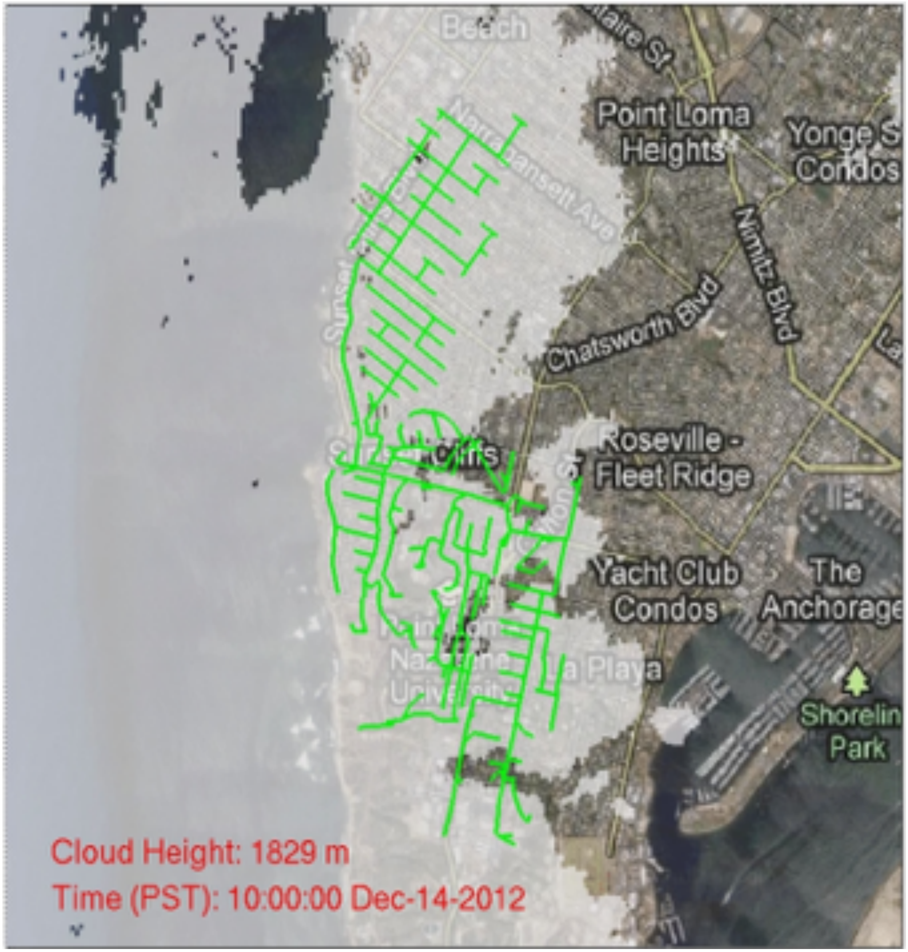
Short Term Solar Forecasting Using Sky Imagery and Its Applications in Control and Optimization for a Smart Grid



Projection of clouds using sky imagery on a feeder in San Diego city from our study on impacts of high PV penetration on distribution feeders.

LANL Winter School
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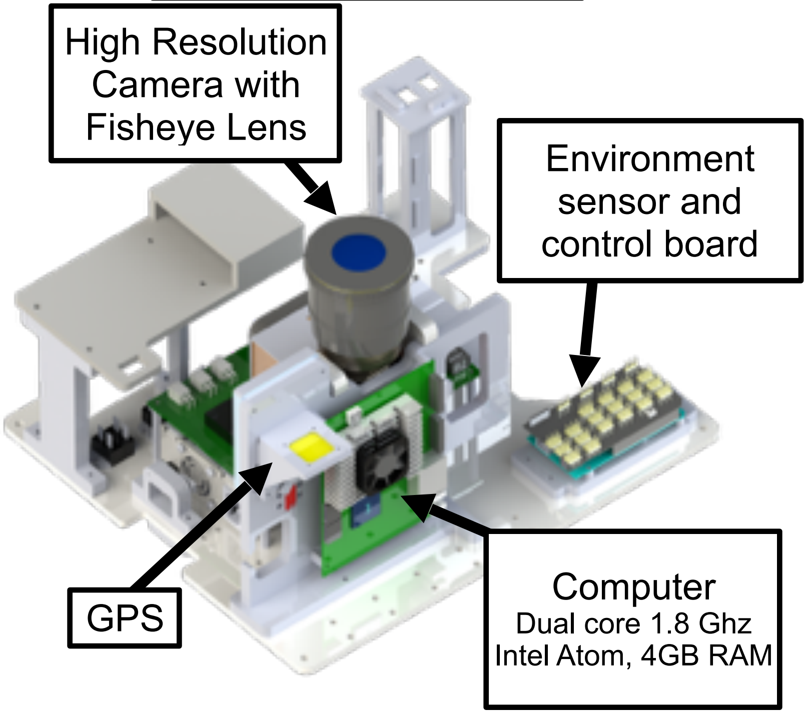
Short term solar forecasting using sky imagery

Hardware

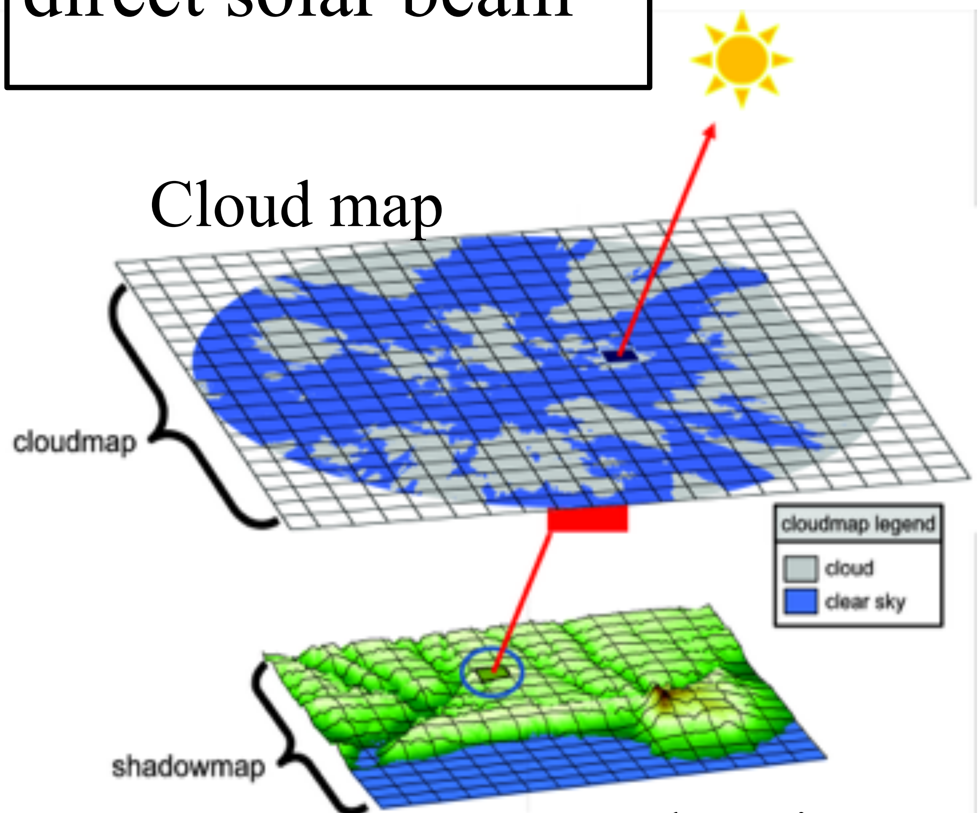


USI Deployed in Redlands, CA

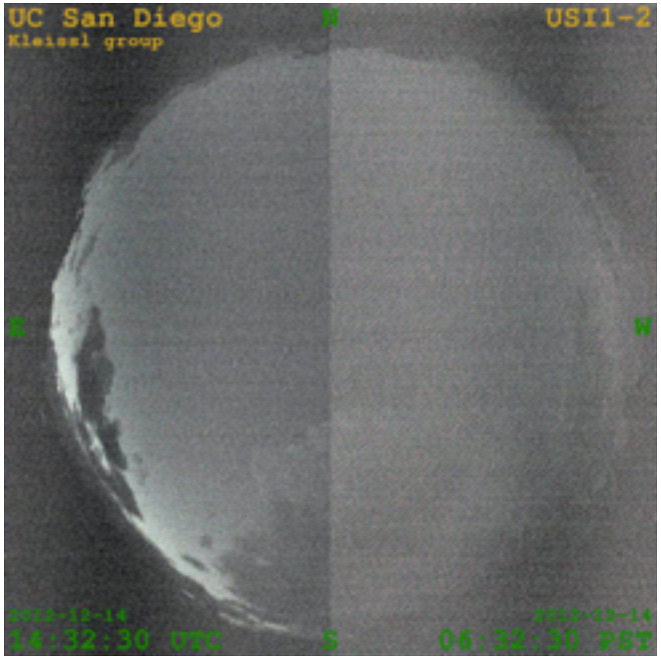
Short term solar forecasting using sky imagery

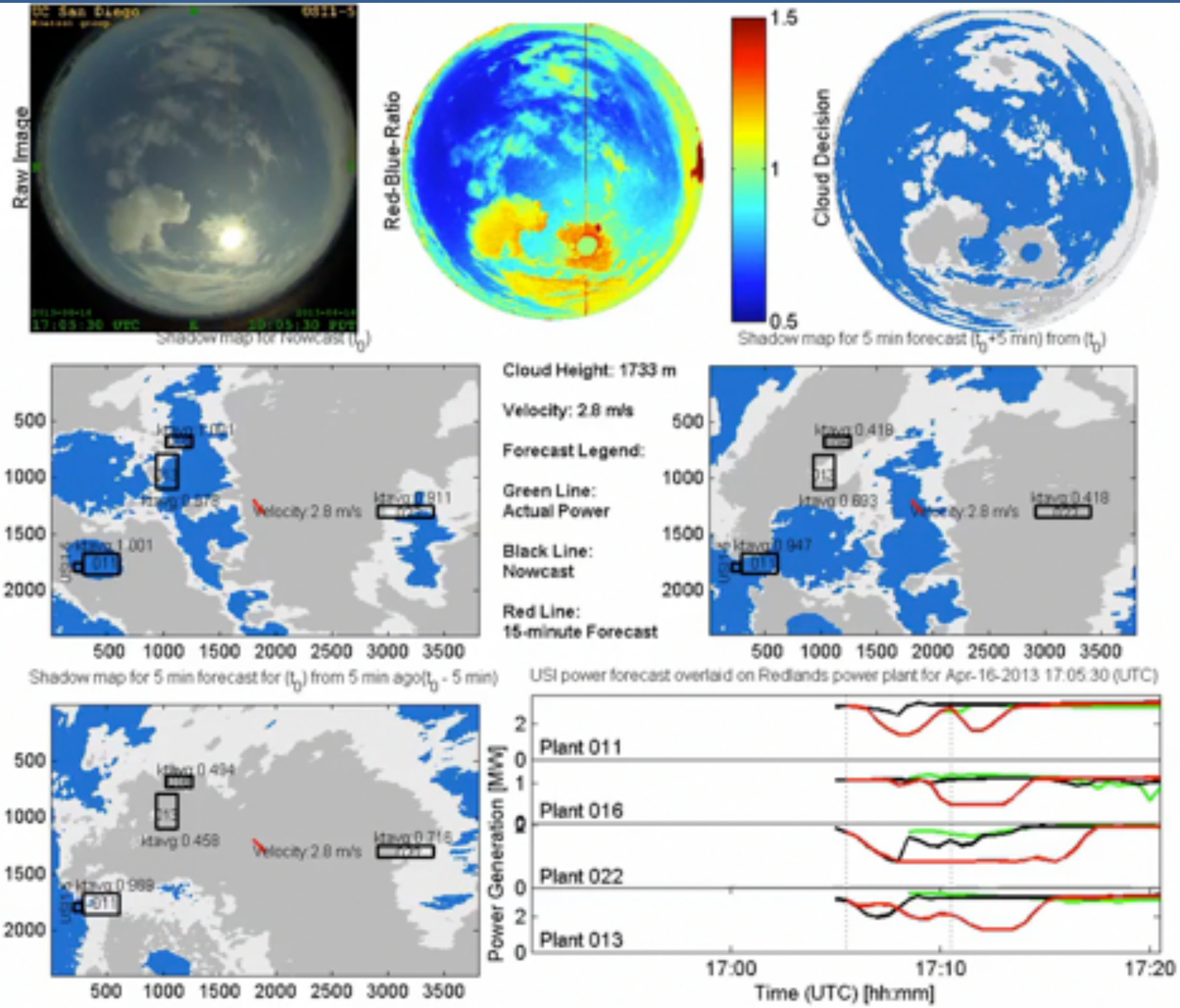
- Basic steps [1,2]:
  - Cloud detection
  - Cloud height determination
  - Cloud direction and velocity determination
  - Ray tracing/ Projection of cloud to the ground based on the Sun's location for irradiance forecast
  - Convert from irradiance to power forecast
- Provides 15-minute forecast every 30 seconds down to ground resolution of 2m x 2m.

Ray tracing of direct solar beam



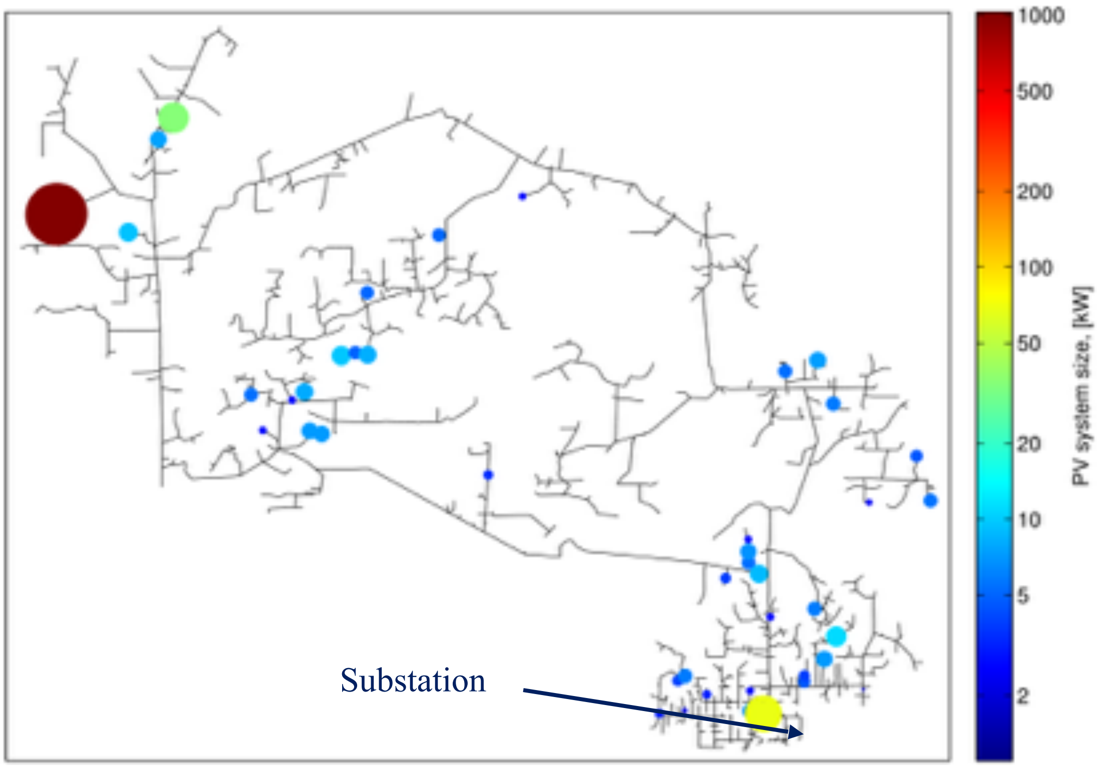
Short term solar forecasting using sky imagery





Model SDG&E feeder

- Large feeder (10 x 10 km^2) with peak load (11.12 MW) in rural area
- 1 large 2MW-PV site at the end of the feeder; Total PV: 2.3 MW peak.
- 1 large 2.5 MW load at the end of the feeder



Feeder A configuration with PV systems in circles

General information Fallbrook Feeder		
General	***Buses***	2463
	Nodes	6125
	Devices	4374
Conductors	***Length of three-phase lines***	311.953 kft / 95.08 km
	Length of two-phase lines	252.695 kft / 77.02 km
	Length of one-phase lines	18.518 kft / 5.64 km
Substation	***Voltage Level***	12 kV
Loads	***Total Active Power***	11.1225 MW
	Total Reactive Power	6.5007 MVar
	Number Of 1-Phase Loads	***556***
	Number Of 3-Phase Loads	***29***
Transformers	***Number Of Transformers***	1 (substation)
	Number Of Voltage Regulators	7
Capacitor Banks	***Total Number Of Capacitor Banks***	5 at 5 different locations
	Rating	4.3 MVar

Summary on characteristics of Feeder A

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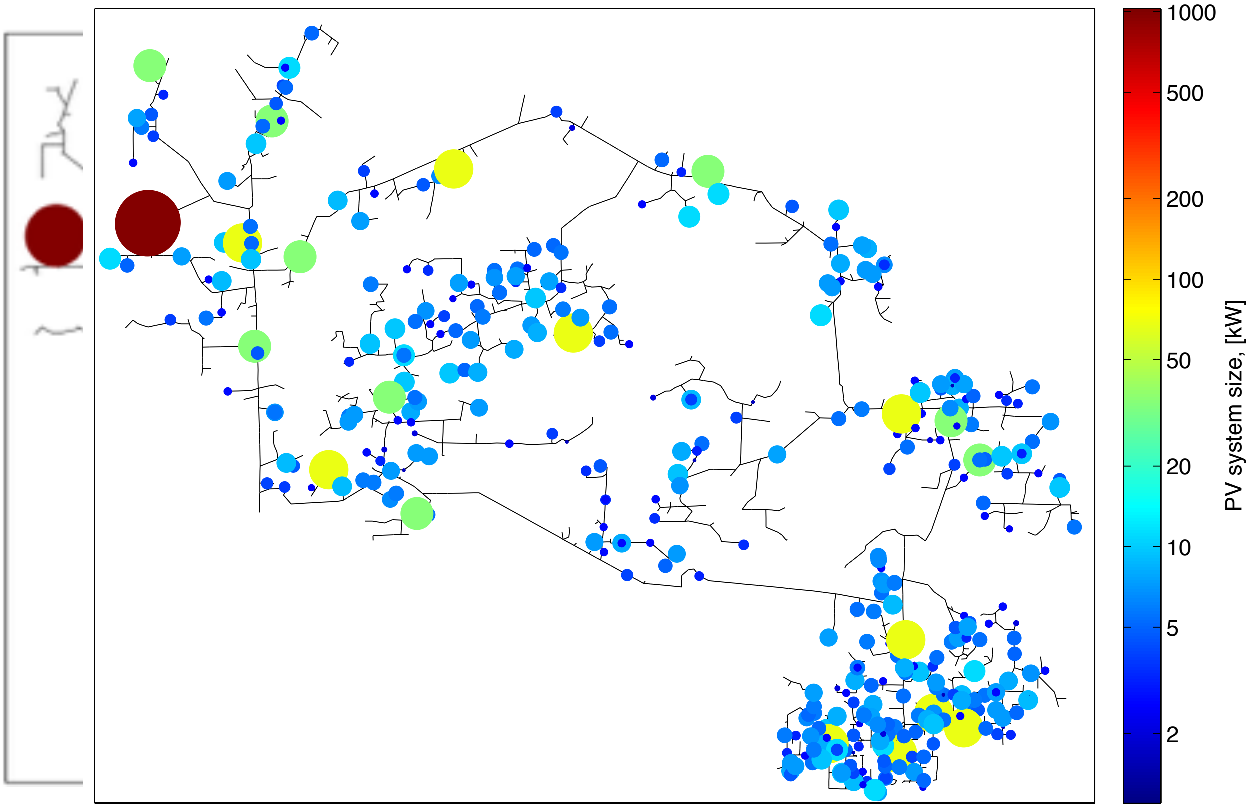

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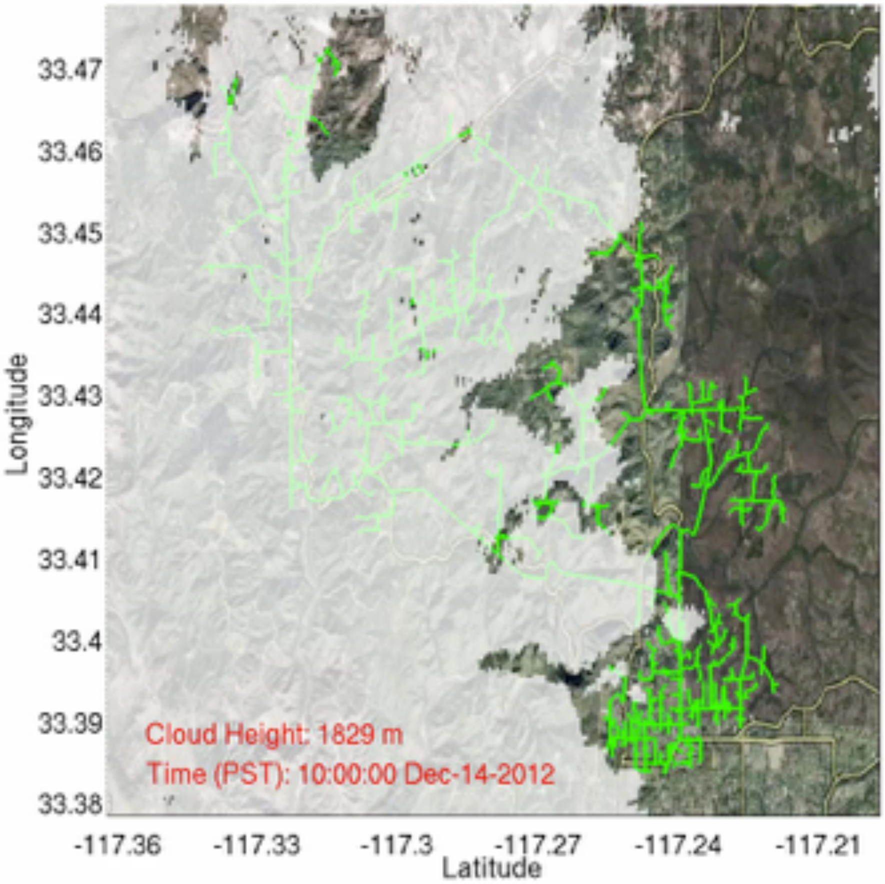
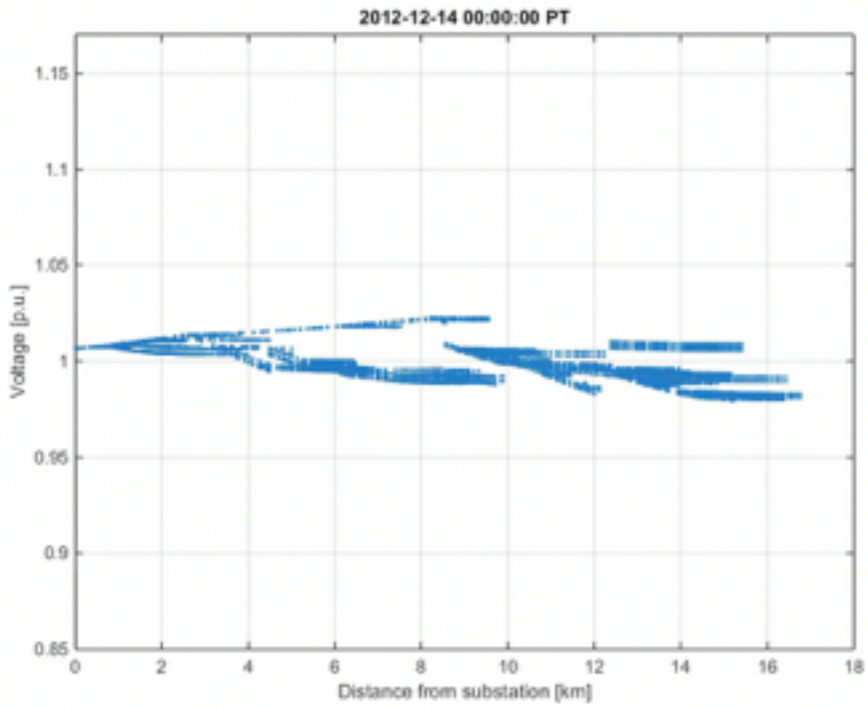
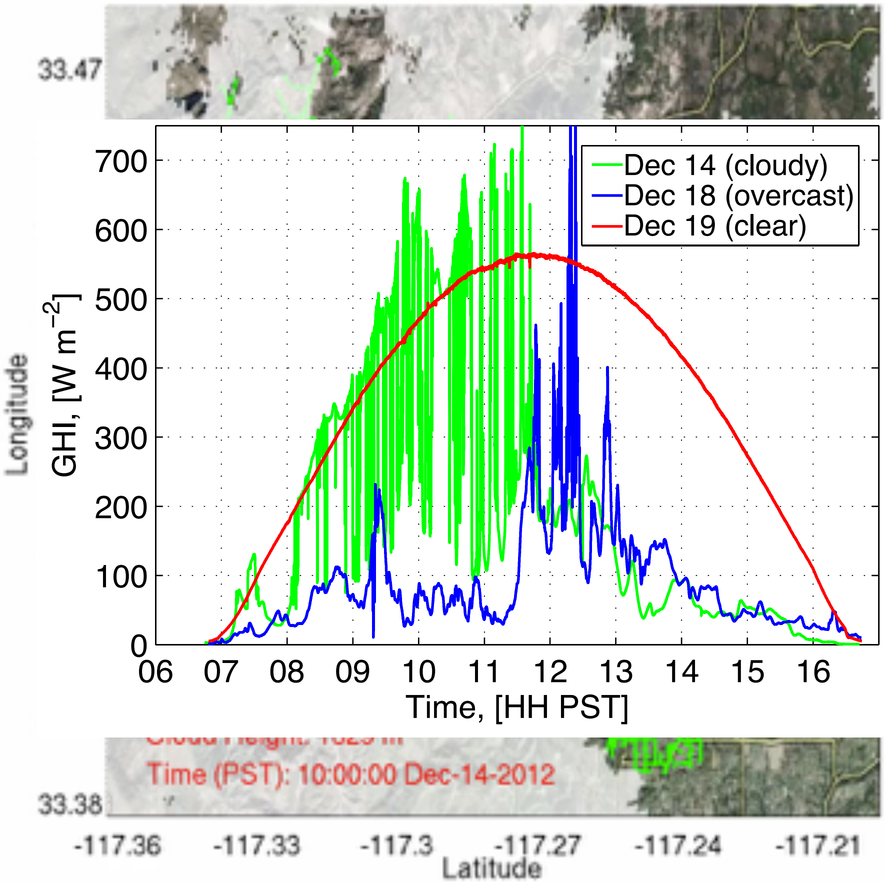
Summary on characteristics of Feeder A

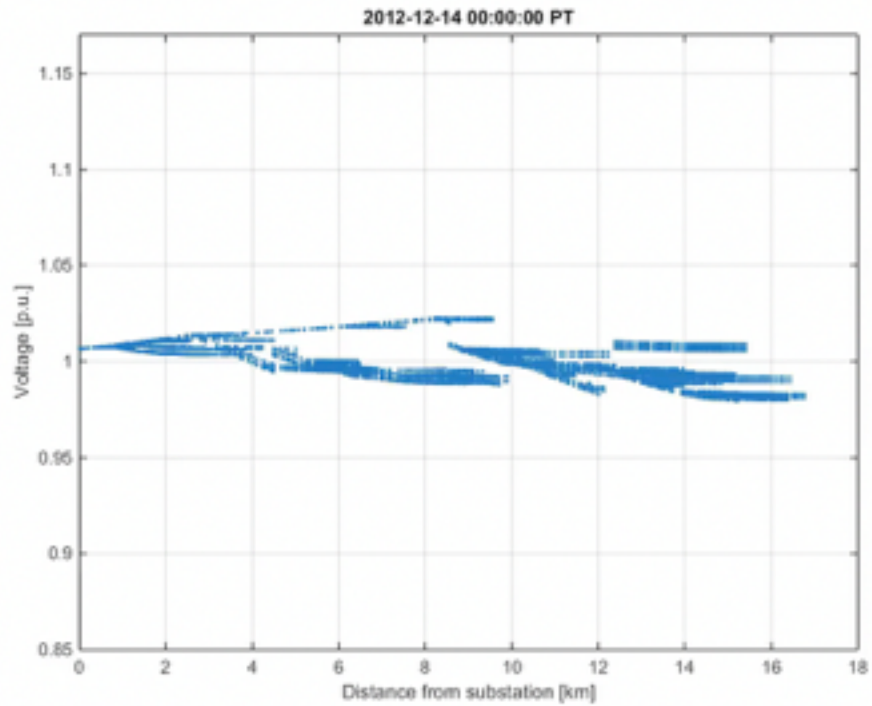
Impacts of high PV penetration on Dist. systems





Impacts of high PV penetration on Dist. systems





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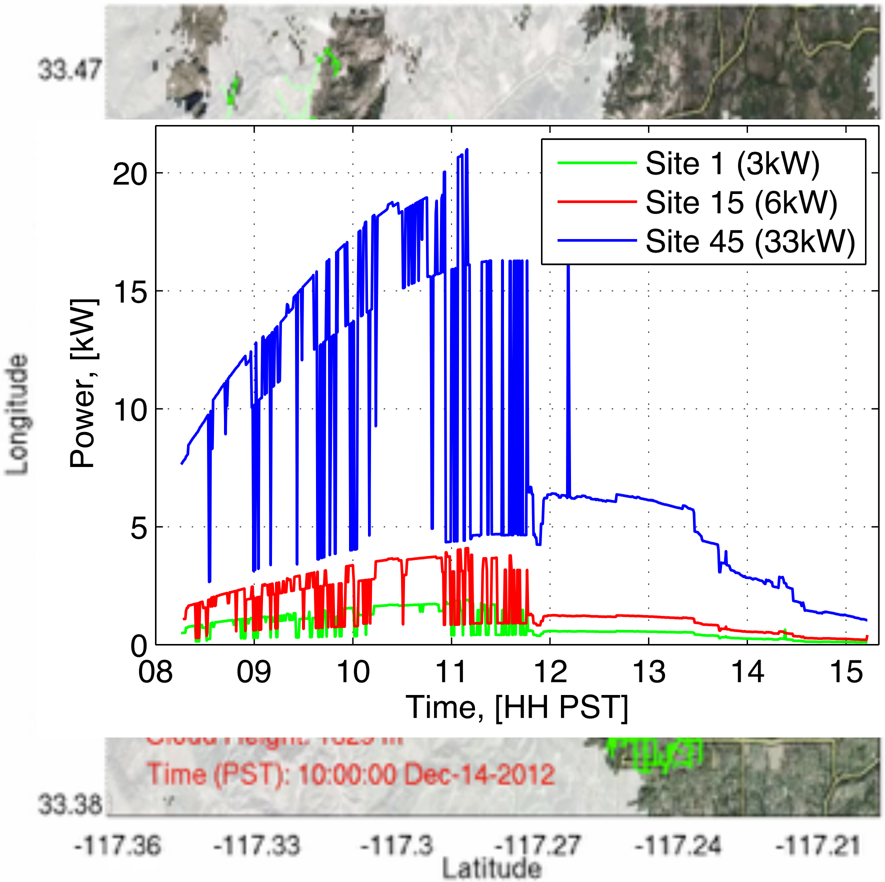
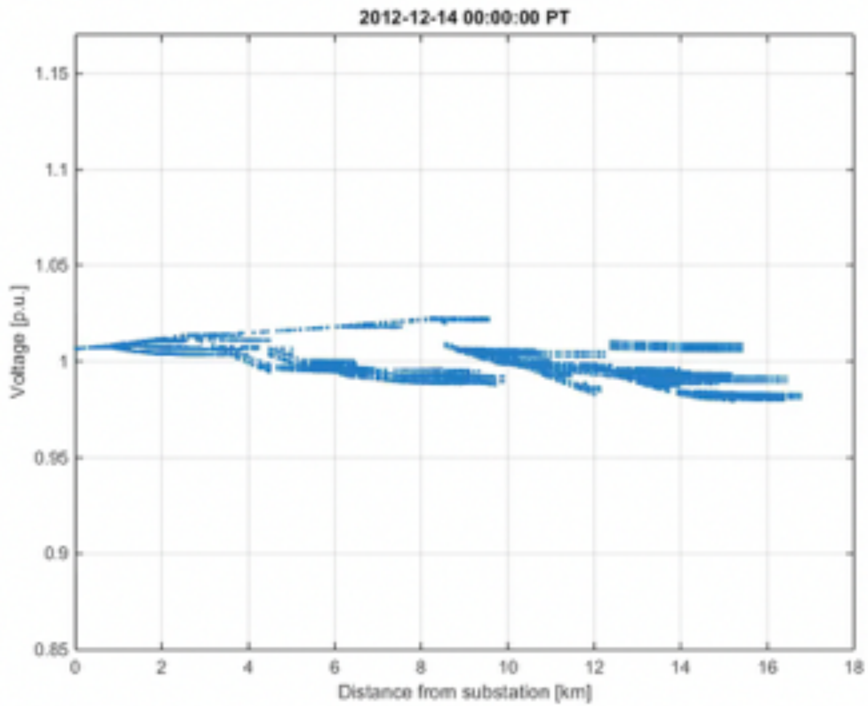
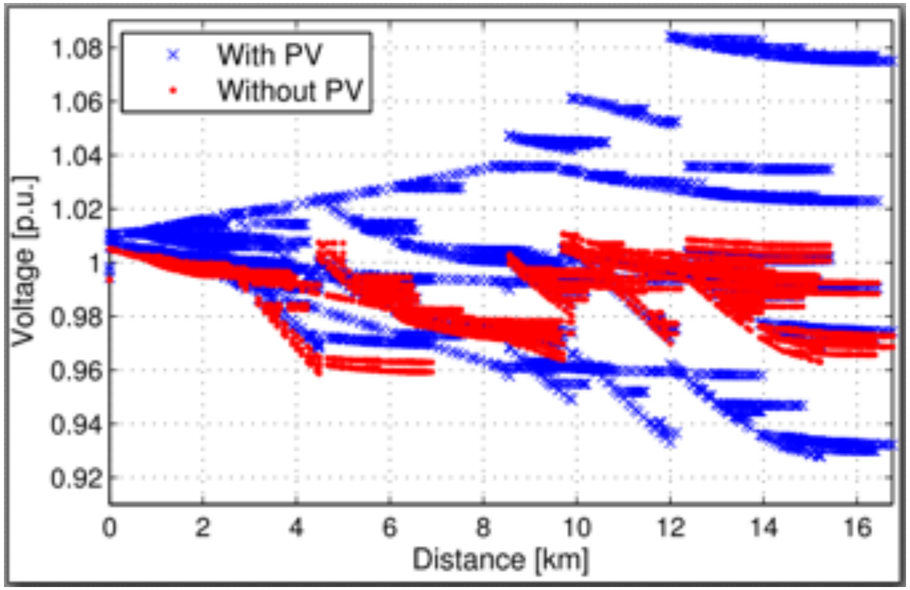
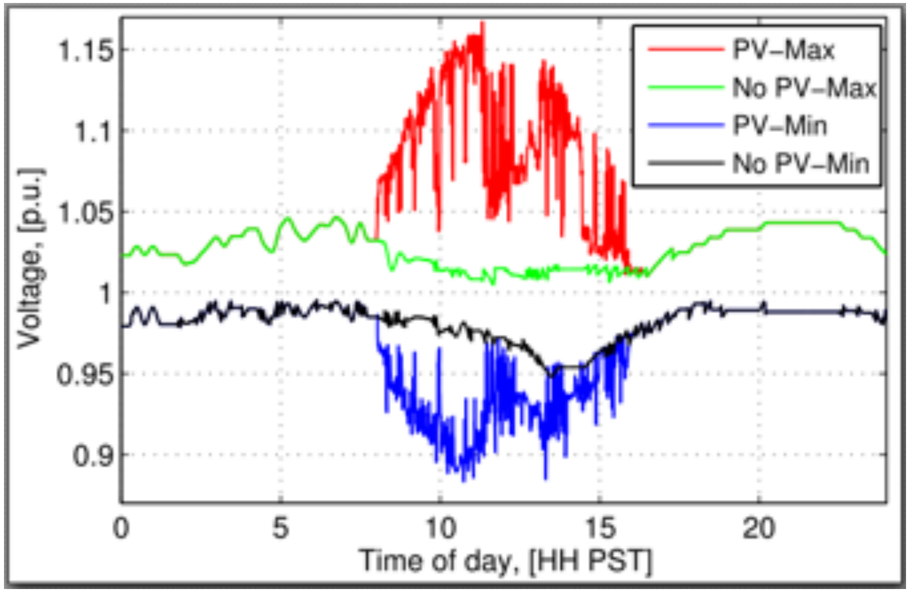




Comparison: With v.s. Without PV

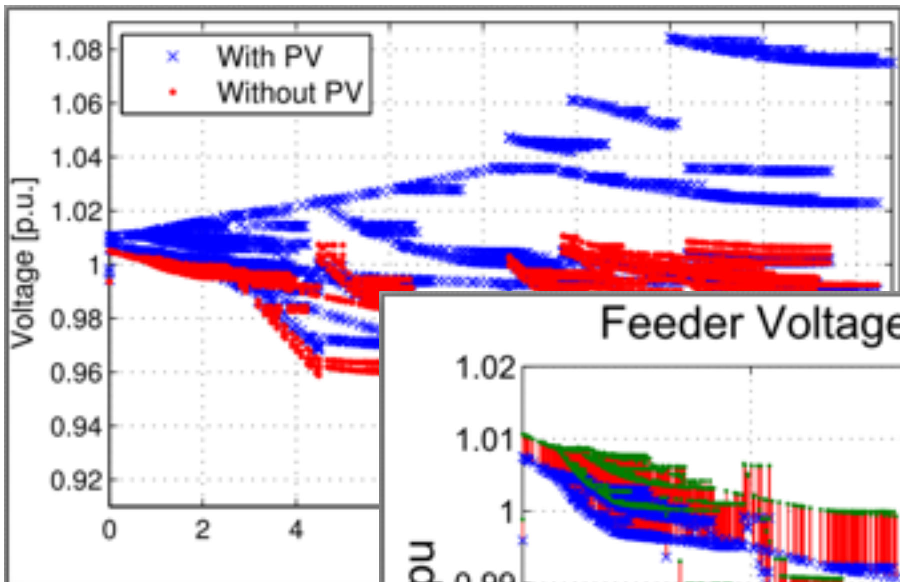


Voltage profile snapshot at 1300 PST

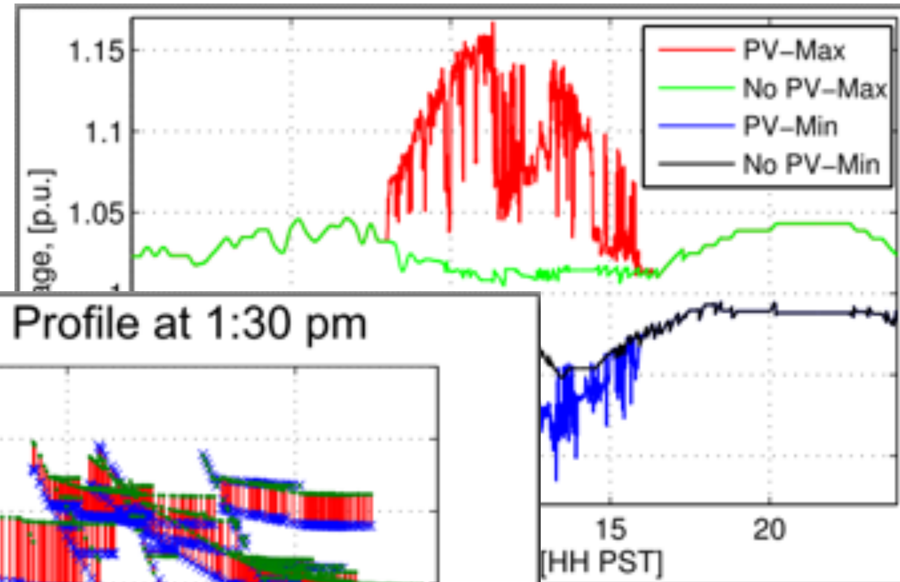


Max-min voltage profile on Feeder A during the partly cloudy day with 100% PV pen.

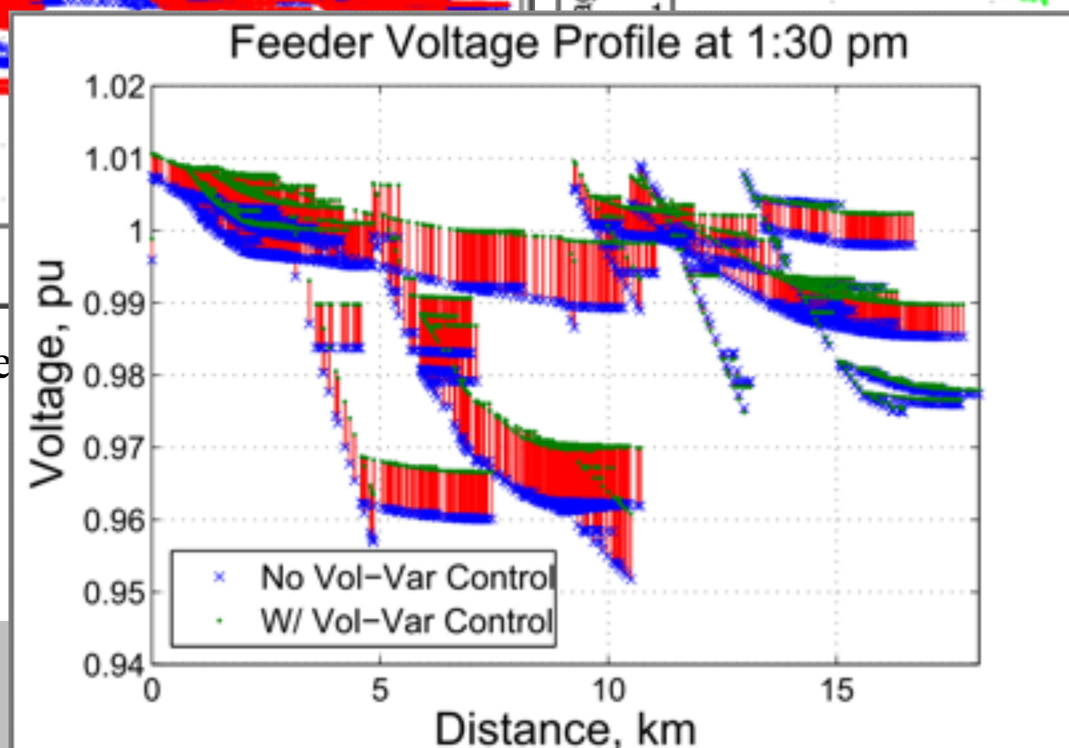
Comparison: With v.s. Without PV



Voltage profile



Feeder A during the 100% PV pen.



UCSD Laboratory

Optimization and control using PV inverters and Energy Storage systems

$$\min_{p_{\mathrm{PV}}, q_{\mathrm{PV}}, p_{\mathrm{ES}}, q_{\mathrm{ES}}} \sum_{t \in \tau} (J_{\mathrm{loss}} + \alpha_1 J_{\mathrm{power}} + \alpha_2 J_{\mathrm{ramp\_viol}} + \alpha_3 J_{\mathrm{ES\_cc}} + \alpha_4 J_{\mathrm{TO}} + \alpha_5 J_{\mathrm{VoltExcursions}})$$

$$\text{s.t.} \quad \forall t \in \tau \begin{cases} (p_k^t)^2 + (q_k^t)^2 \le S_k^{max}, & \forall k \in \mathcal{G} \cup \mathcal{S}, \\ V_{\min} \le v_k(t) \le V_{\max}, & \forall k \in \mathcal{G} \cup \mathcal{S}, \\ D_{\mathrm{dis}}^k \le d_k(t) \le D_{\mathrm{ch}}^k, & \forall k \in \mathcal{S}, \\ 0 \le c_k(0) + \frac{1}{C_k} \sum_{i=1}^{T} d_k(i) \le 1, & \forall k \in \mathcal{S}, \\ \text{Power flow equations hold} & \end{cases}$$

$$J_{\mathrm{ramp\_viol}} = \sum_{i}^{n} \left[\left(\frac{dp_{\mathrm{PV}}^i}{dt} \right)^2 - R_R^2 \right]_+ = \sum_{i}^{n} \left[\left(\frac{dp_{\mathrm{PV}}^i}{dt} \right)^2 - \left(\frac{P_{\max}^i}{60s} \right)^2 \right]_+$$

Ramp rate <10%/min

$$J_{\mathrm{TO}} = \sum |\Delta s| = \sum_{i=1}^{N_{\mathrm{VR}}} \sum_{t=0}^{T} \left| s_t^i - s_{(t-1)}^i \right|, \quad \frac{v_{t-1}^i - v_{\mathrm{ref}}^i}{v_{\mathrm{bw}}^i} - \frac{1}{2} \le s_t^i \le \frac{v_{t-1}^i - v_{\mathrm{ref}}^i}{v_{\mathrm{bw}}^i} + \frac{1}{2}, i = 1, 2, \ldots, N_{\mathrm{VR}}$$

UCSD Microgrid

UCSD Microgrid

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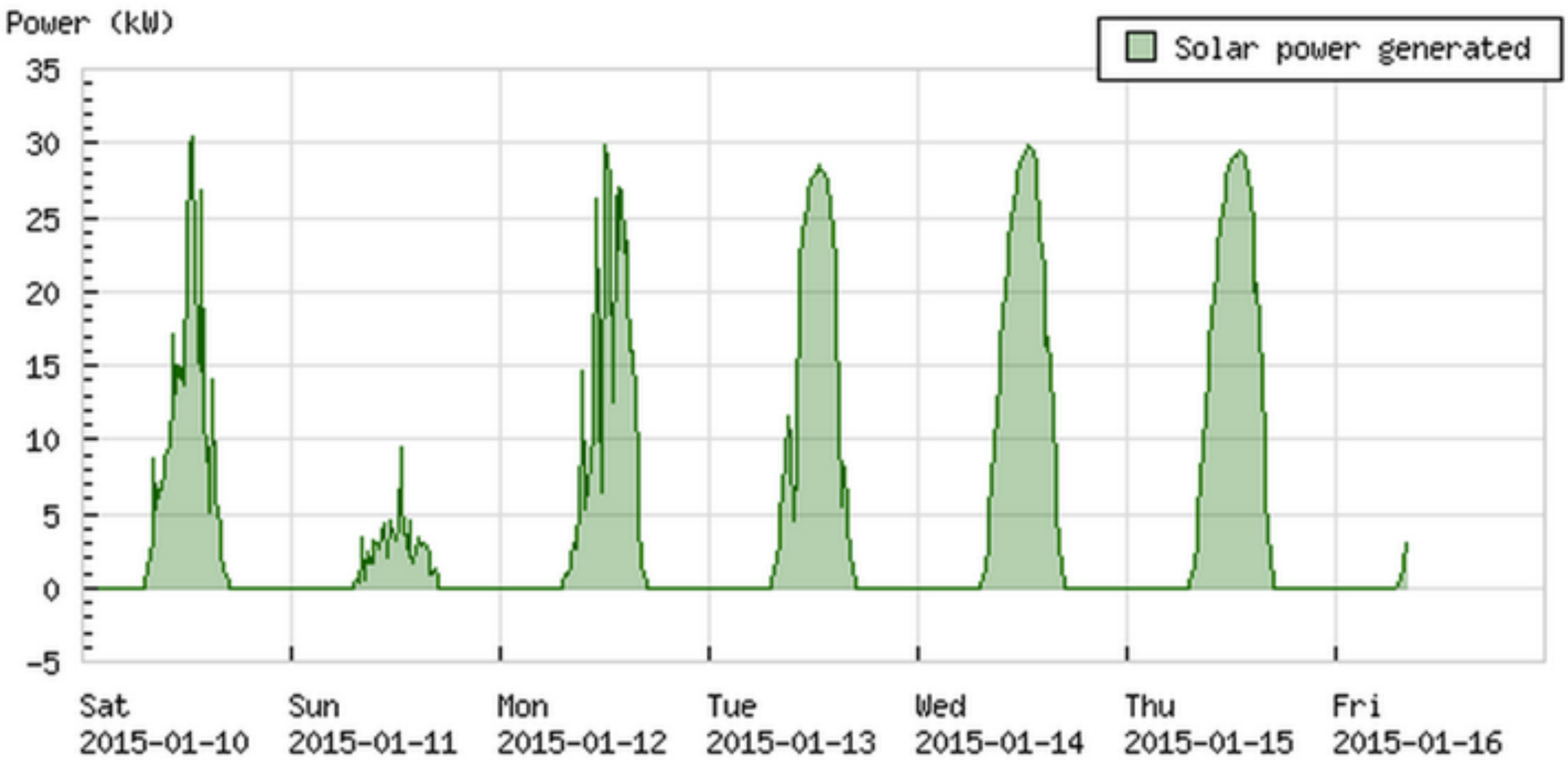
UCSD Microgrid

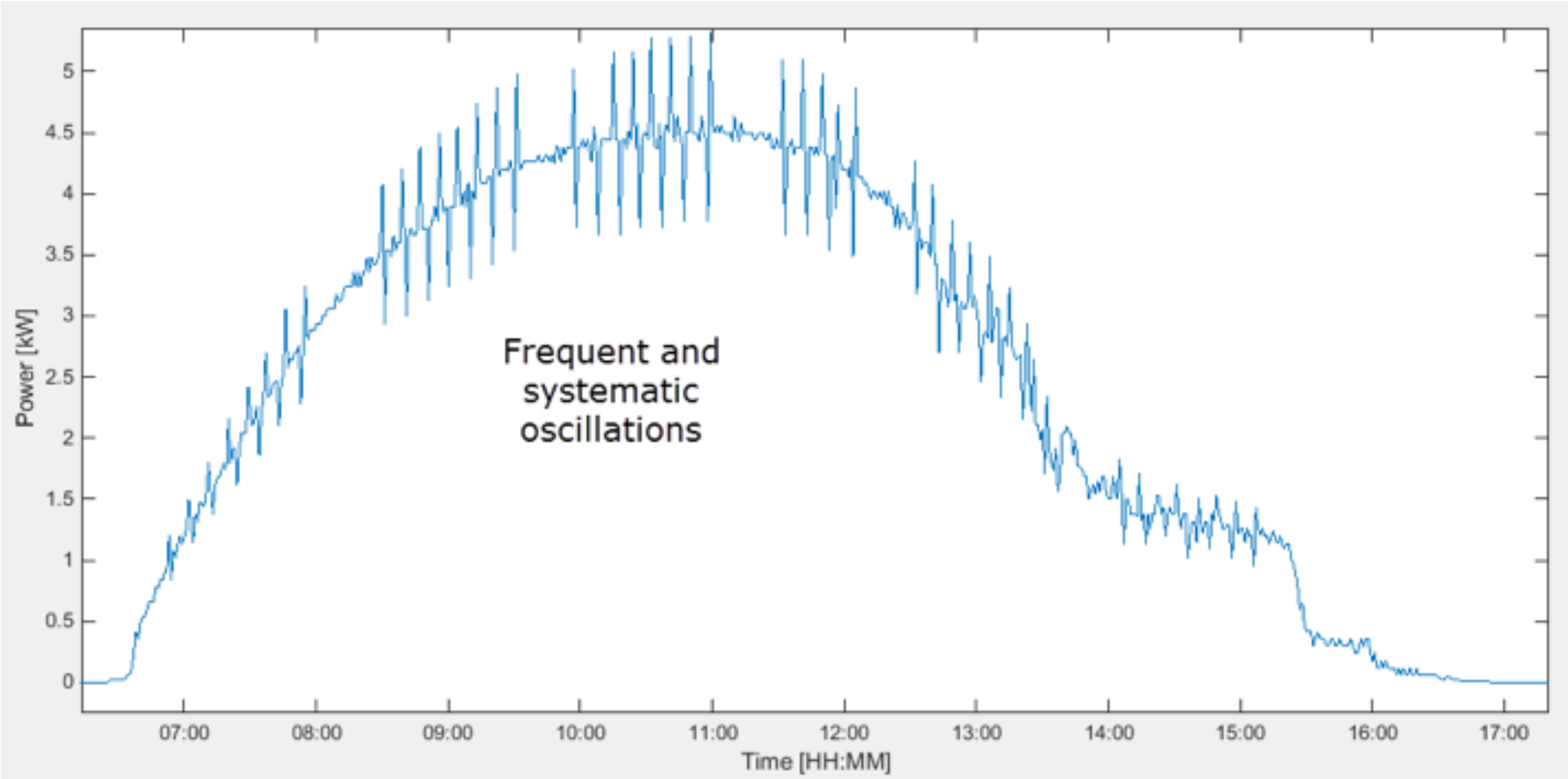
- 42 MW peak load
- 3.1 MW PV
- 2.8 MW Fuel Cell
- 30 MW Natural gas plant generating 80% annual demand
- 1.8 MW / 11.2 MWh electric energy storage
- Meters 50,000 data points for power, voltage, current, temperature, etc.
- 5 PMUs currently, and planning to install 15 more in coming year

UCSD Microgrid



UCSD Microgrid

Thank you! Questions?



- Food for thought: SolarCity's 1-min data

Contacts

- If you are interested in the videos, please contact me using my email below and I'll send them separately to you since some of them are quite large in size.
  - Andu Nguyen: andunguyen.ucsd@gmail.com or andunguyen@ucsd.edu
- You can also contact my advisor if you are interested in our work in general. His email is below:
  - Jan Kleissl: jkleissl@ucsd.edu