APPLICATION OF WIRELESS BATTERY CHARGING FOR E-BIKEN OF WIRELESS BATTERYCHARGING FOR E-BIKE

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Abstract - *Inductive Power Transfer (IPT) represents a widely investigated issue with respect to modern battery charging methods, by providing a wireless solution. IPT is applied across a large variety of applications, from Watt to kWatt power levels. Although IPT features great benefits in terms of safety and comfort, the most significant drawback consists of relatively poor power conversion efficiency. In this thesis, a 100W wireless charging equipment for E-bikes which improves efficiency is proposed. Complete magnetic structure designs, as well as transmitter and receiver efficient architectures, are deeply exposed. The efficiency of the designed solution is shown by simulation results.*

Key Words: Battery Charging, Contactless Battery Charging, Inductive Power Transfer, Wireless Charging.

1. INTRODUCTION

Research is focused on renewable energy sources and energy saving to reduce fossil fuel consumption and emission. Moreover, to reduce air pollution electric vehicles are widely promoted. In this field, important issues are diagnostic systems to improve power train reliability. For automotive applications, inductive power transfer based battery charging is gaining great popularity over wired-based charging.

Inductive Power Transfer (IPT), based on magnetic coupling, can be exploited to address energy from the electric mains to the electric load. The magnetic coupling occurs by means of two coil windings: the power transmitter winding, connected to the mains, is the primary inductor; the power receiver winding, connected to the load, is the secondary inductor. IPT-based battery charging for a vast range of power targets is a widely researched issue. Consumer handheld devices and electric vehicles represent some of these applications. For all cases, covering the range from Watt to kWatt power levels, the most important advantages brought by the IPT-based wireless battery charging are safety and comfort. Indeed, by avoiding power cords, electrocution danger is prevented. Moreover, if the wireless solution is employed, battery charging is automatically provided by only placing the load device next to magnetic pad which transmits the required power. In

spite of the benefits linked to the wireless charging solution, the conventional wire-based recharge is still more convenient as far as power conversion efficiency is concerned. Accurate measurements of input and output power and efficiency as well are required since the simulation step even by PC-based wattmeter. Even if for low power applications, such as mobile phones, wireless battery charging systems are fully available on the market, for high power levels, such as in automotive systems, a widespread commercialization is still far to come. Research is therefore focused on efficiency-related issues aiming at reducing consumption from the electrical mains, especially if kWatt power levels are interested.

In the literature, several innovative solutions for different power levels aim at enhancing the magnetic coupling efficiency of the inductive structure and of the power conversion stages. In prototypes of kWatt contactless charging systems with reference to efficiency issues are presented. The wireless method gives the opportunity of battery charging while the vehicle is in motion. In the literature, advanced technologies for wireless dynamic charging are investigated.

In this seminar, a 100W IPT-based wireless charging system which is addressed to electric bicycles batteries and improving the overall power conversion efficiency is proposed. The IPT based charging method is particularly appropriate for E-bikes, due to the small amount of stored electric charge among all the electric vehicles. Urban cyclers generally need automatic and fast charging operations: IPT would allow charging by only parking the bicycle in a proper space.

Design procedure of the magnetic structure is thoroughly analyzed. Three different IPT solutions are compared through the magnetic field simulation tool and the best choice in terms of cost, weight and magnetic coupling is explained. Power electronics systems are properly designed, too. Results of electronic simulation tests are provided to show the efficiency of the proposed architecture. A very high efficiency is achieved by the designed IPT system, exceeding the 90% value. Although the proposed Inductive Power Transfer system is specifically addressed to a 100W E-bike

battery recharge, it can be conveniently adapted to kWatt prototypes for all electric vehicles charging.

2.1: Wireless Charging for Low-Power Application

The wireless battery charging for low power device ranges from ultra-low power application, such as wireless sensors or implantable device, to consumers electronic devices, such as smartphone or notebooks. The ultra-low power devices ranges from µw to mw power levels of the consumer electronic devices ranges from some W(e.g. mobile phones) to tens of W (e.g. laptops).

2.2: Wireless Sensor Networks and Biomedical Application

In wireless sensor networks (WSN) the use of wires for the power supplying is generally impossible, since the wireless sensors are inherently hard to reach from the human beings, like in meteorological data collecting or military application. In similar Applications, the wireless solution represents the best option for both communication and power supplying. This application corresponds to ultra-low power levels, ranging from µw to mw.

A wireless charging vehicle (WCV) travels along a planned path inside the network and recharges the sensors, through an inductive power transfer link. In a power transfer inductive link is proposed to supply the batteries of the WSN nodes. The distance between the inductive coils is in the range (1-10) mm.

The use of the environmental energy harvesting in order to supply the sensors can be considered as a form of wireless battery charging batteries and the super capacitors of sensor nodes are respectively supplied by radio-frequency waves and solar power. Wireless power transfer is also convenient in biomedical application for the supply of implantable devices.

2.3: Consumer Electronic Devices and Household Appliances

The following range of power level is represented by the electronic consumer devices, such as mobile phones and notebooks. For this application, the power level range from some W. This wireless charging is based on the inductive power transfer (IPT) between two coupled coils: one of them is placed inside the device and connected to the electric battery. By positioning the mobile device upon the pad, the charging operation automatically starts through magnetic induction. More than 200 companies have joined WPC. One of the most attractive benefits brought by wireless battery

charging for consumers electronic is the opportunity to simultaneously charge different devices on the same pad, as suggested by Fig. 2.3

Fig. 2.3: Commercial Example of a Wireless Multi-Charging Station

Innovative topology of power receiver of wireless battery charger for consumer devices is proposed.

2.4: SYSTEM DESCRIPTION

2.4.1: The IPT - System Description

In Fig. 2.4.1, a typical schematic of an inductive power transfer system is shown. The DC-DC stage is highlighted in the figure. For battery charging application, the electrical power flow the DC-link to the battery.
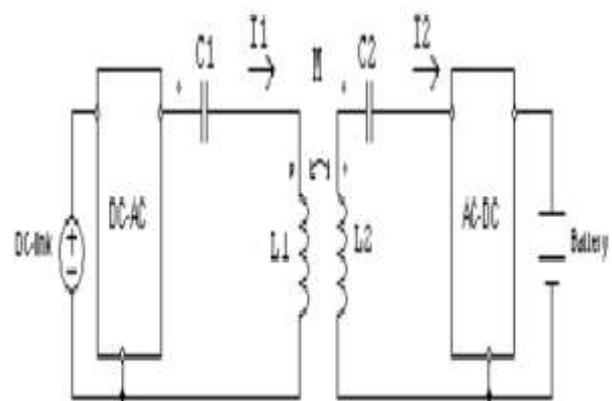
Fig. 2.4.1: A Typical Schematic of an IPT System

The inductive power transfer occurs between two magnetically coupled coils. Their self-inductances are L_1 and L_2 the mutual inductance is M, L_1 and L_2 correspond respectively to the primary and the secondary coil. The primary-side DC voltage source is connected to the electrical grid; the secondary-side DC section is the load representing

the battery to the charged. Since the power transfer between the coupled coils is in AC, two intermediate stages are needed: a DC-AC in the primary side and an AC-DC in the secondary side.

Since the coils are loosely coupled, a reactive network is needed in order to maximize the power transfer efficiency and to optimize the power factor, if the system works at the resonance. This reactive network is named compensated circuit and includes two capacitors, one for each side. In the example of the figure, both the compensated capacitors C_1 and C_2 are connected in series with the primary in series with the primary and the secondary coils.

The main parts of the IPT systems will be described in the following.

2.4.2: Compensation Network

A reactive network is required in order to maximize the power transfer efficiency towards the load and the power factor towards the source. Since the reactive element needing to be compensated are the coupled inductors, the compensation elements are capacitors. According to Fig. 3.1 the capacitor connected to the primary coil is the primary capacitor C_1, whereas the capacitor connected to the secondary coil is the secondary capacitor C_2.

According to the type of connection between the coils and their compensation capacitors, four different compensation topologies are possible: series-series (SS) series-parallel (SP). Parallel-series (PS) and parallel-parallel (PP). For each of these four solutions, the first word (letter) refers to primary side, whereas secondary side, as highlighted in Fig. 2.4.2 choosing a specific topology rather than another one depends on the specific application.
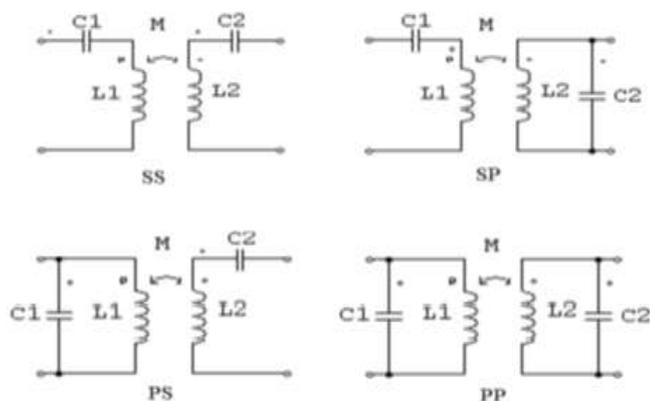
Fig. 2.4.2: The Four Main Compensation Topologies

The SS choice allows selecting the compensation capacitances depending only on the self-inductance, no matter what the load and the magnetic coupling are.

Therefore, in case of misalignment between the coils, the system keeps working under resonance in spite of the mutual inductance variation.

For this reasons, the SS topology turns out to be convenient for EV battery charging. Indeed, in IPT charging of vehicles, the perfect alignment between the coils just represents an ideal case and even small misalignment are unavoidable.

2.5: Power Converter

Due to the AC nature of the inductive coupling between the coils, the voltages across the primary and the secondary side are alternating. The power source is the electrical grid, whereas the power load is the rechargeable battery. Two power converts are required, one in the primary side and the other one in the secondary side. In the primary side a double stage is generally employed, resulting from the cascade of an AC-DC and DC-AC (this DC-AC is the one highlighted Fig. 2.4.1). The goal of this double stage is to increase the power frequency from 50 Hz. (or 60 Hz) of the grid to tens of kHz of the IPT. In the secondary side an AC-DC stages is needed in order to supply the DC battery. Since the AC-DC stages in the primary side is quite standard, the scientific research generally focuses on the stage between the primary DC section and the secondary dc section.

Different solutions have been investigated, concerning the primary DC-AC stage and the secondary AC-DC stage. As far as the secondary side is concerned, two possibilities have been mainly exploited to connect the secondary AC side to the DC battery: a passive rectifier plus a DC-DC converter or an active AC-DC stage.

2.6: Advantages:

i.   Low infection risk- For embedded medical devices, transmission of power via a magnetic field passing through the skin avoids the infection risks associated with wires penetrating the skin.
ii. Durability- Without the need to constantly plug and unplug the devices, there is significant less wear and tear on the socket of the device and the attaching cable.

2.7: Application:

i.   Low power application are generally supported of small consume electronic devices such as cell phones, handheld devices, some computers, and similar devices which normally charge at power levels below 100 watts.

ii.   High power battery charging generally refers to inductive charging of batteries at power level above 1 kilowatt.

3. CONCLUSIONS

This seminar has dealt with wireless battery charging for e-bike. An inductive power transfer (IPT) system for an E-bike battery charging has been designed and assembled. The target is a 36V 10 Ah LiFePo$_4$ battery and the power level ranges from 100W to 250 W.

After the magnetic design of the IPT coils, the electric model of the coupling structure has gained and acquired from an electronic simulation tool, in order to complete the design of the whole system.

A series-series (SS) compensation topology has been chosen for the capacitive network that has been connected to the coupled coils. In the assembled open-loop prototype, a half-bridge converter in the transmitter side and a four-diode rectifier in the receiver side have been studied.

A magnetic characterization of the region surrounding the assembled prototype has been made as well. According to the magnetic field exposure guideline, by ICNIRP, a minimum 25 cm distance from the center of the system is suggested as safety distance.

For this system, an investigation has been carried out on different magnetic coupling structures, all compliant with an E-bike wheel, and the best option in terms of system efficiency and tolerance to lateral misalignments has been defined. The investigation has been made according to the result of 3D magnetic simulations and their elaboration.

4. ACKNOWLEDGEMENT

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