EVTeC 2025
7th International Electric Vehicle Technology Conference 2025

Verification of Big Data Analysis on Dynamic Wireless Power Transfer for Electric Vehicles Focused on Traffic Signal GPS

Yutaka Shikauchi [1)] Kota Fujimoto [1)] Osamu Shimizu [1)] Hiroshi Fujimoto [1)]
Shuji Kawano [2)]
1) Graduate School of Frontier Sciences, The University of Tokyo, Kashiwa, Chiba, Japan
E-mail: shikauchi.yutaka22@ae.k.u-tokyo.ac.jp
2) Honda R&D Co., Ltd. Tochigi, Japan
E-mail: shuji kawano@jp.honda

ABSTRACT: Dynamic wireless power transfer (DWPT) system primarily consists of transmitter coils embedded in the road to send power and receiver coils installed in electric vehicles (EVs) to receive power. By utilizing the DWPT system, EVs can receive power while driving, which is expected to improve driving range and reduce the battery capacity required. However, studies specifically focus on the potential of DWPT to reduce battery capacity is limited. Previous study has analyzed the minimum battery capacity required for EVs under the assumption that DWPT is conducted when vehicles are stationary and the brake is applied, with a focus on vehicles operating on general roads. However, this analysis did not consider conditions related to intersections, and it did not ensure that the vehicles were indeed stopped. In this paper, we conduct an analysis using the GPS data of vehicles traveling on general roads in Kashiwa city and traffic signal GPS information. We analyze the ratio of DWPT conducted per drive cycle under the condition that power transfer occurs when a vehicle is within 30 meters of a traffic signal, and we compare these results with those of previous study.

KEY WORDS: Dynamic wireless power transfer, Electric vehicles, Big data.

1. INTRODUCTION

Electric vehicles (EVs) have gained attention as a sustainable mode of transportation that emits no greenhouse gases (GHGs) during operation, contributing to the realization of a more sustainable transport society. However, challenges remain, including the GHG emissions generated during the manufacturing of EVs, and the production of the electricity used for charging, as well as the limitations imposed by the range, which depends on the battery. Equipping EVs with larger batteries to extend the driving range not only increases GHG emissions during battery production but also increases vehicle weight, leading to higher rolling resistance and increased energy consumption during driving [(1)-(3)].

Dynamic Wireless Power Transfer (DWPT) has emerged as a promising solution to extend EV range while minimizing battery weight [(4)-(9)]. DWPT is particularly effective when implemented on highways and near intersections, and it is gaining global attention as a potential solution to address the challenges faced by EVs. Additionally, Stationary wireless power transfer, which transfers power to stationary vehicles in parking lots, is also being studied [(10)]. Fig. 1 illustrates the structure of vehicles and the DWPT system demonstrated in Kashiwa city. The vehicle in Fig. 2 is equipped with receiver coils that collect power from transmitter coils embedded in the road. With this system, the driver simply needs to drive on roads equipped with DWPT, and power is continuously supplied to the EV's battery. This reduces not only the amount of battery needed onboard the vehicle but also the GHG emissions associated with battery production. For these reasons, DWPT is expected to become a key technology that

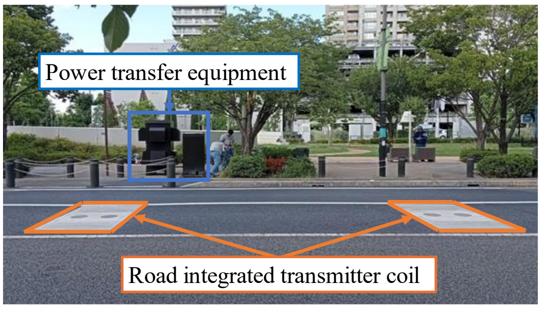

Fig.1. Road utilized for the demonstration of DWPT.

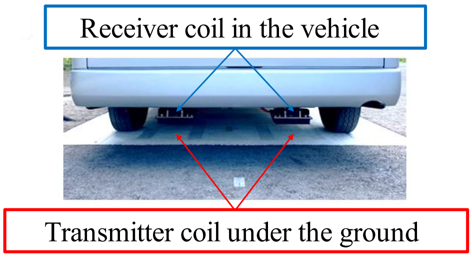

Fig.2. Vehicles utilized for the demonstration of DWPT.

addresses the challenges of EVs and promotes their widespread adoption.

While the benefits of DWPT in reducing EV battery weight have been acknowledged, few studies have discussed the minimum required battery capacity for EVs. Previous study conducted in Kashiwa city, estimated the minimum necessary battery capacity under the assumption that DWPT is performed when the vehicle is stationary (11). However, this analysis was limited to situations where the vehicle is stopped, without utilizing GPS data to confirm whether the stop occurs near an intersection. Studies have also been conducted on the optimal placement of DWPT systems (13). This study does not assume that the transmitter coils are embedded near traffic signals. This study assumes that the transmitter coils are embedded 30 m in front of the traffic signal.

In this study, we focus on the presence of traffic signals as the defining criterion for proximity to an intersection. Using the GPS data from both traffic signals and vehicles, we conducted an analysis based on the assumption that power transfer through DWPT occurs when the distance between the traffic signal and the vehicle is within 30 meters (5). The ratio of power transfer per drive cycle was calculated using both the method employed in this study and conventional methods. Ultimately, these results were compared to determine the extent to which they align with previous study and to validate the accuracy of earlier studies.

The structure of this paper is as follows: Chapter II provides a detailed explanation of the GPS data for vehicles and traffic signals used in this study. Chapter III outlines the conditions under which DWPT is performed in both previous study and this study. Chapter IV describes the method used to analyze the ratio of DWPT conducted per drive cycle. Chapter V presents the results of the analysis, showing the ratio of power transfer per drive cycle for each method. Finally, Chapter VI concludes the paper with a summary of the findings.

2. DETALS OF THE DATA USED

In this chapter, we explain the vehicle data and traffic signal GPS information utilized for the analysis.

2.1. Vehicle big data

The big data analyzed in this study is based on a database sampled every 3 seconds for vehicles following a typical drive cycle. These driving data were collected only when the vehicles were online. The dataset comprises data from a total of 913

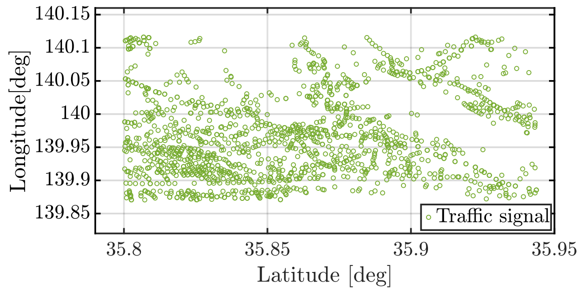

Fig.3. Locations of traffic signal in Kashiwa city.

vehicles collected over a three-month period from February 1, 2023, to April 30, 2023. The driving data includes both trips that are confined to the Kashiwa city area and trips that originate outside Kashiwa but pass through the city for at least one sampling point. Moreover, the analysis is limited to vehicles driving on general roads, excluding data from non-road areas such as parking lots, highways, ferry routes, and other roads.

2.2. GPS information on traffic signals

The traffic signal GPS data used in this study is restricted to signals within Kashiwa city. Fig. 3 shows the actual GPS coordinates (latitude and longitude) of the traffic signals utilized. The target traffic signals are specified by their latitude and longitude, forming a rectangular boundary around the Kashiwa city area. The latitudes of the upper and lower boundaries are 35.9438132 deg and 35.8002341 deg, respectively. The longitudes of the left and right boundaries are 139.8703181 deg and 140.1162723 deg, respectively. Within this area, a total of 1,605 traffic signals are present, accounting for 0.62 % of all traffic signals nationwide.

3. CONDITIONS FOR DWPT OPERATION

This chapter explains the conditions under which DWPT is conducted. The conditions are divided into two categories: those based on previous study and those applied in this study.

3.1. Conditions used in previous study (Case 1)

In previous study, the following conditions were considered for DWPT operation (11):

- The vehicle's speed is 0.
- The brake is applied.
- The vehicle is located on a general road.

DWPT is conducted when the above conditions are met.
In other words, it was assumed that vehicles satisfying these three conditions are mostly located at intersections.

3.2. Conditions used in this study (Case 2)

In this study, the following conditions are considered for DWPT operation:

・The distance between the vehicle and the traffic signal is less than 33.3 meters.

・ The vehicle is located on a general road.

In this study, DWPT is conducted when these conditions are satisfied. The reasoning behind these conditions is as follows: In previous study, DWPT could be conducted even when the vehicle was stopped outside of an intersection. because the GPS information of the traffic signal is not considered. Since most traffic signals are located at intersections, the conditions in this study focus on this aspect. By applying these conditions, it is expected that the analysis of DWPT operation near intersections will be more accurate compared to previous study. In addition, it is set to 33.3 m in consideration of the road width in Japan.

4. ANALYSIS FOR THE FREQUENCY OF DWPT OPERARTION

In this chapter, we analyze the ratio of DWPT operation per drive cycle. The analysis method is almost identical for both cases, with the difference being the flag $f_{dwpt\ i,j}(t)$ for each case. The flag $F_{dwpt\ i,j}(t)$ is assigned a value of 1 when the conditions for DWPT operation are met, and a value of 0 when the conditions are not met. The subscript i indicates that the value belongs to the i - th vehicle in the database, while the subscript j means that the data point is the j - th sampling point for that vehicle. For instance, F_{dwpt} [3,106] indicates that the data belongs to the 3rd vehicle in the database and the 106th sampling point for that vehicle.

The number of DWPT operation V_{flag}, which represent the sum of the data points that satisfy the conditions for DWPT operation among all the data points stored for the vehicle, with a total number of x_j data points stored for the vehicle, can be expressed as follows:

$$V_{flag} = \sum_{j=1}^{x_j} F_{dwpt\ i,j} \tag{1}$$

$F_{dwpt\ i,j}(t)$ is the flag that takes a value of 1 when the conditions for DWPT are satisfied at time. Furthermore, the total sum of the time-series data is V_{total}.

This represents the total number of data points x_j collected for the i-th vehicle over the time series. Therefore, the ratio of DWPT operation per drive cycle for the i-th vehicle, denoted as R_{dwpt}, can be expressed as follows:

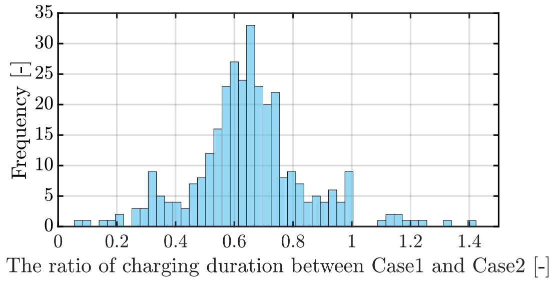

Fig.3. Ratio of DWPTs conducted in the two cases R_{case}

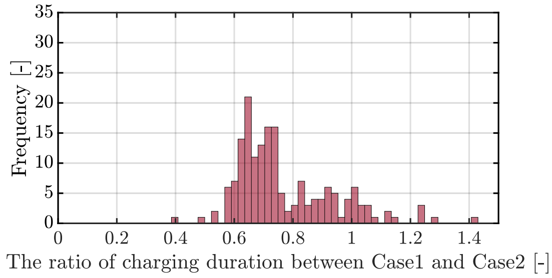

Fig.4. Ratio of DWPTs conducted in the two cases R_{case} (Except for R_{dwpt1} and R_{dwpt2} exceeding 0.1 and 0.9).

$$R_{dwpt} = \frac{V_{flag}}{V_{total}} \tag{2}$$

By applying the above analysis to all vehicles, the frequency of DWPT operation can be calculated for each vehicle.

This paper verification the following Analyze the percentage of vehicle drive cycles in which DWPT was conducted in Case 1, the condition of the previous study, and in Case 2, the condition of this study. R_{dwpt1} be the fraction of DWPTs conducted in one drive cycle for i - th vehicle under the conditions of Case 1 and R_{dwpt2} under the conditions of Case 2. This is obtained by Equation (2), respectively. Furthermore, to verify that the DWPT is consistent in Case1 and Case2, two ratios, R_{case} can be expressed as follows:

$$R_{case} = \frac{R_{dwpt2}}{R_{dwpt1}} \tag{3}$$

5. ANALYSIS RESULTS

In this chapter, we present the ratio of DWPT conducted per drive cycle for the same data in Cases 1 and 2. The ratios are calculated using Equation (3), and the results are analyzed to determine how Case 2 compares to Case 1 in terms of frequency.

From the results shown in Fig. 3, the data exhibits a normal distribution around 0.6, with a mean value of 0.66. Additionally, the variance is confirmed to be 0.051. Therefore, since the meaning is not close to 1, it is evident that the analysis results of this study differ from those of previous study. Moreover, since the mean value is below 1, it indicates that the conditions for DWPT in Case 1, as established in previous study, are more easily satisfied, being 1.51 times larger compared to Case 2.

These results suggest that there are relatively few vehicles stopped near intersections within the analyzed vehicle dataset. This is because vehicles that stop on the shoulders of general roads are also judged to be stopped at the intersections with the conventional method. Consequently, this situation may impact analyses regarding the minimum battery capacity required for EVs conducted in previous study. Future works will aim to further analyze the vehicle data used and explore the reasons behind the significantly larger differences observed between Cases 1 and 2.

Fig. 4 shows the results of data elimination. The data were eliminated from the results of Case 1 and Case 2 when the ratio of DWPTs performed on the vehicle per drive cycle was less than 0.1 and greater than 0.9. Eliminating this data improves the meaning to 0.78. In the future, we will further investigate appropriate values for data exclusion for vehicles.

6. CONCLUSITON

In this study, we established a new condition based on the distance between vehicles and traffic signals to analyze the frequency of DWPT per drive cycle. While previous study evaluated DWPT including instances of vehicles stopped outside intersections, this study focused exclusively on situations where the distance to the traffic signal is less than 33.3 meters. As a result, the frequency of DWPT operation was found to be approximately 1.51 times higher on average compared to this study with the previous study, indicating that the conditions set in this study make DWPT less likely to occur.

Especially, the findings suggest that many of the stopping positions in the previous study were outside the intersection. This result has significant implications for assessments related to battery capacity, which influences the driving range of EVs. Future work will aim to clarify the reasons for the discrepancies observed between this study and previous studies through further data analysis.

ACKNOWLEDGMENT

This work was partly supported by JST-Mirai Program Grant Number JPMJMI21E2 and Council for Science, Technology and Innovation (CSTI), Cross-ministerial Strategic Innovation Promotion Program (SIP), the 3rd period of SIP “Smart energy management system” Grant Number JPJ012207 (FUNDING AGENCY: JST).

REFERENCES

(1) H. Fujimoto, O. Shimizu, S. Nagai, T. Fujita, D. Gunji and Y. Ohmori, "Development of Wireless In-wheel Motors for Dynamic Charging: From 2nd to 3rd generation," 2020 IEEE PELS Workshop on Emerging Technologies: Wireless Power Transfer (WoW), Seoul, Korea (South), 2020, pp. 56-61.

(2) K. Takashima, T. Imura and Y. Hori, "Theorization of a Compatible Method for Far-field Leakage Magnetic Field Reduction and High Efficiency Power Transfer Using Adjacent Transfer Coil in Dynamic Wireless Power Transfer," 2024 IEEE Wireless Power Technology Conference and Expo (WPTCE), Kyoto, Japan, 2024.

(3) Ryo Matsumoto, Hiroshi Fujimoto, "Activation Timing Control Using On-board Camera for Dynamic Wireless Power Transfer Under Circuit Parameter Variations" The 6th International Electric Vehicle Technology Conference (EVTeC2023), Yokohama, Japan, 2023.

(4) A. Kamineni, M. J. Neath, A. Zaheer, G. A. Covic and J. T. Boys, "Interoperable EV Detection for Dynamic Wireless Charging With Existing Hardware and Free Resonance," in IEEE Transactions on Transportation Electrification, vol. 3, no. 2, pp. 370-379, June 2017.

(5) G. Guidi and J. A. Suul, "Minimizing Converter Requirements of Inductive Power Transfer Systems With Constant Voltage Load and Variable Coupling Conditions," in IEEE Transactions on Industrial Electronics, vol. 63, no. 11, pp. 6835-6844, Nov. 2016.

(6) Sumiya, Hayato & Takahashi, Eisuke & Yamaguchi, Nobuhisa & Tani, Keisuke & Nagai, Sakahisa & Fujita, Toshiyuki & Fujimoto, Hiroshi. (2021). Coil Scaling Law of Wireless Power Transfer Systems for Electromagnetic Field Leakage Evaluation for Electric Vehicles. IEEJ Journal of Industry Applications.

(7) Jin Katsuya, Shuji Kawano, Kenichiro Takahashi, 150kW Dynamic Wireless Power Transfer Inverter Control Technology, Transactions of Society of Automotive Engineers of Japan, 2023-2024, Volume 55, Issue 5, Pages 942-947, 2024.

(8) M. Maemura, T. Kurpat, K. Kimura, T. Suzuki and T. Hashimoto, "Improvement of the Power Transfer Efficiency of a Dynamic Wireless Power Transfer System via Spatially Distributed Soft Magnetic Materials," 2022 Wireless Power Week (WPW), Bordeaux, France, 2022, pp. 332-337.

(9) T. Newbolt, P. Mandal, H. Wang and R. Zane, "Feasibility of Dynamic Wireless Power Transfer to Mitigate Load Demands Under Resiliency Events," *2024 IEEE Power &*

Energy Society General Meeting (PESGM), Seattle, WA, USA, 2024, pp. 1-5.
(10) K. Kusaka and J. - i. Itoh, "Input impedance matched AC-DC converter in wireless power transfer for EV charger," 2012 15th International Conference on Electrical Machines and Systems (ICEMS), Sapporo, Japan, 2012, pp. 1-6.
(11) Kota Fujimoto, Osamu Shimizu, Hiroshi Fujimoto, Jin Katsuya, Tetsu Sato, "Feasibility Study for Dynamic Wireless Power Transfer in Simulation with Big Data Focusing on Battery Capacity Requirement of Electric Vehicles", the 27th edition of the International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM), Ischia, Italy, 2024.
(12) D. Gunji, K. Hata, O. Shimizu, T. Imura and H. Fujimoto, "Feasibility Study on In-motion Wireless Power Transfer System Before Traffic Lights Section," 2019 IEEE PELS Workshop on Emerging Technologies: Wireless Power Transfer (WoW), London, UK, 2019, pp. 302-307.
(13) Y. Honma et al. “Locational Analysis of In-Motion Wireless Power Transfer System for Long-Distance Trips by Electric Vehicles: Optimal Locations and Economic Rationality in Japanese Expressway Network.” Networks and Spatial Economics, vol. 24, pp. 261–290, Jan. 2024.