This article has been accepted for publication in a future proceedins of this conference, but has not been fully edited. Content may change prior to final publication. Citation information: DOI10.1109/UPEC55022.2022.9917793, 2022 57th International Universities Power Engineering Conference (UPEC)

Review of Wireless Charging of EV

Muhammad Salman Sikandar
Department of Electronic and Electrical Engineering, Brunel University, UK
muhammadsalman.sikandar@brunel.ac.uk

Mohamed Darwish
Department of Electronic and Electrical Engineering, Brunel University, UK
mohamed.darwish@brunel.ac.uk

Christos Marouchos
Department of Electrical Engineering, Cyprus University of Technology
Limassol, Cyprus
christos.marouchos@cut.ac.cy

Abstract—**Electrified transportation will minimise greenhouse gas emissions while also lowering gasoline prices. To encourage adoption of electrified transportation, a variety of charging networks must be established in a user-friendly environment. WEVCS (wireless electric vehicle charging systems) could be a viable alternative technology for charging electric vehicles (EVs) without the need for a plug. The work done in the area of wireless power transfer technology for electric vehicles is described in this paper.**

I. Introduction

Battery charging options for electric vehicles (EVs) include both contact and wireless charging. Contact charging uses the metal contact between the plug and the socket to deliver electricity, whereas wireless charging uses the magnetic *field*. Wireless charging has the advantages of minimal contact loss, no mechanical wear, safety, and reliability over contact charging. As a result, wireless charging is gaining popularity [1].

Currently, there are two techniques for charging electric vehicles: plug-in charging and wireless charging, with the former being the most common. High charging efficiency can be achieved with plug-in charging. However, there are a number of drawbacks to plug-in charging, including the charging cables possibly posing a trip hazard, the hassle of physically inserting and removing the charger, and the corrosion of the charger cables with time, which could provide a risk to the user. Wireless charging can help with these issues, and it can also operate in conjunction with monitoring systems [2].

The automobile industry has shifted toward an environmentally friendly alternative, namely electric vehicles. Electric vehicles, sometimes known as EVs, are driven and powered by one or more traction motors. An electric vehicle is powered by energy from distant power sources collected via a collector system. The car is powered by a massive traction battery, which is charged by plugging it into an electrical socket [3].

There are numerous wireless power transfer (WPT) methods, including microwave power transmission, inductive-coupling-power transmission, laser power transmission methods, magnetic resonance coupling [4].

II. EV's Wireless Charging Type and Technology

In high-power uses, such as EVs and plug-in electric vehicles (PEVs) in stationary applications, Wireless Charging Systems (WCS) have been proposed. WCS can provide more benefits in terms of simplicity, dependability, and user friendliness than plug-in charging systems. WCS have a limitation in that they can only be used when the automobile is parked or in stationary modes, such as at parking lots, garages, or at traffic lights**.** Furthermore, stationary WCS have obstacles such as EMC issues, limited power transfer, heavy designs, shorter range, and higher efficiency. The dynamic mode of operation of the WCS for EVs has been investigated in order to increase the two areas of range and sufficient battery storage volume [5].

This technology enables battery storage devices to be charged while the vehicle is in motion. The car uses less expensive battery storage space and has a longer range of travel [6]. However, before becoming widely accepted, a dynamic WCS must overcome two major obstacles: a significant air gap and coil misalignment. The coil alignment and air-gap distance between the source and receiver determine the power transfer efficiency [7] [8]. For compact passenger vehicles, the usual air-gap distance ranges from 150 to 300 mm, whereas it may grow for bigger vehicles. Because the automobile is driven automatically in dynamic mode, aligning the optimal driving position on the transmitter coil is simple [5].

A. Basic operating principle

Fig. 1. shows the fundamental block diagram of the static WCS for EVs. AC mains from the grid are converted into high frequency (HF) AC through AC/DC and DC/AC converters to facilitate power transfer from the transmission coil to the reception coil.

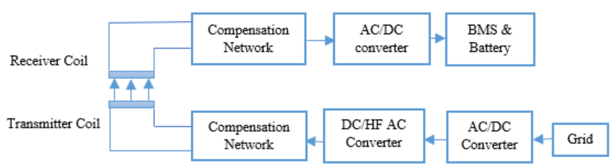

Fig.1 Basic block diagram of static wireless charging system for Electric Vehicles

This article has been accepted for publication in a future proceedins of this conference, but has not been fully edited. Content may change prior to final publication. Citation information: DOI10.1109/UPEC55022.2022.9917793, 2022 57th International Universities Power Engineering Conference (UPEC)

On both the transmitting and receiving sides, compensatory topologies based on series and parallel combinations are used to increase overall system efficiency [9] [10]. The oscillating magnetic flux fields are converted to HF AC by the receiving coil, which is usually positioned below the car. The HF AC is then converted to a steady DC supply that the on-board batteries use. To avoid any health and safety hazards and to assure steady operation, the power control, communications, and battery management system (BMS) are also integrated. To eliminate any unwanted leakage fluxes and improve magnetic flux distribution, magnetic planar ferrite plates are used on both the transmitter and receiver sides [5].

B. Wireless power transfer methods

There are different types of method by which wireless charging could be possible. ~~In~~ Fig.2 illustrates these different types. There could be other methods or technologies which are used but, in this paper the focus is on these four types.

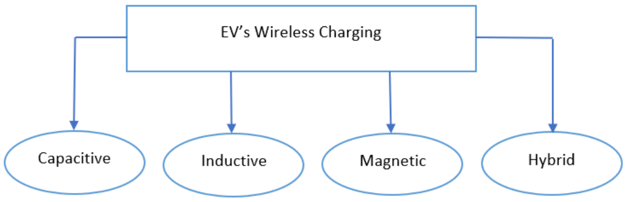

Fig.2 Different types of Wireless charging system technologies

Since the development of wireless charging systems for electric vehicles, four different methodologies for WEVCS design have been used. Traditional inductive power transfer (IPT), capacitive wireless power transfer (CWPT), magnetic gear wireless power transfer (MGWPT) and resonant inductive power transfer (RIPT). Table 1 provides an overview of the wireless power transfer systems available for battery-powered electric cars (BEVs) [11] [12] [13].

Table1: Overview of different methods of WPT for EV's

WPT Methods	**Efficiency**	**EMI**	**Frequency Range(kHz)**
Inductive	Medium/High	Medium	10-50
Capacitive	Low/Medium	Medium	100-150
Permanent magnet	Low/Medium	High	0.05-0.500
Resonant inductive	Medium/High	Low	10-150

WPT Methods	**Price**	**Size/Volume**	**Design**	**Power level**
Inductive	Medium/High	Medium	Medium	Medium/high
Capacitive	Low	Low	Medium	Low
Permanent magnet	High	High	High	Medium/Low
Resonant inductive	Low	Medium	Medium	Medium/Low

1) Capacitive wireless power transfer

The low cost and ease of use of CWPT technology, which employs superior geometric and mechanical coupling capacitor topologies [14] is particularly beneficial for low-power applications, such as portable electronics [15]

Fig. 3 illustrates a typical schematic representation of a CPWT based on a series resonant circuit. Instead of coils or magnets, coupling capacitors are used in the CWPT to transport power from the source to the receiver. Through power factor adjustment circuitry, the primary AC voltage is delivered to an H-bridge converter. High-frequency AC generated by the H-bridge passes through coupling capacitors at the receiver side. The CWPT, unlike the IPT, can handle both high voltage and low current.

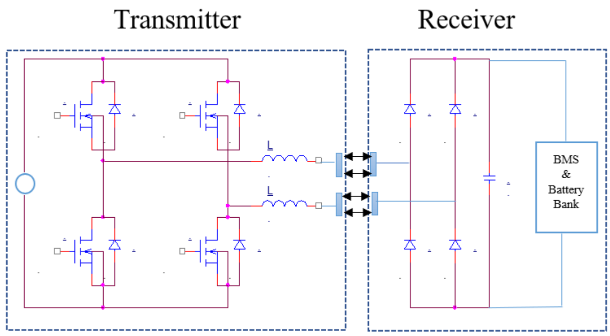

Fig.3. Schematic diagram of Capacitive Wireless Power Transfer

Additional inductors are added in series with the coupling capacitors to lower impedance between the transmitter and receiver sides at the resonant arrangement. This configuration also aids in the implementation of soft switching into the circuits. Similarly, using rectifier and filter circuitry, the received AC voltage is converted to DC for the battery bank or load [5].
The size of the coupling capacitor and the distance between two plates have a direct impact on the power transmission level. CWPT gives excellent performance and improved field limitations developed between two plates of the capacitor for a small air gap [16]. Due to huge air gaps and high-power level requirements, the use of CWPT in EVs has been limited thus far.

2)Magnetic gear wireless power transfer

As shown in Fig.4, the magnetic gear WPT (MGWPT) differs from both the CWPT and the IPT.

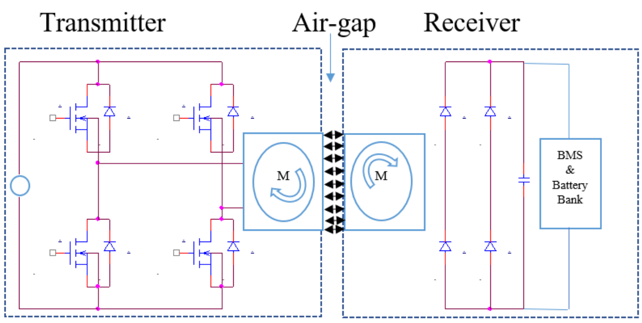

Fig.4. Schematic Diagram of magnetic gear based WPT

In contrast to other WEVC methods that use coaxial cables, this approach uses two synchronised permanent magnets (PM) placed side by side. The transmitter winding receives the main power as the current source, which produces a mechanical torque on the primary PM. The primary PM rotates and generates a torque on the secondary PM through mechanical interaction when the mechanical torque is used. The primary PM in a pair of synchronised PMs operates as a generator, while the secondary PM collects electricity and distributes it to the battery via the power converter and BMS [5].

3)Inductive power transfer

The classic IPT's basic block diagram is shown in Fig.5. It is based on a number of different electric vehicle charging systems. IPT has been tested and used to transfer contactless power from the source to the receiver in a number of applications ranging from milliwatts to kilowatts. The primary coil of the magnet-charge, referred to as a charging paddle (inductive coupler), was put into the vehicle charging port, where the secondary coil received electricity and allowed the EV to be charged. The University of Georgia exhibited a 6.6 kW Level 2 EV charger that could charge from 200 to 400 V battery voltage at a 77 kHz operating frequency. A 10 KVA coaxial winding transformed offers numerous advantages in this universal IPT, including as an easy-to-modify power range and inductive coupling design flexibility [17].

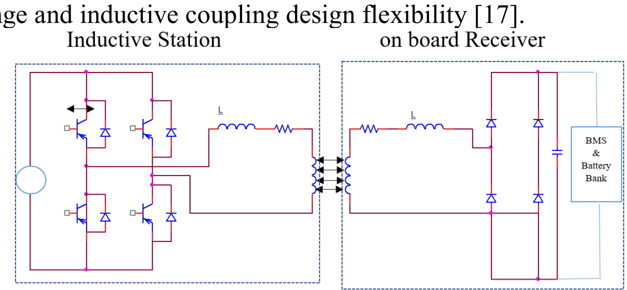

Fig.5.Schematic Diagram of Traditional Inductive Power Transfer

4)Hybrid Charging System

Fig.6. shows a block diagram of the hybrid wired/wireless charging system. The DC power module and the central control unit comprise the power supply side, which supplies either the wired or wireless charging EV. The DC power module is composed primarily of the input power factor correction (PFC) and DC/DC converter, which offers galvanic isolation between the input utility grid and the output. Note that the commercial DC/DC module is utilised extensively for wired EV charging, resulting in a very low price for the module. Utilizing a commercial DC/DC power module rather than building one integrated with the inverter is therefore cost-effective. A two-wire switch is utilised to supply power to either the wired or wireless mode. The output voltage of the DC power module can be adjusted in response to an instruction from the central control unit's CAN bus [18].

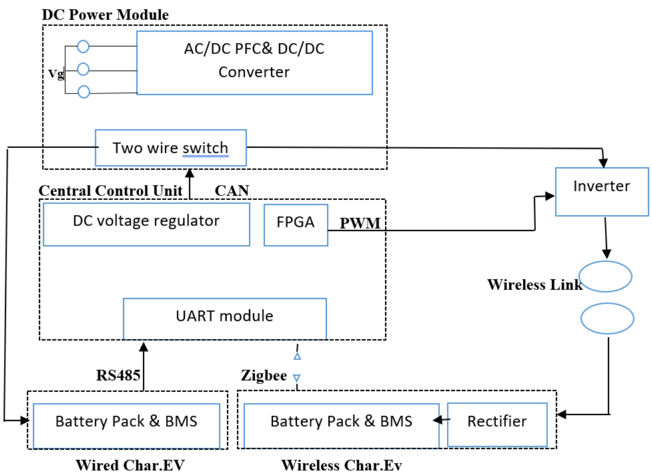

Fig.6. Block diagram of the hybrid charging system

The primary components of the central control unit are the universal asynchronous transmitter-receiver (UART) module, the DC voltage regulator, and the inverter. The UART module manages serial communication and collects information from the battery management system (BMS). Two types of serial communication modalities are provided, including cable and wireless. RS485 is used for wired communication, whereas Zigbee is used for wireless. The DC voltage regulator is based on a PI controller that accepts the real-time battery charging voltage and current as inputs and outputs the DC module output voltage. In addition, when wireless charging mode is activated, the inverter transforms DC electricity to AC for wireless communication [18].

In actuality, each hybrid charging system has its own parking lot. Thus, only one charged object, either the EV with cable charging or the EV with wireless charging, must be charged by the hybrid system at any one moment. Charging two or more electric vehicles simultaneously is not possible. Consequently, the central control unit operates in either the wired mode or the wireless mode [18].

This article has been accepted for publication in a future proceedins of this conference, but has not been fully edited. Content may change prior to final publication. Citation information: DOI10.1109/UPEC55022.2022.9917793, 2022 57th International Universities Power Engineering Conference (UPEC)

As shown in Fig.5, the DC power module and the central control unit (except the inverter) are shared across the two charging modes, which minimises the total cost of the hybrid charging system. The cost of the DC power module is proportional to its rated power, which is the product of its maximum output voltage and current requirements. It is important, from a cost perspective, to design a hybrid charging system that meets the minimum rated power need for the DC module while also supporting both wired and wireless charging modes for a given battery charging profile [18].

III. Discussion

In high-power uses, such as EVs and plug-in electric vehicles (PEVs) in stationary applications, Wireless Charging Systems (WCS) have been proposed. the development of wireless charging systems for electric vehicles, four different methodologies for WEVCS design have been used. Traditional inductive power transfer (IPT), capacitive wireless power transfer (CWPT), magnetic gear wireless power transfer (MGWPT) and resonant inductive power transfer (RIPT). The low cost and ease of use of CWPT technology, which employs superior geometric and mechanical coupling capacitor topologies is particularly beneficial for low-power applications, such as portable electronics. In contrast to other WEVC methods that use coaxial cables, this approach uses two synchronised permanent magnets (PM) placed side by side. IPT has been tested and used to transfer contactless power from the source to the receiver in a number of applications ranging from milliwatts to kilowatts. each hybrid charging system has its own parking lot. Thus, only one charged object, either the EV with cable charging or the EV with wireless charging, must be charged by the hybrid system at any one moment. Charging two or more electric vehicles simultaneously is not possible

References

[1] Y. Chen, H. Zhang, S.-J. Park, and D.-H. Kim, “A Switching Hybrid LCC-S Compensation Topology for Constant Current/Voltage EV Wireless Charging,” IEEE Access, vol. 7, pp. 133924–133935, 2019

[2] X. Mou, D. T. Gladwin, R. Zhao, H. Sun, and Z. Yang, “Coil Design for Wireless Vehicle-to-Vehicle Charging Systems,” IEEE Access, vol. 8, pp. 172723–172733, 2020

[3] M. Sato, G. Yamamoto, D. Gunji, T. Imura, and H. Fujimoto, “Development of Wireless In-Wheel Motor Using Magnetic Resonance Coupling,” IEEE Transactions on Power Electronics, vol. 31, no. 7, pp. 5270–5278, Jul. 2016

[4] C. Qiu, K. T. Chau, T. W. Ching, and C. Liu, “Overview of Wireless Charging Technologies for Electric Vehicles,” Journal of Asian Electric Vehicles, vol. 12, no. 1, pp. 1679–1685, 2014

[5] C. Panchal, S. Stegen, and J. Lu, “Review of static and dynamic wireless electric vehicle charging system,” Engineering Science and Technology, an International Journal, vol. 21, no. 5, pp. 922–937, Oct. 2018

[6] S. Lukic and Z. Pantic, “Cutting the Cord: Static and Dynamic Inductive Wireless Charging of Electric Vehicles,” IEEE Electrification Magazine, vol. 1, no. 1, pp. 57–64, Sep. 2013

[7] S. Moon, B.-C. Kim, S.-Y. Cho, C.-H. Ahn, and G.-W. Moon, “Analysis and Design of a Wireless Power Transfer System With an Intermediate Coil for High Efficiency,” IEEE Transactions on Industrial Electronics, vol. 61, no. 11, pp. 5861–5870, Nov. 2014

[8] F. van der Pijl, P. Bauer, and M. Castilla, “Control Method for Wireless Inductive Energy Transfer Systems With Relatively Large Air Gap,” IEEE Transactions on Industrial Electronics, vol. 60, no. 1, pp. 382–390, Jan. 2013

[9] J. L. Villa, J. Sallan, J. F. Sanz Osorio, and A. Llombart, “High-Misalignment Tolerant Compensation Topology For ICPT Systems,” IEEE Transactions on Industrial Electronics, vol. 59, no. 2, pp. 945–951, Feb. 2012

[10] K. Kalwar, S. Mekhilef, M. Seyedmahmoudian, and B. Horan, “Coil Design for High Misalignment Tolerant Inductive Power Transfer System for EV Charging,” Energies, vol. 9, no. 11, p. 937, Nov. 2016

[11] K. A. Kalwar, M. Aamir, and S. Mekhilef, “Inductively coupled power transfer (ICPT) for electric vehicle charging – A review,” Renewable and Sustainable Energy Reviews, vol. 47, pp. 462–475, Jul. 2015

[12] S. Y. R. Hui, W. Zhong, and C. K. Lee, “A Critical Review of Recent Progress in Mid-Range Wireless Power Transfer,” IEEE Transactions on Power Electronics, vol. 29, no. 9, pp. 4500–4511, Sep. 2014

[13] T. W. Ching and Y. S. Wong, “Review of wireless charging technologies for electric vehicles,” IEEE Xplore, Dec. 01, 2013

[14] C. Liu, A. P. Hu, B. Wang, and N.-K. C. Nair, “A Capacitively Coupled Contactless Matrix Charging Platform With Soft Switched Transformer Control,” IEEE Transactions on Industrial Electronics, vol. 60, no. 1, pp. 249–260, Jan. 2013

[15] A. Hu, L. Xiang, and G. Tang, “Vibration Signal Analysis Based on Hilbert-Huang Transform,” IEEE Xplore, Oct. 01, 2008

[16] J. Kim and F. Bien, “Electric field coupling technique of wireless power transfer for electric vehicles,” IEEE Xplore, Apr. 01, 2013

[17] F. Musavi and W. Eberle, “Overview of wireless power transfer technologies for electric vehicle battery charging,” IET Power Electronics, vol. 7, no. 1, pp. 60–66, Jan. 2014

[18] Q. Deng et al., “Wired/Wireless Hybrid Charging System for Electrical Vehicles With Minimum Rated Power Requirement for DC Module,” IEEE Transactions on Vehicular Technology, vol. 69, no. 10, pp. 10889–10898, Oct. 2020