Chapter 1: Introduction

Due to the paucity of petroleum supplies, electric vehicles (EVs) are now increasingly employed as an alternative to traditional transportation systems. Over the past 20 years, numerous researches have been conducted to develop effective EV charging techniques [1]-[3]. A cursory examination of few wireless charging technologies produced revealed that ICPT is a viable and practical alternative for EV wireless charging. This study includes comparable circuit analysis and ICPT system features, as well as the development of research into charging coil designs, leakage inductance compensation configurations, power level enhancing, and misalignment toleration. The deployment of EV charging has depended heavily on improvement of these characteristics [4]-[5].

1.1 Historical Background of Wireless Power Transfer (WPT):

The phrase "Wireless Power Transfer" (WPT) refers to a number of power transmission methods. This method helps to reduce hazardous waste produced by disposal of the 6 billion batteries used annually in battery-operated electronic equipment, as well as situations where linking cable is not feasible (such as charging cardiac pacemakers, laptops, mobile devices and toys). Significant research is required to advance wireless power transfer technologies.

A linked magnetic resonance power transmission system called "Witricity," as seen in Figure 1.1, was introduced in 2007 by a physics research team at the Massachusetts Institute of Technology (MIT) under the direction of Professor Marin Soljacic. They conducted experiments to show effective nonradioactive power transmission at distances up to 8 times the coil radius. Over distances greater than 2 meters, this technology was able to transmit 60 watts with 40% efficiency [4].

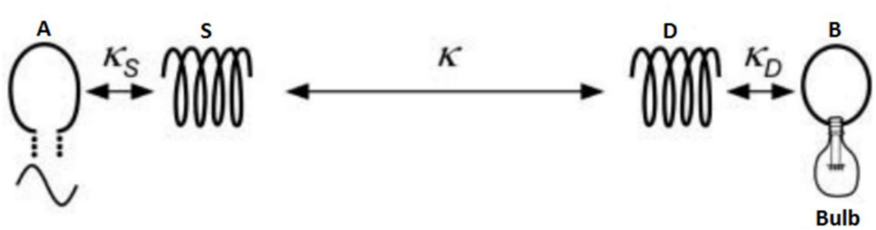

Figure 1-1 Schematic of experimental set-up [4].

The drive circuit's single copper loop with a radius of 25 cm, designated A, produces a sine wave with a frequency of 9.9 MHz. The supply and device coils mentioned in the text are designated as S and D, respectively. B is a wire loop that is connected to the resistive lamp load.

The numerous 'S' shows direct connections between the things the arrows point to. To guarantee that the direct connection between coil D and loop A is zero, the angle between them is changed. The coils S and D are coaxially aligned. Negligible direct connections exist between B and A, B and S [4]. Scientists from all around the world are now interested in wireless power transfer technology as a result of the appearance of this discovery. The MIT group experiment was replicated in 2008 by Intel, who was able to wirelessly power a light bulb at 75% efficiency albeit at a shorter distance.

The WPT techniques are split into near-field region and far-field depending on the distance, as depicted in section 1.2. Near field approaches are used to transmit energy over small distances, whereas far field strategies are used to transmit energy over greater distances.

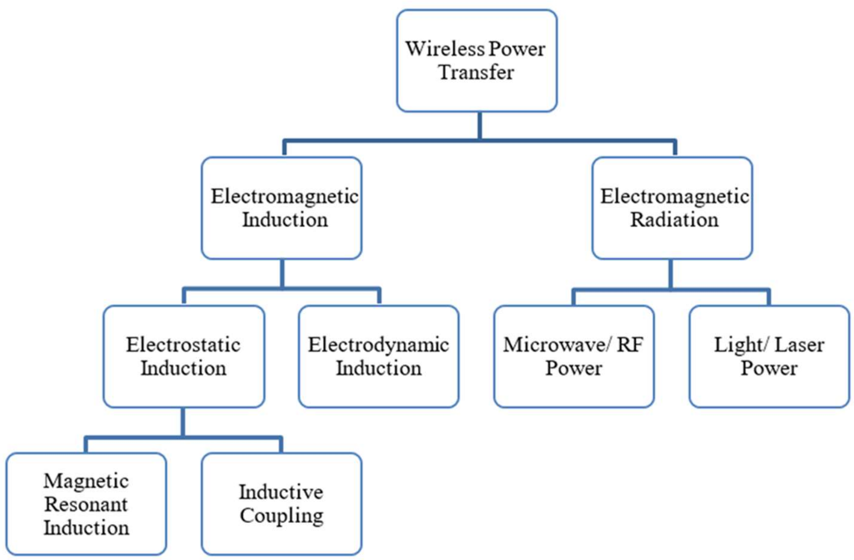

Figure 1-2 Classification of WPT techniques

The idea of wireless vehicle charging has attracted more attention than stationary wired charging technique [6][8][14]. Parking lots with wireless charging stations might guarantee that your vehicle gets charged up to its time to leave the place [13]. Wireless charging facilities can be found on the conventional road network might even be positioned at crossroads or over longer stretches of highway, increasing the range of electric vehicles [16]-[18]. Other applications may be benefited from improvements in wireless energy transfer, such as the continual use of electric vehicles in a warehouse attributable to the installation of wireless charging tracks in the floor [15]-[16]. The achievement of wireless energy transfer systems with simultaneous high efficiency and high-power transfer over a range of airborne distances has, however, proven challenging.

1.2 Classification of Wireless Power Transfer Systems:

There are numerous varieties of wireless power transfer systems, depending on a number of factors. As you move closer to the radiating source, the EM fields take on a different form, which also affects wireless. They can be grouped into:

- Near field
- Mid field
- Far field

The boundary between the zones is limited to one wavelength in the case of near field radiation. One to two wavelengths of electromagnetic radiation make up the transition zone, which separates the two zones. The distance between the emitting source and the receiver in a far field is greater than twice the wavelength [2].

WPT	Merits	Demerits
Inductive coupling	Simple, safe, and effective with shorter distance transfer	Short drive train distance Requires precise alignment
Resonant magnetic coupling	Large transmission distance, Radiation free	Adjusting the resonance frequency for various devices is difficult.
EMI radiation	Long-distance drive train efficiency is really high.	Radiation.

Table 1-1 Merits and demerits of WPT technologies

The following categories of wireless power transmission mechanisms [11] can be made based on how the transmitter and receiver are coupled:

- Resonant Wireless Power Transfer through Electromagnetic Induction
- Resonant Capacitive Power Transfer (Electrostatic Induction)
- Laser and microwave power transfer methods (far field transfer)

Microwave beam forming, one of the far-field technique approach, has recently been applied to EVs and PHEVs. A model with an 80% RF-DC conversion efficiency that employs a roadside transmitter to fuel the EV was put forth [13]. For the past 15 years, this approach has been becoming more popular in lower power appliances such as charging portable gadgets. Because the electromagnetic fields produced in far-field techniques are greater than those involved in near-field techniques, near-field transmission is safer for people to employ. [14]-[16].

In order to account for this, the design of such a system model uses the near field transmission-related inductive power transfer (IPT) approach in WPT. Although near-field solutions have limitations in terms of transmission range, lower data rates, and sensitivity to transmitter and receiver location, all of these factors may not have an impact on performance for current applications that only require lower data transfer for short distances. Several researchers have suggested that these technologies can also aid in security. [17].

WPT is now used in many mobile devices, electric vehicles, and home appliances due to its benefits [18]. It's also employed in photovoltaic satellites and defence systems.

1.2.1 Inductive power transfer:

In the current practical applications of near field transmission, there are two primary techniques that can be focused exclusively on coupling involved within them. These coupling methodologies are outlined below.

- Inductive Coupling
- Capacitive coupling.

Inductive coupling is a near-field method that uses magnetic fields to transmit energy between two coils. For transmission via sender to receiver, both coils would be arranged near each other. To transmit energy between two coils without the use of a physical medium, the mutual induction criteria are used. When current is passed via the primary coil, a magnetic field is generated over a short distance. When the receiver coil comes into contact with this field, voltage is induced in it. Such an induced voltage has the potential to power a wireless device or maybe even a storage system. The magnetic field is used to transfer electrical power through one coil to another. Inductive coupling transfers energy between coils due to mutual induction. Figure 1-1 depicts a high-level overview of inductive coupling. A transformer is an excellent example of how mutual induction works because there is no physical connection between primary and secondary coils.

Since inductive power transfer can maintain higher efficiency, it is employed in a variety of near field applications where it can manage a myriad of power loads without significant issues and with greater efficiency [14]. The distance between the transmitter and receiver as well as their mutual position affect the accuracy of the transfer. However, this method is only effective over short distances. The power transmission will indeed be reduced if the space between coils is widened or if secondary coil is positioned independently of primary coil. Inductive coupling is still being developed for use in power transmission over larger distances [13].

There are many significant advantages of employing the IPT approach in this system:

- Environmentally Friendly: Because IPT includes two individually enclosed sections, it can operate in severe situations. The effects of dirt, dust, or chemicals are minimal. It doesn't produce any carbon leftovers of any kind that could affect the environment. One concern about the magnetic influence on people was brought up in IPT. However, other studies conducted at the University of Auckland's medical school demonstrate that there are no detectable adverse biological consequences at low frequencies [15]. Unlike radio frequencies, these low frequencies typically lack the necessary power density to warm human body cells.
- Robustness and Reliability: Since there is no direct friction in these systems, there isn't electrical deterioration or wear and tear. These components of electrical systems are fully shut off, which prevents any form of chemical weathering in the conductor portions. As a result, less maintenance is needed.

1.3 WPT for Electric Vehicle:

The Paris Declaration on Electro Mobility and Climate Change and Call to Action established a global rollout target of 100 million battery-electric automobiles and 400 million battery-powered vehicles by 2030 [5] in order to achieve the goals of the Paris Agreement. By the end of 2025, just 2.26 million electric vehicles with batteries (BEVs) as well as plug-in hybrid electric vehicles (PHEVs) are expected to be in use worldwide, or around 8% of all vehicles [6]. Customers consider a number of factors to be key barriers to EV adoption, including a short driving range, prolonged charging times, a dearth of adequate charging infrastructure, and a somewhat expensive purchasing price in comparison to conventional automobiles with internal combustion engines (ICEVs) [7].

However, despite the fact that many of them have introduced preferential purchasing policies to promote EVs, governments are nonetheless concerned about the possible rise in power consumption with carbon emissions brought on by EV charging, particularly during periods of high demand. Wireless power transfer solutions for EV charging appear to hold the most promise for overcoming these limitations.

WPT technology presents a compelling replacement to cabled charging and has the potential to transform global transportation and boost EV market growth. Research and development of EV technologies have increased as a result of the demand for a sustainable mode of transportation brought upon by the fossil fuel depletion and the sharp increase in carbon emissions that severely pollute our environment.

The range of standard EVs is a well-known hurdle for clients who have yet to completely embrace eco-friendly motorization. Additionally, shortcomings including bulky and bulky batteries, high costs, and protracted charging periods are problems that present battery technology is unable to readily address. A more user-friendly charging technique makes financial sense since EVs are progressively becoming a more popular choice among car owners, thanks in part to government tax breaks and bonuses. WPT is a handy replacement for a wired charging system since vehicle simply needs to park vehicle over a TX unit buried under ground, and the charging process is initiated by the RX unit mounted on the chassis. A more user-friendly charging method makes financial sense since EVs are gradually becoming an increasingly popular among owners, notably with government incentives and benefits. WPT provides a convenient substitute for a wired charging system since the driver only needs to park their car over a TX coil buried under ground, and RX coil installed on the chassis starts the charging process.

One of the major issues that would be resolved by wireless EV charging is the annoyance of having to get out of the automobile to connect to a charging station.

The following are some of the advantages of wireless EV charging [8]:

- By removing galvanic connectivity between charging facility and electric vehicle, the charging method is simplified, and any potential safety concerns with the functioning of the electrical apparatus are eliminated.
- For charging EVs used for public transit, a completely automated power transfer that does not require moving mechanical parts is especially attractive because it

permits a charging of electric vehicle to be habituated with everyday driving via 'opportunity charging' at stations, taxi stands, or cross roads along the route.

- A galvanic connection frees the charging station from movable mechanical parts, reducing the amount of maintenance required.

Static and dynamic charging WPT are two intriguing areas in WPT for EV applications. In the static case, an altered parking lot or garage might be used to charge the EV. A dynamic WPT scheme comprises several embedded coils in the road to continually charge the EV in a designated charging lane [9]. This facilitates charging and may lead to smaller batteries, which would allow for 20% less necessary capacity and quicker charging periods [10] [11]. WPT technology has the disadvantage of lower pickup power and transfer efficiency as opposed to conductive power transmission [12]. It is caused by a number of factors, and much recent research has focused on ways to improve EV wireless charging systems. Load-balancing management approach has been suggested by Theodoropoulos et al. for higher efficiency of wireless charging. In order to maximise efficiency, some research has studied various types of main supply topologies used for EV inductive charging [14]. Some researchers developed new materials, such as Y. D. Chung et al., who created a high-temperature superconducting resonating coil to improve power transfer efficiency. Design and placement of the coil structure can also have an impact on the PTE of EV wireless charging [16].

Toyota [37] has created a smart parking assist system that employs navigation systems and self - parking to correct coil misalignment and auto-pilot the car towards its charging bay with more precision. However, a significant disadvantage is the requirement for additional fine-tuning circuitry to achieve millimetre accurate alignment between coils as once automobile is stopped. A recent patent proposes a light-activated mechanical system that uses a series of photoelectric detectors, an electric servo control system, or an 3D machine driver to position the coils. Because of the complexity and likely wear of moving components, this is less attractive and less inexpensive in mass production. Many corporates are targeting on these technologies, including the Evatran Wireless Charging Outlet, the Volvo Wireless Charger for Electric Mobility, and the Delphi Wireless Charger System. Evatran has invented a new method of charging electric vehicles (EVs) using 'electric juice,' which is a shoebox-sized adapter called Plug-less Power, which is a novel wireless charging system for electric vehicles that employs induction charging principle.

A plug less charging system comprises charging coil pads where the automobile must be parked. A control tower monitors the system's operation and the charging of your car. A 10-

pound adaptor affixed to the vehicle's undercarriage is the only alteration necessary in the vehicle to charge this method. There is no true power transfer between the coil pads and the adapter; rather, an electromagnetic field created by the magnetic coil positioned here between the adapter and the parking pad stimulates charge in the batteries. A normal plug-in system may also be used to charge the EV [40]. Figure 1-3 shows timeline of electric vehicles and its past, present and future.

1.4 History of Electric Vehicles:

Electric cars are those whose propulsion comes from electric motors rather than internal combustion engines. They can be powered by electricity produced by fuel cells or batteries. Since its invention in the 19th century, electric cars have had a long and fascinating history and seen in the Figure 1-3. Here are some significant moments in the development of electric vehicles:

The Hungarian physicist and clergyman Nyos Jedlik constructed the first electric motor in 1828 and used it to power a miniature model car. The first electric locomotive was created by Scottish scientist Robert Davidson in 1837 and ran on galvanic cells (batteries). With an electric vehicle known as La Jamais Contente, Belgian Camille Jenatzy established the global land speed record in 1899 at 105.88 km/h (65.79 mph).

Electric vehicles gained popularity in the United States in the early 20th century, particularly among urban dwellers because they were quiet, simple to use, and did not generate offensive pollutants. Henry Ford created the mass-produced Model T in 1908, which greatly increased the availability and affordability of gasoline-powered vehicles. As a result of the electric starter's invention in 1912, petrol automobiles no longer required manual cranking.

Due to the discovery of cheap oil, the development of internal combustion engines, and the growth of road networks, electric vehicle sales fell in the 1920s and 1930s.In order to lessen air pollution and reliance on oil, Congress created the Electric Vehicle Development Act in 1966, allowing for the study and development of electric vehicles.

The Prius, the first mass-produced hybrid electric vehicle in the world, was introduced by Toyota in 1997. Its petrol engine and electric motor were integrated to increase fuel economy and lower pollution. Tesla Motors launched the Roadster, a powerful sports automobile that only used electricity, in 2006. It could accelerate from 0 to 100 km/h (0 to 60 mph) in less than four seconds and had a range of more than 300 km (200 miles).

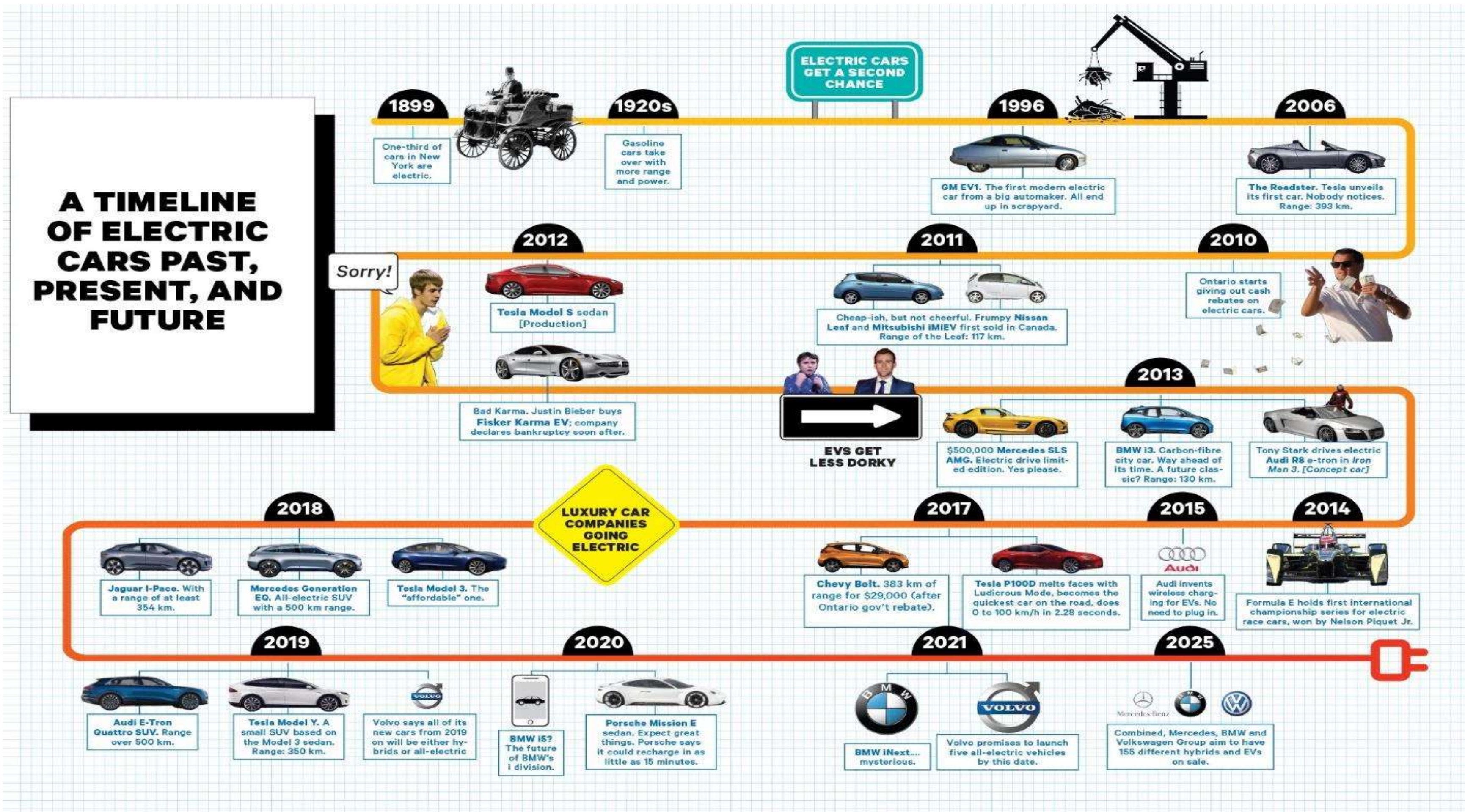

Figure 1-3 History of electric vehicle

Nissan unveiled the Leaf, the first mass-market all-electric vehicle, in 2010. It could be recharged at home or at public charging stations and had a range of roughly 160 kilometres (100 miles). Tesla introduced the Model S in 2015, a high-end car with a range of more than 500 kilometres (300 miles) and the ability to utilise a network of superchargers to recharge quickly.

More than 10 million plug-in electric vehicles were sold globally in 2020, making up nearly 4% of all vehicle sales. Future electric vehicle use is anticipated to increase along with their cost, efficiency, and availability.

1.5 Objective of Research:

The objective of present research is to contribute in the advancement of wireless power transfer technology for HEVs:

- To design low power WPT system for hybrid electric vehicle.
- To develop laboratory prototype for WPT system for HEV.
- To design power pads for low power and high efficient power transfer for HEV.
- To analyze and investigate results obtained using proposed system.

1.6 Research Contribution:

The goal of the work is to develop a hardware prototype of induction charging for the storage system of HEV. Design and analysis have been done using ANSYS Electronics Desktop and ANSYS Twin Builder.

- As per findings from simulation and prototype results, circular and square types of coils are most suited for power pads for stationery low power WPT.
- It has also been proved in case of circular coils that, when misalignment is less than the radius of the coil, more is the efficient WPT system.
- The SS topology has shown the ability to attain high levels of wireless power transfer efficiency. Resonant circuits are used to reduce losses of electricity during power transfer, rendering them a desirable option for HEVs.

1.7 Thesis Organization:

Chapter 1: Introduction:

General background of electric vehicles and wireless charging, classification of wireless power transfer, inductive power transfer, objective of thesis, original contribution of thesis and thesis organization.

Chapter 2: Literature review:

In this chapter, a brief overview of the design of square and circular coil design presented and derived physical parameters.

Chapter 3: Analytical Design of Circular and Square Coil:

In this chapter analytical study using ANSYS Electronics Desktop and ANSYS Twin Builder has been done. Simulation results have been obtained and many types of plots are presented.

Chapter 4: Simulation:

This chapter presents comparative assessment of the simulation results (circular and square) topology of the coils and suggests suitable for the application.

Chapter 5: System Model (Software and Hardware):

This chapter provides a detailed description of the experimental set-up of hardware.

Chapter 6: Result and discussion:

This chapter provides detailed discussion of the simulation and hardware prototype results and discussions related to it.

Chapter 7: Conclusion and future work:

It provides discussion of the results, conclusions, and scope of future work.

Appendices:

This chapter includes appendix A to F and all are related to circuit diagrams that are used for hardware prototype implementation and code for control signal generation.

Publications:

This chapter includes list of publications arisen from this research work.

Thesis ends with references.