* 1. Motivation

In recent decades, there have been significant developments and breakthroughs in  
technology. The use of a variety of autonomous electronics devices; such as mobile  
phones, laptops, tablets and home appliances has significantly increased due to consumer  
demands [1]. Such electronics contain on-board energy storage modules in the form of  
lithium based batteries. These batteries have normally been charged by conventional  
battery chargers through physical contacts. This form of connection increases the risk of  
short circuits; either by water or foreign objects crossing the contacts, or due to damaged  
connectors. In addition, different electronic devices have different power ratings as well  
as a variety of standardized chargers. For example, mobile phones have different plug-in  
chargers and power ratings than laptops. This is not only limited to low power devices  
but it is also applicable to medium to high voltage battery operated equipment such as  
fork lifts, Electric Vehicles (EVs) and electric public transport systems. Standardised  
chargers create inconvenience to the users when they travel to another country. Moreover,  
when such electronic devices are upgraded or replaced, the chargers also need replacing  
even though they may still be in good working order. These unused devices end up in  
landfill because of improper recycling. This is known as electronic waste (E-Waste). Worldwide 20 to 50 million tonnes of E-Waste is annually generated.

Over the last few years, fossil fuel prices have increased rapidly because of the reliance  
on limited hydrocarbon energy sources (such as petrol, diesel and gas) for power  
generation and advanced transportation systems. The utilisation of  
such fuels creates greenhouse gas emissions, which cause dramatic environmental  
changes on a global scale. According to the 2015 key world energy statistics released by  
the International Energy Agency (IEA) in 2016, total energy consumption reached  
approximately 13699 MToe(Millions of Tonnes of Oil Equivalent). In order to reduce the usage of fossil fuels, electrified transportation requires the set-up of a wide variety of charging networks to create user-friendly environments and to tackle green-house and fuel price hikes. To compete with gasoline powered cars, EVs are required to have a long travelling range with an efficient refuel capacity. These features can only be achieved by installing a larger battery bank with continual charging facilities. However, a larger battery bank increases the overall price  
of EVs and requires additional charging time. Such limitations are the biggest hurdles in  
making EVs a reliable transportation alternative.

In order to tackle these issues, Wireless Charging Systems (WCS) are one of the up and  
coming technologies which have the potential to provide contactless charging facilities in  
low, medium and high power consumer electronic products. WCS technologies have  
been proven to have significant advantages to charge in high power applications including  
electric vehicles (EVs) [9], and Plug-In Electric Vehicles (PEVs) [10] in a stationary [11]  
and dynamic modes. This technology can offer safe, secure and user friendly charging  
techniques that are environmentally sound. WCS can provide a common charging  
platform for most electronic devices so different electronic products do not require  
separate standardised chargers to charge their batteries. Moreover, it can help to reduce  
the battery storage requirements by providing a continuous dynamic charging facility  
wirelessly. This technology can reduce toxic and non-biodegradable hazardous E-waste  
by establishing a common charging platform for all electronic products.

In summary, wireless power transfer technology in the field of electric vehicle charging  
can offer the following advantages [11, 12]:  
1. *Convenience*: As the wireless charger does not require any standard plugs in order  
to charge the EVs, it is possible to use different wireless power chargers such as slow charging or fast charging. In addition, this feature can help to reduce E-waste issues because one wireless charger can charge a variety of PEVs even though  
they would be manufactured by different companies.

2. *Safety*: Plug-in chargers may create shock, sparks and other security risks due to  
improper handling or damage, whereas wireless electric vehicle charging systems  
(WEVCS) operate without any physical contact with the receiver devices.  
WEVCS are more durable due to their plugless operation.

3. *Operation reliability*: Wireless power can operate in high risk environments  
including flammable, explosive, high temperature and humid conditions. Wireless  
power can also enable the dynamic charging of devices.

However, for WEVCS to become more use friendly two areas must be investigated. These  
are power level and health and safety issues related to electromagnetic compatibility  
(EMC) and electromagnetic interference (EMI).

**1.3.1. Overview of Research Topic**The investigation and design of the wireless charging system for PEVs requires a focus  
on a number of different research areas. These include magnetic material, shape, winding  
design, power electronics circuits and computer modelling simulation.  
• *Material*: The magnetic core material and its shape are important in the design of  
the wireless charging system. At high frequency, the material and its shape can  
help to increase the power handling capability and reduce the size of the unit. The  
selection of conductors and insulators requires additional research.  
• *Winding*: Windings of different sizes and shapes have been proposed by the  
researchers in the design of the WCS for PEVs. Proper design of the size and shape of the windings can improve the overall power transfer efficiency. For this,  
background research must be conducted including some practical experiments.  
• *Power electronics circuits*: The passive magnetic components such as inductors  
and transformers are mainly used in the electronics circuitry in the application  
requirements. Without proper circuit design, the overall system cannot reach its  
optimum performance even though high efficiency magnetic components are  
integrated in the system. This can ONLY be done by proper research of the power  
electronics circuitry.  
• *Computer simulation modelling*: Since the introduction of efficient workstation  
devices, computer simulation techniques have been applied to visualise physical  
phenomena to build and optimise the wide variety of prototypes without  
constructing the actual physical device. The accuracy level of the simulation  
software brings many advantages from prototypes to real product manufacturing  
as the simulation results are as accurate as the experimental and calculated results.  
As a result, the simulation modelling techniques become a significant part of the  
research.

**1.3.2. Objectives**

The major objective of this research is to investigate current wireless charging systems  
for EVs (including wireless transformers) to reduce size and shape, and improve power  
transfer efficiency with a significant reduction in health and safety issues which can assist  
to create user-friendliness.

**1.4. The Contribution of this Research Project**Even though WEVCS offer more advantages over the plug-in EV chargers, there are still  
challenges to overcome. Such challenges are associated with health and safety, finances,  
power range limitations, infrastructure development and maintenance. In addition, the  
technology requires advanced safety features to deal with factors such as electromagnetic  
compatibility (EMC) and electromagnetic interference (EMI). Furthermore, WEVCS  
should be capable of competing with the existing plug-in charger in terms of high  
efficiency power transfer capability. The power transfer efficiency of the WEVCS relies  
mostly on the wireless transformer efficiency due to the large airgap between the  
transmitter and receiver pads. Current power converters are capable of delivering high  
efficiency high density power due to advances in the semiconductor devices such as IGBT  
and MOSFET. However, the overall system efficiency drops due to poor coupling  
coefficient in the wireless transformer.

The purpose of this project is to investigate and improve current WCS for EVs in terms  
of health and safety issues such as electromagnetic compatibility (EMC).

2.1. Introduction

Our forefathers marveled at the invention of Thomas Edison's glowing light bulbs (1879), however, to us 21st centurions, the light bulb is nothing out of the ordinary. When computers, cell phones, laptops, iPods and Electric vehicles were invented our antennas tweaked. Now, this is what you call invention! However, as time progresses we get used to these devices, and they seem to be less fascinating. In fact, charging all these appliances has become so very cumbersome. Each appliance has its own set of chargers overflowing with all sorts of wires.  When you're on your way to work and your Electric car beeps in hunger for a battery charge, haven't you wished your Electric car battery could get 'self charged'. Well your plight has been heard by **Prof. Marin Soljacic** from Massachusetts Institute of Technology (MIT), is the one who has proved that magnetic coupled resonance can be utilized in order to transfer energy without wires.

 This concept of wireless electricity is not new. In fact, it dates back to the 19th century, when Nikola Tesla used inductive coupling method with resonant case to transfer power wirelessly.In comparison to plug-in chargers, WCS have more advantages in the form of simplicity, reliability and user  
friendliness [24]. The problem or limitation associated with WCS is that they can only be  
utilised when the vehicle is parked or in stationary modes such as in car parks, garages or  
at traffic signals [11]. In addition, stationary WCS have some challenges such as  
electromagnetic compatibility (EMC) issues, limited power transfer, bulky structures,  
shorter range and higher efficiency [25-27].

In order to improve both areas (range and sufficient volume of battery storage), a dynamic  
mode of operation of the WCS for EVs has been researched [28, 29]. This method allows  
battery storage devices to be charged while the vehicle is in motion. The vehicle requires  
less volume of expensive battery storage which increases the range of the transportation  
[12]. However, before a dynamic WCS becomes more widely accepted, it has to  
overcome two main hurdles: a large air gap and coil misalignment. The power transfer  
efficiency depends on the coil alignment and the air gap distance between the source and  
receiver [25, 30]. The average air gap distance varies from 150 mm to 300 mm for small  
passenger vehicles while it may increase for larger vehicles. Aligning the optimal driving  
position on the transmitter coil can be performed easily because the car drives  
automatically while in the dynamic mode. In addition, different compensation methods  
(such as series and parallel combinations) are employed on both the transmitting and  
receiving sides to reduce parasitic losses and improve system efficiency [31, 32]

**Why was WiTricity not Developed before?**

It is often said 'necessity is the best teacher' and can be applied in this case as well. Only in this century, has the need for wireless electricity emerged so rapidly, spearheaded by the agony caused by the cumbersome charging of endless devices. Earlier people didn't need it, so they didn't think about it.

2.2. Theory of Wireless Power Transfer (WPT)

The basic block diagram of wireless charging systems for EVs or PEVs is shown in Figure  
2.1. To transmit energy, a WCS utilises a standard power supply (mains/battery energy  
storage) and converts it to the necessary voltage/current/frequency to allow for wireless  
power transfer to occur. Figure 2.1 illustrates this process in the form of an induction  
charging method for a PEV. In this illustration, the mains AC power is converted into DC  
using AC/DC rectifiers, filters and PFC circuitry. The filtered DC is fed into HF AC converters to convert the DC into an appropriate HF AC source for the primary winding.  
To reduce losses and improve performance, primary and secondary compensation circuits  
should be employed. As the primary and secondary windings are inherently separated by  
an air gap defined by minimum vehicle ride height legislations, typically 100mm, the  
energy transfer characteristics are typical to that of an air-core transformer. A varying  
current in the primary winding creates magnetic field which generate varying  
electromotive force (EMF) or voltage in the receiver coil. On the receiving side, the EV  
power conversion starts at the secondary winding. The HF AC voltage is rectified and  
filtered into a DC source and then transferred to the battery management system (BMS).  
This device includes the battery charger, protection circuits and SOC information. From  
this point onwards, DC power can be directed into the battery banks. In general, the  
receiver coil is installed underneath the car at a distance from the ground, while other  
electronics are inbuilt into the car.

Figure 2.1. Basic diagram of a wireless charging system for EVs

Advanced WCS tend to utilize methods of controlled feedback loops to more accurately provide energy transfer details to increase efficiency. Figure 2.2 illustrates an advanced closed loop for WCS. In comparison with traditional WCS, the feedback has two important features: dual internal charge controllers and wireless communication systems. By providing two charge  
controllers, one on the transmitter and another on the receiver, the charging characteristics  
can be managed on both sides of the wireless transfer medium. In-built wireless  
communication systems allow communication between the source and receiver with a  
number of different parameters. These parameters include power transfer, efficiency,  
charging level, load level and control parameters. The information exchange can be  
employed utilising universal wireless communication protocols such as Wi-Fi, Bluetooth and near-field communication (NFC). The placement and isolation of communication  
devices from the internal WCS high voltage are one of the challenging tasks for a  
designer, but it is solved with the help of technology advances.

Figure 2.2. Advanced closed loop wireless charging system for EVs