Electric vehicle integration in the grid: experiences from the Danish V2G projects ACES and Parker

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Outline

• ACES and Parker projects and EV related projects at DTU

• Controlling an EV for the benefit of the grid

• Understanding the impact on the local distribution grid

• Frequency control using unidirectional and bidirectional (V2G) charging

• Consequences in term of battery degradation

• Lessons learned
EV (related) projects at the Center for Electric Power and Energy - DTU

- EDISON 2008 – 2011
- NIKOLA 2013 – 2016
- COTEVOS 2013 – 2016
- ELECTRA 2013 – 2018
- EnergyLab Nordhavn 2015 – 2019
- Parker 2016 – 2018
- ACES 2017 – 2020
- CAR 2018 – 2020
Distribution Feeder in Rønne
- LV grid: 400 V
- 10/0.4 kV 400 kVA distribution transformer
- 4 subfeeders: 110 known load consumptions
- 8 10 kW DC chargers
- Common district heating

The ACES project
Across Continents Electric vehicles Services

Budget: 10 MDKK (=1.4 M€)
Public grant (EUDP): 55%
Equivalent person-months: 130 over 3y (04/17-03/20)
Public chargers and EVs used in the demo:
20 Nissan Leaf and env-200

www.aces-bornholm.eu

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Partners: Nissan, Mitsubishi Corporation, Mitsubishi Motors Corporation, PSA ID, NUVVE, Frederiksberg Forsyning A/S, Insero A/S, Enel and DTU.

Duration: August 2016 to January 2019.

Budget: Two million euros, funding by EUDP

Demonstrate that contemporary electrical vehicles can participate in advanced smart grid services.

More info: www.parker-project.com

Thomas Parker, 1843 – 1915
Investigated AC and DC (V2G) charging/control options for electric vehicles

- Charging options considered:
  - 10 kW DC via external charger bidirectional control
  - 3.7 - 11 - 22 kW AC via internal charger unidirectional control
Getting to the local grid – the driving behavior matters

• Considering realistic driving/charging behaviour, what’s the expected loading impact on two representative distribution grids assuming a 100% EV scenario?

• If reinforcement is necessary, what would be a fair value for a load deferring?

• historical driving characteristics of private conventional vehicles from Denmark

![Graph showing historical driving characteristics]

• home plug-in behavior of EVs from Japan

![Graph showing home plug-in behavior]

Getting to the local grid – the driving behavior matters

- LV grid: 400 V
- 10/0.4 kV 400 kVA
- 4 subfeeders: 127 known load consumptions
- Common electric heating (40% of the houses)

Mean distribution: 42% phase a, 33% phase b, 25% phase c.

Assumed load: 40% in phase a, 30% in phase b, 30% in phase c.
Getting to the local grid – the driving behavior matters

• In the most conservative scenario, we assumed that the potential plug in events are split in 4 sets of 25% EVs each: 16:00, 17:00, 18:00 and 19:00. EVs are equally distributed on phases (for the 3.7 kW).

• Throughout the whole study NO work-charging nor public charging is considered (each customer will solely charge at home).

• **Single-phase chargers (3.7 kW); Three-phase chargers (11.1 kW)**

- Higher rated power of the chargers ➔ less EVs charging at same time, but higher peak consumption.
Frederiksberg Forsyning and Bornholm configurations

Aggregator

OCPP based protocol

Bi-directional energy flow
CHAdeMo 2.0
Standardized protocol

Grid Services
Energy to/from Electric Grid

Bi-directional Energy Flow

Distributed Energy Storage

Vehicle System Link Software – Software Defined Charging Station

Control signals

Bi-directional energy flow
Primary Frequency Control – bidirectional (V2G) or unidirectional flow

- The most straightforward control logic for providing frequency control is to use droop (pure proportional) controllers – as commonly done in conventional power plants.
- Depending on the capability of the device, the characteristic can be symmetric or not and use either bidirectional (V2G) or unidirectional power flow.

- The droop is the measure of how much the machine is sensitive to frequency changes and is the value that quantify its contribution to primary frequency/power regulation.
- \[ \Delta f_{\text{nom}} = -k_{\text{droop}} \frac{\Delta P_{\text{nom}}}{P_{\text{nom}}} \]
Realizing bidirectional (V2G) control with commercial vehicles in Denmark – 14 h/day provision

Realizing unidirectional frequency control with private vehicles in Bornholm (DK) – ACES smart charger

Equipment used:
EVSE: charger controller 6-32 A 3-ph
EV: Tesla model S

Controller running:
Frequency control (remote meas)
Response time around 5-6 seconds (mostly on the EV side)

https://brokergraphs.syslab.dk/d/AcNHuXFZk/electric-vehicle-data?orgId=1
Assessing the impact in term of degradation – how much driving and V2G services affect battery life

The characteristics of a 40 kWh battery with NMC cells are taken in account.

The EV is subject to a driving pattern of 45 km/day (average driven distance in DK = 9kWh)

The EV provides 14 h/day of frequency regulation with a ±10 kW reserve

Quantification of calendar and cycling ageing

A. Thingvad, M. Marinelli, “Influence of V2G Frequency Services and Driving on Electric Vehicles Battery Degradation in the Nordic Countries,” EVS 31 and EVTeC 2018, Kobe, 30 Sep. – 03 Oct 2018
Calendar and cycling degradation depending on the initial daily SOC (60 vs 80%)

Recharging at 60%

Recharging at 80%
Calendar and cycling degradation depending on the initial daily SOC (60% vs 80%)

- Combined operation has the highest degradation.
- 1.54% more than driving only and 3.09% more than parked only

- Combined operation has the highest degradation.
- 1.09% more than driving only and 2.76% more than parked only

Lessons learned

• Current market structures and framework conditions facilitate demand response/DER participation to a lesser extent: the most beneficial aspects are hardly leveraged.

• Technology and social aspects are equally important: the focus on social practices will help the move away from a “technology push” approach to smart Grids.

• Uncertainty in the amount of power&energy provided by heterogeneous sets of units is crucial for large-scale applications, particularly frequency based services.

• Mimicking the response of conventional power plants when providing balancing services with heterogonous aggregation of DERs is necessary to replace conventional units.

• Wear of equipment (EVs particularly) seems to be limited, despite heavy usage.
STAY TUNED! –

CHECK RESULTS ON THE PROJECTS WEBSITES

• ACES: www.aces-bornholm.eu
• CAR: www.sbcar.eu
• Parker: www.parker-project.com
References and further readings


• A. Zecchino, A. Thingvad, P. B. Andersen, M. Marinelli~, “Suitability of Commercial V2G CHAdeMO Chargers for Grid Services,” EVS 31 and EVTeC 2018, Kobe, 30 Sep. – 03 Oct 2018