DC Fast Charging - Where do we Stand?

Dr. Arindam Maitra, EPRI
EVS 27, Barcelona, Spain
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Public Charging May Address “Range Anxiety”

- Fast charging requires high power
- Unique challenges in terms of infrastructure, operational cost due to demand charges
- Creating a sustainable business case will require economics that match utilization.
- Simple and convenient solution has potential to strengthen range confidence; address psychological “barrier”
- Planned in coordination with home and work place charging solutions in region
- Potential to increase traffic for some retail locations
Market for DCFC is Small & Location Dependent

• Most energy is still likely to be transferred at home
• Location is everything – I-5 San Diego/LA corridor DCFC sees heavy traffic
• Consumers are willing to pay (on average) between $10-20/charge

Total Energy Consumption for 1 Month: 1,034 kWh

Friday before Thanksgiving

Total Energy per Day (kWh)

Graph showing willingness to pay per session (charge) for DCFC (80 kW) per single cut household, with costs ranging from $0 to $90.
DC Fast Charge Connectors in US

SAE Combo

CHAdeMO

Tesla
Current Status of DC Fast Charging in US

- Public DC fast charger deployments in the North America:
  - **CHAdemo**: A DC charging protocol developed and adopted as a standard in Japan; limited to approximately 50kW
  - **Tesla Supercharger**: a proprietary protocol developed by Tesla Motors; 120kW

- Approximately 200 CHAdemo chargers deployed in the US

- Tesla has deployed eight Supercharger stations in the US, some with multiple fast chargers, with plans to deploy more than two dozen additional stations by late 2013

- Products that include the US Standard SAE Combo connector are expected by the end of 2013
  - Chevy Spark and BMW i3 are first vehicles expected to use Combo
## Charging Preferences

### Preferred Charging Locations*

<table>
<thead>
<tr>
<th>Location</th>
<th>Plug-In Hybrid Version (n=509)</th>
<th>Battery-Only Version (n=499)</th>
</tr>
</thead>
<tbody>
<tr>
<td>At your place of work</td>
<td>77%</td>
<td>77%</td>
</tr>
<tr>
<td>Public parking garage</td>
<td>72%</td>
<td>61%</td>
</tr>
<tr>
<td>Shopping centers/malls</td>
<td>70%</td>
<td>66%</td>
</tr>
<tr>
<td>Airports</td>
<td>60%</td>
<td>52%</td>
</tr>
<tr>
<td>Grocery stores</td>
<td>59%</td>
<td>52%</td>
</tr>
<tr>
<td>Restaurants</td>
<td>53%</td>
<td>45%</td>
</tr>
<tr>
<td>Entertainment locations</td>
<td>52%</td>
<td>49%</td>
</tr>
<tr>
<td>Hospitals</td>
<td>51%</td>
<td>40%</td>
</tr>
<tr>
<td>On street, metered parking</td>
<td>51%</td>
<td>50%</td>
</tr>
<tr>
<td>Government offices/buildings</td>
<td>48%</td>
<td>47%</td>
</tr>
<tr>
<td>Sporting Venues</td>
<td>42%</td>
<td>35%</td>
</tr>
<tr>
<td>Fitness centers</td>
<td>41%</td>
<td>40%</td>
</tr>
<tr>
<td>Coffee shops</td>
<td>37%</td>
<td>32%</td>
</tr>
<tr>
<td>Places of worship</td>
<td>31%</td>
<td>34%</td>
</tr>
</tbody>
</table>

* Preferred charging locations are based on 3-hour charging for the Plug-In Hybrid Version and 8-hour charging for the Battery-Only Version.
Charge Profiles using Eaton 50KW Charger

![Graph showing charge profiles and power vs SOC]

- **Eac(Leaf)** = 21.28KWh
- **Eac(iMieV)** = 10.47KWh
- **Eac(Leaf)** = 13.15KWh
- **Eac(iMieV)** = 4.16KWh
- **Eac(Leaf)** = 8.14KWh
- **Eac(iMieV)** = 6.30KWh

Starting Battery Empty
Effect of Starting Battery Capacities on Charge Profile

Leaf Charge Profiles for Various Starting Battery Capacities

<table>
<thead>
<tr>
<th>Starting Battery Capacity (kWh)</th>
<th>TOTAL Pac (Pdc)</th>
<th>CC MODE Pac</th>
<th>CV MODE Pac</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kWhr</td>
<td>21.28 (19.18)</td>
<td>13.15</td>
<td>8.14</td>
</tr>
<tr>
<td>13.6 kWhr</td>
<td>8.62 (7.52)</td>
<td>1.30</td>
<td>7.32</td>
</tr>
<tr>
<td>16.4 kWhr</td>
<td>5.98 (5.13)</td>
<td>0.33</td>
<td>5.65</td>
</tr>
<tr>
<td>17.2 kWhr</td>
<td>4.38 (3.67)</td>
<td>4.38</td>
<td></td>
</tr>
</tbody>
</table>
SOC Profiles under Different Command Currents

![Graph showing SOC profiles under different command currents](image)

- Power (120A) kW
- Power (100A) kW
- Power (80A) kW
- Power (60A) kW
- Power (Eaton 125A)
Starting Battery Capacity – DC Fast Charging versus 240V Charging

- 240V charging ends at 101 min
- Energy charged using 240V is more than DCFC charging (~ 5.93 kWh)

- 240V charging ends at 165 min
- Total energy charged is same for both DCFC and 240V
Harmonics vs Power

Harmonic spectrum indicates 3\textsuperscript{rd} harmonic – possibly a single phase ancillary load
What Applications Make Sense?

• Business Models, customer needs, and utilization

• Low utilization Level – Economics of low-utilization sites will be dominated by capital costs for equipment installation and demand charges

• **Intermediate utilization Level** – Intermediate-utilization charging happens once fast charging demand at one location is high enough that *multiple ports* can be profitably installed and total charging capacity can be shared between number of vehicles at once

• **High utilization Level** – High-utilization charging occurs once charging is common enough that fast charging is a *customer expectation*. This level will also support multi ports and controlled charging of number of vehicles at once

![Graph showing 25 KW Fuji Electric Energy (kWh) from 11/3/2012 to 12/3/2012]
Intelligent Universal Transformer (IUT) – a Paradigm Shift

Distribution Transformer

Intelligent Universal Transformer (IUT™)
Medium-Voltage IUT Based DC Fast Charger

- **Conventional DC Fast Charger** needs a new three-phase service
  - Three-phase transformer
  - Three primary conductors and associated medium voltage fuses
  - Three high-current service conductors
  - 208/480 Vac DC fast charger
  - Overall efficiency (w xfmr) ~88-91%
  - Installation costs

- **IUT Direct DC Fast Charger**
  - Combines service transformer and DC fast charger into one unit
  - Needs only one primary conductor, no isolation transformer and no secondary conductors
  - Overall efficiency >95%
  - Installation costs

(a) Conventional DC fast charger with low-voltage power electronics
(b) EPRI DC fast charger with medium-voltage IUT
1. Multilevel active-front-end (AFE) converter is located at service entrance
2. AC input can be interrupted with high-voltage 12-kV vacuum switch
3. Low-voltage DC distribution system serves the charging station
4. DC voltage can be interrupted with a DC circuit breaker
5. Charger output is Chademo compatible
Utility Direct Fast Charger with CHAdeMO Interface

PC Display Control Console

DSP board

Medium Voltage DC-DC Charger

Vehicle Side Battery Management System

Interface

1, 7 GND

d1

2 RDY

4 PWR+

5 PWR−

6 CAN+

8 CAN−

9 d2

10

I_{ref}

V_{ref}

CMD

2.4kV rms
2.4KV 50kW Medium Voltage IUT Based DC Charger – Efficiency Comparisons

Efficiency vs Power (as % of Full Load)

- 200V Commercial FC
- Overall 2.4KV IUT FC
- 200V Commercial FC + Conventional Transformer
- 2.4KV AFE Converter Efficiency

% Load vs % Efficiency graph showing the efficiency of different configurations at various load levels.

- 200V Commercial FC: Efficiency remains relatively constant across the load range.
- Overall 2.4KV IUT FC: Efficiency is slightly higher than 200V Commercial FC.
- 200V Commercial FC + Conventional Transformer: Efficiency is lower than other configurations.
- 2.4KV AFE Converter Efficiency: Efficiency is the highest among all configurations.
Summary of IUT – DC Fast Charging Application

- Can be less expensive than current 208/480 VAC DC fast chargers
- Significantly lower installation costs
- More flexible operation—integrate on-site renewables and storage
- Can manage multiple charging connectors and standards seamlessly
- The IUT can be a utility-owned asset and a third party can manage the ‘service station’ portion
- Next steps
  - Public demonstration of field-ready, certified unit (hopefully in 2014)