Enabling V2G: Technology Overview and Policy Implications

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Advancing Vehicle-to-grid technologies
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The V2G idea and motivation

- Use batteries and chargers in EVs for grid storage, balance fluctuating wind and solar, possibly participate in electric markets...
- Create a second use when the car is parked (average 23 h/day)
- Brings a payment to the EV owner, thus lowering TCO
- Makes very low-cost storage available to the grid, enabling renewable energy to provide >> 50% of electricity
Key Aspects of the V2G concept

- EVs already have both the battery and conversion equipment (charger and motor drive)
- Most light vehicles are parked 95% of the time, typically near a plug
- To provide grid services, existing components may need minor adjustments, e.g.
  - change charger to bidirectional charge & discharge
  - add controls and signaling to respond to grid
- Aggregation means meet trip needs of any individual, and also meet aggregate need for balancing or reserves by TSO
- Light vehicles become part of the solution for CO₂, rather than the biggest problem
How V2G works — User’s view
1 Plug in your car to any charger
2 Charge Battery safely and efficiently in V2G Mode
3 MAKE MONEY by providing power capacity and sending energy back and forth to regulate the Grid

OR SAVE COSTS by using stored energy from EV batteries to reduce building energy peak consumption
You're ready to drive with the charge you set for the day with advance trip planning using a mobile fleet management app.
We will need storage for high-penetration renewables, to meet CO2 goals, but…

Storage is expensive

So, how to bring up enough storage at least cost?
Purpose-built Storage is expensive

Lazard: Capital cost $1K - $5K / kW

Lazard LCOS v4.0, 2018
Capital Cost of EV storage

- Assuming AC charging, power conversion on-board EV ...

- Demo: Replace on-board charger with 15 kW bidirectional ~$3000 qty 300

- OEM build: Design change of 10 kW on-board charger for bidirectional flow, per-vehicle ~$300

- Add communications and logic to on-board charger and charging station (EVSE). Demo qty: ~$400 incremental cost. OEM: ~$150 per EVSE

  - Demo projects: Capital cost $3400 for 15 kW charger or $227/kW

  - OEM production: Capital cost $450/10 kW = $45/kW

- Service and customer support adds $150/year or $10/kW/year
EV storage is not expensive

EV storage
Demo $227/kW
EV storage is not expensive

EV storage Demo $227/kW OEM production $45/kW
Example revenue

- US PJM regulation (System operator service, like balancing): $US 1,200 per EV per year, if consistently plugged in 23h/day at 19 kW.

- Denmark, Primary reserves market, earning €1,600/EV/year, only selling during off-work hours at 10 kW.

- US, typical standard peak/off peak rate arbitrage, $50-$200/year.

- Thus, need to understand market to understand business model—varies from $50 to $1800/EV/year.
The economics are Improving

• On-board (AC) charger, lower cost
• AC charging 1/3 to 1/2 cost of DC charging
• Bidirectional (V2G) is 13x revenue of controlled charging, but more complex.
• Higher power per car means higher revenue (higher power means kW in/out, may not need higher kWh battery)
• Consistency of driver plug-in when parked, higher revenue
Commercial Operation
Today
DENMARK V2G installations
AFA JCDECAUX fleet in Copenhagen
UK’s first V2G installation in Nissan Technical Center in Cranfield + Newcastle University
US projects underway in California and PJM

V2G School Busses in California

Stationary storage in PJM
BMW MiniE with VSL inside
AC, three-phase charging + V2G

Tested to charging standards at National Renewable Energy Lab, Golden, CO
Participating OEMs

- BMW (demonstrations)
- Honda (Development of commercial EV with V2G built-in)
- Nissan Europe (commercial Leafs & eNV200s warrantied for V2G via DC)
- The Lion Electric (commercial sales of V2G busses)
- Renault (mass produced V2G capable vehicle)

- Some have done detailed studies of effect on warrantee & battery life & decided that is not a problem
Policy Approach
Regulatory steps needed for a state

- Regulatory changes to allow EVs to provide grid services, including backfeeding (V2G)
  - Interconnection: Safely connect a mobile battery and inverter to the electric grid (governed by law & standards).
  - Credit for export: Fair payment for discharging.
  - Allow offering EDC and RTO services
Support for demonstration program(s)

- Why? Initial program costs more than self-supporting, so some incentive or subsidized demonstration needed

- Needed to test small scale and decide if, and how to, deploy large scale

- Could be done by utility, fleet user, or a state agency

- Some form of support by state helpful (either approved utility rate base, or state subsidy for incremental cost).
END

More information:
https://crew.udel.edu/v2g/
twitter @Willett Kempton
First demonstration, Oct 2007
Running EV from TSO Control Signal
UD, Delmarva Power, PJM, Pepco Holdings
Many Contributed
To these technologies, policies demos, and research results…
Components of a V2G system
Three Components of GIV

- **Aggregation Server** (in central location)
  - Real time operation of a set of vehicles
  - Provide services to an electric grid entity
- **EV with Vehicle Smart Link** (VSL, in car)
  - Control charging, report to server
- **Electric Vehicle Supply Equipment** (EVSE)
  - Grid location, internet portal, power connection, meter, interconnect permit
Nuvve Aggregates EVs and sells grid services

VSL

1. Nuvve aggregation server calculates power available from all vehicles
2. Offers power bids in TSO market
3. Dispatch vehicles as power adjustments are needed

EVSE

One or 2-way power flow

IP communication with Nuvve server

Energy services delivered at connection point to the grid

Aggregation Server

Offers power bids, and reconciles statements to, grid operator

2-way communication