

# 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



# 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 - LiIon




# Plug-in cars & electric utilities

Plug-in cars

- Need power to charge
- Have batteries

Utilities:

- Can't handle peak demand
- Could use peak shaving

Plug-in cars and utilities are natural partners



# 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



# Time of charge effects

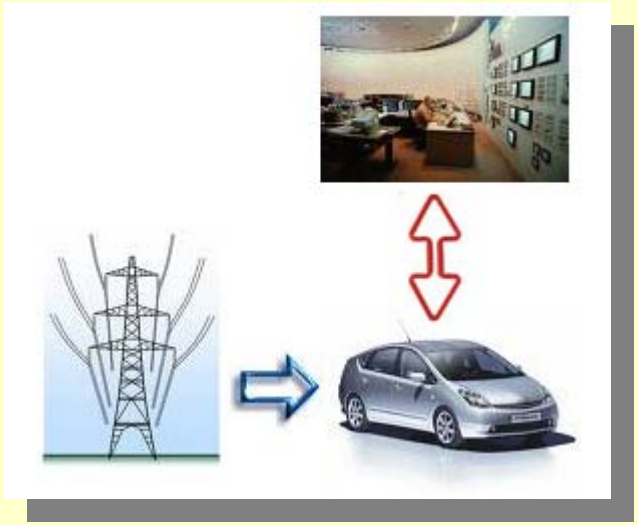
| *Scenarios* | *Production Cost* | *Capacity Cost* | *Avoided Gasoline* | *Emissions* | *Distribution Impacts* |
|---|---|---|---|---|---|
| **Charge at Home Anytime** | **Good** | **Worse*** | **Good** | **Better** | **Worse*** |
| **Delay to 10pm** | **Better** | **Best** | **Good** | **Good** | **Best** |
| **Optimized to Off-peak** | **Best** | **Best** | **Good** | **Worse** | **Best** |
| **Opportunity Charging** | **Worse** | **Worse*** | **Best** | **Best** | **Worse*** |

Courtesy of Xcel Energy



# Smart Charge

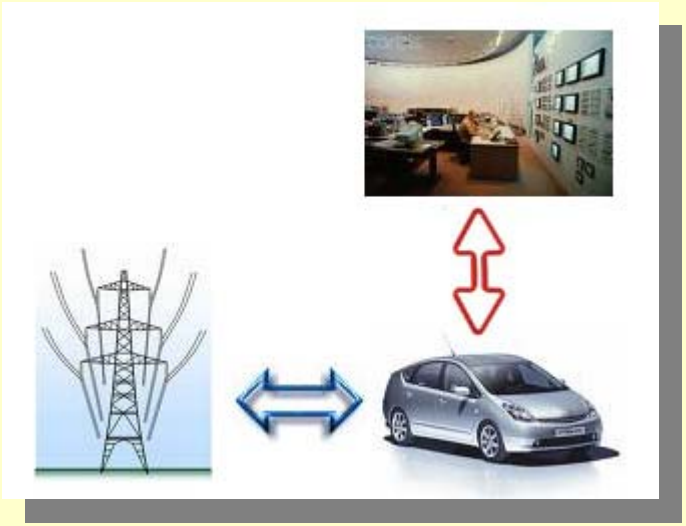
- Charging disabled during peak demand
  - Utility does so remotely
  - Added benefit: logging & monitoring





# 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





# Vehicle-To-Home (V2H)

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



# V2G - challenges & solutions

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



# 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

# 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



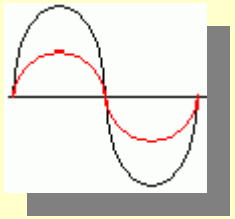
# Line voltage

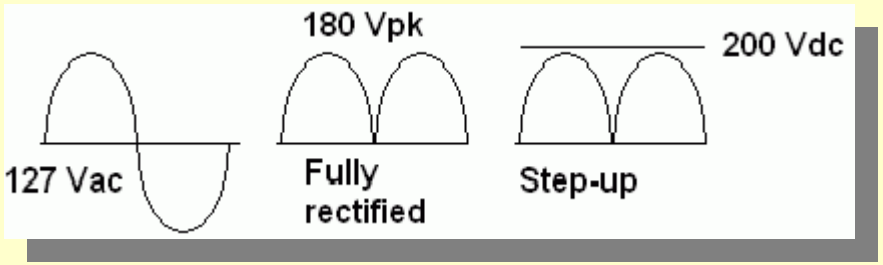
- Line voltage:
  - 120 Vac, 1 phase, Line + Neut (general)
  - 208 Vac, 3 phase, 2 lines only (industrial)
  - 220 Vac, 1 phase, 2 wire (Europe)
  - 240 Vac, 1 phase, 3 wire (house drier outlet)



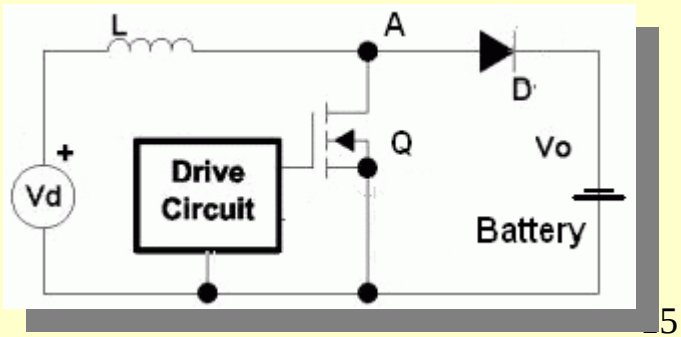
# PFC topology

- 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





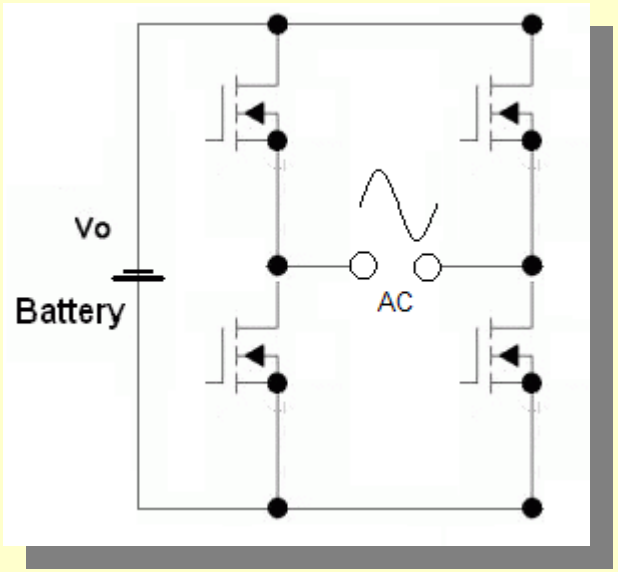

- Can't use standard PFC topology with these PHEVs





# Bridge topology

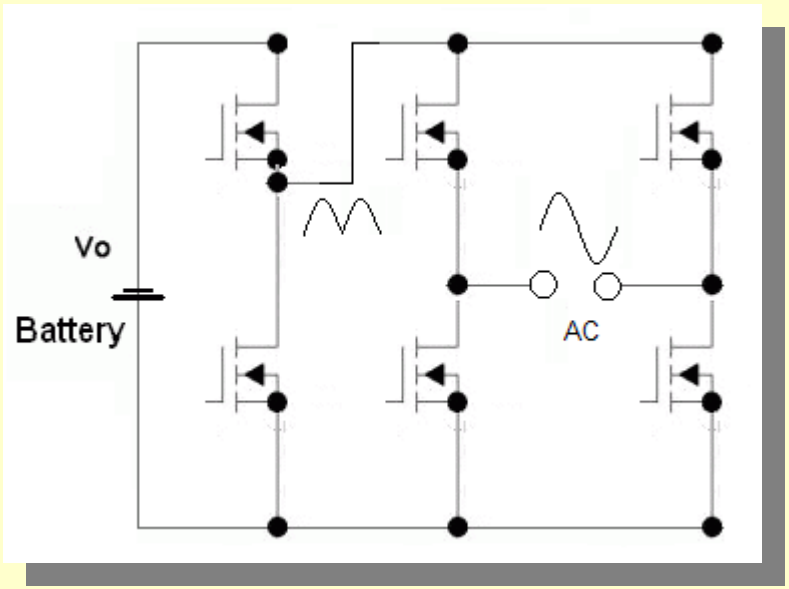
- Ideal for Inverters
- At max Vline (240 Vac): 340 Vpk
- Vbatt > Vline-pk
- Can't use standard Bridge topology with these PHEVs





# Bridge + Unfolder topology

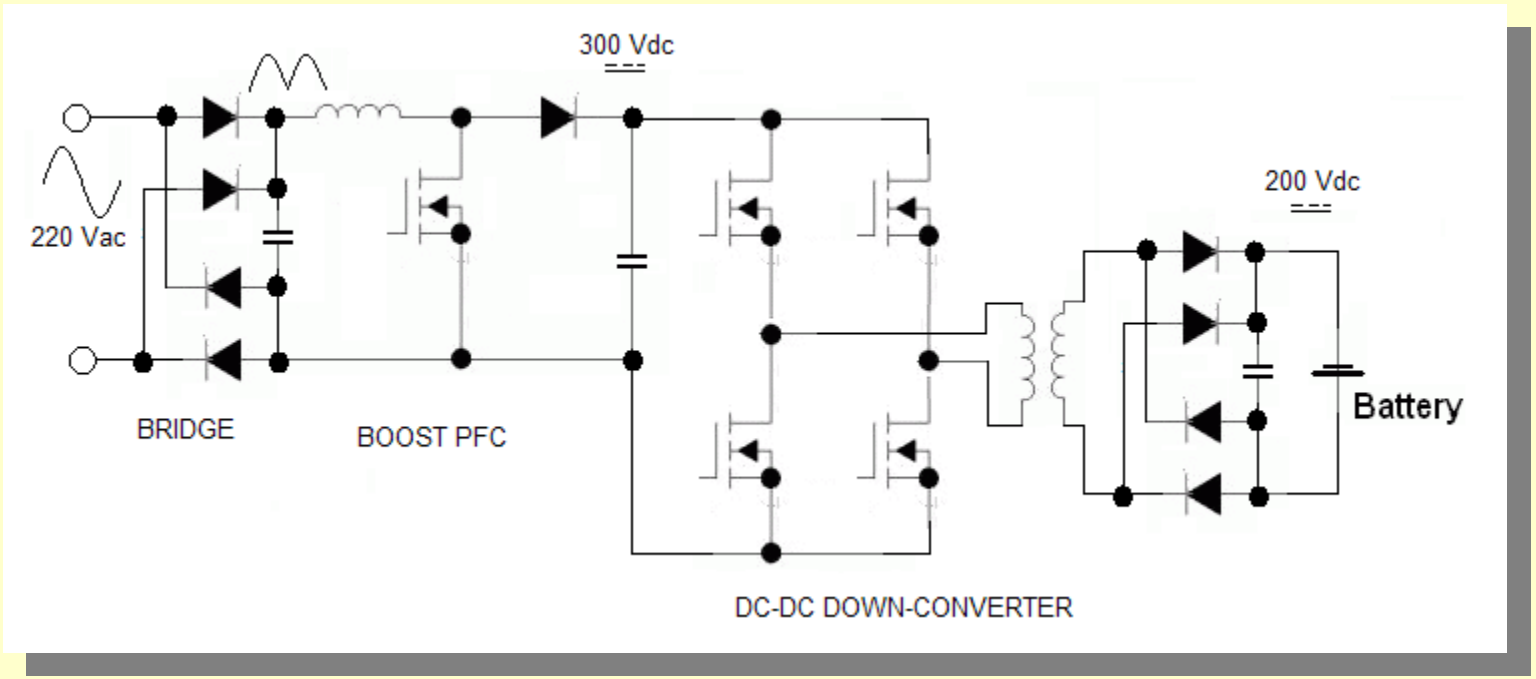
- Ideal for Inverters
- At max Vline (240 Vac): 340 Vpk
- Vbatt > Vline-pk
- Can't use standard Bridge and Unfolder topology with these PHEVs





# Transformer Topology

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

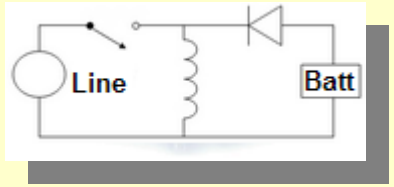



- Works, but it's complex

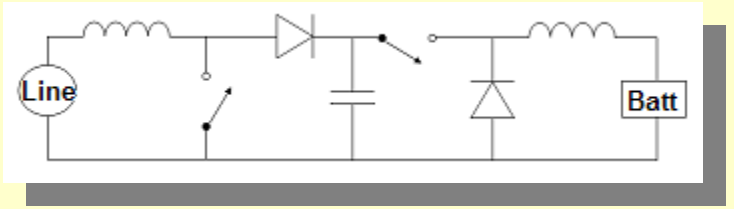


# Transformer-less Topologies

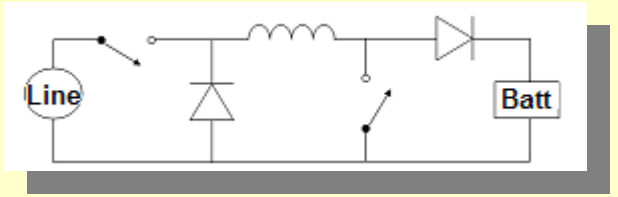
- Inverting topology (Buck-boost)




- Cascaded Buck-Boost




- Cascaded Boost-Buck




They work, and are simpler



HybridsPlus

# Battery chemistry

- Laptops: Cobalt LiIon
  - Laptop fires -> safety concerns on LiIon
  - Short calendar life, number of cycles
- PHEVs: Iron Phosphate LiIon (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)



# 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



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# Our V2G Project

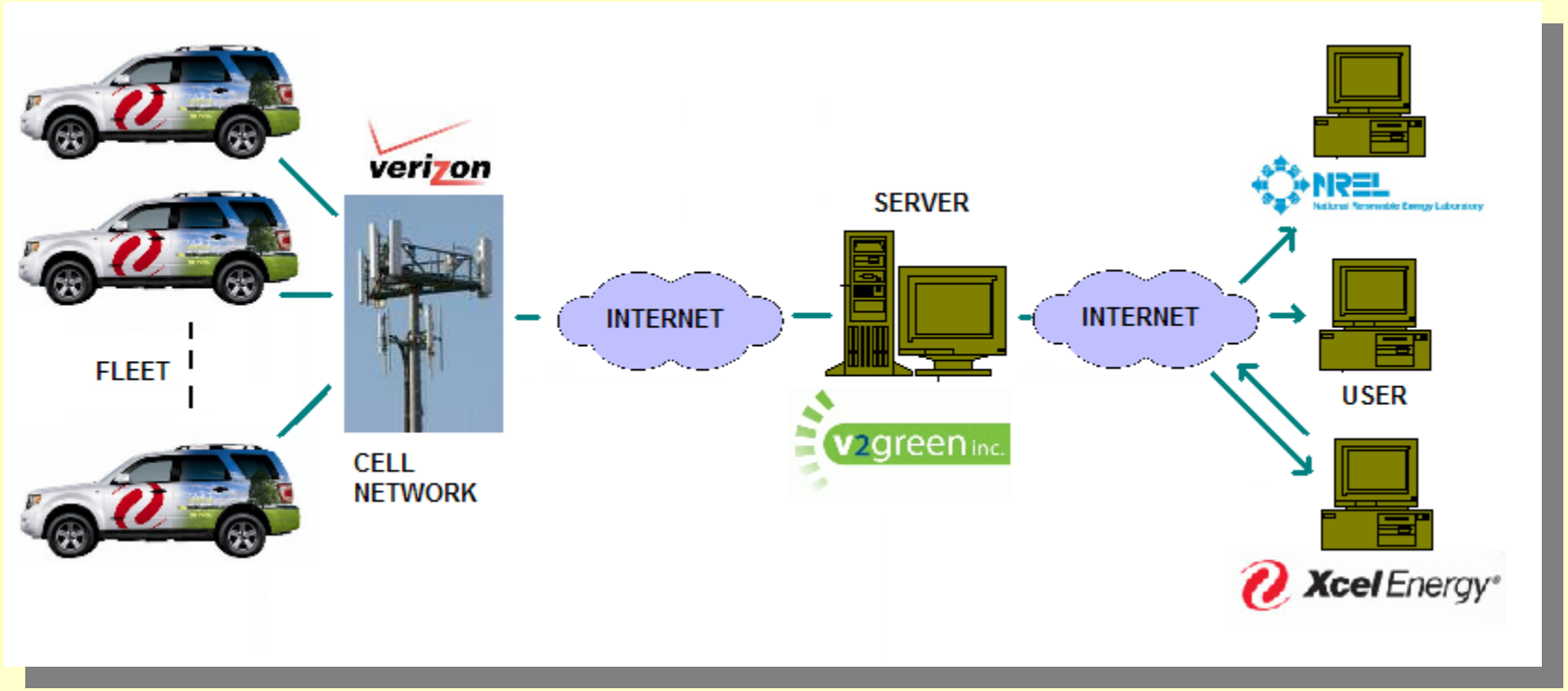
- First V2G fleet: 6 Ford Escape PHEVs
  - 3 vehicles in Xcel Energy's fleet
  - 3 vehicles to Xcel Energy employees
- Smart Charge, V2G, real time logging
- Study of performance and effects



# Our V2G team

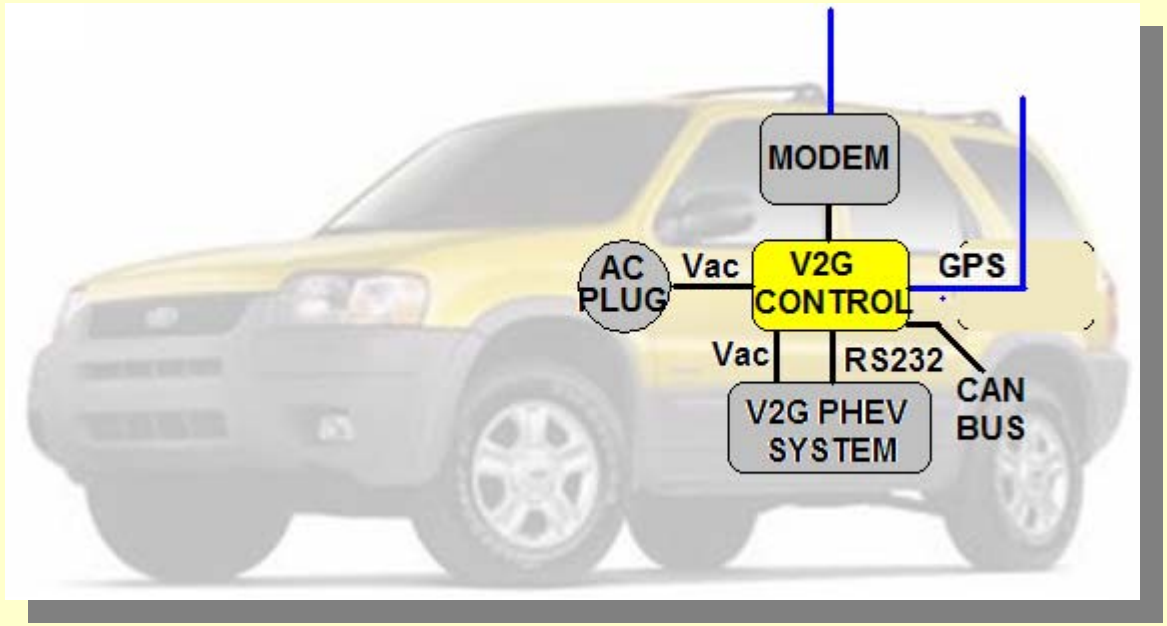
- Team:
  - Xcel Energy
    - Instigator
    - First order for 6 vehicles
  - V2Green
    - On board controller (VCM)
      - GPS, Cell modem, power meter
    - Web based interface
  - Hybrids Plus
    - PHEV conversion: Ford Escape
    - Power electronics: Inverger™
  - NREL
    - V2G compliance testing

# System block diagram





# PHEV block diagram





# PHEV conversion

- Replace stock battery with 12 kWh LiIon packs
- Add Charger
- Add AC plug



# V2G conversion

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



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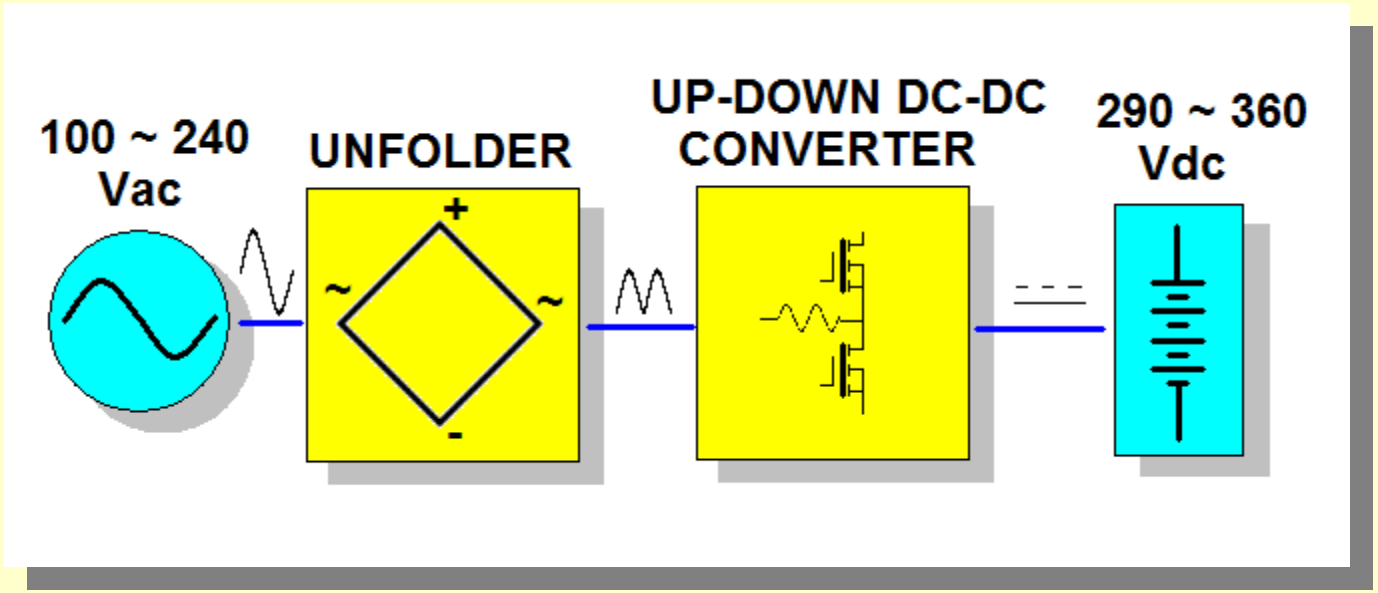
# Inverger™ specs

- 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

# Inverger™ block diagram

- Bidirectional
  - Shared electronics in either direction
- Transformerless
  - Unfolder, Buck and Boost converter





# 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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