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Emerging Trends in Wireless Charging of Electric Vehicles

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Abstract

Electrical Vehicles can only be successfully implemented when the constraints regarding limited energy storage units, power of batteries on-board and its limited lifetime are solved. Hybrid and Wireless charging systems for electric vehicles offers an alternative solution towards these problems by reducing the on-board battery size which also extends the electric vehicle range considerably which provides new opportunities for the future of even autonomous electrical vehicles. This review paper gives an overview about the emerging Wireless Power Transfer (WPT) technologies for EV applications. It gives a comparative description of conductive charging and wireless charging which is followed by the study of Static Wireless Charging and Dynamic Wireless Charging. Technical aspects of WPT systems, coil/pad designs and power converters are also reviewed with the implementation of a prototype.

Keyword- Wireless Charging, Electric Vehicle, Roadway Electrification

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I. INTRODUCTION

The earliest wireless power technology developed was inductive power transfer between two coils of wire ever since the transformer was created in the 1800s. In 1890, Nikola Tesla experimented wireless power transfer through capacitive and inductive coupling using Tesla coils that generated high AC voltages. He experimented with a large coil operating in thousands of kilovolts in 1899 at high altitude. By 1901 he sought attempted to build a large high-voltage wireless power station in New York.

Maurice Hutin and Maurice Leblanc in 1892 patented a method using resonant coils coupled inductively to transfer wireless power at resonant frequency of 3 kHz.

The Wireless Power Consortium published Qi inductive power standard which enables high efficiency charging and powering of devices of up to 5 watts over a air gap of 4 cm in August 2009. Marin Soljačić and his team at MIT in 2007 used a transmitter with dual resonance that transferred 60W of power to a dual resonance receiver over 2 meters which had a 25 cm diameter secondary coil tuned to 10 MHz at about 40% efficiency.

Dr. Christopher A. Tucker and Professor Kevin Warwick in 2011 reproduced Tesla's 1900 patent which demonstrated power transmission over a distance of 4 m with an effective efficiency of 60% with a coil diameter of 10 cm tuned to 27.50 MHz. Electric vehicles like Plug-in Electric Vehicles, and Plug-in Hybrid-Electric Vehicles are grown to become popular choice over gasoline powered (ICE) vehicles in developed countries, in order to reduce greenhouse gases and counter air pollution. EVs have better performance over ICE vehicles by the use of high voltage energy storage systems, efficient state-of-art electric motors and electrified power train. The inefficient charging infrastructure limits the adoption of EVs into the market. The paper aims to discuss about the different aspects of charging adopted in electric vehicle briefly and to cover the aspects associated with wireless charging.

II. LITERATURE SURVEY

Studies by J.M Miller were conducted on energized tracks of coils embedded on roads that are sequenced in synchronism with vehicle passage in the field of wireless charging [1]. To mitigate the power pulsations built to couple power from a series of embedded coils, high-power capacitors are installed at both in vehicle and the grid. The result shows a considerable reduction of 84% in charging current to the vehicle battery and 81% from the power grid. A Dynamic wireless charging system of EVs for slow moving traffic applications were done by A Zaheer.[2] This paper presents the magnetic design of an Induction Power Transfer system for a dynamic charging of EV, to continuously deliver 15kW of power to an EV, within ±200mm lateral misalignment. In addition, the aim of the system to utilize the shielding effect provided by the vehicle, as the field producing components of the system are shielded by the vehicle body in all operating conditions. Compensation topologies is required for the leakage inductances present in the loosely coupled transformer. Zhang, W., and Mi, C. C. provided an extensive review about existing compensation topologies for the loosely coupled transformer in High- Power Wireless Power Transfer Systems [3]. Compensation topologies are evaluated for achieving maximum efficiency according to the various areas where WPT is applied. Resonant networks used passively to attain constant voltage or current output independent of load are summarized.

In order to reduce switching stress, electromagnetic interference and switching loss in the Dynamic Charging systems, soft-switching operation of the converter are designed by M. Moghaddami, to create a Single-Stage AC– AC Converter for three-Phase Inductive Power Transfer Systems[4]. Since short life capacitors are eliminated, the proposed network is assumed to have prolonged lifetime. The proposed converter could be built with only seven switches and the regulation control technique for current can fully regulate the output power and the output current with respect to user defined values.

A 3-kW wireless charging for Sightseeing Car using supercapacitors is designed by Zhu and team [5]. To establish high efficiency and stable power transfer, a coupler having ferrite and magnetic shield is optimized first. The coupler designed requires less ferrite in material compared to the standard planar ferrite coupler without compensating wireless power transfer performance. Secondly, the supercapacitor model is employed in WPT, so that the variation between supercapacitor's equivalent load resistances and charging time could be optimized. For maintaining contant charging current under variable load a buck converter using PI controller is installed in the secondary. The results shows a constant charging current about 31.5A over an air gap of 15 cm. The system efficiency and the peak power transfer are found to be 88.05% and 2.86kW respectively.

For a sustainable Hybrid Energy Storage System with longer battery life, Akar, F. designed an Energy Management Strategy for a battery/ultracapacitor[6]. This paper suggests an Energy Management System (EMS) for a ultra-capacitor/battery Hybrid Energy Storage Systems (HESS) which can regulate SOC of ultracapacitors but can also control the power profile of the battery using a fuzzy logic controller and rate-limiter.

If the future meant increased number of EVs then power management in the existing infrastrure of supply are to be improved. Mou, Y. and Xing, H designed a decentralized Demand-Side Management for Plug-in Hybrid EV (PHEV) charging for a Smart Grid with low-voltage transformers (LVTs) [7]. The objective was to shave the load profile of LVTs, while satisfying the need for each consumer charge their PHEV by the specified time.

The most recent advancements in the field of static and dynamic wireless power transfer in EVs shows the simulation, prototype design and demonstration of Dynamic Wireless Charging System with 25kW for EVs in roadway by Reza Tavakoli [8]. The study recognised the constraints of driving conditions practically and designed a model to reduce misalignments and the dynamics inflicted by EVs while passing over charging pads embedded in the road. The energy efficiency is measured be 86% for vehicles with lateral alignment, but can be enhanced over 90% with the sequential activation and deactivation of the coils.

III. EXISTING CHARGING TECHNOLOGIES

For the development of EVs in the market, charging plays an important role. EVs have the disadvantage over gasoline engine vehicles since it requires more time to refuel, have far lesser range and limited to no charging stations at all. Some of these problem could be reduced by using a fast charger that can transfer high power with higher efficiency and also by increasing the capacity of the battery. Hence charging in EVs is possible either by conductive and inductive charging. Conductive charging has evolved that standardisation have been set and recognised. While inductive charging is an emerging field.

A. Conductive Charging

Conductive charging requires a direct connection from the electrical power supply to the EV. EVs either have onboard power electronic converters that can plug into high capacity electrical outlet. But in the case of off board chargers, converters and the regulators are connected outside the vehicle.

The charging levels used in electric cars consists of three standard levels. All electric cars at homes can be charged with level 1 and level 2 charging stations. Level 3 chargers - also known as DC Fast Charging stations – are more powerful hence it is faster than level 1 and level 2 charging. Hence level 3 chargers are not suitable for all vehicles.

The standard conductive charging based on the level of power transfer levels are classified as follows. AC Level 1 charger is less than 2 kW and level 2 chargers is 4-20 kW. It offers the same power as the ones installed for residential charging and can be used by all electric cars. DC Level 3 chargers have more than 20 kW up to 120kW. Level 3 are called DCFC or fast charging stations.

Level	*Charging Time Approx. Estimate (Low Battery)*
1	*200 km : +/- 20 hours* *400 km : +/- 43 hours*
2	*200 km : +/- 5 hours* *400 km : +/- 11 hours*
3	*80% - 200 km: +/- 1/2 hour* *80% - 400 km: +/- 1 hour*

B. Inductive Charging

Wireless power technologies are classified by following methods - near-field techniques like Inductive Coupling, Resonant Capacitive Coupling, Resonant Inductive Coupling and Magneto dynamic Coupling and far-field techniques like microwaves and lasers. For achieving wireless high power transfer it is necessary to have magnetic coupling coefficient as possible. The static wireless charger for the applying power levels of more than 20 kW for an SUV is undergoing standardization. Even more recently a company called Evatron upgraded Tesla Model S with an ultra-thin receiving coil on board to accept inductive power wirelessly using existing connectors in the vehicle.

In the case of dynamic wireless charging, KAIST have developed Online Electric Vehicle (OLEV) which was later commercialised. The 5th generation of OLEV has an S-type power supply rail for Dynamic wireless charging EVs, capable of transferring 22 kW power at an air gap of 20 cm with a lateral tolerance of about 30 cm. Korean Rail Road Research (KRRI) has been developing a very high speed train having an efficiency of 83% to transfer maximum power transfer of 820kW at an air gap distance of 5 cm. Spain has been operating a 10 km bus route with dynamic wireless power transfer since December 2014.

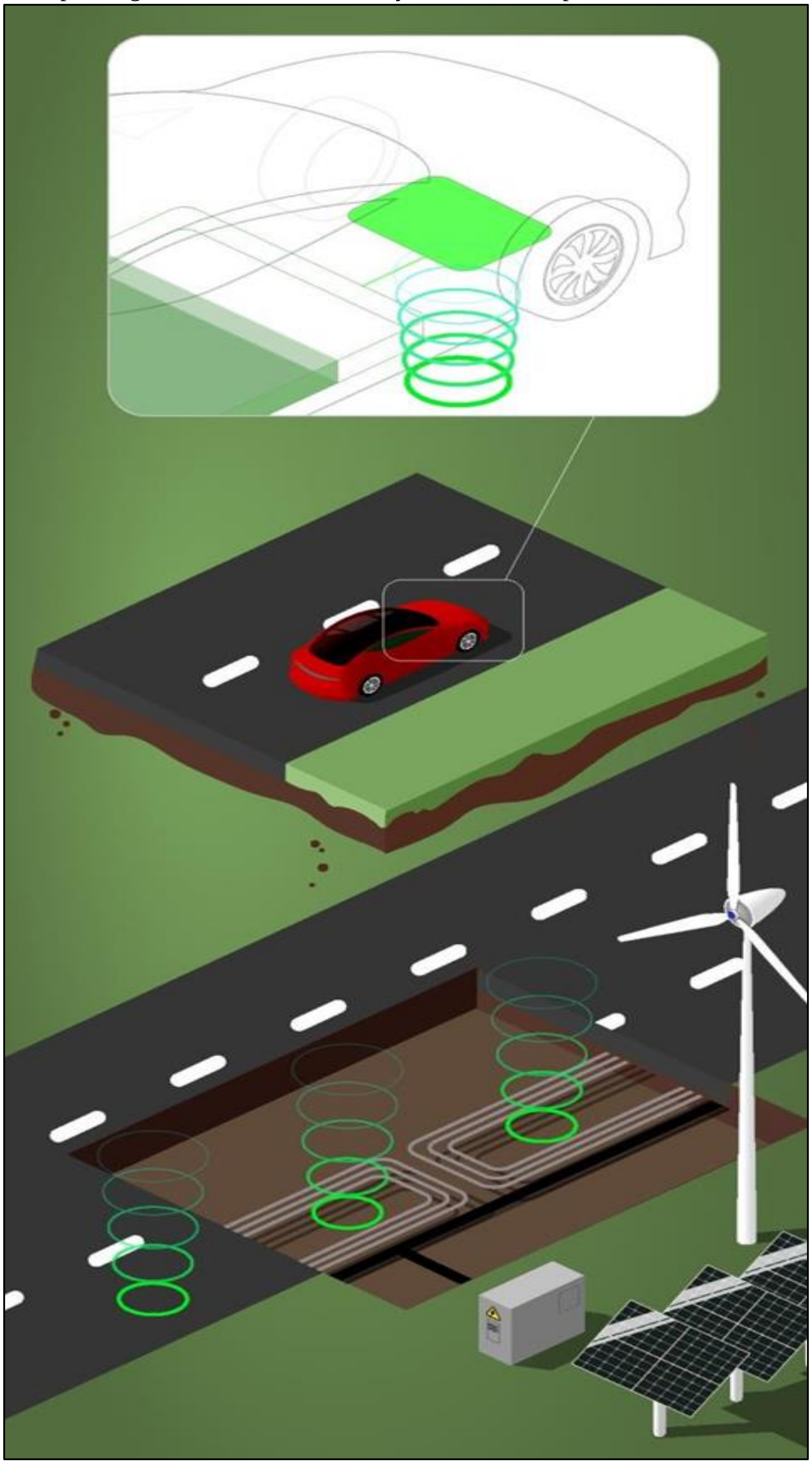

Fig. 1: Tesla's plan to siphon energy from dynamic charging roadways in the future

IV. SIMULATION

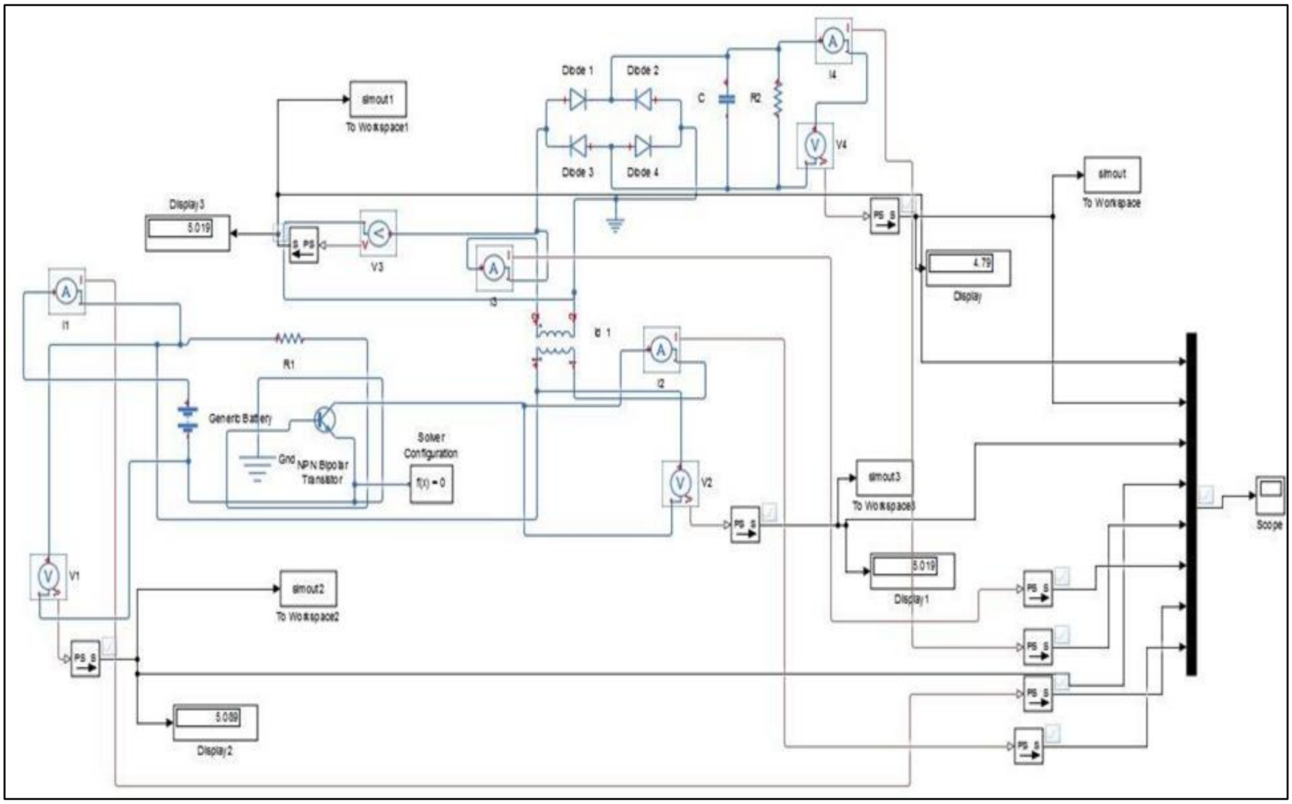

Fig. 2: The Simulink model of Wireless Power transfer between primary and secondary coil is demonstrated

For the simulation of the wireless transfer of power in Electric Vehicles, a circuit was designed to analyse the waveforms and power transferred at the secondary side of the coil in this paper. The high frequency sinusoidal current was produced using a sinusoidal voltage generated from the H-bridge which is described in the oscillator circuit at the primary side of the coil to be embedded inside the road. Due to magnetic resonance coupling sinusoidal voltage of about 20V was recorded at the secondary side of the coil.

V. HARDWARE

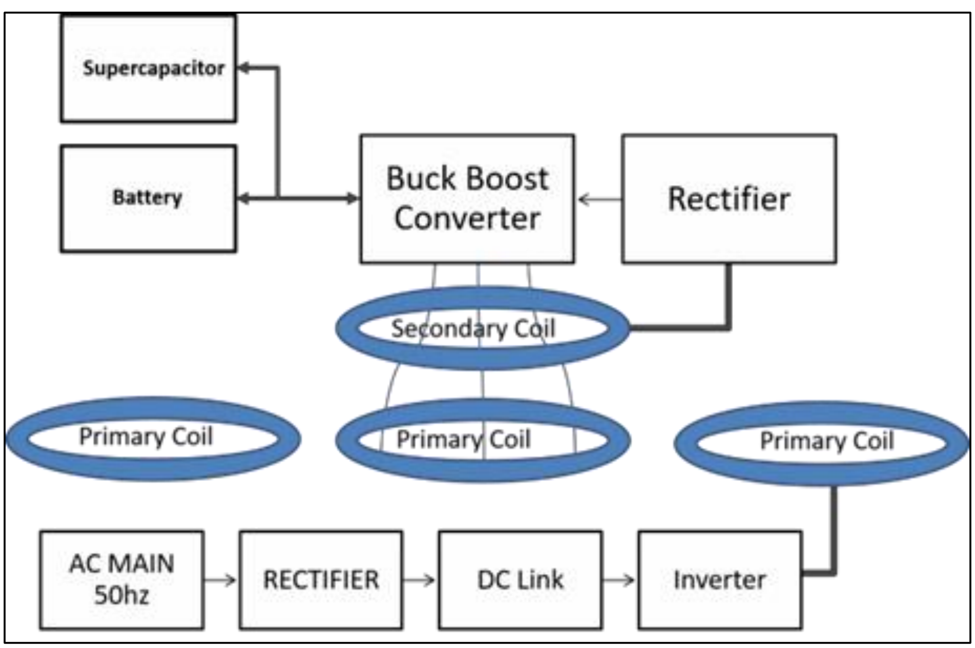

Fig. 3: Block diagram of Dynamic Wireless Power Transfer from Transmitting to receiving pads

The block diagram gives the components necessary to build the circuit. The primary side circuit is reduced to an oscillatory circuit with the help of H-Bridge. The oscillator circuit in the transmitter produces high frequency magnetic field of frequency 160 kHz. This at resonant frequency enables receiver coil to transfer maximum power transfer due to induction. The receiver coil consists of a full – bridge rectifier whose power output is fed to the battery and capacitors for charging.

The following factors are considered while designing hardware. For short ranged WPT, two coil system can be employed. Air gap distance of about- 100mm to 300 mm is generally needed. Size of coil should be larger than transmission distance. Low reluctance path and magnetic shielding are provided by ferrite bars or plates. Coils used for DWPT are mainly of two types but they differ in terms of primary coil design-one uses single coil and the other segmented coil design. Single coil design generates redundant emf with low efficiency. A design with cross segmented power supply with two pairs of power cable and I-type ferrites solve this issue.

The following procedure was required to design the coil.

- For single coil transmitter, the tendency of a high frequency AC to flow through only the outer layer of a conductor is called skin effect. This increases the resistance of the conductor, increasing the power loss.
- In order to reduce this effect, coil diameter of about 0.09mm is selected.
- To lower the Loss factor, $\lambda = \frac{P_{loss}}{P_{out}}$, the product of Q

and K is kept higher as is seen from the curve. Q is

Dependent on the positioning of the coils to one another which will always be lower due to air coupling. K is kept higher to compensate for the losses.

- Coil quality $Q=\frac{XL}{R}$

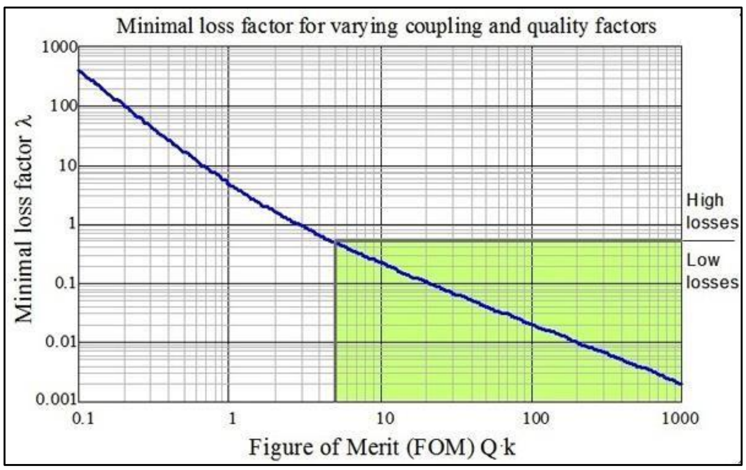

Fig. 4: Relation between loss factor and Figure of Merit

- To increase inductive reactance,
  XL = Lω = L x 2πf L and f have to be increased.
- In order to improve L, we could increase the length of the conductor but in turn would increase the resistance.
- So ferrite plate is used below the coil to focus magnetic fields and to reduce unnecessary emission

Design the transmitter and the receiver circuit are as follows.

- Now after determining the inductance, resonant frequency of the LC circuit is calculated.
- L=6.3 μH and C= 157nF

Given by the formula:

$$F = \frac{1}{2\pi\sqrt{LC}}$$

We get F=160 kHz

- Thus, a 157nF capacitor is connected in series with the transmitter.
- Another 157nF capacitor is connected in parallel with the receiver coil.
- To increase the current in the transmitter, an H- bridge with the help of MOSFETs is built, in order to apply alternating voltage to the loads.
- This produces sinusoidal current due to its oscillatory properties.
- Firstly a 555 timer IC with a duty cycle of 50% and variable frequency according to the position of a trimmer.

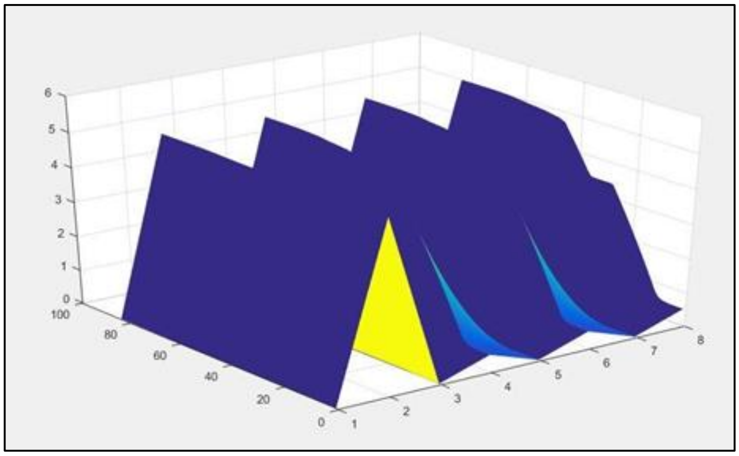

Fig. 6: Theoretically measured Voltage in the secondary coil using Simulink

- That signal will then connect to the high end pin of the first driver and the low end pin of the second.
- Thus turns on and off two diagonal MOSFETs simultaneously.
- Inverter IC will invert the signal and provides it for the low end of the first driver and the high end of the second driver in order to control the other two MOSFETs.
- The AC voltage thus created, produces a sinusoidal current in the transmitter to induce oscillating magnetic field around it.
- The receiver side coil consists of 7 turns and when it is placed in the above magnetic field, current is induced at a frequency equal to the resonant frequency of the transmitter coil.
- This induced current is converted to dc using full bridge rectifier and regulated to 5 V DC to charge the battery and the capacitors using a buck converter.

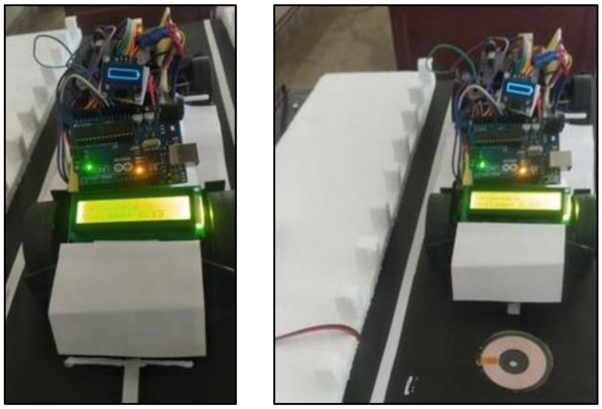

Fig. 5: Finished prototype

VI. RESULT

After the implementation of the prototype, the secondary voltage induced was found in the range from 4.3V to 4.8V for an input voltage of 5V applied in the primary coil with a resonant frequency of 160 khz at an airgap distance of about 1 cm. Therefore, static wireless power transfer was successfully done.

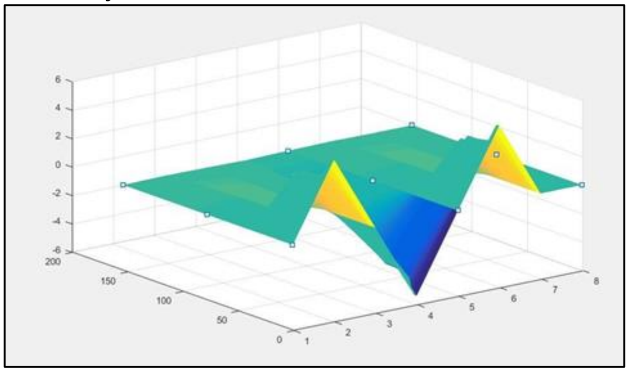

Fig.7: Theoretically measured Current in secondary coil using Simulink

VII. CONCLUSION

This paper contains a review about emerging wireless charging technologies and its application in the field of Electric vehicle. A literature survey of the technologies incorporated in the WPT was done. The existing technologies of conductive and inductive charging were reviewed. The WPT is important for the advancements of autonomous vehicle in the near future. It is found that many competitors in the EV market is largely fragmented and the vast majority of the players functioning in the global Wireless EV Charging market like Bosch GmbH, Continental, Toyota Motor Corporation, Toshiba, WiTricity, Qualcomm and Evatran Group are taking steps to raise their market footprint.

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