- Uncoordinated Dynamic Hosting Capacity
  - Interconnection using autonomous advanced inverter functionalities without communication to the utility
  - Time-series analysis and probabilistic screens
  - May or may not involve curtailment risk, depending on the inverter settings and size
  - Example: Volt-var control functionality for PV inverters

- Coordinated Dynamic Hosting Capacity
  - Flexible interconnection, where curtailment risk is accepted by the PV developer as an alternative to paying for traditional distribution upgrades
  - Inverters have communications capabilities
  - Uses time-series analysis and probabilistic screens
  - Example: New York Flexible Interconnect Capacity Solution

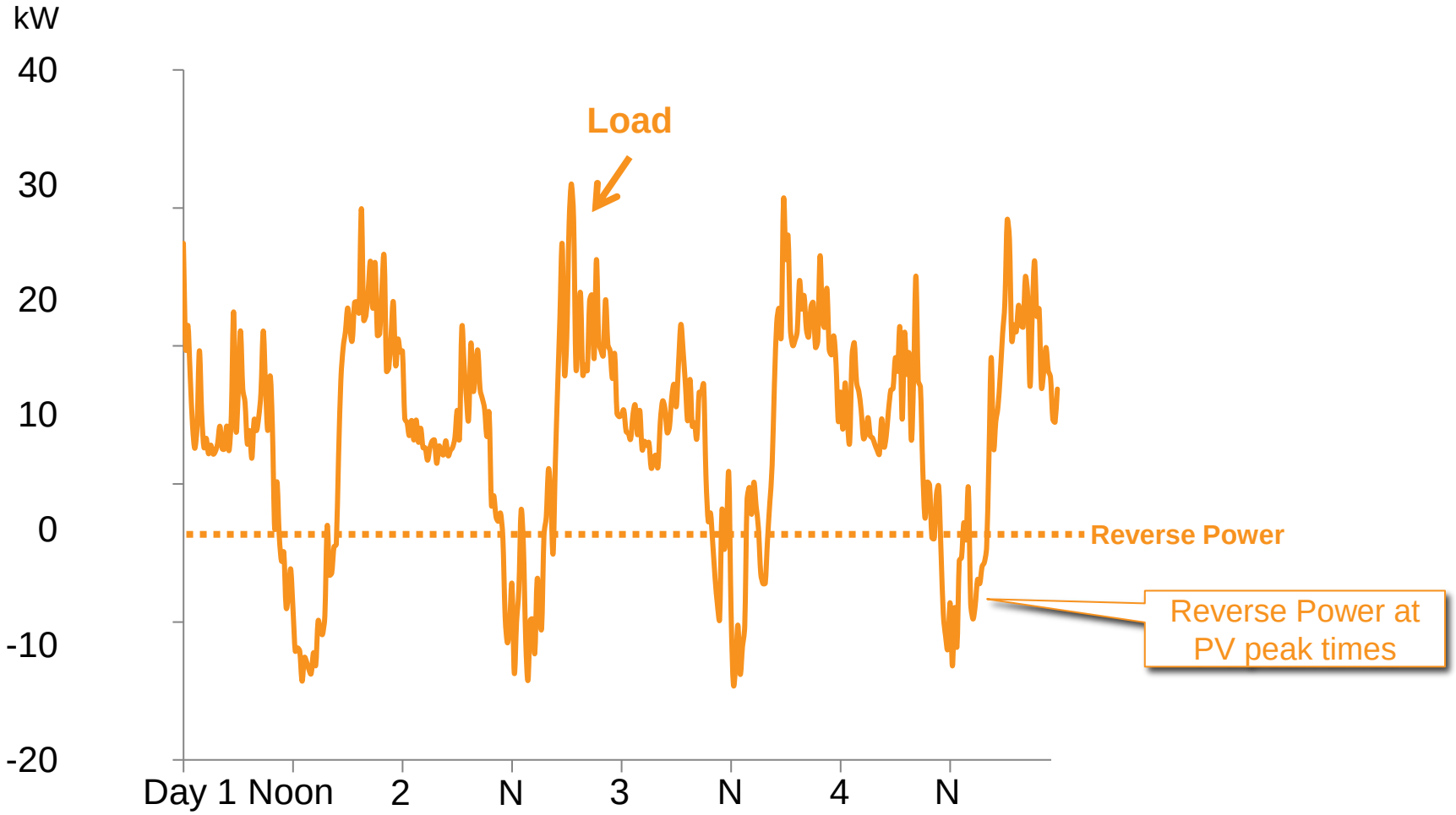
Source: NREL



Source: https://www.mdpi.com/1996-1073/12/13/2576

Example of PV Impacts on Hosting Capacity – Voltage Fluctuation/Increase (1)

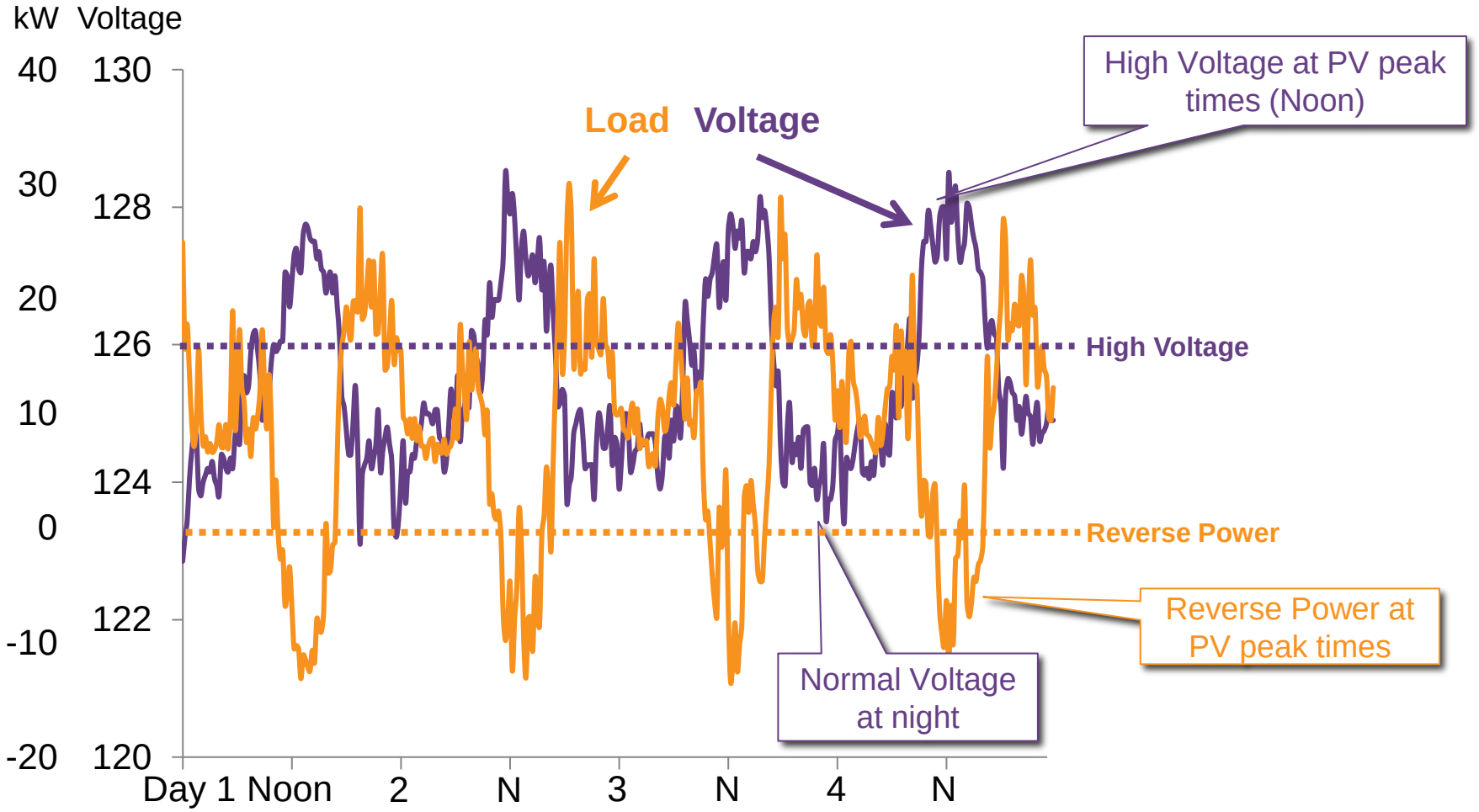
Overvoltage at service transformer due to reverse power flow caused by residential PV DG in Hawaiian Electric (HECO)'s distribution system



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

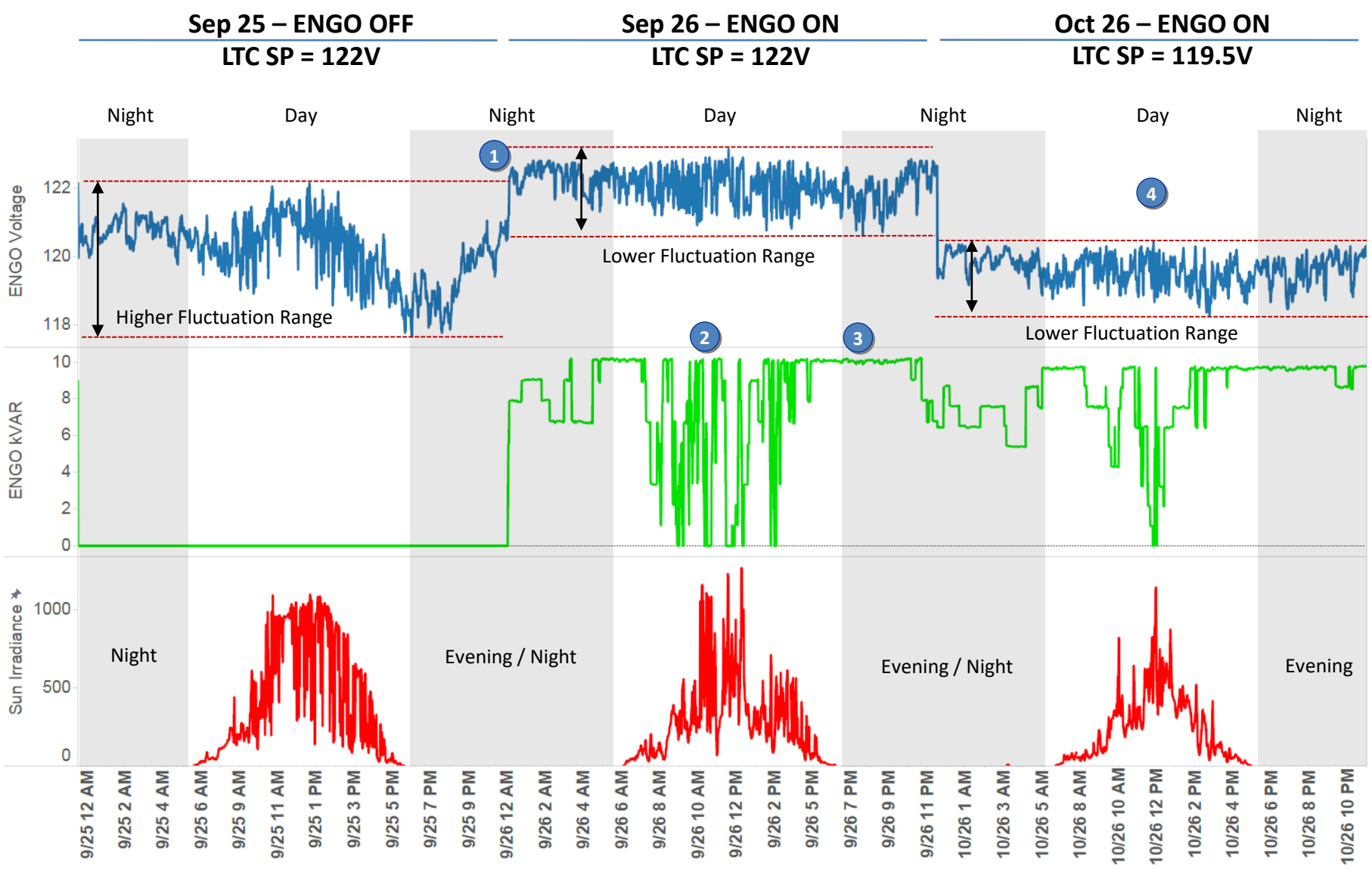
Example of PV Impacts on Hosting Capacity – Voltage Fluctuation/Increase (2)

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

Volt-Var Control at the Grid Edge

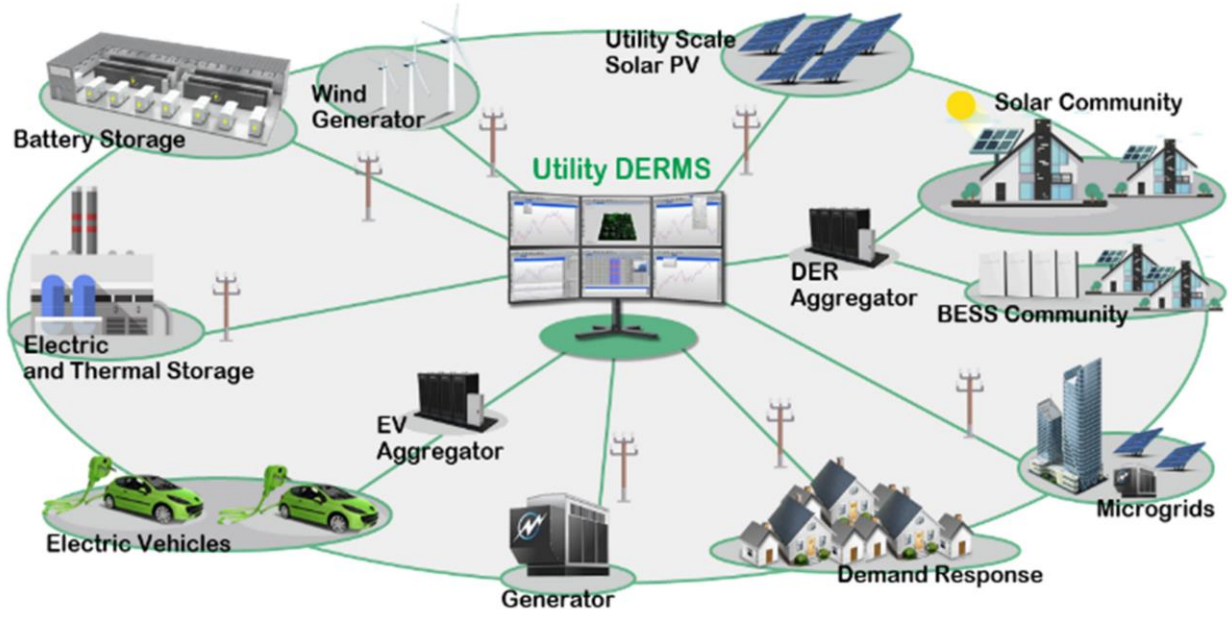


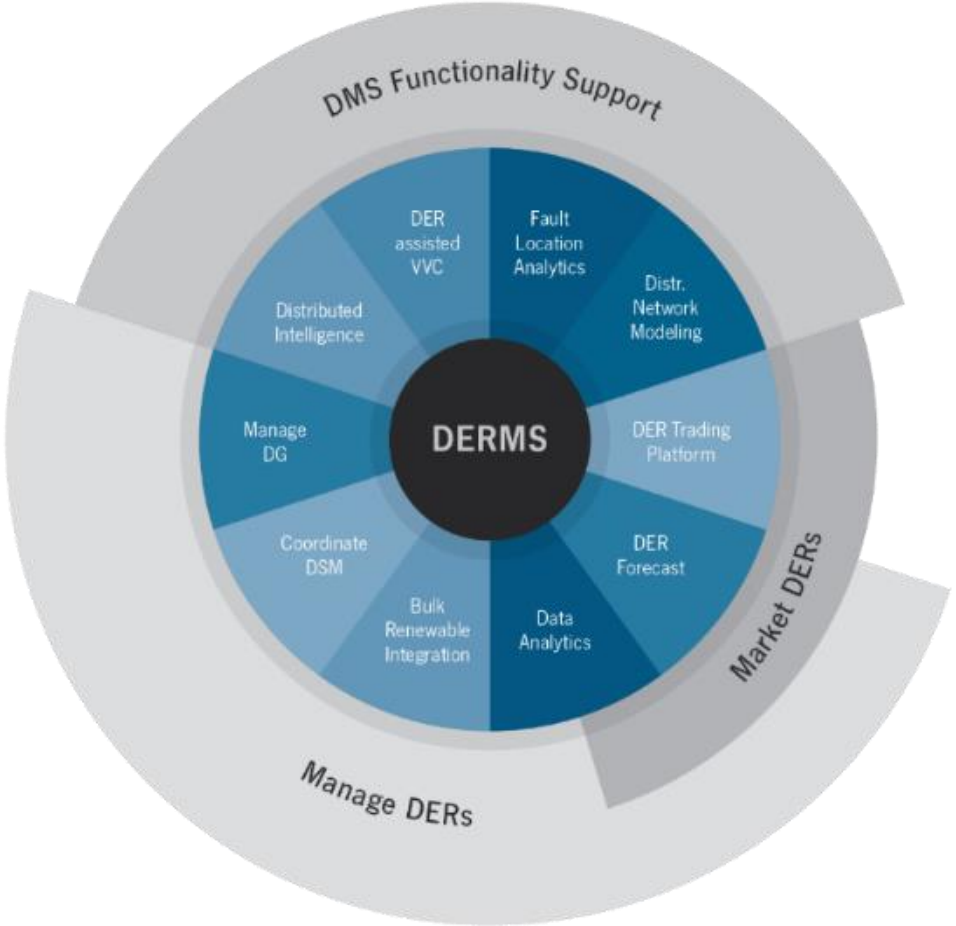
1. **Fluctuation Reduction:** ENGO voltage fluctuation range reduces when ENGO units are active
2. **Daytime Operations:** During the day time, ENGO units provide dynamic VAR support to compensate for PV generation volatility (e.g. cloud cover)
3. **Night Time Operations:** During the night time, ENGO 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.

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

DER Management Systems (DERMS)

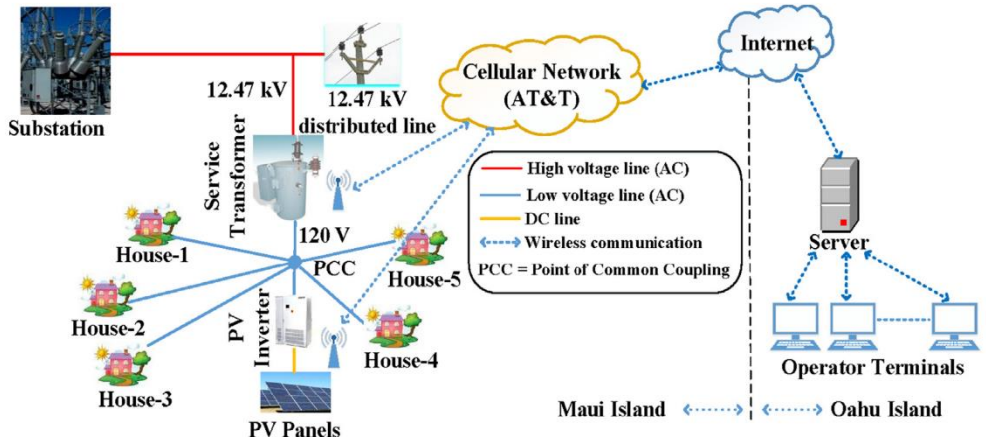
- DERMS, is used to describe software platforms that provide a variety of functions, from controlling and aggregating fleets of behind-the-meter DER, to enabling utilities to integrate them into their grids

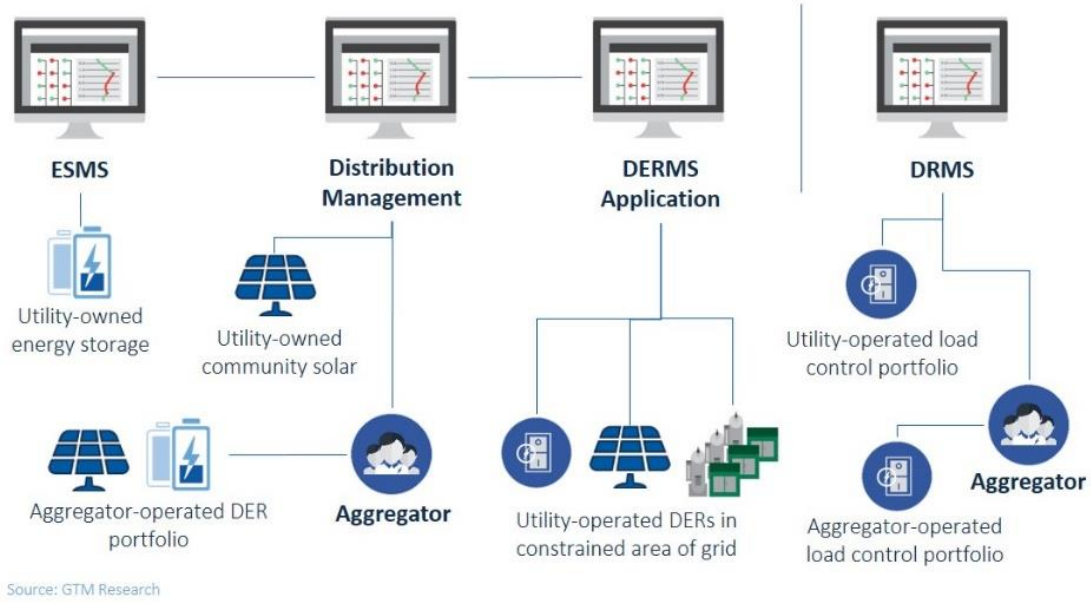


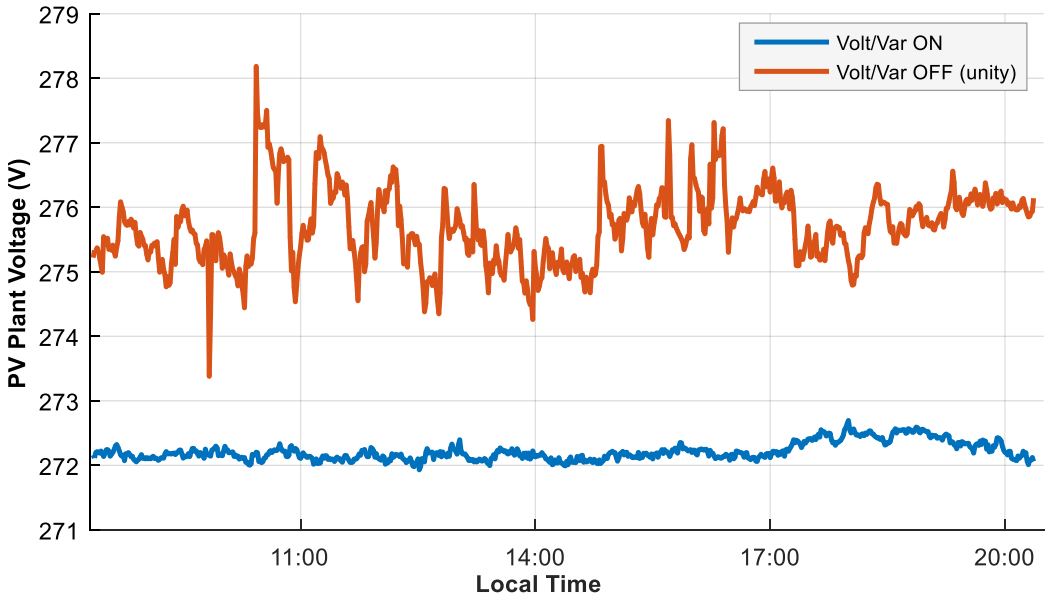


Hosting Capacity Increase Using DER

- Utilization of smart inverters and power electronics-based assets (e.g., distribution-class Static Var Compensators – SVC) for dynamic volt-Var control and optimization of distribution operation, including peak demand reduction, energy efficiency applications, losses reduction, hosting capacity increase (self-mitigation of voltage variability caused by PV proliferation) and multi-objective applications





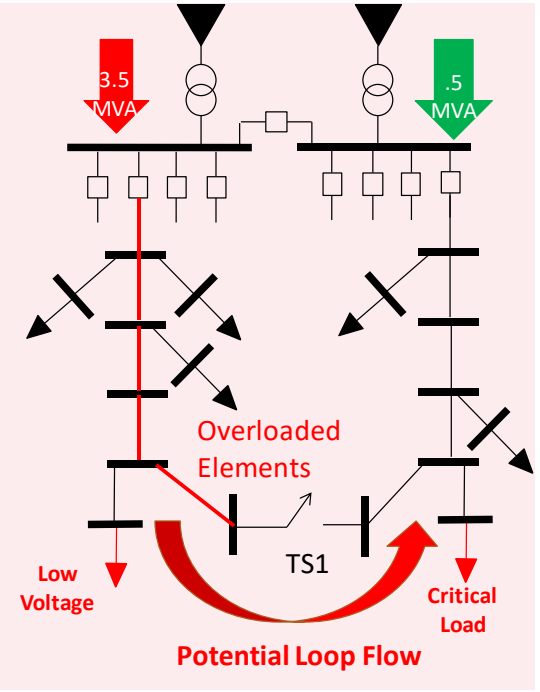


Volt-Var Control Using Smart Inverters (Self-Mitigation of Impacts from PV-DG Variability)

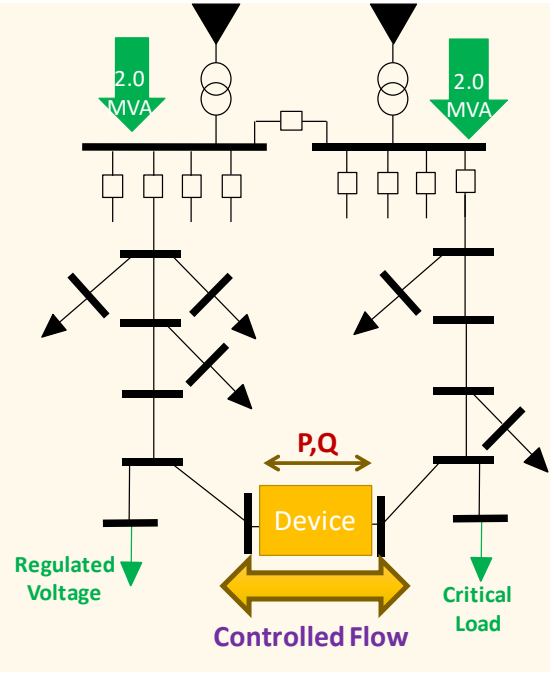
Hosting Capacity Increase Using Distribution FACTS Devices

- 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

Non-Wires Alternatives

- Non-Wire Alternatives (NWA) - The utilities industry has developed state of the art processes to select when an NWA is a suitable solution to address a system need. The industry and research groups has developed tools to calculate the benefit cost of NWA solution
- NWA Definition per HECO Distribution Planning Working Group (DPWG):

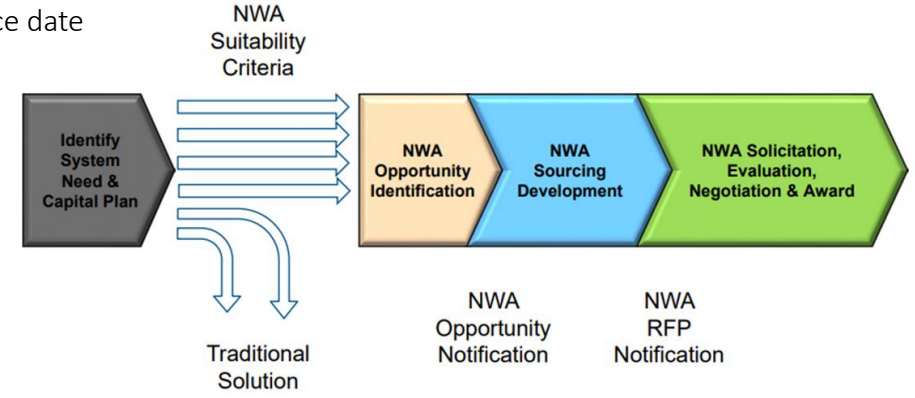
  A Non-Wire Alternative is an electricity grid project that uses non-traditional transmission and distribution (T&D) solutions, such as distributed generation (DG), energy storage, energy efficiency (EE), demand response (DR), and grid software and controls, to defer or avoid the need for conventional transmission and/or distribution infrastructure investments.

- Suitability Criteria are defined including Timing, Cost and Time Period. Example below

Criteria	Potential Elements Addressed	
Project Type Suitability	Project types include Load Relief and Reliability*. Other categories currently have minimal suitability and will be reviewed as suitability changes due to State policy or technological changes.	
Timeline Suitability	Large Project	36 - 60 Months
	Small Project	18 - 24 Months
Cost Suitability	Large Project	> $1M
	Small Project	> $300k

Utility Defined

1. Define Grid Needs
   - Size, duration, in-service date
2. Opportunity Criteria
   - Timing & Cost
3. Sourcing Options
   - Demand Response
   - EE
   - Enhanced Control
   - DER



Locational Value Categories

Value Category	California[27]	New York[28]
Distribution	Avoided Feeder/Substation Costs	Avoided Distribution Capacity Infrastructure
	-	Avoided Distribution O&M
	Avoided Distribution Voltage/Power Quality Costs	-
	Avoided Reliability Costs	Net Avoided Outage Costs
	Avoided Resiliency Costs	Net Avoided Restoration Costs
	-	Avoided Distribution Losses
Transmission	Avoided Transmission Capital Expenditures	Avoided Transmission Capacity Infrastructure and O&M
	-	Avoided Transmission Losses
Generation	Avoided System Resource Adequacy (RA) and Local RA	Avoided Generation Capacity (ICAP), with Reserve Margin
	Avoided Flexible RA / Avoided Renewable Integration Costs	-
	Avoided Energy (via LMP)	Avoided Energy (LBMP)
	Avoided Ancillary Services	Avoided Ancillary Services
	RPS Costs	
Environmental / Society	Avoided GHG Costs (via LMP)	Net Avoided GHG (social cost of carbon)
		Net Avoided Criteria Air Pollutants
		Avoided Water Impacts / Avoided Land Impacts
	Avoided Societal Costs / Avoided Public Safety Costs	Non-Energy Benefits

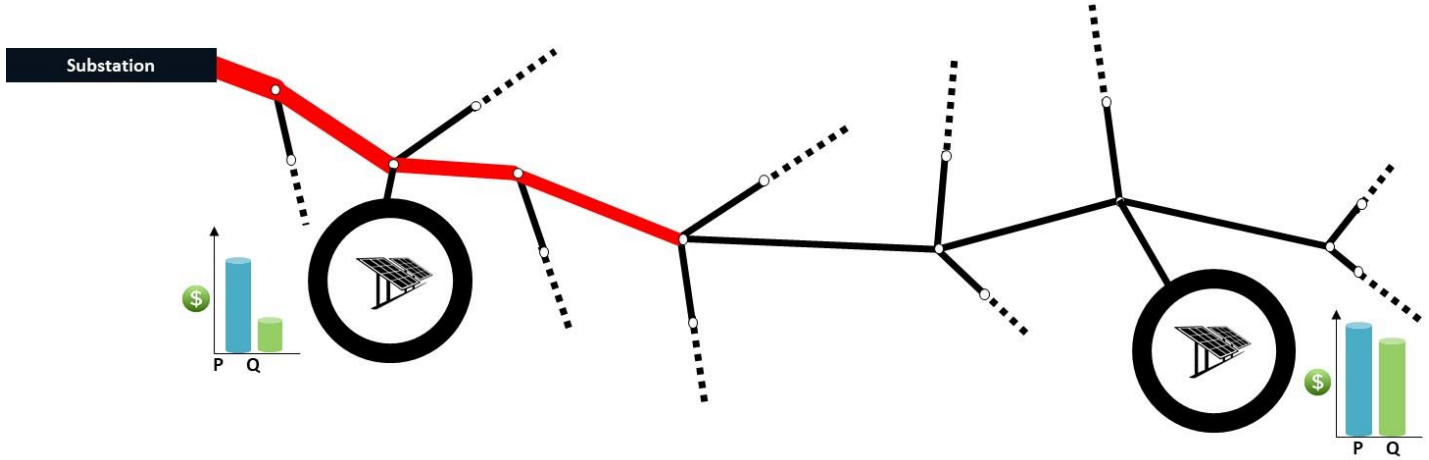
Source: Source: MADRI Integrated Distribution Planning for Electric Utilities: Guidance for Public Utility Commissions

Value of DER/NWA - Accurate Grid & DER Benefit-Cost Analysis

- Calculate the value of DER on a locational and temporal basis in terms of grid avoided costs, especially on sub-transmission and distribution systems.
- Framework that enables a calculation of the Locational Marginal Value (LMV) of incremental kW and kVar of DER injection - DER compensated based on distribution grid needs at a given location and time vs. by type, by circuit voltage level and by region
- Value of DER as Non-Wires Alternatives (NWAs) compared to traditional investment
  - Line thermal overloads
  - Voltage violations (under-voltages or over-voltages)

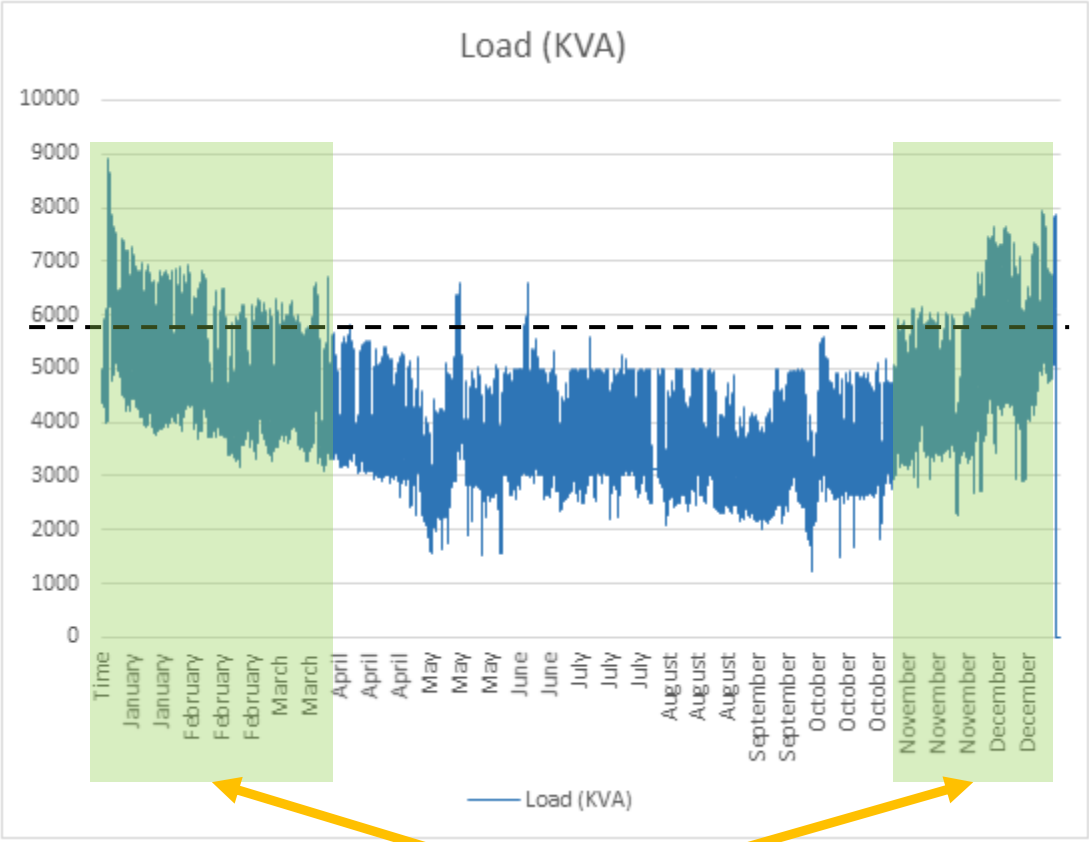
LMV demonstrates the value of injections to improve power factor and reduce loadings upstream. The DER farthest from the station will have greater value than the one closer as it benefits ALL overloaded sections plus it reduces losses to a greater extent.

Effects of Locational Marginal Value

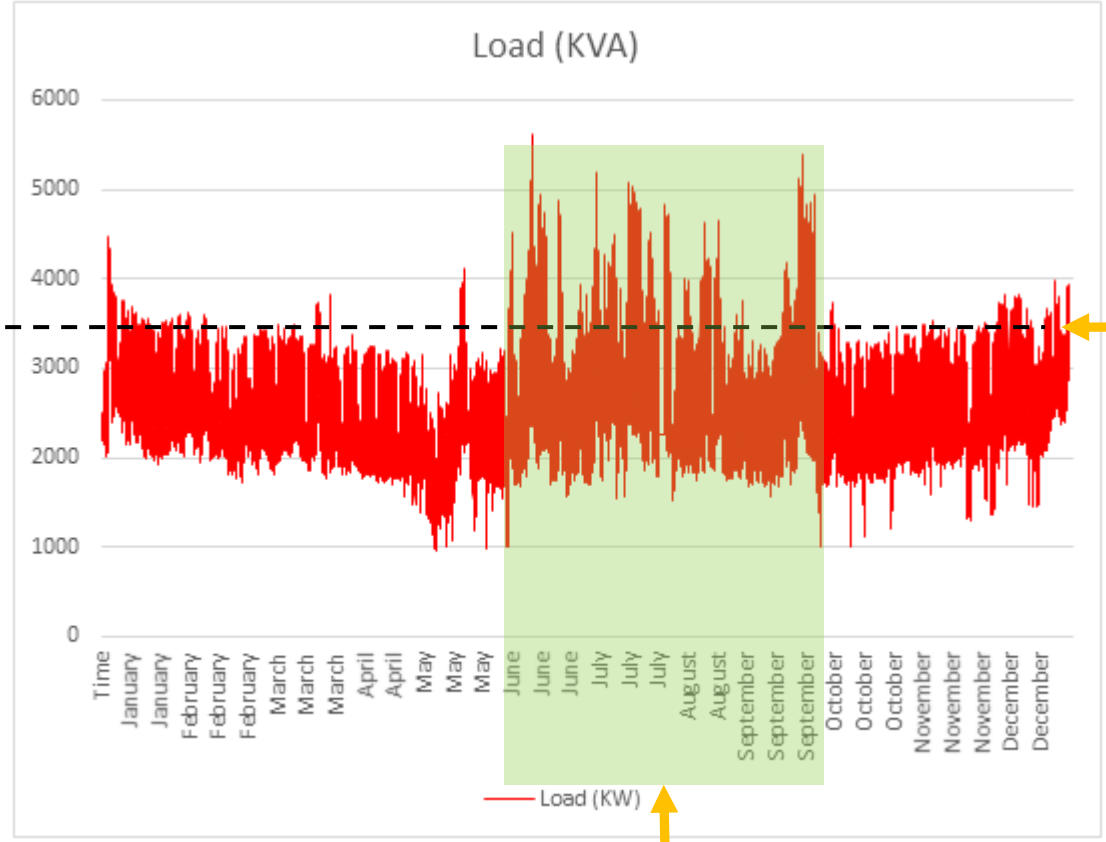


Value is Temporal

Winter Peak



Summer Peak

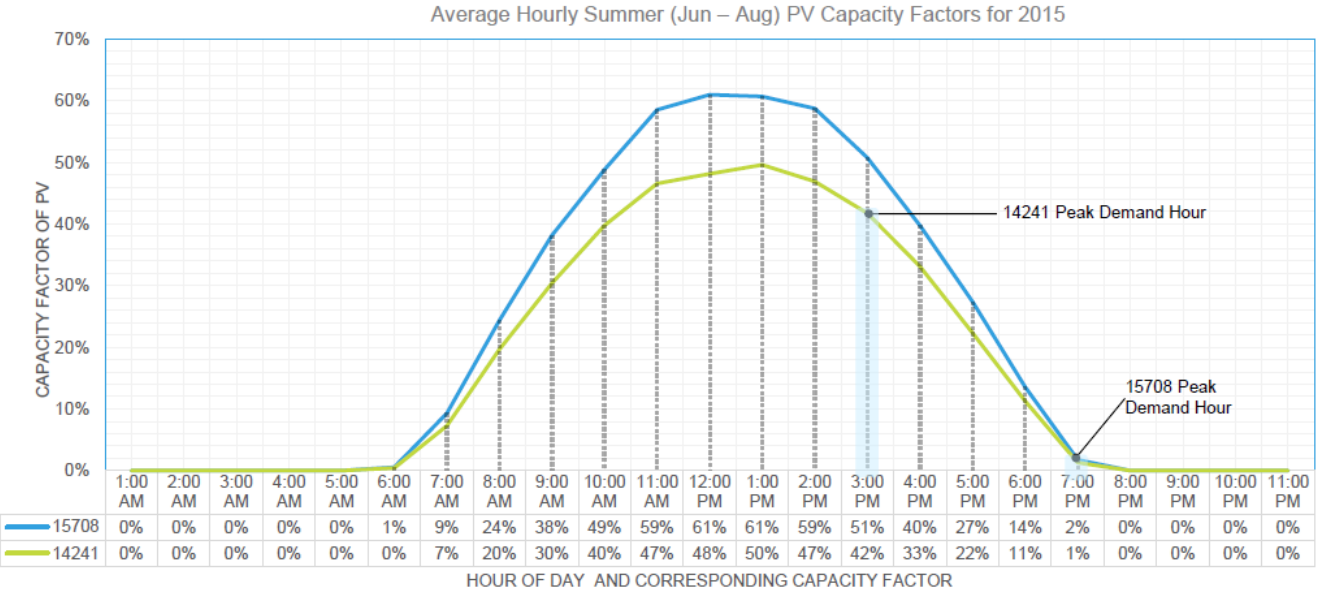


Feeder rating

Potential value for downstream DER

Potential value for downstream DER

Example – Accounting for Impacts of Solar PV in Pepco DC/MD



	1:00 AM	2:00 AM	3:00 AM	4:00 AM	5:00 AM	6:00 AM	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM	11:00 PM
15708	0%	0%	0%	0%	0%	1%	9%	24%	38%	49%	59%	61%	61%	59%	51%	40%	27%	14%	2%	0%	0%	0%	0%
14241	0%	0%	0%	0%	0%	0%	7%	20%	30%	40%	47%	48%	50%	47%	42%	33%	22%	11%	1%	0%	0%	0%	0%

Note: Actual hourly production capacity will rarely achieve 100% of nameplate rating due to factors which include cloud cover, panel efficiency loss due to temperature, panel tilt and orientation, and shading

In order to accurately account for the impact of Distributed PV in planning, PHI requires:

- The hourly production profile of the resource for the peak period (typically summer)
- The nameplate capacity of the resource on the circuit, transformer or substation
- The hour of the greatest feeder, circuit, or transformer peak

Source: Pepco

Capacity Relief Estimation Using DERs (2)

The peak reduction impact of PV can range from 0% to ~60% of nameplate PV depending on the coincidence of the PV production with the peak load hour

Pepco MD Feeders					
Feeder	Historical Peak (MVA)	Feeder Peak Hour	Nameplate PV (kW)	PV Capacity Factor for Feeder Peak Hour	PV Impact on Peak (kW)
14241	7	15	1088.66	42%	454.30
14165	8.5	17	746.99	22%	166.51
14161	8.4	22	760.395	0%	0.00
14492	5.3	15	1692.88	42%	706.44
14245	6.5	14	1298.78	47%	609.16
Pepco DC Feeders					
15708	8.3	19	277.955	2%	4.88
15172	6.5	17	208.58	27%	57.10
15710	5.5	16	3.35	40%	1.33
14712	6.3	16	138.495	40%	55.05
14713	9.4	17	356.04	27%	97.46
15701	7.9	16	451.322	40%	179.40
15702	8.1	17	346.249	27%	94.78
15703	9.1	19	208.22	2 %	3.66

No impact

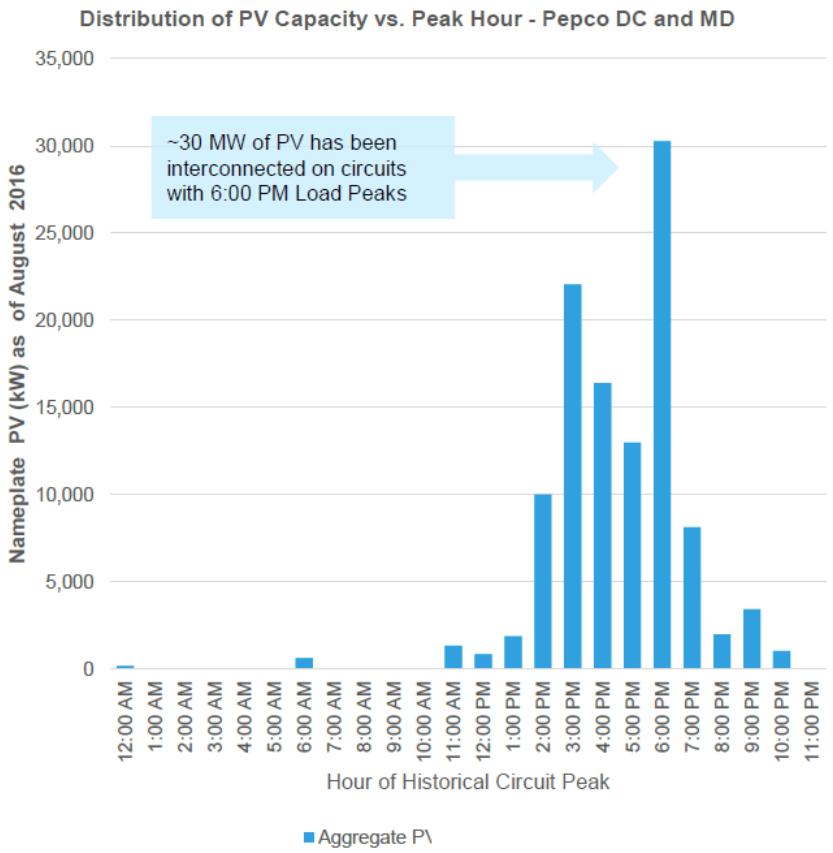
Significant impact

Note: This is an extrapolation based upon the production curves presented in the previous slide. For planning purposes PHI can model each feeder individually to account for the impacts of PV.

Source: Pepco

Capacity Relief Estimation Using DERs (3)

The majority of installed PV capacity in Pepco MD/DC is interconnected on feeders with loads that peak at either 3:00 PM or 6:00 PM

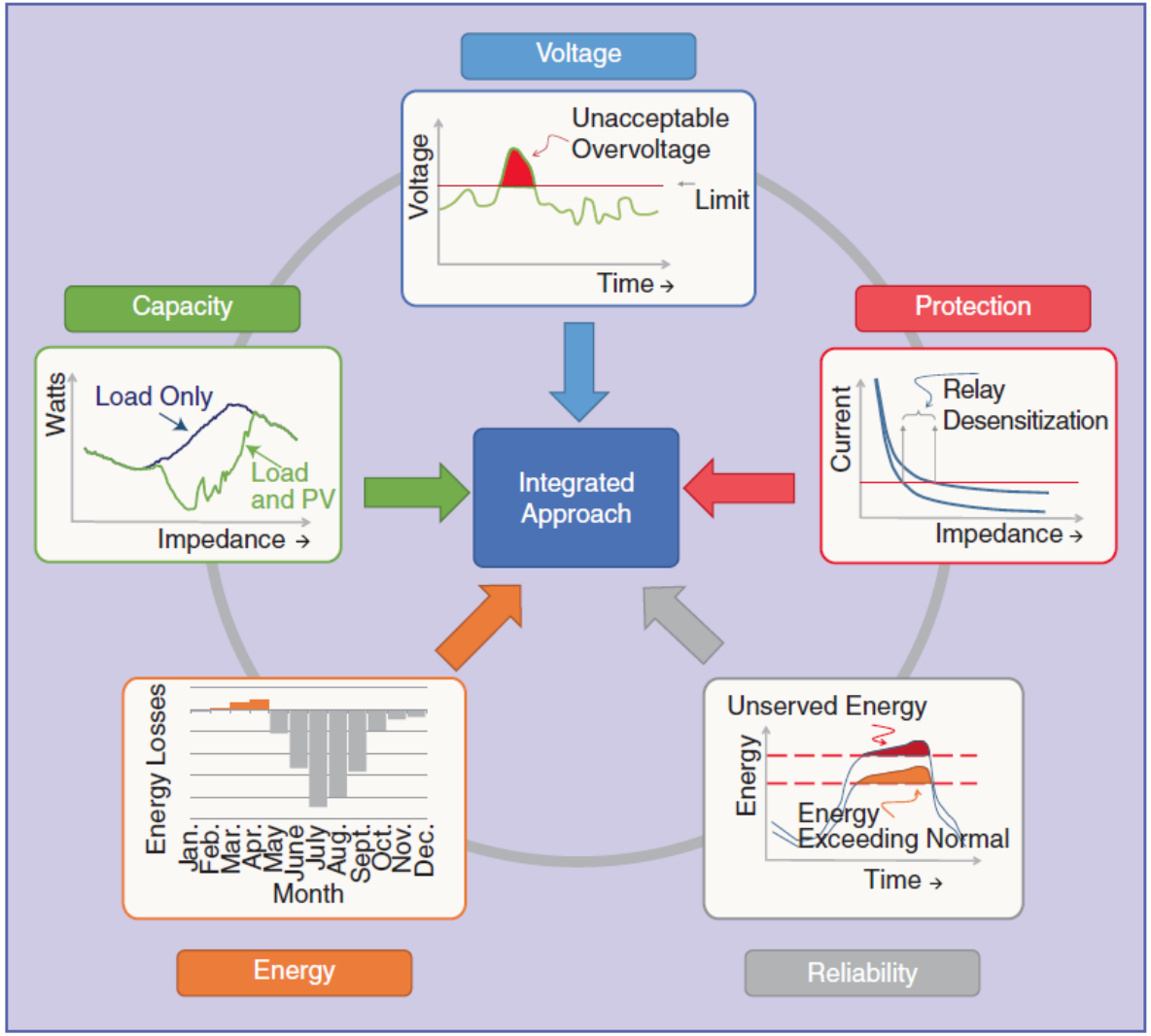


*Blue bars represent distribution of aggregate PV capa
with feeders with peak load for the hour ending on the

Source: Pepco

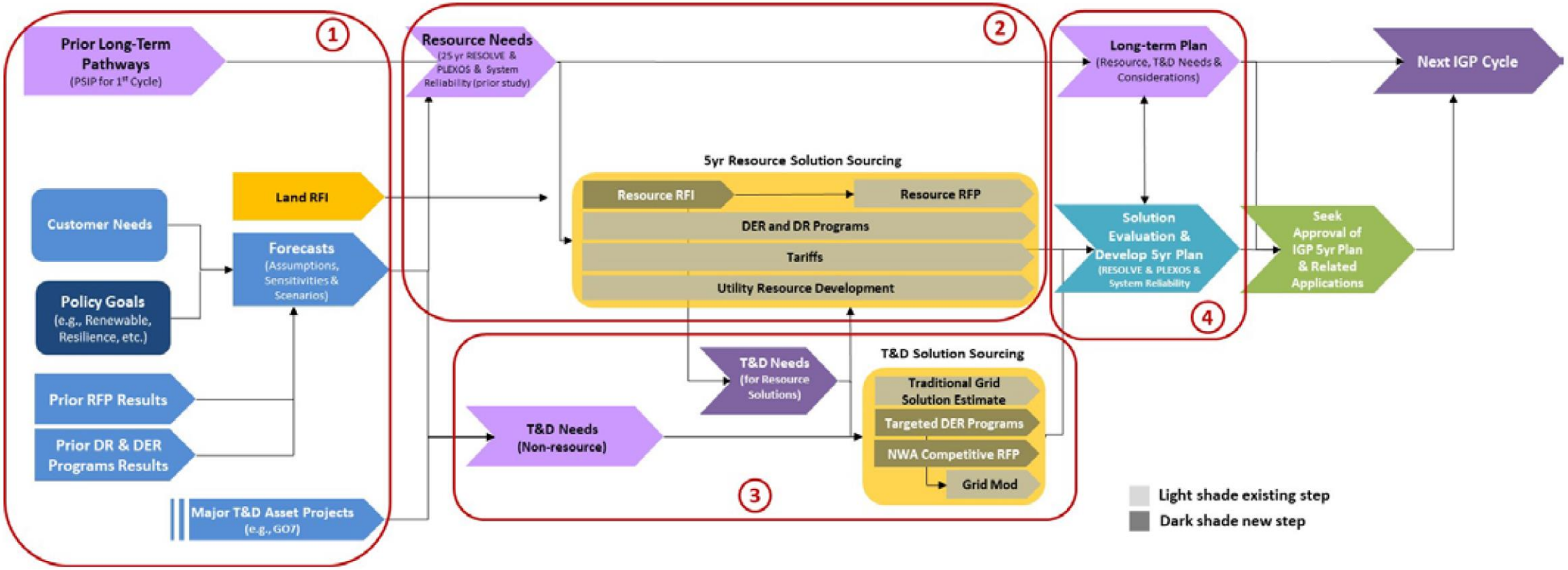
- The impacts of solar must be adjusted according both to the production profile of the resource and the attributes of the circuit, transformer, or substation.
- In some cases, where the circuit, transformer, or substation experience a peak load later in the day or early in the morning PV may not provide any capacity relief.

DER Impacts/Benefits – Integrated Approach



Source: http://ieeexplore.ieee.org/document/7048005/

Hawaii's Integrated Grid Planning Process (T&D)

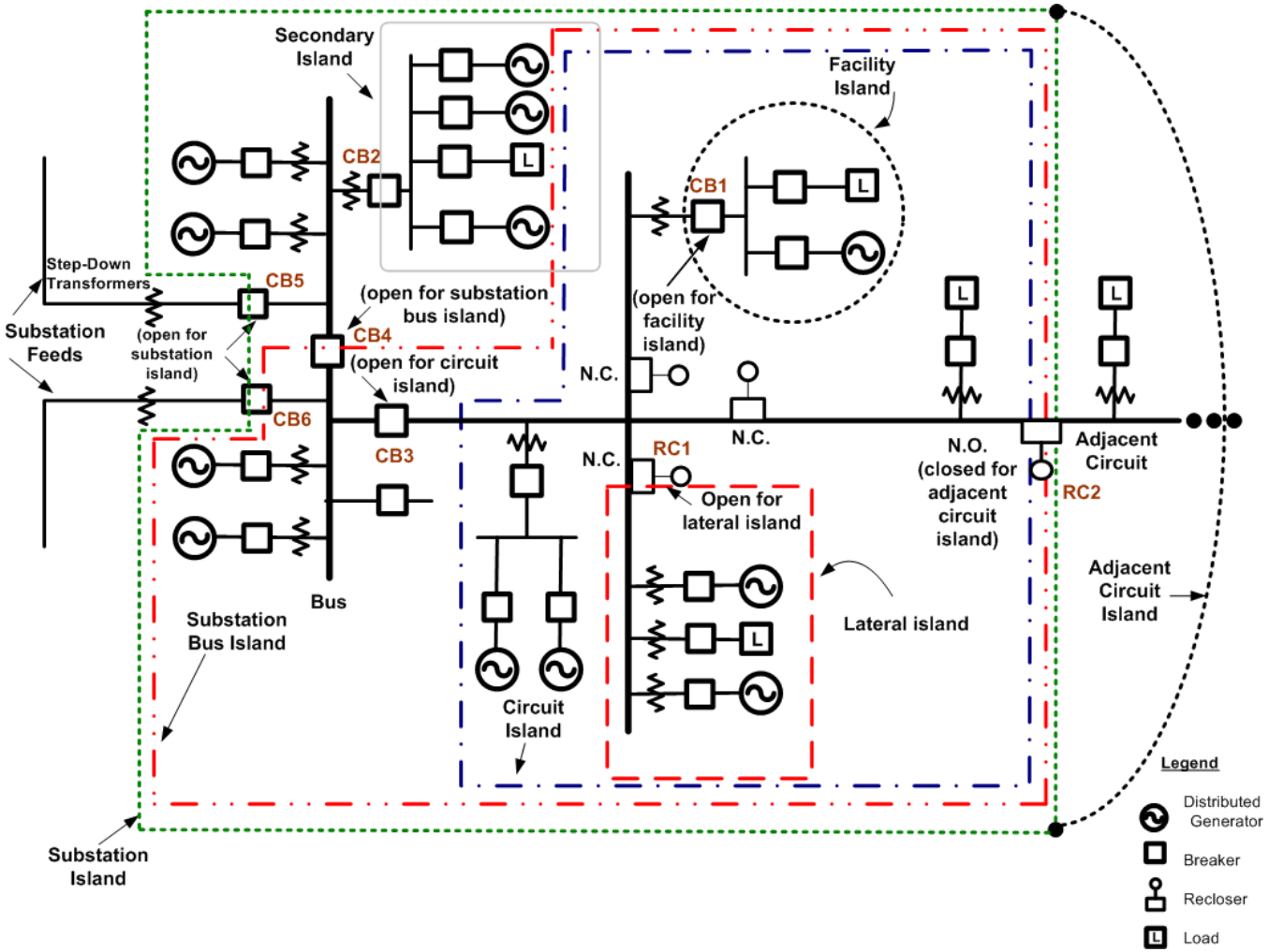


Source: HECO https://www.hawaiianelectric.com/clean-energy-hawaii/integrated-grid-planning

1) Forecasts and planning inputs
2) Resource needs and sourcing
3) Transmission and distribution needs and alternatives
4) Near-term action plan and long-term pathway

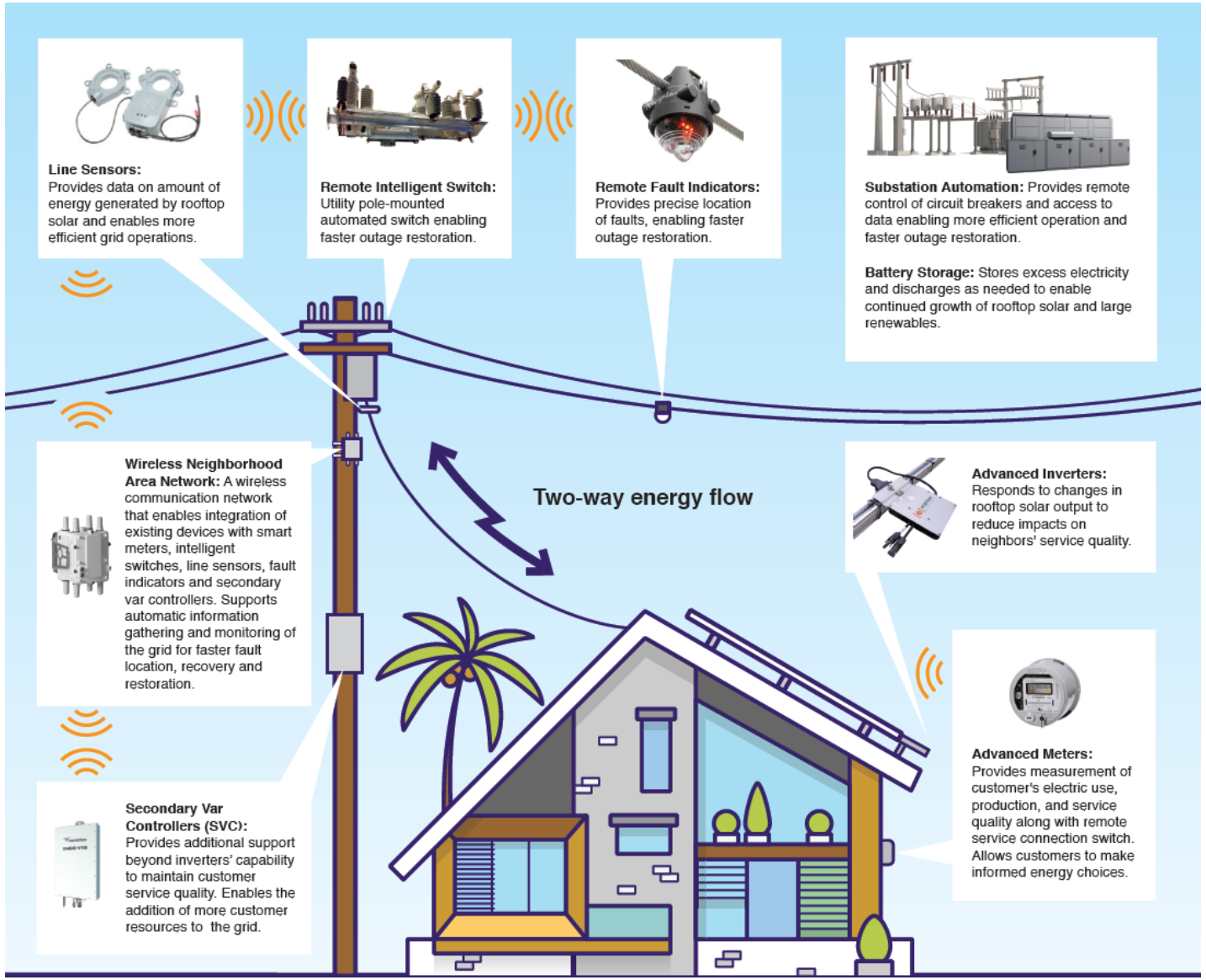
Microgrids

- Microgrids are defined as "A group of interconnected loads and distributed energy resources (DER) with clearly defined electrical boundaries that acts as a single, controllable entity with respect to the grid and can connect and disconnect from the grid to enable it to operate in both grid-connected and island mode"
- Microgrids provide an opportunity to realize the potential benefits of DER adoption to
  - Improve reliability and resilience via intentional islanding during utility grid disruptions,
  - Enhance the operational efficiency of the grid by providing local support (e.g., volt-var control, peak shaving, etc.) when needed,
  - Facilitate and manage DER integration



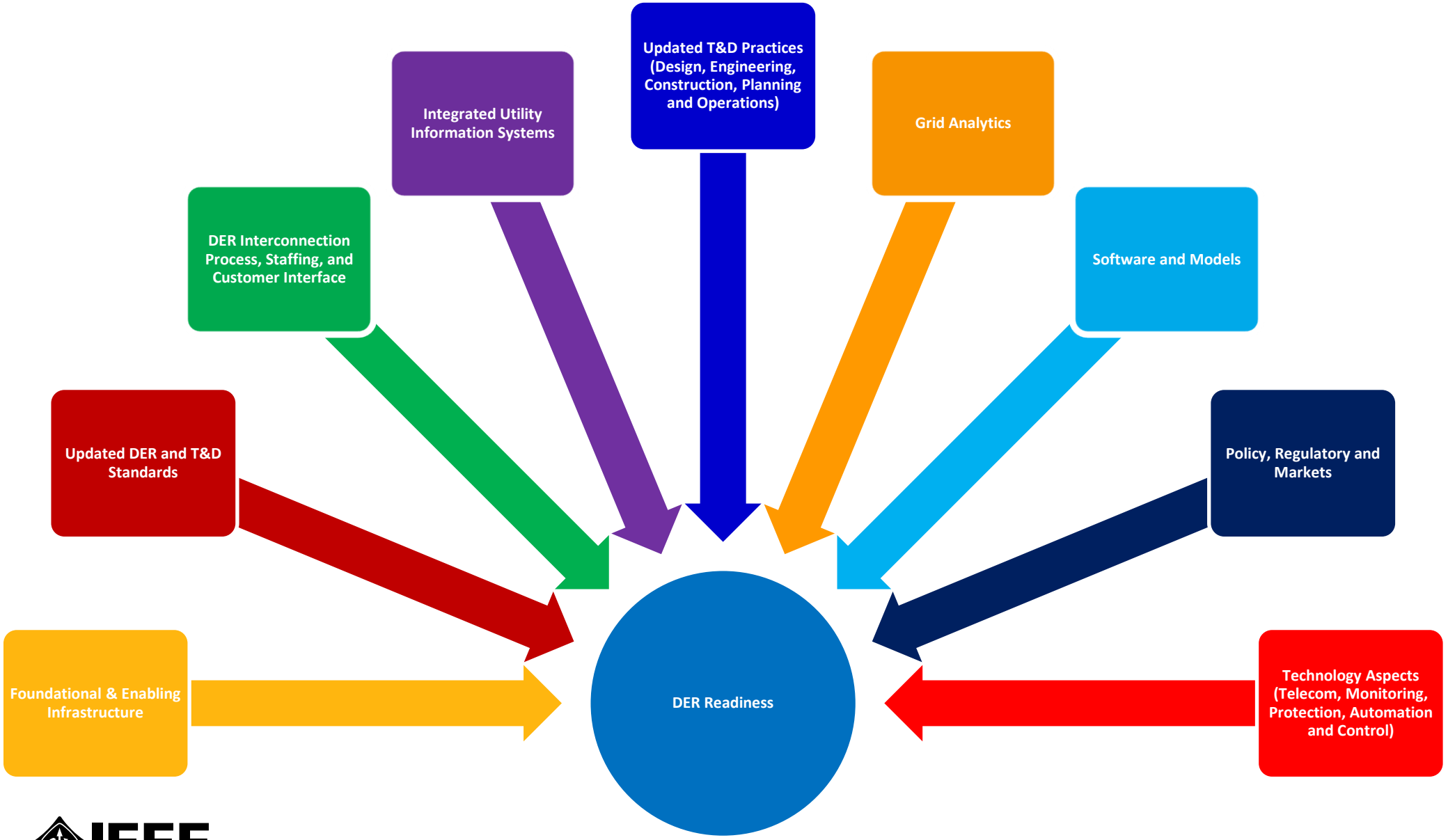
Source: IEEE 1547.4 – 2011 IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems https://ieeexplore.ieee.org/document/5960751

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



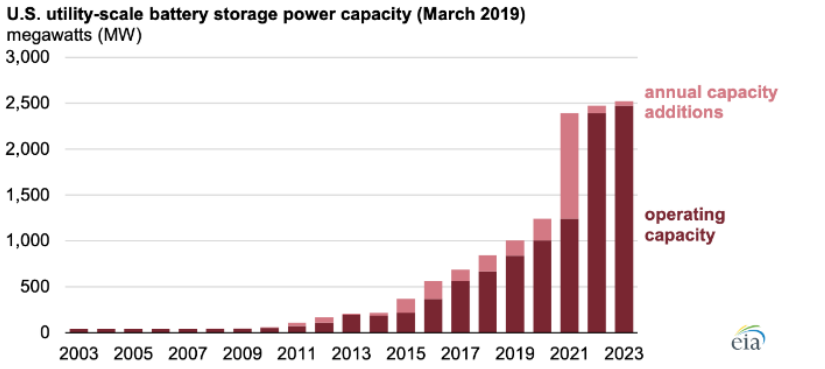
Source: M. Asano, Grid Modernization Applications in a High DER Environment, 2018 IEEE PES T&D Conference and Exposition, Denver CO

DER Readiness Concept – Modular Framework



Foundational & Enabling Infrastructure

- Capital investments (reliable and resilient grid)
- New feeders and substations (e.g., express/dedicated feeders)
- Aging infrastructure replacement
- Infrastructure hardening
- Energy storage
- Switchgear
- Voltage regulation/control and protective devices
- Intelligent Electronic Devices (IEDs)
- Telecommunications infrastructure
- Advanced Metering Infrastructure (AMI)



Source: https://www.eia.gov/todayinenergy/detail.php?id=40072#

Foundational & Enabling Infrastructure → DER Readiness

Updated DER and T&D Standards

- Review/update of smart inverter standards to include prospective DER applications (e.g., volt-Watt, volt-VAR, voltage and frequency ride through, etc.)
- Review/update of equipment standards to consider prospective DER penetration scenarios (e.g., service transformers, voltage regulators, load tap changers, protection relays, sensors, power electronics voltage regulation/control equipment, etc.)
- Development and/or review and update of cybersecurity standards

Updated DER and T&D Standards

DER Readiness

IEEE Std 1547™(2003 and 2014 Amendment 1) Standard for Interconnecting Distributed Resources with Electric Power Systems

- **IEEE Std P1547™(full revision)** Draft Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces
- **IEEE Std 1547.1™(2005 and 2015 Amendment 1)** Standard for Conformance Tests Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems
  - **IEEE Std P1547.1 (full revision)** Draft Standard for Conformance Tests Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces

IEEE Std 1547.2™(2008) Application Guide for IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems

IEEE Std 1547.3™(2007) Guide for Monitoring Information Exchange, and Control of Distributed Resources with Electric Power Systems

IEEE Std 1547.4™(2011) Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems

IEEE Std 1547.6™(2011) Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Networks

IEEE Std 1547.7™ (2013) Guide to Conducting Distribution Impact Studies for Distributed Resource Interconnection

IEEE Std P1547.8™ Draft Recommended Practice for Establishing Methods and Procedures that Provide Supplemental Support for Implementation Strategies for Expanded Use of IEEE Std 1547-2003

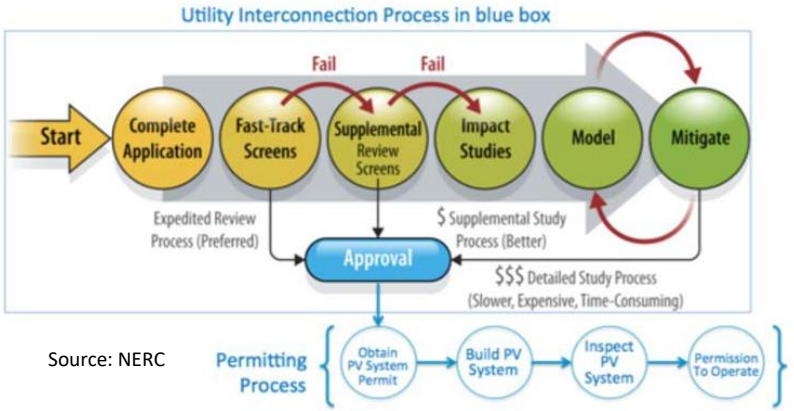
Source: IEEE

DER Interconnection Process

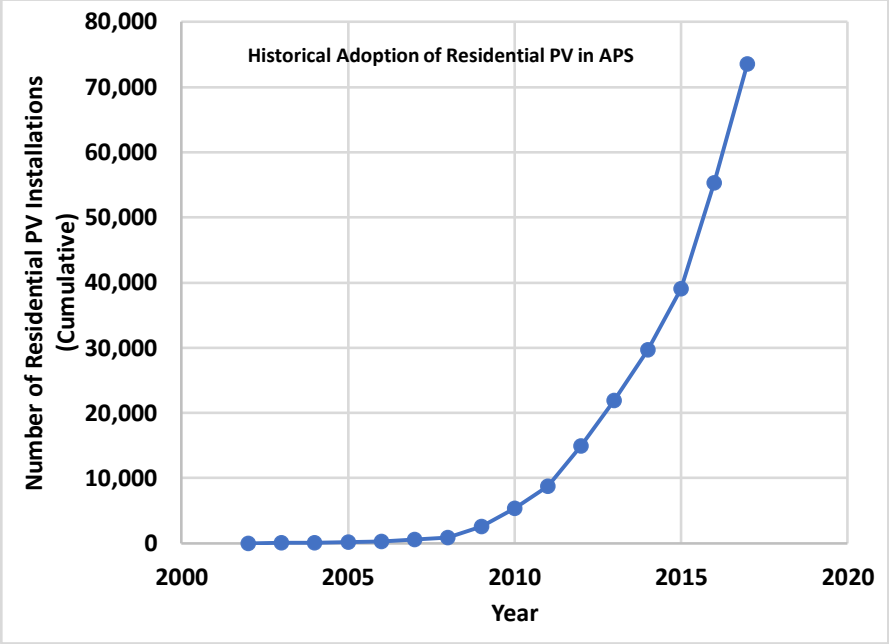
DER Interconnection Process, Staffing, and Customer Interface

- Review/update of DER interconnection process:
  - Requirements for modeling, simulation and analysis of DER interconnection requests
  - Automation of DER interconnection process via online portals (customer applications, data collection, inspections, approvals, etc.)

DER Readiness



Source: NERC

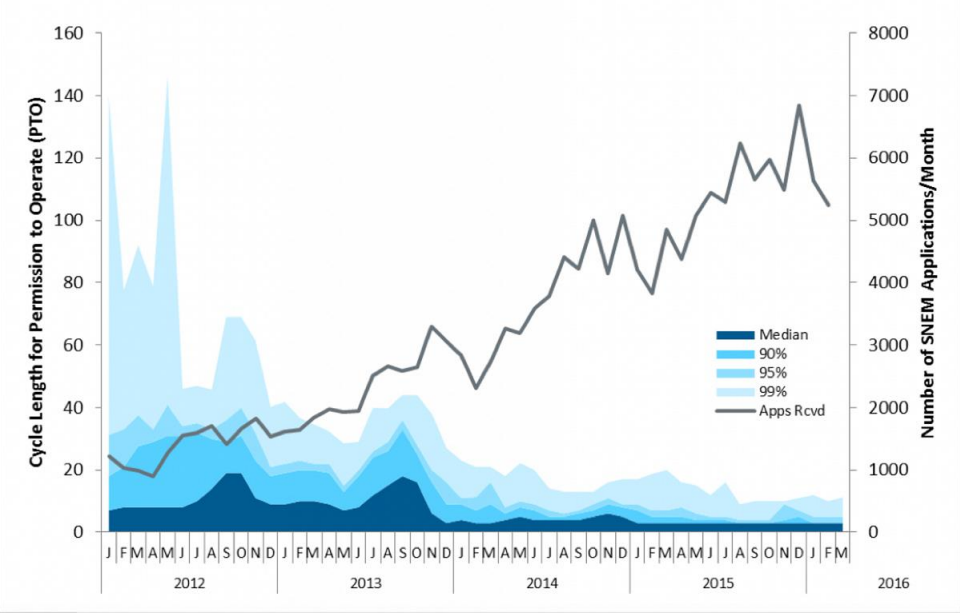


D. Haughton, Distribution Automation and DER at APS, 2018 IEEE PES Transmission and Distribution Conference and Exposition, Denver, CO

Integrated Utility Information Systems

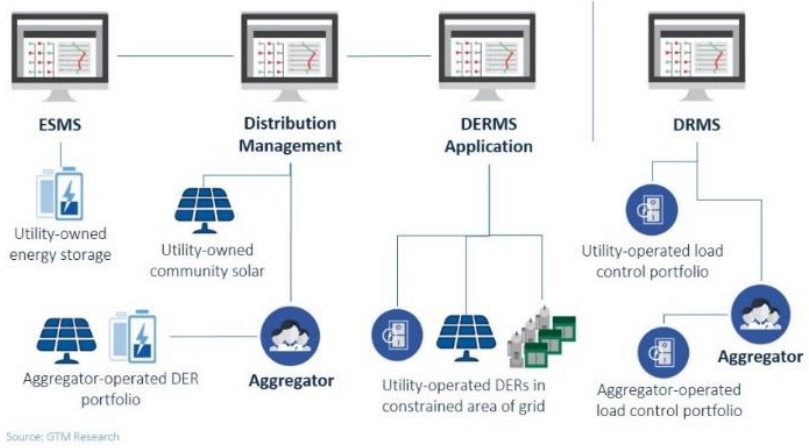
Integrated Utility Information Systems

- Integration of automated DER interconnection process into IT system
  - Implementation of DER Management System (DERMS)
  - Integration of DER interconnection and existing processes (e.g., approved/installed DER should be added into GIS and CYME models automatically)

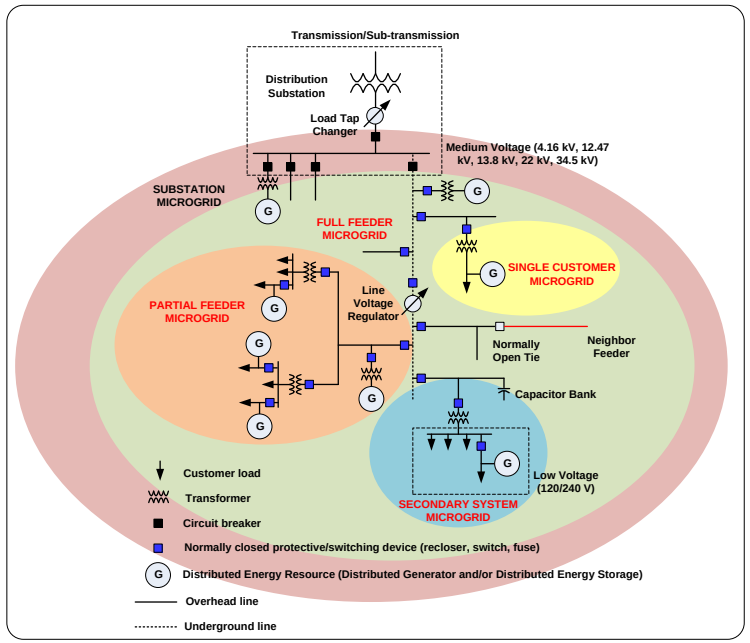


Source: https://www.nrel.gov/dgic/interconnection-insights-2017-10.html

DER Readiness



Updated T&D Practices



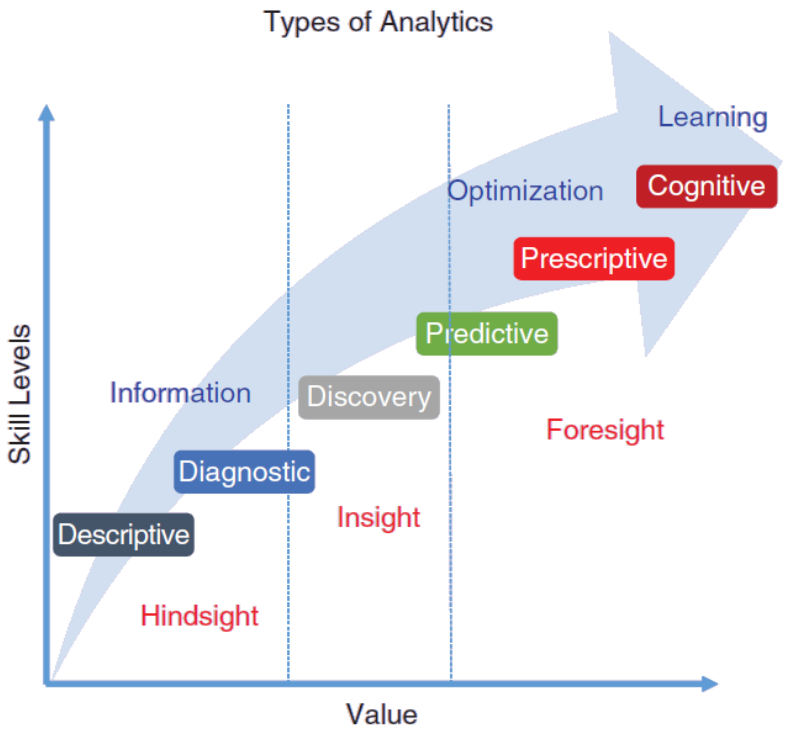
Source: J. Romero Aguero et al., The Utility and Grid of the Future: Challenges, Needs, and Trends, IEEE Power and Energy Magazine, Sep/Oct 2016

Updated T&D Practices (Design, Engineering, Construction, Planning and Operations)

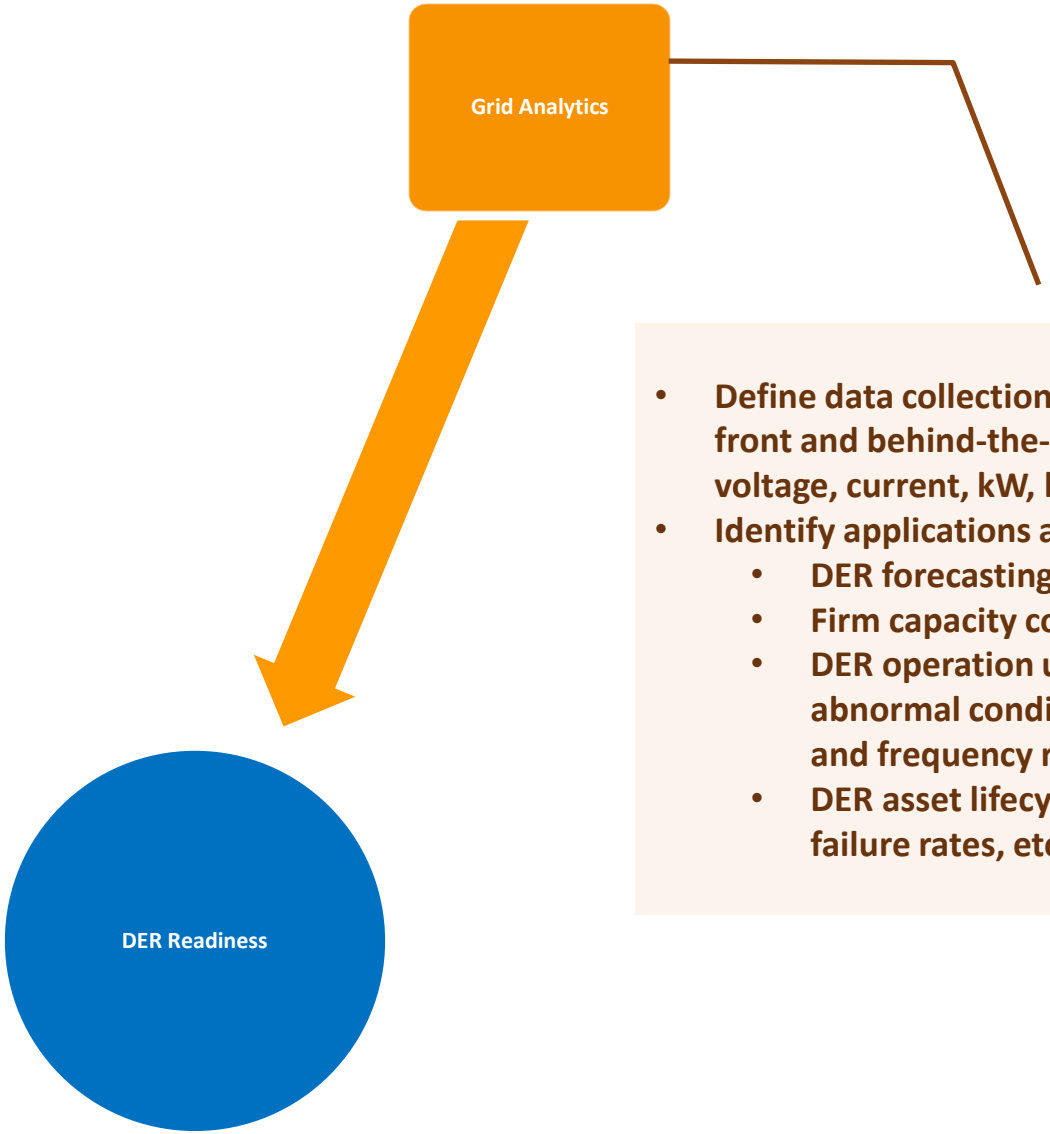
DER Readiness

- **Review/update of planning practices**
  - **DER hosting capacity**
  - **DER impact studies**
  - **Firm capacity contribution from DER**
  - **Consideration of DER in load forecasting activities**
  - **DER forecasting**
  - **Review of distribution automation practices for feeders with DER**
- **Review/update of operations practices for feeders with bi-direction power flow**
- **Review/update of design and construction practices for DER-ready feeders and substations**

Grid Analytics



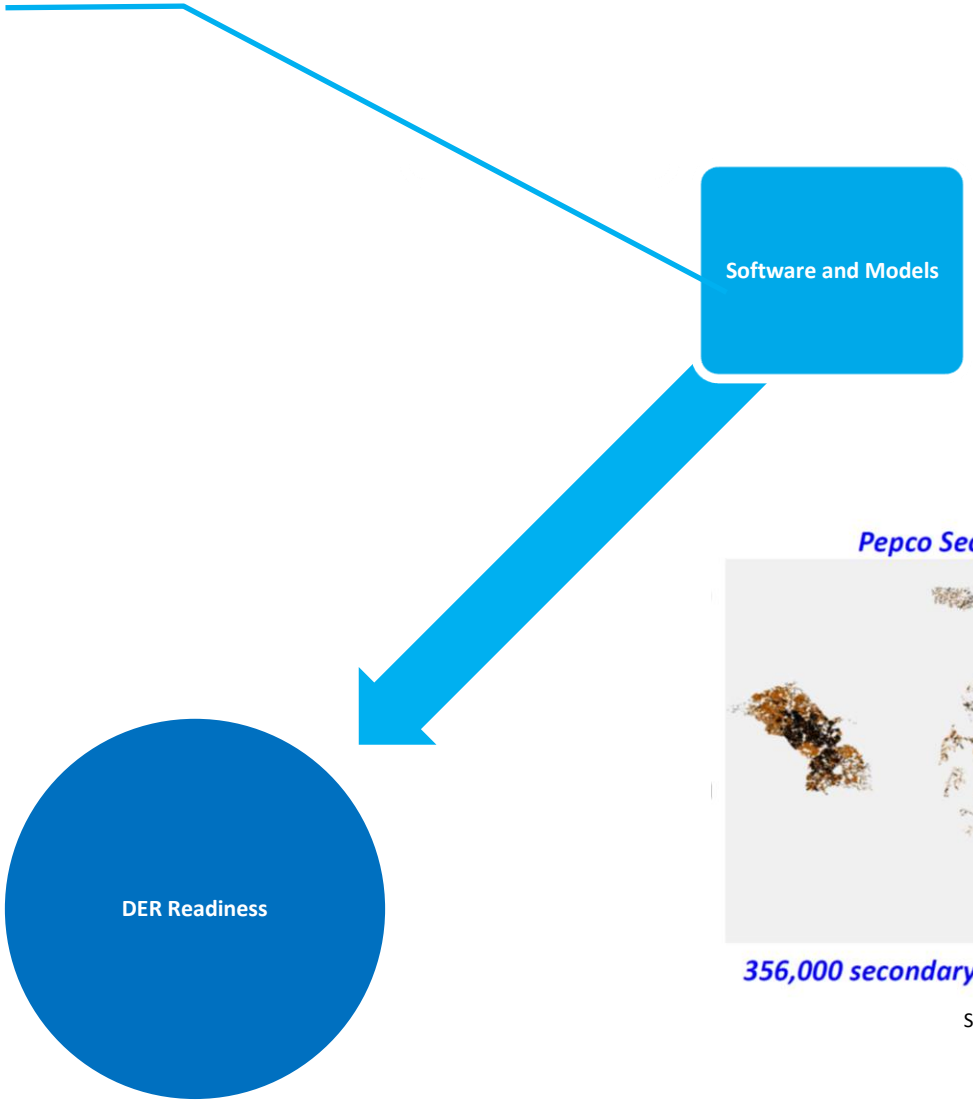
Source: J. Romero Aguero et al., Managing the New Grid, IEEE Power and Energy Magazine, Jul/Aug 2019



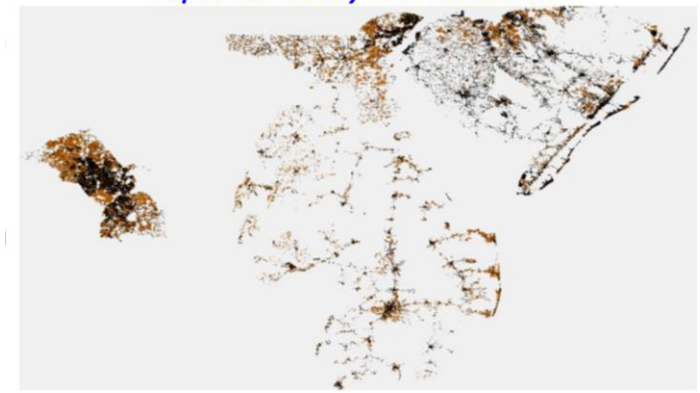
- Define data collection requirements for in-front and behind-the-meter DER (e.g., voltage, current, kW, kvar, kWh, kvarh, etc.)
- Identify applications and solutions for
  - DER forecasting
  - Firm capacity contribution from DER
  - DER operation under normal and abnormal conditions (e.g., voltage and frequency ride-through)
  - DER asset lifecycle analysis (e.g., failure rates, etc.)

Software and Models

- DER hosting capacity
- DER impact studies
  - DER adoption scenarios
- DER forecasting
- Firm capacity contribution from DER
- Value of DER/grid
- Distribution planning (power flow) models (time-series analysis)
- Feeder protection/control models
- Secondary system models
- Dynamic/transient models
- Irradiance models
- DER model validation (fault current contribution, volt-Var performance, etc.)



Pepco Secondary Distribution ISM

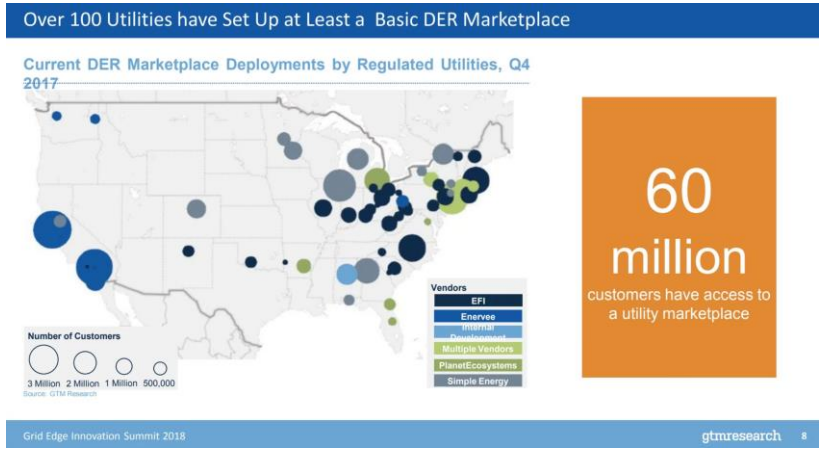


356,000 secondary models, 3.9 million components

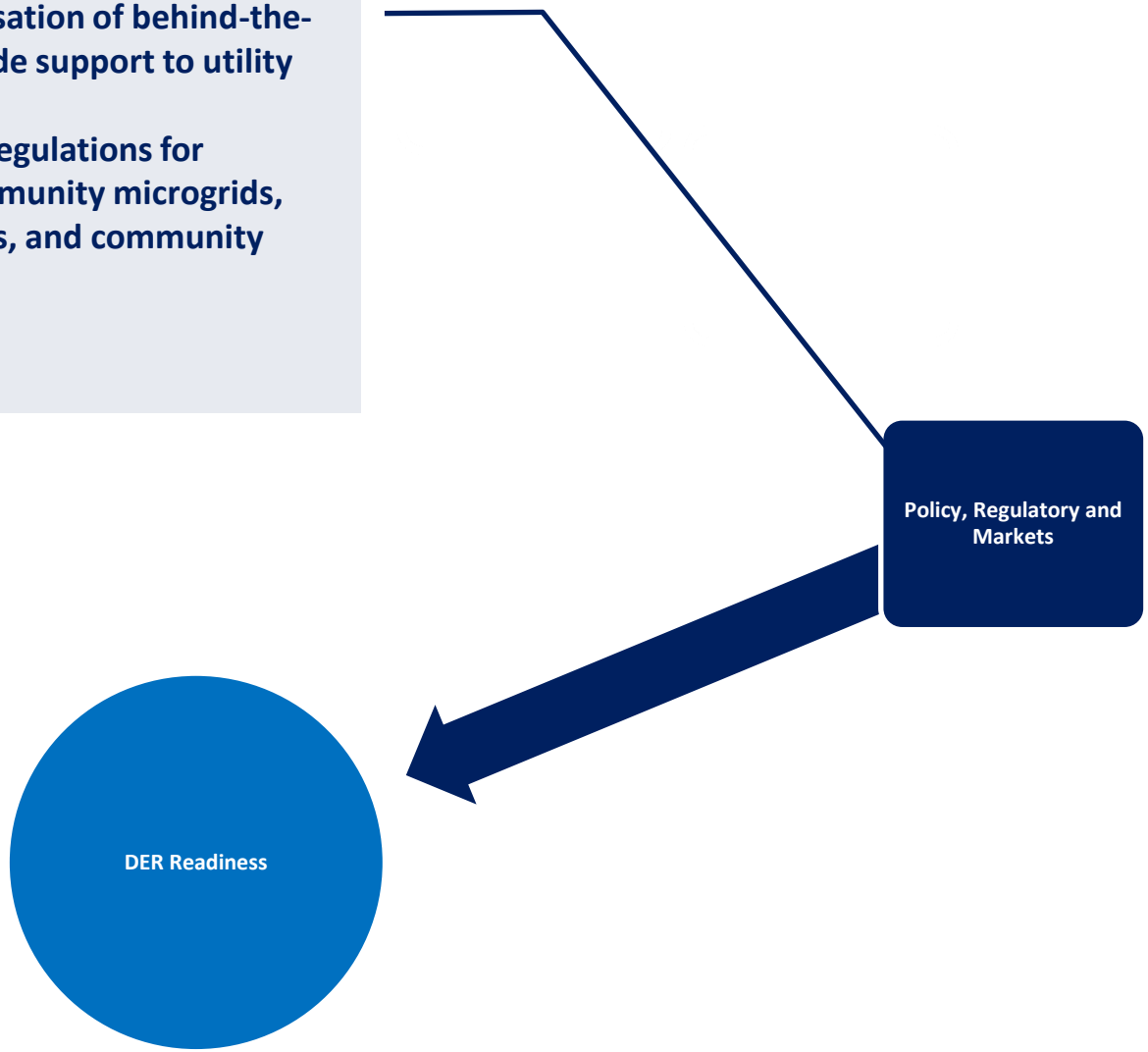
Source: Pepco Holdings Inc.

Policy, Regulatory and Markets

- Review/update of regulations for utilization/compensation of behind-the-meter DER to provide support to utility grid
- Review/update of regulations for deployment of community microgrids, virtual power plants, and community solar
- DER marketplace



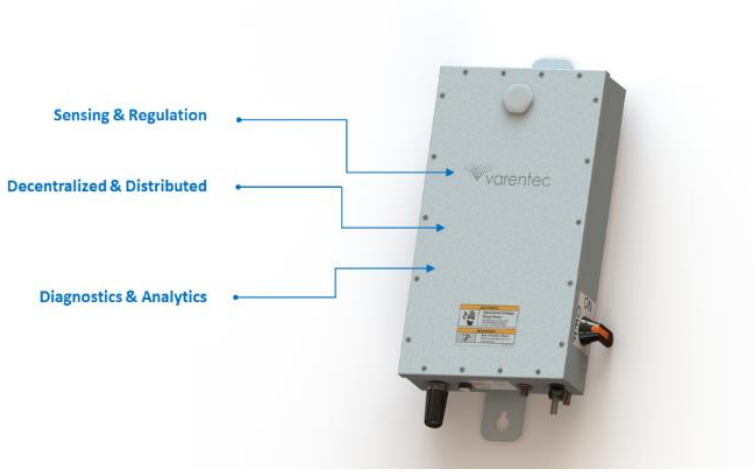
Source: https://www.greentechmedia.com/articles/read/distributed-energy-poised-for-explosive-growth-on-the-us-grid



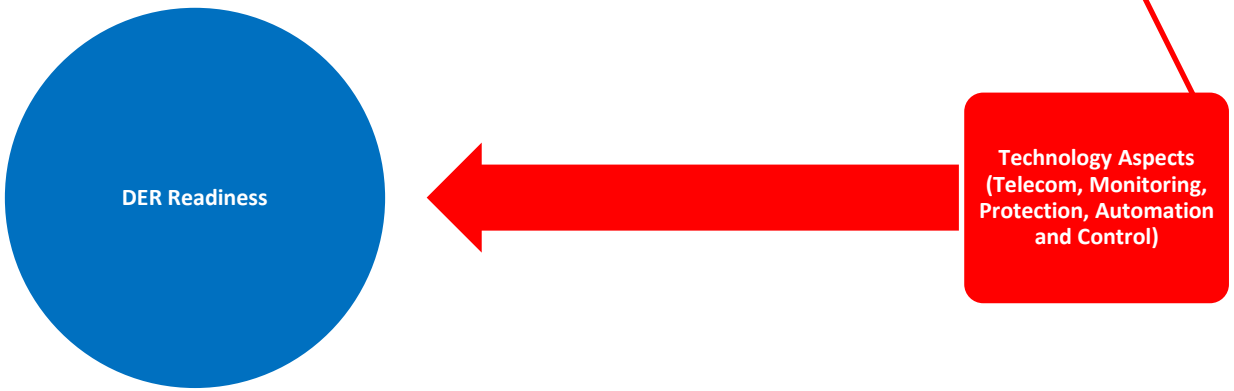
Technology Aspects

Source: ConnectDER

- **Requirements for telecom, monitoring, protection and automation and control equipment for in-front and behind-the-meter DER and/or impacted by DER (sensors, reclosers, switchgear, relays, voltage regulators, capacitor banks, LTCs, power electronics-based voltage regulation/control equipment, etc.)**
- **Interoperability, cybersecurity, IoT and smart cities requirements for integration of DER**



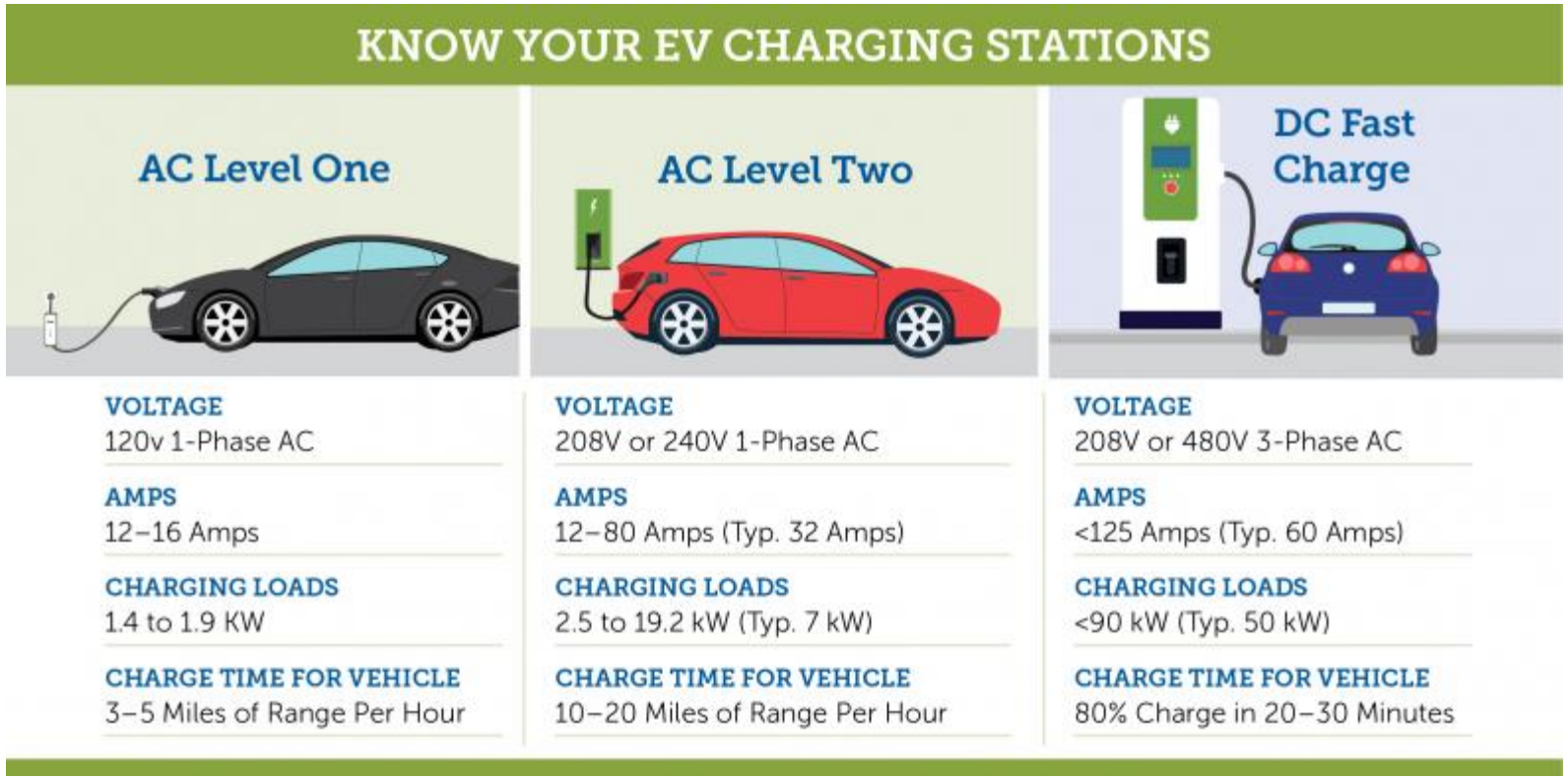
Source: Varentec



Conclusions

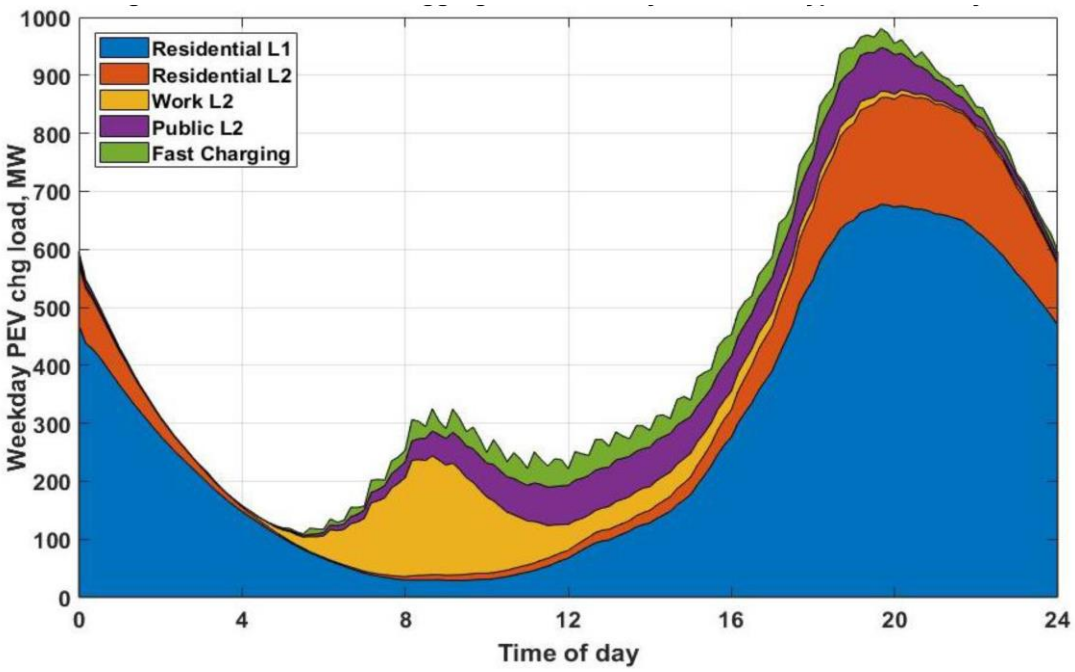
- Interconnection studies are necessary but not enough particularly when large proliferation of DER is expected
- Studies for large scale DER tend to be “deterministic”. Studies for residential and commercial scale DG require statistical analyses for handling uncertainty about location and occurrence. Moreover, they require analyzing a set of representative feeders and extrapolating results to overall system. These studies analyze both steady state and dynamic conditions
- Dynamic/transient impacts of DER cannot be identified using conventional distribution analysis software, more detailed modeling and simulations and specialized software are necessary
- Typical impacts are voltage rise/fluctuations, reverse power flow, reactive power fluctuations, interaction with voltage regulation and control equipment, localized overloads (distribution transformers and lines), etc.

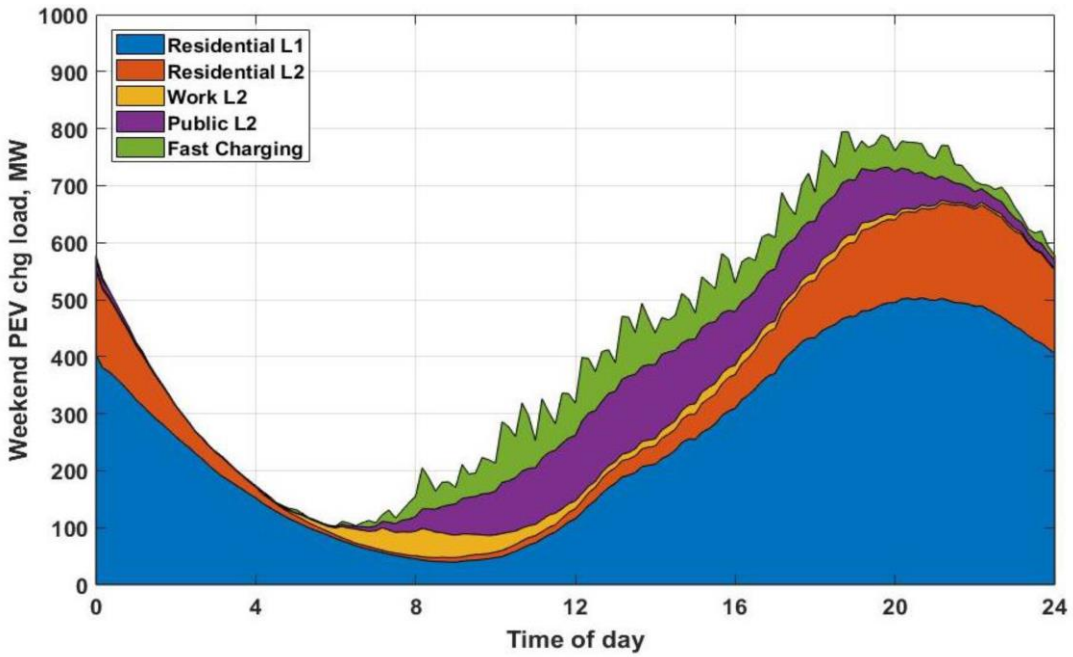
Electric Vehicle Charging Levels (SAE J1772)



Source: PNM https://www.pnm.com/ev-charging

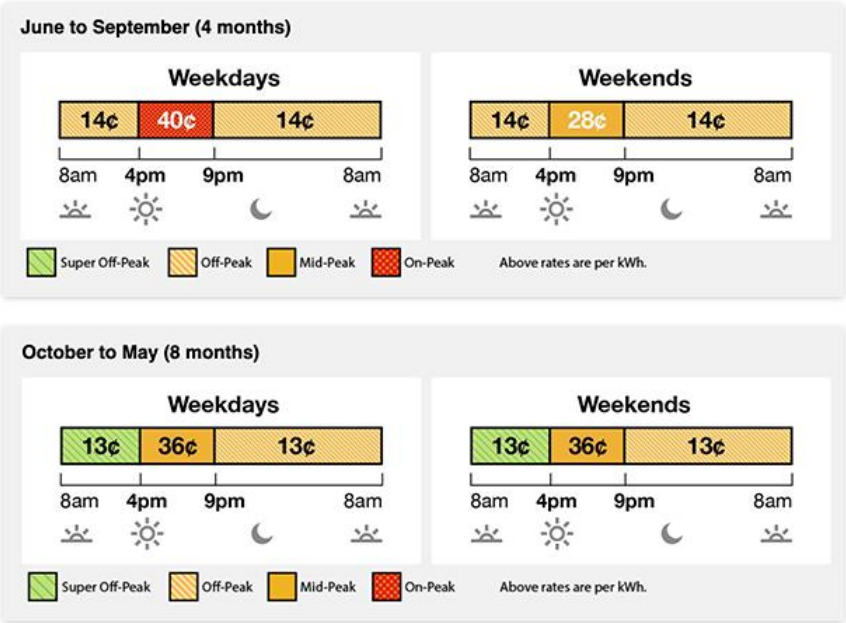
Electric Vehicle Charging Patterns



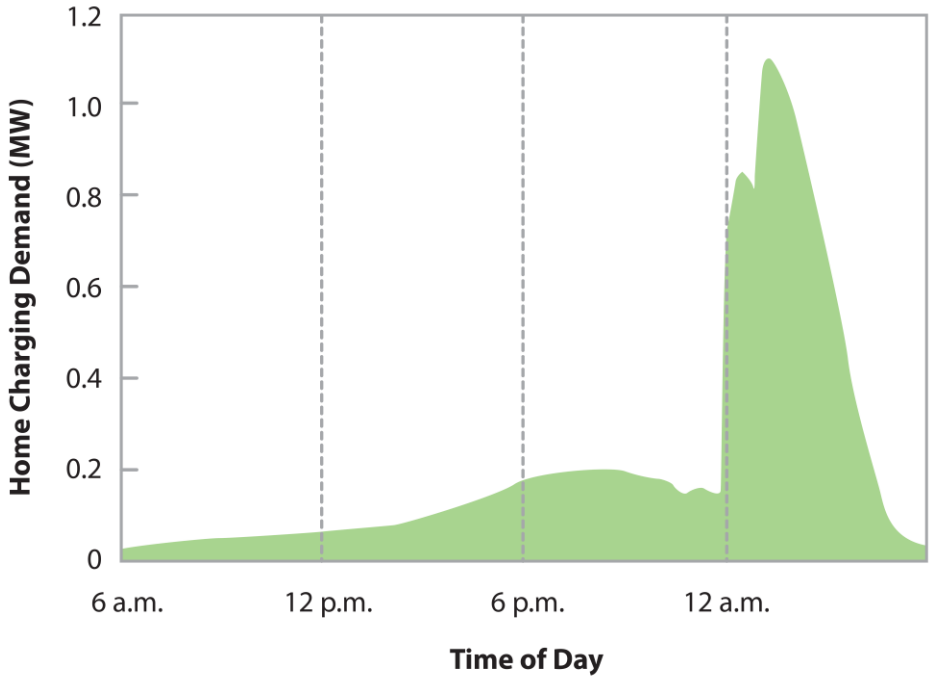


Source: NREL and California Energy Commission https://www.nrel.gov/docs/fy18osti/70893.pdf

Time of Use Rates and EV Charging Profile Modification



Source: EnergySage https://news.energysage.com/sce-tou-rates/

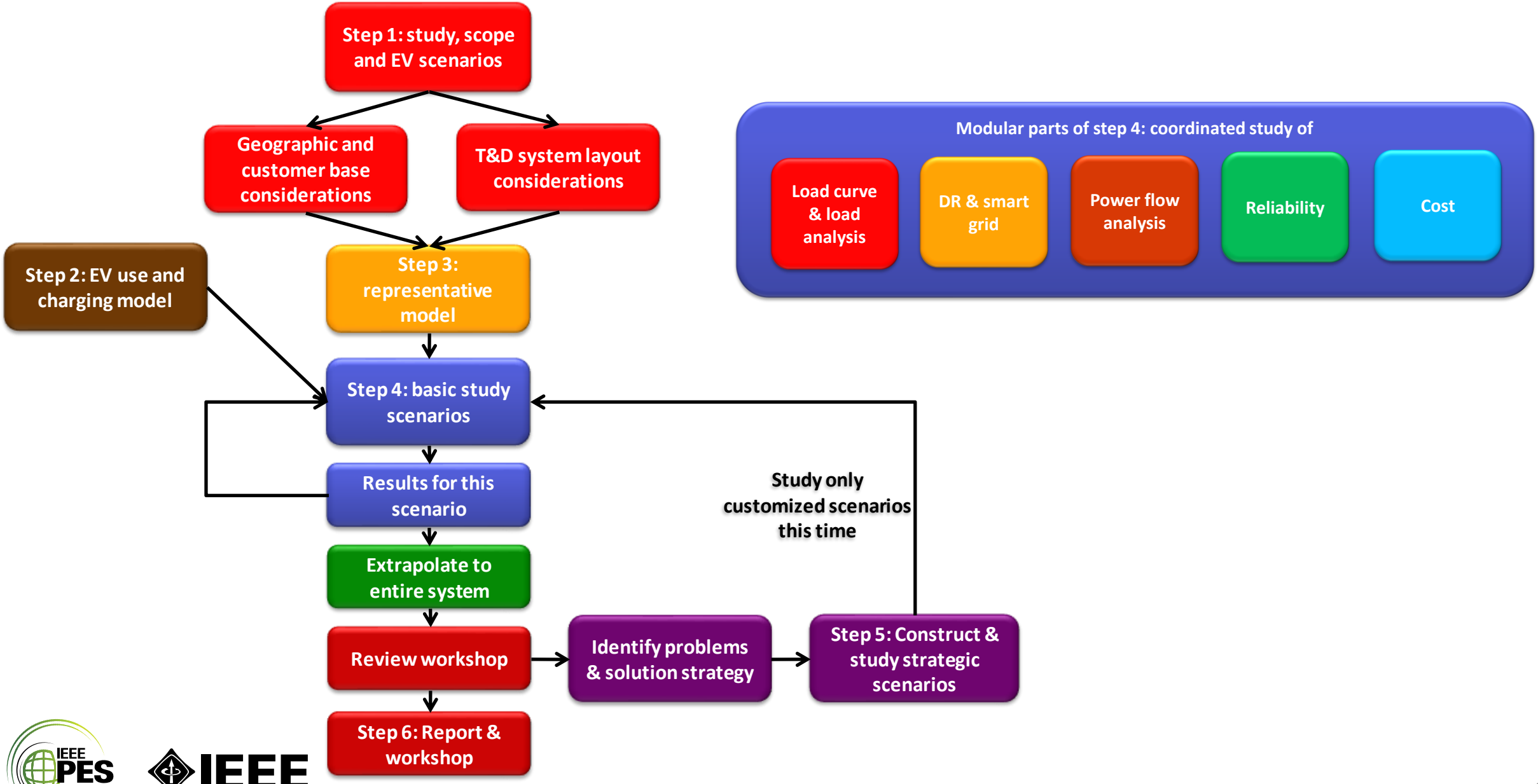


Source: Idaho National Laboratory
https://avt.inl.gov/sites/default/files/pdf/arra/PluggedInSummaryReport.pdf

Impact Studies for Integration of Electric Vehicles in Distribution Systems

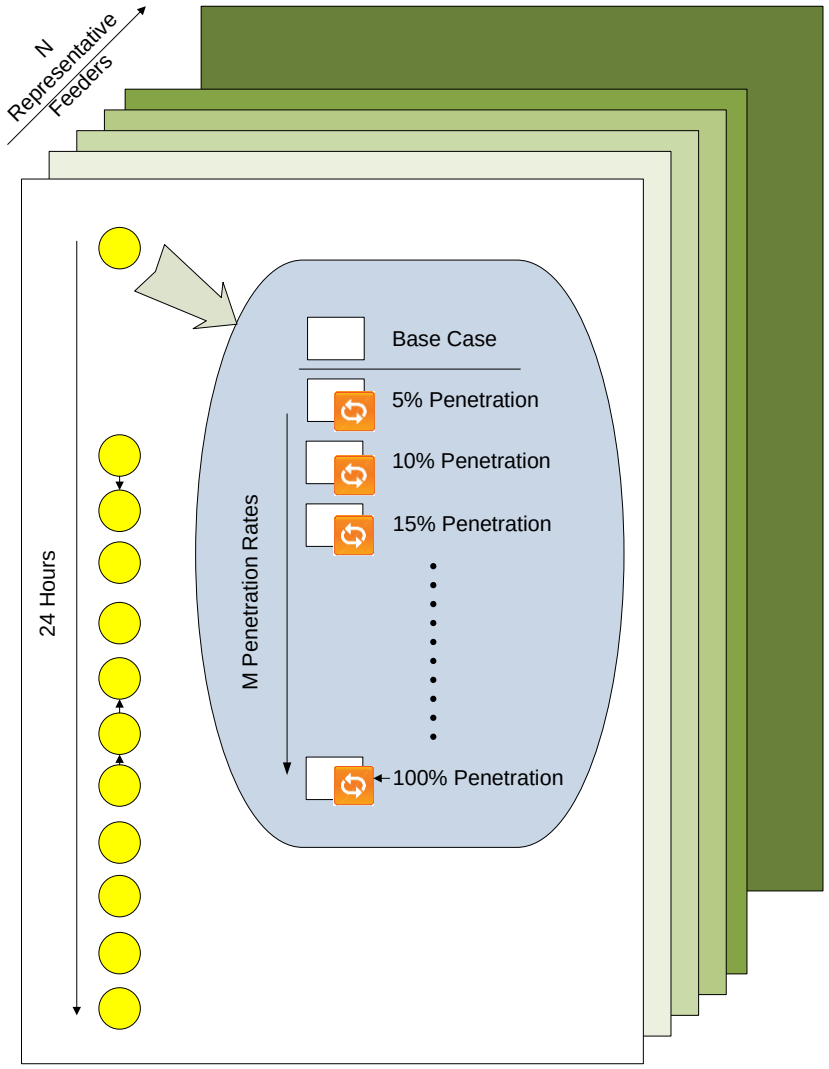
- Evaluate integration impacts of Electric Vehicles (EVs) on planning and operations of power distribution systems, including those on:
  - Voltage, voltage profile and current
  - Equipment loading and lifecycle
  - Voltage and current imbalance
  - Power and energy losses
  - Power factor
  - Load cycling and control
  - Power quality, reliability and operability of the system
- Propose solutions for addressing issues created by the potential large-scale adoption of EVs on power distributions systems, including distribution capacity increase, intelligent load control, incentives and utilization of Distributed Energy Resources (DER)

Methodology

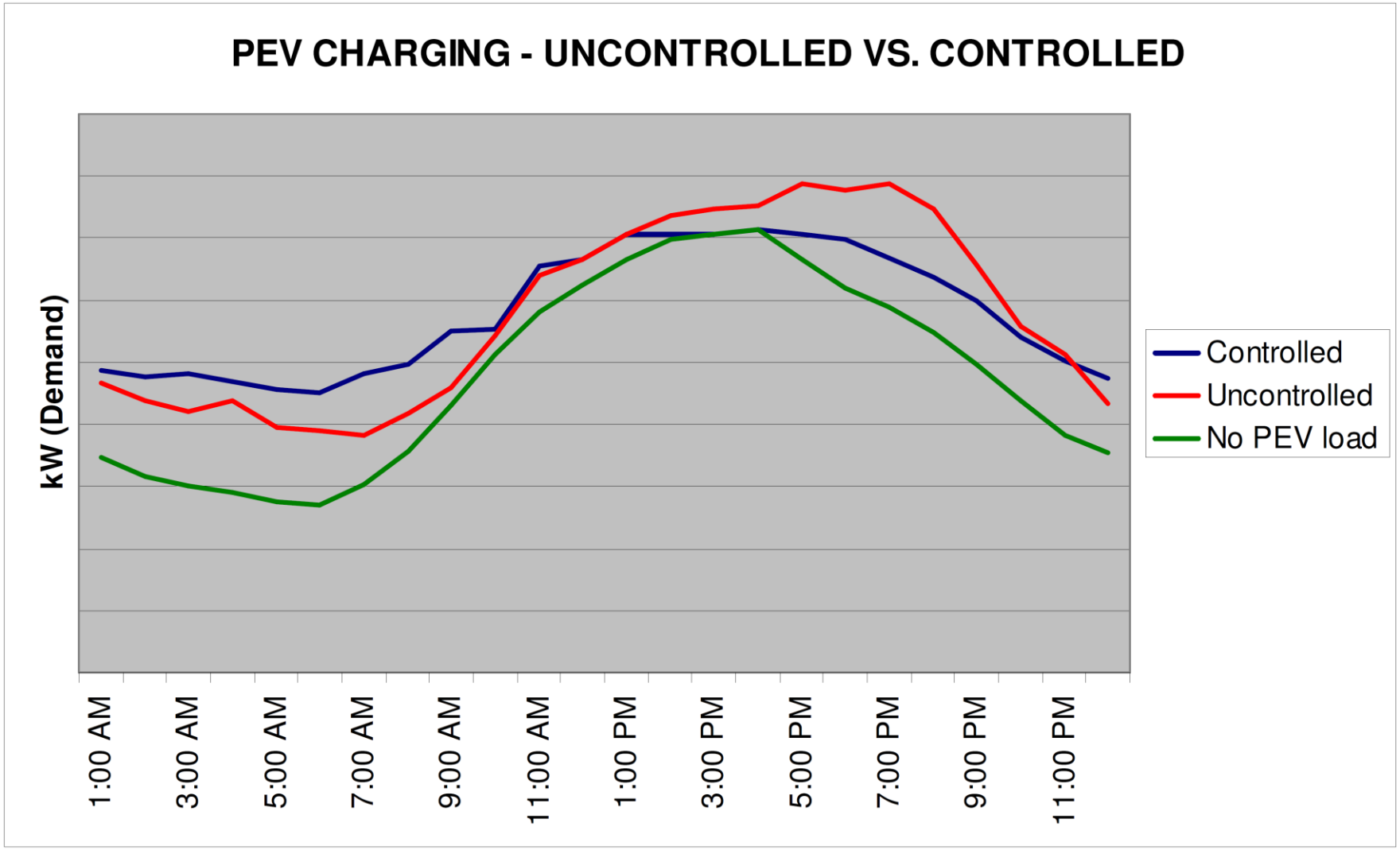


Simulation Approach

- **Number of EVs:**
  - Penetration rate: defined as number of EVs per household
- **Number of charging EVs:**
  - Charging scenario
  - Coincident factor: how many EVs are charging simultaneously
- **Location of charging EVs:**
  - Random assignment or based on demographic study



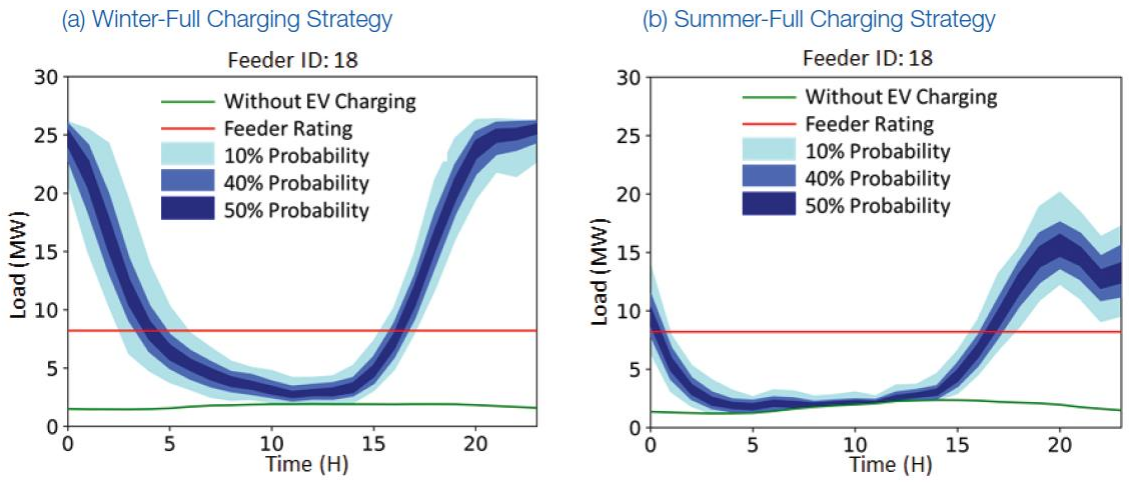
Results – Uncontrolled vs. Controlled EV Charging Scenarios (Example)

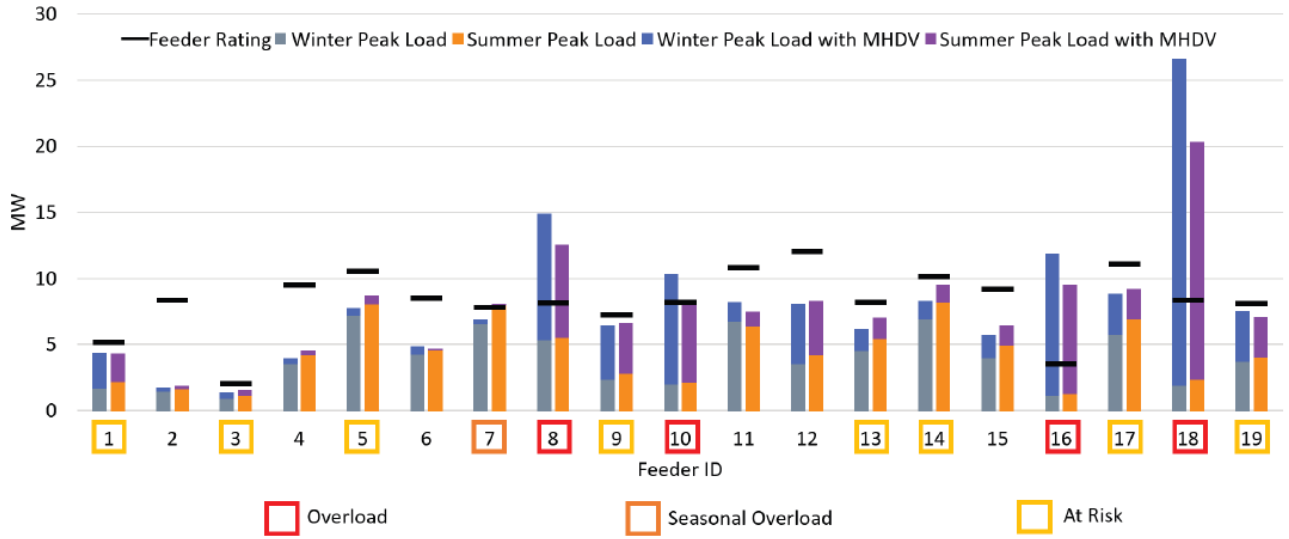


EV Integration Impacts – Examples

- Violation of feeder and substation planning limits during normal and contingency conditions due to loading increase caused by EV charging (e.g., EV charging may coincide with peak demand of residential feeders)
- Overloaded assets due to peak loading increase (e.g., service and power transformers, overhead line conductors, underground line cable, etc.)
- Low voltage due to loading increase and overloaded assets
- Reduced lifecycle of key assets due to changes in loading patterns of service and power transformers
- Voltage/current imbalance increase
- Power and energy loss increase

Impact of Electric Fleets on Distribution Feeders – Full Charging Strategy





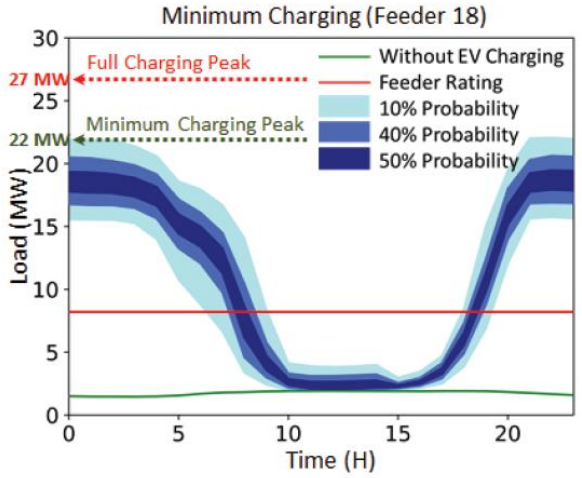
[21] "At Risk" = over 80% of rated load in one season.

Source: National Grid https://www.nationalgridus.com/media/pdfs/microsites/ev-fleet-program/understandinggridimpactsofelectricfleets.pdf

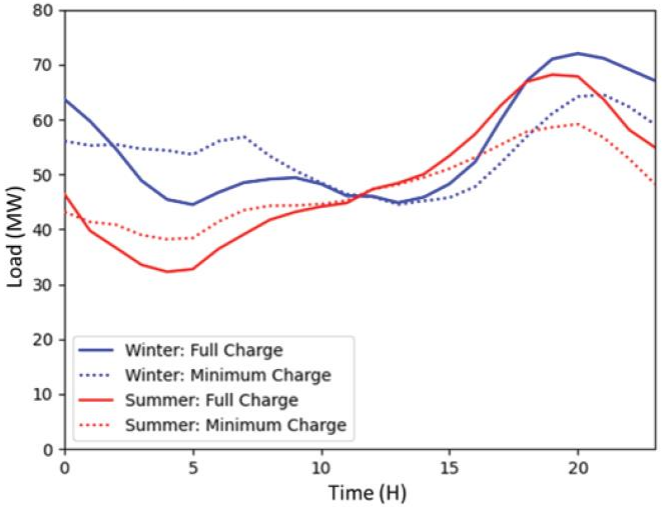
EV Integration Solutions – Examples

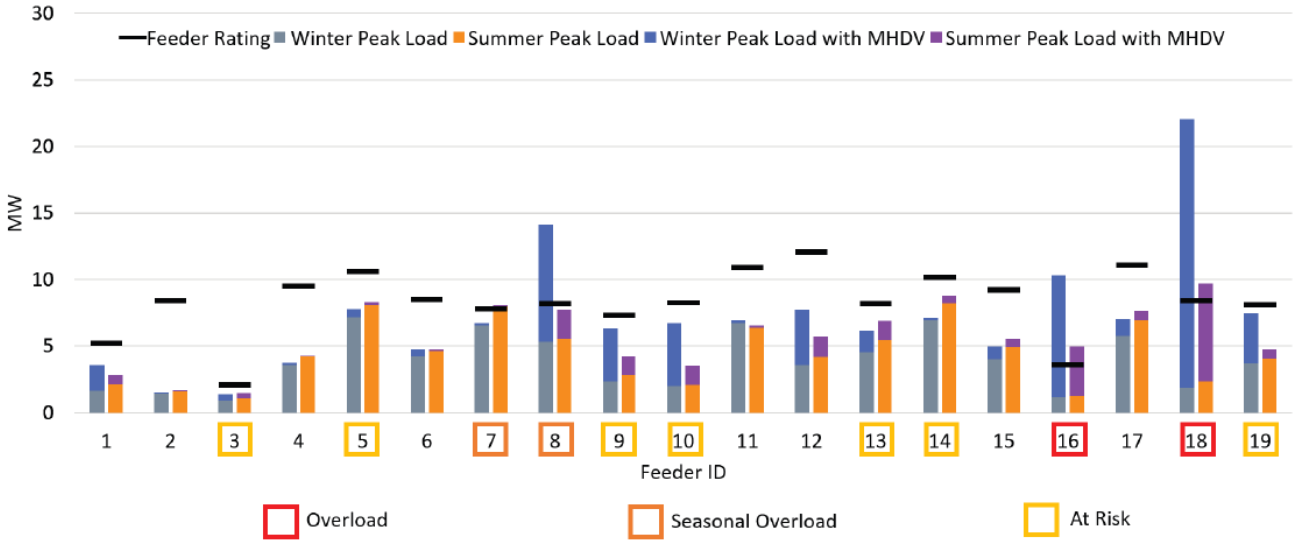
- Traditional T&D solutions
  - Replace overloaded transformers (upgrade)
  - Replace overloaded conductors/cable (reconductoring)
  - Eliminate undervoltage via reconductoring and capacitor banks
  - Build new feeders and substations (capacity increase)
- Intelligent solutions
  - Load control and curtailment
  - DER dispatch
  - Time-variant rates
- Usually, optimal solution portfolio includes a combination of traditional and intelligent solutions

Impact of Electric Fleets on Distribution Feeders – Minimum Charging Strategy



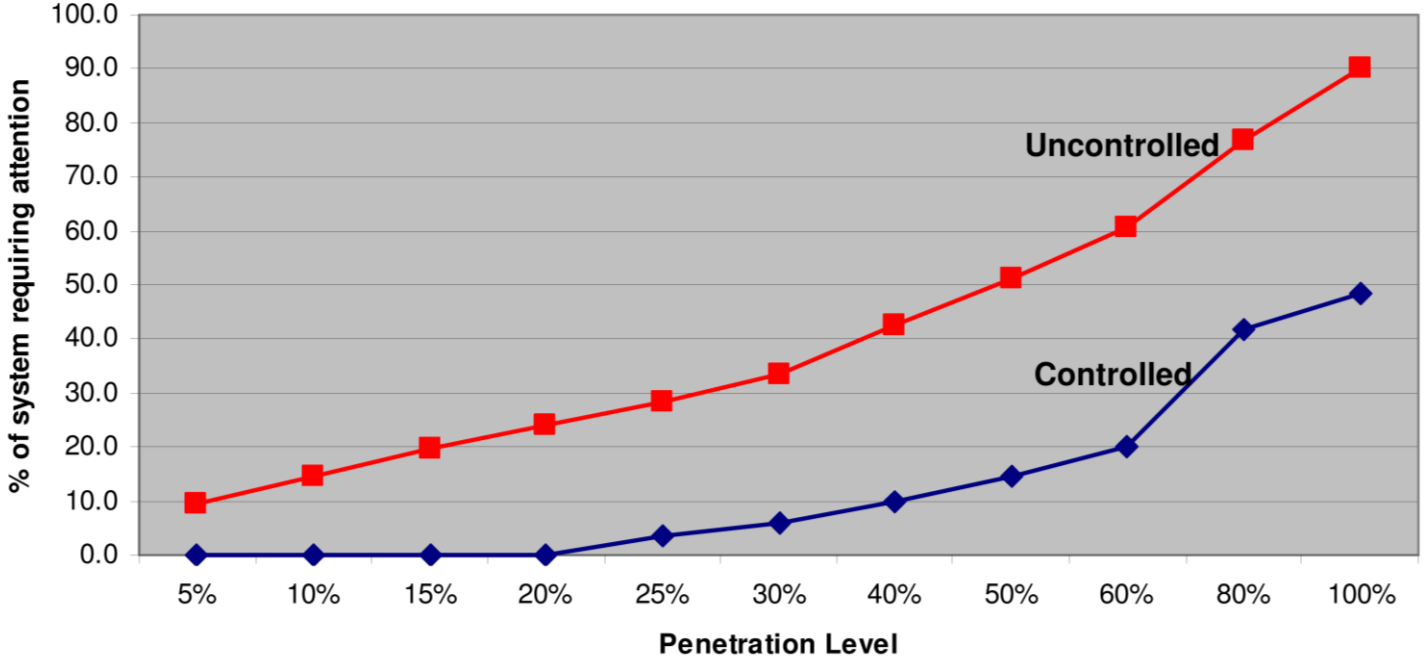
Impact on Substation Loading

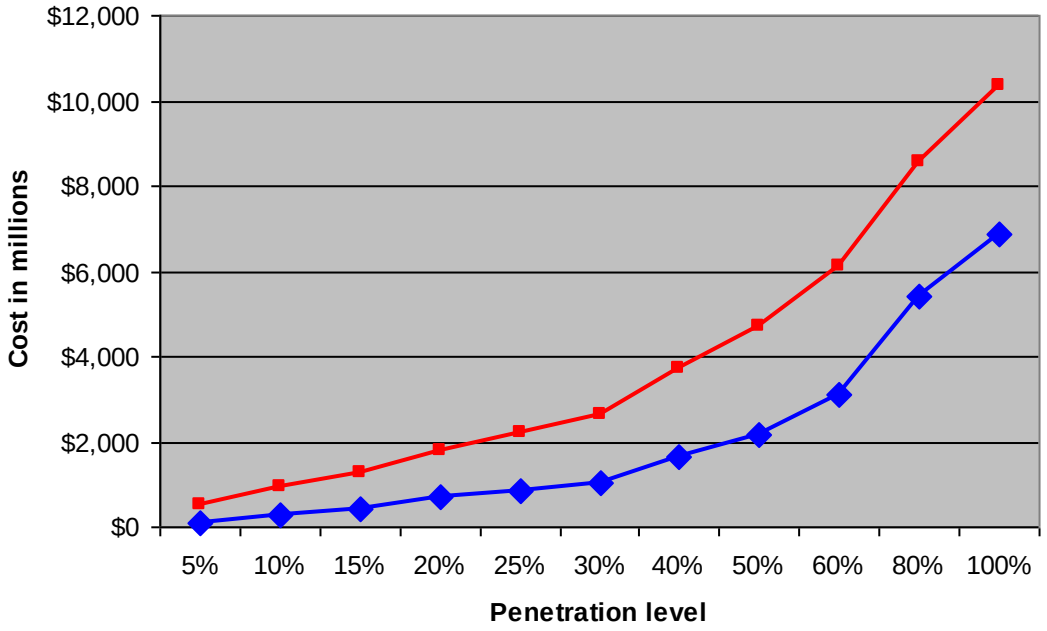




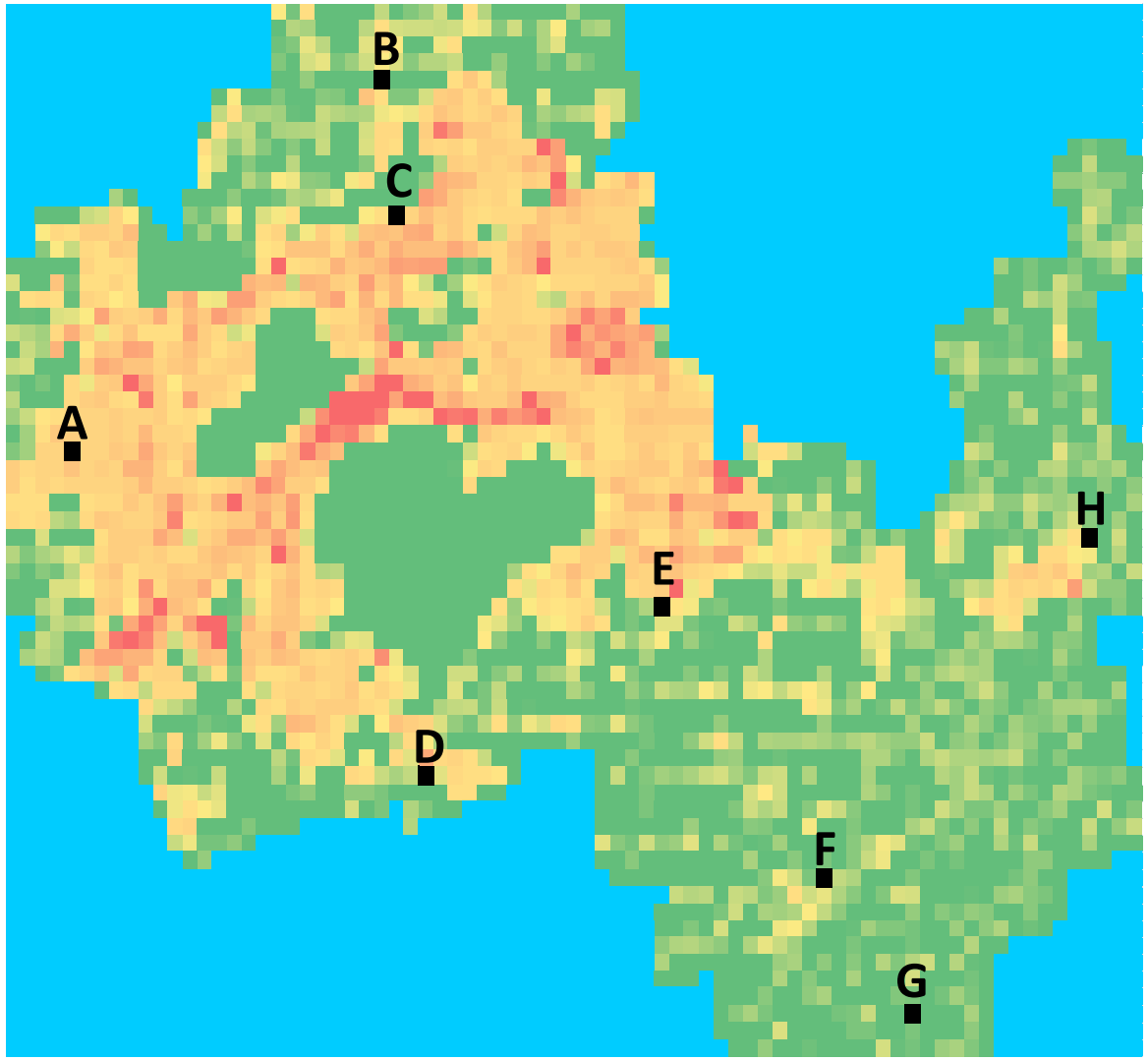
Source: National Grid https://www.nationalgridus.com/media/pdfs/microsites/ev-fleet-program/understandinggridimpactsofelectricfleets.pdf

System Integration Impacts & Costs vs. EV Penetration Level – Example

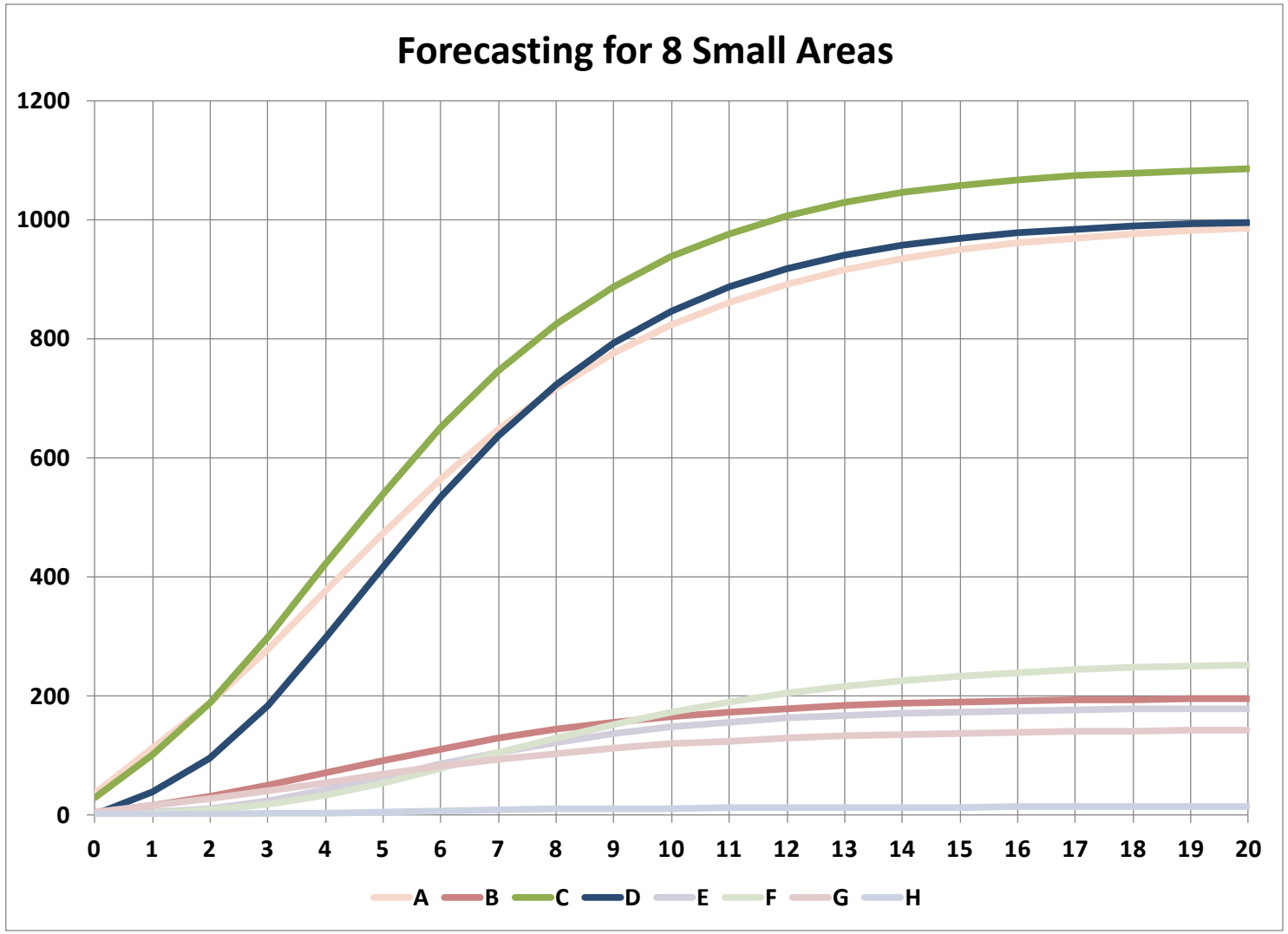




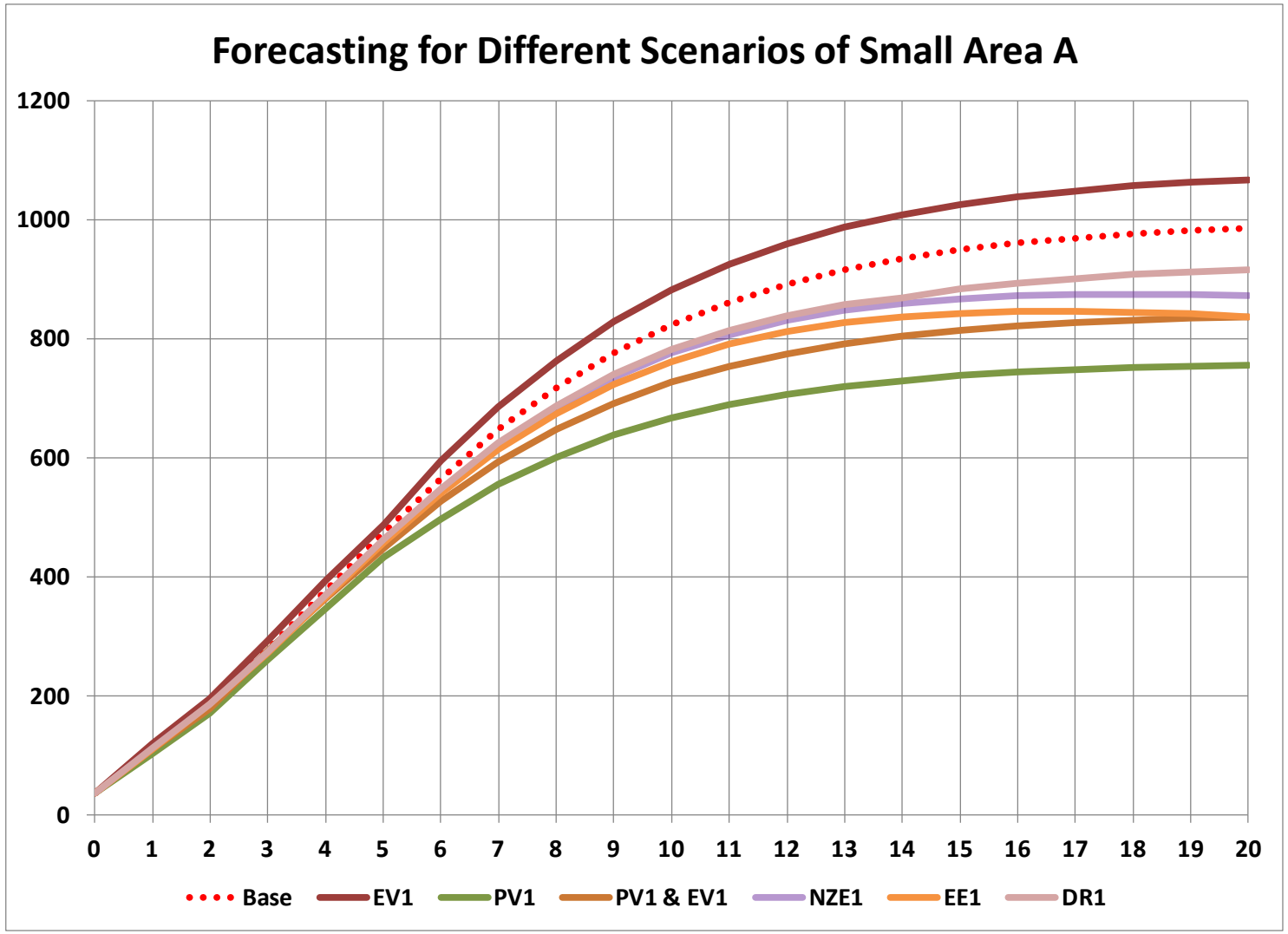
Spatial Characteristics of EV Integration Impacts – Annual Peak Demand



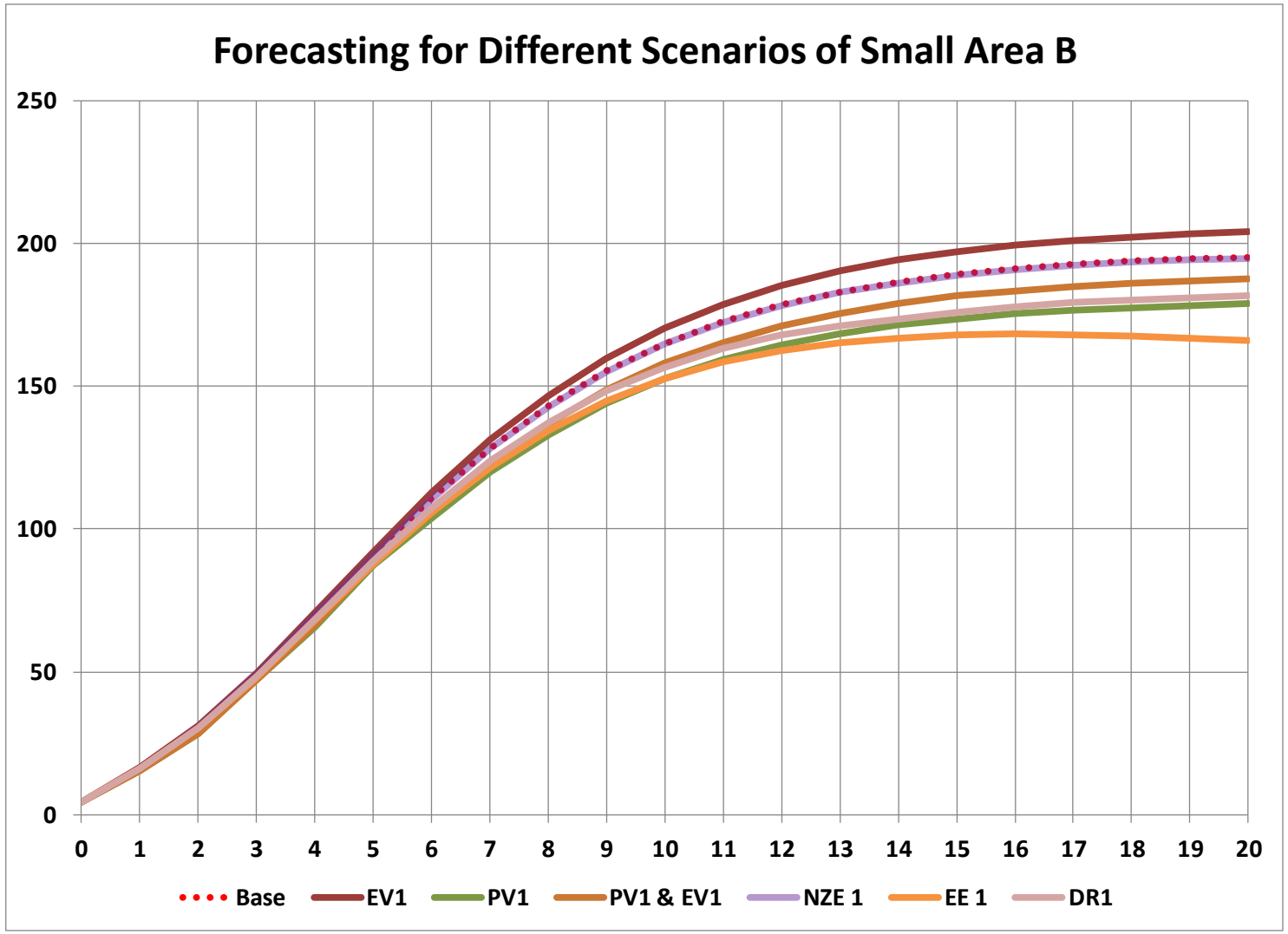
S-curve forecasting for 8 small areas (kW) – Annual Peak Demand



S-curve forecasting for small area A (kW) – Annual Peak Demand

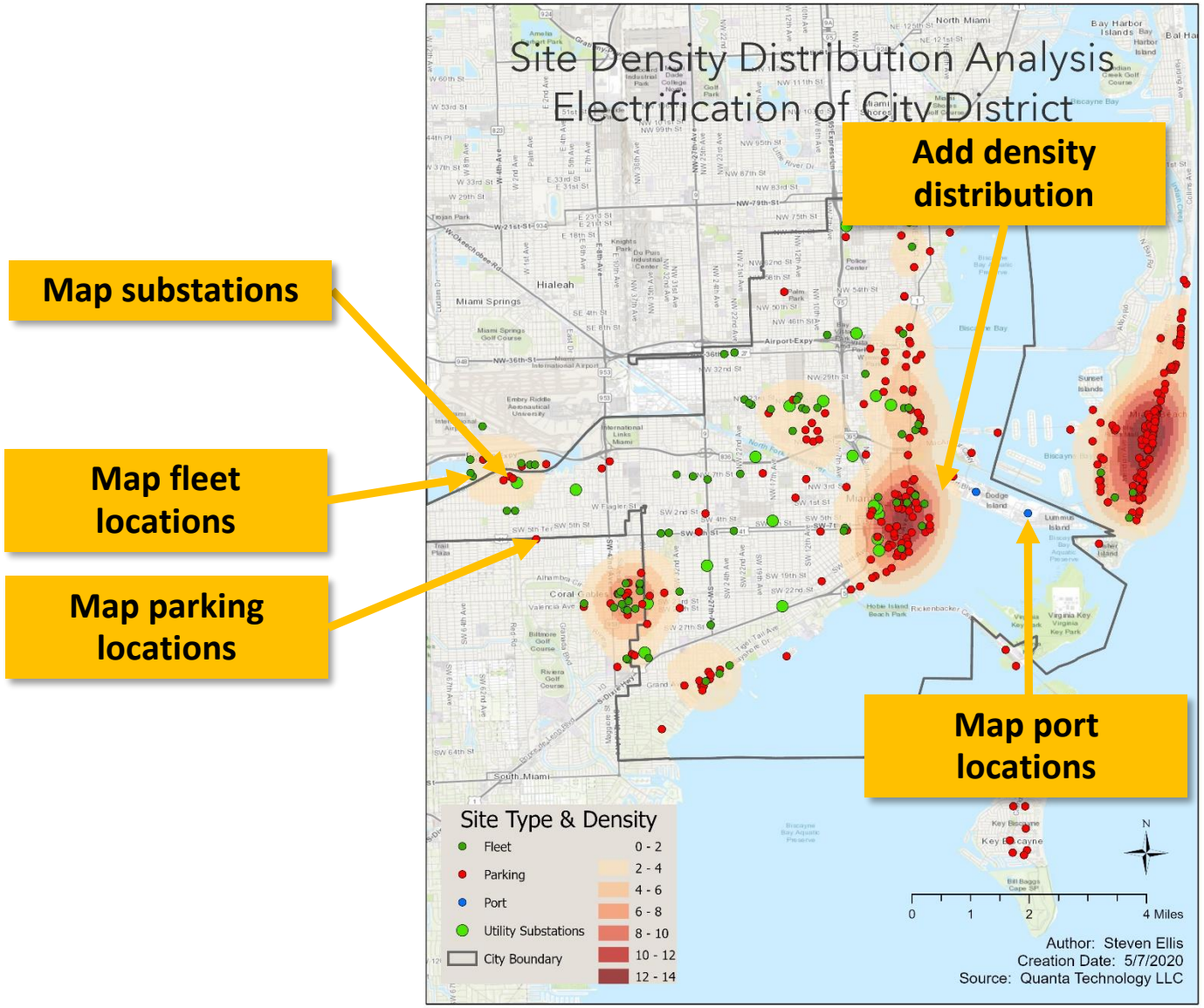


S-curve forecasting for small area B (kW) – Annual Peak Demand

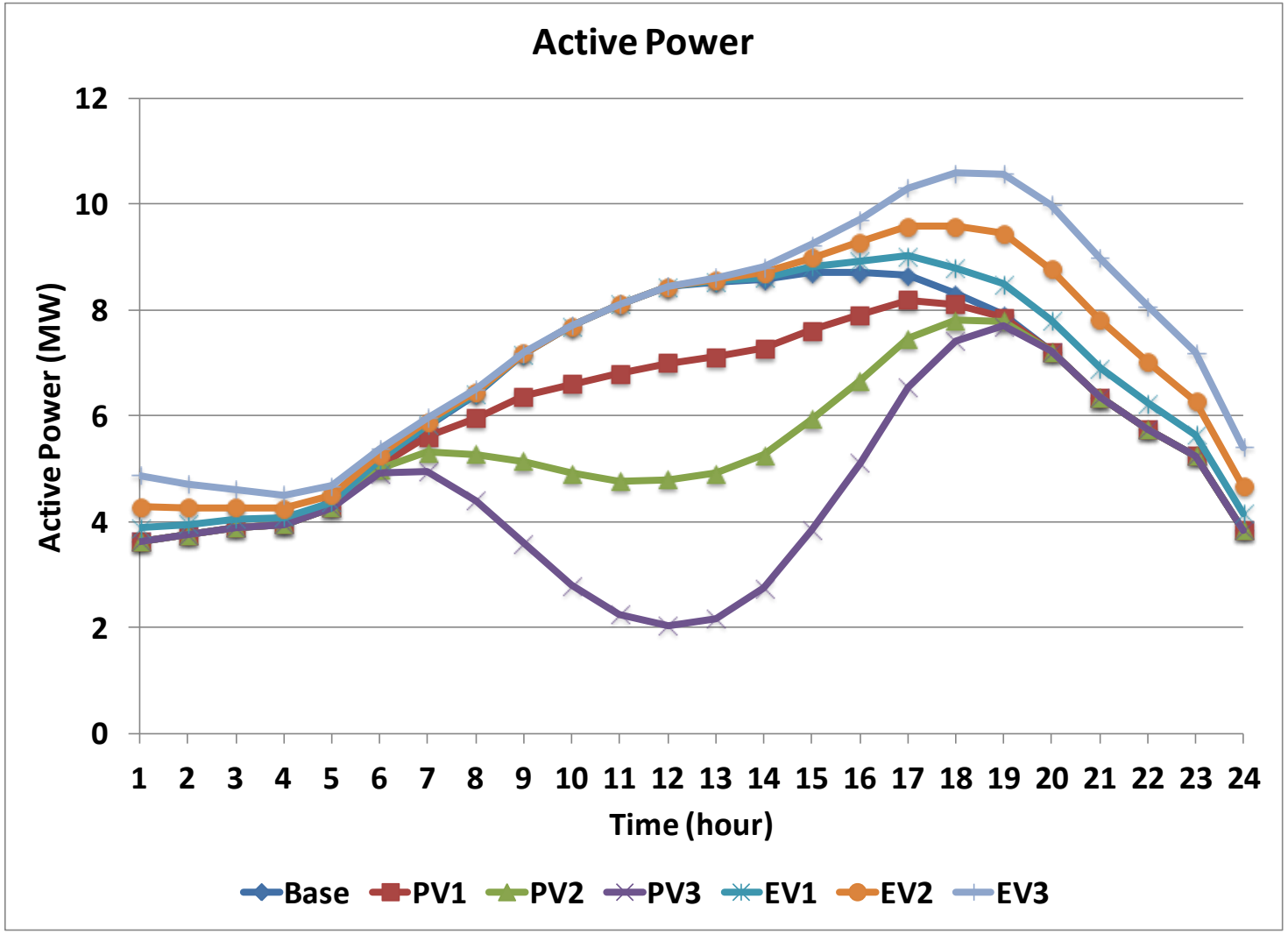


Transportation Electrification – Impacts of Fleets

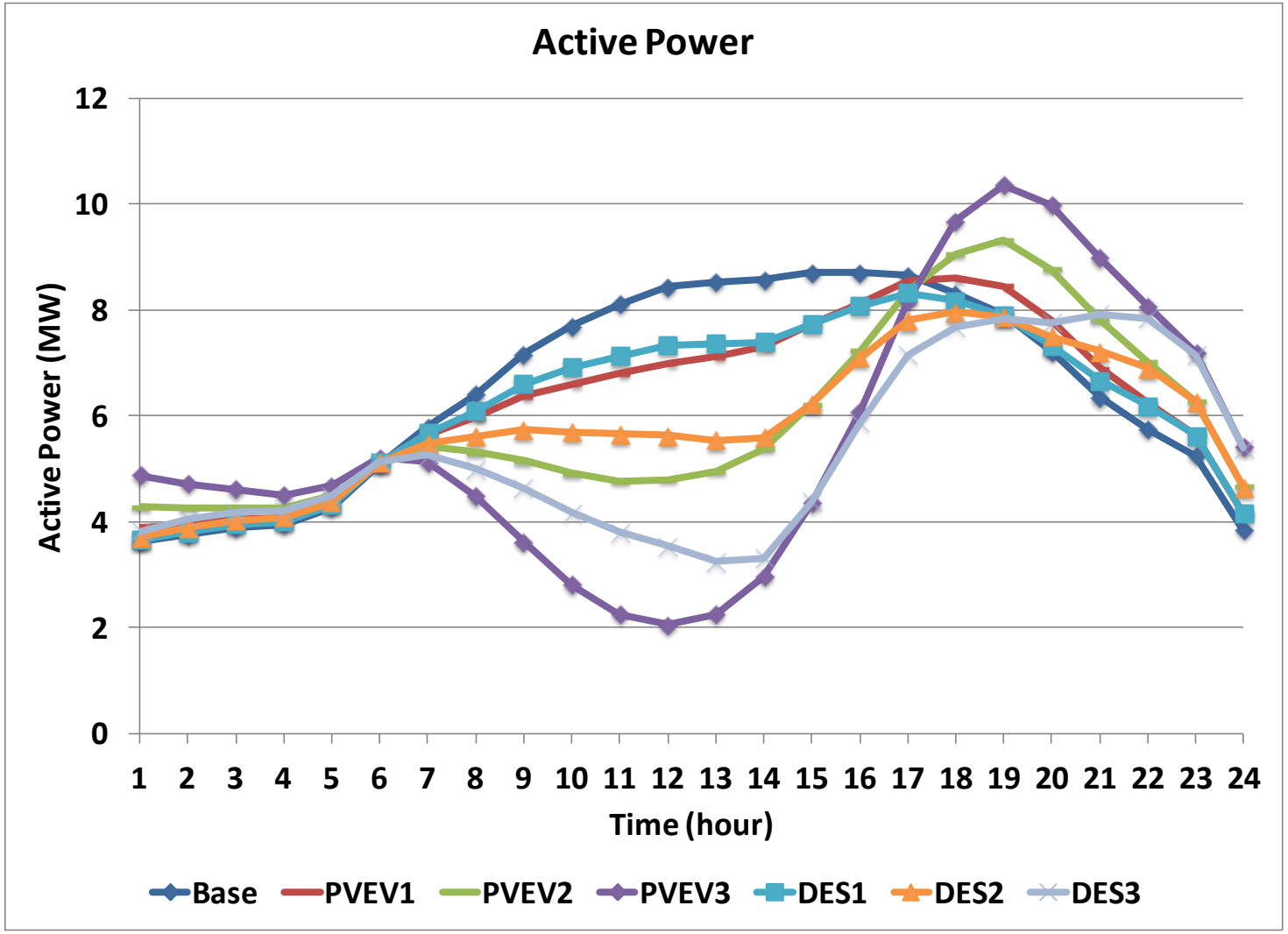
- Consider potential impact of transportation electrification in existing downtown infrastructure
- Methodology can localize future, projected charger load impacts on substations service territory:
  1. Identify and map substations via GPS or latitude/longitude coordinates
  2. Identify key commercial, retail, and fleet facilities in specified territory, and then estimate corresponding charger load growth
  3. Facilities are linked to specific substations via a distance algorithm
  4. New load growth from electrification is added to current substation rating and compared against its max rating
  5. Substations are then ranked against their max rating to determine whether substation is at risk due to load



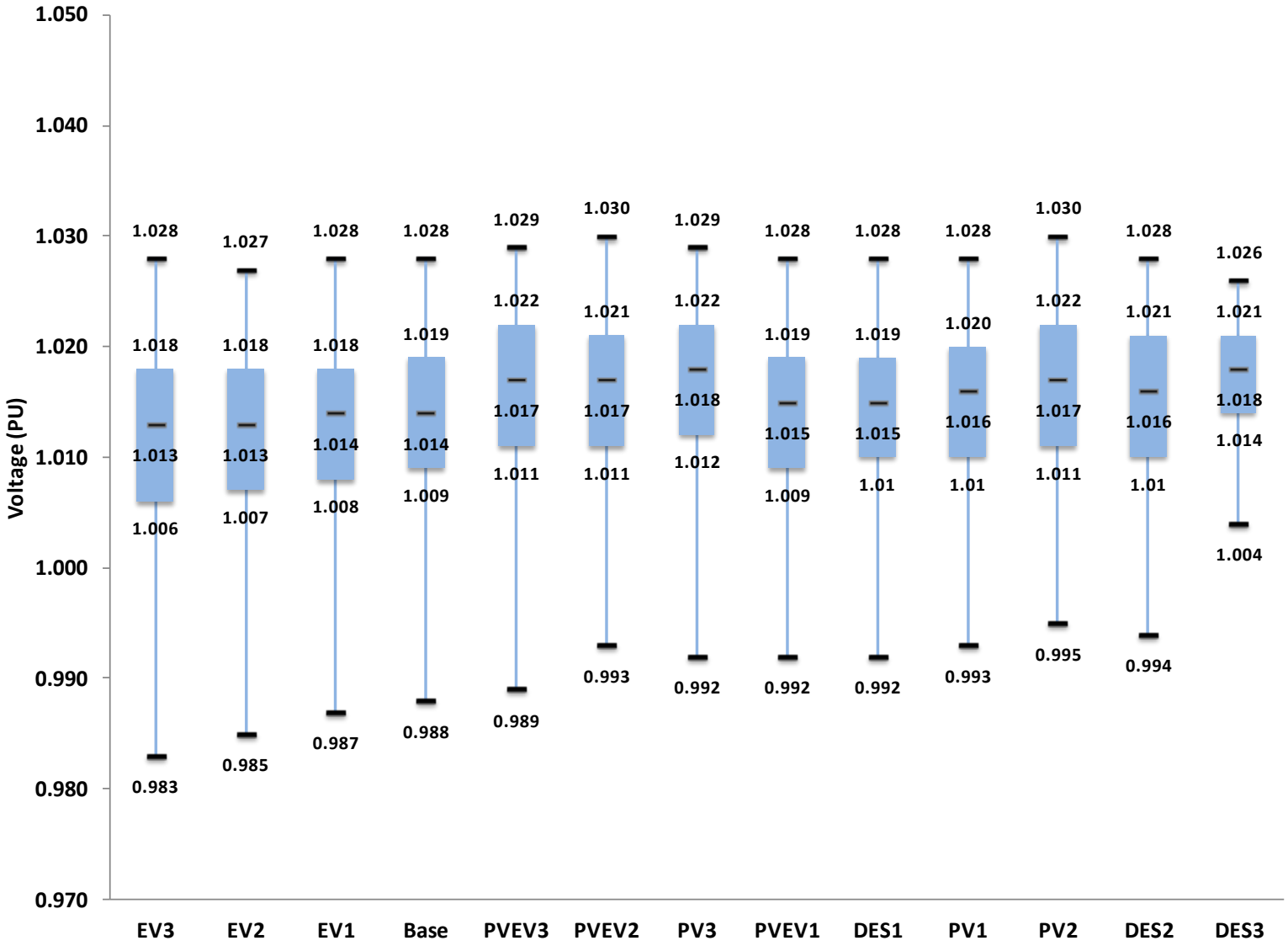
EV, PV-DG and DES synergies



EV, PV-DG and DES synergies



EV, PV-DG and DES synergies



Conclusions and Recommendations

- EV integration impacts may be significant even at low penetration levels if charging is uncontrolled.
- Impacts include:
  - Overloaded distribution transformers
  - Overloaded conductors and cable
  - Low voltage to customers
  - Violations of planning limits
- Most of these impacts can be resolved by directly or indirectly controlling the time and duration of EV charging
- Utilities should understand the potential impact of EVs on their respective service territories.
- Set up a system to identify new EVs when they come onto the system. A key to managing costs and keeping impacts to a minimum through pro-active actions is to know where the EVs are before problems become serious.
- Study how EV adoption rates, particularly on a local-area basis, can be predicted or trended, in order to support planning of required additions
- EVs may have an impact at low penetration levels, especially in areas of early adopters (clusters)

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