**International Journal of Research Publication and Reviews**

Journal homepage: www.ijrpr.com ISSN 2582-7421

# A Review on Progress in Wireless Charging Technologies for Electric Vehicles

***D. Sai Kumar[1] and Dr. D Rajesh Babu[2]***

#Department of Electrical and Electronics Engineering, GMRIT, Rajam, Andhra Pradesh, India
22341a0230@gmrit.edu.in[1] and babu.d@gmrit.edu.in [2]
DOI: https://doi.org/10.55248/gengpi.5.0324.0797

**ABSTRACT—**

The surge in popularity of electric vehicles (EVs) can be attributed to significant advancements in performance and driving range. Traditional EVs rely on cable charging, but major manufacturers like Tesla, BMW, and Nissan are spearheading the development of wireless charging technology, eliminating the need for cumbersome wires. This wireless, inductive charging not only enhances safety by eliminating sparks but also opens up possibilities for dynamic charging, allowing EVs to charge while in motion. Once fully implemented, this innovation could reduce the reliance on large batteries and alleviate range anxiety associated with EVs. Countries such as Korea, Germany, and the UK are actively driving the adoption of wireless charging. Extensive research literature delves into the technical aspects of wireless charging, including communication protocols, coil design, and compensation methods. Innovative approaches such as utilizing superconducting materials in coil designs are explored for their potential to enhance charging efficiency. Safety concerns related to wireless charging are addressed along with an overview of relevant standards. Additionally, the study provides an economic analysis of the costs associated with various wireless charging setups. Overall, this research contributes to the understanding of wireless EV charging and highlights its transformative potential for the industry.

***Keywords***— Electric vehicles (EVs), wireless power transfer (WPT), and wireless charging of EVs, Coils, Mutual inductance, Charging facility

## Introduction

The transportation sector is a significant contributor to climate change, primarily due to CO2 emissions [1]. In 2017, it consumed approximately 60% of the world's oil production, highlighting the urgent need for cleaner options [2]. Electric vehicles (EVs) have emerged as a crucial element in transitioning to a more sustainable energy society [3]. Recent advancements in EV technology have notably enhanced their performance and range, with several models readily accessible in today's automotive market. [4] However, effectively and efficiently charging these EVs remains a significant challenge, putting pressure on power grids [5].

Traditional methods of charging involve physically connecting electric cables to EVs, which can pose risks, especially in adverse weather conditions, leading to sparking during plugging and unplugging. This limitation restricts the applicability of EVs in certain environments, such as those near airports and petrol stations. Consequently, there has been increasing interest in more flexible and convenient charging methods, notably wireless charging technology. Major companies like Tesla, BMW, and Nissan have begun developing EVs equipped with wireless charging capabilities, eliminating the need for bulky cables. This wireless, or inductive, approach not only mitigates the risks associated with physical connections but also enables innovative possibilities, such as charging devices while driving. The concept of wireless power transfer (WPT) dates back to the late nineteenth century, pioneered by Nikola Tesla with his creation of a wireless lighting bulb. Tesla utilized high-frequency AC potentials between closely spaced but separated metal plates to power the bulb, marking the beginning of wireless charging technology. However, unresolved technological challenges, such as low power density and efficiency over longer distances, have hindered the widespread adoption of WPT technology.

Advancements in wireless power transfer (WPT) technology in recent years have enabled the utilization of "strongly coupled" coils for charging wirelessly over distances exceeding two meters [7]. There are two primary WPT technologies: Inductive Power Transfer (IPT) and Capacitive Power Transfer (CPT), each with distinct principles. IPT operates within magnetic resonance in the strongly coupled regime, establishing a connection between transmitting and receiving coils. On the other hand, CPT relies on the interaction of electric fields between interconnected capacitors. However, CPT is limited to low-power applications with extremely narrow air gaps, typically ranging from 10^-4 to 10^-3 meters, due to the coupling capacitance dependence on device surface area.

In contrast, IPT can operate over much larger air gaps, spanning multiple meters, and can deliver significantly higher output power, potentially exceeding 10 kW. WPT, encompassing both CPT and IPT, enables power transfer without physical connections, thereby enhancing safety and convenience, especially in everyday applications like TVs, telephone adapters, and induction heaters [11-14]. Additionally, WPT finds applications in the medical field, such as charging pacemakers and other implantable medical devices, which fall under the category of active implantable medical devices (AIMD) [15]. Furthermore, WPT technology is utilized in radio frequency identification (RFID), sensors, and robotics [18-22].

## LITERATURE REVIEW

In Philip Machura's paper, "A Critical Analysis of Wireless Charging for Electric Vehicles," and Quan Li et al.'s research, there's a thorough examination of EV charging through Wireless Power Transfer (WPT) technologies. It highlights key areas of study such as coil design, communication, and safety standards. While challenges like infrastructure investment and network impact exist, both the academic and industry communities are striving towards solutions ready for the market to foster a cleaner, low-carbon transportation future [1].

The paper assesses various charging methods including wireless, wired, and conventional charging for airport shuttle buses. It suggests that bi-directional wireless charging can minimize distribution network impact and offer cost-effective electrification. Additionally, future research will explore broader applications such as co-driving control for connected and automated electric vehicles at signalized intersections with wireless charging, extending the EV range and reducing travel costs. This proposed eco-driving method and wireless scheme aim to enhance urban transport, with future work focusing on optimizing driving behaviour and charging area placement [2].

Furthermore, there's a discussion on the optimal location of wireless charging facilities for electric vehicles, emphasizing the importance of capturing flow in the stochastic user equilibrium model. The article discusses the optimal design of wireless charging electric vehicles, particularly the OLEV electric vehicle system developed by KAIST [3]. It concentrates on optimizing power transmitter allocation and battery size to reduce system costs, proposing a mathematical model using Genetic Algorithms with potential applications beyond fixed routes and OLEV systems [4].

Moreover, there's a review of foreign object detection for magnetic coupling-based electric vehicle wireless charging systems, outlining various methods and limitations and suggesting future research directions. [5] Another article focuses on Wireless Power Transfer (WPT) systems for EVs, developing a new model and achieving improved efficiency, especially with dual receivers. Future work will address converter efficiency and renewable energy integration [6].

Additionally, an optimization model for Electric Buses (EBs) and Depot Wireless Charging (DWC) infrastructure is discussed, demonstrating benefits and suggesting future research directions, including combined models and stochastic programming [7]. A survey explores the state of wireless charging for EVs, identifies research directions, and acknowledges potential challenges and opportunities. [8] Finally, a new IPT system utilizing compensated coils is introduced, reducing the need for complex control methods and enabling dynamic power delivery [9].

## METHODOLOGY: -

Adopting wireless charging systems for electric vehicles (EVs) presents a more convenient and safe charging approach. Moreover, dynamic charging systems offer a novel solution to address 'range anxiety' while reducing the initial costs associated with owning an EV. In this section, we will examine the crucial components and characteristics of a wireless power transfer (WPT) system intended for EV charging. Furthermore, we will investigate an innovative wireless charging concept specifically designed for urban transportation networks.

1.1 Wireless Charging System Components:

The conventional wireless charging system for electric vehicles (EVs) consists of two main subsystems: the vehicle assembly (VA) and the ground assembly (GA). The distance between these subsystems, known as the air gap, varies depending on factors such as the specific vehicle, its ground clearance, and the condition of the road. The main components within these subsystems are:

1.1.1 GA (Ground Assembly):

The grid connection links to the electricity grid, while the rectifier and high-frequency inverter transform low-frequency alternating current power into high-frequency alternating current electricity for wireless power transfer. A primary compensation network, either a series or parallel arrangement of inductors and capacitors, is employed to enhance power transfer efficiency and minimize reactive power. The primary or transmitter coil (Tx) generates the primary magnetic field.

1.1.2 VA (Vehicle Assembly):

The secondary or receiving coil (Rx) gathers the magnetic field generated by the primary coil. On the secondary side, a compensation network adjusts power transfer by decreasing receiver inductance, similar to the primary side. Additionally, a high-frequency rectifier converts the high-frequency AC output from the receiving coil to DC power. A filter network is also present to enhance the DC power, ensuring a steady and ripple-free current for battery charging. Finally, a battery system stores the received electrical energy.

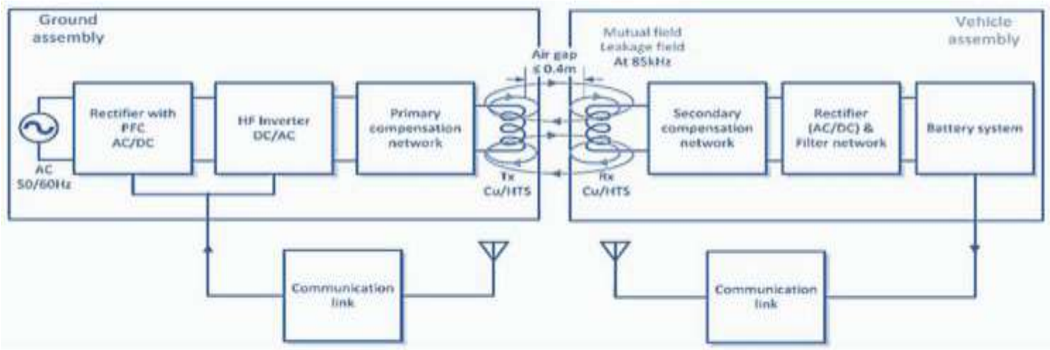
1.1.3Wireless Charging Infrastructure for Cities Systems:

The Wireless Power Transfer (WPT) system for Electric Vehicle (EV) charging comprises two primary subsystems: the Ground Assembly (GA) situated beneath the road surface and the Vehicle Assembly (VA) integrated into the vehicle underbody. Within the GA are components such as the grid connection, rectifier, high-frequency inverter, primary compensation network, and primary/transmitter coil (Tx), while the VA includes the secondary/receiving coil (Rx), secondary compensation network, high-frequency rectifier, filter network, and battery system. These subsystems' capabilities enable functionalities like Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V), supporting energy storage and balancing the grid demand, particularly with the integration of renewable energy sources.

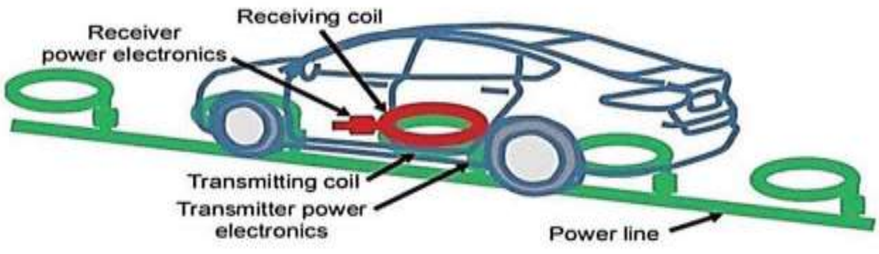
The proposed urban transportation wireless charging method aims to recharge electric vehicles (EVs) as they approach signalized junctions, thereby extending their driving range. This system relies on vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication to enable EVs to decide whether they can pass through an intersection without stopping. Crucial to this setup is the control segment near the signalized intersection, which is essential for optimizing energy replenishment and ensuring seamless passage through the intersection. This segment encompasses both the upstream and downstream sections of the intersection, aiming to minimize unnecessary stops with an air gap typically less than 0.4m.

Power conversion involves multiple stages, including AC/DC/AC conversion, to bridge low-frequency grid power to high-frequency AC for efficient transmission. Various converter topologies, such as H-bridge, multi-level converters, and matrix converters, are being explored to achieve high-efficiency power transfer. Bidirectional power transfer capability supports functionalities like Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V), facilitating energy storage and grid demand balancing, particularly with the integration of renewable energy sources.

As halting not only consumes energy but also extends travel duration, the proposed urban transit wireless charging system exchanges information through a communication link and operates with an air gap typically under 0.4m. Power conversion involves AC/DC/AC stages to convert low-frequency grid power to high-frequency AC for effective transmission. Various converter configurations, such as H-bridge, multi-level converters, and matrix converters, are being investigated for efficient power transfer. Through V2V and V2I communication, an EV approaching a signalized intersection can gather information about its location and the Signal Phase and Timing (SPAT) of the traffic light. Based on this data,




**(a)**




**(b)**

The method system represents a strategic approach aimed at overcoming the limitations of EVs and improving their practicality. In this setup, EVs are recharged as they approach signalized intersections, thereby extending their driving range. Essential components of this setup include V2V (vehicle-to-vehicle) and V2I (vehicle-to-infrastructure) communication systems. By leveraging these systems, the vehicle can assess whether it can safely pass through the intersection at its current speed. The system prioritizes avoiding stops at intersections due to their negative impacts, such as energy wastage, increased travel time, and a diminished driving experience. This approach aligns with the principles of eco-driving control.

Strategies for reducing speed are implemented as vehicles approach signalized intersections to avoid sudden stops. By maintaining lower speeds near intersections, both individual driving experiences and overall intersection efficiency are enhanced. The implementation of the wireless charging system involves positioning the designated wireless charging area before the signalized intersections, within a dedicated lane reserved for connected and automated electric vehicles. This area is dynamic, allowing vehicles to recharge energy while in motion. A control segment is introduced near the signalized intersection to ensure efficient and effective energy transfer, encompassing both the upstream and downstream areas of the intersection. The effectiveness of the wireless charging system depends on various factors, including the length of the control segment, the initial position of the control segment, and the location of the intersection's stop line. The objective is to optimize power replenishment while ensuring seamless passage through the intersection.

1.2 Models of Wireless Charging and Power Usage for EVs:

To evaluate the effectiveness of the wireless charging system, it's crucial to model the energy consumption of electric vehicles (EVs). This can be achieved using a power-based model that takes into account various factors such as vehicle weight, acceleration, speed, road incline, rolling resistance, and aerodynamic drag. This model calculates the power required by the wheels at any given moment, which is then used to determine energy consumption. Additionally, changes in the state-of-charge (SOC) of the EV's battery throughout the driving cycle are considered. The battery's voltage and power characteristics are also modeled based on internal components, with voltage calculated for both charging and discharging operations.

1.2.1Wireless Charging System Design:

The wireless charging system is engineered to minimize power losses and enhance power transfer efficiency. The selection of compensation topology, coil design, and control strategies are crucial in attaining these goals. Different compensation topologies, such as Series-Series (SS), Series-Parallel (SP), Parallel-Series (PS), and Parallel-Parallel (PP), are examined to assess their respective benefits and drawbacks.

The design of coils is a pivotal element of the wireless charging system. Circular planar coils are frequently employed, with their configurations selected to enhance system efficiency and address alignment challenges between transmitter and receiver coils.

## RESULTS & DISCUSSIONS:

Wireless Charging Infrastructure for Cities Systems:

The proposed wireless charging plan for public transit networks presents a unique approach to enhancing the feasibility and cost-effectiveness of electric cars (EVs) within urban environments. By utilizing signalized crossings, this system effectively tackles range anxiety and provides EV owners with a seamless and efficient charging process.

Consequently, the results of the program show significant potential for reducing EV downtime and extending their overall driving range. By integrating advanced V2V and V2I communication technologies, it becomes possible to anticipate and avoid unnecessary stops at intersections. This approach aligns with eco-driving principles, which emphasize minimizing energy wastage while ensuring a consistent flow of traffic.

Discussions regarding this scheme underscore its potential advantages for both individual drivers and urban traffic management. Decreased stops at intersections not only enhance the driving experience but also boost the overall efficiency of the transportation system. These conclusions affirm the feasibility of this wireless charging scheme as a viable solution to alleviate range anxiety and promote the adoption of EVs in urban environments

Models of EV Energy Consumption and Wireless Charging:

The adoption of a power-based energy consumption model for electric vehicles (EVs) offers valuable insights into their energy efficiency and performance. The model's backward structure facilitates a thorough examination of power generation, losses, and utilization, under real-world driving conditions. Findings indicate that implementing eco-driving techniques alongside dynamic wireless charging can result in notable enhancements in energy efficiency. Through enabling EVs to recharge while in motion, the model demonstrates the capability to maintain a higher state of charge and decrease the frequency of lengthy recharging stops.

System Parameter-Based Methods for Detecting Metal Objects*:*

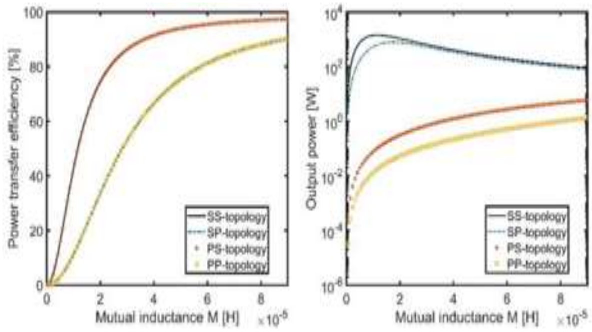
The detection of metal objects near the wireless charging system is essential for ensuring safety and efficient power transfer. System parameter-based approaches have proven effective in detecting the presence of foreign objects on the transmitter (Tx) pad. Findings indicate that these methods, which utilize alterations in electrical parameters caused by metal objects, serve as reliable safety measures in dynamic wireless charging systems. They enable swift identification of obstructions and can activate safety protocols to mitigate the risk of accidents and system damage.

Compensation Networks for Power Transfer Optimization:

Compensation networks are crucial components in maximizing power transfer efficiency within wireless charging systems. Various compensation network topologies are explored, such as Series-Series (SS), Series-Parallel (SP), Parallel-Series (PS), and Parallel-Parallel (PP).

The results illustrate that the choice of compensation network topology significantly influences power transfer efficiency and overall system performance. Different configurations offer distinct advantages, with some being better suited to specific applications while others offer greater flexibility or reduced complexity. Discussions revolve around the trade-offs associated with various compensation network designs. For instance, the SS configuration demonstrates excellent power transfer efficiency but may require more intricate control strategies. On the other hand, the SP configuration strikes a balance between performance and control complexity.

The selection of compensation network topology depends on the specific requirements of the wireless charging system. These networks play a crucial role in optimizing power transfer efficiency. Additionally, battery models provide insights into the impact of wireless charging on battery performance. By analyzing charge and discharge characteristics, these models offer potential for optimizing battery usage and extending its lifespan.




## Conclusions:

Wireless Power Transfer (WPT) systems for charging electric vehicles (EVs) have been extensively explored, revealing numerous critical aspects. Our investigation into WPT systems has uncovered their importance in addressing EV limitations, particularly the issue of limited driving range. As society prioritizes reducing energy consumption and emissions, EVs offer a cleaner transportation option. However, their restricted range has hindered widespread adoption. WPT technology emerges as a solution to this problem by enabling on-the-go charging, thus reducing "range anxiety." Key components of WPT systems, including coil structure and compensation topology, have been closely examined to enhance transfer efficiency, misalignment tolerance, and component durability. Traditional materials like copper are being supplemented with newer options like High-Temperature Superconductors (HTS) for their unique advantages.

In summary, this research makes a significant contribution to Electric Vehicle Wireless Power Transfer, especially focusing on dynamic systems. As the world transitions towards electric energy in transportation, the potential for reduced CO2 emissions and a cleaner environment becomes apparent. However, there are still hurdles to overcome to make electric vehicles and WPT systems practical and sustainable. Our commitment to adhering to electromagnetic emission limits and advocating for stricter standards for vehicular applications demonstrates our dedication to safety and sustainability. Since the introduction of a voluntary guideline for stationary chargers in 2016, progress towards binding standards for dynamic wireless charging has begun, marking a new phase in electric vehicle charging technology. As the global shift towards electric vehicles progresses, the potential for reducing CO2 emissions at the point of application is promising. Nonetheless, we must also consider the broader impacts on energy distribution networks. Stationary wireless chargers operate similarly to traditional conductive chargers, with peak demand typically occurring in the evening.

***REFERENCES:***

[1]. Machura, P., & Li, Q. (2019). A critical review on wireless charging for electric vehicles. Renewable and Sustainable Energy Reviews, [209-234], [26].

[2]. Guo, Z., Lai, C. S., Luk, P., & Zhang, X. (2023).Techno-economic assessment of wireless charging systems for airport electric shuttle buses. Journal of Energy Storage, [107-123], [12].

[3]. Zhang, J., Tang, T.-Q., Yan, Y., & Qu, X. (2021). Eco-driving control for connected and automated electric vehicles at signalized intersections with wireless charging. Applied Energy, 282, 116215. doi:10.1016/j.apenergy.2020.116215

[4]. Riemann, R., Wang, D. Z. W., & Busch, F. (2015). Optimal location of wireless charging facilities for electric vehicles: Flow-capturing location model with stochastic user equilibrium. Applied Energy,58(Part A), 1-12. doi:10.1016/j.apenergy.2015.01.033

[5]. Jang, Y. J., Ko, Y. D., & Jeong, S.(Optimal Design of the Wireless Charging Electric Vehicle [126- 896], [1-5].

[6]. Tian, Y., Guan, W., Li, G., Mehran, K., Tian, J., & Xiang, L. (2022). A review on foreign object detection for magnetic coupling-based electric vehicle wireless charging. Green Energy and Intelligent Transportation, 1(2), 100007.

[7]. Mohamed, N., Aymen, F., Alqarni, M., Turky, R. A., Alamri, B., Ali, Z. M., & Abdel Aleem, S. H. E. (2022). A new wireless charging system for electric vehicles using two receiver coils. Electrical Engineering, 13(2), 101569.

[8]. Alwesabi, Y., Wang, Y., Avalos, R., & Liu, Z. (2020). Electric bus scheduling under single depot dynamic wireless charging infrastructure planning. Energy, 213, 118855.[9]. Jang, Y. J. (2018). Survey of the operation and system study on wireless charging electric vehicle systems. Transportation Research Part C, 95, 844-866.

[9]. Lee, K., Pantic, Z., & Lukic, S. M. (2014). Reflexive Field Containment in Dynamic Inductive Power Transfer Systems. IEEE Transactions on Power Electronics, 29(9), [21].

[10]. International Energy Agency (IEA). Global Energy & CO2 Status Report 2017, IEA; 2018.

[11]. BP, "BP Energy Outlook 2017,". [Online]; 2017. Available: ⟨https://www.bp.com/ content/dam/bp/pdf/energy-economics/energy- outlook-2017/bp-energy-outlook2017.pdf⟩. [accessed 14 March 2018].

[12]. Adnan N, Nordin SM, Rahman I, Vasant P, Noor MA. An overview of electric vehicle technology: a vision towards sustainable transportation. Intell Transp Plan: Breakthr Res Pract 2018.

[13]. Sachan S, Adnan N. Stochastic charging of electric vehicles in smart power distribution grids. Sustain Cities Soc 2018;40:91–100.

[14]. Adnan N, Nordin SM, Althawadi O. Barriers towards widespread adoption of V2G technology in smart grid environment: from laboratories to commercialization. Sustain Inter Netw 2018:121– 34.

[15]. Tesla N. Apparatus for Transmitting Electrical Energy. New York, USA Patent 1119732; 1914.

[16]. Kurs A, Karalis A, Moffatt R, Joannopoulos J, Fisher P, Soljacic M. Wireless Power Transfer via Strongly Coupled Magnetic Resonances. Science 2007;317(5834):83–6.

[17]. Regensburger B, sinha S, Kumar A, Vance J, Z Popovic, KK Afridi. "Kilowatt-Scale Large Air- Gap Multi-Modular Capacitive Wireless Power Transfer System for Electric Vehicle Charging," in IEEE Applied Power Electronics Conference and Exposition (APEC), San Antonio, USA; 2018.

[18]. H. Liu, D.Z.W. Wang, Locating multiple types of charging facilities for battery electric vehicles, Transp. Res. B Methodol. 103 (2017) 30–55, https://doi.org/ 10.1016/j.trb.2017.01.005.

[19]. C.A. García-V´ azquez, F. Llorens-Iborra, L.M. Fern´ andez-Ramírez, H. S´ anchez-Sainz, F. Jurado, Comparative study of dynamic wireless charging of electric vehicles in motorway, highway and urban stretches, Energy 137 (2017) 42–57, https://doi.org/10.1016/j.energy.2017.07.016.

[20]. R.C. Majhi, P. Ranjitkar, M. Sheng, Assessment of dynamic wireless charging based electric road system: a ssscase study of Auckland motorway, Sustain. Cities Soc. 84 (2022), 104039, https://doi.org/10.1016/j.scs.2022.104039.

[21]. Jang YJ, Jeong S, Lee MS. Initial energy logistics cost analysis for stationary, quasi-dynamic, and dynamic wireless charging public transportation systems. Energies 2016;9(7):483.

[22]. Mouhrim N, Alaoui AEH, Boukachour J. Optimal allocation of wireless power transfer system for electric vehicles in a multipath environment. In: 2016 3rd international conference on logistics operations management (GOL). IEEE; 2016. p. 1e7.

[23]. Liu Z, Song Z. Robust planning of dynamic wireless charging infrastructure for battery electric buses. Transport Res C Emerg Technol 2017;83:77e103. [25] Ceder A. Public transit planning and operation: modeling, practice and behavior. CRC press; 2016.

[24]. Fiori C, Marzano V. Modelling energy consumption of electric freight vehicles in urban pickup/delivery operations: analysis and estimation on a real-world dataset. Transp Res D 2018;65:658–73.

[25]. Jeong S, Jang YJ, Kum D. Economic analysis of the dynamic charging electric vehicle. IEEE Trans Power Electron 2015;30(11):6368–77.

[26]. He J, Huang HJ, Yang H, Tang TQ. An electric vehicle driving behavior model in the traffic system with a wireless charging lane. Physica A 2017;481:119–26.

[27]. C. S. Wang, O. H. Stielau, G. A. Covic, "Design consideration for a contactless electric vehicle battery charger", IEEE Transactions on Industrial Electronics 52(5):1308-1314, 2005.

[28]. J. H. Holland, Adaptation in Natural and Artificial Systems, MIT Press, Cambridge, MA, 1975.

[29]. D. E. Goldberg, Genetic Algorithms in Search, Optimization and Machine Learning, Addison- Wesley, Reading, Mass, 1989.

[30]. Petersen M, Fuchs FW. Development of a 5 kW Inductive Power Transfer System Including Control Strategy for Electric Vehicles. In: International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management, Nuremberg, Germany; 2014.