Electricity Distribution and Grid Management - Where do we Stand?

Dr. Arindam Maitra, EPRI
EVS 27, Barcelona, Spain
November 20, 2013
# PEV Charging Options

<table>
<thead>
<tr>
<th>Name</th>
<th>Level 1 AC</th>
<th>Level 2 AC</th>
<th>Level 2 DC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>120V AC, 1 phase</td>
<td>208/240V AC, 1 phase</td>
<td>200V-480V, 3 phase AC</td>
</tr>
<tr>
<td>Amps (max)</td>
<td>16a</td>
<td>80a (30a typical)</td>
<td>70a @ 480V (max 200a)</td>
</tr>
<tr>
<td>Power</td>
<td>1.44 kW</td>
<td>3.3 – 6.6 kW (max 19.2 kW)</td>
<td>Up to 90 kW</td>
</tr>
<tr>
<td>Standardized</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Range/charging hour</td>
<td>~5 miles</td>
<td>~10 – 20 miles</td>
<td></td>
</tr>
<tr>
<td>Connector</td>
<td>SAE J1772</td>
<td>SAE J1772</td>
<td>SAE combo</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CHAdeMO</td>
</tr>
</tbody>
</table>

Data is still being gathered how much power customers “need”

Source: Electric Drive Transportation Association, [www.electricdrive.org](http://www.electricdrive.org), Society of Automotive Engineers (SAE)
Distribution Impacts of PEV Charging

- Local distribution transformers are among the first equipment impacted.
- Charge power is the likely dominant factor determining impact, not time-of-day.
- Charge power is increasing—automotive OEMs trend to about a four-hour charge time.
  - 19.2 kW is the maximum for residential AC charging.
- TOU rates and other off-peak charging programs mitigate upstream impacts but offer limited help to local transformers.
  - Especially true with clustering.
PEV Location Determination Using Smart Meter Data

Household 04 With PEV, Week Starting: Sunday, May 15, 2011

<table>
<thead>
<tr>
<th>Power [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunday</td>
</tr>
<tr>
<td>Monday</td>
</tr>
<tr>
<td>Tuesday</td>
</tr>
<tr>
<td>Wednesday</td>
</tr>
<tr>
<td>Thursday</td>
</tr>
<tr>
<td>Friday</td>
</tr>
<tr>
<td>Saturday</td>
</tr>
</tbody>
</table>

Data Type
- 15 minute raw signal
- 3.7kW PEV charging
Aggregate PEV Demand

Hourly Demand per PEV (kW)

- **Peak Demand**: 720 W / PEV
- **Average Energy Consumption**: 5 kWh / day
- **75% of charging occurs** between 4 – 9 pm

**Demand strongly correlates with home arrival**
Different Charging Algorithms Impact Timing, Magnitude of Demand

- Timed charging increases per vehicle peak demand, but shifts load away from the peak
  - May be possible to create a second peak, but diversity can minimize
- Managed off-peak charging best combination
  - Low peak demand
  - Fill nighttime valley
  - How to implement on a widespread basis?
Service Transformer Overload Risk

Risk = P(Impact) * E(Overloads)

Little to no risk for most circuits (Median = 0.4)

Risk Factors
- High PEV penetration
- Existing loading
- Transformer size
- Customer allocation
Circuit Characteristics and Design – 4KV Versus 13KV Systems

Clustering cannot result in widespread system impacts

Circuit “AA” (4KV)

Circuit “Z” (12.47KV)
Localized peaks do not always correlate with substation demand.

Controlled Charging must consider loading conditions for both substation and individual distribution transformers.
Overall customer voltages do not vary greatly over time (Good voltage regulation)

AMI Low Voltage Occurrence – Consumers Energy

0.005% of Customer hours < 114V

Majority of hours spent at the upper range of the ANSI requirements
3 CA Distribution Circuits

- 8% penetration with different charging rates for the three circuits
  - Circuit EE – 358 potential PEV customers out of a total of 2803 utility customers
  - Circuit U – 318 potential PEV customers out of a total of 2482 utility customers
  - Circuit V – 426 potential PEV customers out of a total of 3325 utility customers
Sensitivity of Different PEV Charge Levels on Example 25KVA Distribution Transformer Loading
Increasingly High Charge Rates Create Disproportionate Grid Impacts – 3 CA Distribution Circuits

<table>
<thead>
<tr>
<th>Charge Rate</th>
<th>Circuit EE Count of Transformers at Risk (%)</th>
<th>Circuit U Count of Transformers at Risk (%)</th>
<th>Circuit V Count of Transformers at Risk (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3</td>
<td>5 (2%)</td>
<td>7 (2%)</td>
<td>37 (23%)</td>
</tr>
<tr>
<td>6.6</td>
<td>62 (22%)</td>
<td>88 (30%)</td>
<td>103 (64%)</td>
</tr>
<tr>
<td>9.6</td>
<td>192 (67%)</td>
<td>132 (45%)</td>
<td>136 (84%)</td>
</tr>
<tr>
<td>19.2</td>
<td>285 (100%)</td>
<td>229 (78%)</td>
<td>155 (96%)</td>
</tr>
<tr>
<td>Total Xfmrs</td>
<td>286</td>
<td>292</td>
<td>161</td>
</tr>
</tbody>
</table>

9.6 kW → 45 – 84% of Transformers Potentially at Risk

19.2 kW → 78 – 100% of Transformers Potentially at Risk

0
100
200
300
400
500
600
Transformers at Risk
Circuit EE
Circuit U
Circuit V

Total
19.2
9.6
6.6
3.3
ESB Distribution Field Trial
ESB Residential Network Field Trial Measurements

Fig. 3. Sample 24-hour residential demand and EV demand profiles for single customer with EV charging occurring during peak load hours.

Fig. 5. Probability distribution function of EV connection times recorded during the field trials.

Fig. 4. Sample 24-hour residential demand and EV demand profiles for single customer with EV charging occurring during off-peak load hours.

Fig. 6. Probability distribution function for the occurrence of EV charging over a 24-hour period.
ESB Residential Network Field Trial Measurements

Voltage and Current Profiles for a Household at Remote End of Feeder for the 24-hour Period
Phase 1 PEV Distribution Impact Study

- EPRI concluded multi-year Phase 1 – 19 utilities ~ 40 circuits

Negligible Impacts
- System losses
- Primary voltage
- Power quality

Initial Impacts
- High power PEV Charging (>6.6KW)
- Transformer overloads and Loss of life
- Low secondary voltages

Planning Adjustments
- Equipment sizing
- Asset-to-customer allocations
- Transformer ratings

Distribution analysis will guide smart charging implementations

- EPRI Report ID # 1024101
  - Compilation and cross cutting results
  - Summaries of general concerns, asset risks, contributors, impact of charging profiles
Key Elements for Territory Wide Assessment

PEV Characteristics

Distribution Asset Data
- Asset Loading Database
- Asset Characteristics Database

Probabilistic Risk Assessment

- Hot Spot Analysis

Asset Upgrade Assessment

PEV (Demand)

PEV (Overload)

PEV (Capacity)
Latest Research Shows Mid to Long-Term Impact of Charging Load Over Time of Day