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How driver behaviour and parking alignment affects inductive charging systems for electric vehicles

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ABSTRACT

Inductive charging, a form of wireless charging, uses an electromagnetic field to transfer energy between two objects. This emerging technology offers an alternative solution to users having to physically plug in their electric vehicle (EV) to charge. Whilst manufacturers claim inductive charging technology is market ready, the efficiency of transfer of electrical energy is highly reliant on the accurate alignment of the coils involved. Therefore understanding the issue of parking misalignment and driver behaviour is an important human factors question, and the focus of this paper. Two studies were conducted, one a retrospective analysis of 100 pre-parked vehicles, the second a dynamic study where 10 participants parked an EV aiming to align with a charging pad with no bay markings as guidance. Results from both studies suggest that drivers are more accurate at parking laterally than in the longitudinal direction, with a mean lateral distance from the centre of the bay being 12.12 and 9.57 cm (retrospective and dynamic studies respectively) compared to longitudinally 23.73 and 73.48 cm. With current inductive charging systems having typical tolerances of approximately ±10 cm from their centre point, this study has shown that only 5% of vehicles in both studies would be aligned sufficiently accurately to allow efficient transfer of electrical energy through induction.

1. Introduction

Research and innovation into electric and alternatively fuelled vehicles – which includes pure Battery Electric Vehicles (BEV), Hybrid Electric Vehicles (HEV), Plug-in Hybrid Electric Vehicles (PHEV), or fuel cell vehicles (e.g. hydrogen) – is continuing at pace as they are viewed as a sustainable way to reduce both the dependency on fossil fuels and carbon output. The number, or available range, of 'electric miles' can be increased by storing energy in batteries located within the vehicle in order to power the drivetrain. When this store is depleted the batteries need to be recharged. This is typically done by plugging in a wired, or conductive, cabled system which is connected to the electricity grid. An emerging technology to support green driving is inductive charging.

Inductive, or wireless, charging uses an electromagnetic field to transfer energy between two objects, and offers an attractive alternative to the users having to physically plug in their EV or PHEV to charge the batteries. To initiate charging the user simply parks over a transmitting inductive coil which is embedded in the ground, and the receiving coil located on the vehicle automatically detects this and charging begins. Whilst inductive charging technology is market ready, the efficiency

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of transfer of electrical energy is highly reliant on accurate alignment of the coils involved. He and colleagues envision that high-power, high-efficiency wireless power transfer technologies will be mature in the 'near-future' (He et al., 2013).

The key challenge in an automotive application is to transfer power over an air gap at an acceptable level of efficiency whilst meeting any legislative requirements, such as ensuring safety levels are met with respect to human exposure to electromagnetic fields (ICNIRP, 2010; IEEE, 1992). A possible solution is resonant inductive coupling. This is the near-field (or short distance) wireless transmission of electrical energy between two coils that are highly resonant (or oscillate) at the same frequency. The efficiency of the energy transfer is a function of the frequency and alignment of the coils. Misalignment can occur across the vertical distance of the air gap, as well as lateral, longitudinal and angular misalignment. The efficiency of energy transfer generally drops rapidly once the misalignment reaches approximately 15–20 cm (Stanton, 2014). As a result, the control system will cut off the power, or the transfer will not commence when the efficiency is below 80%. However, an optimised system with perfect alignment of the two coils can result in transfer efficiencies of over 95%, which is comparable with wired charging.

Fig. 1 shows a typical wireless charging system. The power drawn from the supply is first rectified (or converted) through an AC/DC converter before being transformed to a high frequency (kHz) resonant signal by the inverter in the transmission pad installed on the ground. This energy is transferred across the air gap to the receiving pad on the vehicle through magnetic coils. At the receiving end, it is once again rectified to charge the battery in the vehicle. Development in coil design (i.e. multiple coils, field shaping, etc.) may result in marginal improvements in the physical efficiency bandwidth; however, the weak link in the chain is the driver and how accurately they can park, or drive over the coil to maximize energy transfer efficiencies.

Inductive power transfer (IPT; also known as wireless power transfer (WPT)) as a concept has been around for almost 200 years with its roots in both Ampere's (1826) and Faraday's (1831) Laws. In the 1890's Nikola Tesla demonstrated how wireless power transfer can be used to illuminate incandescent lamps in New York. From these promising beginnings the technology largely remained untapped until recent years when in 2007 a team of researchers at MIT again demonstrated transmission of 60 W across a 2.5 m air gap to illuminate a light bulb.[1] Concurrent development was being conducted by, amongst others, researchers at the University of Auckland who were investigating the wireless transfer of higher power ratings suitable for powering vehicles or changing plug-in vehicles.[2]

In the UK the Society of Motor Manufacturers and Traders (SMMT) report that 9151 vehicles eligible for the UK Governments 'Plug-in car grant' – which offers a subsidy of up to £5000 off the purchase price of a plug-in vehicles (i.e. either BEV or PHEV) – have been purchased since the scheme began in January 2011 until April 2014.[3] This equates to only 0.13% of new vehicle registration during this same time. Whilst this landscape is changing, as according to the same SMMT figures just over 1200 plug-in vehicles were sold in March 2014 alone, adoption rates for the uptake of EVs to the mass market is still very low. A report for the European Council suggested that the main barriers for adoption were, high purchase price, range anxiety, uncertainties associated with battery life and other factors relating to new and unfamiliar technology (Wallis and Lane, 2013). Add to these the problems associated with users having to plug-in and charge the EV (as reported by Wellings et al., 2010), slow refuelling rates (Pearre et al., 2011), unwillingness to find alternative transportation if needed (Tamor et al., 2013), and the fact that charging cables do not respond well in extremes of hot or cold temperatures (Boys and Covic, 2013). Those who have driven an EV will also appreciate the associated inconvenience of having to interact with a potentially dirty, wet, heavy, inflexible cable in potentially wet, cold, icy environmental conditions, as well as the time taken to physically plug the vehicle in. Wireless charging could also reduce the accidental, or malicious, unplugging of a charging vehicle as there is no physical interaction point. All of the above factors equate to possible reasons why EV ownership has not taken off (as yet).

Whilst inductive charging will not physically increase the capacity of a battery, it may help remove the inconvenience factor of plug-in vehicles. Drivers will be able to just park their vehicle in a designated parking bay, and charging will begin automatically with no need to locate a cable and physically plug it in. A report by Carroll and Walsh (2011) suggests that 'opportunity charging', i.e. charging the vehicle little and often during the day when the EV is not in use, can lead to significant improvements in range compared to that available from a single overnight vehicle charge. This was as a result from being able to utilise over 100% of battery state of charge per day. Such opportunistic charging may be facilitated by the inherent ease and convenience associated with inductive charging systems.

A review of the literature reveals that limited research has been conducted into parking behaviour, which has been primarily focused on parking orientation and preferences (Cullinane et al., 2004; Kobus et al., 2012), gender differences (Wolf et al., 2010), desired clearance between vehicles (Gadgil and Green, 2005), parking related crashes and incidences (Green, 2006) or vehicle-to-vehicle gap in real-world parking (Thornton et al., 2014). The most relevant study for this current paper was conducted by Cullinane et al. (2004) whose research for the University of Michigan Transportation Research Institute (UMTRI) evaluated parking accuracy of 102 vehicles, in three different types of parking bays (angled, parallel and perpendicular). This was a retrospective analysis with participants not being aware that their parking would be assessed. Their research found no difference between the size of the vehicle and lateral parking accuracy, with drivers attempting to keep a constant amount of exit space on the drivers' side of the vehicle in angled and perpendicular parking, and with parallel

1 http://www.sciencecodex.com/mit_demonstrates_wireless_power_transfer.
2 http://www.qualcomm.com/media/documents/files/inductive-power-transfer-systems-ipt-fact-sheet-no-1-basic-concepts.pdf.
3 http://www.smmt.co.uk/2014/05/April-2014-eV-registrations/.

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