Design of a Wireless Dynamic Vehicle Charging System

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Abstract:

This project will demonstrate the design of a Wireless Power Transmission (WPT) system with the goal of being able to supply enough power to charge an Electric Vehicle (EV) by showing different results while testing for different frequency values and varying distances that a designer must consider when attempting to transmit power wirelessly efficiently. The results found that for coils with a 4 in. diameter using 14-gauge wires testing at 25, 50, 100, and 150 kHz to supply the most power from a distance of 2 inches with a simulated efficiency of 40.67 % and 19.00 % for a hardware implementation when supplying power to a 5W load.

Introduction:

Electric Vehicles (EVs) are growing in popularity and demand as a new form of transportation. In the state of Tennessee, the number of registered EVs have increased from about 8,136 of total EVs in 2020 to about 20,309 of total EVs in 2022 and is predicted to keep increasing to 200,000 by the year 2028 [1]. EVs have been produced and manufactured mostly as Plug-in Electric Vehicles (PEVs) which utilize Battery Energy Storage Systems (BSEE) and plug-in charging stations [1]. One method of charging can be implemented in EVs which can provide a contactless solution to EV charging. This is known as Wireless Power Transmission (WPT). For this work, a WPT system will be designed and tested to determine optimal conditions to use in an EV charging system that can be scaled up to meet the power and energy requirements to charge an EV.

Background:

WPT systems work on the principle of Mutual Inductance in Magnetically Coupled circuits. When two inductor coils are in proximity with each other and as current is flowing through one inductor, a magnetic flux is produced that can be received by a neighboring inductor that can produce a voltage when the magnetic flux is changing over time, which requires an AC signal to pass through the inductor coils [2]. This can be used to design a simple WPT system, but because inductors in AC circuits can cause a phase shift with the input voltage and current which can effectively reduce the power being supplied and will reduce the overall efficiency of the system. This is known as inductive reactance, and to improve this design capacitors can be implemented to counteract the phase shift between the voltage and current and improve the overall efficiency by canceling the inductive reactance with the reactance from the capacitor. The reactance values will be equal when the AC signal's frequency is equal to the resonance frequency, f_r, and this system's efficiency will increase. The circuit schematic for this resonance circuit is shown in Fig. 1.

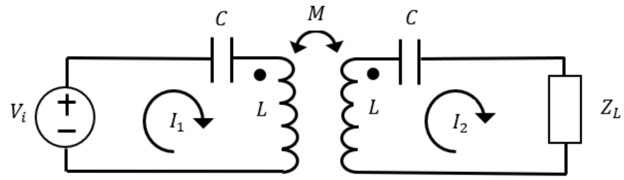

Figure 1. LC Resonant Circuit

$$f_r \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

In (1), L represents the inductor value of the coils, and C represents the capacitor value that will be in series with the transmitter and receiver coils to create the resonance circuit. For testing purposes, a DC power supply will be used, and because it was stated before to transmit power wirelessly an AC signal is required. To supply power wirelessly from the DC power source, a High-Frequency Inverter will need to be implemented to convert the DC input from the power source into a high-frequency AC signal. Having a high-frequency AC signal is beneficial to increase the range and efficiency of a WPT system because this will increase the Quality-factor, Q, of the inductor coils. This is defined as the ratio of the inductive reactance to the total equivalent resistance of the coils. The High-Frequency Inverter which will be implemented is shown in Fig. 2 which consists of four MOSFETs and drivers which will provide enough voltage and current at the gate of the MOSFETs to allow sufficient current to flow from the drain to the source of the MOSFETs to the load which will be the LC Resonant Circuit.

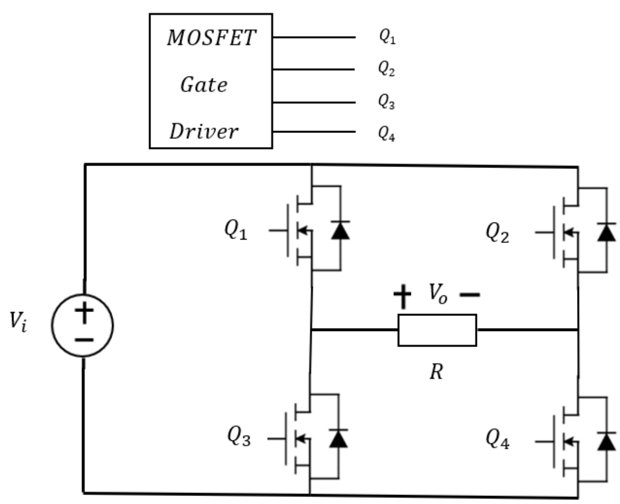

Figure 2. High-Frequency Inverter

$$Q = \frac{X_L}{R} \tag{2}$$

Design Objectives:

This project will combine the circuits discussed in the Background section to design a WPT system that will be tested by dynamically changing the distances between the two coils in the LC Resonant Circuit by measuring input and output power to determine the overall efficiency to provide information that will be useful when designing a WPT system for an EV. The results will be collected in both hardware and simulation using MATLAB Simulink to verify the results from the hardware implementation. The WPT system will utilize 100 μH for the inductor coils using 14-gauge wire with a 4 in. diameter and will be tested by adjusting the distances between the two coils to supply power to a 5W DC load, and the input frequency. Figures 3-5 show the schematic for the WPT system, the Simulink model, and the hardware implementation, respectively.

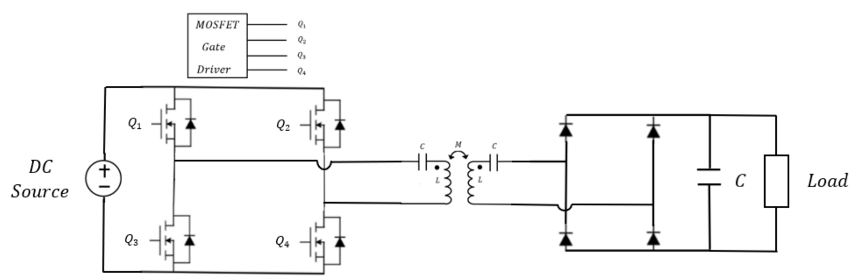

Figure 3. WPT System Schematic

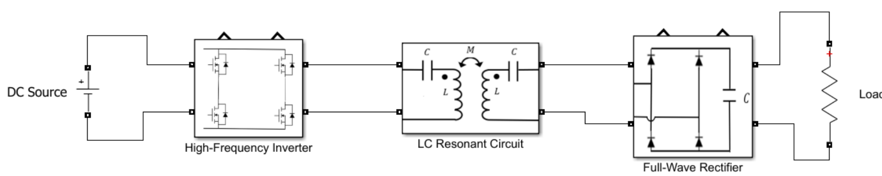

Figure 4. Simulink Model

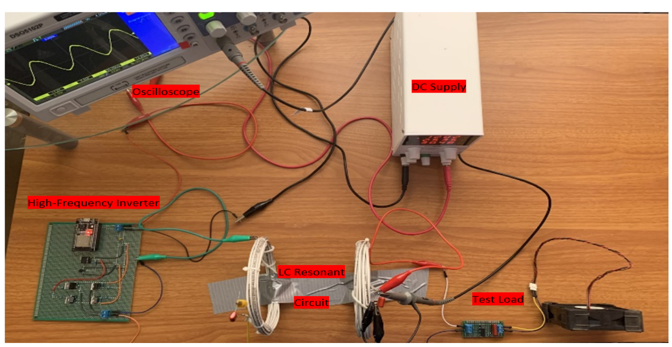

Figure 5. Hardware Implementation

The results will be collected from both Simulink and hardware implementation. This will be done by varying the distances between the two coils at a distance of 2, 4, and 8 inches, and the frequency from 25, 50, 100, and 150 kHz respectively. For each case, the efficiency of the system will be measured to determine the best position to have the coils based on the dimensions of the coils which can be used to design a full-scale implementation. Figures 6-9 show the results collected for the efficiency of the system with respect to the increasing distances of the coils input frequency of 25, 50, 100, and 150 kHz, respectively.

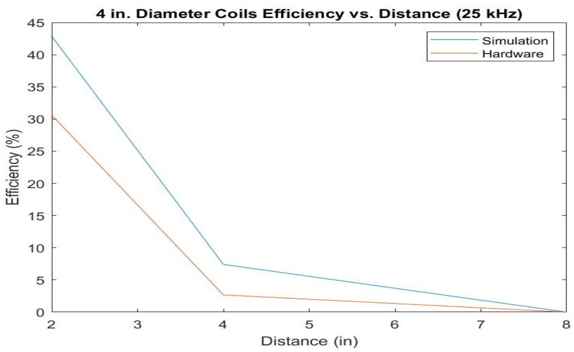

Figure 6. Efficiency at 25 kHz

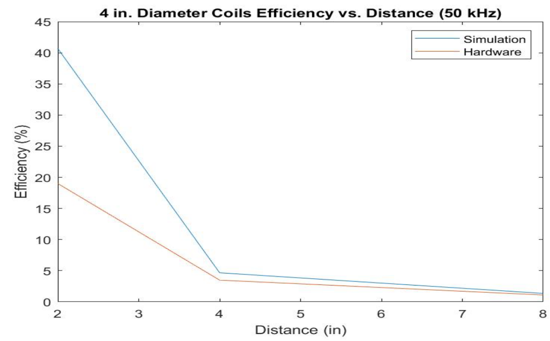

Figure 7. Efficiency at 50 kHz

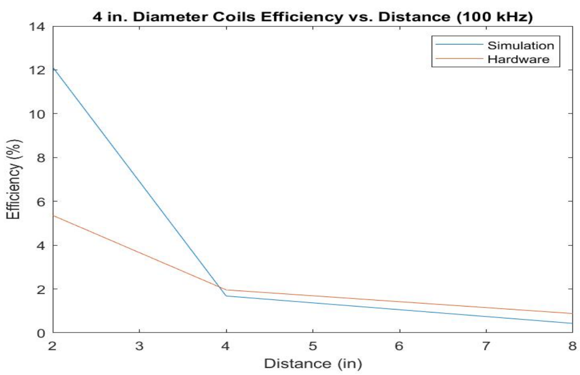

Figure 8. Efficiency at 100 kHz

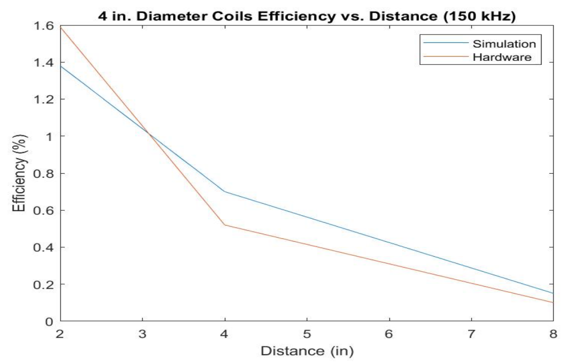

Figure 9. Efficiency at 150 kHz

Based on these results, in every case the maximum efficiency is found to be about half the size of the coils at 2 in. and when the distance increases, the efficiency decreases. To implement this with an EV, the designer should consider designing the coils to have a diameter that is about double the size of the distance from the transmitter and receiver coils to achieve maximum efficiency. The designer should also consider what input frequency to use, because at different frequency values the efficiency can change, and can lead to waste of power.

Conclusion:

This project implemented a WPT system in both hardware and simulation which demonstrated based on the results that there are optimal conditions that need to be satisfied to ensure efficient transmission of power wirelessly over a long distance. These conditions are based on coil design, and selection of frequency which was shown in the results to have an impact on the efficiency over the distance between the transmission and receiver coils. The best performing system was at 50 kHz for a 4 in. diameter coil designed using 14-gauge wire.

Recommendations:

Testing different coil designs such as rectangular and comparing it with circular designs. Utilizing different gauges of wire to design the coils and testing different frequencies which were shown to have an impact on efficiency over the distance between the two coils.

References:

[1] ETCleanFuels. (2022, October 27). Numbers - EV and EVSE. Drive Electric TN.
[2] ALEXANDER, C. H. A. R. L. E. S. K., & O., S. A. D. I. K. U. M. A. T. T. H. E. W. N. (n.d.). Fundamentals of Electric Circuits, 6th ed. MCGRAW-HILL EDUCATION, C2017 pp. 555-564.