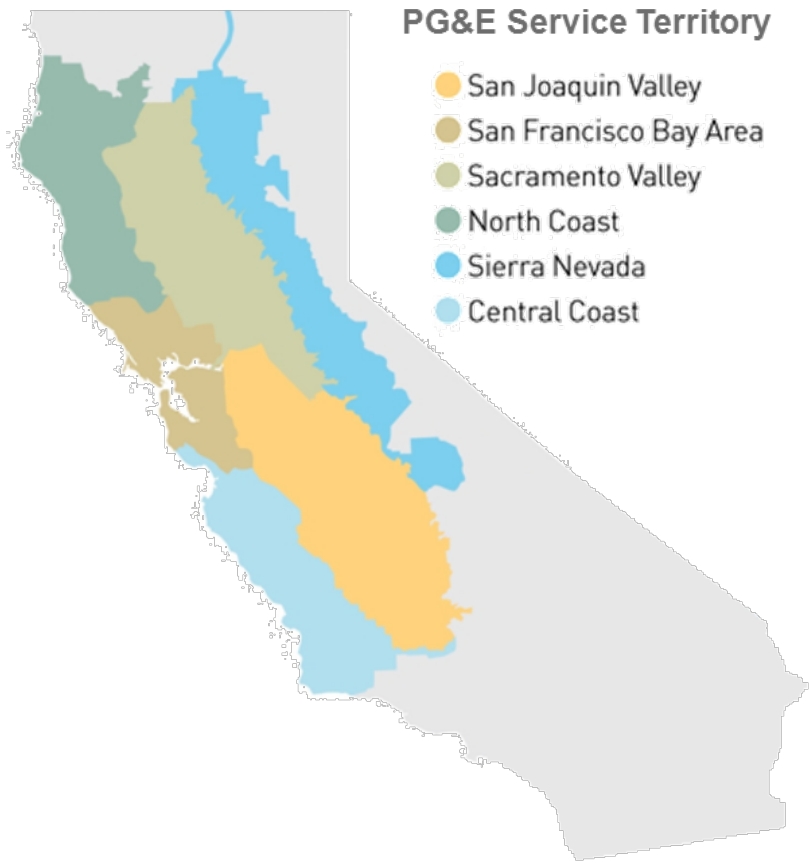
Andrew Yip

Pacific Gas and Electric Company (PG&E)

PG&E HIGH PENETRATION SOLAR PV

CURRENT STATUS AND RESEARCH

PG&E Overview



Company Facts

- Fortune 200 company located in San Francisco, CA
- $14B in operating revenues in 2010
- 20,000 employees

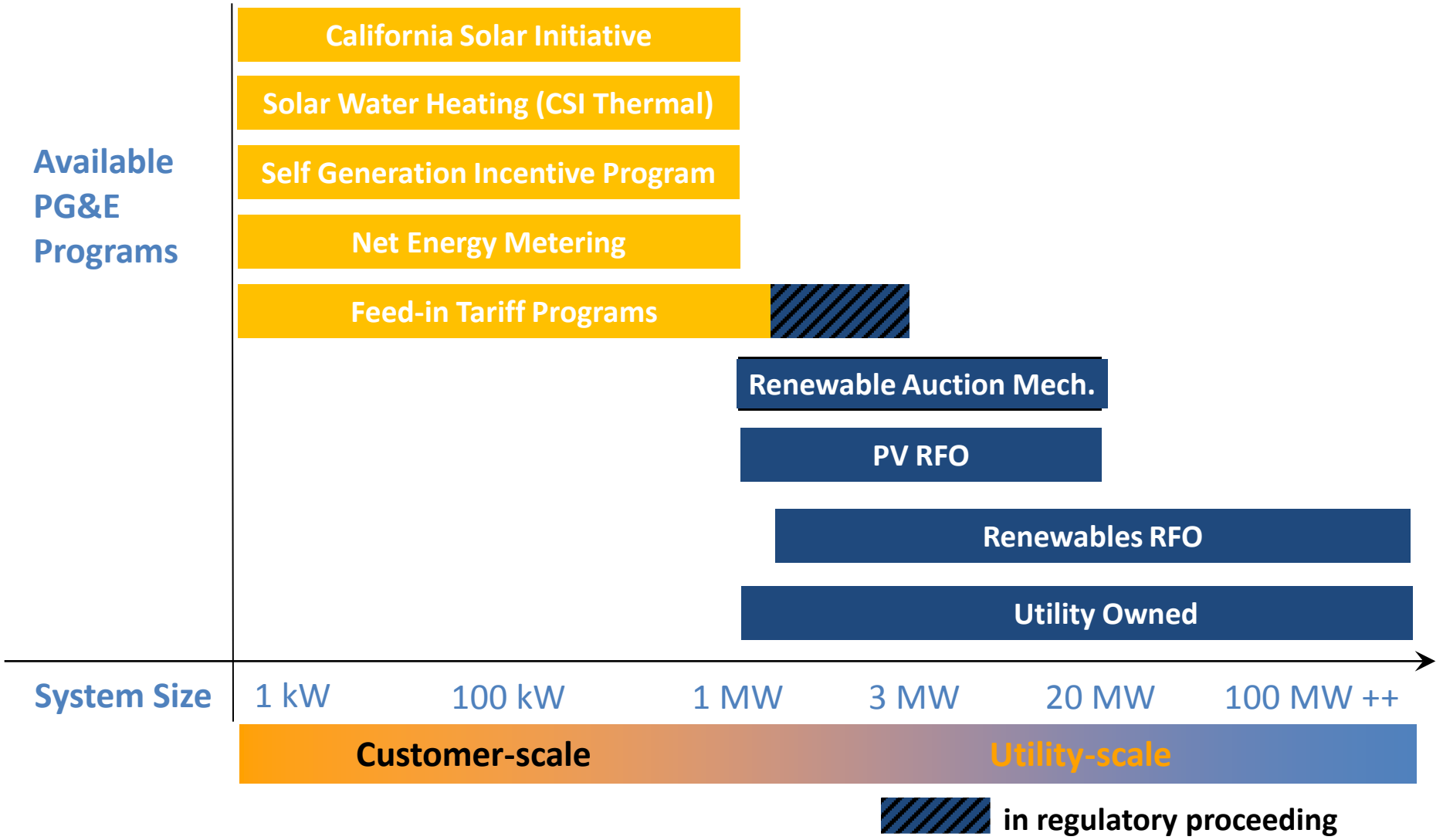
Energy Supply

- Services to 15M people:
  - 5.2M Electric accounts
  - 4.3M Natural Gas accounts
- Peak electricity demand: 20,000 MW
- Over 50% of PG&E's electric supply comes from non-greenhouse gas emitting facilities

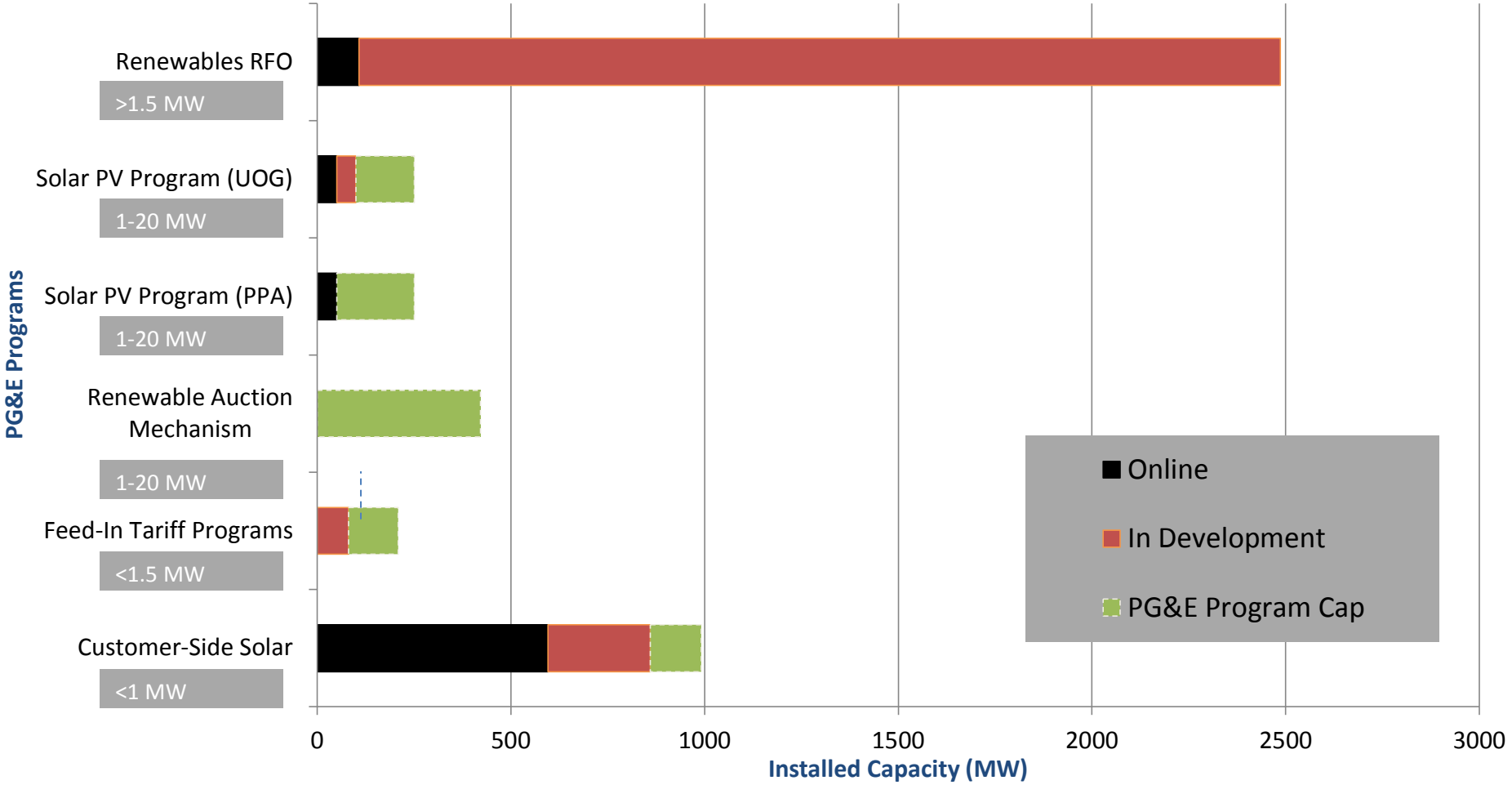
Service Territory

- 70,000 sq. miles with diverse topography
- 160,000 circuit miles of electric transmission and distribution lines
- 49,000 miles of natural gas transmission and distribution pipelines

PG&E Renewable Energy Programs



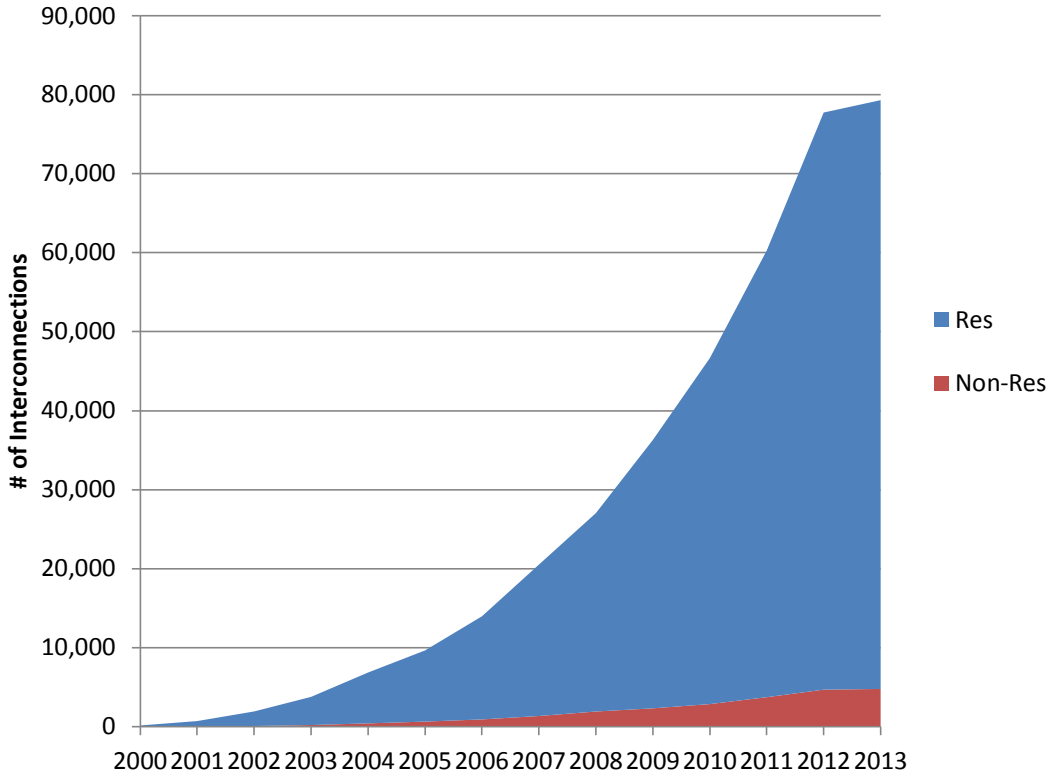
Solar PV Programs



Note: Customer-Side Solar PV Online value includes projects associated with various customer-side incentive programs. In-development and PG&E Program Cap value only includes projects in the California Solar Initiative mass market program.

PG&E and Distributed PV

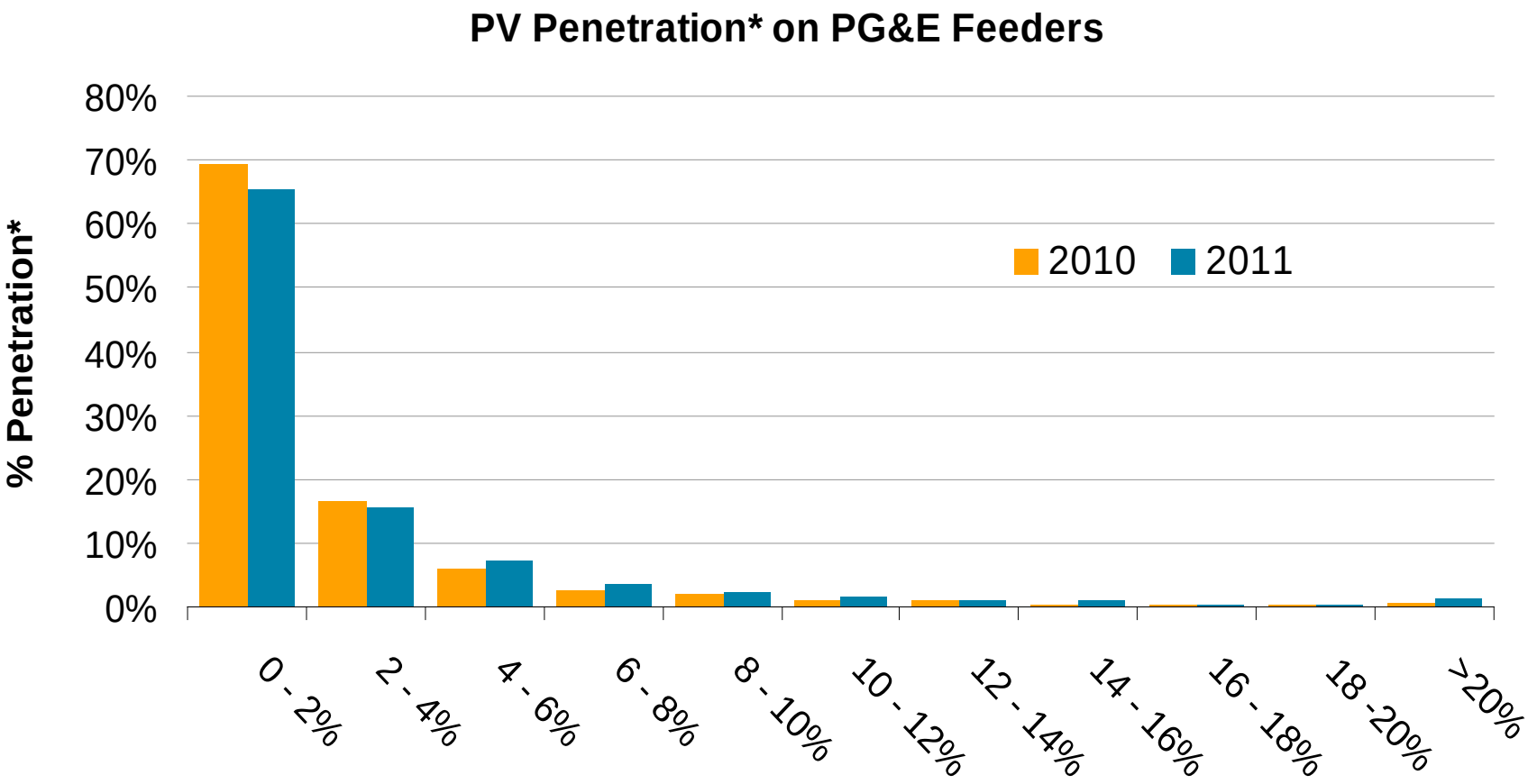
- PG&E is a leader in distributed PV
  - > **79,000 installations**
  - > **802 MW** (CEC AC)
  - ~ **30%** of US total
  - PG&E serves **~5% of US population**
  - Over 17,000 interconnections in 2012



PV Penetration Status

- Overall high penetration of PV in PG&E territory (relative to other utilities)
- However, feeder-level penetration is generally low (relative to feeder max demand)
- On the other hand, high concentrations of PV exist in some localized areas (i.e., on individual transformers)

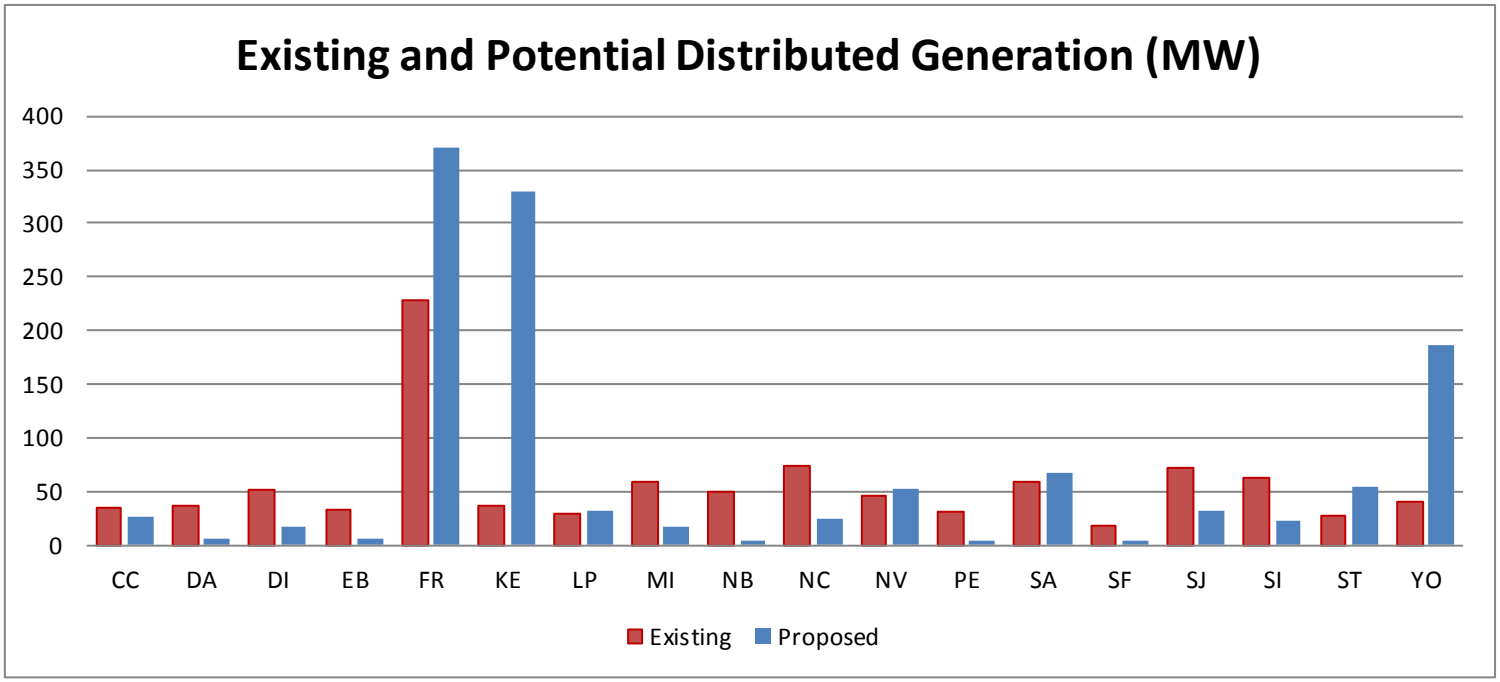
PV Penetration by Circuit



** % PV Penetration = PV MW (CEC AC) / 2009 Feeder Max Demand*

Currently, DG penetration is low at about 5% of System Peak

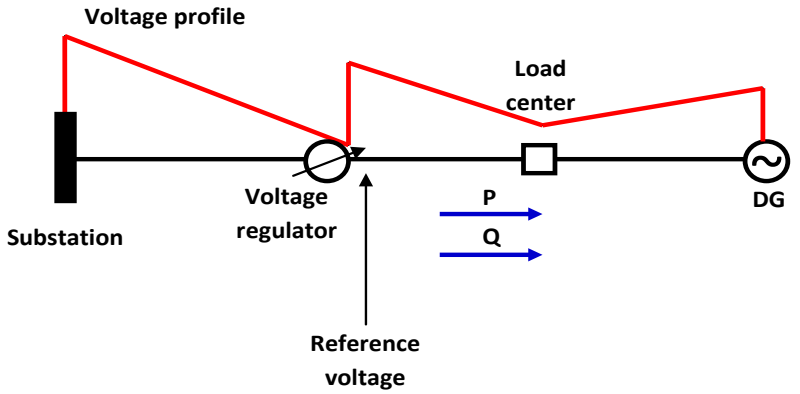
Penetration = installed DG as a % of total system peak (22,000MW)



	CC	DA	DI	EB	FR	KE	LP	MI	NB	NC	NV	PE	SA	SF	SJ	SI	ST	YO	TOTAL
Existing	36	38	52	33	229	37	29	59	50	74	46	31	59	19	72	63	28	40	995
Proposed	27	7	18	6	371	330	33	18	5	25	52	4	68	4	32	23	55	186	1264

At Low Penetration, DG System Impacts are Manageable

- All DG's are studied individually for potential impact and mitigated prior to physical interconnection
  - Studies focus on Safety, Equipment Loading, Voltage Fluctuation and Islanding
- For most feeders, aggregate DG is less than local load, and power flows on the feeders are still from the substation out in a radial mode
- All identified issues are mitigated to have less than significant system impacts

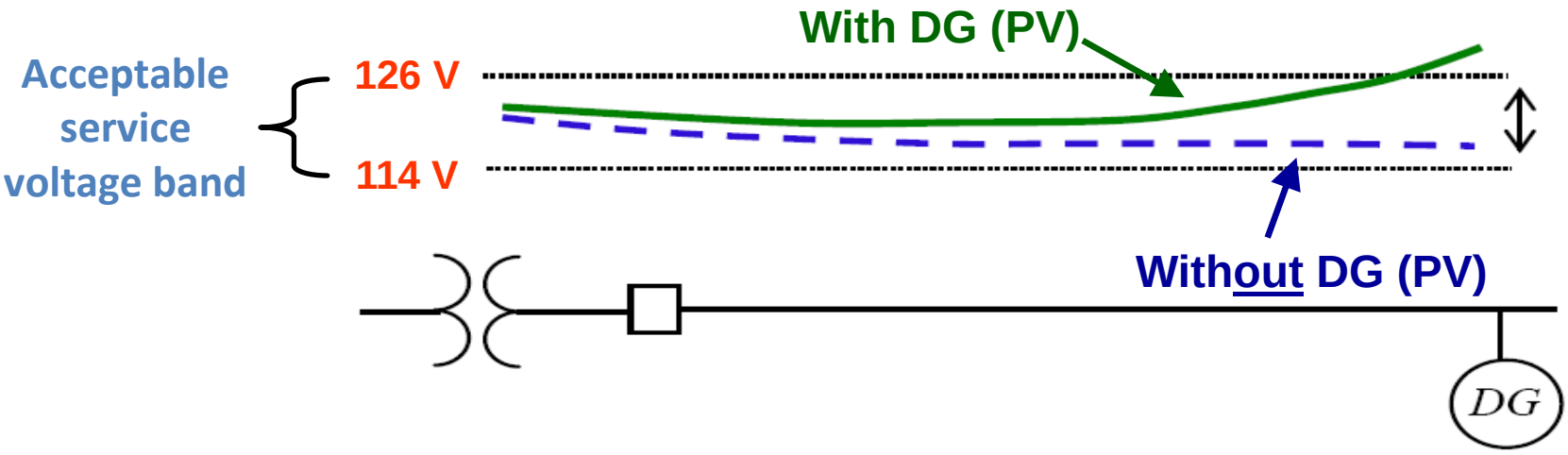


Voltage Concerns

Electric Rule 2

Nominal Two-Wire And Multi-Wire Service Voltage	Minimum Voltage To All Services	Maximum Service Voltage On Residential And Commercial Distribution Circuits		Maximum Service Voltage On Agricultural And Industrial Distribution Circuits
		Class A	Class B	
120	114	120	126	126
208	197	208	218	218
240	228	240	252	252
277	263	277	291	291
480	456	480	504	504

- DG (PV) can impact the voltage profile along a given feeder, driving the service voltage outside of acceptable ranges at points – particularly in low-load conditions



PV and the Distribution Grid: Challenges

PV can cause…

- **Service voltage** to exceed the acceptable range
  - Can lead to inverter trip-offs (potential domino effect)
- **Flicker**
  - Due to inverter trip-offs or rapid cloud cover

In what cases?

- ***High concentrations*** of PV beyond a single transformer
- ***Large PV*** on feeders
- PV at points on feeder ***already close to voltage limits***

Voltage Mitigations

Today, voltage impacts of PV on the grid are generally addressed by **adjusting settings** or **relocating** distribution system equipment, including:

- **Capacitor banks**
- **Load tap changers**
- **Voltage regulators**
- **Bucking transformers**

In certain situations with fast voltage fluctuations due to intermittency, **reconductoring** may be the only effective mitigation measure. **Energy storage** is an alternative but has higher capital cost and market operational uncertainties

PV and the Distribution Grid: Today

- Examples of grid problems caused by PV and mitigation strategies employed

Concern	Mitigation Strategy
A facility's 10-kW PV system (inverter) trips off-line when customer load is light due to high service voltage	Adjust voltage regulator settings
Generators at a facility downstream of a 1-MW PV system trip off-line due to high service voltage	Adjust capacitor bank settings

- Generally, few impacts today despite the relatively high number of PV systems
- However, requirements for mitigation may increase in future with increased penetration of PV in localized areas

PV and the Distribution Grid: Potential Future Strategies

- In the future, the negative impacts of PV on the grid may be mitigated in a variety of ways

Reconductor lines

Distribution Management Systems (DMS) (e.g., Volt/Var Optimization (VVO)

Require curtailment of PV generation

Install new equipment (e.g., voltage regulators

"Smart" inverters

Current Research for Distributed Solar PV

- Collaborative efforts
  - Development and Analysis of a Progressively Smarter Distribution System (UC Irvine)
  - Advanced Grid-Interactive Distributed PV and Storage (Solar City/Tesla Motors/ UC Berkeley)
  - PV and Advanced Energy Storage for Demand Reduction (SunPower/KEMA)
  - Quantification of Risk of Unintended Islanding and Re-Assessment of Interconnection Requirements in High-Penetration of Customer-Sited Distributed PV (GE)
  - Screening Distribution Feeders: Alternatives to the 15% Rule (NREL/Sandia/CPR)
  - Tools Development for Grid Integration of High PV Penetration (BEW)

- Other research areas
  - Two internal studies to assess the impacts of PV on the PG&E distribution system with separate focus on (a) 1-20 MW systems and (b) smaller (e.g., residential) systems.
  - A DOE SEGIS-funded, EPRI-led project involving National Grid, Excel Energy, and Detroit Edison that will explore how utility-inverter communication can enable “smart” inverters to optimally provide grid support. PG&E is supporting this project in an advisory role.

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Q &A AND DISCUSSION