

High Power and Dynamic Wireless Charging of Electric Vehicles (EVs)

Veda Galigekere (PI), Group Leader
Electric Drives Research Group

Email: galigekerevn@ornl.gov

Phone: 865-341-1291

Burak Ozpineci, Section Head

Vehicle and Propulsion Science Section

Email: burak@ornl.gov

Phone: 865-341-1329

Oak Ridge National Laboratory (ORNL)

2023 U.S DOE Vehicle Technologies Office Annual Merit Review
June 14, 2023 Project ID: ELT197

ORNL is managed by UT-Battelle, LLC
for the US Department of Energy

This presentation does not contain any proprietary,
confidential, or otherwise restricted information

Overview

Timeline

- Start Date: Oct 2019
- End Date: March 2022
- 100% Complete

Budget

DOE Total Share: \$11,400K

FY \$K	ORNL	INL	NREL
FY19	\$3,075	\$675	\$250
FY20	\$2,900	\$875	\$250
FY21	\$3,025	\$825	\$250
Total	\$9,000	\$2,325	\$750

Barriers

- **Power Density:** Developing a compact vehicle coil and power electronics assembly which can receive 200 kW power dynamically
- **Efficiency:** Achieving 90 % efficiency in a vehicle integrated dynamic wireless charging system
- **Controllability:** Identifying and implementing a control and communication system which can perform wide range power regulation without compromising efficiency or power density

Partners

National Laboratories



Veda Galigekere, Lincoln Xue,,
Gui-Jia Su, Omer Onar, Shajjad
Chowdhury, Jon Wilkins, Larry
Seiber, Cliff White, Nolan Hayes
and Burak Ozpineci



Richard Carlson,
Bo Zhang, Timothy
Pennington



Andrew Meintz and
Cory Sigler

External Partners



Hyundai Kia
American
Technical
Center



American
Center for
Mobility



Virginia Tech
Transportation
Institute

FY22 Milestones

Milestones

Lab	Date	Milestones	Status
ORNL	12/31/2021	Validate functionality of the high power dynamic wireless charging system	Completed
ORNL	3/31/2022	Evaluate performance of dynamic wireless EV charging system based on performance	In-Progress
INL	6/30/21	Analysis and simulation of proof of concept of active EM-field shielding	Completed
INL	Summer 2022	Assist with the evaluation and demonstration of the ORNL high power dWPT system (ACM test track)	Planned
NREL	9/30/2021	Complete test cases for HD Vehicles with different designs, allocations and EV models	Complete

Go/No-Go Decision Point

Lab	Date	Go/No-Go Decision	Status
ORNL	12/30/2021	If basic functionality of robust dynamic wireless EV charging is proven at low speed tests, proceed with performance evaluation.	Go

Any proposed future work is subject to change based on funding levels

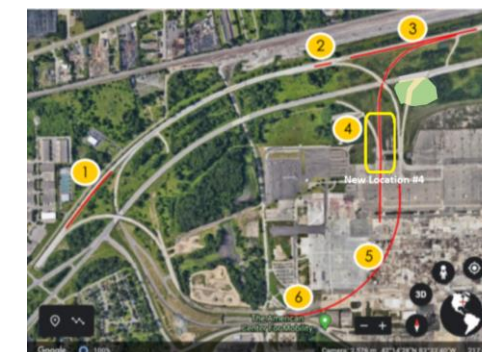
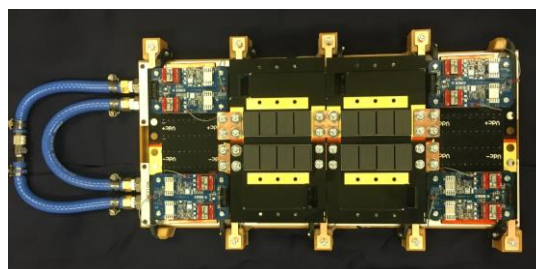
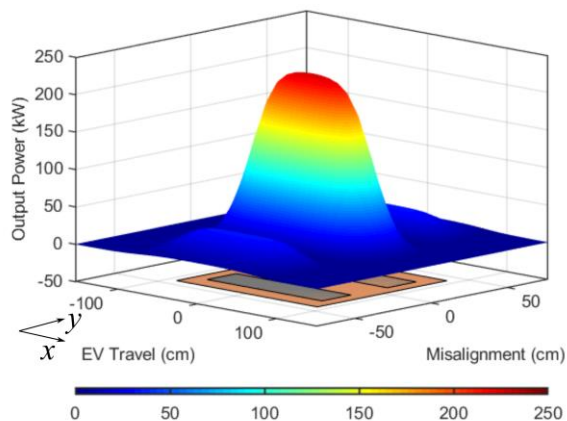
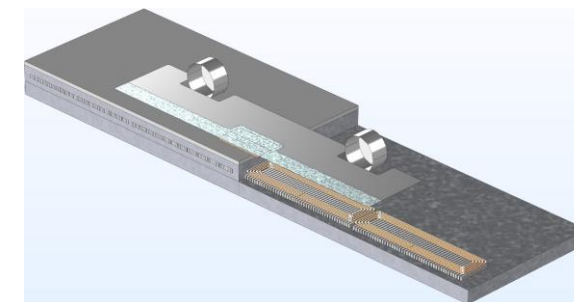
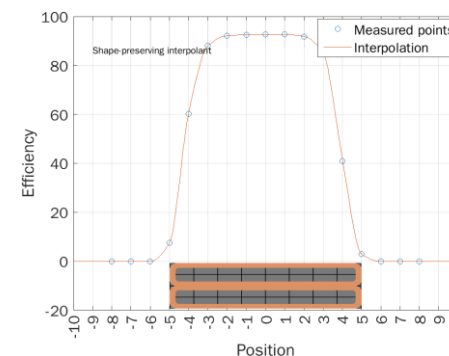
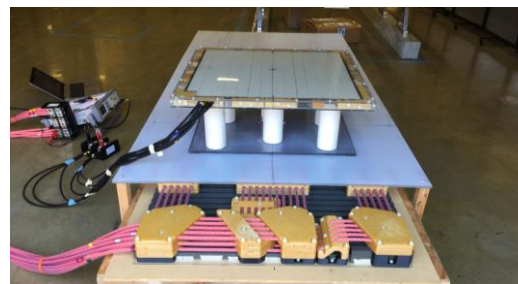
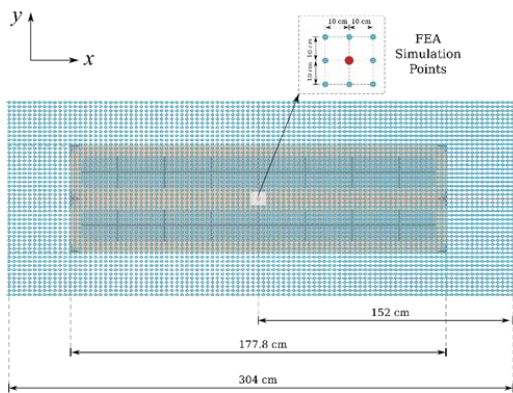
Approach: Proof of Concept Validation

Analytical and simulation studies

Hardware design and development

Laboratory validation of 200 kW DWPT

Real world validation of 200 kW DWPT



Detailed simulation and analytical design-oriented study

Hardware development and benchtop validation

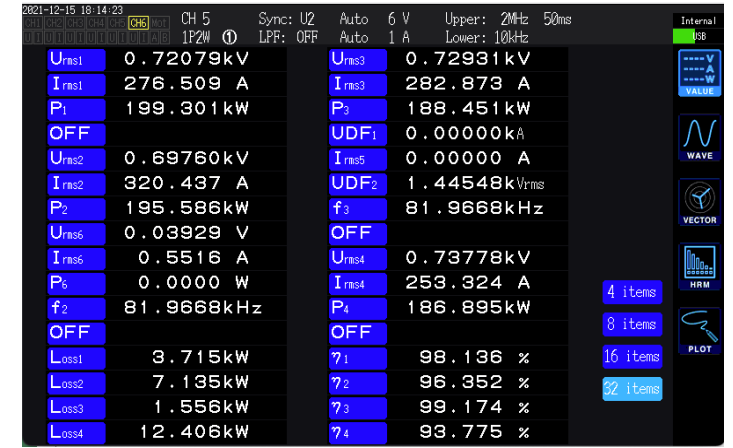
Laboratory Validation of 200 kW DWPT using dynamic inductive charging emulator

Planned 200 kW 55 mph DWPT validation at ACM

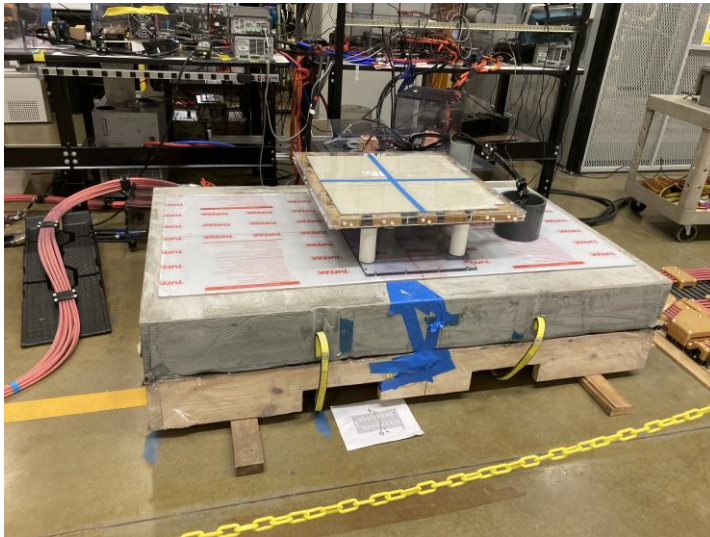
Technical Accomplishments FY23: Validation of Power Transfer Capability in Stationary Mode

Validated power transfer capability and recorded baseline performance

- Validated electrical performance of transmitter embedded in MasterFlow 648 Epoxy Resin Grout (5000 psi)
- Validated electrical performance of WPT system with vehicle coil and aluminum shielding integrated with the vehicle
- No variation in electrical performance in both cases
 - Efficiency 93.7 %
 - No thermal hotspots



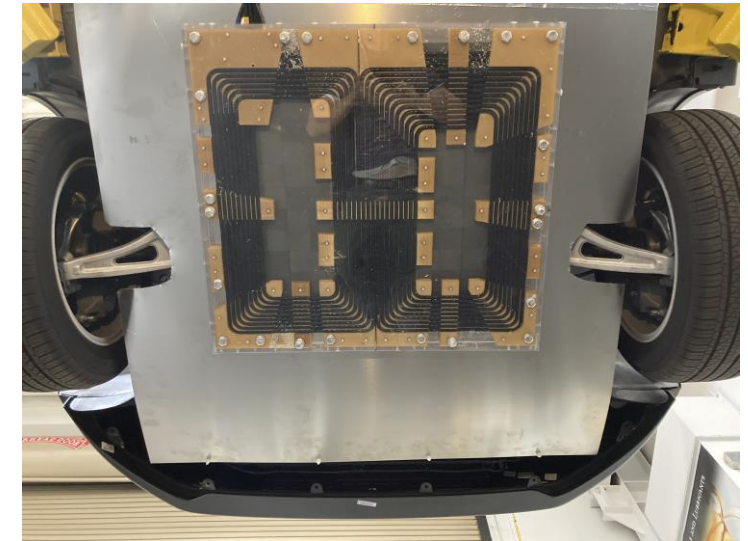
Measured parameters of 200 kW DWPT system in stationary mode



200 kW DWPT system tested in stationary mode with transmitter embedded in concrete



200 kW DWPT system with the receiver coil mounted on Hyundai Kona



200 kW DWPT system with the receiver coil mounted on Hyundai Kona

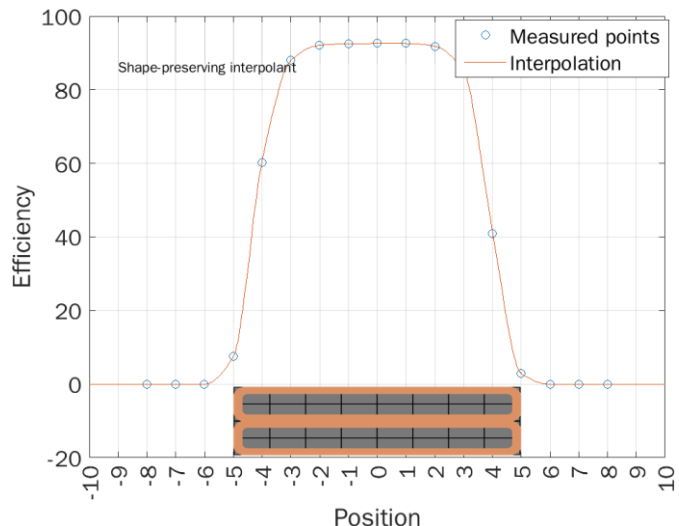
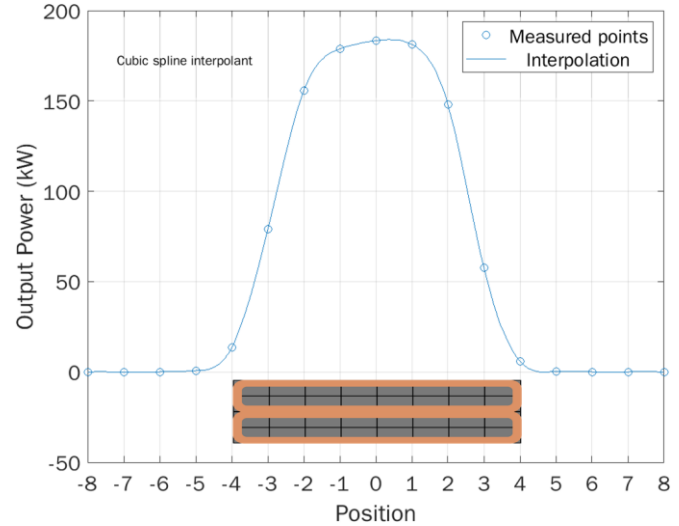
Technical Accomplishments FY23: Validation of Power Transfer Capability in Dynamic Mode

Validated power transfer capability in dynamic mode

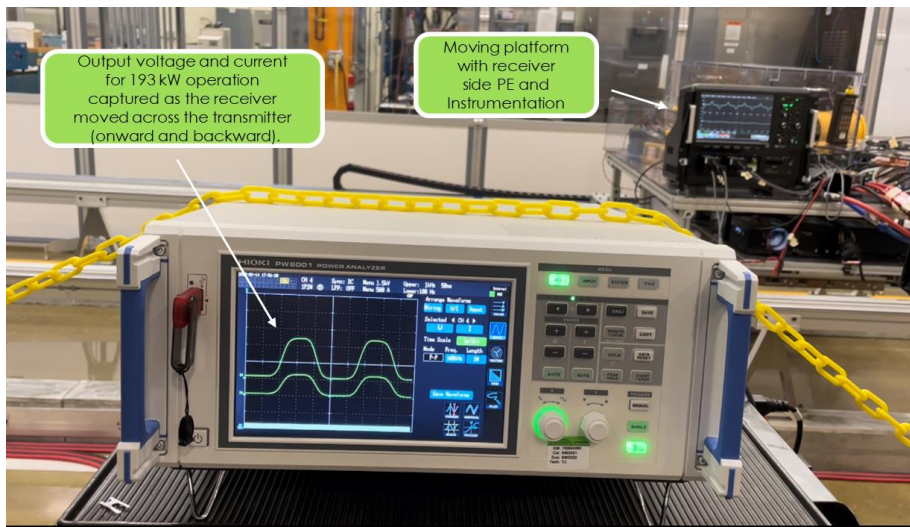
- Validated 4 ground side power electronics units
- Validated 200 kW dynamic operation up to 6 m/s
- Test rig capability
 - Track length: 18 m
 - Payload capability: 100 Kg
 - Speed: ~9 m/s (20 mph)



Dynamic inductive charging setup in the laboratory



Profile of measured output power and efficiency of 200 kW dynamic charging system measured along the length of the transmitter at discrete points



Experimentally measured output voltage and current corresponding to 193 kW operation

Technical Accomplishments FY23: Conducted Lift Test of Transmitter set in Epoxy Grout

Completed preliminary structural test by conducting a lift test

- First concretized coil was evaluated by conducting lift test
- Surface cracks which had occurred after initial setting and curing did not propagate during or after the lift test
- No buckling or deflections observed



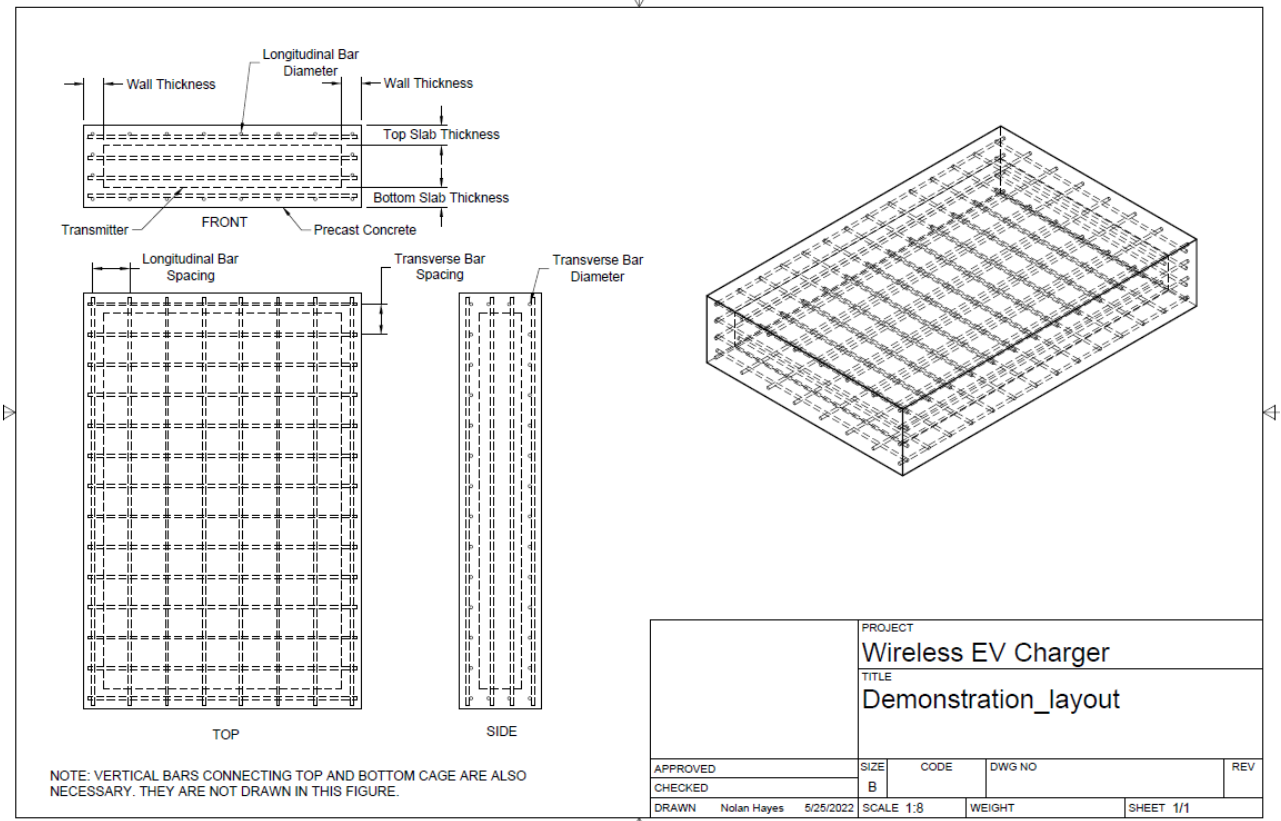
200 kW DWPT system with transmitter set in precast Master flow 648 Epoxy Resin Grout

Technical Accomplishments FY23: Preliminary Structural and Deployment Focused Design Review

Preliminary structural and mechanistic design review of 200 kW DWPT transmitter



200 kW DWPT system with transmitter set in precast Master flow 648 Epoxy Resin Grout



Technical Accomplishments FY23: Preliminary Structural and Deployment Focused Design Review

- Preliminary design study was conducted to prepare for successful embedment for roadway integrated demonstration
- Equivalent design specification
 - Vehicle axle load of 8000 – 32,000 Lbs (Kona 3200 Lbs)
 - Precast concrete shell was designed as a buried box culvert (coil provides no structural support)
 - Loading scenarios were derived using American Association of State Highway and Transportation Officials (AASHTO) Load Resistance and Factor Design (LRFD)
 - Strength capacity of the top slab of the box culvert was calculated for a variety of reinforcement layouts using American Concrete Institute ACI 318 and 440
 - Deflection (displacement) of the top slab was also checked to remain under the limit of $L/360$ to minimize the possibility of damage to the embedded wireless charger device.

Technical Accomplishments FY23: Preliminary Structural and Deployment Focused Design Review

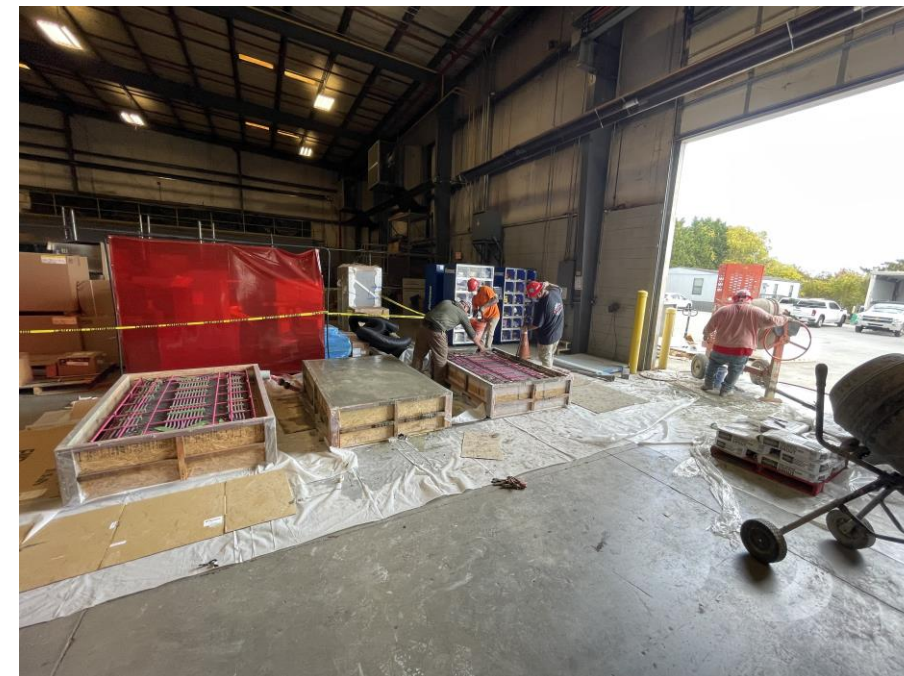
Vehicle	Axle Load	Top Slab Thickness (in)	Short Direction		Long Direction		Reinforcement Size	Diameter (in)
			Reinforcement Size	Reinforcement Spacing (in)	Reinforcement Size	Reinforcement Spacing (in)		
Small vehicle	8000 lb	2.5	#5	4	#5	6	#4	0.5
Small vehicle	8000 lb	2.5	#6	6	#5	6	#5	0.625
Small vehicle	8000 lb	2.5	#8	12	#5	6	#6	0.75
Small vehicle	8000 lb	3	#5	6	#5	6	#8	1
Small vehicle	8000 lb	3	#7	12	#5	6		
Small vehicle	8000 lb	4	#4	6	#5	6		
Small vehicle	8000 lb	4	#6	12	#5	6		
Heavy Truck	32000 lb	3	#8	4	#5	6		
Heavy Truck	32000 lb	4	#6	4	#5	6		
Heavy Truck	32000 lb	4	#8	6	#5	6		

- Observations

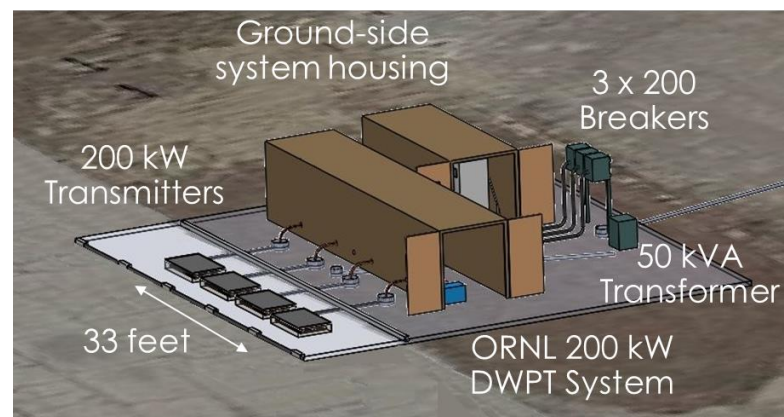
- Reinforcement in the short direction supports loading
- Reinforcement in the long direction is needed for lifting
- Top slab thickness required reduces if reinforcement diameter increases or spacing between reinforcement reduces
- If the loading increases the reinforcement size increases

Status of High-Power DWPT System Validation in ACM

- Planned demonstration/characterization on the road at ACM in summer 2023
- Analyze the power transfer characteristics, including the following:
 - Efficiency, power, and energy profiles
 - Misalignment tolerance
 - Thermal profiles
 - Emissions and shielding
 - Use cases
 - Environmental factors



Coils with fiber glass re-enforcement being concretized



Planned layout for demonstration at ACM



4 primary side HF power electronics units



Concretized DWPT transmitters at ACM

Technical Accomplishments (INL): dWPT Data Acquisition System Completed and Operational Functionality Verified

Goal: Complete data acquisition system for dWPT ground-side and vehicle-side measurements

Issue: Measurement of transient, high-speed in-motion power transfer requires synchronized high-speed data collection from many measurement sources (electrical, alignment, EM-field, veh. speed, etc.)

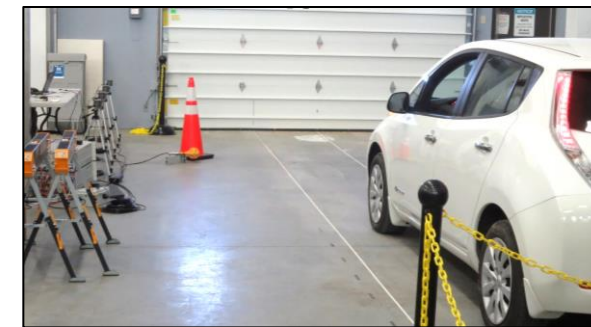
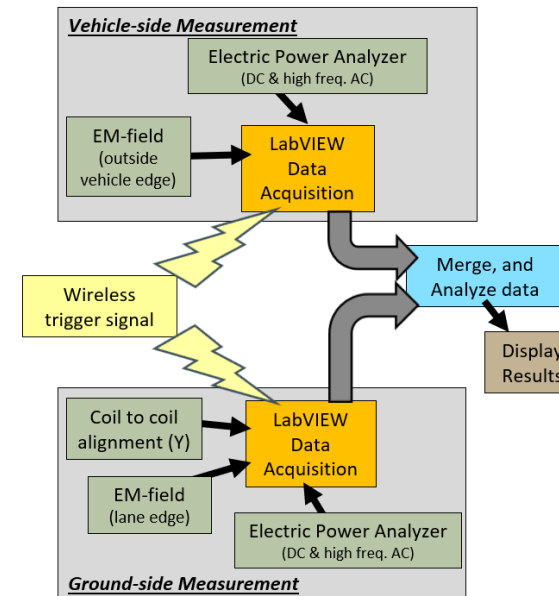
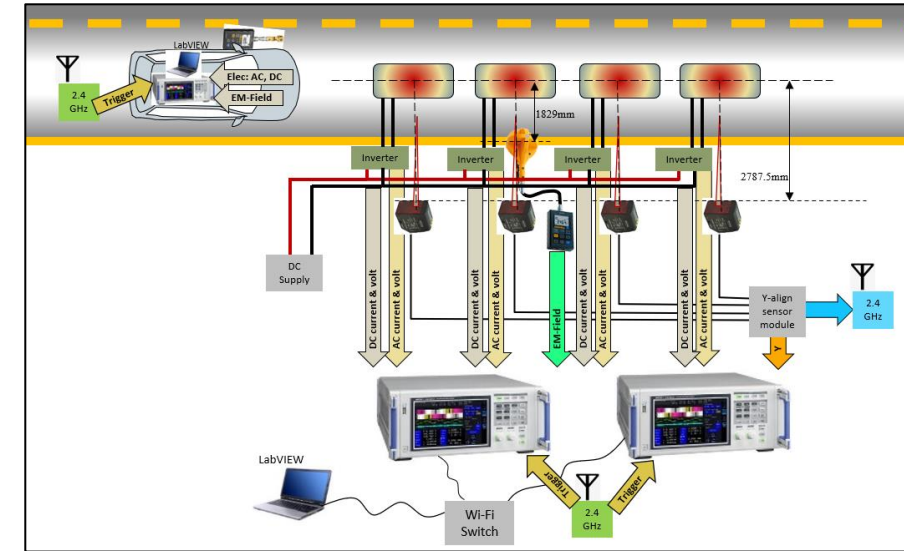
Data acquisition system completed and demonstrated functionality using a production EV

Data Acquisition Features:

- Power analyzers for electrical measurements of the ground-side and vehicle-side power flow
- EM-field probes at the lane's edge and at the edge of the vehicle
- Wireless synchronous trigger to align data capture
- Non-contact distance sensors to measure the vehicle's lane alignment when traveling over each ground coil
- Driver's Alignment Aid (DAA) to enable testing with repeatable lane alignment or misalignment (i.e. coil to coil Y-alignment)

Two rates of measurement

- 1MHz for waveform transient analysis, calibration tuning, and debug
- 100Hz calculated measurement values for fast results of power transfer, efficiency, EM-field, & misalignment



Response to Previous Year Reviewers' Comments

Reviewer Comment: The reviewer commented that the project has been great with the focus on LD EVs, but this could be more applicable to MD/HD EVs.

Reply: This is a very valid observation, and we are exploring use-case analysis for MD/HD EVs. Also, from a system perspective the 200 kW system can be utilized for MD/HD EVs with multiple secondary receivers.

Reviewer Comment: The reviewer remarked the project team has a good group of lab staff, OEMs, and academia. While no transportation agencies or utilities are part of the team




Reply: The team has initiated and are having ongoing discussions with FHWA and several DOTs and stakeholders.

Reviewer Comment: The reviewer suggested that the team expand to include safety and cost analysis to examine non-technical barriers to project feasibility.




Reply: The team has considered EM safety inside the vehicle and at the edge of the lanes. Safety will be of priority while doing real-world tests at ACM. The EVs at Scale consortium is further exploring the cost analysis and non-technical barriers.

Collaboration and Coordination with Other Institutions

Laboratory partners:

	<ul style="list-style-type: none"> • Project lead • 200 kW power dynamic EV charging system design, simulation, hardware development, vehicle integration and validation
	<ul style="list-style-type: none"> • Design of active and passive shielding and data acquisition system for 200 kW dynamic EV charging system
	<ul style="list-style-type: none"> • High level cost study of high-power dynamic wireless EV charging • Study of large-scale deployment scenarios of high-power dynamic EV charging

Coordination with Other Institutions:

	<ul style="list-style-type: none"> • Kona EV for high power dynamic wireless EV charging demonstration • Engineering support and guidance for integration of DWPT system with the vehicle
	<ul style="list-style-type: none"> • Site for 'electrified mile' dynamic charging demonstration (FY21) • Infrastructure and support for demonstration
	<ul style="list-style-type: none"> • Evaluation and guidance of making the ground side coils and power electronics roadworthy

Remaining Challenges and Barriers

- Validating efficient DWPT at 55 mph+
- Evaluate the effect of elements on power transfer profile

Any proposed future work is subject to change based on funding levels

Proposed Future Research

Research:

- Analyze the power transfer characteristics including
 - Efficiency, power & energy profiles
 - Safety
 - Misalignment tolerance
 - Thermal profiles
 - emissions and shielding
 - Interoperability
 - environmental factors

Tasks/Milestones:

- Validate and map performance of vehicle integrated 200 kW dynamic charging system at ACM
- Integrate INL's passive EM-field shielding solution with ORNL's 200kW DWPT system

Any proposed future work is subject to change based on funding levels

Summary

- **Relevance:** Dynamic EV charging can significantly alleviate range anxiety and concurrently reduce the on-board battery requirement (weight and cost reduction)
- **Approach:**
 - Optimal range of power transfer level for feasible dynamic wireless EV charging system has been identified (150 kW – 235 kW)
 - Key R & D necessary to realize a practicable 200 kW dynamic charging system have been identified and being pursued for hardware development
 - Benchtop validation of power electronics and couplers validated to rated power thereby validating 200 kW power transferring capability
 - Dynamic inductive charging is operational and will be used to perform controlled dynamic charging tests to optimize control and efficiency
- **Technical Accomplishments:**
 - Completed high-Level cost and feasibility studies and identified architecture suitable for 200 kW DWPT
 - Completed design, development, and laboratory benchtop validation of primary and secondary side power electronics design of 200 kW DWPT system
 - Completed design, development, and validation of DWPT coils and tuning network
 - Identified and developing active and passive EM-field shielding solutions for 200kW DWPT system
 - Developing data acquisition system necessary for real-world implementation of 200 kW DWPT system
 - Analyzed Feasibility of Large-Scale Deployment of DWPT system on Primary Roadways in Atlanta
 - Developed E-Roads Tool for Analyzing Large-Scale Deployment of DWPT system on Roadways in a Region
 - Completed laboratory validation of 200 kW DWPT in stationary mode
 - Completed laboratory validation of 200 kW DWPT system
- **Collaborations and Coordination with Other Institutions:**
 - HATCI providing an EV and support and guidance on vehicle-integration of DWPT system
 - ACM providing infrastructure and physical proving grounds for validation of 200 kW DWPT system
 - VTTI providing guidance and support to develop roadworthy DWPT coils
- **Future Work:**
 - Validate performance and functionality of 200 kW DWPT system at ACM

Any proposed future work is subject to change based on funding levels