# V2G and Wireless Charging for EVs: Perfect Partners

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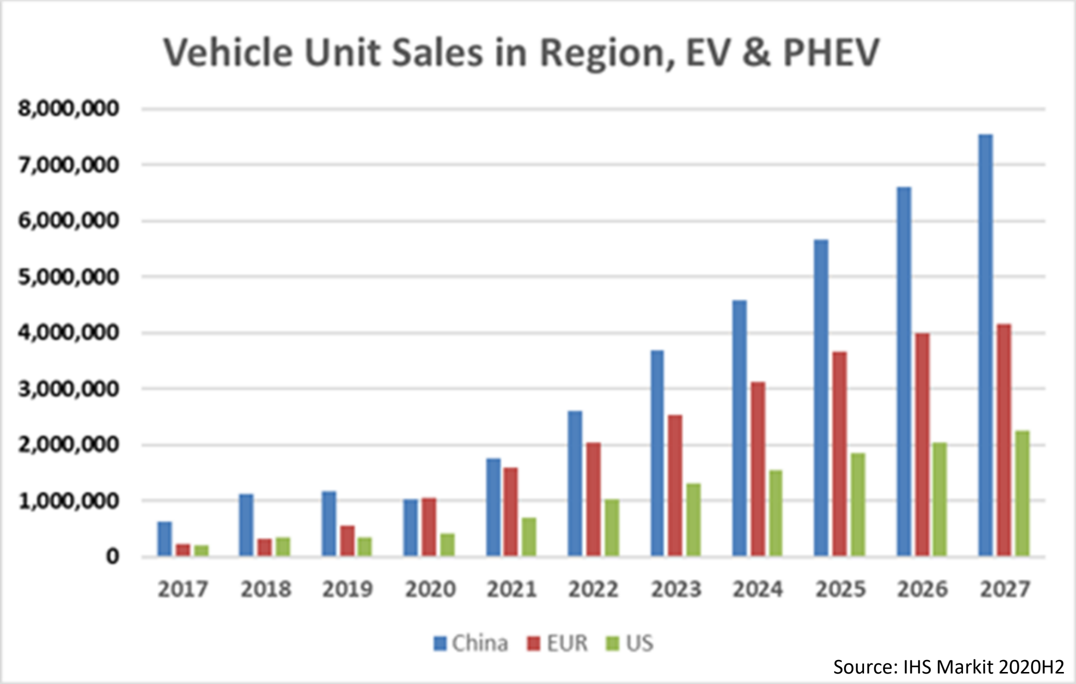
# Global EV/PHEV Sales Projections

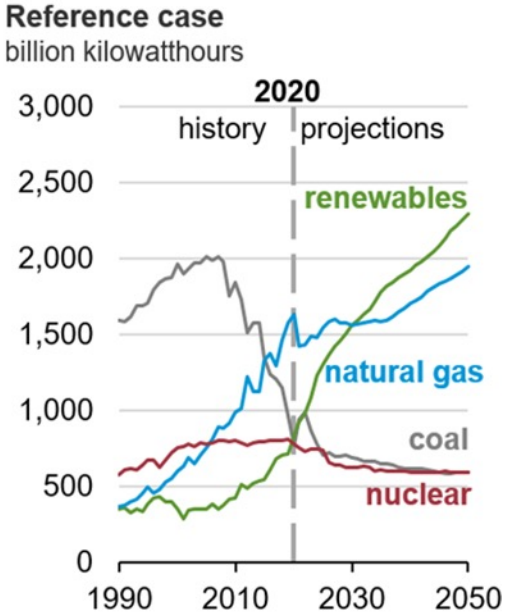



- More EVs create more demand for electric energy

# Electricity Generation for 2020-2050

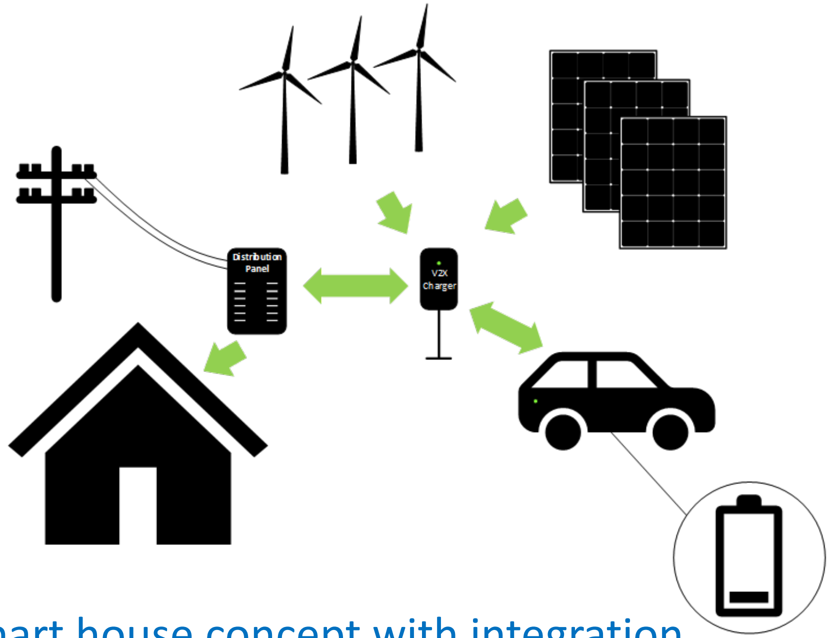
- Most new demand will be met with solar PV panels and other renewables
- Localized small-scale production of electricity will be an important mix
- PV panels on:
  - Houses / roofs
  - Parking lots / garages

Source: watertownmanews.com




Source: U.S. Energy Information Administration (Annual Energy Outlook 2021, eia.gov)

# V2G/V2X Prospect




Smart house concept with integration of renewables and V2G Charger

- V2G: Transfer energy from the car back to the grid
- Largest benefit when integrated with local renewable power generation
- Benefits:
  - Back-up power
  - Store excess renewable energy production
  - Sell power to the grid
  - Smooth out peak electric loads on the grid in the mornings and evenings
- Downsides:
  - Requires large number of participants
  - Requires "work" or deliberate actions by users: *plug-in every time when parked*

# Vehicles That (will) Support V2G

- CHAdeMO (plug-in charging standard) vehicles are the only ones to support V2G today

Nissan Leaf

Nissan e-NV200

Mitsubishi Outlander

- CCS standard for V2G is planned for 2025 (CharIn – Charging Interface Initiative)
- Upcoming vehicles (enabled typically via OTA update):

Ford F-150 Lightning

Volkswagen ID.5

Renault Zoe

# Plug-in Charging Habits

- Plugging in is inconvenient:
  - ~45% of users do not plug in daily at home
  - ~75% of users do not plug in daily at work
  - Low participation is detrimental to V2G technology adoption!

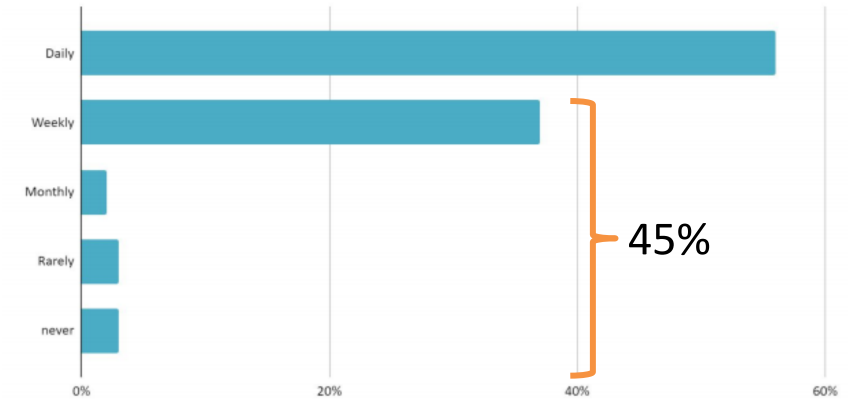



Figure 7: Frequency of home-charging among EV owners

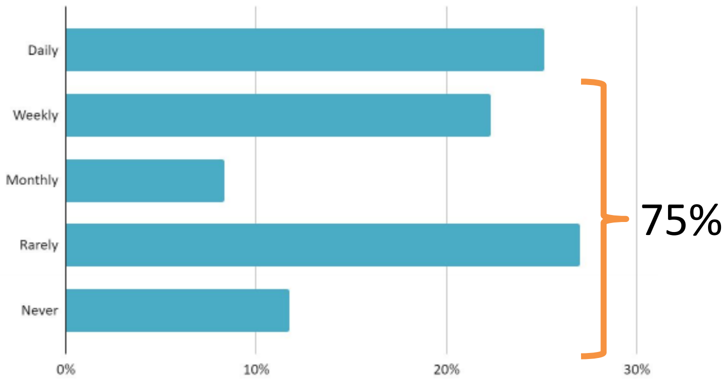
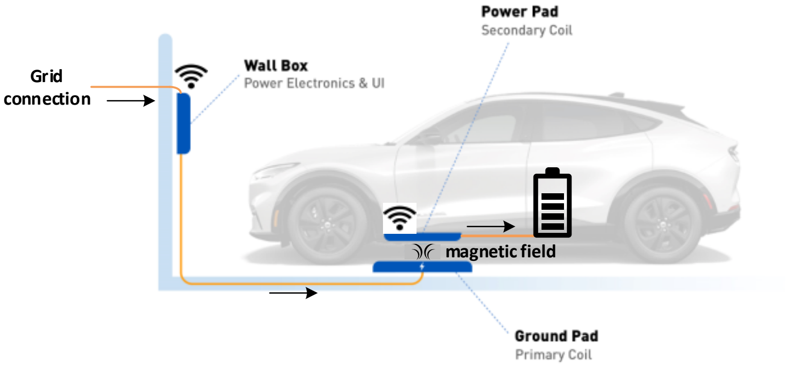



Figure 8: Frequency of workplace charging among EV owners with access to it

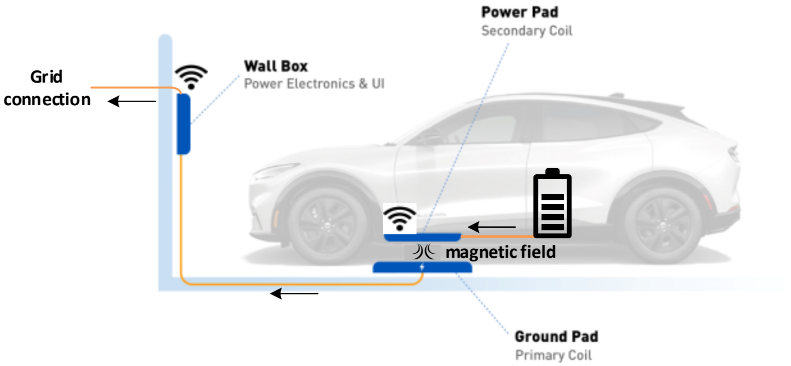
Source: https://pluginamerica.org/wp-content/uploads/2021/02/2021-PIA-Survey-Report.pdf

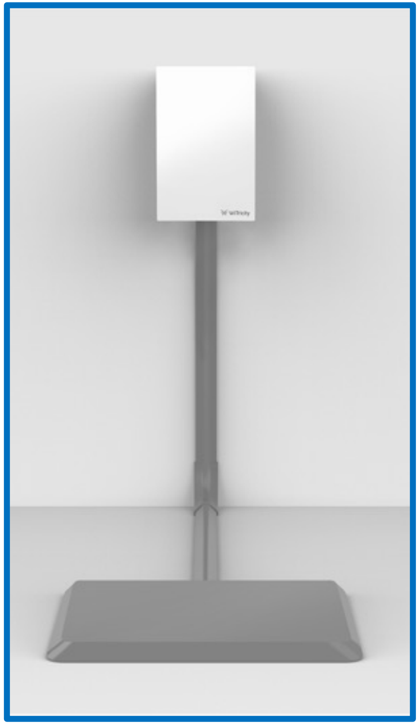
# Wireless V2G Energy Transfer (W-V2G)

- Energy from the grid delivered to the battery




- Energy from the battery delivered to the grid



Off-board wireless charging hardware (wall box, ground cable, and ground pad)

# Prospect of Wireless V2G Energy Transfer (W-V2G)

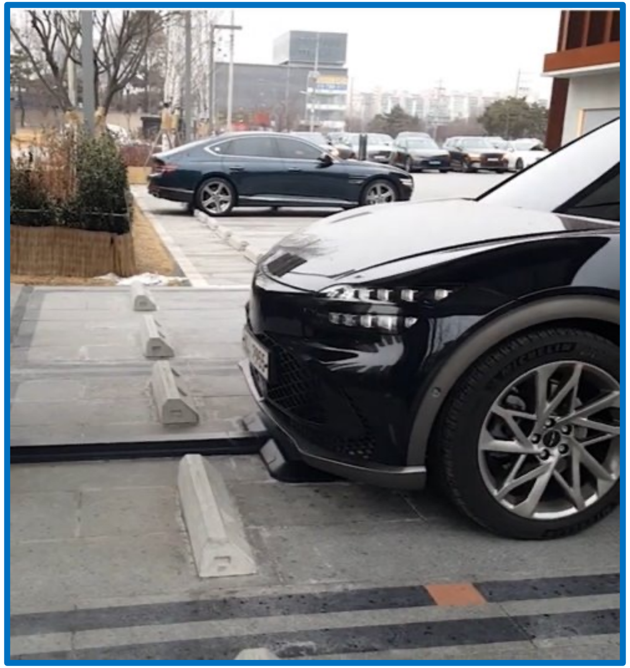
- Solves problem of vehicle being connected to the grid
  - Automatic – park and get online
  - Operates independently in the background
- Maximizes value of locally-generated electricity
  - Sell at peak demand times
  - Sell at public charging location where price is higher
  - Passive income

Example:

| Time of the day | Scenario | Action (energy) |
|---|---|---|
| 0AM-6AM | Off-peak | Buy |
| 6AM-10M | Peak | Sell |
| 10AM-2PM | Off-peak @ Home or office | Store Excess or buy excess |
| | Off-peak @ Office | Sell |
| 2PM-7PM | Peak | Sell |
| 7PM-12PM | Off-peak | Sell |

# Technical Advantages of W-V2G

- Reliable / robust
  - No moving parts
  - All cables fixed and protected
- Efficient (>90%)
- Wireless charging is naturally bidirectional
- Added complexity of vehicle side electronics to make it W-V2G-capable is very low



EV parked over wireless charger

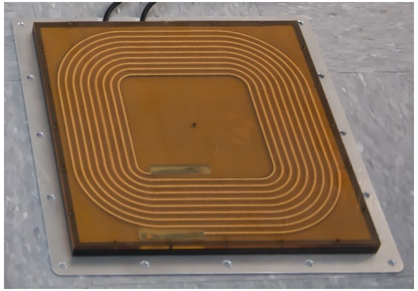
# Global Standards that will Cover W-V2G

- All standards currently under development:
  - Communications: ISO 15118(-20)
  - W-V2G/V2X power transfer: SAE J2954 and IEC 61980

# V2G Wireless Power Transfer Demonstration at 7.7kW with SAE Standards Compliant Coils (WPT2-Z2)

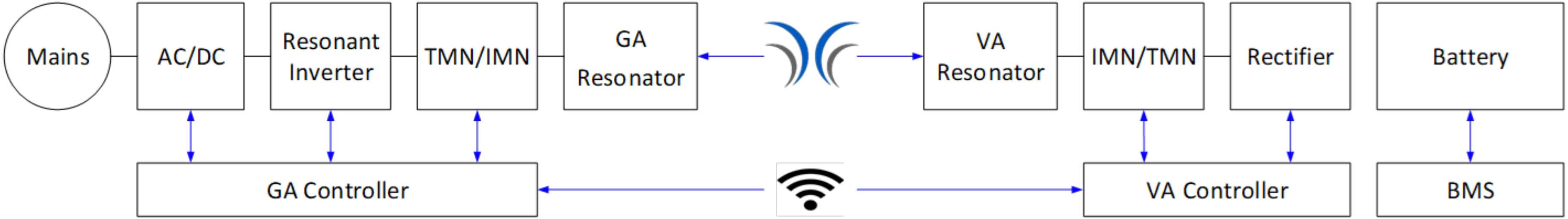
- GA coil is SAE J2954 WPT3 standards equivalent universal coil (11 kW)
- VA coil is SAE J2954 WPT2-Z2 standards equivalent (7.7 kW)
  - Ground clearance: 140 mm – 210 mm
- GA larger than VA - most other work has symmetric GA/VA coils


GA coil
75cm x 60cm x 6cm



VA coil
35cm x 35cm x 2cm

# V2G System Description

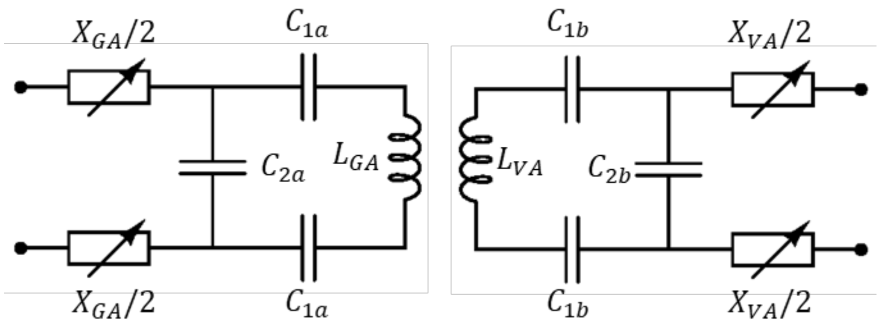



- Power level: 7.7kW drawn from the grid
- Project goal: deliver a minimum of 6.44 kW to load
- Key specifications:
  - Keep changes from unidirectional system at the minimum
  - All MOSFETs should operate at ZVS
  - Battery voltage range is both G2V and V2G operation is 280V – 420V
  - Ground-side bus voltage range in G2V operation is 400V – 500V
  - Ground-side bus voltage range in V2G operation is 400V

# V2G System Description

| Component | Value |
|---|---|
| $C_{1a}$ [nF] | 270 |
| $C_{2a}$ [nF] | 264 |
| $X_{GA}/2$ [$j\Omega$] | 4 – 16 |
| $L_{GA}$ [$\mu H$] | 35.1 – 38.1 |
| $k$ | 0.09 – 0.221 |

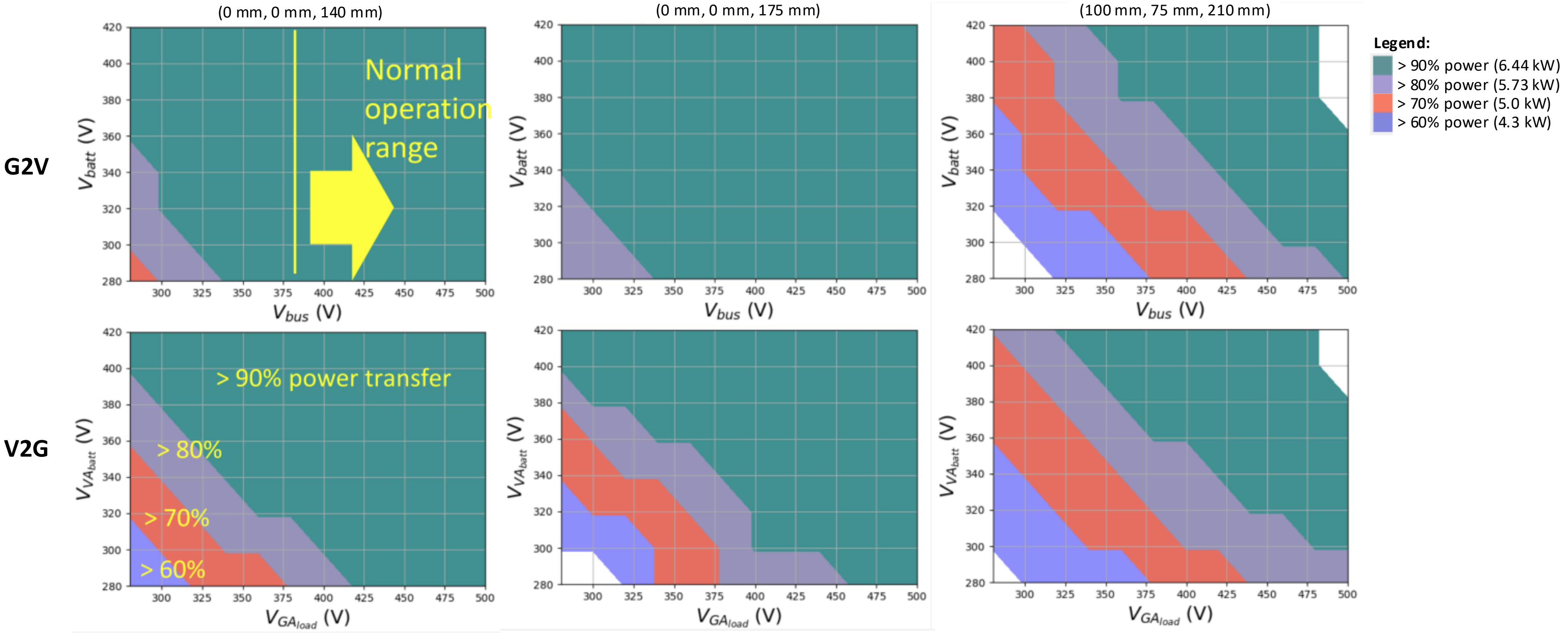
GA VA




| Component | Value |
|---|---|
| $C_{1b}$ [nF] | 250 |
| $C_{2b}$ [nF] | 170 |
| $X_{VA}$ [$j\Omega$] | -6 – 7.5 Ω |

- System validation steps:
  - Analyze the system capability using FHA (First Harmonic Analysis)
  - Validate analysis through switching circuit simulations
  - Build and test hardware

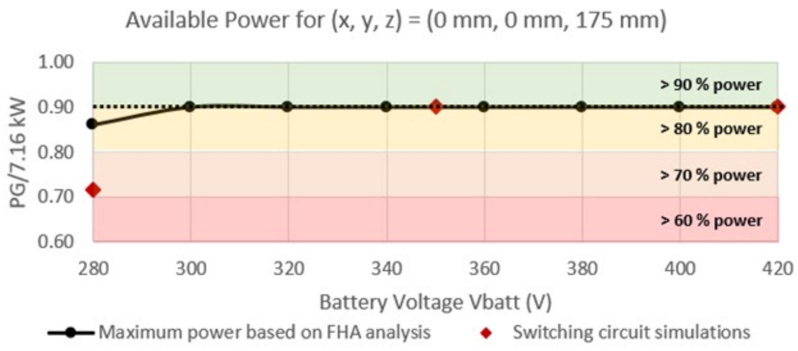
# FHA: Expected Performance

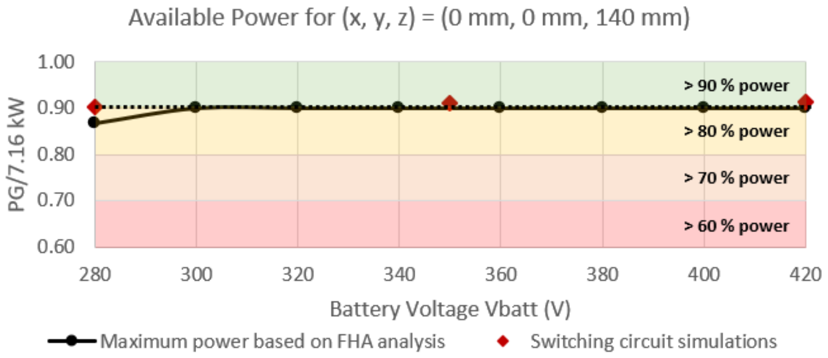


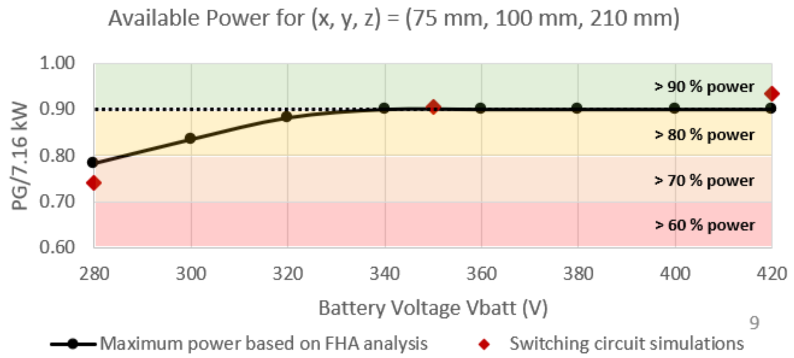

- Power limited when battery voltage is low (~280V)
- High discharge rates are discouraged at low battery voltages (depleting completely the battery)

# Results of V2G Switching Simulations

- Discrepancies between FHA and simulation at low battery voltage
- ZVS limit on the VA MOSFETs is not correctly predicted
- Slightly less available power at nominal coupling than at weak coupling



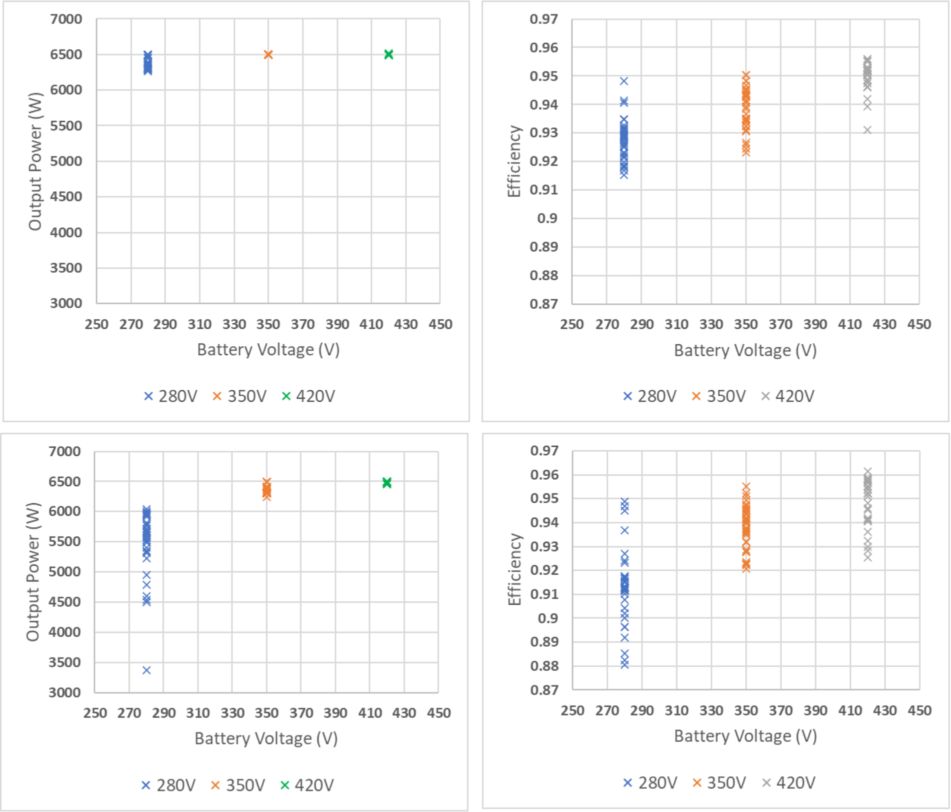



# V2G Hardware Results

- G2V operation is efficient
  - $\eta_{PFC}$ = 97% including aux. power
  - $\eta_{DC-DC}$ = 93.9% on average
- V2G operation is efficient
  - $\eta_{DC-DC}$ = 93.3% on average
- Round trip efficiency is ~82.4%
- Low battery voltage case:
  - V2G available power is limited
  - Much power cannot be taken anyway since the battery will be depleted
- The results largely agree with simulations / analysis

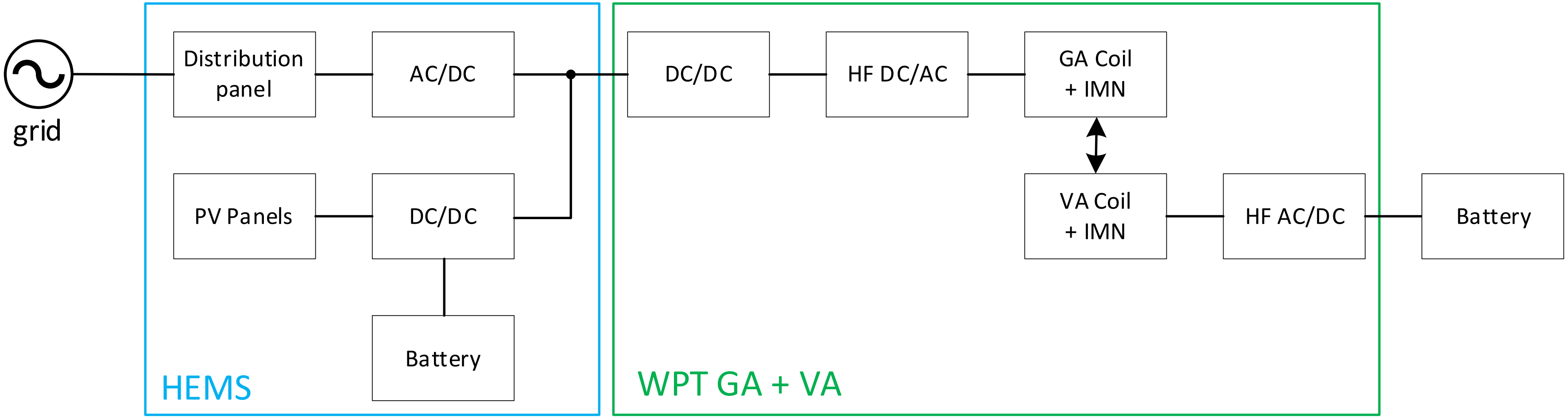
G2V

V2G



# Future WPT V2G Systems

- Increased power level (especially in G2V direction)
- Simplified VA electronics
- Integration of multiple chargers and renewable sources



# Conclusions

- Wireless charging is a perfect partner of V2G technology
  - Solves participation issue
  - Automatic use
  - Maximizes value
    - Of stored charge in the battery
    - Of locally generated electric energy
- High performance and practical V2G system was demonstrated
  - SAE-compliant system was adapted for bidirectional power transfer
  - 6.44kW delivered at the output (in both G2V and V2G directions)

Thank you!

Questions?

# Other Relevant Standards

- IEEE 1547: Interconnection and Interoperability of Distributed Energy Sources with associated Electric Power Systems
- IEEE 2030.5: Standard for Smart Energy Profile Application Protocol
- UL 1741: Requirements for Inverters acting as Distributed Energy Sources
- UL 9741: Electric Vehicle Power Export Equipment, bidirectional EV charging
- OpenADR (Open Automated Demand Response): Communication between Utilities, Aggregators, and Customers
- OCPP 2.0.1: Communication between Charging Station and Station Operator