UM 1716

Reliability Commission Workshop

OPUC, January 19, 2016

Agenda

1. Introductions and Goals – 5 mins
2. Debbie Lew – General Electric – 25 mins
3. Colton Ching – Hawaiian Elec – 25 mins

---Break - 5 mins ---

4. PGE, PAC, Idaho – 15 mins each
5. Other Parties – 15 mins

UM 1716

Reliability Workshop

January 19, 2016

DEBBIE LEW

GE Consulting

COLTON CHING

Vice President, Energy Delivery for Hawaiian Electric

UM 1716

Reliability Impacts of Distributed PV

Debra Lew

Oregon PUC Workshop on Resource Value of Solar

Jan 19, 2016

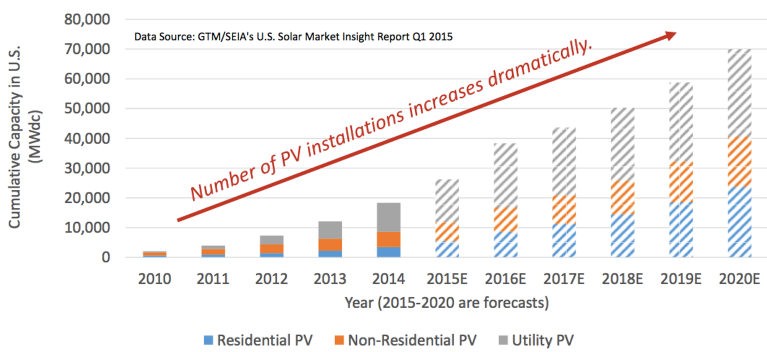
Imagination at work

1) Reliability impacts of distributed PV are manageable.

2) Good planning can save money, time, and effort.

Distributed PV growing quickly

Development and forecast of Solar PV in the United States.



Many benefits

Capacity – Producing power near peak periods

Avoided energy

Avoided emissions

Producing power at load centers – less losses

Reduced transmission congestion

Potential deferring of distribution upgrades

System and localized benefits with smart inverters

Low penetrations of distributed PV – reliability impacts at the feeder level

Reliability impacts are at the feeder level with low penetrations of DER

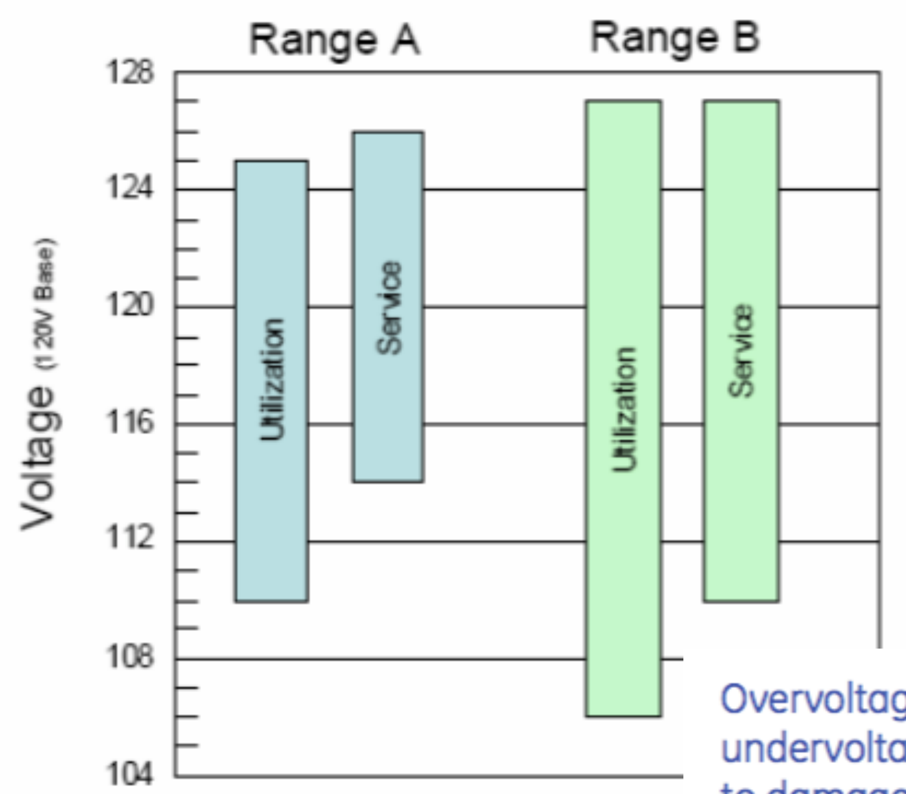
Islanding

Voltage regulation

Thermal limits

Protection

Back-feeding

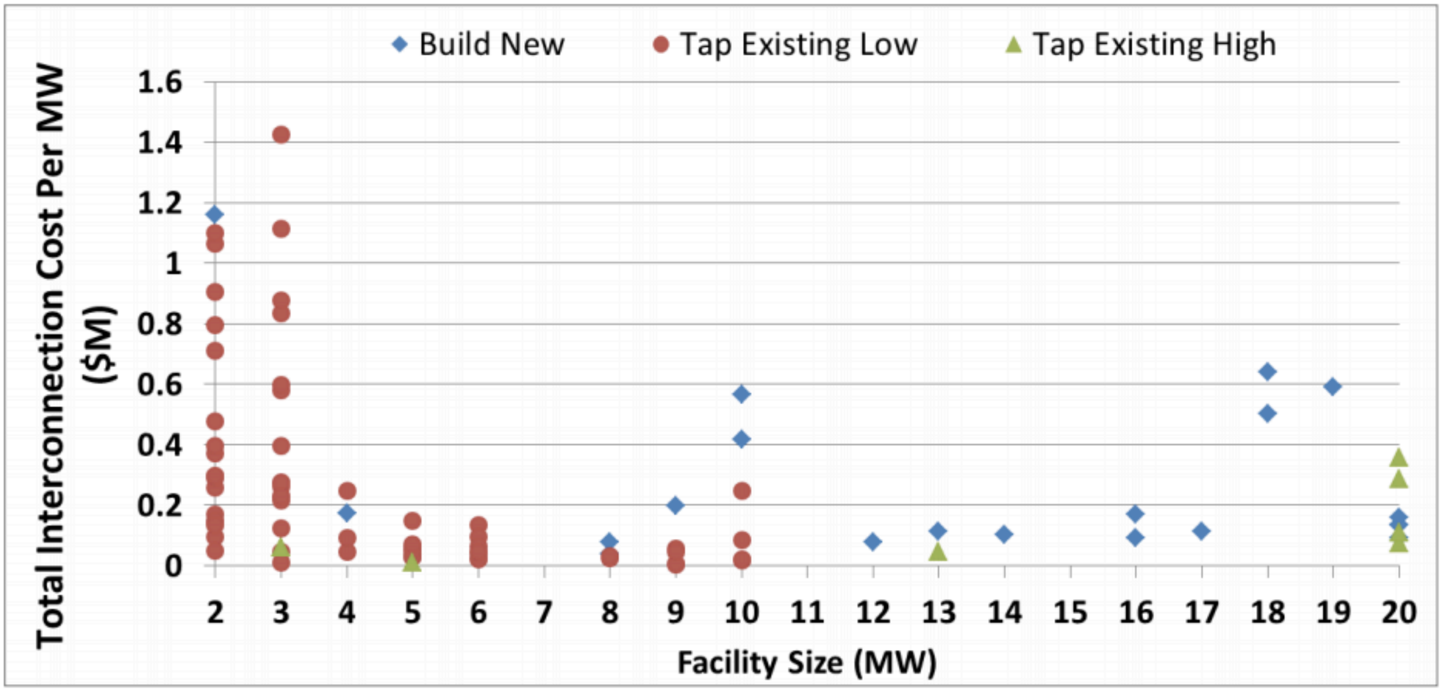


Overvoltages or undervoltages may lead to damaged equipment, misoperations, loss-of-life

Transient voltage deviations (harmonic distortion, sags, swells, surges) are unacceptable

Survey of interconnection costs for 100 systems

Cost Analysis –
Cost Per MW vs. Facility Size



Ranged from $2,444 to $1,424,400. 50% less than $133,833.

37

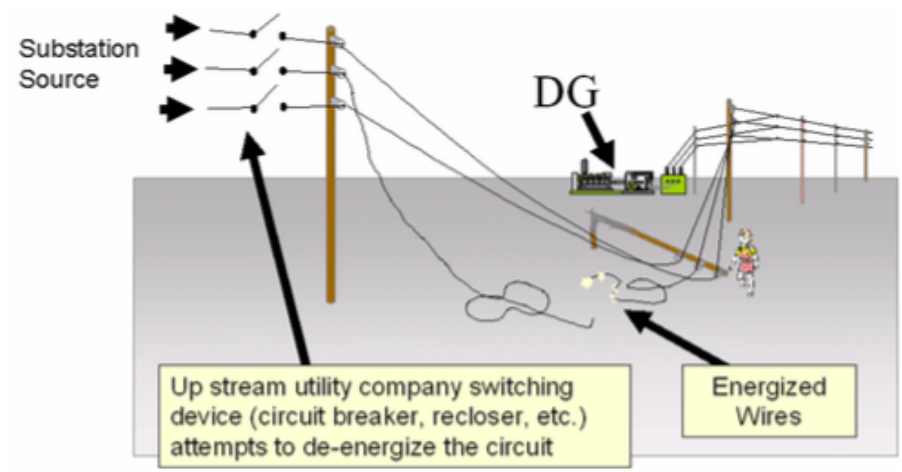
http://energy.sandia.gov/wp-content/gallery/uploads/dlm_uploads/Analysis-of-100-SGIP-Interconnection-Studies.pdf

Islanding is a very remote possibility

The possibility of islanding is extremely remote as many electrical parameters have to match up to make this possible.

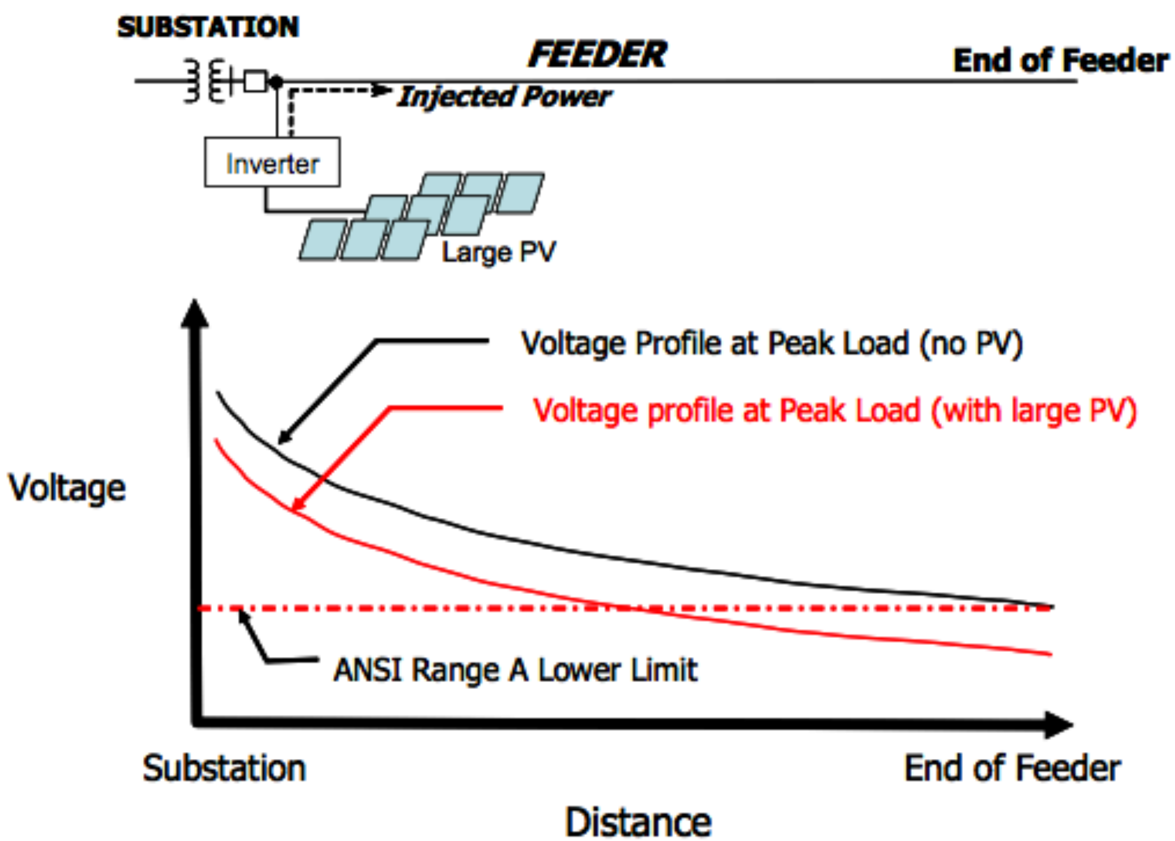
Consequences of islanding include:

- Safety
- Equipment damage
- Recloser operation



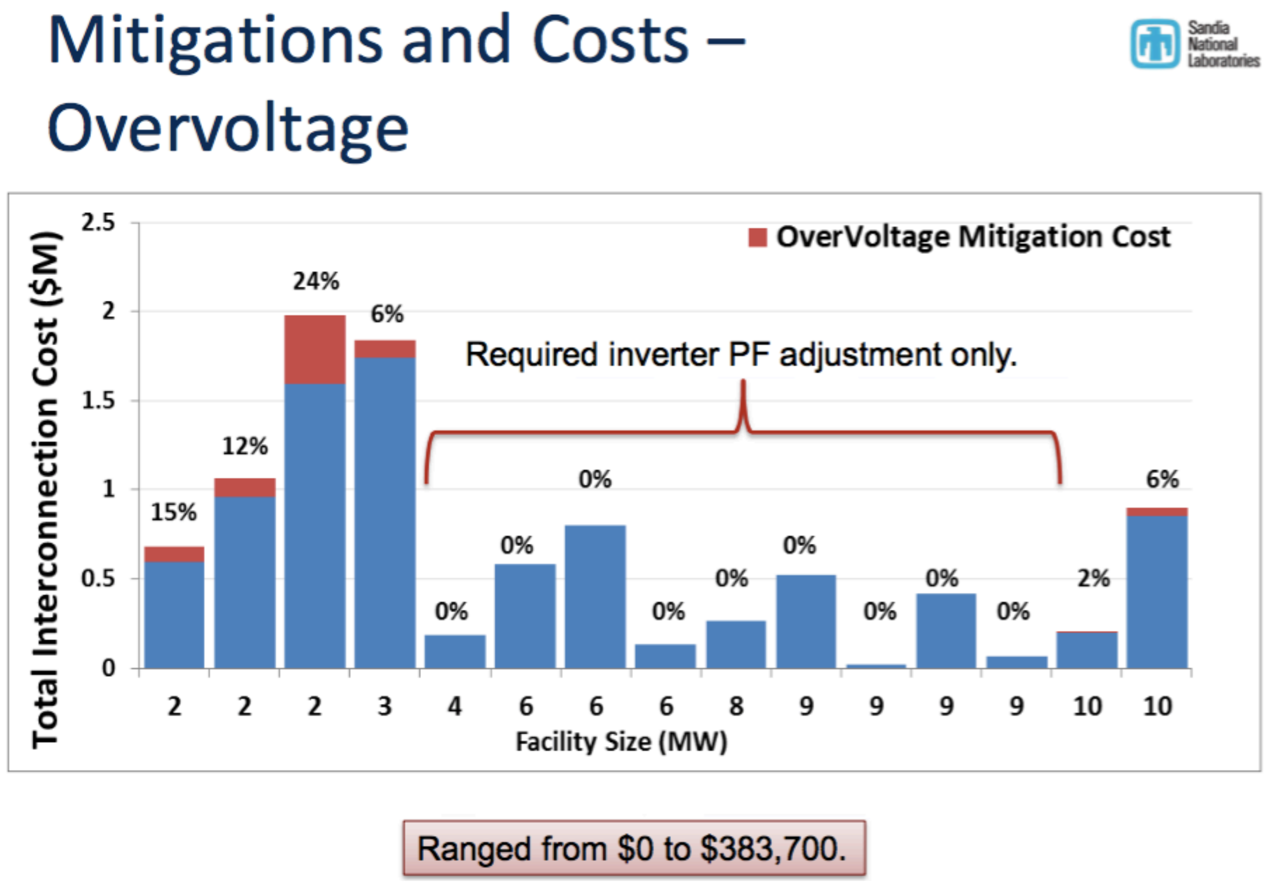
Graphic source: McGranaghan, EPRI, Sandia 2008-0944, 2008

Voltage impacts are more common



Graphic source: McGranaghan, EPRI, Sandia 2008-0944, 2008

Costs of voltage mitigation from survey of 100 systems



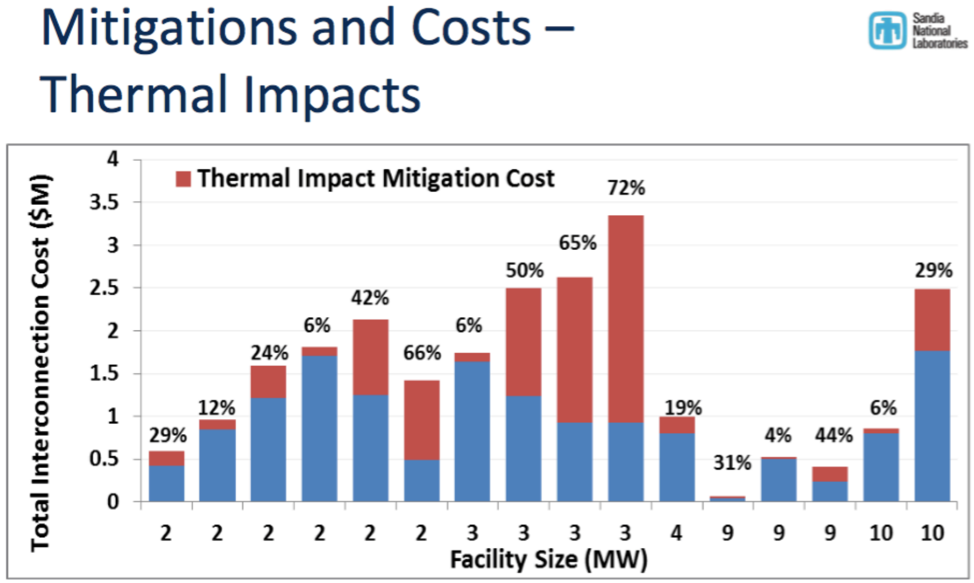
http://energy.sandia.gov/wp-content/gallery/uploads/dlm_uploads/Analysis-of-100-SGIP-Interconnection-Studies.pdf

Thermal limits

Conductor overloads

Transformer overloads

Mitigations and Costs – Thermal Impacts



Ranged from $20,000 to $2,415,100. Included upgrades to conductor sections and voltage regulation equipment.

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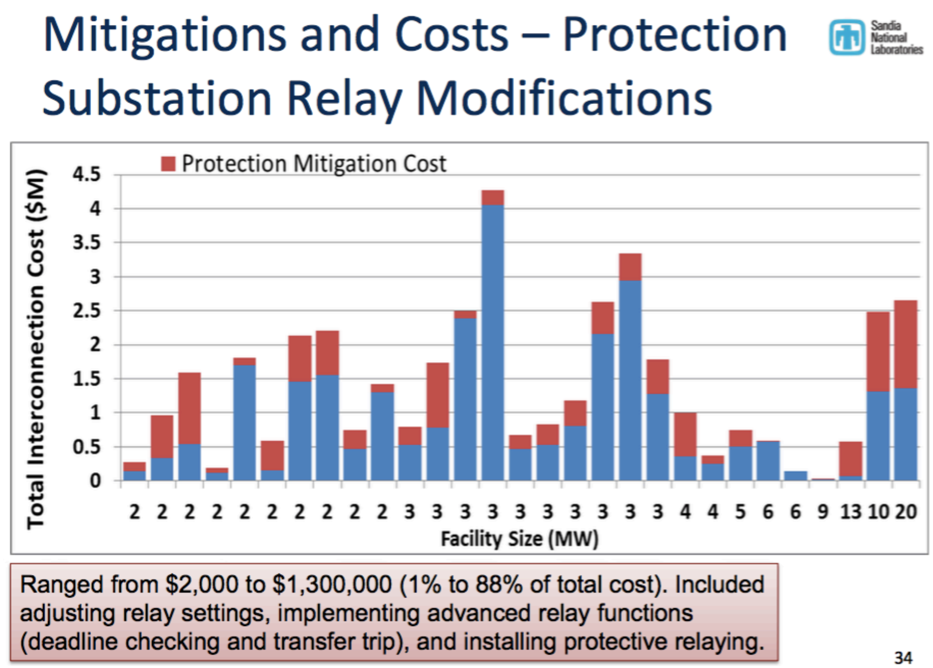
http://energy.sandia.gov/wp-content/gallery/uploads/dlm_uploads/Analysis-of-100-SGIP-Interconnection-Studies.pdf

Protection impacts are also more common

In case of a fault, protection devices act to isolate the fault, clear the fault, while keeping in operation as much of the rest of system as possible.

- Overcurrent relays and circuit breakers
- Reclosers
- Sectionalizers
- Fuses

Check for miscoordination, nuisance tripping, or hampering of fault detection.



http://energy.sandia.gov/wp-content/gallery/uploads/dlm_uploads/Analysis-of-100-SGIP-Interconnection-Studies.pdf

Screening processes

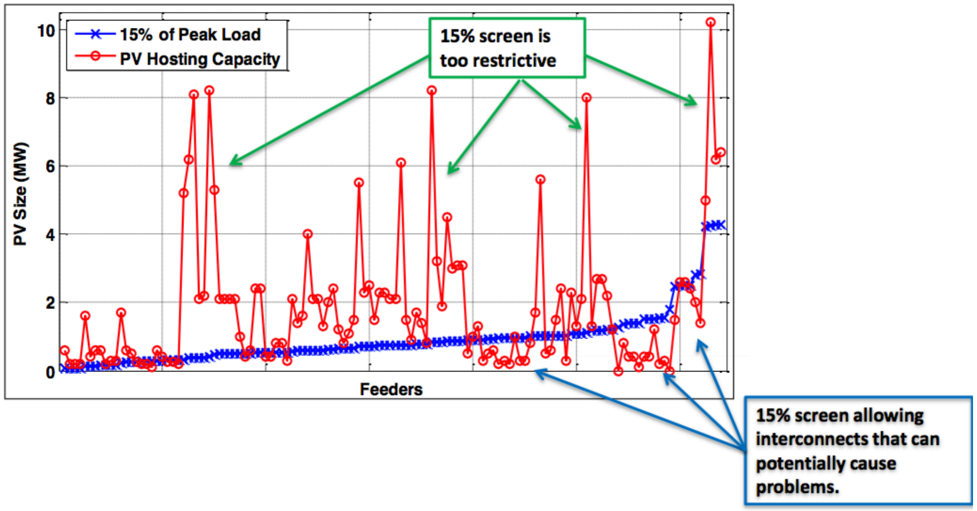
Initial screens: Max penetration < 15% of peak load

Supplemental screens: < 100% minimum load

Recent Sandia study finds 15% screen to be inaccurate

Alternatives: Clustering approaches; Automating study processes

Accuracy of 15% of peak load screen for 128 feeders



It is very difficult to do screening that is both simple and accurate!

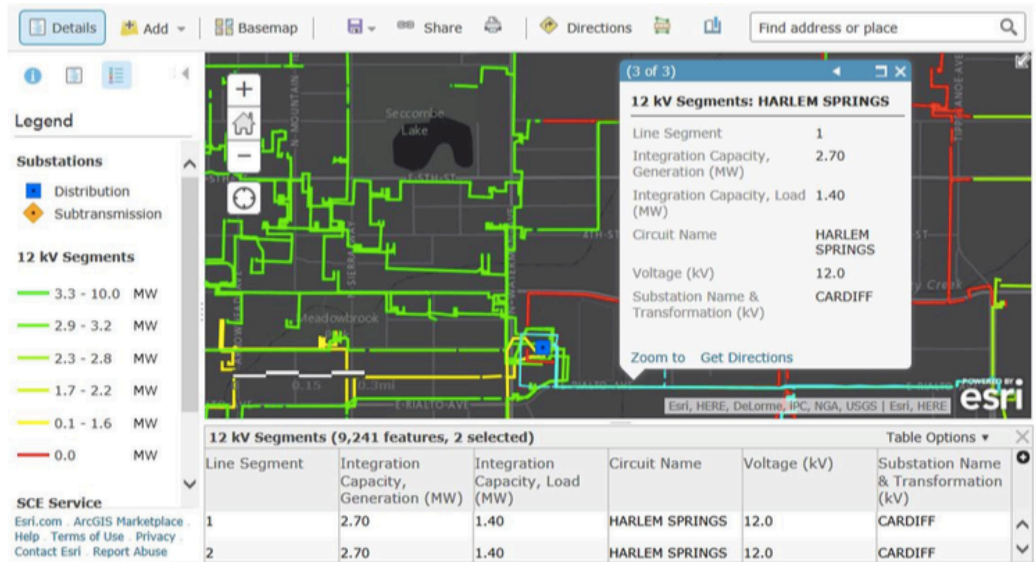
Graphic source: Broderick, Sandia, UVIG PV Workshop, Oct 13, 2015

Integration Capacity Analysis in Distribution Resource Plans

California utilities submitted DRPs to CPUC in 2015, which included:

- Integration capacity analysis
- Locational net benefits
- DER growth scenarios

For example, PG&E examined hosting capacity on >3000 feeders



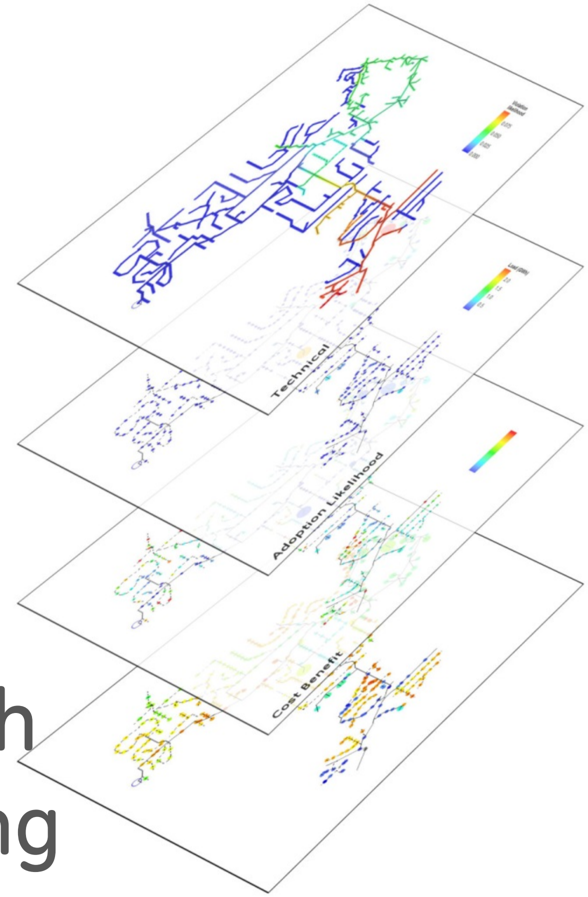
Graphic source: SCE Distributed Energy Resource Interconnection map

GE DER Toolkit

Framework for evaluating DER impact

- Technical impacts
- Economic impacts
- Adoption prediction

Intersection of layers can determine feeder upgrades, high priority feeder sections, targeting of customers, etc.



High penetrations – reliability impacts at distribution and bulk power system level

Reverse power flow (back-feeding)

Radial feeders may require infrastructure upgrades:

- Bidirectional voltage regulators
- Overcurrent protection devices and schemes

Secondary networks are more tricky:

- Network protectors disallow reverse power flow
- Conservative penetration levels, reverse power relays or dynamically controlled inverters are options
  http://www.nrel.gov/docs/fy09osti/45061.pdf

Bulk power system reliability impacts

Concern that aggregated DG may act like a single large generator

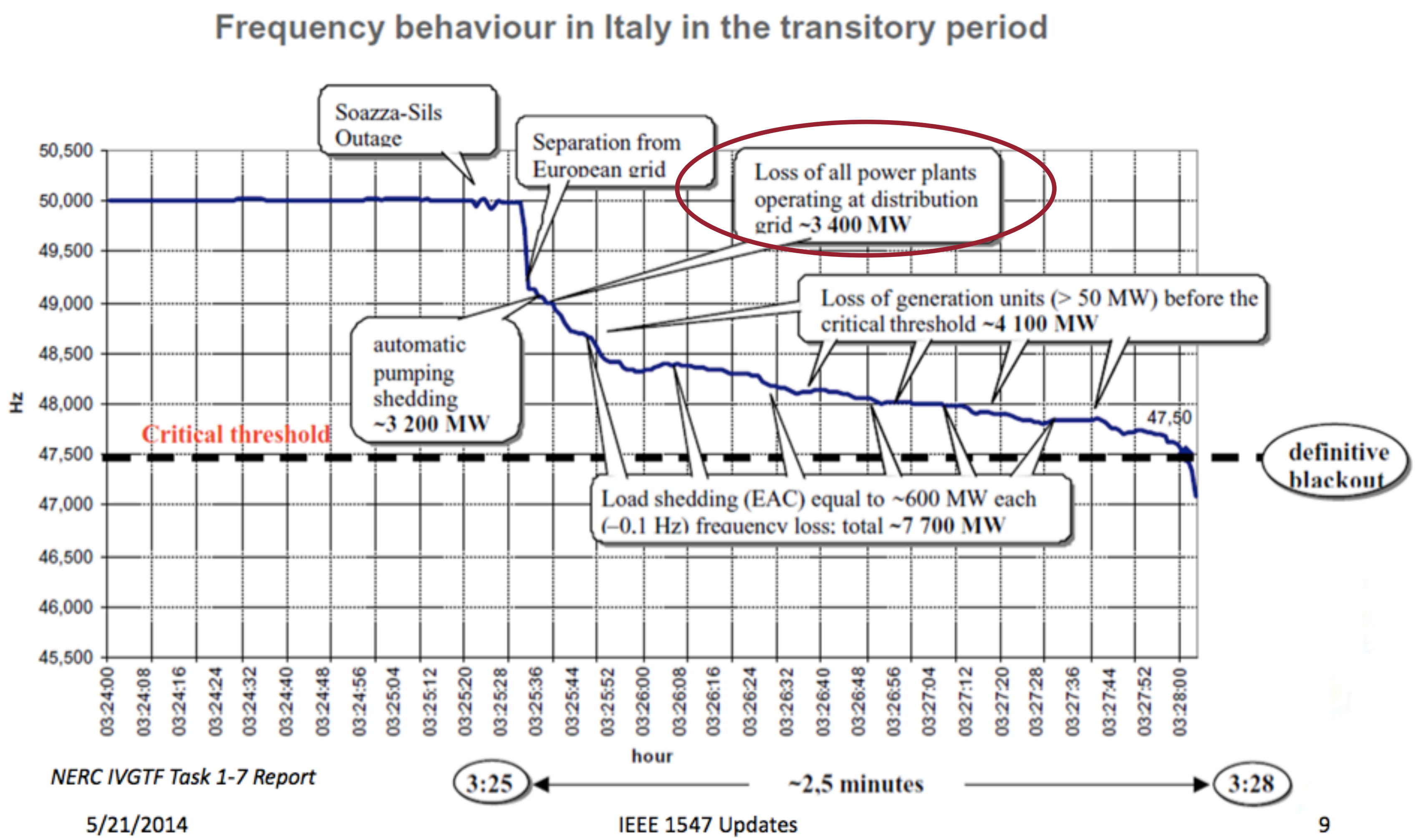
- Voltage ride-through
- Frequency ride-through

Impacts of high penetrations of inverter-based generation (inertia, frequency response)

Under-frequency load shedding

System balancing with high penetrations of solar

Loss-of-DG contributed to blackout in Europe



Sept 28, 2003 event

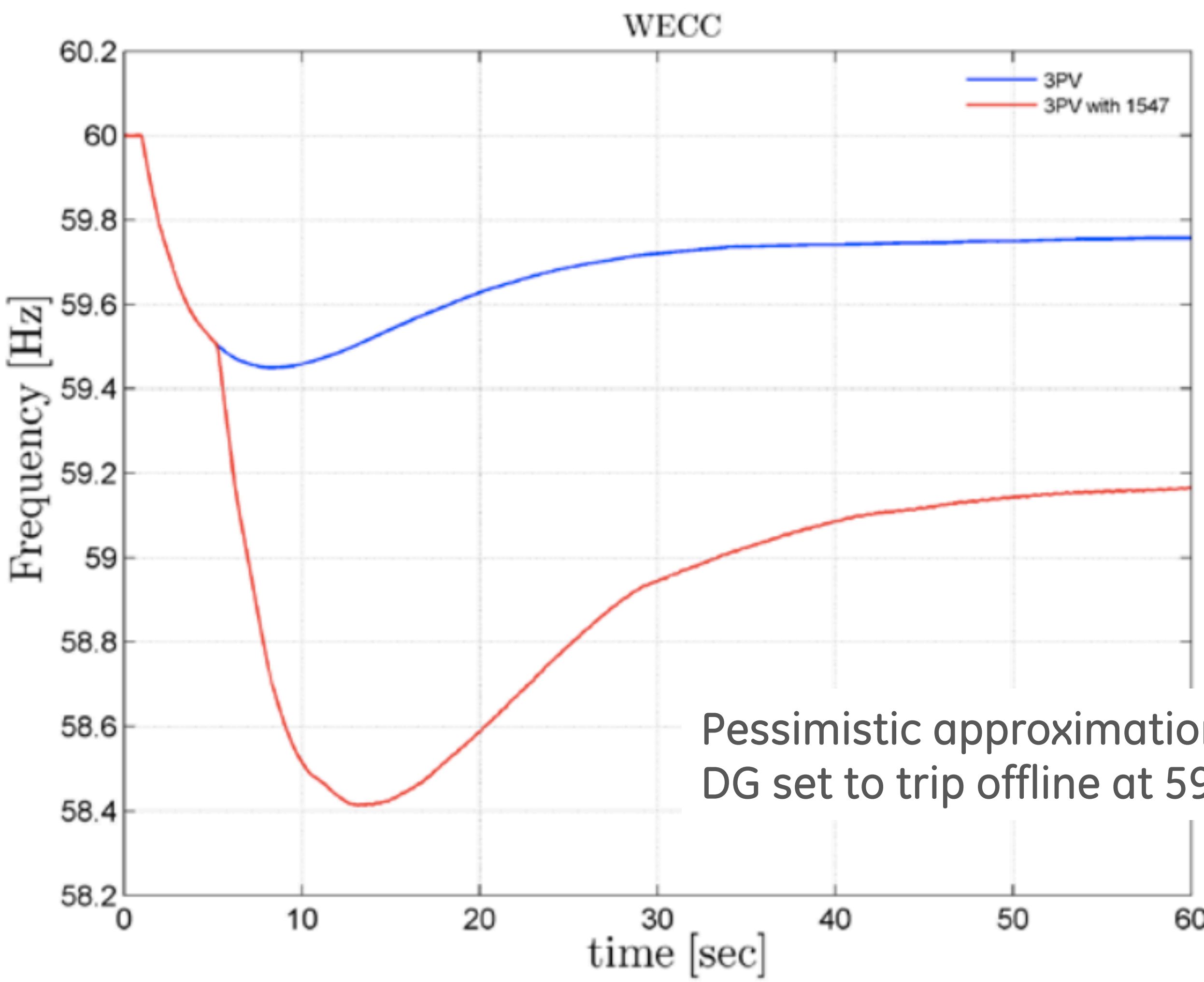
Germany inverter retrofit program

- The European system can handle the shut down of only 3 GW generation, therefore a retrofit of PV systems is necessary (diesel gen sets will be modified as well).
- Retrofit in Germany already started and will last until end of 2014
- 350,000 systems have to be changed. Studies say it will cost about € 400 million ($US 520 million)
- No replacement of inverters! Only settings of inverters and protection devices have to be changed
- If possible droop function will be activated, if not shut down frequency will be equally distributed between 50.2 Hz and 51.5 Hz
- Logistics of the process is costly. Four transmission system operators supervise 900 distribution system operators
- If frequency drops below 49.7 Hz several GW of PV in Italy will shut down due to the Italian guidelines so Italy needs a retrofit program as well.

SMA Solar Technology AG 21

B. Ernst, SMA, UVIG Anchorage, May 2014

Frequency response to extreme event with DG underfrequency trip



Pessimistic approximation of 1547 DG set to trip offline at 59.4-59.5Hz

Miller, GE, http://www.nrel.gov/docs/fy15osti/62906.pdf

IEEE 1547 and Smart inverters

Evolving interconnection requirements

Low penetrations → High penetrations

Do No Harm

(IEEE 1547-2003)

Focus on safety

Trip off for abnormal voltage and frequency

No active voltage regulation

Transition while we work out new standard

(IEEE 1547a-2014)

Allows but does not require voltage and frequency ride-through and voltage regulation

Support the grid

(CA Rule 21, HI, likely 1547rev)

Requires voltage and frequency ride-through

Reactive power control

Communicate and control

(CA SIWG phases 2&3)

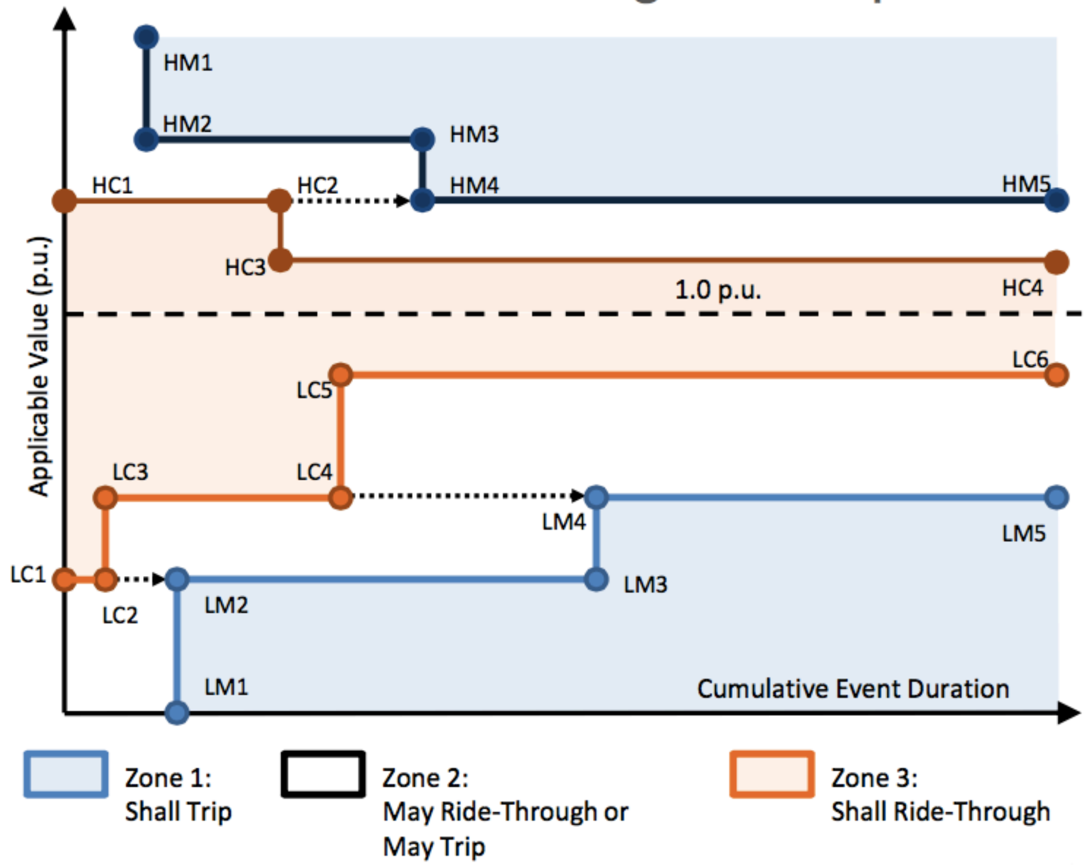
Control real power output based on signal, set point, max, frequency

Regulating or spinning reserves

http://grouper.ieee.org/groups/scc21/1547_revision/1547revision_index.html

IEEE P1547: Proposed Requirements

High-level overview on ride-through and trip

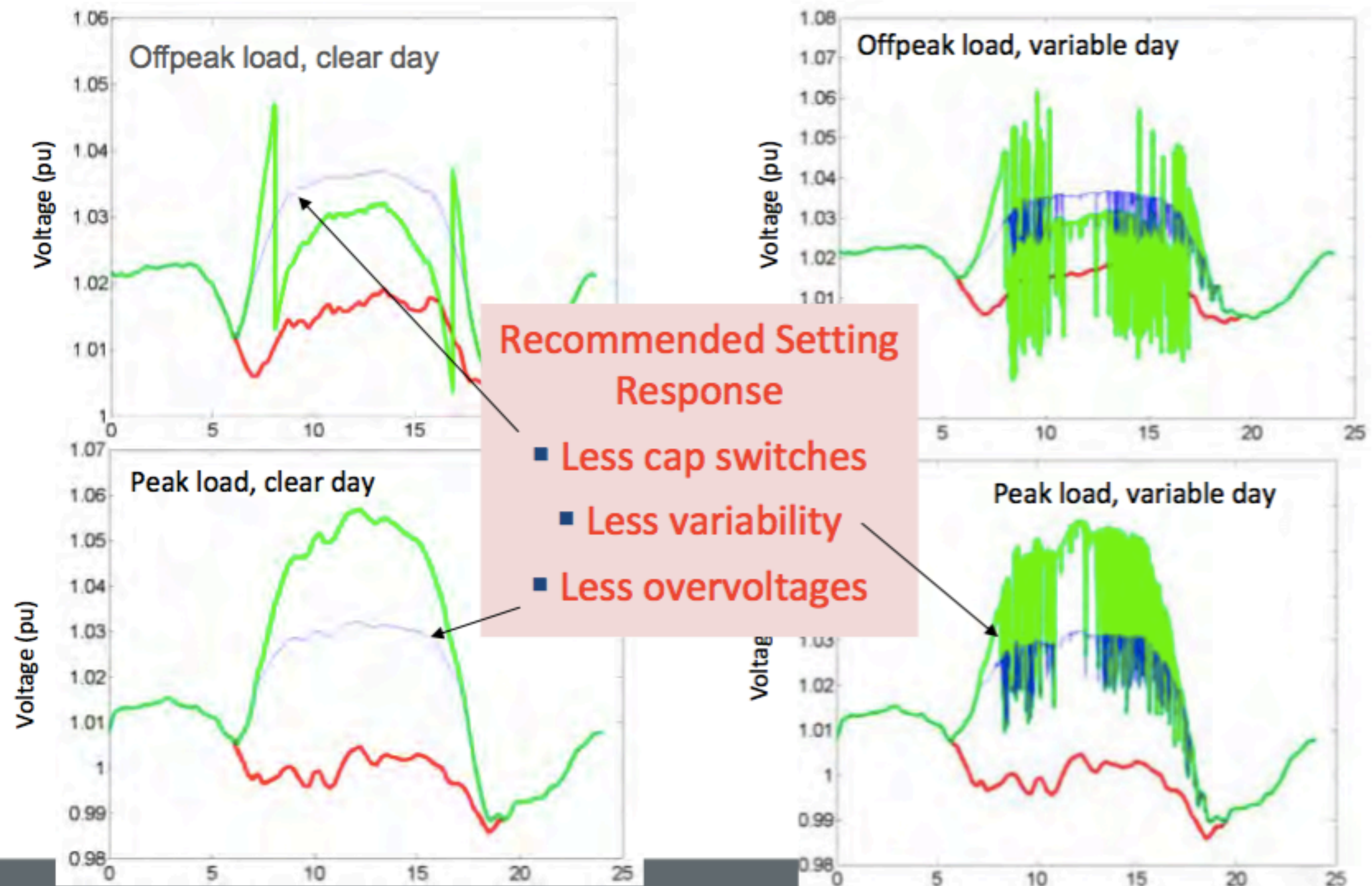


Utility Variable-Generation Integration Group

Boemer, EPRI, UVIG PV Workshop, Oct 13, 2015

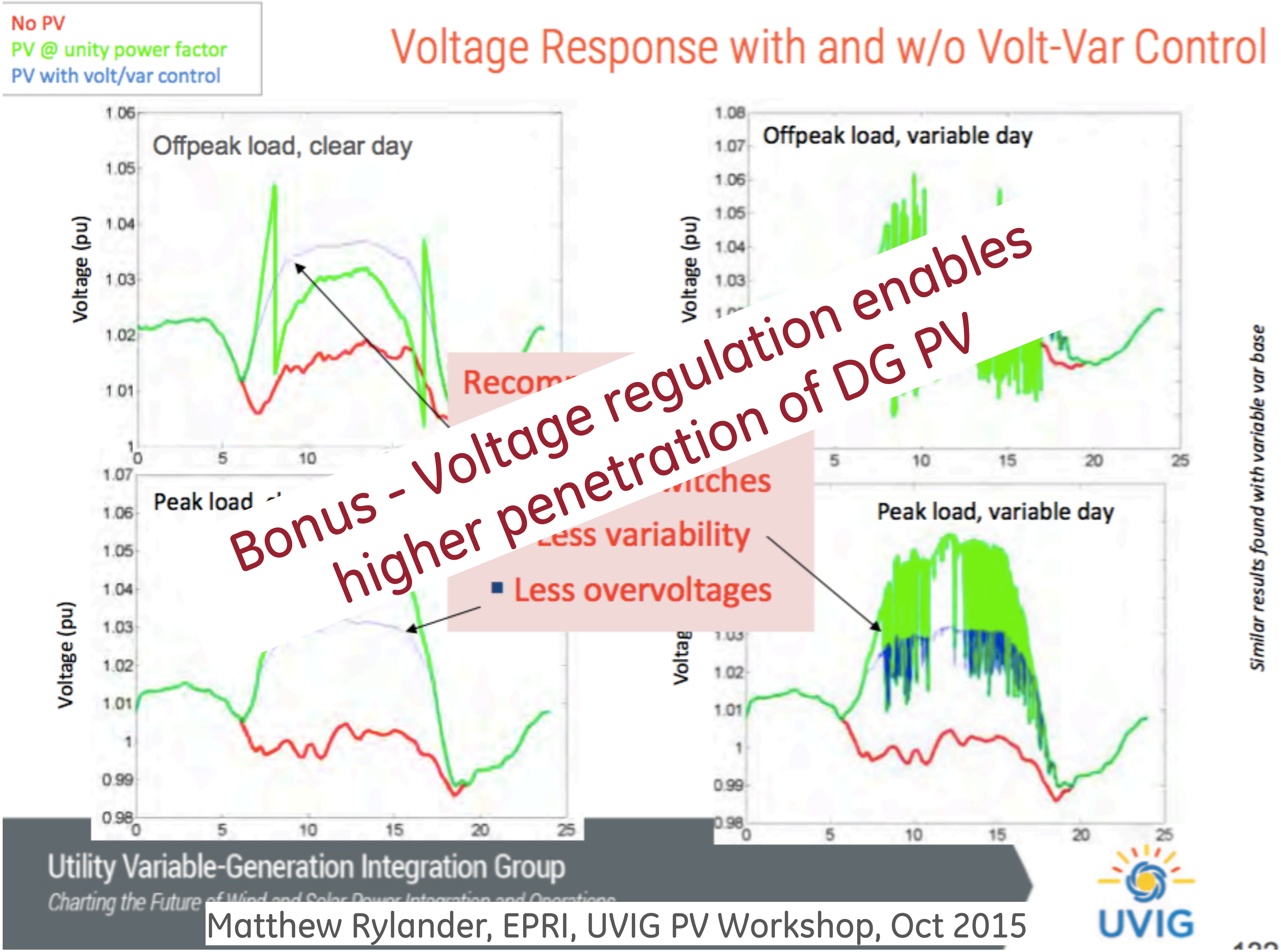
Voltage Response with and w/o Volt-Var Control

No PV
PV @ unity power factor
PV with volt/var control



Similar results found with variable var base

Matthew Rylander, EPRI, UVIG PV Workshop, Oct 2015



Voltage Response with and w/o Volt-Var Control
No PV
PV @ unity power factor
PV with volt/var control
Offpeak load, clear day
Offpeak load, variable day
Peak load, variable day
Voltage (pu)
Recom
itches
Less variability
Less overvoltages
Bonus - Voltage regulation enables higher penetration of DG PV
Similar results found with variable var base
Utility Variable-Generation Integration Group
Charting the Future
Matthew Rylander, EPRI, UVIG PV Workshop, Oct 2015
UVIG

Conclusions

Distributed energy resources are creating a paradigm shift

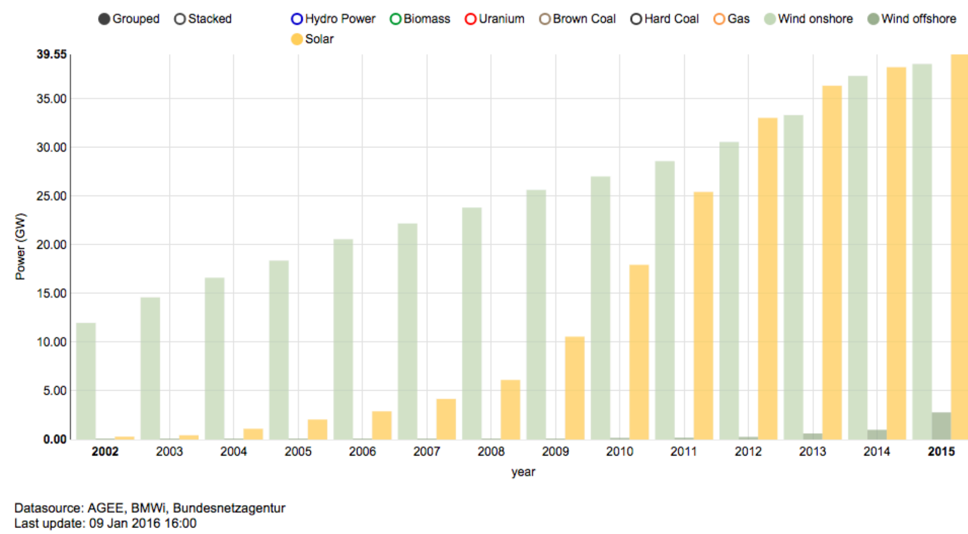
Reliability impacts of DG PV are manageable. Backfeeding is manageable in many cases.

We have the technology to solve many issues with different 'smart' inverter functions.

As DG PV grows, it needs to support the grid.

Don't decouple economics and reliability.

The line between bulk power system and distribution system is disappearing.



Graphic source: Fraunhofer ISE, Energy Charts

Selected References

Basic DG PV interconnection
https://www1.eere.energy.gov/solar/pdfs/advanced_grid_planning_operations.pdf

Handbook on high penetration PV integration for distribution engineers
http://www.nrel.gov/docs/fy16osti/63114.pdf

Smart inverters http://www.nrel.gov/docs/fy15osti/65063.pdf

Case studies of high penetration of DG PV
http://iea-pvps.org/index.php?id=295&eID=dam_frontend_push&docID=2210

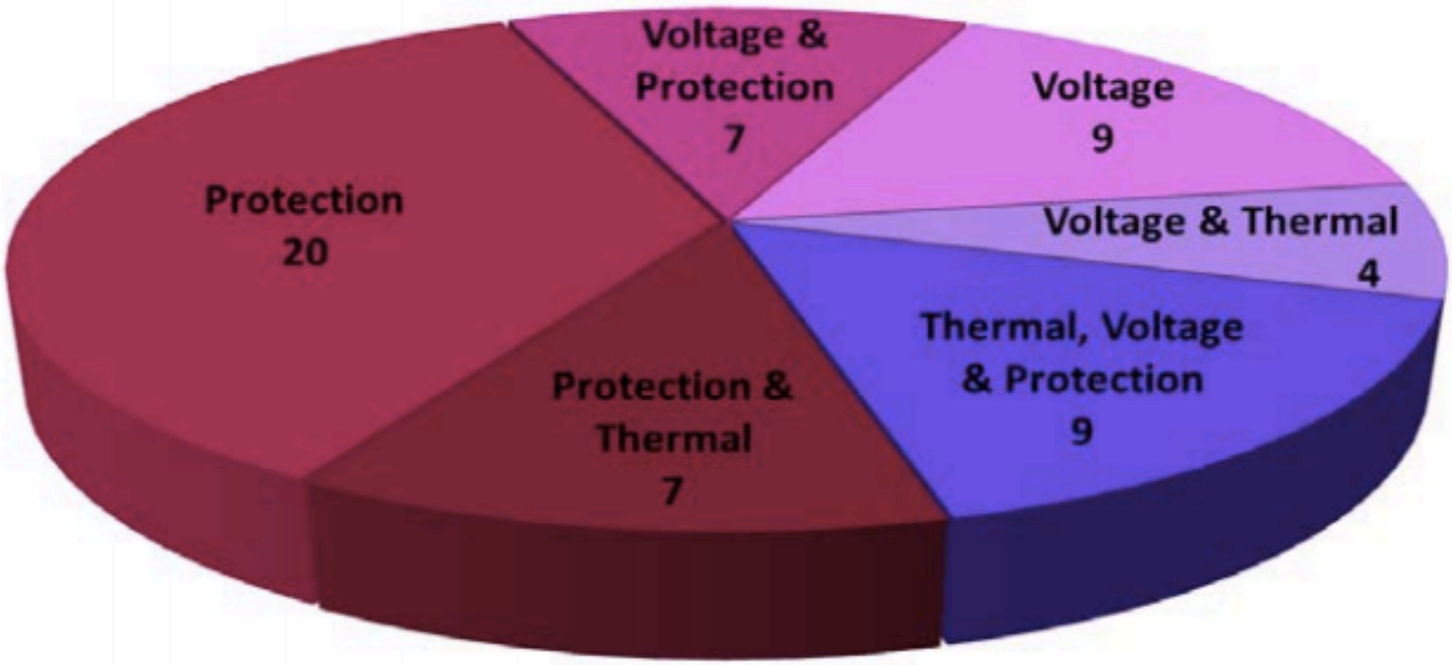
Interconnection cost survey
http://energy.sandia.gov/wp-content/gallery/uploads/dlm_uploads/Analysis-of-100-SGIP-Interconnection-Studies.pdf

CA Distribution Resources Plans
http://www.cpuc.ca.gov/General.aspx?id=5071

Contact Debbie at
Debra.lew@ge.com
303-819-3470

Extra slides

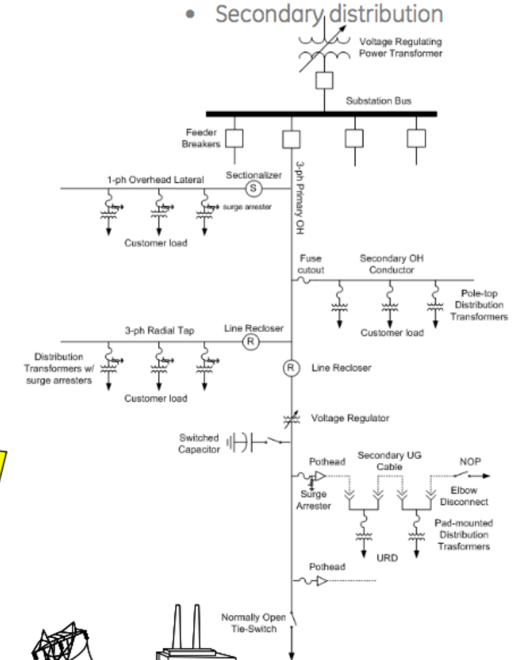
Survey of 100 interconnection studies for adverse impacts

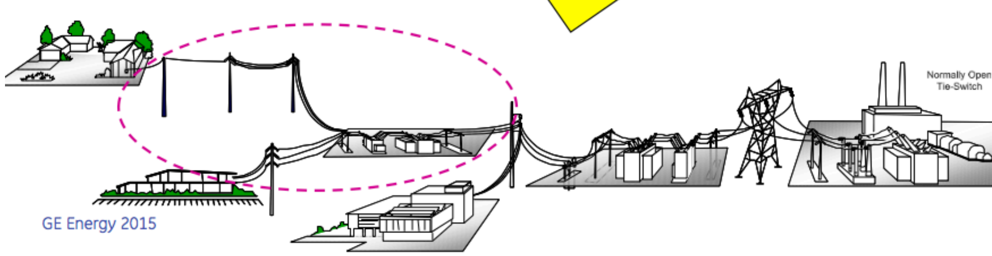


http://energy.sandia.gov/wp-content/gallery/uploads/dlm_uploads/Analysis-of-100-SGIP-Interconnection-Studies.pdf

Distribution System Components

- Distribution substations
- Primary feeders
- Laterals and branches
- Service transformers
- Secondary circuits
- Service drops





GE Energy 2015

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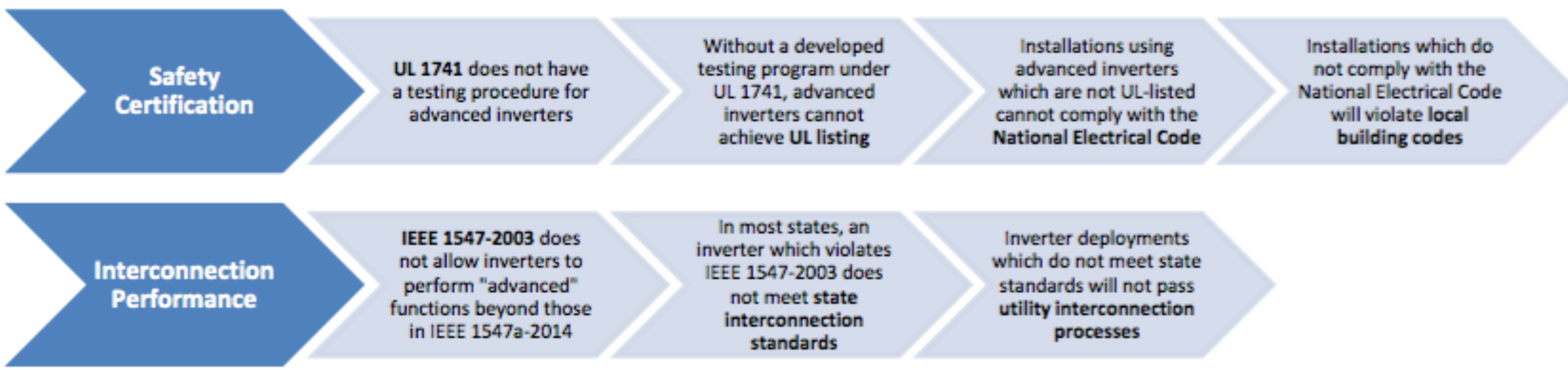
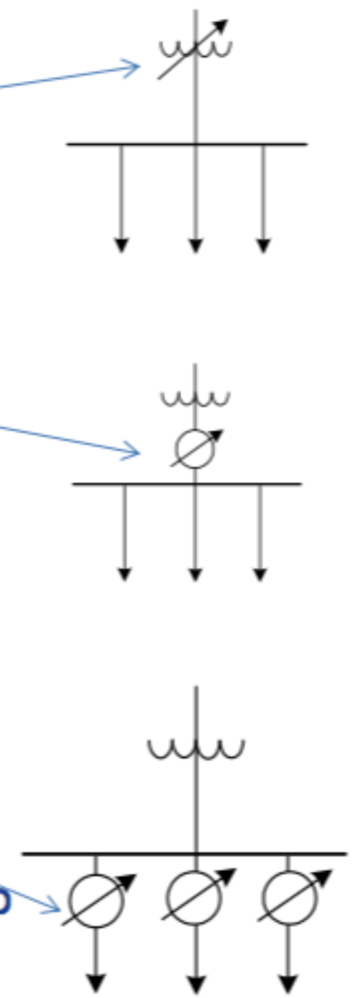
Interconnection and safety requirements

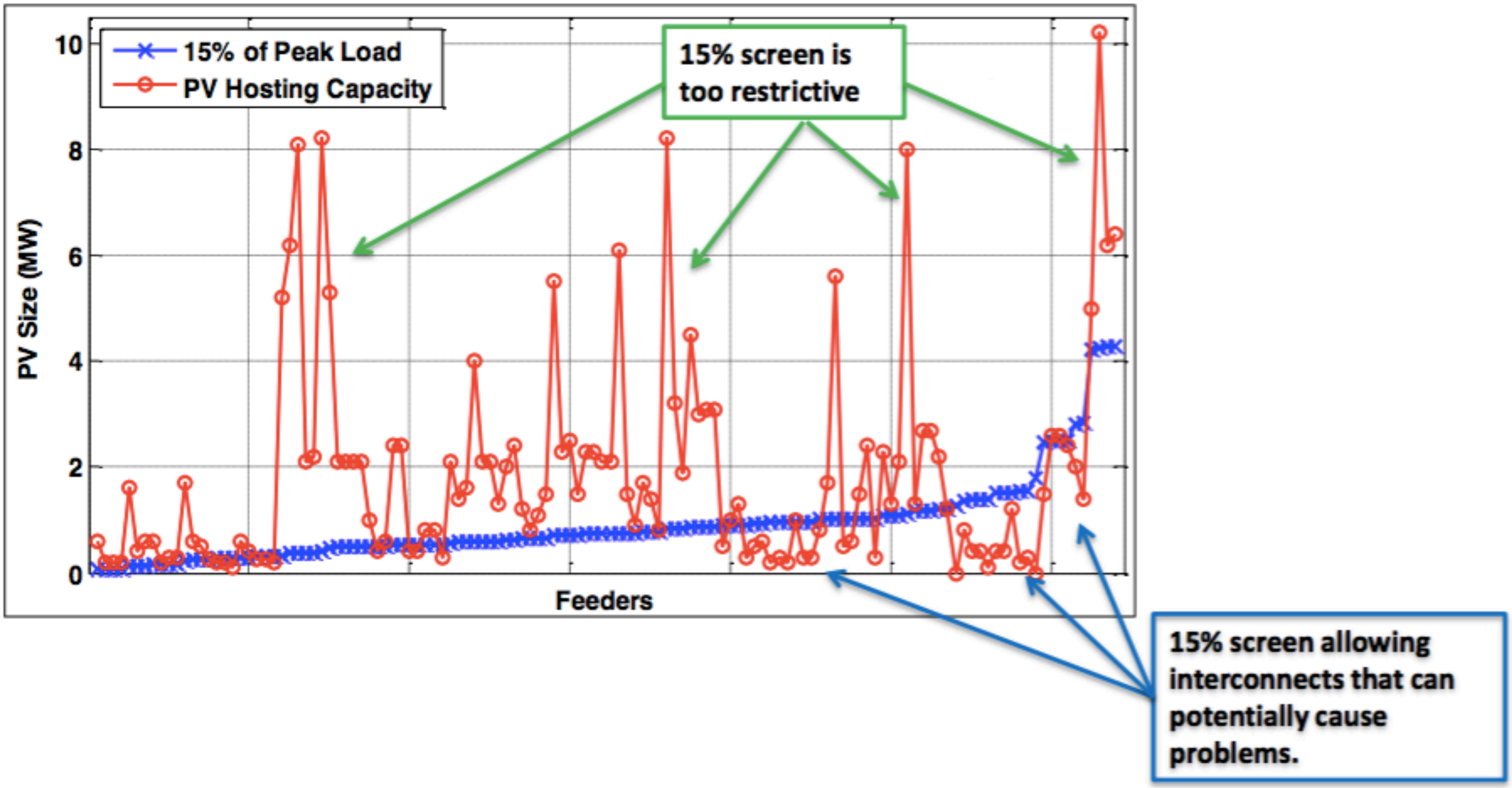


Voltage Regulating Equipment and Solutions

- Substation Transformer LTC (Load Tap Changer)
  - Simple and convenient
- Bus Regulator
  - Similar to LTC, but allows bypass
- Shunt Capacitors
  - Provide voltage rise and power factor correction
  - Very cost effective solution
- Feeder voltage regulators
  - Best regulation (close to load)
  - Expensive
- Reconductoring
  - Larger conductor size reduces impedance and voltage drop

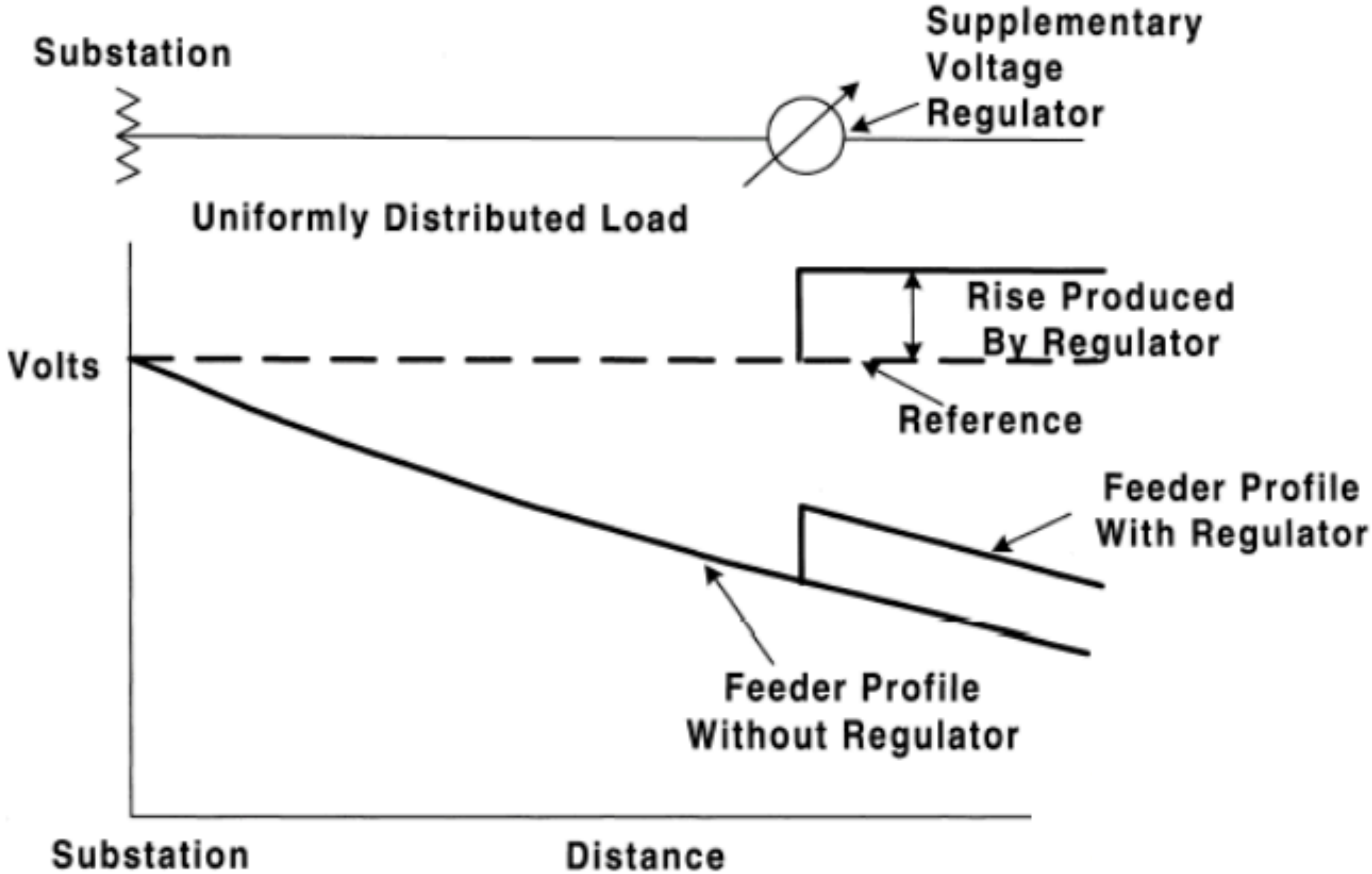


Accuracy of 15% of peak load screen for 128 feeders

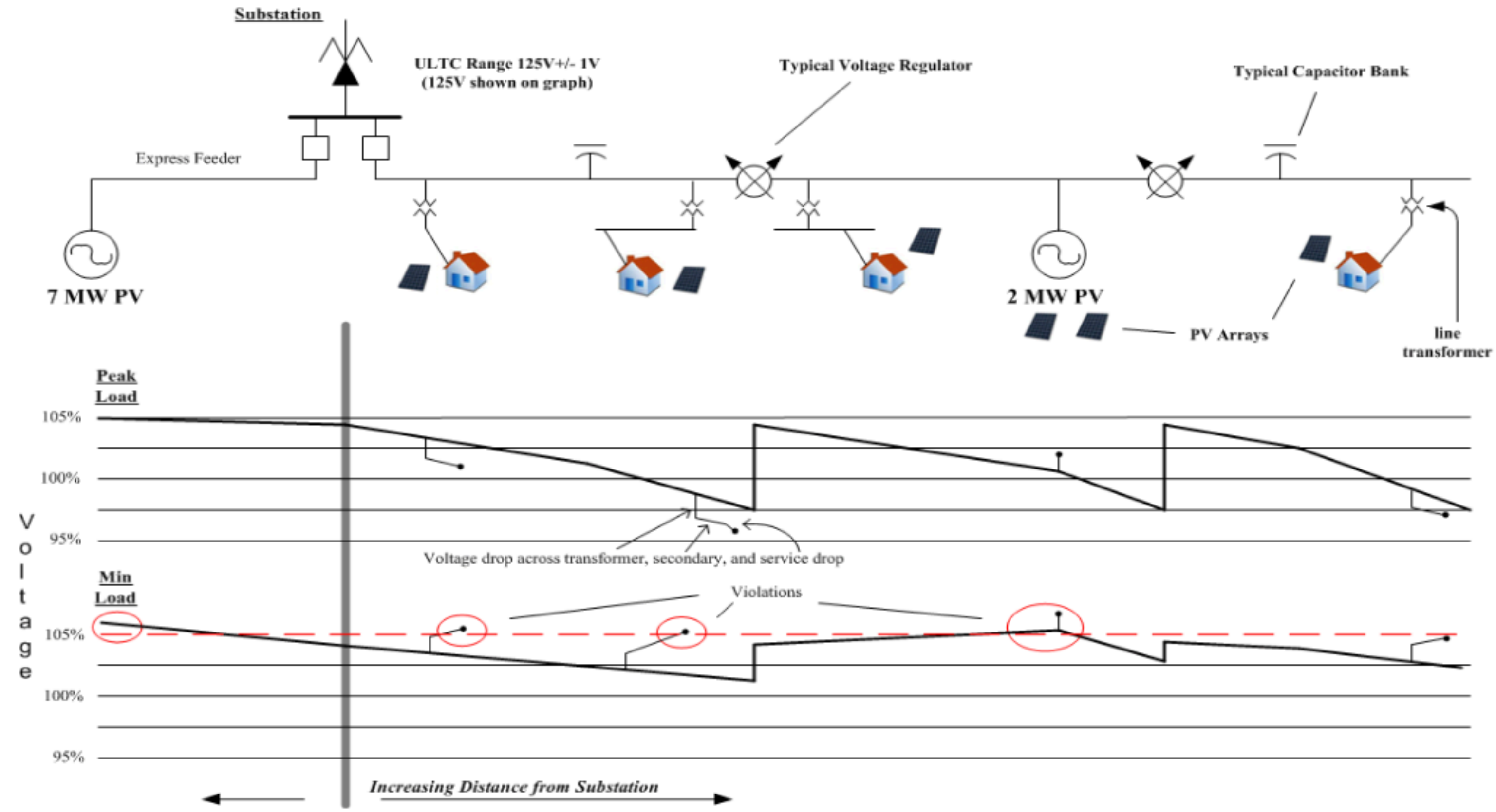


Broderick, Sandia, Oct 2015 UVIG

Feeder Voltage Regulators



Typical Voltage Regulation with Violations at the Meter

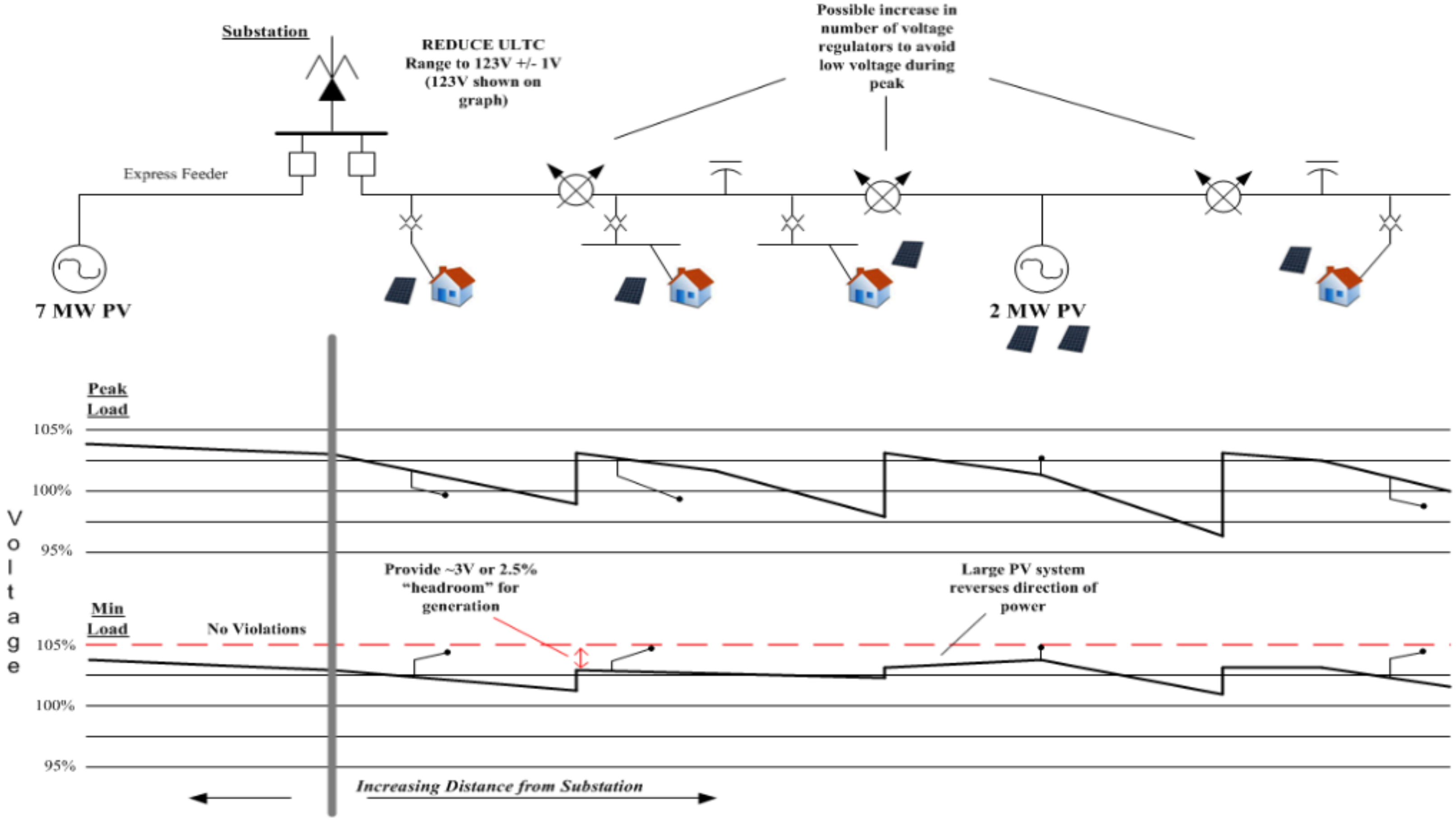


Pepco Holdings, Inc

19

Source: Steve Steffel, PEPCO

Voltage Regulation with "Headroom" to Mitigate Violations



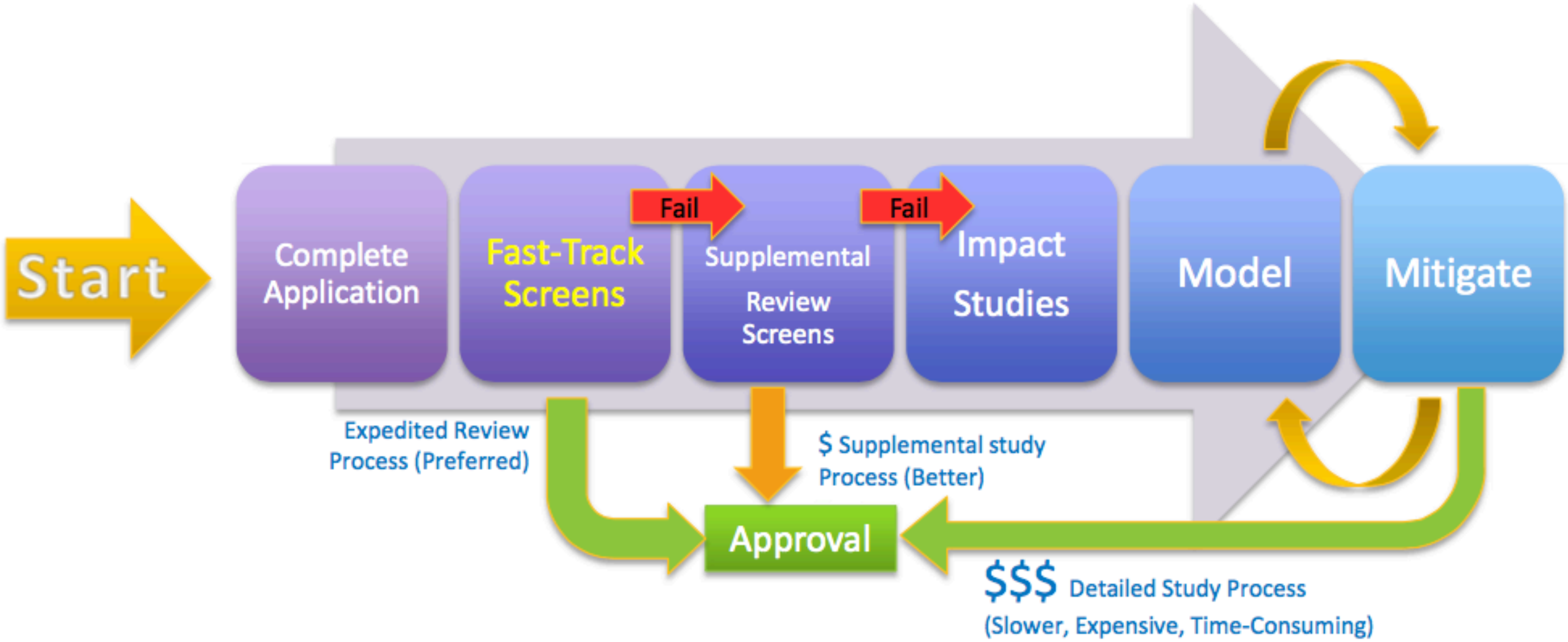
Pepco Holdings, Inc

20

Source: Steve Steffel, PEPCO

Universal Interconnection Process

Energy Systems Integration



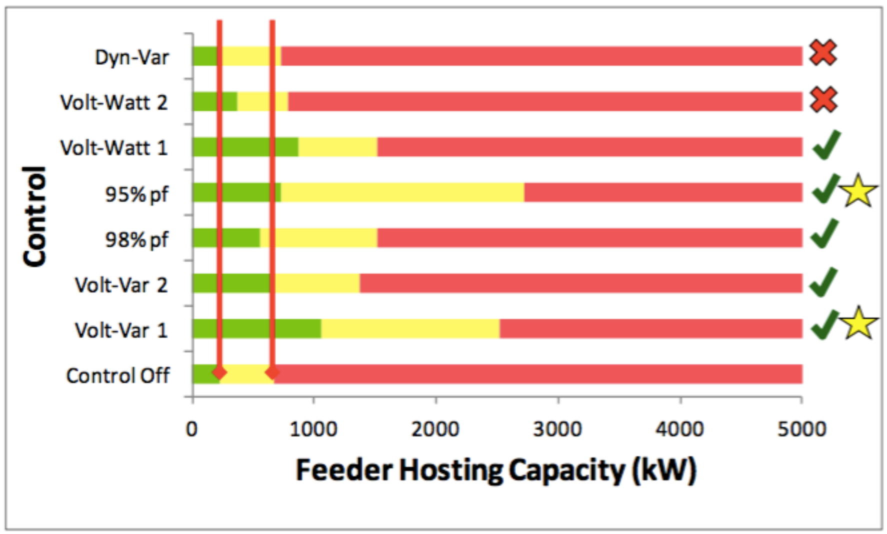
There are significant differences amongst U.S. Electric utilities in practices, processes, tools & models and mitigation strategies.

Coddington, NREL, Distributed Generation Interconnection Collaborative, Jul 2014

Increased hosting capacity with smart inverters

Customer-Owned PV

Advanced Inverter Summary



No observable violations regardless of PV size/location

Possible violations based upon PV size/location

Observable violations occur regardless of size/location

SunShot U.S. Department of Energy

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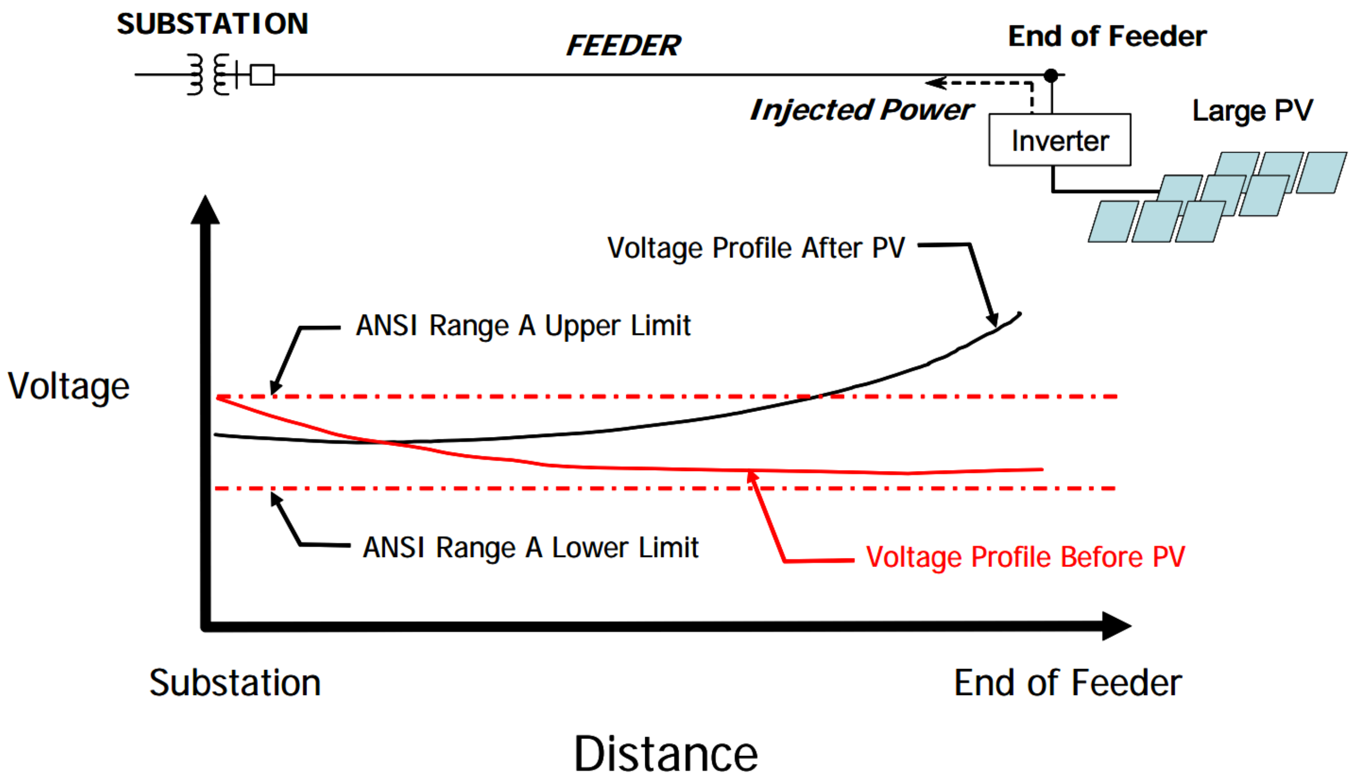
EPRI ELECTRIC POWER RESEARCH INSTITUTE

Brooks, EPRI, UVIG DG User Group, May 2014

Voltage impacts of DG PV



Graphic source: McGranaghan, EPRI, Sandia 2008-0944, 2008

Common Mitigation Strategies

Energy Systems Integration

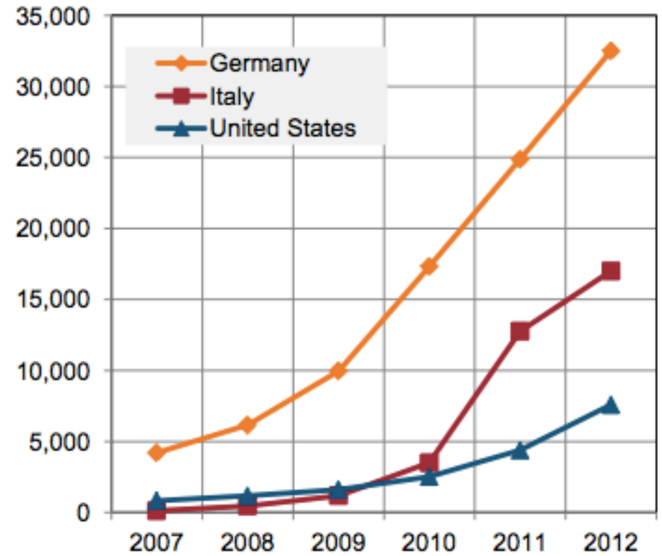
Type	SW (5)	Central (3)	California (4)	NE (7)
Voltage Regulation devices (13)	4	1	3	5
Upgraded line sections (16)	4	2	4	6
Modify protection (16)	4	3	3	6
Power factor controls (8)	4	1	x	3
Direct Transfer Trip (12)	2	3	1	6
Static VAR Compensator (SVC) (1)	1	x	x	x
Communication/Control Technology (11)	4	1	2	4
Grounding transformers (8)	2	2	2	2
Advanced inverters (11)	3	2	3	3
Capacitor control modifications (1)	x	x	x	1
Reclosers (3)	x	1	x	2
Volt/VAR Controls (1)	x	x	x	1

Coddington, NREL, Distributed Generation Interconnection Collaborative, July 2014

DER and the Bulk System

- High penetration DG deployment levels will affect bulk system reliability and performance
  - Generation commitment & dispatch
  - Voltage & flow patterns
  - Dynamic response (inertia, voltage recovery, frequency response, etc.)
- A major concern is the risk of system collapse or cascading outages due to DG tripping (possibly GWs) following bulk system contingencies
  - Frequency & voltage events are common
  - It is desirable for DG to have a measure of tolerance (FRT, VRT)

Cumulative PV Installed Capacity in MW, at Year's End



In each case, the majority of the installed capacity is in distribution networks

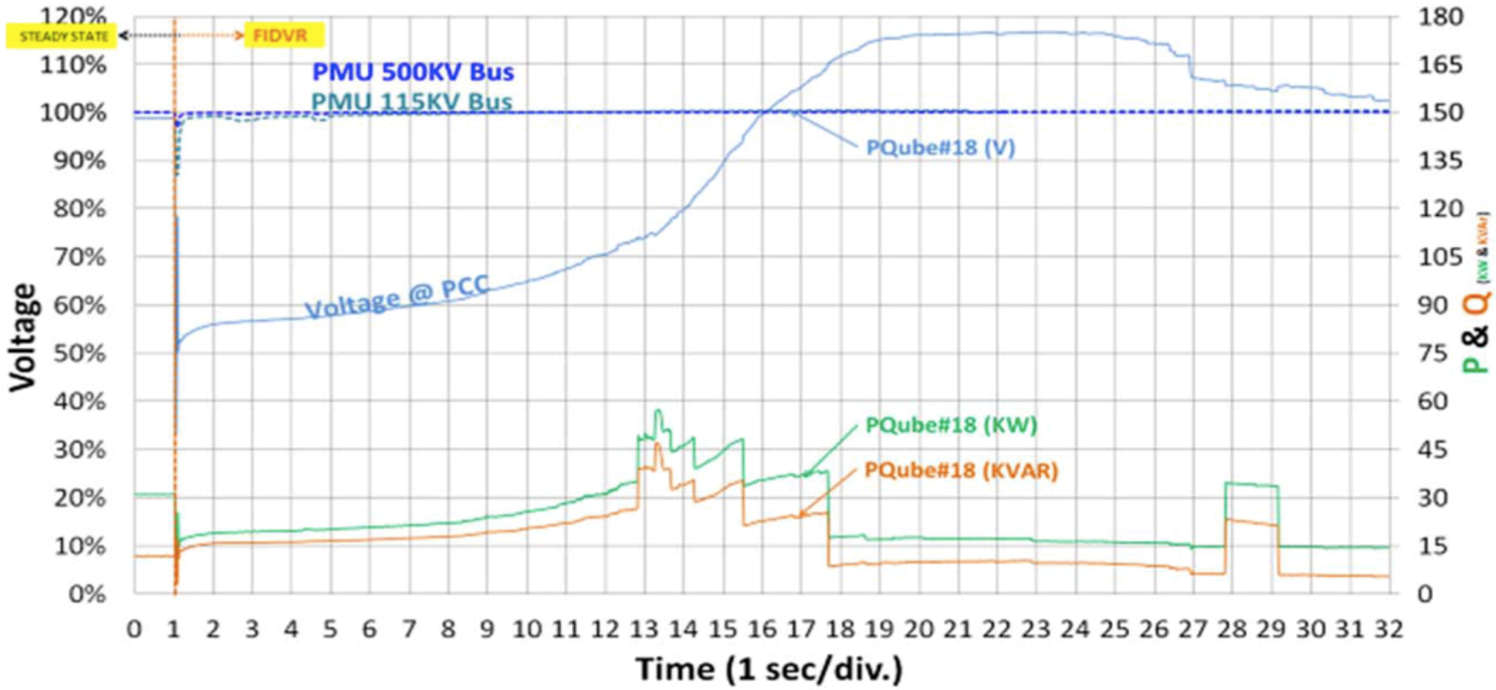
Germany: on sunny, light load days, PV supplies for 45% of the load.

3

A. Ellis, Sandia, UVIG, Portland Oct 2013

Distributed generation is in a tricky position

Figure from R. Bravo, SCE, FIDVR Working Group Meeting, CERTS



- Transmission – DG should not trip to support trans. grid
- Distribution – DG should trip if fault is on dist. circuit
- Manufacturer – Can't design a "clairvoyant" DG

B. Mather, NREL, UVIG, Portland, Oct 2013

California Rule 21 – Phase 1 (Nov 2016)

High-value autonomous functions

Voltage and frequency ride-through

Volt/VAR control (dynamic reactive power)

Anti-islanding

Ramp rate controls

Fixed power factor

Soft-start

Table Hh-1: Voltage Ride-Through Table

Region	Voltage at Point of Common Coupling (% Nominal Voltage)	Ride-Through Until	Operating Mode	Maximum Trip Time
High Voltage 2 (HV2)	V ≥ 120			0.16 sec.
High Voltage 1 (HV1)	110 < V < 120	12 sec.	Momentary Cessation	13 sec.
Near Nominal (NN)	88 ≤ V ≤ 110	~~Continuous Operation~~ Indefinite	Continuous Operation	~~Continuous Operation~~ Not Applicable
Low Voltage 1 (LV1)	70 ≤ V < 88	20 sec.	Mandatory Operation	21 sec.
Low Voltage 2 (LV2)	50 ≤ V < 70	10 sec.	Mandatory Operation	11 sec.
Low Voltage 3 (LV3)	V < 50	1 sec.	Momentary Cessation	1.5 sec.

Table Hh-2: Frequency Ride-Through Table

System Frequency Default Settings	Minimum Range of Adjustability (Hz)	Ride-Through Until (s)	Ride-Through Operational Mode	~~Default Clearing~~ Trip Time (s)
f > 62	62 - 64	No Ride Through	Not Applicable	0.16
60.5 < f ≤ 62	60.1 - 62	299	Mandatory Operation	300
58.5 ≤ f ≤ 60.5	Not Applicable	Indefinite	Continuous Operation	Not Applicable
57.0 ≤ f < 58.5	57 – ~~60~~ 59.9	299	Mandatory Operation	300
f < 57.0	53 – 57	No Ride Through	Not Applicable	0.16

California Rule 21 – Phase 2

Communications between DER and utility

DER includes storage, demand response, EVs

California Rule 21 – Phase 3

Autonomous

- Frequency/watt
- Voltage/watt
- Dynamic current support
- Smooth frequency deviations

Communications and Control needed

- Connect/disconnect
- Set and/or limit real power
- Respond to prices
- AGC/spinning reserve

Oregon Public Utilities Commission

Docket UM 1716 Reliability Impacts Workshop #1

DER Experience in Hawaii

Colton K. Ching

January 19, 2016

Agenda

Background

DER Integration Technical Challenges

Advanced Inverters

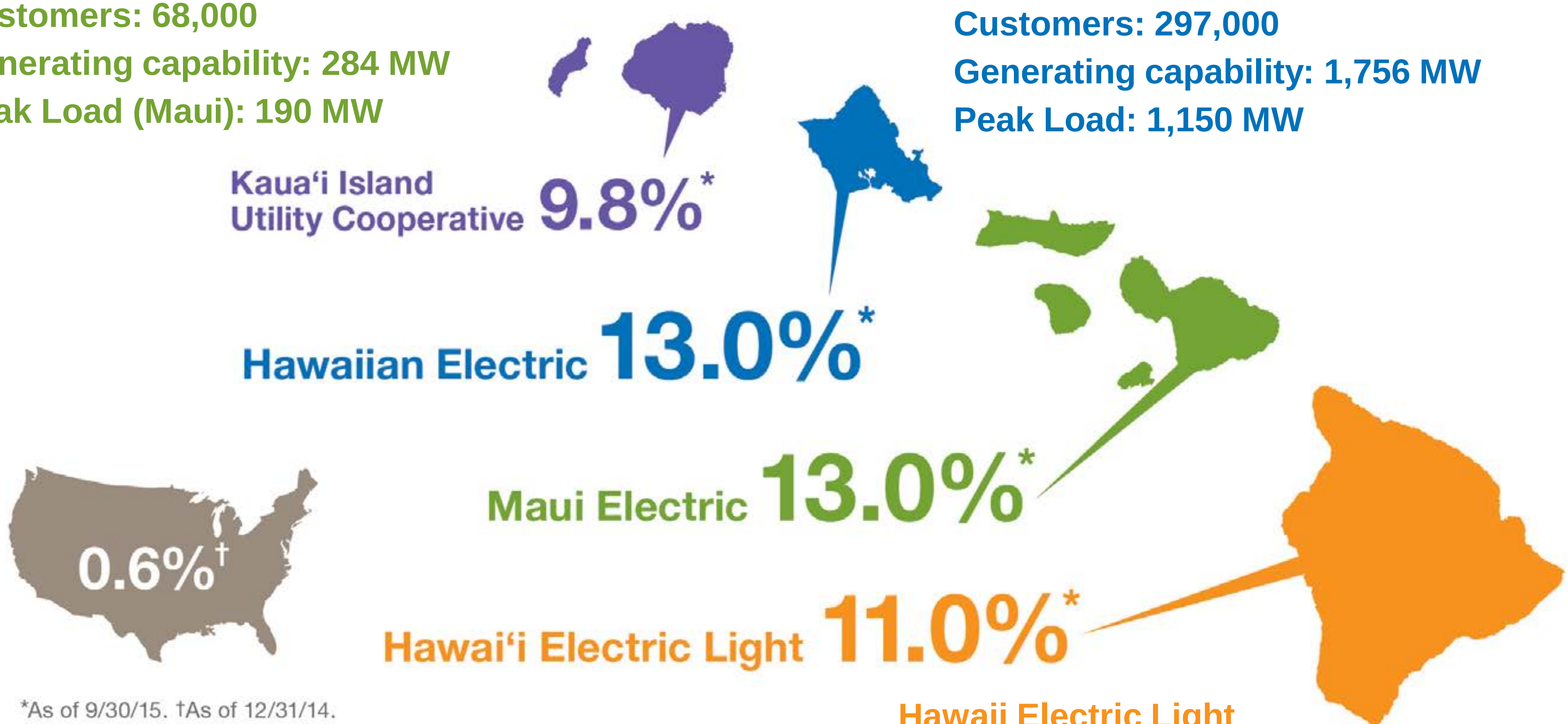
Closing Thoughts

Hawaiian Electric
Maui Electric
Hawai‘i Electric Light

Hawaiian Electric: 3 Electric Utilities, 5 Separate Grids

Maui Electric
Serves islands of Maui, Molokai, and Lanai
Customers: 68,000
Generating capability: 284 MW
Peak Load (Maui): 190 MW

Hawaiian Electric
Serves island of Oahu
Customers: 297,000
Generating capability: 1,756 MW
Peak Load: 1,150 MW

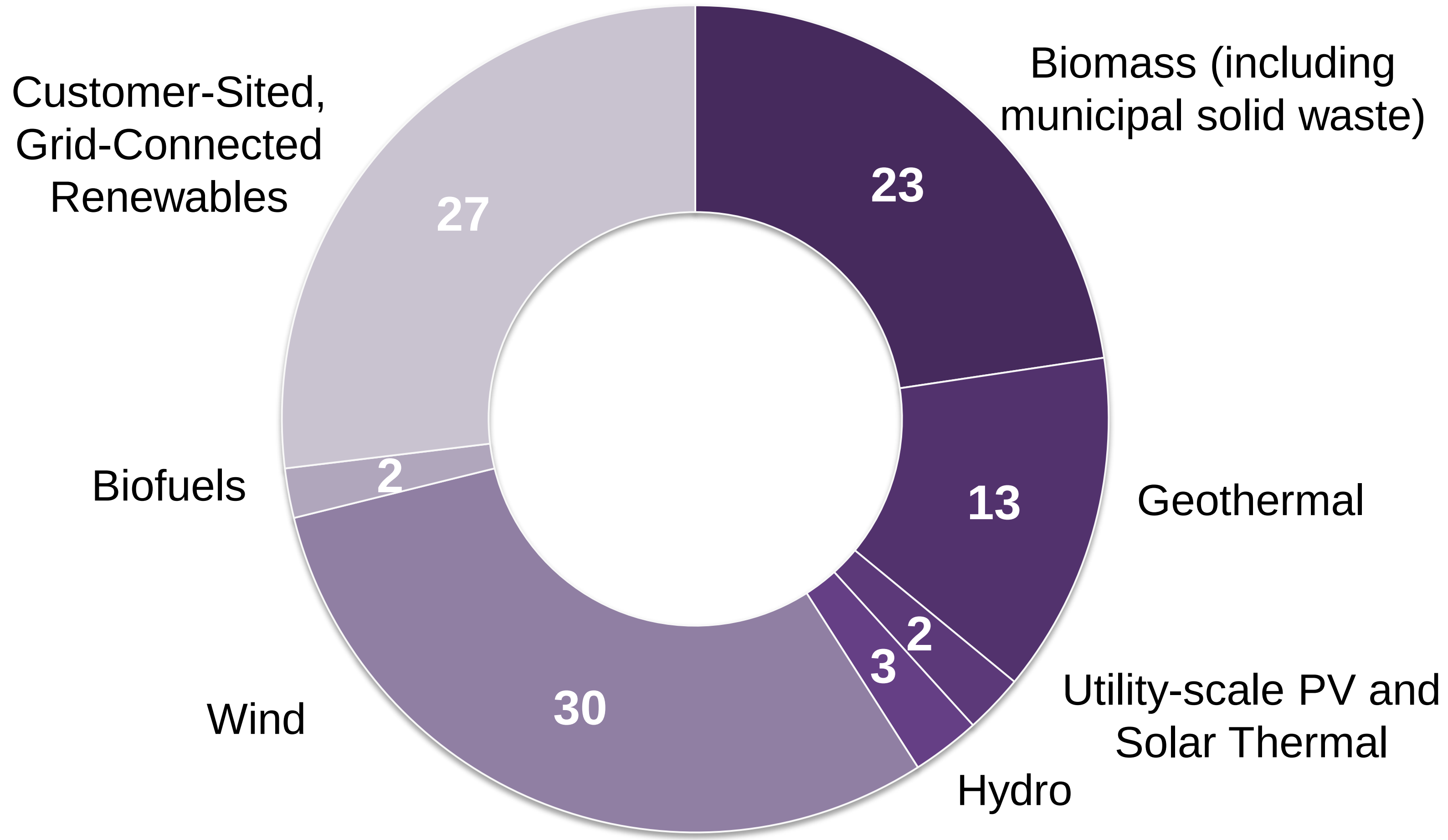


*As of 9/30/15. †As of 12/31/14.
National data courtesy of Solar Electric Power Association.

Hawaii Electric Light
Serves island of Hawaii
Customers: 81,000
Generating capability: 293 MW
Peak Load: 190 MW

Hawaiian Electric has a diverse mix of renewable energy resources, including distributed solar

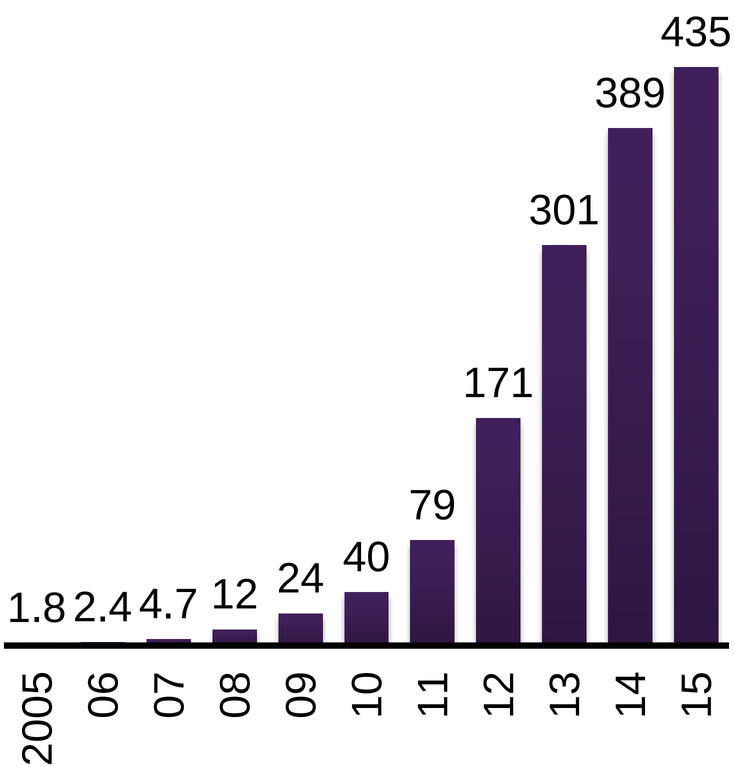
Hawaiian Electric Companies RPS of 21.3% for 2014



Hawaiian Electric
Maui Electric
Hawai‘i Electric Light

Our system experienced exponential growth in photovoltaics

Cumulative Installed Distributed PV



Key Policy Drivers

Renewable Portfolio Standards (RPS)
- Was 40% by 2040
- Effective July 1, 2015, Legislature increased RPS to 100% by 2045

Net Energy Metering (NEM)
- Exported generation credited at retail rate
- Statute prohibits placing additional charges or controls on NEM customers

Renewable Energy Income Tax Credit
- 35% income tax credit, or $5,000 per system, whichever is less

Green Energy Market Securitization (GEMS)
- Signed into law 6-27-13
- Provides low-cost capital to finance PV systems to underserved market: low-credit homeowners, renters, and nonprofits

30% of Single Family Homes on O`ahu have Rooftop PV

74,000 rooftop PV applications APPROVED in total

15,000 applications approved since October 2014

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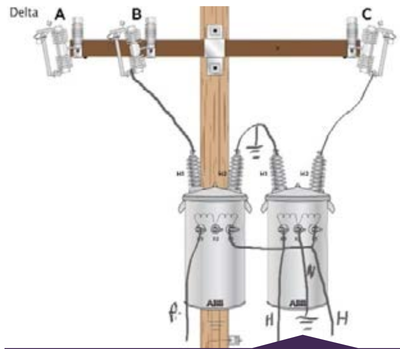
PV systems and inverters are becoming a growing part of our distribution system

Distribution Wood Poles*

Company	Count
HECO	59,000
HELCO	52,000
MECO	30,000
Total	**141,000**



Distribution Transformers*

Company	Count
HECO	32,000
HELCO	24,000
MECO	12,000
Total	**68,000**

PV Systems*

Company	Count	kW
HECO	38,000	294,000
HELCO	8,000	61,000
MECO	8,000	63,000
Total	**54,000**	**418,000**

* Approximate numbers

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DER Integration Technical Challenges

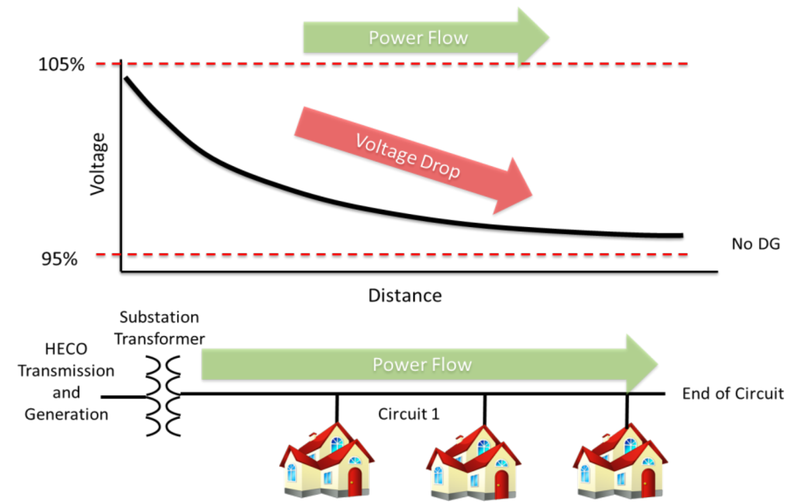
Advanced Inverters

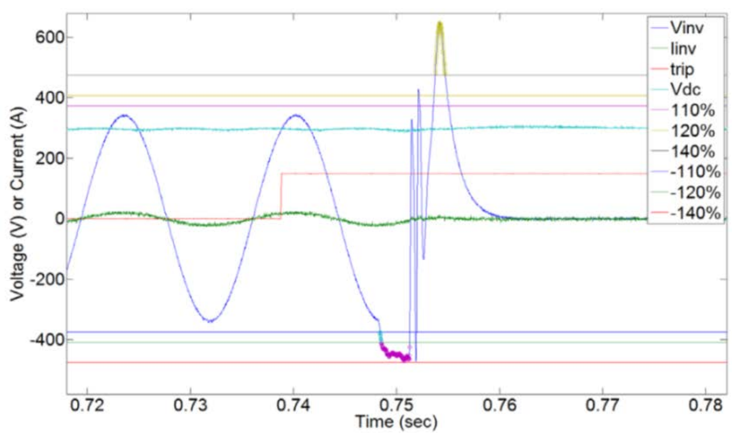
Closing Thoughts

3 key technical issues to be addressed for a safe and reliable interconnection

Key Technical Issues

1. **System Level**
   - Steady state and transient stability
2. **Circuit Level**
   - Thermal Capacity Over Load
   - Voltage Flicker
   - Voltage Regulation Impacts
   - Islanding
   - **Load Rejection Over Voltage**
   - Ground Fault Over Voltage
3. **Over voltage issues**
   - Primary
   - Secondary
   - Imbalance across phases





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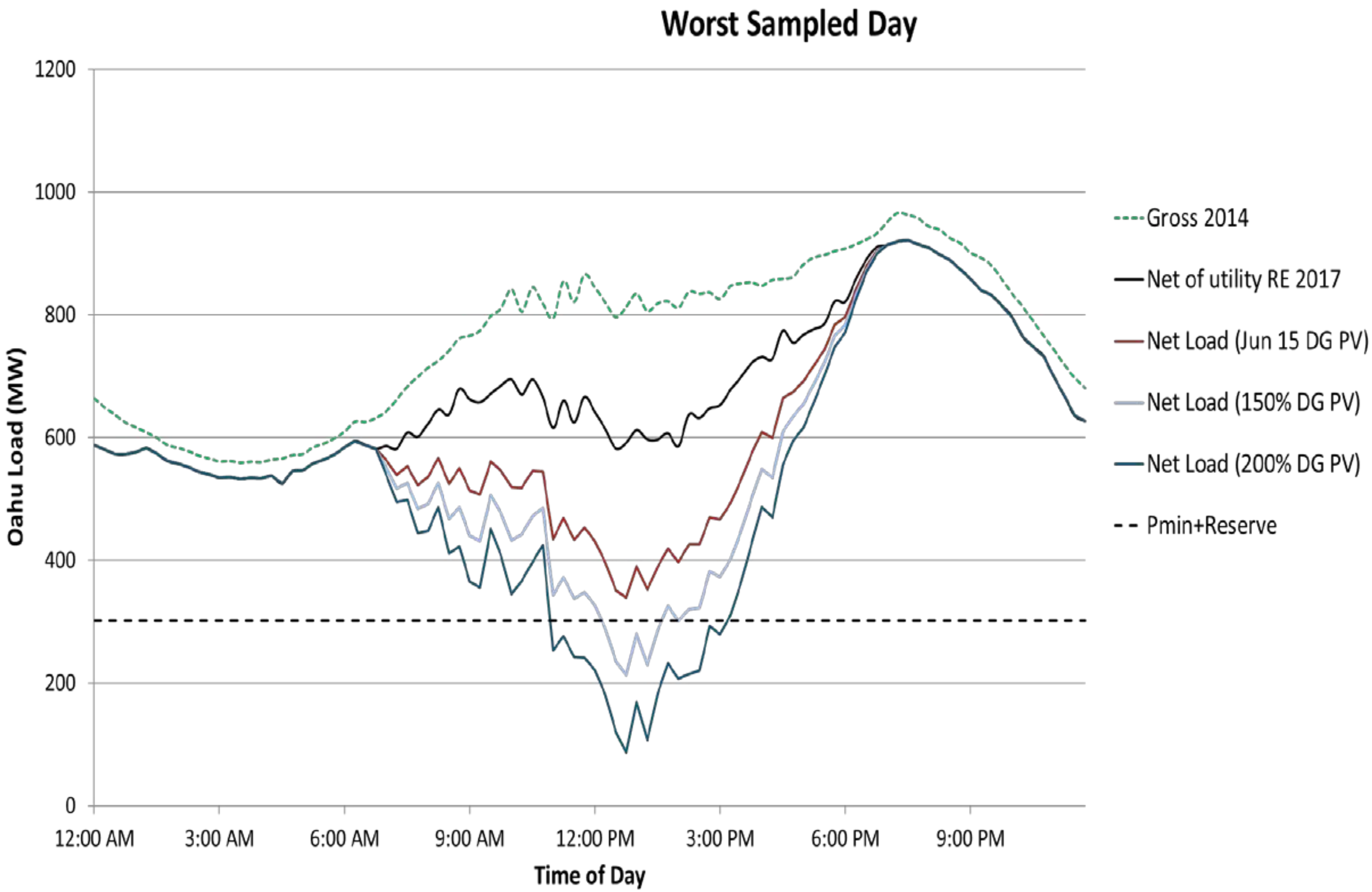
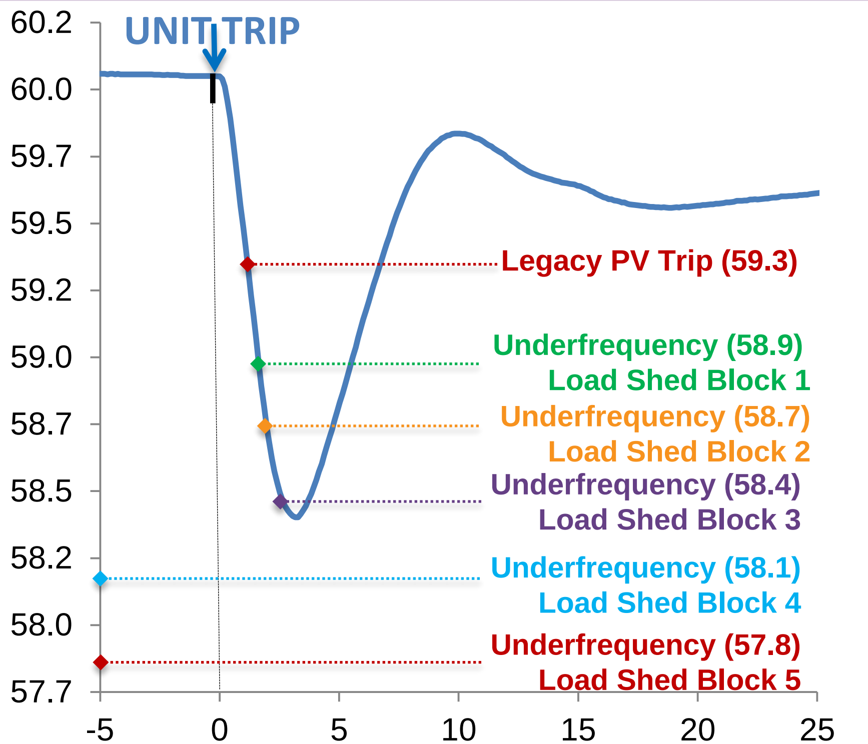
① System Level Issues: Variable generation is reducing conventional



1 System Level Issues:
Bulk power system reliability is lower than in the past

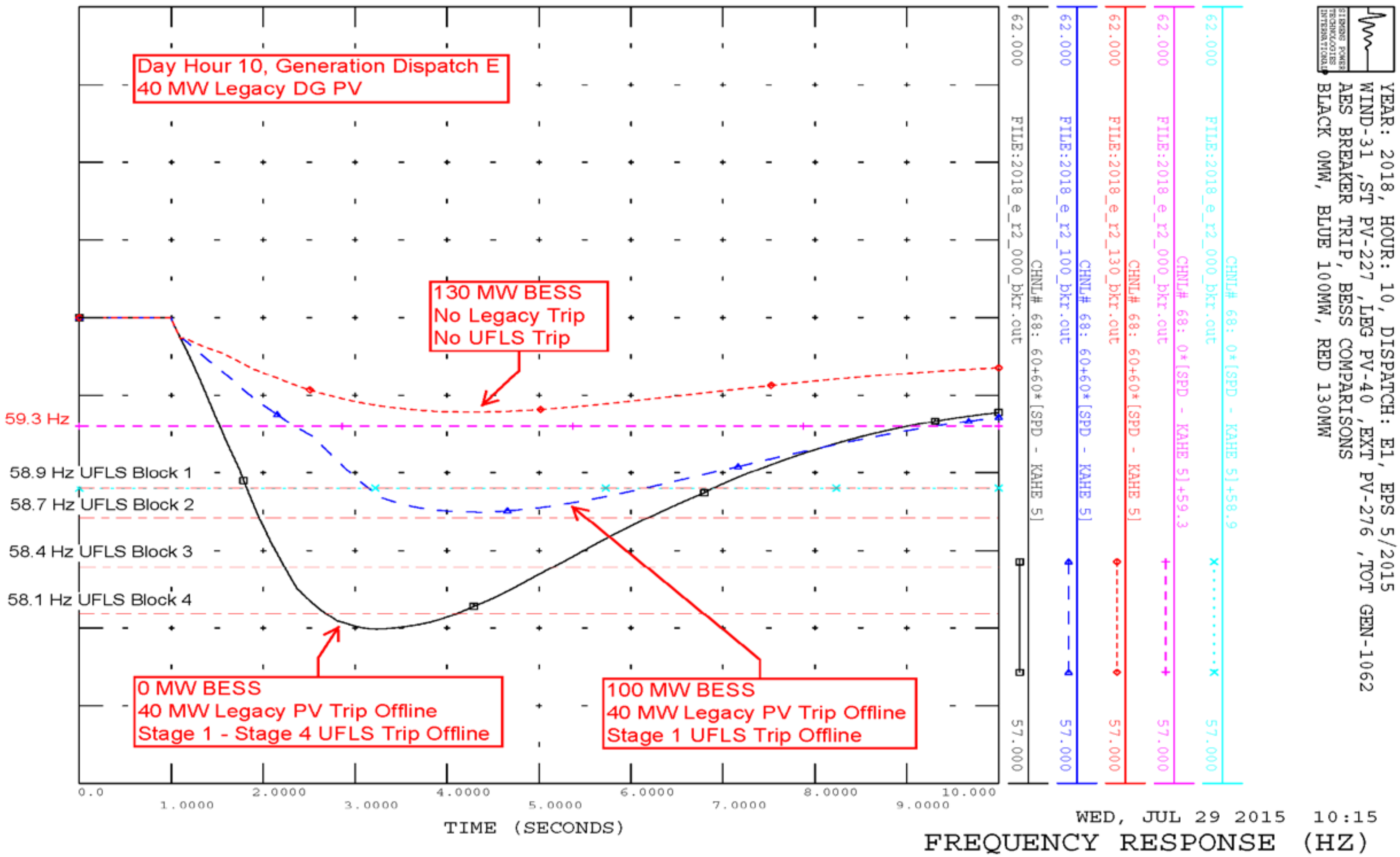
Actual Frequency Response to a Generating Unit Trip – O'ahu



Today a large generator trip or system fault during peak PV periods results in:

- Loss of system inertia due to reduction in rotating generation
- Loss of "legacy" PV which acts like a secondary generation loss
- Reduced effectiveness of UFLS due to rooftop PV
- Potential of massive load shedding (3-4 of 5 blocks of UFLS)
- Faster rate of change of frequency

1 System Level Issues: BESS can provide fast frequency response



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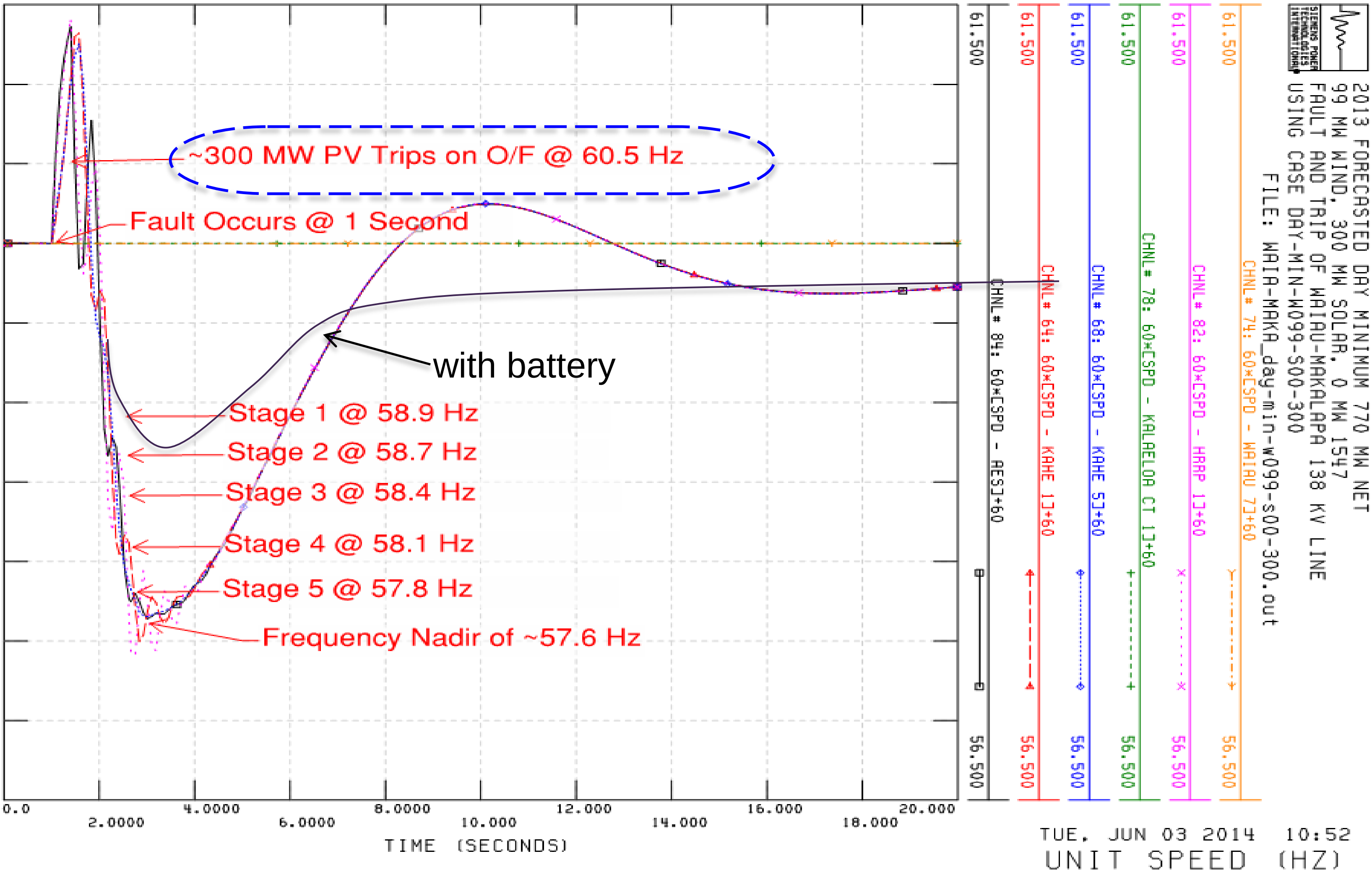
① System Level Issues:
BESS helps with transmission line faults (overfrequency)



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① System Level Issues:
We are working through rooftop PV challenges

Cannot be Measured
Rooftop PV output can only be estimated

Uncontrollable
Cannot be turned on or curtailed

"Legacy" PV
~60 MW of PV trips offline at 59.3 Hz
~175 MW of PV trips offline at 60.5 Hz

Underfrequency Load Shed Schemes
Decreases effectiveness of UFLS

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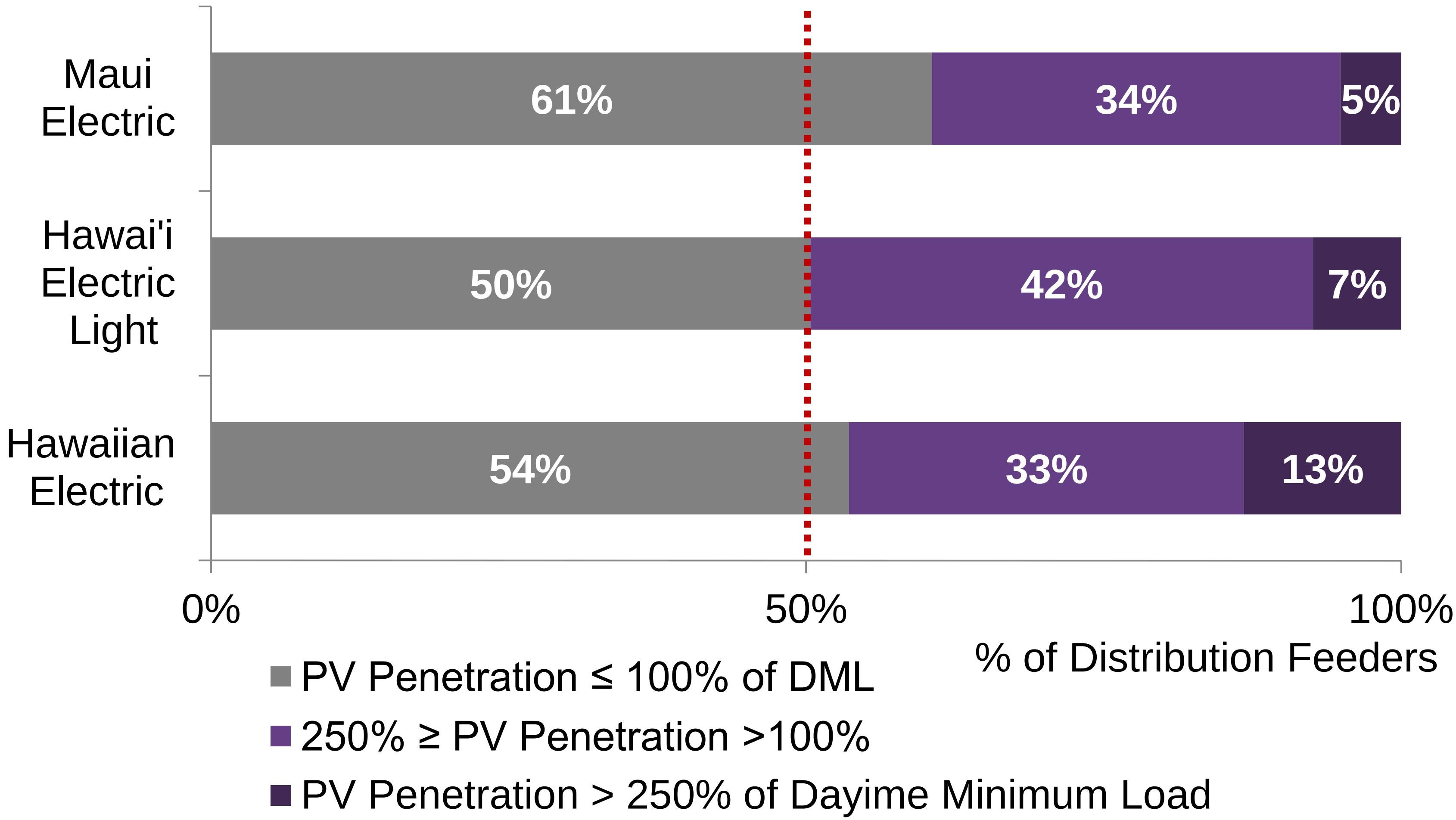
2 Circuit Level Issues:
Reverse power flow is the new normal

Hawaiian Electric Companies Distribution Feeder PV Penetration of Daytime Minimum Load



Approaching the point where 50% of circuits backfeed at the substation

2 Circuit Level Issues:
Hawaiian Electric continue to progress interconnection policies

15% of Circuit Peak Load

(Pre-2013)

50%, 75%, 100%, 120% of Daily Minimum Load (DML)

Representative Studies

(2013)

250% of DML

Transient Overvoltage

(2014)

Hosting Capacity

Advanced Inverters

(2015)

② Circuit Level Issues: 3 keys to a more effective interconnection process

System Level Hosting Capacity

System level screens for each unique island grid balancing system level reliability, safety, and cost-effective service to all customers

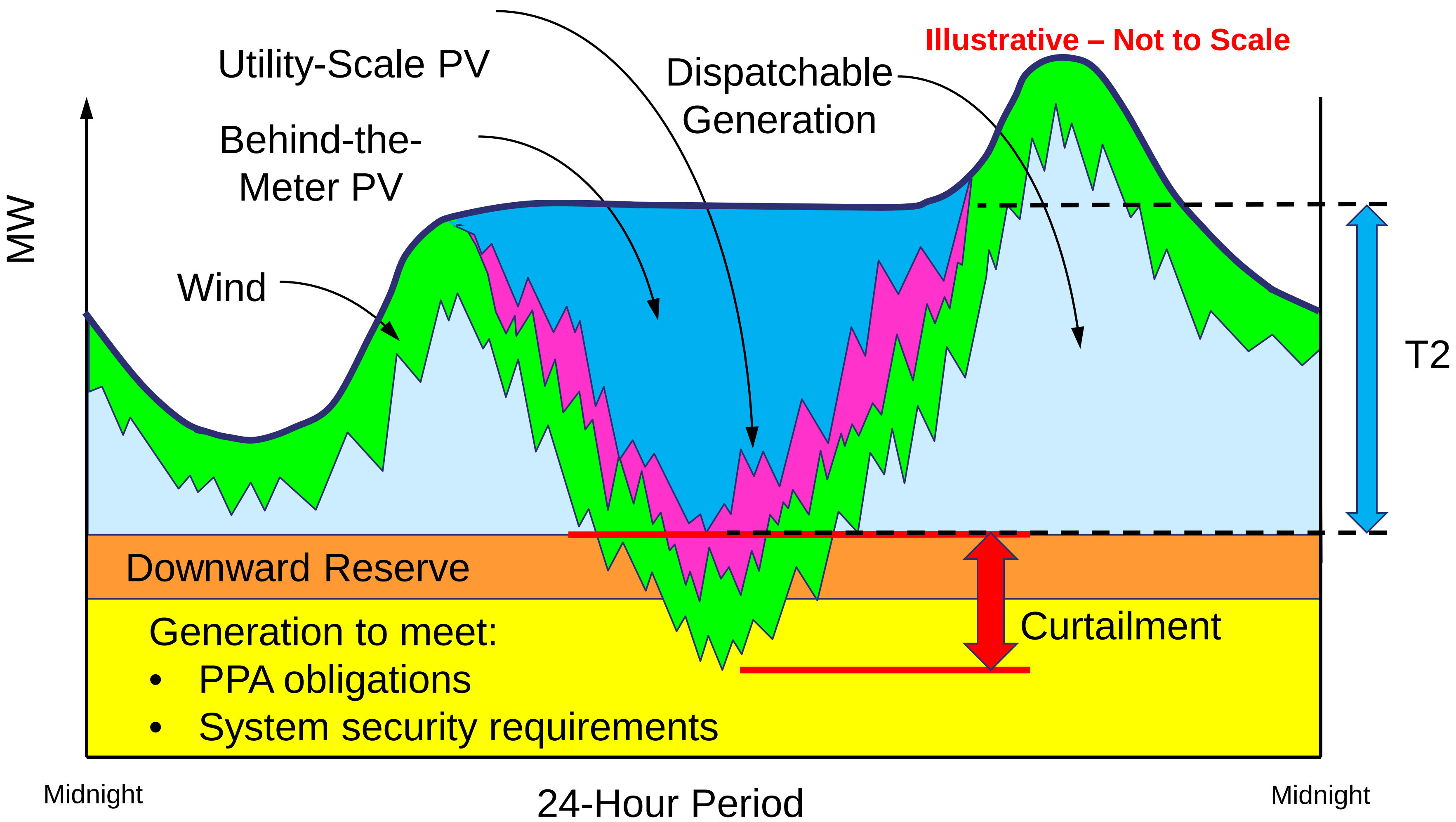
Circuit Level Hosting Capacity

Conduct circuit level hosting capacity unique to each circuit to enable efficient interconnection process and proactively mitigate impacts

Advanced Inverters

Establishment of advanced inverter standards (power factor, volt-watt, frequency-watt, communications, etc.) to cost-effectively and safely integrate distributed energy resources

② Circuit Level Issues: Propose to set a system-level hosting capacity to prevent excess energy



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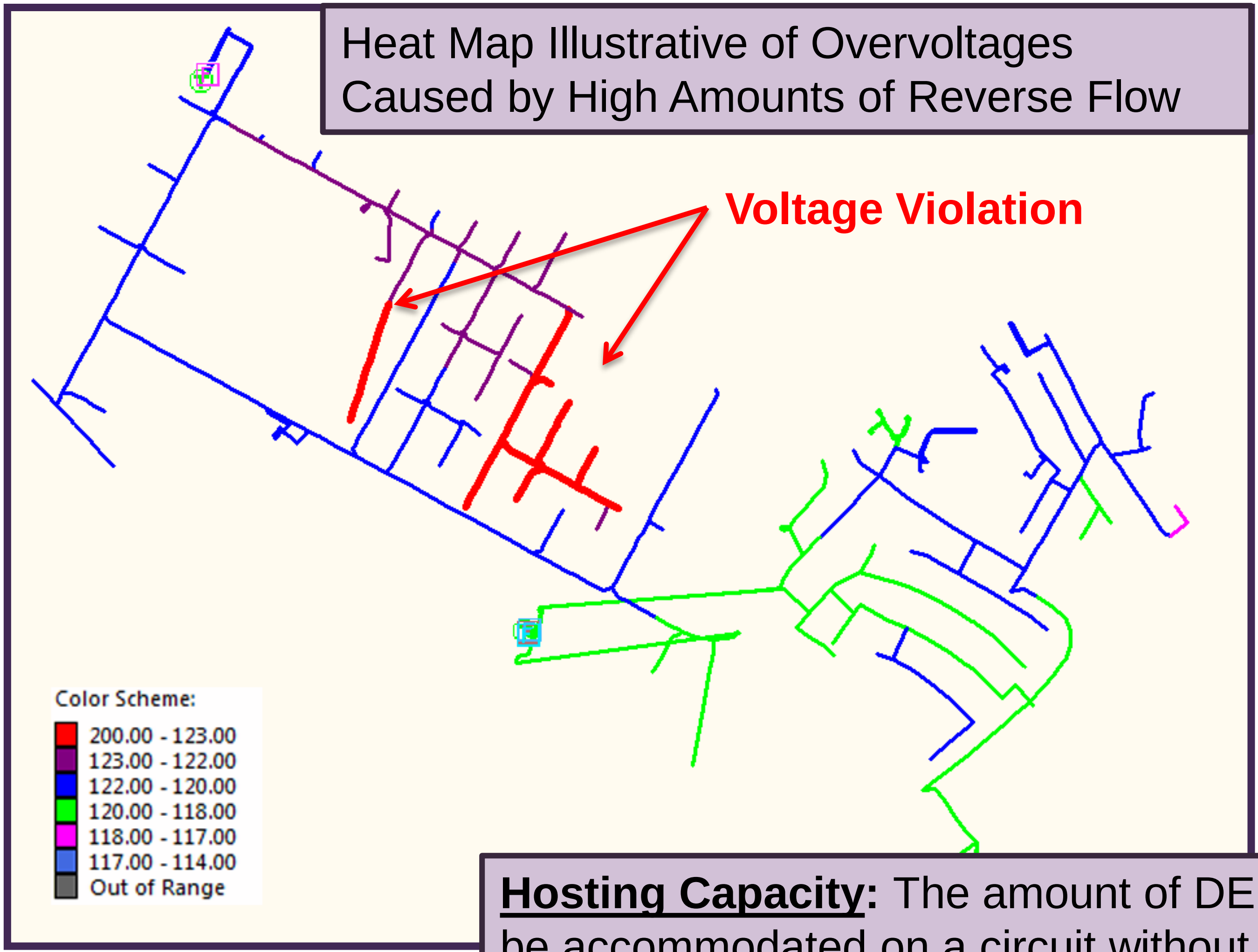
② Circuit Level Issues: At the distribution level, circuit "hosting capacity" method used to plan

Heat Map Illustrative of Overvoltages Caused by High Amounts of Reverse Flow



Hosting Capacity: The amount of DER (PV) that can be accommodated on a circuit without adversely impacting operations, power quality, or reliability.

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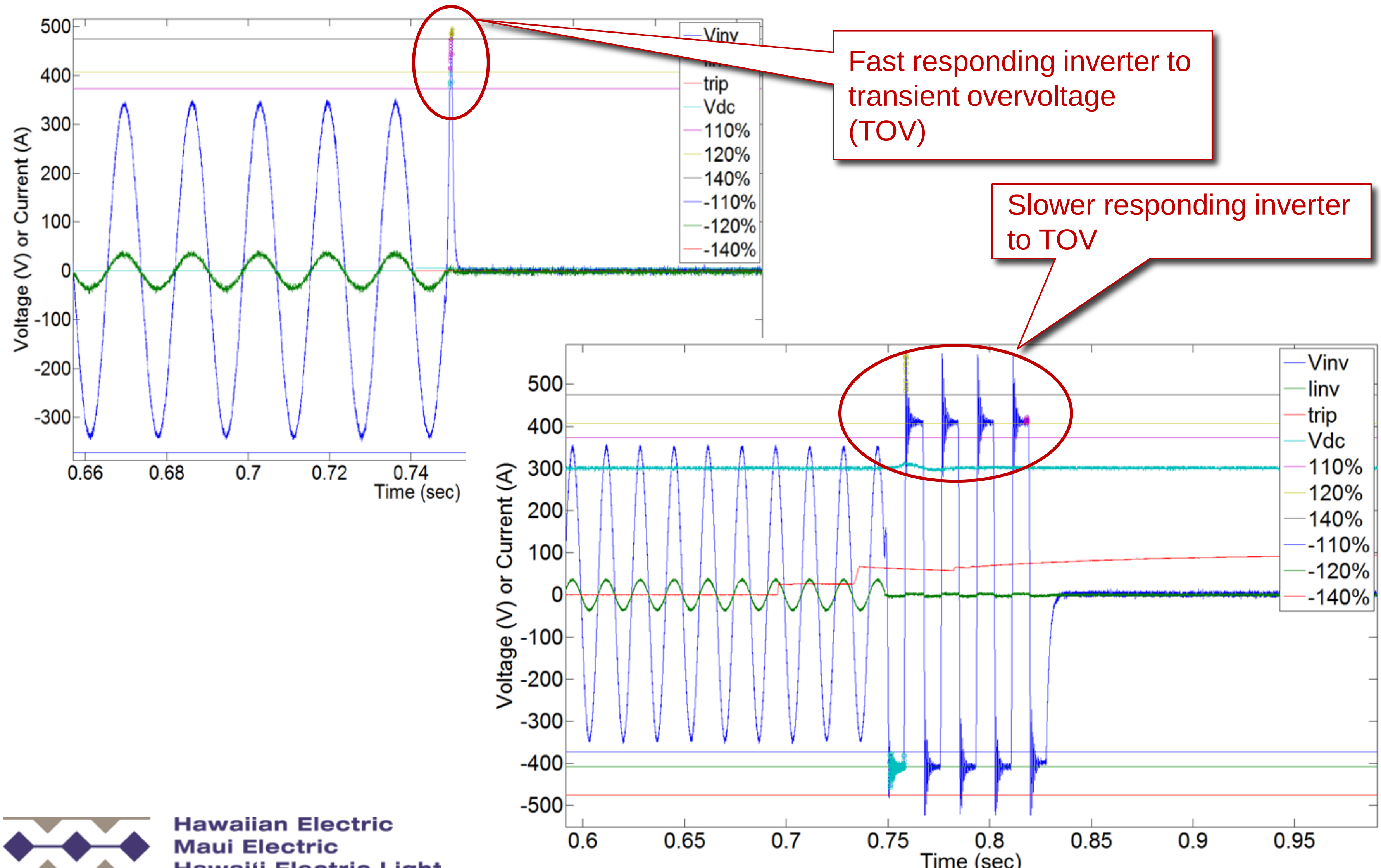
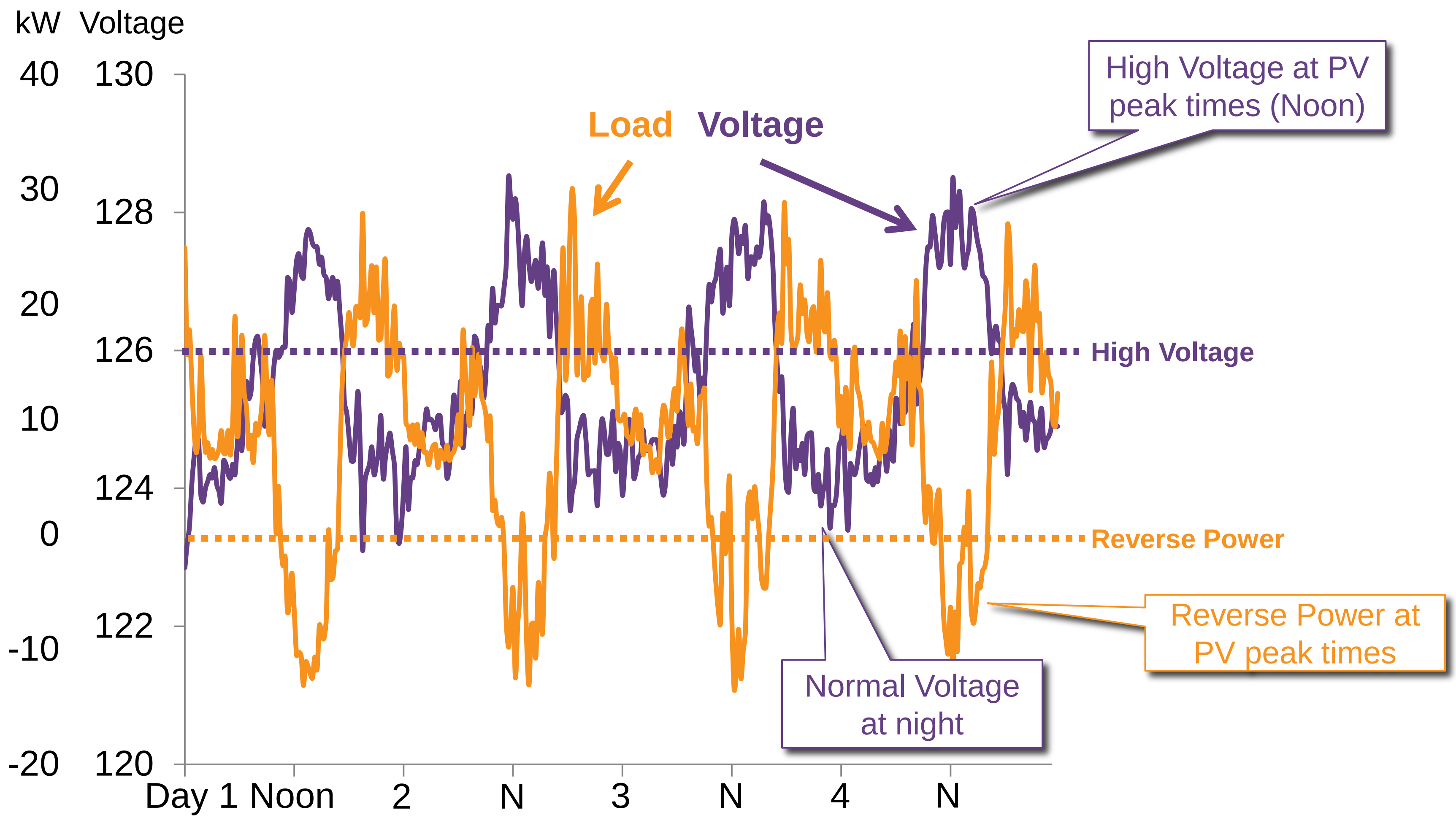
③ Overvoltage Issues: Testing at NREL provided an opportunity to solve DER integration issues in a real world environment



③ Overvoltage Issues: The Next Challenge: Real world overvoltage events demonstrate that PV systems can cause overvoltage



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The Hawaii PUC recently approved Advanced Inverter standards

New capabilities will benefit all customers by:

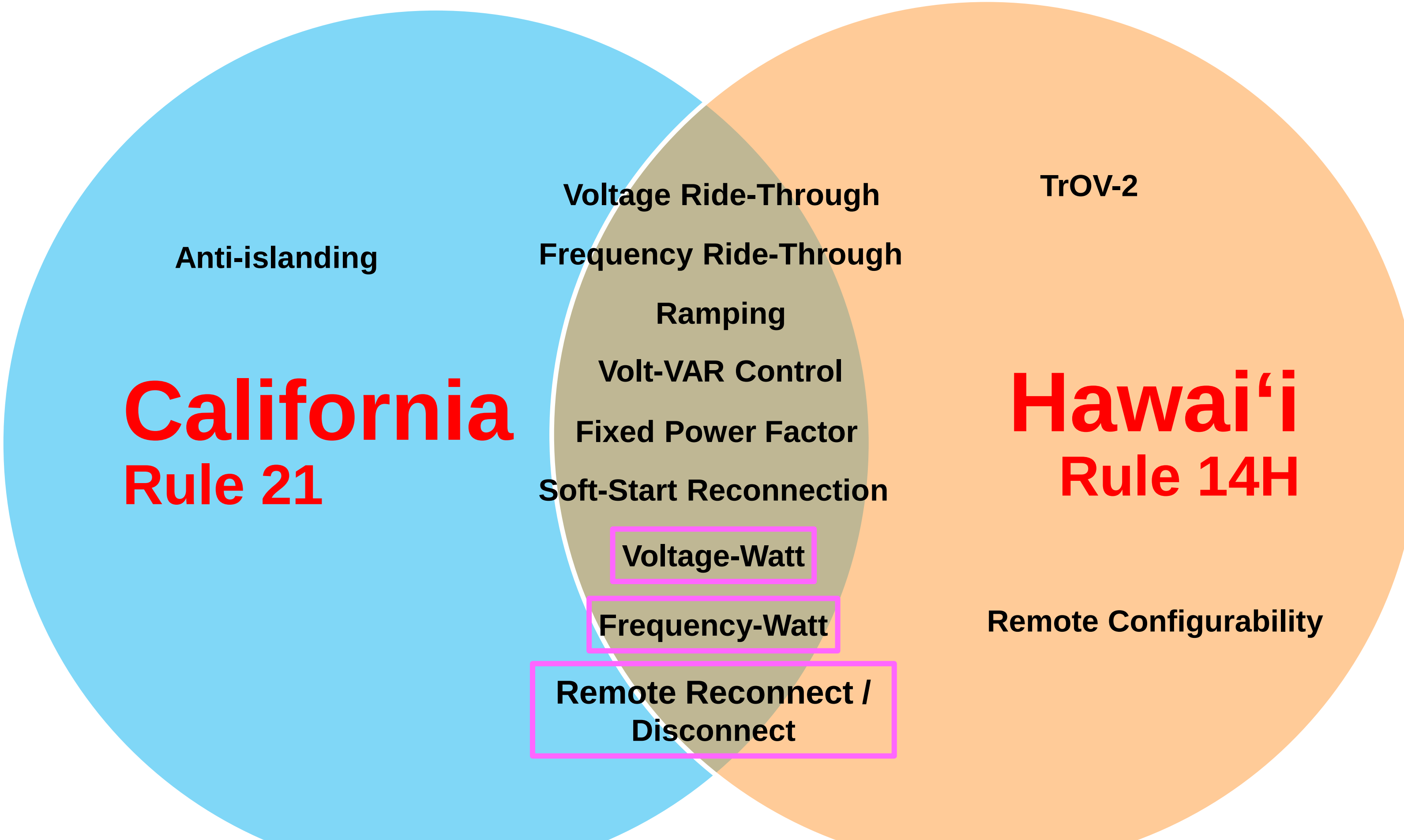
- Allowing safe integration of higher levels of DER systems
- Reduce risk of damaging customer and utility equipment
- Maintain grid resiliency and reliability for customers

Support new Customer Self-Supply, Customer Grid-Supply, and other DER programs

Continue to collaborate with Inverter Manufacturers to advance DER technologies and technical policies, establish self-certification process until national standards (UL-1741) are established

Advanced inverter functions are important to the continued deployment of DER in Hawai‘i

Where possible we aligned HI Rule 14H with CA Rule 21 advanced inverter standards



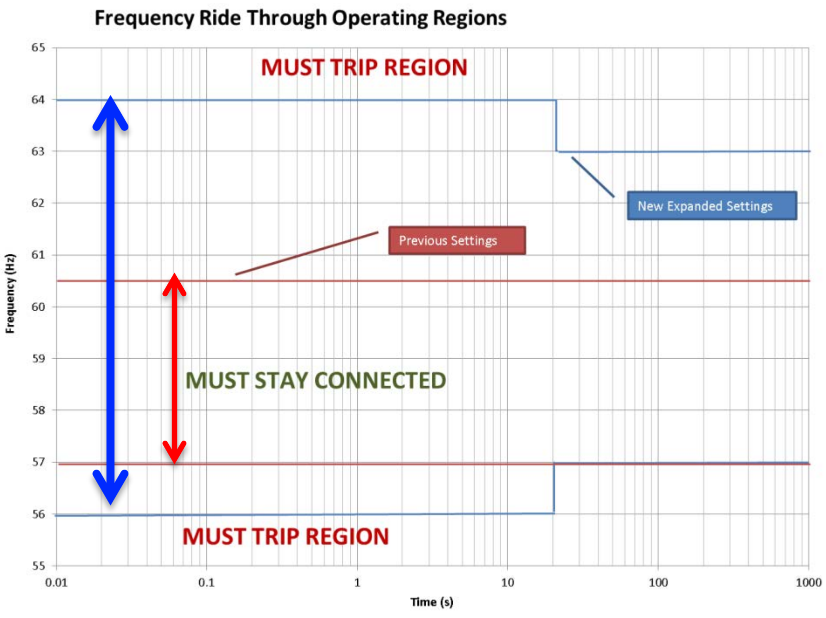
Hawai’i accelerated certain Advanced Inverter functions sooner than California

SIWG Phase 3

SIWG: Smart Inverter Working Group

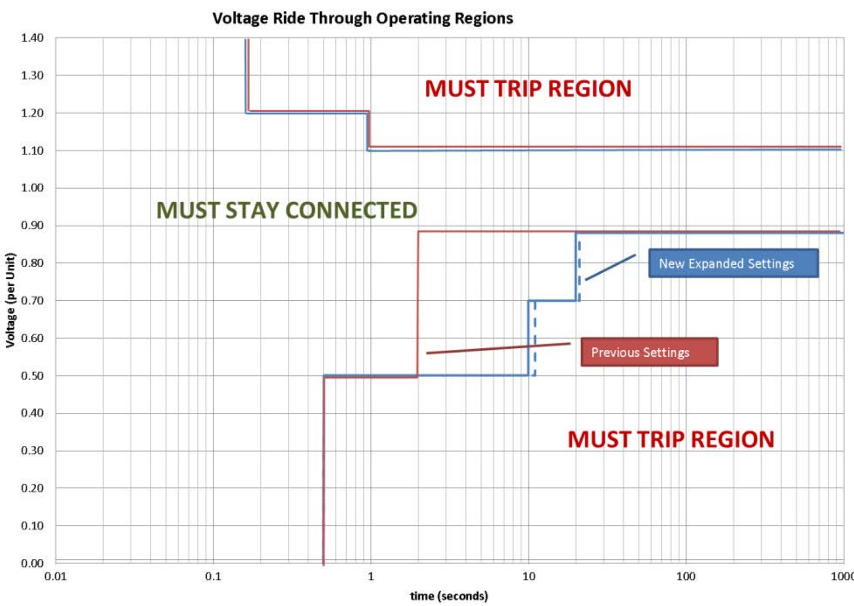
Ride-through standards were established to assist during system disturbances

Low/High Frequency Ride-Through



Inverter will ride-through system contingencies (i.e. loss of large load or generating unit)

Low/High Voltage Ride-Through



Inverter will ride-through system or circuit disturbances (i.e. short circuit faults)

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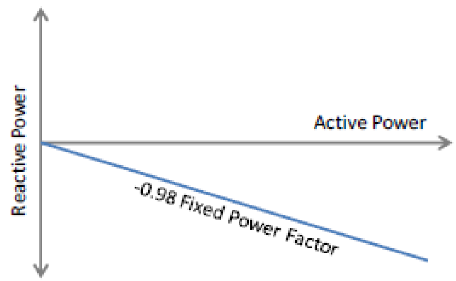
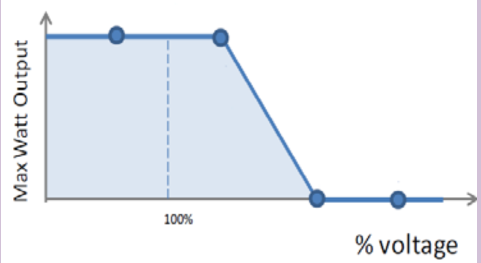
Adoption of autonomous advanced inverter voltage functions may mitigate voltage issues

Fixed Power Factor



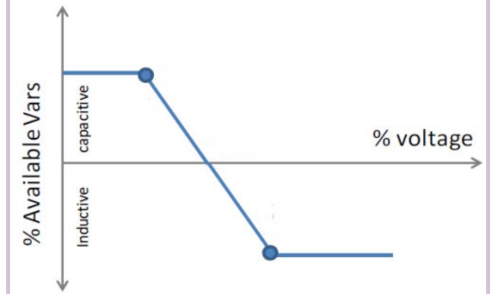
Provides voltage support; mitigate high voltages. May increase system losses.

Volt-Watt



Mitigates secondary high voltage by reducing real power as a function of voltage.

Volt-Var



Circuit voltage optimization; regulates voltage as a function of vars.

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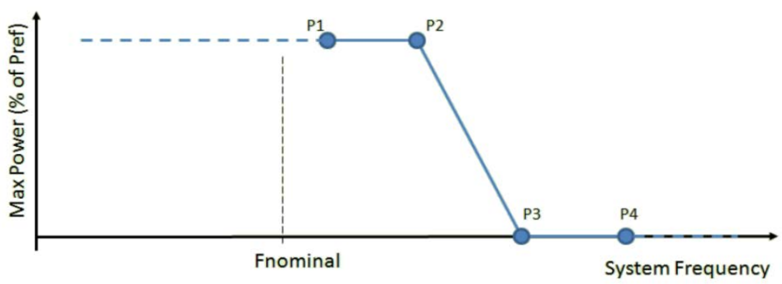
Source: EPRI Report 3002001246

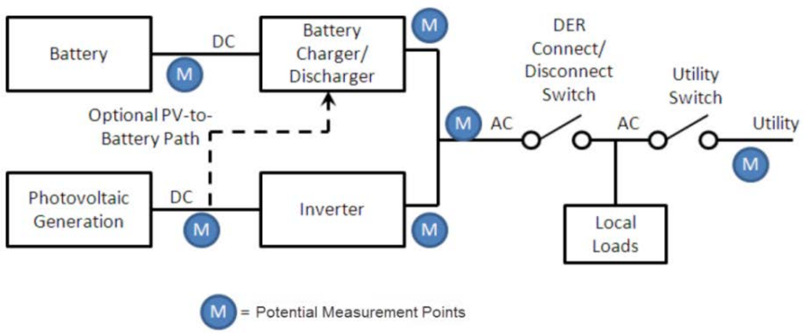
Advanced inverters may provide system support

Frequency-Watt



May assist in over-frequency due to of loss of load/excess energy

Communications



Remote configurability, measurement, and visibility capabilities

Remote Connect/Disconnect

Utility sends command to inverter to disconnect or reconnect system. To be used during system emergencies or system restoration.

Soft-Start

Gradually raises the inverter power output to coordinate with the ramping capabilities of the bulk generating system. Mitigates frequency swings during system restoration.

Source: EPRI Report 3002001246

Nation leading adoption schedule for advanced inverter technical standards

Activation Required Within 12 months of Approval of UL 1741 Supplement A

- Volt-Watt
- Ramping
- Soft-Start reconnect
- Frequency-Watt
- Remote Reconnect-Disconnect
- Remote Configurability

Activation of individual functions may occur sooner based upon system needs

Activation Required January 1, 2016

- Fixed Power Factor

Activation Required October 1, 2015

- Transient Overvoltage-2
- Full Voltage Ride-Through
- Full Frequency Ride-Through

Hawaiian Electric's Advanced Inverter Timeline

2014 — 2015 — 2016

- **Apr 2014** Begin TrOV inverter testing at NREL
- **Aug 2014** File revised FVRT settings in DER docket as supplemental IR response
- **Sep 2014** Issue FVRT RFI to inverter industry
- **Nov 2014** Issue request to inverter industry to implement two-phased FVRT changes
- **Dec 2014** Phase 1 "Interim" FVRT reprogramming
- **Feb 2015** Issue new TrOV and FVRT requirements to inverter industry
- **June 2015** File Rule 14H Stip and FSOP in DER docket
- **Oct 2015** PUC issues DER D&O 33258
- **Nov 2015** New Self-Certification Process for Advanced Inverters & new Qualified inverter list posted
- **Dec 2015** File Advanced Inverter Test Plan with PUC
- **Jan 2016** Advanced Inverters required. Fixed Power Factor added to TrOV and full FVRT requirements

2016

Testing of Advanced Inverters to be conducted within 6 months after PUC approves Test Plan (further testing after 6 months anticipated)

Phase 2 of DER proceeding

- Advanced inverter functionalities and activation timeline
- Communications and control of inverters

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Industry collaborations lead to successful outcomes for customers and the utility

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

- Collaborative research on advanced inverter function
- TrOV-2 test protocol and pending inverter performance testing

MAITAI

Manufacturing Alliance of Inverters Technical Assessment of Integration Issues

- Ad hoc group of only inverter manufacturers
- Working with MAITAI on AI issues, requirements, and processes

FIGII Forum for Inverter Grid Issues & Interconnection

- Ad hoc group of select inverter manufacturers and other stakeholders
- Drafted test procedures on of Load Rejection Overvoltage (LROV) and Ground-Fault Overvoltage (GFOV)

AITWG (Advanced Inverter Technical Working Group)

- Hawaiian Electric working group consisting of MAITAI, inverter manufacturers, NREL, EPRI, and Hawaiian Electric personnel
- Technical issues with broader inverter industry representation

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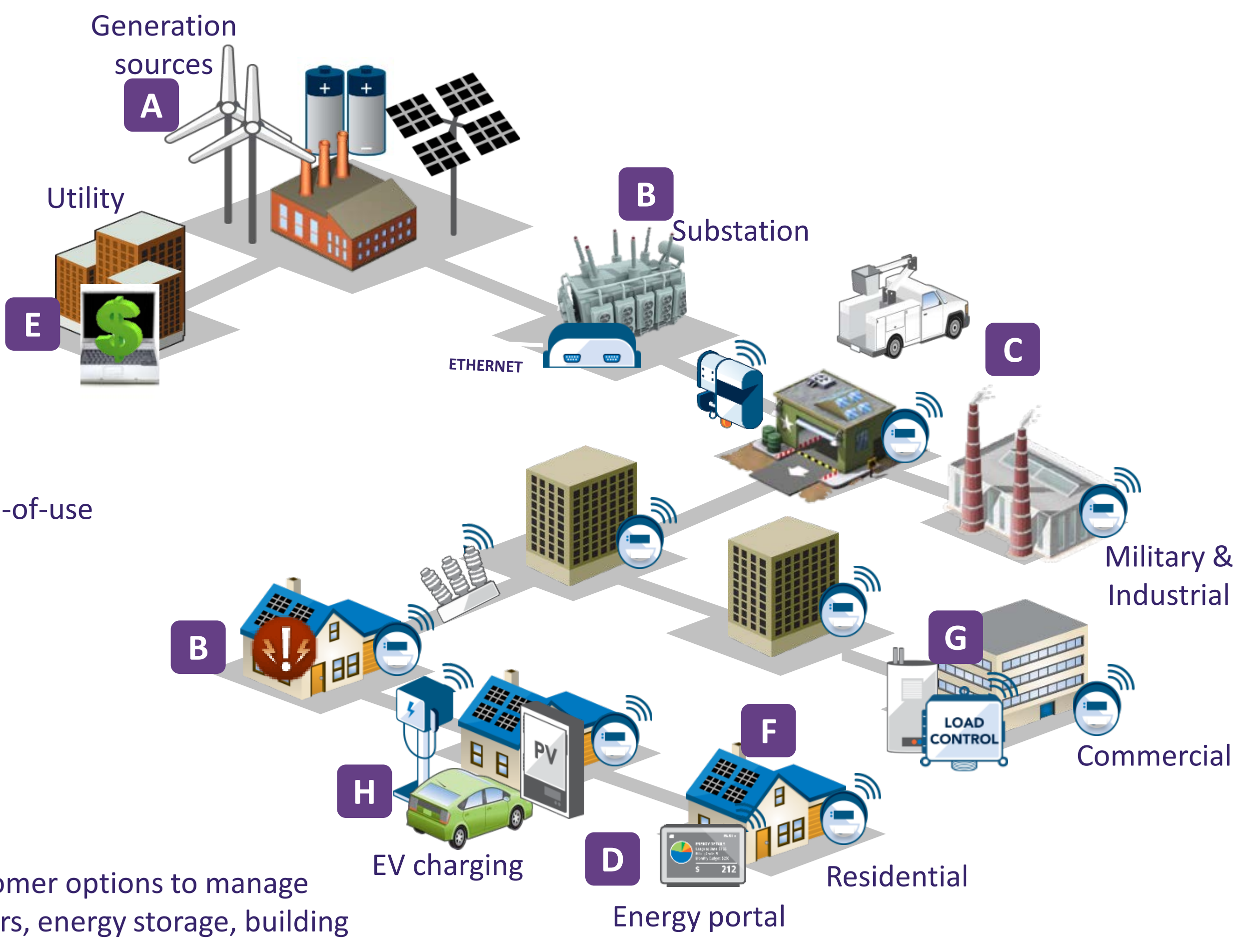
Solutions to renewable energy integration involves a comprehensive view of your load, generation and grid

- **A** Diverse portfolio of energy resources; Fast-start, flexible generation (offline reserves)
- **B** Improved outage management
- **C** Reduced dependence on central station resources
- **D** Near real-time energy information for and from customers
- **E** Alignment of supply and demand (time-of-use rates, innovative tariffs)
- **F** Increased visibility and use of distributed resources to provide grid services
- **G** Demand response and load management
- **H** Use of emerging technologies and customer options to manage the grid (e.g. EV charging, smart inverters, energy storage, building energy management systems, microgrids, etc.)



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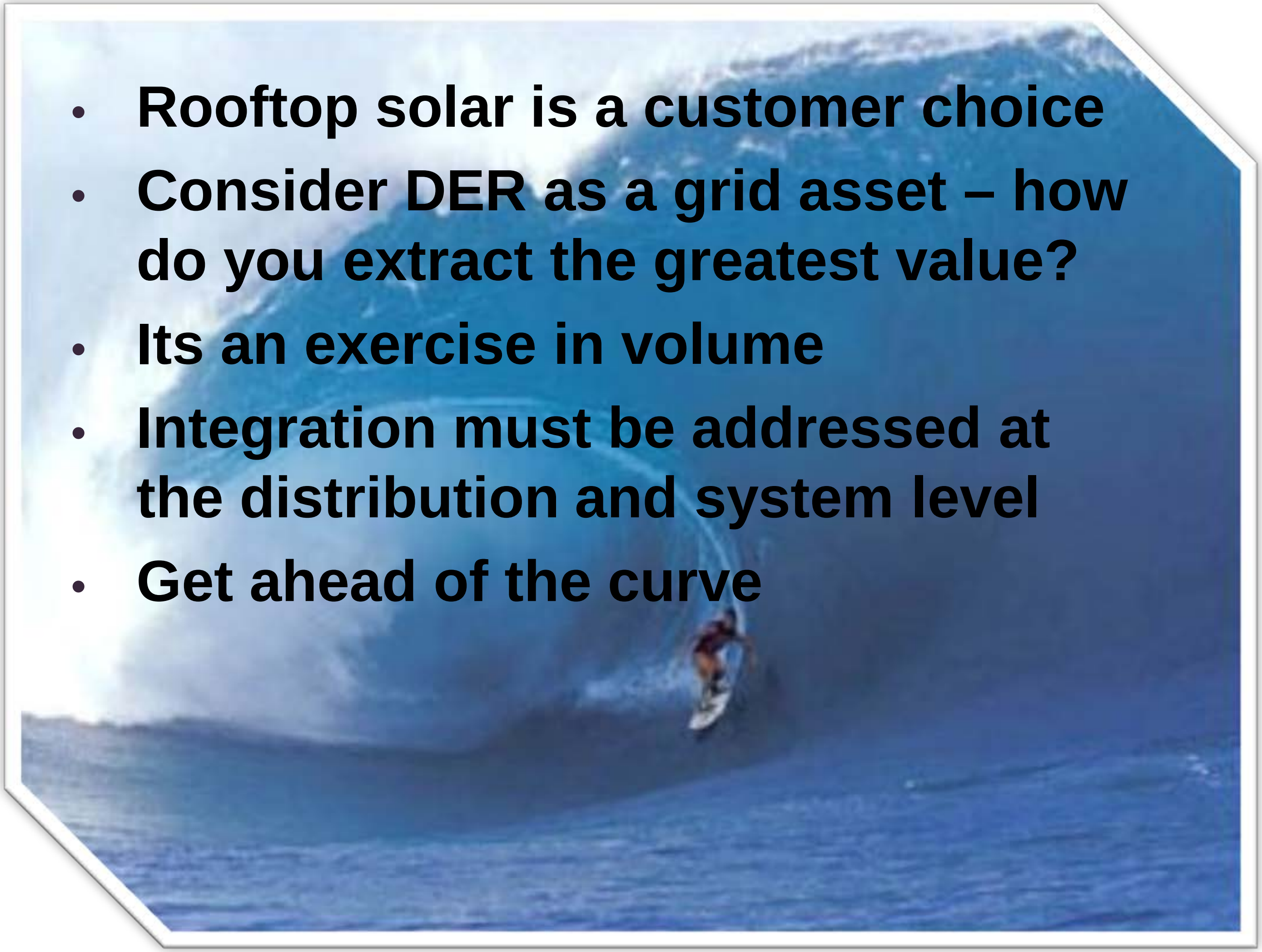
DER integration lessons learned



- **Rooftop solar is a customer choice**
- **Consider DER as a grid asset – how do you extract the greatest value?**
- **Its an exercise in volume**
- **Integration must be addressed at the distribution and system level**
- **Get ahead of the curve**

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Colton K. Ching
Vice President Energy Delivery
colton.ching@hawaiianelectric.com

Mahalo!

BREAK

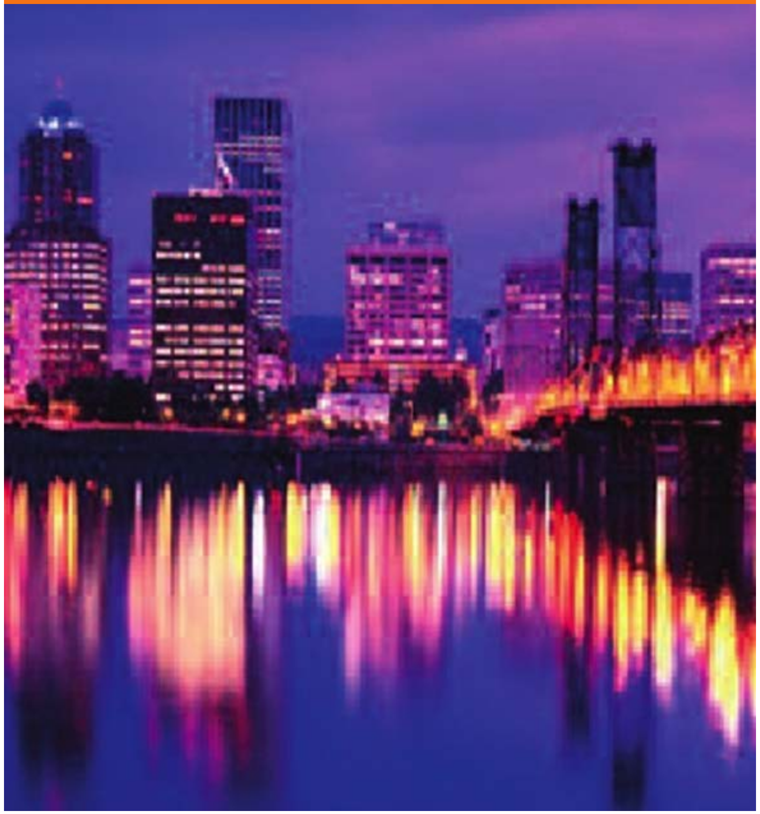
UTILITIES

- PGE
- PAC
- Idaho

OTHER PARTIES

- IREC
- COMBINED - TASC, NW Seed, OSEIA, Renewable Northwest, Environment Oregon

UM 1716: Reliability Impacts Workshop #1



Date: 19 January 2016

Presenters: Darren Murtaugh

Portland General Electric

Basic Overview: Reliable T&D System

- Main objectives of a well-planned system
  - Safety and Protection
    - System is designed to protect public and crew safety
    - Electrical equipment is suitably rated for the intended use
    - Electrical equipment is protected from overloads, faulted conditions, etc
  - Consider both normal and contingency conditions
    - Studies include a range of system forecasts
  - System must be designed to:
    - Enable effective and flexible maintenance plans
    - Maintain adequate system voltage and frequency
    - Maintain energy balance for load and generation changes
    - Maintain system stability and adequacy following a disturbance
    - Achieve restoration and continuity of service following a disturbance

Today's Discussion

- How distributed solar can influence system planning, design, and operation from a reliability standpoint

- Review potential impacts with respect to: generation, transmission, and distribution facilities

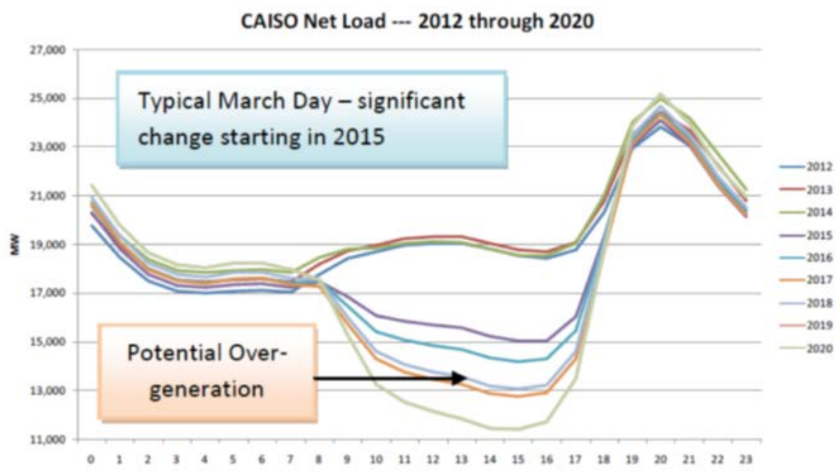
Generation Impact

- Alters generation capacity investment
  - Offsets generation during peak solar output
    - Peak output typically occurs from 10:00 AM – 4:00 PM
  - Requires adequate balancing and regulating capability
    - e.g., ramping units, energy storage

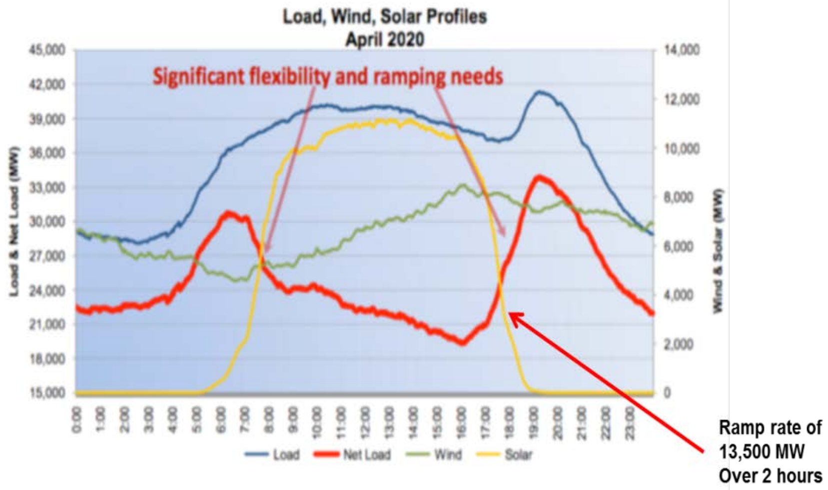
- Ramping and Variability Impacts of Non-Dispatchable Solar Generation
  - High ramping of solar generation during morning and evening
    - Include in forecast when scheduling resources

Generation Impact

The Duck Chart

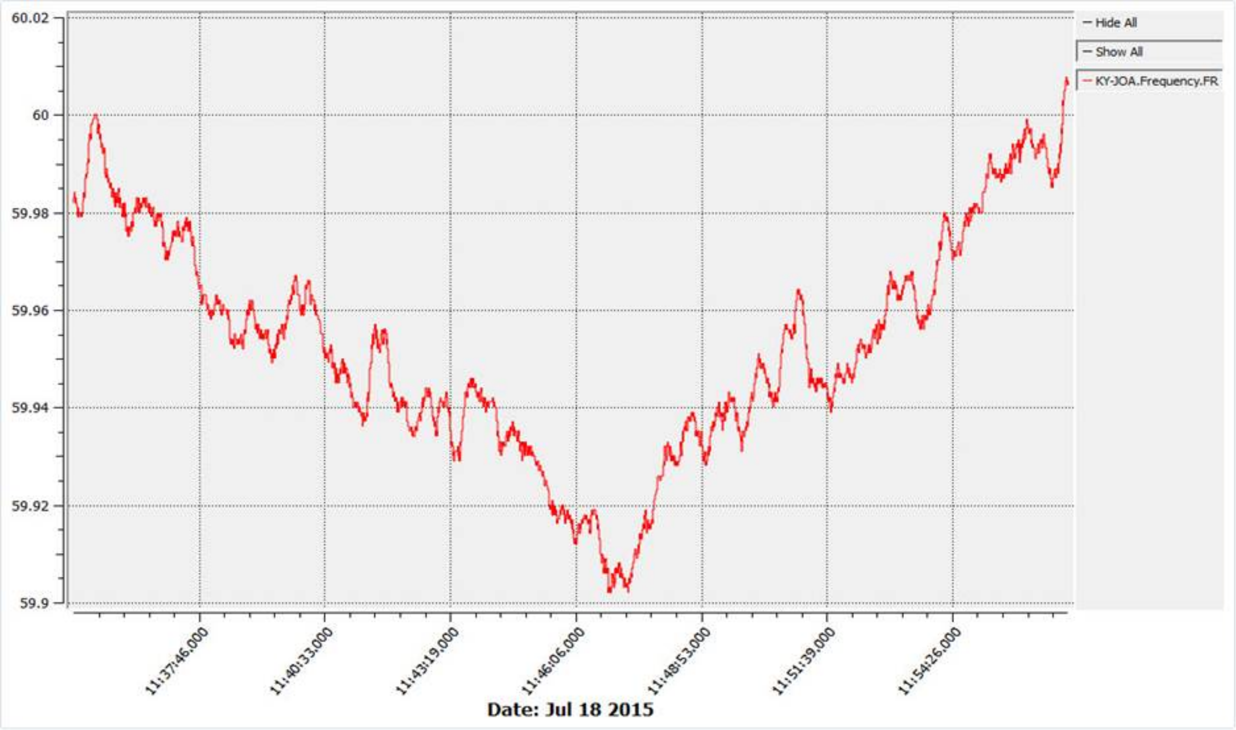


Potential 2020 Ramping Issues



Weather Changes (Cloud Cover)

Actual System Event in California – July 18, 2015
Frequency Decline Due to Sudden Change in PV Output (Cloud Cover in SoCal)
(Similar Response to Loss of 1000 MW Generation)



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Transmission Impact

- Displaces conventional generation
  - May alter transmission flow at high penetrations
  - Greater detail needed in transmission models; State Estimation
  - Regional coordination

- Under-Frequency Load Shedding (UFLS) Program
  - NERC Requirement (PRC-006)
    - Designed to maintain transmission system reliability during a major event
    - WECC approximation is 0.1 Hz decline for every 1,000 MW lost
    - Required to shed up to 28% of system load (high speed)
    - Incidental loss of distributed generation is detrimental to the program

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Distribution Impact

- Distribution Feeder Operation
  - Safety
    - Isolation during feeder repair (anti-islanding)
  - Feeder voltage profile optimization
    - Requires Smart Inverters
    - Requires visibility & control to ensure coordination with system devices
  - Power Quality
    - Feeder management requires independently metered loads and resources
    - Low-voltage ride-through during/following system disturbance
  - Protection
    - Feeder phase balancing and neutral current
    - Potential effect on fault detection and device coordination

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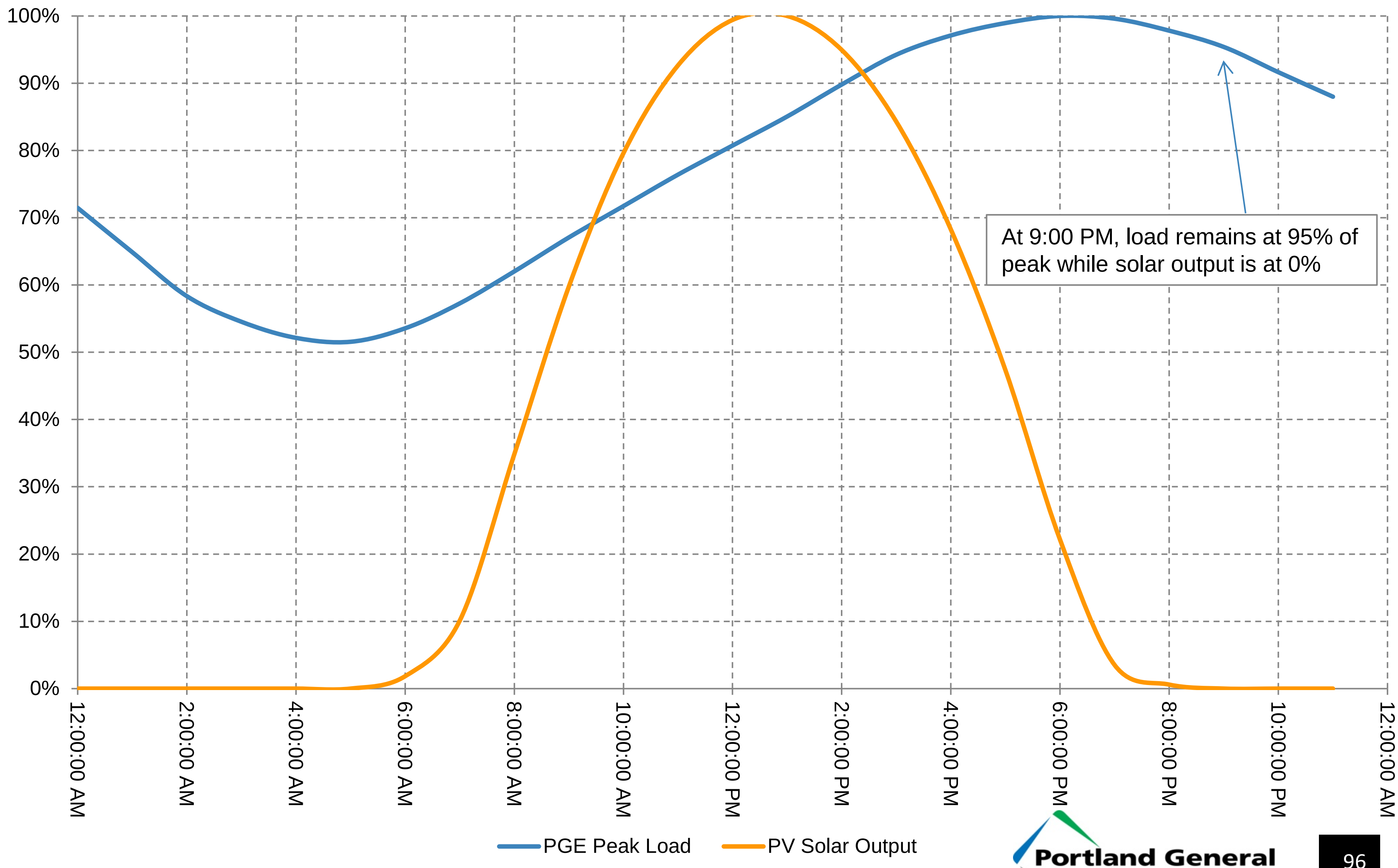
Distribution Impact

- Potential microgrid opportunities (islanding)
  - Continuity of service during a feeder outage
    - Crew safety during feeder repair
    - Requires visibility and control
    - Consider pairing with distributed energy storage
    - Consider resynchronization following an islanding event

- Distribution capacity investments
  - Potential benefits are location specific
  - System is built to address both summer and winter peak
  - Peak loading conditions are not coincident with peak solar output
  - Consider impact for high penetrations during light loading conditions

PGE Peak Summer Load versus PV Solar Availability

Solar data obtained via http://pvwatts.nrel.gov/pvwatts.php



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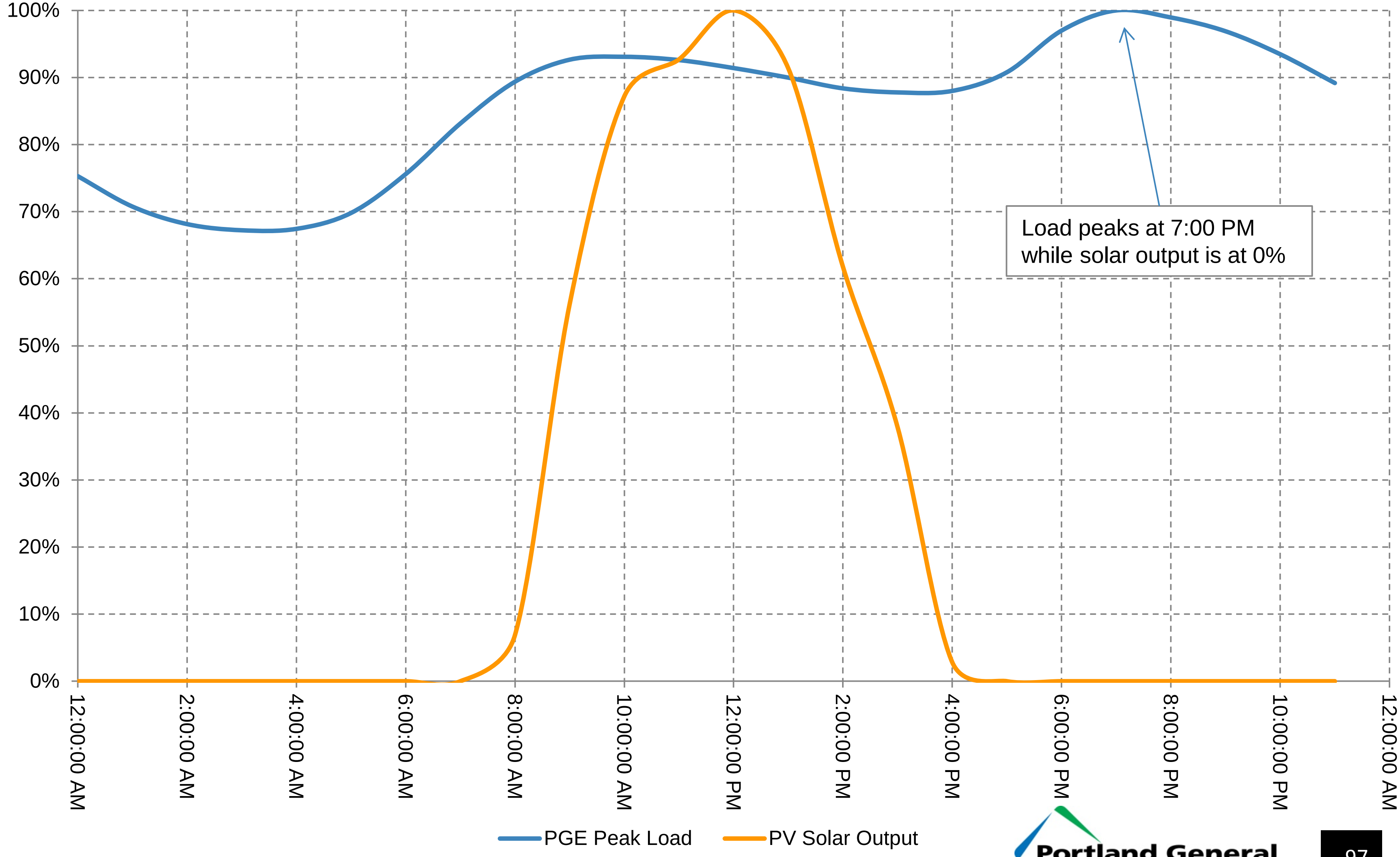
PGE Peak Winter Load versus PV Solar Availability

Solar data obtained via http://pvwatts.nrel.gov/pvwatts.php



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Future Reliability & Operational Impacts

- At what penetration of distributed solar will PGE see reliability and operational impacts?
  - PGE is tracking developments in CA and HI

Future Reliability & Operational Impacts

- Standards development for anti-islanding, islanding, synchronization
  - IEEE 1547; revised standard going to ballot next year
  - Include under-frequency ride-through and low-voltage ride-through
  - Allow for voltage control capability and active power management

- Visibility and Control
  - Select and implement a technology platform for enhanced visibility and control
  - Develop/upgrade communication infrastructure for increased data flow
  - Consider benefits of Net Metering vs Independently Metered DERs

Future Reliability & Operational Impacts

- Energy Supply
  - Invest in energy resources with fast cycling capability
  - Include adequate frequency response and energy reserves
  - Investigate use of energy storage to address solar high ramp rates

- Training
  - Adapt operational procedures and system design to effectively integrate DERs
  - Tools/procedures to forecast and schedule system loads and resources

Q&A

UM 1716 – Reliability Impacts Workshop

Reliability and Operational Impacts from solar

January 19, 2016



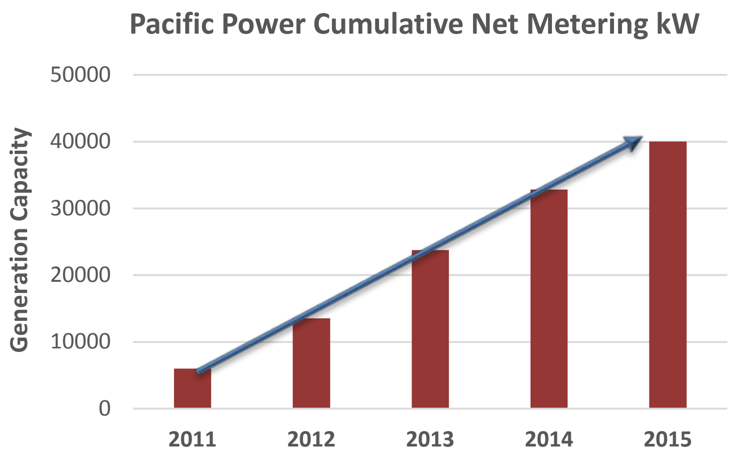

PACIFICORP

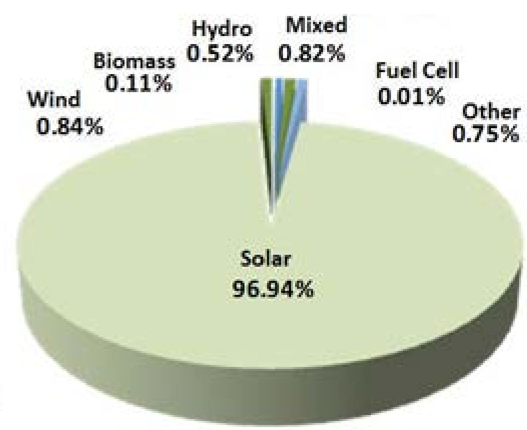
Let's turn the answers on.

Growth in Distributed Energy Resources

<u>Pacific Power - Oregon</u>

- More than 4,500 net metering customers
- 40 megawatts of net metered distributed energy resources
- 97% of distributed energy resources are solar photovoltaic systems
- Approximately 11 megawatts of net metering generation interconnected under *Oregon Solar Incentive Plan*

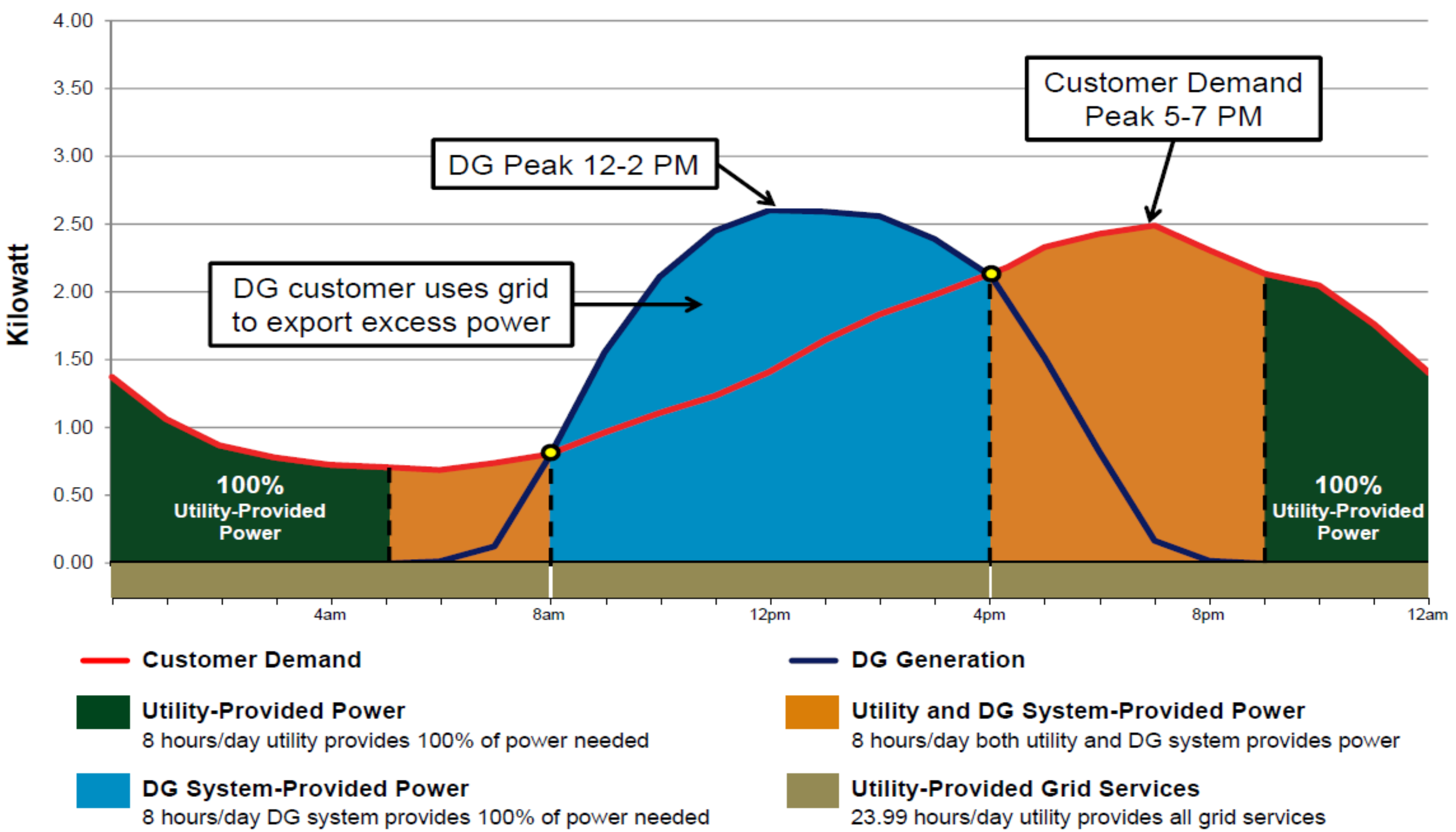




Risks Imposed by Distributed Generation

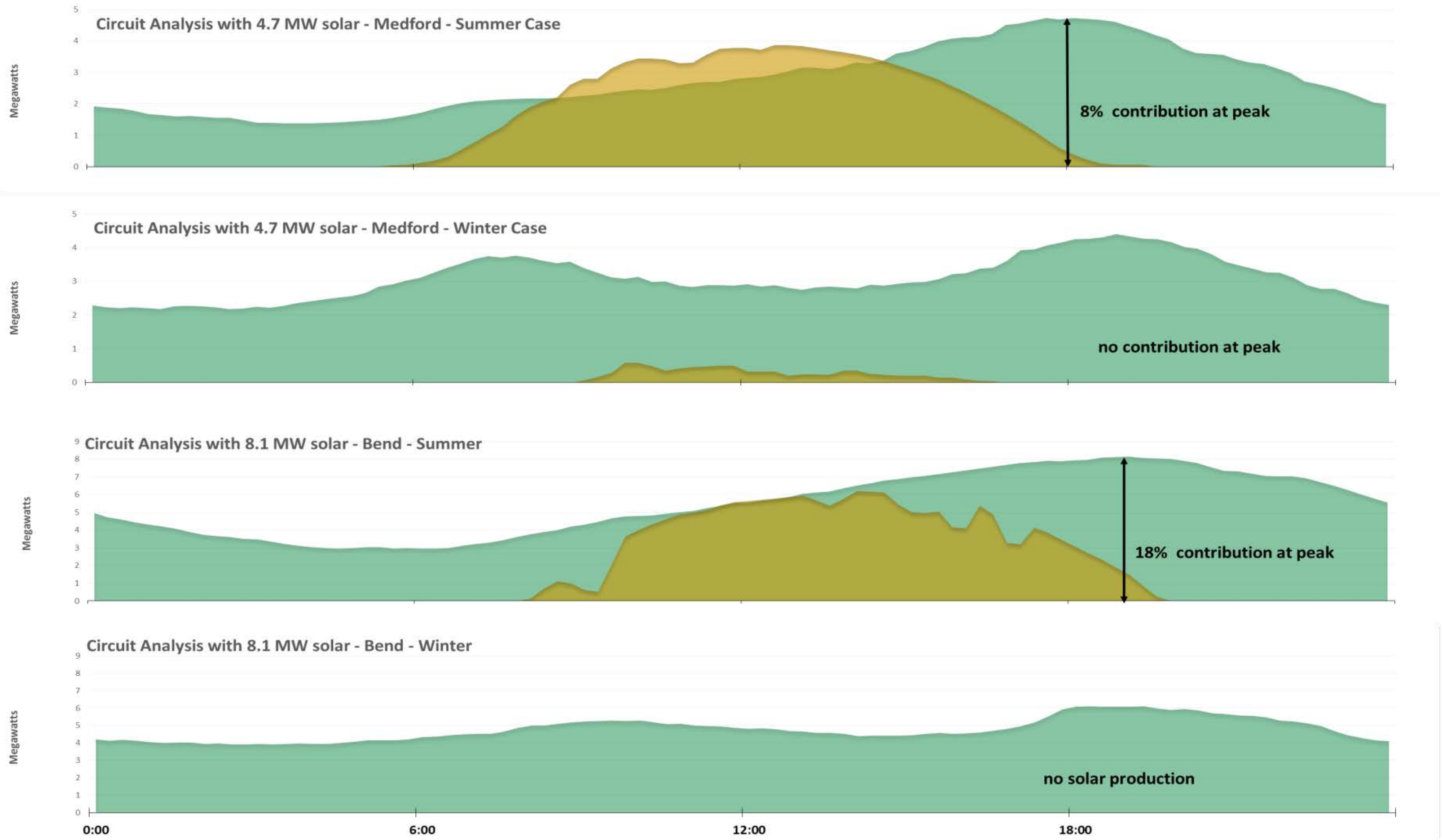
- **T&D capacity risks**
  - ❑ *Limited contribution to peak loading*
  - ❑ *Variable power generation*
  - ❑ *Supply uncertainty*
- **T&D system risks**
  - ❑ *Power Quality*
  - ❑ *Reliability*
  - ❑ *System Planning*
  - ❑ *Operations Management*

Contribution to Peak Circuit Load



A similar chart, titled the "3 States of Net Metering" can be found in a 2013 report by Crossborder Energy. Thomas Beach and Patrick McGuire, *Evaluating the Benefits and Costs of Net Energy Metering in California,* at p.10 (2013). http://votesolar.org/wp-content/uploads/2013/01/Crossborder-Energy-CA-Net-Metering-Cost-Benefit-Jan-2013-final.pdf

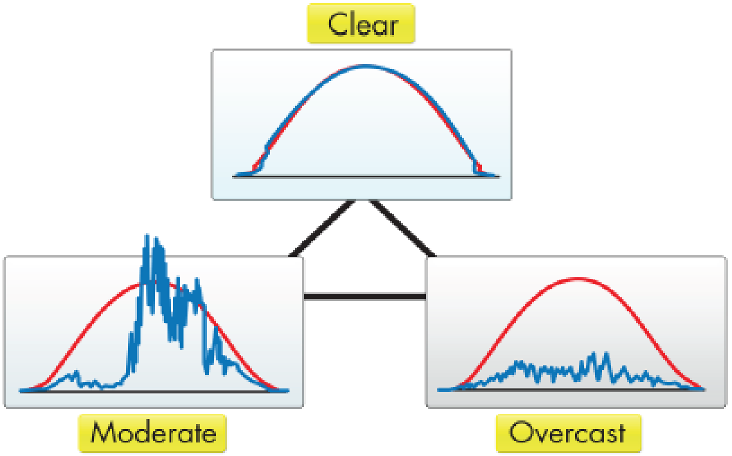
Contribution to Peak Circuit Load

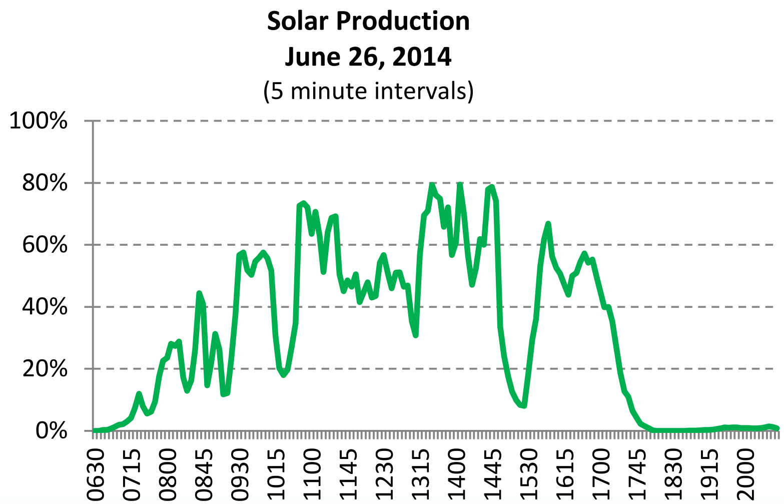


Note: Production data from a residential solar installation connected to each circuit was scaled to each circuit's peak load.

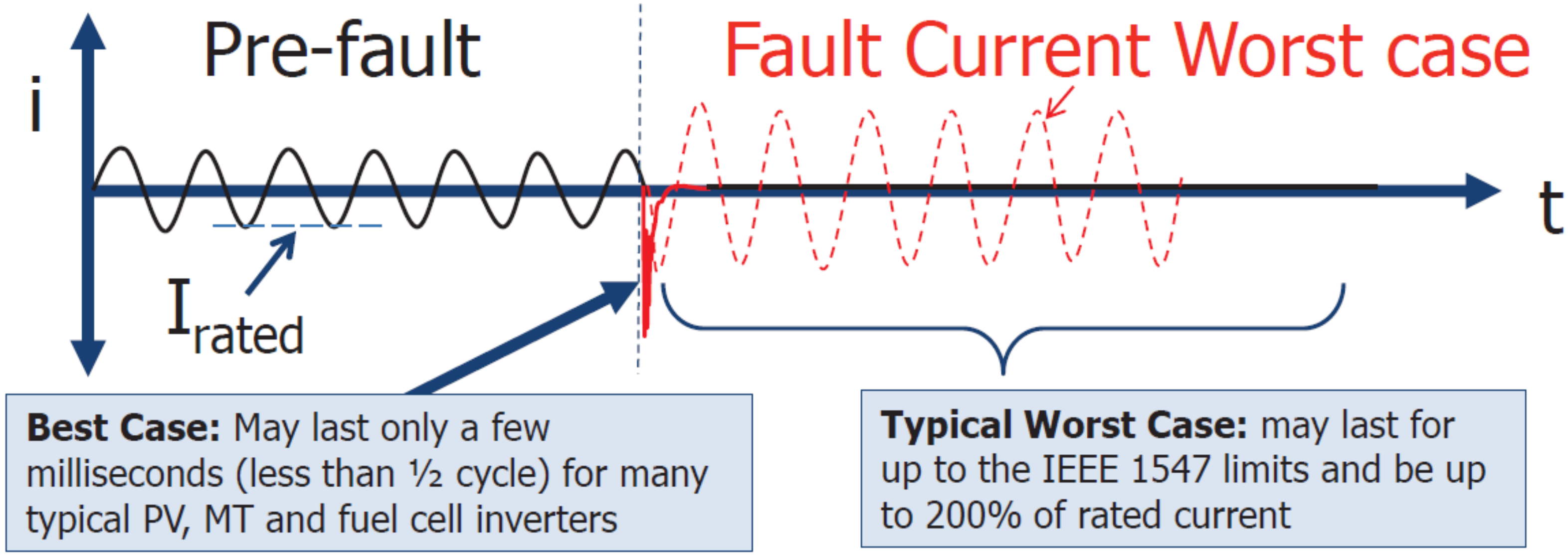
Voltage Regulation & Variation Issues

- Steady state voltage (ANSI C84.1 voltage limits)
- Voltage excursions and regulator cycling
- Voltage flicker
- Line drop compensator interactions
- Reverse power flow interactions





Fault Current Contribution



<u>Note</u>: The exact nature and duration of the fault contribution from an inverter is much more difficult to predict than a rotating machine. In the worst case if fault contributions do continue for more than ½ cycle, they are typically **1 to 2 times** the inverter steady state current rating

Risk Mitigation

- **Distribution Equipment**
  - Regulator controls change out
  - Check line drop compensation interaction with voltage regulator
  - Verify reactive power from capacitor banks connected on the circuit
- **Protection and Control**
  - Verify increased fault levels are within limits
  - Study impact of current on breaker, fuse and recloser coordination
  - Ensure effective grounding of all three phase interconnection projects
- **Additional Costs**
  - Increased engineering and operating costs
  - Planning study complexity and frequency
- **New and Evolving Technologies**
  - Smart Inverter
  - Energy storage

Berkshire Hathaway Energy Collaborative Effort

- PacifiCorp, NV Energy and MidAmerican Energy Company performed several studies on rural and urban circuits to help understand voltage issues caused by high penetration of distributed energy resources
- Rural circuits were found to be more susceptible to power quality issues due to increased levels of solar resources
- Increased voltage regulator operations were identified to be a common challenge with high levels of solar generation on rural circuits
- All businesses are in the process of developing a comprehensive interconnection study guideline

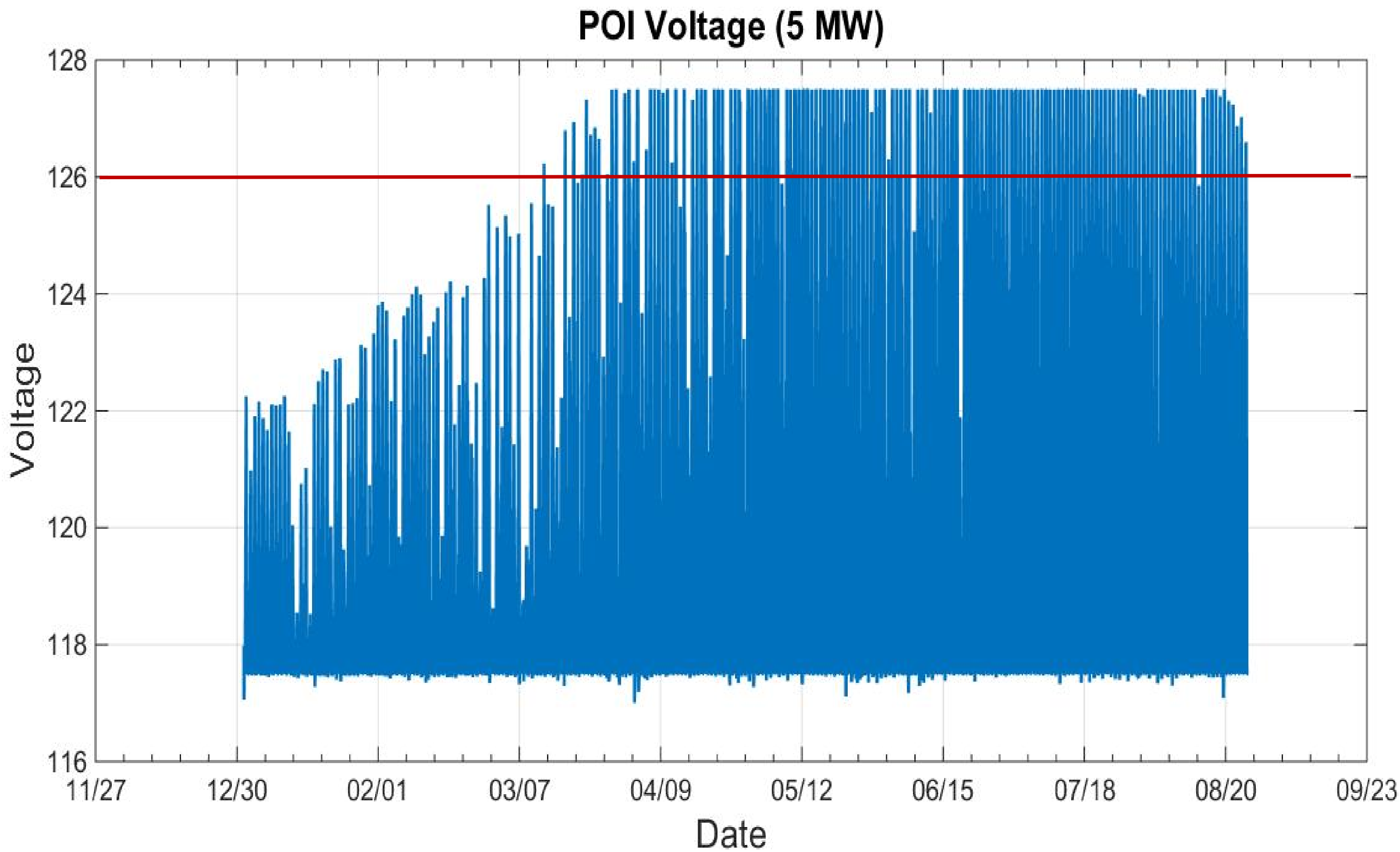
OPUC UM-1716 Solar Reliability Impacts Workshop #1

David Angell

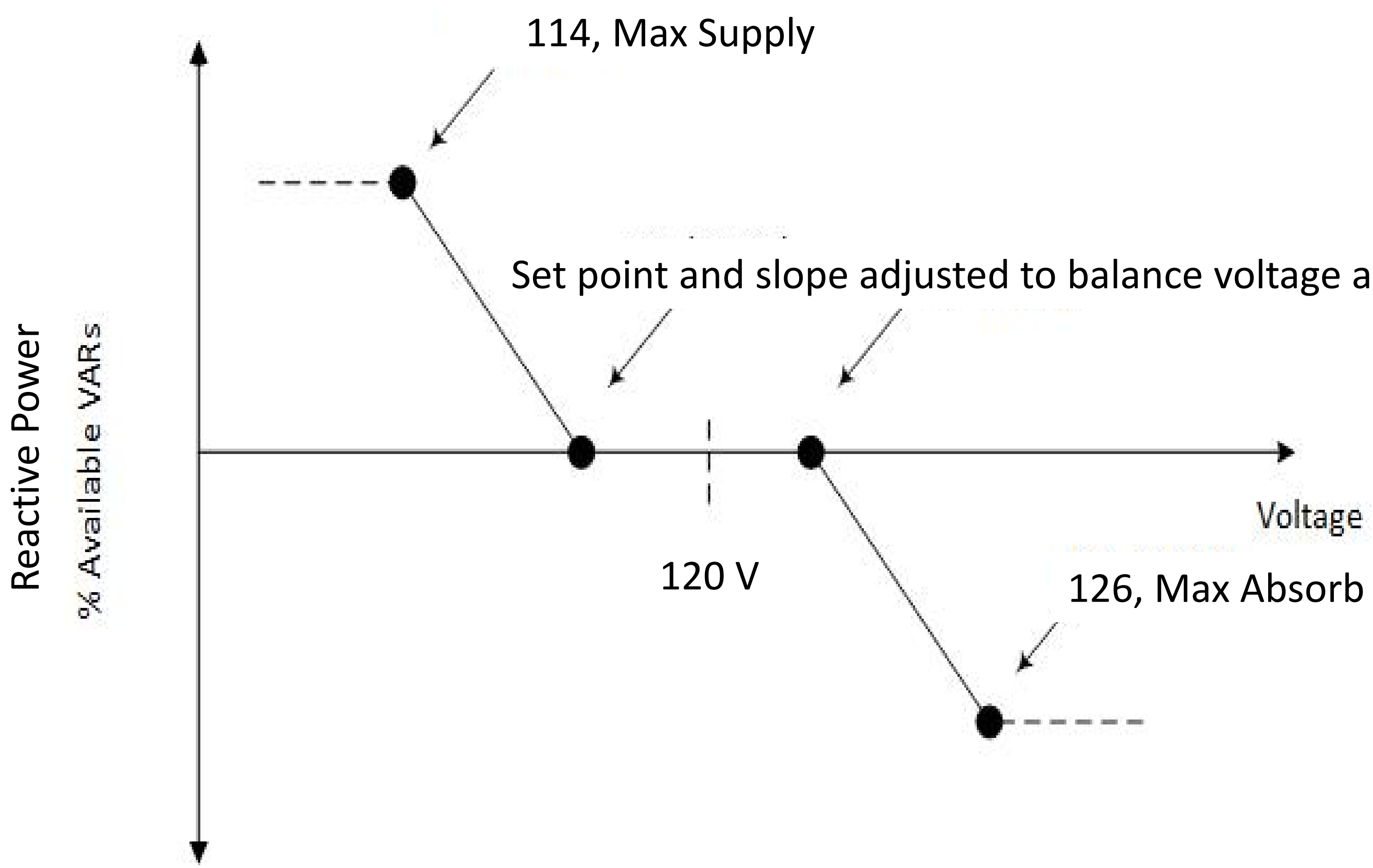
Solar Plant Reliability Impacts

- Distribution System Impacts
  - Voltage Management
  - Flicker
  - Reactive Power
  - Voltage Regulating Devices
- Grid Impacts
  - Regulating Reserves
  - Frequency Regulation

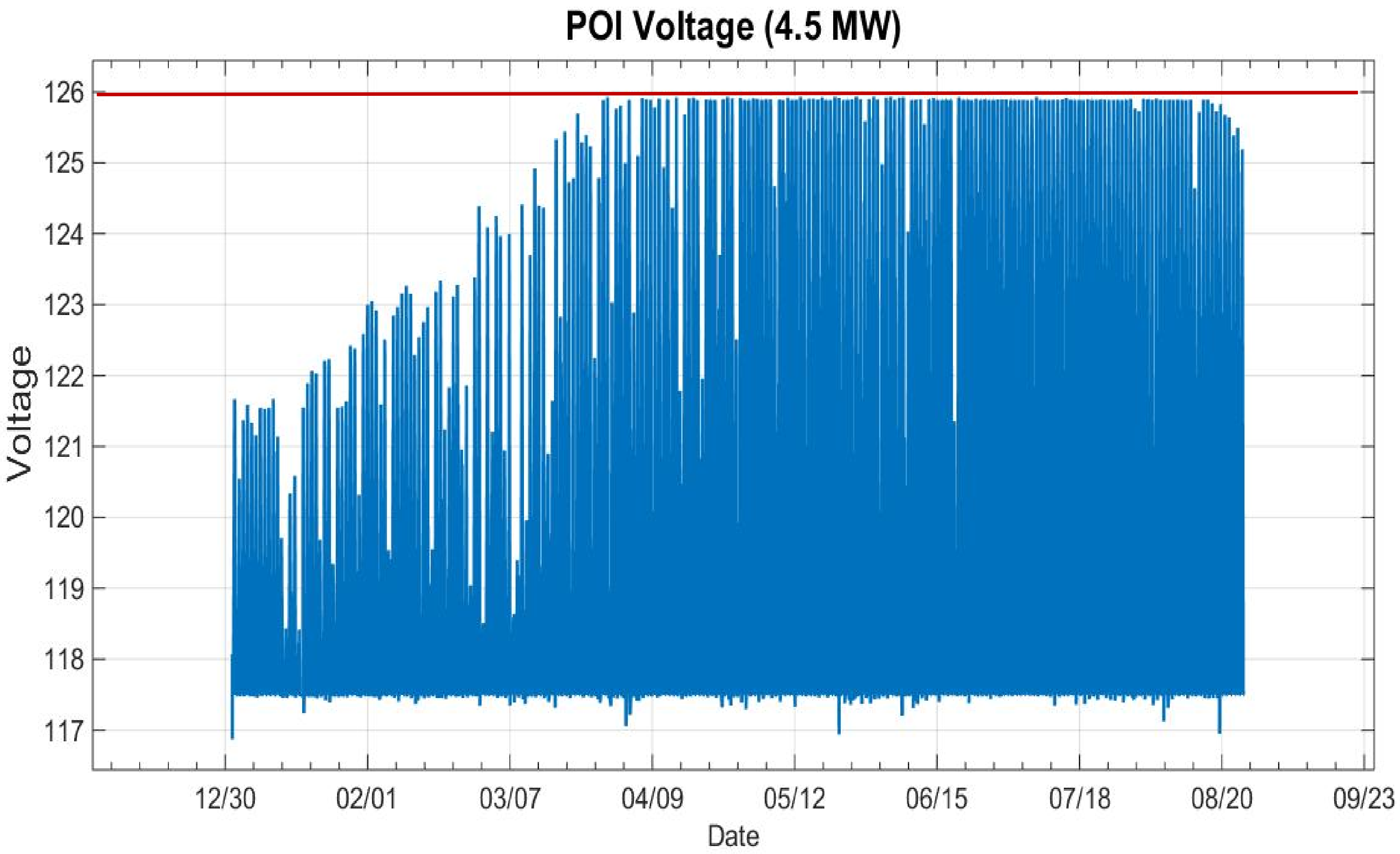
Steady-State Voltage



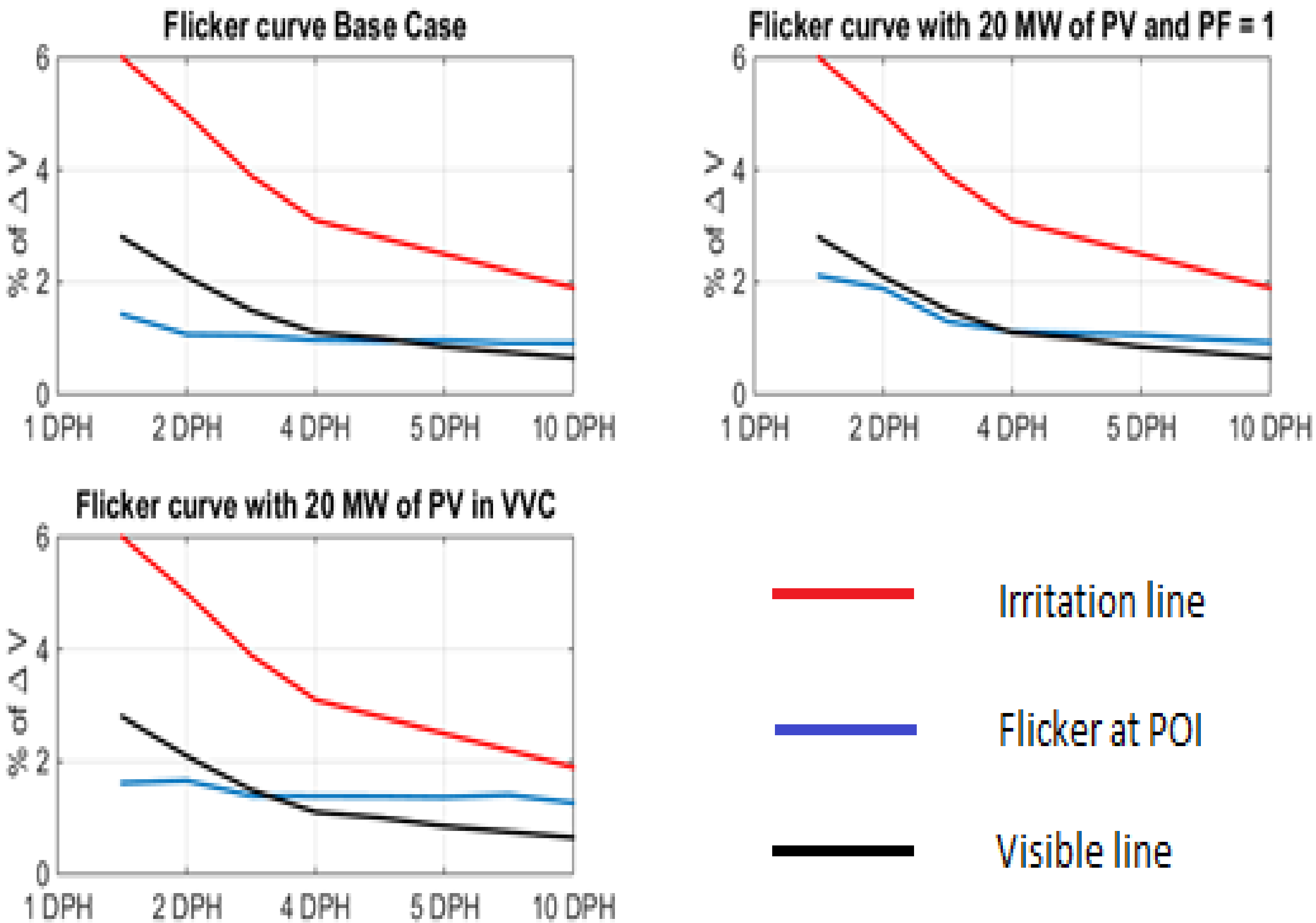
Inverter Volt/VAr Control



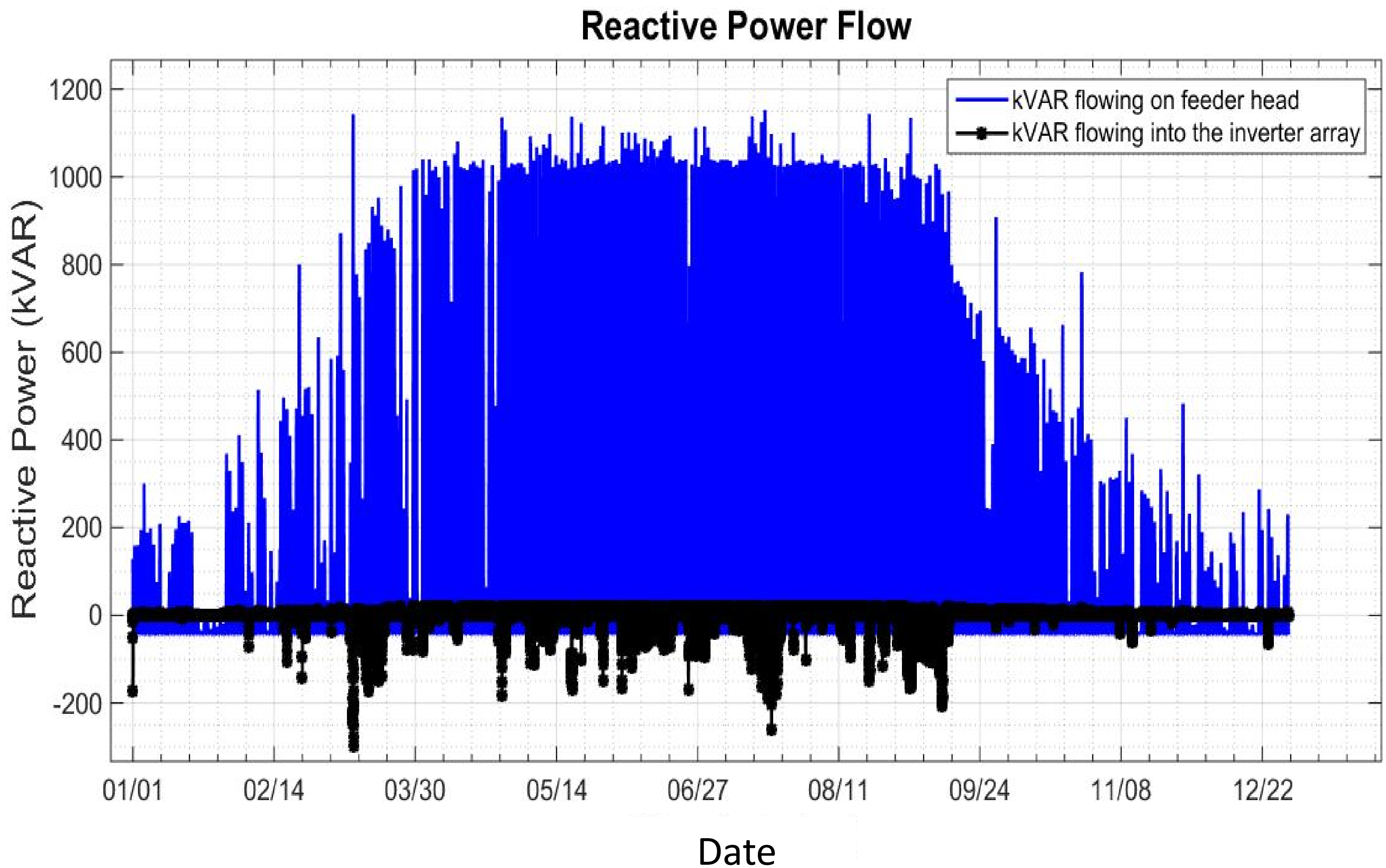
High Voltage Eliminated by Power Output Limit



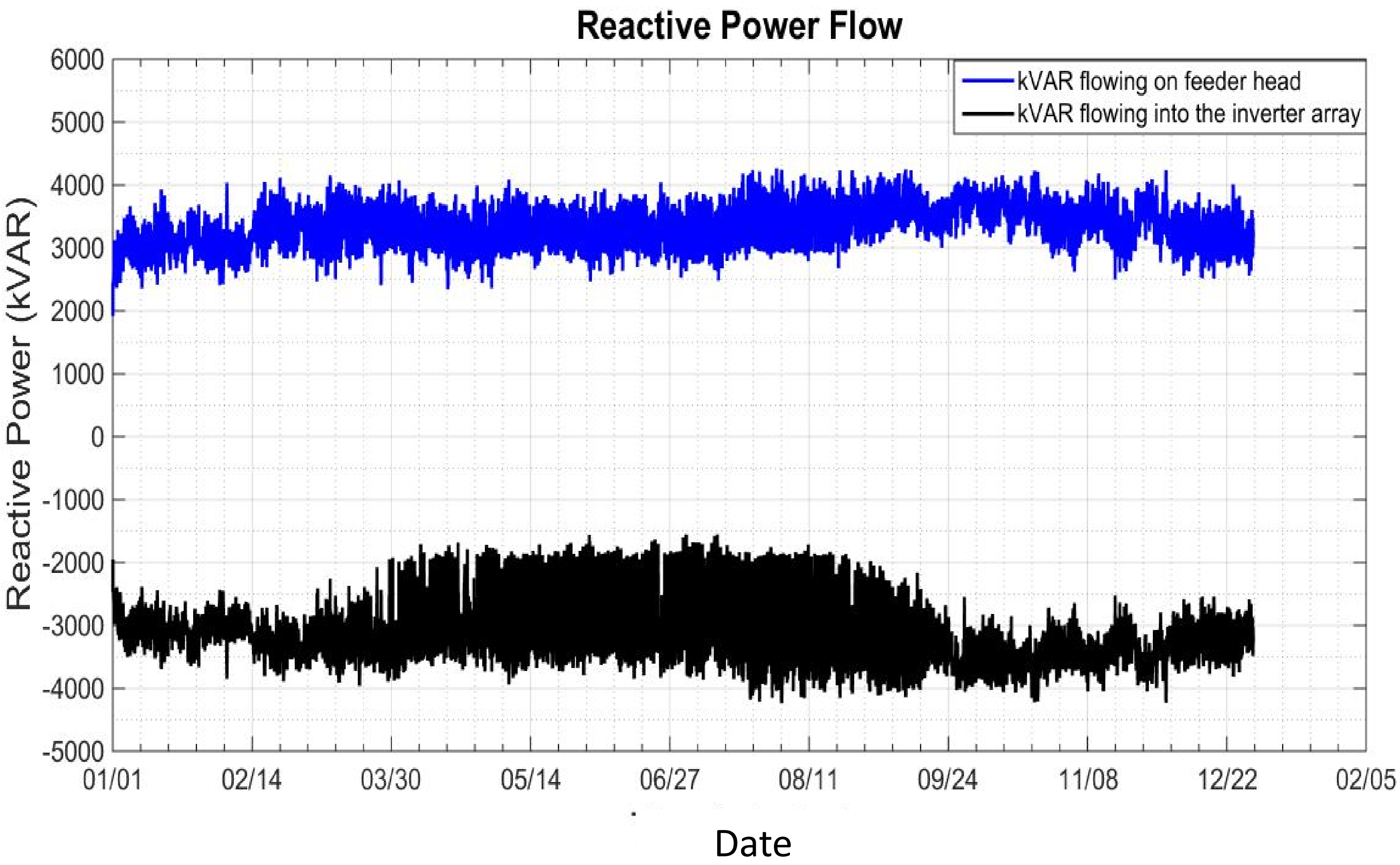
Transient Voltage (Flicker)



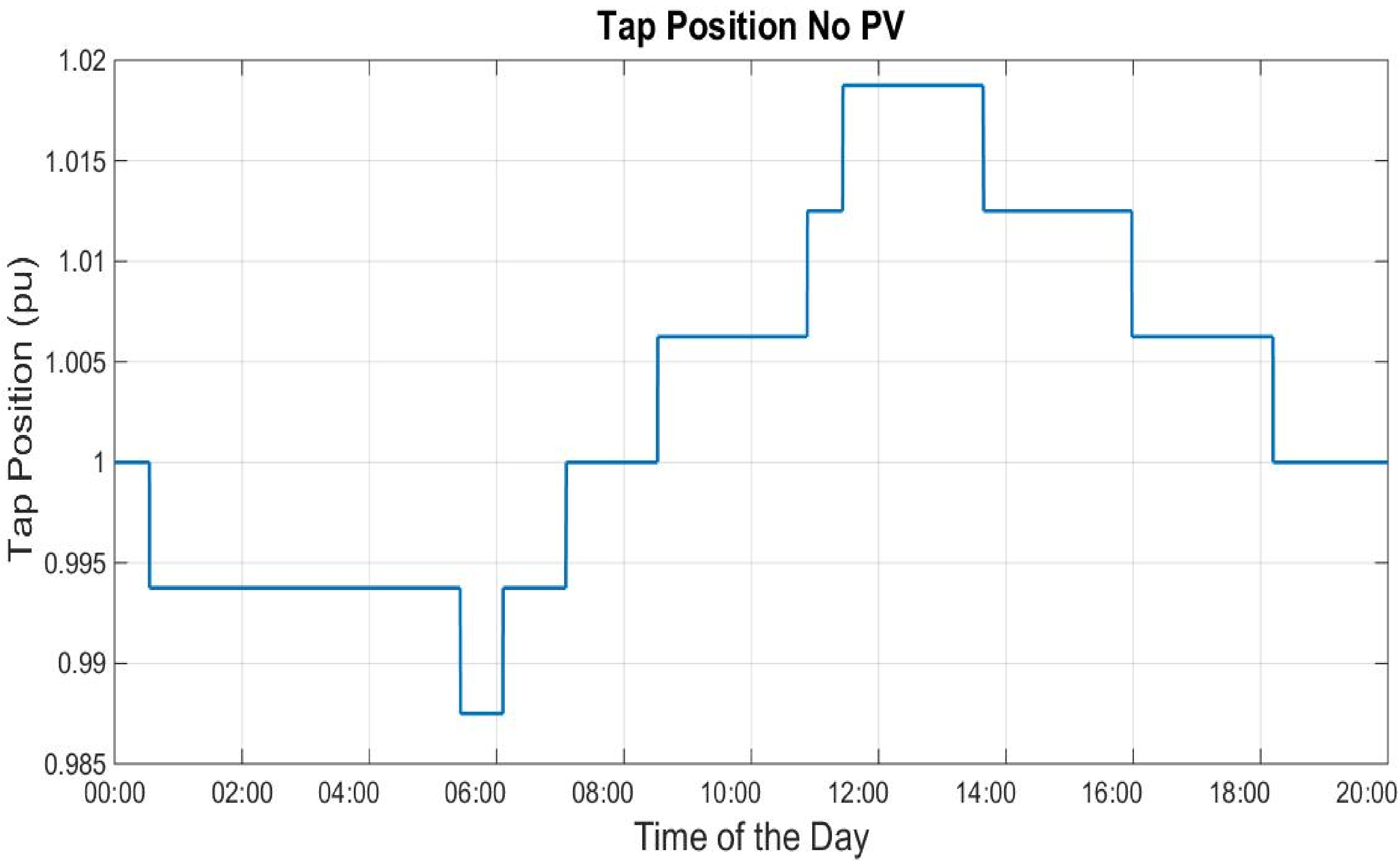
Feeder Reactive Power Flow Due to Solar Generation



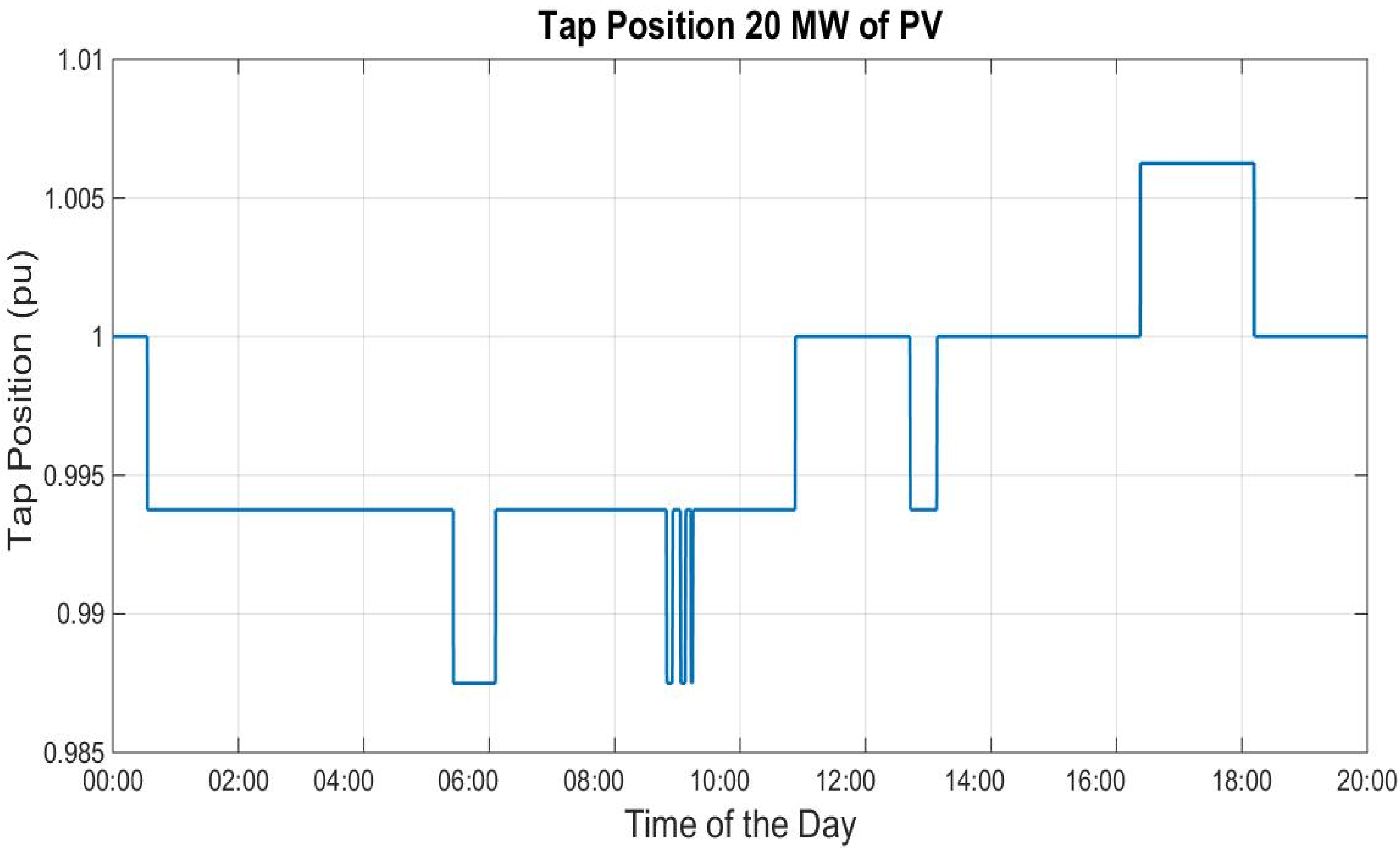
Reactive Power Flow Due to Inverter Volt/VAr Mode



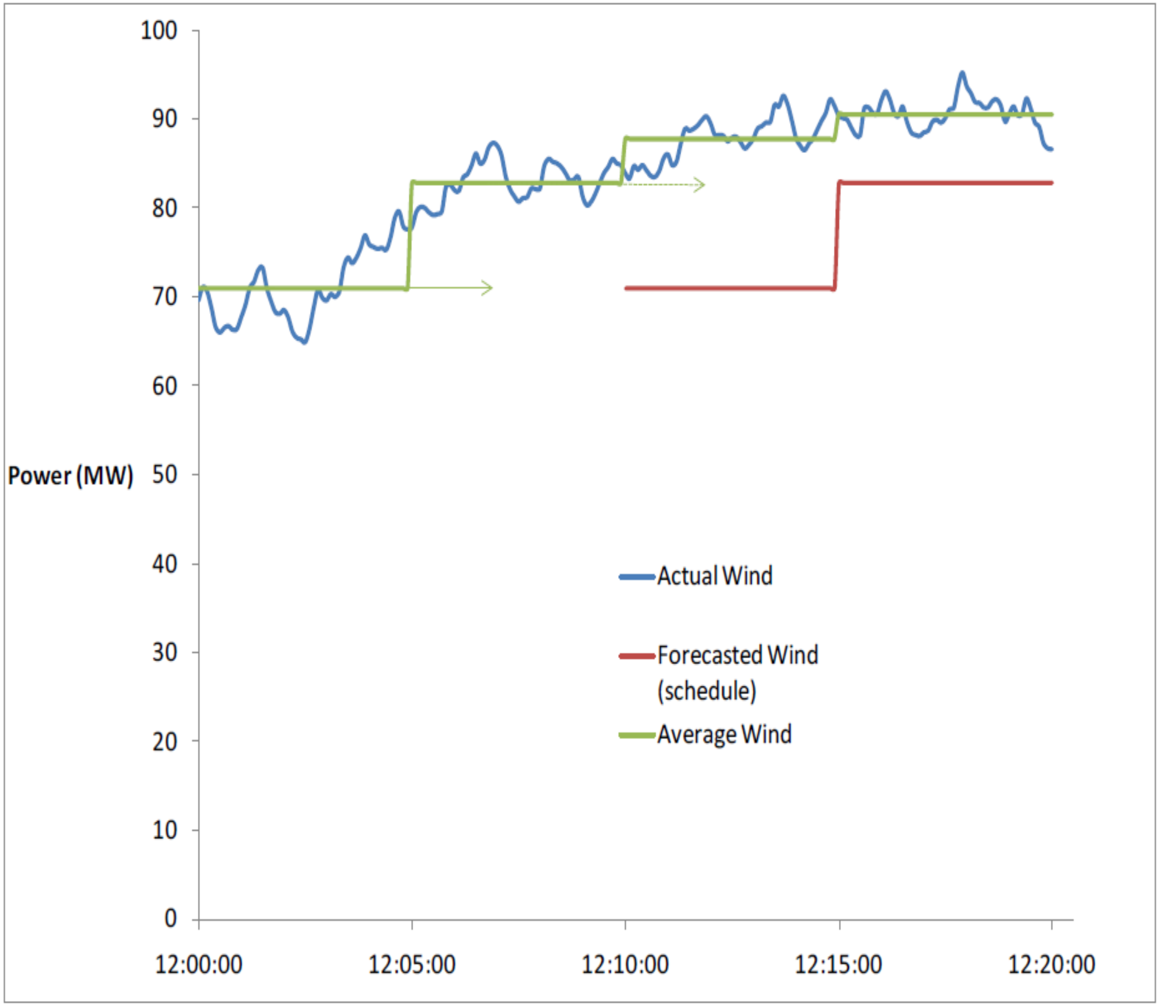
Substation Transformer Load
Tap Changer Operation - Base



Substation Transformer Load Tap Changer Operation – PV



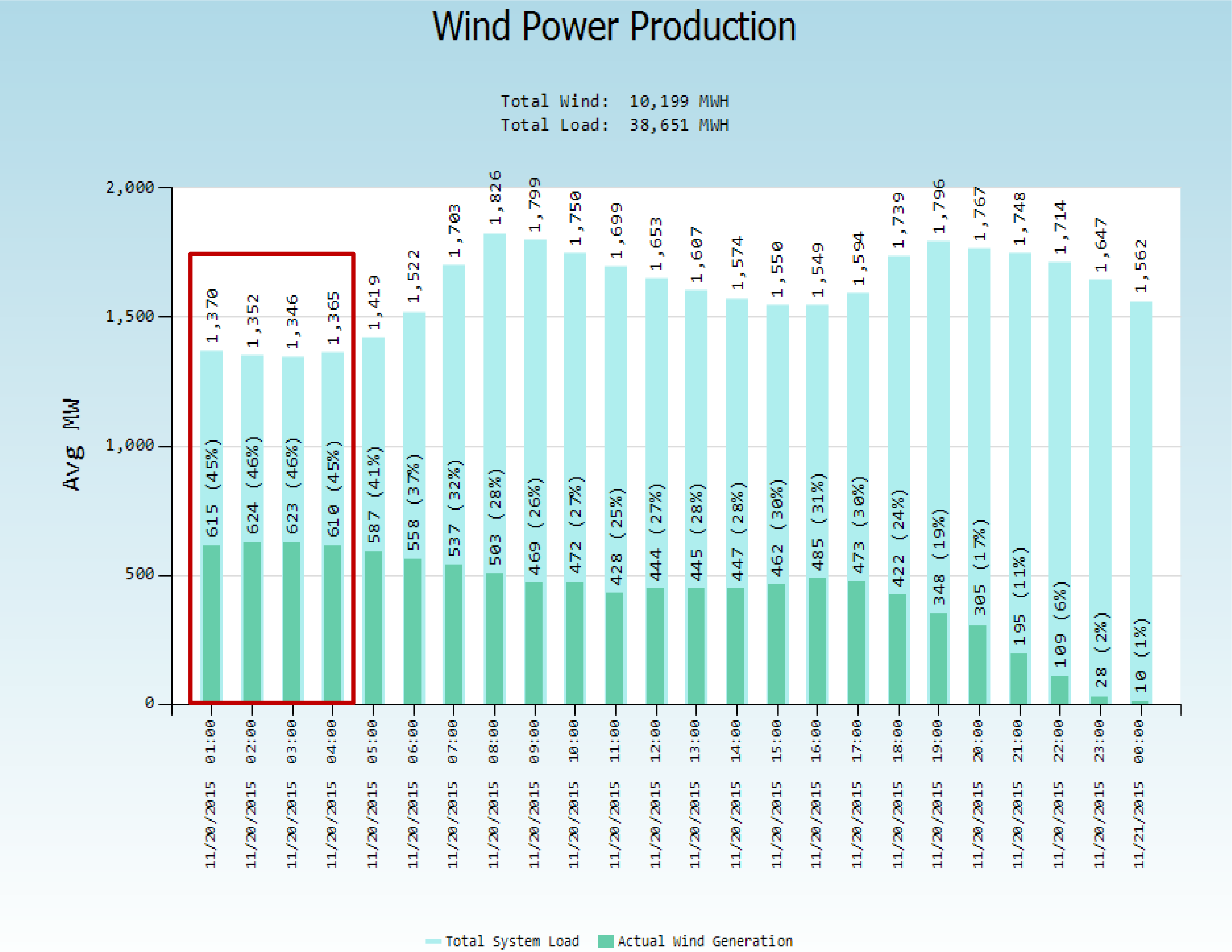
Regulating Reserves Uncertainty and Variability



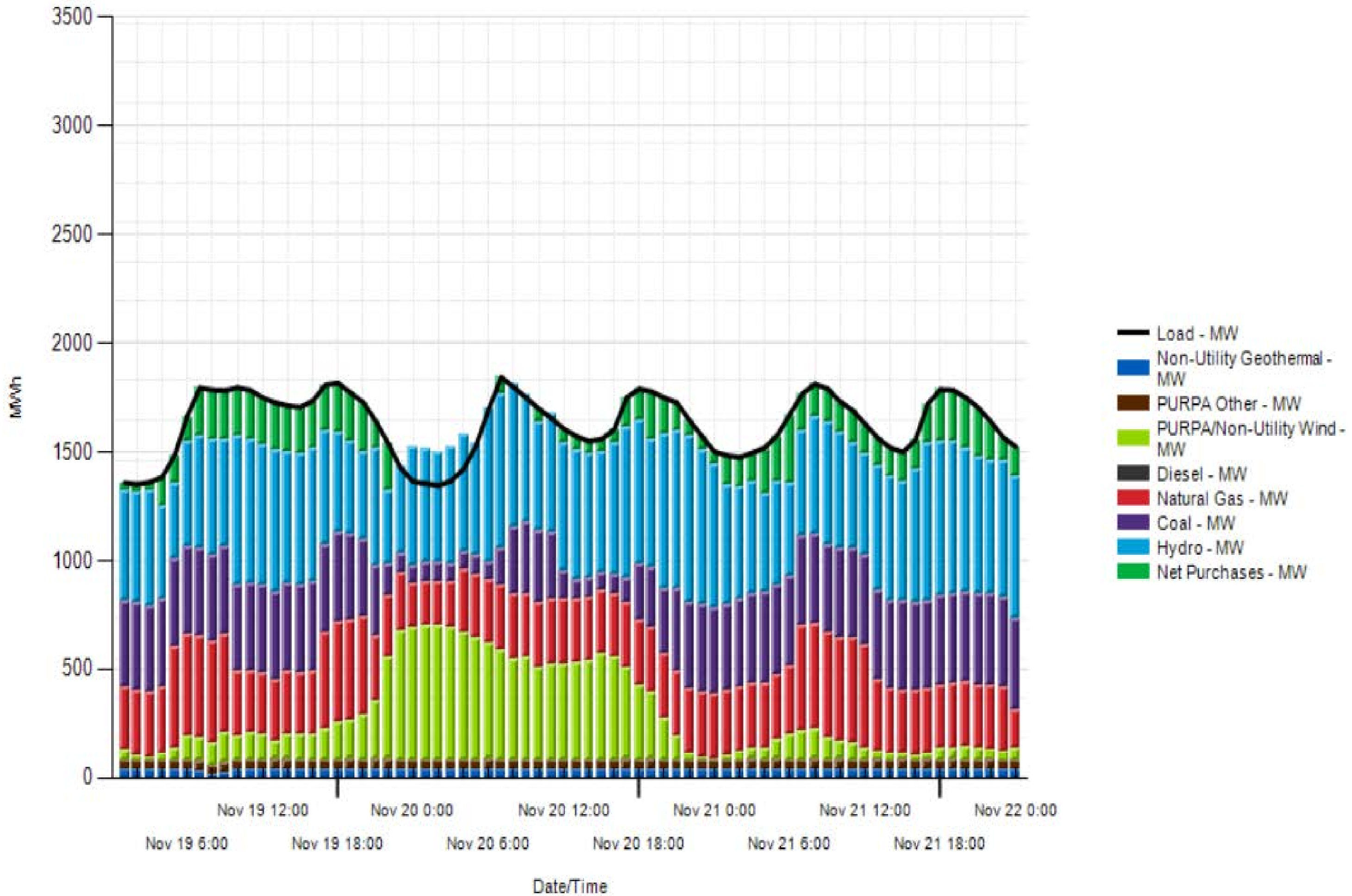
- Downward reserves have historically been less needed for power system reliability
- Power systems with large amounts of variable generation … raise the importance of both upward and downward reserves

Source: NREL Operating Reserves and Variable Generation

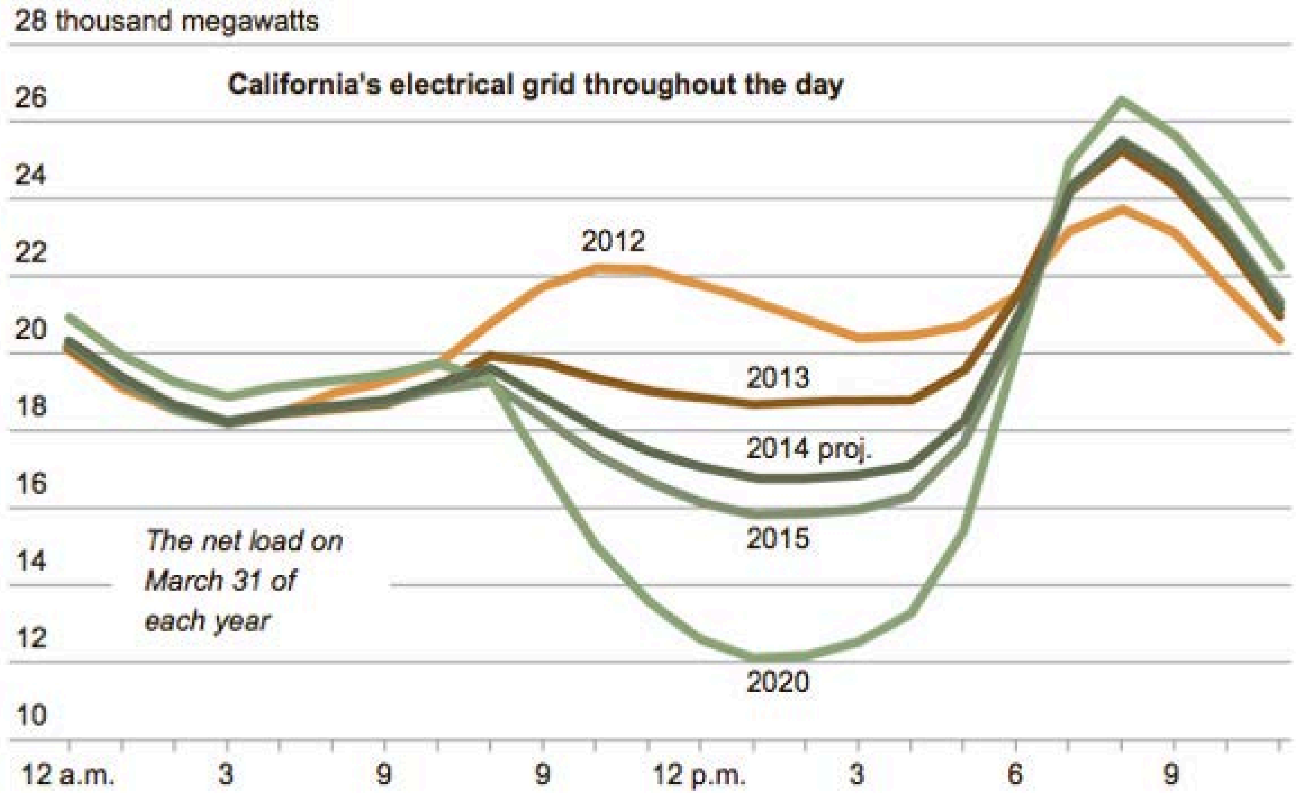
Light Load Concern



Regulating Reserve Requirements Yield Oversupply

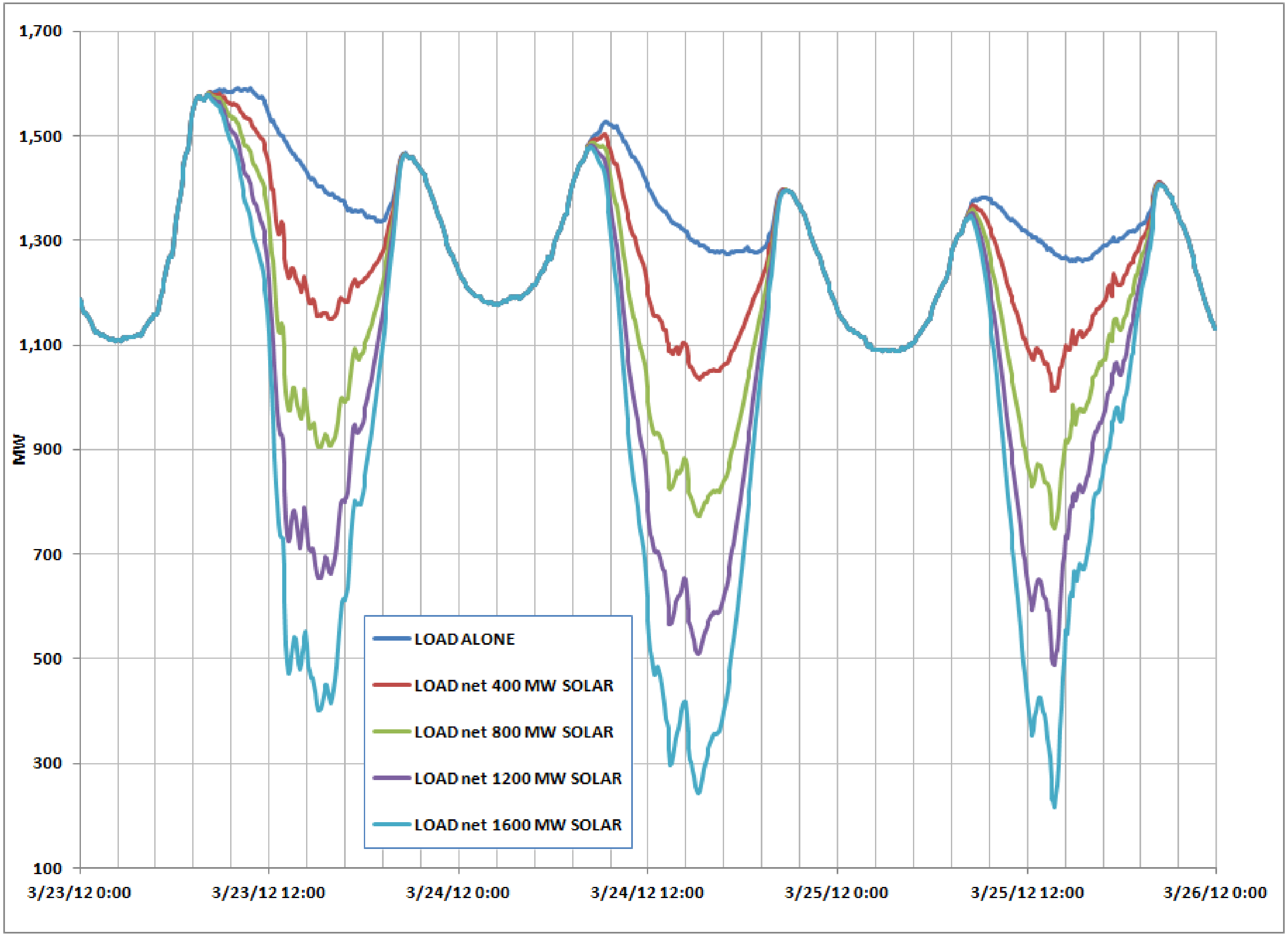


Duck Curve - CAISO

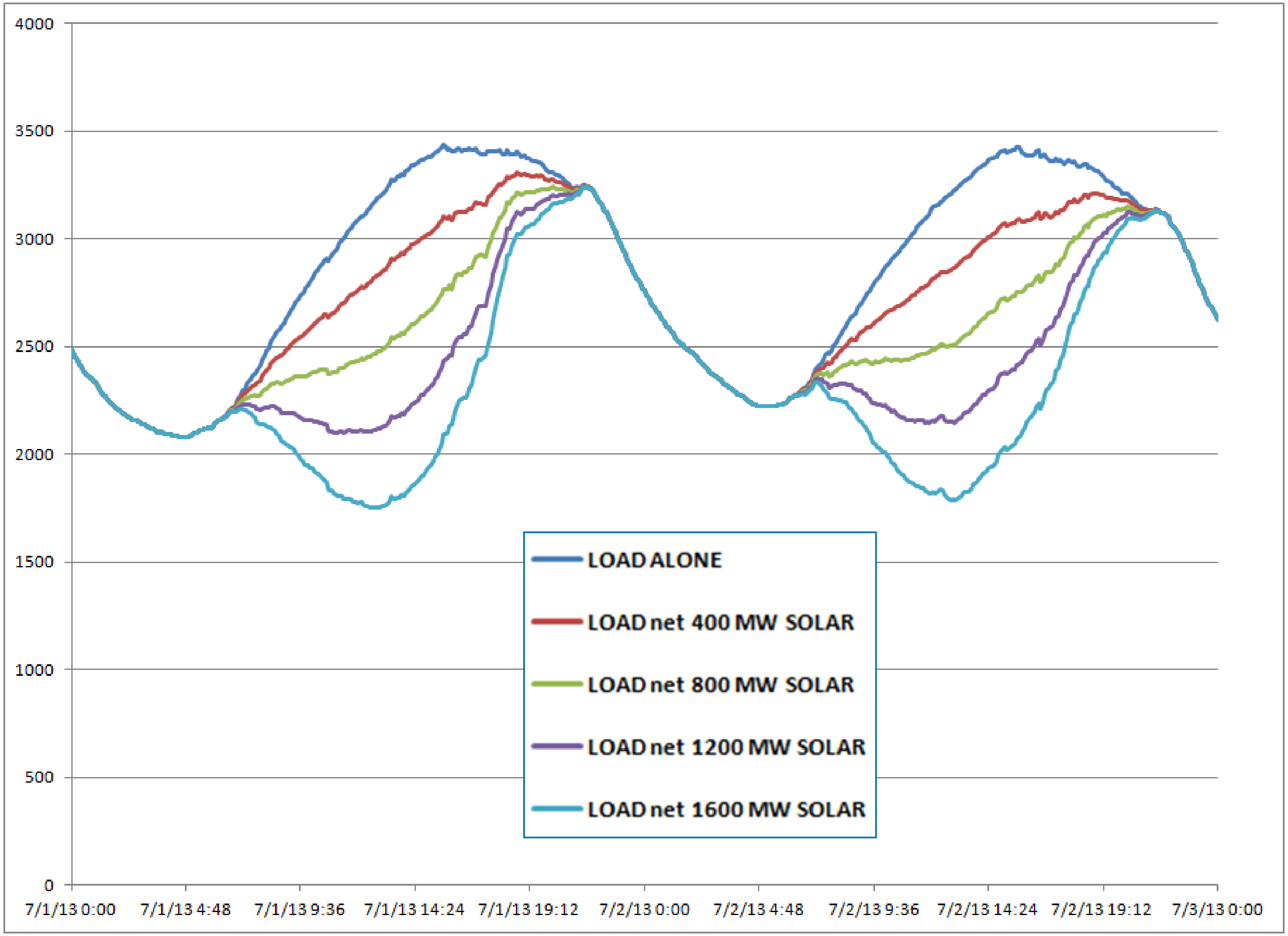


Source: CalISO

Duck Curve – Idaho Power



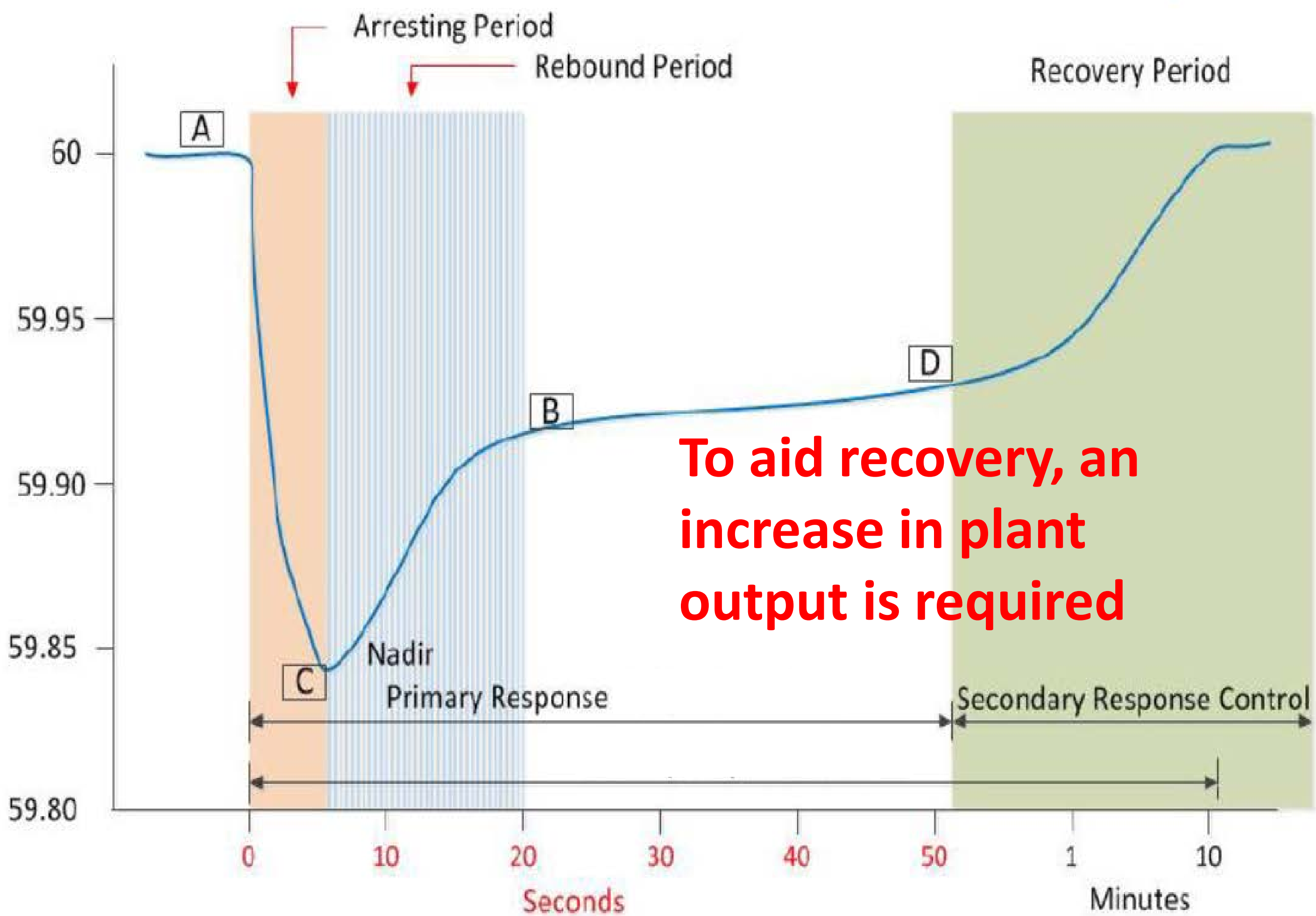
July Duck Curve – Idaho Power



Frequency Response

Solar plants have no inertia to help arrest decline

- It would be ideal if all resources could be counted on to provide both primary and secondary response at all times. - John Underhill



To aid recovery, an increase in plant output is required

http://www.ferc.gov/CalendarFiles/20110120114503-Power-and-Frequency-Control.pdf

Source http://www.nerc.com/docs/pc/FRI_Report_10-30-12_Master_w-appendices.pdf

Interstate Renewable Energy Council, Inc.

Shaping our future with clean energy

Oregon UM 1716 – Resource Value of Solar Reliability Impacts Workshop

Sara Baldwin Auck
Regulatory Director
January 19, 2015
www.irecusa.org
@IRECUSA

Interstate Renewable Energy Council, Inc.

Shaping our future with clean energy

Independent non-partisan, 501(c)3 non-profit organization working nationally to expand and simplify consumer access to reliable and affordable distributed clean energy by:

- Developing and advancing regulatory policy innovations
- Generating national model rules, standards, and best practices
- Providing clean energy workforce training, education & credentialing
- Informing and guiding fact-based regulatory decision-making and national workforce development efforts
- Fostering collaborative partnerships and consensus-building to achieve workable solutions

Formed in 1982

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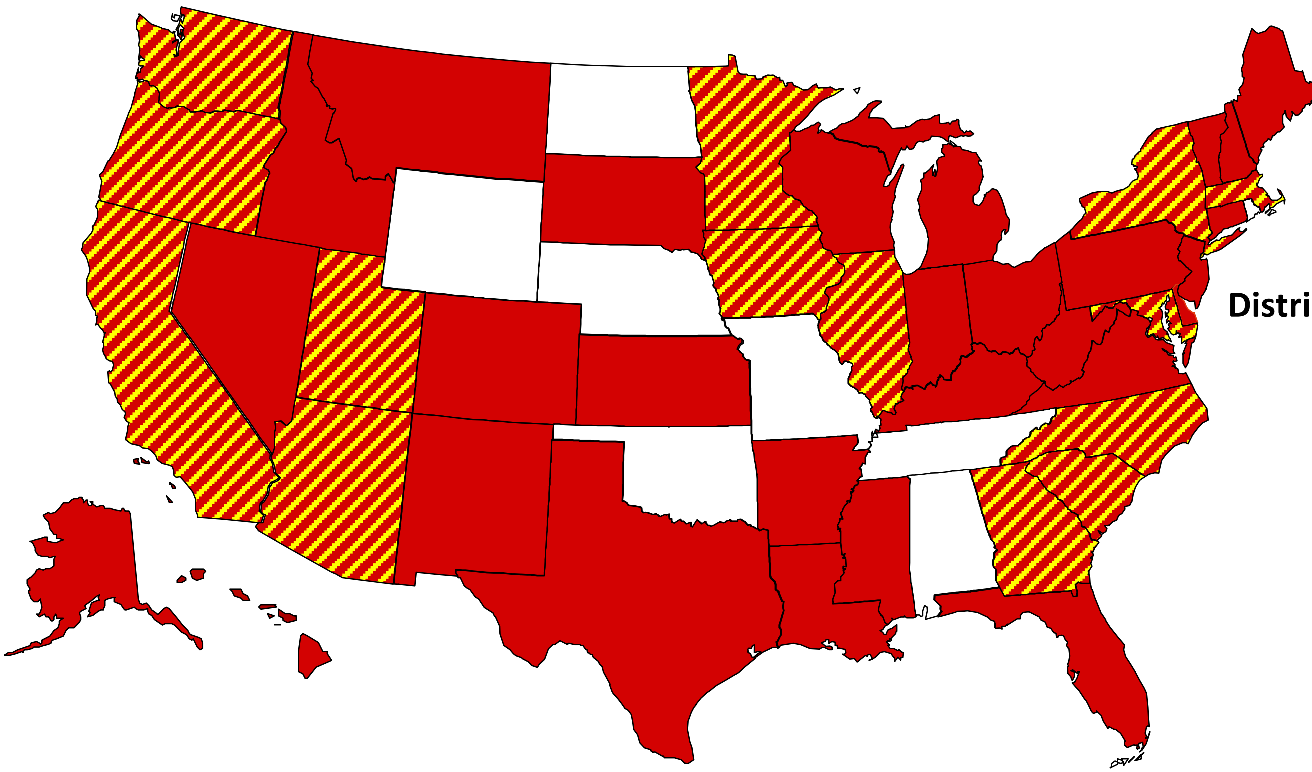
IREC's National Regulatory Engagement



IREC Regulatory Activity 2007-2015

IREC Current/Active Regulatory Engagement

Distributed Energy Regulatory Policies:

* Shared/Community Renewables

* Interconnection

* Grid Modernization

* Distributed Energy Storage

Permitting

Third Party Financing

Net Metering, Solar Valuation, VOST

Virtual Net Metering

** Indicates 2016 priority issues*

Oregon Interconnection Rules: Designed to Address Reliability & Safety Impac

- Interconnection processes (i.e., Small Generator Interconnection Rules[1]) are designed to ensure safety and reliability, as well as to identify and address any adverse system impacts or minor modifications necessary to accommodate connection to the grid.

- Rules define "Adverse System Impact": A negative effect caused by the interconnection of a small generator facility that may compromise the safety or reliability of a transmission or distribution system *OAR* ***860-082-0015***

- 4-Tier Interconnection Review process ensures more complex systems receive more sophisticated, in-depth review

- Rules contain 4 references to "Reliability" and 5 references to "Safety"

- Oregon's Interconnection 2014 Grade[2]: A

1 Oregon Administrative Rules, Division 82 Small Generator Interconnection Rules, available at; http://arcweb.sos.state.or.us/pages/rules/oars_800/oar_860/860_082.html
2 Freeing the Grid State Interconnection Grades, 2014, available at www.freeingthegrid.org (2015 grades forthcoming)

IREC Interstate Renewable Energy Council

Rules Address Cost Responsibility

- "Study costs. Whenever a study is required under the small generator interconnection rules, **the applicant must pay the public utility for the reasonable costs incurred in performing the study.**" *OAR **860-082-0035(1)***
- "System upgrades. A public utility must design, procure, construct, install, and own any system upgrades to the public utility's transmission or distribution system necessitated by the interconnection of a small generator facility. A public utility must identify any adverse system impacts on an affected system caused by the interconnection of a small generator facility to the public utility's transmission or distribution system. The public utility must determine what actions or upgrades are required to mitigate these impacts. Such mitigation measures are considered system upgrades as defined in these rules. **The applicant must pay the reasonable costs of any system upgrades**." *OAR **860-082-0035(4)***
- "A public **utility may require the interconnection customer to pay for interconnection facilities, system upgrades, or changes to the small generator facility or its associated interconnection equipment** that are necessary to bring the small generator facility interconnection into compliance with the small generator interconnection rules or IEEE 1547 or 1547.1" *OAR 860-082-0025(1)(e)(c)*

Evolution of Grid Planning to Capture DER Benef

- Integration of high penetrations of solar and other distributed energy resources (DER), including energy storage necessitates an evolution in grid planning practices

- Proactive approaches can help minimize costs, while also ensuring full range of benefits are captured

- High penetration states are working towards more proactive/integrated grid planning methodologies and approaches

- Low penetration markets can learn/benefit from other states' experience

IREC Interstate Renewable Energy Council

Oregon has Time to Adapt

- Solar penetration levels in OR are significantly below HI, CA, and MA (among other states)
- There is time to consider and develop more proactive approach to minimize costs and maximize benefits
- In lieu of reactionary or pre-emptive approaches, OR stands to benefit from proactive approaches to integration of solar (and other DERs)
- Commission could explore options further with future workshops or technical conferences

IREC Interstate Renewable Energy Council

Thank You!

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SolarCity

Oregon UM 1716: Resource Value of Solar

Reliability Impacts Workshop

Ryan Hanley
Senior Director
Grid Engineering Solutions

January 19th, 2016

Executive Summary

- Solar PV integration concerns are mitigated through geographic diversity, smart inverter functionality, and proactive utility planning

- PV, smart inverters, and other distributed energy resources (DERs) provide benefits to the grid and ratepayers

- Distribution interconnection and planning must modernize in order to capture the potential benefits of PV and DERs

Agenda

Technical Concerns and Mitigations

Solar PV and DER Benefits

Integrated Distribution Planning

1

Intermittency

Concern: High DER penetration and its potential intermittency could cause excessive voltage flicker and increased tap operations on substation LTCs and line regulators

Traditional Mitigation: Change regulator settings, limit output of DER, install new line regulators, replace transformers, or reconductor

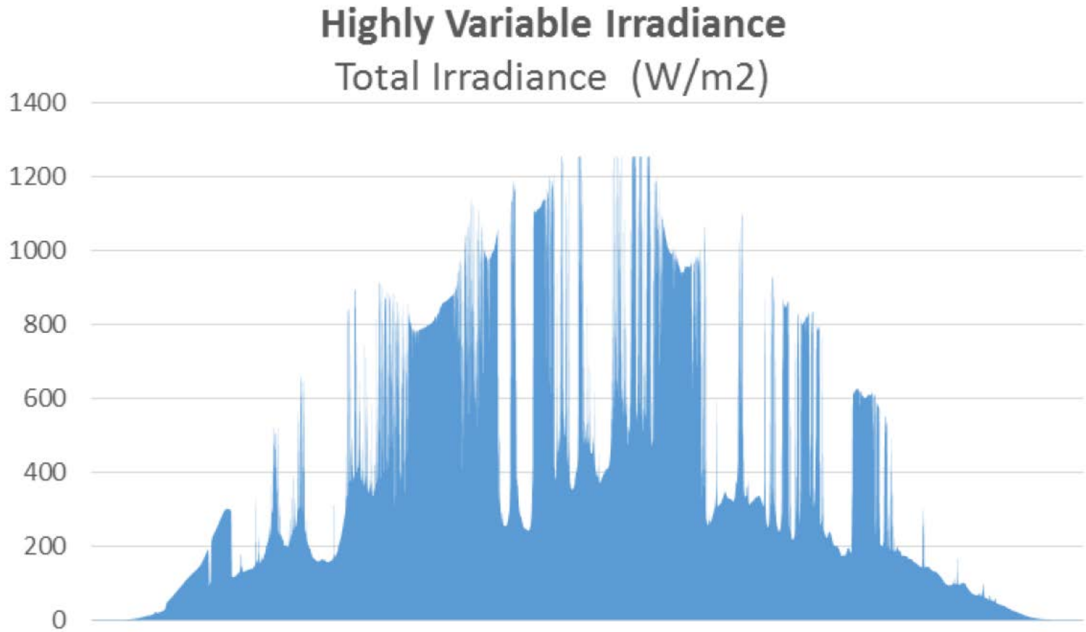
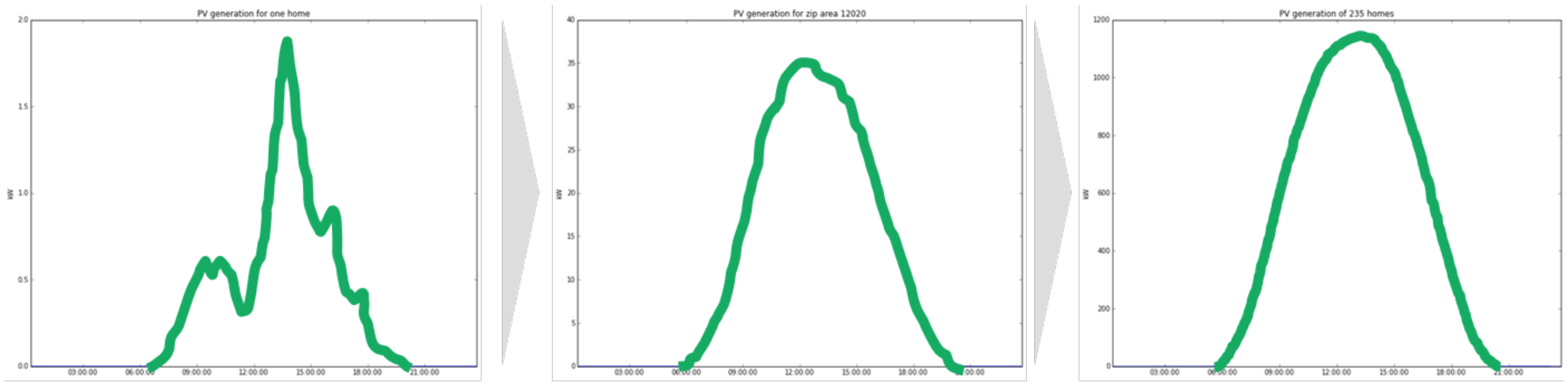


Image Sources: ARENA

1

Intermittency

Mitigation Alternative: inherent *geographic diversity* of distributed generation mitigates risks from PV variability



Single Home | 6 Homes | 235 Homes

PV variability diminishes with geographic diversity

Source: SolarCity production data

2

Steady-State Voltage

Concern: Reverse power flow from DER could contribute to steady-state overvoltage violations

Traditional Mitigation: Change voltage regulating settings, install new voltage regulating equipment, replace transformers, reconductor, and limit output of DER

Mitigation Alternative: Utilize advanced inverter capabilities

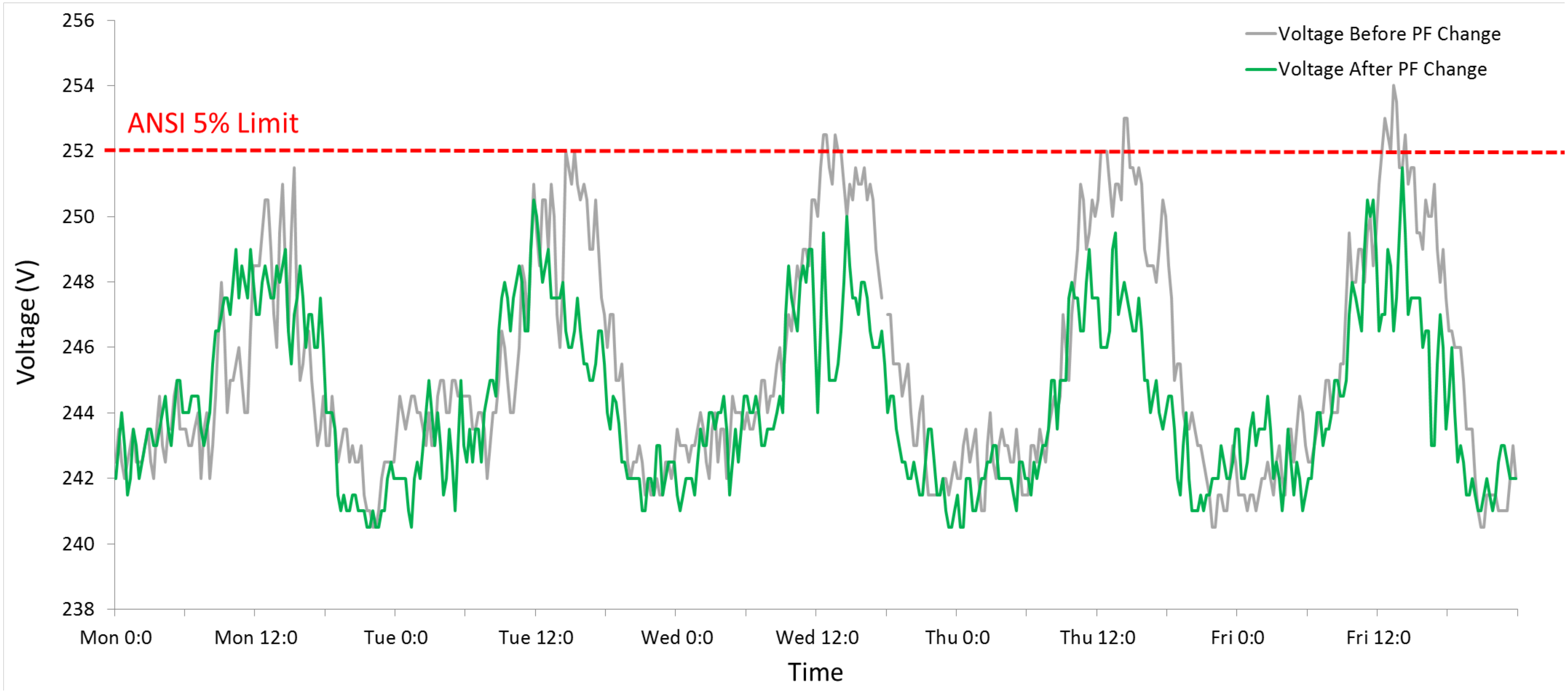
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

"An advanced PV inverter, at near-zero marginal cost, could have the ability to virtually eliminate voltage variation on a distribution feeder resulting from variations in the real power output of PV.

2

Field results: Smart inverter reactive power support

275 inverters and 5 MW PV



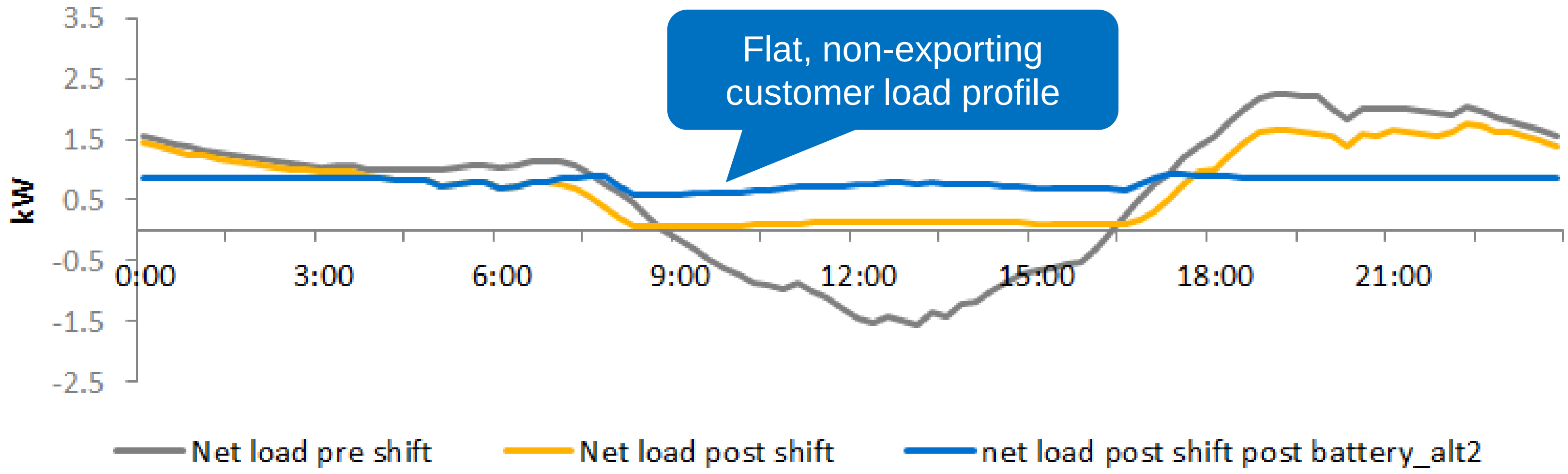
Source: SolarCity field demonstration data, 2015

Bi-Directional Power Flow

Concern: Bi-directional power flow from DERs could result in equipment overloads, and/or impact operation of unidirectional relays and voltage regulating equipment

Utility Mitigation: Replace overloaded equipment or limit DER output

Mitigation Alternative: dynamically manage PV output via advanced inverters, and/or utilize load shifting to absorb excess generation

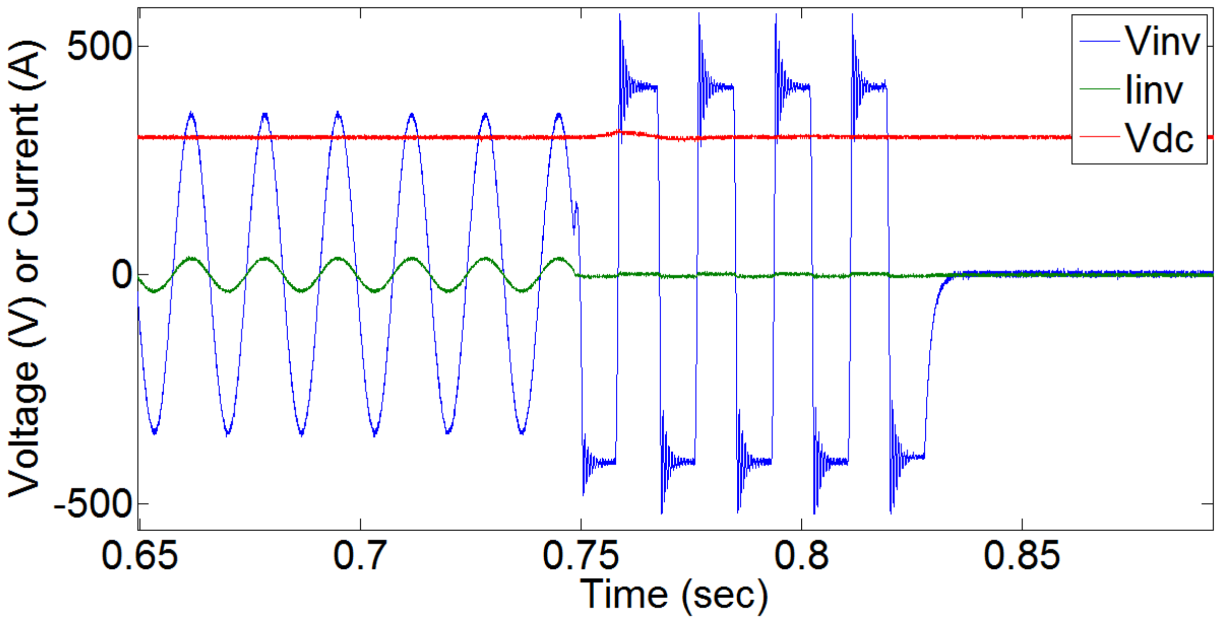


Source: SolarCity analysis

4

Transient Overvoltage

Industry testing removed Transient Overvoltage as a DER integration concern, raising interconnection limits in Hawaii



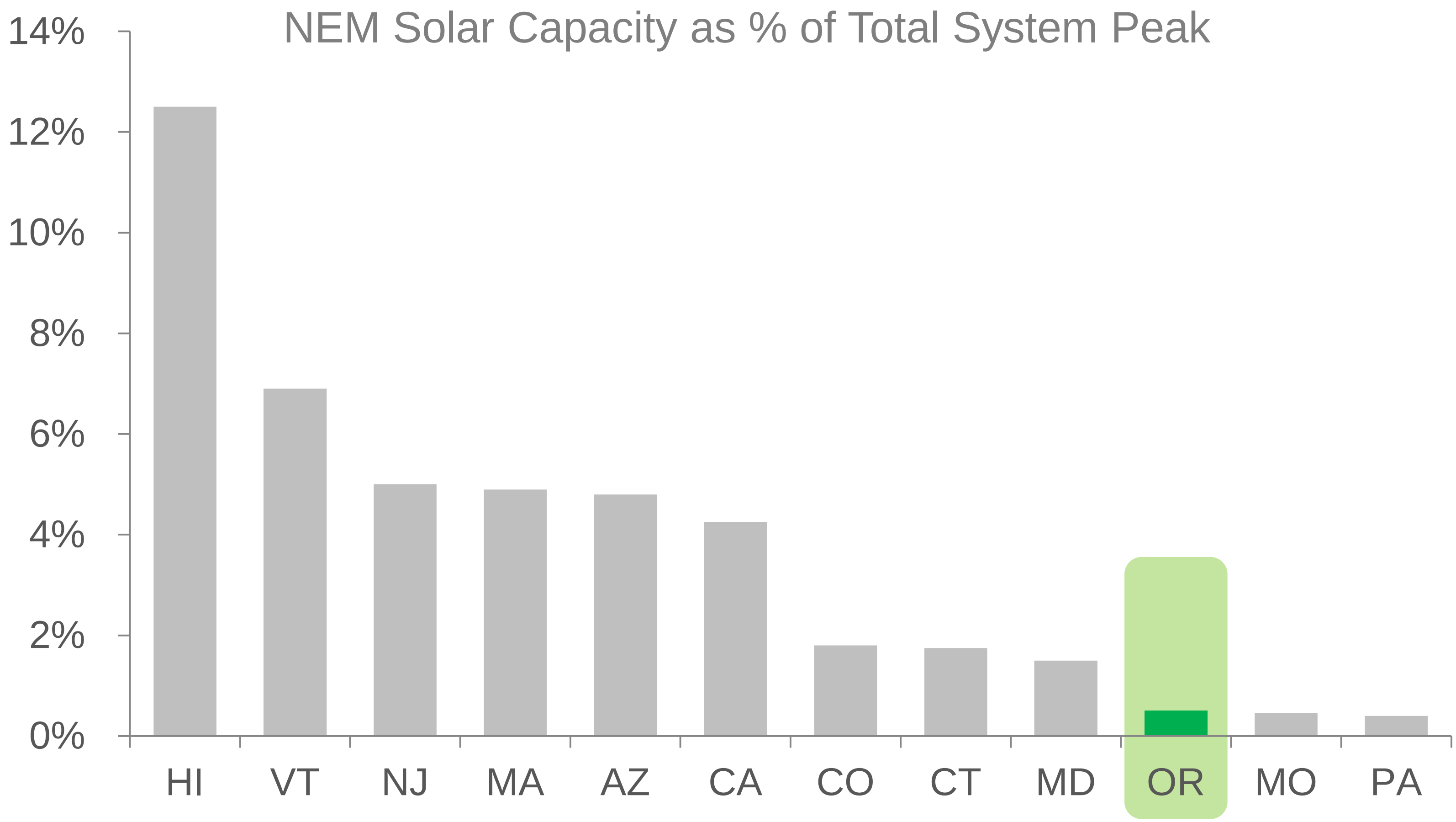
Hawaiian Electric

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

SolarCity

Source: NREL “Inverter Load Rejection Over-Voltage Testing”, February 2015

Ultimately, Oregon penetration trails other higher penetration states, reducing potential integration impacts and costs



Source: Estimated NEM solar capacity as % of total system peak

Agenda

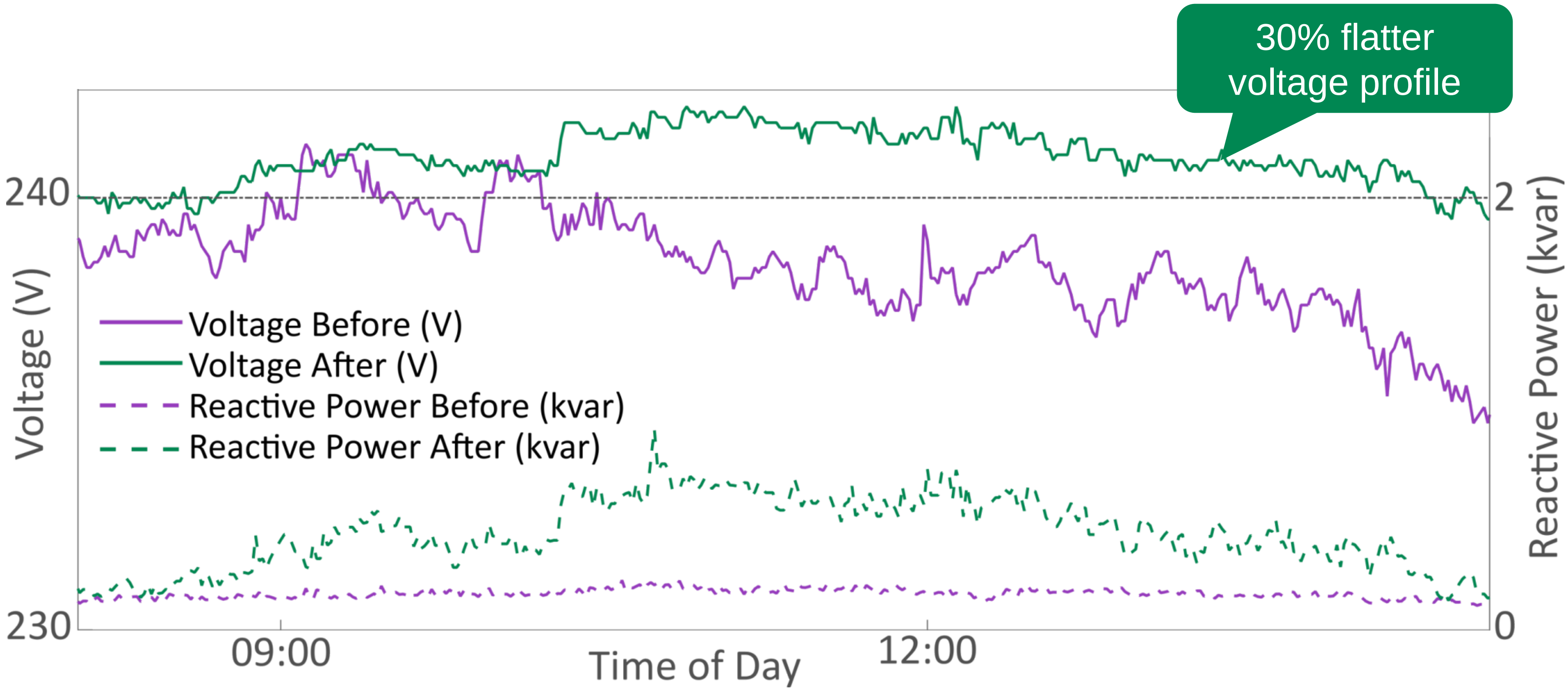
Technical Concerns and Mitigations

Solar PV and DER Benefits

Integrated Distribution Planning

Smart inverters can improve feeder voltage, power quality, and conservation voltage reduction benefits

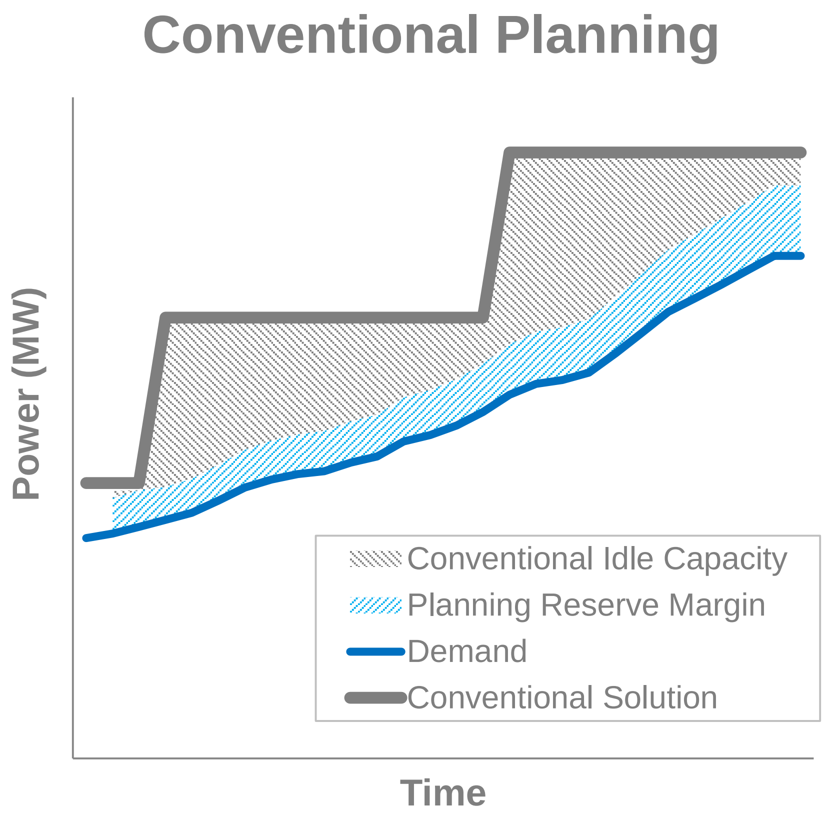
140 inverters and 700kW of PV providing dynamic Volt/VAR support

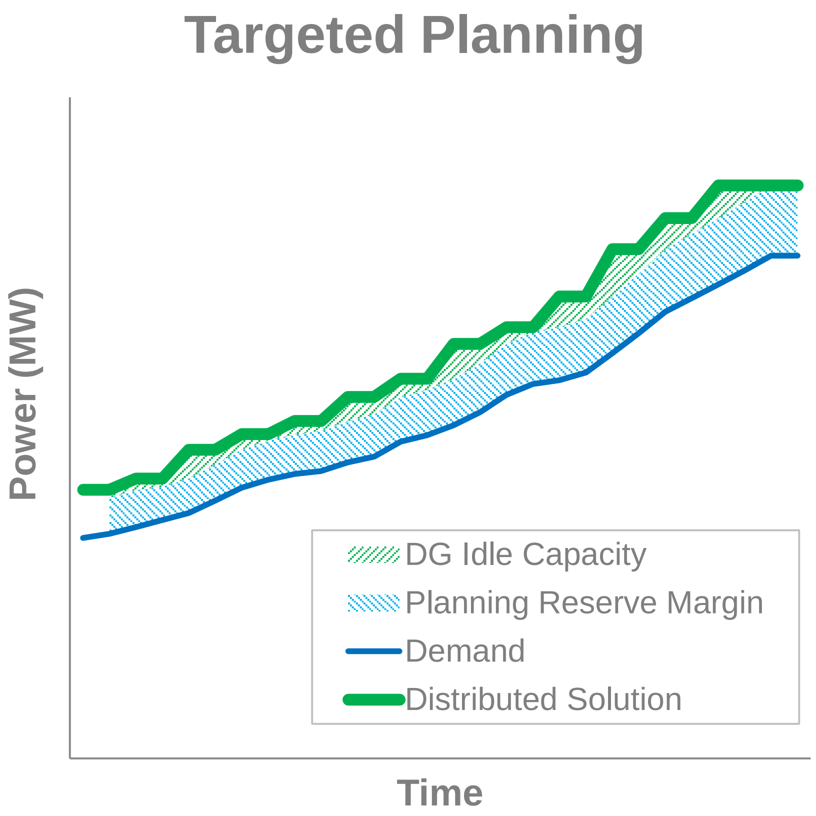


"PV inverters could even mitigate the effects of load-induced voltage variations elsewhere on the feeder." –NREL

Source: SolarCity field demonstration data, 2015

PV and distributed energy resource portfolios can defer and/or replace traditional grid investments





Agenda

Technical Concerns and Mitigations

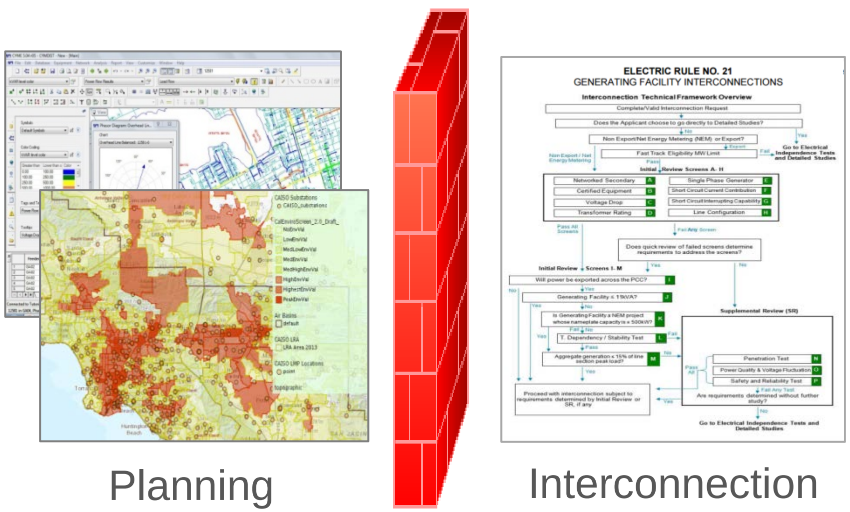
Solar PV and DER Benefits

Integrated Distribution Planning

Challenge: Existing utility interconnection, planning, sourcing, and data sharing processes do not leverage DERs to benefit the grid and enable customer choice

Solution: Modernize distribution processes by adopting a holistic *Integrated Distribution Planning* framework

Traditional Planning

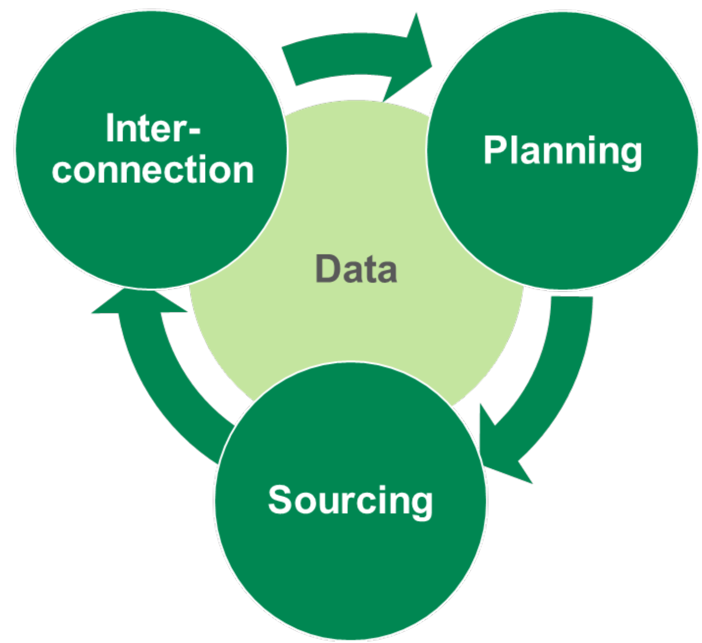


Planning

Interconnection

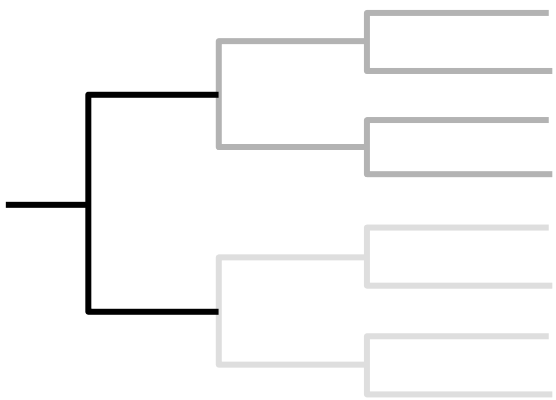
Image Sources: CYME, Kevala, PG&E

Integrated Distribution Planning



Modernize PV and DER interconnection by phasing out universal screens in favor of feeder-specific *hosting capacity* analyses

Screen-Based



At low PV penetration levels, screening methods can enable timely decisions

Hosting Capacity

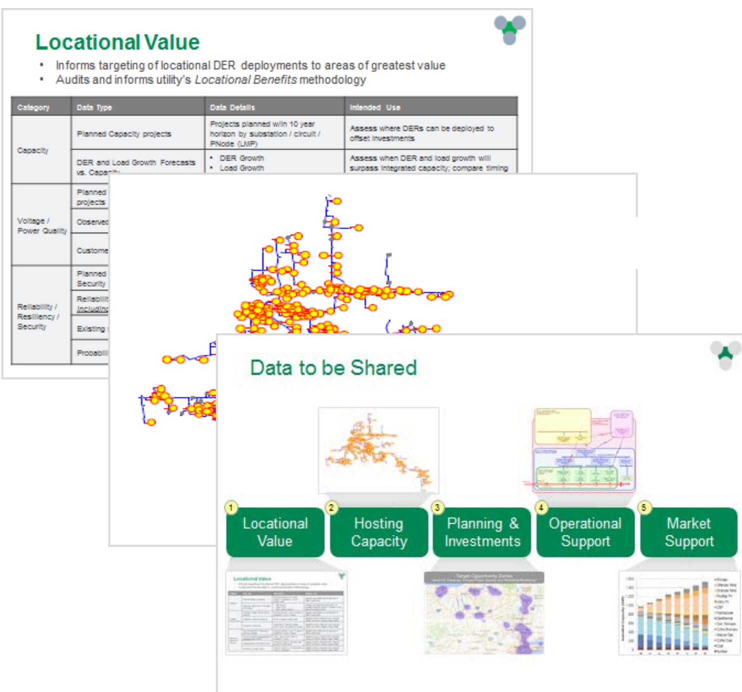
At high PV penetration levels, circuits need to be individually assessed for DER hosting capacity

Image Sources: EPRI

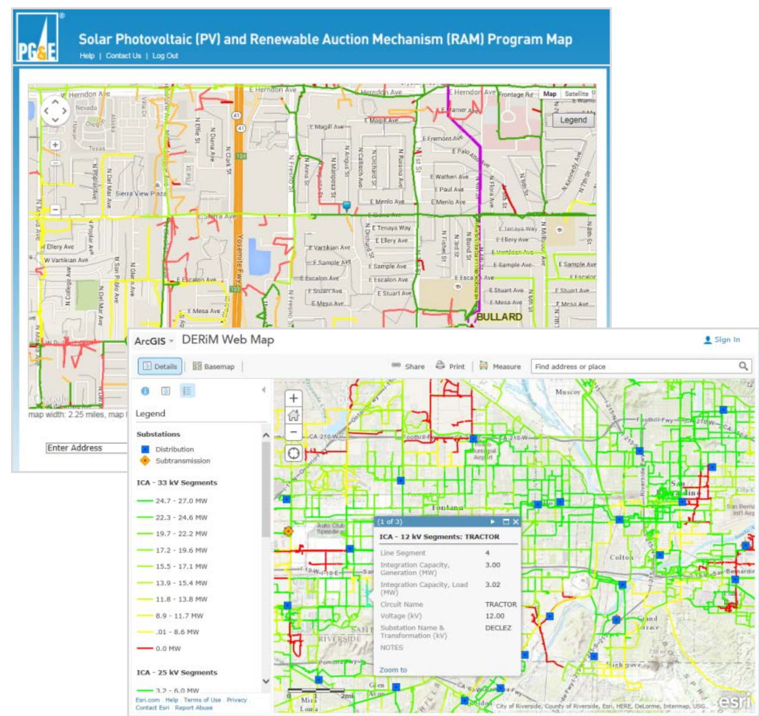
Challenge: Utility data critical for driving innovation is not accessible by broader industry

Solution: Utilities must commit to data transparency and access to enable industry innovation

Data Transparency



Data Access



SolarCity

Thank you

Summary and Next Steps

UM 1716