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Wireless Power Transmission For Dynamic Dual Pick-Up Electric Vehicle Using Multi-Parallel Segmented Rails

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ABSTRACT

Conventional static wireless power transmission has been modified into dynamic powering due to the disadvantages of frequent charging and non-running powering. These disadvantages can be overcome by the dynamic powering topology that is charging while running the vehicle. This paper presents dynamic powering of an electric vehicle with multi parallel segmented rail and a dual pick-up receiver side. Wireless power transmission emits electromagnetic radiations, which is harmful to human body. In dynamic powering these radiations will be higher, in order to reduce these radiations the segmented rail concept with modular transmitters are used. To increase the power received by the vehicle the dual pick-up receiver side is included. This paper also includes the compensation circuit used for the resonant power transfer, spiral coil design and simulation results.

Keywords: *Dual pick-up, electric vehicle (EV), LCL compensation, segmented rails, wireless power transfer.*

1. INTRODUCTION

Wireless electric vehicles are classified into roadway powered EV or on-road charging and stationary charging of EV which is an alternative to the internal combustion engines. The main challenges in wireless power transfer systems are minimum charging time and better power transfer efficiency. The major drawback of static wireless power transmission is carrying a battery with an electric vehicle, the cost and size of the battery and also frequent charging times of battery [1]. So in order to reduce these drawbacks next, it was introduced on-road charging of electric vehicle, which can run with or without batteries.

Wireless power transfer system basically consists of two parts, one is ground part that is to be installed in the ground side which includes grid supply, a rectifier, inverter and a compensation network with the primary coil. The secondary part or mobile part, which is to be fitted in the vehicle. It includes receiver coil with compensation network (if needed), rectifier and a dc-dc converter connected to a motor. However, in on-road powering there will be great exposure to radiation in the public. According to ICNIRP-International commission on non-ionizing radiation powering, the standard outlined is below 200 Ma/M2 at 100 kHz for public subjection, above this value will affect the human and other animal’s nervous system. The maximum specific absorption rate (SAR) is below 2 W/kg and the power density is below 10 W/m^ {3}, above this value will affect the human cells [1]. So for the protection of human inside the vehicle a shielding of aluminium, copper and iron body is provided. The segmented rail topology is used to reduce the public exposure of humans outside the vehicle and at the pedestrians, while using a long rail concept there will be high emissions of electromagnetic radiations.

An efficient compensation topology is an important part of resonant power transfer. The basic types include SS, SP, PS and PP. The naming of these compensation are done as the connection of capacitors in primary and secondary. If compensation capacitors are connected series with the primary coil and also series in the secondary coil, it is named as SS compensation. Likewise, all are others. There are many compensation topologies also available. These types differ in their utilization of capacitance. Parallel-series and parallel-parallel compensation topologies will regulate current flowing into the parallel resonant circuit which results in large size and cost of the inverter. In those most efficient resonant compensator topology become LCL topology due to its constant current characteristics. This LCL topology has an advantage of it acts as a current source in primary and also have a unity power factor in secondary. So there is no need for extra power factor correction in secondary.

To increase the power transfer from primary to the secondary the receiving coil is dueled and the together receiver size should be same as the transmitter, so that the power can be picked up by the receiver efficiently [2]. Here in this paper, a multi parallel segmented rail with a dual pick up receiver side is explained. Here a single inverter is provided and an oven gapped magnetic field (within 12.2cm) is formed between transmitter and receiver. In order to reduce the electromagnetic radiations, the transmitters are shut off or inactive by switching when the vehicle moves away.

2. SYSTEM OVERVIEW

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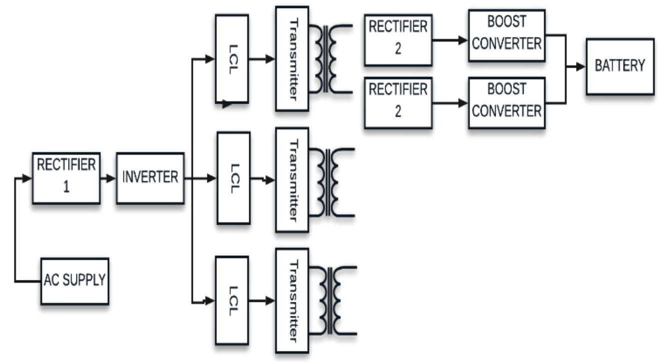

Figure 1 Typical wireless conversion-chain.

For on-road powering, the system may be long rail or segmented rail. For safety purposes the segmented rail concept is chosen. A single inverter with multiple modular transmitters are used for powering. The area covered by transmitting and receiving coil should be the same, so that power transfer can be improved. For improving transmission efficiency, the receiver section is dueled. The dual pick up section is provided with two receiver coils with two rectifier and connected to one battery or a Brushless DC motor. The block diagram representation of this scheme is as shown in Fig 1. The complete recharge system is as shown. This on-road powering wireless charging is for all kinds of electric vehicles. In this technique, an individual needs to simply place the vehicle over a transmitting coil fitted in the ground. To receive the power transmitted there will be a receiving coil attached under the electric vehicle. When these two coils come in position, the power gets transmitted wirelessly. The system is charging wirelessly by on-road so there is no need for a battery or a small charging battery is required. This design would help in reducing the manual operation like plugging in and plugging out. The more accurate design will improve the power transfer efficiency.

Ground part or transmitting part consists of grid supply, rectifier, single inverter with multiple modular transmitters. Mobile part or vehicle part consists of rectifier with a dc-dc converter and a BLDC motor or load connected to it. The wireless inductive coupling will transfer power from supply mains to load equipment, which would be the BLDC motor or rechargeable battery.

The AC supply is converted into a dc powered supply- by an AC to DC converter (Rectifier 1). Then, the DC power is converted to a high frequency AC to drive the transmitting coil through a compensation network. The inverter is designed and implemented by a full-bridge topology. The circuit diagram is represented in Fig 3. The high frequency alternating current after compensation creates an alternating magnetic field in the air gap, by electro-magnetic induction the power is transferred to the receiving coil. At resonance the power gets transferred and the efficiency and power transfer can be improved. Then, the AC power is rectified (Rectifier 2) and a chopper circuit is also added in-order to achieve the desired voltage.

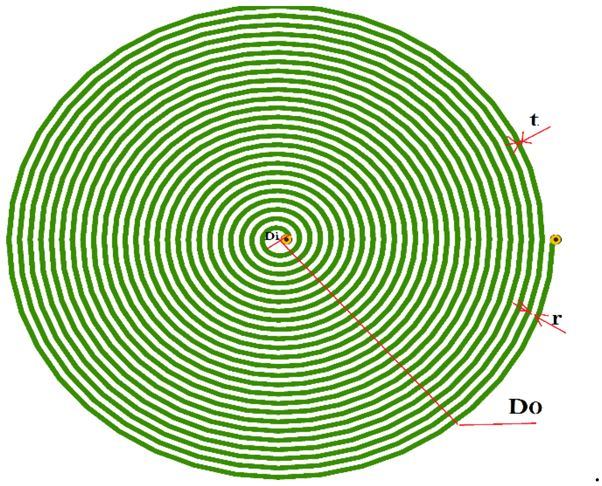

Figure 2. Coil Diagram.

3. LCL COMPENSATION TOPOLOGY

In compensation topologies the most widely used compensation is LCL compensation. At resonance LCL will act as a current source, the transmitter coil current is controlled by the inverter output voltage with-out considering the coupling and load condition, which makes primary control easier. By accurate tuning of LCL parameters the reactive power compensation can be done. So the system will supply only reactive power. So the required VA rating can be minimized.

A. Design Procedure

LCL resonant compensation topology has an advantage of constant current characteristics, so it becomes the most widely used one. In recent era LCL topology is considered as an ideal resonant topology used in the primary part of the network. As it acts as a current source in the primary, so the inductance in secondary will not affect the primary inductance.

The printed spiral coils (PSC) are considered for the design of transmitter and receiver part, because of its characteristics like small volume, low cost, high precision and high-integration. Spiral coil mutual inductance is an important parameter in transfer efficiency. Here printed spiral coil of single layers are used as transmitter and receiver coils.

B. Calculation of Inductance of Multilayer Circular Printed Spiral Coils

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By using inductive power transfer, system can deliver power in large air gaps at very high frequencies.

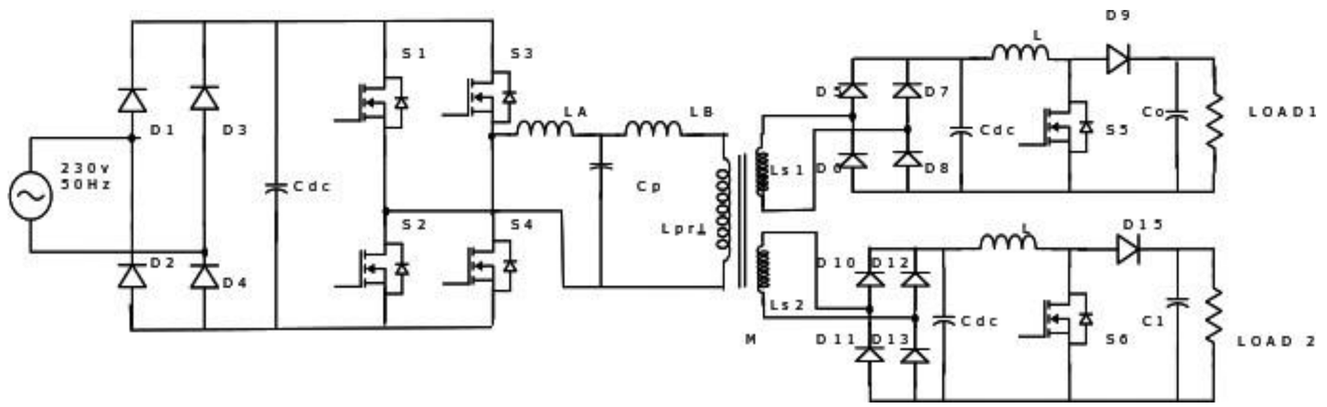

Figure 3. Circuit diagram of segmented rail with dual pickup receiver.

In recent era LCL topology become the most efficient compensation topology for the inductive power transfer. The printed spiral coil inductance has a very high influence on the power transfer efficiency of the system. So in calculating the LCL parameter, the printed spiral coils take a major role [3].

The inductance of a single layer of printed circuit layer depends on its structure. The coil diagram is as shown in Fig 2. Di and Do are in and out diameters of the coil, m represents the number of turns in the coil, t is the width of one copper layer and r represents the gap between two adjacent copper layers. The simplified form of inductance of the single layer of PSC can be written as

L = (μ° $m^2 D_{avrg}\ \ Z1)/2$ (ln $\frac{Z2}{\sigma}$)+$Z3*\sigma+Z4*\sigma$ (1)

[illegible]

Where μ_0 is the magnetic permeability of free space, Davrg is the average diameter of the coil and Davrg = $\frac{Di+Do,}{2}$,σ represents fill ratio of the coil $\sigma=\frac{Do-Di}{Di+Do}$, Z1, Z2, Z3, Z4 are the layout dependent coefficient based on the geometry of the coil, for the circular coil Z1=1, Z2=2.45, Z3=0, and Z4=0.2,

By considering the transmitter and receiver in series, they are equivalent to a single inductor.

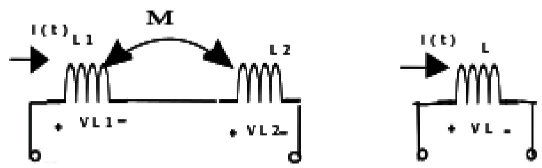

Figure 4. Equivalent inductance in a single coil

By Kirchhoff's voltage law,

V= VL1+ VL2+ V12+ V21

V= L1 $\frac{di}{dt}$+ M $\frac{di}{dt}$+ + L2 $\frac{di}{dt}$+ + M $\frac{di}{dt}$

V= (L1+L2+2M) $\frac{di}{dt}$+

L= L1+L2+2M$

L1 and L2 are the inductances of two independent circular PSCs. L represents the equivalent inductances when considering L1 and L2. VL represents the voltage that measured across L1 and L2. V12 and V21 is the mutually induced voltages of L1 and L2. M is the mutual inductance [4]. Consider the two inductances of PSCs are same, so L1=L2=L,

Then it can be written for double layer PSCs as:

L' =2L+2M

C. LCL parameters design

The total inductance of the whole circuit can be represented as,

L1= $((4*U\_dc)/(2\pi\omega\ I\_pset))$ (2)

By using the formulas of primary inductance current and in-phase condition a set of equations can be generated. The relation between coupling coefficient, self-inductance, and mutual inductance can be used for solving the equations [4].

M1= k1*$\sqrt{Ls1Lp}$ (3)

k1 depends on as it is chosen, more accurately the value of k1 must be between 0.1 and 0.5. Air cored inductances such as, Lp and Ls1 are used with considering an amount of magnetic losses, so less core loss. In air-cored cases the coupling coefficient must be below 0.5. After solving the three variables L1, L2 and M1, C1 can be found out by the constant-current condition. For the easy of calculation k1 can be adjusted to near the value of C1. This is another advantage of improved LCL networks.

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4. SIMULATION RESULTS

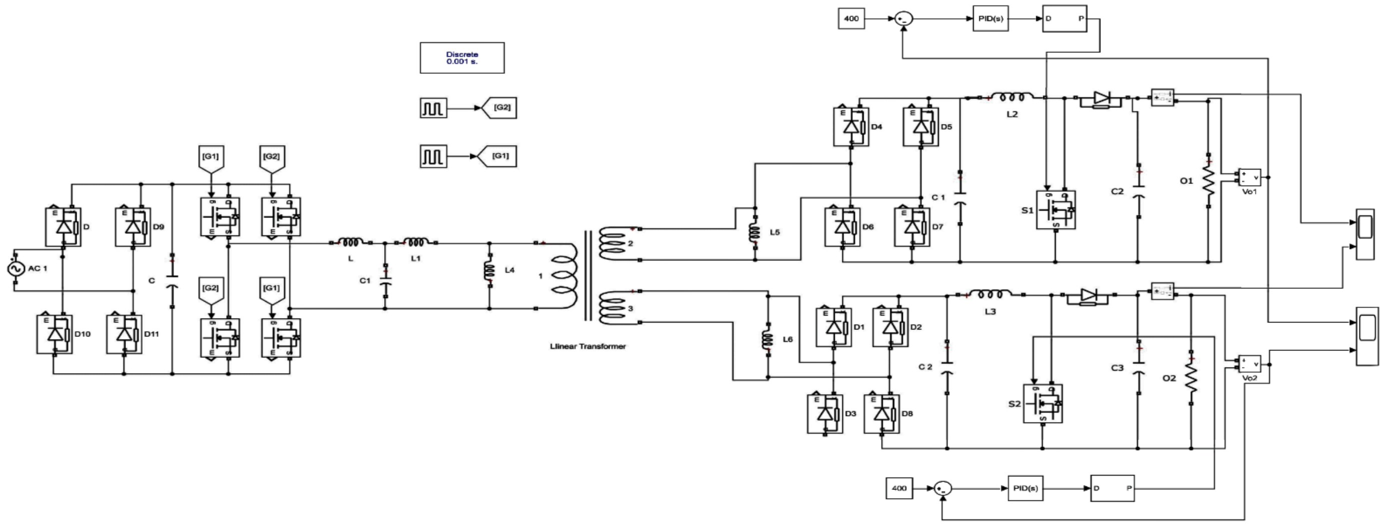

Figure 5. Circuit diagram in MATLAB/simulink

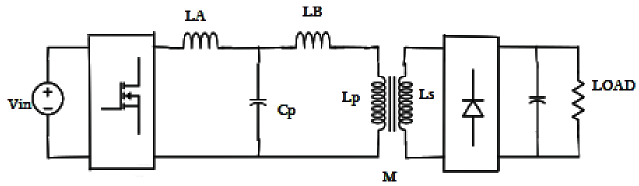

Figure 6. The experimental system schematic diagram

The simulation work is done in MATLAB/Simulink. The circuit is as shown in Fig 5.

An input voltage of 230V AC is given as input to the circuit. It is then rectified into dc by using a diode rectifier. A dc-link capacitor is provided in order to get a constant voltage at the dc terminal. This dc voltage is converted into high-frequency AC by using a high-frequency inverter circuit. Inverter AC is then supplied to the printed spiral coils through an LCL compensation network.

The input voltage (grid voltage), primary side inverter output current, primary output current and primary output voltage obtained during the simulation is as shown in Fig 7 and Fig 8. Fig 7 represents the unzoomed waveforms and Fig 8 indicates zoomed version. An electro-magnetic field is induced between these primary and secondary PSCs. By the mobile part of the electric vehicle, this induced high-frequency AC voltage is converted into DC by the rectifier circuit. The desired 400 V output voltage can be achieved by a closed-loop dc-dc boost converter circuit. The secondary induced voltage and its output current and voltage waveforms are as shown in Fig 9. Here only a single side pick-up is shown. The usage of dual pick-up doubles the voltage than a single receiver side.

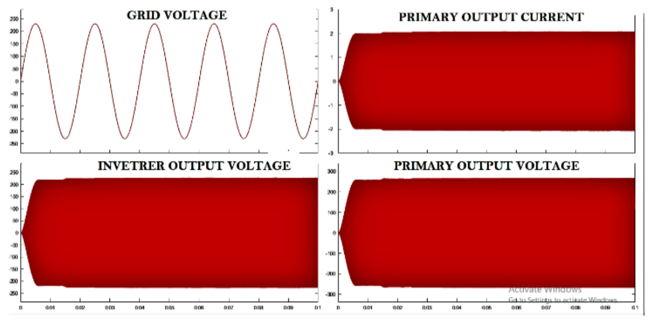

Figure **7**. Waveforms of grid voltage, inverter output voltage, primary output current and primary output voltage

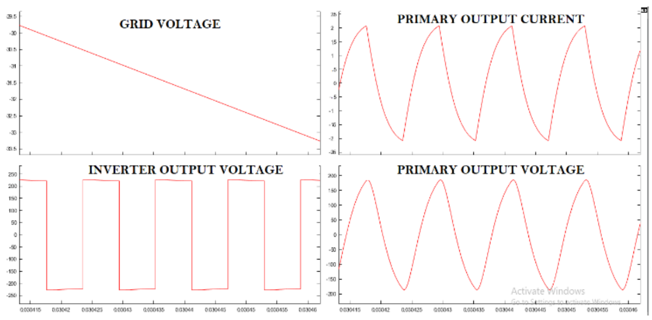

Figure **8**. Zoomed waveforms of grid voltage, inverter output voltage, primary output current and primary output voltage

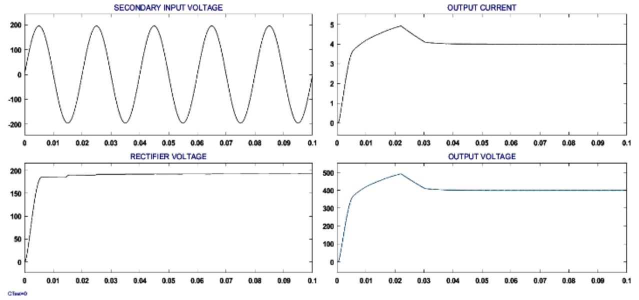

Figure **9**. Simulation results of secondary input voltage, rectifier voltage, output current and output voltage

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TABLE I

DESIGNVALUES

PARAMETER	VALUE
Vin_ac	230V
Fs	85kHz
Ipset	3A
Cp	0.1µF
LA	30.6µH
LB	1.6µH
M1	2.1µH
M	417µH
M2	0
Lp	33.4µH
Ls1=Ls2	16.7µH

5. DESIGN VALUES

The designed parameters for LCL compensation is shown in Table I. Designed parameters are given in the simulation, the switching frequency is selected as 85 kHz. The parameters are arranged as in the block diagram representation, as reflected in Fig 6. The grid voltage is given as the input to the rectifier. It is then converted into a high-frequency AC. This AC voltage is supplied into the transmitter coil of 25 turns. The mutual inductance between primary and secondary transmitter is calculated as 2.1µH by (3).

The mutual inductance between the dual-pickup section is made to zero, so that the maximum power can be transferred. LCL compensation is used in the primary side only, assuming there is no compensation circuit in the secondary, as in the primary side LCL resonator is selected.

6. CONCLUSION

Electric vehicle becomes the present and future of the world as it is free from pollution and benefits in a reduction in the usage of fossil fuels. This paper explains about the on-road charging concept that will be the future technology for an electric vehicle. Wireless charging concepts will be implemented by 2023, the segmented rail concept will be the leading one. In particular, when the roads are electrified with wireless charging capability, will leads to mass usage of EV regardless of battery technology. In this paper a wireless power transfer technology with a multi parallel segmented rails which forming an oven magnetic field in the transmitter and receiver gap is elucidated. The segmented rail concept introduces transmitter deactivation when the vehicle moves away, so that power transferred to the receiver side is optimum. In order to increase the power transfer efficiency a dual pickup receiver side also included in this system. The coordination between the two receiver section can allocate a constant power for the entire system. The efficiency will be higher than any other on-road WPT system. The system is simulated and the results are plotted.

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