Practical EV integration cases for static and dynamic wireless power transfer

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Agenda

• Introduction to Flanders’ DRIVE
• Project introduction
• Dynamic charging public transportation
  • System, Infrastructure and bus
  • Results
• Stationary charging car
  • System and car
  • Results
• Concluding
Introduction to Flanders’ DRIVE

Flanders’ DRIVE

- Research institute for the vehicle and mobility industry developing and presenting technological solutions in R&D domains:
  - Clean and Energy-Efficient Vehicles
  - Intelligent Driver and Traffic Systems
  - Lightweight Solutions
  - Intelligent Development Tools
  - Advanced Manufacturing Processes

- Open innovation approach driven by the industry
- High-tech Infrastructure for vehicle, system and component testing
- Wide international network of 170 partners
Project Introduction

Flanders' DRIVE project "Inductive charging"

Research of the technical feasibility and practical applicability towards inductive charging of electric vehicles

1 October 2010

30 June 2013

Charging at bus stops
Charge while driving

Slow wireless charging
Fast wireless charging
Why this research?

Specific benefits
User-friendly and safe:
- Wireless, no charging cable
- Automatic, no intervention required
- Invisible, no visible pollution
- Reduced risk of vandalism and theft

Specific challenges
- Energy efficiency sufficiently high
  - Distance between transmitter and receiver
  - Positioning of vehicle on charging strip
- Safety because of magnetic field
- Minimum extra weight of vehicle on account of adding of inductive system
- Integration of system in road surface
  - ….

Project partners

Vehicles
- VOLVO
- VAN HOOL

Inductive systems
- inverto
- BOMBARDIER

Grid management
- INFRA
- ENERGY ICT

Communication
- S-PARK
- Mobiler

Research centers
- BRUGOCVCN-OBB
- DRIVE

Universities
- Vrije Universiteit Brussel
- KATHOLIEKE UNIVERSITEIT LEUVEN

Supporting organisations
- Longwell
- Vignes en Wateren

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Dynamic charging:

System, Infrastructure, Bus

Test track overview

• Total track length of 600 meters
• Two inductive sections
• Different road pavements
  • Section 1 – Concrete
  • Section 2 - Asphalt
System architecture dynamic charging

• Way side system, 120+ kW capable

• Bus system 80 kW; resistive waste and battery charging
  • Bidirectional DC/DC to charge and discharge

Test track in concrete

Segmentation

• Incorporation of other systems in the pavement giving new functions to the pavement:
  - joint scheme; polymer rebar
  - overall execution

• Long durability – assembly of small parts in the road used solutions from outside the paving industry

• Long term behavior
Test track in asphalt

Segmentation

- **Incorporation** of other systems in the pavement giving new functions to the pavement:
  - joint scheme
  - temperature
  - compaction of smaller zones
  - overall execution

- **Long durability** – assembly of small parts in the road used solutions from outside the paving industry

- **Long term behavior**

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Van Hool’s test bus fitted for dynamic charging

Integration of the system in a A360Hyb, a hybrid diesel-electric city bus
ElectroMagnetic Field (EMF) shielding

Shielding material selection

Shielding required!

Ground clearance

- Static clearance: 260 mm
- Min clearance: 150 mm
- Trajectories should contain as less level variation as possible
- ‘ELC’, Electronic Leveling Control allows for further optimizations

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Dynamic charging:

Results

Power in relation to lateral and height variation

The driver should keep his bus in track, with maximally 40 cm variation.

Performance deviations due to roadwork tolerances

Note that these results are from prototypes!
High speed power on asphalt

- System power ramp up is within 50 ms
- Power transfer optimization through segment switching optimization
- At 60 kph and 60 kW transferred power : 1 kWh energy per kilometer

EMF outside the vehicle

**Static** at 25 kW

- ICNIRP 2010
- ≤ 27 μT at 20 kHz

**Dynamic** at 15 kph, 40 kW

Tested system, 100 kW at a long transmitter
Short term rollout via stationary charging approach

**Charging stations are positioned:**
1. in the depot and/or
2. at start/end stops and/or
3. en-route at selected bus stops

**Trajectory dependencies:**
1. Vehicle battery dimensioning
2. Inductive system configuration
3. Need for energy network proximity to lower infrastructure investment
4. Infrastructure sharing
5. Safety conditions

Inductive system application scenarios

Comparing two systems ...

**Fixed position inductive system**
- Receiver
- Transmitter
- Power Transfer 150 kW
- Dynamic charge operation
- Ability to control magnetic stray fields
- Up time / lifetime
- Shielding requirements
- Innovation requirement

**Lowering inductive system**
- Receiver
- Transmitter

- A system from which the receiver is placed on the transmitter allow for better control of the magnetic field, in order to stay within limits
- Consequently system adaptation is required for dynamic operation
Application of fixed position and lowering

- Better EMF control
- Weight reduction of 100 kg
- Hybrid static-dynamic mode

Change in civil works approach

- Intense road works in project
- Reduced road works in next generation
Concluding ... dynamic charging

Research
- Inductive system 80 kW, while standing still (bus stop) and when moving (up to 70 km/h)

Results
- Energy efficiency: 88 - 90%
  - 40 cm "positioning tolerance" – Long stretches: positioning support system
  - Distance transmitter – road surface: 10 cm
- The used early receiver prototype in fixed position was out of ICNIRP limits
- Charging while driving requires more elaborate adjustments to the powertrain of the bus
- Integration in road surface: concrete and asphalt are possible, however tolerances hint towards prefabricated modules
- Impact of road traffic on road surface with integrated inductive systems?
- Static and dynamic charging are technically feasible and comparable to one another

Stationary charging:
System, Car
System architecture stationary car charging

- **Architecture**

  ![Diagram of system architecture]

- **Energy management & control**

  ![Energy management & control diagram]

- **Secondary placement as true add-on below the car, thus no integration into the body**

- **No EMF shielding used since car body construction does provide high shielding effectiveness**

- **User interfacing**

  ![User interfacing image]

Stationary inductive systems

<table>
<thead>
<tr>
<th></th>
<th>inverto</th>
<th>BOMBARDIER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum power</td>
<td>3.6 kW</td>
<td>22 kW</td>
</tr>
<tr>
<td>Supply voltage</td>
<td>240 V&lt;sub&gt;AC&lt;/sub&gt; single phase</td>
<td>380 V&lt;sub&gt;AC&lt;/sub&gt; three phase</td>
</tr>
<tr>
<td>Resonance frequency</td>
<td>125 - 145 kHz</td>
<td>140 kHz</td>
</tr>
<tr>
<td>Output source behavior</td>
<td>Current</td>
<td>Current</td>
</tr>
<tr>
<td>Control interface</td>
<td>CAN</td>
<td>CAN</td>
</tr>
<tr>
<td>Pickup unit size</td>
<td>77 x 61 x 7 cm (lxbxh)</td>
<td></td>
</tr>
<tr>
<td>Pickup unit size with rectifier</td>
<td>80 x 60 x 3 cm (lxbxh)</td>
<td></td>
</tr>
<tr>
<td>Pickup unit weight</td>
<td>25 kg</td>
<td>25 kg</td>
</tr>
<tr>
<td>Rectifier cooling</td>
<td>Air</td>
<td>Water</td>
</tr>
<tr>
<td>Application</td>
<td>Static charge only</td>
<td>Static charge only</td>
</tr>
<tr>
<td>Rectification and DC/DC conversion</td>
<td>Integrated in pickup unit</td>
<td>Separate unit</td>
</tr>
</tbody>
</table>

- **inverto**
  - Single phase
  - single coil

- **BOMBARDIER**
  - Three phase
  - CPS

Note that these are prototype specifications!
Measurement program

- Power & Efficiency – open air, integrated
- EMF – open air, integrated inside and outside

- EMF – influence on car system and key components

Stationary charging:
Results
Measured times are according to the definition that the charging phase ends when 80% SoC is reached. The remaining time is for conditioning.

Efficiency increases with the power in both systems.
Efficiency vs. State of Charge

Efficiency is depending on:

1. Lion battery voltage; however for both systems in opposing direction

2. Integration; existing environment influences the magnetic design

Power vs. displacement

The 3.6 kW system is hardly not influenced by displacement → Frequency tuning

The 22 kW system has a fixed tuning for the applicable clearance

Note that these results are from prototypes!
Efficiency vs. Displacement

**Efficiency vs. Displacement**

**Efficiency**

- **3.6 kW**
  - Xna → Xin → Yna → Yin
  - Displacement (cm)
  - Efficiency

- **22 kW**
  - Xna → Xin → Yna → Yin
  - Displacement (cm)
  - Efficiency

Note that these results are from prototypes!

**EMF**

- **3.6 kW**
  - Image of car
  - ICNIRP 2010
  - ≤ 6.25 μT at 140 kHz

- **22 kW**
  - Initial prototype
  - Final prototype

Note that these results are from prototypes!
Static inductive charging of cars

Research
- Inductive systems 3.6 kW (7h charging) and 22kW (1h charging)
- Volvo C30 electric (add-on approach)

Results
- Energy efficiency: 90% (94% for charging with charging cable)
  - 30 cm “positioning tolerance”
  - Distance transmitter – receiver 10 cm
- Magnetic fields within ICNIRP Limits
- Inductive systems for cars are possible from 3.6 kW to 22kW

Looking forward

Introduction into stationary charging of (hybrid) electric cars:
- Infrastructure: transmitter on garage floor, suited connection to power supply
- OEM will make choice depending on type of vehicle, customer demand ...
  - first charging at home/work
- First introduction as of 2015, possibly as an option
Concluding ...
The next step in Belgium - Bruges

**Bruges - Belgium**

- **Bus type**: Van Hool A308 E
- **Drive line type**: Full Electric
- **Power transfer**: Static inductive
- **Track length**: 5.4km
- **Power transfer**: Up to 140kW
- **Charge time**: 9 minutes
- **Start of operation**: Q1 2014
- **Localization**: historic city center
- **# Vehicles**: 3

*Development supported by [logo]*

Oct 24, 2013

**Volvo Car Group completes successful study of cordless charging for electric cars**

“Inductive charging has great potential. Cordless technology is a comfortable and effective way to conveniently transfer energy. The study also indicates that it is safe,” says Lennart Stegland, Vice President, Electric Propulsion System at Volvo Car Group, and adds “There is not yet any common standard for inductive charging. We will continue our research and evaluate the feasibility of the technology in our hybrid and electric car projects.”
Summary

Inductive charging of electric buses and cars is

- Technically feasible
- Practically applicable
- Electrically safe

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