Enhancing the role of EVs as grid proactive DER

The Danish experience

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DTU Risø Campus
Outline

• About DTU and CEE (Center for Electric Power and Energy)

• On EVs and grid integration...

• Lessons learned from the Danish Nikola and the EU ELECTRA project
  ➢ Flexibility definition
  ➢ Field tests in a distribution grid
  ➢ Lab tests in SYSLAB

• Current activities in the Danish ACES and Parker projects
  ➢ Scaling up the analysis in Bornholm
  ➢ Field trial in Frederiksberg Forsyning

• Lesson learned
About DTU – 2016 figures

3834 Master students (1528 from abroad)
7127 Bachelor students
99 nationalities
28% women

5895 total staff
106 nationalities
38% women

2117 Professors and researchers
-> 43% international

1217 PhD students
-> 53% international

2561 support (adm, tek, service)
-> 9% international

670 M€ income
more than 50% based on external grants

5744 publications
10.1 citation IF
Center for Electric Power and Energy (CEE)
Department of Electrical Engineering

**Strong power system and renewable energy research**
CEE’s strategic research themes:
- **Digital Energy Solutions**
- **Interconnected Energy System**
- **Optimized Electric Energy Technologies**
The center has ~100 staff members, including >30 PhDs and >10 postdocs. CEE links with 1,000+ researchers at DTU within energy research.

**Close industrial collaboration**
100+ industrial partners in 80+ ongoing projects. Partners: Energinet (DK), Danfoss (DK), Siemens (GE), China Electric Power Research Institute (CN), DONG Energy (DK), ELIA (BE), National Grid (UK), Svenska Kraftnät (SE), STATNET (NO), Fingrid (FI), RED Electrica (ES), TenneT (NL), ABB (DK), Vestas (DK), IBM (CH), EPRI (US) etc.

**Active European player**
*Ongoing EU-projects*: Best Path, EcoGrid EU, IDE4L, ELECTRA, COTEVOS, CEMIS, TwinPV, NANOPYME, WetMate. *Recently completed EU-projects*: TWENTIES (transmission operation), Anemos Plus (forecasting tools), WILMAR (wind energy modelling), and many more.

**Publications and impact**
90 WoS journal publication in 2016
Scientific impact factor: 11.7

Read more: [www.cee.elektro.dtu.dk](http://www.cee.elektro.dtu.dk)
Concerning integration...

- What does integration mean?
  - *put together parts or elements and combine them into a whole*

- Integration of resources (EV, wind, PV...) with respect to power systems:
  - Consider them as "normal" source like all the others with "honors" (remuneration) and *duties* (ancillary services) needed in order to properly control system *voltages and frequency.*
EV from different perspectives

Researcher (me)

System operators

Government (at least DK!)

EV owner
EV related projects at CEE

- EDISON 2008 – 2011
- NIKOLA 2013 – 2016
- COTEVOS 2013 – 2016
- EnergyLab Nordhavn 2015 – 2019
- ELECTRA 2013 – 2018
- Parker 2016 – 2018
- ACES 2017 – 2020
Methodological approach adopted

Interaction with the other DER (DSM; PV; CHP; WIND; Storages)

**Active Power**
- Bidirectional
- 1 or 3 phases
- Resp. time
- Duration (SOC)
- Islanding
- User willingness

**Reactive Power**
- f/P I/II
- V/Q
- MV-LV Trafo/Line congestion
- MV congestion due to fast charging area
- Microgrid Islanding
- Over-voltages management
- LV network balancing

**MV/LV Network physical constraints**
- Static
  - Unbalanced
  - Balanced LF
  - Monte Carlo
  - Optimization
- Dynamic (transient analysis)
  - f/P I/II
  - Islanding
  - LVRT
- Harmonic
Defining theoretical and practical flexibility attributes

Figure 1: (a) Theoretical and (b) practical attributes of a flexibility service (excluding the location).

Investigated AC and DC (V2G) charging options for EVs

Grid power ↔ Battery power

+/-10 kW
3 phases

30 kWh battery
BMS

On-board charger

Both methods are subject to efficiency losses
SYSLAB experiments on V/I droop control in unbalanced setup

Equivalent X/Rac ratio = 0.37

Controllers and communication architecture

\[
\begin{align*}
\Delta U &= 11.5 \, V \ (= 0.05 \, \text{pu}) \; ; \; U_{\text{nom}} = 230V \\
\Delta I &= 10 \, A \; ; \; I_{\text{nom}} = 10A \\
\Delta U / U_{\text{nom}} &= 5\% \\
\Delta I / I_{\text{nom}} &= \frac{\Delta U}{U_{\text{nom}}} = 5\%
\end{align*}
\]

- **EV**
- **EVSE**
- **Grid**
- **Smart Charging Controller**
- **Measurement Unit**

- Maximum Charging Current
- Communication
- Power Flow

(b) Phase-to-neutral voltage (pu)

- Ideal droop
- Real droop 1
- Real droop 2

(b) Phase-to-neutral voltage (pu)

- Ideal droop
- Real droop 3
Setup for voltage unbalance experiments
dumb charging

Test Scenarios 2, 3 and 4 Voltages and Load and Charging Currents

- Voltage [V]
- Current [A]

Load and EVs

EVs
Test field in Borup LV feeder (DK)

Test field in Borup (DK) – multiple services
Test field in Borup (DK) – multiple services

- Congestion management
- Voltage regulation
- Frequency control

Max & min EV charging rate
Max & min threshold

$$I_{EV_{max}}$$
$$threshold_{max}$$

$$I_{EV_{min}}$$
$$threshold_{min}$$

$$sign(k)$$

Controller

$$I_{meas}$$
$$U_{meas}$$
$$f_{meas}$$

$$I_{EV_{max}}$$
$$k > 0$$

$$I_{EV_{min}}$$
$$k < 0$$

$$threshold_{min}$$
$$threshold_{max}$$

$$[A][V][Hz]$$

EV current limit $$I_{EV_{limit}}$$
Inertial response vs frequency response analysis in SYSLAB
Components’ characteristics

<table>
<thead>
<tr>
<th>Device</th>
<th>Capability</th>
<th>P0 (kW) SC1</th>
<th>P0 (kW) SC2</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>0–48 kW</td>
<td>24</td>
<td>24</td>
<td>IVECO genset</td>
</tr>
<tr>
<td></td>
<td>−20–30 kVAR</td>
<td></td>
<td></td>
<td>S = 60 kVA, 2 pole pairs</td>
</tr>
<tr>
<td>Aircon</td>
<td>10 kW @ 11 ms</td>
<td>−</td>
<td>~4</td>
<td>Wind turbine type 4</td>
</tr>
<tr>
<td>Battery</td>
<td>±15 kW</td>
<td>9</td>
<td>−</td>
<td>Vanadium redox battery, 120 kWh</td>
</tr>
<tr>
<td></td>
<td>±12 kVA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dumpload</td>
<td>0–78 kW</td>
<td>7</td>
<td>21</td>
<td>Resistor load bank</td>
</tr>
<tr>
<td>EV1</td>
<td>6–16 A (1.4–3.7 kW)</td>
<td>2.5</td>
<td>2.5</td>
<td>Nissan leaf 2016, 30 kWh lithium battery</td>
</tr>
<tr>
<td>EV2</td>
<td>6–16 A (1.4–3.7 kW)</td>
<td>2.5</td>
<td>2.5</td>
<td>Nissan e-NV200 2014, 24 kWh lithium battery</td>
</tr>
<tr>
<td>EV3</td>
<td>6–16 A (1.4–3.7 kW)</td>
<td>2.5</td>
<td>2.5</td>
<td>Nissan e-NV200 2015, 24 kWh lithium battery</td>
</tr>
</tbody>
</table>

M. Rezkalla, A. Zecchino, S. Martinenas, A. M. Prostiejkovskj, M. Marinelli, “Comparison between synthetic inertia and fast frequency containment control based on single phase EVs in a microgrid,” In Applied Energy, 2017
Controllers’ characteristics

- Frequency and RoCoF are measured every 200 ms, the controllers’ response is almost instantaneous and communication delay (10–20 ms) to each EV/EVSE pair is optimised by controlling them independently. EVs reaction time spans between 200 and 300 ms.

- The whole control and actuator chain has an overall latency equal to 400–500 ms.
Results Study case 1 (no wind)

Fig. 9. Study Case 1 (load steps) – (a) Frequency, (b) RoCoF, (c) EVI’s set-point vs absorbed current.
Results Study case 1 (no wind)

Fig. 10. (a) Frequency, (b) RoCoF, (c) EV1’s absorbed current.
ACES project: Make Bornholm a (great) island again

DTU Elektro
Institut for Elektroteknologi

10 MDKK
Total Budget

5.5 MDKK
Danish Funds (EUDP)

3.5 years
130 PM
(= 3 persons full time)

BORNHOLMS ENERGI & FORSYNING

NISSAN

NUVVE
3 main research areas – some of the research questions investigated

1. DSO vs TSO coordination and grid modelling
   - Can a large set of EVs contribute to balance an islanded power system without inducing local grid issues?

2. EV aggregating functions
   - Contract phase: for how long, how large, and how fast the aggregated power of EV fleet should be ready on a daily, weekly or monthly basis when contracting with the system operator?

3. Services economic and technical analysis
   - How much the degradation of the battery, while providing system services, affects the service profitability?
   - What is the saturation level of the ancillary service market in term of EV population?
Methodology for the economic assessment

**Input 1:** EVSE and EV data
- Analyze property, location and number of EVSE and EV

**Input 2:** energy and grid data (production/consumption)
- Analyze energy mix (renewable vs conventional)

**Input 3:** ancillary service market price
- Analyze hourly/weekly price

Calculate V2G charging/discharging profile (power, energy)

- Calculate revenue of ancillary service
- Calculate degradation of battery
- Estimate residual value of the EV (trade-in)
- Verify influence on frequency (TSO view)
- Verify influence on voltage (DSO view)
- Assess whether there is a cost reduction in CAPEX and OPEX or a benefit in more renewable
Chargers architecture for frequency ctrl (Parker configuration in Frederiksberg)

Aggregator

OCPP based protocol

Control signal to the whole fleet

Bi-directional Energy Flow

Grid Services
Energy to/from Electric Grid

Vehicle System Link Software (VSL)

– Software Defined Charging Station

Distributed Energy Storage

Bi-directional energy flow
CHAdeMo 2.0
Standardized protocol

Bi-directional energy flow
CHAdeMo 2.0
Standardized protocol
Some of the lessons learned so far

- **Current** series-produced **EVs** can provide **ancillary services** at the distribution level. Controller and infrastructure is made from standardised components: such control schemes could potentially be integrated in the EVSE with minimal development effort which makes such solution economically attractive.

- **Overall delay**, including all communication and measurements, can be contained within 1 second.

- The granularity of the control, with the 1 A discretization, does not help to obtain a smooth response, as each EV can change its output with a 10% step. Also, current “undershooting” up to 1 A → potential accuracy problem when providing services.

- Even with a simple decentralised autonomous droop controller, can **solve some of the power quality issues taking advantage of IEC61851**... however, large power steps at the nodes with poor voltage quality could introduce even more severe problems like large voltage oscillations.

- Very fast frequency control is perfectly doable with existing cars. Also the domain of inertial response can be entered, although with doubtful benefits.
Stay tuned!

www.aces-bornholm.eu
www.parker-project.com

Results download

This section collects the publicly available results produced in form of joint papers, thesis and reports
