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Development of Wireless Power Transmission System for EV Charging

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ABSTRACT: This paper presents a new localization method for electric vehicles (EVs) that are charged via wireless power transmission (WPT). To ensure optimal charging, our approach involves measurement of the transfer efficiency of the individual transmission coils to determine the most efficient to be used. With the proposed technology, the wireless charging system can self-determine the most efficient coil to transmit power to an EV's position based on sensors activated by its wheels. This not only improves charging performance but also reduces energy loss by autonomously activating the coil with the highest transfer efficiency. The results show that with the proposed system, it is possible to find the coil with maximum transmitting efficiency without the use of actual power transmission and comparison of the measured efficiency.

KEYWORDS: Wireless power transmission, car charging, electrical vehicle, efficiency, charging pad, sensor network, smart charger.

I. INTRODUCTION

Transportation plays a major role in day-to-day life. According to [1], approximately 70% of the United Kingdom (UK) households own a minimum of one vehicle. In 2016, the UK alone had more than 30 million cars registered and driven on the roads. The vehicle licensing statistics shows that in 2016, around 3.3 million cars were registered for the first time and 42,000 of the vehicles were ultra-low emission vehicles (ULEVs) [2]. It has also been predicted that by 2030, about 60% of all new vehicles sales in the UK will be electric vehicles (EVs) [3], regarded as one of the most promising alternatives to the fossil fuel vehicles. Statistics indicate that in July 2018, 162,000 plug-in EVs (PEVs) were used on the roads. Furthermore, the number of electric cars models and brands available in the UK market have also grown rapidly during the recent years. Today in the UK, 75 different models of PEVs are available with roughly 20,000 charging points installed around the country [4].

However, charging cables are still used to connect the cars to the charging stations which is not sustainable [5] in the long-term. One of the obvious advantages of wireless power transmission (WPT) over wired ones is its significantly lower cost of infrastructure maintenance. Since it was first proposed by Sultanbek *et al.* [6], in 2007, WPT has gained popularity due to its simplicity and functionality [7]. Over the past few years, it has been implemented in a wide range of applications from household applications [8], [9] to medical implants [10]. In the past few years, researchers have been working towards implementation of WPT technology in the EVs [11], [12]. They have been able to develop a method to transmit power to the EV with inductive WPT (IWPT) [13] as well as capacitive WPT (CWPT) techniques [14]. IPWT especially offers many advantages, such as its ability to transfer power both unidirectionally and bidirectionally [15], [16]. Also, the transmission efficiency has significantly improved over the years. Currently, efficiency of the WPT system can reach up to 96% however, it strongly depends on the transmitter and receiver loop alignments [17].

The contribution of this paper resides in proposing a novel approach to location-based car charging. The charger uses a sensor array to detect the car position based on the activated sensors beneath the wheels. When the sensors are activated, the algorithm calculates the size of the vehicle and estimates the transmission loop with highest efficiency around the current EV position. Since the sensors are interconnected to the transmitter, communication between the vehicle and the smart charger is required. If the car changes its position, the network will sense any variations instantly and compensate the transmitting coil accordingly.

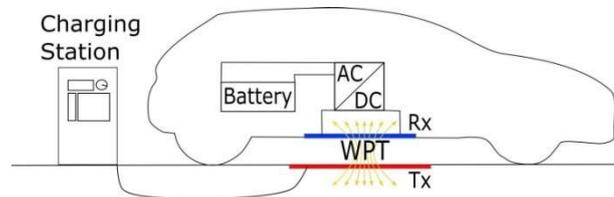


FIGURE 1. EV wireless power transmission charging with the charging pad placed under the vehicle.

We demonstrate that the proposed location-based smart charger also reduces the amount of energy required to locate the loop with highest efficiency, thus the array network uses a low power supply. With the proposed sensor network, a car maximizes the actual charging time since the car position is instantly sensed without interrupting the charging process.

II. RELATED WORK

A conventional EV WPT charger is shown in Fig. 1 where the transmitter loop is placed under the EV and the receiver loop is fitted on its body. The parking spot is designed to offer the driver sufficient parking space and safe exit. However, the spatial freedom in parking spaces is also a challenge for the WPT transmitter design [18]. According to [19], the minimum parking space for a car is 4.8m in length with 2.4m width. Therefore, the WPT charger should ideally be able to transfer power with its highest efficiency regardless of the vehicle position.

Different methods of IWPT have been proposed in recent years. For instance, the authors in [20] proposed replacing the circular coil structure of the pad with quadrature coil combined with DD coil design. New DD-DDQ coil design improves a pad's charging zone and therefore reduces the cost of the pad. A tripod was proposed in [21] where the transmitter unit is built with 3 individual charging coils connected to each other in a circular structure. According to the authors, the proposed structure reduced the magnetic flux leakage. The location finder technique using laser [23], [24] can determine the location of the vehicle with a millimeter range accuracy. However, such a system requires computer-based processing methods, which increase the power consumption of the whole system.

Distinct methods to improve the spatial freedom of WPT charger were proposed by [22], where the power transmission is combined with a super capacitor (SC) to form an energy buffer. A multi-coil charger was also investigated in [25]– [27] to increase the receiver's flexibility based on free positioning of the transmitter. The proposed multi-loop transmitter contains two or more loops which are embedded in the same transmitter. The loop used to transmit power to the receiver is calculated based on the measured results of the individual transmissions. The advantage of this method is that the power is consistently transmitted with the highest possible efficiency. However, continuous communication between the transmitter and receiver has to be established and numerous measurements have to be conducted such as calibration during the charging period and after, in case the object re-positions.

III. WIRELESS CHARGING PADS MODEL

A vital aspect of the car charging pad design is to cover multiple positions of a car in a parking facility. To sense the position of the vehicle, the wheels need to be placed within the pre-marked parking spaces. For experimental purposes, the properties of the three prominent EV models used in the UK are presented in Table 1, and the dimensions of a cars are illustrated in Fig. 2. While designing a charging system, the most crucial factors that need to be considered are the distance between the center of the rear and front wheels (wheelbase), marked as D , as well as the distance between the left and right front wheels (track distance), marked as B .



	Height	Wheelbase
Renault Zoe		
Tesla Model S		

TABLE 1. Dimensions of the three most popular car currently in the U.K. market. [28].

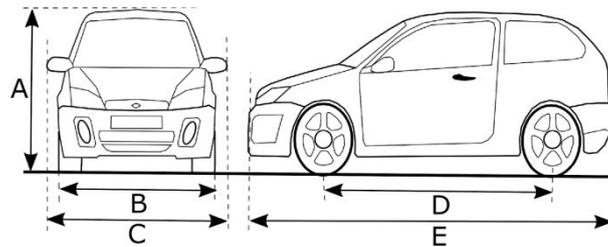


FIGURE 2. A car’s dimensions; height (A), track distance (B), width (C), wheelbase (D), and length (E).

The most common EVs on the UK roads are Renault Zoe, Tesla Model S and BMW i3 [28]. With respect to the dimensions of EVs, it is evident that despite the similarities between the length of the Renault Zoe and BMW i3, their widths differ. Tesla Model S is a considerably larger vehicle. Therefore, depending on the wheelbase and the track distance, it is possible to determine the model of a vehicle based on the activated sensors. Upon successful determination of the EV’s dimension, the system can effectively calculate the optimal transmit coil to be used based on the current parking position.

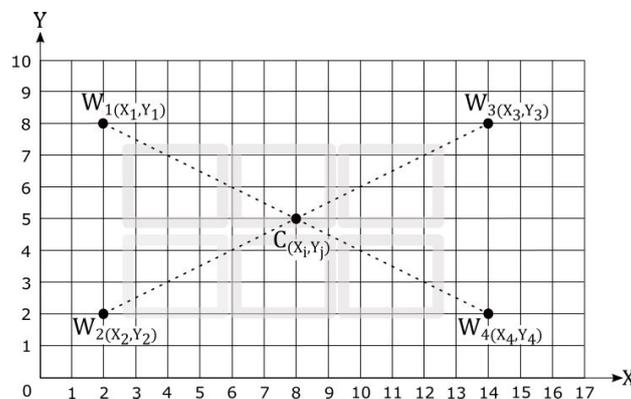


FIGURE 3. Two-dimensional network of the parking space which is used to calculate the EV position, size and the WPT coil with highest efficiency of charging.

The location of the vehicle in the parking space can be computed by its coordinates within the cartesian plane, where each of the four vertices of the vehicle has known coordinates as shown in Fig. 3. From these coordinates, properties such as the width and length can be calculated. The coordinates of each wheel are given by $W_i = W_{(x_i, y_i)}$. To determine the wheelbase and track distance, the distance between the wheels is calculated.

IV. PROPOSED WIRELESS CHARGING PAD

The smart WPT proposed in this paper is information-centric such that a wireless sensor array is integrated with the charging system to a-priori determine the positions of each wheel of the parked vehicle before activating the transmitter coils. Once successfully parked, the weight of the vehicle activates the sensor array underneath the wheels. The control unit senses this outcome as a logic ‘1’ on its input. Based on the combination of the sensed logic inputs,



the algorithm determines the most suitable coil to transmit power at the given car's position. The control unit activates the corresponding switch on the switching circuit based on computation results. Thereafter, the electrical switch connects the wireless charger in the EV with the transmitter coil, initiating power transmission. The flowchart of the system is illustrated in Fig. 4.

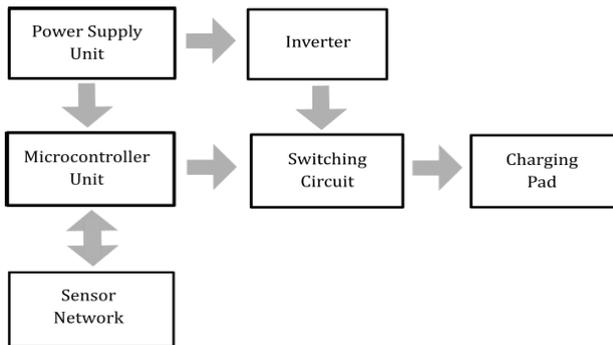


FIGURE 4. Block diagram of the proposed charger with the micro controller as the main intelligent element between the sensors and the charging pad.

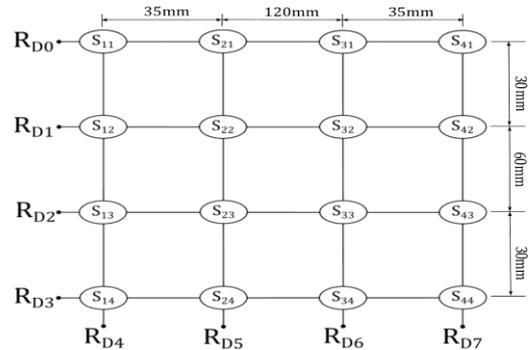


FIGURE 5. Charging pad sensor network that senses the car wheels to calculate of a car's receiver coil.

Fig. 5 illustrates a parking space model which consists of an inbuilt array of 16 independent sensors. The proposed sensor array can be described as a 4x4 matrix, where each set of four sensors is responsible for determining the position of a wheel. The precision of calculating the car's position can be optimized by increasing the number of sensors. However, that will simultaneously increase the complexity of the control unit and algorithm. In the end, the cost of implementation will also increase. Alternatively, precision can be enhanced by using existing sensors to measure the position of three or two wheels in diagonal positions. Thus, the algorithms require at least two wheels to be positioned diagonally in order to determine the charger's position.

V. THE CONTROL UNIT

All feasible combinations of the four sensors under each wheel are presented in Fig. 7, which further explains the logic in Fig. 6. In the proposed system, logic "1" indicates that the sensor is activated, while "0" indicates otherwise. It is also possible to reverse the system logic such that logic "0" indicates that the sensor is active. Upon activation of the sensors beneath each wheel, the control unit triggers the corresponding switch to connect the charger to the relevant coil.

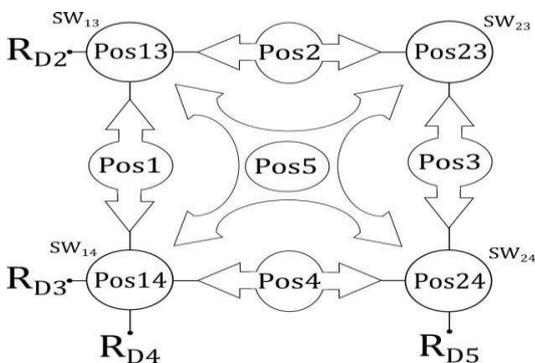


FIGURE 6. Sensor networks under a single wheel. The network can determine 9 different placements of the wheel. Four positions when the single sensor is activated and additional five position depends on the combination of the activated sensors.

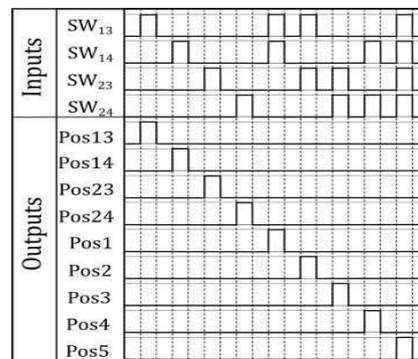


FIGURE 7. All possible combinations of a single wheel position. The positions Pos12, Pos14, Pos23, and Pos34 are sensed directly on the input of the micro-controller, while the positions Pos1 to Pos5 are determined depending on the combination of the switches Sxy activated simultaneously.

The proposed coil system consists of six rectangular coils as shown in Fig. 8. Rather than a single large coil, we adopted six smaller coils to cover the area of interest and at the same time optimize the energy consumed by the system. The open ends of each coil are linked to the connector COM, which is permanently connected to the inverter. In contrast, the opposite end of the coils is connected to independent switches. Therefore, connection RB0 is linked to switch SW0 on the switching board, RB1 to SW1 and so on. Once the related switch is triggered according to the calculations, the coil with highest efficiency is activated to transmit power to the EV.

VI. SIMULATION AND RESULTS

To evaluate the proposed system, the experimental results are presented in this section. As mentioned, the H-bridge inverts the DC voltage provided by the power supply. The inverted square wave voltage is then applied to the transmitter coil. Following this the output of the inverter was measured and compared with the received voltage on the receiver coil on a time scale as presented in Fig. 8. In the figure, the output voltage of the inverter, presented in blue line is not square shape.

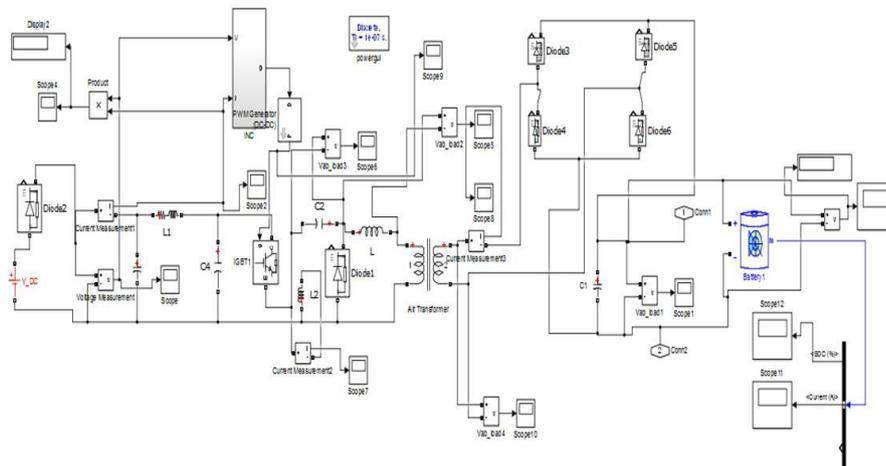


Fig. 8. Simulation of Wireless power transmission system

This is due to inductance of the transmitter coil. The peak of the output voltage is just below 10V. This drop from the 12V supplied to the inverter represents a significant loss. Nevertheless, a drop in the semiconductor components is expected. Furthermore, the voltage on the receiver side is illustrated as dotted black line in the same figure. The received voltage is measured when the transmitter and receiver are fully aligned. At its peak, the received voltage reached 13.5V.

The results of simulation are as follows:

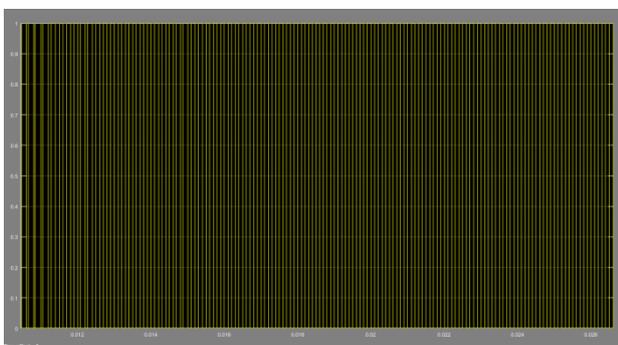


Fig. 9 Gate pulses for operation of converter

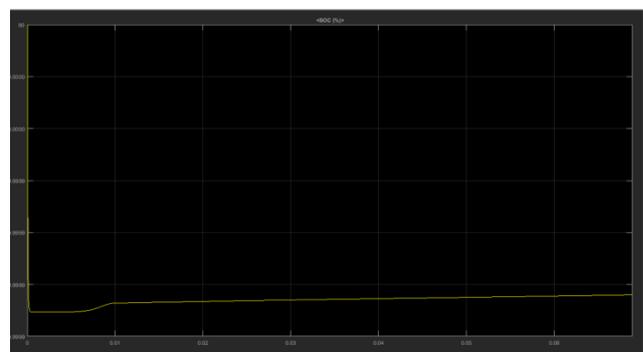


Fig. 10. A Soc increasing after start of charging (Battery 12v 7amp)

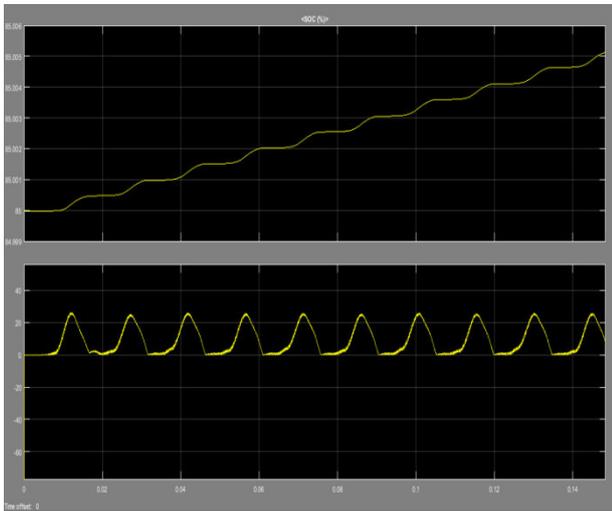


Fig. 10. B Soc current (Battery 12v 7amp)

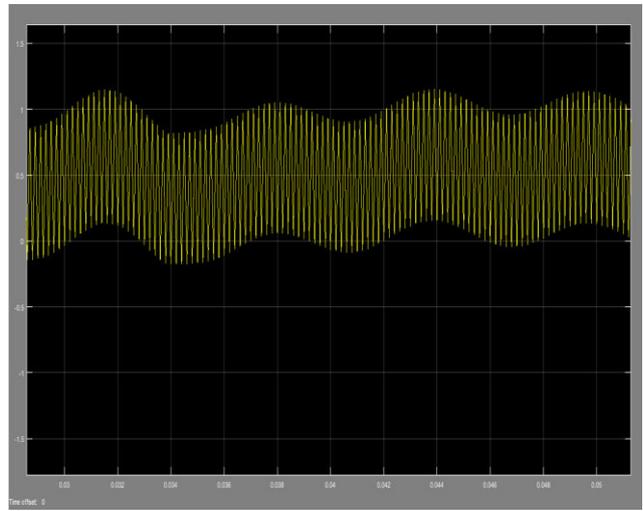


Fig. 11 Inductor current

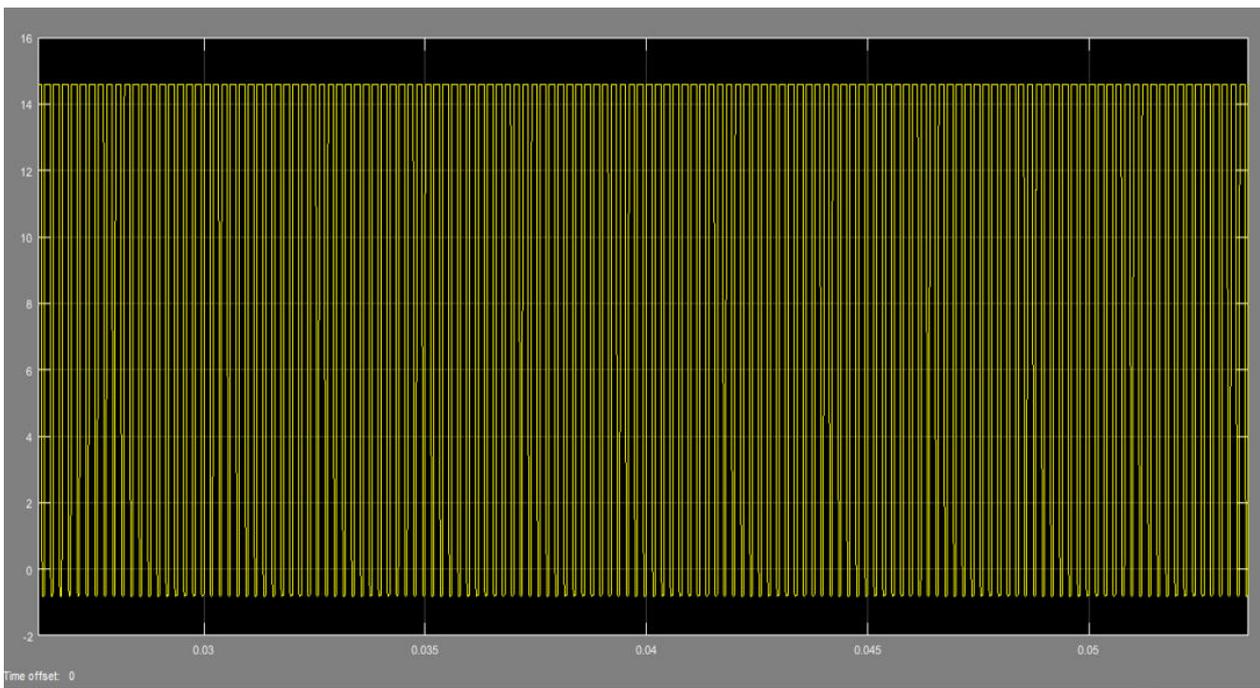


Fig. 12 Voltage across coil while transmitting the power output of wireless transmission

VII. CONCLUSION

In this paper we investigated a smart charging system for EVs. The proposed system can autonomously determine the position of the receiver, which allows the charging pad to utilize only the coil with the highest transfer efficiency for charging the EV. This technique optimizes the operations of the charging pad as the optimal coil can be determined almost immediately after the EV is located on the parking spot. Furthermore, the proposed design improves the efficiency of the charging system as the transmitter is not required to carry out measurements on each coil in order to determine the one with highest efficiency for each location. Thus, our solution eliminates the energy losses in the optimal coil selection process which can be significant in energy-intensive systems such as car charging. Finally, the proposed method of charging is more reliable since the car position is detected instantly and recalibration of the charger is not required if the car slips out of position.



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