Preparing the Distribution Grid to Embrace PEV

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How Much Load is a 40 Mile Range EREV & 100 Mile Range Nissan Leaf?

**PLASMA TV**

- Annual Energy: 623 kWh

**SET TOP BOX**

- Annual Energy: 263 kWh

**Average Annual Energy Consumption** = 865 kWh

**CHEVY VOLT**

- Extended Range Electric Vehicle

- Average Annual Energy Consumption = 1890 kWh

  Volt is approx. 11% load increase to the average Home

**Nissan Leaf**

- All Electric Vehicle

- Average Annual Energy Consumption = 2964 kWh

  Volt is approx. 17% load increase to the average Home
Energy

Annual Residential Electricity Consumption

12231
1890

Opportunity to Alleviate Issues Related to Nighttime Over Generation

Adequate Energy Supply to Meet any Realistic Penetration
Charging Infrastructure
PEVs Generally Have Three Charging Options

120V – Level 1
Portable cordset
Use any 120V outlet
Up to 1.44 kW

240V – Level 2
Permanent charge station (EVSE)
Typ. 3.3 – 6.6 kW, but up to 19.2 kW

DC Fast Charging
Up to ~ 50 – 60 kW
Fast, expensive
Standard not yet in place
## Why the Concern?

<table>
<thead>
<tr>
<th>Device</th>
<th>Power Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Air conditioning</td>
<td>3 – 20 kW</td>
</tr>
<tr>
<td>Water heater (40 gallon)</td>
<td>4.5 – 5.5 kW</td>
</tr>
<tr>
<td>Clothes dryer</td>
<td>1.8 – 5 kW</td>
</tr>
<tr>
<td>Plug-in Electric Vehicle</td>
<td>1.44 – 10.0 kW</td>
</tr>
</tbody>
</table>

Unplanned “*per capita*” load growth
## Peak Demand

### Average Peak Summer Demand Per Household (KW)

<table>
<thead>
<tr>
<th>Location</th>
<th>Demand (KW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tesla (240V@80A)</td>
<td>19.2</td>
</tr>
<tr>
<td>PEV (240V@32A)</td>
<td>7.7</td>
</tr>
<tr>
<td>PEV (240V@15A)</td>
<td>3.6</td>
</tr>
<tr>
<td>PEV (120V@12A)</td>
<td>1.4</td>
</tr>
<tr>
<td>SanFrancisco, CA</td>
<td>3.0</td>
</tr>
<tr>
<td>Hartford, CT</td>
<td>4.3</td>
</tr>
<tr>
<td>Dulles, VA</td>
<td>4.6</td>
</tr>
<tr>
<td>South Bend, IN</td>
<td>6.0</td>
</tr>
<tr>
<td>Springdale, AR</td>
<td>7.7</td>
</tr>
</tbody>
</table>

**PEV Peak Demand Depends on Charging Capacity (Voltage/Amperage)**

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Planning for PEV Peak Demand

• Unlike transmission systems, most distribution systems do not have full electrical model to each customer.

• There is no widespread continuous load monitoring system that can detect transformer/cable overload.

• In most cases, transformer failure is the first indication of overload (example, heat spells).

Challenges in Detecting Overload in Distribution System
### Distribution Impacts

- **Thermal Overloads**
  - Xfmr aging
- **Voltage Regulation**
  - Secondary voltages
- **Losses**
- **Imbalance**
- **Power quality**
  - Harmonics

### Identify

- Load Behavior
- Asset Risk
- Impact Likelihood
- Planning Factors
PEV Adoption, Types, Charge Preference, & Customer Behavior

• Localized Adoption
  – Initial PHEV adoption is likely to be geographically contained within residential neighborhoods

• PEV Types
  – Voltage connection
  – Battery size
  – Demand level

• Charging Behavior
  – Correlate with statistical driving patterns
Distribution Impact Phase I –
Planning for Near-Term PEV Demand

• Detail electrical model of selected feeders that includes each customer

• Assessment of different PEV charging type and penetration

• Hourly analysis using 8760 hours load profile to assess impacts

• Qualitative evaluation of distribution capacity margins and asset risk

• PEV clustering impacts

Near-term Planning Horizon
Load only operation
Customer behavior driven
Market projections
Mainly residential charging

 Evaluated Impacts
Feeder demand
Thermal overloads
Steady-state voltage
Losses
Imbalance
Power quality
Hourly Loading Levels

**Feeder #1**

Summer peaking
Load Factor: 39.6%
Peak: 11.4 MW

**Feeder #2**

Winter peaking
Load Factor: 64.8%
Peak: 8.68 MW
Substation Versus Transformer Loading

Localized peaks do not always correlate with substation demand.

Controlled Charging must consider loading conditions for both substation and individual distribution transformers.
Aggregate PEV Demand

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

Hourly Demand per PEV (kW)
PEV Proliferation (Clustering)

Clustering cannot result in widespread system impacts

Cluster
\[
\frac{\#PEV}{\text{Total Customer}} > \text{avg}
\]
Circuit Characteristics and Design – 4KV Versus 13KV Systems

Clustering cannot result in widespread system impacts
Evaluating Distributed Demand Impacts

Assets close to the customer most at risk

Potential risk

Impact Unlikely

Projected Demand

Number of Customers

kVA/Customer

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Uncontrolled PEV Demand vs. Asset Capacity

Largest Initial Impact

Potential Impact at High Penetrations
Service Transformer Overload Risk

Risk = P(Impact) * E(Overloads)

Risk Factors
- High PEV penetration
- Existing loading
- Transformer size
- Customer allocation

Little to no risk for most circuits (Median = 0.4)
PEV Load Type and Charge Time Sensitivities – Transformer Capacity Evaluation

PEV charging level is a dominant driver compared to PEV charge time.
Smart Charging Helps – If Done Right

Shifts the charge load to nighttime, but spreads it out relatively evenly over 6 hours.

Only shifting the time without evening out the profile can make the situation worse.
Benefits of Smart Charging

PEV charging level is a dominant driver compared to PEV charge time.

### Total Cost Impact of PEV: Duke Service Territory

<table>
<thead>
<tr>
<th>Charging Level (kW)</th>
<th>Average Unit Cost Txf/Service</th>
<th>Subst/Ckt Exit Unit Cost</th>
<th>Total Unit Cost</th>
<th>Estimated Three Year Revenue</th>
<th>Payback (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3</td>
<td>146</td>
<td>150</td>
<td>296</td>
<td>636</td>
<td>1.38</td>
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<tr>
<td>6.6</td>
<td>334</td>
<td>303</td>
<td>637</td>
<td>636</td>
<td>2.97</td>
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<td>9.9</td>
<td>440</td>
<td>459</td>
<td>899</td>
<td>636</td>
<td>4.20</td>
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<td>13.2</td>
<td>632</td>
<td>632</td>
<td>1264</td>
<td>636</td>
<td>5.91</td>
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<tr>
<td>16.5</td>
<td>753</td>
<td>793</td>
<td>1546</td>
<td>636</td>
<td>7.22</td>
</tr>
</tbody>
</table>

### Total Cost Impact of PEV: SMUD Service Territory

**EPRI Phase I Analysis**

**Distribution Transformers**

- 240V 30A Peak (5pm)
- 240V 30A Off-Peak (10pm)
- 240V Diversified Charging
- 120V 12A Peak (5pm)
General Study Findings

Negligible Impacts

- System losses
- Primary voltage
- Power quality
- Voltage imbalance

Potential Impacts

- Service transformer overloads
- Low secondary voltages

Planning Adjustments

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

Minimal impacts at near-term penetrations

Phase II Project

System wide screening tool to identify overall asset risks
Need System Wide Evaluation

Advanced tools are required to evaluate and justify potential benefits & impacts

Assess:
- System wide impacts
- Risk sensitivities
- Cost analysis

Accounting for:
- Potential PEV penetrations
- Changing customer behavior
- Entire system asset
- Planning practices
- TOU rate and market influences