evs 27

The 27th INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION.

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Vehicle Charging as a Source of Grid Frequency Regulation

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AeroVironment

Organized by Fira Barcelona avele

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In collaboration with EVAAP EDTA

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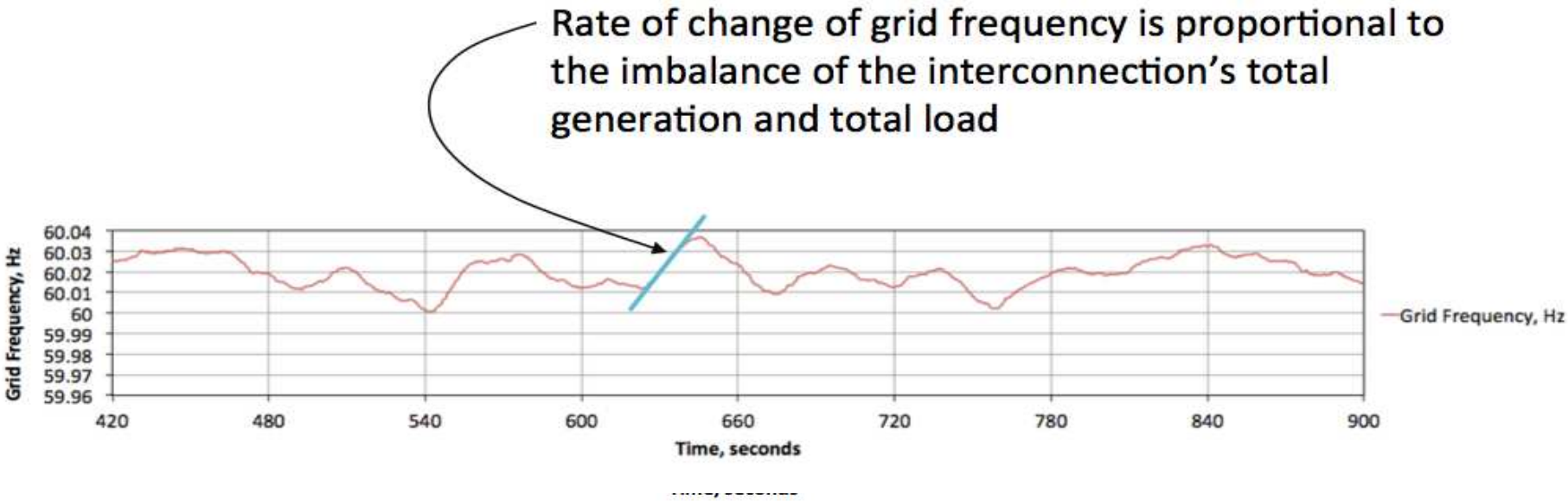
Power Grid Interconnection and Control Area

Interconnection

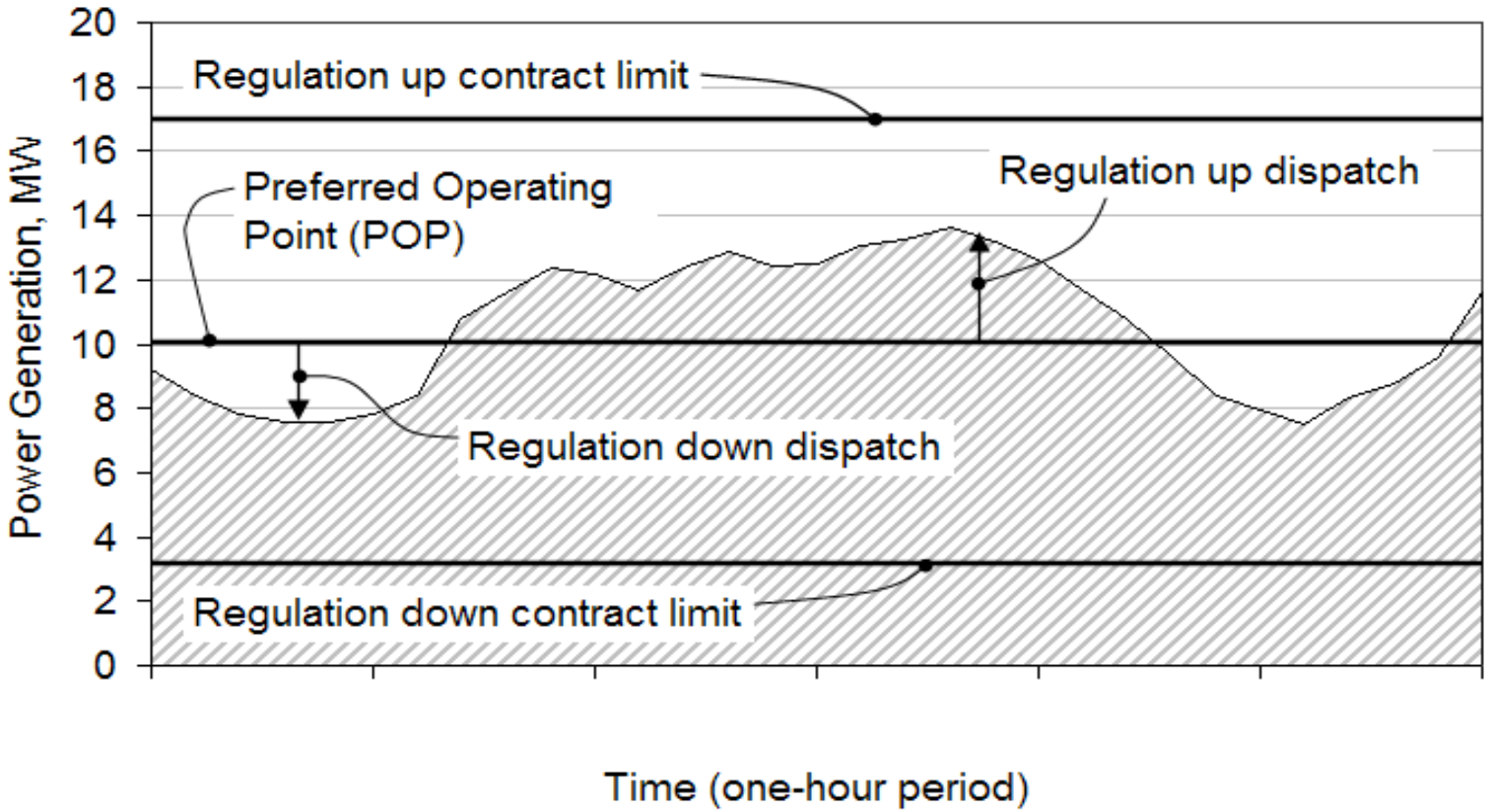
A. Brooks, Vehicle-to-Grid Demonstration Project: Grid Regulation Ancillary Service with a Battery Electric Vehicle, California Air Resources Board, 12-2002
http://www.arb.ca.gov/research/apr/past/01-313.pdf

Grid Frequency shows overall balance of supply and demand



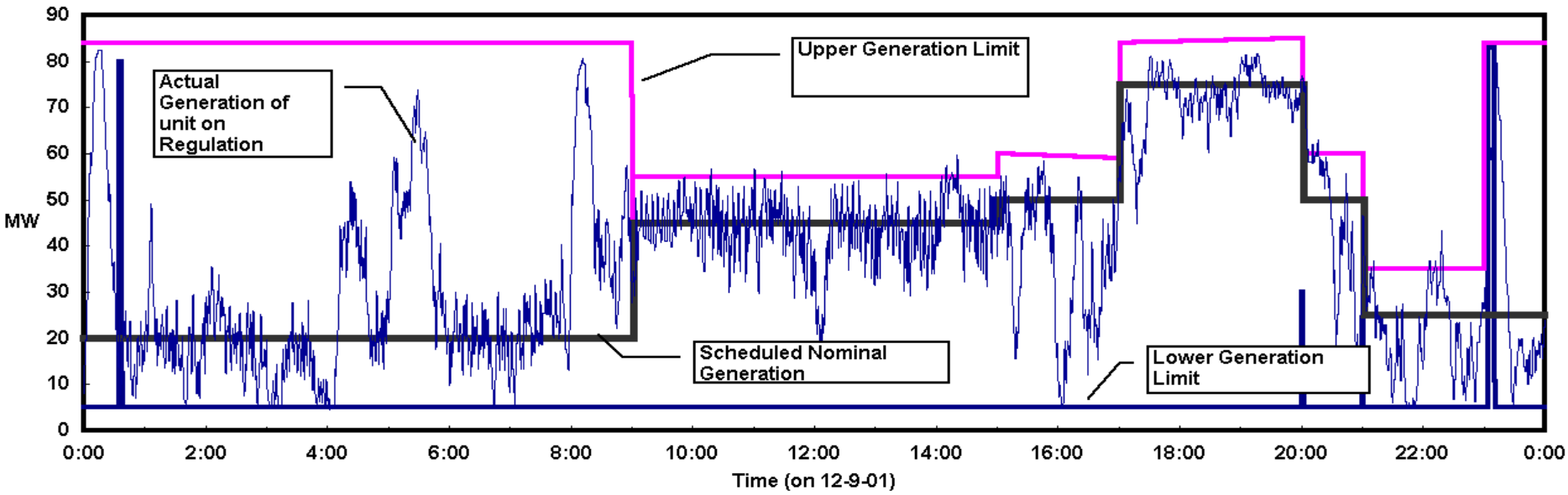
- Grid frequency is regulated by a control loop that responds to deviation of actual frequency from target frequency
- Powerplants contract to provide real-time control of power output to grid operator's Energy Management System (EMS)
- Powerplants also have autonomous frequency responsive generation

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



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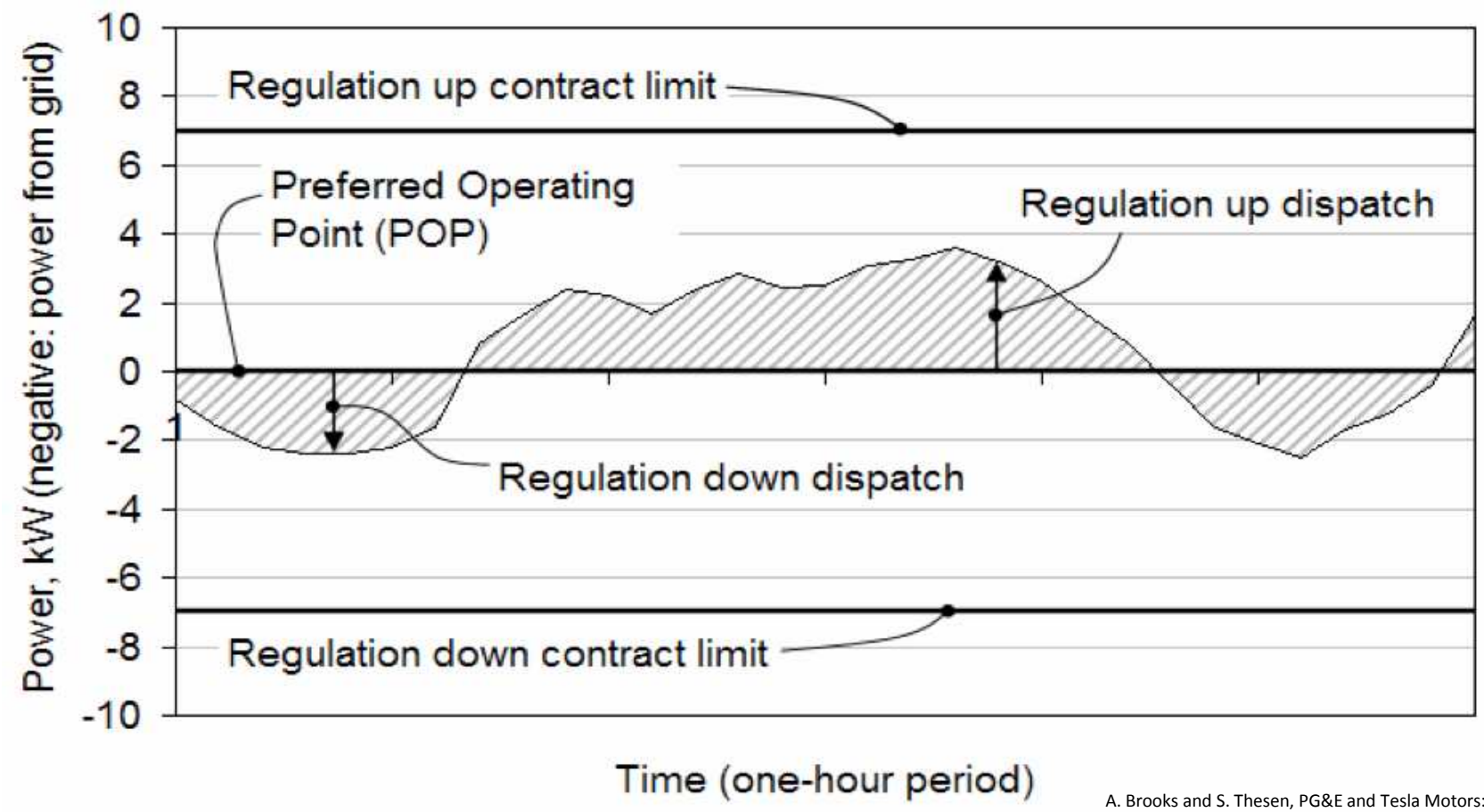
Vehicle to Grid (V2G) Frequency Regulation



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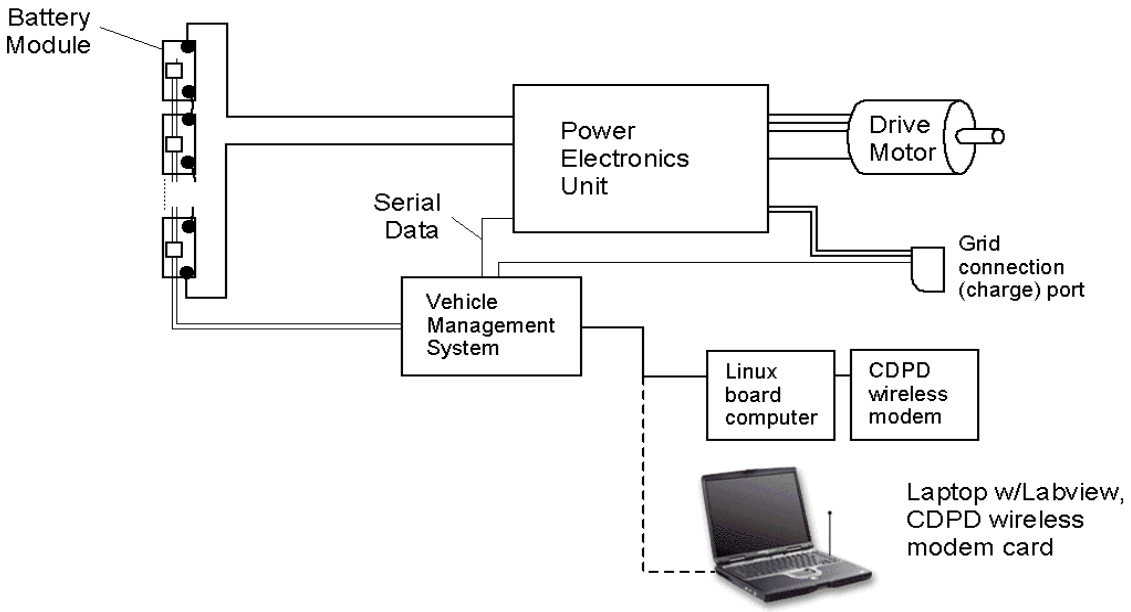
AC Propulsion V2G Project 2001

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
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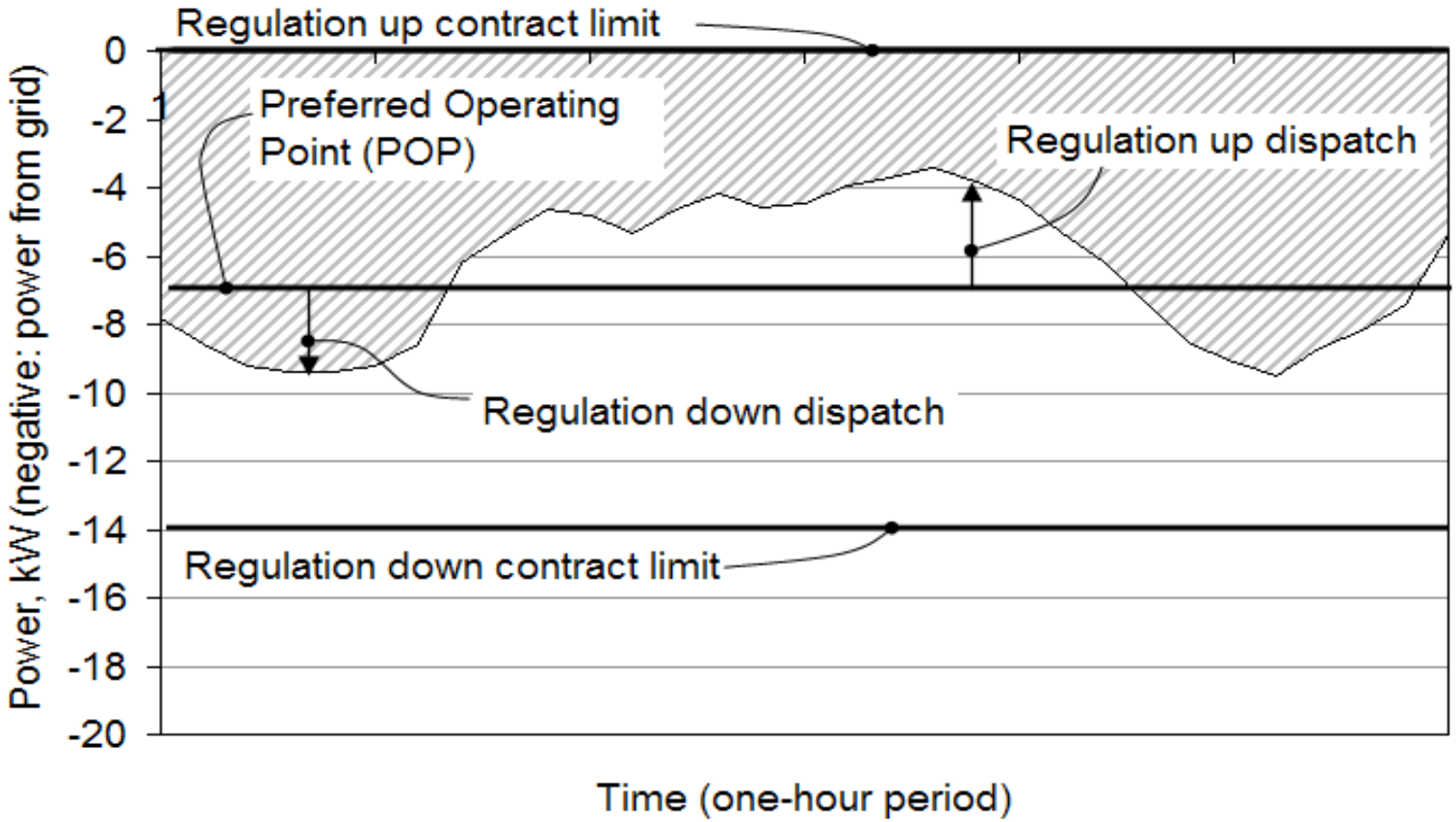
Concerns About Bidirectional V2G Services

- 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 with Load Control



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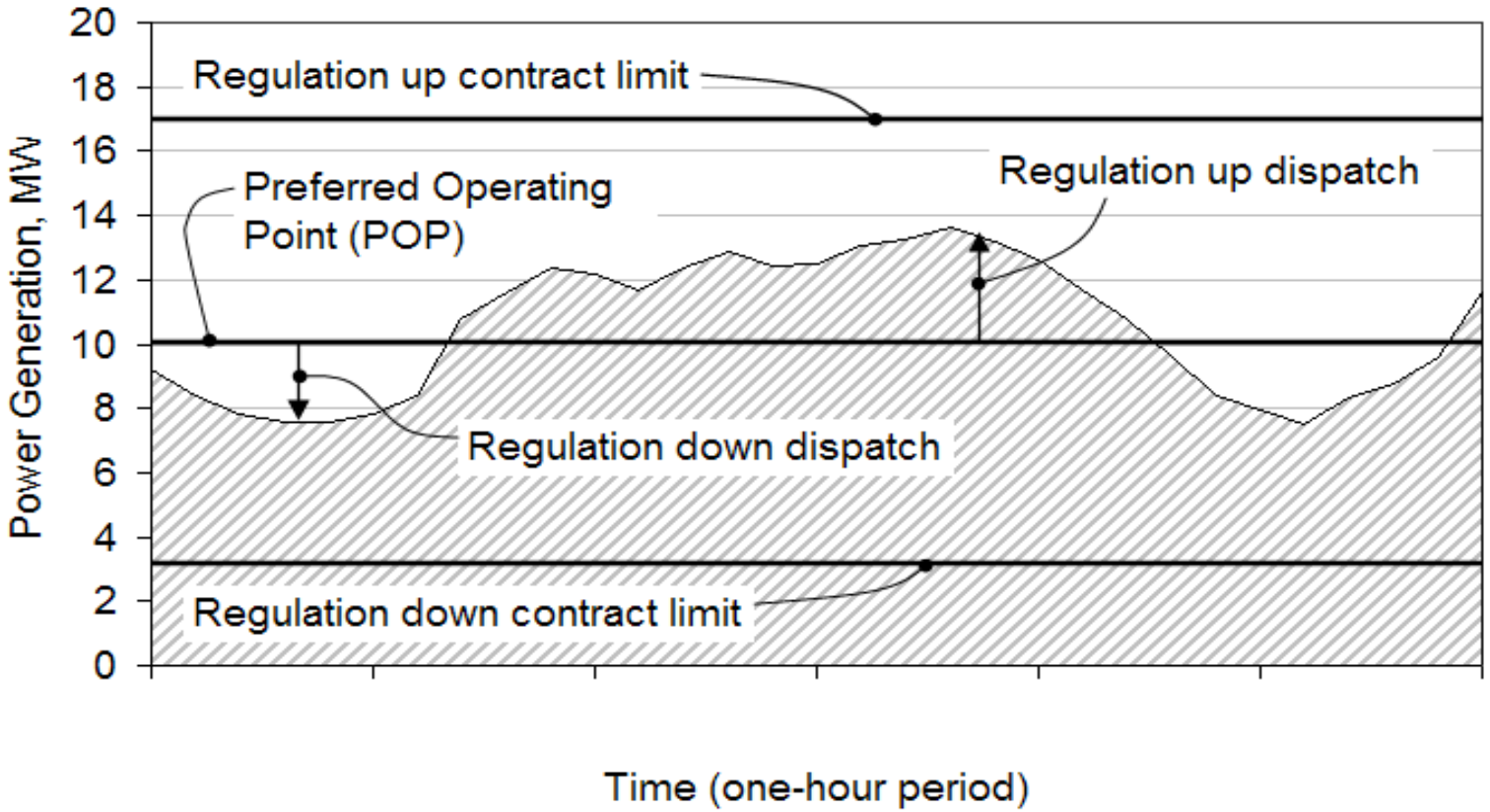
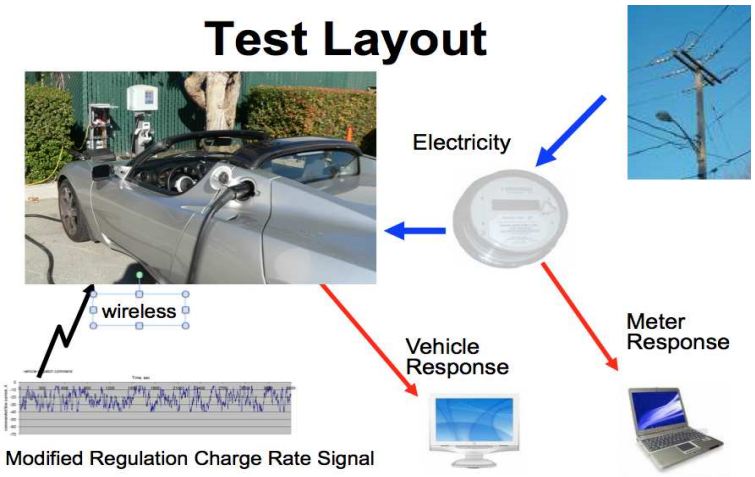


A. Brooks and S. Thesen, PG&E and Tesla Motors: Vehicle to Grid Demonstration and Evaluation Program. EVS23, December 2007.

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

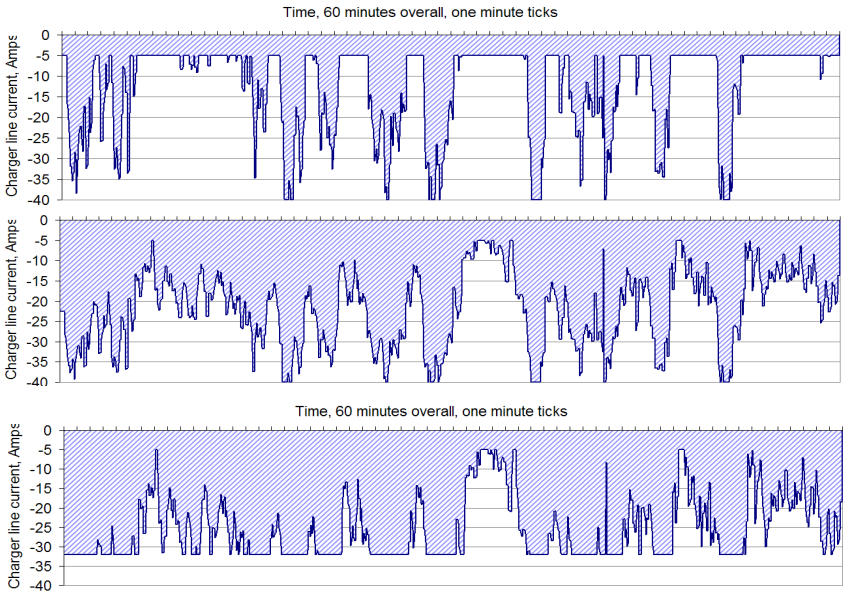


Three power profiles tested

Regulation down

Balanced regulation down and regulation up

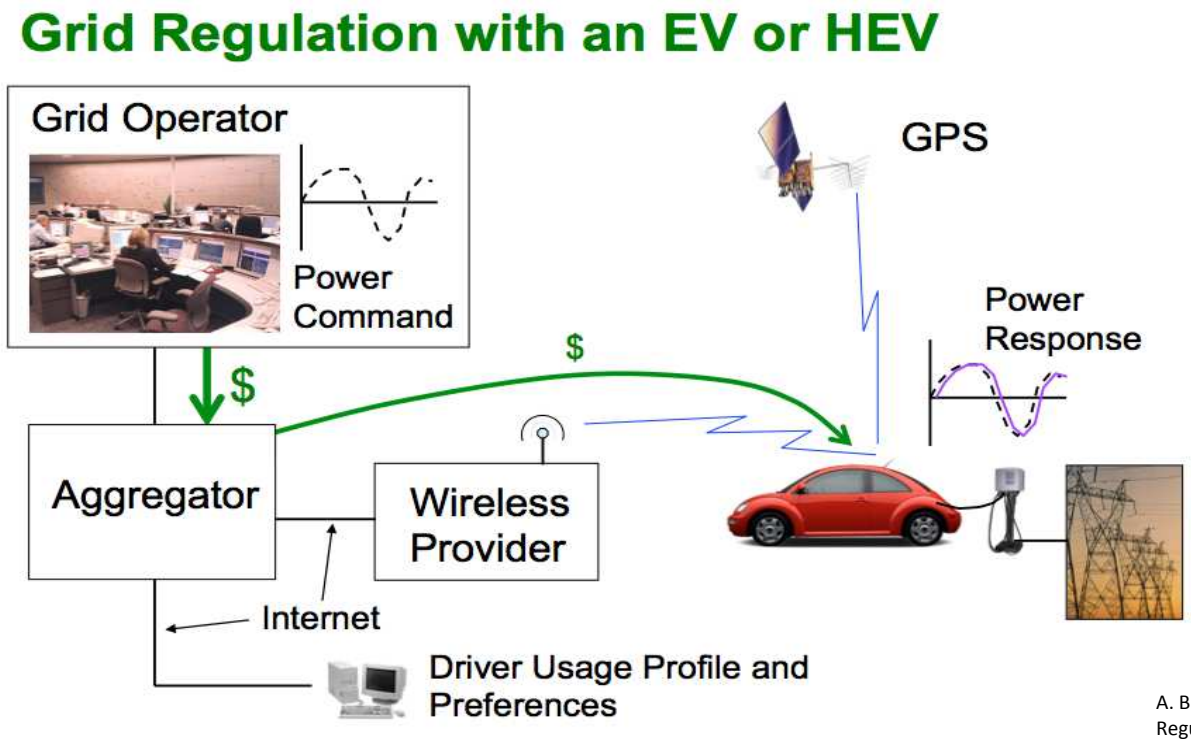
Regulation up



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



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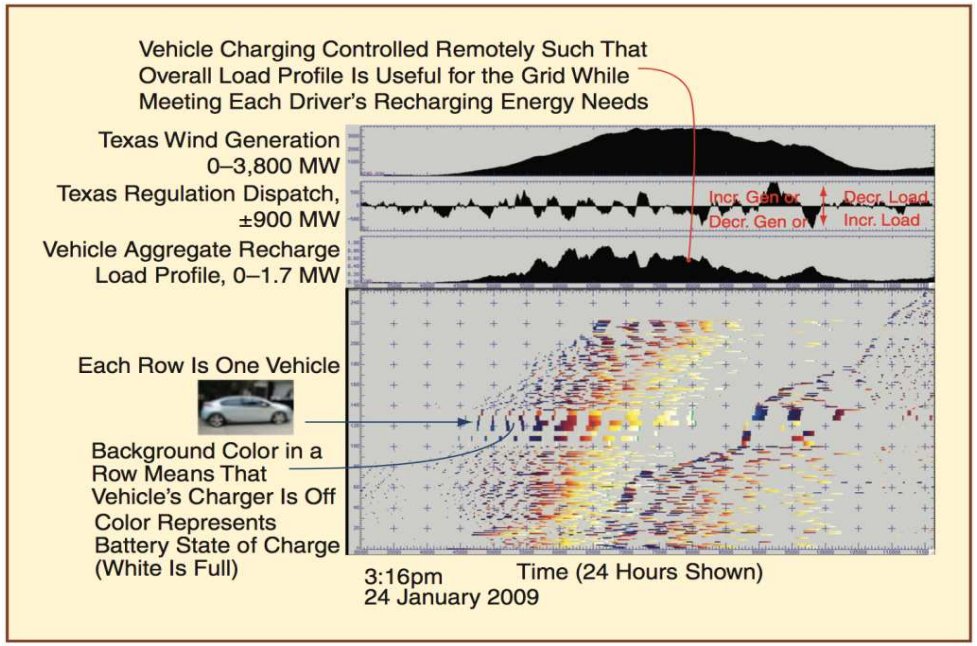
Google Regulation with Vehicle Charging Load 2009

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



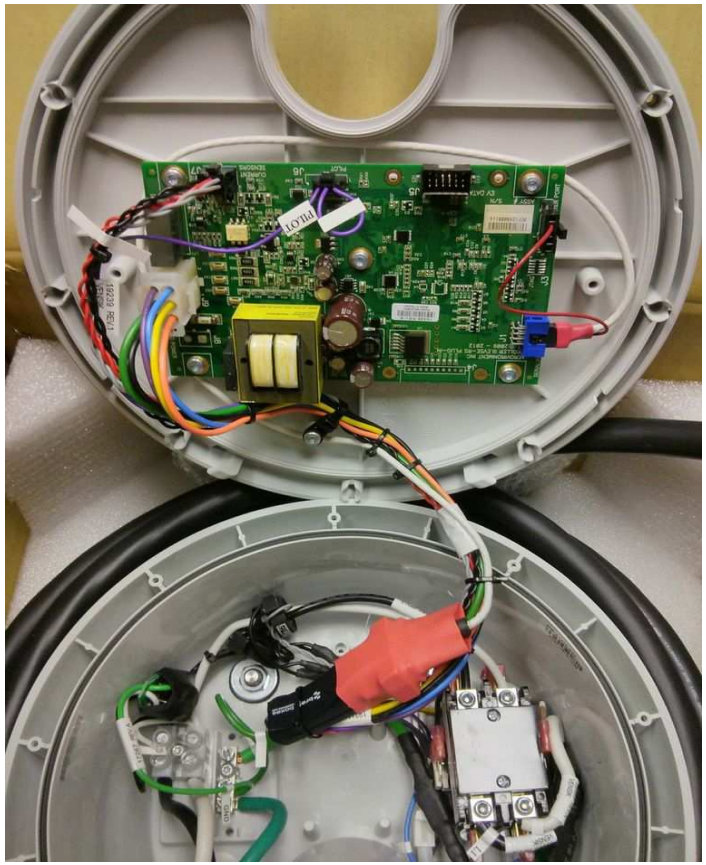
A. Brooks, et.al., Demand Dispatch, IEEE Power and Energy Magazine, May/June 2010.

Autonomous Frequency Responsive Vehicle Charging

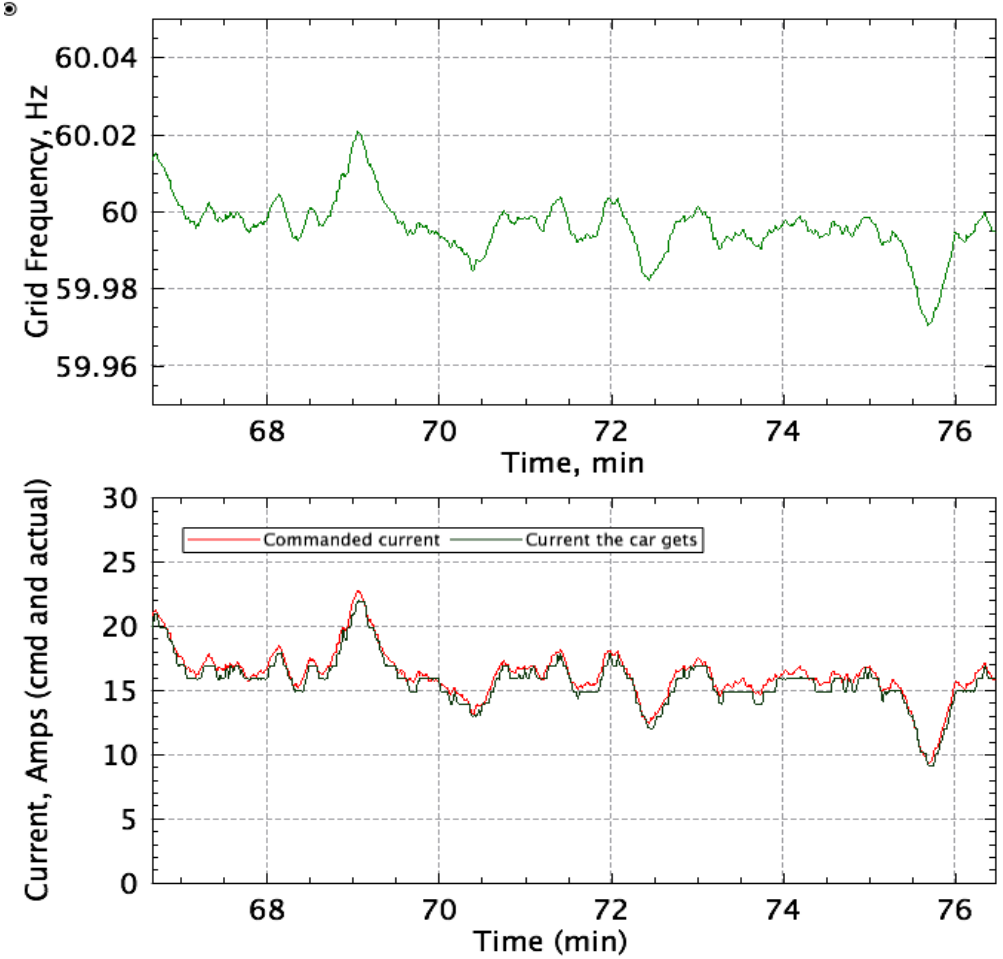
- Much of the regulation dispatched power command based on frequency error
- Measure grid frequency at EVSE
  - Eliminate need for communication
  - Faster response possible
  - Low cost modification to EVSE

Frequency Responsive EVSE Prototype

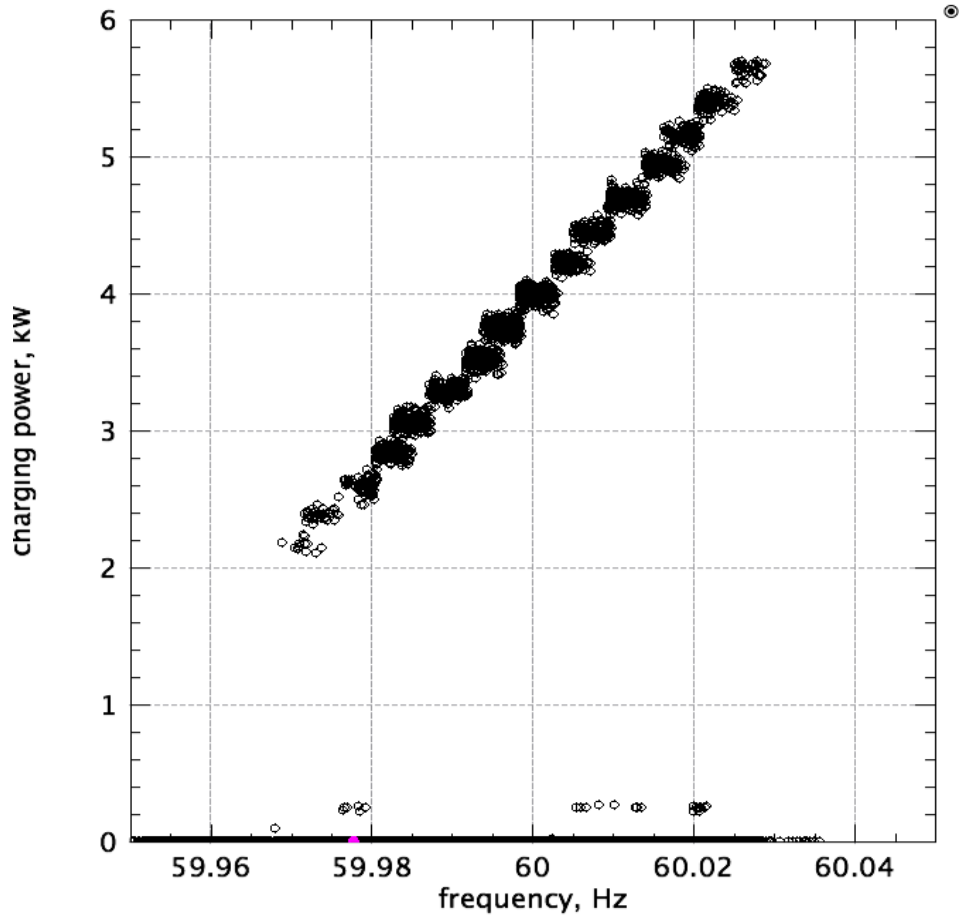
- At start of charge session, determines dynamic range of charge current available.
- EVSE measures frequency to 10 microHz resolution at 1 second update rate
- Calculated frequency error and frequency rate of change
- Calculates commanded line current based on frequency error and rate of change
- Adjusts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



Graph of frequency and response, BMW ActiveE

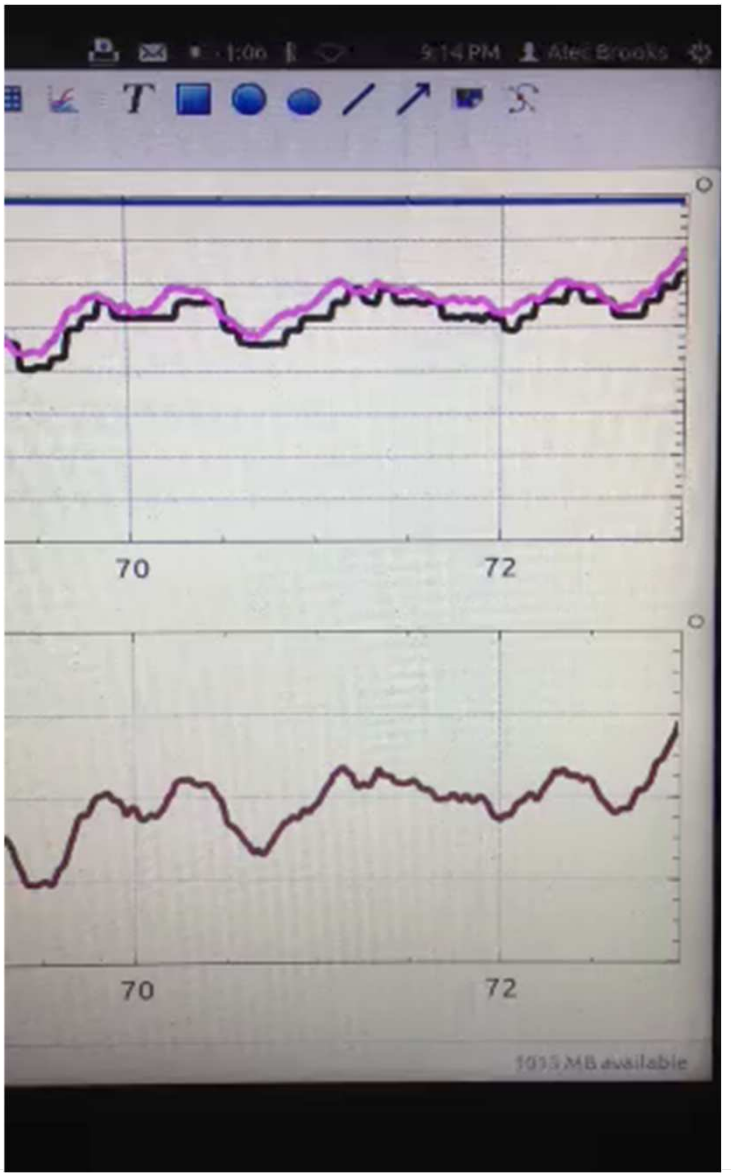


Charge Power vs Grid Frequency, BMW ActiveE



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?

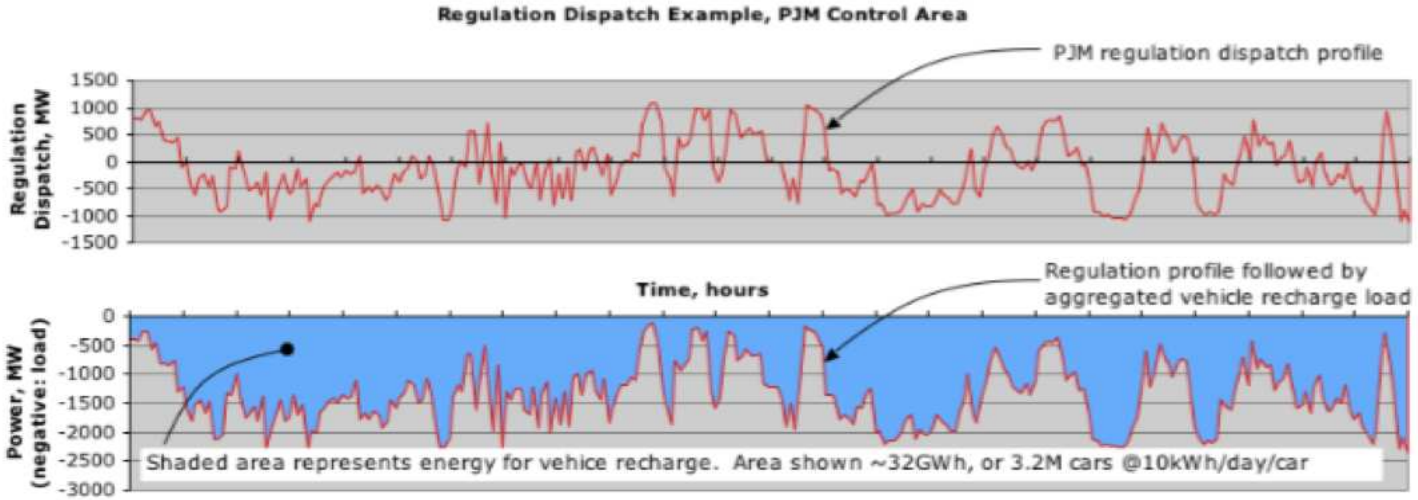
- Would it be possible to provide all frequency regulation with vehicle charging?
- California example:
  - 400MW up and down regulation typical in Calif.
  - With only load, load would vary between 0 and 800MW
    - Daily energy at average 400MW is 9600 MWh
  - Vehicle energy use: 3 mi/kWh, or 3000 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



Regulation value ~$0.02 to 0.04/kWh of recharge energy

A. Brooks, guest lecture, Stanford CEE176b, May, 2011.

evs 27 Final Thoughts

- Difficult to realize value of services provided
- Grid operators are reluctant to change their current way of doing things
- Standards: J1772 allows pilot duty cycle to change at any time. IEC 61851-1 does not allow duty cycle change within 5 seconds of previous change.
  - All vehicles tested respond in 1 second or less