Locating and Scheduling PHEV in V2G

Smart Grid FY2010 Review

Russell Bent, Alan Berscheid, David Izraelevitz, Feng Pan
LANL Smart Grid Team
Renewable, PHEV, V2G

Renewable:
- Clean
- Variability in generation

Plug-in Hybrid Electric Vehicle:
- Clean
- Increased demand for power
Renewable, PHEV, V2G

- PHEVs are storage devices
- Vehicle-to-grid (V2G): valley filling and peak shaving

Understand the claimed benefits through model and simulation
Outline

- PHEV – Past, Present, Future
- PHEV – Supporting Infrastructures
- Locating PHEV Exchange Stations in V2G
  - Two-stage Stochastic Program
  - Case Studies
- Scheduling PHEV Charge in V2G
- Conclusion
PHEV History

- 1665-1825
  - Flemish Jesuit Prist, Chinese Emperor, Frenchman, British Steam "car"

- 1839
  - Robert Anderson: first electric vehicle

- 1886
  - 28 cell battery taxicab in England

- 1900
  - 1,575 electric, 936 gasoline cars

- 1913
  - 6,000 electric, 182,809 gasoline cars

- 1966
  - US congress: EV

- 1977-1997
  - GM: $20M R&D

- 1993
  - Toyota: G21

- 1997
  - Toyota Prius

- 2004
  - 36K-47K Prius in US Market

http://www.hybridcars.com/history/history-of-hybrid-vehicles.html
PHEV Present

- **PHEV**
  - 8% increase per year
  - Sales up 3% 2010
  - 5/10: 28,202; 6/10: 21,679
  - 40 miles of charge depleting range
  - **Need additional supporting infrastructures**
PHEV Supporting Infrastructures

- Less cost and structures
- Ownership of batteries
- Higher cost
- Sizable battery bank (**important in V2G**) **important in V2G**
- Controllable **important in V2G**
Locating PHEV Exchange Stations in V2G

Locate exchange stations to

- Serve PHEV demands
- Support power grid as power storages
- Connect to power grid without expansion

Similar research:

- Facility location: locate facility to minimize the cost of serving all demands
- Generation expansion: optimally site new generation on a power grid
Two-stage Stochastic Program

First stage:

- Decide on the locations and capacities exchanges stations.
- Prior to know the exact battery demand, load, generation capacity (scenario).

A scenario: random variables battery demand, load, renewable generation capacity are realized.

Second stage (recourse action for each scenario):

- Distribute batteries for PHEV demand
- Discharge batteries for loads
First Stage

- Second stage objective value
- Evaluate $x, w$ at scenario $\omega$

\[
\begin{align*}
&\min_{x, w} \sum_{i \in I} (f_i x_i + r_i w_i) + E_{\Omega}[h(x, w, \xi)] \\
&\quad l_i x_i \leq w_i \leq u_i x_i, \quad \forall i \in I.
\end{align*}
\]

- $f_i$: fixed cost to open an exchange station at $i$
- $r_i$: storage cost per battery at station $i$
- $x_i$: 0-1 variable situating an exchange station at $i$
- $w_i$: number of batteries stored at station $i$
Second Stage

At station $i$, batteries can be allocated for battery demand $t_i^\omega$ and for grid $s_i^\omega$

$$s_i^\omega + t_i^\omega \leq w_i, \ i \in I.$$  

Serving battery demand is modeled as a *Transportation Problem*

- Traffics are modeled as routes
- Cost of exchanging battery at station $i$ from route $j$ is $c_{ij}$

*Linearized DC power flow* is used for grid

- Each exchange stations are linked to a bus and serves as power source

Objective function:

$$h(x, w, \xi) = \min \sum_{i \in I, j \in J} c_{ij} y_{ij}^\omega + \sum_{j \in J} h_j q_j^\omega + \sum_{u \in N} o_u \beta_u^\omega + \sum_{u \in N} g_u \delta_u^\omega.$$
Simulation Setting

- Renewable generation
  - Renewable level 0 – 1: for example, at level 0.3, a generator is renewable with probability 0.3
  - Renewable capacity can be 0, 0.5, or 1 of its maximum capacity with equal probability
- Load at a bus is a uniform random variable between 0.5 and 1 of the maximum bus load
- Battery demand
  - Vehicle-to-population: 0.78, PHEV-to-vehicle: 0.1, battery demand: 10%
  - The total demand is equally distributed to each route as the average demand
  - Battery demand at each route is a uniform random variable between 0.5 and 1.5 of the average demand
- 100 scenarios
Case Study I: A Synthetic city

Power grid (IEEE-RTS-79)
- Generation capacity is 2999 MW, load is 2880 MW

Transportation
- 8 by 11 grid, 10 traffic routes, 28 exchange station locations
- Population is 344850
Case I: Grid Only

- GE-1 is the base case
- In GE-2 to GE-5, increase penalty cost for load shedding to stimulate opening exchange stations
- Below renewable level 0.3, no much load shedding
- With stations, below renewable level 0.8, less than 10% load shedding
- Maximally 25 of 28 stations without expanding the grid
- Some relief from exchange stations
Case 1: V2G

- Without the grid, opening 6 stations will satisfy all battery demand.
- In V2G-1, 6 stations are fixed. In V2G-2 to V2G-5, open 6, 8, 10, 12 stations.
- Reduction in load shedding is limited.
- Large increase in unmet battery demand.
- 25 stations are needed to reduce load shedding.
- The positions of stations in V2G1 limit the discharging capacity.
Case I

- V2G reduces the load shedding caused by renewable variability at low renewable level.
- At higher level of renewable, trade-offs between load shedding and unmet battery demand is high. The benefit of V2G is not obvious.
- The synthetic city has relatively low population.
Case II: Greater Miami Area

Power grid

- Generation capacity is 8200 MW, load is 6400 MW

Transportation

- 100 traffic routes, 316 exchange station locations
- Population is 5414712
Case II: Grid Only

- There is 2% load shedding without renewable.
- In GE-3 to GE-5, load shedding is less 5%
- In GE-2, opening 2 – 4 stations reduces load shedding at low renewable level
- Maximally 180 stations without expanding the grid
Case II: V2G

- Without the grid, opening 106 stations will satisfy all battery demand.

- In V2G-1, 106 stations are fixed. In V2G-2 to V2G-5, open 0%, 10%, 20%, 50% more stations.

- In V2G-1, reduce load shedding but increase unmet battery demand.

- In V2G-2, by relocating 106 stations, reduce load shedding and almost serve all demand at low renewable levels.

- In V2G-3, V2G has obvious benefit even at renewable level 0.5.
Case Study: Conclusion

- Proposed a two-stage stochastic program for locating exchange stations
- Locations of exchange stations are important.
- The benefit of V2G is more obvious at renewable level $\leq 0.5$.
- The benefit of V2G is more obvious with higher population-to-load ratio.
Scheduling in V2G

- Scheduling of charging batteries
  - Uncertainty in demand
  - Centralized charging v.s. decentralized charging (pricing)
- Scheduling of charging and discharging batteries
  - Storing power for later use
Scheduling Battery Charging in V2G

Typical Day

- Battery charging request
  - [starting time, end time], unit
- Power grid
  - Available generation capacity, cost

[2,6],20  [2,20],300  [10,11],5
A Scheduling Model

Assumption:

- No penalty on preemption
- Uniform charge rate

Parameter (random):

- Demand: size ($d_i$), starting time ($a_i$) and end time ($b_i$)
- Supply: generation capacity ($g_i$), cost ($c_i$)

Variable:

- $X_{it}$: 1 if charging demand $i$ at time $t$

Multi-stage optimization problem – Online Optimization
Deterministic Version

Transportation Problem

\[
\begin{align*}
\text{min} & \quad \sum_{t} c_t \sum_{i} x_{it} + L \sum_{i} x_{i(T+1)} \\
\text{s.t.} & \quad \sum_{t} m_{it} x_{it} + x_{i(T+1)} \geq d_i \\
& \quad \sum_{i} x_{it} \leq g_t
\end{align*}
\]

Bipartite graph links demands and time step

\[
m_{it} = 1 \text{ if } a_i \leq t \leq b_i
\]

Polynomial time algorithms
Future Work

- Scheduling problem:
  - Online optimization – make here-and-now decision to hedge future uncertainty
  - Control decentralized decision through pricing

- Location problem:
  - Algorithms to solve large instances