Infrastructure Working Council (IWC) Meeting Materials

Day Two Presentations
November 19, 2015
National Electric Transportation Infrastructure Working Council

The Future of Evs and Fast Charging 800V

Dr. Christian Jung, Project Lead E-Mobility Systems Design
O. Bitsche, F. Grill, N. Lobenstein, J. Mittnacht

November 18th 2015
Atlanta, Georgia
Most of today's electric vehicles show a realistic electric range of less than 120mi / 200 km. The experience shows that this approach doesn't satisfy all customer expectations.

Success Factors e-Mobility

- Electric range comparable to ICE vehicles
- Fast charging
- Comfortable handling regarding the charging procedure
To fulfil Porsche’s Performance Requirements, permanent innovations are necessary.

\[ P = U \times I \]
Motor Sport serves as Test Laboratory for New Technologies:
800V HV Battery, almost 1000 hp System Power.
800V optimizes Customer Benefits and Vehicle Characteristics.

- Short Charging Time
- Comfortable Handling
- Weight Reduction
This Technical Innovation requires the Adaption of some Components and the Rollout of 800V Infrastructure.

- Electrical Machine
- Power Inverter
- HV Battery
- Onboard Charger
- HV Heater
- HV Wiring Harness
- Plugs/Sockets
- DCDC 48V & 12V
- Infrastructure
By an Additional Invest of ca. 5 % the Capacity of a Charging Station can be Increased by 60%.

Example of a charging station applicable for all vehicles from 200 V to 900 V with CCS Standard:

Charging station with 6 charging points

- Substation: High voltage
- Transformer: Medium voltage
- Rectifier: Industrial voltage
- DC/DC Converter: Direct voltage (galvanically isolated)
Example Fast Charging: Trip from Berlin to Lindau (ca. 450mi / 720 km)

- BERLIN
- Charging 50kW
- BEV
- ICE
- BEV*
- Fueling
- Fast charging
- Lindau
- Charging 50kW
- 8 h
- 5.5 h
- 6 h

*Target fast charging
<table>
<thead>
<tr>
<th>Power (kW)</th>
<th>Volts</th>
<th>Charging Time (minutes)</th>
<th>Limited by</th>
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</thead>
<tbody>
<tr>
<td>50</td>
<td>400</td>
<td>80</td>
<td>Infrastructure</td>
</tr>
<tr>
<td>100</td>
<td>400</td>
<td>40</td>
<td>Plug / Battery Cell</td>
</tr>
<tr>
<td>150</td>
<td>400</td>
<td>29</td>
<td>Plug (350 A)</td>
</tr>
<tr>
<td>150</td>
<td>400</td>
<td>26</td>
<td>Plug (350 A)</td>
</tr>
<tr>
<td>225</td>
<td>800</td>
<td>17</td>
<td>Battery Cell</td>
</tr>
<tr>
<td><strong>Target</strong>: „Charging = Fueling“</td>
<td>800</td>
<td><strong>Further Potential of Reduction at 800V</strong></td>
<td></td>
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</tbody>
</table>
Zusammenfassung: **800V** ist die Kerntechnologie für den Durchbruch der E-Mobilität.

**Vehicle characteristics are comparable to ICE vehicles regarding**
- **electric range,**
- **charging time,**
- **comfortable handling.**

**Success Factors e-Mobility**

**Chances 800 Volt**

The 800 V technology
- reduces **charging time** by 79%,
- reduces the **vehicle weight** significantly,
- Suppliers, infrastructure partners and OEMs **confirm** the feasibility.
Thank you for your attention!
EV Storage Accelerator

Proving Commercial Viability and System Benefits of Energy Storage from Electric Vehicles

Scott Fisher, Director, Alternative Energy, NRG eVgo

EPRI IWC Meeting, November 19, 2015
Project Background

**Description**
9 Nissan and Honda electric vehicles with bidirectional power flow driving and providing energy storage at the UC San Diego campus

**Goals**
- Test Honda and Nissan approaches to bidirectional power flow
- Advance inverter technology and standards for electric vehicles
- Identify and test energy storage use cases appropriate for EVs
- Share data and insights to inform VGI Roadmap and other stakeholder processes

**Funding**
Originally selected to receive an award under CEC PON 14-301 – but funding transitioned to technology fund under NRG settlement with CPUC

**Technology Precedents**
Builds off of technology developed by NRG, University of Delaware and Honda/BMW as part of 2013-2014 V2G demonstration with PJM

Builds off of V2G technology developed by Nissan, Princeton Power, and others as part of LA Air Force Base project
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Vehicle to Grid (V2G) Technology – What is it?

- Uses vehicles as a behind-the-meter energy storage device
- Power flows to the vehicle and from the vehicle
- Could provide energy storage services to the grid or to a home or building

A key enabling technology is the inverter to take DC power from battery to grid AC power.
Does V2G Make Sense? An Unusually Polarizing Technology With Lots of Opinions

**V2G Doesn’t Make Sense**

"We’ve said it many times before, but once more for emphasis -- vehicle to grid is a dumb idea"
- Smart Grid News (4/29/2013)

- Lack of automaker interest
- Negative impact on battery life
- Value of energy storage low compared to value of driving
- What happens when storage is needed, but device is on the road?
- Regulatory issues too complicated
- “V1G” just as good

**V2G Makes Sense**

"Vehicle-to-grid (V2G) is the banner idea for a larger and more complex challenges involving plug-in vehicles and grid operations"
- Greentechmedia (4/10/2012)

- Honda and Nissan and other OEMs undertaking V2G R&D
- Customer has already “paid for” most or all of energy storage system (battery, enclosure) – potential for radically cheaper form of storage
- Bidirectional energy storage more valuable than “V1G”
- Fundamental inverter technology already developed for other applications
Isn’t “V1G” just as good? And much easier?

- The technology for V1G (one-directional power flow) is more readily available, easier to implement and has a number of important use cases.

- But V2G – if we can get it right – has advantages:

  “Bidirectional capabilities avail a larger capacity and longer duration resource than controlled charging. V1G can only provide grid value during the times that the vehicle is charging...for a typical California residential PEV customer, controlled charging will amount to about 2 hours per day. A vehicle that can discharge its battery to the grid can provide grid services whenever it is plugged-in and able to communicate with the grid.”

  - CPUC Vehicle Grid Integration Whitepaper
Why is the **EV Storage Accelerator** Important?

The project is positioned to build critically important OEM support for and to answer many vital questions about V2G:

- **OEM Involvement**
  - **Honda** and **Nissan** are both committed to investing in the project as a way to test technology, use cases, regulatory/codes barriers, and market opportunity for V2G

- **Questions the project will address**
  - **UL listing** – Will EV-based inverter approaches emerge that meet utility interconnection specs?
  - **Automaker involvement** – will OEMs get comfortable with both market opportunities and battery impact to move forward?
  - **Product value** – Is an energy storage resource valuable if not available 100% of the time (because it is mobile)? Does it provide sufficient value to ratepayers, the system, customers and project developers?
How do EVs compare to Fixed Storage as a DER?

Important to separate out questions about market for behind-the-meter storage from questions about technology...

- **Resource Availability**
  - EVs are only driving **4%** of the time, but availability of vehicular storage may not always align with local/system needs, and may require consumer behavioral changes.

- **Cost**
  - How do the benefits provided by V2G compare to the costs of additional battery cycling, adding mobile inverters, bidirectional charging capabilities, and going through full utility interconnection processes?

- **Standards & Readiness**
  - What additional codes & standards need to be developed or tested in order for V2G technology to gain utility acceptance and clear, timely, and cost effective interconnection?
Technical Project Aspects

- 9 Vehicle & L2 EVSE on or near the UCSD campus
- 7 sites on or near the UCSD campus
- 6 Nissan LEAFs using UL listed bi-directional CHAdeMO Princeton Power inverter
- 3 Honda Accord PHEVs utilizing onboard bi-directional vehicle inverter developed jointly by UD and NRG
- Summer 2015 to Summer 2018
### The Context: Other EV Pilots in California

<table>
<thead>
<tr>
<th>Project</th>
<th>Sponsors / State Funding (if applicable)</th>
<th>Brief Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>iChargeForward</td>
<td>PG&amp;E and BMW</td>
<td>18-month program to test V1G demand response capabilities using 100 BMW i3 customers, as well as second life batteries to provide backup DR</td>
</tr>
<tr>
<td>EVSP Smart Grid Development Program</td>
<td>SDG&amp;E</td>
<td>Test communications protocols and integration with home energy management systems for how to integrate V1G EV charging load into other customer load management efforts</td>
</tr>
<tr>
<td>LA Air Force Base</td>
<td>DOD / CEC</td>
<td>Explore V2G capability of an all-electric non-tactical fleet of 36 military EVs across 4 facilities, participating in ancillary services markets</td>
</tr>
<tr>
<td>LBNL Smart Charging</td>
<td>LBNL / CEC</td>
<td>Smart Charging of Plug-in Vehicles and Driver Engagement for Demand Management and Participation in Electricity Markets</td>
</tr>
<tr>
<td>Smart Charging and Storage</td>
<td>UCLA / CEC</td>
<td>Demonstration of PEV Smart Charging and Storage Supporting Grid Objectives</td>
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<td>Resident PEV Communication</td>
<td>Chargepoint / CEC</td>
<td>Next-Generation Grid Communication for Residential PEVs</td>
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<tr>
<td>Demand Clearing House</td>
<td>Center for Sustainable Energy / CEC</td>
<td>ISO/IEC 15118 Demand Clearing House to Enable Standardized Vehicle-Grid Integration</td>
</tr>
<tr>
<td>Distribution System Services</td>
<td>EPRI / CEC</td>
<td>Distribution System Aware Vehicle to Grid Services for Improved Grid Stability and Reliability</td>
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## Relevant Regulatory Processes & Key Issues

<table>
<thead>
<tr>
<th>Regulatory Process</th>
<th>Issues Currently In Scope</th>
<th>Timeframe for Resolution</th>
<th>Issues Not Yet In Scope</th>
</tr>
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<tbody>
<tr>
<td>CPUC</td>
<td>Utility pilot program development for MUDs, public charging, disadvantaged communities</td>
<td>3-6 months</td>
<td>Long term utility ownership model</td>
</tr>
</tbody>
</table>
| AFV & Utility Pilots | Treatment of DER load  
Cost certainty for interconnection  
Streamlining for non-exporting DERs | 6-12 months (load treatment) | Mobile inverter standards (e.g. SAE J3072)                                             |
| Rule 21 Inter-connection | Circuit-by-circuit generation and load interconnection capacities | Complete                | Valuing locational benefits of DERs (next DRP cycle)                                   |
| DRP                | How to meter and establish the actual impact/value of a DR resource on the grid  
“Bidirectional DR” pilots to absorb excess renewable energy | 6-12 months             |                                                                                         |
| RA/LTPP            |                                                                                           |                          | Capacity payments for mobile NGRs                                                      |
| CAISO              |                                                                                           |                          |                                                                                         |
| ESDER              | Aggregation under NGR needs to be enabled                                                  | 3-6 months               | Must offer obligations must be resolved for mobile resources                            |
| FRACMOO            |                                                                                           |                          |                                                                                         |
Codes and standards are critical

<table>
<thead>
<tr>
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<tr>
<td><strong>NEC</strong> - Local code enforcement to NEC 625 and UL 2202 (EVSEs)</td>
</tr>
<tr>
<td><strong>Anti-Islanding</strong> - Utility requirement for conformance with UL 1741 (that refers to IEEE 1547 standard)</td>
</tr>
<tr>
<td><strong>Rule 21</strong> - Emerging requirements in California for smart inverters</td>
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- Princeton Power EVSE designed to meet standards
- Vehicles not within code enforcement jurisdiction
- NEC 625.48 (2017) would clarify rules
- Princeton Power EVSE designed to meet standards
- Vehicles not ever capable of meeting certain UL 1741 standards (e.g., inverter needs to be bolted to ground)
- SAE J3072 passed in May 2015 to conform to IEEE 1547 anti-islanding standards
- The challenge is how to get utilities comfortable with J3072
- 3 Hondas in project meet J3072

- Princeton Power EVSE designed to be adaptable to emerging standards
- Meeting Rule 21 requirements further down the product development path

**No major obstacles – product development necessary to lower inverter/EVSE costs**

**A number of obstacles – project hopes to get first Honda vehicles in front of utilities for anti-islanding testing**
Key Stakeholders
Dynamic Wireless Power Transfer

*Grid Impacts Analysis*

Tony Markel, Andrew Meintz, and Jeff Gonder

EPRI EV IWC Meeting
Atlanta, GA
November 19, 2015
Electrified Roadways Implementation Benefits

• Electrified Roadways Opportunity
  o Expand vehicle utility and value
  o Integrate with renewable resources and grid operations

• Electric Vehicles (EVs)
  o Roadway electrification extends operable range

• Plug-In Hybrid Electric Vehicles (PHEVs)
  o Fully electrified operation possible even with a medium-size battery

• Hybrid Electric Vehicles (HEVs)
  o Fuel displacement from a more-electrified operation
Background Analyses

• Electrified roadway grid impact analysis builds on NREL's previous incremental in-motion wireless power Transfer (WPT) rollout evaluation for urban areas [1].
• Used 2010 Census Combined Statistical Area (CSA) geographic boundaries to analyze road segments and vehicle miles travelled (VMT) within region.
• Datasets from NREL's Transportation Secure Data Center [2] were paired with a specific CSA in multiple regions to investigate applications to seven CSA regions.
• Work concluded that if 1% of the road miles within a geographic region were electrified, 25% of the fuel used by the “fleet” could be displaced.
• Simulated hourly loads to show some alignment with renewables generation and potential curtailment reduction.

Source: NREL

https://www.youtube.com/watch?v=gqfih5swB8Q
Multi-Platform Analysis Completed

- **Transit Bus Analysis**
  - Minneapolis route data used to select charge points and battery sizes
  - For same net present value as HEV solution, WPT bus achieves 50% cut in consumption from conventional

- **Heavy Truck Simulations**
  - Target moderate- to high-grade roadway segments
  - 100-kW WPT on 1.5% or greater grade allows engine downsizing and 9% fuel savings

- **Light-Duty Vehicles**
  - Target urban areas and highly utilized roads show 1% of roadway cuts consumption by 25%
ARC: 2011 Regional Travel Survey

- Down select of Atlanta CSA from the previous analysis – consistent full-week data for vehicles in the study
- Focus on most used roadways in the incremental in-motion WPT rollout provides scenario for initial deployment
- Roadway segments (green network on the map) and the ARC travel data generate weekly time distribution for vehicle miles travelled (graph below)

Previous analysis roadway (green) to selected roadway from 2013 HPMS (black) with the 2010 Census CSA Boundary (blue dashed) and 2013 CSA boundary (orange)

Hourly distribution of VMT on selected roadways for a "typical" week of travel

ARC - Atlanta Regional Commission [3]
HPMS – Highway Performance Monitoring System
Electrified Roadway Load Forecasting

- The Federal Highway Administration's HPMS 2013 data set was used on the road segments highlighted in black on the map to produce daily VMT for the proposed electrified roadways.
- The grid power used by these roads for various levels of total VMT is shown in the graph below using the weekly distribution from the ARC 2011 study.
- Grid power has been calculated to 484 Whr per VMT based on the 2014 RAV4 EV (similar 26 mpg as the production-weighted MY2014 car and truck EPA fuel economy) Representative of fleet consumption.

Electrified roadway grid load for a "typical" week on the designated roads as a percent of total HPMS defined VMT.
Seasonal Load Scenarios – Fall

- Atlanta region grid load determined from the power consumed within the 2013 Atlanta CSA (orange line on map) taken from NREL 2013 Eastern Renewable Generation Integration Study (ERGIS) [4]
- The grid load for the four seasons has been determined by averaging the hourly load throughout a week for each hour within the season
- Graphs show hourly load growth with electrified roadway load over the baseline at from each fractional VMT scenario (colored text indicates the percent)

Electrified Roadway Scenarios added to Typical Fall Grid Load

Vehicles: Grid
5% = 0.76%
10% = 1.52%
25% = 6.17%
...
Seasonal Load – Winter & Spring

Electrified Roadway Scenarios added to Typical Winter Grid Load

Vehicles : Grid
5% = 1.16%
10% = 2.32%
25% = 5.80%
...

Electrified Roadway Scenarios added to Typical Spring Grid Load

Vehicles : Grid
5% = 1%
10% = 2%
25% = 5%
...
Seasonal Load – Summer & Highest Week

Electrified Roadway Scenarios added to Typical Summer Grid Load

Vehicles: Grid
5% = 0.70%
10% = 1.17%
25% = 4.28%
...

Electrified Roadway Scenarios added to Highest Week Grid Load

Vehicles: Grid
5% = 0.62%
10% = 1.24%
25% = 3.10%
...
Result Discussion

• The findings indicate that electrifying 5% of all VMT on high-capacity roads in the Atlanta area could increase peak hour grid demand by a little over 100 MW, which is a little less than a 1% load increase.

• 5% electrification of VMT is the lowest roadway electrification case examined in the preceding grid analysis.
  - Represents an aggressive penetration of WPT-enabled vehicles.
  - HEVs have been commercial for over 15 years, but still account for less than 3% of new car sales [6].

Absolute and incremental percentage load impacts from the 5% of light-duty VMT electrified roadway scenario added to the baseline highest yearly grid load week.
Results

- **Not included here**
  - Stationary charging of the vehicles along with electrified roadway power
  - Differences in powertrain implementations’ ability to utilize roadway
    - All EVs: fully functional
    - HEVs/PHEVs: should have large enough e-drive system to maintain highway speeds
  - System layout and its impacts on power delivery and quality
  - Integration of both light-duty and heavy-duty utilization profiles

- **Future analysis and testing should consider other WPT implementation challenges**
  - Fall and winter midday trough accentuated with electrified roadway loads
  - Infrastructure and load profile differences depending on the class of vehicle (light, medium, heavy-duty) and powertrain to be served (EV, PHEV, HEV)
  - The ability to charge batteries rather than just meeting the instantaneous driving load
  - Data presents “hourly” average power and its impact
    - Analysis by Highways England in [7] has shown that sub-hour maximum power flow is influenced by the design and layout of the WPT system
Highways England Report – System Layouts

Example DWPT System- Layout 1 [7]

- Each coil can supply up to 100kW of power to a secondary coil
- Up to 2 coils can be energised in the same segment (i.e. connected to the same inverter)
- Each inverter can supply up to 200kW
- Coil length can be tailored to suit larger or shorter vehicles.

Power demand per mile of motorway for 30% light vehicle and 50% heavy vehicle penetration at 55 mph, DWPT system layout 1 [7]

Example DWPT System- Layout 2 [7]

- Each coil is 9m long and is connected into a single continuous power transfer segment of up to 40m (long can be 20m)
- Each segment can supply up to 140kW of power to a secondary coil
- One segment can provide power to only 1 vehicle
- Non-equipped vehicles present on the same segment as a vehicle using the segment will result in the system switching off until the appropriate headway is established
- Each inverter can supply up to 140kW

Power demand per mile of motorway for 30% light vehicle and 50% heavy vehicle penetration at 55 mph, DWPT system layout 2 [7]
Simulated Power Flows Impacted by Speeds and Headway

Dynamics of 0-150 kW in 0.1s

Even higher at lower speeds
Discussion – Roadway WPT Scenarios

Many WPT mechanization concepts for dynamic power transfer, one example is shown in the image below.

Many open questions as to what should be the design criteria for such systems:

• How should the spacing of primaries along the roadway be optimized for power delivery to various load sizes?

• What is the minimum power level that secondary receivers on light-duty and heavy-duty vehicles need to provide the infrastructure flexibility?

• How does traffic impact peak power required by the grid and what limitation should be placed on transients?

• Would the use of integrated energy storage with the daily / weekly traffic patterns become a valuable grid device?

A roadway WPT system based on [8]; buffering infrastructure limits impact on power systems.
Potential Impacts to Vehicle Adoption

- ORNL analyzed several regions for vehicle preferences
- Roadway WPT vehicle capabilities add 5-20% to 20yr adoption potential [9]

SF=San Francisco
SD=San Diego
AVG=Average SF/SD
Bat10=10% lower cost
Testing and Demonstration Activities

• Multi-unit testing for grid integration
  o Three 3-kW units on a distribution grid with varied DC sources and level 2 AC chargers

• NREL campus shuttle application
  o 1.5-mi loop; 60–75 circuits per day; 2–3 charging locations

• Future opportunities
  o Target airport shuttles with fixed routes
  o Medium-duty delivery routes
References


Update on Networked Infrastructure Standards

John Halliwell
Principal Project Manager

EPRI IWC, Atlanta, GA
November 19, 2015
Content

- The landscape – what are we talking about?
- What is the end goal? (visions may vary)
- Status Updates
- Next Steps
Network Infrastructure Landscape
Two of the Possible Visions

- **Consumer – Consumer Advocate**
  - Just let me roam with as few credentials as possible
  - Oh, and one bill sounds nice
  - I don’t want to have to belong to your club
  - Keep it simple

- **Charge Station Host and/or Owner**
  - What happens if my EVSP goes out of business, raises rates or isn’t the best fit for me?
  - What can I do to lower the cost to operate?
  - I want happy customers
  - I want minimal hassle with all of this
Consumer View

FREE TO ROAM!

One Bill
Session 1
Session 2

One-Credential
An RFID to Rule Them All

An RFID to Rule Them All
Charge Station Owner/Site Host View

INTERCHANGEABLE NETWORKS
and CHARGE STATIONS
We have a Ways to go to Fully Support Either Vision..

- Status of the “pieces”
  - NEMA Update?
  - OCA Update?

- Discussion - What’s Next?
Desirable Traits of a Standard Network Protocol

- Maintain basic behavior of charge stations across networks
  - User Access/authentication
  - Measurement of Time and Energy for a charge session
  - Ability to communicate all the above
  - Remote start/stop of a charge session
  - Site host and charging user billing activity

- Protocol has sufficient breadth to meet communications needs across service providers and networks

- Structured to allow innovative or unique feature implementation

- Broad industry participation in development and implementation

- Robust security

- Certification process
Some Practical Hurdles to “Network Mobility”

Moving networks at a charge station:

- Redirect communications to new network server (IP address)
- If cell modem account was maintained by EVSP, how is it transferred?
- User credentials – still valid or need to switch to new EVSP credential?
- How do I know what features will still work?
- What about branding, support call center, and customer experience?

How does an EVSP deal with:

- Transfer of user/account info (site host and charge station users)
- What if station capabilities are less than the network’s “typical station”? 
- Are the charge station user credentials supported?
- Can you support site host expectations?
- How do you deal with charge station firmware upgrades?
Together...Shaping the Future of Electricity
Wireless Charger for Electric Vehicles: Safety, Efficiency, and Other Practical Considerations

Zion Tse, Yabiao Gao, Antonio Ginart, Blair Farley

UGA College of Engineering,
Southern Company Services
Challenges in EVWC

- **Backgrounds & Commercial Chargers**
- Charger Design
- Safety & Health
- Charging Efficiency
- Air Gaps & Misalignments
Why WC?

- **Convenience**
  - No plug-in required
- **Weather proof**
  - Buried underground
  - No exposure to rain, snow/ice
- **Low risk of system damage**
- **Safety**
  - No physical electrical connections required
- **Dynamic/Opportunity Charging** for reducing
  - Range anxiety/battery storage problems
  - Frequent charging whenever opportunities available
Key Players in EV Wireless Chargers

- WiTricity Delphi (Startup from MIT, 2m, 60W WC)
- Plugless Charger (Low-cost L2 household Charger)
- Qualcomm Halo IPT (EV Integration)
- Oak Ridge National Lab (Dynamic WC)
- OLEV (Electric Bus in South Korea)
- WAVE (Startup from University of Utah)
- PRIMOVE (Bombardier – WC Tram in Manheim)
WiTricity Delphi

Startup from MIT, Prof. Marin Soljacic - WC 60W Light Bulb (2m)
Qualcomm Halo IPT

Highly integrated System (WC+EV+User Interface)
Prototype of Dynamic Charging EV
WAVE (Startup from Univ. of Utah)

– WC Electric Buses with 50kW using Opportunity Charging
KAIST OLEV (S.Korea)

Power Electric Buses. DWC100kW, 20-cm air gap, 85%, for 4/5 battery reduction
Challenges in EVWC

• Backgrounds & Commercial Chargers
• *Charger Design*
• Safety & Health
• Charging Efficiency
• Air Gaps & Misalignments
UGA WC Hardware Setup

- 5kW WPT Prototype driven by Our IGBT Power Inverter
- Controller@20kHz AC

3-axis Platform for studies of

- WC Efficiency with Coil Misalignments/Air Gaps
- Safety & Heating Issues with Inserts of Metal /Electronic Appliances
Challenges in EVWC

• Backgrounds & Commercial Chargers
• Charger Design
• Safety & Health
• Charging Efficiency
• Air Gaps & Misalignments
Safety Tests - Human exposed to WC field

Nissan Leaf in the lab installed with our 5kW Wireless Charger

Safety Tests - Human exposed to WC field

ICNIRP Standards: Max Human Field Exposure< 27.3uT; Average Field <6.25uT

Field Strengths for 4 parts of human body along with the distance from the coils (power: 2kW).

Average field strength on the human body (power 2kW)

ICNIRP Standards:
For 2kW WC, 60cm away from the coil center REQUIRED.
Scale up for High WC power.
Thermal effect measurement on models at four levels of power.

Iphone/ipad models to mimic situations accidentally inside WC system.

The temperature rise or induced-voltages could damage electronics and also affect the functionality of medical devices close to the EVWC system.

WC-induced Voltages by at different distances from the coil center.
Temperature rise on a Soda Can

The temperature rise (~110°C) could potentially cause can explosion.
Nissan Leaf with Evatran Level2 3.3kW Plugless Charger

Safety Tests - Human exposed to WC field

ICNIRP Standards: Max Human Field Exposure < 27.3μT; Average Field < 6.25μT

Magnetic Field Strength at different distance from the WC system

ICNIRP Standards: ~70cm away from the coil center REQUIRED.
Safety Tests - WC induced Heating

Soda Can, Time Duration: 1 Min, Outdoor Temp (11.6 °C)

Risks: (1) Skin burns (2) Explosion (Metal Container with Compressed Gas)
Summary

- WC chargers have potential risks in human RF exposure & RF-induced heating/voltages.
- For 2kW WC,
  - >60-70cm away from the coil center required.
  - 100C heating of soda can < 1min.
- Risk assessments may be not thoroughly studied or disclosed by the WC company.
- Further study required to study how high-power RF affects human health (infants, pregnant women)
- Policies and guidelines are required for safe WC chargers
Challenges in EVWC

• Backgrounds & Commercial Chargers
• Charger Design
• Safety & Health
• Charging Efficiency
• Air Gaps & Misalignments
WC Efficiency sensitive to Air Gaps/Misalignment

Practical Issues: e.g. Tyres with low pressure /Parking Misalignment

- Efficiency under different air gap
- Air gaps affect mutual inductance & freq.

15cm, 90%
20cm, 85%
25cm, 80%
35cm, 30%

Blue line: WC Efficiency
Efficiency with Misalignment & Air Gap

- Bench test has shown an optimal WC efficiency of 90%
- 10cm air gap or misalignment results in 60-70% WC efficiency
- 20cm air gap or misalignment results in 30-40% WC efficiency
Efficiency Loss by Electronics Inserts

- Once the magnetic field was blocked by the test pieces, the efficiency was reduced
- The energy was converted to eddy currents that heat up the electronics.
- 1 ipad (~500cm²) causes ~5-20% loss in efficiency

WC efficiency influenced by the number of test pieces placed in between the transmitter and receiver
Summary

- WC efficiency can be reduced by electronic inserts (metal objects)
- WC efficiency achieves ~90% in benchtop testing conditions
- Air gaps/Misalignments significantly reduce the WC Efficiency
- Reduction ~ 30%/10 cm Air gaps/Misalignments
Challenges in EVWC

- Backgrounds & Commercial Chargers
- Charger Design
- Safety & Health
- Charging Efficiency
- Air Gaps & Misalignments
Model for Optimizing WC with Air Gaps/Misalignments

Neumann formula describes mutual inductance between 2 coils

\[ r = \sqrt{a^2 + b^2 + g^2 - 2ab \cos(\phi - \theta)} \]  \hspace{1cm} (5)

\[ d\vec{p} = a(-\sin\phi \vec{x} + \cos\phi \vec{y})d\phi \]

\[ d\vec{s} = b(-\sin\theta \vec{x} + \cos\theta \vec{y})d\theta \]  \hspace{1cm} (6)

\[ d\vec{p} \cdot d\vec{s} = ab \cos(\phi - \theta)d\phi d\theta \]

Combine equations (4)-(6):

\[ M = \frac{\mu_0 \pi a^2 b^2}{2(a^2 + b^2 + g^2)^{1.5}} \left(1 + \frac{15}{32} \alpha^2 + \frac{315}{1024} \alpha^4 + \frac{15015}{65536} \alpha^6\right) \]  \hspace{1cm} (7)

where \[ \alpha = \frac{2ab}{a^2 + b^2 + g^2} \]

\[ \mu_0 \] is the magnetic constant
Principles

1) With mutual inductance known, we can work out
   a. impedance
   b. phase angle
   c. optimal operating frequency
      under different air gaps/misalignments

2) We have designed Magnetic Sensor for 3D-Air Gap, Alignment Detection (0.2cm accuracy)
Efficiency with Misalignments/Air Gaps

Efficiency remains relatively level under different misalignments/air gaps.
Summary

• Freq. tuning controller dynamically tunes the operating frequency to compensate the negative effect from air gap/misalignment
• Maintain high WC efficiency (20cm)
• Enabling technique for dynamic/opportunity charging where air gaps/alignments vary.
Conclusions

• **Safety:** WC has potential risks in human RF exposure & RF-induced heating/volts.
• **Efficiency:** Bench test has achieved efficiency of <90%, an optimal estimate to be achieved in household wireless EV chargers
• **Air gaps/Misalignments** decrease efficiency
• which can be tackled by freq. tuning
• Freq. tuning is an important for WC charger design, e.g dynamic/opportunity charging