UNPLUG WITH

WAVE

Wireless Advanced Vehicle Electrification

Project ID: elt240

Wireless Extreme Fast Charging for Electric Trucks (WXFC-Trucks)

Principal Investigator, Michael Masquelier

Wireless Advanced Vehicle Electrification

June 13, 2019

LA DWP Los Angeles Department of Water & Power

UtahState University

Schneider Electric

Cummins

LA THE PORT OF LOS ANGELES

TTSI

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WXFC-Trucks | Overview

Timeline

- Project start date: August 2018
- Project end date: November 2021
- Percent complete: 10%

Budget

- Total project funding
  - DOE share: $4,292,137
  - Contractor Share: $5,546,103
- Budget Period 1:
  - DOE share: $1,356,828
  - Contractor Share: $2,113,903
- Budget Period 2:
  - DOE share: $2,616,130
  - Contractor Share: $3,015,537
- Budget Period 3:
  - DOE share: $319,179
  - Contractor Share: $416,664

Barriers

- Meeting the window of time to deliver a medium voltage feed to the charge site
- Obtaining the necessary permits for the project
- Acclimating drivers to electric vehicles requires changing driver habits (or other personnel) for plugging in the vehicles and aligning the trucks over the wireless chargers

Partners

- WAVE, Inc. – Project Lead
- Cummins Inc. (Cummins)
- Schneider Electric (Schneider)
- Utah State University (USU)
- Port of Los Angeles (POLA)
- Total Transportation Services Inc. (TTSI)
- Los Angeles Department of Water and Power (LADWP)

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WXFC-Trucks | Relevance

Impact

- The California Air Resource Board shows that 41% of all greenhouse gas emissions (429.5 $MMTCO_2e$ in California in 2016) is due to transportation
- 7.8% of all greenhouse gas emissions was from heavy duty trucks (https://www.arb.ca.gov/cc/inventory/data/graph/treemap/sector_activity_2000-16.htm)
- Enabler for this major pollution transportation sector to become all-electric
  - Fully charged vehicles in roughly 20-minutes means minimal down time to refuel and minimal impact on existing route planning
  - No cables means hands-free instant start of charging with no special personnel required
- Overcoming the charging time obstacle leads to a 3x to 4x reduction in actual fuel costs for vehicle operation
- Accelerate manufacturing and deployment of electric heavy-duty trucks

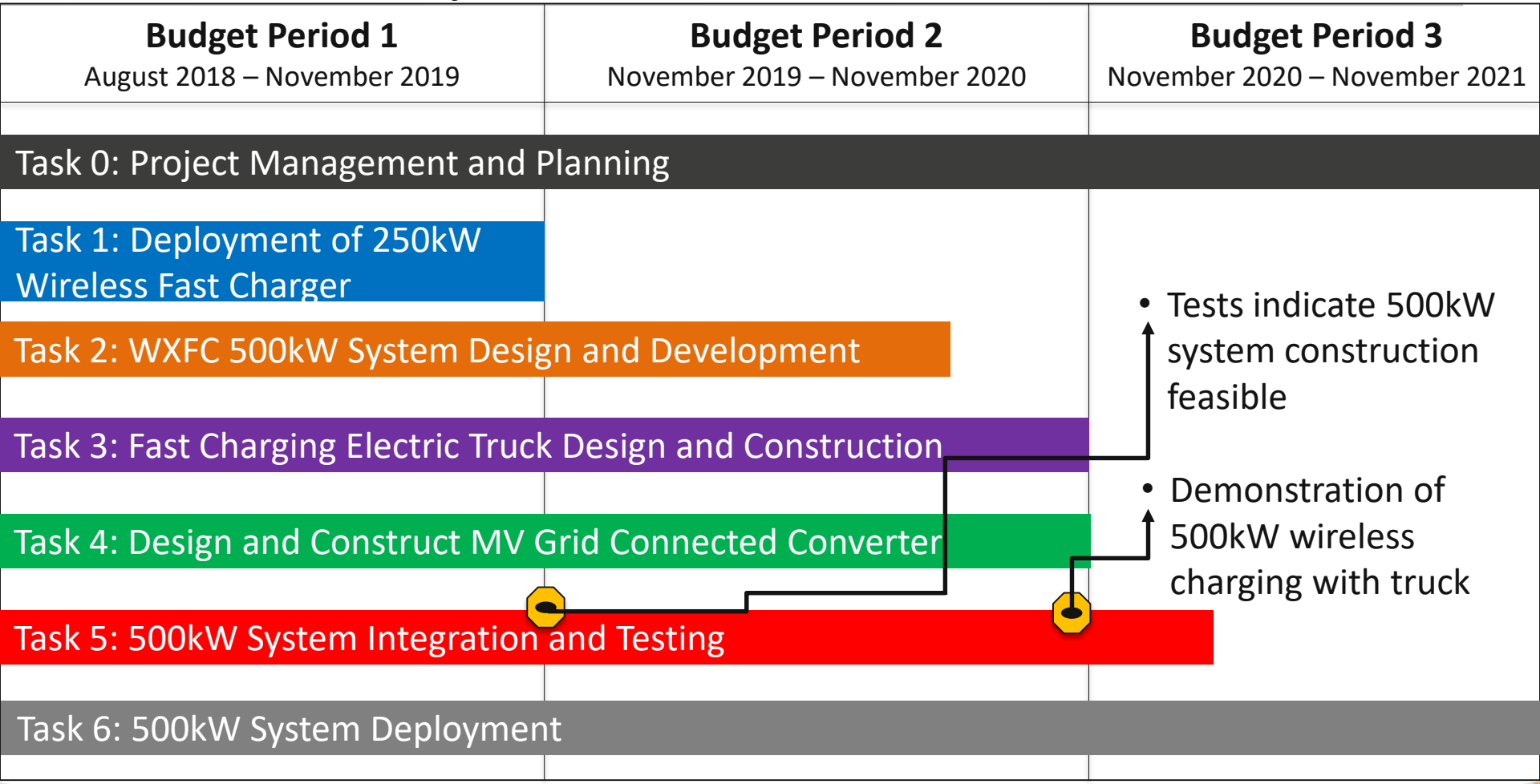
Objectives

- Wireless extreme fast charging
- MV grid to DC converter
- Extreme fast charging capable electric truck

WXFC-Trucks | Relevance

FOA Objective	WXFC-Truck Expected Outcomes
Recharge battery in half the time	• New system with 500 kW wireless charging
Develop and verify vehicles equipped with XFC, charger installation and demonstration	• W-XFC system deployment and operation at POLA with two Class-8 trucks customized to support XFC. • Deployment in two stages. First early deployment with 250 kW charging and second final deployment at 500 kW • Combined, over two years of evaluation data and best practices
System design and grid infrastructure impact	• Direct MV 3-phase AC to DC single stage conversion solution to reduce grid integration costs, system size and weight, and improve efficiency.
Catalyze manufacturing and adoption of electric trucks	• Project goal targets key barrier to market adoption • Over two years of system hardware demonstration and evaluation are performed at one of the world's highest volume shipping ports at a critical time with zero emission requirements in place by 2035

WXFC-Trucks | Milestones



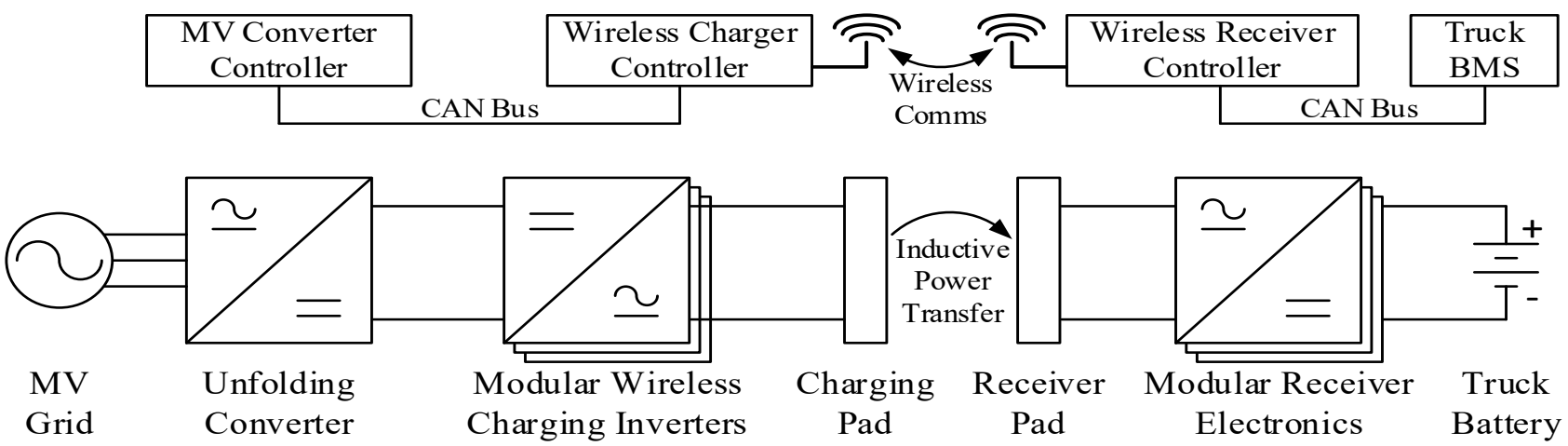
WXFC-Trucks | Approach

Design and simulation

Industrialization

Prototyping

Field operation and evaluation



Block diagram of the WXFC system from MV grid to truck battery.

WXFC-Trucks | Approach

500kW MV Grid Connected AC/DC Supply Approach

- 3-phase unfolder with a soft DC bus two-level output
- Develop the 3-phase unfolder to achieve direct MV grid connection with switches commutating at the line frequency
- Design the series stacked isolated DC/DC converters to achieve the voltage step down function from MV naturally with near unity conversion ratio to obtain high efficiency

Extreme Fast Charging Capable Electric Truck Approach

- Investigate appropriate battery chemistry (LTO cells or NMC cells)
- Design custom thermal management for the cell to facilitate charging at 3C
- Select appropriate battery pack capacity and cell chemistry to integrate with electric powertrain applicable to Class 8 drayage applications

WXFC-Trucks | Approach

500kW Wireless Charging System Approach

- Deploy 250kW charger with initial truck integration to demonstrate appropriate charging gap and form factor
- Leverage deployment experience with 250kW charger
- WAVE has experience integrating with different OEMs

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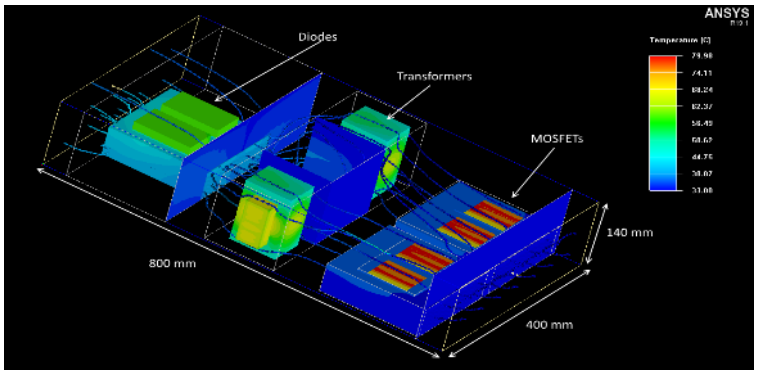
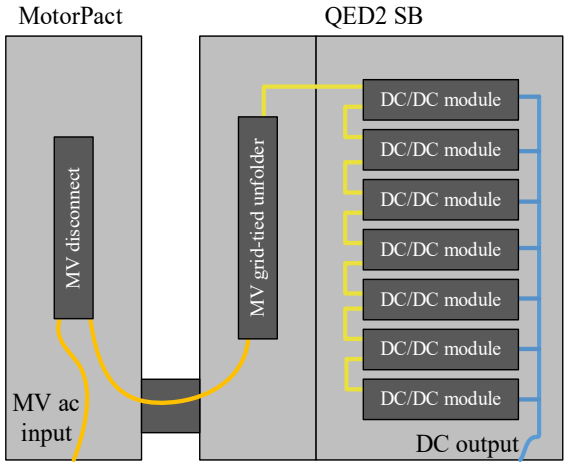
WXFC-Trucks | Technical Accomplishments & Progress

MV Grid Connected AC/DC Supply Progress

- Active coordination between USU, WAVE, and SE on converter specifications and the interface with the wireless charger
- Selected and ordered the major power components with long lead time for the ac-dc converter
- Completed the thermal analysis for the power semiconductor devices and transformers to determine the system mechanical layout and cooling solution
- Proposed a plan for the MV rated enclosure for the power converter with minimized footprint
- Developed a low voltage low power prototype to validate the modeling and control strategy
- Started to design the transformer for the dc-dc converter modules





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WXFC-Trucks | Technical Accomplishments & Progress

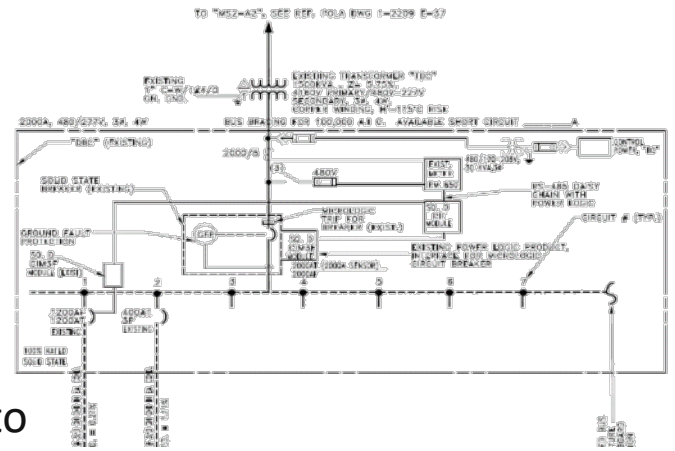
250kW Wireless Fast Charger Integration Progress:

- Initiated contact with five class-8 truck vendors and enlisted TTSI to assist in the approval of a truck to be the recipient of the 250kW installation
- Site for the 250kW charger and primary equipment location has been determined

WXFC System Design Process:

- Pad geometry simulated that greatly reduces stray fields to enable the higher power to be safely transferred over the potentially wider gap
- Impacts on site design to accommodate the additional power have been evaluated
- Truck mounting system requirements for the new pad-set have been communicated to the truck vendor

Infrastructure Design (In-progress):

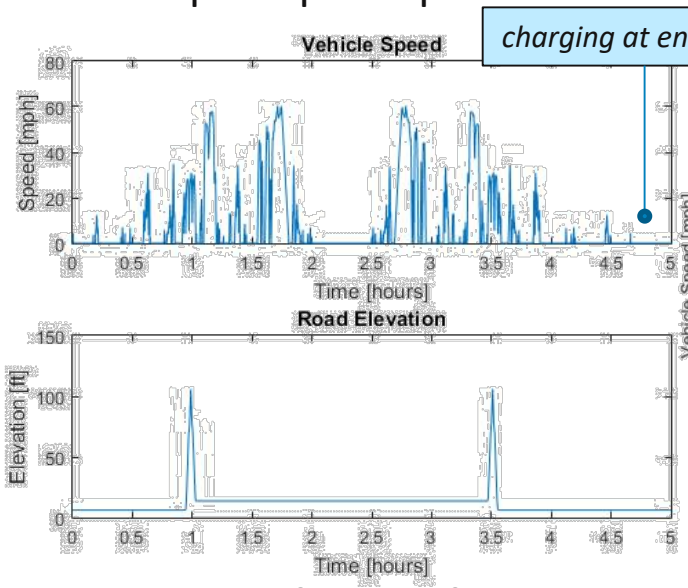


WXFC-Trucks | Technical Accomplishments & Progress

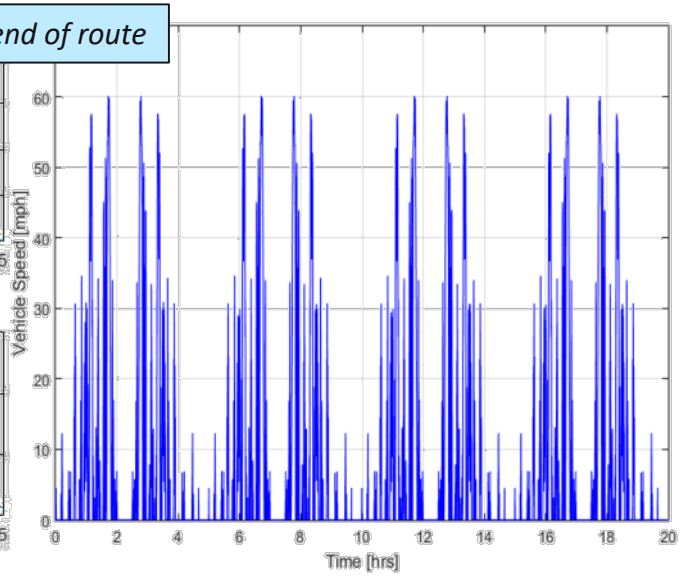
Duty Cycle Requirements for Drayage at POLA

Using NREL drayage cycle and bridge network near POLA, constructed a round-trip duty cycle of:

- 40 miles selected as it exceeds majority of TTSI's typical local drayage routes
- TTSI desires ability to operate fast charging battery electric trucks up to 20 hours/day
- Overall work day duty cycle: **four** 40-mile round-trips including charging, loading, low-speed port operation



40-mile roundtrip



Four round-trips per day

Characteristic	
Distance (mi)	159.77
Time (hr)	19.987
Average Total Speed (mph)	7.94
Average Moving Speed (mph)	24
Idle Time (hr)	3.37
Stops/Mile (1/mi)	1.935
Characteristic Acceleration (m/s2)	0.117
Aerodynamic Speed (mph)	42.16
Kinetic Intensity (1/mi)	0.5361

Work day route metrics

WXFC-Trucks | Technical Accomplishments & Progress

Truck & Powertrain Design

- Kenworth T680 Series
- 236” wheelbase
- Air suspension on front and rear axles to support kneeling over primary plate
- Overall truck length with a 45’ container is < 65’
- Powertrain
  - 330 kW of continuous power to achieve ≥30 mph when fully loaded on Vincent Thomas Bridge

Battery Selection

- Battery selected to achieve useable energy and charge power requirements:
  - Useable energy of > 140 kW-h
  - Supports charge power of 500 kW
- Selected battery:
  - 212 kW-h total capacity
  - Supports 500 kW (near 3C charge) for life of project
  - NMC/graphite battery cell chemistry
- Thermal management during extreme high power charging is a focus area of study

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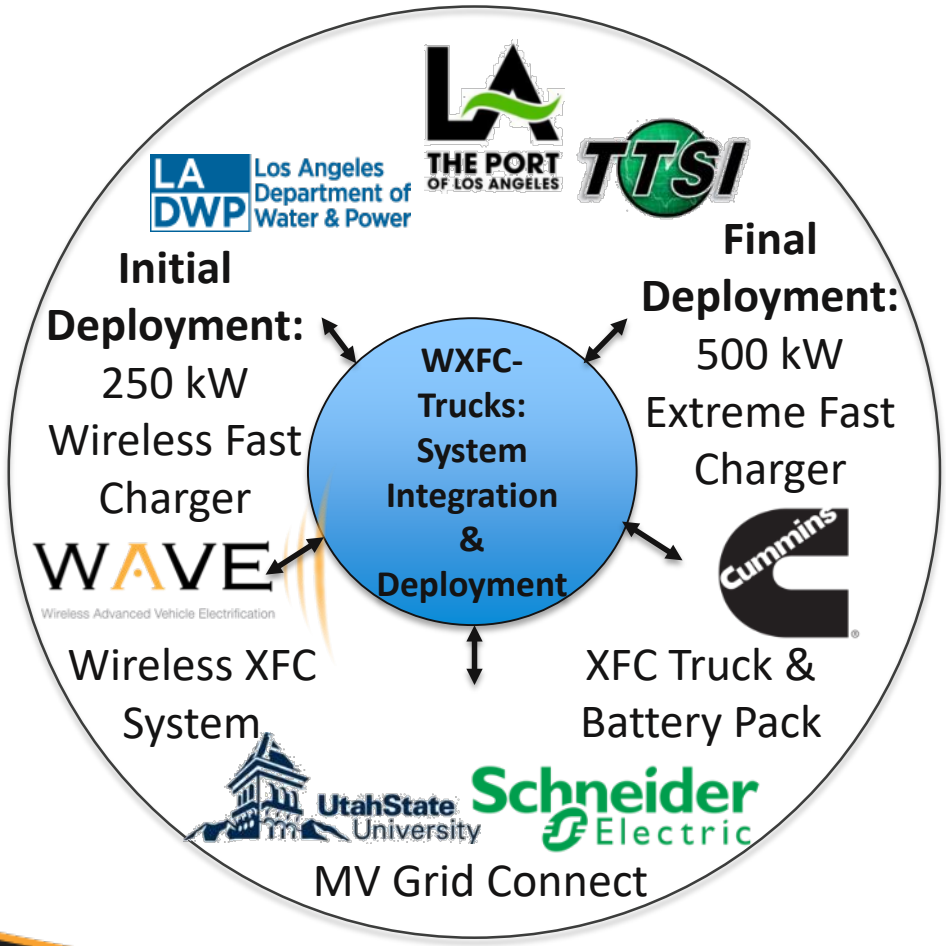
WXFC-Trucks | Response to Previous Reviewer Comments

- **This project has not been reviewed.**

WXFC-Trucks | Collaboration & Coordination with Other Institutions



- **The Port of Los Angeles** – Deployment Partner
- **Los Angeles Department of Water & Power** – Deployment Partner
- **Total Transportation Services Inc.** – Port Trucks Partner
- **Cummins** – Truck Integration and Electric Drivetrain Partner
- **Utah State University** – Research Partner
- **Schneider Electric** – Electrical Supplier, Industrialization Partner

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WXFC-Trucks |Remaining Challenges & Barriers

MV-Grid Converter:

- Confirm converter layout to satisfy the MV related high voltage isolation requirements according to UL standard
- Design of the high frequency, high power and high isolation voltage transformer for high efficiency and reliable system operation
- Validate the control strategy of the new topology and interactions between the AC-DC and inverter stages

250kW System:

- Selection of a truck that will provide the high-power charging interface required
- Demonstrating the 250kW transfer over the wide gap

500kW System:

- Difficulty increasing power density
- Simulation to a sufficient level that a real solution is demonstrable for both pads and equipment

WXFC-Trucks |Proposed Future Research

- Complete the converter voltage map and enclosure design according to the UL standard
- Demonstrate the dc-dc power converter module with 80 kW rated power
- Complete construction of the 3-phase MV unfolder
- Design thermal management system for battery pack
- Extreme fast charged electric truck construction and testing
- Integration with wireless charging hardware
- Complete simulation of variants of the pads to determine an optimal 'real world' solution, showing:
  - Total power transfer with estimated losses
  - Sensitivity to gap and alignment changes
  - A 'small' form factor
- 500kW wireless charging demonstration with truck
- WFXC system and trucks operation data analyzed and reported

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

WXFC-Trucks |Summary

This project brings together all three critical components needed to solve the barrier for adoption of electric heavy duty vehicles:

- High-efficiency MV grid supply to lower energy costs and reduce total footprint of equipment
- High-efficiency, high-energy density wireless extreme fast charger
- An all-electric vehicle capable of high C-rate charging and equipped to handle a wireless charging system

This project's overall system approach is driving research that will result in a highly cost-effective solution that will make adoption of all-electric fleets not only viable, but very compelling.

Critical success factors include:

- Development of a 500kW wireless charging system
- Development of a Class-8 truck powertrain with a battery pack capable of reliably and repeatedly charging at a greater than 3C-rate up to 500kW
- Development of a modular direct MV 3-phase AC to DC power converter