Joint Transportation Research Program

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Feasibility Study and Design of In-Road Electric Vehicle Charging Technologies

Introduction

Electric roadways (ERs) or dynamic wireless charging (DWC) lanes offer a dynamic and wireless charging method that has the potential of giving electric vehicles (EV) limitless range while they are moving. Heavy-duty vehicles (HDVs) are expected to be early adopters of the DWC technology due to the increased benefits offered to vehicles that are travelling on fixed routes. The goal of this project was to assess the feasibility of ERs in Indiana and design a test bed for in-road electric vehicle charging technologies. The project had the following objectives:

- Conduct a literature review and research best practices.
- Determine selection criteria and identify candidate locations for DWC lanes based on a comprehensive list of demand-related, cost-related, EV-related, and other criteria.
- Design a flexible test bed using modeling and simulation techniques: determine the overall architecture of the interconnection with the electric grid and explore the architecture of the onboard pick-up and charging system.
- Assess the financial feasibility and risk of the technology.
- Offer recommendations to INDOT regarding the implementation of the technology.

Findings

The most suitable locations for implementing DWC lanes are on interstates that are characterized by high truck traffic (i.e., on I-70, I-65, I-465, I-90, and I-94), near airports and ports, and away from EV charging stations. Access to the power network is also important. A relatively small portion of I-65 S (between Indianapolis and Louisville), could be powered at 100% market penetration. The percentage of roadway powered rapidly increases as market penetration decreases.

A DWC power system that is capable of powering HDVs, assuming 100% penetration level and purely electric drivetrains, was designed for a suitable road segment on I-70. For 100% penetration, an average load of 2.2 MW/mi is predicted. An average power consumption of 0.6 MW/mi is obtained for 25% penetration. Significant power ramp rates that can reach as high as ±15 MW/s are also observed.

The multi-objective design of the power conversion and wireless transmitter/receiver system of the technology proves the technical feasibility of the technology. Adequate power can be transmitted across the relatively large airgap (26 cm) between the transmitter and receiver cores. To overcome the large airgap, the transmitter conductors and core will introduce loss (kW-level) into the pavement. The overall system size (cost) and loss can be significantly reduced if the airgap between the transmitter coil (in the roadway pavement) and receiver coil (on the vehicle) can be reduced.

Using I-65 S as a case study, it was found that DWC is economically feasible for the developer and financially competitive for the EV owner at high and medium future projections of EV market penetration levels. The DWC system costs were in the range of $6.3–6.6 M/lane-mile, assuming full lane prefabricated construction. From an operator's perspective, the ER technology is competitive at a breakeven point of 30 cents/kWh. Payback periods for an early adoption deployment of the technology are found to range between 20 and 25 years. Risk analysis unveiled high risks associated with lower projected EV penetration levels, while low risks were associated with a penetration level of 75% for medium and heavy-duty trucks within a 40-year project implementation period.

Implementation

Implementing the DWC technology jointly with major pavement preservation activities is recommended. Several pavement replacement activities are scheduled for the near future for segments on I-70 that can be potential locations for an ER pilot. While the most suitable locations for the outright commercial operation of this technology are on interstates, a small testbed on a lower-class road project is needed to prove the technology in the field, under real environmental factors and traffic loads.

Based upon the case study on I-65 S, the existing substations are unlikely to serve future DWC needs for HDVs. Thus, consideration should be given to the construction of new substations to support EVs as market penetration expands.

The proposed layout of the power distribution network and the traffic data-driven design methodology for the charging system can be used as a guide to inform future DWC power system designs. The DWC system requires a great amount of power, and aggregate power demand may fluctuate significantly. Transmission and distribution systems' available capacity and capability to accommodate the significant power fluctuations are important factors to consider when planning a new implementation of the technology.

Charging HDVs at levels of 180 kW can be feasibly accomplished using existing transmitter/receiver and power converters—pending validation of the models and the mechanical integrity of the pavements with the embedded transmitter. Model validation and pavement integrity could be readily performed using a small section (12×15 ft.) of an ER test bed.

The use of prefabricated slabs in the ER roadway pavement installation may be used for test beds at the early stages of implementation of the technology since this method allows for trial and error during the slab fabrication process. In the future though, in-situ installation methods may be desirable to achieve economies of scale.

The level and growth of DWC equipped-EV penetration are among the top contributors to the project's economic success. DWC system cost also has a great impact on its economics. Regulations and incentives that support the adoption of DWC equipped EVs, particularly HDVs, would significantly improve this technology's competitiveness and feasibility. Large scale deployment can significantly reduce the high initial investment.

Investments in renewable energy resources (solar and wind) in the vicinity of ERs can reduce the electricity costs and associated greenhouse gas emissions. Renewable energy generation can be complemented with battery energy storage for addressing the intermittent nature of renewable energy generation and reducing impacts on the power grid.

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