Electric Vehicles & the Grid: From Problem to Opportunity

11:00 - 12:45
Wed, 27 September 2023
Theater Hall, Delft X, TU Delft
## Electric vehicles & the Grid: From Problem to Opportunity

<table>
<thead>
<tr>
<th>Time</th>
<th>Speaker</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>11:05</td>
<td>Sebastian Rivera, Assistant professor, DCES</td>
<td>Power electronics for Energy hubs for EV charging</td>
</tr>
<tr>
<td>11:20</td>
<td>Gerd Kortuem, Full professor, IDE</td>
<td>EV charging: Human aspects &amp; responsible AI</td>
</tr>
<tr>
<td>11:35</td>
<td>Gautham Ram, Assistant professor, DCES</td>
<td>Vehicle to grid: Technology trends &amp; challenges</td>
</tr>
<tr>
<td>11:50</td>
<td>David Shipworth, Professor, UCL Energy Institute</td>
<td>Vehicle-to-grid vs vehicle-to-home from an end-user perspective</td>
</tr>
<tr>
<td>12:05</td>
<td>Pedro Vergara, Assistant professor, IEPG</td>
<td>Smart charging at scale (ROBUST)</td>
</tr>
<tr>
<td>12:20</td>
<td>Jianning Dong, Assistant professor, DCES</td>
<td>High-efficient wireless charging of EVs</td>
</tr>
<tr>
<td>12:35</td>
<td>All speakers</td>
<td>Audience questions with speakers panel</td>
</tr>
</tbody>
</table>
Transport emissions

- Transport emissions = 7.2 Gt CO₂
- ~17% of all emissions

Trucks include road freight vehicles with a gross vehicle weight of more than 3.5;

59 Gt CO₂e = Net emissions 2019 - CLIMATE CHANGE 2023 - Synthesis Report, IPCC
Take the bike, bus & train

- Electric cars are not the only solution
- Bike > Train, Bus, tram > (Electric) car
Mobility & Energy transition need to go hand-in-hand

- Electricity generation mix (Note: May not account for emissions due to production of fuel source)

1 kWh ~= 6 km EV range

(Plug in) hybrids have a key role

- Go for fully electric cars in the near term (1-5y) in your country if
  1) build fast charging infrastructure, 2) significantly decarbonize its electricity grid, 3) bring affordable EVs in the market

- If not, plug-in hybrids can reduce emissions by 1.5-4x in near term (1-10y)

Honda Civic
Toyota Prius (4.4kWh)
Chevrolet Volt (18.4 kWh)
Tesla Model 3 (75 kWh)

Power Electronics for Energy hubs for EV charging

Dr. Sebastián Rivera, DCE&S
Presentation Outline

• Charging Systems for Medium- and Heavy-Duty EVs
  o EV Charging Infrastructure.
  o Heavy-duty EV Charging Standards
  o DC Charging options for Heavy Duty EVs
  o Commercially Available High-Power Chargers
  o Challenges

• Energy Hubs
  o Energy Hub Concept.
  o EHs for HD Chargers.
  o Dual purpose of EH-based Charging infrastructure

• Ongoing Research
  o Highly-Efficient and versatile Multiport PEBBs.
  o Modular structure for ≥MW vehicles (beyond MCS).
  o Energy Hubs for the Railway System

• Conclusions and Outlook
Charging Systems for Medium- and Heavy-Duty EVs
EV Charging Infrastructure: AC and DC Charging

- **Onboard Chargers**
  - Dedicated AC Chargers
  - Integrated Chargers

- **Off-board Chargers**
  - Auxiliary DC Chargers
  - Others
    - Battery Swapping
    - Wireless Charging

**AC-Chargers**
- **AC Charging Stds.**
  - SAE J1772
  - IEC 61851
  - GBT 20334
  - NACS
  - SAE J3068

**DC-Chargers**
- **DC Charging Stds.**
  - SAE J3271/MCS
  - SAE J3105
  - CHAdeMO
  - SAE J1772 (CCS-1)
  - IEC 61851 (CCS-2)
  - GBT 20334
  - NACS (Tesla Supercharger)

**Charging Power kW**

*Annual TU Delft PowerWeb Institute Conference | 27 September 2023 | Dr. S. Rivera*
# Heavy-duty EV Charging

- Charging standards above 1 MW

<table>
<thead>
<tr>
<th>CHAdeMO/ChaoJi</th>
<th>MCS</th>
<th>NACS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Power</td>
<td>900 kW</td>
<td>3750 kW</td>
</tr>
<tr>
<td>Typ Power</td>
<td>TBD</td>
<td>1000 kW</td>
</tr>
<tr>
<td>Output voltage</td>
<td>50 - 1500 V</td>
<td>500 - 1250 V</td>
</tr>
<tr>
<td>Maximum current</td>
<td>600 A</td>
<td>3000 A</td>
</tr>
<tr>
<td>Comms.</td>
<td>CAN</td>
<td>TCP/IP (differential PLC)</td>
</tr>
<tr>
<td>Region</td>
<td>China, Japan</td>
<td>Europe, US</td>
</tr>
<tr>
<td>V2X</td>
<td>Yes</td>
<td>Under development</td>
</tr>
<tr>
<td>Plug type</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
EV Charging Infrastructure: DC Charging of HD EVs

• DC Charging options for Heavy Duty EVs
State-of-the-art High-power Chargers

- High-power chargers in the market
  - Commercially available chargers reach up to 600 kW
  - Modular structure using 20-50 kW PEBB
  - Similar approach is not suitable for +MW Chargers (+100 of modules)
  - Higher power blocks are required.
  - Several challenges arise: heavier, magnetics design, power
EV Charging Infrastructure: DC Charging of HD EVs

- DC Charging options for Heavy Duty Evs: Practical demonstrator NREL

![Diagram of EV charging infrastructure]

NREL +1MW HD EV Charger

- Power Output: 400kW - 1.2 MW
- Voltage Range: 220 - 1500 V
- Output Current: 800 A
- AC Input: 13.8 kV
- Onsite Storage Power: 400 kW
- Onsite PV Generation: 400 kW
- Isolation: HF
- Efficiency: 98%
EV Charging Infrastructure: Challenges

- Main challenges for +MW charging
  - Conventional discretization of power modules may not be suitable.
  - Increasing the power rating of PEBBs challenges the design of magnetics.
  - Substantial increase the stress on the electric power grid.

- Regional Challenges
  - EU prioritized the decarbonization of the HD vehicle sector.
  - Two TEN-T corridors have a key node in the Gerland Province.
  - Urban logistics will exponentially increase the demand for HD chargers.
  - Most of EU logistic routes have distances below 500 km.
Energy Hubs for EV Charging
Energy Hub Concept: Transportation Decarbonization
Energy Hub Concept

- Energy hubs create multiport pathways for different energy carriers to enable the modernization of the electric system and further electrification of industry processes as energy prosumers (bidirectionality).

Seamless integration of HDEV charging infra.
Enhanced grid flexibility
Scalable and tailored solution for dif. applc.
EV Infrastructure as a Versatile Grid Asset

Charger Circuit Topology

- LF isolation transformer + 12-pulse rectifier + 2 channel Buck
- PFC + LLC + Buck (3-ph version uses 3 identical stages)
- AFE + LLC + Buck

Grid Storage
- Long-term (days)
- Short-term (hours)

Active filter
- STATCOM

Capabilities:
- Excellent
- Good
- Insufficient²
- Uncapable
- Limited¹
- Partially²

EVSE state legend:
- with EV plugged-in
- without EV

Inertia
- Reactive power
- Harmonics
- Phase imbalance
- Voltage support
- Grid forming
- Short circuit current supply
- Black-start support

- 3-ph
- 1-ph
- 3-pulse rectifier + 2 channel Buck
- 3-ph
- 1-ph
- 3-ph

TU Delft

Annual TU Delft PowerWeb Institute Conference | 27 September 2023 | Dr. S. Rivera
# EV Infrastructure as a Versatile Grid Asset

## Capabilities:
- Excellent
- Good
- Insufficient
- Limited
- Partially
- Uncapable

## EVSE state legend:
- with EV plugged-in
- without EV

### Charger Circuit Topology

- **AFE + LLC + Buck**
  - 1-ph
  - 3-ph

- **AFE + LLC + Buck + Stationary battery**
  - 1-ph
  - 3-ph

- **NPC + LLC + Buck**
  - 1-ph
  - 3-ph

### Grid Storage

- Long-term (days)
- Short-term (hours)

### Active filter

- STATCOM

### Reactive power

- Inertia

### Harmonics

- Voltage support

### Grid forming

- Harmonics

### Short circuit current supply

- Black-start support

---

**TU Delft**

Annual TU Delft PowerWeb Institute Conference | 27 September 2023 | Dr. S. Rivera
Ongoing Research Projects
Energy Hubs for Heavy Duty EV Charging

- To design, develop and demonstrate versatile multiport PEEBs for interfacing HD chargers (above 1 MW).
- To coordinate and control several energy sources, storage and loads.
- Alleviate the impacts of high-power EV charging on the grid.
- 100 kW demonstrator under development.

Aimed for Megawatt Charging System (MCS) Standard
Modular high-power fast charging system for HDEVs

- To develop a scalable highly-efficient modular heavy duty EV charging system aiming to the 4-40 MW range.
- Systematic assessment for developing conductive and inductive solutions.
- To propose and identify optimal power size of PEBBs.
- 100 kW demonstrator under development with tailored magnetic design.
Energy Hubs for the Railway System

- DC powered railway infrastructure in the Netherlands can reach its full potential. More train lines can be added without compromising nor saturating the electric grid.

- Energy efficient power processing hubs will maximize energy from braking besides integrating energy systems based in different carriers.

New fast IC train Amsterdam - Rotterdam - Breda

Simplified topology of the railway network

PhD candidate Julián Rojas

Annual TU Delft PowerWeb Institute Conference | 27 September 2023 | Dr. S. Rivera
Conclusions and Outlook

- +MW charging entails several challenges, opening new opportunities for researchers.

- Tenfold increase in the output power requires novel approaches for the size of converter modules.

- Grid integration of HD charging infrastructure will further stress electric grid, specially in densely populated areas in the NL.

- Energy Hubs for HD EVs open new possibilities to maximize grid utilization and even provide additional functionalities that will support the power grid modernization. Their versatility can be used in the electrification of other sectors.

- HD EV Charging infrastructure can serve as a great opportunity to showcase the benefits of DC distribution at different levels.
Bedankt voor uw aandacht

Dr. Sebastián Rivera, DCE&S
Designing a Smart Electric Vehicle Charge Point for Algorithmic Transparency

Gerd Kortuem | Kars Alfrink
Industrial Design Engineering | TU Delft
27 Sept 2023
Transparent charging station

Credit: The Incredible Machine, Alliander, ElaadNL, TUD, AMS Responsible Sensing Lab

A speculative design artefact & research instrument for investigating Algorithmic Transparency
Intelligent EV Charging

Optimizing energy distribution
Aligning demand & supply
Algorithms will become increasingly sophisticated

INPUT
SYSTEM
- GRID CAPACITY
- ELECTRICITY PRICE
- SOLAR AVAILABILITY
CAR
- BATTERY CHARGE
- SHARED OR PRIVATE
USER
- TIME TO LEAVE
- NEXT DESTINATION
- CHARGING PRIVILEGES

SMART CHARGING ALGORITHM

OUTPUT
CHARGING INSTRUCTIONS
CHARGING STATIONS
Data en technologie moeten bijdragen bij aan vrijheid van bewoners. Data en algoritmen hebben niet het laatste woord. Menselijkheid gaat altijd voor.

Welke data worden verzameld? Waarvoor? Daarover zijn we altijd transparant.

We houden rekening met de verschillen tussen individuen en groepen, zonder gelijkwaardigheid uit het oog te verliezen.

Bewoners en gebruikers hebben zeggenschap over de vormgeving van onze digitale stad. De overheid, organisaties en bedrijven faciliteren en monitoren ontwikkelingen en gevolgen.

Data die overheden, bedrijven en andere organisaties uit de stad genereren en over de stad verzamelen zijn gemeenschappelijk bezit.

Intelligent & Inclusive EV Charging

Public values

- **INCLUSIEF**
  - We houden rekening met de verschillen tussen individuen en groepen, zonder gelijkwaardigheid uit het oog te verliezen.

- **ZEGGENSCHAP**
  - Data en technologie moeten bijdragen bij aan vrijheid van bewoners.

- **MENSELIJKE MAAT**
  - Data en algoritmen hebben niet het laatste woord. Menselijkheid gaat altijd voor.

- **OPEN EN TRANSPARANT**
  - Welke data worden verzameld? Waarvoor? Daarover zijn we altijd transparant.

- **LEGITIEM EN GECONTROLEERD**
  - Bewoners en gebruikers hebben zeggenschap over de vormgeving van onze digitale stad. De overheid, organisaties en bedrijven faciliteren en monitoren ontwikkelingen en gevolgen.

- **VAN IEDEREEN VOOR IEDEREEN**
  - Data die overheden, bedrijven en andere organisaties uit de stad genereren en over de stad verzamelen zijn gemeenschappelijk bezit.

DUIDELIJK OVER DATA

www.tada.city

Unpredictable charging experience
Perceived unfairness of decisions
Systematic bias
Transparent charging station version 1

Credit: The Incredible Machine
Findings

Expert

Facts + Explanation → Adoption

Expectations of Control ← Facts + Explanation

Citizen

Findings — Citizens

- Algorithms are convenient
- Transparency is burdensome
- Transparency suggests (but does not afford) control

New concerns: Algorithmic anxiety and coping mechanisms
- “How does the algorithm judge me?”
- “What do I need to do to ‘please’ the algorithm?”
- “How can I outwit the algorithm?”
- Intentions of “gaming” & vehicles moving to other parts of the city because there’s good charging there

Beyond individual experience - towards societal control
Intelligent Algorithms
Embed and Make Policy

System Developer → create
AI System → create
Built-In Safeguards

AI System → understand
Explanations → use

Decision Support → use

Automated Decision → use

Decision Subject → use

Interactive Controls

Human Controller

Intervention Requests → appeal to

Third Party

Tools for Scrutiny

Explanations → inspect

<table>
<thead>
<tr>
<th>Type of Objection</th>
<th>Example</th>
<th>Concerns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existence</td>
<td>“Charging shouldn’t be made smart at all.”</td>
<td>Who made the policy, and why?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Who should determine policy?</td>
</tr>
<tr>
<td>Policy</td>
<td>“Shared cards get priority. I don’t drive a shared car so I think this is nonsense.”</td>
<td>Who made the policy, who can change it, how can I contact them?</td>
</tr>
<tr>
<td>Faulty outcome</td>
<td>“I charged a shared car but I did not receive the priority I am entitled to.”</td>
<td>What was the intended outcome? What is the actual outcome? Why did this change?</td>
</tr>
<tr>
<td>Unfair outcome</td>
<td>“I work shifts and the system assumes office hours so I am always screwed.”</td>
<td>What are the assumptions behind the policy? Who else is adversely affected?</td>
</tr>
</tbody>
</table>
Contestable by Design

Built-in safeguards
External adversarial system • Formal constraints

Interactive controls
Negotiate, correct, or override machine decision
• Feedback loop back to training • Supplement local contextual data

Explanations
Traceable decision chains • Behavioral explanations
• Sandboxing • Local approximations • Justifications

Intervention requests
Human review • Supportive, synchronous channels • Third party representation • Collective action • Dialectical exchange

Tools for scrutiny
Norms linked to implementation • Documentation • Formal proofs • Comparative measures • Opaque assurances

Final Reflection

Speculative design on transparency inspired empirical research which informed a new research programme on contestable AI
Credits:
Marcel Schouwenaar, The Incredible Machine
Thijs Turel, AMS Responsible Sensing Lab
Kars Alfrink, IDE
Neelke Dorn, TPM
Alliander, ElaadNL
Vehicle to Grid (V2G)
Technology trends & challenges

Dr. Gautham Ram
Assistant Professor (TU Delft)

Electrical Sustainable Energy (ESE) Department

DC systems, Energy conversion & Storage Group

Design and control of components for charging of electric vehicles and integration into future grids

Research themes

- Power electronics for EV charging
- Smart charging, V2G & grid integration
- Battery modelling & ageing
- Electrification of Heavy-Duty vehicles

Gautham Ram
What is V2G?

- EV is a big battery on wheels (50-100 kWh, 95% Stationery)
- In numbers: 10 kW power * 7M car = 70 GW power capacity
- → Software Vs hardware (e.g., Generators, transformers)
- → Decentral Vs Central

Source: Nissan, http://www.amsterdamvehicle2grid.nl
Trend 1: Compact V2G chargers

- 6kW (OVO)
  - 52x23x69 cm
  - 27 kg

- 7.4 kW
  - (Wallbox Quasar)
  - 35x35x15 cm
  - 20 kg

- 10kW (Magnumcap)
  - 60x36x162 cm
  - 260 kg

- 20kW
  - (Fermata FE-20)
  - 94 x 76 x 28 cm
  - 57 kg

1. High frequency isolation
2. Soft-switching topologies
3. Silicon carbide wide bandgap devices

→ Higher power (~20kW) & Higher efficiency
Trend 2: Using EV as storage for PV

1. Zero net emissions
2. Both are direct current (DC)
3. EV as storage for PV (V2G)
4. Reduced EV-PV grid impact
5. Proximity (Onboard or rooftop PV)
6. Generation in summer & in day
   • Workplace charging 😊

Source: DC comics, TU Delft solar team
Integrated DC solution

DC/DC Converter → DC link → DC/AC Inverter → Solar Inverter

PV Panels

MPPT

Isolated EV charger (DC/DC)

PV MPPT converter (DC/DC)

AC Grid

DC/AC Inverter

AC Inter-connection

Inverter (DC/AC)

AC Grid

EV

Project funded by: TKI Urban Energy, RVO, Netherlands

PV panels 10 kWp
Trend 3: Integrated DC solution

- DC-DC connection of EV-PV → Improved efficiency
- Only one DC/AC converter → Lower cost of converter
- Bi-directional capability → Charge / V2G

[Diagram showing components of an integrated DC solution with PV panels, EV charger, Inverter, and AC Inter-connection.]
Trend 3: Integrated DC solution

- DC-DC connection of EV-PV → Improved efficiency
- Only one DC/AC converter → Lower cost of converter
- Bi-directional capability → Charge / V2G
- Four power flows → Easy power management

Isolated EV charger (DC/DC)  
PV panels 10 kWp  
PV MPPT converter (DC/DC)  
DC link  
Inverter (DC/AC)  
AC Inter-connection  

1. PV → EV  
2. Grid → EV  
3. EV → Grid  
4. PV → Grid
EV + V2G + PV + Battery

- Goal: Multi-Port DC Converter for PV Charging of Electric Vehicles with flexibility of battery storage
- Combining Smart hardware + Smart charging

PhD project:
Wiljan Vermeer

PhD Defense of Wiljan Vermeer
4 Oct 2023, TU Delft
1700-1900

Project partners: PRE, Stedin (Flexgrid)

Reference: https://www.tudelft.nl/en/Flexinet; Project funded by: TKI Urban Energy, MOOI
PhD project: Siddhesh Shinde

12 short & bent heat pipes

Reference: https://www.tudelft.nl/en/Flexinet; Project funded by: RVO MOOI
Trend 4: V2G with onboard solar

Sono motors:
- 1.2kW PV → 456 half cells over the body
- 54 kWh LFP battery → 305 km (WLTP range)
- V2G on AC -> 11kW bidirectional OBC
Trend 5: Onboard V2G charger

- DC V2G off-board power converter:
  - No size and weight limitation
  - But needs investment for charger

- AC V2G uses on-board power converter:
  - More expensive charger - Automotive grade
  - But comes for ‘free’ with EV
  - Type 1 or Type 2 Plug, ISO 15118 comm.
Trend 6: Vehicle to Load (V2L)

- Hyundai: V2L for standalone (offgrid) power requirements - 240V, 3.6 kW, 15 A
- Kia V2L: Kia EV 6 with 3.7 kW standalone (offgrid) power
Trend 6 extension: Vehicle to Vehicle (V2V)

- V2L -> Extension is V2V
  - Sono motors: 3.7 kW V2L/V2V
  - GMC Hummer: 6kW V2L/V2V from 170/200kWh battery
Trend 7: Vehicle to Home/Building (V2H/B)

Ford F150 lightning

- 9.6kW V2L power (10x 120V & 1x 240V outlet)
- V2H standalone with Delta converter
+ Ford charge pro 80 amp
Trend 7: Vehicle to Home/ (V2H/V2B) + PV + Batt

- PV panels 10 kWp
- Battery Storage
- Batt-PV Bidirectional (DC/DC)
- DC link
- Inverter (DC/AC)
- Batt-PV Bidirectional (DC/DC)
- EV charger Bidirectional (Isolated) DC/DC
- Battery Storage + Off-grid
- Local AC grid
- DC (V2G) charging of EV
- AC charging of EV

PhD project – Carina Engstrom
Postdoc – Gautam Rituraj
Trend 8: V2G with Automated EVs

Automated EV = Battery on wheels

Source: Tesla

PhD topic
Alvaro Menendez Agudin
Challenges for V2G

1. Bidirectional chargers (on or off board)
2. Battery capacity degradation (?)
3. Competition from stationery storage
4. Incentives for user to participate (End-user friendly apps)
   • Market mechanisms at DSO & TSO level – for energy & power
   • “Net metering” reduces the incentive for storage
   • Frequency regulation - minimum bid size & delivery period
5. Aggregation and coordination of millions of EVs \(\rightarrow\) ICT
6. Standardization on security/privacy
7. Standards: CHAdeMO is V2G ready (as early as 2014), CCS ongoing (2023-25)
Want to learn more?

Free Online Courses

ELECTRIC CARS: TECHNOLOGY, BUSINESS, POLICY

www.tiny.cc/ecarsx
Want to learn more?

- Lecture video
- Exercises
- Panel discussion
- Online forums

www.tiny.cc/ecarsx
V2G vs V2H from the end-user perspective: a story of control and risk allocation

David Shipworth
PowerWeb conference 2023
Central vs personal control

• Power systems control
  - **Risks:** Lower uptake; psychology of control -> more complaints; less tailored
  - **Benefits:** Firm dispatch; central control; deterministic

• Contractual control
  - **Risks:** Lower participation; Supplier/OEM reputational risk; defection in extreme conditions
  - **Benefits:** ‘Informed consent’; behavioural science mechanisms can help sign-up.

Ref: Siemens PJM platform
Central vs personal control

• **Market mechanisms**
  - **Risks:** Market defection in important edge cases (extreme events)
  - **Benefits:** Economic efficiency; price discovery; supplier ecosystem incentives.

• **Voluntary mechanisms**
  - **Risks:** Unreliability; Low penetration
  - **Benefits:** Low to zero cost; potential for pro-social engagement.
V2G is transactional. V2H is personal

- **Home is personal**
  - Home engages emotions
    - Shelter; security; comfort; etc
  - Home places financial decisions in a different context.
    - What is the payback period on a new kitchen?
    - What is the value of keeping your family safe?

Ref: https://www.ford.com/trucks/f150/f150-lightning/gallery/?intcmp=vhp-seconNav-gallery
V2G vs V2H operating scenarios

- **‘Normal’**
  - Grid view: V2G=V2H
    - Risks: Energy/carbon
  - User view: V2G≠V2H
    - V2H: Netted off bill at home rate
    - V2G: Credited on bill at (low) grid rate
    - Risks: Financial

- **‘Constrained’**
  - Grid view: V2G=V2H
    - Risks: Power/financial
  - User view: V2G≠V2H
    - V2H: Netted off bill at home rate.
    - V2G: Credited on bill at (high) grid rate
    - Risks: Power/financial/comfort

- **‘Blackout’**
  - Grid view: V2G≠V2H
    - Risks: Power/financial/priority services register
  - User view: V2G≠V2H
    - V2H: Have power
    - V2G: Don’t have power
    - Risks: Health/security/comfort
Benefits of a user-centred hierarchy:
Car → Home → Neighbours → Others

- **Power Systems**
  - Reduces flexibility market defection risk
  - Reduces grid defection risks
  - Reduces load shedding costs
  - Engages autarkic users
  - Promotes product bundling (EV+PV+Batt+HEMS)

- **Users**
  - Engage psychology of control
    - Give users control and they rarely take it.
    - Deny users control and they rarely grant it.
  - Activate loss/risk aversion
    - Users act to avert losses over realising gains.
  - Mobilise climate crisis salience
    - Foregrounds energy users’ planning
Smart Charging at Scale – ROBUST and DRIVE2X Projects

Assistant Prof. Pedro P. Vergara
Intelligent Electrical Power Grids (IEPG)
EV sales keep growing fast

Electric vehicle sales across all transport modes had a steady growth over the last decade (and majorly during the Covid-19 pandemic).
2050 could see more than 1b EVs on the road
EV growth is a “double-edged sword”
EV charging flexibility as an opportunity

DRIVE2X Project: Delivering Renewal and Innovation to Mass Vehicle Electrification Enabled by V2X Technologies

ROBUST: Robust sustainable electricity system through regional flexibility

EV charging at a scale...
DRIVE2X Project: Delivering Renewal and Innovation to Mass Vehicle Electrification Enabled by V2X Technologies

18 partners, 8 countries, Power systems-led
DRIVE2X’s objective

To develop new knowledge, tools, models, and technologies to cope with a V2X-based mass EV deployment future for Europe

1. V2X flexibility markets
   - New AI and ICT tools enabling exploitation of V2X flexibility

2. V2X charging technology
   - Affordable, user-friendly bidirectional chargers

3. The social side of V2X
   - EV user expectations as key success factors of uptake

4. V2X upscaling studies
   - Novel modeling approaches and roll-out frameworks
Overarching marketplace concept & BMs

**BM6** Distribution network management through procurement of local V2X flexibility

**BM5** Flexibility services offered by building or facility managers to DSOs

**BM4** Building tariff optimization leveraged by parking lot smart charging

**BM1** Flexibility services offered by EV owners or prosumers to network operators

**BM3** Prosumer tariff optimization leveraged by residential smart charging

**BM2** Flexibility services offered by EV owners to building managers
TUD is working towards an EV platform to facilitate V2X services
ROBUST Project: Robust sustainable electricity system through regional flexibility

1. Technische oplossingen
2. Tarievenring en aansluitafspraken
3. Markt-oplossingen
4. Interventies

Assets
Nu
Doel ROBUST
Voor TSO & DSO & BRP
Integreren nieuwe KV-tarievenstelsel
Voor TSO & E-markten
Preventieve netverzwareing
WP aansturing
Curtailing

Onderzoeksvragen
- Flex-potentieel? Knelpunten?
- Welke waarde ontstaat, voor wie?
- Effectiviteit van oplossingsrichtingen?
- Hoe werken oplossingsrichtingen samen?
- Hoe ziet het flexysteem eruit?
- Randvoorwaarden, eisen?
- Balans lokaal / nationaal? Platform?
- Spelers, handelsperspectieven?
- Validatie gedrag, dataviligheid, waarde,
ROBUST’s objective

Proof-of-principle delivery of an optimal ratio between flexibility and grid reinforcement.
TUD is working towards flexibility quantification.

- Taxonomy for flexibility
- What is flexibility in distribution system?
- Why EV integration in the power grid is a big deal?
- Impact of smart charging and Network tariffs on LV network

Flexibility is the key

- Efficient aggregation
- Together we are stronger. (Aggregation)
- What if flexibility does not work?
- Re-dispatch and capacity limitation from EV fleets
- Network reinforcement
- Up regulation and impact of cost on re-dispatch

Challenge: An efficient and scalable approach is required that provides precise solutions rather than mere approximations.
Thank you for your attention.

TU Delft
High Efficiency Wireless Charging of EVs

Jianning Dong
Assistant professor, ESE/DCE&S, Faculty of EEMCS

TU Delft
DCE&S
DC systems, Energy conversion & Storage
Why charging wirelessly?
A history perspective

1897: Tesla WPT patent

1901: Tesla’s Wardenclyffe Tower

1966: Microwave powered helicopter


1970s: Boom of power electronics

Dynamic charging patents

1990s – early 2000s

2006: MIT 2m 60 W WPT experiment

2009: OLEV by KAIST

1950s – 1990s

Fast development of EVs
- Renewed attention for dynamic charging
- Standards defined for wireless charging of EVs
- Commercial development

1897 – 1917

2009 – now

1950s – 1990s

1990s – early 2000s
Classifications of wireless power transfer technologies

Near-Field
- Electric Field
- Capacitive Coupling
- Magnetic Field
- **Inductive Power Transfer**

Far-Field
- Solar
- Micro-Wave
- Lasers
- Radio Wave

---

Inductive Power Transfer for Electrical Vehicles

www.witricity.com

Subsea Charging

www.unplugged.no

Space Solar Power Transfer

IPT based wireless charging: application examples

E-bike charging


Bus opportunity charging

200 kW IPT charger
- 1 min charging at stops = 3.3 kWh
- Enough to cover 2.5 km for a rate of 1.3 kWh/km*.

Advantages
- Significant reduction of battery size and weight
- Lower cost and complexity compared to dynamic charging

Research funded by EU project PROGRESSUS
https://progressus-ecsel.eu/


TU Delft startup company:
https://www.tilercharge.com/
Inductive Power Transfer: System Topology
Wired charging system topology

Efficiency from plug to battery:

Assume: 99% efficiency each stage
Total efficiency: \(99\%^4 = 96\%\)
Reality: <95% end to end
**IPT system topology**

Primary DC/AC
- Current or voltage source
- Half or full bridge

Compensation
- 4 basic ones: series or parallel
  - S-S, S-P, P-S, P-P
- High order compensations

Secondary AC/DC
- Current or voltage source
- Half or full bridge
- Active or passive
Is high efficiency possible?

Wired charging:

From plug to battery:

Assume: 99% efficiency each stage
Total efficiency: $99\%^4 = 96$
Reality: <95% end to end

From grid to battery:

Added: two passive compensation stages
(~99.7% efficient)
Replaced: HF transformer -> air-core transformer
(>98% efficient)
Total efficiency: $99\%^3*98\%*99.7\% = 95$
Reality: <95% end to end

Wireless charging:

But how? A multi-objective optimisation problem

Search space

- Dimensions
- Number of turns/strands/coil diameter
- Core material/shielding material
- Compensation topology
- Core arrangement
- ...

IPT system model

- 3D FEA, inductance evaluation
- Circuit model
- Loss models
- Weight/volume calculation
- ...

Conflicting objectives

- Aligned efficiency
- Stray field
- Gravimetric power density
- Area power density
- ...

---

Design Examples
High efficiency 3.7 kW IPT system

Variable series compensation capacitor

Switch-controlled capacitor (SCC) as compensation

7.7 kW IPT system universal for 400 V and 800 V batteries

Voltage/current doubler (V/I-D) converter $\rightarrow$ Multicoil design

2 sets of rectangular coils

Bipolar pads (BPPs) $\rightarrow$ Compact solution

Slight efficiency difference between the two charging modes!

High efficiency 20 kW IPT system

Test result

Wide high efficiency range: mode shifting

- Mode-switching as output power decreases, to increase $D_p$ and $D_s$, hence $\delta$

Other Challenges
Safety and foreign object

Combined EV and foreign object detections

EV and foreign object detection auxiliary coils: transmitter (left) and receiver (right)


- EV and metallic foreign object detection simultaneously using high frequency injection;
- Complicated detection circuit;
- Unable to detect “living objects”.

TU Delft
Heavy duty vehicle charging

Pantograph and catenary free wireless tram

Wireless solution for ultra-high speed vacuum tube train (hyperloop), MSc study at DCE&S
Questions?