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Design Optimisation for an Efficient Wireless Power Transfer System for Electric Vehicles

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Abstract

Wireless Power Transfer (WPT) has been used to transfer small amounts of power over small distances to run smartphones, RFID tags, smart watches and even biomedical implants without any electrical contact. A popular application for this is the wireless charging of electric and hybrid electric vehicles. However, designing systems to send large amounts power over large distances while maintaining appreciable efficiency is hard to do. In this paper, an overview of a typical WPT system has been given. Simple design equations have been given to calculate inductance, capacitance, power, quality factor and coupling coefficient to optimise coil design for electric vehicle application. Further, a comparison has been made between the popular coil shapes and the effects of the change of coil parameters like number of turns, pitch and inner and outer radius on efficiency of the coil has been studied.

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Keywords: Wireless Power Transfer, Electric Vehicles, Design Optimisation, Coil Shapes, Quality Factor, Coupling Coefficients.

1. INTRODUCTION

Inductive Wireless Power Transfer is the use of time-varying magnetic fields to transfer power over short and medium distances to electric loads. It was first used by Nikolai Tesla in the early 20th century and has since been developed prominently over the past three decades in research labs around the world [1]. It has been used prominently to transfer power to consumer electronics like smartphones, electric toothbrushes and in audio systems of Apple iPhones [2]. WPT has also been used experimentally in biomedical implants where pacemakers have been powered using WPT technologies [3], [4]. RFID tags used in prisons and ID cards for identification use WPT systems to gather information from tags and other remote sensors [5]. WPT has been viewed as a viable alternative in consumer goods and in other applications like wireless sensor nodes as it reduces the need for wires, decreases the size required for charging apparatus in consumer goods and reduces the risk to users due to electrical shocks In certain applications like biomedical and RFID, where size is a big concern, the use of WPT has helped engineers reduce the size of the devices [6].

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Nomenclature

L	Inductance	V_o	Output Voltage/Secondary Coil Voltage
N	Number of Turns of Coil	P	Power
D_{in}	Inner Coil Diameter	Q	Quality Factor
D_{out}	Outer Coil Diameter	k	Coupling Factor
w	Width of Conductor	R_o	Outer Radius of Coil
p	Pitch of Coil	R_i	Inner Radius of Coil
C	Capacitance	S_w	Conductor Diameter
f	Frequency	I_o	Output Current/Secondary Coil Current
M	Mutual Inductance		

Recently, research has been going on in the use of WPT to transfer energy to static and dynamic Electric Vehicles [7], [8]. Wireless charging of electric vehicles can increase the ferry range of the vehicles and reduce the size of battery packs, thus reducing the cost of the whole system. In this regard, Wang *et. Al.*, has produced a very efficient method for wireless transfer of power to stationary vehicles [9]. Research teams at universities like KAIST, Auckland University and the California PATH program have made a lot of headway in the wireless charging of dynamic vehicles [10], [11], [14]. They have transferred power at various power levels and frequencies at efficiencies as high as 85% over distances of up to 1m. India is one of the largest importer of oil in the world, which it cannot afford to remain so, given the economic and environmental constraints. Electric scooters are popular in the Indian markets, and it is only a matter of time before electric cars swarm the Indian auto market too. The wireless charging of electric vehicles will make them more popular as it gives the user portability and quick charging. The policy of electric vehicle progression has increased in the past few years in India.

Among all the WPT technologies, the use of resonant inductive WPT has been seen to be the most efficient to transfer power at medium distances to EV's. The use of a resonance topology increases the coupling between the coils and reduces the need to transfer power with higher current. Additionally, the power transfer method must be as efficient as possible to reduce losses and to deliver the required power to the vehicle. In this paper, the procedure for design of resonant WPT has been outlined and comparisons have been made between the various shapes of coils for WPT systems. Different parameters have been changed in each coil to find the optimum size and shape of the coil for a WPT system.

2. Overview of Standard WPT System

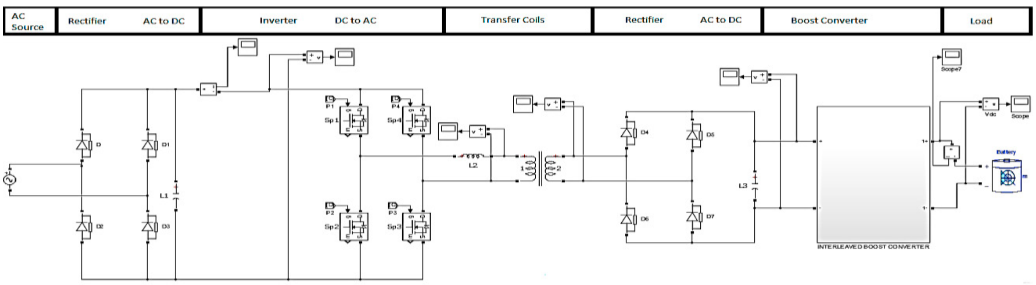

Fig 1: Structure of a Typical WPT System

Any wireless power transfer system can be broadly divided into two parts- the transmitter and the receiver.A WPT system needs an input power which can be given power from either AC or DC sources. In case of AC sources, the input power is first rectified. The rectifier stage may also contain a Power Factor correction module. The rectifier stage provides controlled power to the rest of the system. The next stage is a boost converter that boosts the DC voltage to a higher value as required by the receiver stage. For boost ratios less than 1.5, switching losses are less in Z source converters as compared to conventional converters [12]. Hence the use of Z source network can also be employed. The inverter stage consists of a full-bridge switching network that converts the DC waveform into a high frequency square wave. The frequency chosen is high to increase efficiency and decrease losses in the transmitter stage.This stage converts the High Frequency Square wave output of the inverter stage to High Frequency Sine wave using passive components capacitors and inductors. The frequency is matched in both the transmitter and receiver stage to increase the efficiency of power transferred. The incoming AC power from the pick-up coil is converted into DC again to charge the battery.

3. Design of a WPT System