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Toward Efficient Very Low Frequency Wireless Power Transfer for EVs: From Grid to Battery

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Abstract—This paper aims to improve the efficiency, affordability, and safety of Wireless Power Transfer (WPT) devices. Wireless inductive charging is quite common in devices like smartphones, charging electric vehicles, and presents significant challenges due to high frequency electromagnetic fields that can be dangerous for users and those nearby. Current systems are expensive due to the use of specialized materials and components. By developing WPT systems with drastically reduced frequency levels, this research has the potential to significantly impact the widespread adoption of affordable, safe, and efficient WPT devices for high-power applications like electric vehicle charging. In this article, the authors presents a first step toward a WPT system functioning at a very low frequency, *i.e* 400 Hz.

Index Terms—Wireless Power Transfer, Inductive Coupling, Low Frequency, Grid to Battery, Charging Electric Vehicle.

I. INTRODUCTION

The utilization of Wireless Power Transfer (WPT) devices has risen in popularity over recent years due to their widespread usage in a variety of applications, including smartphones, electric toothbrushes, and electric vehicles (EVs). Despite significant progress in the development of electric vehicles, they still come with certain drawbacks, such as high costs and issues related to charging. The primary challenges associated with EV charging are the limited availability of charging stations and the extended charging times required for full battery capacity [1]. It is worth mentioning that there are two primary methods for charging electric vehicles: conductive charging and wireless charging. Conductive charging is the mainstream technique due to its efficiency, cost-effectiveness, and electromagnetic compatibility.

However, different prototypes of Wireless Power Transfer (WPT) systems have been developed during the last few years [2]–[4] and have shown relevant results. According to recent reviews, most of the devices rely on an Inductive Power Transfer (IPT) principle. In Electric Vehicle (EV) applications, IPT-based systems are composed of two magnetically coupled coils, forming a loosely coupled transformer that allows power transmission from the grid to the EV battery through power electronic converters, thanks to well-chosen resonant capacitors. Recent developments have shown good results in terms of power ranging from few kW to tens of kW, and performances, with efficiency ranging from 80% to 95%, as reported in recent state-of-the-art reviews [2]–[4].

However, the use of Wireless Power Transfer (WPT) chargers for EVs presents two main challenges : 1) compliance with health standards regulating radiated electromagnetic fields, and 2) comparison with its wired counterpart in terms of efficiency, of power and costs. For instance, the Society of Automotive Engineers (SAE) has set a standard for resonance frequency at $85\pm 5\%$ kHz for a light-duty passenger vehicle [5]. Additionally, IEEE C-95.1-12345-2014 provides insight into human safety from the high-frequency magnetic field [5]. Furthermore, the use of specific ferrites, Litz wire, and fast power components to operate at high frequencies can increase costs and limit competitiveness with wired systems. Despite these drawbacks, wireless charging is gaining attention due to its convenience, automation, and weatherproof capability, as proved by some recent review articles [2]–[4].

This paper focuses on the efficiency of WPT system from perspective of transferring power from the grid to the battery. It's important to mention that the efficiency of the system is primarily influenced by two critical components: the power electronic converters and the loosely coupled transformer. The weak coupling between the transmitter and receiver pads results in a decrease in the efficiency of power transfer through the magnetic field. Furthermore, the efficiency of the power electronic converters can affect the overall efficiency of the WPT system [5]–[7].

The aim of this study is to explore methods for improving the efficiency, reducing limitations and costs, and improving user acceptance of WPT systems by significantly lowering the frequency of electromagnetic fields used in the system. The ultimate goal is to contribute to the development of a safer, more cost-effective, and widely embedded WPT solution. While most of the demonstrators presented in the recent reviews were running at high frequencies, ranging from 20 kHz to 85 kHz, this paper proposes a WPT system operating at a frequency of 400 Hz, which may result in a decrease in the effectiveness of the magnetic power transfer. However, this lack of efficiency is likely to be compensated by reducing the power loss in the power electronic converters, such as by using lower switching frequencies, as we will explain in this paper. It is worth noting that a lower frequency also helps to reduce the overall cost of the wireless solution.

II. WPT SYSTEM DESCRIPTION AND PRELIMINARY RESULTS

The WPT system, as illustrated in Fig. 1, is generally composed of a rectifier (AC-DC converter) that converts the 50 Hz AC voltage from the network to a DC voltage. An inverter is then used to convert the rectified voltage into a 400 Hz voltage, which is applied to the transmitter pad (consisting of self-inductance L_1 and Resistance R_1) in series with the capacitor C_1 to establish resonance. On the EV side, the receiver pad (consisting of self-inductance L_2 and Resistance R_2) is connected in series with the capacitor C_2 which serves as the input to a rectifier for charging the battery.

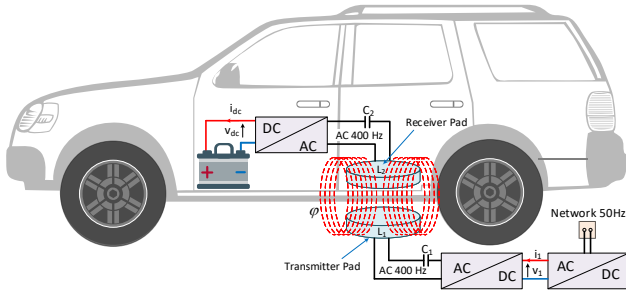


Fig. 1. Schematic of the studied WPT system.

The whole experimental bench is home-made, and the magnetic part has been designed by the open-source software FEMM [8]. It is composed of two coupled coils and uses ferrite plates to increase the coupling. It allows to realize experiments with different magnetic coupling configurations, and offers several degrees of freedom, *i.e.* one can modify the airgap from 50 to 300 mm, and the number of layers of the primary and of the secondary coils can be change from 1 to 7. The resulting inductance for both sides is between 4.5 to 23 mH and the magnetic coupling coefficient ranges from 0.1 to 0.6.

Measurements realized on the system show that the relative differences of the self inductance values of each layer are under 4% between FEM calculations and measurements.

According to the simulation results, supplied power from the source to the transmitter side is 10 kW, and the receiving power on the load side is 8.3 kW. Therefore the achieved global efficiency is around 83%. It is worth noting that the converters used for these tests were made using IGBTs, which were chosen to match the experimental conditions.

After having verified the good operation of the experimental bench, tests could be carried out with the system thus designed. Several operating points were studied and compared with the theoretical performances obtained by the simulation.

III. CONCLUSION

This paper presents the first step toward IPT-based systems operating at very low frequencies, which is of a great interest for safety, system integration and cost reduction. It is worth mentioning that the system has not been optimized so far,

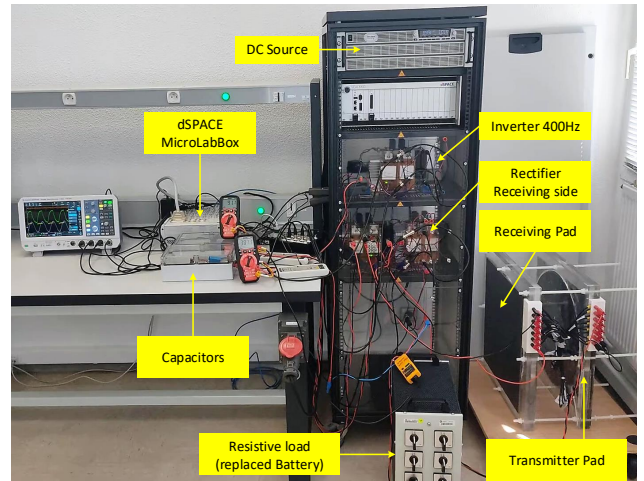


Fig. 2. Experimental test bench of the WPT system.

and further improvement are expected. However, interesting observations can be made from this preliminary work. Indeed, simulations show that the lower efficiency of the IPT can be partially compensated by the better efficiencies of the power converters, and the efficiency can reach up to 80% considering grid to battery transfer, which will be compared to experimental results in the final paper.

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