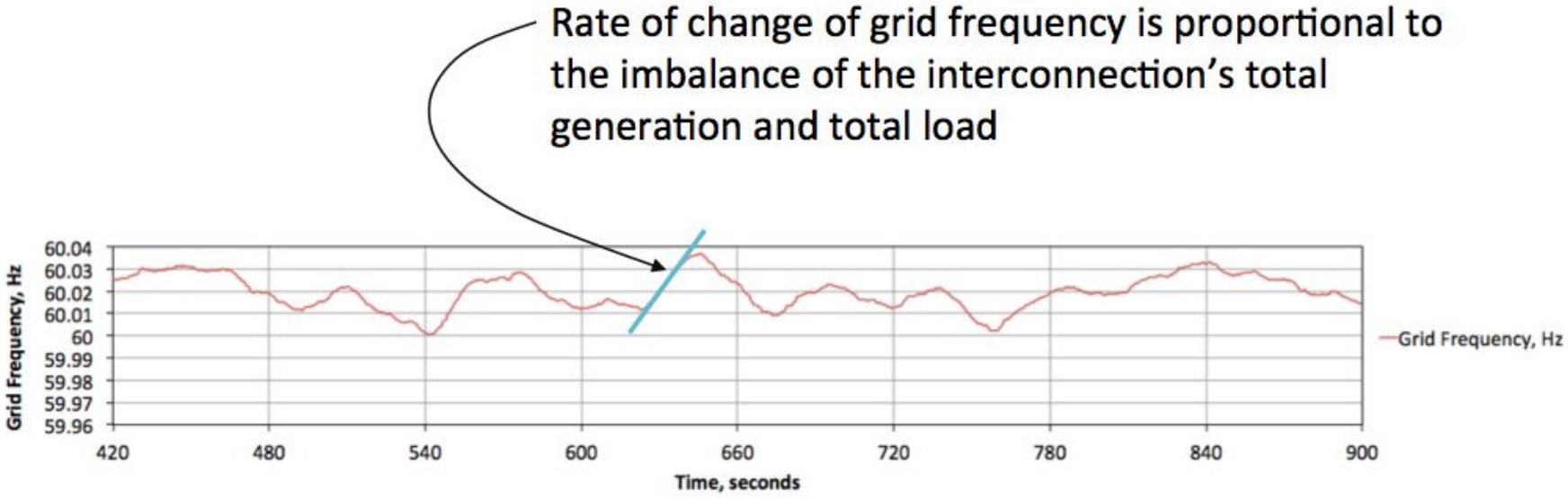
Real Time Applications for Smart Charging

Alec N Brooks
VP and CTO, Efficient Energy Systems

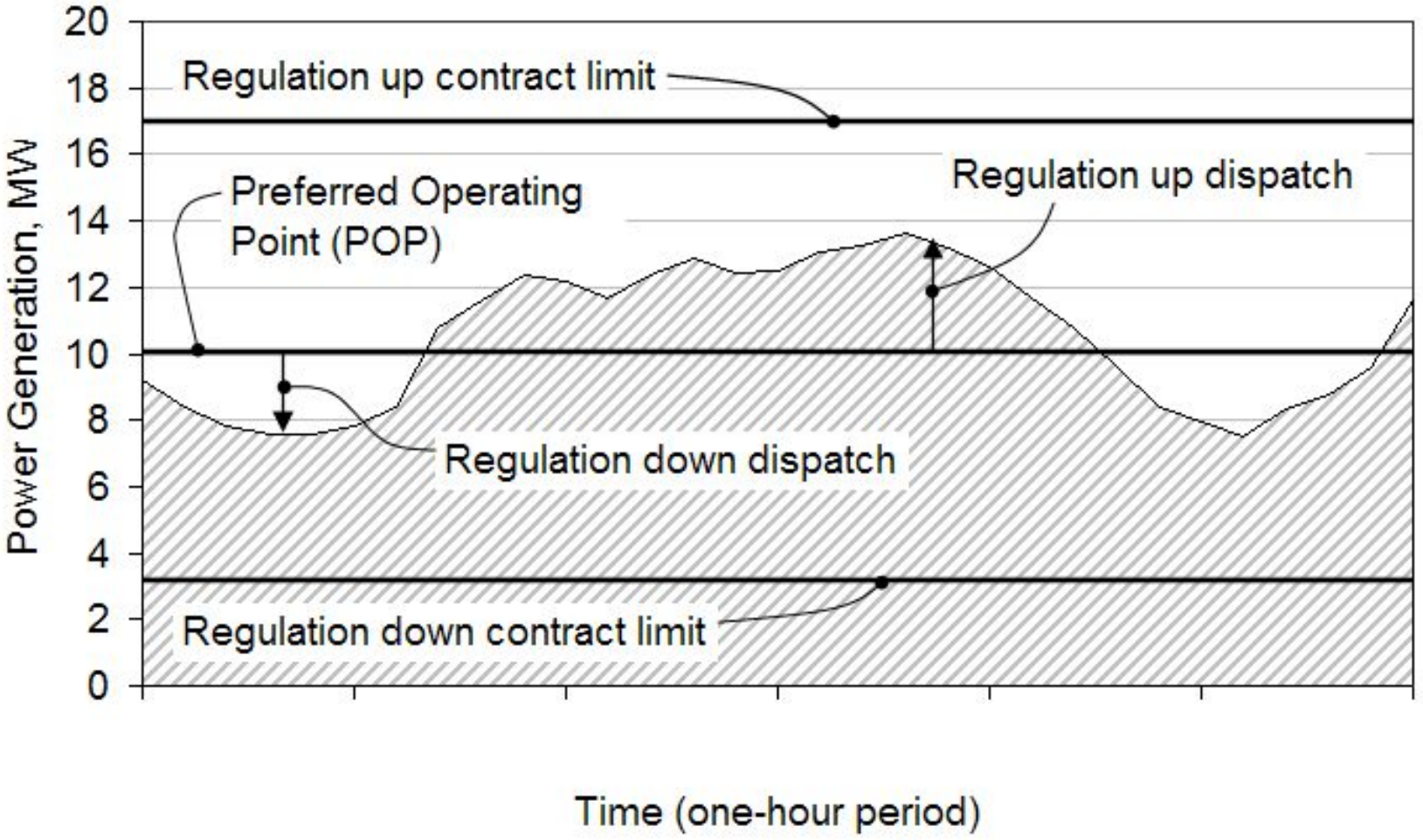
UCS Smart Charging Workshop
June 3, 2016

Grid Frequency trace shows overall balance of supply and demand



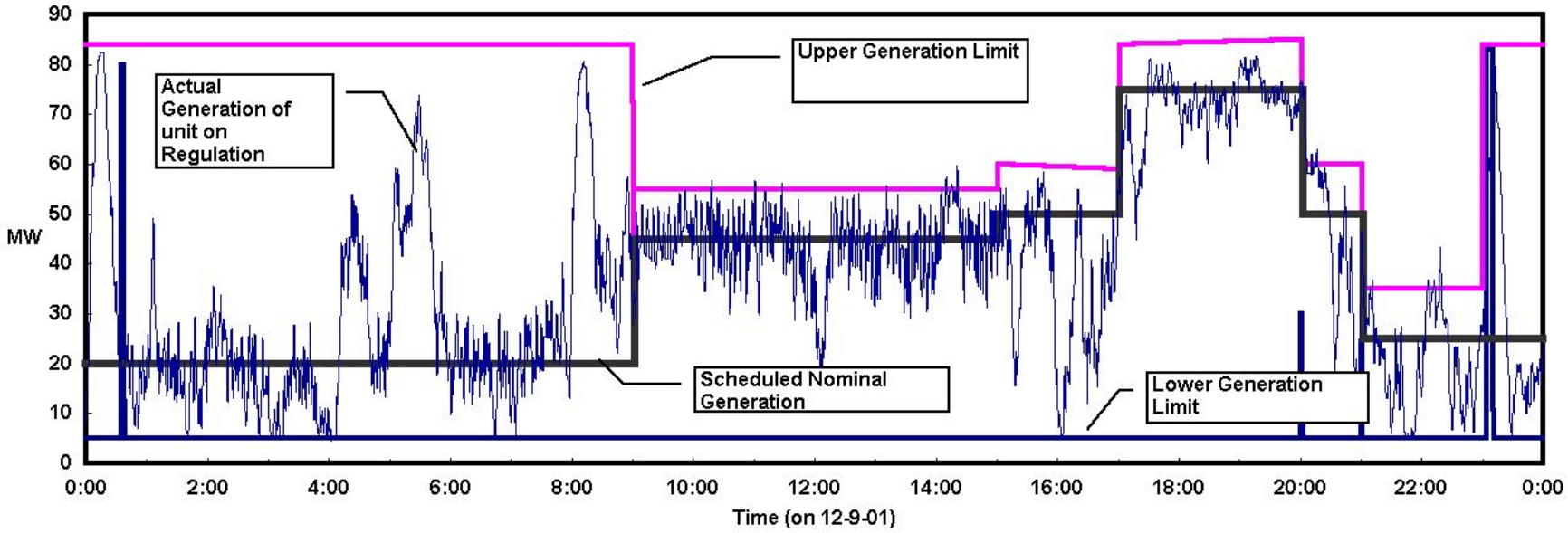
- Grid frequency is regulated by a control loop that responds to deviation of actual frequency from target frequency
- Powerplants contract to provide real-time control of power output by the grid operator's Energy Management System (EMS)
- Powerplants also have autonomous frequency responsive generation, aka "droop characteristic"

Frequency Regulation Definitions



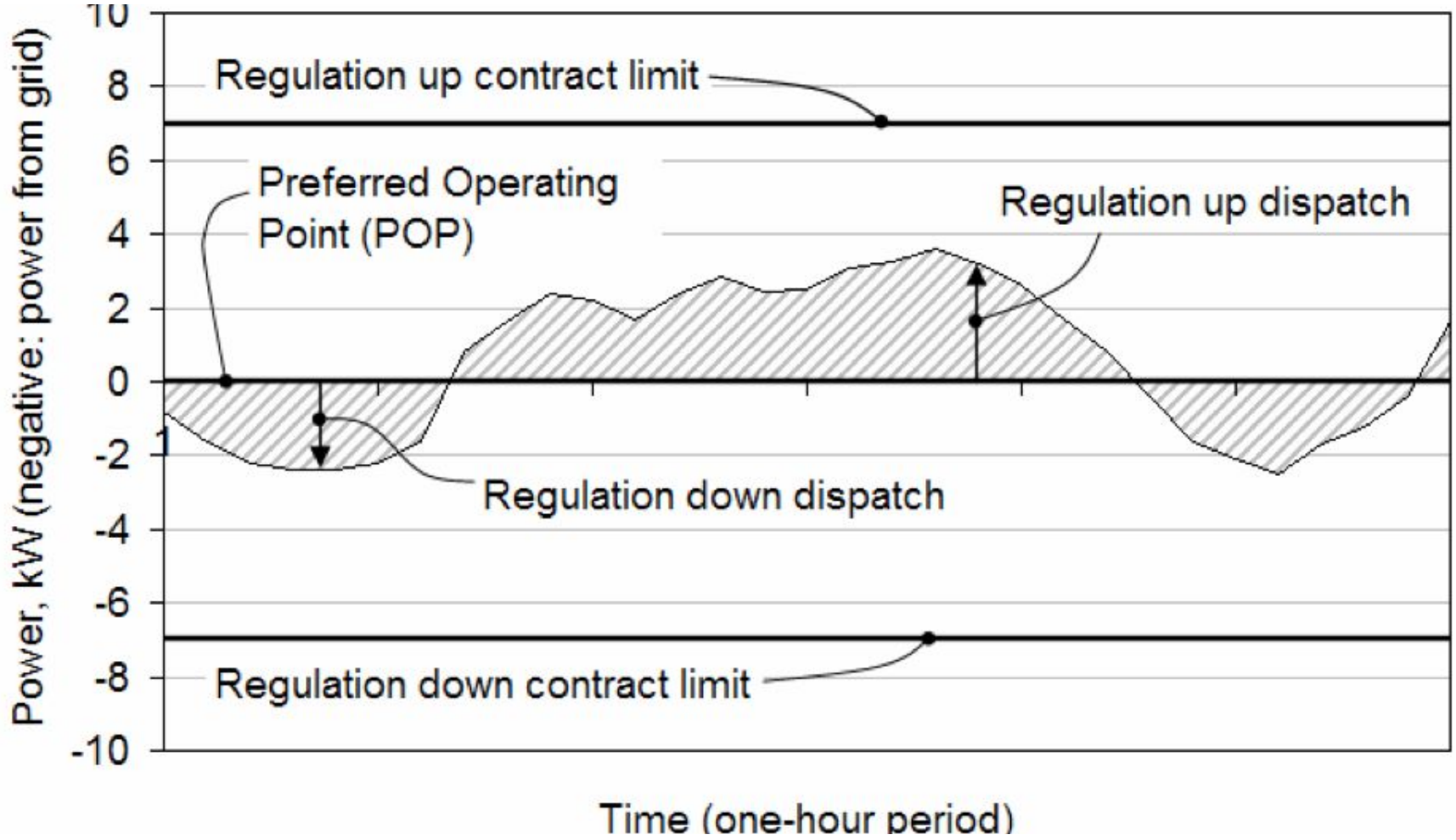
A. Brooks and S. Thesen, PG&E and Tesla Motors: Vehicle to Grid Demonstration and Evaluation Program. EVS23, December 2007.

Frequency Regulation Dispatch Example



A. Brooks, Vehicle-to-Grid Demonstration Project: Grid Regulation Ancillary Service with a Battery Electric Vehicle, California Air Resources Board, 12-2002 http://www.arb.ca.gov/research/apr/past/01-313.pdf

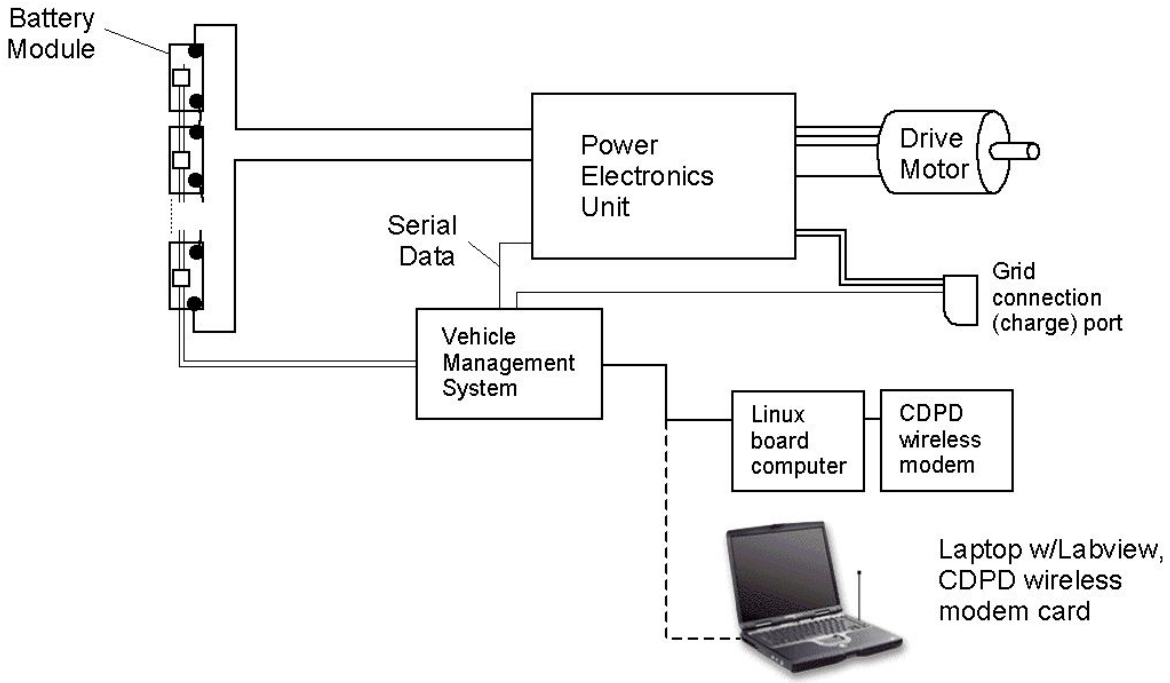
Vehicle to Grid (V2G) Frequency Regulation



A. Brooks and S. Thesen, PG&E and Tesla Motors: Vehicle to Grid Demonstration and Evaluation Program. EVS23, December 2007.

AC Propulsion V2G Project for CARB, 2001

Bidirectional Power Grid Interface

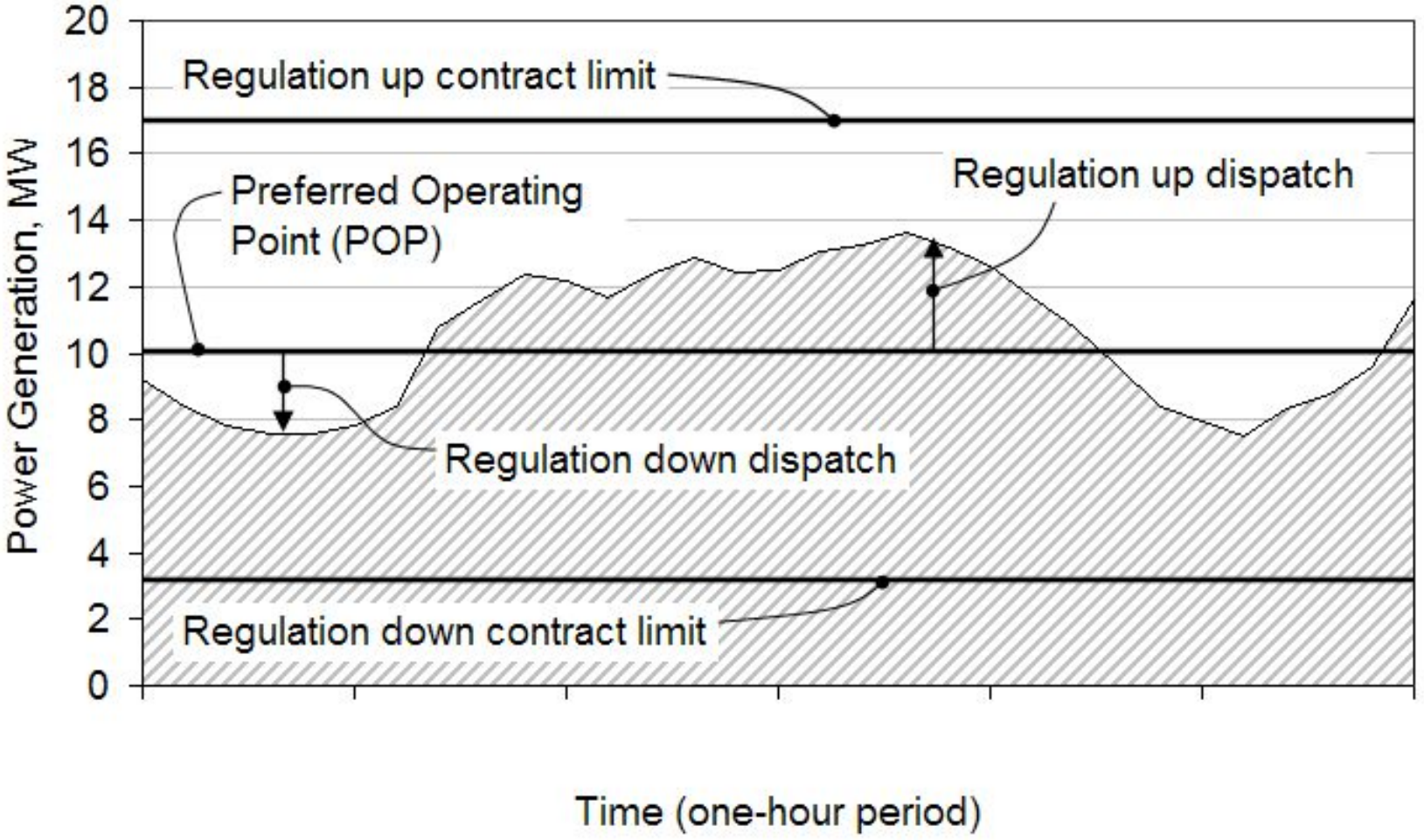


A. Brooks, Vehicle-to-Grid Demonstration Project: Grid Regulation Ancillary Service with a Battery Electric Vehicle, California Air Resources Board, 12-2002 http://www.arb.ca.gov/research/apr/past/01-313.pdf

Concerns About Bidirectional V2G Services

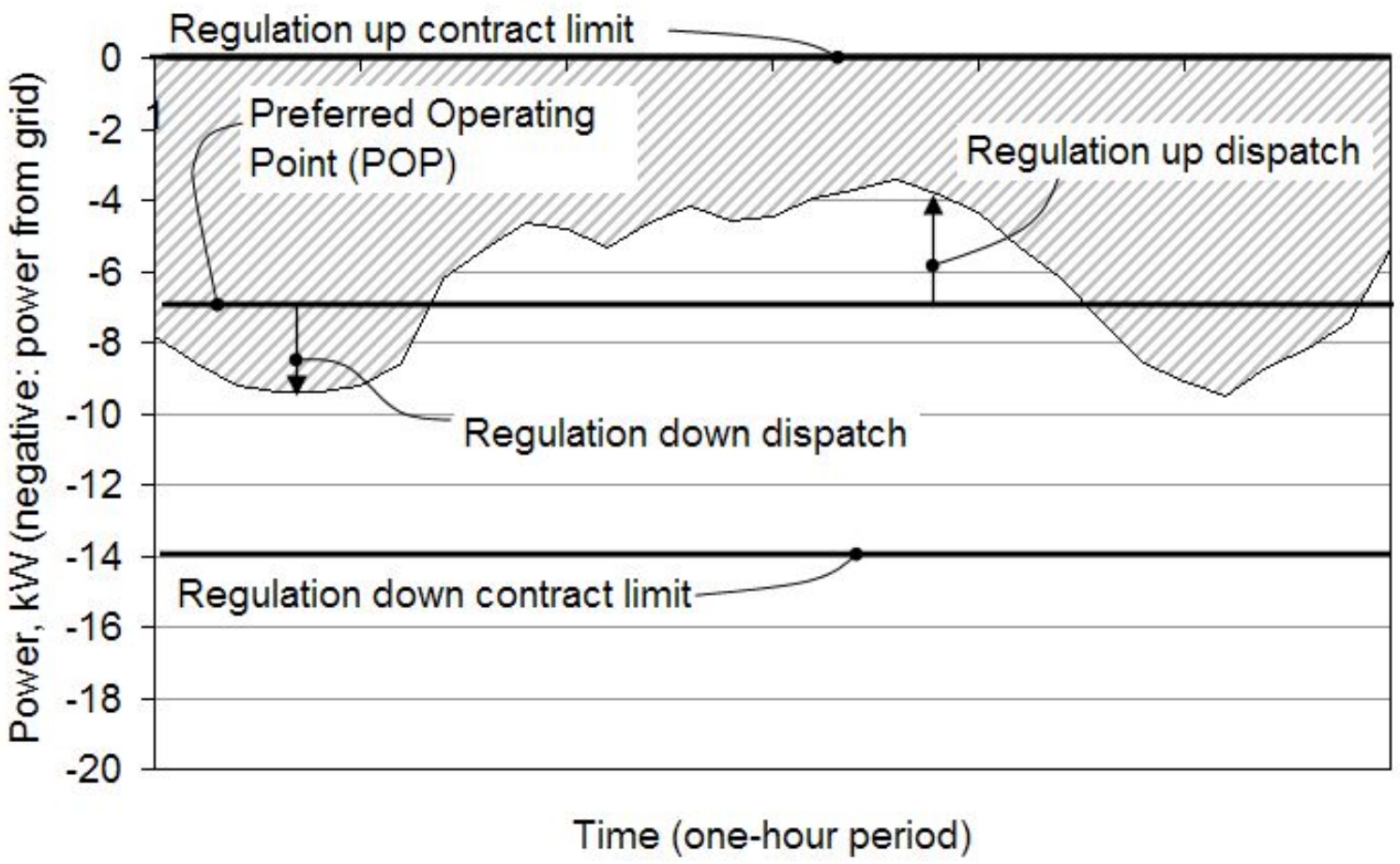
- Automakers, vehicle drivers often express strong objection to V2G
  - Additional battery degradation due to additional battery energy throughput
  - Battery won't be charged when driver needs it to be if the grid can withdraw energy
  - Concerns in technical and regulatory areas when returning electricity to grid

Frequency Regulation Definitions



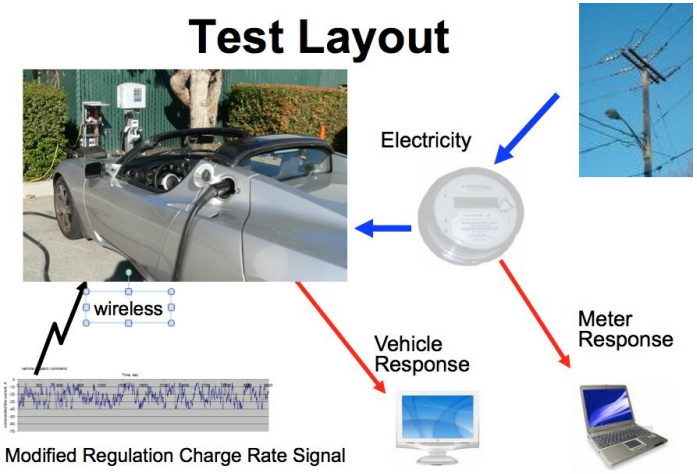
A. Brooks and S. Thesen, PG&E and Tesla Motors: Vehicle to Grid Demonstration and Evaluation Program. EVS23, December 2007.

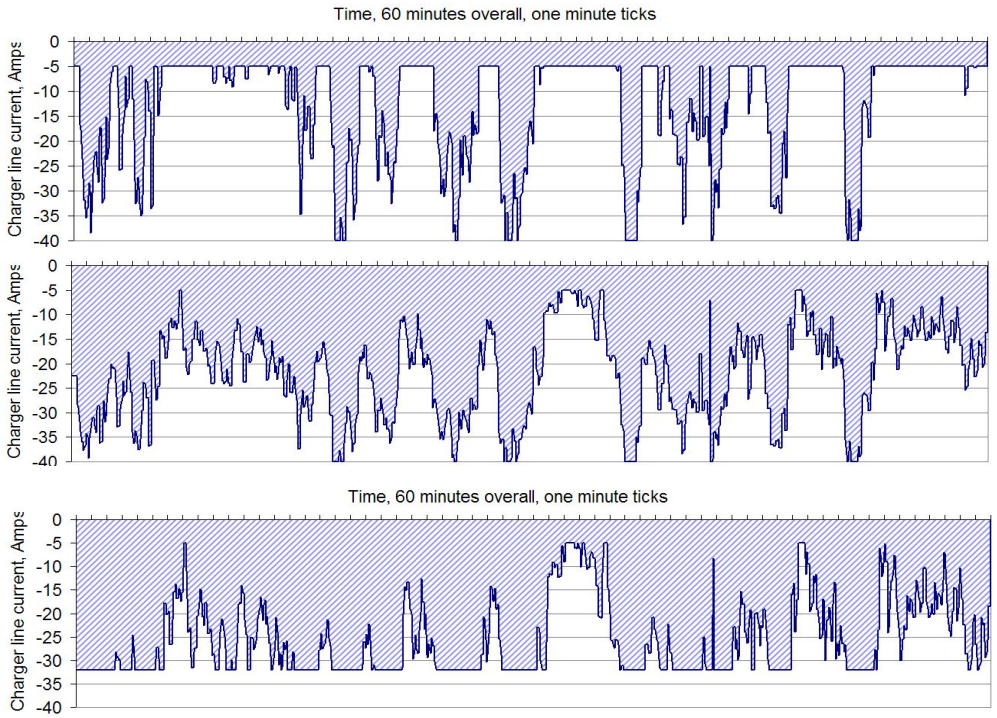
Frequency Regulation with Load Control



A. Brooks and S. Thesen, PG&E and Tesla Motors: Vehicle to Grid Demonstration and Evaluation Program. EVS23, December 2007.

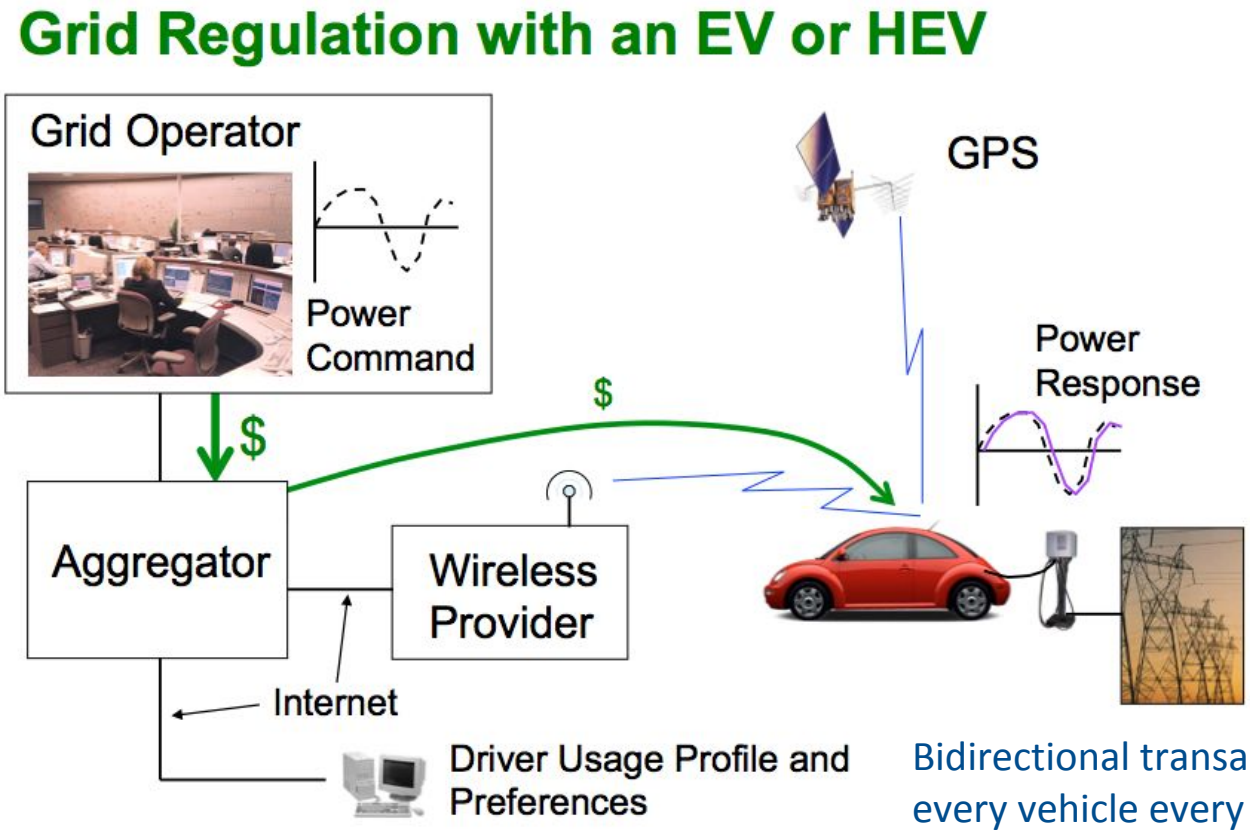
Tesla and PG&E: Regulation while Charging project, 2007





A. Brooks and S. Thesen, PG&E and Tesla Motors: Vehicle to Grid Demonstration and Evaluation Program. EVS23, December 2007.

Aggregation and Communications Overhead

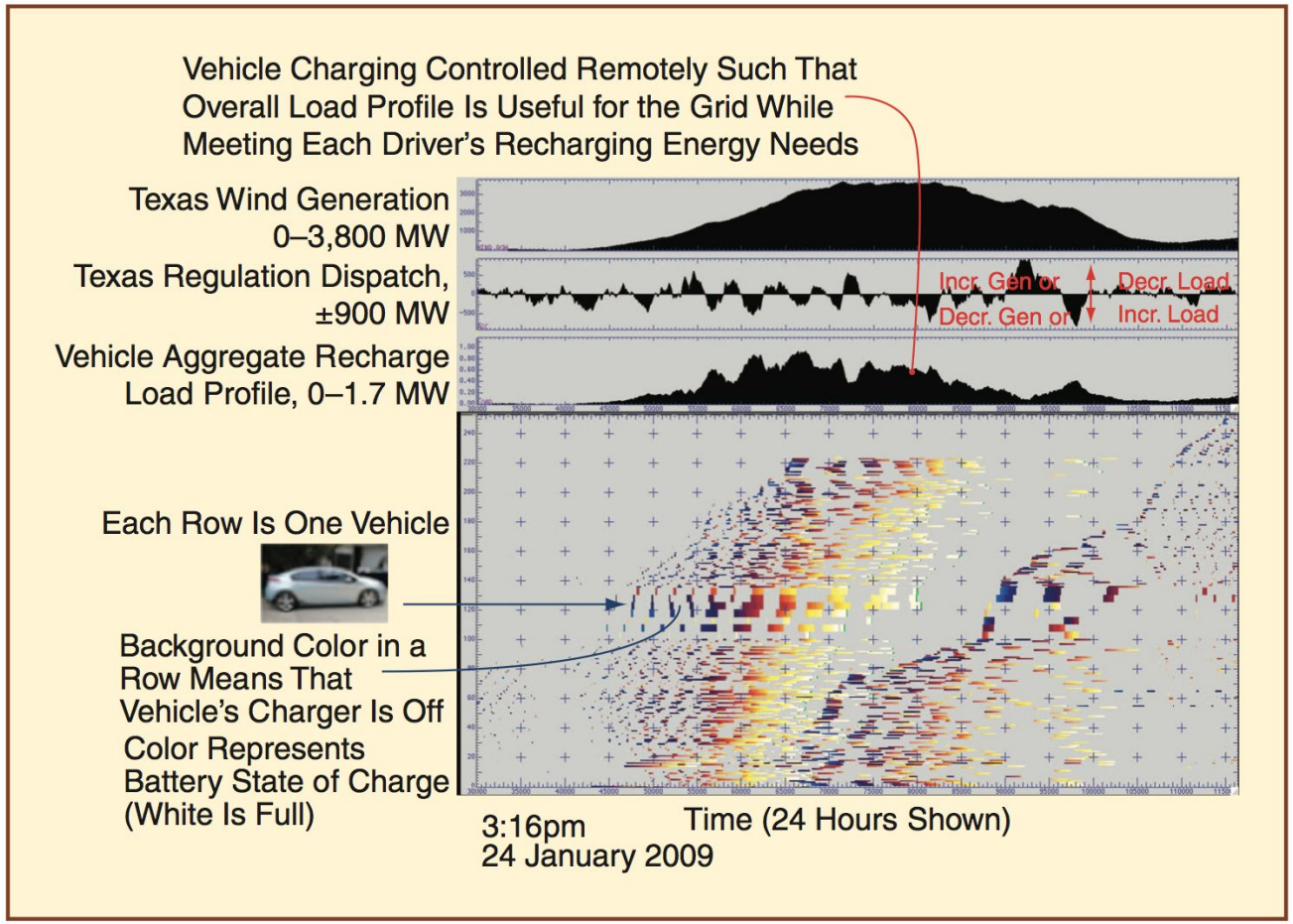


Bidirectional transaction with every vehicle every 4 seconds

A. Brooks, Vehicle-to-Grid Demonstration Project: Grid Regulation Ancillary Service with a Battery Electric Vehicle, California Air Resources Board, 12-2002 http://www.arb.ca.gov/research/apr/past/01-313.pdf

Google Regulation with Vehicle Charging Load 2009

- Control charging of each vehicle only on or off
- Low-latency communication with a small subset of vehicles every 4 seconds.



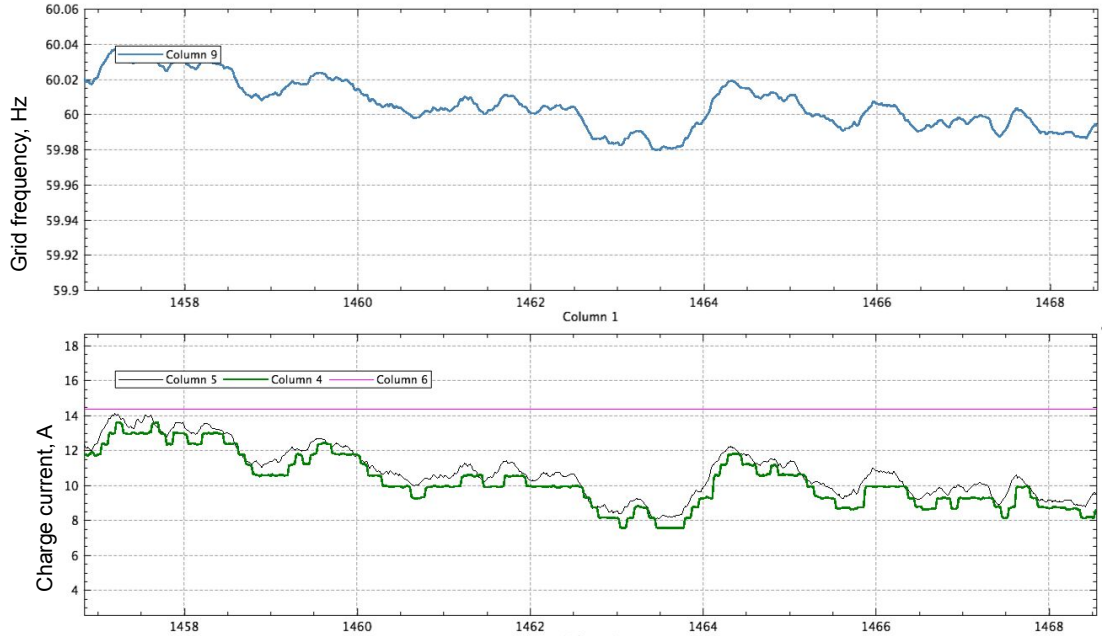
A. Brooks, et.al., Demand Dispatch, IEEE Power and Energy Magazine, May/June 2010.

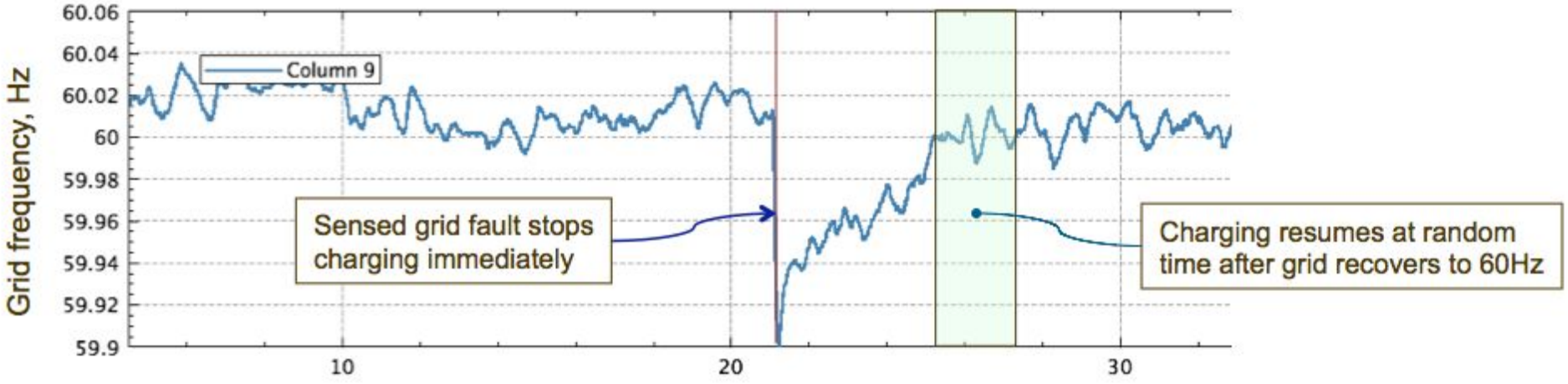
Autonomous Frequency-Responsive Vehicle Charging

- Much of the regulation dispatched power command based on grid frequency error from 60Hz
- Measure grid frequency at EVSE and modulate charging power based on frequency error
  - Eliminates need for real-time communication
  - Fast response
  - Low cost to implement in EVSE

Frequency Responsive Charging Details

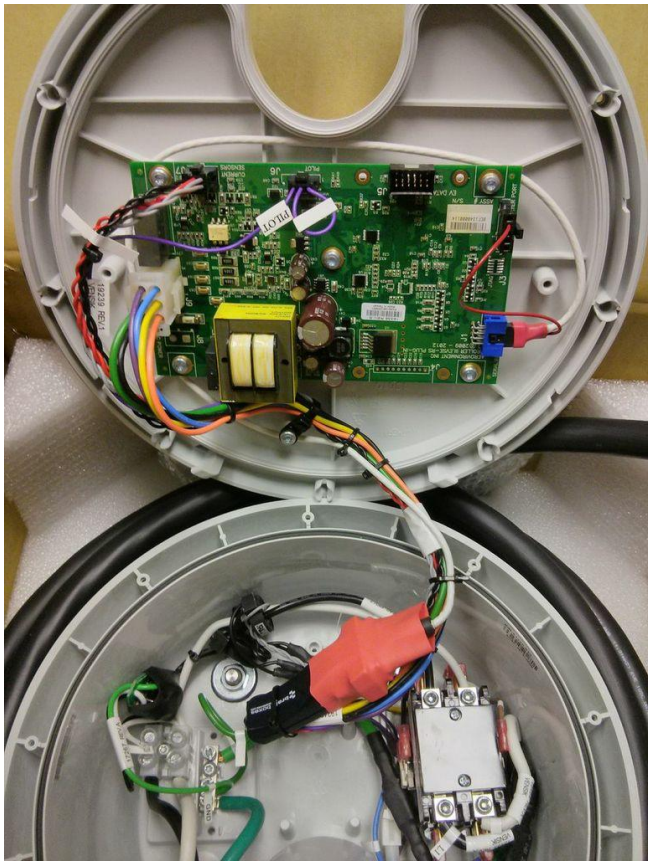
- EVSE measures grid frequency
  - Vehicle charge rate modified based on grid frequency
- Provides function like powerplant droop characteristic to support grid frequency regulation
- Provides both primary and secondary frequency response
- Charging stops immediately on



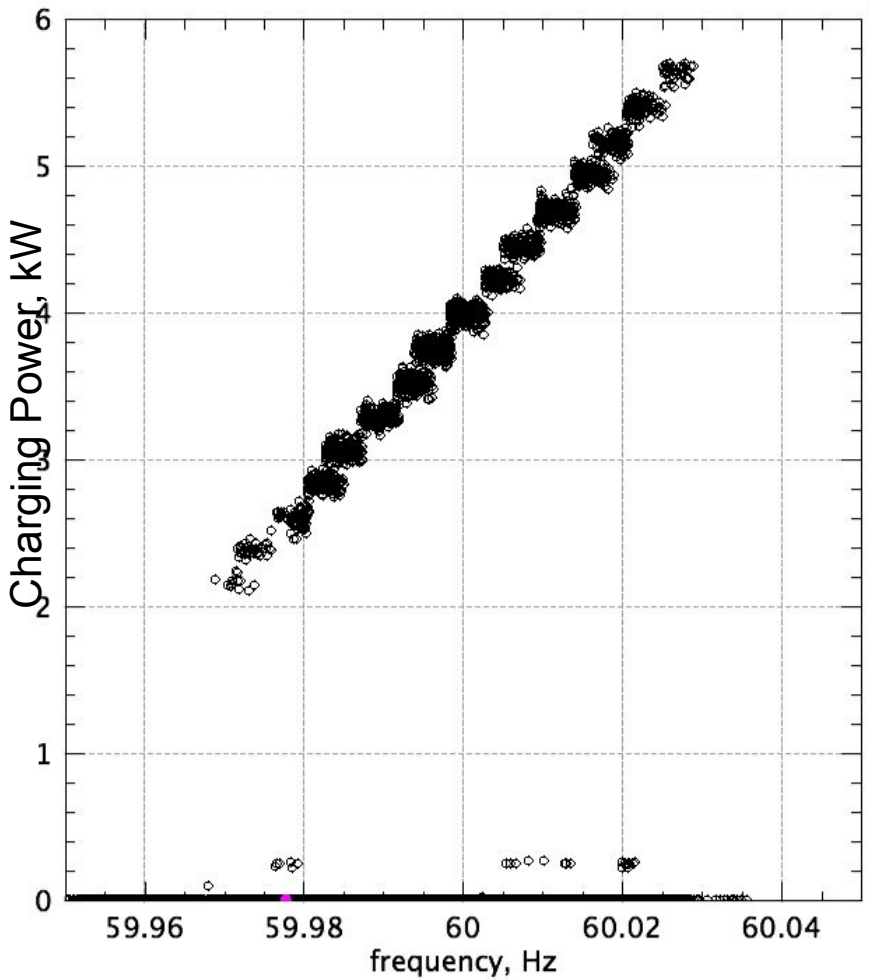


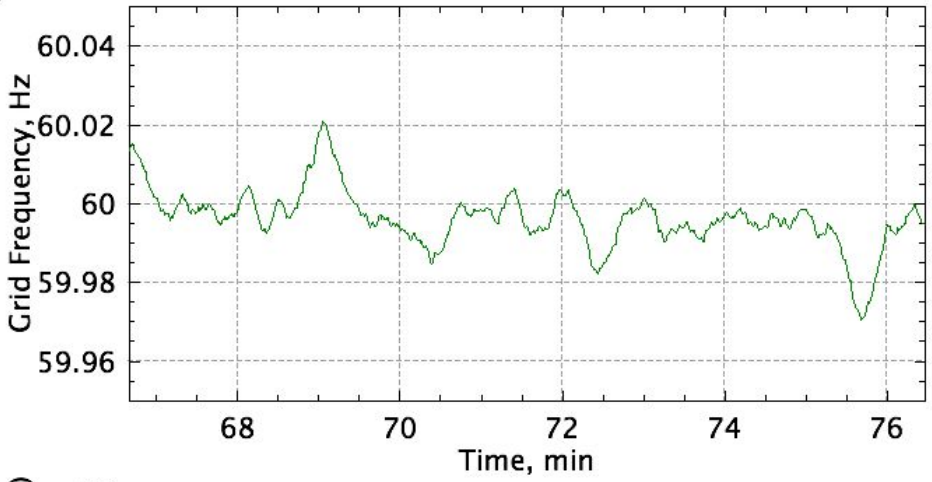
Frequency Responsive EVSE Prototype

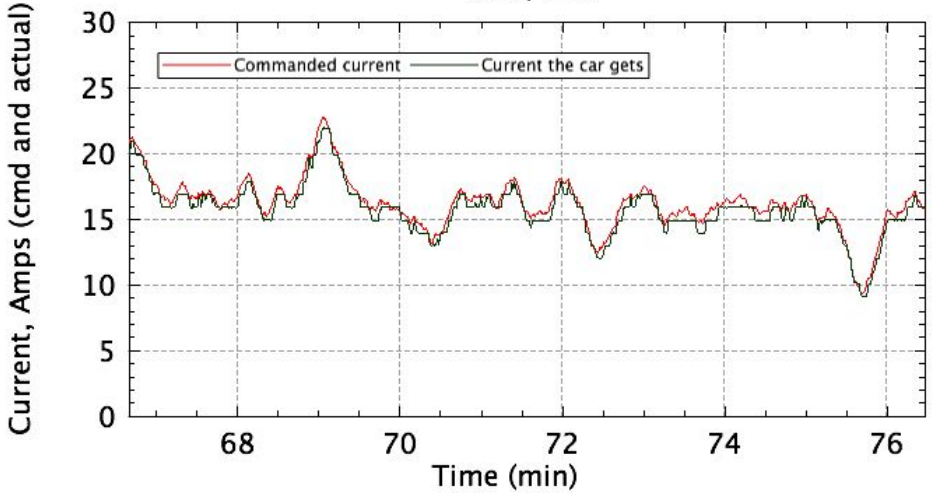
- At start of charge session, determines dynamic range of charge current available.
- EVSE measures frequency to 10 microHz resolution at 1 second update rate
- Calculates frequency error and frequency rate of change
- Calculates commanded line current based on frequency error and rate of change
- Adjusts pilot duty cycle to indicate new charge current limit to vehicle, at 1 second update rate
- Reports real time data through serial port



Charge Power vs Grid Frequency, BMW ActiveE





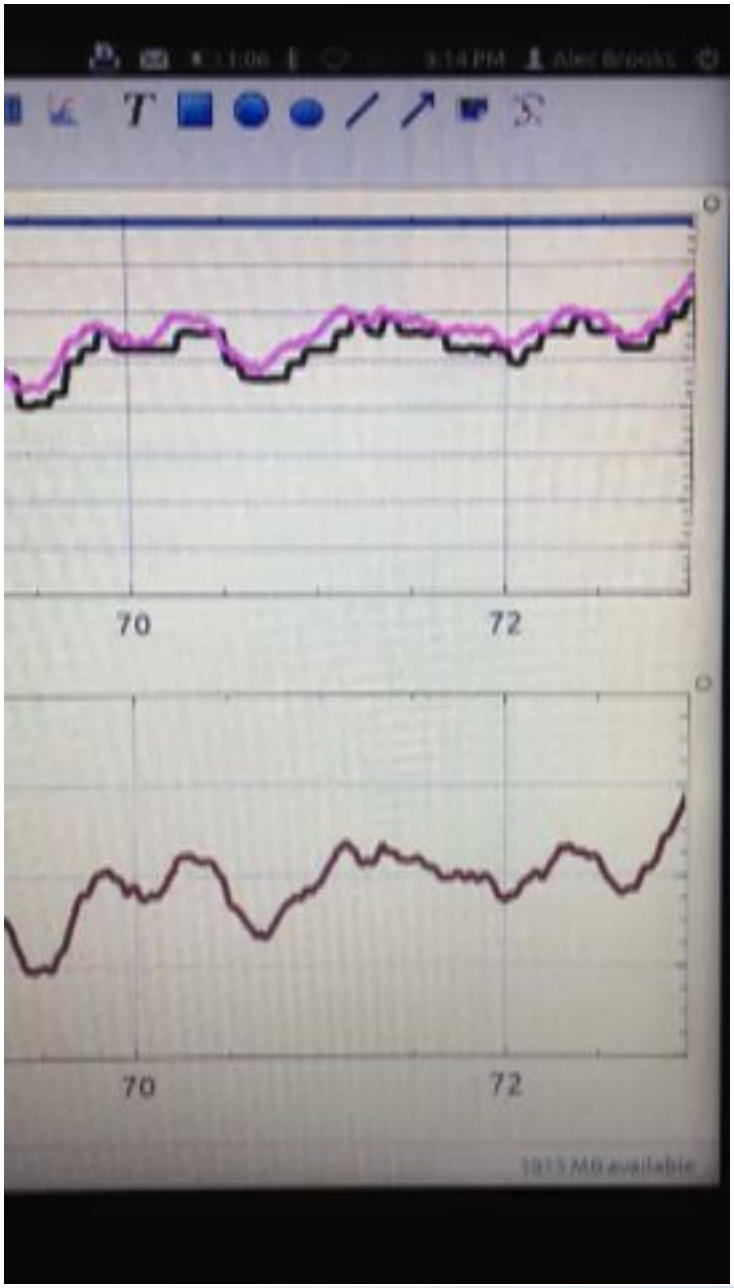


A.Brooks, Vehicle Charging as a Source of Frequency Regulation, EVS27 Nov. 2013. http://goo.gl/C6XEu7

Real Time Frequency Responsive Charging

purple: commanded AC current
black: measured AC current
scale: 0 to 16 Amps AC

Grid frequency sensed by EVSE
scale: 59.96 Hz to 60.04 Hz



Providing all Frequency Regulation with Vehicle Charging?

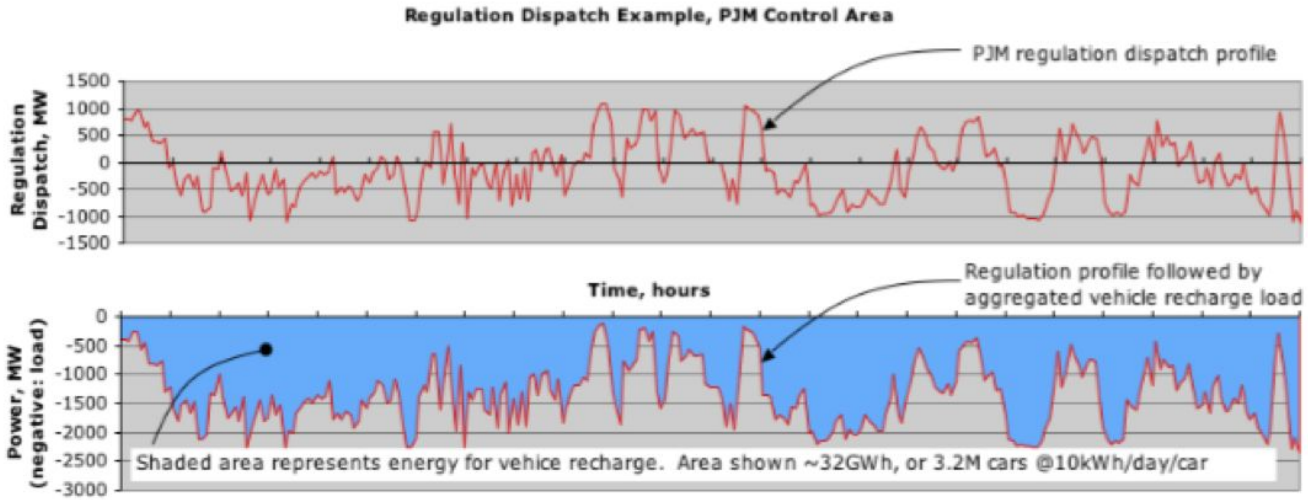
- Would it be possible to provide all frequency regulation with vehicle charging?
- California example:
  - 400MW up and down regulation typical in Calif.
  - With only load, load would vary between 0 and 800MW
    - Daily energy at average 400MW is 9600 MWh
  - Vehicle energy use: 3 mi/kWh, or 3000 miles per MWh
    - Total daily miles: 3000*9600 = 29 million miles/day
  - Assume 29 miles per day per vehicle, so ~1 million vehicles could provide all of the regulation capacity in California (out of 22 million cars in California)
  - Charge timing would have to be spread throughout the day

PJM Example – all regulation with vehicle charging

- PJM 24 hours regulation power profile

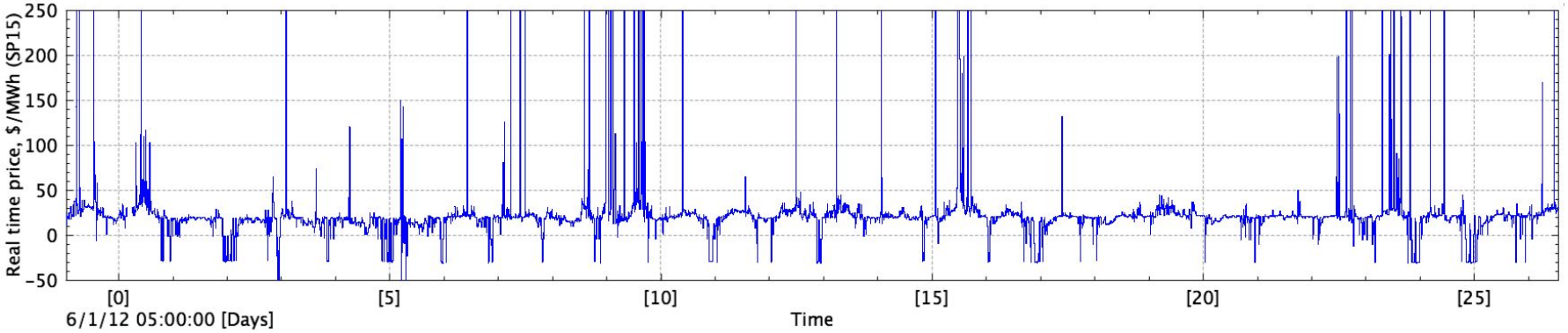
Grid operators need real-time control of power or load in order to keep the grid balanced

Control of vehicle chargers can provide accurate and fast response power control to grid operators

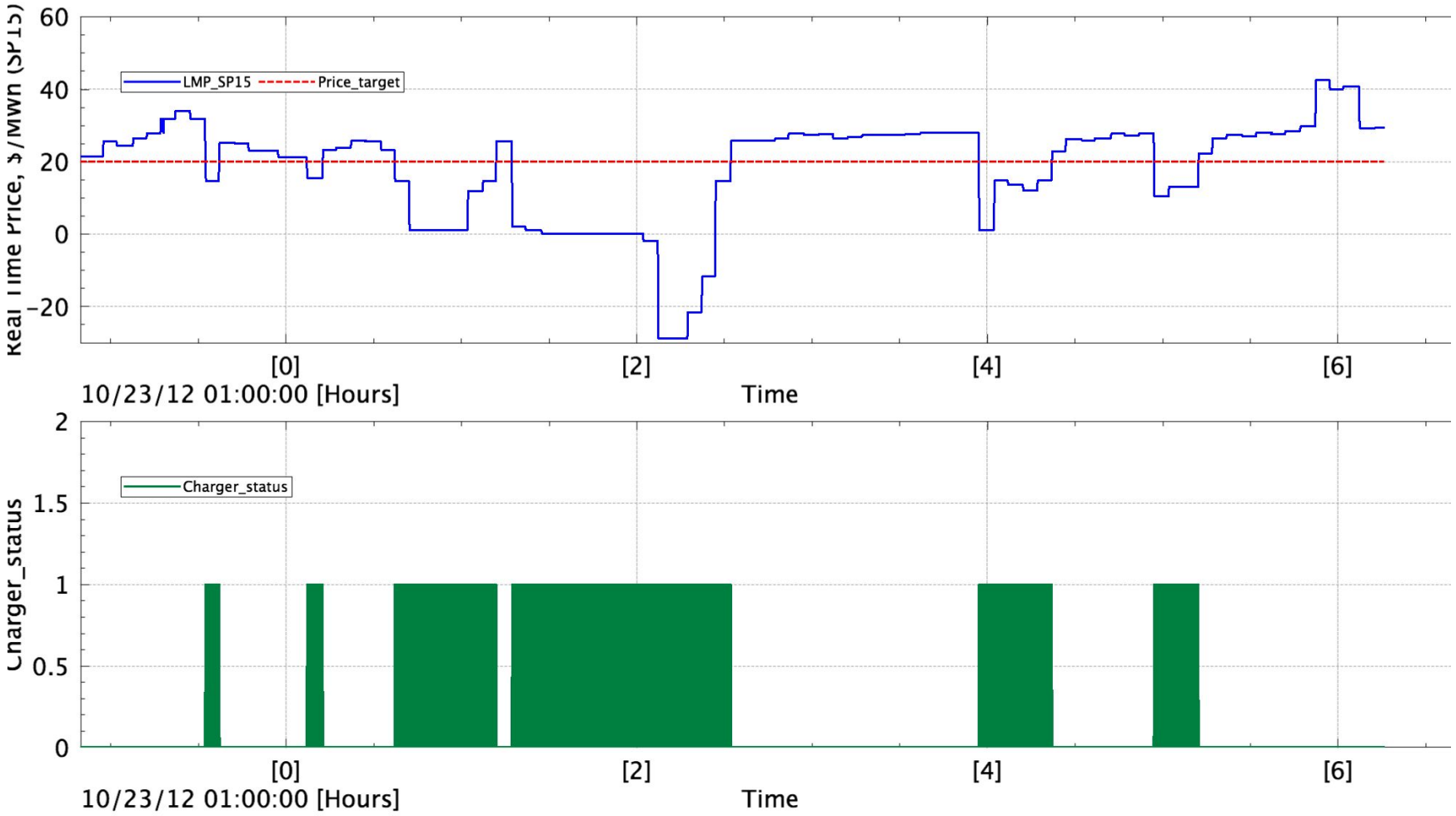


Cost Based Charging

- Charging based on real time wholesale LMP
- Long term LMP data sample from Cal ISO web site
  - Sampled every 15 seconds for several months



Charging Enabled Below Target LMP



Final Thoughts

- Difficult to realize value of EV charge rate and timing flexibility given current grid ancillary services definitions and typical utility tariffs
- SAE J1772 standard allows control of charging timing and rate with today's vehicles
  - Vehicles respond fast to changes in control pilot duty cycle
- Autonomous or semi-autonomous real-time charging controls are straightforward to implement
- Financial benefit per vehicle likely to be low – we need low-cost solutions