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Research Article

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Static and dynamic wireless charging system for electric vehicle

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ABSTRACT

Electrified transportation will help to reduce greenhouse gas emissions and petrol prices. Electrified transportation demands that a wide variety of charging networks be set up, in a user-friendly environment, to encourage adoption. Wireless electric vehicle charging systems (WEVCS) can be a potential alternative technology to charge electric vehicles (EVs) without any plug-in problems. This paper outlines the currently available wireless power transfer technology for EVs. In addition, it also includes wireless transformer structures with a variety of ferrite shapes, which have been researched. WEVCS are associated with health and safety issues, which have been discussed with the current development in international standards. Two major applications, static and dynamic WEVCS, are explained, and up-to-date progress with features from research laboratories, universities, and industries is recorded. Moreover, future upcoming concepts-based WEVCS, such as "vehicle-to-grid (V2G)" and "in-wheel" wireless charging systems (WCS) are reviewed and examined, with qualitative comparisons with other existing technology.

KEYWORDS: Wireless charging, Battery management system, Electric vehicle

INTRODUCTION

Wireless Charging Systems (WCS) have been proposed in high-power applications, including EVs, and plug-in electric vehicles (PEVs) in stationary applications. In comparison with plugin charging systems, WCS can bring more advantages in the form of simplicity, reliability, and user friendliness. The problem or limitation associated with WCS is that they can only be utilized when the car is parked or in stationary modes, such as in car parks, garages, or traffic signals. In addition, stationary WCS has some challenges, such as electromagnetic compatibility (EMC) issues, limited power transfer, bulky structures, shorter range, and higher efficiency. In order to improve the two areas of range and sufficient volume of battery storage, the dynamic mode of operation of the WCS for EVs has been researched. This method allows the charging of battery storage devices while the vehicle is in motion. The vehicle requires less volume of expensive battery storage and the range of transportation is increased. However, a dynamic WCS has to face two main hurdles, a large air-gap and coil misalignment, before it becomes widely accepted.

The power transfer efficiency depends on the coil alignment and air-gap distance between the source and receiver. The average air-gap distance varies from 150 to 300 mm for small passenger vehicles, while it may increase for larger vehicles. Aligning the optimal driving position on the transmitter coil can be performed easily because the car is driven automatically in dynamic mode.

In addition, different compensation methods, such as series and parallel combinations, are employed on both the transmitting and receiving sides to reduce parasitic losses and improve system efficiency. In this review paper, the fundamental operation of WCS for EVs, including methods of power transfer, is analyzed. In addition, a variety of wireless transformer structures are explained in order to improve power transfer efficiency. This paper also outlines current developments in the static and dynamic modes of WEVCS in both the commercial and university sectors (Panchal *et al.*, 2018).

BASIC OPERATING PRINCIPLE

The basic block diagram of the static WCS for EVs is illustrated in Figure 1. To enable power transfer from the transmission coil to the receiving coil, AC mains from the grid is converted into high frequency (HF) AC through AC/DC and DC/AC converters. In order to improve overall system efficiency, series and parallel combinations based compensation topology are included on both the transmitting and receiving sides. The receiving coil, typically mounted underneath the vehicle, converts the oscillating magnetic flux fields to HF AC. The HF AC is then converted to a stable DC supply, which is used

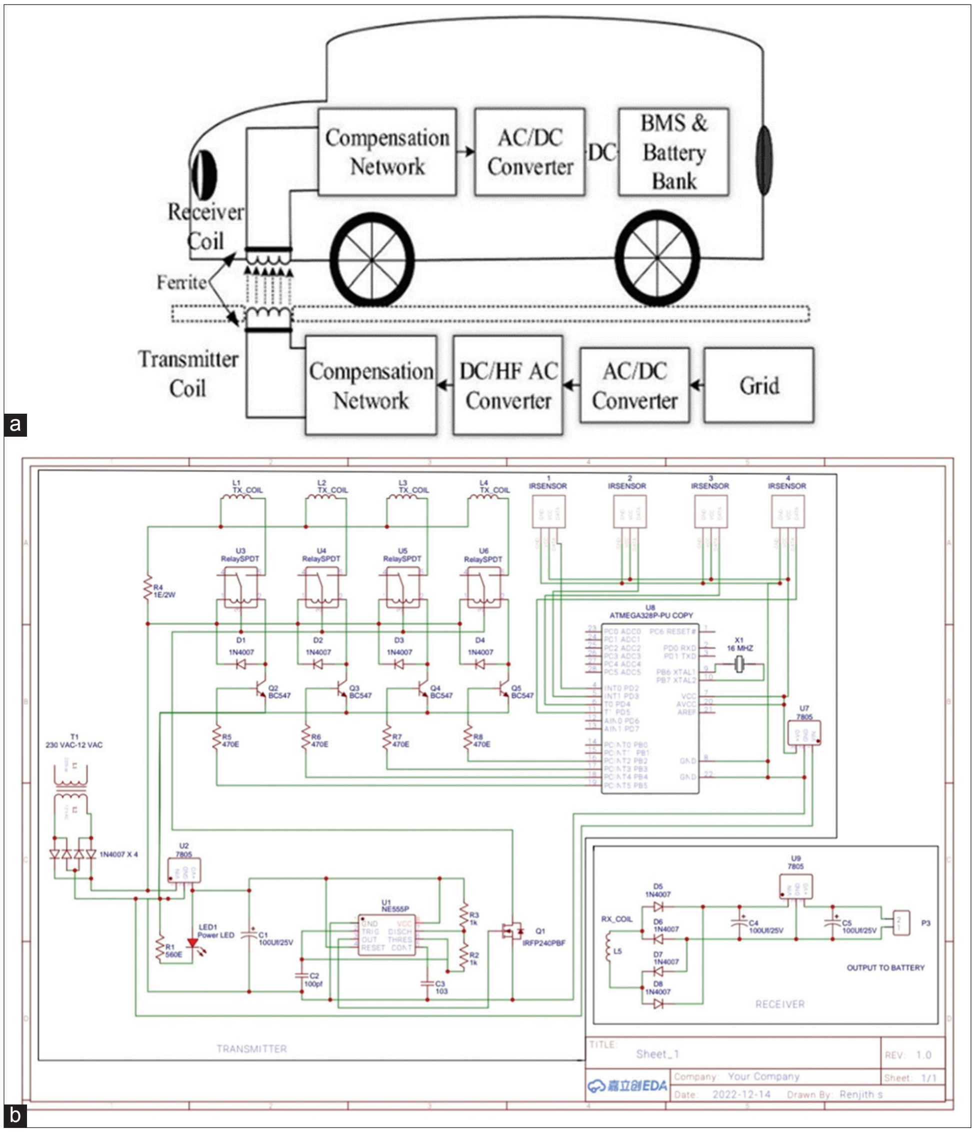

Figure 1: a) Basic block diagram of static wireless charging system for EVs and b) Circuit diagram

by the onboard batteries. The power control communications, and battery management system (BMS) are also included, to avoid any health and safety issues and to ensure stable operation. Magnetic planar ferrite plates are employed at both transmitter and receiver sides, to reduce any harmful leakage fluxes and to improve magnetic flux distribution.

WIRELESS POWER TRANSFER METHOD

Since the introduction of wireless charging systems for EVs, four methods for the design of WEVCS have been utilized: traditional inductive power transfer (IPT), capacitive wireless power transfer (CWPT), magnetic gear wireless power transfer (MGWPT) and resonant inductive power transfer (RIPT).

COIL DESIGN

An air-core wireless transformer design is used in the WPT to enable electrical power flow from the source to the receiver sides. Figure 2 shows the possible designs of the WPT system, several planar coil shapes such as circular, rectangular, and hybrid configurations that are used to improve the performance and solve the misalignment problems between the transmitter and receiver (Figures 3 & 4). Also, the corresponding advantages and weaknesses of each model are presented in the same table. In the literature, multiple WPT structures for automotive applications are evaluated to assess the magnetic coupling and feasibility. Most of these studies investigated structures that contain circular designs. Recently, a circular planar structure was tested for a 2 kW inductive power transfer. It was proved that its null zone is the lowest compared to the other models. Therefore, this geometry is selected in this study (Mohamed *et al.*, 2022).

APPLICATION OF WEVCS

Depending on their applications, wireless electric vehicle charging systems can be separated into the following two important scenarios to transfer power from the source to the battery bank and into the car (Jang, 2008; Machura & Li, 2009).

Static Wireless Electric Vehicle Charging System (S-WEVCS)

WEVCS unlocks another door to provide a user-friendly environment for consumers (and to avoid any safety related issues with the plug-in chargers). Static WEVCS can easily replace the plug-in charger with minimal driver participation, and it solves associated safety issues such as trip hazards and electric shock. Figure 5 shows the basic arrangement of static WEVCS. The primary coil is installed underneath in the road or ground with additional power converters and circuitry. The receiver coil, or secondary coil, is normally installed underneath the EVs front, back, or center. The receiving energy is converted from AC to DC using the power converter and is transferred to the battery bank. In order to avoid any safety issues, power control and battery management systems are fitted with a wireless communication network to receive any feedback from the primary side. The charging time depends on the source power level, charging pad sizes, and air-gap distance between the two windings. The average distance between lightweight duty vehicles is approximately 150-300 mm. Static WEVCS can be installed in parking areas, car parks, homes, commercial buildings, shopping centres, and park 'n' ride facilities. Many prototypes have been developed by universities at the research and commercial levels. Their prices vary from approximately USD 2700-13,000 from charging levels 3.3-7.2 kW. Their power levels meet with the recently announced international SAE standards (J2954) power class for levels 1 (3.3 kW) and 2 (7.7 kW), including frequency ranges 81.9-90 kHz. Currently, the SAE organization is working on the standards, which are related to allowable misalignment and the installation location of the receiver pads in the car. A number of prototypes have been presented with various mounting locations, such as the front, rear, and center of the receiver pads underneath the car. The Oak Ridge National Laboratory (ORNL) is mostly focusing on improving power transfer efficiency by coil designing while the University of Auckland has proposed some hardware and software (including charging pad development) to improve plug-in efficiency. Overall, prototypes or lab experiments of stationary WCS for EVs have been developed from power ranges 1-20 kW, air-gap distance 100-300 mm with efficiency from 71 to 95%.

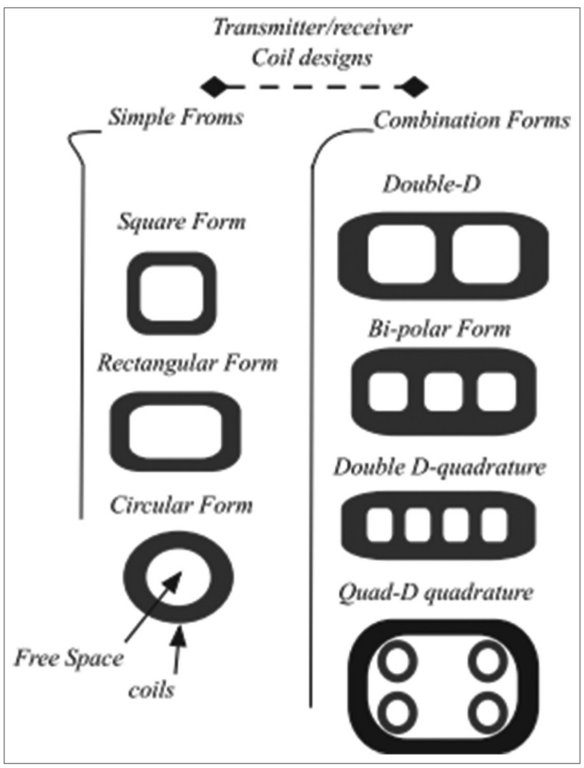

Figure 2: Coil shapes

Dynamic Wireless Electric Vehicle Charging System (D-WEVCS)

Plug-in or BEVs are suffering due to two major obstacles-cost and range. In order to increase range, EVs are required to charge either quite frequently or to install a larger battery pack (which results in additional problems such as cost and weight). In addition, it is not economical to charge a vehicle frequently. The dynamic wireless electric vehicle charging system (D-WEVCS) is a promising technology, which can reduce the problems associated with the range and cost of EVs. It is the only solution for future EV automation. It is also known as a "roadway powered", "online" or "in motion" WEVCS. As shown in Figure 6, the primary coils are embedded

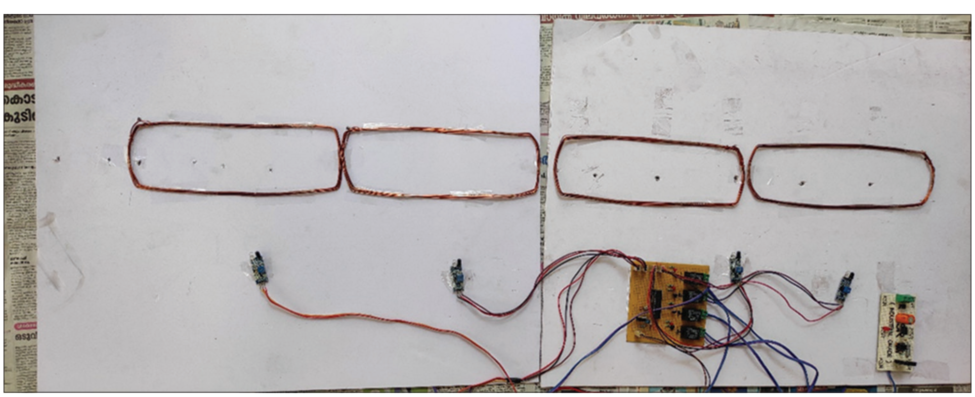

Figure 3: Transmitters

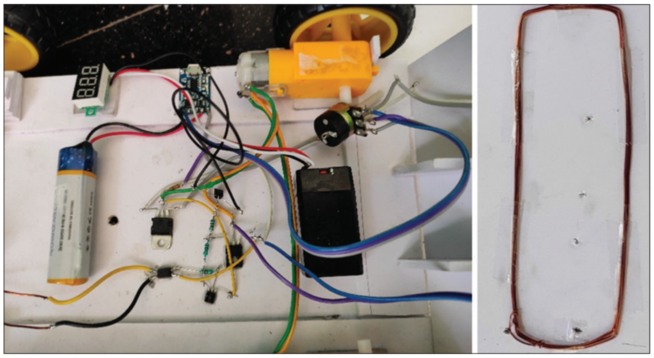

Figure 4: Receiver

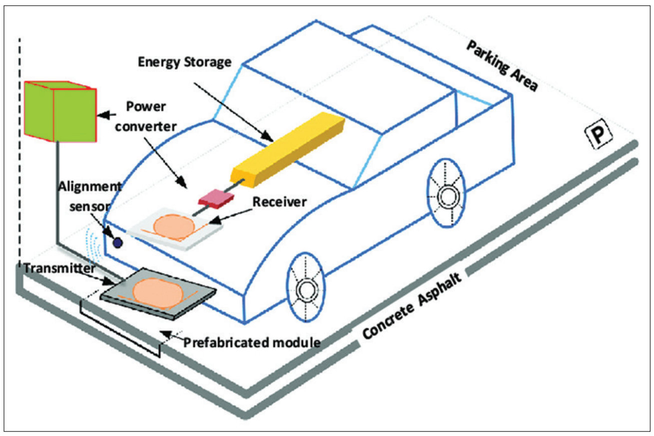

Figure 5: Basic diagram of Static wireless electric vehicle charging system

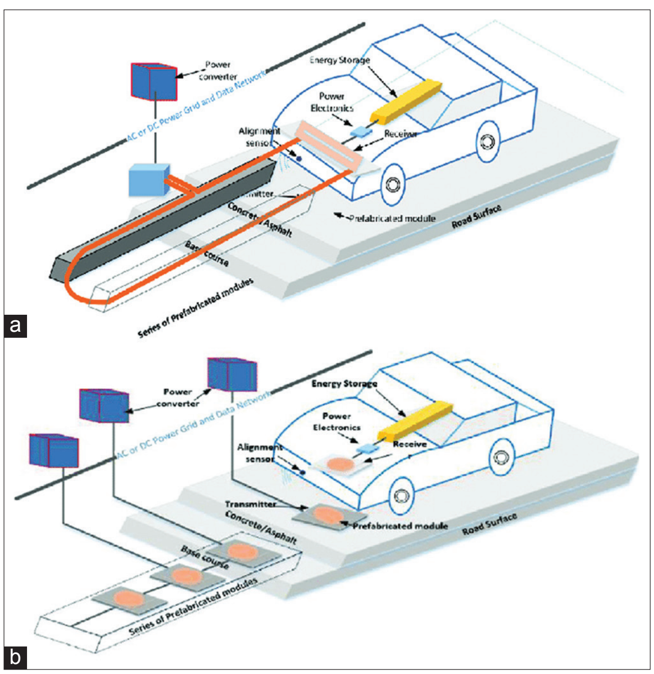

Figure 6: Basic diagram of dynamic wireless electric vehicle charging system

into the road concrete at a certain distance with high voltage, high frequency AC source and compensation circuits to the microgrid and/or RES. Like static WEVCS, the secondary coil is mounted underneath the vehicles. When the EVs pass over the transmitter, it receives a magnetic field through a receiver coil and converts it to DC to charge the battery bank by utilizing the power converter and BMS. Frequent charging facilities of EVs reduce the overall battery requirement by approximately 20% in comparison to the current EVs. For dynamic WEVCS, transmitter pads and power supply segments need to be installed on specific locations and pre-defined routes. The power supply segments are mostly divided into centralized and individual power frequency schemes as shown in Figure 6(a) and (b). In the centralized power supply scheme, a large coil (around 5-10 m) is installed on the road surface, where multiple small charging pads are utilized. In comparison with the segmented scheme, the centralized scheme has higher losses, and lower efficiency including high installation, and higher maintenance costs. Overall, the installation of the initial infrastructure for this technology would be costly. With the help of self-driving cars in the future, it will help to create the perfect alignment between the transmitter and receiver coils which can significantly improve the overall power transfer efficiency (Deflorio *et al.*, 2015). Dynamic WEVCS can be easily incorporated in many EV transportation applications, such as light-duty vehicles, buses, rail, and rapid transport.

CONCLUSION

This paper presents a basic overview of the WEVCS for stationary and dynamic applications with current researched technology. In addition, a variety of core and ferrite shapes have been demonstrated, which have been utilised in the current wireless charging pad design. Health and safety issues have been raised and current developments in international standards are tabled for WEVCS. State-of-the-art stationary and dynamic WEVCS have been studied and tabled, with current research and development from a variety of public and private organisations. Finally, upcoming future technologies are investigated and simulated with the utilisation of FEM. Overall, the latest developments in the area of WEVCS are included in this article.

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