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

EV Fleet charging station

BEV
PHEV

EV Fleet
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

State of charge

Max charge rate

Max charge

All paths must be two-phase

Time
Example charging paths

![Graph showing example charging paths]

- SOC (kWh)
- Time (hour)
- $T_u = 4.88$ h
Deterministic solution

Choose $m,r$ to maximize $rT$ when signals are deterministically $m+r$ or $m-r$.
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

![Graph showing State of Charge (SOC) over time](image)
Dynamic update

\[ T_u = 4.88 \text{ h} \]
Results

\[ T_u = 4.92 \]
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