Dynamic Wireless Power Transfer

Grid Impacts Analysis

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EPRI EV IWC Meeting
Atlanta, GA
November 19, 2015
Electrified Roadways Implementation Benefits

• Electrified Roadways Opportunity
  o Expand vehicle utility and value
  o Integrate with renewable resources and grid operations

• Electric Vehicles (EVs)
  o Roadway electrification extends operable range

• Plug-In Hybrid Electric Vehicles (PHEVs)
  o Fully electrified operation possible even with a medium-size battery

• Hybrid Electric Vehicles (HEVs)
  o Fuel displacement from a more-electrified operation
Background Analyses

- Electrified roadway grid impact analysis builds on NREL's previous incremental in-motion wireless power Transfer (WPT) rollout evaluation for urban areas [1].
- Used 2010 Census Combined Statistical Area (CSA) geographic boundaries to analyze road segments and vehicle miles travelled (VMT) within region.
- Datasets from NREL's Transportation Secure Data Center [2] were paired with a specific CSA in multiple regions to investigate applications to seven CSA regions.
- Work concluded that if 1% of the road miles within a geographic region were electrified, 25% of the fuel used by the “fleet” could be displaced.
- Simulated hourly loads to show some alignment with renewables generation and potential curtailment reduction.

Source: NREL

https://www.youtube.com/watch?v=gqfih5swB8Q
Multi-Platform Analysis Completed

• **Transit Bus Analysis**
  - Minneapolis route data used to select charge points and battery sizes
  - For same net present value as HEV solution, WPT bus achieves 50% cut in consumption from conventional

• **Heavy Truck Simulations**
  - Target moderate- to high-grade roadway segments
  - 100-kW WPT on 1.5% or greater grade allows engine downsizing and 9% fuel savings

• **Light-Duty Vehicles**
  - Target urban areas and highly utilized roads show 1% of roadway cuts consumption by 25%
ARC: 2011 Regional Travel Survey

• Down select of Atlanta CSA from the previous analysis – consistent full-week data for vehicles in the study

• Focus on most used roadways in the incremental in-motion WPT rollout provides scenario for initial deployment

• Roadway segments (green network on the map) and the ARC travel data generate weekly time distribution for vehicle miles travelled (graph below)

Previous analysis roadway (green) to selected roadway from 2013 HPMS (black) with the 2010 Census CSA Boundary (blue dashed) and 2013 CSA boundary (orange)

Hourly distribution of VMT on selected roadways for a "typical" week of travel

ARC - Atlanta Regional Commission [3]
HPMS – Highway Performance Monitoring System
Electrified Roadway Load Forecasting

- The Federal Highway Administration's HPMS 2013 data set was used on the road segments highlighted in black on the map to produce daily VMT for the proposed electrified roadways.
- The grid power used by these roads for various levels of total VMT is shown in the graph below using the weekly distribution from the ARC 2011 study.
- Grid power has been calculated to 484 Whr per VMT based on the 2014 RAV4 EV (similar 26 mpg as the production-weighted MY2014 car and truck EPA fuel economy) Representative of fleet consumption
Seasonal Load Scenarios – Fall

- Atlanta region grid load determined from the power consumed within the 2013 Atlanta CSA (orange line on map) taken from NREL 2013 Eastern Renewable Generation Integration Study (ERGIS) [4]
- The grid load for the four seasons has been determined by averaging the hourly load throughout a week for each hour within the season
- Graphs show hourly load growth with electrified roadway load over the baseline at from each fractional VMT scenario (colored text indicates the percent)

Electrified Roadway Scenarios added to Typical Fall Grid Load

Vehicles : Grid
5% = 0.76%
10% = 1.52%
25% = 6.17%
...
Seasonal Load – Winter & Spring

Electrified Roadway Scenarios added to Typical Winter Grid Load

Vehicles : Grid
5% = 1.16%
10% = 2.32%
25% = 5.80%
...

Electrified Roadway Scenarios added to Typical Spring Grid Load

Vehicles : Grid
5% = 1%
10% = 2%
25% = 5%
...

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Seasonal Load – Summer & Highest Week

Electrified Roadway Scenarios added to Typical Summer Grid Load

Vehicles: Grid
- 5% = 0.70%
- 10% = 1.17%
- 25% = 4.28%
...

Electrified Roadway Scenarios added to Highest Week Grid Load

Vehicles: Grid
- 5% = 0.62%
- 10% = 1.24%
- 25% = 3.10%
...

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Result Discussion

- The findings indicate that electrifying 5% of all VMT on high-capacity roads in the Atlanta area could increase peak hour grid demand by a little over 100 MW, which is a little less than a 1% load increase.

- 5% electrification of VMT is the lowest roadway electrification case examined in the preceding grid analysis:
  - Represents an aggressive penetration of WPT-enabled vehicles
  - HEVs have been commercial for over 15 years, but still account for less than 3% of new car sales [6]

Absolute and incremental percentage load impacts from the 5% of light-duty VMT electrified roadway scenario added to the baseline highest yearly grid load week.
Results

- **Not included here**
  - Stationary charging of the vehicles along with electrified roadway power
  - Differences in powertrain implementations’ ability to utilize roadway
    - All EVs: fully functional
    - HEVs/PHEVs: should have large enough e-drive system to maintain highway speeds
  - System layout and its impacts on power delivery and quality
  - Integration of both light-duty and heavy-duty utilization profiles

- **Future analysis and testing should consider other WPT implementation challenges**
  - Fall and winter midday trough accentuated with electrified roadway loads
  - Infrastructure and load profile differences depending on the class of vehicle (light, medium, heavy-duty) and powertrain to be served (EV, PHEV, HEV)
  - The ability to charge batteries rather than just meeting the instantaneous driving load
  - Data presents “hourly” average power and its impact
    - Analysis by Highways England in [7] has shown that sub-hour maximum power flow is influenced by the design and layout of the WPT system
Highways England Report – System Layouts

Example DWPT System- Layout 1 [7]

- Each coil can supply up to 100kW of power to a secondary coil.
- Up to 2 coils can be energised in the same segment (i.e., connected to the same inverter).
- Each inverter can supply up to 200kW.
- Coil length can be tailored to suit longer or shorter vehicles.

Example DWPT System- Layout 2 [7]

- Each coil is 9m long and is connected into a single continuous power transfer segment of up to 40m long (can be 20m).
- Each segment can supply up to 140kW of power to a secondary coil.
- One segment can provide power to only 1 vehicle.
- Non-equipped vehicles present on the same segment as a vehicle using the segment will result in the system switching off until the appropriate headway is established.
- Each inverter can supply up to 140kW.

Power demand per mile of motorway for 30% light vehicle and 50% heavy vehicle penetration at 55 mph, DWPT system layout 1 [7]

Power demand per mile of motorway for 30% light vehicle and 50% heavy vehicle penetration at 55 mph, DWPT system layout 2 [7]
Simulated Power Flows Impacted by Speeds and Headway

Dynamics of 0-150 kW in 0.1s

Even higher at lower speeds
Discussion – Roadway WPT Scenarios

Many WPT mechanization concepts for dynamic power transfer, one example is shown in the image below.

Many open questions as to what should be the design criteria for such systems:

• How should the spacing of primaries along the roadway be optimized for power delivery to various load sizes?

• What is the minimum power level that secondary receivers on light-duty and heavy-duty vehicles need to provide the infrastructure flexibility?

• How does traffic impact peak power required by the grid and what limitation should be placed on transients?

• Would the use of integrated energy storage with the daily / weekly traffic patterns become a valuable grid device?

A roadway WPT system based on [8]; buffering infrastructure limits impact on power systems.
Potential Impacts to Vehicle Adoption

- ORNL analyzed several regions for vehicle preferences
- Roadway WPT vehicle capabilities add 5-20% to 20yr adoption potential [9]

SF=San Francisco
SD=San Diego
AVG=Average SF/SD
Bat10=10% lower cost
Testing and Demonstration Activities

• Multi-unit testing for grid integration
  o Three 3-kW units on a distribution grid with varied DC sources and level 2 AC chargers

• NREL campus shuttle application
  o 1.5-mi loop; 60–75 circuits per day; 2–3 charging locations

• Future opportunities
  o Target airport shuttles with fixed routes
  o Medium-duty delivery routes
References


