Innovative Applications of Wireless Charge Transfer for Smart Vehicle Electrification

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OUTLINE

- Introduction
  - Why EVs?
  - Current Technology for Wireless Transfers
- Case Study 1: Charging Buses at Bus Stops
- Case Study 2: Vehicle to Vehicle Wireless Charging
- Conclusions
**WHY EVS?**

*In President’s Obama’s 2011 State of the Union address, he called for putting 1 million electric vehicles on the road by 2015. This goal was meant to reduce the country’s dependence on oil!*

- Regular Gasoline Powered Vehicles Disadvantages
  - Environmental Concerns
    - General pollution including air emissions
    - Availability of fossil fuels in the future
  - Health Concerns
    - Exposure to gasoline can lead to cancer (long term)
  - Political Issues
    - Reliance on countries

- EV Disadvantages
  - Driving Range
  - Recharge Time
  - Availability of charge stations

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<table>
<thead>
<tr>
<th>Vehicle Name</th>
<th>Charging Time*</th>
<th>Driving Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low Speed Vehicles</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dynasty iT Sedan</td>
<td>6 hours</td>
<td>30 miles</td>
</tr>
<tr>
<td>ZENN (Zero Emissions, No Noise)</td>
<td>6 – 8 hours</td>
<td>30 – 50 miles</td>
</tr>
<tr>
<td>Chrysler GEM Car</td>
<td>6 – 8 hours</td>
<td>30 – 40 miles</td>
</tr>
<tr>
<td><strong>City Speed Vehicles</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Citroen C1 ev’ie</td>
<td>6 – 7 hours</td>
<td>60 – 70 miles</td>
</tr>
<tr>
<td>NICE Mega City</td>
<td>8 hours</td>
<td>60 miles</td>
</tr>
<tr>
<td>Stevens Zecar</td>
<td>6 – 8 hours</td>
<td>50 miles</td>
</tr>
<tr>
<td><strong>Highway Vehicles</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMW Mini E</td>
<td>3.5 hours</td>
<td>100 miles</td>
</tr>
<tr>
<td>Chevrolet Volt (2013)</td>
<td>3 hours</td>
<td>38 miles</td>
</tr>
<tr>
<td>Fiat 500e</td>
<td>4 hours</td>
<td>80 miles</td>
</tr>
<tr>
<td>Ford Focus BEV</td>
<td>4 hours</td>
<td>76 miles</td>
</tr>
<tr>
<td>Mitsubishi MiEV i</td>
<td>7 hours</td>
<td>62 miles</td>
</tr>
<tr>
<td>Nissan Leaf</td>
<td>8 hours</td>
<td>73 miles</td>
</tr>
<tr>
<td>Tesla Roadster</td>
<td>3.5 hours</td>
<td>200 miles</td>
</tr>
<tr>
<td>Toyota RAV4</td>
<td>5 hours</td>
<td>80 – 100 miles</td>
</tr>
</tbody>
</table>
Current Battery Charging Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Requires Changes to Infrastructure</th>
<th>Requires Uniformity in Battery Placement and Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plug-in Charging</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Battery Swapping</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Inductive Power Transfer (IPT)</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

- **Recharge time**
  - Swap batteries – Better Place
  - Quick charge stations – Tesla

- **IPT**
  - Traffic Light
  - Roadway Strips
  - Parking Lots
  - Bus Stops

Current research has focused on building larger batteries to drive further distances.
- Increase costs
- Larger battery = heavier vehicle = requires more energy to drive distances = not a lot more range.
<table>
<thead>
<tr>
<th>Name</th>
<th>Technology</th>
<th>Efficiency*</th>
<th>Distance</th>
<th>Transfer Rates (in sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Companies</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bombardier</td>
<td>PRIMOVE</td>
<td></td>
<td></td>
<td>Up to 200 kW</td>
</tr>
<tr>
<td>Qualcomm</td>
<td>Qualcomm Halo</td>
<td></td>
<td></td>
<td>Up to 7 kW</td>
</tr>
<tr>
<td>Siemens</td>
<td>&gt;90%</td>
<td>15 cm</td>
<td>3.6 kW</td>
<td></td>
</tr>
<tr>
<td><strong>Research Groups</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ORNL</td>
<td>90 – 94%</td>
<td>25 cm</td>
<td>7 kW</td>
<td></td>
</tr>
<tr>
<td>KAIST</td>
<td>OLEV</td>
<td>85%</td>
<td>20 cm</td>
<td>180 kW at 60 Hz</td>
</tr>
<tr>
<td>Stanford</td>
<td>&gt;97%</td>
<td>6.5 feet</td>
<td>10 kW</td>
<td></td>
</tr>
<tr>
<td><strong>Start-Ups</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eaton</td>
<td>HyperCharger</td>
<td></td>
<td></td>
<td>200 kW – 1MW</td>
</tr>
<tr>
<td>EvaTran</td>
<td>Plugless Power</td>
<td>&gt;90%</td>
<td>10 cm</td>
<td>3.3 kW</td>
</tr>
<tr>
<td>WiTricity</td>
<td>&gt;90%</td>
<td>10 – 20 cm</td>
<td>3.3 kW</td>
<td></td>
</tr>
</tbody>
</table>

- Measurement of efficiency varies. Typically measured from wall plug to EV battery.
- References: Company websites.
Case Study 1

CHARGING BUSES AT BUS STOPS
Opportunity

- 28% of all greenhouse gas emissions in 2011 for the United States were from transportation related sources (EPA)

- United States is also the second highest carbon dioxide emitter after China

- Bus transit is the second leading carbon emitter per passenger mile after private commuting vehicles

- Adoption of electric vehicles by commercial fleets is an easier implementation strategy for these vehicles since commercial fleets typically have predetermined routes and scheduling
STUDY

- Determine whether wireless charging at specifically designated bus stops throughout New York City can help to increase the feasibility of electric buses for city use both from an operational and a financial standpoint.

- MTA
  - 5900 buses and 2000 vans/cabs for para transit
  - Hybrid bus

- Other ongoing trials
  - 5-year trial in United Kingdom
  - 3 month zero-emissions trial in Bangalore, India
Case Study 2

VEHICLE TO VEHICLE WIRELESS CHARGING: TAXIS
**Objective**: To increase the effective driving range of EV without changing current infrastructure or battery/charging technology.

**Implications**: Increase the fraction of users who can use EVs for daily commutes and local trips.

Current proposals for using IPT as a method to charge EVs, do NOT utilize vehicle-to-vehicle charging systems. Our proposal to use this method is NOVEL!
Feasibility Analysis

- Types of Charging
  - Quick Charge*
  - Fast Charge*

- Battery Charge Rate
  - Varies by Battery Type; Higher C indicates faster charge rates possible

- Overall Battery Life
  - Affects overall battery capacity by 1%/year

- Heat Generation

Nissan Leaf Example:

\[
\frac{100 \text{ miles}}{10 \text{ minutes}} \times \frac{1 \text{ minute}}{60 \text{ seconds}} \times 30 \text{ seconds} = 5 \text{ miles/traffic light}
\]

\[
\frac{80 \text{ miles}}{30 \text{ minutes}} \times \frac{1 \text{ minute}}{60 \text{ seconds}} \times 30 \text{ seconds} = 1.3 \text{ miles/traffic light}
\]

Reference:
V2V Wireless Charging Model Framework

- **Stochastic Simulation**
  - **Driving Distance Distribution Data**
    - NYC Taxicab 2012 Analysis
    - RHTS Commuter Vehicles
  - **Scheduling Rendezvous**
    - Random Meetings
  - **Routing EVs**
    - Dijkstra’s Algorithm
    - Fisheye Routing
    - All EV Taxi Fleet?
  - **Incentives for Participation**
    - Nash Bargaining for 2 players

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NYC Taxicab Driving Data Set

- Available via OpenFOIL bill
  - Similar to Oakland, CA and Chicago, IL
- 192 million entries in two csv files
  - Medallion number, drivers license ID, pick up date and time, drop off date and time, passenger count, trip time, trip distance, pickup latitude and longitude, drop off latitude and longitude, ....

- Accuracy of data
  - Depends on method utilized by driver for meter
APPLICATION: FEASIBILITY OF ALL ELECTRIC TAXI FLEET

- Calculate cumulative driving distance of taxicabs during a shift:
  \[ \text{total distance} = \sum \text{distance with paid customer} + \text{distance to find next customer} \]

- Distribution: Rician

- Two estimates based on distance calculation for finding new passenger

- Without charge transfer: failure rate: approx 18.8%-29.7%
V2V SIMULATION

Assumptions:

- All cars enter the system with 100 units of charge
- Charge and travel distance normalized (1 unit charge = 1 mile travel distance)
- Charge transfer occurs at a traffic light intersection wherein cars are stopped for 30 seconds
- Assume loss-less transfers
- External factors that can cause a car to use more than 1 unit of charge to travel 1 mile are NOT included in the model

Step 1: Add Cars
Step 2: Drive Cars
Step 3: Calibrate Cars
Step 4: Remove Cars
Probability of refueling a vehicle is highly dependent on assumed driving distribution.