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Interconnection of High Penetration PV on Distribution Circuits

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NNSA
National Nuclear Security Administration

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Study Process for Interconnections in Utah

- Interconnection rule **R746** describes the Interconnection requirements for generating facilities up to 20 MW. The rule describes in detail the interconnection process and screening criteria.
  - Level 1 Interconnection Review: Inverter based generation capacity of 25 kW or less.
  - Level 2 Interconnection Review: Generation capacity of 2 MW or less which fails to meet Level 1 requirements.
  - Level 3 Interconnection Review: Generation capacity of 20 MW or less which fails to meet Level 1 or 2 requirements

- The interconnection review process performed by the utility at Levels 1 and 2 consists of 10 screens to determine quickly and efficiently the level of study required by the utility. The intent of the screening process is to allow generators to interconnect quickly that are very unlikely to cause problems to the utilities distribution system.

Level 3: Interconnection Studies

- If an Interconnection customer fails the screening criteria, which often occurs when the aggregate generation on a feeder >15% peak load, then the generator is typically evaluated under Level 3.
- The Level 3 Interconnection review can involve 3 studies: a feasibility study, a systems impact study and a cost estimate study.
- The goal of the studies is to determine **if** the generator has the potential to create adverse impacts on the utilities distribution systems. If adverse impacts are identified, the utility will estimate the costs for system upgrades to mitigate the adverse impacts and charge the costs to the generator interconnecting to the system.

Grid Integration Challenge

- Are high penetration scenarios technically feasible?
- What are the impacts and mitigation? What is the cost?
- How should we plan the grid to enable high penetration?

Definition of Variable Generation (VG) Penetration Level

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- From the distribution system point of view
  - VG Capacity / Peak Load of line section or feeder*
  - VG Capacity / Minimum Load
  - VG Capacity / Feeder, Transformer or Station Rating
- From the bulk system point of view
  - Annual VG Energy / Annual Load Energy*
  - VG Capacity / Peak Load or Minimum Load

* Definition most commonly used

- Often used in policy and procedures
  - Penetration by energy used in State RPS targets
  - Penetration by capacity used in the context of interconnection procedures (screening)

Definition of VG Penetration Level

- Example for distribution system

	Peak / Min (MW)	Penetration for 1 MW PV
Feeder Load	3 / 0.9 [1]	33% / 111%
Station Load	10 / 3 [1]	10% / 33%
Station Rating	20 MVA	5%

[1] Minimum Load may be in the range of 20% to 40% of Peak Load

- Example for bulk system

	Load		Penetration for 1 GW PV	
	Peak/Min (GW)	Energy (GWh)	By Capacity	By Energy [3]
Utility (LSE)	5 /2 [1]	24,000 [1]	20% / 50%	6%
Balancing Area	50 / 20 [2]	240,000 [2]	2% / 5%	0.6%

[1] e.g., SDGE, 2009 [2] e.g., CAISO, 2009 [3] Assumes 16% annual capacity factor

What is High Penetration?

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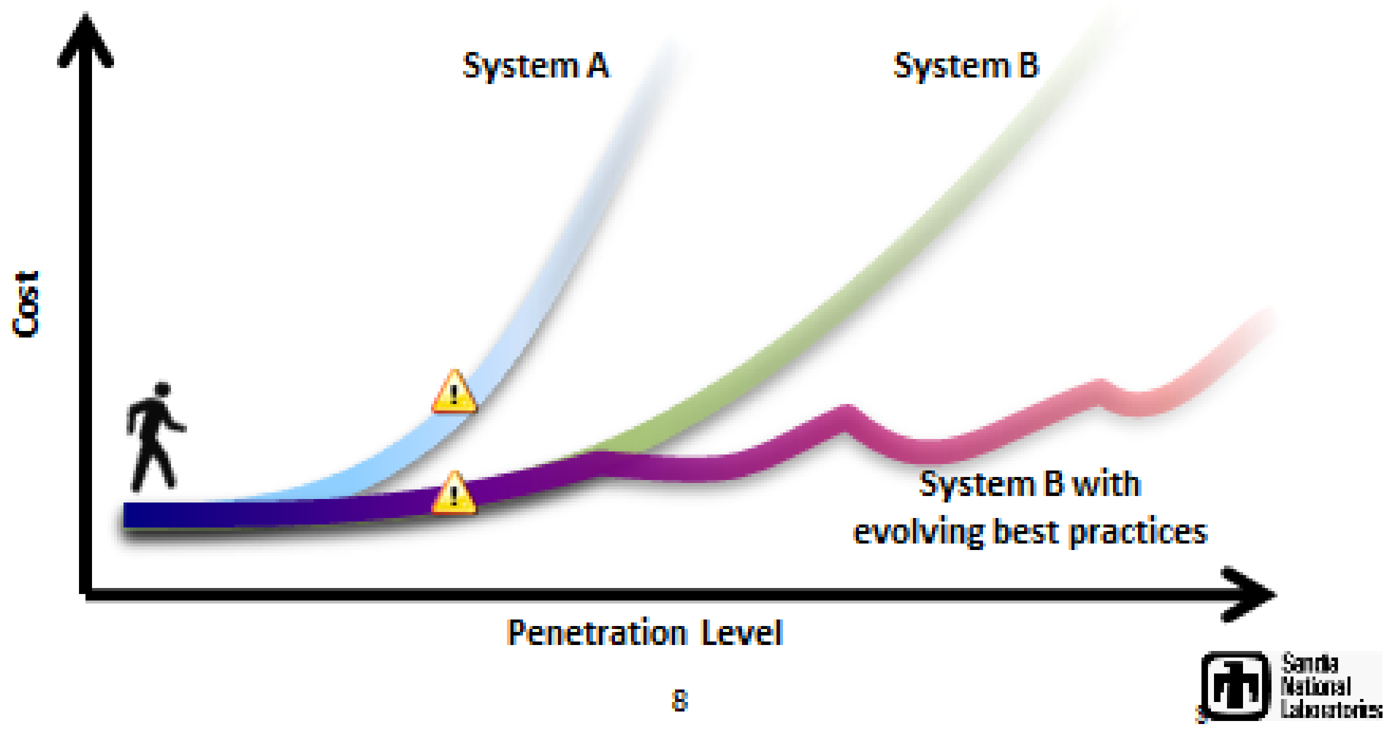
- It depends!
  - With respect to what part of the system?
    - Feeder or Local Grid? >50% by capacity?
    - BA/Market? Interconnection? >5% by energy?
  - Assuming Business-As-Usual or Best Practices?
    - Technology, Standards, Procedures, Market, Regulatory…
- High penetration is a concern when…
  - Performance & reliability would be <u>materially</u> impacted

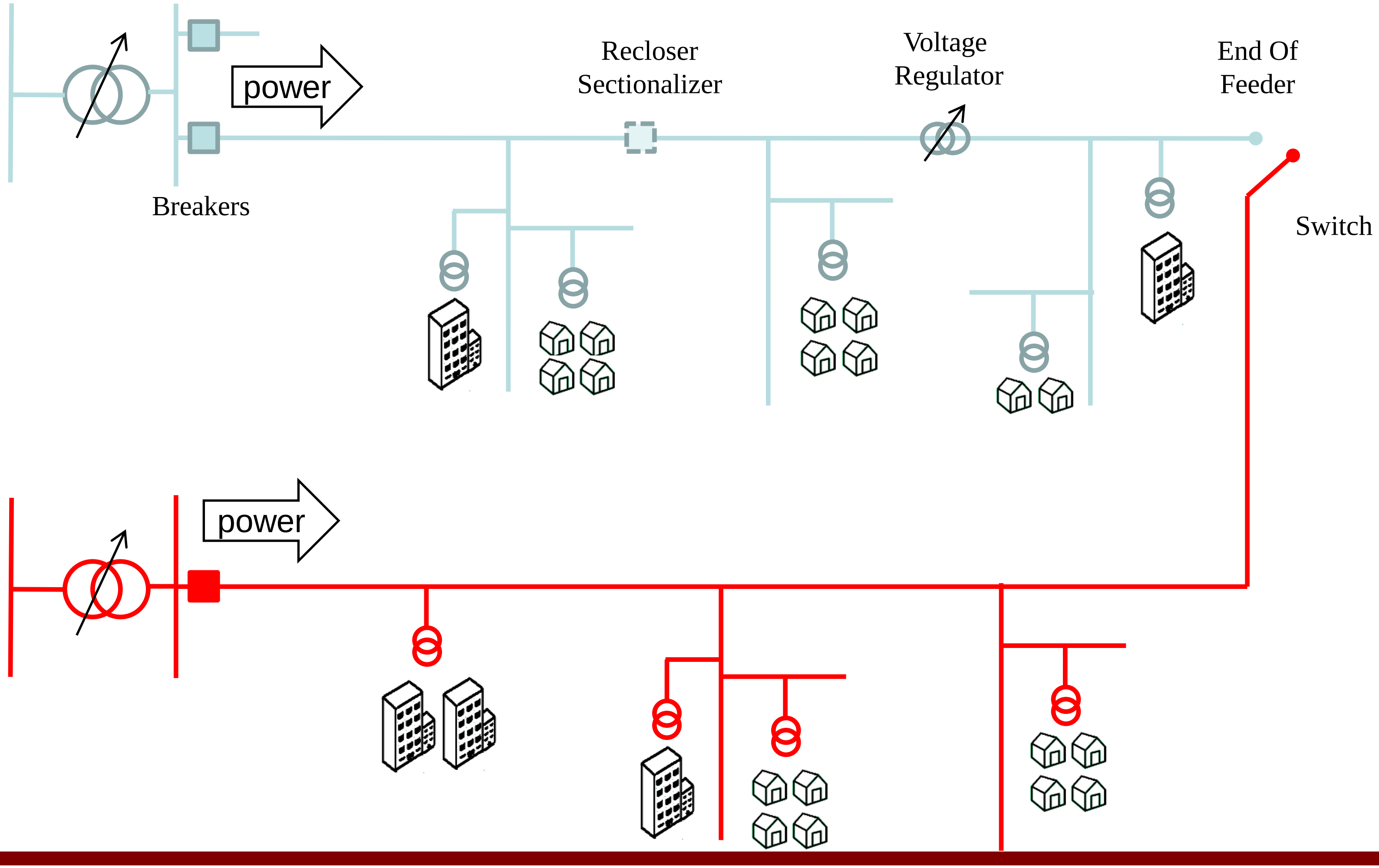
    AND
  - Cost of mitigation and cost allocation are objectionable or unacceptable to stakeholders

Are There Penetration Limits?

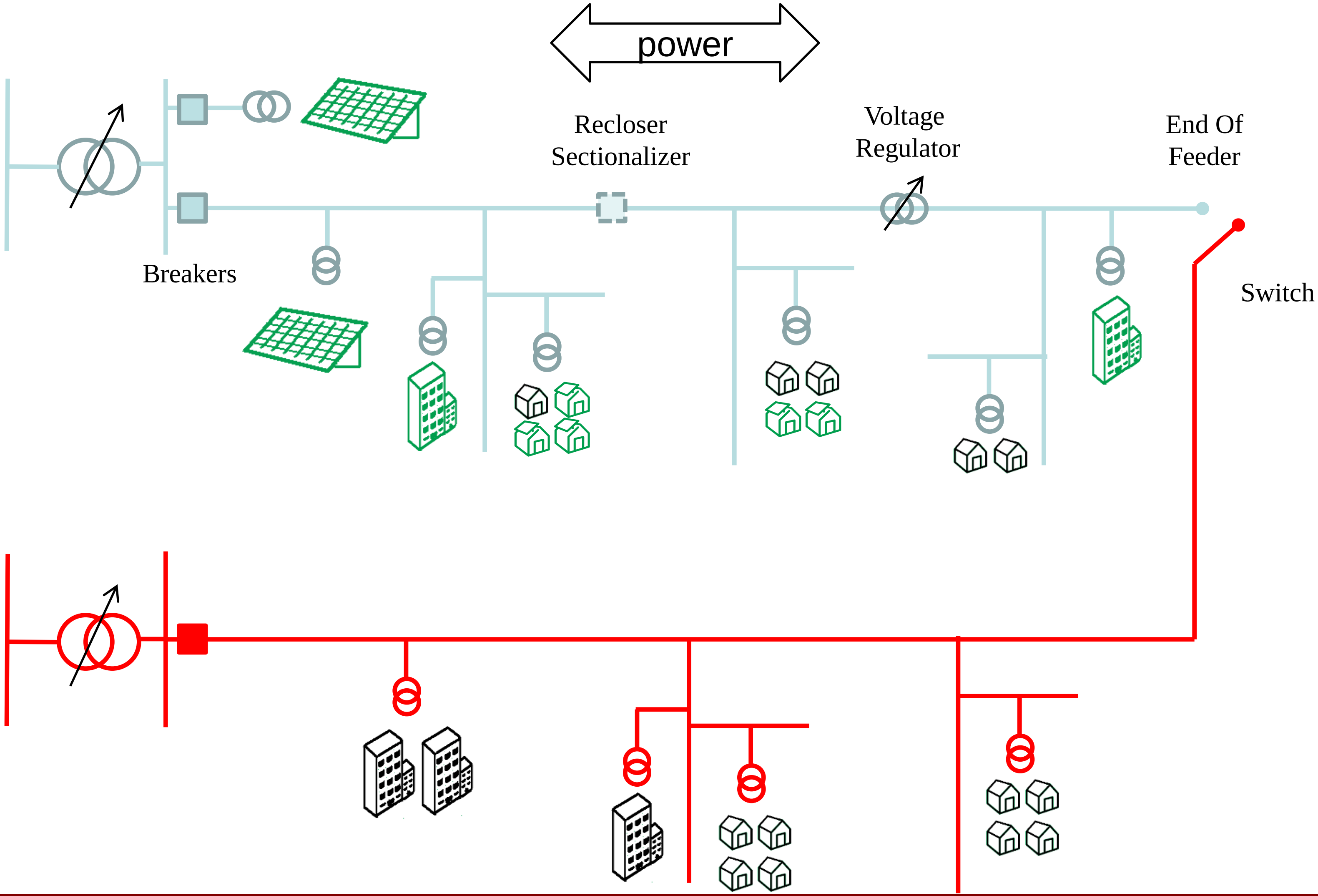
- **There are no <u>absolute</u> technical limits to PV penetration**
  - Cost is the issue, and this is system-specific



Distribution System



Distribution System with High Penetration PV

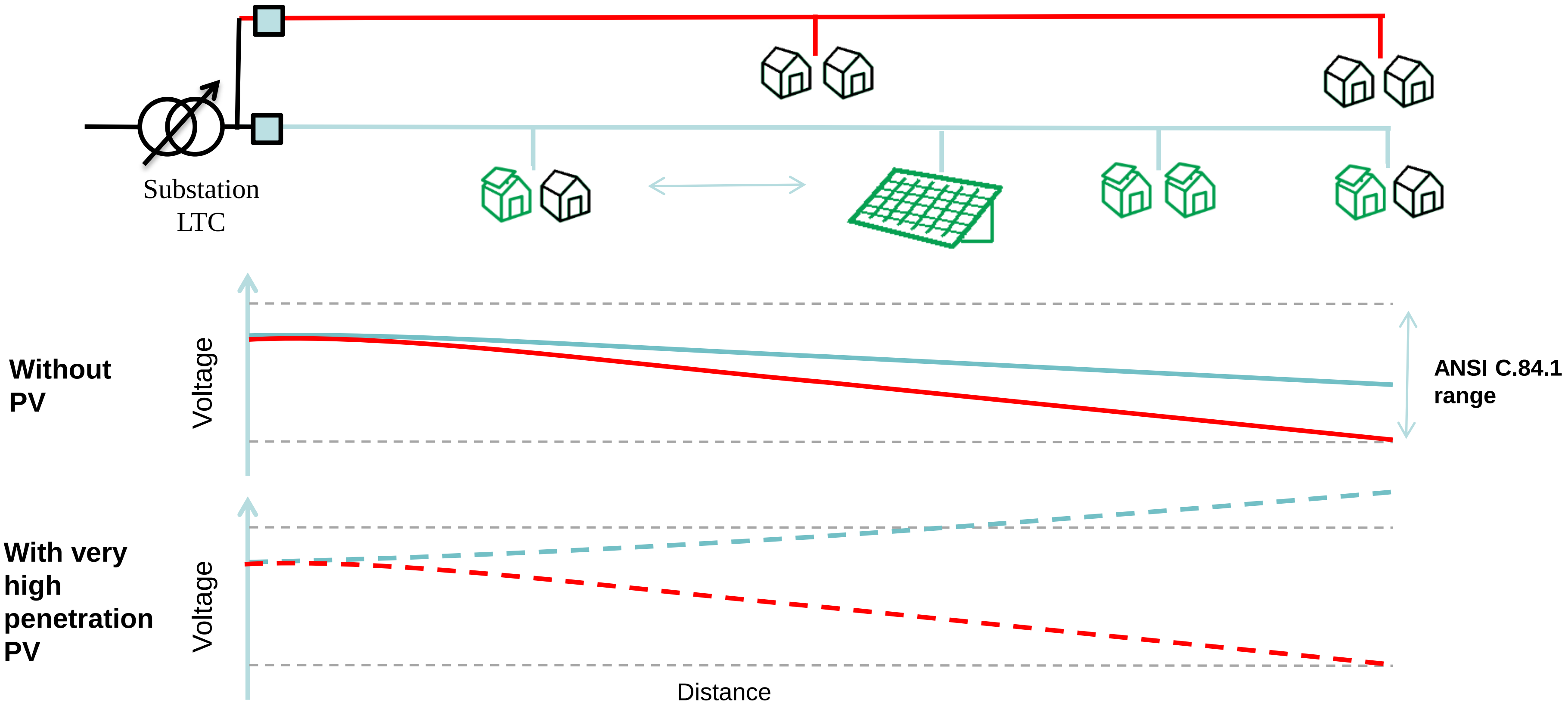


Distribution System Integration

- Voltage Regulation
  - Ability to maintain customer voltage within range
  - Wear-and-tear on voltage control equipment (e.g., tap operations) due to variable output
- Power Quality
  - Flicker, harmonics
- Protection
  - Performance of relays and other protection equipment
  - Risk of unintentional islanding
- System planning and operations
  - Feeder load switching, maintenance, outage management
  - Controllability and visibility of distributed resources
  - Possible impact on bulk system

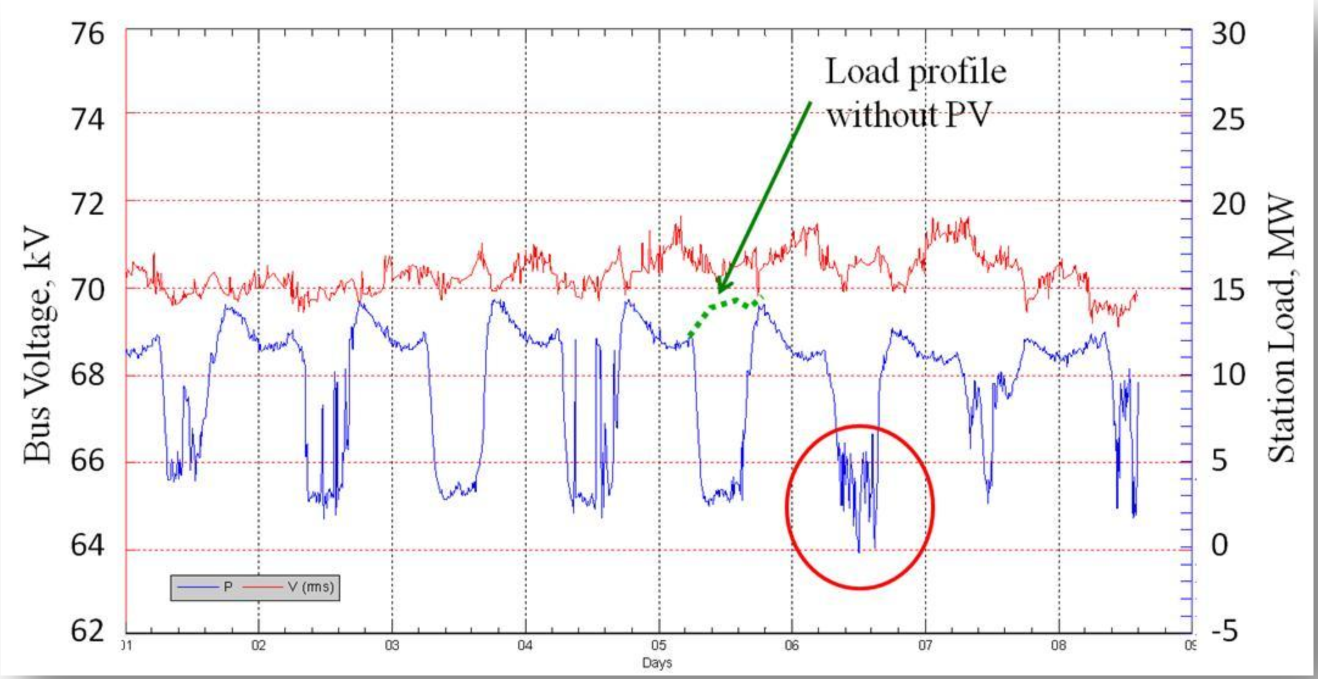
Voltage Regulation Issue

- High voltage at end of feeder
  - Most commonly encountered issue for high penetration PV
  - Worse on long feeders with PV at the end



Voltage Regulation Issue

- High penetration does not always lead to voltage issues
  - Short urban feeder
  - PV connected to the feeder head close to the substation
- Example below: PV is connected next to strong urban feeder head, station voltage does not change



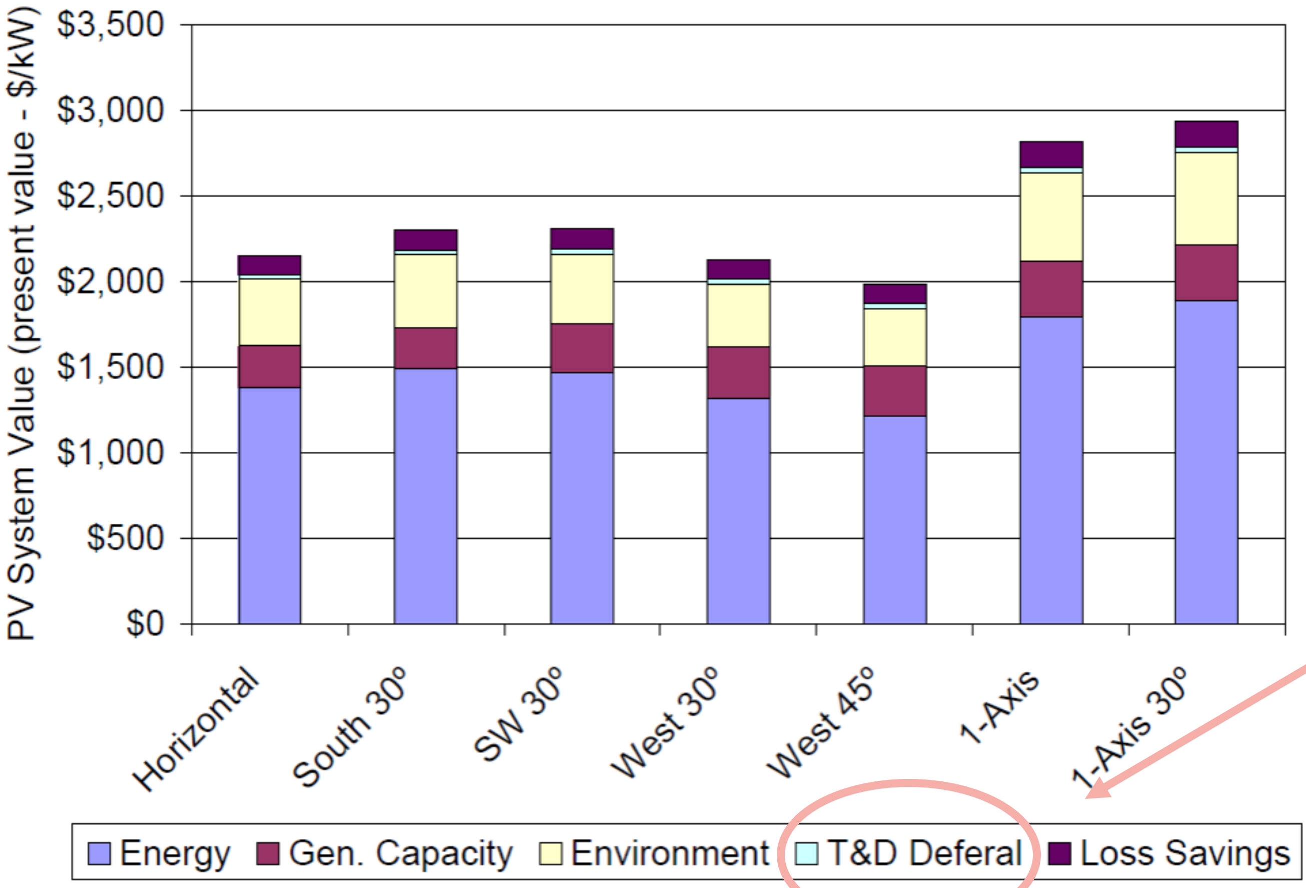
Voltage Impact Mitigation- Now and in the Future

- Examples of lower cost mitigation measures:
  - Upgrade fixed capacitor banks to switched banks.
  - Voltage regulation equipment updated with new voltage control set points.
- Examples of higher cost mitigation measures:
  - Interconnection generator power factor set to offset voltage rise.
  - Capacitors and Voltage regulation equipment added/removed from the distribution circuit
- ***Future:*** Allow PV smart inverters to manage the voltage at the point of interconnect. Not easy to do from a codes and standards perspective as established standards would need to be changed.

Studies on the System Benefits of PV

- Transmission and Distribution (T&D) deferral.
- Peak shaving with Storage
- Integration of PV and demand response programs

PV Benefits-Transmission and Distribution (T&D) Deferal

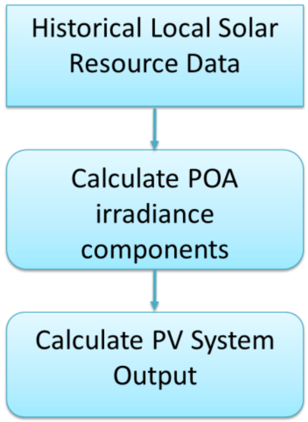


T&D Deferal is the smallest value and difficult to capture.

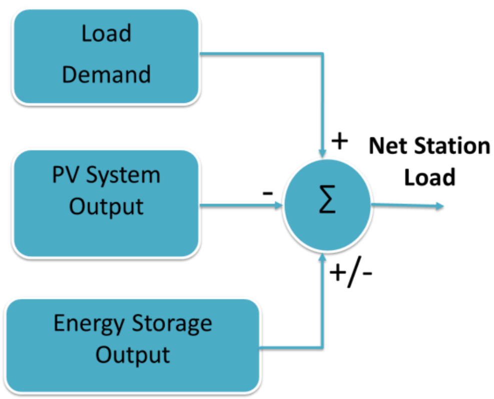
Figure ES-1. Present value for 15 MW of PV by configuration ($/kW-AC).

Source: The Value of Distributed Photovoltaics to Austin Energy and the City of Austin. Prepared by Clean Power Research, L.L.C. March 17, 2006

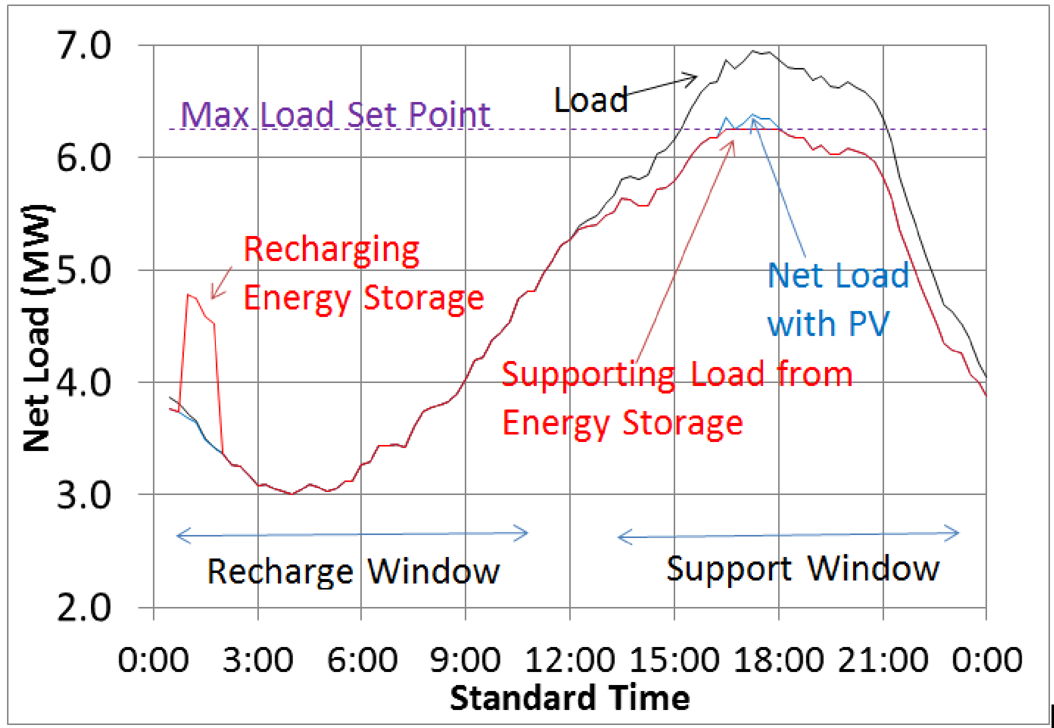
Peak shaving with Storage



Estimation of PV array Output

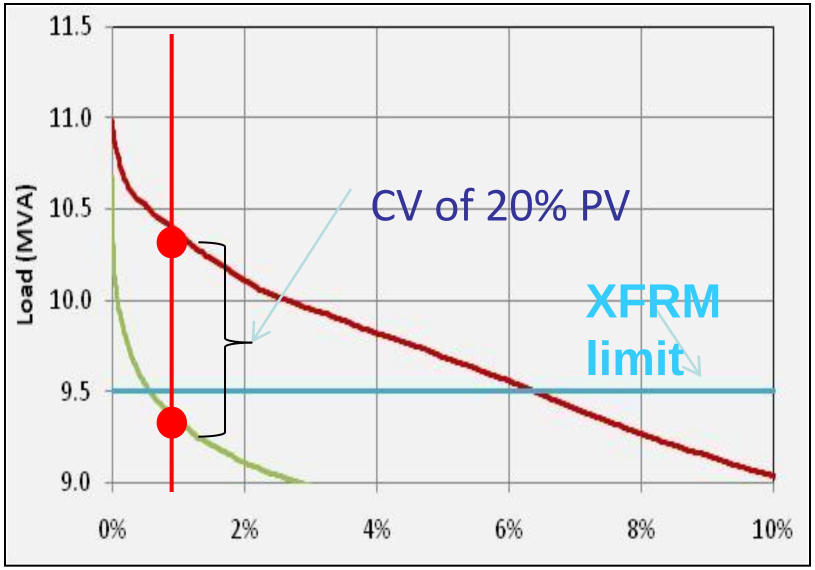


Simulation Model



Source: Transmission and Distribution Deferment Using PV and Energy Storage. IEEE PV Specialist Conference 2011. Mark Ralph, Abraham Ellis, Dan Borneo, Garth Corey from Sandia National Laboratories, Sara Baldwin from Utah Clean Energy.

Deferal value of PV



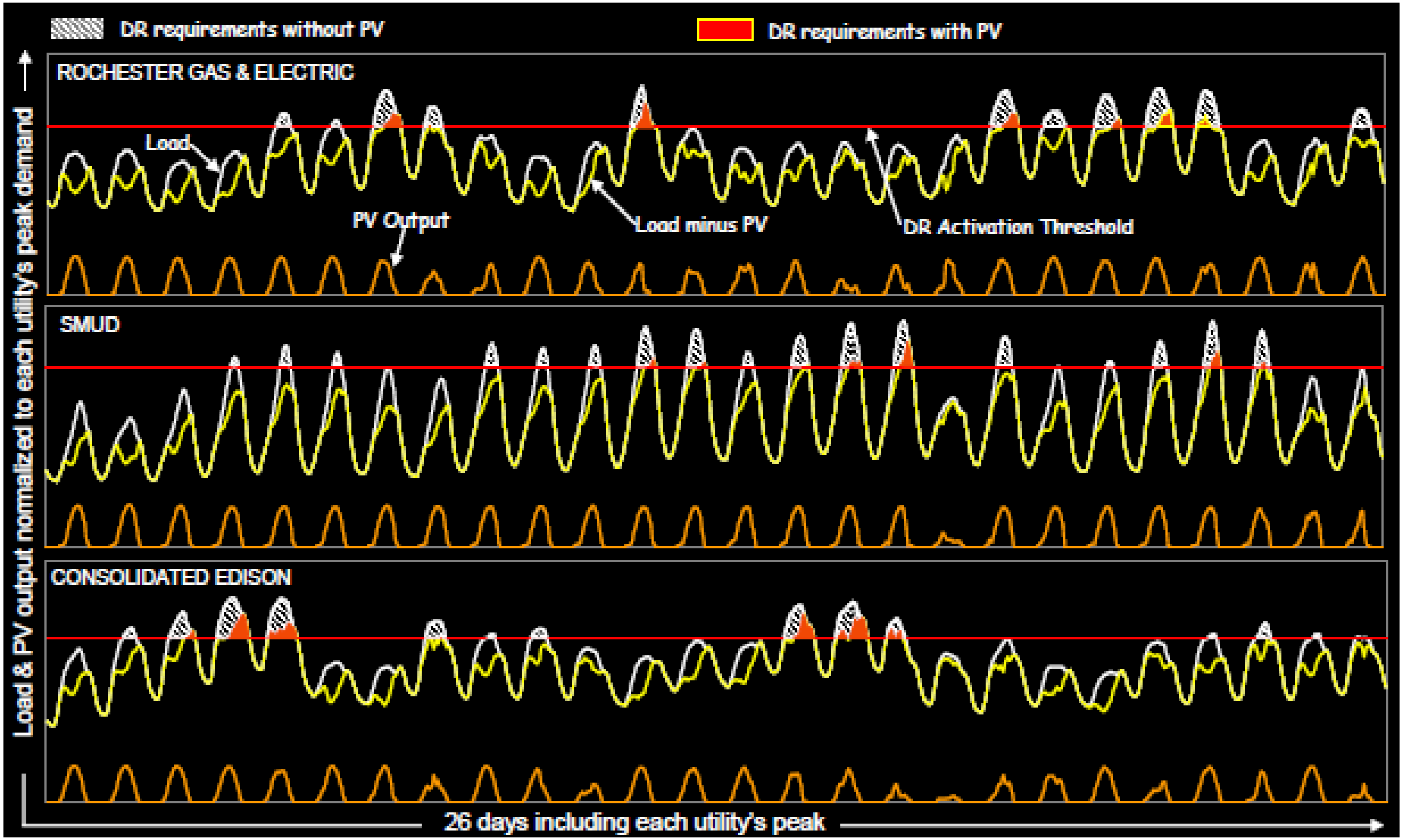
Load Duration Curve

The method for estimating the deferral value involves analysis of a full year of load data. The red curve in the figure above shows when the load on the substation transformer is projected to exceed the transformer rating.

The green curve shows the net substation load with 20% penetration of PV. The Capacity Value (CV) of the PV can be seen from the downward shift in the load duration curve of the substation with PV.

The number of hours of exposure is much less!

Integration of PV and demand response programs



Source: Integration of PV into Demand Response Programs.
Richard Perez, et al. Under NREL subcontract AEK-5-55057-01

Conclusions

- The process of interconnecting Solar PV to the electric power system is addressed by both rule and standards to insure a safe and reliable Grid.
- There are many examples of high penetration PV in the USA and elsewhere, where impacts have been minor. However, high penetration in some distribution circuits could cause problems.
- As greater penetrations of solar occur in specific locations, a robust screening and system impact study process will identify which PV systems cause grid impacts and then determine the mitigation measures and associated costs to interconnect.