A need- and willingness-based approach for online electric vehicle charging control


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The balancing act

- Challenges
  - fossil fuels
  - nuclear power
  - renewable energies (RE)
  - energy consumption

Focus on demand
“don’t spend more than what you have”
Why electric vehicles and how?

• Variability from renewables and demand
  – regulation and reserve requirements
  – usually inefficient
  – fossil fuels

• Use plug-in electric vehicles (PEV) to compensate for this variability
  😊 PEVs are flexible loads on power systems
Research problem

- Control PEVs in **real time** to reduce **power variability**
  - within the **distribution network** constraints and distributed **solar** generation
  - low distance to **optimality**
- What is the **tradeoff** between optimality and **ICT** requirements and its main influencing factors?

- **Privacy**
- Dependency on prediction
- Flexibility in constraints and objectives

*ICT: information and communication technologies*
Related work

PEV charging

Factors considered

<table>
<thead>
<tr>
<th></th>
<th>RE</th>
<th>V2G*</th>
<th>Online</th>
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<tbody>
<tr>
<td>Acha et al. 2010</td>
<td>6</td>
<td></td>
<td>7</td>
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<tr>
<td>Binding &amp; Sundström 2012</td>
<td>6</td>
<td>7</td>
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<td>Clement-Nyns et al. 2010</td>
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<td>Galus et al. 2011</td>
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<td>Jahangiri et al. 2012</td>
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<td>Richardson et al. 2012</td>
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<td>Singh et al. 2010</td>
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<td>Sortomme et al. 2011</td>
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<tr>
<td><strong>Our approach (Oa)</strong></td>
<td>7</td>
<td>6</td>
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* Vehicle to Grid

Consider DN constraints

Optimization objective

- Power losses
- Voltage profile
- Costs/price
- Charging rate
- Flat power profile

# of papers
Classifying PEV charging optimization

<table>
<thead>
<tr>
<th>Control method</th>
<th>Optimization approach</th>
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<tbody>
<tr>
<td>Direct</td>
<td>Incentive-based</td>
</tr>
<tr>
<td>+ Certainty</td>
<td>+ Acceptability</td>
</tr>
<tr>
<td>- Acceptability</td>
<td>- Uncertainty</td>
</tr>
<tr>
<td></td>
<td>+ Simplicity</td>
</tr>
<tr>
<td></td>
<td>- Scalability</td>
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<tr>
<td></td>
<td>+ Scalability</td>
</tr>
<tr>
<td></td>
<td>- Complexity</td>
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</tbody>
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Design principles

• Decision at aggregator level: **certain & simple**
• Part of the computation on PEVs: **scalable**
• ICT requirements within acceptable bounds
• Low impact in optimality

**Benchmark: centralized direct control optimization**

<table>
<thead>
<tr>
<th>Model</th>
<th>Continuous</th>
<th>Integer</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>faster</td>
<td>slower</td>
</tr>
<tr>
<td></td>
<td>less realistic</td>
<td>more realistic</td>
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<tr>
<th>Data</th>
<th>All known</th>
<th>Upon arrival</th>
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<tbody>
<tr>
<td></td>
<td>strong assumption</td>
<td>realistic</td>
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<td></td>
<td>absolute best (ref.)</td>
<td>reachable target</td>
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Our approach

1. Sort NfC and WtS
2. Get current demand
3. Add cars in trouble
4. More charging?
5. V2G?

Benchmark
Quadratic (mixed integer) programming

\[
\min_{P_G(k)} \sum \{P_O - P_G(k)\}^2
\]

for every time step k
The PEVs

$$NfC \propto \frac{\text{ReqTimeSlots}}{\text{AvailTimeSlots}}$$

$$WtS \propto \frac{\text{SOC}}{\text{DepTime}} \text{AvailTimeSlots}$$

- With some conditions
  - $NfC = C_{\text{tar}}$ for $C_{\text{noC}} < NfC < C_{\text{tar}}$
  - $NfC = C_{\text{noC}}$ for $NfC < C_{\text{noC}}$

- For a full battery $\rightarrow C_{\text{noC}}$
- If must charge $\rightarrow C_{\text{QoS}}$

- Below a min. charge $\rightarrow C_{\text{noS}}$
- If must charge $\rightarrow C_{\text{noS}}$

For and by every PEV $\rightarrow$ parallelizable & distributable

SOC: state of charge
## The simulation

### Constraints

- **\(-P_{\text{lim}} < p(t) < P_{\text{lim}}\)**
  - power limits on every charge

- **\(SOC(\text{end}) \geq SOC_{\text{tar}}\)**
  - final charge

- **\(SOC_{\min} \leq SOC(t) \leq SOC_{\max}\)**
  - battery energy capacity

- **\(0 \leq \text{totalLoad} \leq DN\text{ Capacity}\)**
  - distribution network capacity

### Data

- **Driving profiles**
  - generated based on latest MiD* survey (100-1000 PEVS)

- **Load profile**
  - for Munich on a given day from SWM* (scaled)

- **Solar profile**
  - 5 x Munich low voltage intake from SWM* (scaled)

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*MiD: Mobility in Deutschland (2008)  
SWM: Stadtwerke München*
Day-specific Munich curves

Profiles and objectives

- Inflexible demand
- Solar generation
- Target for 500 PEVS

Load profile
- 1.6 MW peak
- 0.3% Munich load

Solar profile
- 0.5 MW peak
- 0.3% Munich intake x 5
Power profile

Continuous

Integer

Power profile 600 PEVS (cont.)

Power profile 600 PEVS (int.)

Power profile 1000 PEVS (cont.)

Power profile 1000 PEVS (int.)
Power profile

Continuous

Power profile 600 PEVS (cont.)

Power target

NfC-based

All known

Rec. hor.

Integer

Power profile 600 PEVS (int.)

Power profile 1000 PEVS (cont.)

Power profile 1000 PEVS (int.)

Power (W)

Time (15 min steps)
Performance

Continuous

Mean squared error (cont)

Integer

Mean squared error (int)

Solving time

Number of PEVs
Conclusions

• NfC-based approach advantages
  – privacy
  – forecast-free
  – naturally distributed & efficient
  – independent complexity of PEV and aggregator
  – extendibility (other flexible loads)
  – significantly faster than optimizing
  – comparable results (under certain conditions)

• Performance depends on the relation between load & fleet size
THANK YOU

• Questions?

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References


