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An Integrated LCC Hybrid Topology for Single Inverter FED Inductive Power Transfer in Electric Vehicles

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Abstract- In this paper an integrated LCC compensation topology for EV/PHEV wireless chargers is implemented. The result of the coupling among the additional coil and the main coil on the LCC compensation topology is considered. The recommended topology will decrease the size of the additional coil and make the scheme more compact with very high efficiency. The elementary characteristics of the projected topology are investigated based on fundamental harmonic approximation (FHA). Moreover, based on steady-state model, three categories of operation modes are presented and analyzed. In order to realize zero voltage switching (ZVS), the series capacitor C2 on the secondary side is regulated. Numerical method is used to examine the effect of diverse values of C2 on the turn-off current and the finest value of C2 is selected to build a prototype to validate the study. In this paper an inductive power transfer in electric vehicle with an integrated a LCC compensation topology is inspected.

Keywords- Constant current (CC), constant voltage (CV), electric bicycles (EBs), inductive power transfer (IPT),T equivalent**.**

1. INTRODUCTION

INDUCTIVE power transfer (IPT) schemes are designed to supply power efficiently from a stationary primary basis to one or more portable secondary loads over comparatively hefty air gaps via magnetic coupling. The basic principles of such methods are identical to well-known thoroughly coupled electromechanical devices such as transformers and induction motors, where the leakage inductance is much lesser than the mutual inductance.

This promising technique is developed rapidly and heretofore has been employed in miscellaneous submissions such as wireless charging of biomedical implants, low-power portable electronic devices, under-water power supplies, electric vehicles, and even train applications [6]–[11].

Electric vehicles include large ones like buses and small ones even like electric bicycles (EBs).There are numerous research areas in WPT, such as compensation network and circuit investigates [10]-[16], coil design practices for large gap and misalignment tolerance tie optimization for high efficiency resistor methods, foreign object recognition and safety concerns. Amongst them, compensation topology is very significant because it helps to regulate resonant frequency, minimalize the VA rating of power quantity, increase coupling and power transfer capability, and achieve high efficiency. As for the EV/PHEV application, the coupling coefficient differs with the fluctuation of the vehicle ground clearance and misalignments. It will result in the disparities of the circuit strictures and resonant frequencies for specific compensation topologies. So it is of substantial importance to design an applicable compensation topology for EV/PHEV wireless charging methods.

The assortment of the compensation topology is reliant on the application. In [28], it proposes an optimized technique to assort compensation topology from an economic perception. The results indicated that SS and SP schems were more appropriate for high power diffusion and SS compensation topology needs fewer copper.

Some further novel recompense topologies have been put onward in the writings. A series-parallel-series (SPS) compensation topology was anticipated in [29]. This exacting topology, which was unruffled of one capacitor in series and alternative in parallel with the transmitter coil, and one capacitor in series with the receiver coil, had features of both SS and PS schemes. As a because of parallel capacitor, the resonant situation will fluctuate with the variation of the load condition, zero phase angle (ZPA) of the power supply will not be recognized when the load departs from the designed value. In [31], a LCL parallel resonant circuit was smeared for WPT.

In [32], the LCL system was used equally in transmitter and receiver sides .It creates the track (transmitter) to have perpetual current specifications. This is indispensible for a WPT system with various pickups (receivers). One more compensation topology termed CLCL network was anticipated in [33]. In [34], the CLCL was used in both transmitter and receiver sides and a Mathematical model was offered. Due to the proportioned topology and phase modulated control method, the IPT topology could attain bidirectional power transfer. Though, the inductances of the additional inductors are equivalent to or greater than the inductances of the main coils in these schemes. Furthermore, extra space is required to abode these inductors[35-39].

An integrated LCC compensation topology is presented in this paper. The compensation topology as publicized in Fig. 1.It be made up of one inductor and two capacitors, together with the main coil, designed a structure like to an LCL-T network at both the transmitter (primary) and the receiver (secondary) sides. The inductor (named additional inductor or additional coil in this work) is coupled with the main coil (transmitter coil or receiver coil) on the similar side. So, the additional coil and the main coil can be united together, and additional space for additional inductors is not desirable. This integrated arrangement can also deliver the same amount of power with reduced additional inductances, related with one that is not integrated. With this suggested topology, the resonant frequency is still sovereign of both coupling coefficient and load condition.

Both the output current and the current on the transmitter coil are equal and constant, inapt to load condition. When the WPT technology works proximate to the resonant frequency, it can comprehend power transfer on altered operating conditions by adjusting the input voltage[40-50].

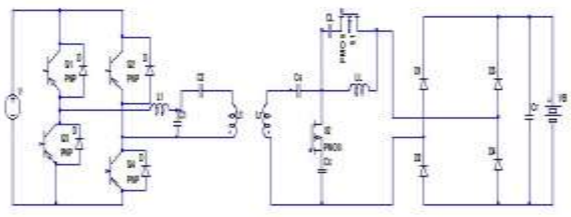

Figure 1: LLC-LCC topology

A hybrid topology with two ac switches (ACSs) and an auxiliary capacitor at receiver side is proposed to accomplish the required CC or CV charging without any reactive power transferring flanked by the transmitter and receiver side. The proposed IPT battery charging technology can charge multiple EBs simultaneously with only a single inverter, which will decrease the cost of construction, facility and floor space. Commonly speaking, the charging power of an EB is around 200 W, so the IPT battery charging technique with a 2-kW inverter can charge at least ten EBs at the same time exploiting the proposed method. Meanwhile, feedback controlling stratagems or the wireless communication bond between transmitter side also the receiver side is not required at all, thus the cost and the involvedness of the whole system can be decreased. The CC mode also the CV mode can be accomplished by turning on/off the ACSs, which are composed of two anti-series-connected MOSFETs or two antiparallel-connected IGBTs. Besides, the ZPA could be achieved during two modes. Finally, an experimental prototype of two IPT battery chargers with 2-A charging current, then a 96-V cell voltage is set up to verify the functionality of the proposed methodology.

Section II analyzes the T-circuit of SS recompense topology centered on fundamental harmonic approximation (FHA), and proposes hybrid topology with CC output and CV output characteristics. The functionality of the simulation setup is validated in Section III. Finally, the conclusion is claimed in Section IV.

2. ANALYSIS

The planned integrated LCC compensation topology is presented in Fig. 1. The transmitter section comprises of a high frequency inverter and a compensation resonant network, which is made up of a LCC compensation network and the transmitter coil. The inverter has a full bridge which is formed by four power MOSFETs ($S1$~$S4$). $Lf1$, $Cf1$, and $C1$ constitute the LCC compensation topology. The receiver side has a symmetrical LCC compensation resonant circuit, rectifier, and LC filter network. In this scheme, not only the two main coils, $L1$ and $L2$, are coupled to each other, but also the main coil and the additional coil on the similar side are tied with each other (Namely, $L1$ is coupled using $Lf1$, and $L2$ is joined with $Lf2$.). The mutual inductances is M,

$$M = k\sqrt{L1\,L2} \qquad \text{.........(1)}$$

where k, *is* the coupling coefficients.

M differs with the shifting of the vehicle ground clearance and misalignment. Generally, the WPT scheme for PHEV/EV has a bulky leakage inductance but a trifling mutual inductance. Only the mutual inductance has involvement to the power transfer. So it is indispensable to reimburse the self-inductance. Frequently, the self-inductance is compensated by adding a series capacitor. For simplicity, in this work the main coils on both the transmitter also the receiver sides are designed with identical capacitance. All of the components used in this sector are idea land only the continuous operation style is considered. The two main coils $L1$ plus $L2$ can be considered as a transformer which can be equivalent to two decoupled circuits containing controlled sources.

The method for how to plan the parameters of IPT battery charger is given in detail below. Thus output voltage Vi of this inverter can be regulated by the inverter with 50% much duty cycle as of the dc voltage E.The output voltage magnitude Vi of first harmonic component can be conveyed as

$$Vi = \frac{2\sqrt{2}E}{\pi} \quad (2)$$

The full-bridge diode rectifier of receiver side is driven by a current source and the input voltage is square wave.The relationship between the rectifier's ac input voltage's RMS value Vo and the dc output voltage VB can be derived with the following equation:

$$Vi = \frac{2\sqrt{2}VB}{\pi} \quad (3)$$

The RMS value of the receiver's ac current Io can be articulated as a function counter to the charging current IB of battery by

$$Io = \frac{2\sqrt{2}IB}{4} \quad (4)$$

substituting the equation (2) and (4)

$$|Gv1 = \frac{Io}{Vi} = \frac{1}{wM} = \frac{IB\pi^2}{8E} \quad (5)$$

By solving (5), the mutual inductance of the loosely coupled transformer is assumed by

$$M = 8E\ IBw\ \pi^2 \quad (6)$$

It can be gotten that the mutual inductance is resolute by the input voltage and output current as well as the operating angular frequency. Similarly, by substituting the values, the voltage gain is given as follows:

$$|GV\quad V\quad | = \frac{Vo}{Vi} = \frac{1}{w^2\ CcM} = \frac{VB}{E} \quad (7)$$

By substituting (6) into (7), the capacitor CC is derived by

$$Cc = \frac{IB\pi^2}{8wVB} \quad (8)$$

The value of inductor LL can be derived by

$$LL = = \frac{1}{w^2\ Cc} = \frac{8VB}{8wIB\pi^2} \quad (9)$$

Capacitor CS can be de*sig*ned as

$$CS = \frac{Cc}{Cc\ LRw^2 - 1} = \frac{IB\pi^2}{4wVB} \quad (10)$$

The capacitor CT is specified by

$$CT = \frac{1}{w^2\ LT} \quad (11)$$

The capacitor CL is prearranged by

$$CL = \frac{1}{w^2\ LL} - \frac{CRCS}{CR - CS} = \frac{IB\pi^2}{4wVB} \quad (11)$$

With specified value of IB and VB of a given battery and given the value of E, LT and LR, the parameters of the IPT battery charger can be determined consequently.

3. SIMULATION

The simulation is done using MATLAB/SIMULINK .It consist of IPT battery chargers 1 and 2 parallel coupled to one inverter was set up using the hybrid topology as presented in fig 2 and the output parameters are both set as 2-A charging current and 96-V cell voltage. The switching strategies are Q1-Q4 = C2M0080120D and S1 - S2 = APT56F50L. Operating frequency is set at 500 kHz. The air gap among transmitter and receiver is 20 mm rendering to the requirement of EBs [12] and consideration of insulation, and both of transmitting coil and the receiving coil are based on a Double-D type structure with two layers. Each D structure coil (coil diameter = 75 mm) has ten turns (Litz wire of 0.04mm/1500 strands), with PC40 ferrite core, whose size is 75 150 10 mm3 placed under the transmitting coil. Electronic loads are used to simulate the battery charging profile.

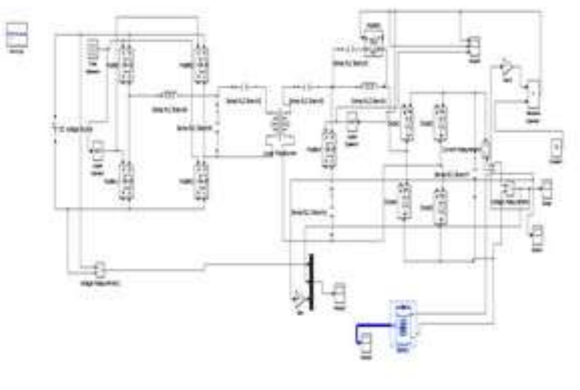

Figure 2: Simulation diagram

In this section, the performance of IPT battery charger 1 is evaluated. Fig. 3 and Fig 4 displays the waveforms of output voltage Vi and output current Ii of the inverter, charging current IB1 , and charging voltage VB1 at CC mode when S1 OFF and S2 ON. In CC mode, the battery equivalent resistance RB1 = VB1/IB1 increases from 36 to 48 , while the charging current is kept at the required 2A and charging voltage vB increases from 72 to 96V. Ii is almost in phase with Vi. VB1 increases to 96Vand then the battery charger was switched to CV mode by turning off S2 and turning on S1. The transient waveforms of mode switching from CC mode to CV mode are revealed in Fig 5 The value of ii decreases a little when switching from CC mode to CV mode, and the switch conduction loss of ACS S1 in CV mode becomes smaller than that in CC mode.

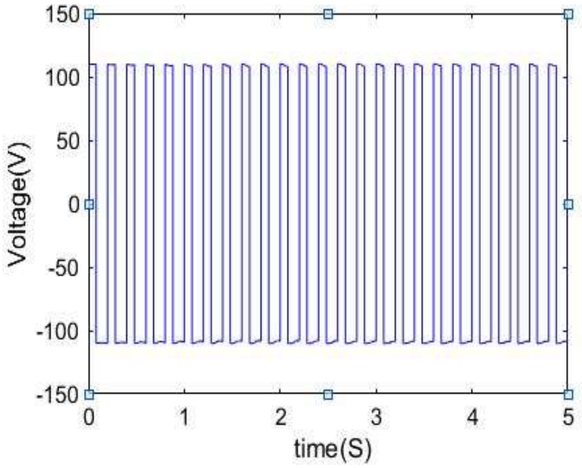

Figure 3: Inverter output voltage

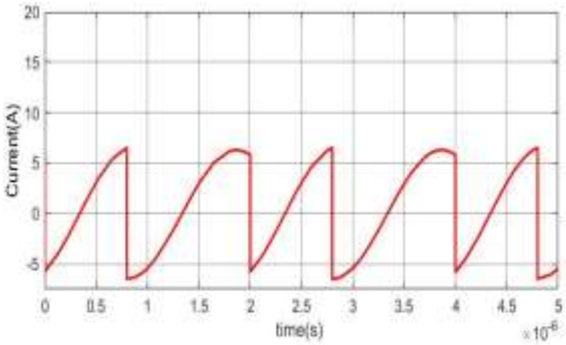

Figure 4: Inverter output current

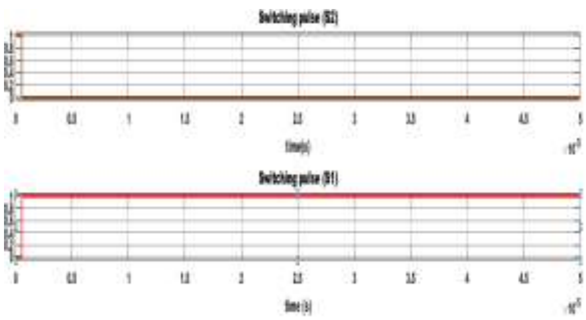

Figure 5: Waveform across switch

The charging current and charging voltage are nearly constant in the course of the transient as displayed in Fig. 6. The waveforms of output voltage vi and output current ii of the inverter, charging current iB1 , and charging voltage vB1 at CV mode and CC mode are exposed in Fig. 7 at RB1 = 48 and 96 , correspondingly. It is obvious that the charging voltage remains nearly constant and it can hardly find the reactive power seen from the inverter. The charging current and charging voltage match the charging profile closely.

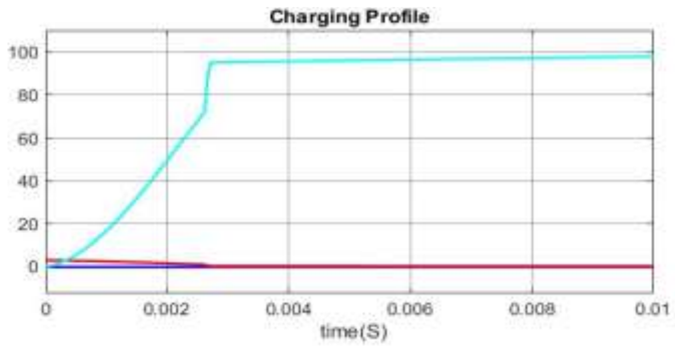

Figure 6: Charging Profile

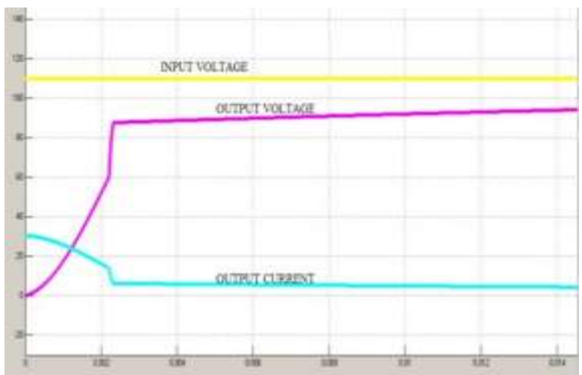

Figure 7: Output waveform

4. CONCLUSION

Electric vehicles, encompassing electric motors, batteries, and power electronics, have important advantages over today's gasoline-powered internal combustion engines. They are quieter, virtually nonpolluting, and more energy efficient, reliable, and durable. Major improvements have been done in various electric drive technology components since the late1980s. For example, advances in power electronics have resulted in small, lightweight DC/AC inverters that, in turn, make possible AC drives that are cheaper, more compact, more consistent, easier to sustain, hig efficient, and more adjustable to regenerative braking than the DC systems used in practically all electric vehicles over the early 1990s. The electric vehicle motor-controller combination is now smaller and sunnier than a analogous internal combustion engine, as well as economy to fabricate and maintain.

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