Distribution & transmission grid planning is key to increasing distributed solar PV generation

Robert Gustafson 02.13.17

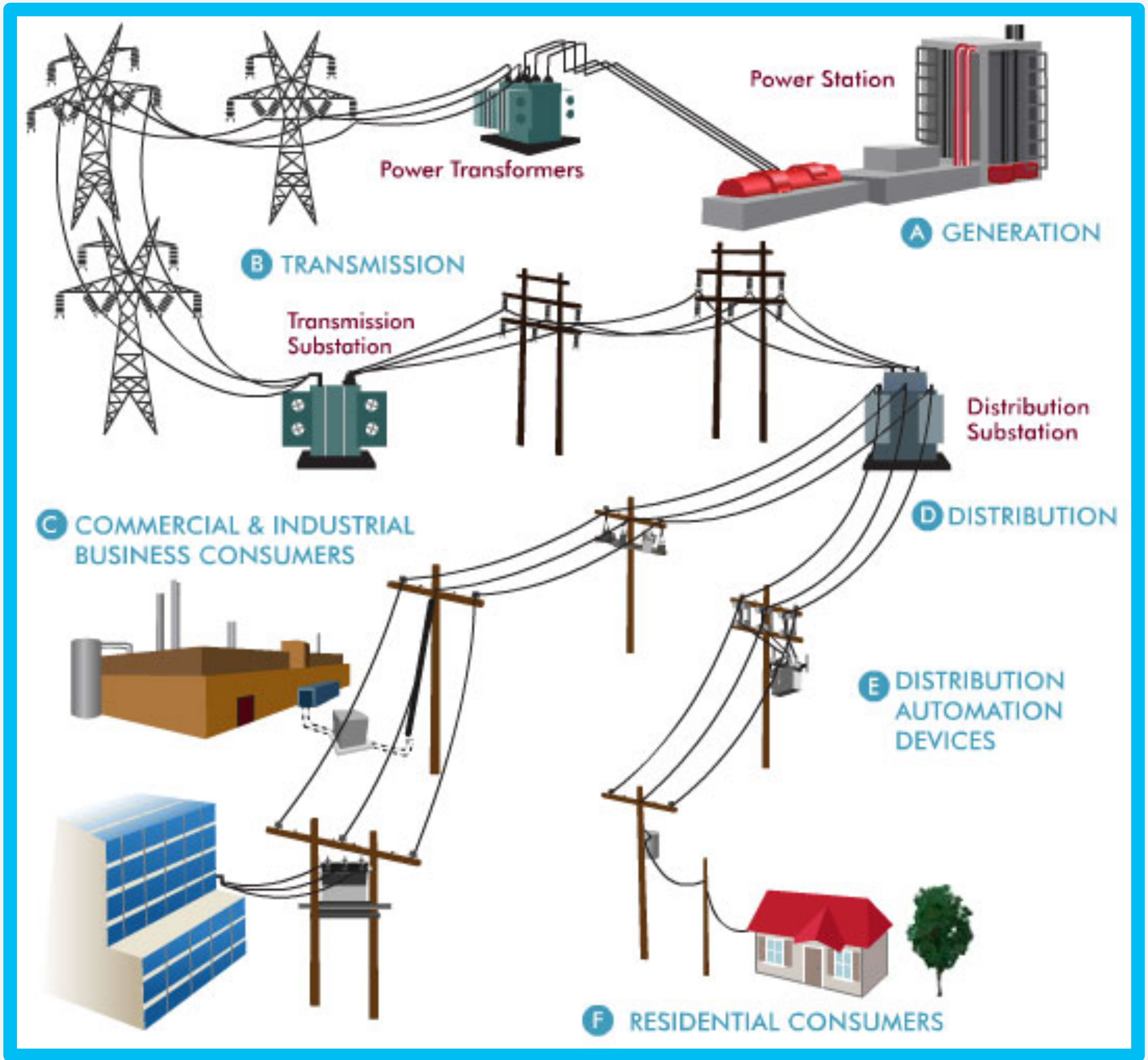
Transmission power lines step voltages down at **transmission substations** and transmit the lower voltage on **subtransmission** power lines to **distribution substations**

This is a utility pole-mounted distribution transformer

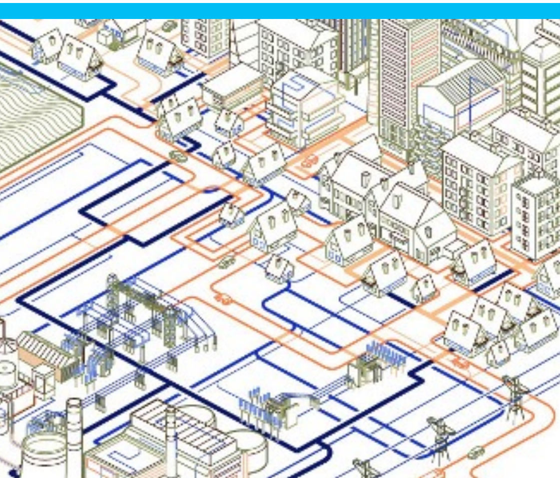
It converts the **primary** (~35 kV) to the **secondary** (120 V) distribution line

Vocab: electrical bushing, transformer, fuse, service drop

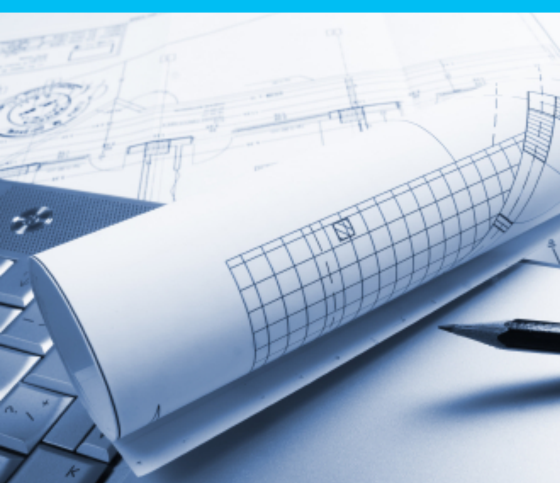
This has been the model for the last **100** years



Distributed solar PV (DSPV) will reduce greenhouse gases, provide grid resiliency, and address underserved customers



Incorporating DSPV will be hard because of the number of involved parties, magnitude of the system, and complex financing



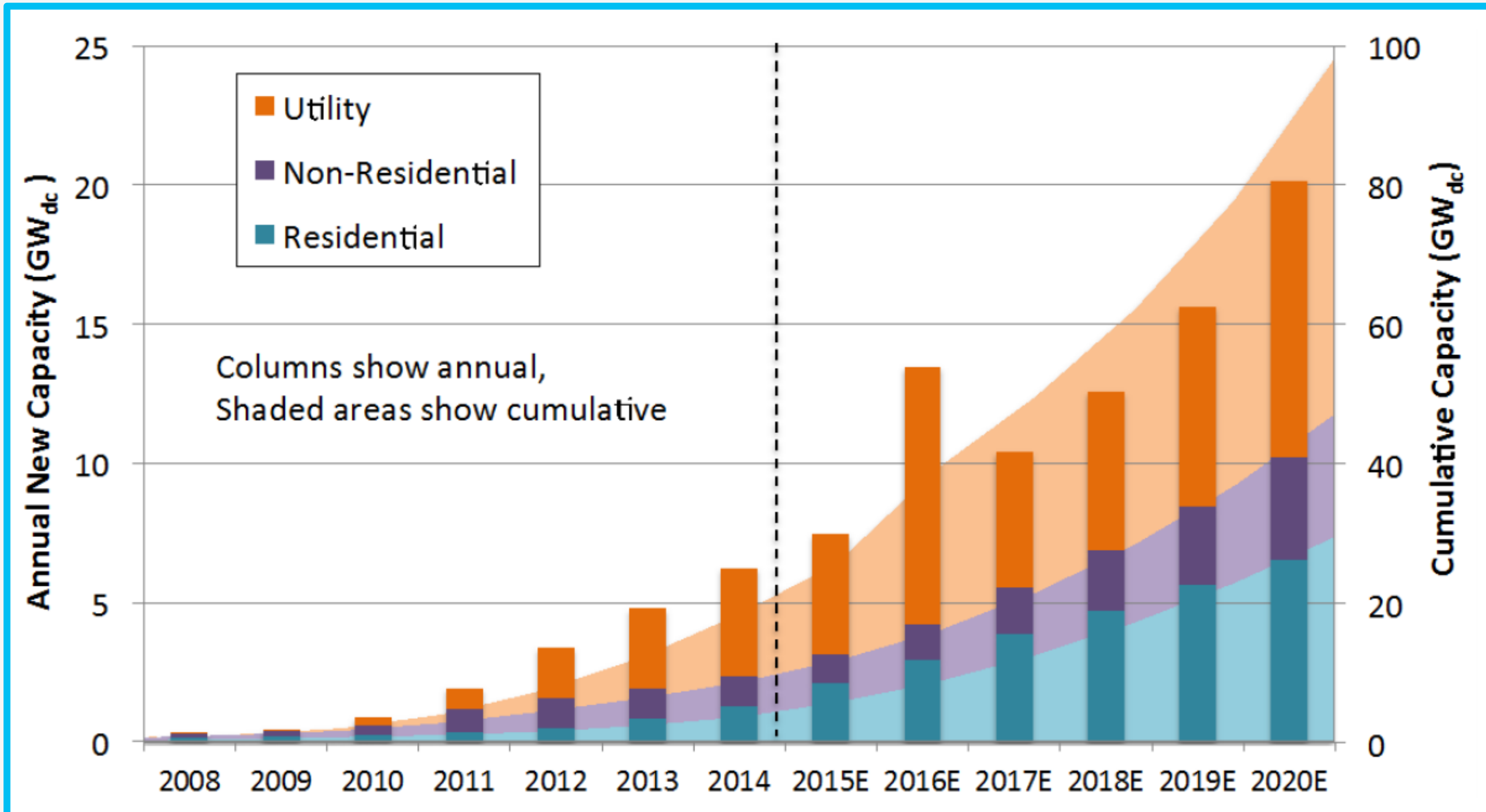
Distribution & transmission grid planning is key to increasing DSPV

Power system operators maintain a reliable grid by constantly balancing consumer demand for energy with generation from a variety of resources.

Table 2. Types of Grid Flexibility

Type	Description
Generator flexibility	Ability of conventional generation to vary output over various time scales
Storage flexibility	Ability to store energy during periods of low demand and release that energy during periods of high demand
Geographic flexibility	Ability to use transmission to share energy and capacity across multiple regions
Load flexibility	Ability to vary electricity demand in response to grid conditions

From 2010 through 2015, DSPV increased sixfold



(Greetech Media Research 2015)

Case Study: In 2014, solar energy contributed 6% of electricity demand in California. Projections estimate this could approach 20% by 2020[3]

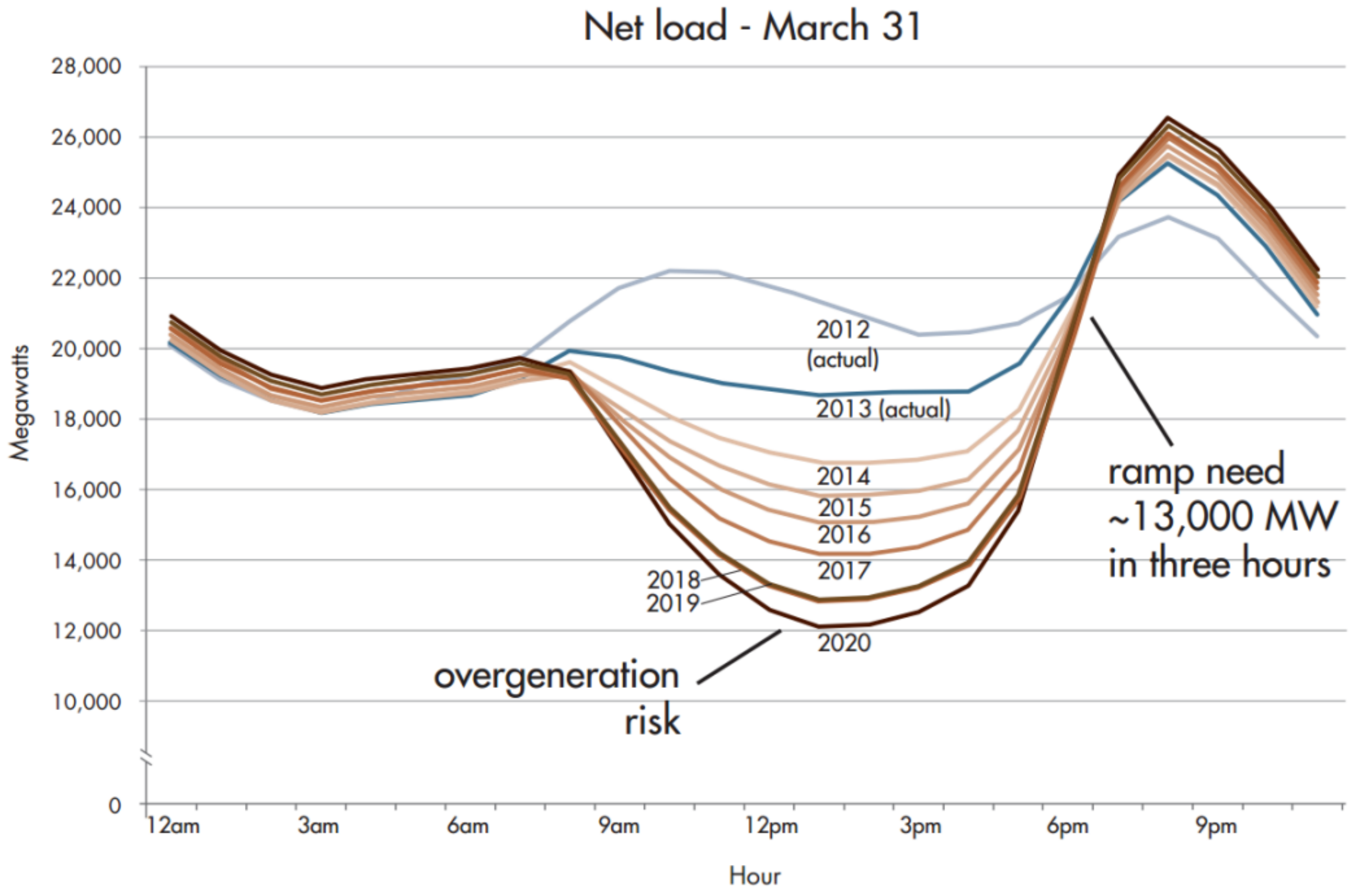


Figure 1. The CAISO duck chart

Source: CAISO 2013

Using curtailment to maintain grid stability undercuts the economics of PV

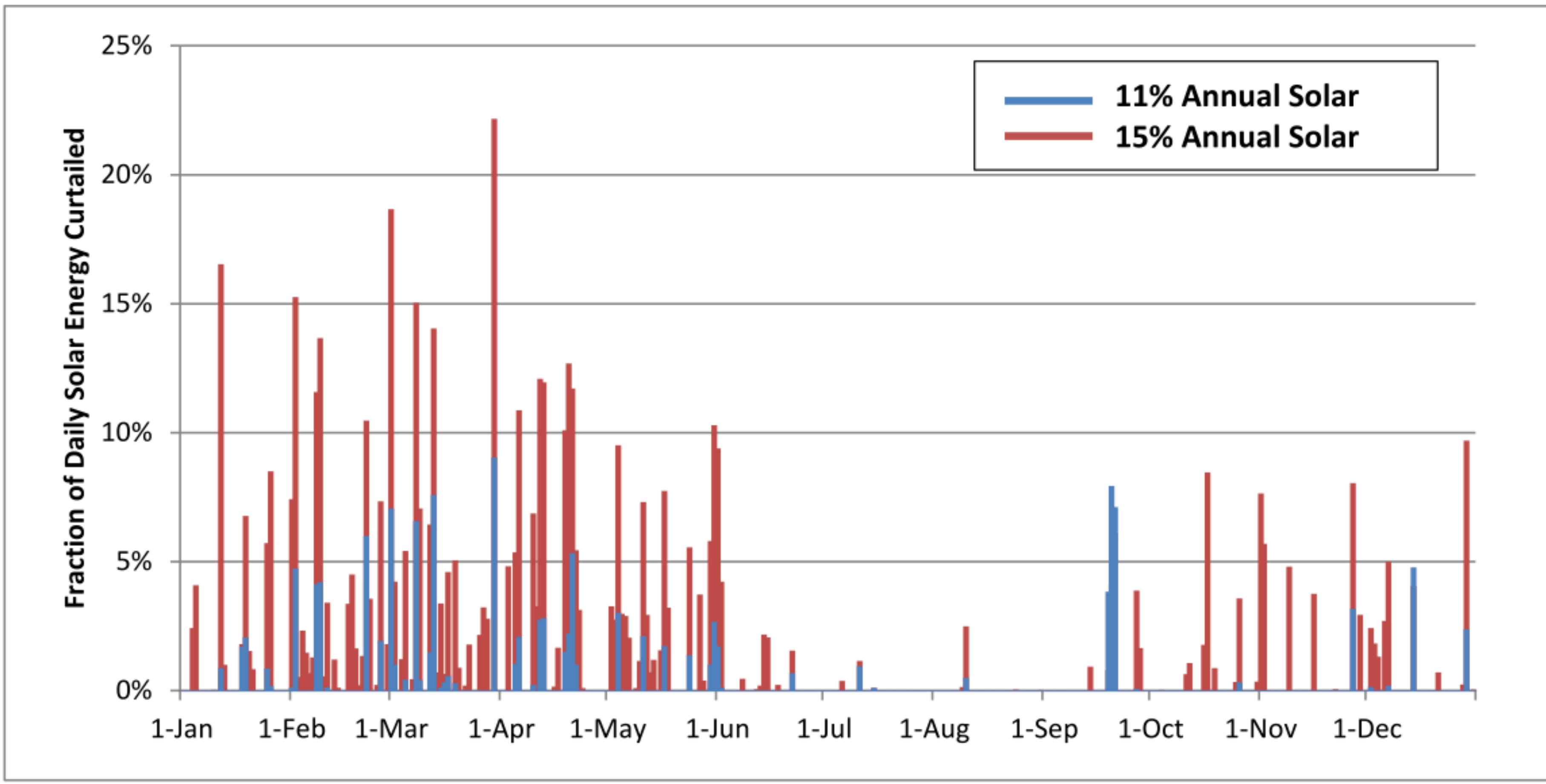


Figure 5. Fraction of daily solar energy potential curtailed in a scenario with 11% and 15% annual solar considering operational constraints in a system with limited grid flexibility

Curtailment increase as solar penetration grows

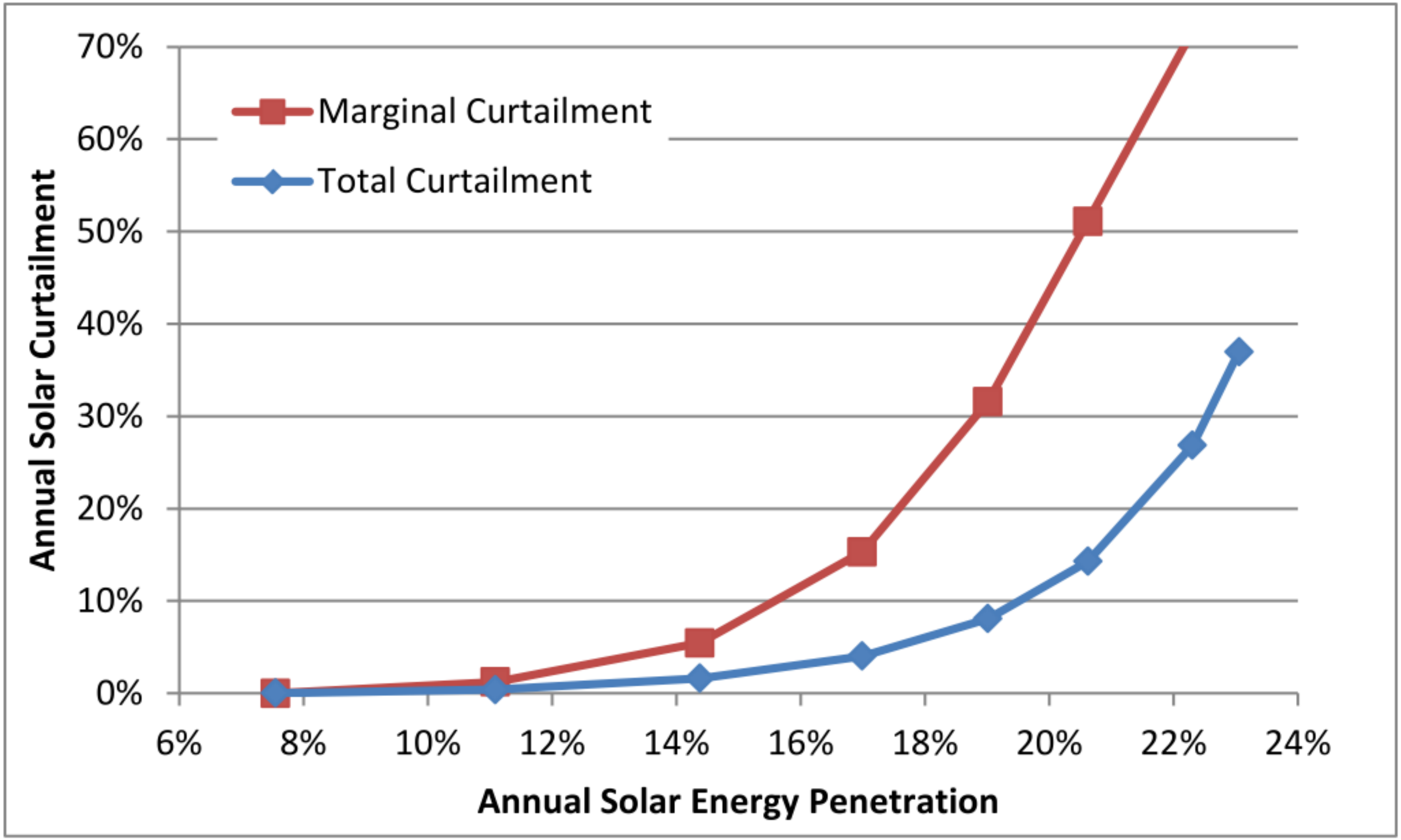
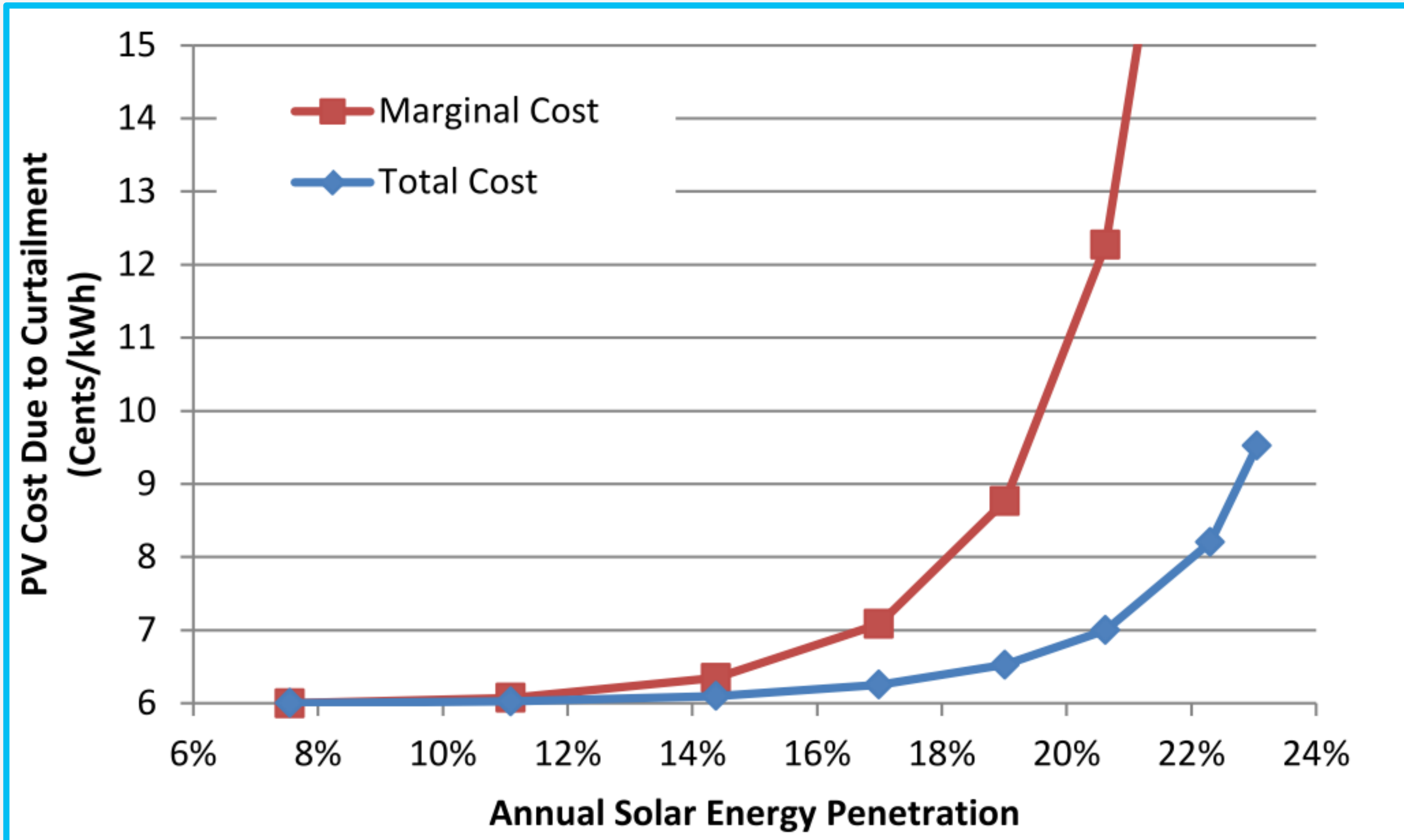
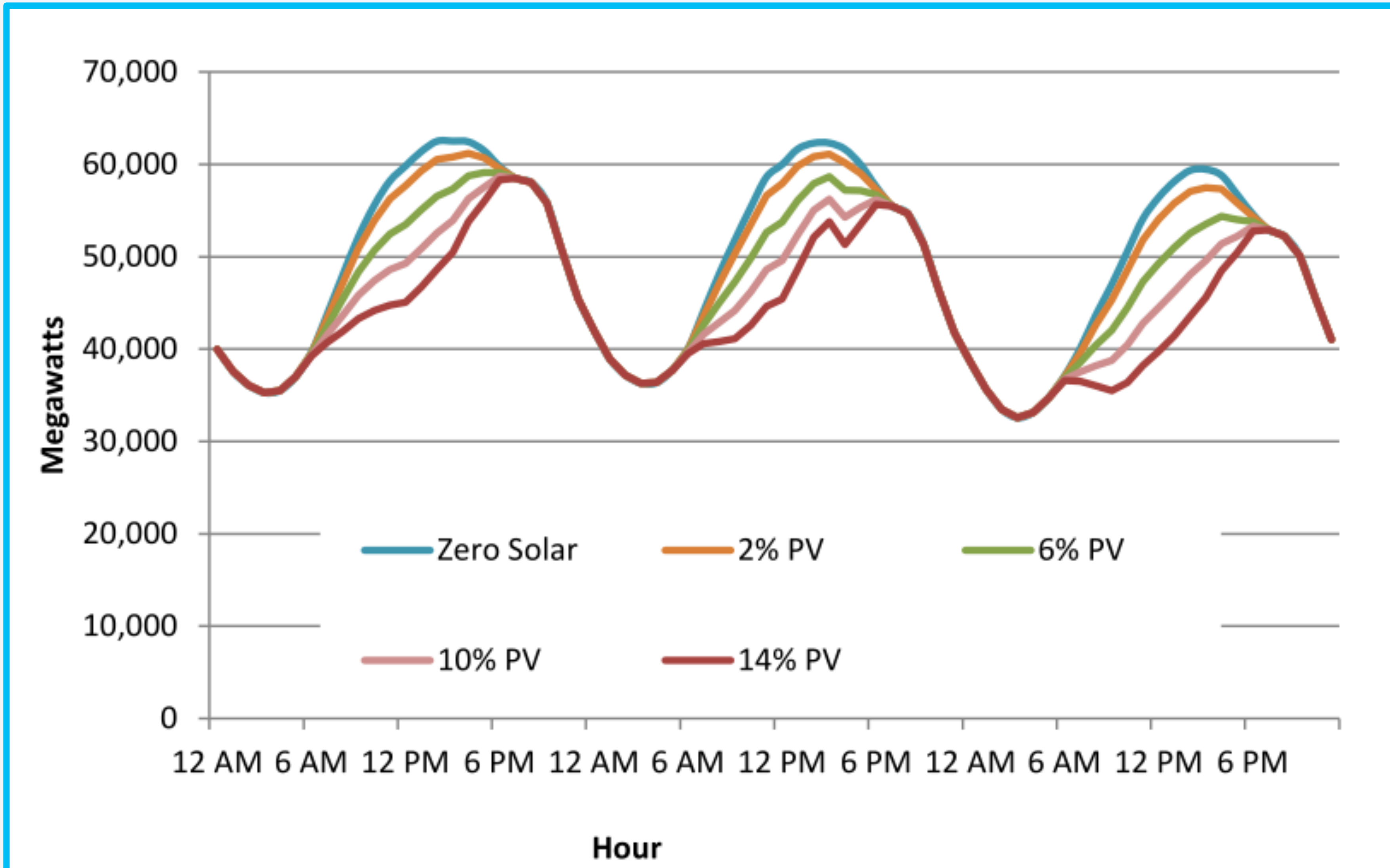


Figure 6. Annual marginal and total solar curtailment due to overgeneration under increasing penetration of PV in California in a system with limited grid flexibility

LCOE increases as curtailment increases



Marginal capacity credit is negative



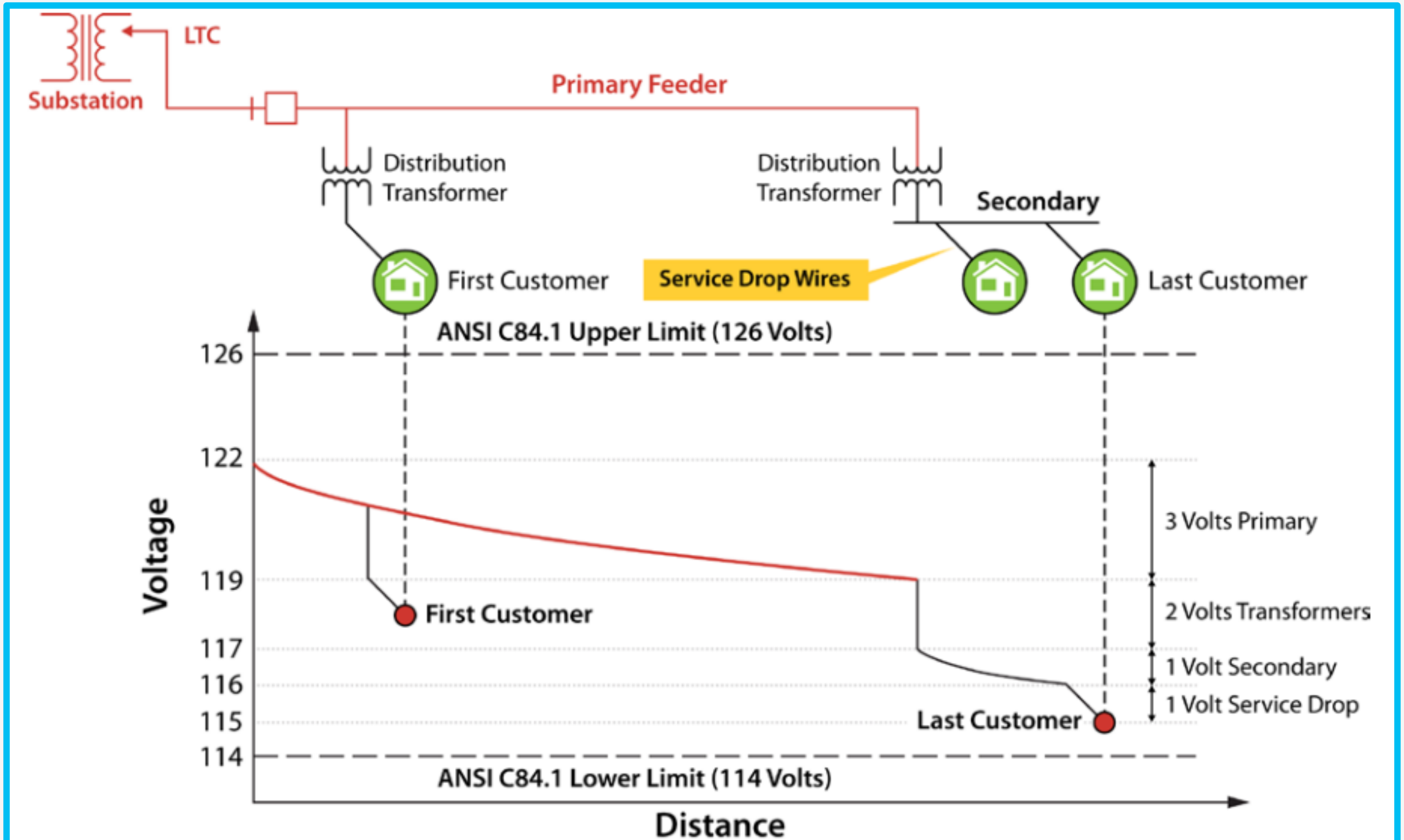
Load and net load profiles for increasing levels of PV in California, July 27–29

Utilities surveyed stated these as their primary concerns

- Voltage regulation
- Reverse power flow
- Protection coordination
- Increased duty on line regulation
- Unintentional islanding
- Secondary networks
- Variability due to clouds
- Capacitor switching

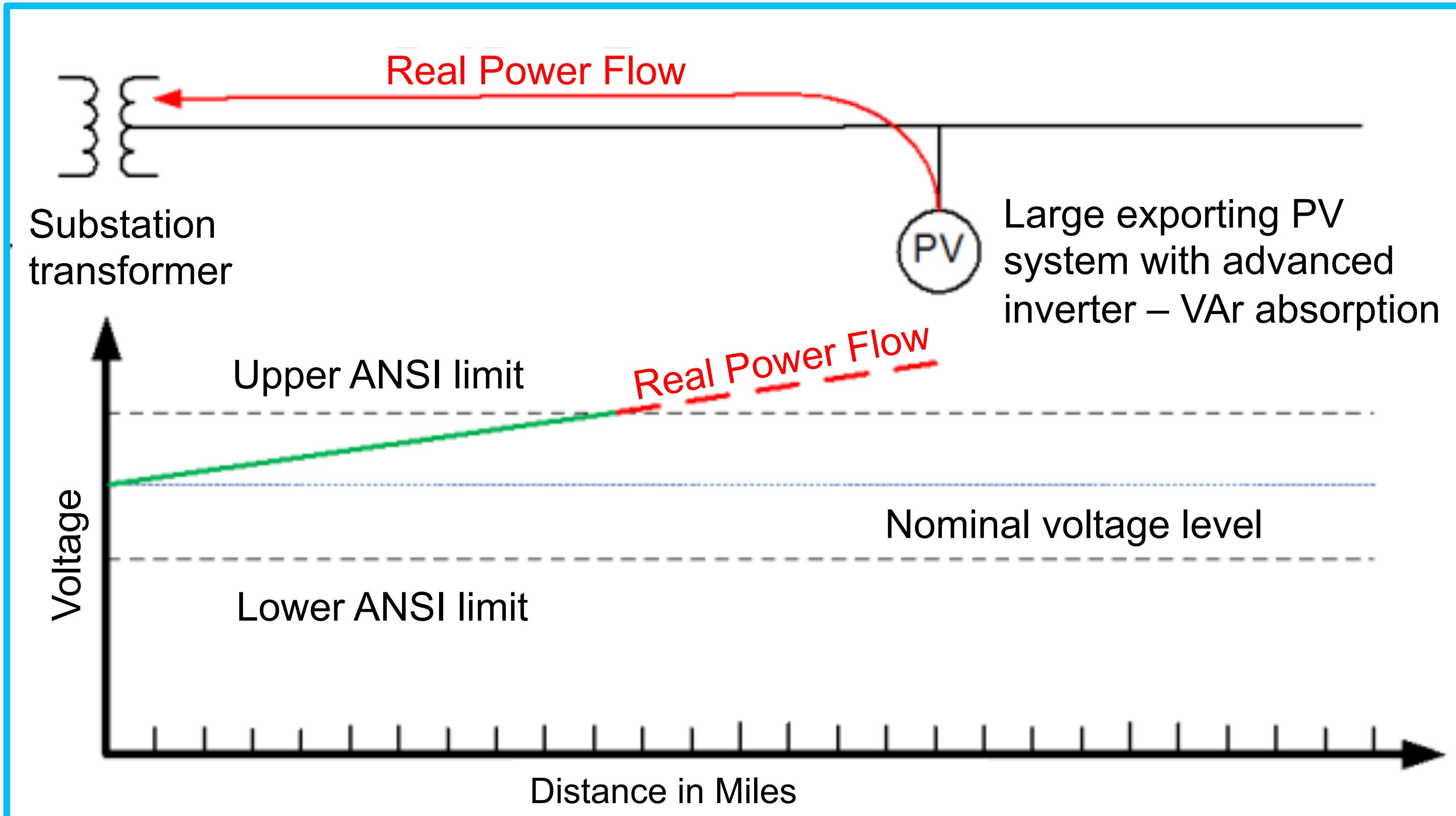
Voltage regulation

Utilities are required to maintain the voltage within ±5% of the nominal value (ANSI 2011)



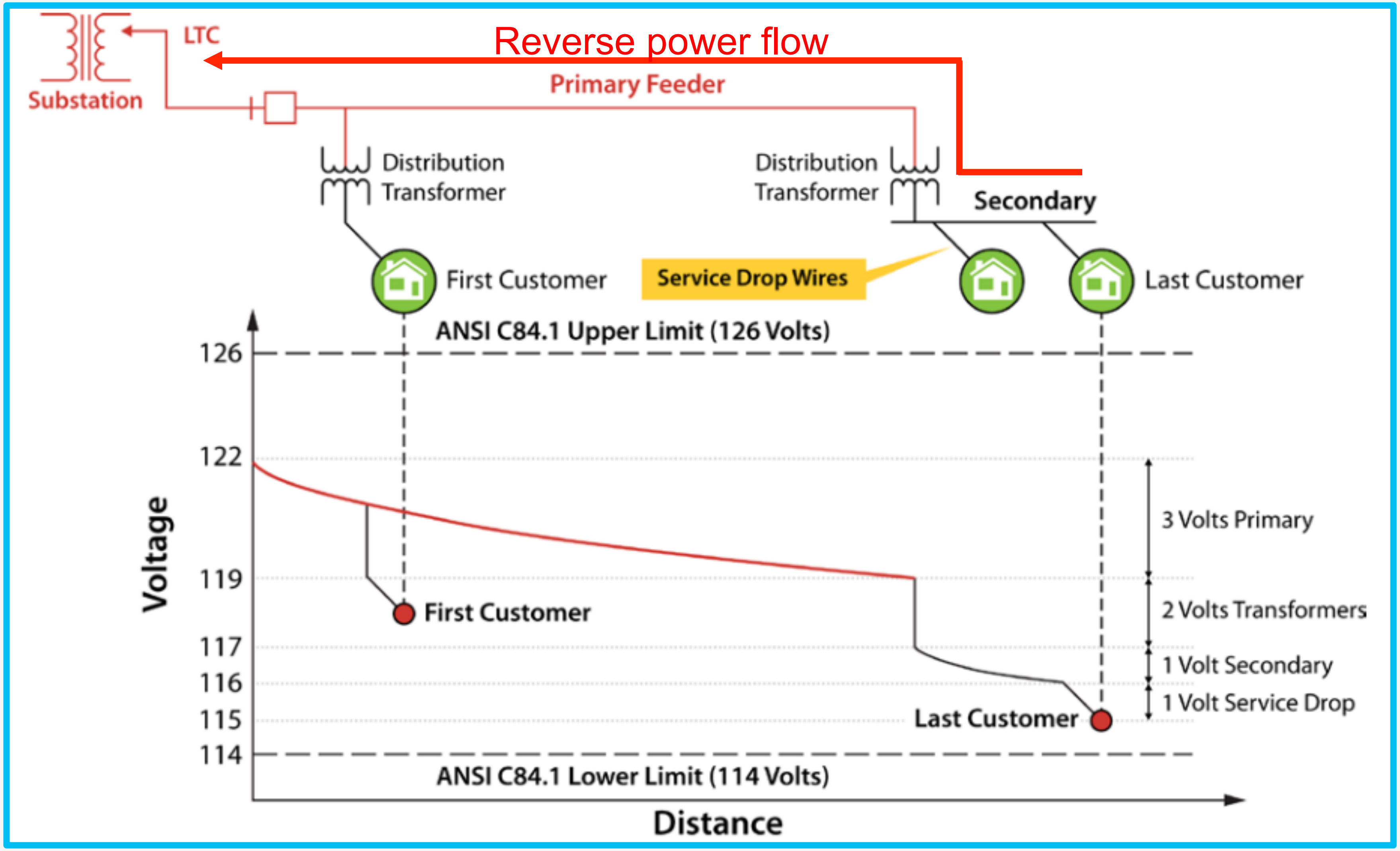
Voltage regulation

Unregulated PV generation can locally drive voltages above the standard limit



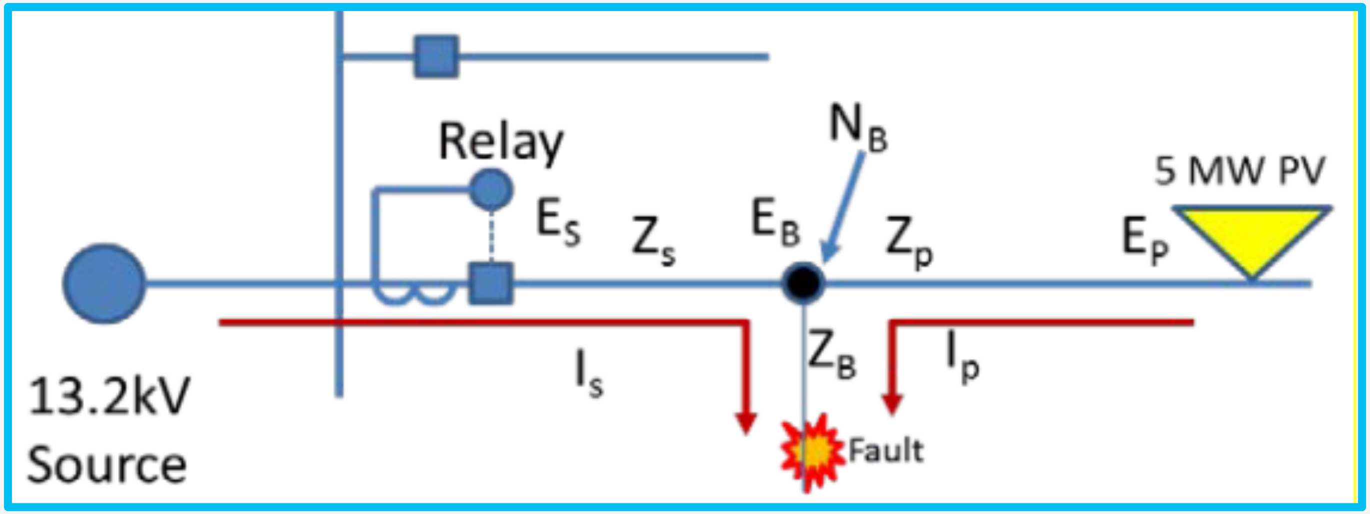
Reverse Power Flow

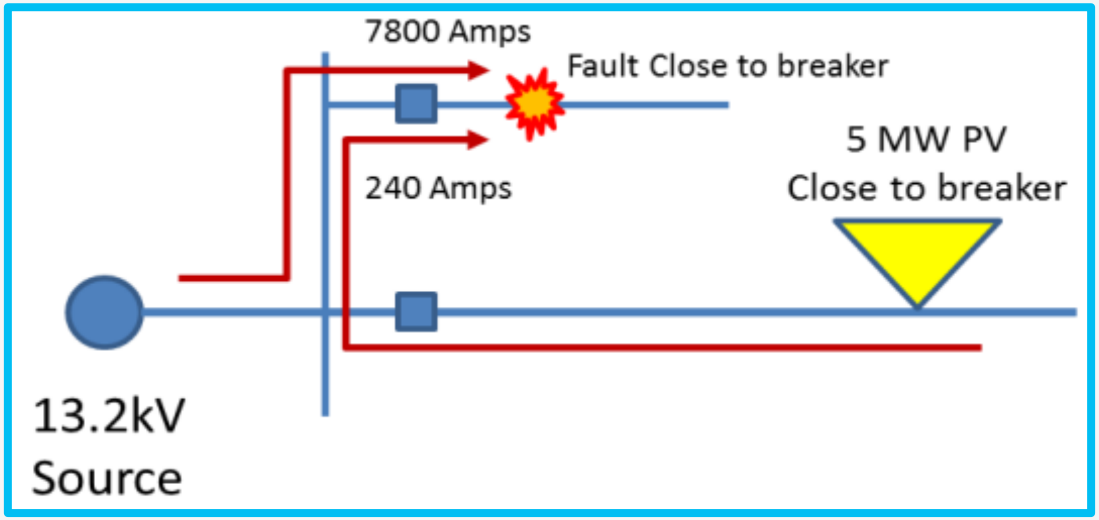
Power can flow back through distribution transformers onto the transmission line, other feeders



Protection coordination

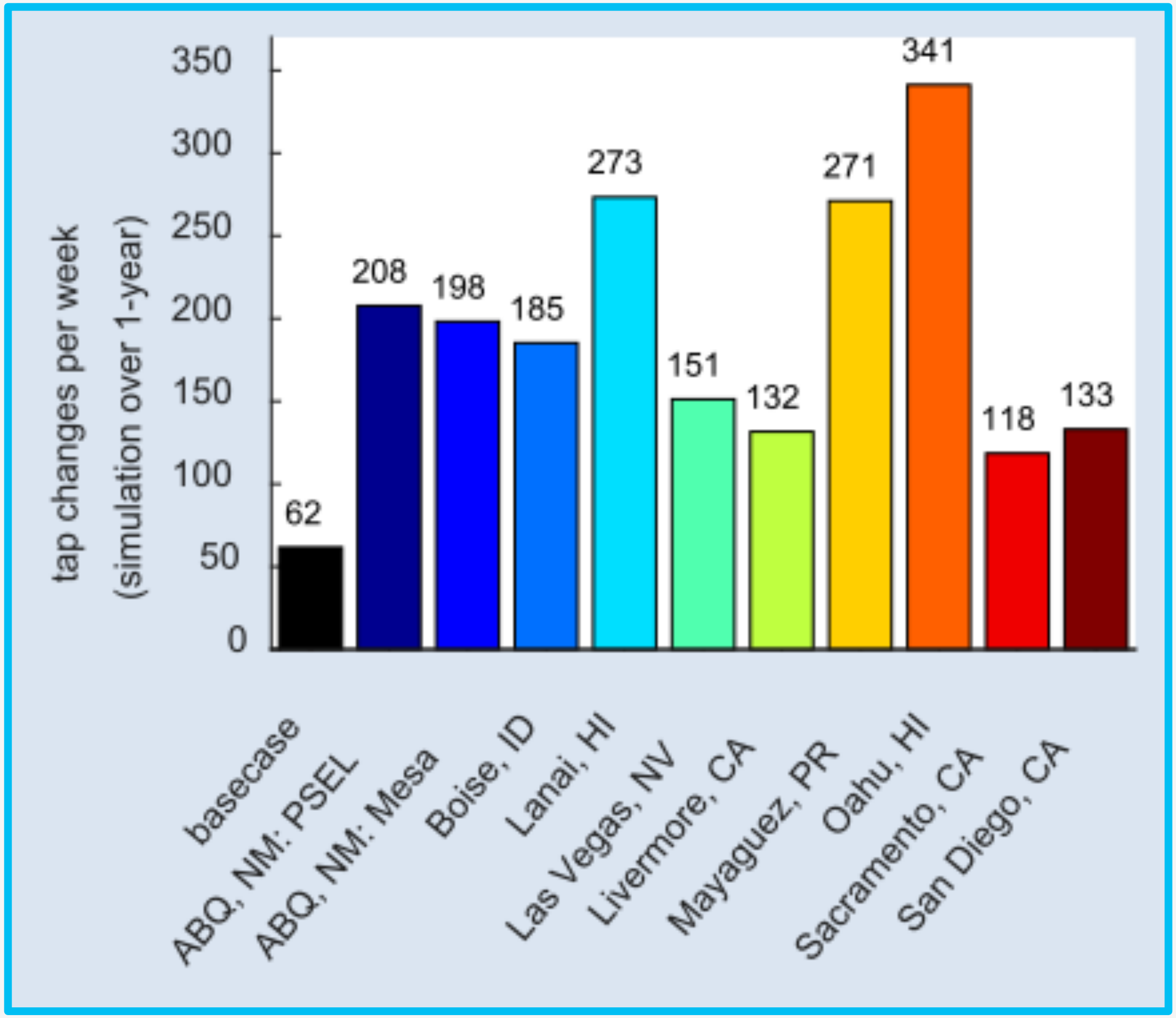
Additional current through a fault can raise the voltage at the fault to fool the relay circuit protector





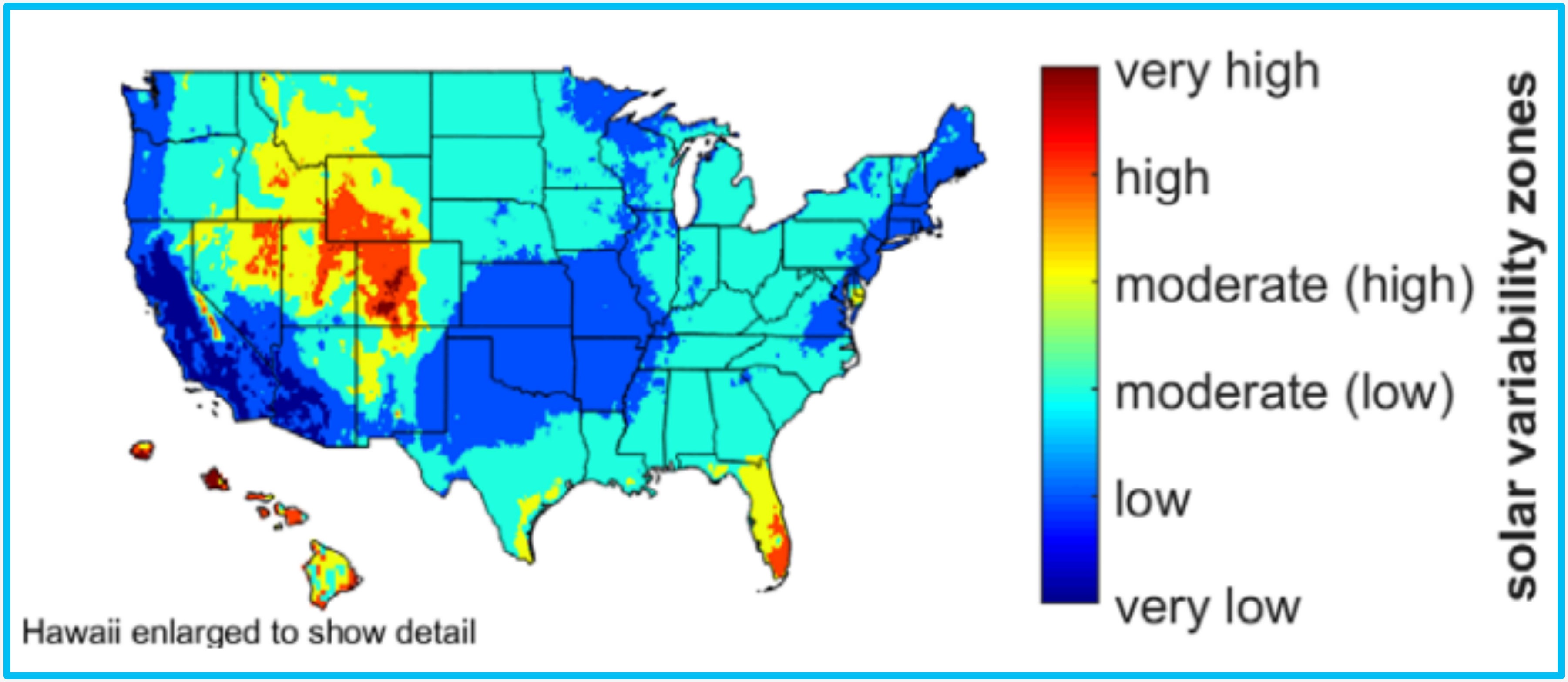
Increased duty on line regulation

Tap-changing line regulators and capacitors may wear earlier from excessive operation



Variability due to clouds

Cloud-driven variability can have a slow (seconds) or long (days) timescale



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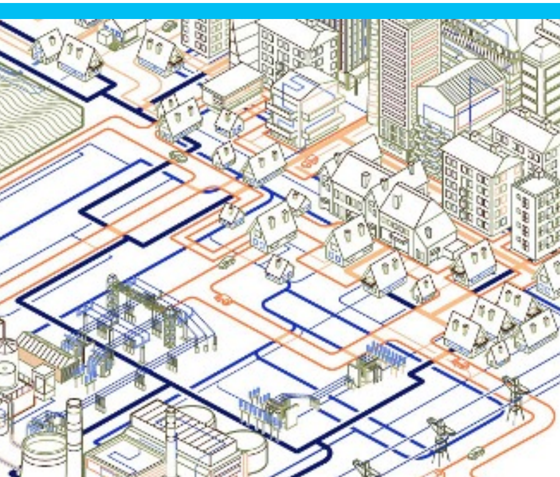

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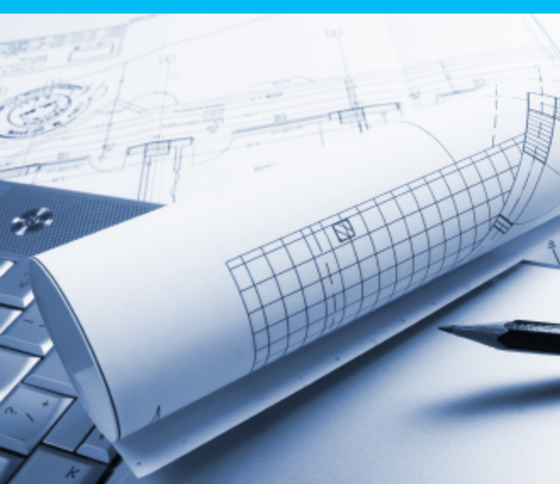
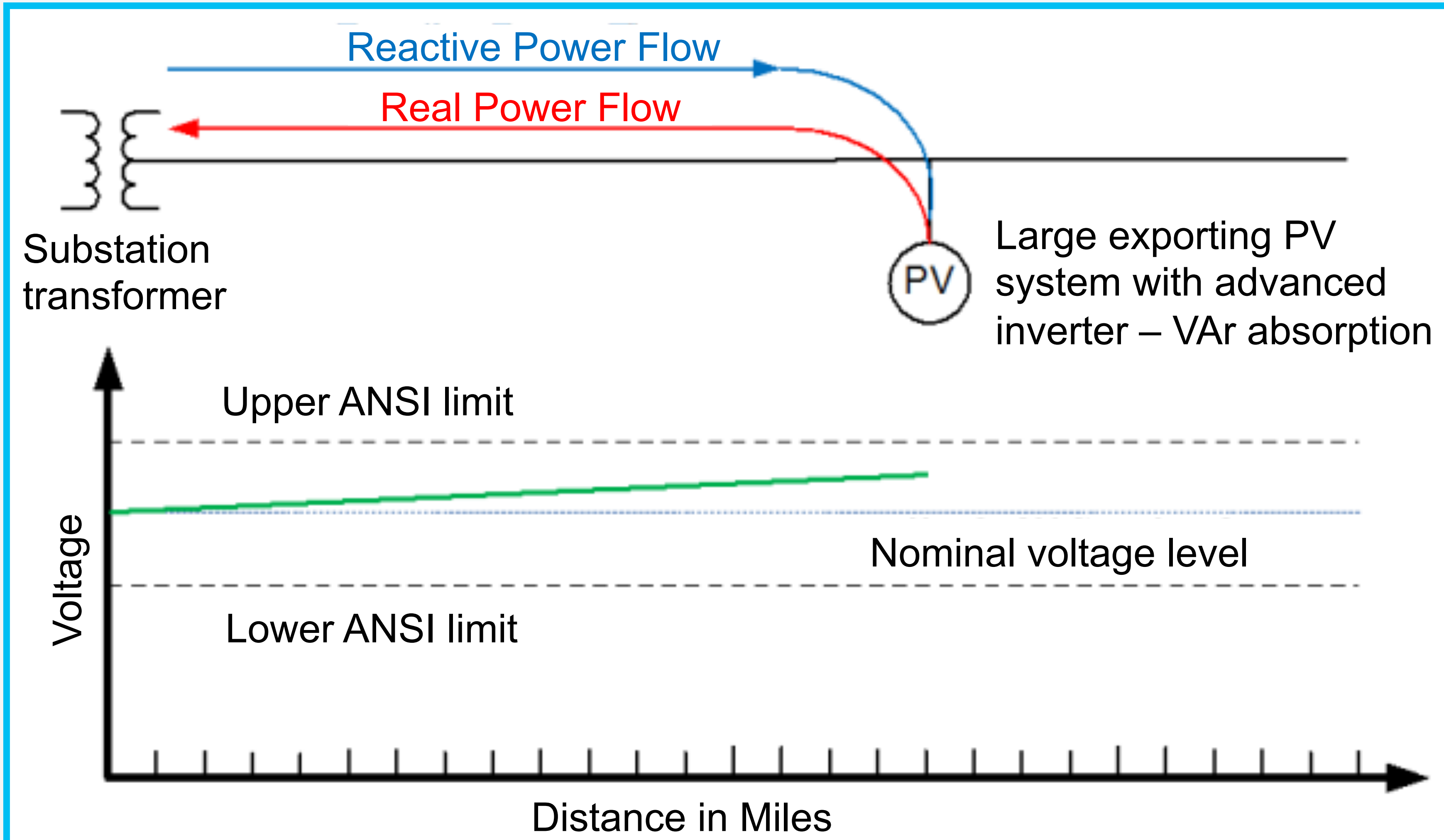


Distribution & transmission grid planning is key to increasing DSPV

Advanced inverters can mitigate voltage-related issues and that 25–100% more PV can be accommodated



Models of the hosting capacity show a 1.5-3x increase when using advanced inverters

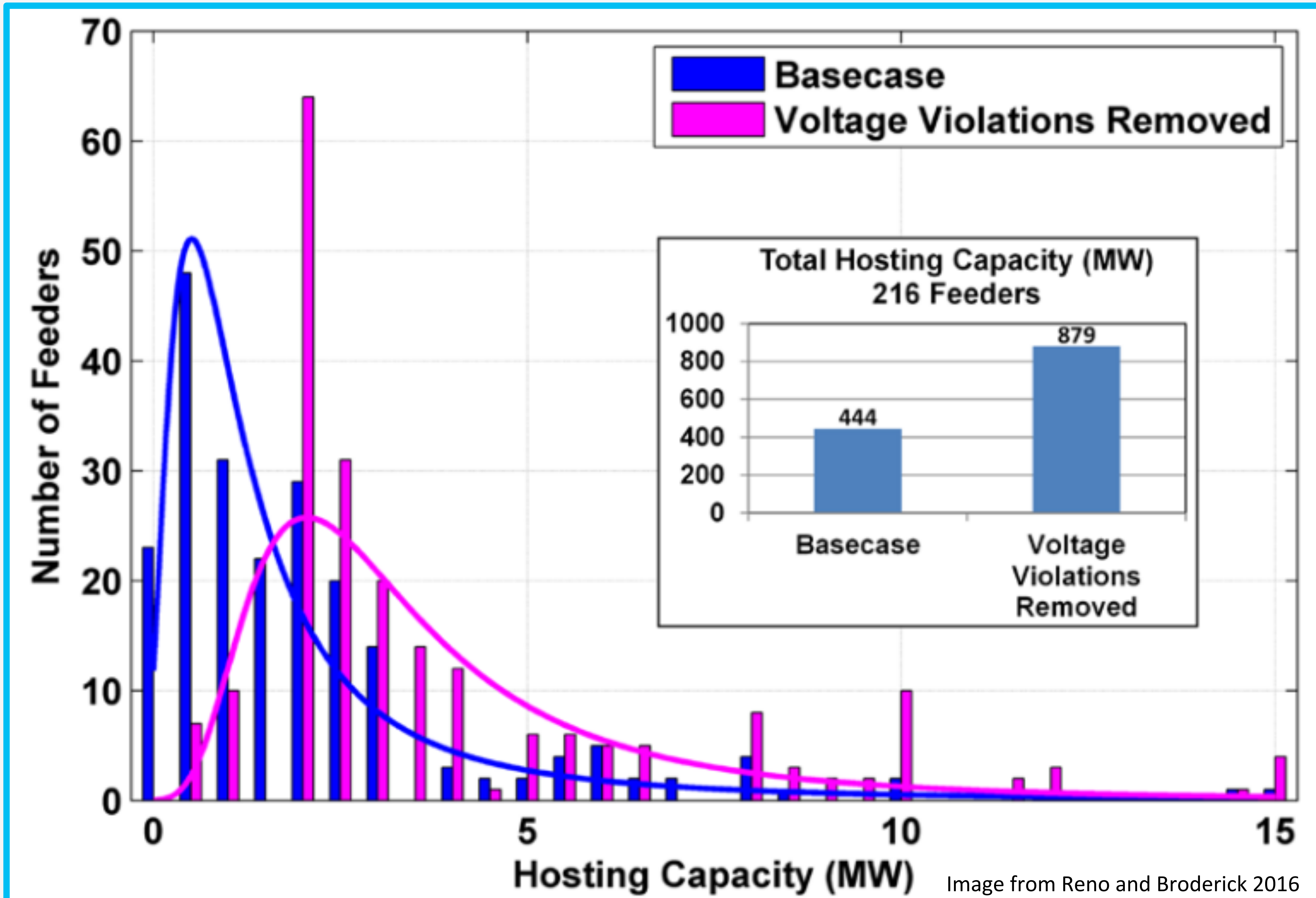
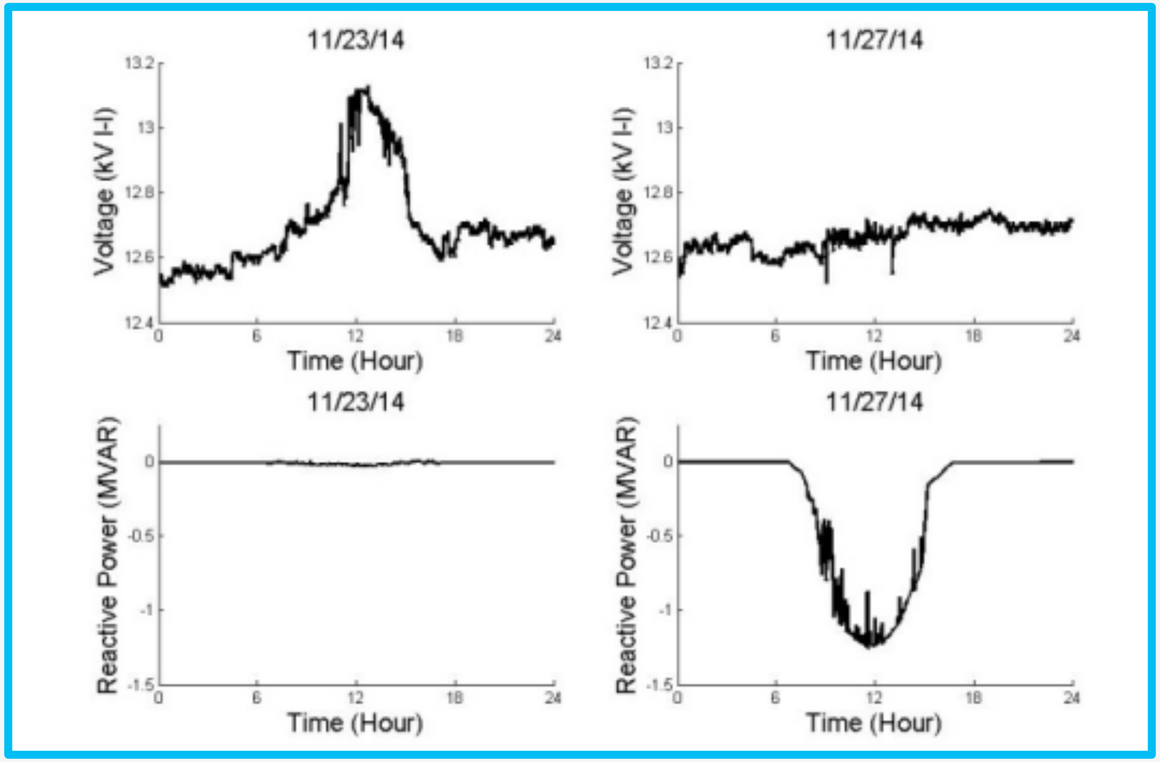


Image from Reno and Broderick 2016

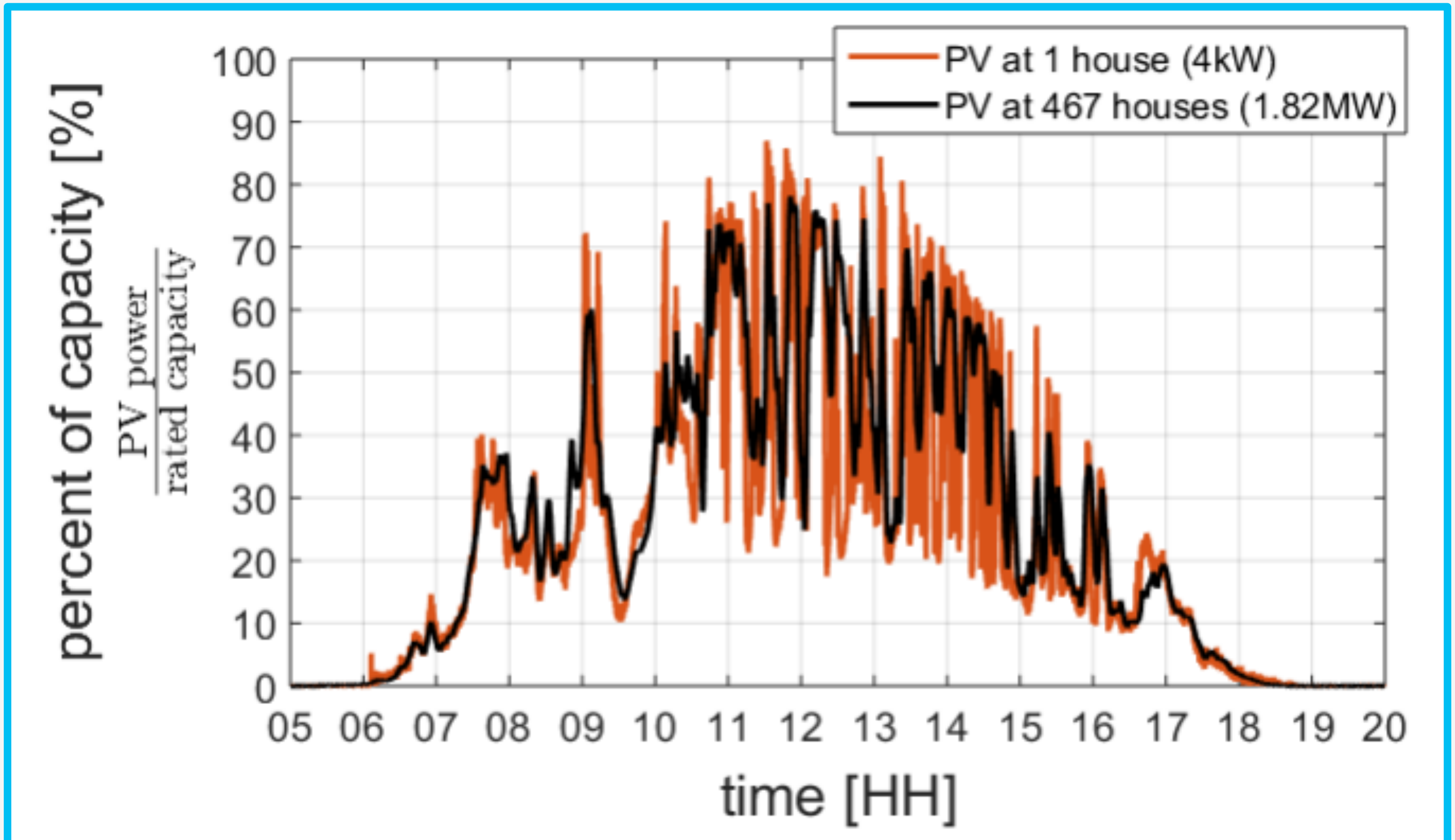
Case Study: Southern California Edison's High-Penetration Photovoltaic Project(1)

The impetus for this project was the approval of Southern California Edison's request to the California Public Utilities Commission to install 500 MW of utility-scale rooftop PV within their distribution system footprint. Starting in 2009, this resulted in a number of distribution circuits that installed very high penetrations of PV in predominantly rooftop systems placed on the flat roofs of large industrial warehouses. These systems were typically sized between



1 MW and 5 MW. NREL partnered with Southern California Edison to study the distribution system impacts of PV integration on these high penetration circuits and to develop, test, and demonstrate the mitigation of these impacts using advanced PV inverter functionality.

Adding together geographically spaced DSPV can smooth out cloud and irradiance driven variability



Stochastic modeling demonstrates the importance of location of DSPV within a feeder network for hosting capacity

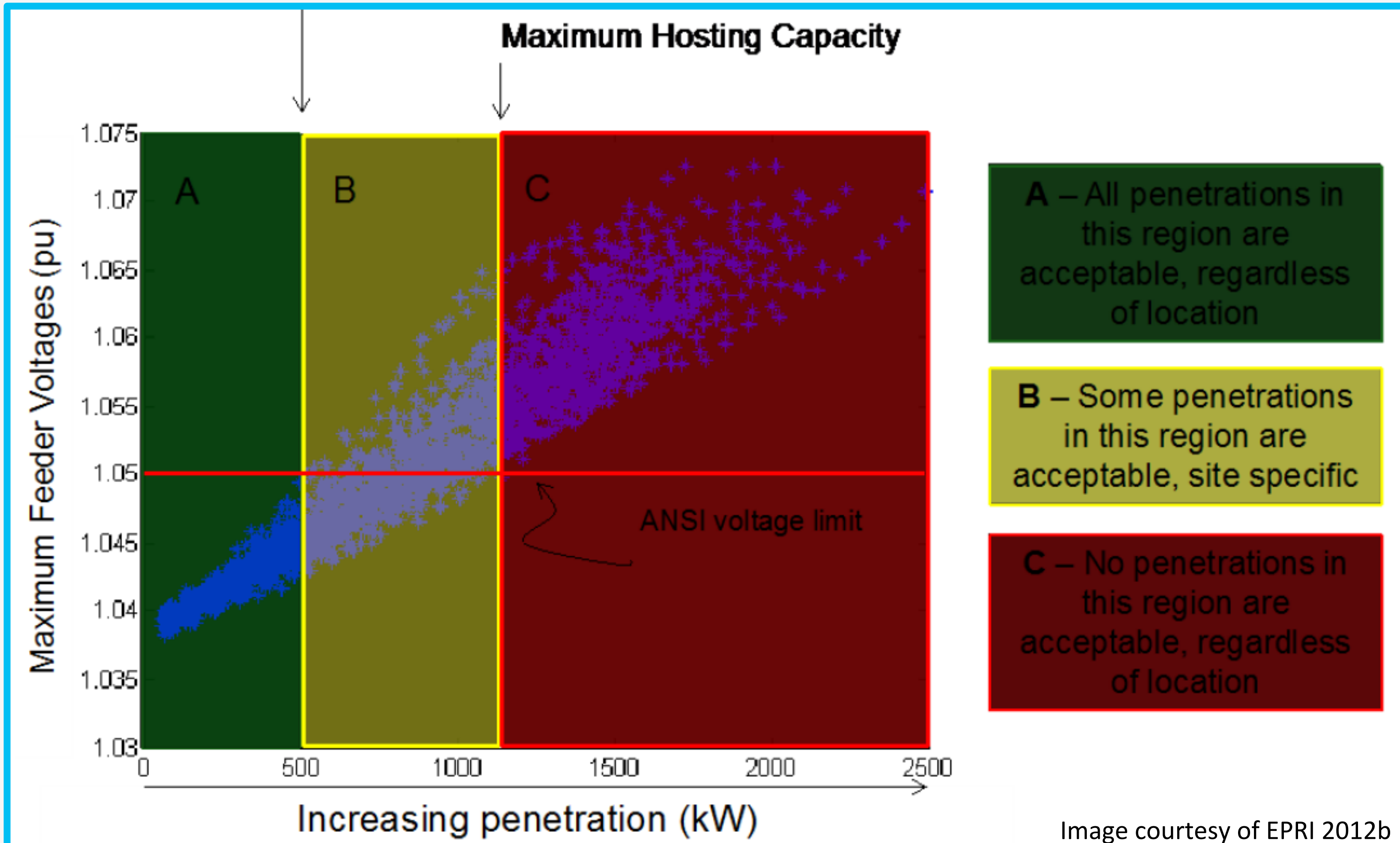
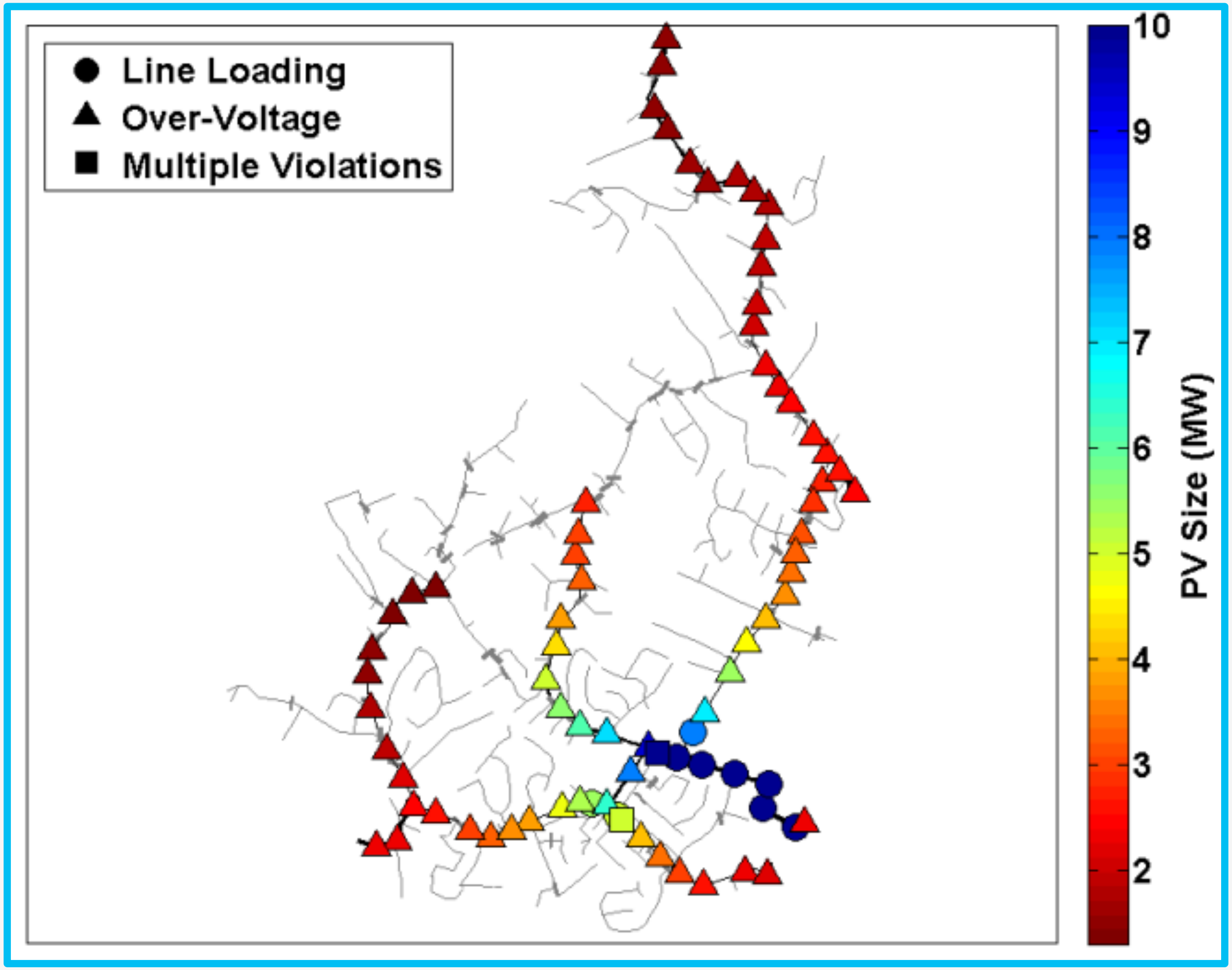
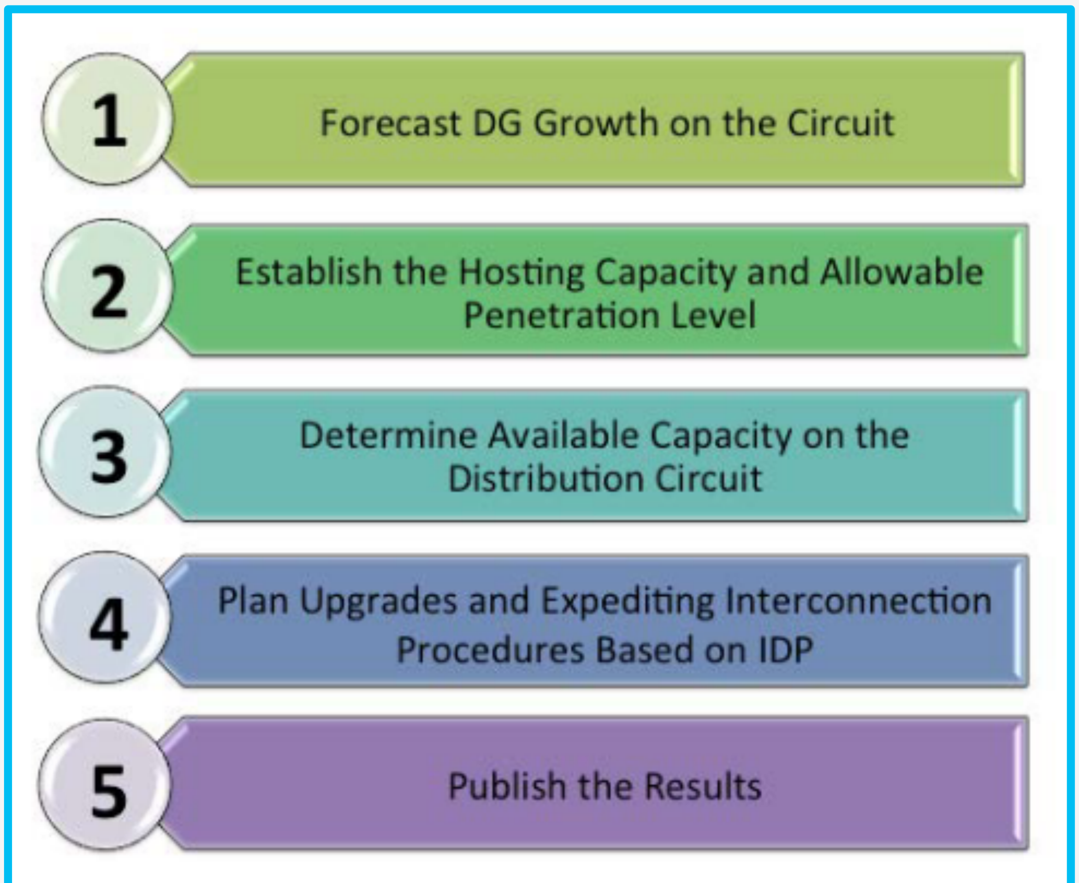


Image courtesy of EPRI 2012b

Hosting capacity violations for the 12.47-kV distribution system EPRI Circuit number 5



Integrated distribution planning is a positive, active policy for increasing hosting capacity



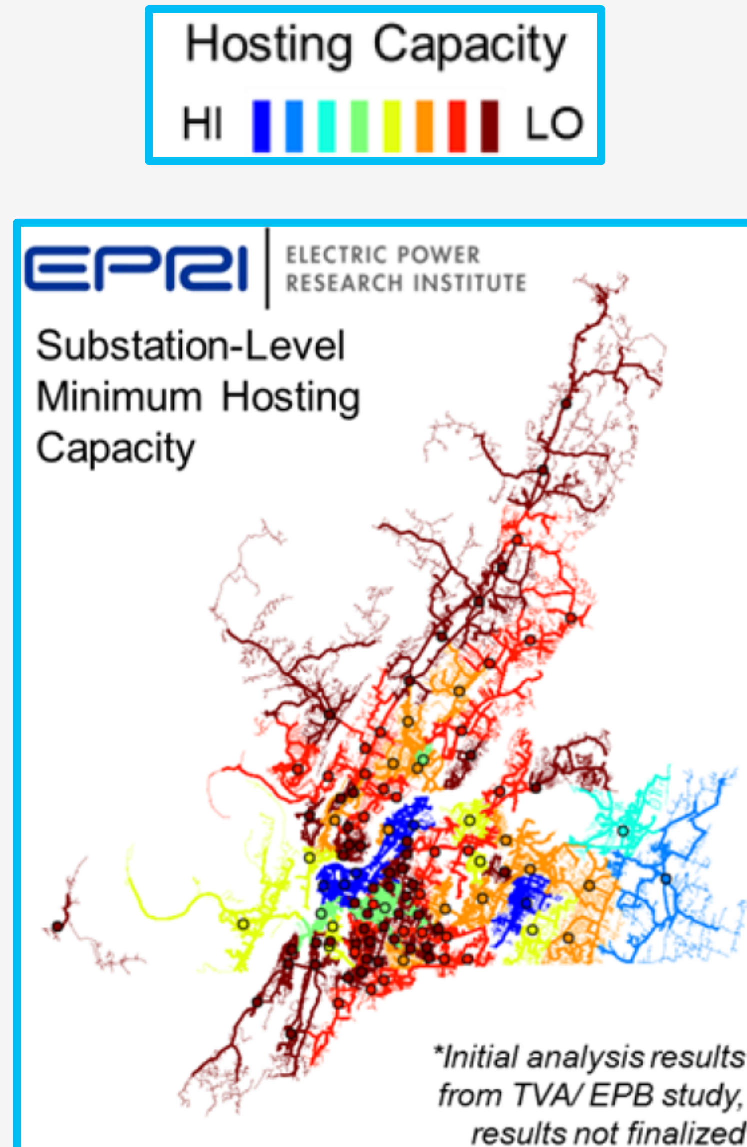
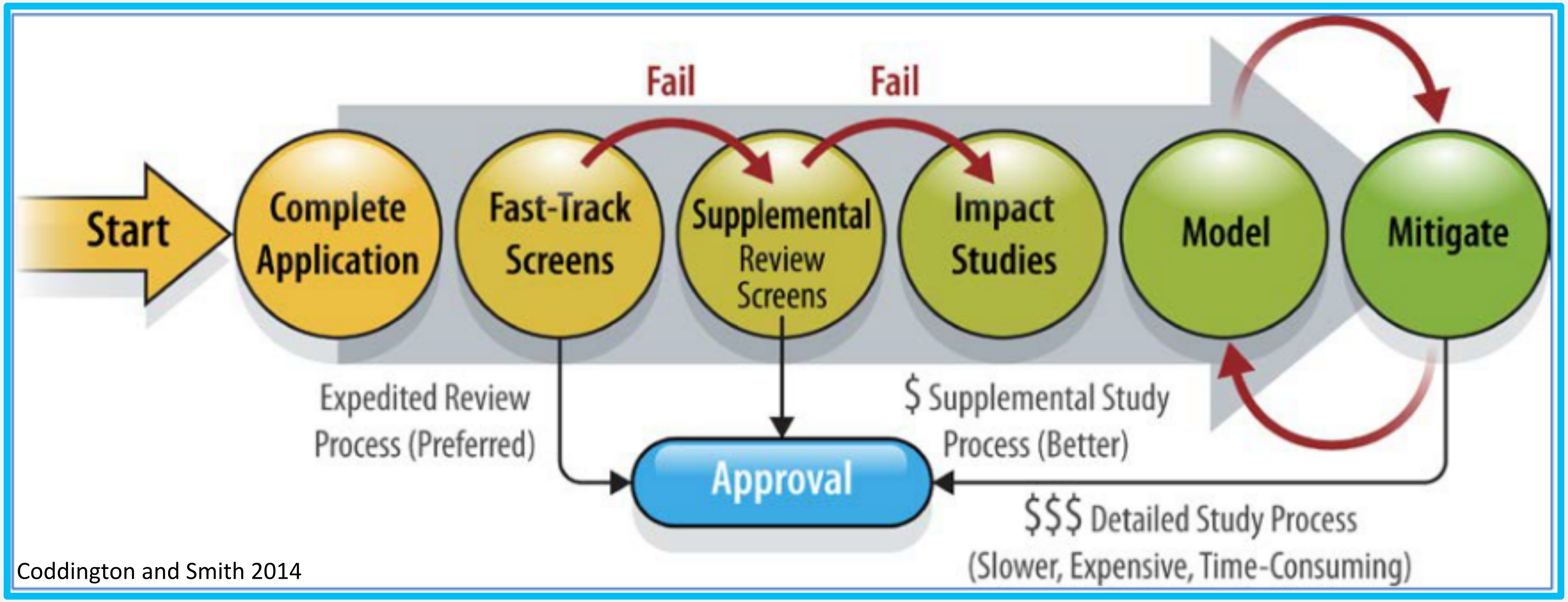


Image courtesy of Lindl et al. 2013

FERC's Small Generator Interconnection Procedures (SGIP) could be amended to updated information



Example technical screens:

1) Aggregate DSPV < 15% of peak load on line section
6) For a single-phase shared secondary, aggregate DSPV capacity < 20 kW

Federal Codes could also be updated

IEEE 1547 2003

- 2003 forbade DER from actively regulating voltages and required them to disconnect during frequency and voltage disruptions.

IEEE 1547a 2014

- Makes provisions to allow utilities to work with DERs to require grid support

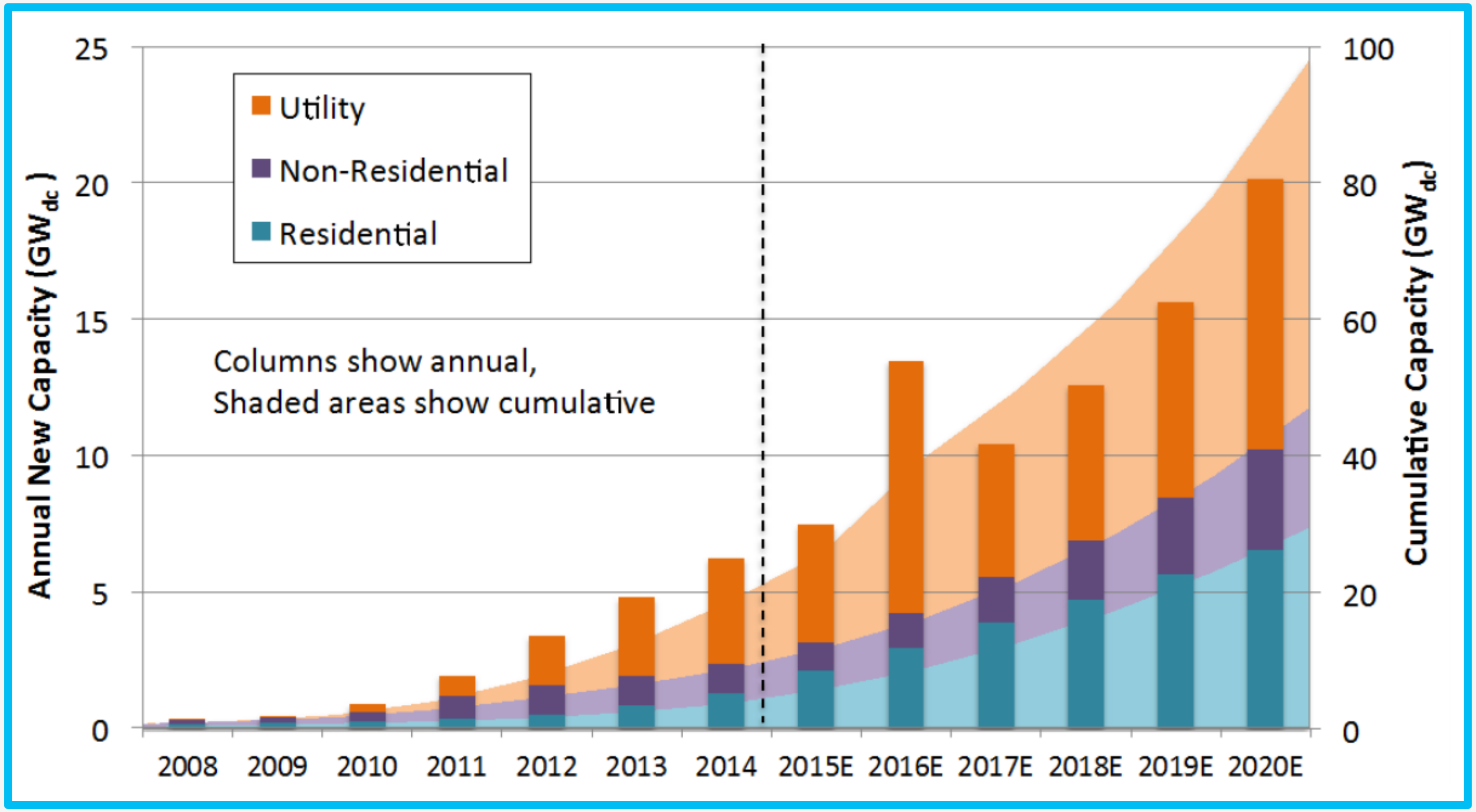
ANSI C84.1-2011

- Specifies acceptable voltage levels for utility services to

NEC/National Fire Protection Association

- The NEC regulates safety for all wiring and installation. The National Fire Protection Association standard 70 article 690 is aimed at protecting PV from starting fires

In summary, distribution & transmission grid planning is key to increasing distributed solar PV generation



170 GW

2030?

References

(1) Palmintier, B.; et al, “On the Path to SunShot: Emerging Issues and Challenges in Integrating Solar with the Distribution System”, **U.S. Department of Energy**, May 2016, available from www.nrel.gov/publications.

(2) Denholm, P; Clark, K; O’Connell, M, “On the Path to SunShot: Emerging Issues and Challenges in Integrating High Levels of Solar into the Electrical Generation and Transmission System”, **U.S. Department of Energy**, May 2016, available from www.nrel.gov/publications.

S1. Clockwise from top, images downloaded from http://fresh-energy.org/2014/04/14/minnesotas-upcoming-residential-energy-code-goes-public/, http://www.businessinsider.com/best-solar-power-countries-2016-3, https://earthzine.org/2010/04/19/ten-steps-to-a-smarter-grid/ February 2017

S2. Clockwise from left, image downloaded from https://en.wikipedia.org/wiki/Electric_power_transmission#/media/File:Pylon_ds.jpg, https://en.wikipedia.org/wiki/Electrical_substation#/media/File:Umspannwerk-K%C3%A4ndelweg_Transformatoren_380kV-110kV-20kV.jpg, https://en.wikipedia.org/wiki/Electric_power_transmission#/media/File:Wood_Pole_Structure.JPG February 2017

S3. Image downloaded from https://en.wikipedia.org/wiki/Electric_power_transmission#/media/File:Pylon_ds.jpg

S4. Image downloaded from http://venturebeat.com/2010/10/29/super-grid-introduction/

S5. Image downloaded from https://cdn.shopify.com/s/files/1/0011/4102/files/CHW-Parkview-Terrace-Aerial-solar-panels.jpg?4644725656679101110

S6. Image downloaded from http://www.rolls-royce.com/~/media/Images/R/Rolls-Royce/icons/kpi-icons/kpi-item/icons/greenhouse-gas-emissions.png?h=155&la=en&w=218, http://www.abb.com/cawp/seitp202/2bf9a7d1cacb1d30c1257ca90029b651.aspx, and http://www.indigowatergroup.com/images/Planning2.jpg

Supporting Notes

Planning tools and techniques are needed to better prepare for uncertainty in the adoption patterns, sizes, and advanced features of high penetrations of DGPV.

Third party ownership - SolarCity, Vivint Solar, and Sunrun… 72% of residential PV installed in 2014 was TPO, up from 42% in 2011. The trend is decreasing as system costs come down and better financing found

Utility ownership largely to meet renewable energy portfolio standards (RPS)

Community solar - This approach could double the number of customers who have access to PV by allowing participation from those who have challenges to individual ownership (e.g., tenants) or building constraints (e.g., high-rise residences, businesses, or poor roof orientation)(1)

A key need for solar value studies, rate design, and distribution-level markets is to develop methods for cost-based service exchanges between PV and the grid. These studies should explore how distribution grid operators might identify, transact, execute, and price PV to provide voltage-management and other services.

In the past few years, there have been major strides in directly estimating such potential limits based on engineering analysis rather than the dated — and often very inaccurate — rule-of-thumb of 15% of peak load -- California Rule 21 and the Federal Energy Regulatory Commission's SGIP are used by most states as models for developing their interconnection procedures. Both share the 15% rule of thumb.

Under most applicable interconnection screening procedures, penetration levels on a switched circuit segment higher than 15% of peak load trigger the need for supplemental studies. The 15% rule derives from a threshold of DGPV not exceeding load with an estimate that minimum load is typically about 30% of peak with a 50% safety margin Hosting capacity is typically expressed as the megawatt value of PV spread across any locations on the feeder that causes the first violation of operating constraints

to estimate that the minimum DGPV hosting capacity for the contiguous United States is approximately 170 GW without imposing any changes to the distribution system. This assumes that DGPV is located according to feeder-level hosting capacity

Beginning in 2012, EPRI, NREL, and Sandia National Laboratories undertook a comprehensive distribution modeling-based project to develop advanced PV interconnection screens for California… (study of 21 of 10,000 distribution circuits in California)

for improving fast-track DGPV interconnections along the lines of California's Rule 21, which institutes a 15% distributed generation penetration limit for fast-track DGPV interconnections

It may be possible to relax some of the voltage regulator limits. While regulators are expected to respond more slowly than a PV array with a passing cloud, a distributed array of PV may vary slowly enough to allow regulators to respond. This will mean some of the limits on PV could be relaxed with planning for a larger DSPV array. *Hosting capacity after relaxing regulator limits*