Development of a Sandwich Coil and LCC Converter-Based Wireless Charging System for Intelligent Electric Vehicles

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Abstract—Wireless power transfer (WPT) is becoming the dominant method for charging electric cars, yet there is currently no equitable method for quantifying the power transfer. This article presents the Faraday coil transfer-power measurement (FC-TPM). FC-TPM utilizes sensor coils that do not make physical contact and are not connected to a circuit in order to measure the electromagnetic field generated by WPT. It then calculates the actual power that is sent across the space between the transmitter and reception coils. The measured quantity is the actual electromagnetic power, which represents the direct distribution of energy that clearly distinguishes the losses on both sides. The FC-TPM exhibited a hardware accuracy of 0.1% when tested with a 1-kW WPT system across a Rx coil sandwich with a maximum distance of 10 cm. Equitable metering encourages enterprises and people to adopt energy-conserving decisions and promote technological advancements by offering comprehensive information and accurately allocating cost burdens. This article is complemented by a film that emphasizes the crucial contributions made by this article.

Keywords—Sandwich coil, LCC Converter, Faraday coil, Wireless power transfer

I.INTRODUCTION

In an effort to decarbonize the transportation sector, the Indian government announced intentions to outlaw the sale of internal combustion engine automobiles by 2040. A number of nations, notably France, have already made plans to take gasoline and diesel cars off the road in an effort to improve air quality and reduce emissions of pollutants. One of the biggest threats to the UK's environmental health at the moment is air quality [1]. It is expected that the primary substitute for these vehicles would come from Railway Applications (RA). Wireless charging is one possible charging infrastructure for this RA adoption [2]. Wireless charging will help to alleviate problems that current EV customers are facing. These problems include the need for users to plug in their vehicles, the wide range of adapters needed to accommodate the many chargers available in GB, the variety of smartphone apps available, and the declining necessity of installing bulky, expensive cables in public spaces [3]. In addition, wireless charging may be very important for the advancement of driverless cars [4]. When an operator is not needed for the car to operate, these vehicles shouldn't need a user to plug them in. In this case, driverless vehicles will just pull up next to a wireless charger and start up [5]. Street charging may benefit from wireless charging as well. Many prospective users who don't have a driveway of their own are concerned about this. In urban areas or apartment buildings, for instance, the absence of a private driveway may be a barrier while charging an electric vehicle [6]. As the public's interest in reducing the use of fossil fuels and associated pollution grows, Railway Applications (RA) is becoming a viable substitute for traditional gas-powered cars [7]. Because EV batteries have a limited capacity, the development and growing use of RA necessitates the placement of charging stations in strategic locations [8].

Large-scale, directly grid-connected charging stations, particularly those that are quick and very quick, put strain on the stability and dependability of the power grid due to problems with power gaps, voltage sag, and peak demand overload [9]. Although photovoltaic (PV) production has been integrated with EV charging infrastructure by certain academics, research on this topic still views PV integration as a small percentage of the power source for EV charging stations [10]. Regarding the increased need for fast charging throughout the day, the quick growth of photovoltaic (PV) production maximizes power usage during peak hours by providing sufficient daytime generation [11]. A battery energy storage system (BES) may be used to balance power gaps, smooth PV power, and adjust the DC bus or load voltage in response to the erratic nature of solar energy [12].

In this study, a multiport DC/DC converter is used for the EV charging station instead of three individual DC/DC converters, due to the high-power density and high efficiency characteristics of the multiport power converters [13]. There are two topologies for charging station designs within the aforementioned research: AC bus and DC bus. Non-isolated multiport converters, which are often developed from buck or boost converters, may have a more efficient design, a better power density, and a more compact form factor than isolated multiport converters [14]. Consequently, this article uses a DC bus non-isolated construction with Sic switches to increase efficiency and reduce power losses.

II.OBJECTIVE

Processing a Sandwich Coil based LCC Converter Circuit, the project's main goal is to create and implement a smart wireless charging solution for electric cars. The unique sandwiched topology in the transmitter and reception coils—whose operating frequency of 160 kHz is much lower than the current WPT system up to megahertz—is the key to the design.

III.PROPOSED SYSTEM

A. METHODOLOGY

With sandwich coupling technology, energy is transferred to a receiving coil extremely effectively when a transmitting coil delivers electromagnetic waves adjusted to a frequency that matches the resonance of a circuit containing the receiving coil. Our suggestion is to include a compensating coil for Hybrid Coupling into the main coil system. After the integration and the coupling effect of the two Sandwich coils at the same side of the wireless charging system are analyzed, five more coupling effects emerge, as illustrated in Figure 1.

A wireless charging system for batteries was created and tested, and it had an efficiency of 95.3%. You may find a more thorough examination of the coupling effects of the cross-side coils and the same-side coils in. effectively reduce the system's size and increase its efficiency; yet, the integration process makes the design of a wireless charging system with High Gain LCC converter topologies more difficult. In order to preserve the benefits of high efficiency and compactness while making the design and analysis simpler.

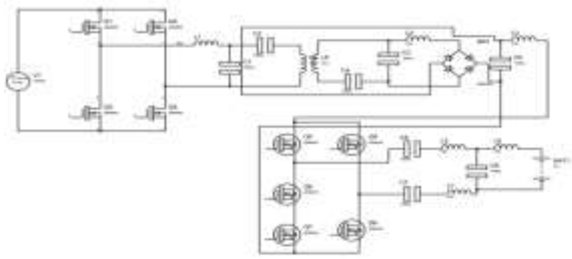

Figure.1 Proposed system circuit diagram

Because they are the primary power transfer carrier and have an impact on the features of the system transfer, topologies are crucial to wireless charging systems. The two fundamental topologies are LC series and LC parallel. These two topologies may be combined to create four more topologies: LC parallel-LC series, LC series-LC parallel, LC parallel-LC series, and LC parallel-LC parallel. The LCL-LCL topology is derived by adding an extra inductor to correct the imaginary component of the LC parallel topology, ensuring that the reflected impedance is completely resistive.

We can quickly determine that the LC parallel topology and the LCL topology share the CC characteristic based on Norton's law. Furthermore, when the load is a powerful voltage source, such as a battery, the LC series-LC series architecture also exhibits a CC characteristic. Therefore, by directly charging the battery using these topologies, we may increase efficiency by eliminating the receiver's cascade DC/DC component. Because many commercial power batteries have certain specifications, the CC/CV approach is commonly employed. A steady current is used to charge the battery initially. The CV stage starts when its terminal voltage reaches a certain value. Currently, the charging device clamps the battery's terminal voltage by acting as a voltage source. After then, the battery's internal resistance and open circuit voltage (OCV) rise steadily until the charging current falls to a threshold, signaling the end of the charging process.

It is evident that the wireless charging systems facilitate the CC stage with ease, whereas the CV stage necessitates the use of extra control algorithms and fast-moving sensors. In order to prevent excessive gas emissions and the electrolysis of the water at the conclusion of the charge, the lead-acid battery is first charged using the CV stage. We will investigate whether the CV stage is required for the charging of lithium-ion batteries because, as far as we are aware, their component materials and electrochemical mechanisms vary from those of lead-acid batteries. Three assessment criteria—the charging time, the charging capacity, and the charging energy efficiency—are used to compare the CC/CV approach with the CC strategy after the contributions of the CV stage to the battery have been examined. The particular parameters of the battery under test. In the experiments that follow, we will examine how charging current rates and temperatures impact battery parameters by influencing the speed of the electrochemical process. The device used for charging and discharging is a MACCOR model 4300 from MacCOR in Tulsa, Oklahoma, USA. The device used for thermostatic control is a Votsch C4-180 from VotschIndustrietechnik in Stuttgart, Germany.

B. LCC CONVERTER

Converters may employ the matching converters and just need to boost or buck the voltage. Occasionally, nevertheless, the intended output voltage will fall inside the input voltage range. It is normally preferable to utilize a converter that can change the voltage when this occurs. Because buck-boost converters only need a single inductor and a capacitor, they may be more affordable. These converters do, however, have a significant degree of input current ripple. This ripple has the potential to produce harmonics, which in many situations call for the use of an LC filter or a large capacitor.

As a result, the buck-boost is either costly or ineffective. The fact that buck-boost converters reverse the voltage is another problem that may make using them more difficult. Cúk converters use an additional inductor and capacitor to alleviate both of these issues. However, the high electrical stress that both Cúk and buck-boost converter operation place on the parts might lead to device failure or overheating. These two issues are resolved by LCC converters.

C. LCC CONVERTER OPERATION

Every dc-dc converter works by quickly turning a MOSFET on and off, usually using a high frequency pulse. The LCC converter is better because of what it does as a consequence of this. For the LCC, inductor 1 is charged by the input voltage and inductor 2 is charged by capacitor 1 when the pulse is high or the MOSFET is active. Capacitor 2 is maintaining the output when the diode is off. The capacitors and inductors are charged when the MOSFET is off or the pulse is low because the inductors send their output to the load via a diode. The output will increase with the proportion of time (duty cycle) when the pulse is low. This is due to the fact that inductors will have higher voltages the longer they charge. But if the pulse lasts too long, the converter will malfunction since the capacitors won't be able to charge as shown in fig 2.

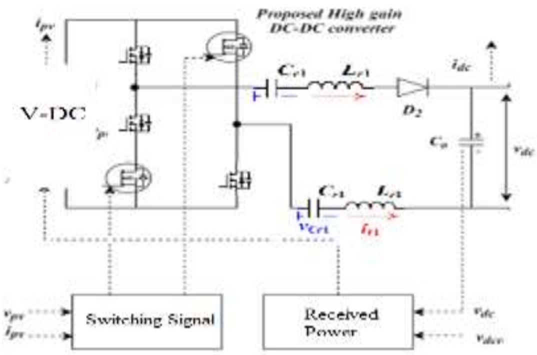

Figure.2 Proposed system LCC Converter

D. SANDWICH COIL BASED POWER TRANSFER

WPT is a good match for the concept of "bidirectional" power transfer, which allows electricity to go from the grid to the load or, conversely, from the load to other grid users. Therefore, in the case of a multi-parking area, a Bi-Directional Inductive Power Transfer (PROPOSED) system may be used to realize the Vehicle-To-Grid (V2G) idea, which consists of the ability to utilize the EV battery as a storage element for other grid users or other cars as well. The concept of "V2G" is based on the active demand theory, in which users simultaneously create and consume electricity.

IV. PRODUCT DEVELOPMENT

A.DESIGN OF THE EACH SUB SYSTEM

Battery charging for electric vehicles (EVs) may be accomplished via the use of Wireless Power Transfer (WPT). A wireless power transfer between two coils that are magnetically connected makes up the WPT. As a result, wireless battery charging is possible with WPT. There are certain comfort and safety advantages to not having wires: the car may charge it automatically without requiring a plug-in operation, and there is no chance of electrocutions for the user. Three varieties of WPT-based battery charging exist: static, semi-dynamic, and dynamic. These types of charging differ depending on the vehicle's state of motion, whether the driver is inside the car, and both.

The semi-dynamic WPT happens when the driver is inside the vehicle and it is stationary, such as during a stop at a traffic red light for a car or an electric bus stop; the dynamic WPT happens when the car is moving, such as when it is traveling down a motorway. The static WPT happens when the vehicle is stationary and no one is inside it, such as during parking time. Yet, there are several disadvantages to dynamic wireless battery charging. Because the vehicle's motion necessitates a large power transmission infrastructure buried beneath the road in order to have adequate charging times, efficient dynamic charging requires higher costs than static or semi-dynamic options because the stationary state of the vehicle allows for the use of fewer coils to achieve the same charging time than in the dynamic case.

In this circuit, L1 and L2 are inductors with a value of 13µH each, while M represents the mutual inductance between them with a value of 4.9µH. The coefficient of coupling between the inductors is denoted by K, with a value of 0.377. Additionally, Rdc represents the DC resistance of the inductors, measured at 8.2mΩ. These parameters collectively define the behavior of the coupled inductors in the circuit, influencing factors such as impedance, resonance, and energy transfer within the system.

For private RAs that may remain motionless for a few hours, static WPT is practical. On the other hand, semi-dynamic WPT is especially suitable for public electric transportation vehicles, like scrubbers, which must move constantly throughout the day and thus necessitate frequent charging procedures in order to achieve appropriate autonomy without requiring larger batteries. Given that wireless battery charging is intrinsically less efficient than traditional wire-based battery charging, the comfort and safety advantages of the wireless approach must be substantial in order to make the static WPT really attractive for charging electric vehicles' batteries. A vehicle's frequent movements may need many battery charges throughout the day.

The material parameters describe the properties of copper wire used in the coil construction, including its resistivity (PCu) at 1.68×10^(-8) Ω•m and relative permeability (µr,Cu) approximately equal to 1, indicating its high conductivity and negligible magnetic permeability. The wire geometry specifies the diameter (D) of 3mm and length (L) of 3.48mm, defining the physical dimensions of the wire. The coil geometry outlines the outer diameter (Dout) of 15mm and the total number of turns (N) spanning 15cm. Finally, the maximum air gap allowed within the coil is limited to 3mm, providing critical parameters for designing and analyzing the performance of the coil assembly within the given specifications.

This is especially true for electric bicycles, which are highly intelligent and comfortable to ride in the kind of congested traffic found in urban areas. The vehicle may be a convenient mode of transportation for regular transfers during the day. Moreover, the E-Vehicle is a clever, environmentally friendly, and lightweight urban mobility solution.

In the near future, more and more people are anticipated to be riding electric bicycles. As a result, WPT would offer an excellent method of battery charging for parked E-vehicles for various reasons. Firstly, the E-Vehicle would automatically recharge every time the cyclist parks it, eliminating the need for the awkward and possibly hazardous plug-in operation. Each bicycle could then be charged and made visible if there were many parking spaces for E-vehicles.

V. Practical implementation

A laboratory prototype of the planned IPT system has been put together, and a number of experimental tests have been conducted to ensure appropriate operation, assess power efficiency, and create a magnetic field. This prototype is intended to be used in applications where a power range of (100-250 W) is required, such as charging an electric bicycle battery. The various components of the built IPT prototype will be explained in the next subparagraphs.

VI. Winding coils

The magnetic coupling that occurs between two coils is how inductive power transfer is accomplished. Two circular coils were employed for the experimental prototype.

VII. SIMULATION RESULTS

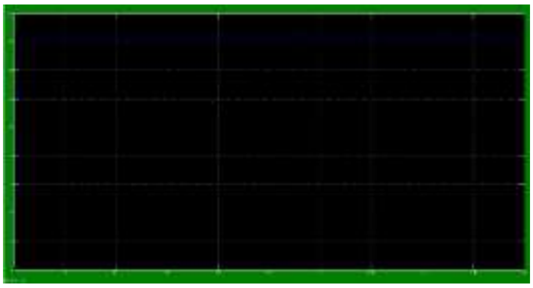

Figure.3 Input voltage of proposed system

Figure 3 depicts the input voltage profile of the proposed system, illustrating the voltage signal applied to the circuitry as an input. This figure provides insights into the voltage characteristics driving the system.

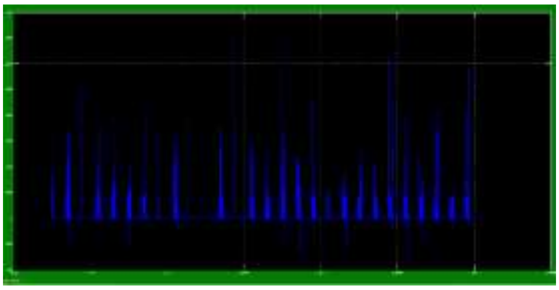

Figure.4 Winding output wave form

Figure 4 presents the winding output waveform, showcasing the waveform generated across the windings of the system. This waveform represents the electrical signal induced within the coils of the system due to electromagnetic induction.

Figure.5 proposed system output voltage discharge wave form

Figure 5 displays the discharge waveform of the proposed system's output voltage. This waveform captures the behavior of the output voltage during discharge cycles, highlighting the discharge pattern and voltage dynamics.

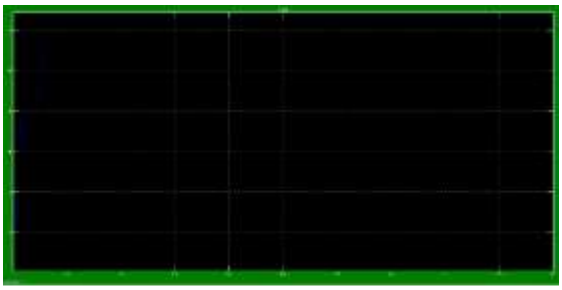

Figure.6 Proposed system output voltage

Figure 6 illustrates the output voltage of the proposed system, showcasing the voltage levels produced by the system over time. This figure provides a comprehensive view of the output voltage behavior, including any fluctuations or trends observed during system operation.

VIII. HARDWARE IMPLEMENTATION

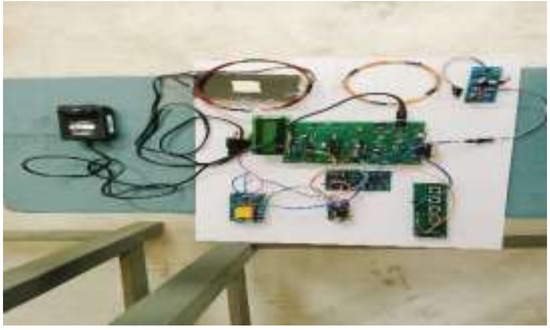

Figure.7 Over all hardware kit

A DC voltage source, which powers the transmitter board's MOSFET drivers and half-bridge; A function generator, which generates the AC waveform that powers the MOSFETS and the main coil; an electrical load, which, depending on the kind of measurements, represents RL in Fig. 7 and consists of either an electronic load or a rheostat;A measuring system consisting of two voltmeters linked to the terminals of the coils and two current probes, used for measuring the current in both coils.

The suggested system utilizes a power scope to detect and measure the major electrical variables in real-time. Additionally, a magnetic probe is employed to characterize the magnetic field of the system.

IX. CONCLUSION

The additional coupling effects are further eliminated or reduced to an insignificant degree by the suggested sandwich coil design, which makes the design of a wireless charging system using the double-sided LCC converter topology easier. Additionally added are the thorough design processes intended to increase system efficiency. The suggested notion is verified by both the experimental and MATLAB simulation findings. When perfectly aligned, the small and very effective wireless charging system can achieve a DC-DC efficiency of 95.5% with an air gap of 150 mm.

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