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Integrating PV on Distribution

Carnegie Mellon Conference on the Electricity Industry

Emerging Phenomena in Changing Electric Energy Systems




March 9, 2011

Navigant Reference: 830282-2304

DISPUTES & INVESTIGATIONS • ECONOMICS • FINANCIAL ADVISORY • MANAGEMENT CONSULTING

Points to discuss today

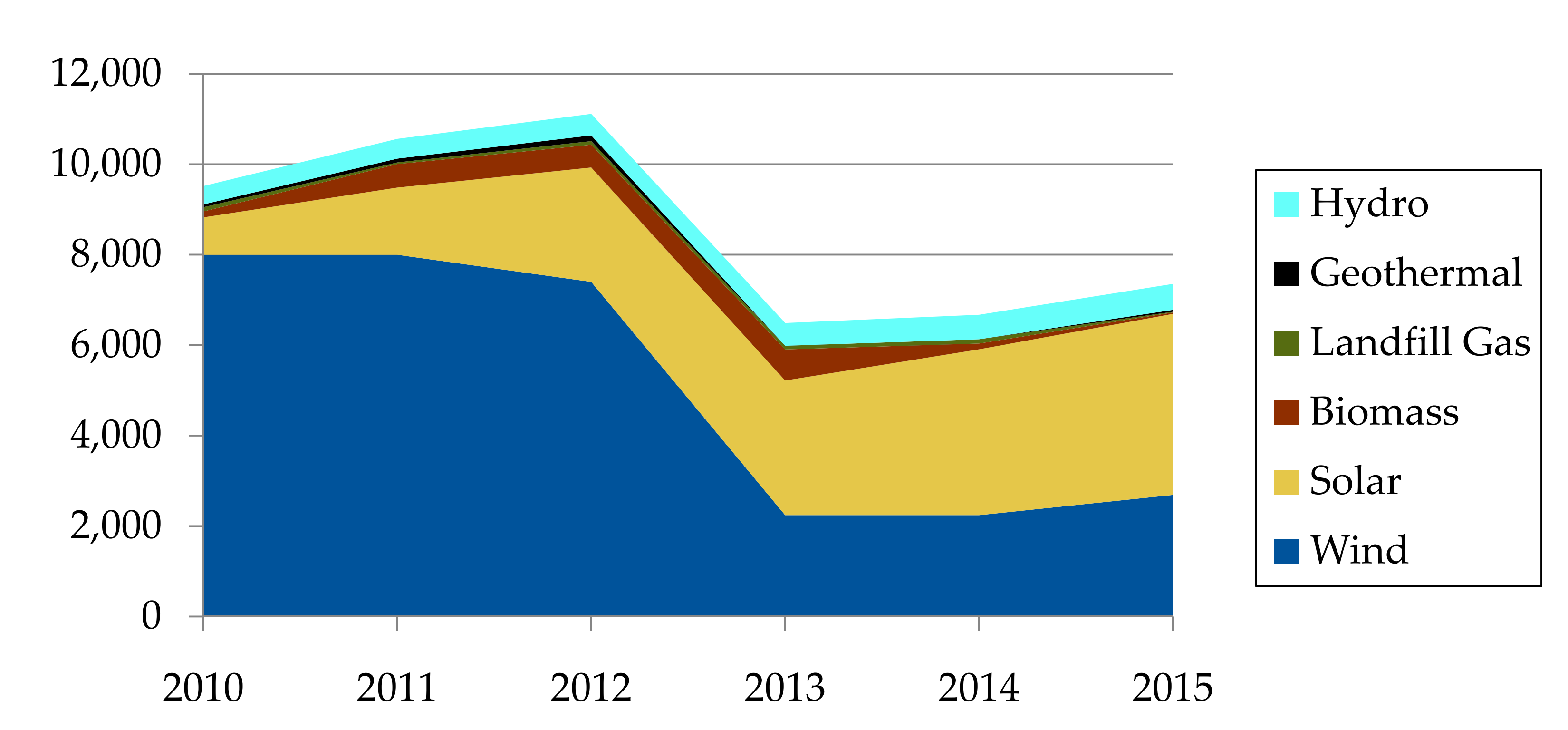
» Distributed PV increasing

» Effects of high penetrations of distributed PV

» Energy storage and distributed PV

PV installations are increasing dramatically, and will exceed annual wind installations by 2013.

Annual Renewable Energy Capacity Additions (MW per year)



Forecasts assume: no renewal of existing federal tax credits after their current expiration dates; and no new federal stimulus program is created.

Source: Navigant Consulting, Inc., January 2009. Note: Solar includes solar PV and CSP; Biomass includes biomass co-firing.

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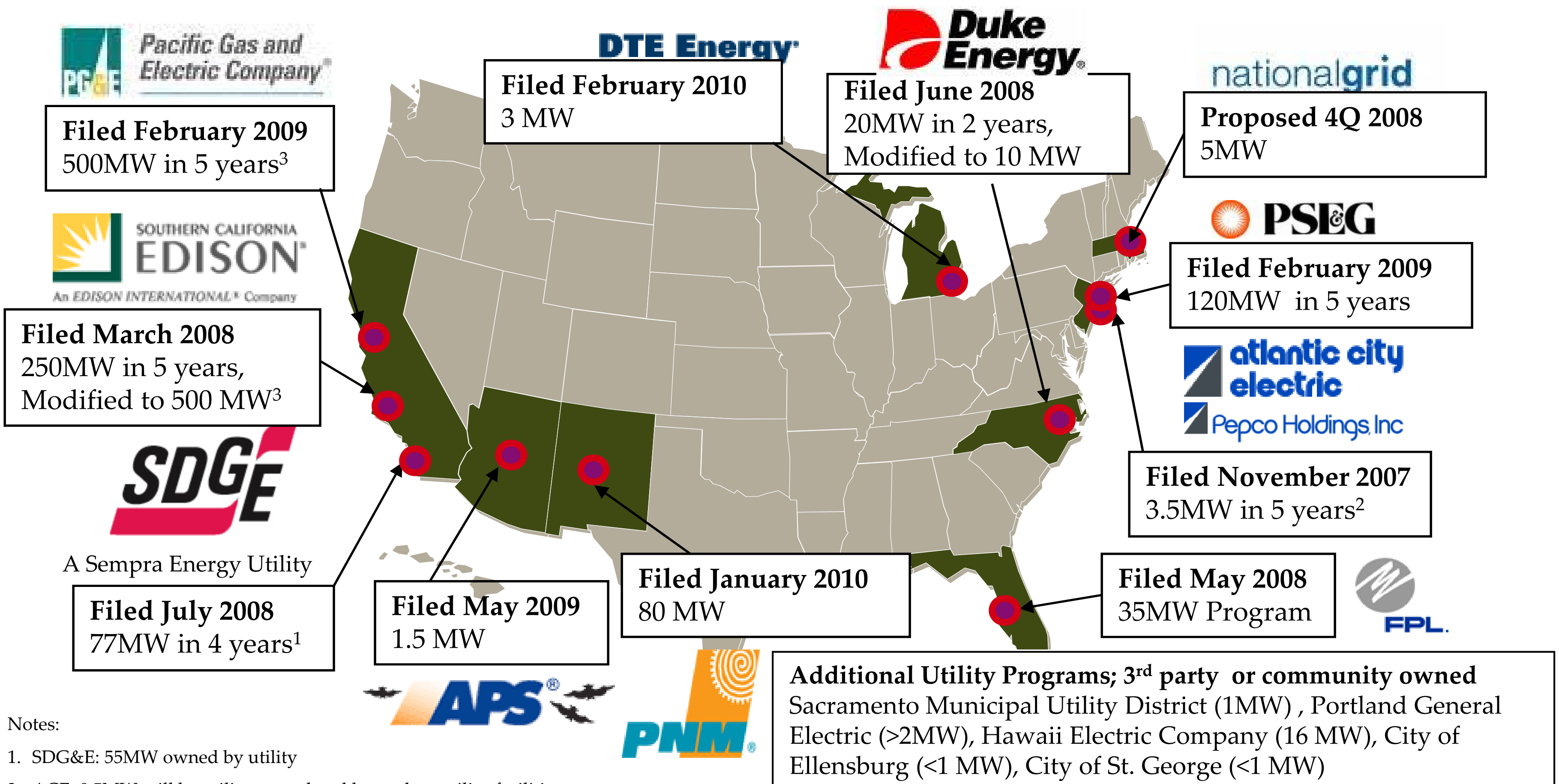
Utilities want to install distributed solar on a large scale and put it in ratebase.

Utility Programs for Distributed PV: Examples of Filings for Rate Basing



Notes:

1. SDG&E: 55MW owned by utility
2. ACE: 0.5MW will be utility owned and located on utility facilities.
3. PG&E and SCE 50% ownership

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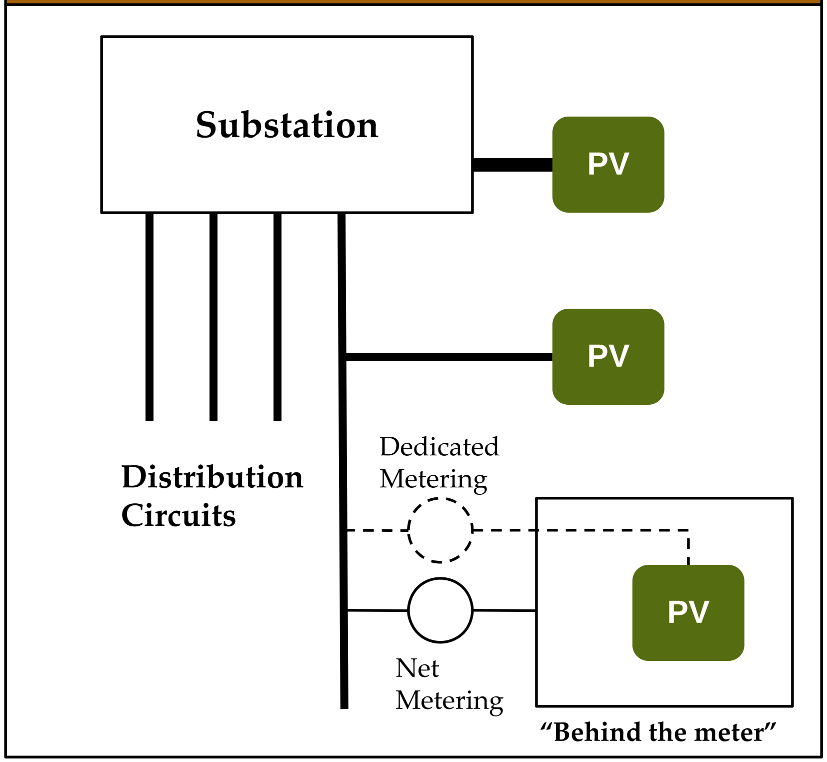
Distributed PV can be connected at three points in the distribution system depending on the location and size of the installation.

Distributed PV can by interconnected at three levels



Substation interconnection assumes that the PV is physically located close to the substation, and a dedicated electrical connection to the low side bus would be made.

Primary Distribution interconnection assumes that the PV is connected directly to the distribution system, and is not integrated with a customer's electrical system.

Behind the Meter interconnection assumes the PV is integrated with a customer's electrical system, and either net metering or dedicated metering could be employed.

Each point has a practical limit based on the impact of the PV on the distribution system.

In addition to high cost, T&D concerns, communications, and regulatory challenges have limited the PV deployed in the past.

Challenges of High PV Penetration	
Transmission and Distribution Concerns	Voltage regulation (D)
	Reverse power flow (D)
	Power fluctuation/frequency regulation (T)
	Harmonics (D)
Communications	Lack of communications throughout the distribution system
	Inverter operating limits (e.g., IEEE 1547)
	Limited ability to forecast PV resource for capacity planning
	Non-standard communications protocols
Regulatory and Business Models	Unstructured interconnection standards and ownership control in some states
	Lack of rate recovery and PV-"friendly" tariffs

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Past research had indicated that distribution performance may degrade if PV exceeded certain penetrations on distribution circuits.

Recommended Limitations on PV Penetration Based On T&D Performance Concerns		
T&D Performance Concerns	**Description of Impact**	**Recommendation for Maximum PV Penetration on Circuit Peak Load**
Voltage Regulation	Adequate voltage regulation may be difficult due to changes in circuit load and power flow while PV is producing. Also of concern is voltage depression after a circuit restoration, when load is restored but PV systems have not come back online.	< 40%
Reverse Power Flow	Changes in PV output can cause the power flow on distribution circuits to vary, and in some high generation/low load cases, the flow could reverse.	5% to 30%
Power Fluctuation/ Frequency Regulation	The variability of PV output due to cloud transients has been shown to create power fluctuations, and may be incompatible with the ramp rates of some central station generation. This variability may require higher levels of system frequency regulation, increasing the cost of accommodating higher penetrations of PV.	5% to 30%

Source: Distributed Photovoltaic Systems Design and Technology Requirements, C. Whitaker, J. Newmiller, M. Ropp, and B. Norris, February 2008, and Navigant analysis, 2008.

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As PV penetration increases, harmonics may become an issue that must be evaluated case by case.

Effects of Harmonics and Limitations on PV Penetration	
Study Country	**Summary of Findings**
Germany (1)	TV loads coupled w/ PV created higher distortion
Australia (2)	Limit found at ~ 18% penetration
Denmark (3)	Up to 30%; TV distortion > PV
Japan (3)	Line-end over-voltages on cluster of 550 houses
Australia (3)	665 homes connected with no significant impacts

Sources
1. Distributed Energy Resources and Waveform Distortion, Math Bollen, Christine Schwaegerl, and Sebastian Schmitt
2. Harmonic Impact of Residential Type Photovoltaic Inverters on 11kV Distribution System, A.A. Latheef, V.J. Gosbell, & V. Smith
3. The Effects of Harmonics Produced by Grid Connected Photovoltaic Systems on Electrical Networks, Abdulvahid Çelebi & Metin Çolak

- In some studies non-linear loads in residences (e.g., televisions) had a greater impact on harmonics than PV inverters.
- Distribution circuits with strong sources, shorter length and higher voltages tended to be less susceptible to excessive distortion.

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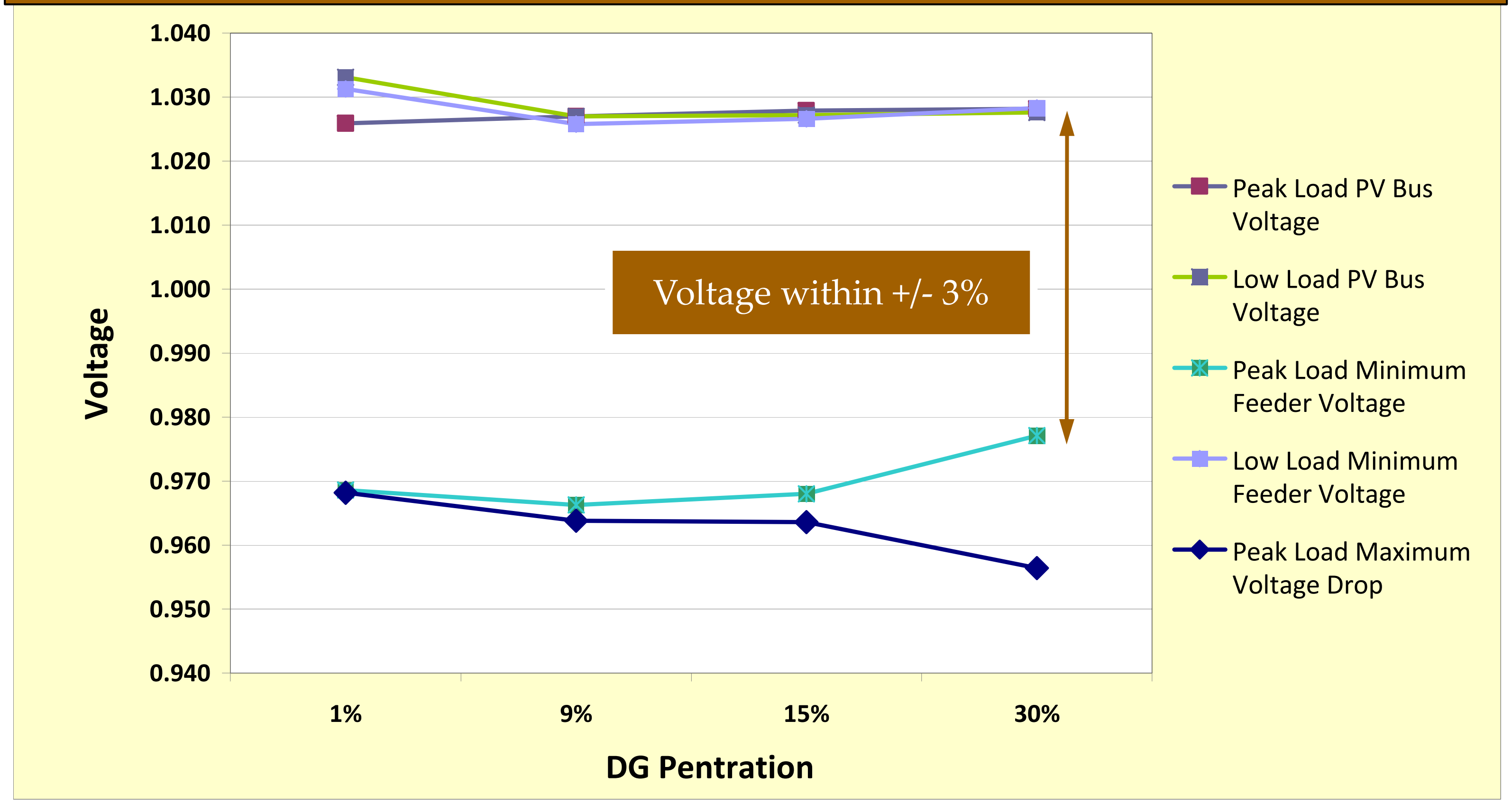
Recent focused studies show that distribution voltage stays within system design criteria even with high penetrations of PV…

On some circuits PV penetration as high as 30% does not exceed voltage limits



Source: Navigant, Analysis of southwest investor owned utility, November 2010.

… even when the PV is located far from a substation.

High PV penetration may not exceed voltage limits, even far from the substation

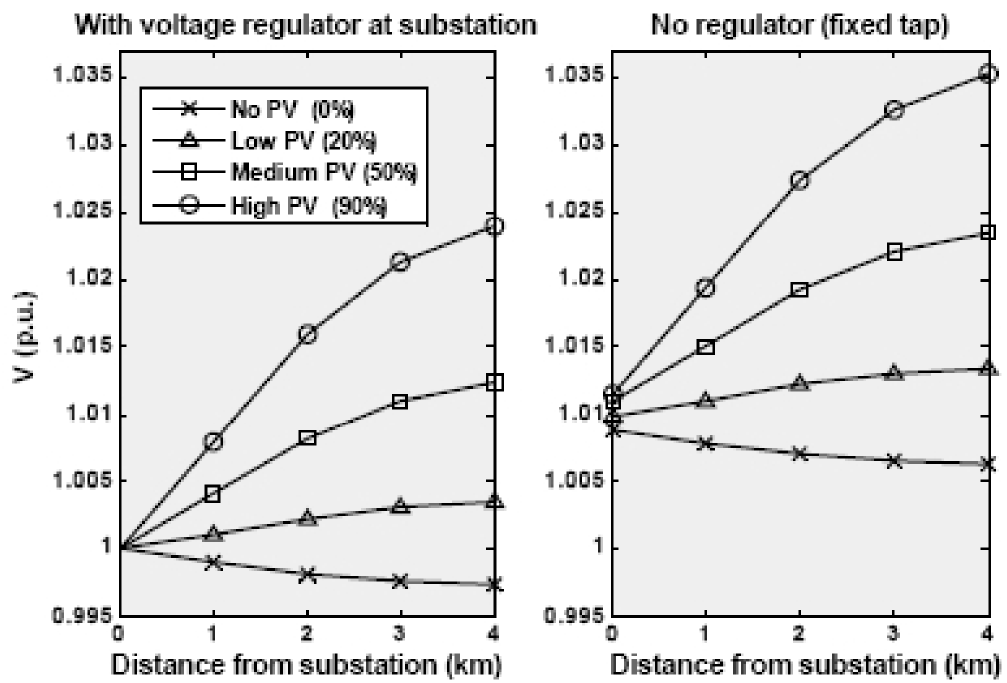


Figure 6 - Change in voltage profile at light load conditions and different level of PV generation in percentage of the rated 2-kW PV per house (uniform distribution of PV sources and loads along the feeder)

Source: Natural Resources Canada. Integration of Photovoltaic Power Systems in High-Penetration Clusters for Distribution Networks and Mini-Grids, 2009.

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Distribution system monitoring conducted by NREL has shown that no adverse conditions occur even in a high penetration solar community.

Source: SunPower

- Anatolia SolarSmart[SM] Homes Community, Rancho Cordova, CA
- Highly energy efficient homes with integrated PV systems
- 2 kW grid-connected PV systems with remotely monitored inverters

Results with Penetrations of 11-13%

- No excessive service or substation voltage due to reverse power flow
- Cloud transients did not adversely affect the distribution system
- No indication that utility voltage transients (capacitor switching) caused PV systems to trip off-line

Source: National Renewable Energy Laboratory. Impact of SolarSmart Subdivisions on SMUD's Distribution System, July 2009.

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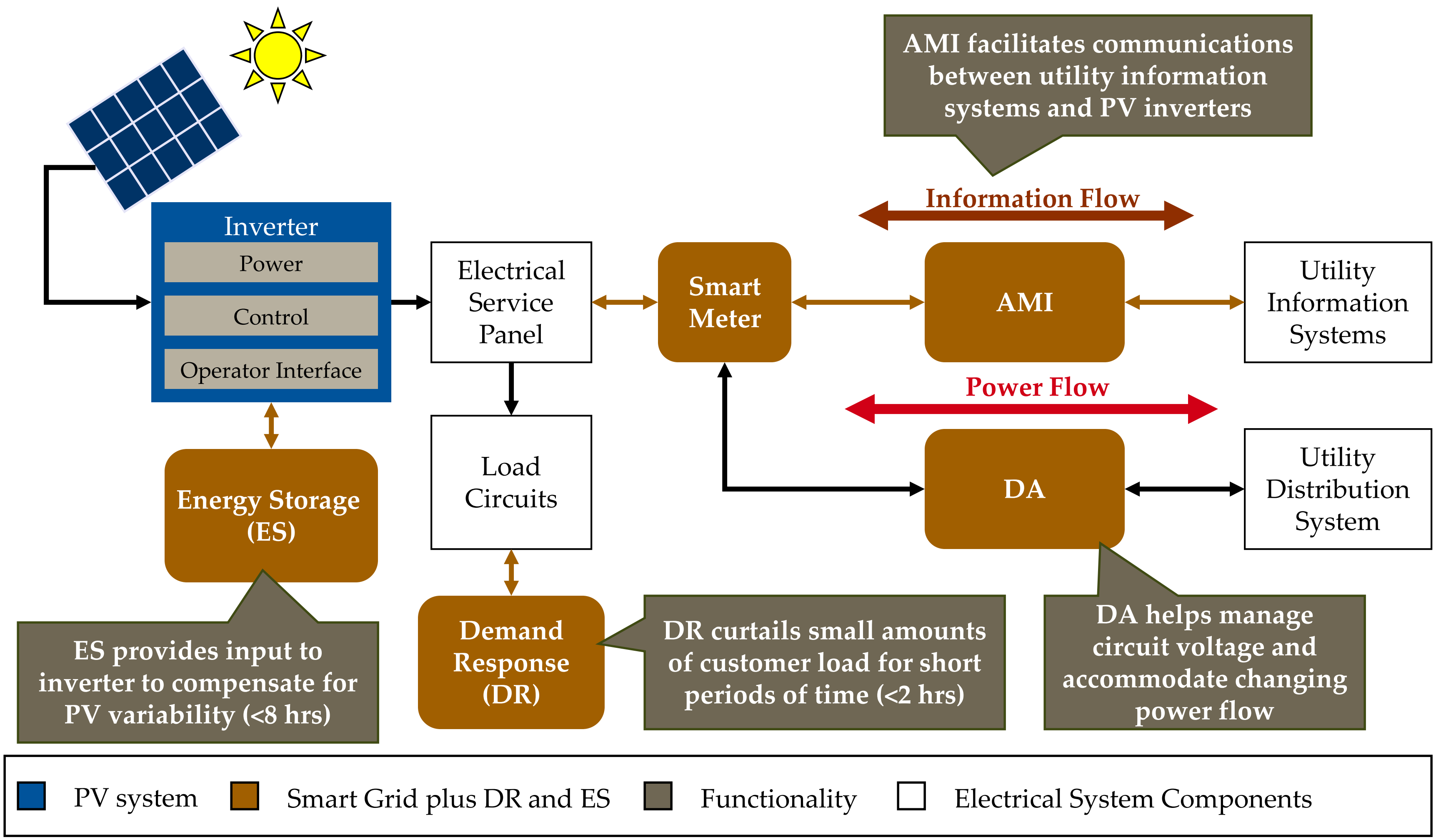
Smart Grid systems support better communications and control between distributed resources and the utility distribution system.



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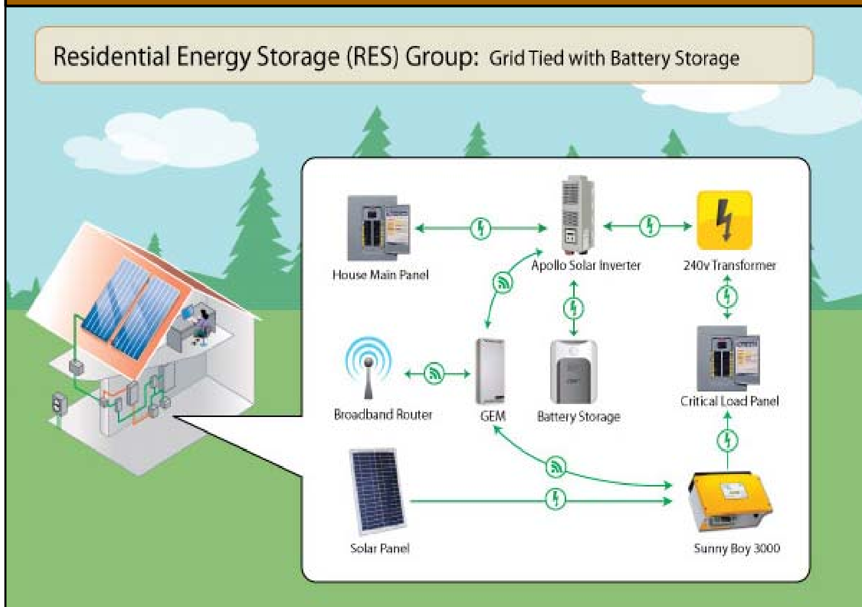
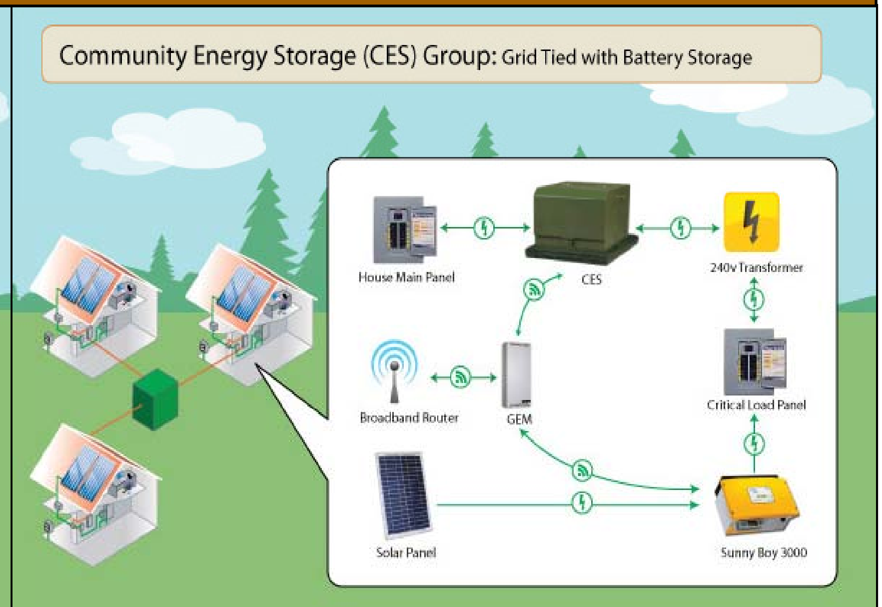
Navigant is working with SMUD to demonstrate the effect of energy storage in a high penetration solar community.

PV and Energy Storage Pilot at Anatolia III Subdivision with 2kW PV per home (Partners: GridPoint, SunPower, NREL, Navigant)





15 systems, 3.6kW/10kWh each	3 systems, 30kW/50kWh each

About 75 additional homes will be part of a control group with PV but no storage.

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This demonstration is designed to help answer several key questions for SMUD.

- Can energy storage increase the “grid benefits” of PV for a utility?
- Can energy storage in a high penetration solar deployment help support SMUD’s “super-peak” from 4 PM to 7 PM, particularly when PV output drops off after 5PM?
- How much storage is necessary?
- Does the location of energy storage matter?
- Can a smart meter be used to monitor and control a PV system, and to what extent?

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The project can potentially enable ten functions, two of which are part of the DOE's standard smart grid benefits framework.

PV-Energy Storage Functions (Preliminary)

Automated Voltage and VAR Control	Automated Islanding and Reconnection	Phase Balancing
Load Shifting	Firming	Bridging Power
Backup Power	PV Generation	End-User Market Participation
Frequency Regulation		

- Standard Smart Grid Function (blue): Automated Voltage and VAR Control; Automated Islanding and Reconnection
- PV-Energy Storage Function (yellow): all other functions

Source: Navigant

Recap

- » Distributed PV will become a significant energy resource in utility systems.
- » Distribution effects from high penetrations of PV may not be as significant as once thought.
- » More work must be done to determine the extent to which PV and energy storage can provide grid benefits.

Key
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