Optimal Contracts For Providing Frequency Regulation Service Using Fleets of Electric Vehicles

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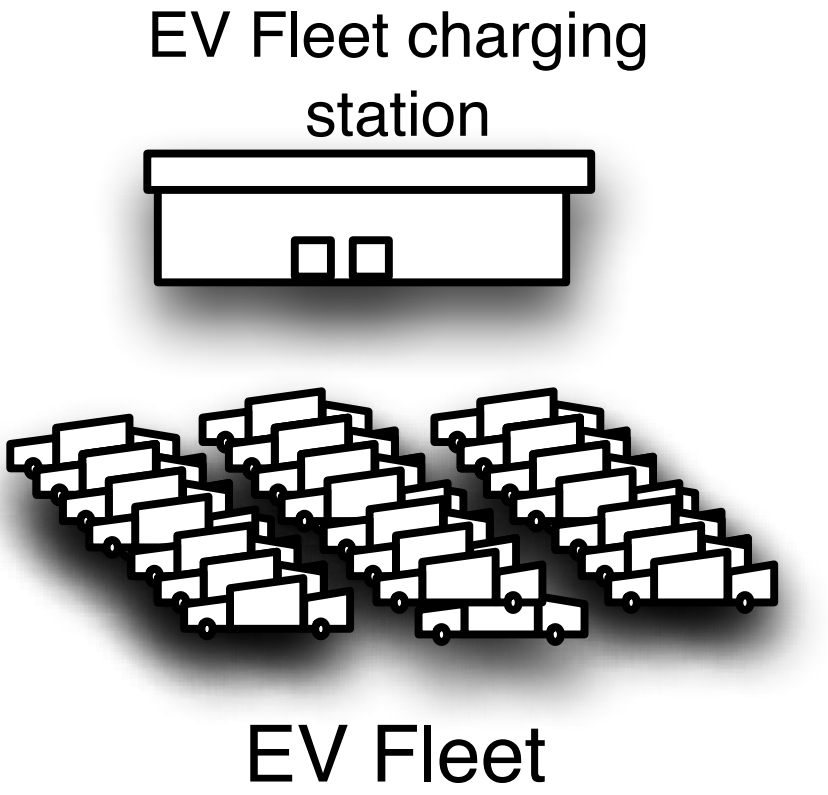
Two important trends

Variable-rate generation

Electric vehicle fleets



BEV
PHEV

Idea

- Dynamically control EV charging rate to absorb generation variability
- Proposed contract
  - Utility takes control of fleet charging rate
  - Fleet fully charged by end of the night
  - Fleet owner paid compensation from *regulation market*

Give up control  Lower electricity price

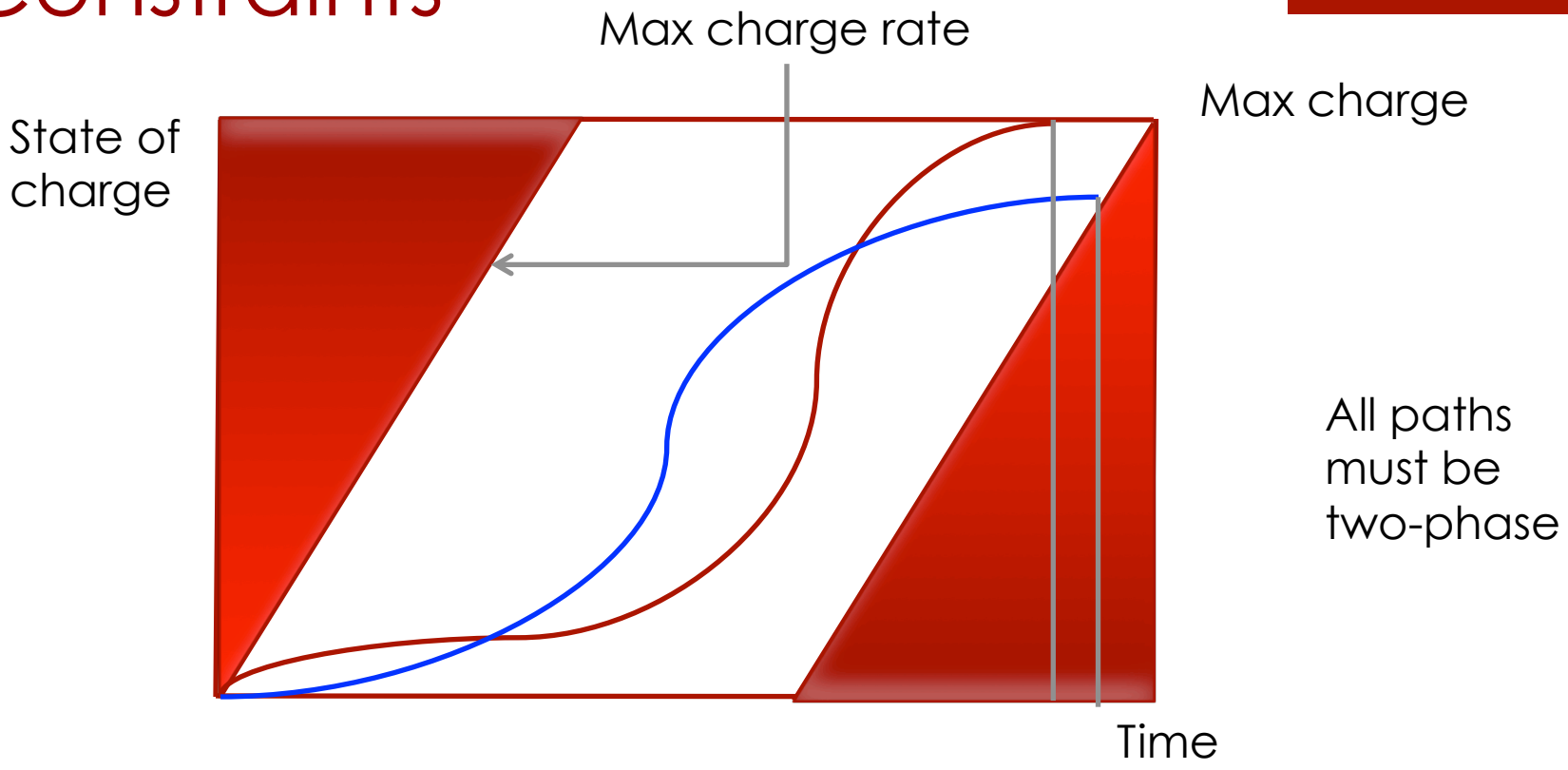
Standard regulation market

- Regulation contract signed between generator and regulator for a certain capacity
- Regulation up/down signals sent every 30s
  - Bounded by contract
- Payment for capacity as well as energy actually delivered

Demand-side regulation

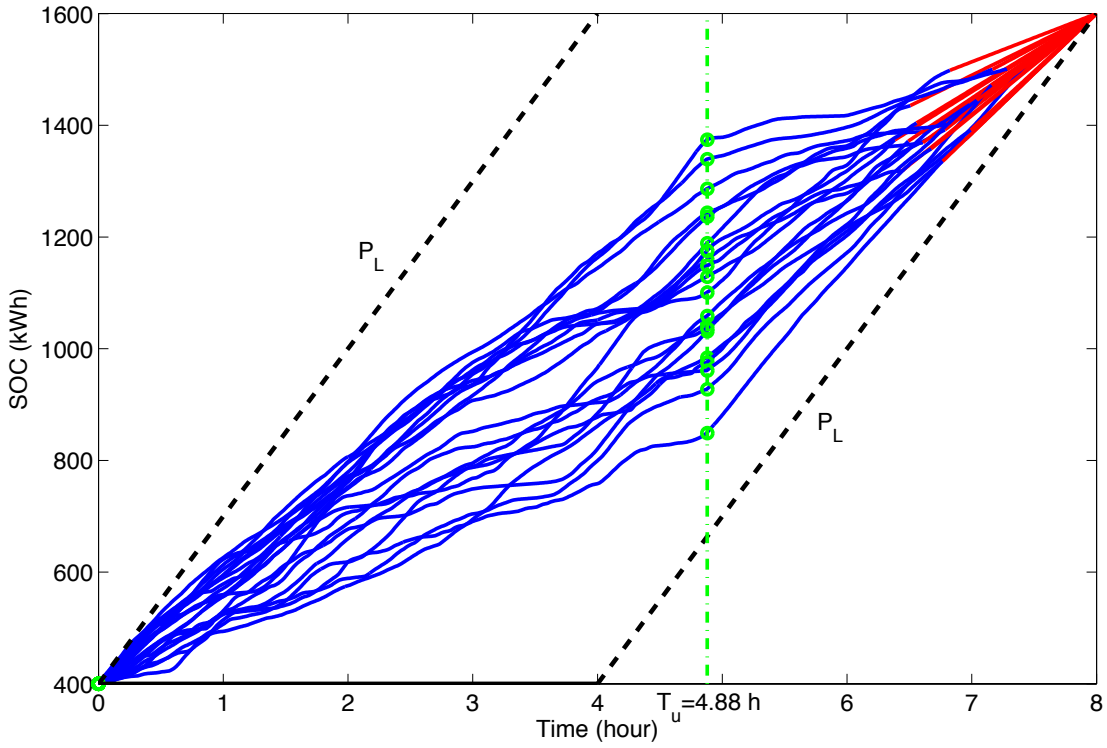
- Control charge rate in response to regulation signals
- Assume contract has two components
  - Duration of regulation
  - Maximum deviation of up/down value from mean rate
  - Example
    - Vary charge rate up or down by up to 25 MW
    - Duration = 8 hours
- Objective: **maximize their product**

Constraints

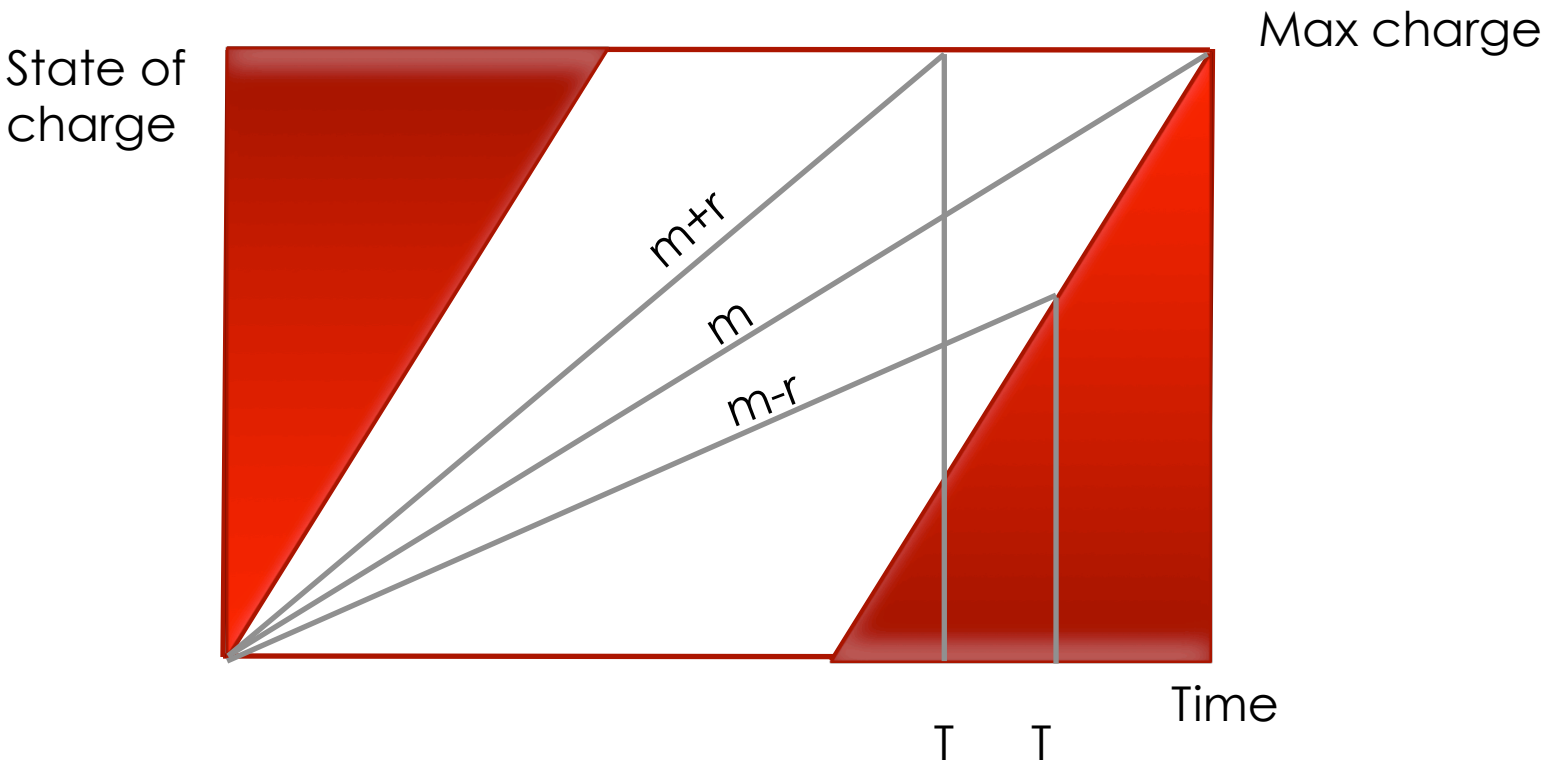


All paths must be two-phase

Example charging paths

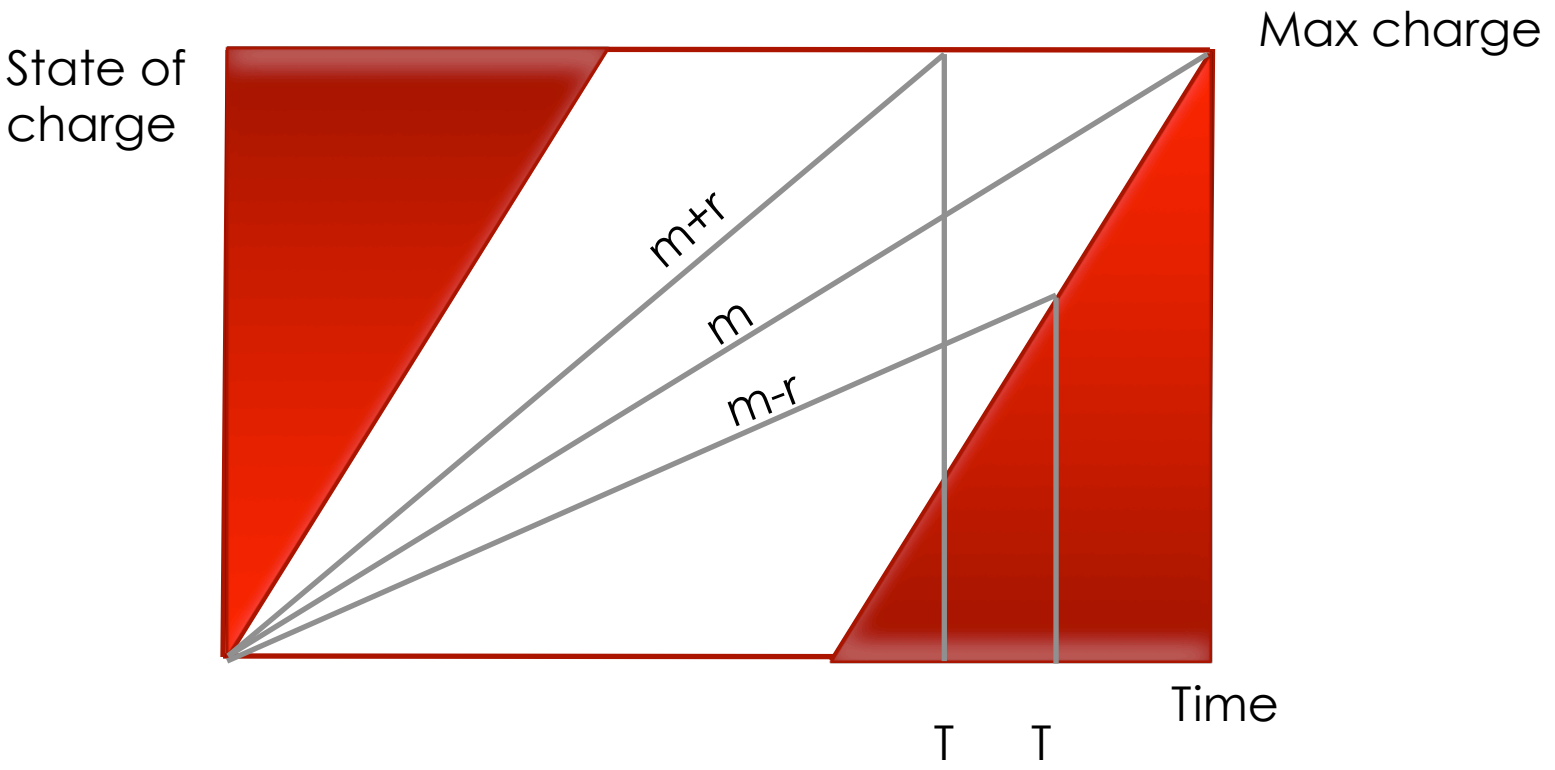


Deterministic solution



Choose m,r to maximize rT when signals are determinstically m+r or m-r

Stochastic solution

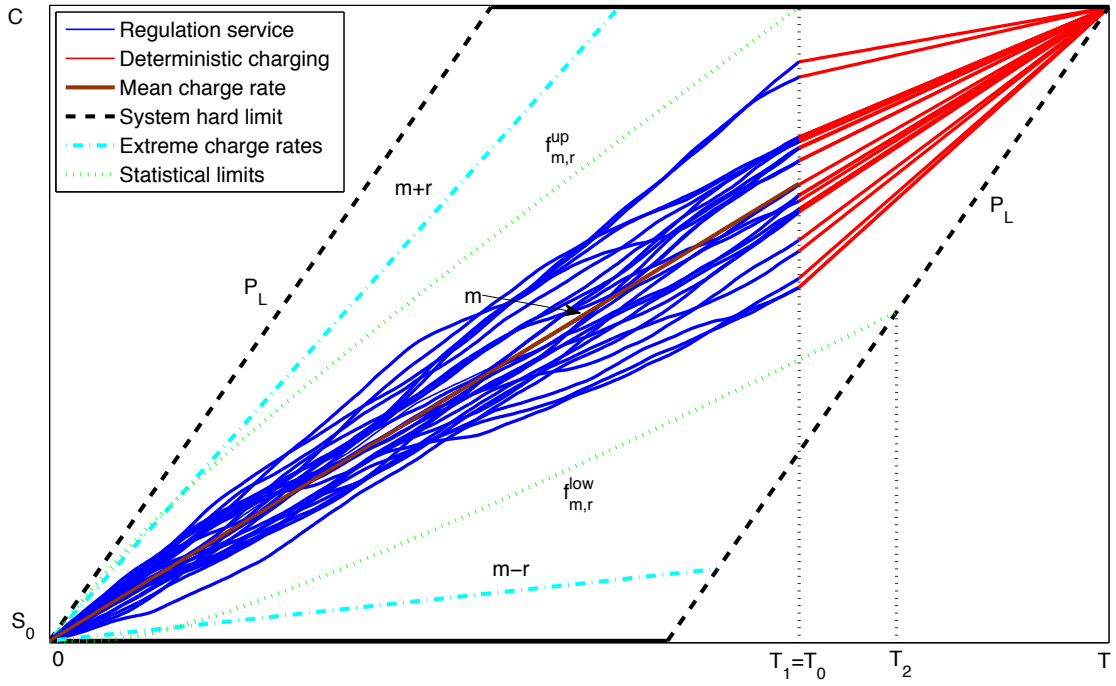


Choose m,r to maximize rT when signals are bounded by m+r or m-r
Assume that signal offsets form a zero-mean Gaussian white noise process

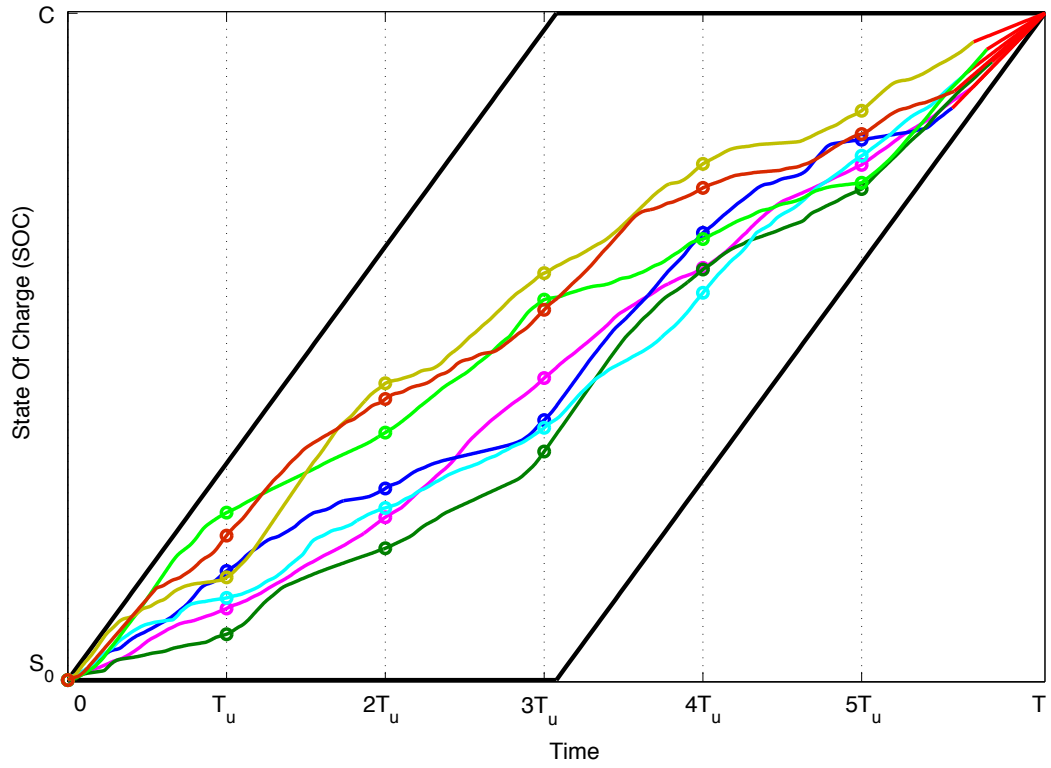
Solution approach

- Constrained optimization
- Analytical solution exists!

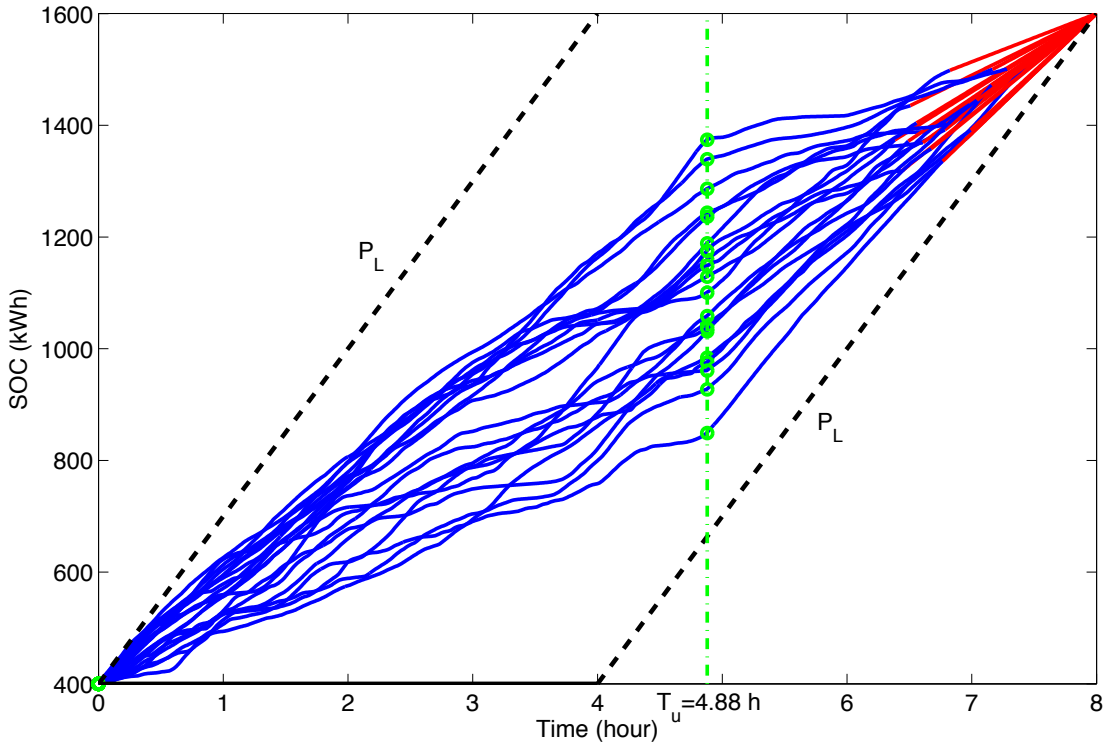
Typical stochastic solution



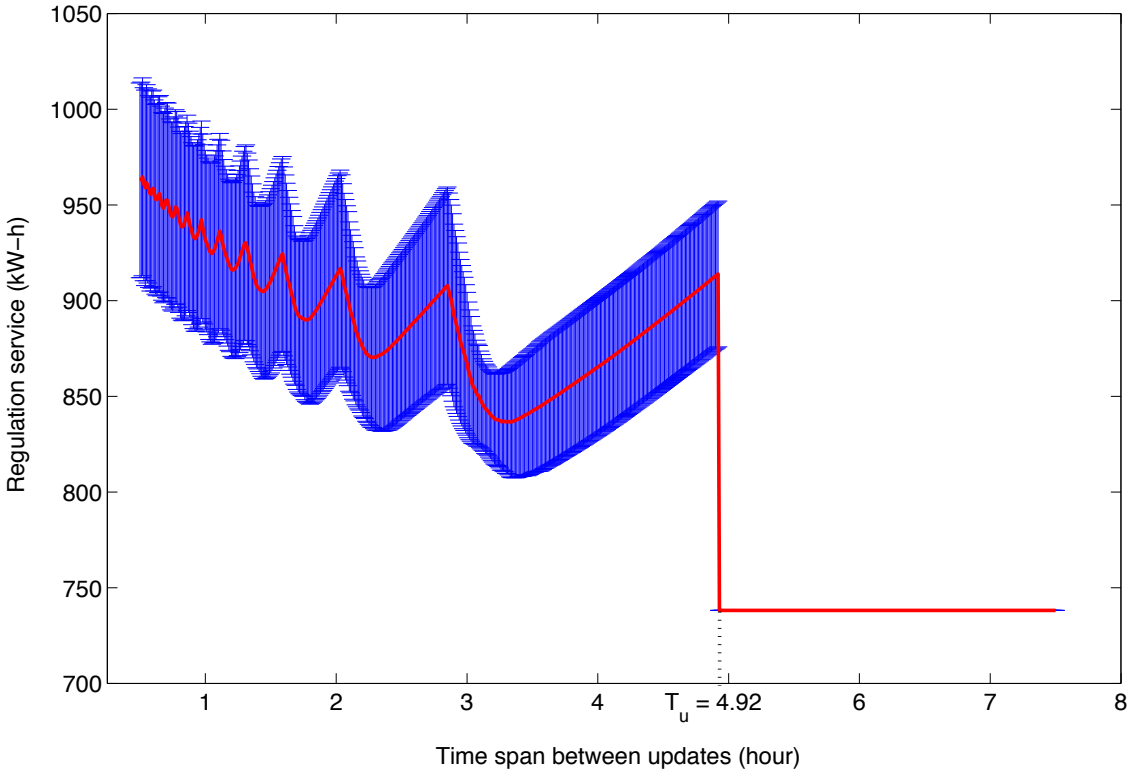
Dynamic optimization



Dynamic update



Results


1050
1000
950
900
850
800
750
700
Regulation service (kW−h)
1
2
3
4
T_u = 4.92
6
7
8
Time span between updates (hour)

Conclusions

- Demand-side regulation can be provided by EV fleets
- Optimal solution is analytically tractable
- One additional optimization during the charging period greatly improves performance