V2G BECOMES REALITY

The tale of the 1st V2G fleet

- Plug-in cars & electric utilities
- Charging and discharging cars
- V2G challenges and solutions
- State of the V2G industry
- Our V2G project
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Plug-in cars

- Battery Electric Vehicles (BEVs)
  - Hard to come by
    - Low production
    - Do-it-yourself conversions

- Plug-in Hybrids (PHEVs)
  - Available as conversions of HEVs
    - Do-it-yourself, Lead-Acid
    - Conversion companies - Lilon
# Plug-in cars & electric utilities

<table>
<thead>
<tr>
<th>Plug-in cars</th>
<th>Utilities:</th>
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<tbody>
<tr>
<td>- Need power to charge</td>
<td>- Can't handle peak demand</td>
</tr>
<tr>
<td>- Have batteries</td>
<td>- Could use peak shaving</td>
</tr>
</tbody>
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Plug-in cars and utilities are natural partners
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Charging / discharging

- Manual Charging
- Smart Charge*
- Vehicle-To-Grid (V2G)*
- Vehicle-To-Home (V2H)

*”Charge Control”
Plain Charging

- Convenience charging
- Overnight charging
- Timed charging: start at 10 PM
## V2G Becomes Reality

### Time of Charge Effects

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Production Cost</th>
<th>Capacity Cost</th>
<th>Avoided Gasoline</th>
<th>Emissions</th>
<th>Distribution Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge at Home Anytime</td>
<td>Good</td>
<td>Worse*</td>
<td>Good</td>
<td>Better</td>
<td>Worse*</td>
</tr>
<tr>
<td>Delay to 10pm</td>
<td>Better</td>
<td>Best</td>
<td>Good</td>
<td>Good</td>
<td>Best</td>
</tr>
<tr>
<td>Optimized to Off-peak</td>
<td>Best</td>
<td>Best</td>
<td>Good</td>
<td>Worse</td>
<td>Best</td>
</tr>
<tr>
<td>Opportunity Charging</td>
<td>Worse</td>
<td>Worse*</td>
<td>Best</td>
<td>Best</td>
<td>Worse*</td>
</tr>
</tbody>
</table>

Courtesy of Xcel Energy
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Smart Charge

- Charging disabled during peak demand
  - Utility does so remotely
  - Added benefit: logging & monitoring
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Vehicle To Grid (V2G)

- Charging disabled during peak demand, or
- Discharging requested, for peak shaving
  - Utility does so remotely
  - Added benefit: logging & monitoring
  - Anti-islanding required
    - Protect power lines workers when grid goes down
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Vehicle-To-Home (V2H)

- Back-up power
  - Activated by owner
  - No anti-islanding
    - Owner is responsible for disconnecting from grid
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V2G - challenges & solutions

- Communications for remote control
- Anti-islanding
- Battery voltage
- Battery chemistry
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Telemetry & remote control

- Link between car and utility

- Internet
  - Wireless WAN
    - Cellular network
    - Pager network
  - Wireless LAN
    - WiFi
    - Bluetooth
  - Wired LAN
    - Carrier communication through power cord

- Direct
  - Automated Meter Reader (AMR) network
  - Radio link
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Anti-islanding

- If grid goes down, power from car could harm linemen
  - Must detect loss of grid voltage
    - Voltage and/or frequency outside specs
    - Difficulties:
      - House power load < V2G power
      - House power load = 60 Hz resonant

- Must stop generating power
- Line stable for 5 min before restoring generation
Battery voltage

- **UPS:**
  - Battery voltage: 12, 24, 48 Vdc
  - Conversion: boost up

- **Solar panels**
  - Array voltage > peak line voltage
  - Conversion: buck down

- **PHEVs: battery voltage is a given**
  - Ford Escape: 290 to 380 Vdc
  - Toyota Prius: 180 to 250 Vdc
Line voltage

- 120 Vac, 1 phase, Line + Neut (general)
- 208 Vac, 3 phase, 2 lines only (industrial)
- 220 Vac, 1 phase, 2 wire (Europe)
- 240 Vac, 1 phase, 3 wire (house drier outlet)
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PFC topology

- Power Factor Correction (PFC)
- Maximum power out of outlet
- Ideal for charging
- Vbatt > Vline-pk
- Line voltage:
  - 120 Vac -> 170 Vpk
  - 208 Vac -> 295 Vpk
  - 240 Vac -> 340 Vpk

- Can't use standard PFC topology with these PHEVs
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Bridge topology

- Ideal for Inverters
- At max Vline (240 Vac): 340 Vpk
- \( V_{batt} > V_{line-pk} \)
- **Can't use** standard Bridge topology with these PHEVs
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Bridge + Unfolder topology

- Ideal for Inverters
- At max Vline (240 Vac): 340 Vpk
- Vbatt > Vline-pk
- Can't use standard Bridge and Unfolder topology with these PHEVs
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Transformer Topology

- Boost up to Vline-pk, then
- DC-DC down to Vbatt

- Works, but it's complex
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Transformer-less Topologies

- Inverting topology (Buck-boost)
- Cascaded Buck-Boost
- Cascaded Boost-Buck

They work, and are simpler
Battery chemistry

- **Laptops: Cobalt Lilon**
  - Laptop fires -> safety concerns on Lilon
  - Short calendar life, number of cycles
- **PHEVs: Iron Phosphate Lilon (nano-phosphate)**
  - Inherently safer – won't burst in flames
  - Long calendar life (operate at lower voltage)
  - Many cycles at 100 DOD
  - Less energy density than Cobalt
  - Higher power density (lower waste heat)
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State of V2G

- V2G studies
  - Governments, educational institutes, utilities
  - Simulations, no real tests
- AC Propulsion
  - Coined term “V2G”
  - 1st with proof of concept of power electronics
  - 1st with proof of concept of remote control
  - Preparing the eBox with V2G
    - 35 kWh storage, 20 kW charger
- Car manufacturers seem to shun V2G
Our V2G Project

- First V2G fleet: 6 Ford Escape PHEVs
  - 3 vehicles in Xcel Energy's fleet
  - 3 vehicles to Xcel Energy employees
- Smart Charge, V2G, real time logging
- Study of performance and effects
Our V2G team

- **Team:**
  - Xcel Energy
    - Instigator
    - First order for 6 vehicles
  - V2Green
    - On board controller (VCM)
      - GPS, Cell modem, power meter
    - Web based interface
  - Hybrids Plus
    - PHEV conversion: Ford Escape
    - Power electronics: Inverger™
  - NREL
    - V2G compliance testing
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System block diagram
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PHEV block diagram
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PHEV conversion

- Replace stock battery with 12 kWh Lilon packs
- Add Charger
- Add AC plug
V2G conversion

- Add Inverter / Charger: Inverger™
- Add V2G controller, cell modem
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Inverger™ specs

- Bidirectional
- Meets IEEE1547 specs for DR
  - Anti-islanding
  - Clean waveform
- Medium power
  - 6 kW in or out, max
- Multi-voltage
  - 120, or 208 to 240 Vac, single phase
- High efficiency (tbd)
  - More expensive, larger
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Inverger™ block diagram

- **Bidirectional**
  - Shared electronics in either direction
- **Transformerless**
  - Unfolder, Buck and Boost converter
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Inverger™ as an 8 Ω resistor

- Resistor:
  - Unity power factor: current prop. to voltage
  - 8 Ω resistor current:
    - 120 Vac: 15 A (max for standard outlet)
    - 208 Vac: 27 A
    - 240 Vac: 30 A (6 KW)
- Charging: Inverger = 8 Ω resistor
- Discharging: Inverger = -8 Ω resistor
  - Unity power factor
  - Minimal distortion in current waveform
Thank you

- PHEV, and V2G, are on the verge of being significant technologies for energy management and environmental solution

- We're excited to be part of it, today

Hybrids-Plus.com

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