QUANTIFYING FLEXIBILITY IN EV CHARGING AS DR POTENTIAL: ANALYSIS OF TWO REAL-WORLD DATASETS

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Fault detection? Restoration?
Data processing?
Privacy, security?
Pricing schemes?

New services & business models

Distributed generation (large scale)
Green energy sources (fluctuating)

ICT infrastructure

Distributed generation (small scale)

Demand side management

PHEV charging (car parks)

PHEV charging (residential)

Local energy storage

MODELING EV CHARGING

Literature:

- Model EV usage from regular vehicle usage
- Aggregated EV load estimation
- Pre-defined EV user types (e.g., residents, taxis, commuters...)
- Flexibility as fraction of time spent charging
- ...

Gap: data-driven EV modeling & real-world flexibility assessment

1. Typical behaviors in terms of time of arrival and departure?
2. Statistical models of sojourn vs time spent charging?
3. What amount of power can we shift over how much time?

C. Develder, N. Sadeghianpourhamami, M. Strobbe and N. Refa, "Quantifying flexibility in EV charging as DR potential: Analysis of two real-world data sets", in Proc. 7th IEEE Int. Conf. Smart Grid Commun. (SmartGridComm 2016), Sydney, Australia, 6-9 Nov. 2016, pp. 600-605.
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**DATASETS: iMove (BE) and ELaadNL**

<table>
<thead>
<tr>
<th>PERIOD</th>
<th>iMove: 03/2012 – 03/2013</th>
<th>ELaadNL: 01/2012 – 03/2013</th>
</tr>
</thead>
<tbody>
<tr>
<td># SESSIONS</td>
<td>8 520</td>
<td>1 141 849*</td>
</tr>
<tr>
<td># USERS</td>
<td>134</td>
<td>about 53 000</td>
</tr>
<tr>
<td>CAR TYPE</td>
<td>Full EV</td>
<td>Unknown mix</td>
</tr>
<tr>
<td>CHARGE POINT</td>
<td>At home</td>
<td>Public</td>
</tr>
<tr>
<td>TRIP DETAILS</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

**iMove**: Flemish EV field trial; data from 50 EVs shared 3 x 2 months

**ELaadNL**: EV innovation in NL; data from ~3000 public stations

*: Analysis on data from 1 Jan.–31 Mar. 2015 (N = 90 562)
TYPICAL ARRIVAL AND DEPARTURE TIMES (1/2)

Daytime charging (9.4%)

Anytime charging, short sojourn (61.5%)

Nighttime charging (29.1%)

Elaad

C. Develder, et al., "Quantifying flexibility in EV charging as DR potential: Analysis of two real-world datasets", 5th Int. Conf. Armand Peugeot Chair, 14-15 Dec. 2017
TYPICAL ARRIVAL AND DEPARTURE TIMES (2/2)

Anytime charging, short sojourn (61.5%)

Nighttime charging (29.1%)

Daytime charging (9.4%)

Park to charge

Charge near home

Charge near work

AM/Noon/PM peaks on weekdays

Shift to later times on weekends

SOJOURN AND IDLE TIMES (1/2)

Average charging time ≈ 3h 42min

Average idle time ≈ 23min

Average charging time ≈ 3h 44min
SOJOURN AND IDLE TIMES (2/2)

**Anytime charging, short sojourn (61.5%)**

- Park to charge
- Charge near home
- Charge near work

**Nighttime charging (29.1%)**

- Week ≈ Weekend
- Longer in weekend

**Daytime charging (9.4%)**

- Shorter in weekend
- Lower var. in week

QUANTIFICATION OF FLEXIBILITY: CALCULATION

\[ P_{\text{FLEX}}(t, \Delta) = \text{Maximal power that DR could either consume constantly, or not at all, in interval } [t, t+\Delta] \]

- Charging session has to include \([t, t+\Delta]\)
- Charging duration \(\geq \Delta\) [else we could not consume in full interval]
- Flexibility = session duration − \(\Delta \geq\) charging duration [we can move it away]

Upper bound: we disregard impact of using/suppressing power in \([t, t+\Delta]\) on flexibility at other times \(t'\)
QUANTIFICATION OF FLEXIBILITY: RESULT

- **Park to charge:**
  - Daytime flexibility
  - Weekend: ≈ volume, but ≠ timing

- **Near home:**
  - Nighttime flex
  - Weekend: lower & more spread

- **Near work:**
  - Daytime flex
  - Low in weekend

C. Develder, et al., "Quantifying flexibility in EV charging as DR potential: Analysis of two real-world datasets", 5th Int. Conf. Armand Peugeot Chair, 14-15 Dec. 2017
CONCLUSION

- Real world data set
- Three major types of charging sessions
- Statistical models of user behavior
- Methodology to quantify flexibility

Application?

E.g., extrapolation of iMove data to 3% of Flemish fleet by 2020:
- ~100k cars out of ~3.2M
- E.g., noon in weekend ⇒ can have ~7MW extra for 2h
BUT... WHAT FLEXIBILITY IS ACTUALLY USED?

Quantification of use of flexibility in relevant use cases:

\[ E_{\text{flex}} = \frac{\text{Energy beyond } t_{\text{BAU}}}{\text{Maximal energy beyond } t_{\text{BAU}}} \Rightarrow 1 - E_{\text{flex}} = \text{fraction charged at } t_{\text{BAU}} \]

\[ T_{\text{flex}} = \frac{t_{\text{coordinated}} - t_{\text{BAU}}}{t_{\text{depart}} - t_{\text{BAU}}} = \text{fraction of idle time exploited to delay} \]

E.g., \( E_{\text{flex}} = 0.2 \Rightarrow \) only 20\% of charge volume is delayed

E.g., \( T_{\text{flex}} = 0.8 \Rightarrow \) end-of-charge at 80\% of flexibility time window

CASE STUDIES: (1) Load flattening, (2) RES balancing
SAMPLE CASE STUDIES

Case (1): Load flattening

Case (2): RES balancing

Fill = over what time span load is deferred


SAMPLE CASE STUDIES

- Near home:
  - $T_{\text{flex}}$ close to 1: charging till last moment, but...
  - $E_{\text{flex}}$ low: reasonable SoC at $t_{\text{BAU}}$

- Near work:
  - Higher $T_{\text{flex}}$ in weekend
  - Reasonable SoC at $t_{\text{BAU}}$

- Park-to-charge:
  - $T_{\text{flex}}$ close to 1
  - Peaked $E_{\text{flex}}$ during daytime
THANK YOU ... ANY QUESTIONS?

... It is not easy being green...
THANK YOU ... ANY QUESTIONS?

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