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**Capacitive Charging System
for
High Power Battery Charging**

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Objective

This project will design, build, demonstrate, and document a Level 3 capacitive charging system, and it will be based on the existing PEZIC prototype capacitive coupler. The system will comply with the SAE RECOMMENDED PRACTICE J2293. The capacitive coupler will be designed to transfer power at a maximum of 600 kW, and it will transfer power by electric fields. The power electronics will transfer power at 100 kW. The coupler will be designed to function with future increases in the power electronics output power and increases in the amp•hours capacity of sealed batteries. Battery charging algorithms will be programmed into the control electronics. The finished product will be a programmable battery charging system capable of transferring 100 kW via a capacitive coupler. The coupler will have a low power loss of less than 25 watts when transferring 240 kW (400 amps). This system will increase the energy efficiency of high power battery charging, and it will enhance mobility by reducing coupler failures. The system will be completely documented. An important deliverable of this project is information. The information will be distributed to the Army's TACOM-TARDEC's Advanced Concept Group,

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and it will be distributed to commercial organizations by the Society of Automotive Engineers. The information will be valuable for product research, development, and specification. The capacitive charging system produced in this project will be of commercial value for future electric vehicles. The coupler will be designed to rapid charge batteries that have a capacity of several thousand amp•hours at hundreds of volts. The charging system built here will rapid charge batteries with several hundred amp•hours capacity, depending on the charging voltage.

Background

A quick disconnect system is required in order to transfer electrical power safely and reliably for both military and commercial electric vehicles. The military is considering electric vehicles, under 20 tons, for combat. The heaviest of EVs, including electric buses, will require larger power supplies, and a coupler capable of transferring the maximum power has not been developed. Several approaches have been applied to solve this problem. In particular, the automotive industry has been experimenting with both inductive and conductive charging systems. These technologies have been in use for quite some time and detailed technical analyses are available. However, the attempt to transfer relatively high power to a primary transportation vehicle on the order of several kilowatts, is a recent advance. These systems have technology specific electromechanical problems, and the extent of field problems inherent to these systems is now being discovered. These problems become more significant as the power transferred increases. A recent example of the potential connector problems is the 10 million cars recalled by Fisher-Price. Their product, POWER WHEELS, is charged at 1 amp via a conductive coupler. All the couplers were replaced in this recall. Typically, it will take a minimum 6 months for potential contact problems to arise in environmentally exposed connectors.

Existing Conductive Charging Systems are not able to rapid charge batteries that have relatively high capacity at several hundred volts. The existing on road electric vehicles are using batteries with around 100 amp•hours capacity. Whereas, golf carts use batteries rated at 220 amp•hours, and fork lifts use batteries rated at 1,000 amp•hours, which require over 1,000 amps to rapid charge. In order to rapid charge these higher capacity batteries, a charger will be required to have output currents well over 200 amps. No conductive systems have been approved by UL that can rapid charge high capacity batteries at the voltage needed for heavy electric vehicles. Conductive systems have the electromechanical problems of arcing. Significant arcing can be caused by dust as small as 2×10^{-5} cm cross sectional area, or by films on the contacts. Arcing of contacts at very high power will create significant coupler failures. This is the reason that so many fine auto makers have chosen inductive charging.

The maximum output power, commercially available, for an inductive charging system is less than 30 kW. Transformers, as used in the inductive coupler, usually have nominal power losses between 5 to 10 percent. For a given transformer, these losses increase as the power and frequency increase. Transformer losses occur from skin effect, proximity effect, and core losses. The inductive coupler is oil cooled at only 25 kW. The inductive charger output power levels are not currently adequate for the high power required to rapid charge future military and commercial vehicles. As power levels increase for electric buses and the like, the charging power will exceed 240 kW.

This project will develop a production prototype capacitive coupler that is able to transfer 600 kW. This patented and novel approach for transferring high power is developed to the prototype level. Dr. Rajendra Singh, of Clemson University, has provided an expert opinion on the future performance of this technology. A calculation shows that at 240 kilowatts, the capacitive coupler will dissipate less than 25 watts (a loss of .01 percent). At 240 kW, the voltage across the coupler will be below 20 volts. The low power loss and voltage of the capacitive coupler will provide the means for increased reliability of the charging architecture, which will increase the operating reliability of EVs. The high efficiency of the capacitive charging system will decrease the total power loss of the electric utility grid system that charges electric vehicles.

Task Descriptions:

Task 1 - Specify the Production Capacitive Coupler

This project will fully specify the capacitive coupler, and it will utilize the ultra capacitor development performed by NASA's Lewis Research Center. NASA has implemented a high energy density ultra capacitor into its hybrid electric bus program, and their experience will be of value here. The dielectric material will determine the performance of the coupler. Dr. Rajendra Singh, of Clemson University, will develop the materials for the coupler and specify a manufacturer. He is an expert in high dielectric constant materials and their processing. The work that Dr. Singh conducts will determine the final specifications of the capacitive coupler. PEZIC will contract blueprints and prototype tooling for the coupler. PEZIC will subcontract to QMI, in Winchester, Kentucky, which will build the tooling and other prototypes materials, and it will subcontract the manufacture of prototype injection molds and parts to TSI of Dayton, Ohio.

Task 2 - Develop Charger Control Software and Hardware

The on-board vehicle controls are currently in development. PEZIC is developing on board controls that may be used in this project, with funding from the Department of Energy. These controls will be designed to be interchangeable with different power electronics. The flexible control board approach will reduce the cost and time of developing new charging systems. The DoE funding will also be used to develop a Battery Charger Test Stand and a Load Simulator. The Load Simulator can be substituted for a battery pack in a laboratory setting. The test stand will monitor the charging systems power factor, state of charge, efficiency, and charge profiles. The Test Stand and Load Simulator will facilitate testing of the battery charger hardware.

Task 3 - Develop Power Electronics

The existing power electronics will require modification to function properly with the capacitive coupler. Utilizing work previously performed on advanced charger hardware will minimize the electronics development. The electronics for the inductive charging system are very similar to the electronics required for this project. The manufacturer of the inductive charger electronics (EVSE) can modify the hardware to function with the capacitive coupler. It is anticipated that the charger will transfer power at resonant frequency. The team member that will supply the power electronics has not been chosen, but several candidates have been identified including SHOTT POWER, AeroVironment, Toyota, Hughes Power, and General Electric. Other charger manufacturers that have not developed inductive charging hardware may be solicited.

Task 4 - Assembly of the System

The system will be assembled and tested. Preliminary tests will indicate the functioning of the capacitive charging System. Engineering changes will be made as required. After assembly and functional testing, the system will be sent to Georgia Tech's NEETRAC for further test analysis.

Task 5 - Document the System

The efficiency of the system will be documented. After laboratory tests, the charging hardware will be interfaced into a vehicle for field tests. The vehicle manufacturer has yet to be determined. The finished charging system will be sent to the appropriate facility, such as UL, for failure analysis.

Task 6 - Final Report

The final report will document the engineering analysis of the capacitive charging system and its integration into the vehicle. NEETRAC will document the system's efficiency, the laboratory tests, the field tests, and the required engineering changes.

Milestone List:

Milestone 1 - Capacitive Coupler

- Milestone 1-1** Specify the capacitive coupler
- Milestone 1-2** Blueprints of capacitive coupler
- Milestone 1-3** Production prototype tooling
- Milestone 1-4** Production prototype capacitive coupler

Milestone 2 - Charger Controls

- Milestone 2-1** Control board and algorithms
- Milestone 2-2** Battery charger test stand
- Milestone 2-3** Battery load simulator

Milestone 3 - Power Electronics

- Milestone 3-1** High frequency power supply (EVSE)

Milestone 4 - Assemble and Test System

- Milestone 4-1** Assembled and functional capacitive charging system
- Milestone 4-2** Test and laboratory evaluation

Milestone 5 - Documentation

- Milestone 5-1** Engineering analysis
- Milestone 5-2** Laboratory test report
- Milestone 5-3** Field test report
- Milestone 5-4** UL certification

Milestone 6 - Final Report

- Milestone 6-1** Final Report

Total Project Cost and Duration

The estimated cost is \$532,175.00 Match funds are provided at a one to one ratio or greater. Match funds consist of in-kind contribution and cash payments. The project will last 24 months.