NATIONAL RENEWABLE ENERGY LABORATORY

Evolving Thoughts on Value of Solar in a Dynamic Local Utility

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Workshop on:

Value of the Solar "Triple Play"

Berkeley Lab

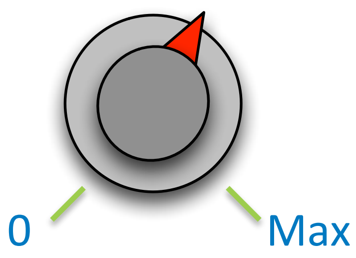
August 28, 2015

Outline

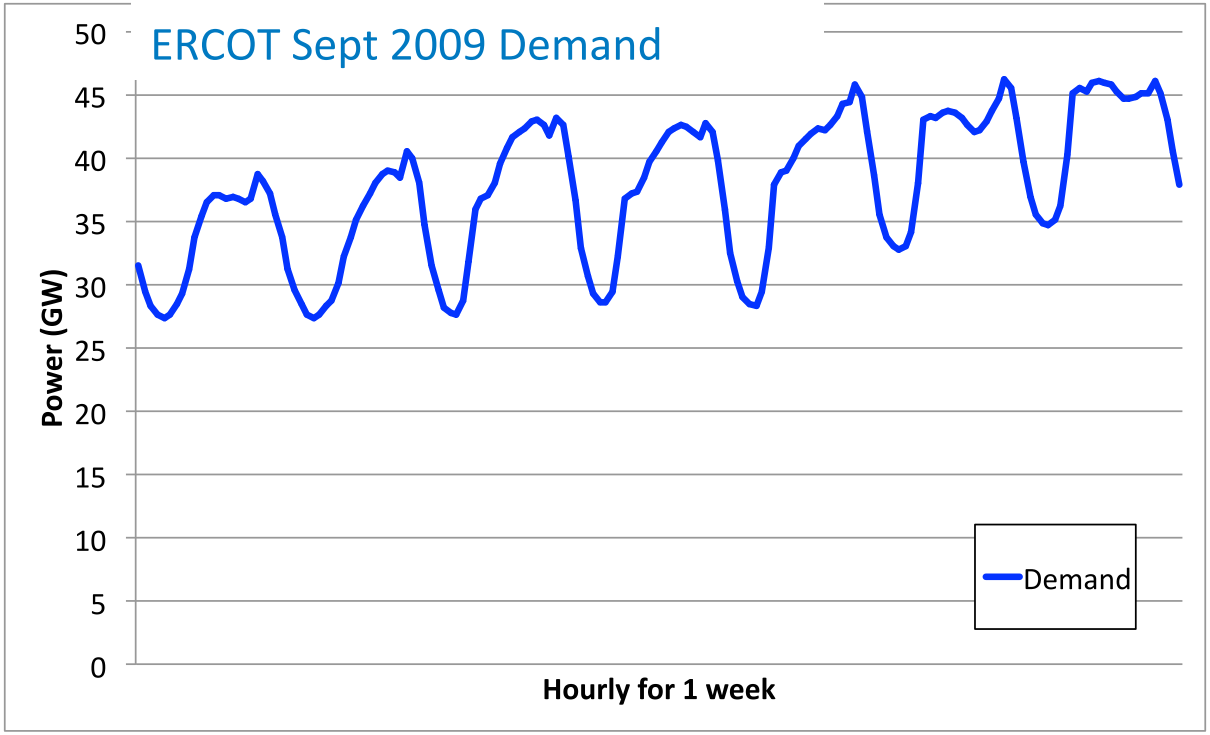
- **10 points on Storage**
- **Distribution Considerations**
  - Background
  - Approaches
- **Value: Solar → "Triple Play"**
  - Value Streams
  - Methods
- **Misc pieces**

#1: Renewables need operational flexibility

Generator Output



Simplified Operations

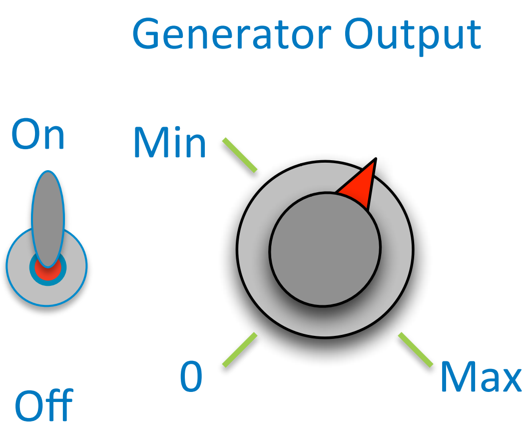


Supply = Demand

(every fraction of a second)

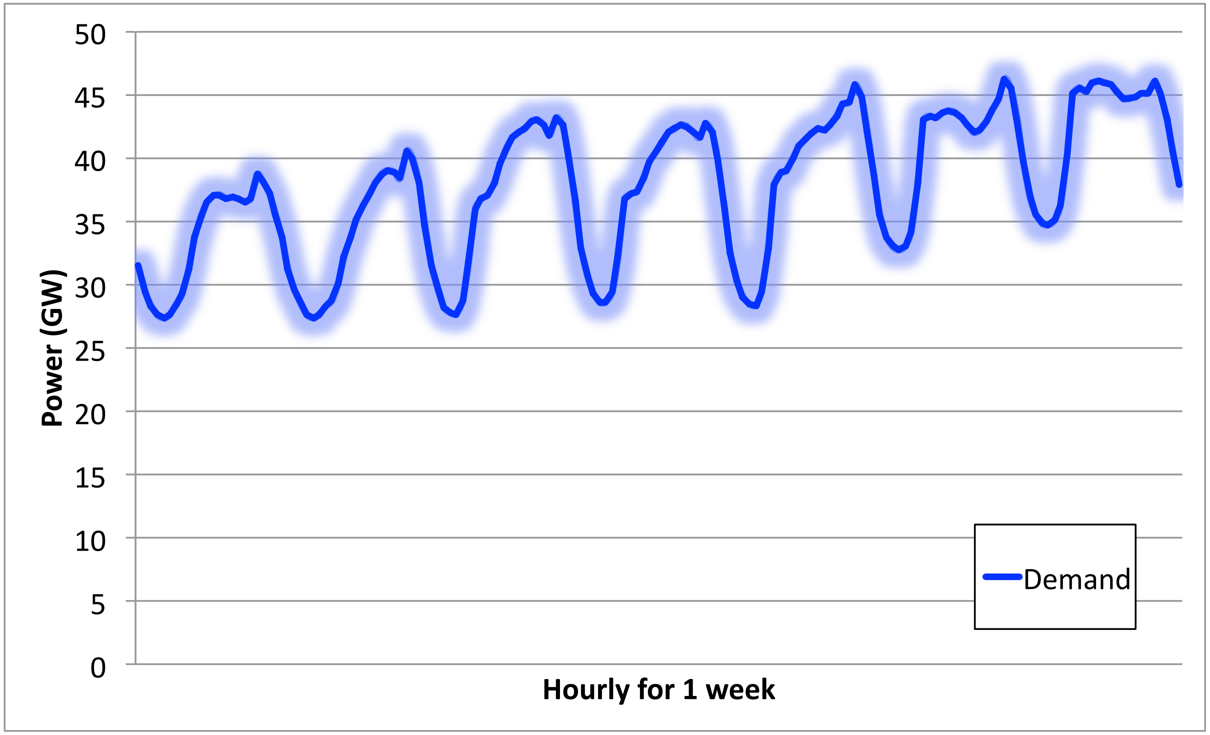
Source: Palmintier

#1: Renewables need operational flexibility



+ **Ramp Limits**
+ **Startup Cost**
+ **Min. Up/Down**
+ **Reserves**

= **Unit Commitment**



Source: Palmintier

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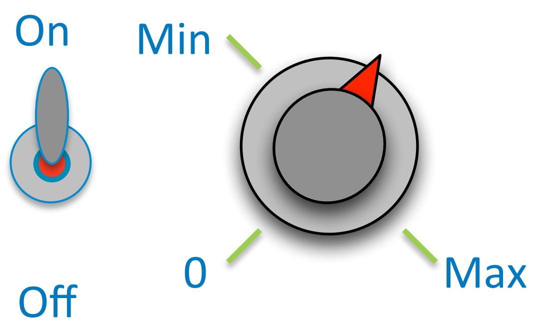

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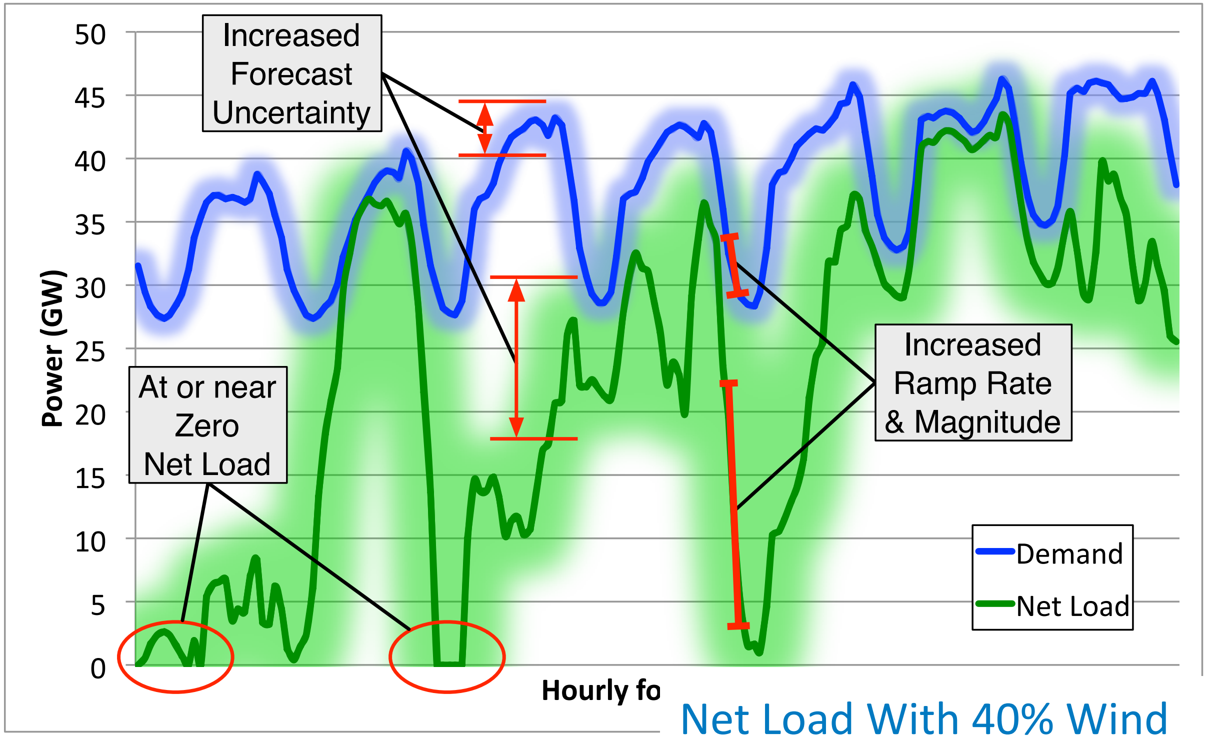


Net Load With 40% Wind

Renewables require increased Operational Flexibility

Source: Palmintier

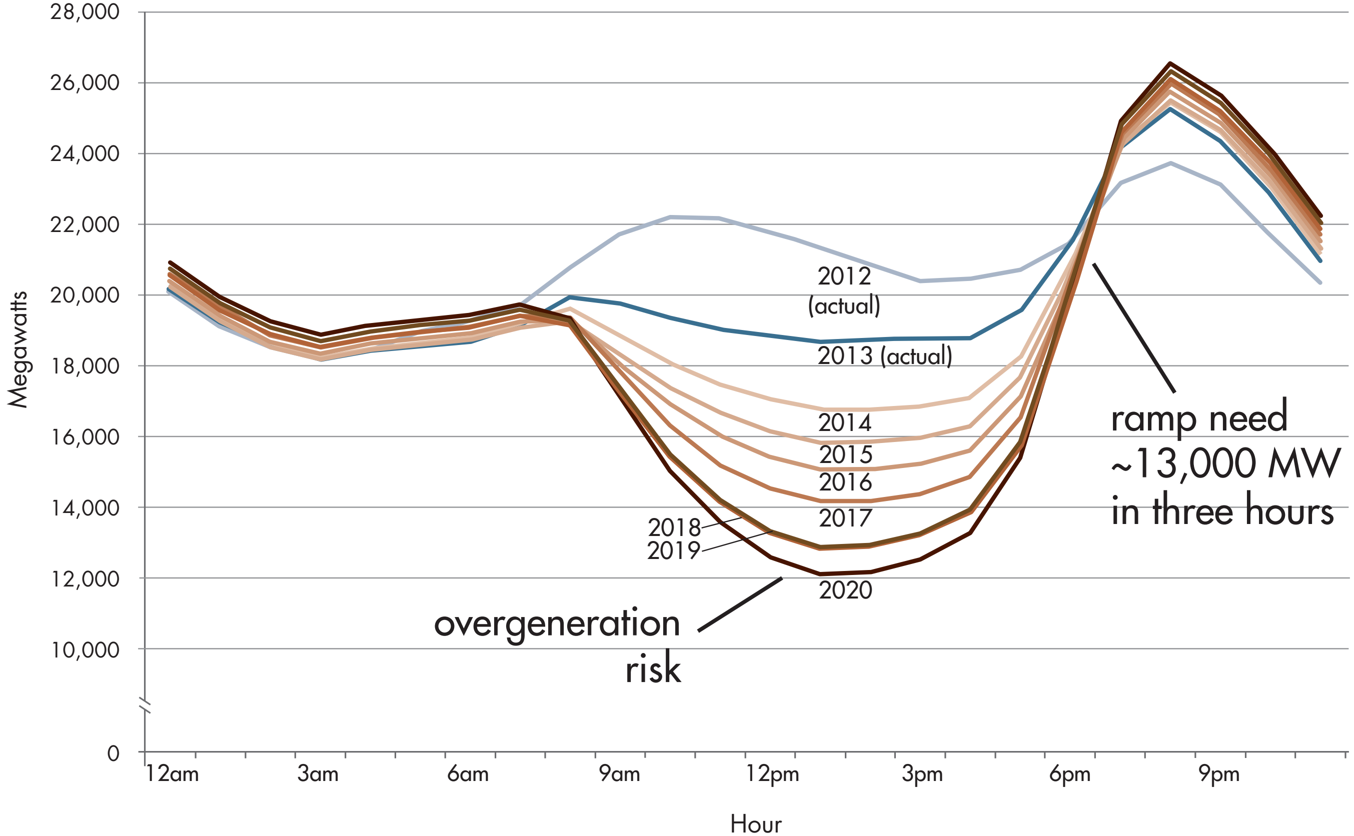
#2: Many Sources of operational flexibility

- **Existing Generation**
    - Technology & Design Dependent
- **Existing Grid Storage (Pumped Hydro)**
- **Renewable Curtailment**
- **Market & Balancing Area Design**
- **Responsive Demand (Virtual Storage)**
- **More Flexible Generation**
- **Thermal Storage**
- **Transmission Interconnection**
- **New Storage Technologies**

OK for ≈<20% (energy) variable renewables

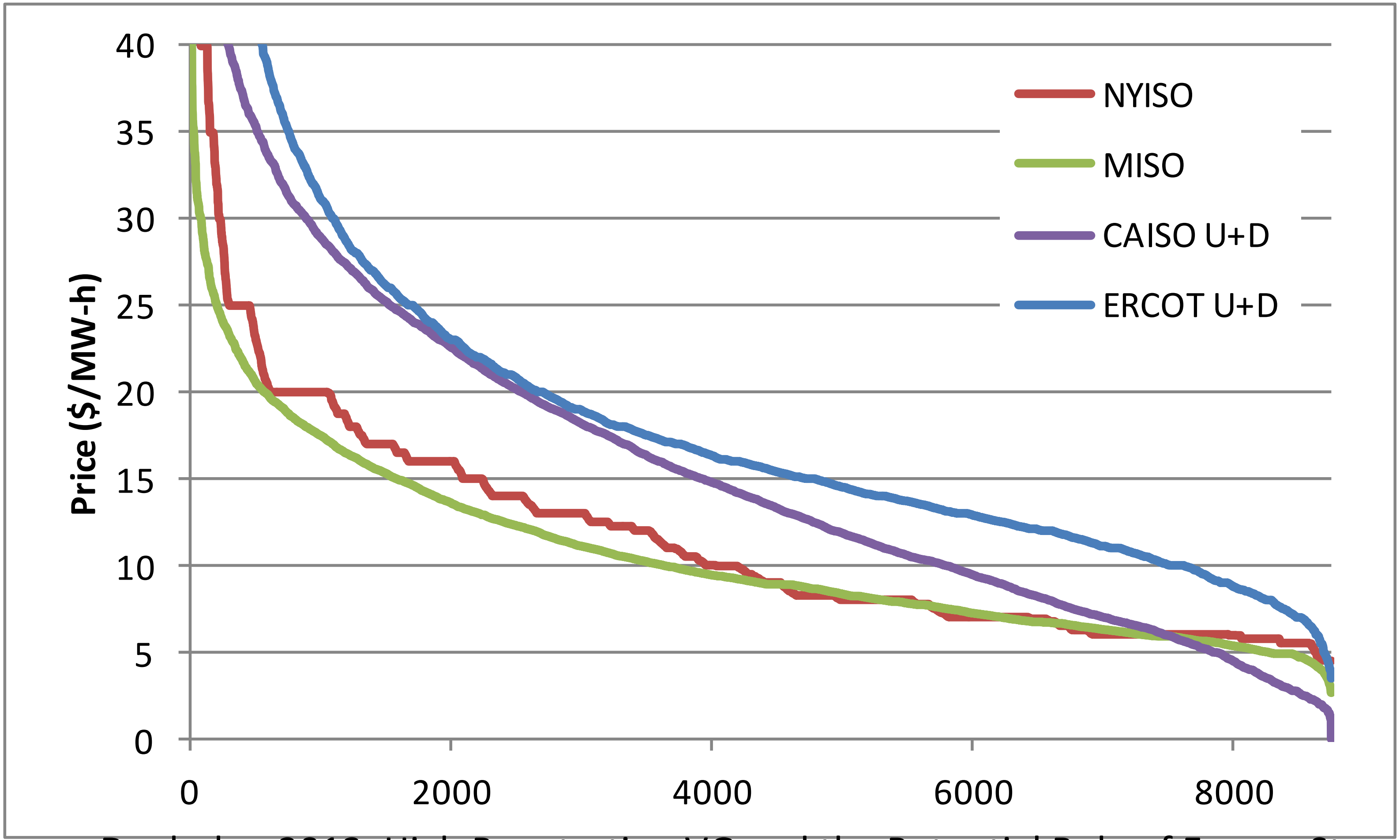
#3: Instantaneous (capacity) Penetration much higher than Energy Penetration

- **Rule of thumb capacity 2-4x energy (1/CF)**
  - Transmission: Energy; Distribution: Capacity
  - CA ISO: 33% renewables (energy): >60% instant



#4: Ancillary Service Markets will saturate

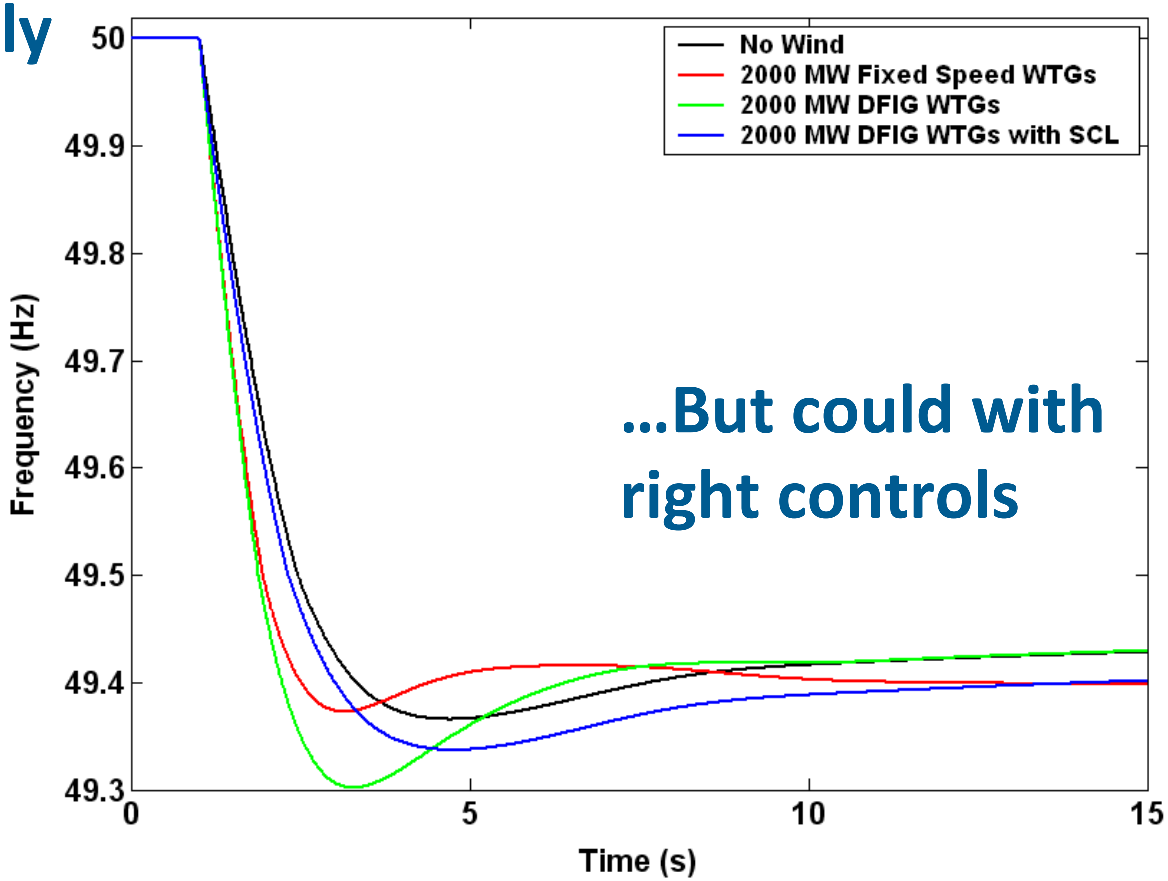
2011 Prices for Regulation



Source: Denholm, 2013, High Penetration VG and the Potential Role of Energy Storage. Presented at ESI Summer School, Golden CO

#5: (Synthetic?) Inertia for high-pen RE

- **Frequency = Grid Heartbeat: Drops on lost supply**
- **Traditional Induction Generators: Resist change.**
- **Inverter Power Electronics (Wind, Solar, Storage): Don't normally**



Lalor, G., Mullane, A., and O'Malley, M.J., "Frequency Control and Wind Turbine Technologies", *IEEE Transactions on Power Systems*", Vol. 20, pp. 1903 – 1913, 2005.

#6: Interconnect Support Opportunities

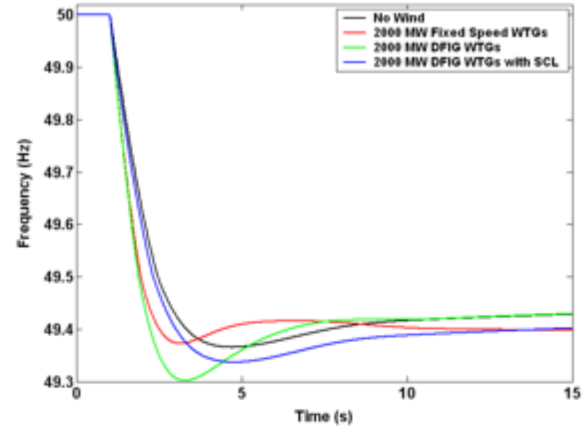
At high penetrations, storage can help meet utility interconnection requests

- **Ramp limits (e.g. Hawaii)**
- **Net export limits without control (e.g. Germany)**

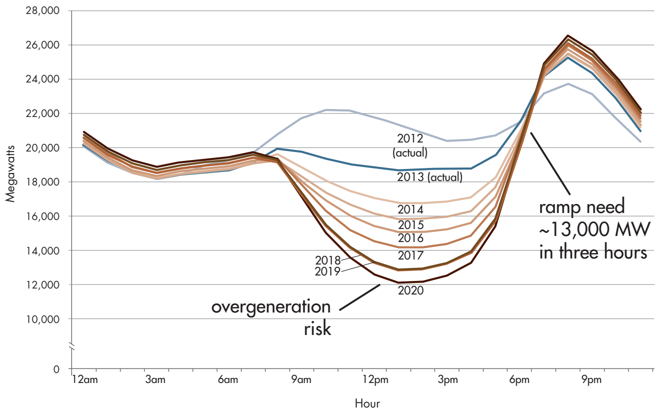
#7: Know thy master

- **Many possible controllers for storage:**
  - Autonomous Storage Only
  - Storage + Other (PV, EV, etc.)
  - Home Energy Management Systems (HEMS)
  - Community Energy Storage
  - Aggregators & Facilities
  - Distribution Management System (DMS)
  - Bulk Power: AGC & EMS
  - Microgrids
- **Different signal rates and objectives**

#8: One size does not fit all



- **Small:**
  - Inertia
  - Ramp limits
- **Medium:**
  - Peak shift support
  - Arbitrage
- **Large: seasonal**
  - Very high renewable energy penetration

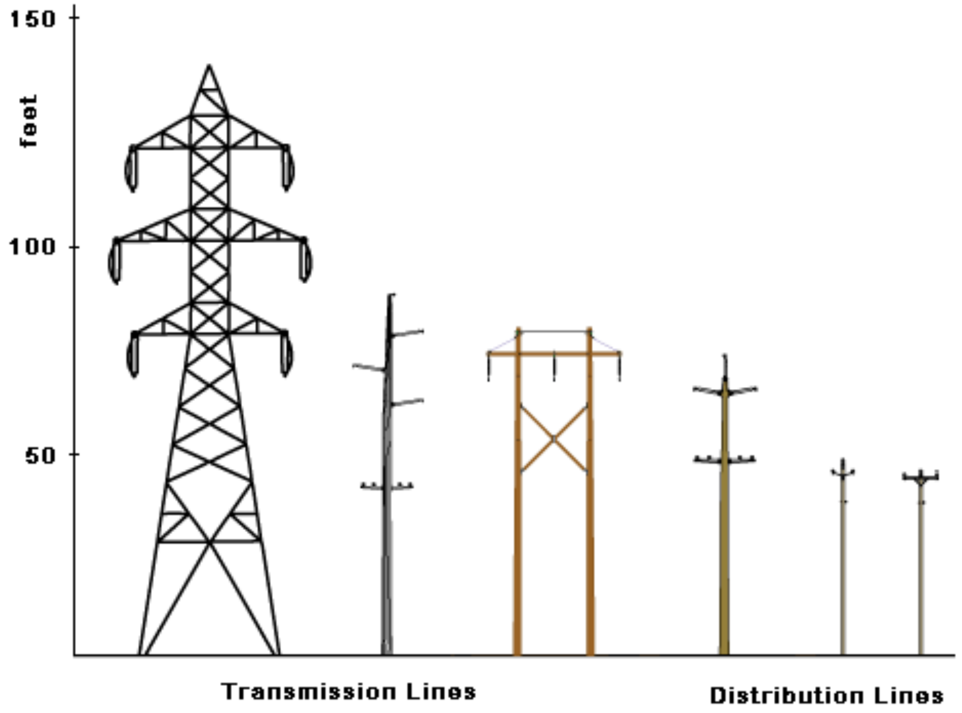


#9 & 10: Distribution

- #9: Key Distribution Concern = Voltage
- #10: Advanced Inverters

Distribution Primer (for DERs)

Transmission and Distribution Systems



Source: Kroposki, NREL

Utility Concerns for Distributed Generation

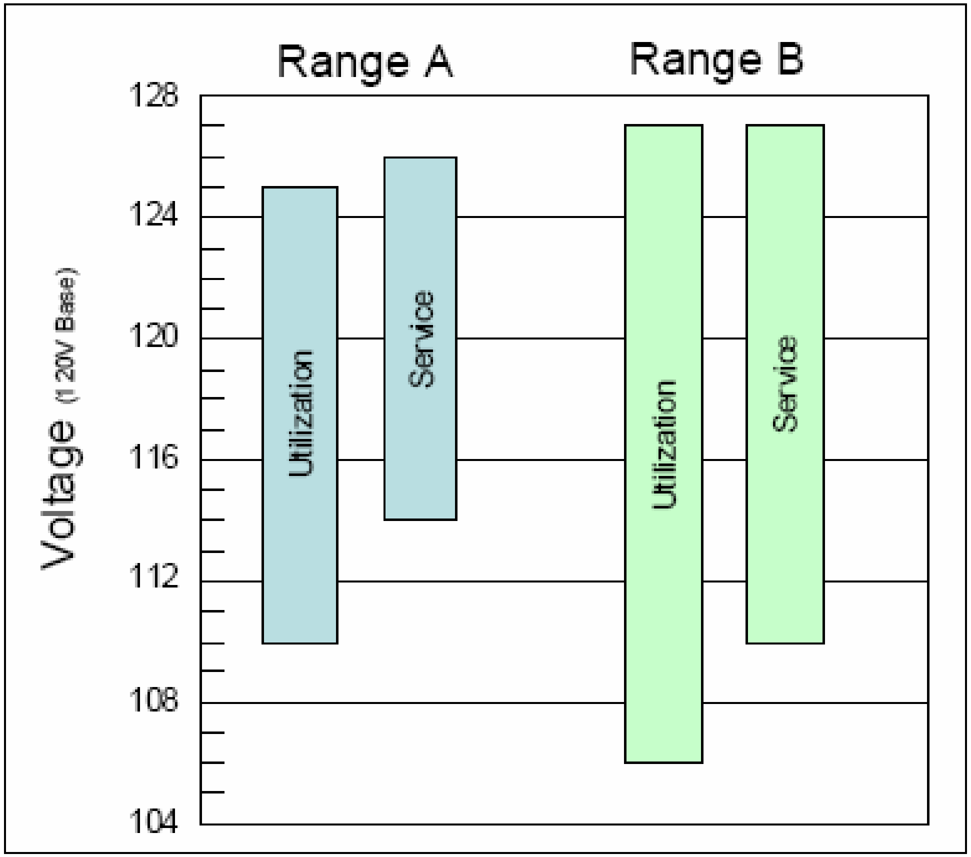
Identified Issues	Relative Priority	Identified Issues	Relative Priority
Voltage Control	High	Equipment Specs	High
Protection	High	Interconnection Handbook	Medium
System Operations	High	Rule 21 and WDAT	Medium
Power Quality	High	IEEE 1547/ UL 1741	Medium
Monitoring and Control	Medium	Application Review	High
Feeder Loading Criteria	High	Clarification of Responsibilities	High
Transmission Impact	Medium	Integration with Tariffs	Medium
Feeder Design	Medium	Coordination with Other Initiatives	Medium
Planning Models	Medium		

Source: Southern California Edison

ANSI C84.1 Voltage Limits

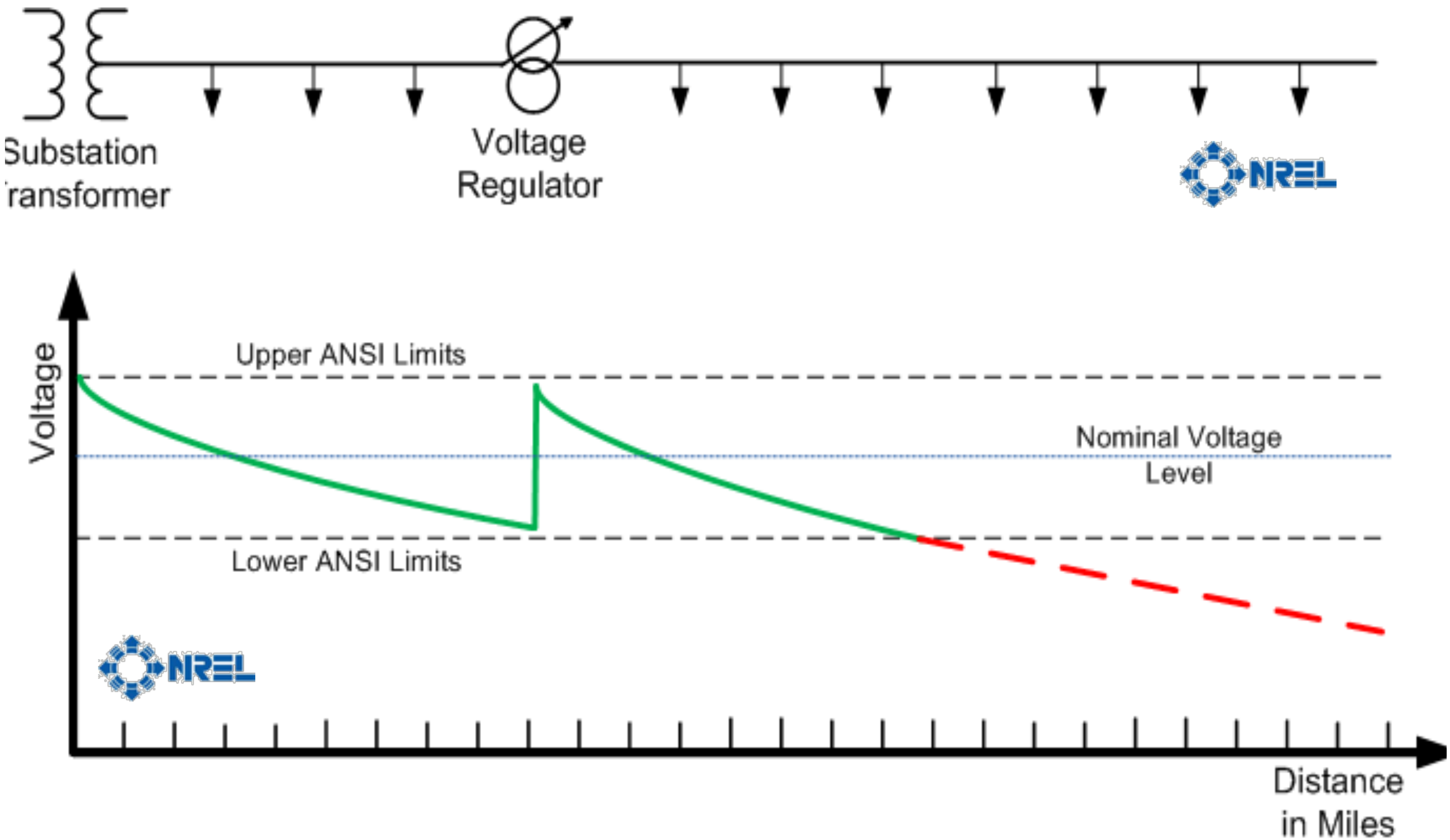
ANSI C84.1
Standard for Electrical Power Systems and Equipment-Voltage Ratings (60 Hz)

- Service Voltage – Voltage at the point of delivery.
- Range A (114-126V) is favorable, Range B (110-127V) is tolerable (for limited time).



OK: +/-5%, **Temporary**: +6%/-8%

Distribution System Voltage Profile



Source: Coddington, NREL

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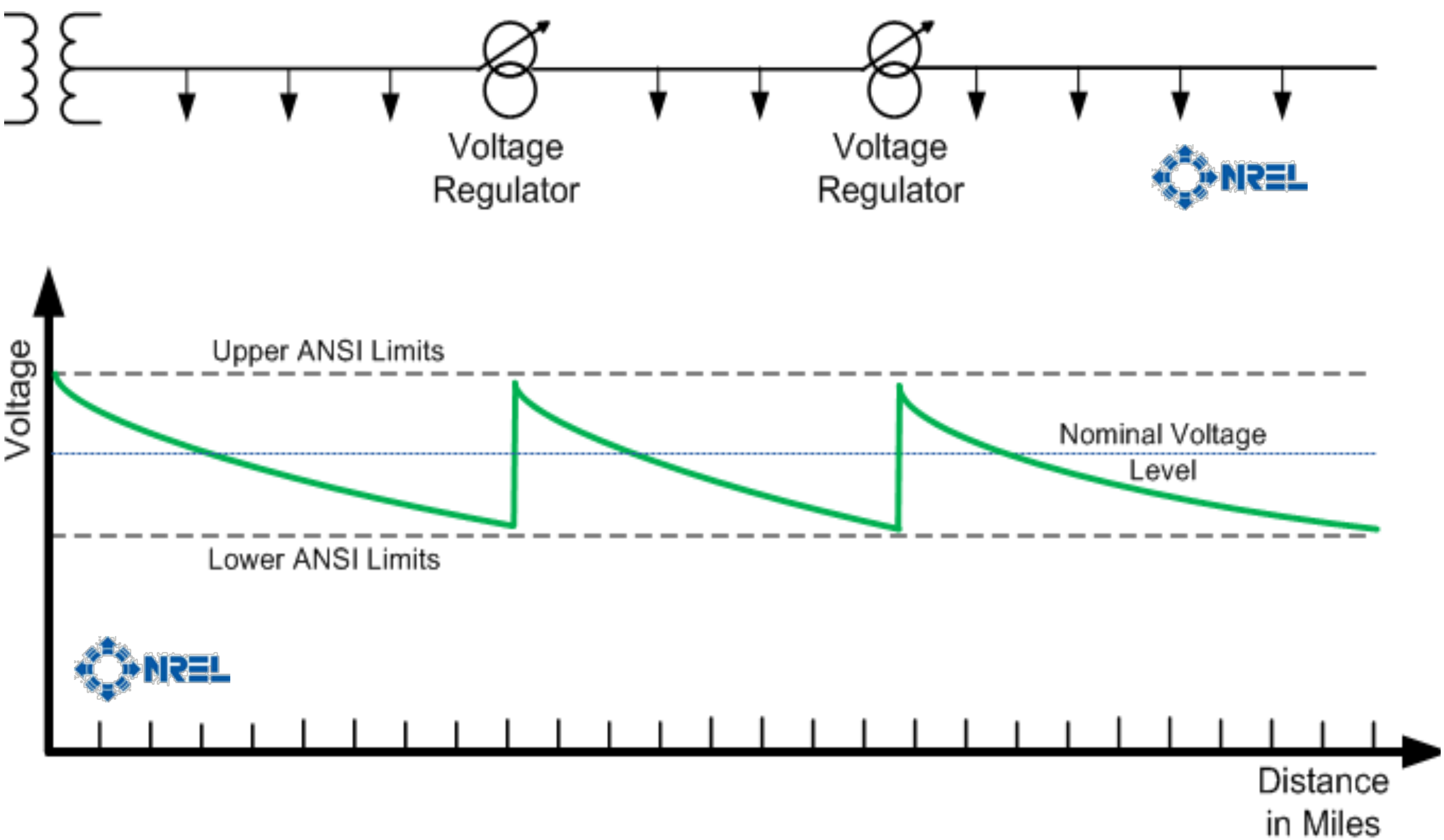


Source: Coddington, NREL

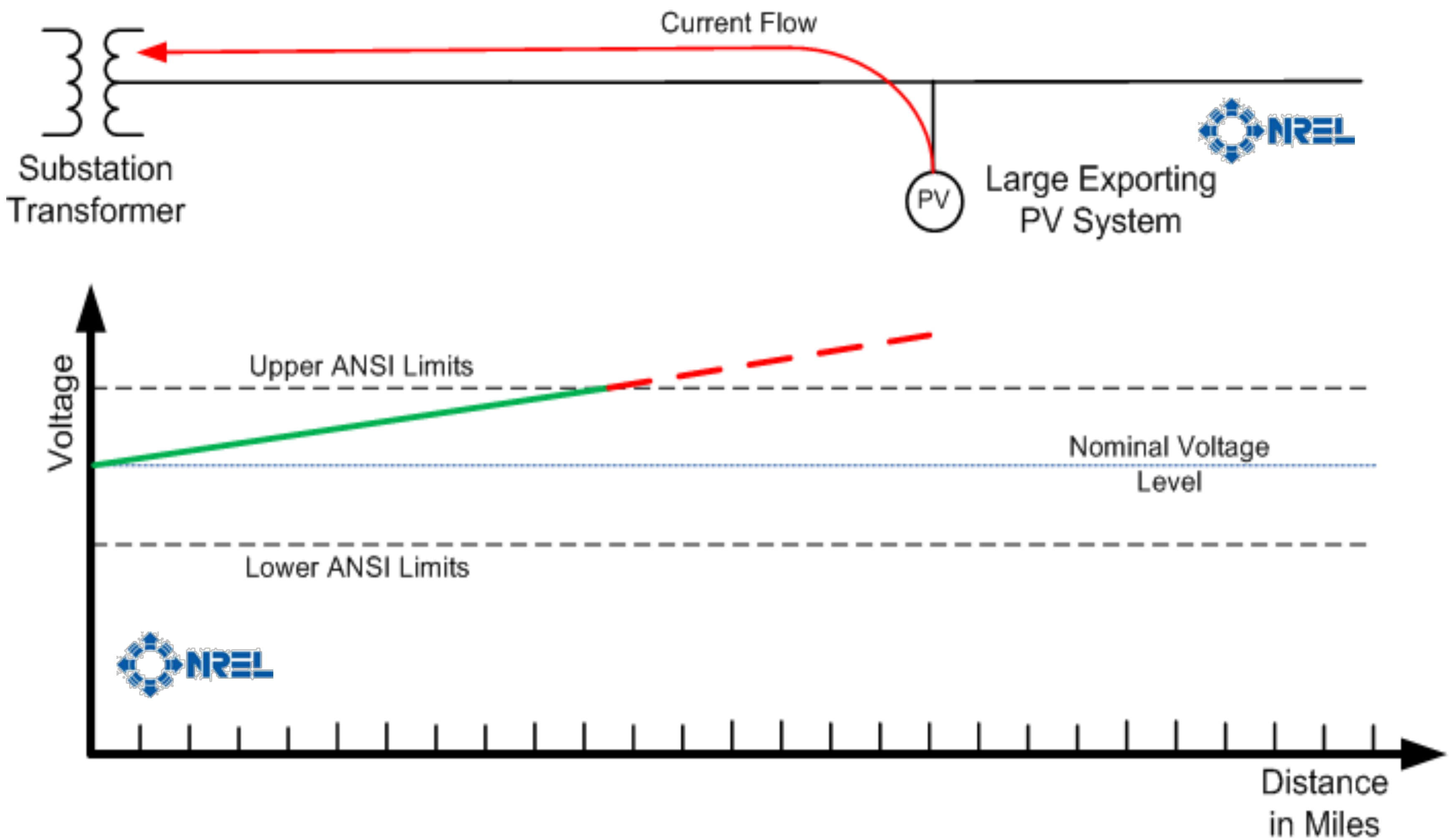
Voltage Regulation Devices

Load Tap Changers (LTCs)

Voltage Regulators

Source: Kroposki, NREL

Distribution System Voltage Profile – Large PV



Source: Coddington, NREL

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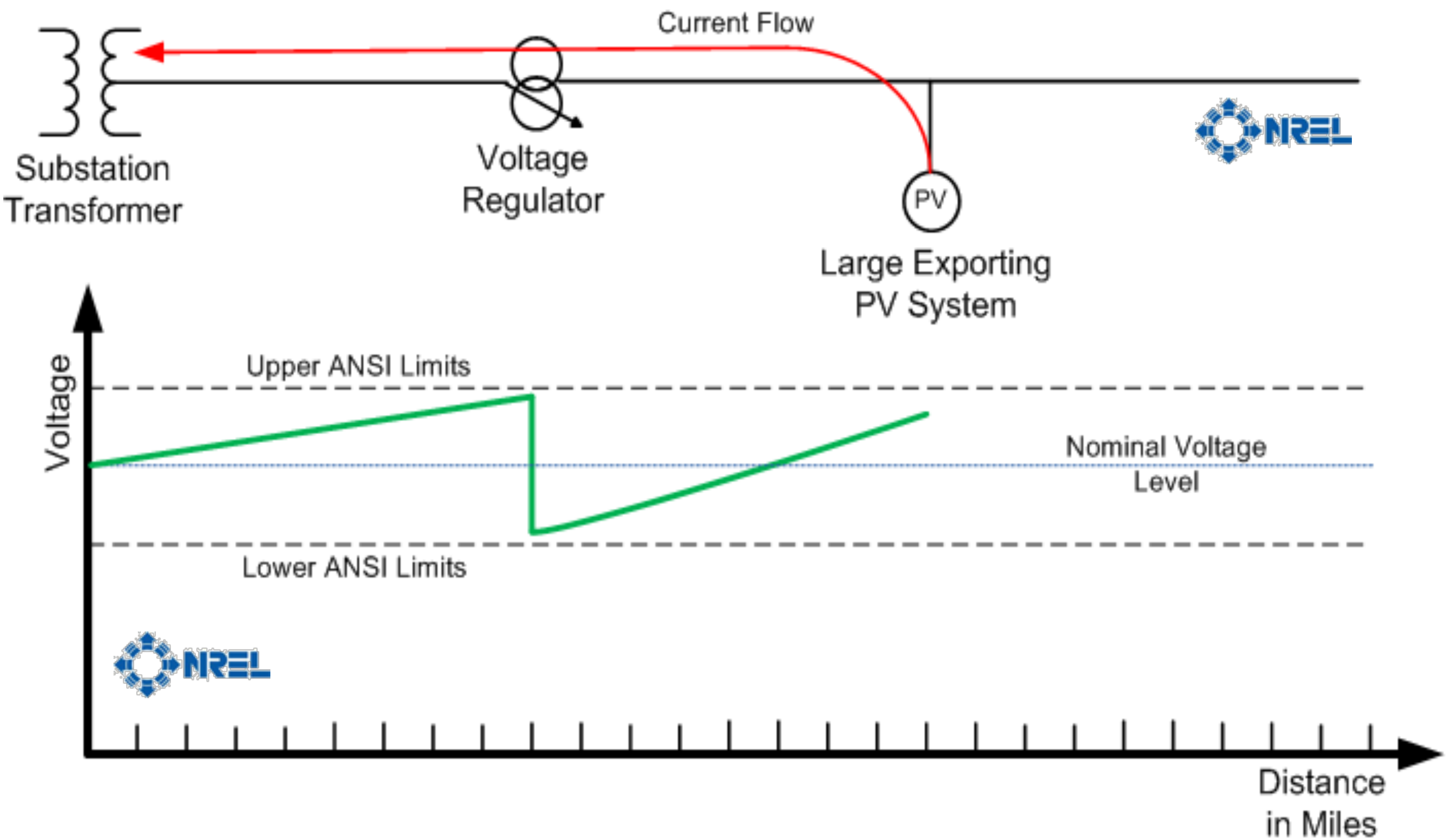
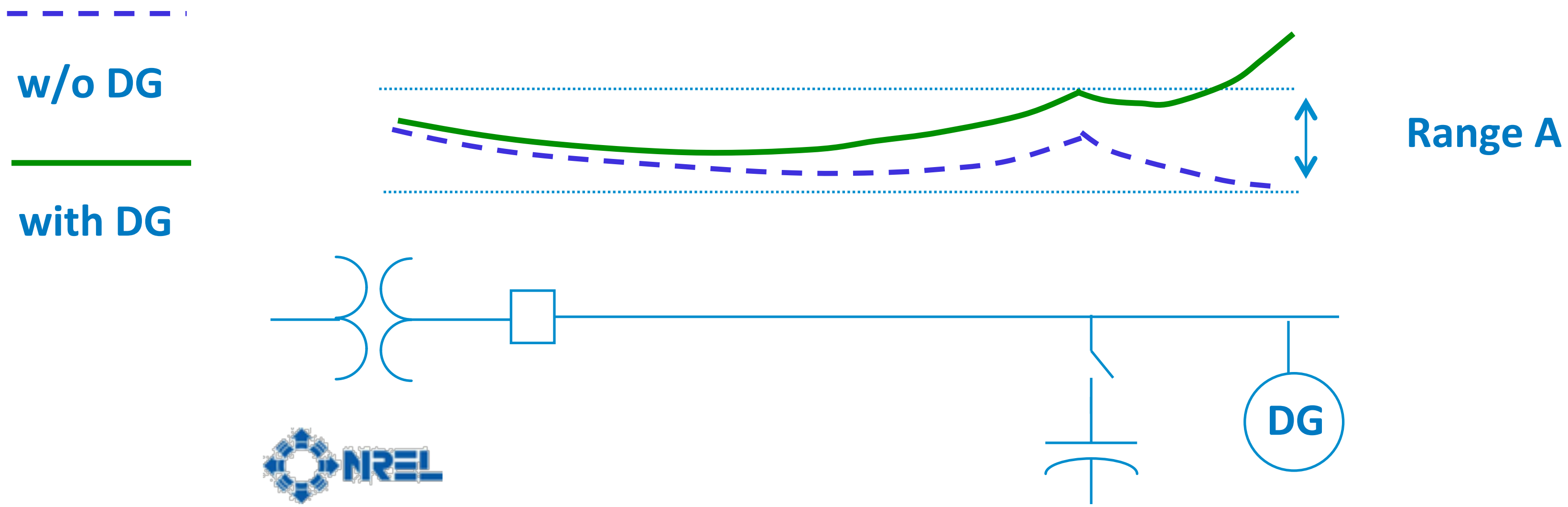


Key: Have to get the settings right for reverse power flow

Source: Coddington, NREL

Voltage Profile, with Caps

- **Alternative: Reactive Power**
  - Inject (Capacitor): Raises Voltage



  - Absorb (Inductor): Lowers Voltage

Source: Coddington, NREL

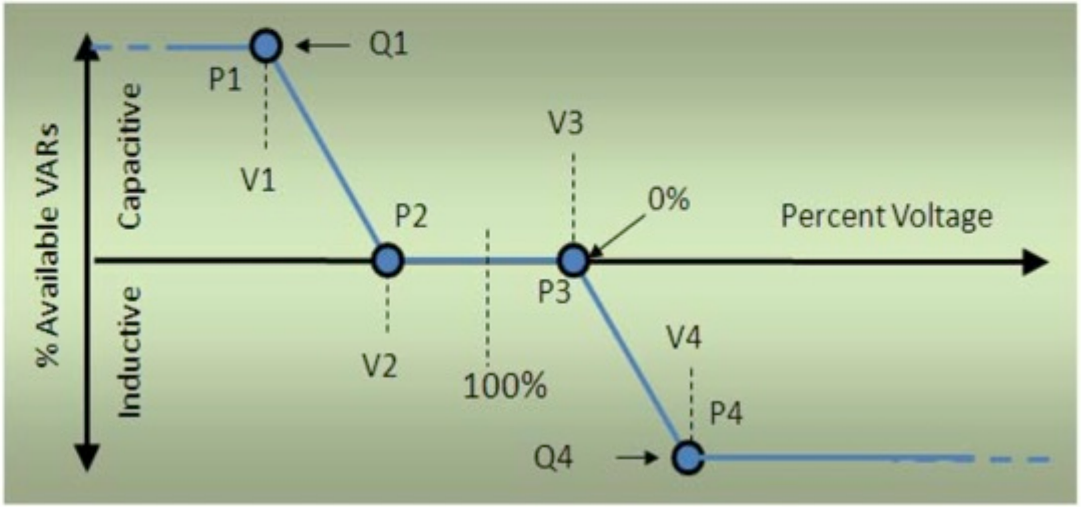
Voltage Regulation Devices

- **Switched Capacitor Banks**
  - Defined by kVAr rating of bank.
  - Voltage rise proportional to rating.

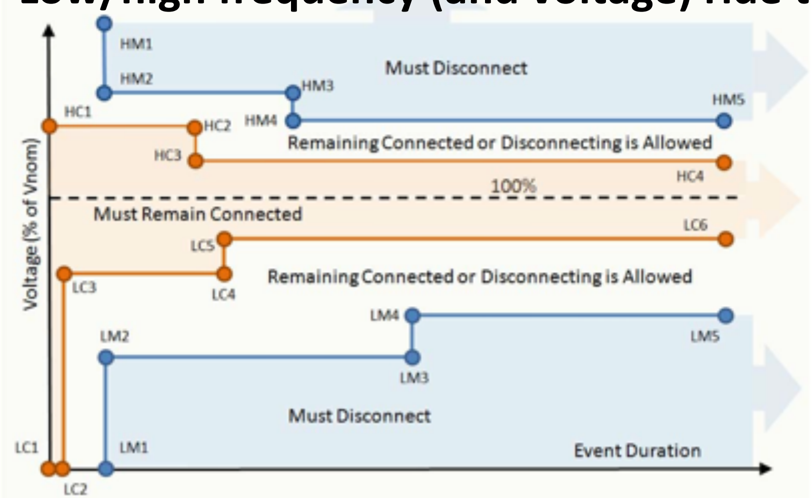
http://www.energyinnovationcorridor.com/page/wp-content/uploads/2011/01/IMG_0574.jpg

Advanced (PV) inverter features

Intelligent volt-var mode: Q(V)



Low/high frequency (and voltage) ride through



Connect/disconnect settings
Anti-islanding
Malfunctioning DER equipment
Maximum generation limit
Fixed power factor
Intelligent volt-VAR
Volt-watt
Frequency-watt
Watt-powerfactor
Price/temperature driven
Low/high frequency ride through
Low/high voltage ride through
Dynamic reactive current
Real power smoothing
Dynamic volt-watt
Peak power limiting
Load and generation following

Source: Common Functions for Smart Inverters, Version 3. EPRI: 2014. Report Number 3002002233

With DERs

- **Static DG:**
  - Overvoltage concern
  - “Easy” with existing approaches
- **Variable DG:**
  - Overvoltage
  - Undervoltage: if system compensates then DG output drops
  - Advanced inverters (or storage/DR) can help
- **Case for Timeseries-based Distribution analysis:**
  - Equipment Cycles
  - Traditional Equipment Delays

Quick note on protection

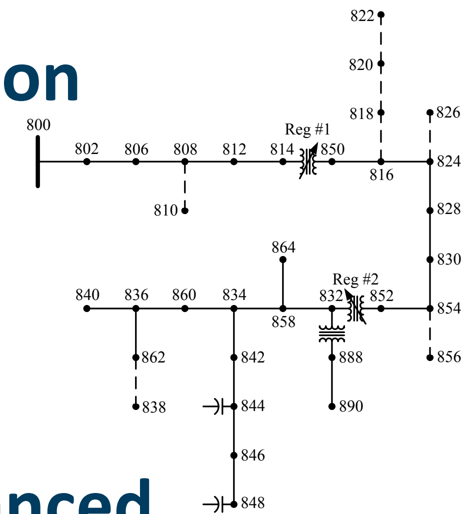
- **DG can change fault currents**
  - Misinterpret location of fault
  - Impact fuse vs. breaker timing
- **Good: Inverter-based = (much) less impact**
  - No rotating intertia to feed current
  - Very short lived
- **Good: Protection settings are "easy"**

What about Reverse Power flow?

- **(usually) technically OK**
  - Conceptually: Up to forward current flows
  - Transformers bi-directional
- **But: Controls & Protection**
  - Need to be set correctly
- **But: T&D Agreements**
  - Some limit *substation-level* injections (feeder to feeder OK)
- **But: Reconfiguration**
  - Common to switch topologies for maintenance, etc.

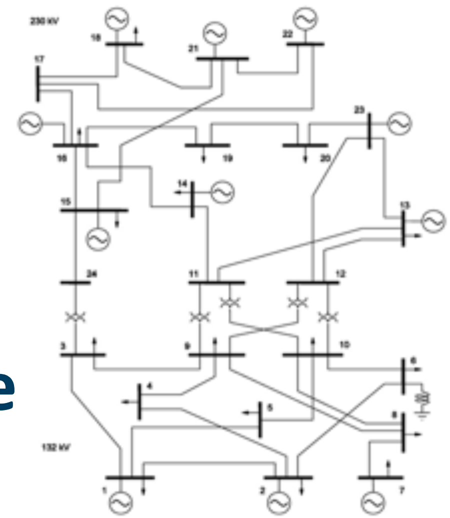
Distribution System Modeling

Distribution



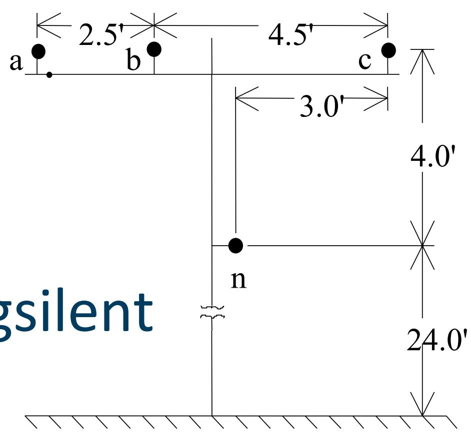
- **Radial**
- **3-ph**
- **Unbalanced**
- **High X/R**

Transmission



- **Meshed**
- **Pos sequence**
- **Balanced**

- **Distribution Tools**
  - OpenDSS
  - GridLAB-D
  - CyME, Synergi, Digsilent



$$\begin{bmatrix} Z_{aa} & Z_{ab} & Z_{ac} \\ Z_{ba} & Z_{bb} & Z_{bc} \\ Z_{ca} & Z_{cb} & Z_{cc} \end{bmatrix}$$

Important: US and Europe have very different distribution system designs

"Alternatives to the 15% rule (of-thumb)"

Itron CSI RD&D Program Manager

PV HOSTING CAPACITY IN DISTRIBUTION SYSTEMS

DEVELOPMENT OF ALTERNATIVE SCREENING METHODS

Why Consider Alternatives to Existing Screening?

- Feeder's ability for hosting PV w/o adverse impact on performance depends upon many feeder-specific factors
- "Rule-of-thumb" penetration limits such as 15% rule are not very accurate
- Typical characteristics used to classify/screen feeders (i.e. voltage class and load level) may not be sufficient
- Example illustrates different hosting capacity for "similar" circuits

Sample analysis results from DOE-funded VT/EPRI Hi-Pen Project

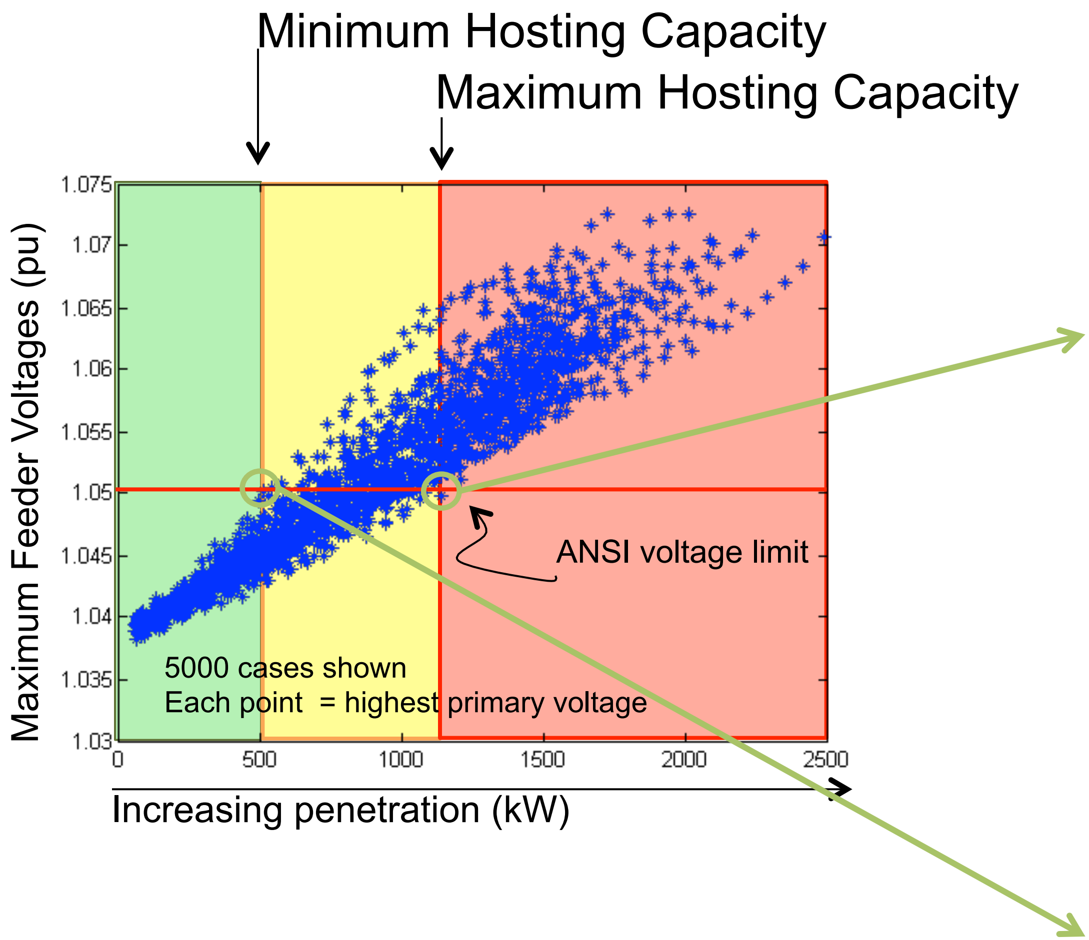
Feeder Characteristics	Feeder A	Feeder B
Voltage (kV)	13.2	12.47
Peak Load	5 MW	6 MW
Minimum Load	0.8 MW	0.7 MW
Minimum Daytime Load	1.1 MW	0.7 MW
Existing PV (MW)	1.0	1.7
Feeder Regulation	Only @ Substation	Yes, highly regulated
Total Circuit Miles	28	58
Feeder "Footprint"	7 mi^2	35 mi^2
Minimum Hosting Capacity		
Due to Voltage Impacts	**>3500 kW**	**250 kW**
Due to Protection Limit	**777 kW**	**390kW**

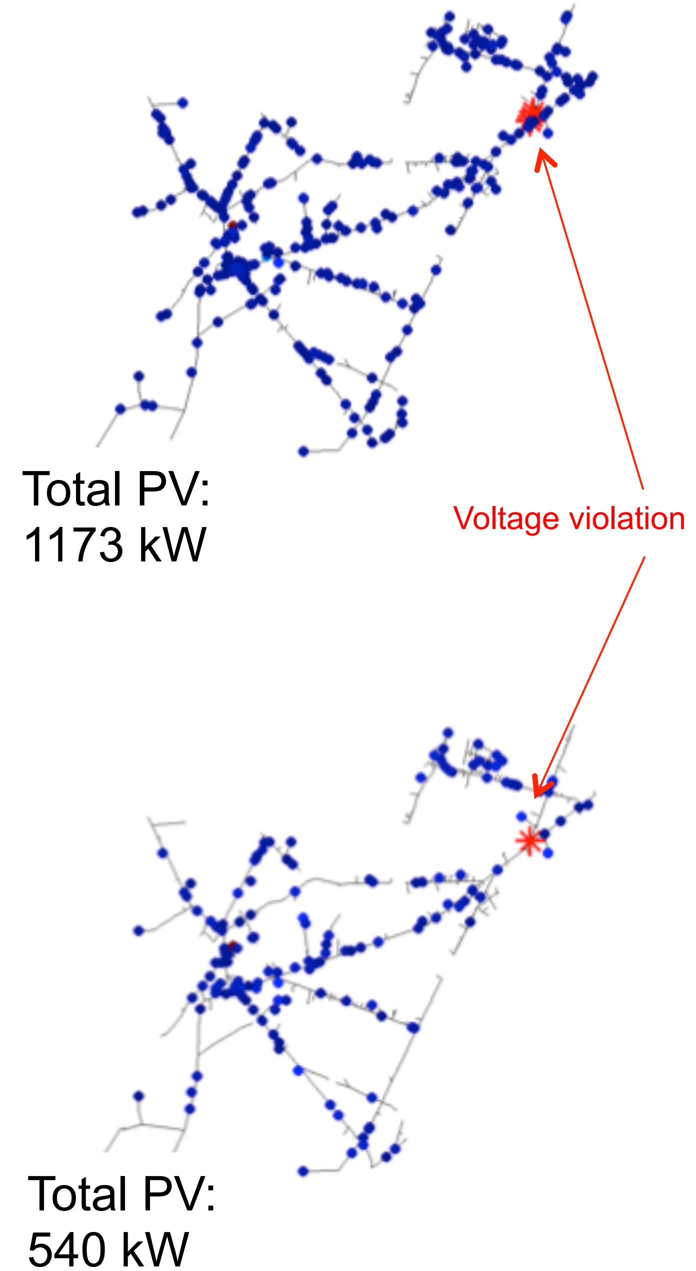
70% of Peak Load

4% of Peak Load

Source: Jeff Smith, EPRI

Hosting Capacity Explanation





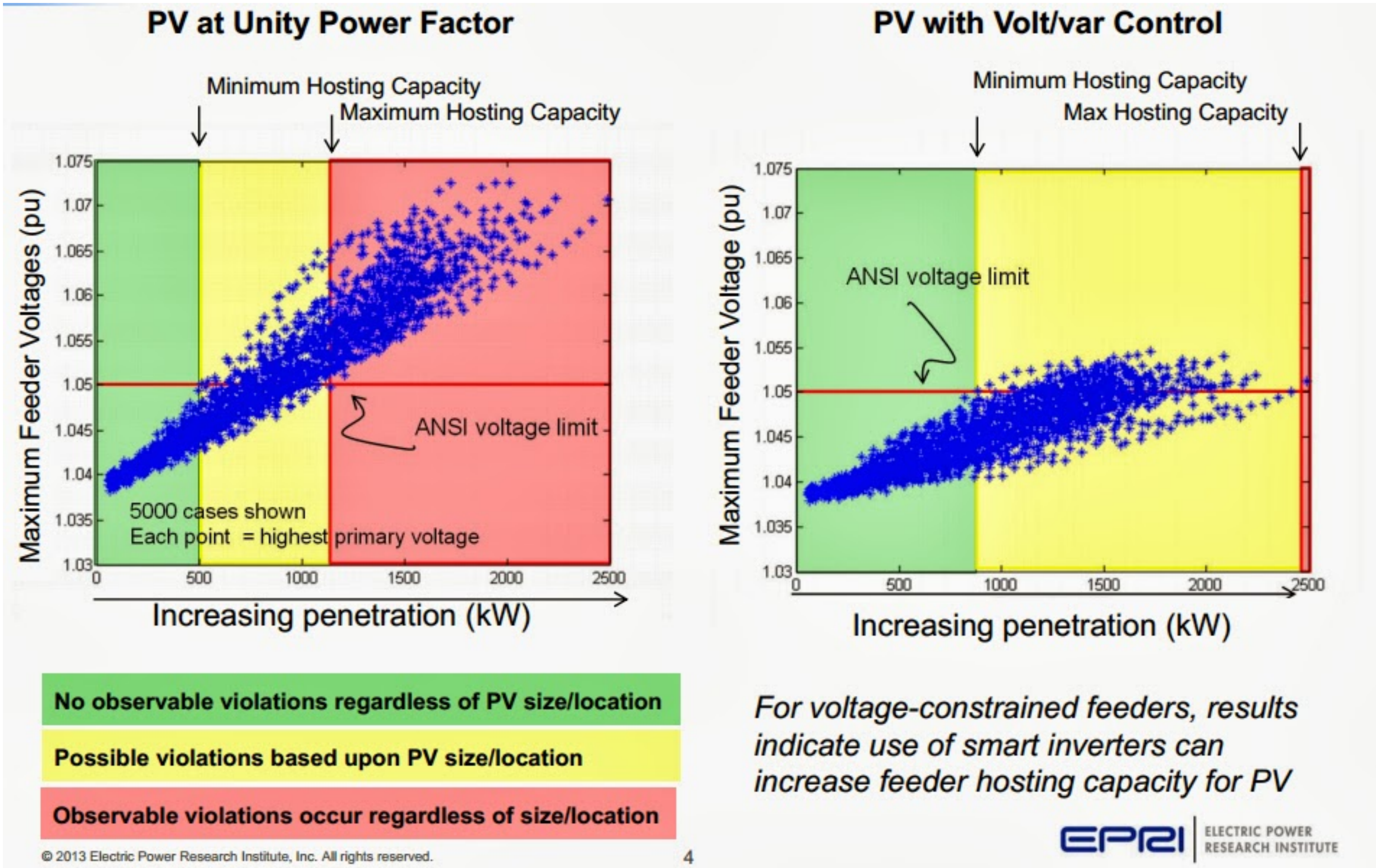
No observable violations regardless of size/location

Possible violations based upon size/location

Observable violations occur regardless of size/location

Source: Jeff Smith, EPRI

Advanced Inverters can help



Implications for Value

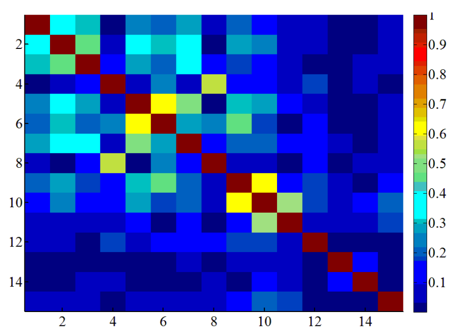
- **Up to a certain point**
  - Minimal cost to interconnect
  - Minimal value for deferred equipment
- **It depends**
  - Feeder by feeder
  - Location on feeder

Statistics for System-wide Distribution

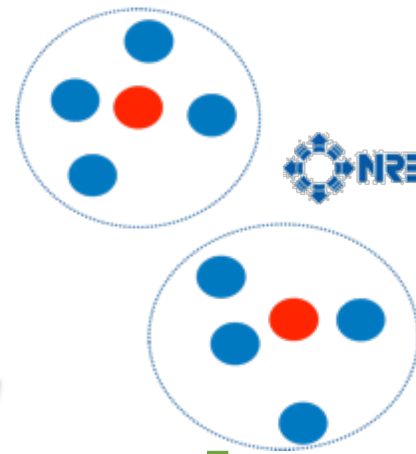
- **If every feeder different, how to generalize?**

Variable	Description
v_1	Peak MVA (summer)
v_2	Peak MVA (winter)
v_3	Current Rating (summer)
v_4	Overhead Miles (3-phase)
v_5	Underground Miles (3-phase)
v_6	Underground Miles (1,2-phase)
v_7	Number of Capacitor Banks
v_8	Number of Voltage Regulators
v_9	Residential Customers
v_{10}	Commercial Customers
v_{11}	Industrial Customers
v_{12}	Irrigation (Agricultural) Customers
v_{13}	Street Lighting Customers
v_{14}	Company Customers
v_{15}	Public Authority Customers
v_{16}	Feeder Head Impedance (X, Pos Seq.)
v_{17}	Region (Northern and all others)

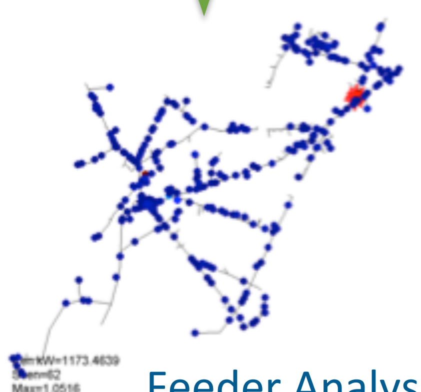
Meta-Data



Pre-processing

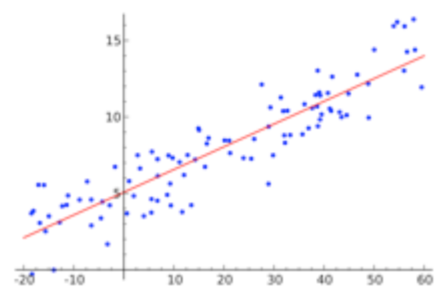


Clustering



Feeder Analysis

Validate:
Do clusters capture phenomena?
(Requires additional feeders)



Regression

Source: Palmintier, NREL

Value of Solar

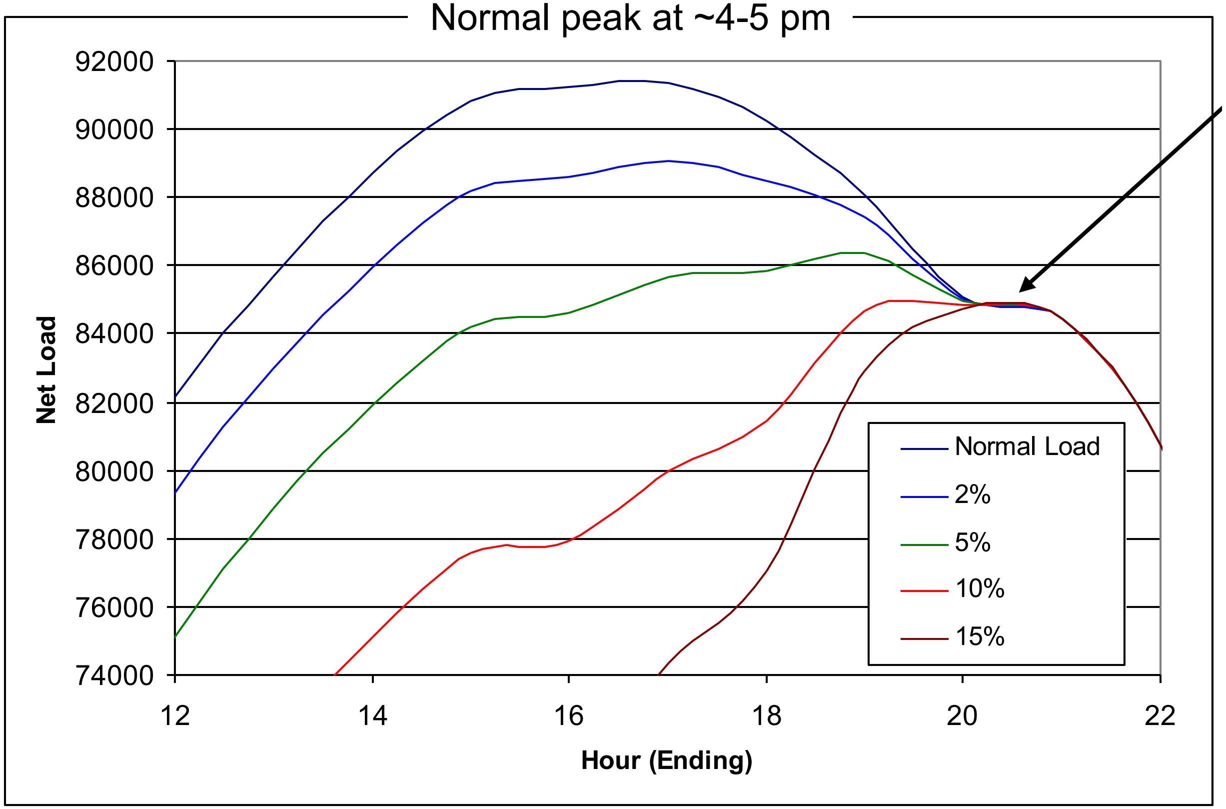
Categories of Value

- Energy
- Environmental
- T&D loss
- Gen Capacity
- T&D Capacity
- Ancillary Services
- “Other”

Categories of Value

- Energy
- Environmental
- T&D loss
- Gen Capacity
- T&D Capacity – Any time, Direct peak & end of line
- Ancillary Services
- "Other"
- Resiliency (Big)
- Arbitrage
- Smoothing
- Interconnection/Ramping

Capacity Value of PV: drops with high PV



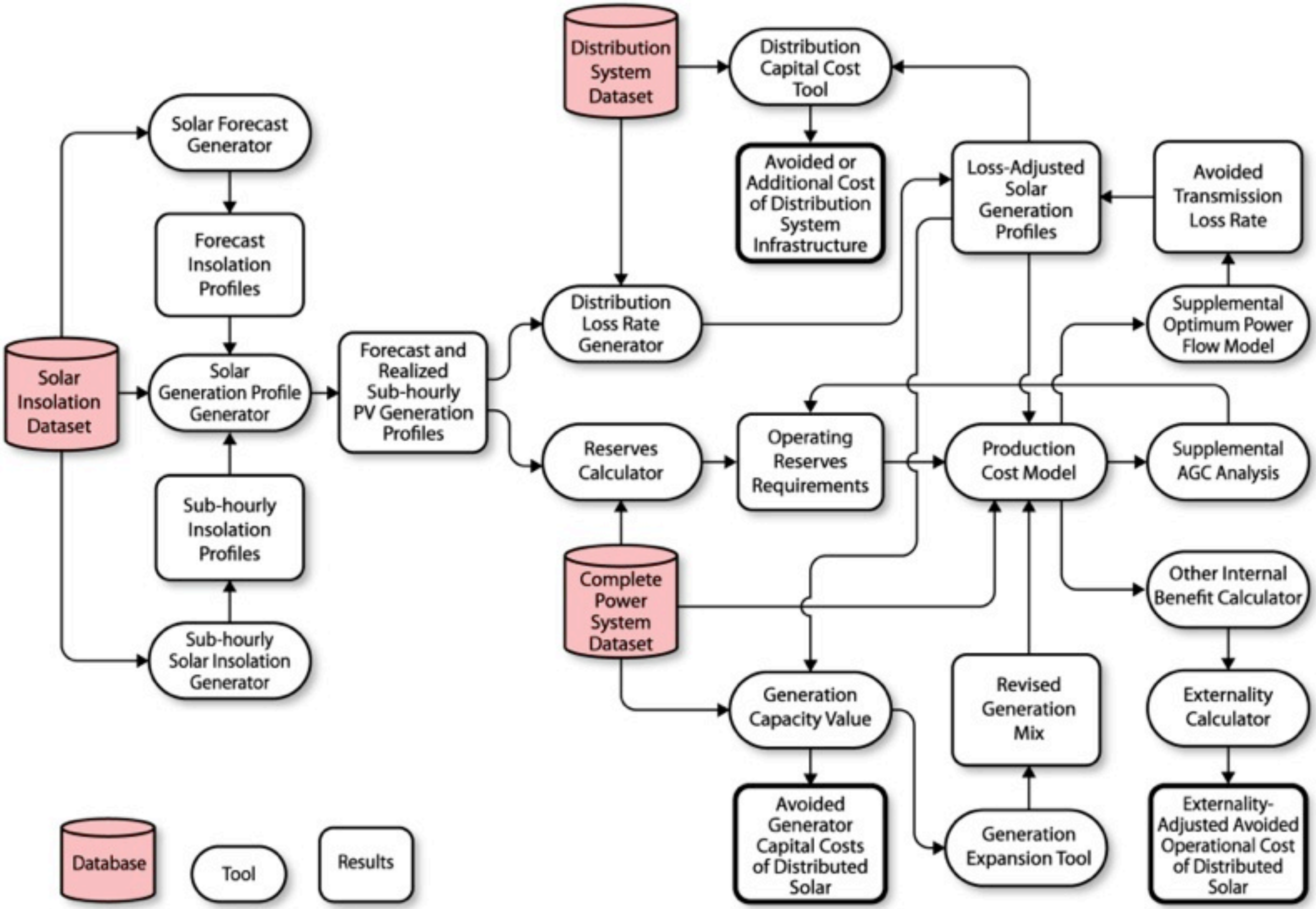
At 10% PV, peak is shifted to 8-9 pm. PV provides no further peak capacity benefits

At this point PV cannot reduce the need for generation capacity

But with Storage… Can better align to peak

Source: Denholm, NREL

A Gold Standard (?) for DGPV Study…



Source: Denholm, et al. (2014)

Generic x`Analysis Sequence?

- **Back of the Envelope**
  - One slide
  - Get support
- **Analyze it to Death**
  - Capture specifics
  - Convince yourself & others
- **Summarize**
  - One slide/table
- **Develop simple model**
  - Spreadsheet
- **Summarize with simple model**
  - For 2:N customer

Data Requirements: Wind, Solar, and Load

- Weather is common driver
- Hourly wind, solar, and load data **must be from same year** for consistent analysis and plausible results
- Use of meso-scale weather models or actual VG production is state of the art (same as integration studies)
- Preserves underlying correlations between wind, solar, and load with temperature, other weather phenomena

The whole is larger than the parts

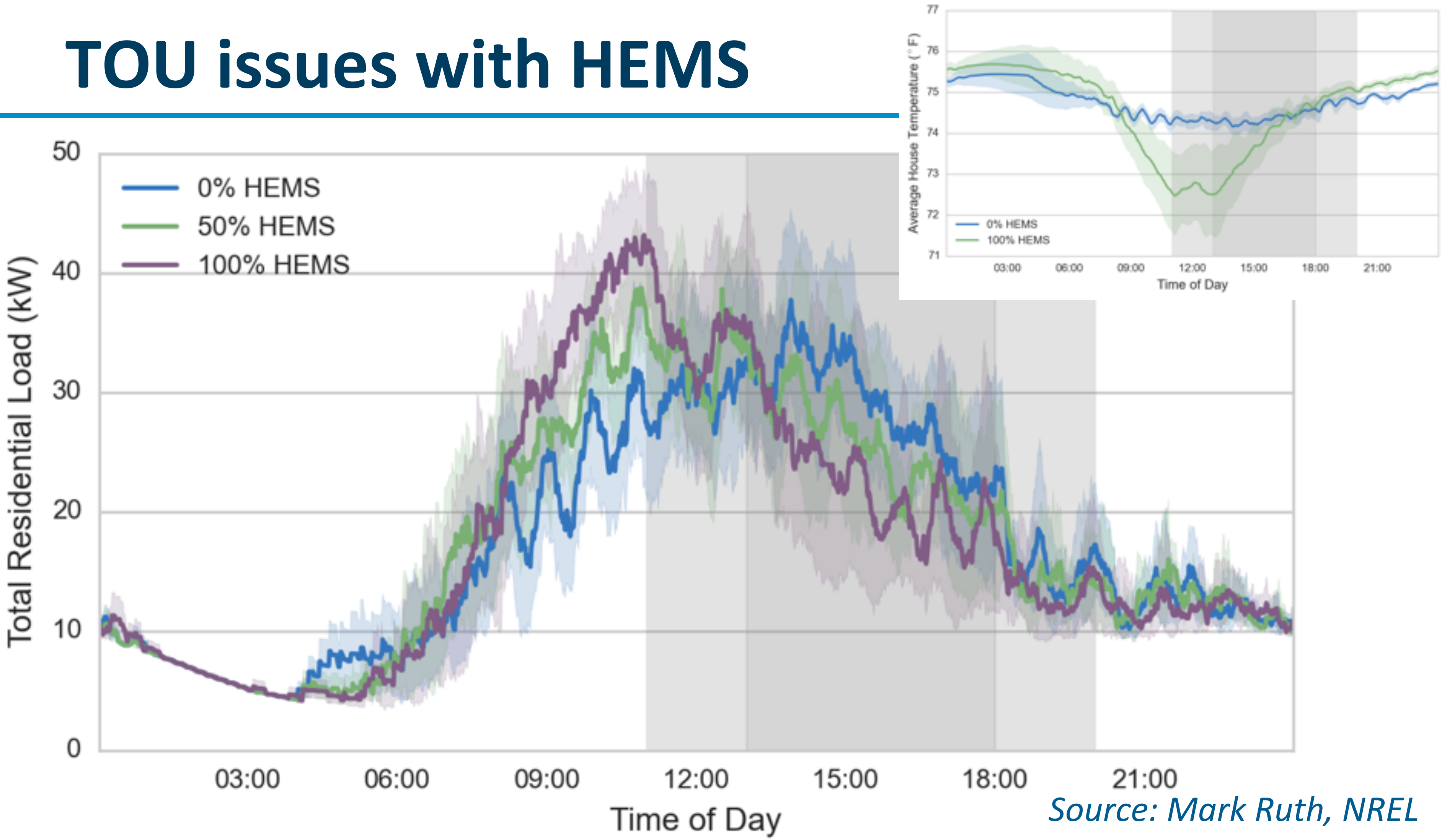
- **For triple play:**
  - Additional value from interactions
    - Can’t separate and add
  - Hence must capture together
- **Challenges:**
  - Storage analysis strongly tied to time dynamics
  - What control strategy for Storage?

Questions to think about

- **Value to who?**
  - IRP: Society, Utility, Customer, Non-participant
  - Regulation/Policy to shift value streams
- **System-wide vs Project specific**
  - Different evaluation approaches

Misc Tidbits

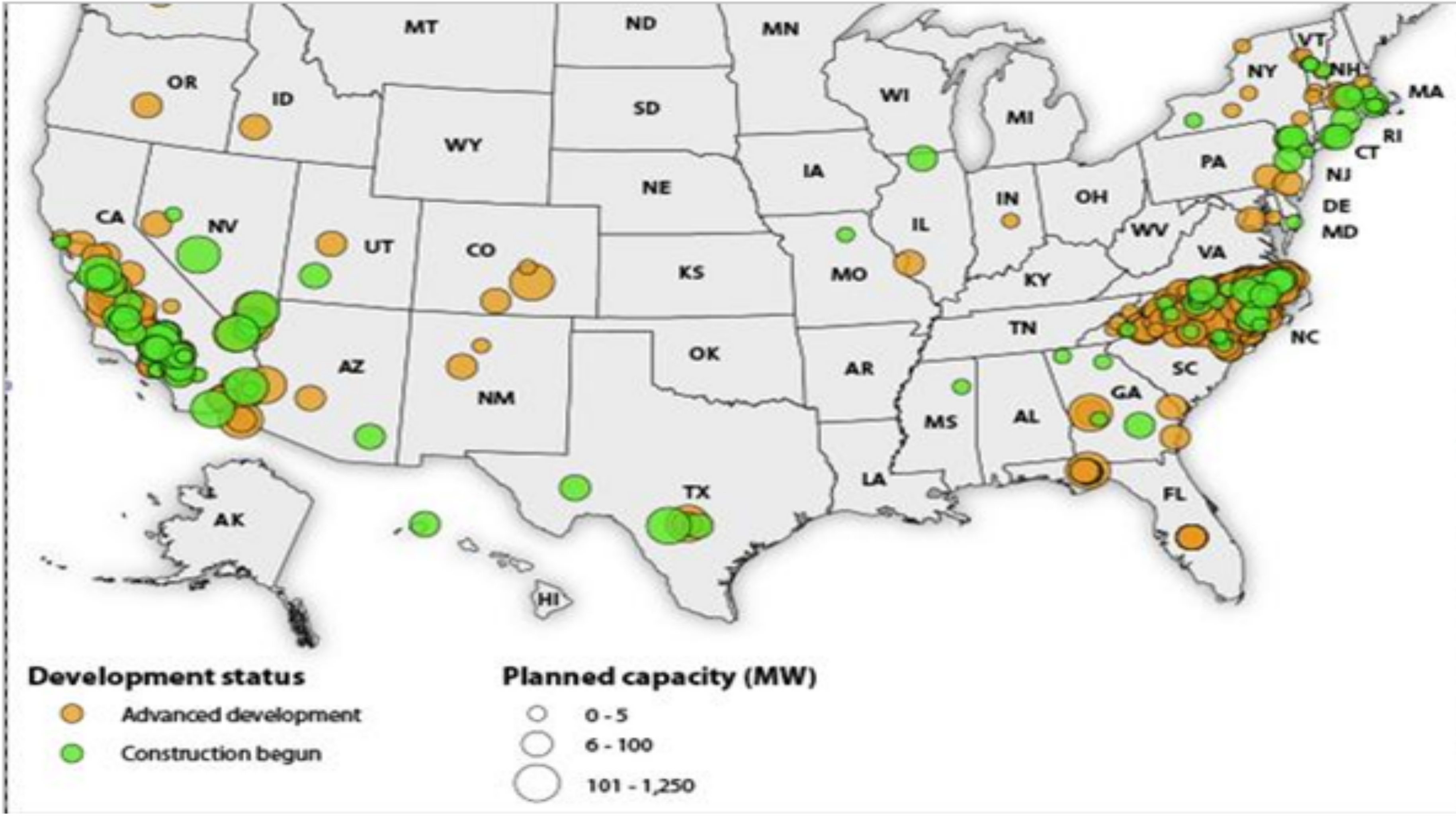
TOU issues with HEMS



Source: Mark Ruth, NREL

Could be mitigated by coordinated HEMS penetration, coordinated operation, and/or alternative pricing

NC: Lots of 1-5MW solar (not community)



Source: SNL Report Feb. 25, 2015

Questions & Discussion

Thanks!

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