



CSI Solar RD&D Program  
[www.calsolarresearch.ca.gov](http://www.calsolarresearch.ca.gov)

**Itron** CSI RD&D  
Program Manager

# Forecasting and Storage Control to Mitigate Large Ramps

Jan Kleissl

Professor, Mechanical & Environmental Engineering, UC San Diego

Co-Director, UCSD Center for Energy Research

<http://solar.ucsd.edu>



Collaborators: Juan Luis Bosch, Dinos Gonatas

# Problem Statement

---

- Higher PV penetration can cause voltage problems on microgrids and feeders.
- California to require energy storage for applications including ancillary services, but needs to be *cost effective*.

# Project Goal

---

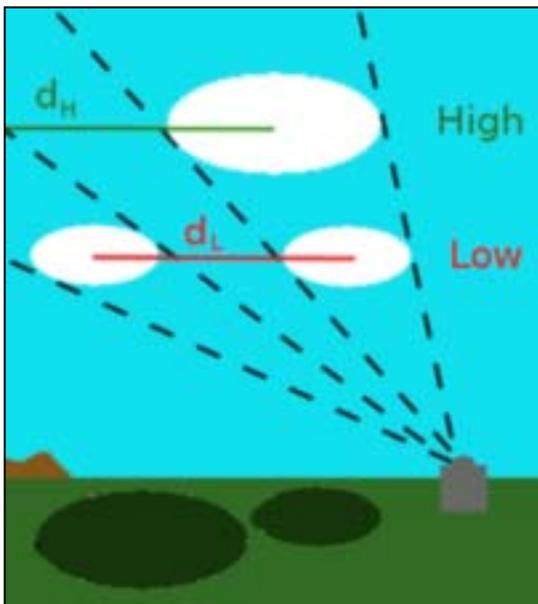
- Mitigate large ramp rates from solar power.
- Reduce storage capacity required to do so.

# Proposed Solution: Smart Ramp Smoothing

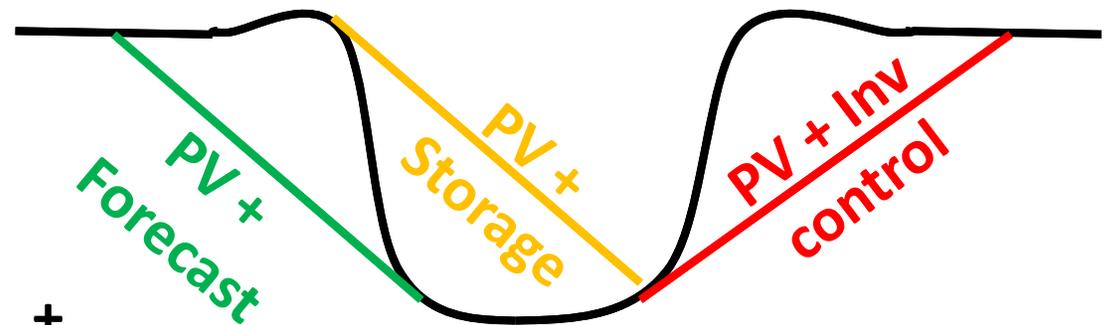
PV Array



Battery



+  
Sky Imaging Camera/  
Production Forecasting



↑  
**Inverter and Battery  
Controls**

# Overview

---

- Task 2: Sky Imager Solar Forecasting
  - More accurate forecasting through cloud height.
- Task 3: Energy Storage Controller and Demonstration

# Task 2

---

- Improve accuracy of sky imager solar forecasting.

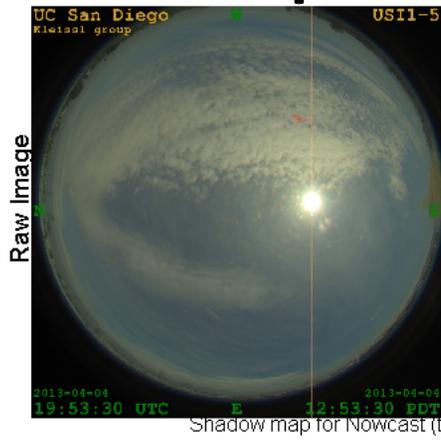
## Deliverables

- Report on accuracy of cloud base height
- Cloud base height algorithm

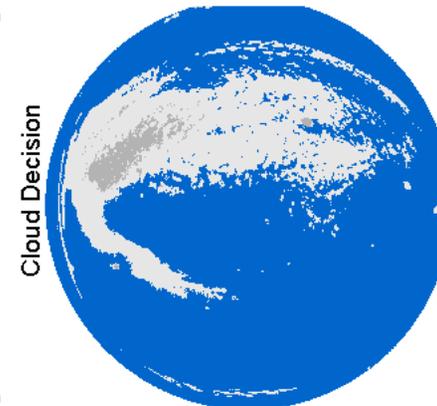
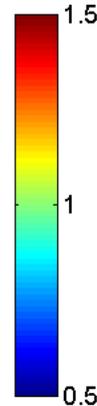
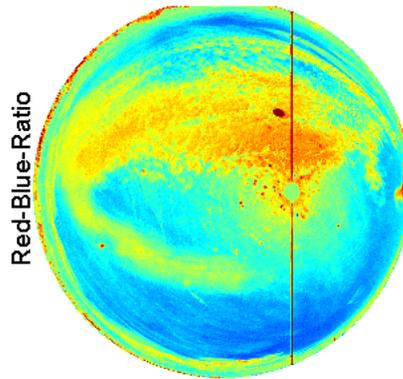
# UCSD Imaging Camera Installation



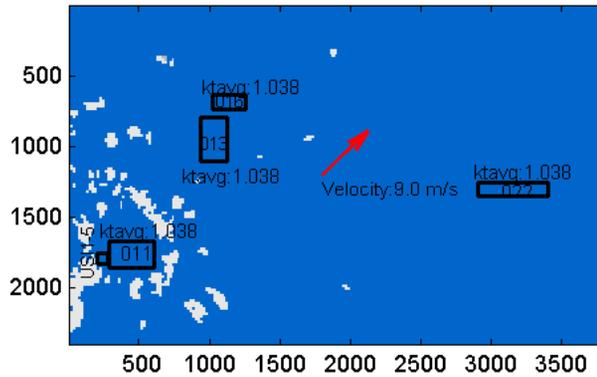
# Example of Cloud Band Results



Shadow map for Nowcast ( $t_0$ )



Shadow map for 5 min forecast ( $t_0+5$  min) from ( $t_0$ )



Shadow map for 5 min forecast for ( $t_0$ ) from 5 min ago ( $t_0 - 5$  min)

Cloud Height: 3414 m

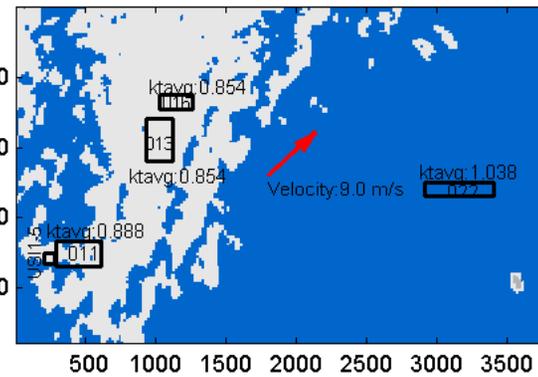
Velocity: 9.0 m/s

Forecast Legend:

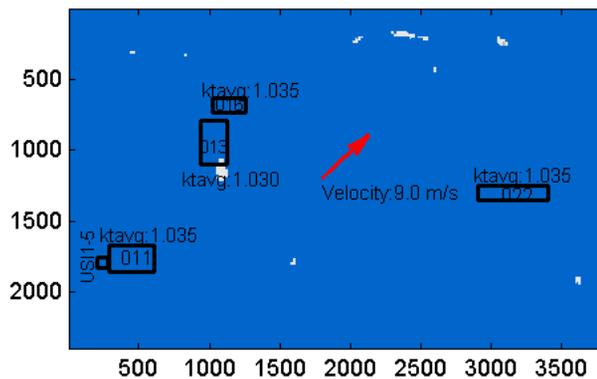
Green Line:  
Actual Power

Black Line:  
Nowcast

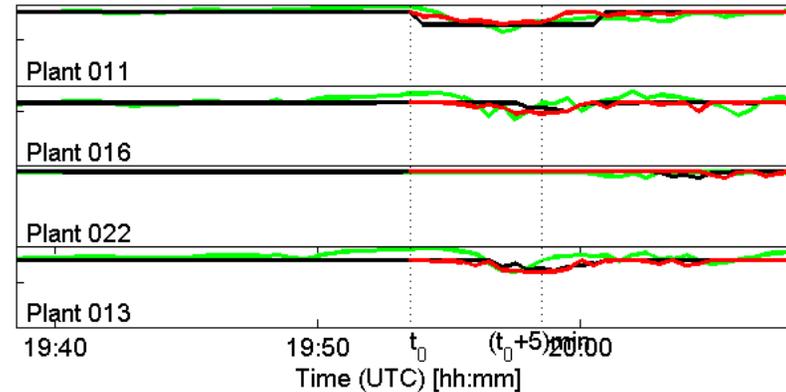
Red Line:  
15-minute Forecast



USI power forecast overlaid on Redlands power plant for Apr-04-2013 19:53:30 (UTC)

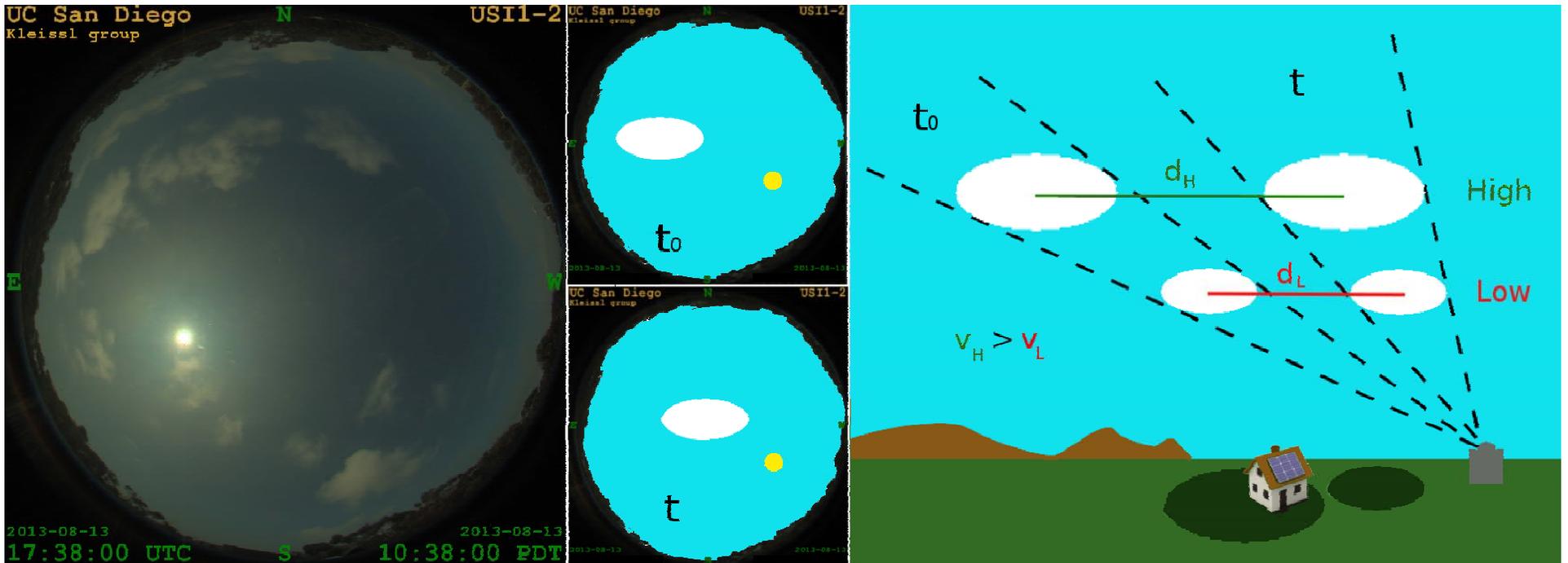


Power Generation



# Cloud Height Optimization

- Cloud height errors result in cloud projection and speed errors.
- Co-located measurements of cloud speed constrain cloud height



# Task 3

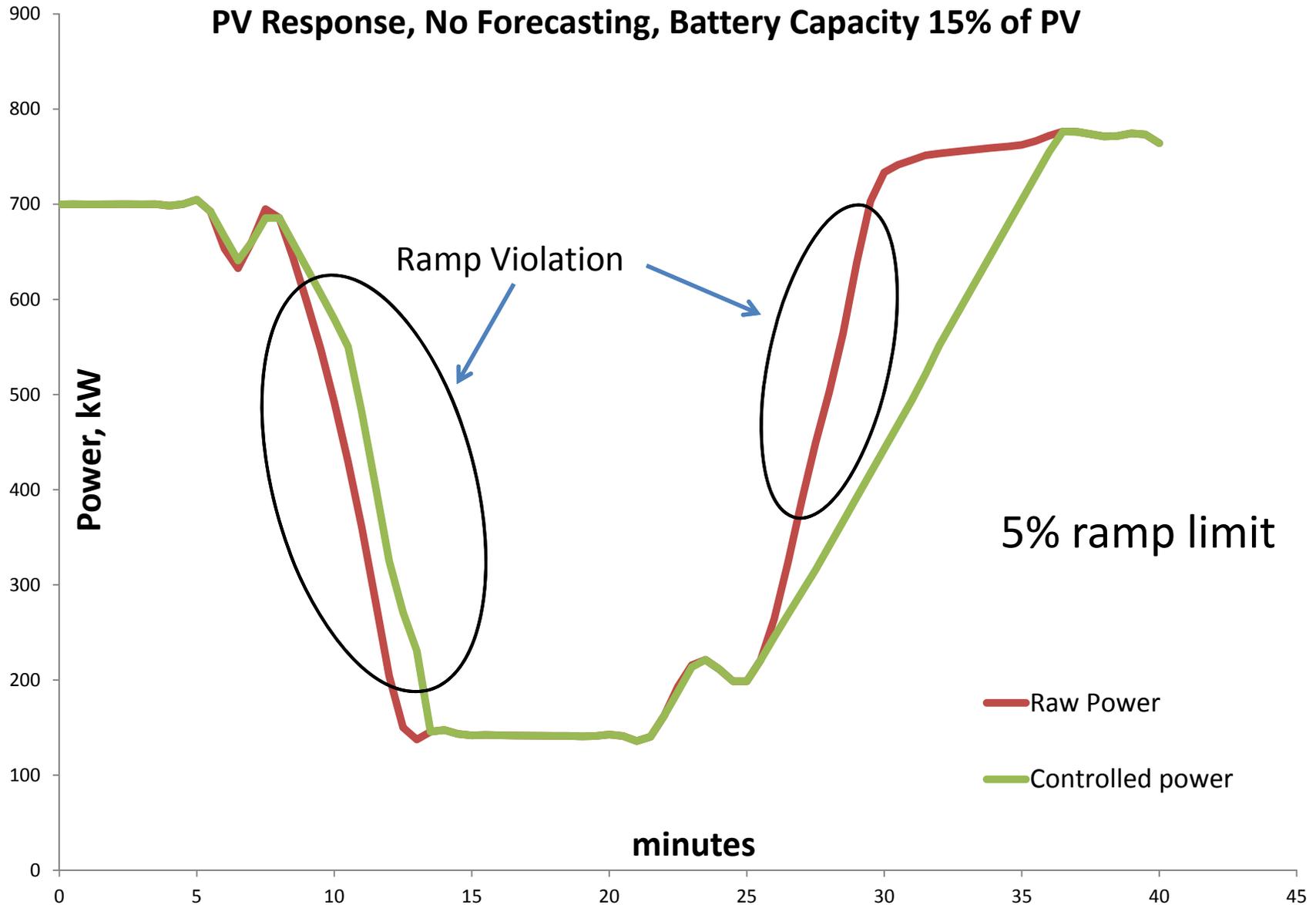
---

- Develop energy storage ramp rate controller.
  - Mitigate large PV ramps
  - Reduce required battery capacity
- Demonstrate on a real storage system.

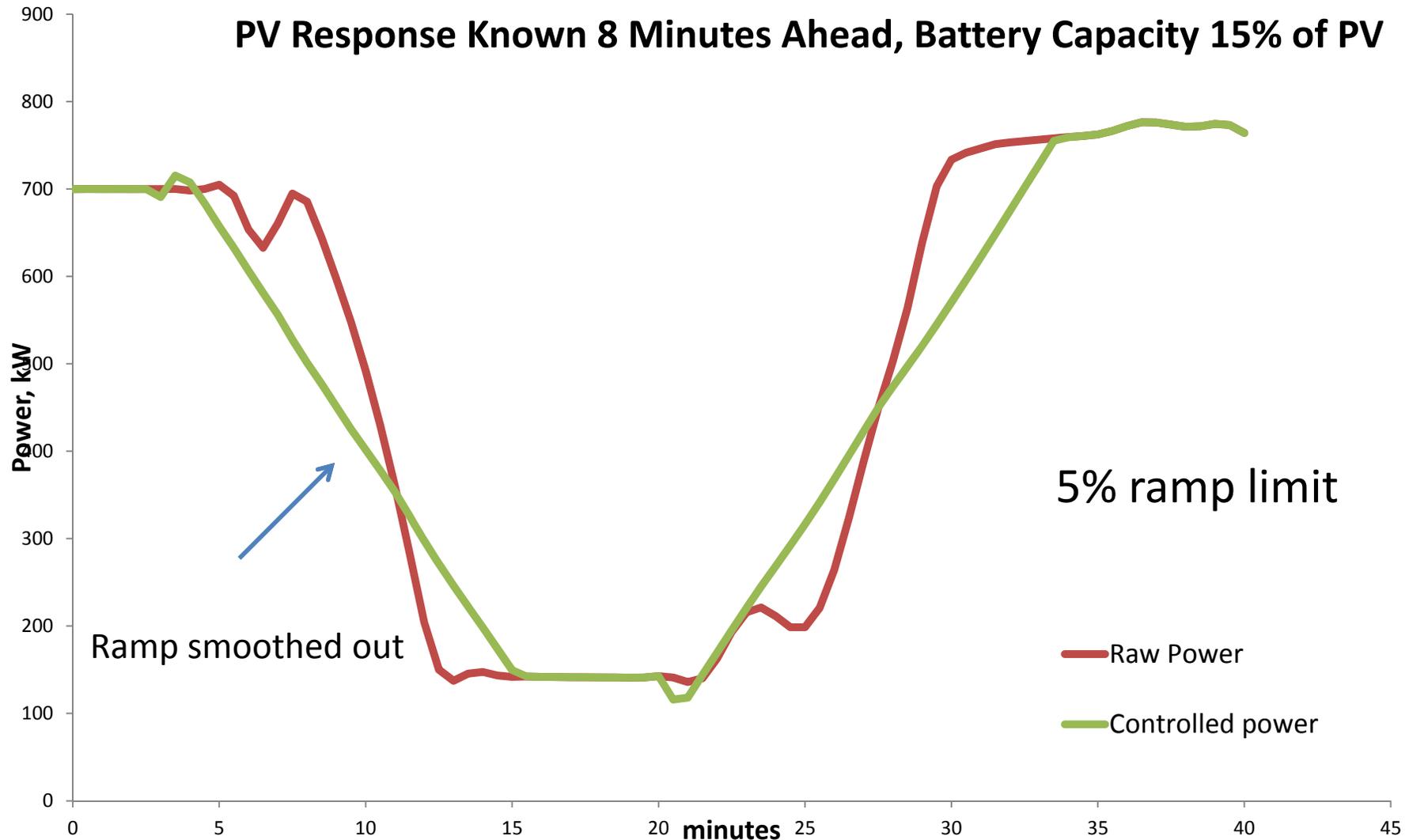
## Deliverables

- Report on performance of the energy storage controller.
- Battery storage and inverter control algorithm.

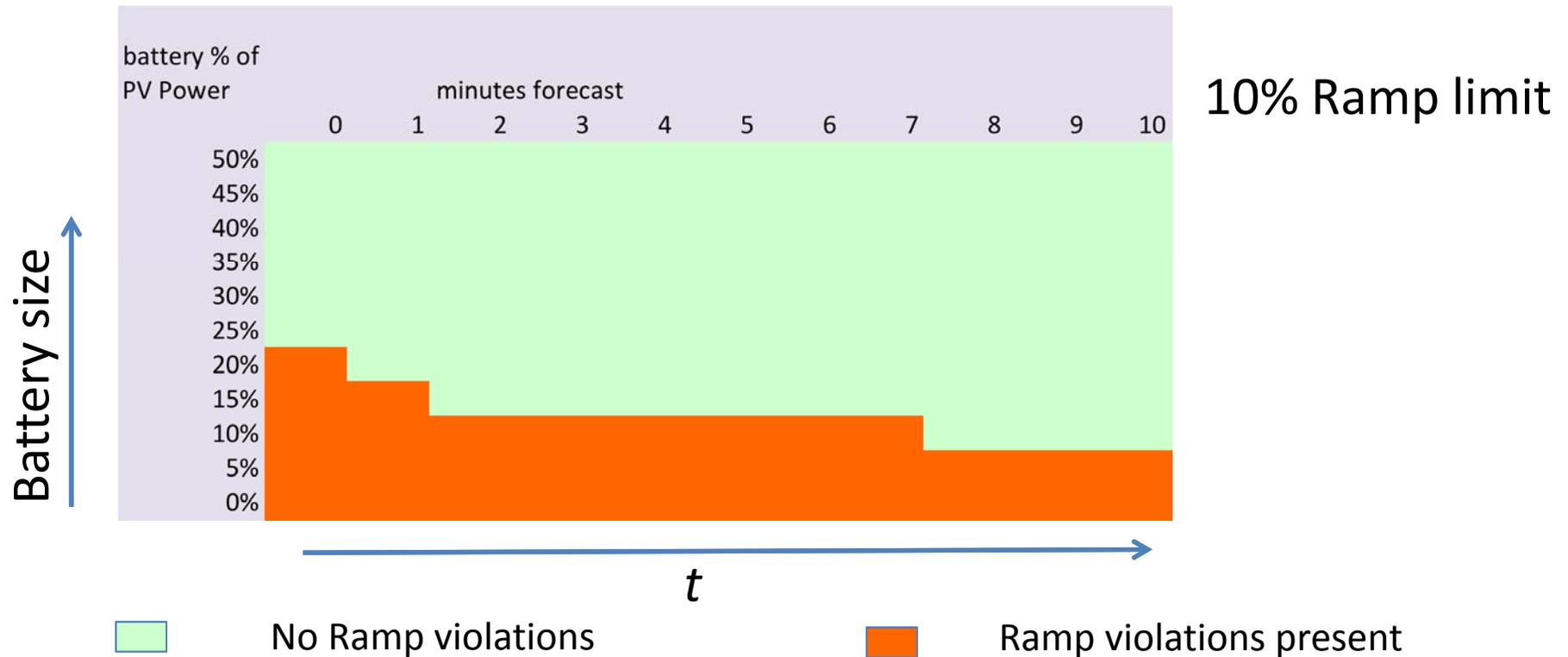
# Ramp Control without Forecasting



# Knowing Future Production Mitigates Ramps



# Ramp Violations Eliminated With Right Combination of Forecast and Battery



- With 8 min forecast, 50% smaller battery is sufficient to reduce ramps.