PHEVs as Dynamically Configurable Dispersed Energy Storage

Mladen Kezunovic, Texas A&M University
Ross Baldick, The University of Texas at Austin
Ivan Damnjanovic, Texas A&M University
Project Team

- **Project Leader**
  - Mladen Kezunovic, Texas A&M University

- **Academic Team Members**
  - Ross Baldick, The University of Texas at Austin
  - Ivan Damnjanovic, Texas A&M University

- **Graduate Students**
  - Chengzong Pang, Seok Kim, Texas A&M University
  - David Tuttle, Mansoureh Peydaayesh, The University of Texas at Austin

- **Industry Team Members**
  - Bajarang Agrawal (APS); Randy Berry (AREVA); Ralph Boroughs (TVA); Dan Brotzman (ComEd); Dan Gabel (ComEd); Jayant Kumar (AREVA); Kale M. Maede (Duke Power); Art Mander (Tri State); Min Liang (EPRI); Jianzhong Tong (PJM); Janos Toth (BCTC); Mark Westendorf (MidWest ISO)
Framework

- Independent System Operator (ISO)
- Electricity Power Network
- Smart Garage (or home)
- Grid-to-Vehicle (G2V)
- Vehicle-to-Grid (V2G)
- Communication

PEVs
Objectives

- Investigating PHEVs/BEVs large scale penetration scenarios and aggregation options;
- Evaluating existing controllable battery chargers to assess capabilities of controlled charging;
- Studying impacts of PHEV/BEVs uses as sources, particularly considering the mobility;
- Understanding of PHEV ancillary services, demand bidding options, and impact on unbundling market offerings;
- Managing development of energy exchange stations in interfaced transportation and electricity networks;
- Analyzing synergy between electricity and transportation impacts of large scale uses of PHEVs in aggregated mode;
- Assessing cumulative environmental benefits.
Contributions and Deliverables

- **Contributions**
  - Impact of PHEVs/BEVs as Dispersed Energy Storage used in Vehicle-to-Building (V2B) for maintenance, outage and demand-side management
  - Development of Smart Garage
  - Control of and Communication with Battery Chargers
  - The role of PHEVs and BEVs in electricity markets;
  - Synergy between Electricity and Transportation Networks.

- **Deliverables**
  - Report on study of different aspects of the G2V and V2G/V2B services related to the use of dynamically configurable dispersed energy storage and related impacts;
  - Software for the analytical study of these impacts.
Team 1: PHEVs/BEVs used in V2B

Power Plant → Transmission & Distribution → Load

Renewable Energy Sources → PHEVs/BEVs
## Research Contributions

<table>
<thead>
<tr>
<th></th>
<th>Grid-to-Vehicle (G2V)</th>
<th>Vehicle-to-Grid (V2G) / Vehicle-to-Building (V2B)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Outage Management</strong></td>
<td>Charging EVs for energy storage</td>
<td>Using the battery energy storage in EVs as an emergency back-up power</td>
</tr>
<tr>
<td><strong>Demand-side Management</strong></td>
<td>Load profile of charging EVs on various modes, time-of-charge, driver’s charging inclination, etc.</td>
<td>Load shifting; Peak clipping; Demand response, etc.</td>
</tr>
<tr>
<td><strong>Asset Management</strong></td>
<td>Impacts of charging EVs on power system equipments (power transformers, etc.)</td>
<td>Impacts of discharging EVs on power system equipments (power transformers, etc.)</td>
</tr>
</tbody>
</table>
Vehicle-to-Building (V2B)

- PHEVs/BEVs may be used to feed power back to home or office building, which is known as “Vehicle-to-Building” (V2B) operation.
- 5-10 year time horizon of V2G vs. 3-5 year time horizon of V2B
Case Study: Demand-side Management

- Peak load shifting with BEVs/PHEVs for a typical summer daily load
- The studied building is 450,000 sq ft;
- There are up to eighty PHEVs/BEVs;
- Maximum capacity of each vehicle battery is 15 kWh;
- The batteries in BEVs/PHEVs are drained on average by 4.0 kWh one way during the driving cycle used;
- The charging levels assumed is AC Level 2: 208-240 VAC.
Case Study: Outage Management

- Diagram of test feeder with smart garages;
- Three nodes are specified as smart garages (nodes 718, 735 and 740);
- Maximum capacity of each vehicle is 15 kWh (10 kWh is available to use for OM);
- Discharge vehicles with state of charge \(\text{soc} > 70\%\);
- BEV/PHEV tariff for charging is 5c/kWh and for discharging is (15-40) c/kWh (depending on different garages). Discharging tariff for node 718 is 40 c/kWh, for node 735 is 30 c/kWh, for node 740 is 25 c/kWh.
## Case Study: Outage Management

### Results for BEV/PHEV battery Generation Scheduling

<table>
<thead>
<tr>
<th>Date &amp; Time</th>
<th>Node 718 (kW)</th>
<th>Node 735 (kW)</th>
<th>Node 740 (kW)</th>
<th>Cost of scheduling ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thursday of 40th week at 11 a.m.</td>
<td>0</td>
<td>320</td>
<td>165</td>
<td>450.6</td>
</tr>
<tr>
<td>Thursday of 20th week at 11 a.m.</td>
<td>0</td>
<td>320</td>
<td>269</td>
<td>572.2</td>
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</tbody>
</table>
Team 2: Smart Garage Development

Problem

Strategic Decision – Network location

Tactical Decision – Parking pricing
Garage Daily Demand Profile
Smart Garage Model Formulation

- Bi-level Optimization Model
  
  **Max.** Total Revenue
  
  s.t. Range of decision variables
  
  Demand of smart garage
  
  **Min.** Travel Cost
  
  s.t. flows on all paths = O-D trip rate
  
  sum of path flows on link $a$ = flow on link $a$
  
  path flows $\geq 0$

  Upper level problem
  
  Lower level problem
Case Study I – Data

- Case Study I: Revenue Source (Parking Fee and V2G Services)
- Consideration - Transportation Network Only and V2G service

4 nodes
Node 2&3: conventional parking garages
Node 4: Smart garage

12 links
Driving Links (solid line)
Walking Links (dotted line)

<table>
<thead>
<tr>
<th>Link</th>
<th>Length $l$ (km)</th>
<th>Capacity $c$ (veh/h)</th>
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<th>Capacity $c$ (veh/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16</td>
<td>600</td>
<td>7</td>
<td>3 – $l^*$</td>
<td>300</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>600</td>
<td>8</td>
<td>3 – $l^*$</td>
<td>300</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>600</td>
<td>9</td>
<td>$l^*$</td>
<td>Inf.</td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>600</td>
<td>10</td>
<td>$l^*$</td>
<td>Inf.</td>
</tr>
<tr>
<td>5</td>
<td>$l^*$</td>
<td>300</td>
<td>11</td>
<td>3 – $l^*$</td>
<td>Inf.</td>
</tr>
<tr>
<td>6</td>
<td>$l^*$</td>
<td>300</td>
<td>12</td>
<td>3 – $l^*$</td>
<td>Inf.</td>
</tr>
</tbody>
</table>
Case Study I – Results
Extended Analysis to include both G2V and V2G, and Electric Power and Transportation Systems
Case Study II – Data

Impact of V2G and G2V Technologies: Numerical Example

- For transportation network, smart parking garage is constructed on node 4 where “L” is distance from node 2.
- For power network, each bus has unique power source and load. Bus 2 and bus 3 have their own operating area and the operating area is divided by the limit of operating area where is distance “L” from bus 2.
Case Study II – Results (Impact of V2G)

Bus 1

Load

Generation

LMP
Case Study II – Results (Impact of G2V)
Team 3: PHEVs/BEVs in Electricity Markets

- The role of PHEVs and BEVs in electricity markets,
- PHEVs and BEVs for Ancillary Services and other grid services,
- Control of and Communication with Battery Chargers.
The role of PHEVs and BEVs in Electricity Markets

- Potential grid services from PEVs:
  - Regulation,
  - Reserves,
  - Emergency load curtailment,
  - Balancing energy.
Control of and Communication with Battery Chargers

- With charge rates around 10 kW, large numbers of PHEVs and BEVs need to be “aggregated” for meaningful amounts of AS, even in garages.

- Assume “aggregator” that:
  - communicates with ISO (using ICCP or similar):
    - Similar to standard issues for generator-to-ISO communication,
  - controls/communicates with PHEVs and BEVs:
    - Challenges due to large numbers of PHEVs & BEVs.
Control of and Communication with Battery Chargers

Grid Operator

Aggregator

Control Signals to modify charge rate

EVSE

J1772 Interface PowerFlow

J1772 Interface Control Pilot Signal
Control of and Communication with Battery Chargers

- Challenge: communication to EVSE or PHEV/BEV likely to be heterogeneous:
  - Cell-phone,
  - Powerline carrier,
  - Radio (FM, zigbee, etc)
  - Internet:
    - Cell-phone connection from car to internet,
    - Wifi connection from car to home area network.

- Solutions must cope with heterogeneity.
Control of and Communication with Battery Chargers

- Experiment at University of Texas:
  - Polled thousands of computers on campus every second for 20 minutes,
  - Greatest round-trip delay less than 0.25 second,
  - Suggests internet is workable for communications,
  - Facilitate communication to large numbers of PHEVs and HEVs.
The role of PHEVs and BEVs in Electricity Markets

- Challenges:
  - Aggregator coordination of large numbers of PHEVs to meet ISO standards for minimum power block of AS,
  - Representing PHEVs in network models,
  - Satisfying ISO performance requirements:
    - Telemetry measurement requirements (e.g., 2-10 seconds required telemetry reporting intervals for providing regulation)
    - Requirements for “immediate” start of response to AS requests from ISO, but J1772 charging standard allowing for 15 second delay.
The role of PHEVs and BEVs in Electricity Markets

- Tradeoff between value of providing grid services and the communication/control complexity and cost of providing them:
  - Higher value AS such as regulation have more stringent control and telemetering requirements,
  - Lower value AS such as reserves have more modest requirements.
The role of PHEVs and BEVs in Electricity Markets

- Challenge: widely varying AS prices.
- ERCOT (from Potomac 2009 report)
The role of PHEVs and BEVs in Electricity Markets

- PJM (from Monitoring Analytics 2010 report)
Conclusions

- The aggregated batteries in PHEVs/BEVs could be used as dispersed energy storage with the large scale penetration;
- It is feasible to use PHEVs/BEVs to provide load leveling, regulation, and other services assuming full mobility of the storage;
- The aggregated battery energy can participate in the electricity markets with controlled charging/discharging and communications;
- Smart garage is a good solution as energy exchange station to implement the synergy between electricity and transportation networks.
Thank You

Questions?