HEV TCP Task 26 Workshop 9: Wireless Charging for EVs
(6-7 Nov. 2018 in Detroit, Michigan USA)

“NREL’s Managed WPT Experiences and Lessons Learned”

Presenter
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Outlines

- Introduction/NREL’s Vision for Demonstrating WPT for EV
- Description of 25 kW WPT system at NREL’s Shuttle
- EMF Testing of On-Vehicle WPT System
- Monitoring and Control of the Wireless Charging
- Description of WPTsim Tool for WPT design
- Design of Greenville AMD Project using WPTsim
- Conclusions/Opportunities
Visions of WPT for EV

Quasi-dynamic WPT

Stationary WPT

Dynamic WPT

https://www.nbcnews.com/mach/mach/futuristic-roads-may-make-recharging-electric-cars-thing-past-nrca766456
Stationary Wireless Charging: 25 kW Wireless Charger at NREL’s Shuttle
Wirelessly Charged Electric Shuttle

- Full electric on-demand service
- 16 passenger
- 62.1 kWh battery capacity
- 100 miles range
- 7600 curb weight, including VA
- 6.6 kW on-board conductive charger

Momentum Dynamics WPT system

- 35.5”x35.5”x2.25” (900x900x57 mm) symmetrical square pads
- 25 kW maximum power transfer
- 20 (19-21) kHz nominal operating frequency.
- Automatic alignment capability.
- 5”-9.5” (125-240 mm) airgap
EMF Testing for In-Vehicle WPT System

✔ Test Methodology

1. Define coordinates.
2. Define a marked safety perimeter.
3. Identify the worst misalignment condition (X, Y, Z, pitch, roll and yaw).
4. Define test zones and points
   - Region I: Under the vehicle
   - Region II: Around and above the vehicle
   - Region III: Inside the vehicle
5. Define the standard limits for each zone (2010 ICNIRP)

<table>
<thead>
<tr>
<th>Coupler Offset &amp; Gap</th>
<th>Max Magnetic Field</th>
<th>Max Electric Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>dX</td>
<td>dY</td>
<td>dZ</td>
</tr>
<tr>
<td>+max</td>
<td>+max</td>
<td>max</td>
</tr>
<tr>
<td>+max</td>
<td>-max</td>
<td>max</td>
</tr>
<tr>
<td>-max</td>
<td>+max</td>
<td>max</td>
</tr>
<tr>
<td>-max</td>
<td>-max</td>
<td>max</td>
</tr>
</tbody>
</table>

EMF Test Results

EMFs before/during alignment (Low Power Excitation)

EMFs around the vehicle (zone II)

<table>
<thead>
<tr>
<th>Misalignment</th>
<th>Max $B_{\text{rms}}$ ($\mu$T)</th>
<th>Max $E_{\text{rms}}$ (V/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position I</td>
<td>16.661</td>
<td>1.7414</td>
</tr>
<tr>
<td>Position II</td>
<td>18.380</td>
<td>2.4091</td>
</tr>
<tr>
<td>Position III</td>
<td>17.696</td>
<td>2.5345</td>
</tr>
<tr>
<td>Position IV</td>
<td>17.152</td>
<td>1.7147</td>
</tr>
<tr>
<td>Position V</td>
<td>18.526</td>
<td>2.0853</td>
</tr>
</tbody>
</table>
**EMF Test Results**

**EMFs inside the vehicle (zone III)**

**Driver seat test points**

**Over VA test points**

<table>
<thead>
<tr>
<th>Test Point</th>
<th>Max $B_{rms}$ (µT)</th>
<th>Max $E_{rms}$ (V/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_A$</td>
<td>0.0328</td>
<td>0.0633</td>
</tr>
<tr>
<td>$P_B$</td>
<td>0.0068</td>
<td>0.0380</td>
</tr>
<tr>
<td>$P_C$</td>
<td>1.0362</td>
<td>0.0257</td>
</tr>
</tbody>
</table>

Magnetic field along $X'$-axis at a height of 27.25” from the floor of the bus

Magnetic field along $Y'$-axis at a height of 6.25” from the floor of the bus
Wireless Charger Operation: Monitored and Managed

Wireless Charging System

System Output Power

Total Energy Delivered

119.5 kWh

System Output Power Now

24.0 kW

Charging

Dashboard Row

Primary Temperature

Output Current and Voltage

Primary Status

PEM Input Config
NREL’s Intelligent Campus Energy Management Plan

NREL Intelligent Campus Integrates:

- **RESs**
- **ESSs**
- **Building loads**
- **EVSEs**
  - AC level 2
  - DC FC (50 kW)
  - Wireless Charger (25 kW)
  - Bidirectional EV
Objective: ‘smart’ integration of wireless charger with surrounding infrastructure on NREL campus (e.g. Renewable Generation, Loads, other EVSEs, etc.)
Results of the Wireless Charging Control

Nice day results: lots of PV generation

Cloudy day results: lack of PV generation
Dynamic Wireless Charging: Feasibility Analysis of DWPT for Autonomous Vehicles at AMDs
It is a design optimization tool that incorporates driving data, vehicle data with charging infrastructure parameters (conductive or wireless).

It is capable of providing optimum design of wireless infrastructures (stationary, dynamic and quasi-dynamic) for certain road scenario.

It is utilized to provide designs for multiple scenarios such as:
- NREL’s circulator shuttle.
- Greenville AMD Project
16 passenger, curb weight 3500 kg, 36 kWh battery capacity and about 45 mph maximum speed
- **Optimization Variables:**
  - Position of each wireless charger.
  - Wireless charger power.
  - EV’s battery capacity.
  - Number of track segments (track length).

- **Optimization Objectives:**
  - Minimum battery capacity.
  - Minimum charging infrastructure cost.
  - Achieve charge sustaining operation.

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**Optimal key design parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Optimal value</th>
</tr>
</thead>
<tbody>
<tr>
<td># wireless chargers</td>
<td>11 out of 17</td>
</tr>
<tr>
<td>Positions</td>
<td>[3 4 5 7 8 9 11 13 14 15 17]</td>
</tr>
<tr>
<td>Power</td>
<td>80 kW</td>
</tr>
<tr>
<td>Battery capacity</td>
<td>12 kWh</td>
</tr>
<tr>
<td># segments per Track</td>
<td>25 (125-meter track length)</td>
</tr>
</tbody>
</table>

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**Optimal WPT positions**

![Map of WPT positions](image)

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**Optimal driving performance**

![Optimal driving performance](image)

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**Map of travel with highlighted WPT segments**

![Map with highlighted WPT segments](image)
Extra effort is required for demonstrating the WPT technology in real world scenarios starting with closed campus scenarios.

Collecting data from real-world projects, including NREL’s shuttle one, to be utilized for better understanding the technology, control design and validating design tools.

Updating and utilizing WPTsim tool for analyzing more complex charge design scenarios (e.g. interstate, urban and rural roads).

Working to have an EasyMile autonomous shuttle operating at NREL campus with the possibility to install a wireless charger to it.
Thank you

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