Wireless Power Transfer Developments and the Potential Impact on Transportation

Omer C. Onar
P.T. Jones

Oak Ridge National Laboratory
National Transportation Research Center (NTRC)

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Outline

- National Laboratory Role in Wireless Charging Technology R&D
  - Experience in Wireless Power Transfer (WPT) Development
  - Dynamic WPT Focused R&D
- WPT Benefits and Constraints
  - Standardization for Emerging Technologies
  - Component level characterizations
- Partners and Plans for WPT Systems Investigation
- Electrified Roadway Impact
  - Vehicle, Grid and Roadway preparation
  - Other lab interaction and cooperation
  - Potential transportation impact
- Conclusions

ORNL is DOE’s largest science and energy laboratory

- $1.6B budget
- ~5,000 employees
- ~5,000 research guests annually
- $500 million invested in modernization
- World’s most powerful open scientific computing facility
- Nation’s largest concentration of open source materials research
- Nation’s most diverse energy portfolio
- Operating the world’s most intense pulsed neutron source
- Managing the billion-dollar U.S. ITER project

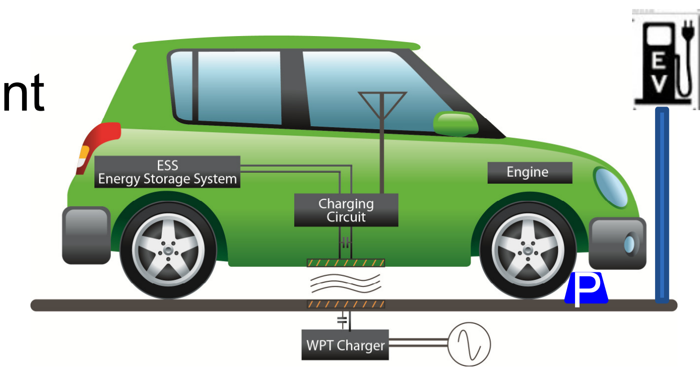
ORNL is uniquely positioned to deliver science and technology for energy

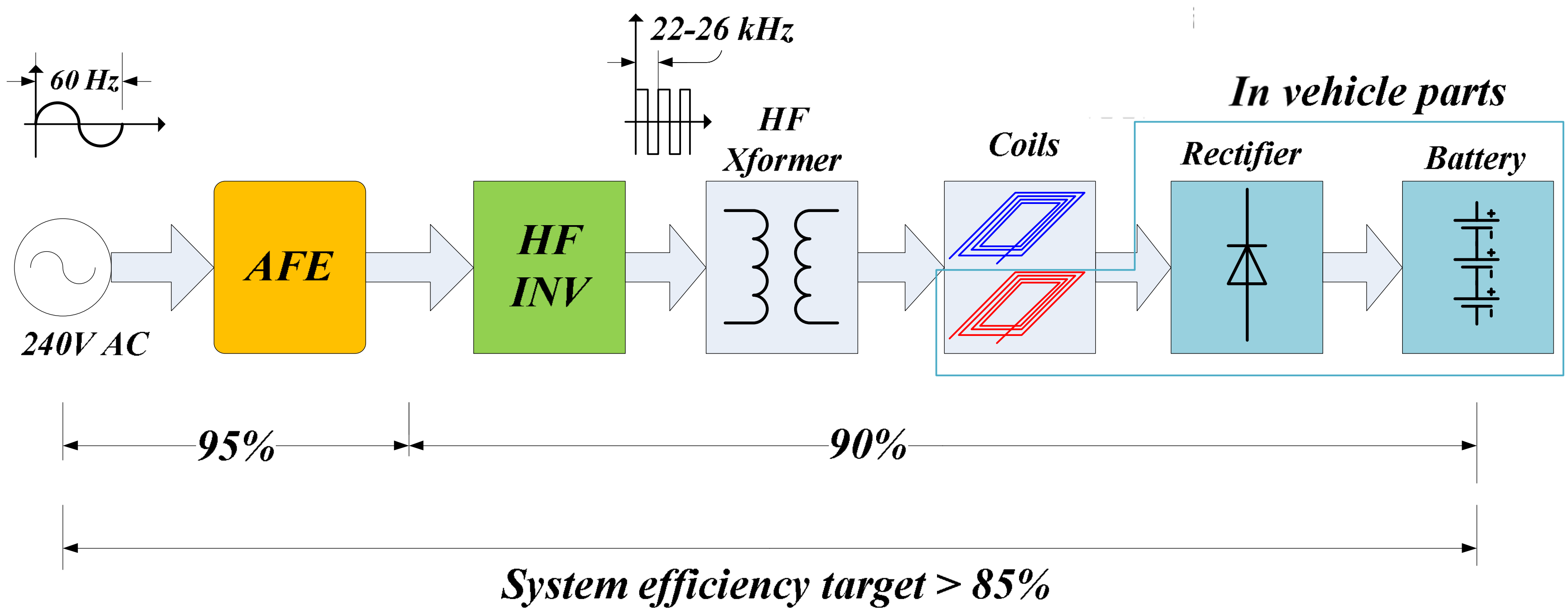
We have an extraordinary set of assets

- Outstanding tools for materials R&D
- Nation's most powerful system for open scientific computing
- Bioenergy Science Center
- Home of National Transportation Research Center
- The nation's broadest portfolio of energy programs
- Unique resources for nuclear technology

National Lab's Role in WPT Technology

- Power Electronics & Coil development, assessment of leakage fields
- Mounting locations and misalignment impacts
- System and component efficiency measurement
- Characterization of subsystem variations
- Inter-lab opportunities with WPT R&D





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Wireless vs. Conductive Charging

- Wireless and conductive charging adhere to similar power classifications and have relevant health and safety requirements – but WPT charging must mitigate fringe fields

Wireless charging with grid-side regulation means no OBC is required – similar to dc fast charge – from vehicle interface direct to on board storage

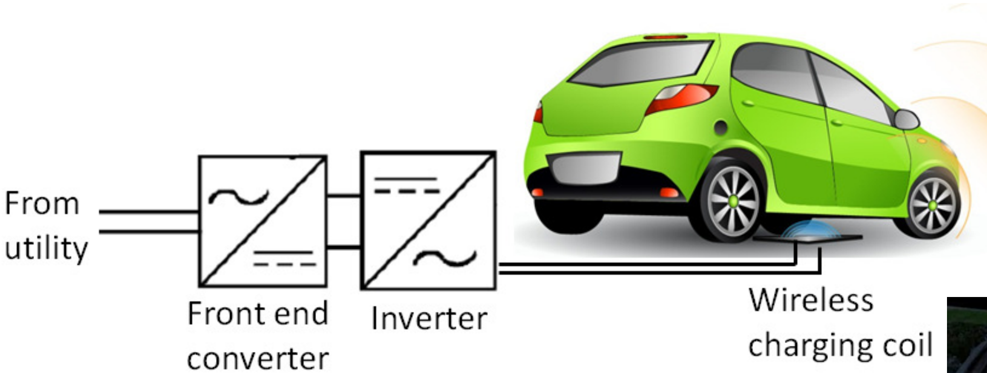
ORNL wireless charging focuses and shields the active zone magnetic field to insure fringe fields are well within international standard limits (ICNIRP)

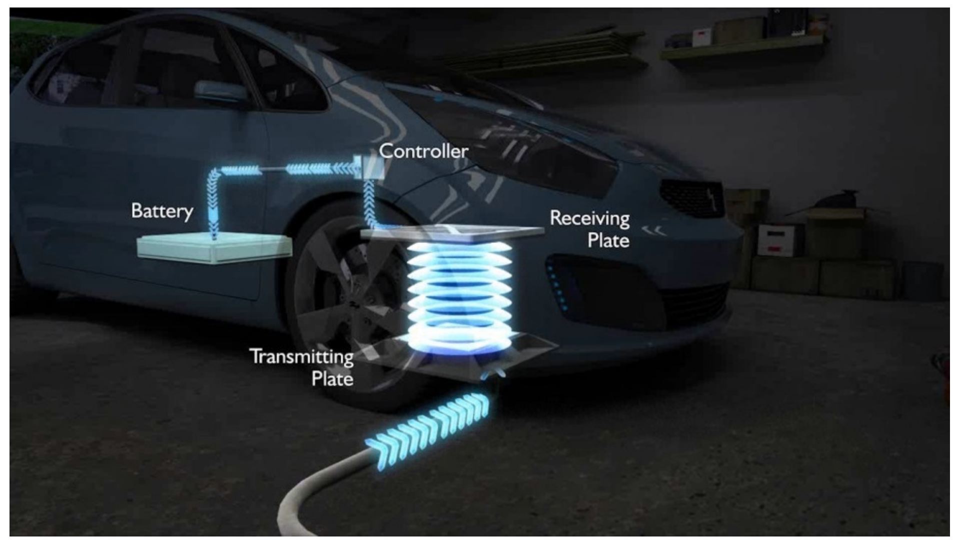
Nissan stock photo, Nissan Leaf application

Future E-Roadways combined with wide spread wireless static charging infrastructure could mean no problems with plug interface

Stationary Wireless Charging

- Current stationary wireless charging activities at ORNL
  - Integration of WPT systems into a plug-in demo vehicle fleet
  - Higher power architecture study to understand basic system characteristics
  - Focus on field generation (Safety, efficiency, power electronics loads)

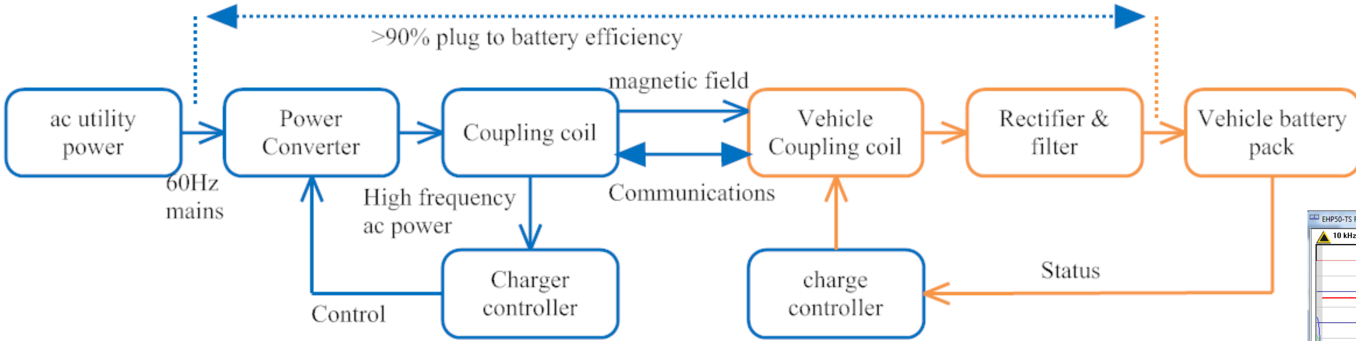


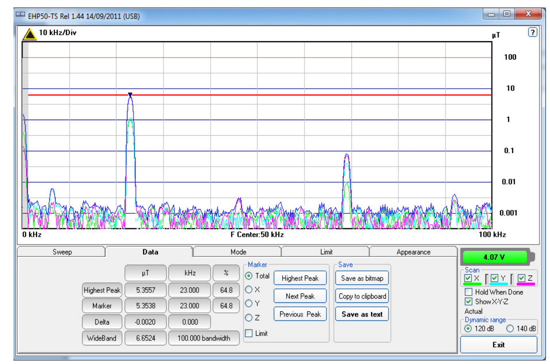


Anytime electrical power is transferred through the air – People are concerned with safety!

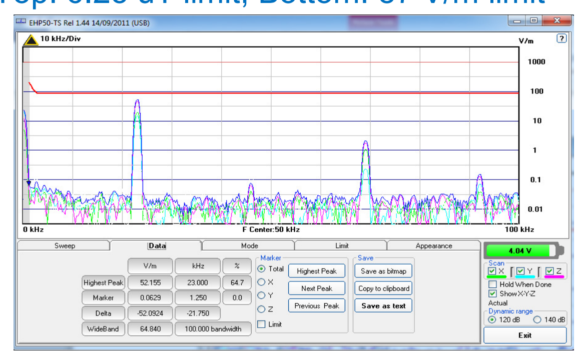
Interoperability and Standardization

- Efficiency measurements and Standardization support
  - Recommendations for WPT center frequency
  - Component level characterizations and impact on R&D and standards





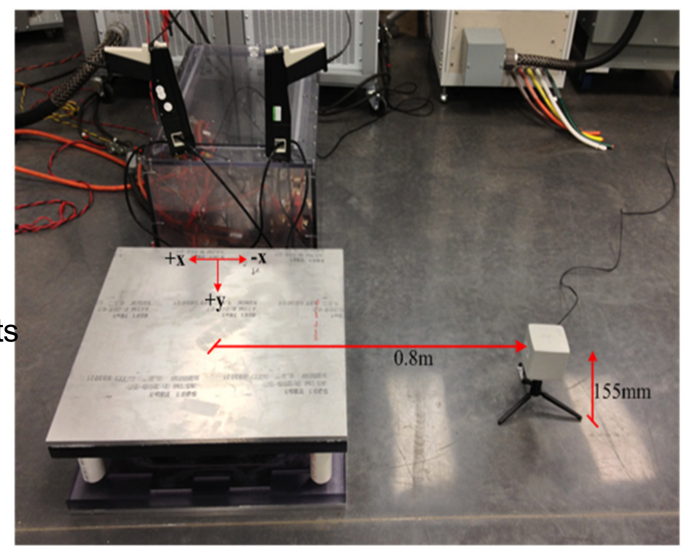
Top: 6.25 uT limit; Bottom: 87 V/m limit



Closest Approach Boundary

- Validated x=0.8m, z=155 mm, @ P=5 kW, and f=23 kHz
- Test position: B=5.36uT, E=52.1 V/m
- At P=7 kW sensor moved to x=0.9m
- Then: B=4.86 uT, E=52.6 V/m

- Narda EH-50D E&H field analyzer used in all E and H-field measurements



ORNL experimental apparatus

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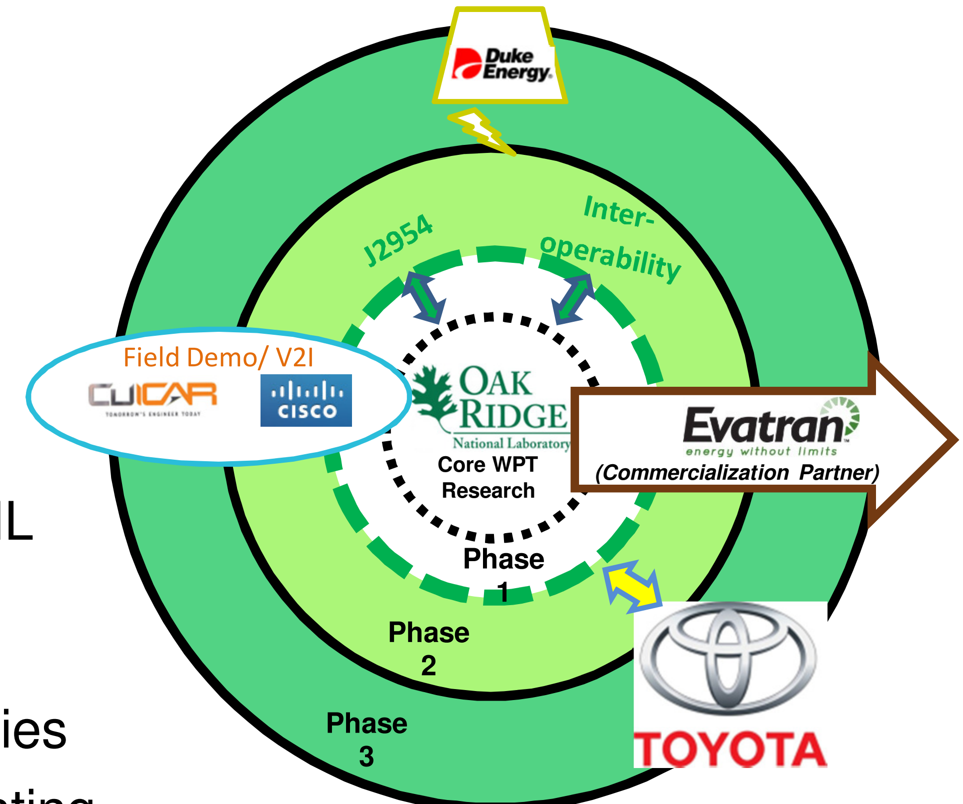
Technology Demonstration Project

Coordinate multi-party team activities to validate 6.6 kW capable wireless power transfer (WPT) apparatus @ 85% efficiency, demonstrate on bench, complete integration designs and begin integration into vehicles

Overall program

- Provide unbiased data to promote technology standards
- Work with Evatran, CU-ICAR and Toyota Motor Co. to integrate ORNL developed WPT technology into demonstration vehicles
  - Static and Dynamic WPT Facilities
- Validate system at independent testing laboratory



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ORNL Dynamic WPT Demonstrator

- Dynamic Wireless Power Transfer (WPT)
  - ORNL demonstration: GEM EV and 6-coil track
  - At issue: motion dependent power pulsations

Laboratory funding of in-motion wireless charging is aimed at developing deep knowledge on the implementation challenges facing vehicle charging while in motion. The U.S. DOE and DOT have supported this technology development and its implications to future highway construction, durability and cost projections. ORNL's research includes the benefits of vehicle & grid-side energy storage for smoothening of coil geometry and pitch induced power fluctuations.

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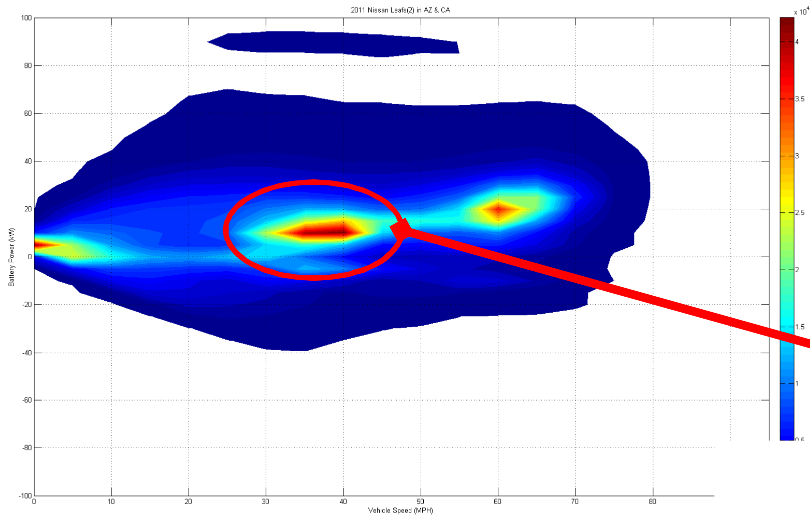
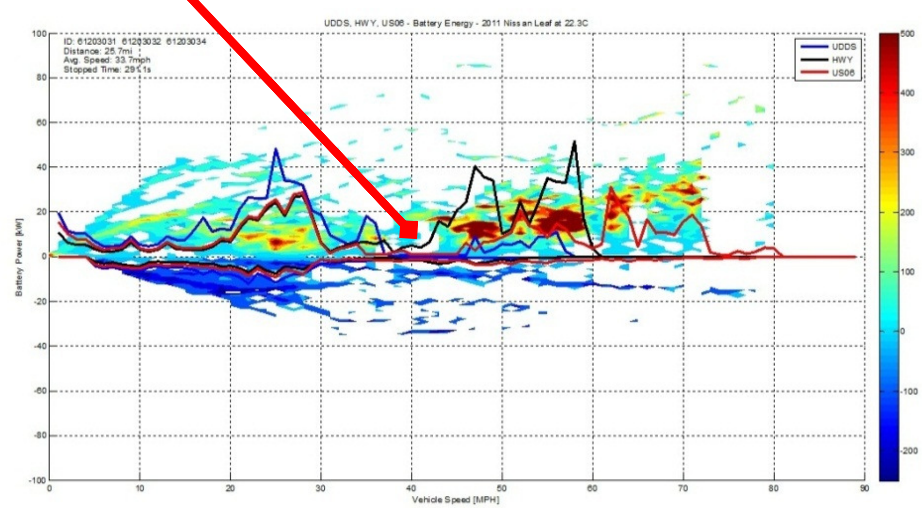
Combined National Lab Dynamic Study

- Combining INL field data and ANL dynamometer test data yielded support information for dynamic considerations



Idaho National Lab ATVA data plot from in-use plug-in EV vehicle data

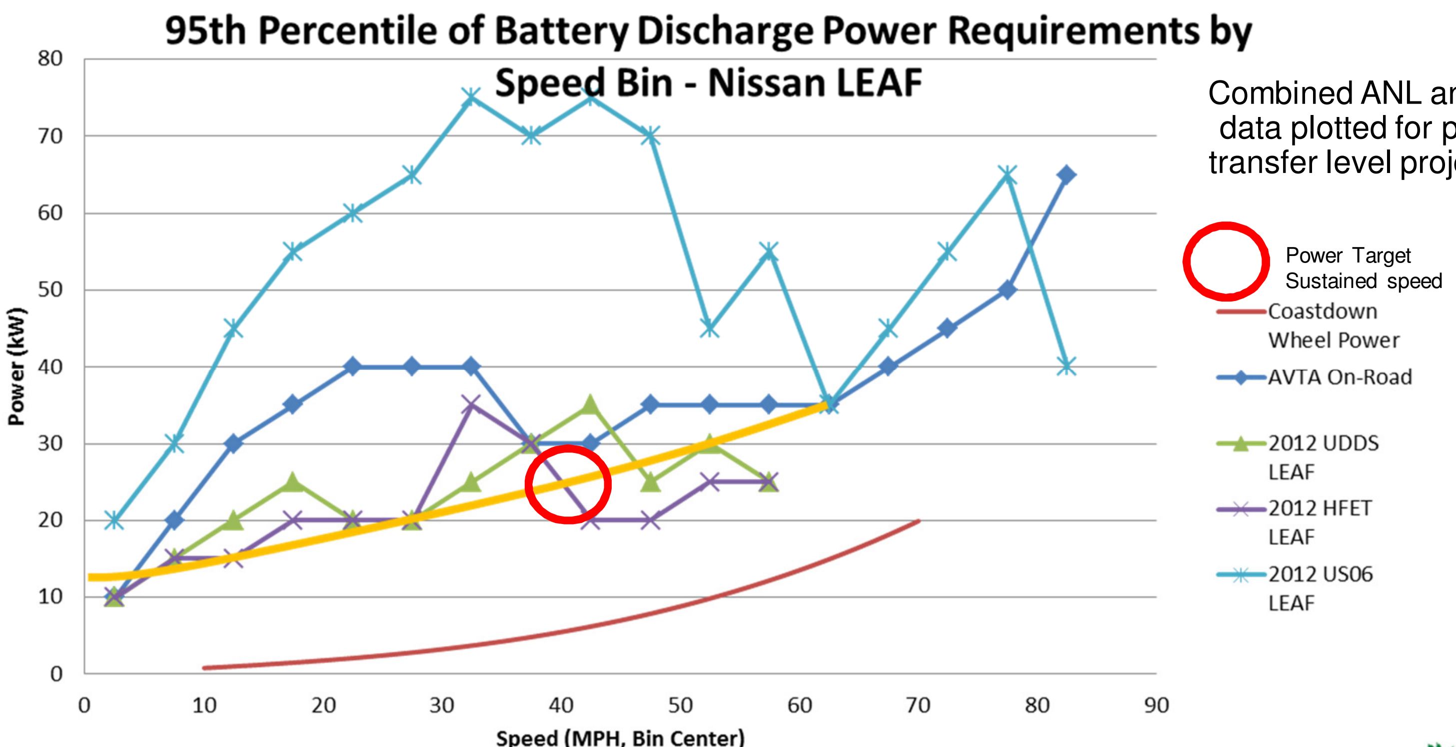
Field data fills in gap from test cycle data



Argonne National Lab APRF data plot from standard Drive cycle data

Dynamic Roadway Power Projections

- Estimate cost and impacts for Electrified Roadway given:
  - Current vehicle information from supporting lab data
  - Current ORNL technology type WPT systems
  - Current traffic volumes for scenario of deployment
- Estimate cost and impacts for Electrified Roadway given:
  - Current vehicle information from supporting lab data
  - No supporting vehicle traffic control systems



Combined ANL and INL data plotted for power transfer level projection

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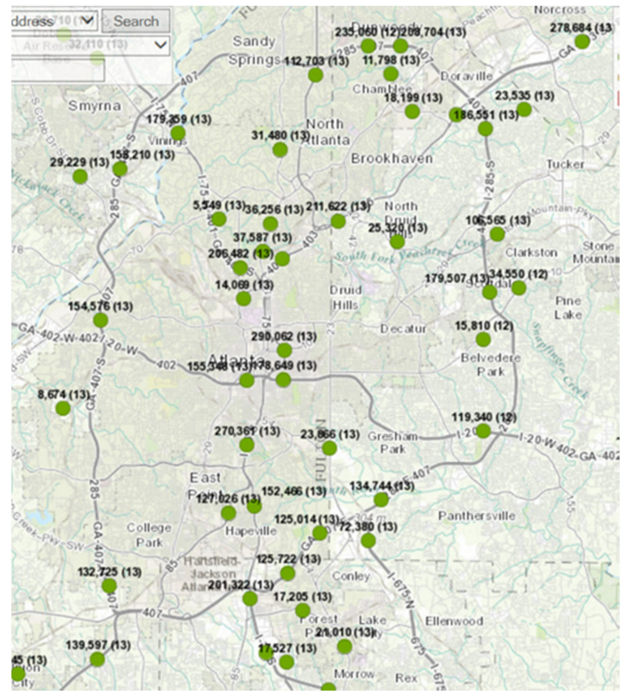
Developing a Scenario of Interest

- **Considerations for DWPT deployment**
  - Environmental/Vehicle load impacts to roadway and WPT tech
  - Road modification traffic interruption, maintenance changes
  - Roadway usage, speeds, time of day



- **Example Scenario- LDV Commuter Routes**
  - HOV lane stem route metropolitan highway
  - Road usage high percentage VMT
  - Speeds varied ➡ higher speed/higher power
  - Replacing high power consumption portion of trip with charging opportunity, maximizes range and reduces ESS size and weight
  - System failure impact, traffic, range and routing

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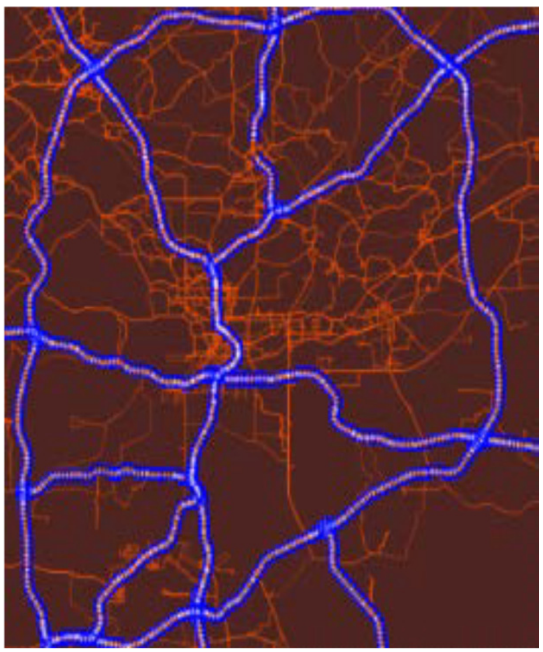
Developing a Scenario of Interest

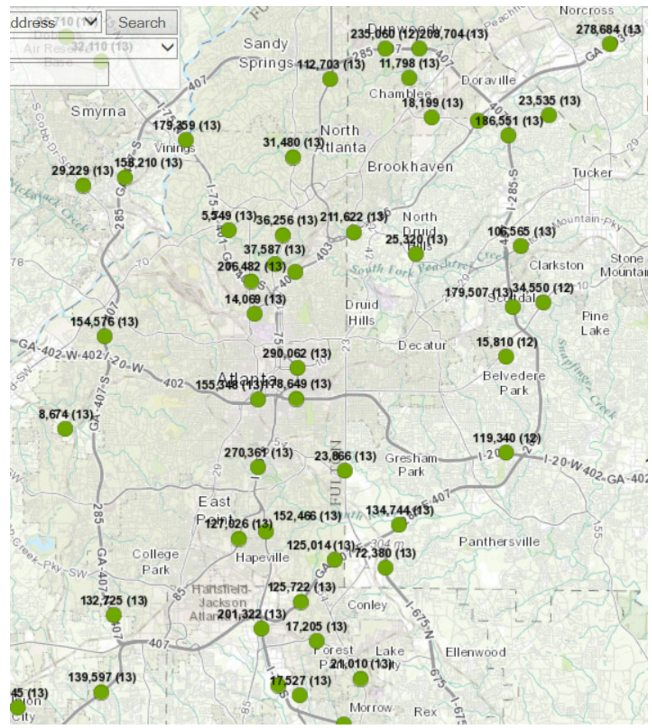
1% of the Roads

- 17% of vehicle miles traveled (VMT)
- Road classifications
- Reducing points of connection to grid
- NREL traffic power required and VMT analysis coordination



http://www.nrel.gov/docs/fy14osti/61937.pdf

Atlanta Region



http://geocounts.com/gdot/

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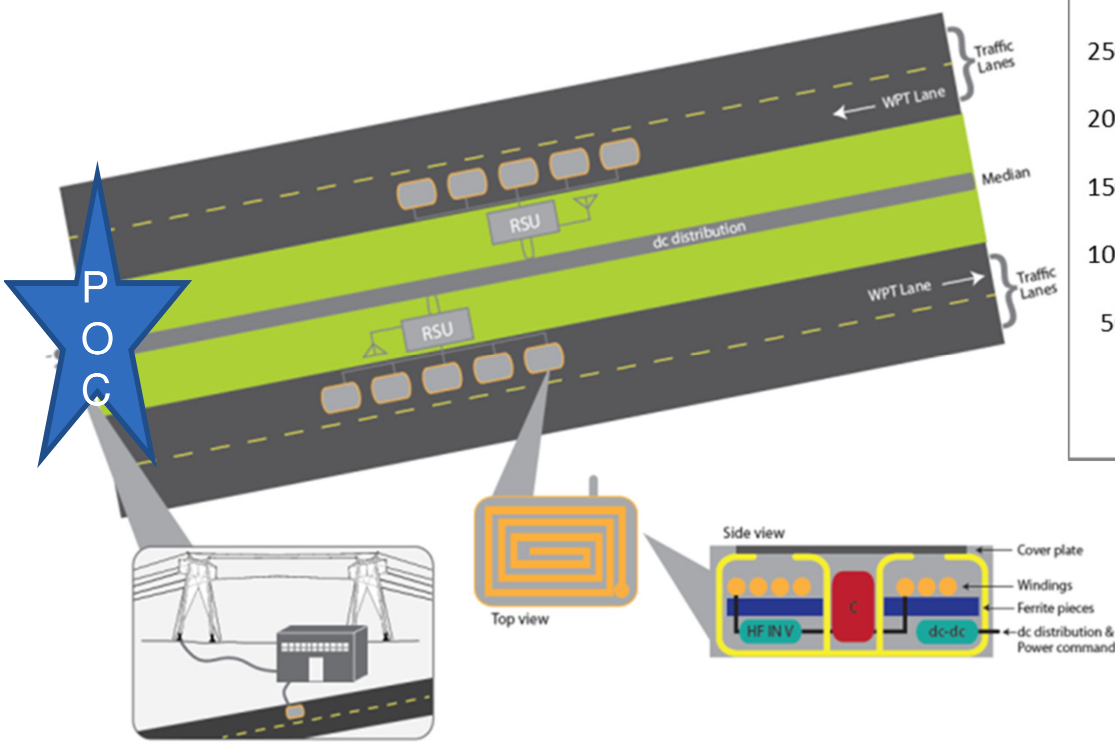
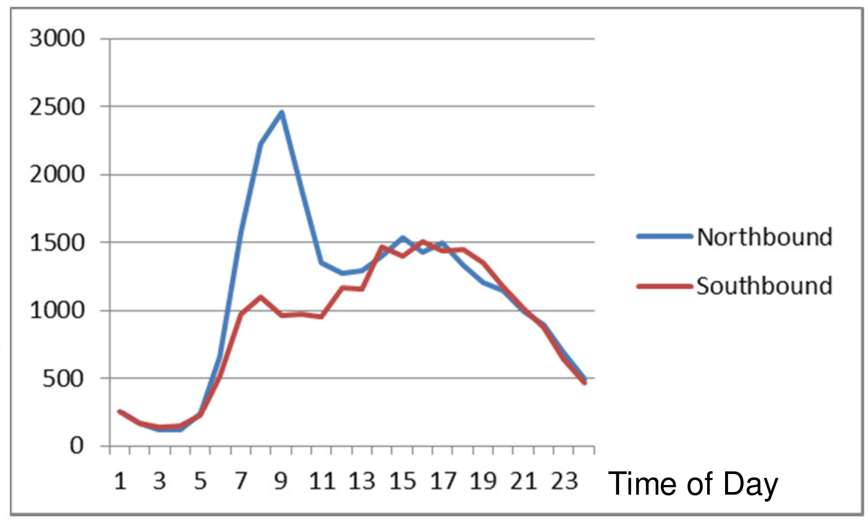
Electrified Roadway Costs - Atlanta

- A 25-30 kW dynamic roadway would cost around \$2.8M/mi of electrified roadway, per lane – with an estimated 30% lane coverage
- Additionally, given time of day load requirements – grid improvement cost must be accounted for:
  - Est. 35% of current traffic volume E-Road capable
  - 100% of vehicles on E-lane are E-Road capable
- Providing power to POC ~ \$350K/lane*mi



I-75 south of Atlanta



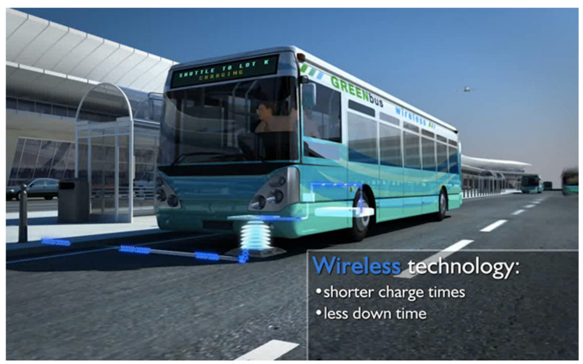
Total System Upgrades
~ \$3.15M/mi

Developing Technology and Deployment Scenarios for WPT Grid Connected EVs

- Evolution of Wireless Charging
  - Develop WPT to commercial deployment in stationary light duty vehicles
  - Scale up power levels and optimize coupling device technology for medium and heavy duty applications
  - Higher power WPT enables shift to dynamic charging or E-roadways

Is this correct?

Stationary Wireless Charging



High Power Wireless Charging

In motion/Dynamic Wireless Charging

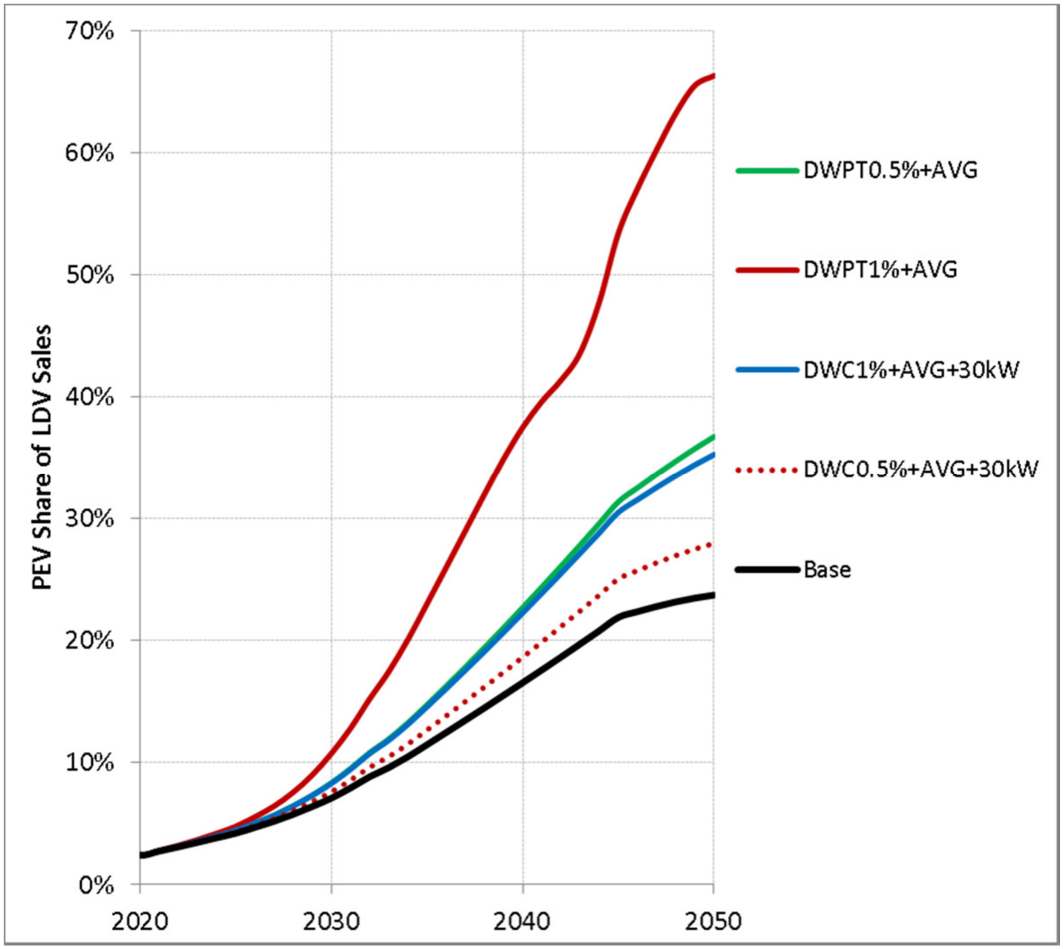
Impacts of Electrified Roadways

- Consumer technology adoption projections for Grid Connected Electric Vehicles (GEVs) based on MA3T analysis

ORNL's Zenhong Lin data from MA3T

Building the Business Case

- •PHEV 10-40 purchase impact
- •Four US Metro Area average
  - •Los Angeles, Long Beach, Anaheim, CA (LA), San Francisco--Oakland, CA (SF), San Diego, CA (SD), and Atlanta, GA (AT).
- •0% Electrified roadways in 2020
- •Base case, 100 kW & 30 kW WPT



year

In conjunction with **Dynamic Wireless Power Transfer: Potential Impact on Plug-in Electric Vehicle Adoption**.- SAE paper 2014-01-1965

Conclusions

- The DOE National Laboratories play an important role in WPT technology and standards development and analysis of projected deployment impacts
- ORNL has numerous programs in wireless charging
  - DOE funded WPT partnership with ICAR, Evatran, Toyota, Cisco and Duke Energy – developing WPT Technology and an WPT evaluation center
  - Stationary wireless charging an ORNL mail delivery vehicle, including full charging site integration
  - DOE funded high power WPT simulations and hardware demonstration
- Data sharing with partners, other national laboratories and with standards committees and task forces
- ORNL is committed to WPT knowledge generation and understanding
  - Looking for opportunities to expand and clarify technology assumptions
  - Publication of results in technical papers, tutorials, and articles
  - Developing scenarios to predict the impact of new transportation systems

Thank You

Questions?

Dr. Omer Onar

onaroc@ornl.gov

P.T. Jones

ptj@ornl.gov

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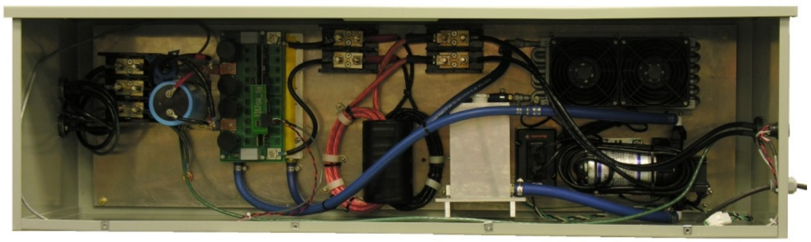
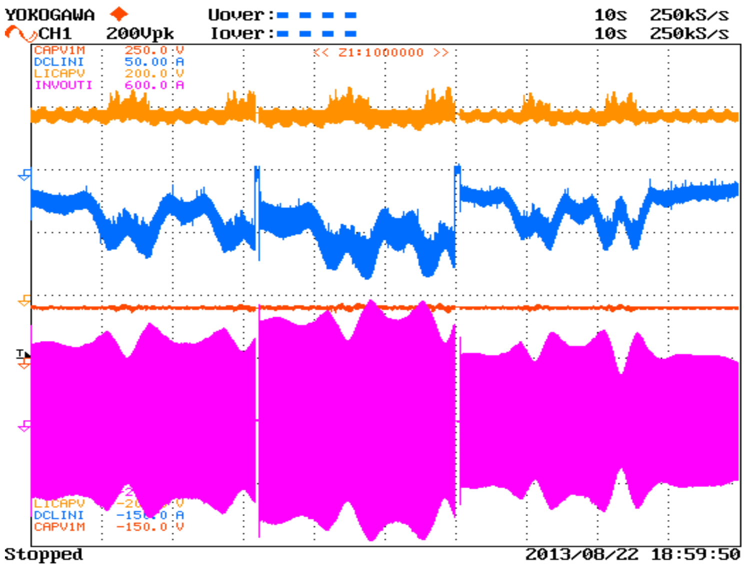
Support Slides

ORNL Dynamic WPT Demonstrator

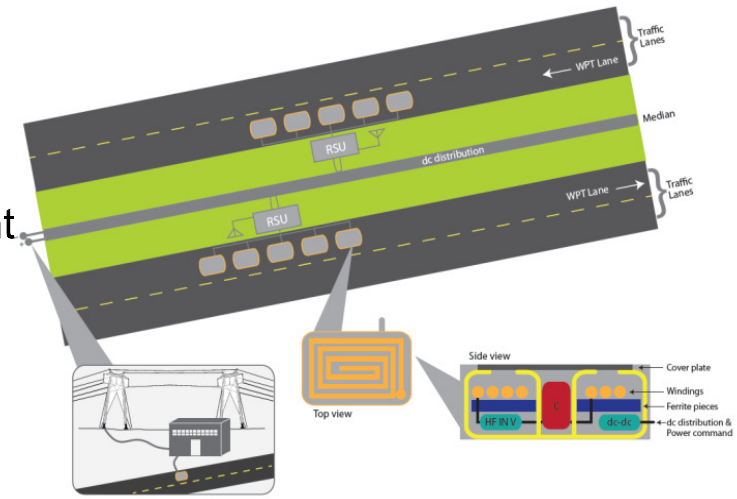
- Dynamic Wireless Power Transfer (WPT) Experimental Results
  - Illustration of system hardware
  - Power flow as function of vehicle position



HF inverter system with HF transformer and self contained thermal management system



  - Future directions in dynamic WPT
    - Infrastructure issues (roadway integrity)
    - Communications requirements (latency)
    - Grid power distribution (intermittency)
    - Coil sequencing and power modulation & alignment
    - Local energy storage (smoothening)
  - Promote dc distribution along highway
  - Highly distributed vs. centralized HF stage



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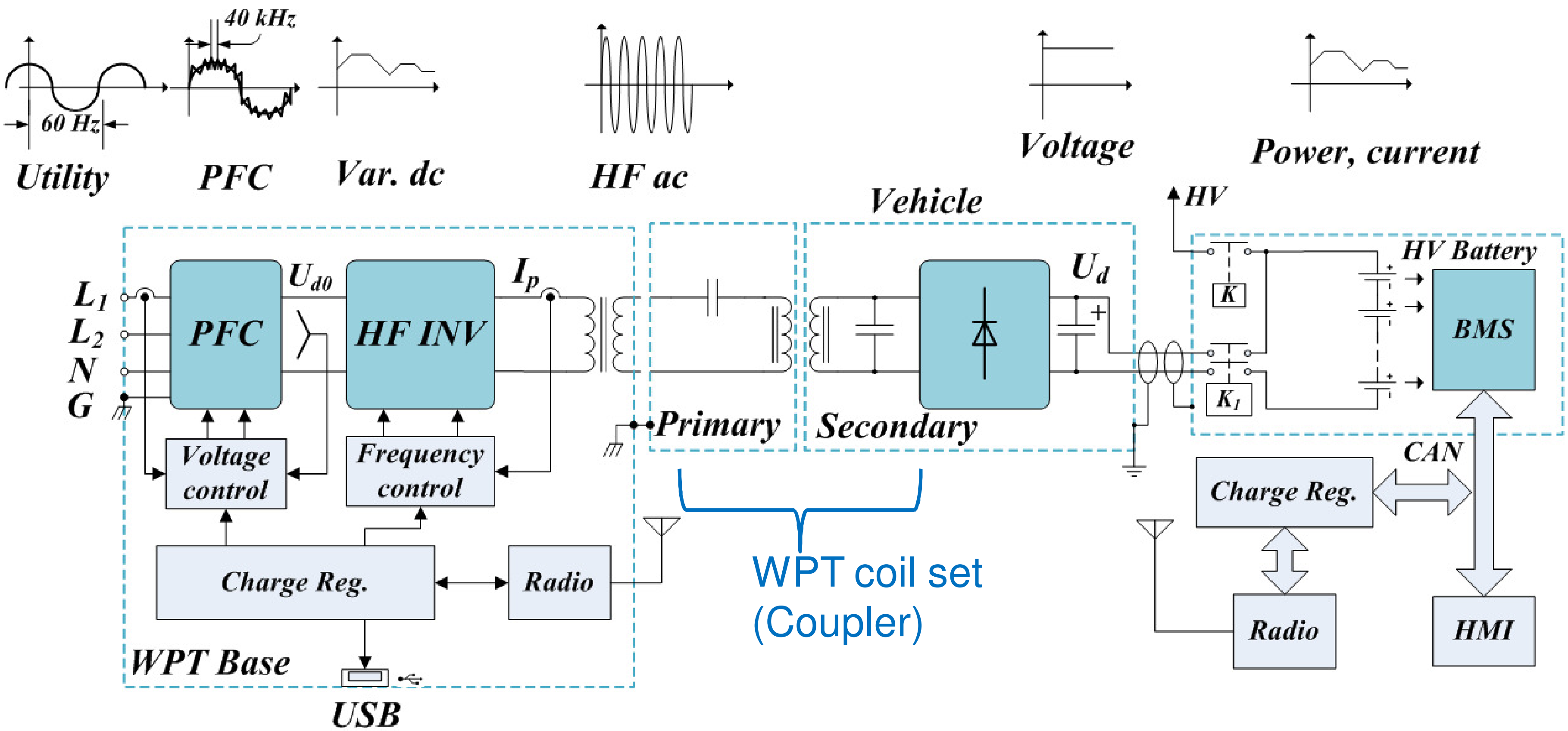
Power Electronics

ORNL Grid-side Regulated WPT

- Wireless charging with grid side regulation moves the vehicle OBC function to the grid connection.



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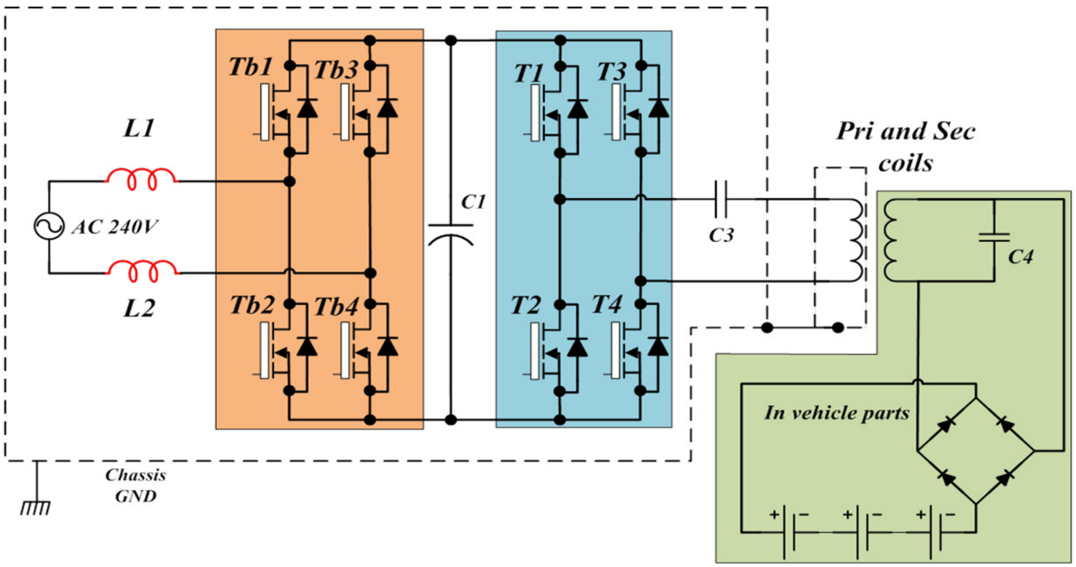
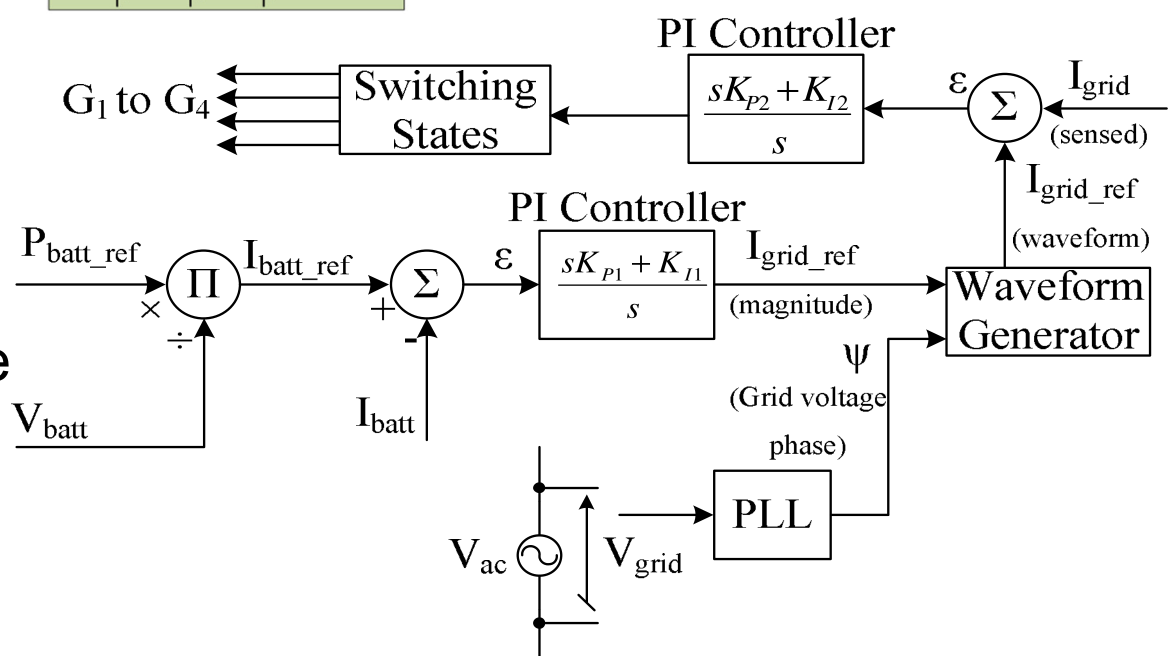
WPT System Complete Control Loop



WPT system block diagram with active front end rectifier with power factor correction

WPT complete control system loop for tracking the reference charging power to the vehicle battery by controlling the DC link voltage to the inverter input through the AFE with PFC



ICAR Connections

& Site Improvements

SC-TAC and the ITIC

Demonstration Site Near Clemson University I-Car (CUICAR) Center

Stationary wireless charging demonstration area (parking lots)

Dynamic WPT charging application area