Short Term Solar Forecasting Using Sky Imagery and Its Applications in Control and Optimization for a Smart Grid
Andu Nguyen (andunguyen@ucsd.edu) and Jan Kleissl (jkleissl@ucsd.edu) at UC San Diego’s SRAF Lab

**Short-term Solar Forecasting**

**Goal:** Forecast solar generation in short time scale (0-30 minutes) with high temporal resolution to build smart controls for storage systems (charge/discharge), power inverters, voltage regulators, smart switching devices, etc. This helps to save generation and maintenance cost while keeping power quality high.

**Algorithm:**
1. **Cloud Detection:** Using image processing to distinguish cloud from clear sky by RBR value.
2. **Cloud projection into an earth coordinate system.**
3. **Cloud speed and direction calculation:** Using image segment correlation.
4. **Modeling cloud motion forward in time using the cloud detection and the motion vectors.**
5. **Projection of cloud shadows on the ground for irradianc forecasting of solar panels.**

Sample of a forecast process done at UCSD. Green line is 5-minute forecast and black line is measured data.

### Issues with High PV Penetration

- High frequency -> Impact frequency control and generators’ synchronization -> power outage.
- Over-voltages -> damage electronic devices (light bulbs, computers, monitors, etc.)
- Voltage fluctuations -> shorten lifetime of voltage regulators, transformers, protection devices, etc.)

Real 12MW (1733 loads) SDG&E distribution feeder with 2.3 MW PV. Simulated case with 5MW installed PV (42%) is shown.

**Centralized and Distributed Control for PV Inverters and ESSs**

We are designing centralized and distributed control for multiple power inverters, storage systems, EV chargers, etc. for UCSD microgrid and SDG&E feeders. The distributed control will (1) mitigate the impact of high penetration PV and (2) optimize the communication and interaction between all devices in smart grid setup.

\[
J(u) = \sum_{t=1}^{T} (J_{\text{loss}}(u(t)) + \delta J_{\text{power}}(u(t)))
\]

**Optimization Problem:**

- \[ \min J \]
- \[ \forall t \in \mathbb{T} \]
- \[ U_{\text{min}} \leq u(t)[v(t)] \leq U_{\text{max}}, \forall t \in \mathbb{G} \]
- \[ 0 \leq \alpha(t) \leq 1, \forall t \in \mathbb{U} \]
- Power flow equations hold

By combining USI forecast and distribution system simulation using OpenDSS, we were able to design and demonstrate the impact of local volt-var control on the distribution network. With appropriate control design, the use of PV inverter reactive support will lessen the adverse impact of high PV penetration.

Cloud cover simulation on SDG&E feeder using sky image forecast. The green lines are feeder distribution lines. Whitish area is covered by cloud.

Results in table below shows that the incorporation of forecast data was shown to dramatically increase system lifetime (6 years extra) and its lifetime profit (360% increase on a 31 kWh storage system).

### Peak load shaving control with Short-term Solar Forecast for Storage System

Control with Sky Imagery Solar Forecast was developed for a 31kW PV tied to a 31 kWh Li-ion at John Hopkins parking structure at UCSD, CA. The solar forecasts were used to optimize the charge/discharge cycling for peak load shaving and battery life longevity. The strategy for peak load shaving is “Time-of-use Energy Cost Management Plus Demand Charge Management.”