SOLAR WIRELESS EV CHARGING SYSTEM

Punjab Engineering College (Deemed to be University)

Department of Electrical Engineering

Major Project, VIIIth Semester

Group 11

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Firstly, we would like to thank our mentor Dr. Tejinder Singh Saggu for guiding us throughout the process of completion of this Major Project and Report, and giving us necessary insights to complete this project.

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Our Sincere thanks to our peers for helping us with even the most minute technicalities related to the project.

This Project helped us expand our horizons in understanding the potential of a user-friendly platform for consumers to create an economic bidding process. We realize the fact that local energy markets can be effective tools to reach energy balance. Increasing retail electricity prices may motivate many local communities to have a local energy exchange for small-scale prosumers.

Punjab Engineering College

(Department of Electrical Engineering)

DECLARATION

We hereby declare that our project work entitled "**Solar Wireless EV Charging System**" is an authentic record of our own work as a requirement of this Major Project under the able guidance of Prof. Tejinder Singh Saggu.

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Approval by Mentor

Certified that the above statement made by the student is correct to the best of our knowledge and belief.

_____________________________(12th May 2023)

Prof. Tejinder Singh Saggu

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1. INTRODUCTION

Consider a future without ever needing to stop to recharge the battery of a personal car, taxi, truck or bus. Instead, power generated by nearby wind and solar resources is delivered wirelessly from the roadway to the vehicle while it is in motion.
Various applications could use the technology and benefit the transition to zero-emission mobility. For example, trucks or buses can top up their battery during their long-distance work cycles instead of driving to a specific charge station site. It also helps the power network by charging vehicles at moments during their journeys, instead of plugging in at peak power demand moments such as in the early evening when people come home from work.

Let us move passengers and not batteries

Not having to stop for recharging will make EVs genuinely autonomous because the vehicles can remain in service for many hours. Maybe the best part is that EVs with a dynamic wireless charging system can have much smaller batteries. Thus, this solution reduces the environmental impact, cost and therefore accelerates the adoption of electric vehicles.

Figure 1.1 Future overtake of this technology

1.1 Need

Electric vehicles have now hit the road worldwide and are slowly growing in numbers. They have their own advantages such as environmental benefits, reducing cost of travel but electric vehicles have 2 major disadvantages:

- Long charging time – 1-3 hours required for charging.
- Non availability of power for charging stations in off city and remote areas.
- Also, to mention the electric vehicle's range anxiety that occupies the owner's face.

Well, here we develop an EV charging system that solves both these problems with a unique innovative solution. This EV charging system will be integrated in the road and delivers following benefits:

- Wireless charging of vehicles without any wires
- No need to stop for charging, vehicle charges while moving
- Solar power for keeping the charging system going
- No external power supply needed
- Coils integrated in road to avoid wear and tear.
- As a long-time perspective, removing the EV batteries or at least of reducing their capacity is also a goal. This will ultimately reduce the cost of on-board batteries.

The system will make use of a solar power station, transmitting coil array, embedded systems, and an electric vehicle to develop the system.

1.2 Statistics

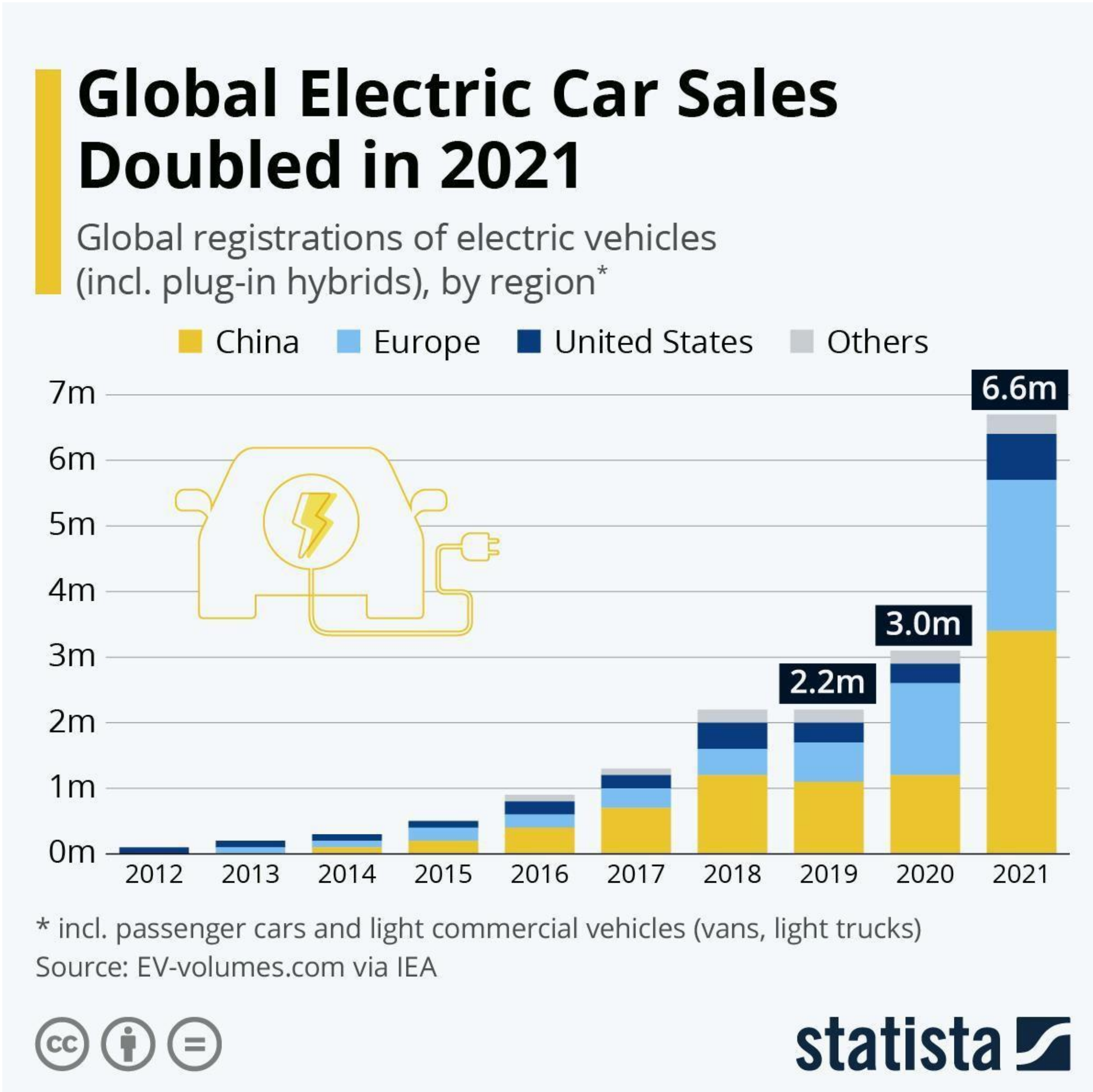


Figure 1.1 Global EV Sales

While 2021 was another difficult year for the car industry, heavily affected by the global chip shortage, global electric car sales more than doubled over the past twelve months, reaching 6.6 million, compared to just 3 million in 2020. That's according to preliminary EV-volumes data cited by the International Energy Agency (IEA), which reports that all net growth in global car sales in 2021 can be attributed to electric vehicles.

1.3 Market Size

Figure 1.2 Global Market

According to a report by BloombergNEF, the global EV market size was estimated at around 3 million units in 2020. The same report forecasts that global EV sales will increase to over 60 million units by 2040.

- The global wireless EV charging market was valued at $118.5 million in 2020.
- The market is expected to grow at a compound annual growth rate (CAGR*) of 50.2% during the forecast period.
- The market is projected to reach $3.07 billion by 2027. This market size includes both static and dynamic wireless charging systems.
- The specific market size for dynamic wireless charging systems may be smaller.
- The growth in the market is attributed to the increasing adoption of electric vehicles around the world.

1.4 Market Validation

1.4.1 Analysis

- Firstly, the sales of electric vehicles (EVs) are on the rise globally, and this trend is expected to continue in the coming years. However, one of the main challenges for EV owners is the inconvenience and limitations of traditional plug-in charging systems, such as long charging times and limited availability of charging stations. This can be particularly problematic for those who rely on their EVs for daily commutes or for fleet operators who need to keep their vehicles operational.
- Secondly, the current technology of charging is limited by the need for physical connections between the EV and the charging station. This requires the driver to manually plug in their EV, which can be time-consuming and inconvenient. Furthermore, the availability and capacity of charging stations can also be limited, especially in high-density areas where many EVs may be competing for the same charging resources.

1.4.2 Synthesis

- A dynamic wireless EV charging system can address these challenges by providing a more convenient, efficient, and seamless way to charge EVs. Instead of requiring a physical connection, dynamic wireless charging systems use wireless charging technology to transfer power from the charging infrastructure to the EV's battery while it is in motion. This means that EVs can charge while they are on the road or parked without the need for manual intervention, which can save time and reduce the need for large numbers of charging stations.
- Moreover, the dynamic wireless charging system can also help to address range anxiety, which is a common concern for many EV owners. By providing a continuous source of power, EV drivers can have more confidence in their vehicle's range and may be more likely to adopt EV technology.

In summary, the need for a dynamic wireless EV charging system arises from the limitations of current charging technologies and the growing demand for more convenient and efficient EV charging solutions as EV sales continue to increase.

2. PROJECT IDEA

2.1 Basic Idea

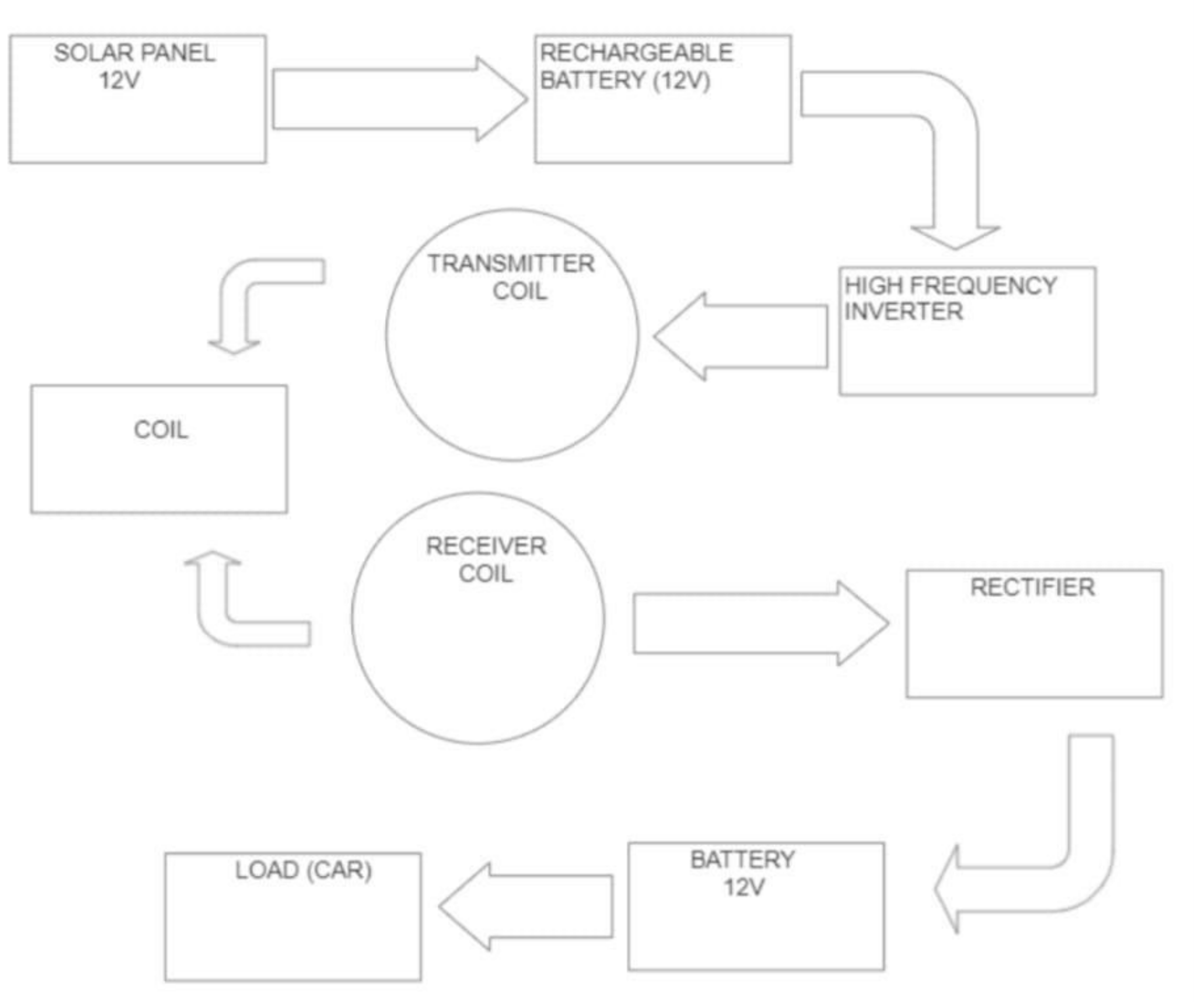


Figure 2.1 basic block diagram

1. The system makes use of a solar panel, battery, high frequency inverter, transformer, copper coils, AC to DC converter, and LCD display to develop the system.
2. The system demonstrates how electric vehicles can be charged while moving on the road, eliminating the need to stop for charging.
3. The solar panel is used to power the battery. The battery is charged and stores dc power.

4. The DC power now needs to be converted to AC for transmission. For this purpose, we here use an inverter.
5. This power is now used to power the copper coils that are used for wireless energy transmission.
6. A copper coil is also mounted underneath the electric vehicle. When the vehicle is driven over the coil's energy is transmitted from the transmitter coil to EV coil.
7. Please note the energy is still DC current that is induced into this coil. Now we convert this to DC again so that it can be used to charge the EV battery.
8. We use AC to DC conversion circuitry to convert it back to DC current.
9. Now we also measure the input voltage using a microcontroller and display this on an LCD display.

Thus, the system demonstrates a solar powered wireless charging system for electric vehicles that can be integrated in the road.

3. OBJECTIVES

- **Demonstration**
  - To show a small-scale demonstration of Wireless Charging of EV.

- **Reducing Heavy battery usage**
  - Reduction in battery weight since there is going to be a minimal discharge during traveling.

- **Reducing Delay due to charging time**
  - There is no delay as a result of the EV stopping to charge because charging happens while the EV is moving.

- **Making wireless charging reliable and accessible**
  - Since road infrastructure of India is still in the development stage, this technology merged with road infrastructure development projects can make wireless EV charging more accessible and reliable.

4. RESEARCH AND WORKING METHODOLOGY

Three methodologies or approaches to analyze the parameters were used in this project: simulation, analytical and measurement. The first approach consists of creating models using specialized software to simulate the model and validate design and the possibility of WPT with given components we have. The second part consists of doing direct analysis on the parameters based on the theory behind each phenomenon. The last part is used to confirm the results from the first two by comparing them to the practical, real case. The tools and software used are explained in the following sections.

4.1 Simulation

Figure 4.1 MATLAB Logo

The tool used to achieve it is MATLAB. This is a well-known programming platform and language used in science and engineering. The MATLAB language is matrix-based, which simplifies implementing math heavy algorithms. For detailed information about the MATLAB platform, the reader can consult its online documentation.

4.1.1 Analyzing the effect of square wave on R-L Circuit

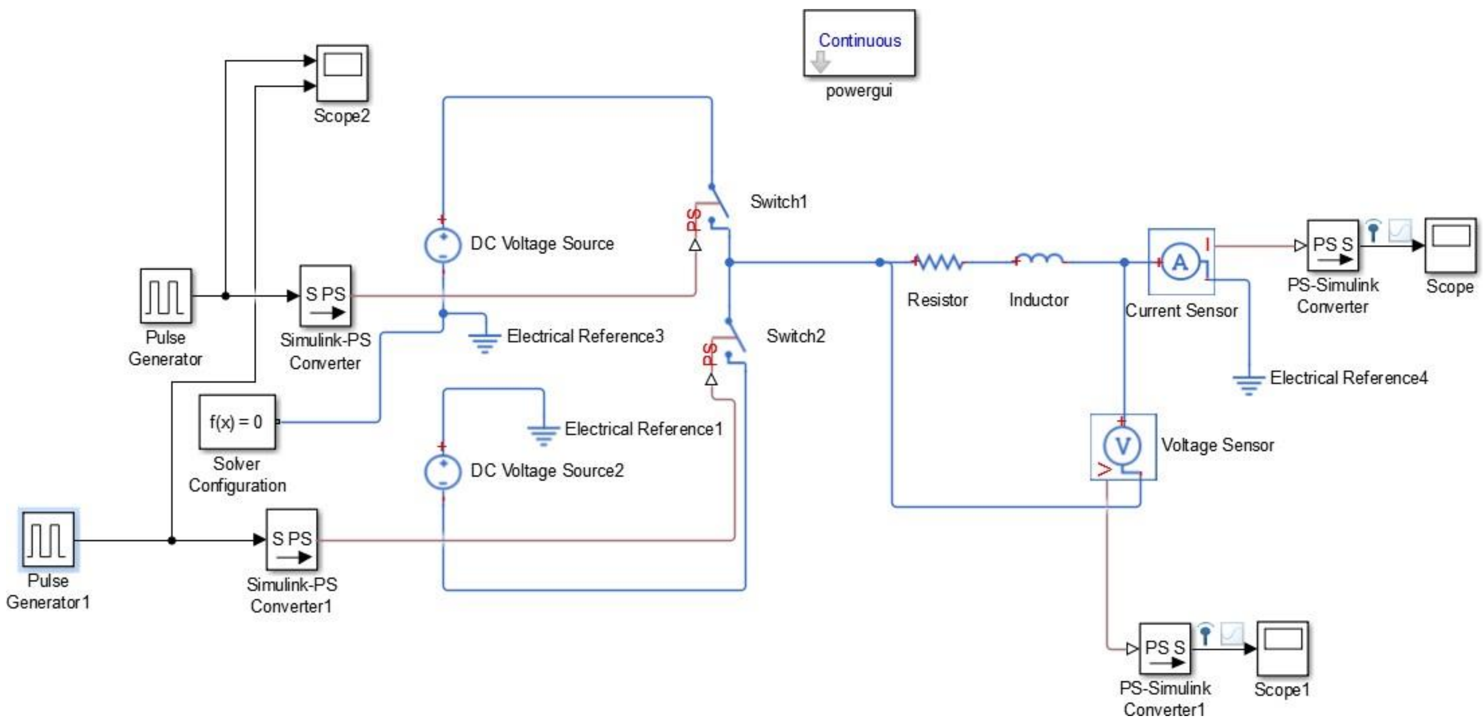


Figure 4.2 R-L Circuit with square wave input

1. Assumptions:
   a. The H-bridge inverter feeds a pure square wave at 20kHz.
   b. The coil is a R-L load.
   c. The MATLAB simulation feeds a pure square wave to a RL load at a certain frequency.
   d. The output current and voltage determines the possibility of WPT.

2. Result: The current has a:
   a. **Transient**, and
   b. **Steady state Response** (Figure 4.3)

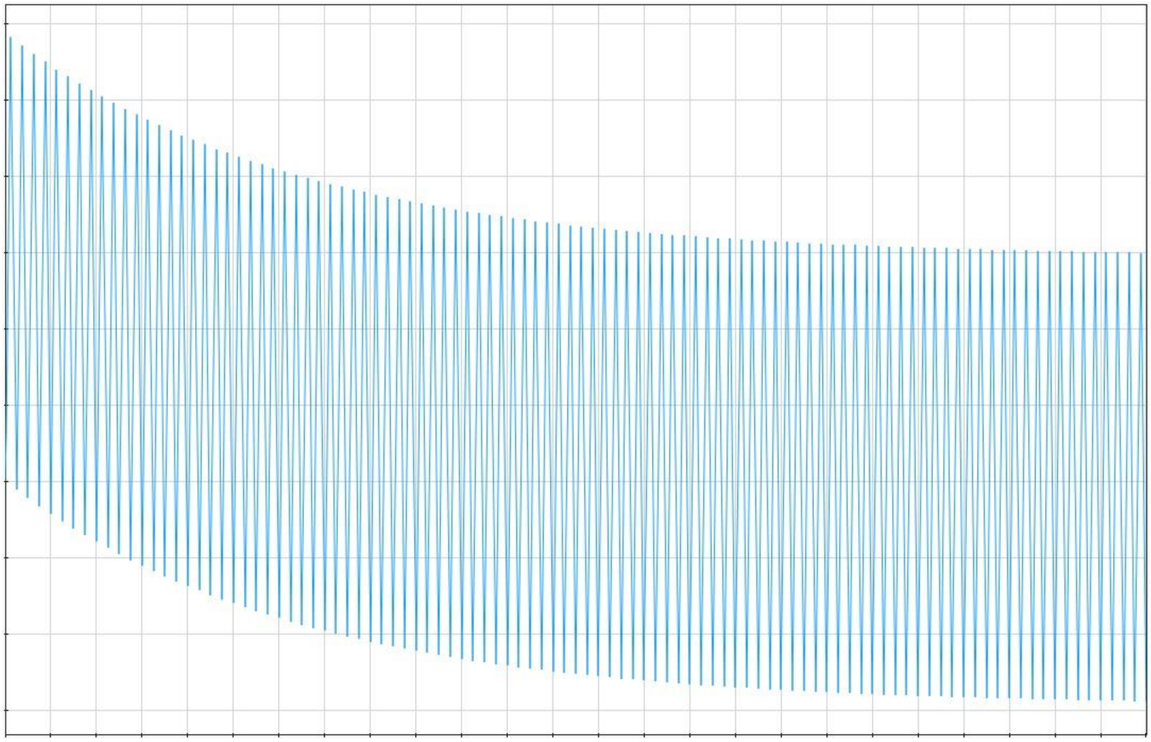


Figure 4.3 Current in Transmitter Coil

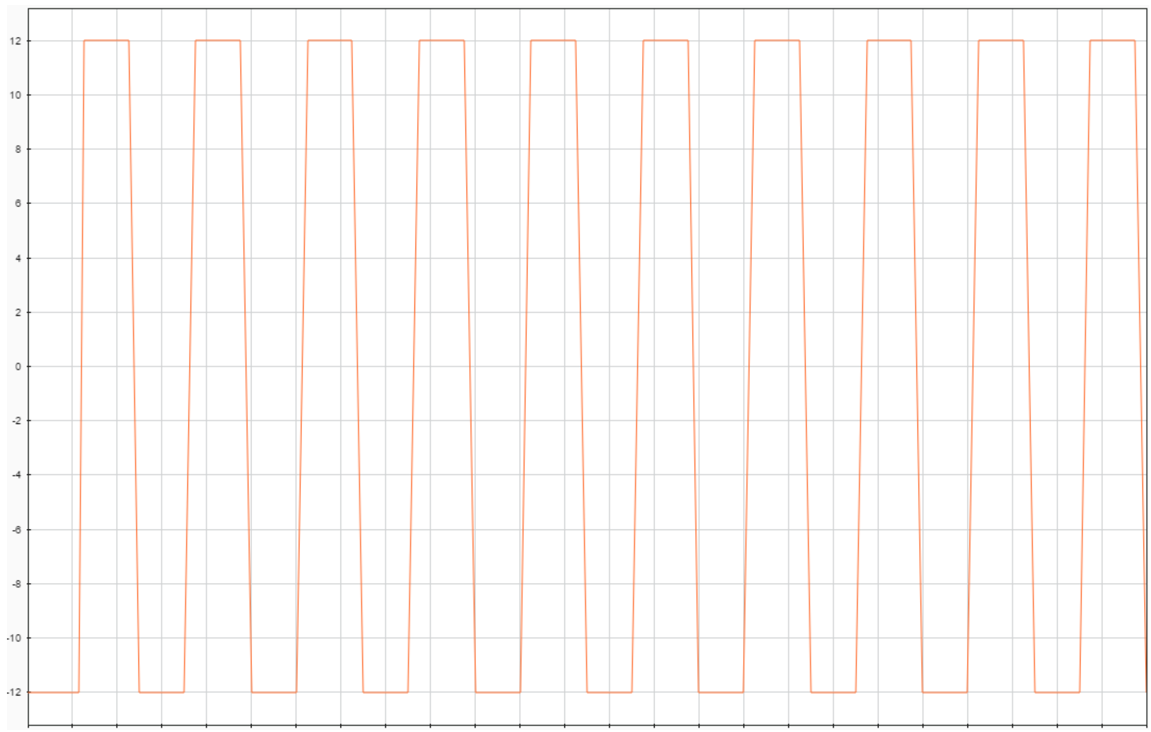


Figure 4.4 Voltage across Transmitter Coil

4.1.2 Conclusion

1. The transient state can remain in a **DC** state for a certain time depending upon the frequency of the system.
2. This DC transient state provides **no WPT** and only **induction heating**.
3. Also, the square wave output contributes to heating of the transformer installed across the inverter.
4. The voltage across coil is a **chopped triangle** wave (instead of a pure square wave) due to inherent conductance

4.1.3 Response of Varying L/R ratio

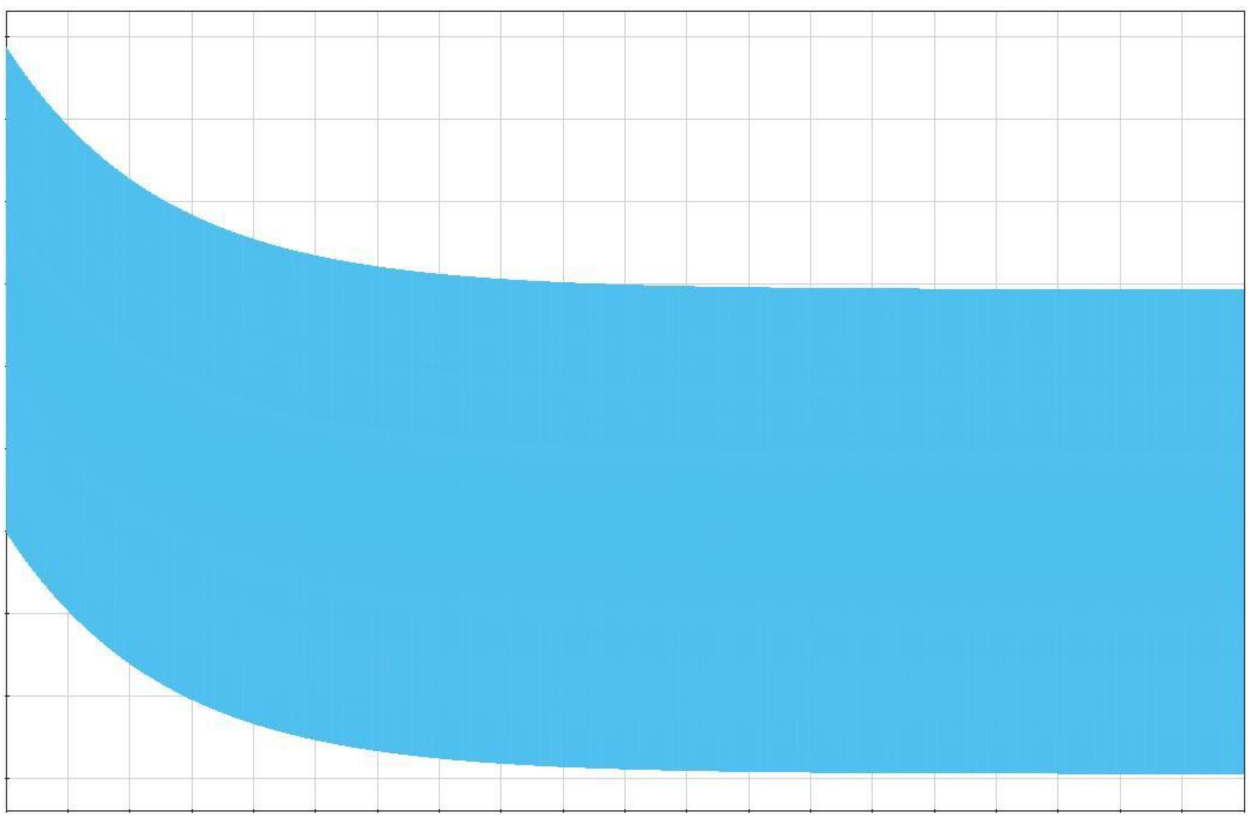


Figure 4.5 L/R = **5.1/4**

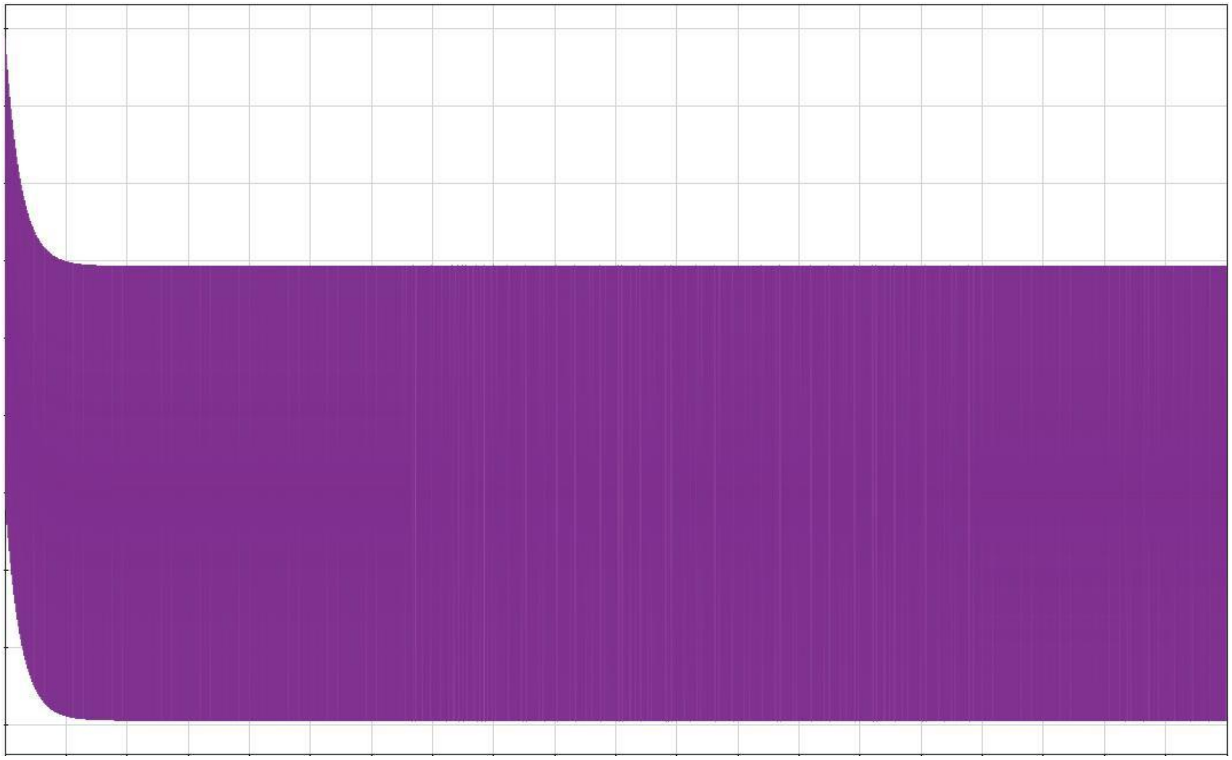


Figure 4.6 L/R = **0.51/4**

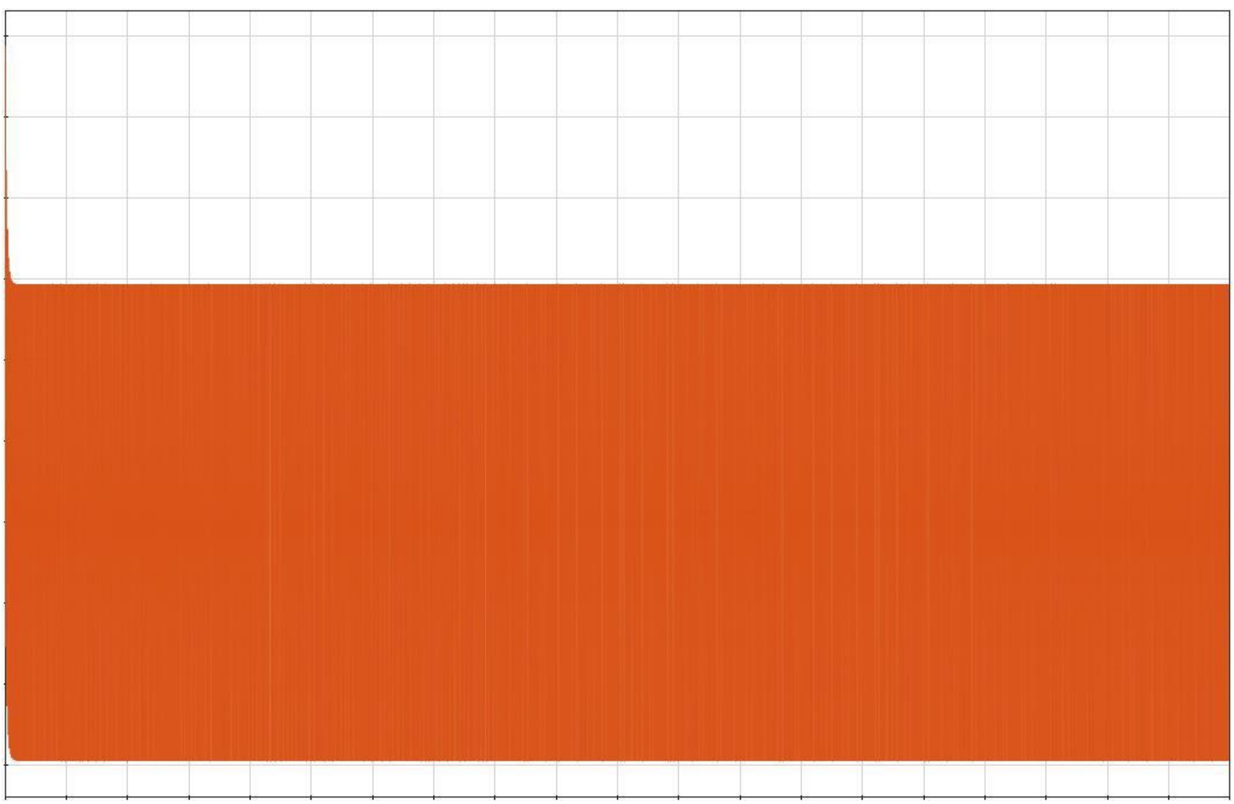


Figure 4.7 L/R = **0.051/4**

4.1.4 Interpretation

1. It can be noted that for a certain frequency, the **transient time period greatly reduces** with a **decrease** in L/R value of the transmitting coil.
2. Also, it is noted that the **RMS current increases** with an **increase** in L/R value.
3. Both RMS values and transient time period vary with **operational frequency**.

THUS, ***optimization of L/R value of coil and operational frequency*** needed.

4.1.5 DC Offset (Special note)

The effect due to the inertial property of the magnetic flux within the system inductance, which decays exponentially, is referred to as DC Offset. When a current change occurs in the primary ac system, one or more of the three-phase currents will have some dc offset…from the necessity to satisfy two conflicting requirements….

1. In a highly inductive network…, the current wave must be near maximum when the voltage wave is near zero; and
2. The actual current at the time of change is determined by prior network conditions.

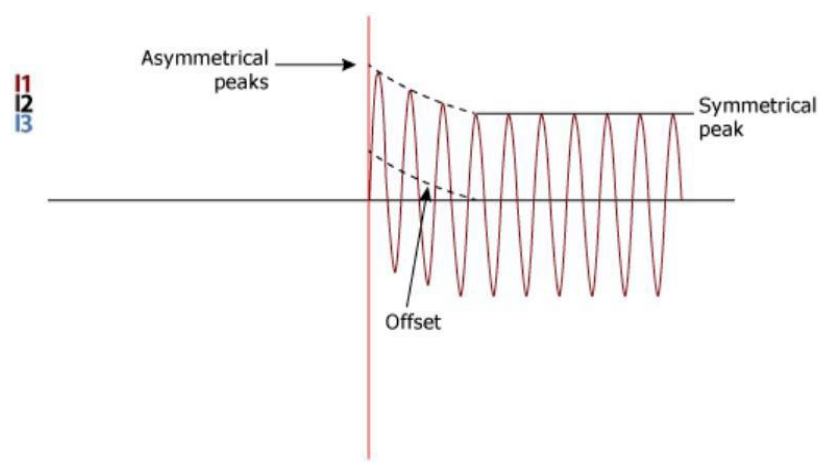


Figure 4.8 DC Offset

4.2 Analytical Approach

4.2.3 Coil Design

Wireless power transfer system consists of coupling device, made of two coils whose setup is a crucial issue in building up a WPTS. The analysis, carried out helps in the determination of the inductive parameters as a function of the coil distance, turn number, turn distance (for spiral coil only) and axial misalignment

4.2.3.1 Basics of electro magnetics

The basics of electromagnetic theory are derived from the Maxwell equations, both in time independent and time dependent cases. The four Maxwell equations are as follows:

$$\oint \vec{E} . \vec{dl} = -\frac{\overrightarrow{\partial B}}{\partial t}$$

$$\oint \vec{H} . \vec{dl} = \vec{J} + \left(-\frac{\overrightarrow{\partial D}}{\partial t}\right)$$

$$\oint \vec{D} . \overrightarrow{ds} = \rho_v$$

$$\oint \vec{B} . \overrightarrow{ds} = 0$$

The quantities $\vec{E}, \vec{H}, \vec{D}$ and $\vec{B}$ are the electric field, magnetic intensity, electric displacement and magnetic flux density respectively.

There are four laws associated with Maxwell: Faraday's law of electromagnetism, Ampere's law, the third and fourth are Gauss laws for the electric and magnetic fields. They are explained as follows:

- Faraday's Law of electromagnetism
  - The line integral of the electric field around a closed loop is equal to the negative of the rate of change of the magnetic flux density through the area enclosed by the loop.
- Ampere's Law

    - This law states that current is a source of the magnetic field, thus the magnetic field is related to the current density.
- Gauss law for electric field
    - This law states that the amount of total electric flux displacement through a given closed surface is proportional to the amount of volume charge ρv in the volume contained by that surface.
- Gauss law for magnetic field
    - This states that all magnetic field lines which enter a particular closed surface must eventually leave the surface, thus there are no magnetic monopoles or sources of magnetic charge.

4.2.3.2 Coil parameters

1. Coil Resistance:

   It is important to calculate the resistance of the primary and secondary coils in WPTS, as they represent the main limitation for the power that can be transferred. If resistances were zero, the efficiency of the transformer would be 100 %. Coil resistances generate joule effect and this heat has to remain at an acceptable level. Minimizing the Joule losses is then a crucial point while designing WPTS, in terms of efficiency and transferable power [1].

$$R = \frac{\rho l}{A_{wire}}$$

   where l is length of the coil, A_{wire} is area of the wire, ρ is resistivity of the coil

2. Coil Inductance and magnetic flux density

   An inductor is a passive two-terminal electrical component that stores energy in its magnetic field. Inductance (L) results from the magnetic field forming around a current carrying conductor and linked with it. Electric current through the conductor creates a magnetic flux proportional to the current. A change in this current creates a corresponding change in magnetic flux which, in turn, by law generates an electromotive force (EMF) in the conductor that opposes this change in current. Thus, inductors oppose changes in current through them. Inductance is a measure of the amount of electromotive force generated per unit change in current. The magnetic flux density is a field that is created by a current in a conductor. It is related to the magnetic field H through the magnetic permeability that characterizes the medium in which the conductor is situated. One of the key factors that define the performance of a WPTS is the coupling coefficient of the coils. It depends on the size and the shape of the coils and on the distance between them. In some cases, it can be analytically calculated starting from the Biot- Savart law .

$$d\vec{B} = \frac{\mu_0}{4\pi} I \frac{d\vec{l} \times \vec{r}}{r^3}$$

that gives, for any point P in the free space, the magnetic induction contribution dB generated by the current I flowing in the infinitesimal portion dl of an electric circuit at distance r from P. The magnetic induction is calculated by integrating along the full circuit. For example, in a point belonging to the axis of a circular coil formed by n turns and lying at a distance d from the center of the coil, the magnetic induction has the same direction of the axis and magnitude equal to

$$B = \frac{\mu_0}{4\pi} nI \frac{2\pi R^2}{(R^2+d^2)^{\frac{3}{2}}} = \frac{\mu_0}{2\pi} nI \frac{A}{(R^2+d^2)^{\frac{3}{2}}} \approx \frac{\mu_0}{2\pi} nI \frac{A}{d^3} (4.7)$$

where R is the radius of the coil, A is its cross-section and d is the distance between coils. The last expression of B holds when the distance from the coil is much longer than the coil radius. If the magnitude of the magnetic induction is constant across the coil cross section, the self-inductance of the coil is given by

$$L = \mu_0 N^2 R \left[ln\left(\frac{8R}{r}\right) - 2 \right]$$

where r is radius of wire

3. Mutual inductance

   It is the phenomenon in which a change of current in one coil causes an induced emf in another coil placed near to the first coil. This parameter is most dependable for design of WPT system.

4.2.3.3 Coil Type

Mainly two types of coil structures are used in WPT. They are helix and spiral coil, and hereafter, assumption is made that the transmitter and receiver coils have equal geometry, dimension, and turn number, the latter one being denoted with N.

1. **Helix coil**

   The left half of Fig. 4.9 (a) sketches the arrangement of the helix coil (wire radius is not in scale with the coil dimension). The turns are packed together in a rectangular section, having base b and height h, and their mean distance from the coil axis is Rm. The self- inductance of each coil can be formulated as

$$L_{Helix} = \frac{0.31\,(R_m N)^2}{6R_m + 9h + 10b}$$

   where N is the number of turns

2. **Spiral coil**

   The arrangement of two aligned spiral coils is shown in Fig.4.9 (b). The self-inductance of a spiral coil can be formulated as

$$L_{spi} = C_1 \mu_0 N^2 R_{avg}\left[ln\left(\frac{C_2}{\emptyset}\right) + C_3\emptyset + C_4\emptyset^2\right]$$

   where the average coil radius Ravg and the fill factor ϕ are expressed as

$$R_{avg} = \frac{(R_o + R_i)}{2};\quad \emptyset = \frac{(R_o - R_i)}{(R_o + R_i)}$$

where d, Ri and Ro are the coil distance, and the coil inner and outer radii, respectively and the coefficients Ci with i=1, 2, 3, 4 depend on the circular coil layout [2].

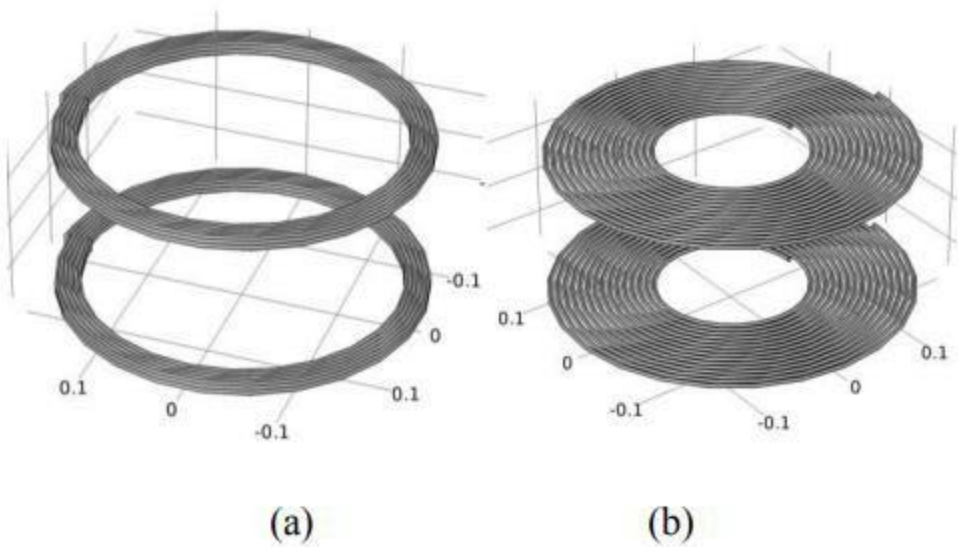


Figure 4.9 (a) helix and (b) spiral coils.

4.2.3.4 Coil coupling arrangement analysis

Further to the preliminary sizing, an accurate analysis of the helix and spiral coil arrangements is developed to compare their inductive performance.

Both helix and spiral coils have been considered and, for each of them, the inductive parameters have been calculated with the end of identifying the set of geometric data that give the better achievements in terms of coupling coefficient.

1. <u>**Helix coil-coupling**</u>

At first, coil misalignment has been set to zero and the FEM analysis has been used to investigate the impact of turn number and coil distance on the self and mutual inductances and on the coupling coefficient. Fig.4.10 shows the magnetic flux density lines of helix coil. The main outcomes of the analysis are illustrated in Figs. 4.11-
4.13. Fig. 4.11 plots the self and mutual inductances against the turn

number for different coil distances, where the turn number ranges around the value found by the preliminary sizing. Figs. 4.12 (a) and
(b) plot the coupling coefficient respectively as a function of the turn number for coil distance of 0.15 m and as a function of the coil distance for N=15. Fig. 4.13 (a) gives the magnetic flux density on the surface of a helix coil with N=15 and current of 1 A. Inspection of the figures show that: i) both the self- and mutual inductances increase about proportionally to the square of the turn number so that the coupling coefficient results marginally influenced by N, ii) the self-inductance does not vary with the two-coil distance because the structure has no magnetic core, iii) the coupling coefficient, like the mutual inductance, decreases as the coil distance increase, iv) the magnetic flux density is high only on a small portion of the coil surface since the turns are packed together and span only a negligible part of the coil radius [3].

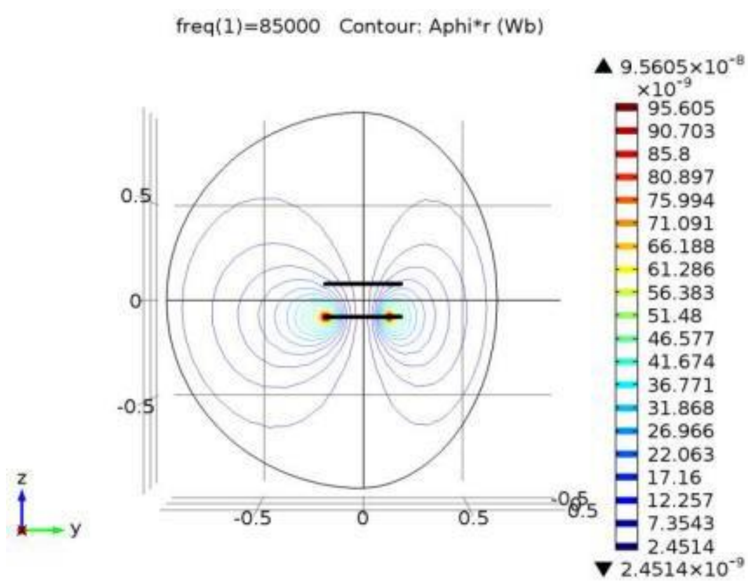


Figure 4.10 Magnetic flux lines of helix coil

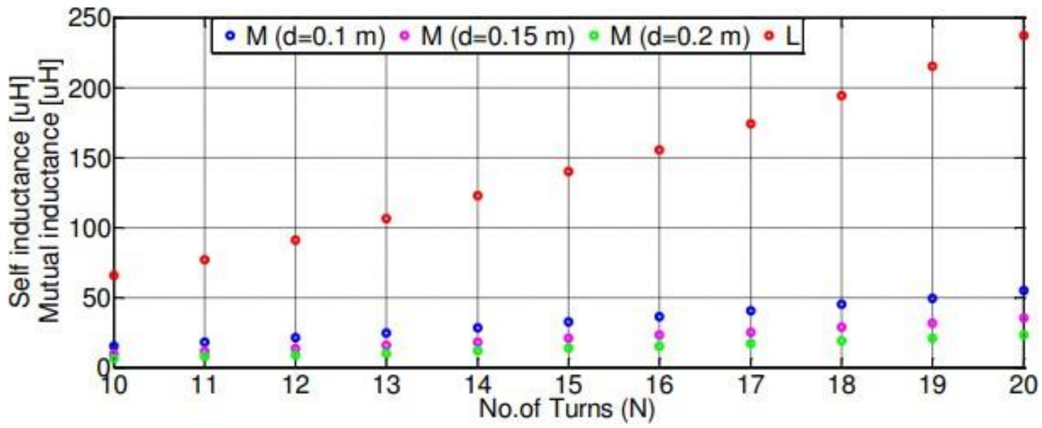


Fig. 4.11 Helix coil-coupling self- and mutual inductance vs. turn number for different coil distances in m.

The impact of the coil misalignment on the coupling coefficient is analyzed for the coils laying on two planes 0.15 m far each other. The outcome of the analysis, plotted in Fig. 4.14, shows that the coil misalignment has a lower influence in the coupling coefficient than the coil distance. For example, increasing the coil distance of 0.1 m (from 0.1 to 0.2 m), causes a decrease of k of about 94% as a percentage of its value at 0.15 m while a coil misalignment of 0.1 m (from 0 to 0.1 m), causes a decrease of k of about 22%.

2. **Spiral coil coupling**

The spiral coil-coupling is analyzed in the same way as the helical one. The main outcomes of the analysis, calculated for the turn distance td set at the reasonable value of 7 mm, are illustrated in Figs. 4.15 and 4.12 (b). Fig. 4.15 plots the self- and mutual inductances against the turn number for different coil distances.
Figs. 4.12 (a) and (b) plot the coupling coefficient respectively as a function of the turn number for coil distance of 0.15 m and as a function of the coil distance for N=15. Fig. 4.13 (b) gives the magnetic flux density on the surface of the spiral coil with the current

of 1 A. The outcomes can be discussed starting from the inspection of Fig. 4.13 (b). Indeed, the magnetic flux density is only 38% compared to the helix coil and the surface of the inner turns is much smaller than the surface of the outer turns so that the flux linked by the inner turns is less. Therefore, the self- and mutual inductances of the spiral-coil coupling are lower than those of the helix counterpart. Nevertheless, the flux density is more uniform across the coil surface and this yields a coupling coefficient that is about 18% greater than the helix counterpart This feature grants a higher efficiency to a WPT system with spiral coil coupling [4].

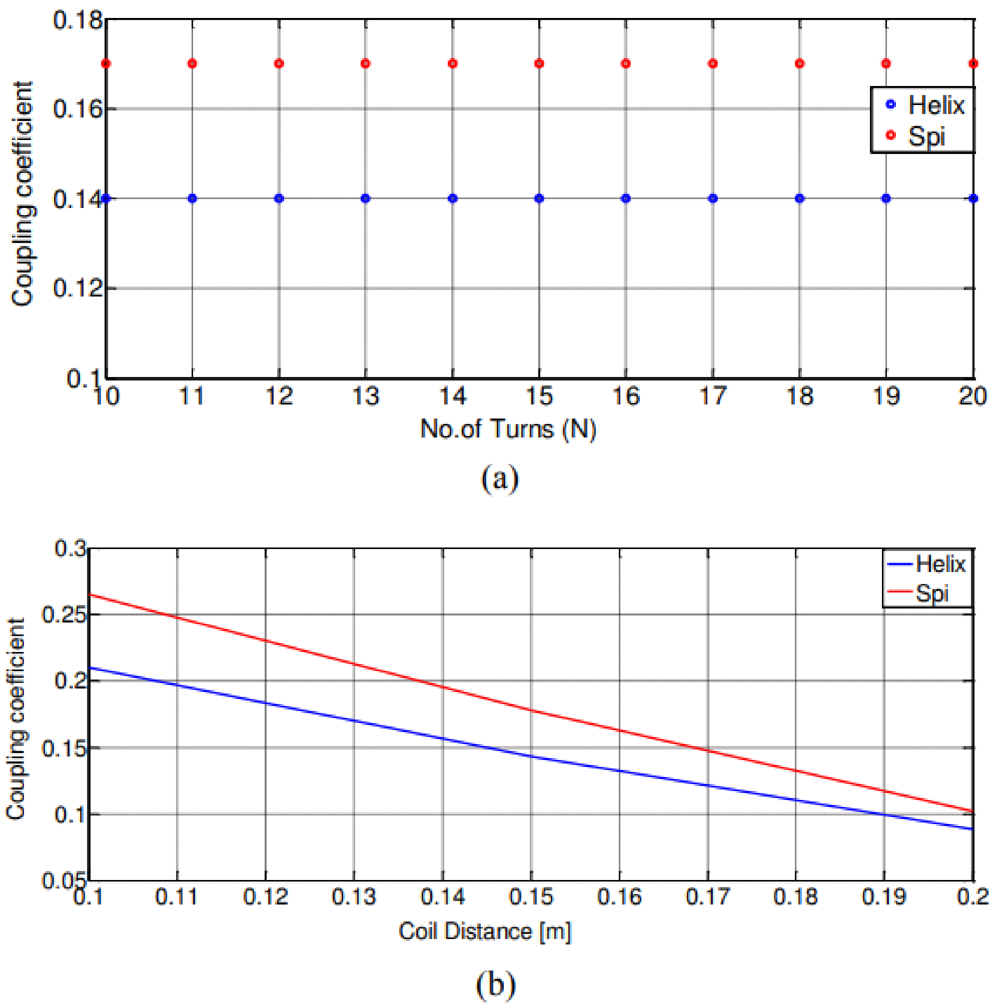
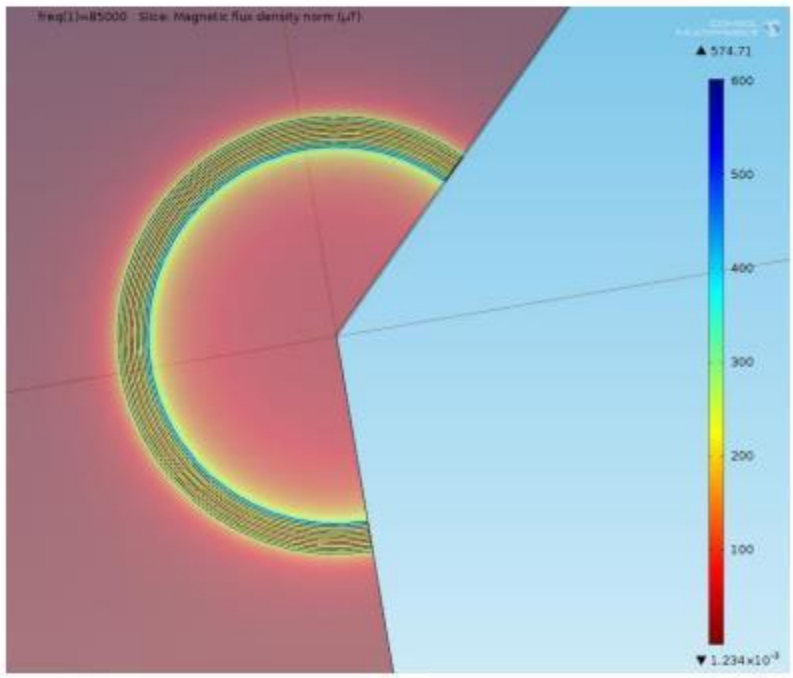
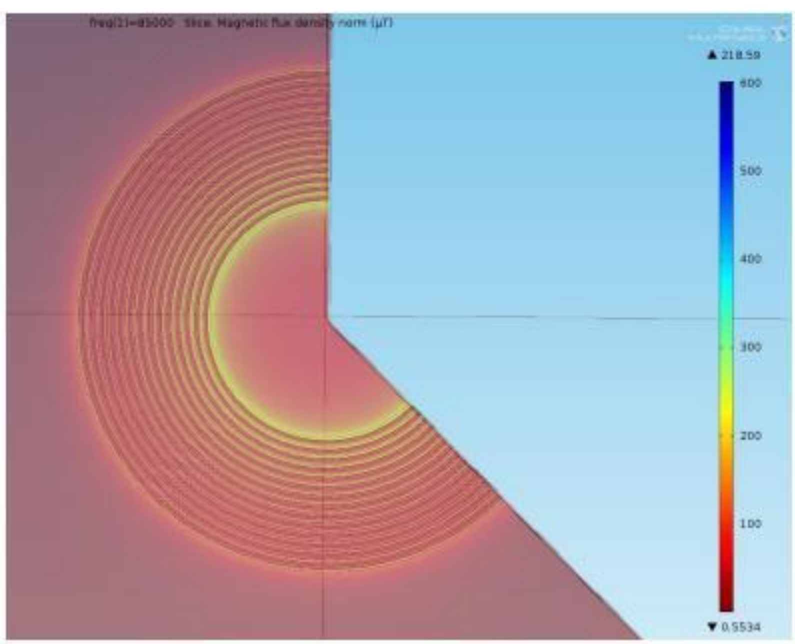


Fig. 4.12 Coupling coefficient vs. (a) turn number (d=0.15 m), and (b) coil distance (N=15) for helix and spiral coil-couplings (td=7 mm for the spiral coil coupling).



(a)



(b)

Fig. 4.13 Magnetic flux density in T on the surface (a) of a helix coil and (b) of a spiral coil (N=15, 1 A, td=7 mm for the spiral coil-coupling).

The impact of the coil misalignment is analyzed for the coils lying on planes 0.15 m far. The outcome of the analysis, plotted in Fig. 4.14, shows that the spiral coil-coupling exhibits larger coupling coefficients than the circular one even in misalignment conditions.
Sensitivity of the coupling coefficient of the spiral coil-coupling to the coil distance is not much less than for the circular one while its sensitivity to the coil misalignment becomes greater as the misalignment increases. For example, increasing the coil distance of
0.1 m (from 0.1 to 0.2 m) causes a decrease of k of about 85% whilst a coil misalignment of 0.1 m (from 0 to 0.1) causes a decrease of k of 30%; instead, a coil misalignment of 0.2 m (from 0 to 0.2) causes k to fall down to 70%. This is because the distributed arrangement of a spiral coil hampers a coil to link the flux produced by the faced coil under a large misalignment. Besides turn number and coil distance, the inductive parameters of the spiral coil-coupling depend on the turn distance. The relationship, plotted in Fig. 4.16 shows that a decrease in the turn distance increases the self- and mutual inductances as it can be readily explained by the fact that such a decrease makes the coil arrangement more similar to a circular one. The coupling coefficient, instead, is practically unaffected by the turn distance. Fig.4.17 and Fig. 4.18 shows Magnetic flux density lines of spiral coil and in misalignment [5].

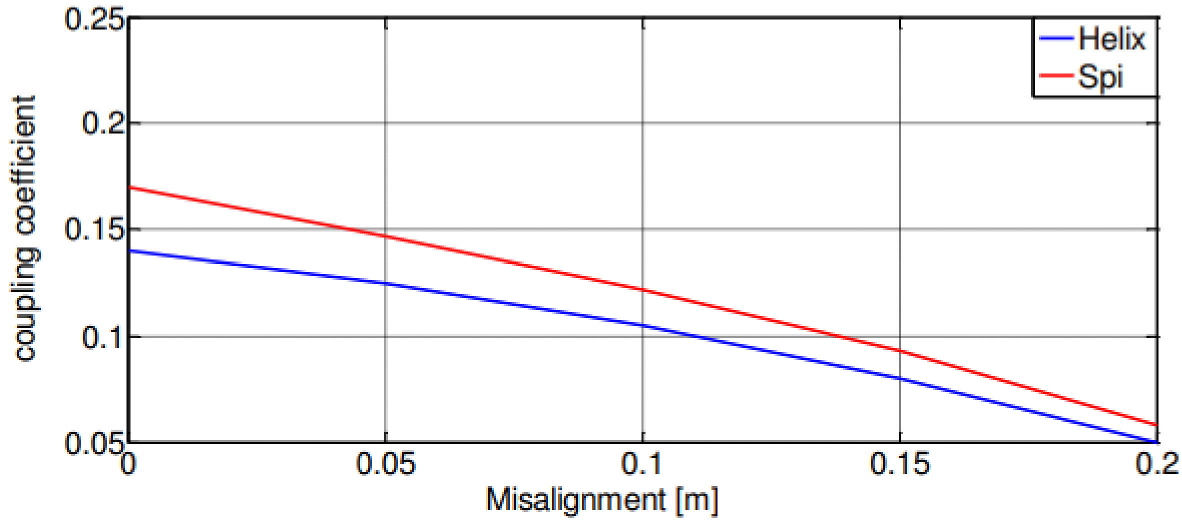


Fig. 4.14 Coupling coefficient vs. misalignment for helix and spiral coil-couplings (N=15, td =7 mm for the spiral coil-coupling).

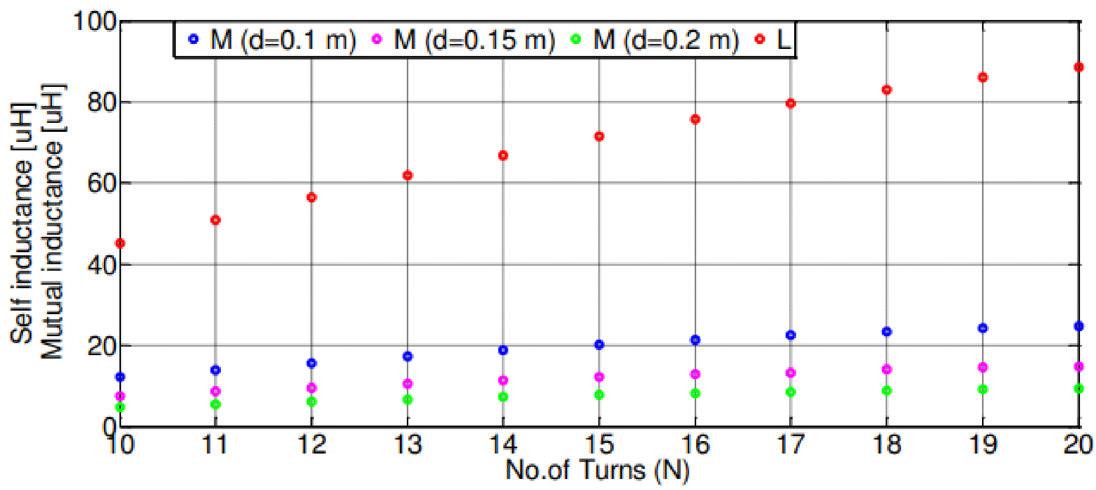


Fig. 4.15 Spiral coil-coupling self- and mutual inductance vs. turn number for different coil distances (td =7 mm).

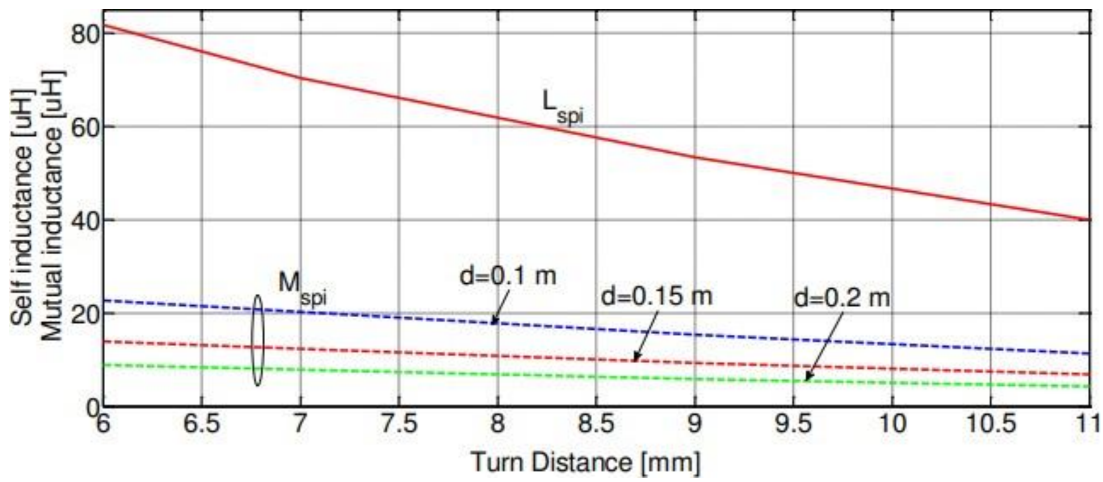


Fig. 4.16 Self- and mutual inductances of the spiral coil-coupling vs. turn distance for different coil distances (N=15).

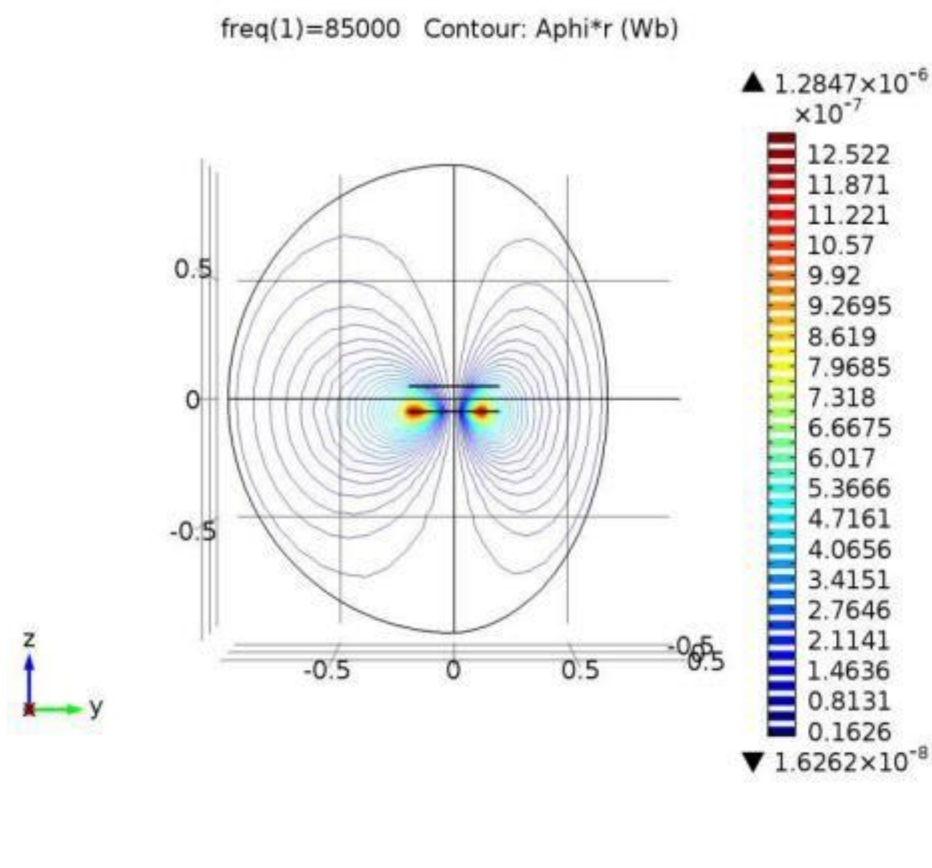


Fig.4.17 Magnetic flux lines of spiral coil

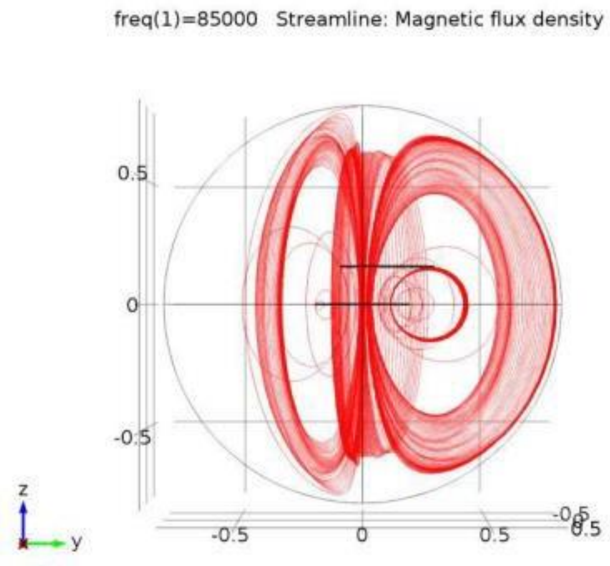


Fig.4.18 Misalignment of coil system.

4.2.3.4 Conclusion

This section has dealt with the coil-coupling of a WPT system intended to charge an electric city-car. At first design of the coil system is presented and by analysis carried out how different coil arrangements affect the performance of the coil- coupling in terms of inductive parameters. It has been found that, for a given outer diameter and distance of the coils, the spiral coil-coupling has a higher coupling coefficient compared to the helix one despite its lower self and mutual inductances.

5. WORK DONE AND CHALLENGES FACED

Majorly work done can be divided into two halves has which are as follows:

- Charging Circuitry
- EV Circuitry

5.1 Components used for the project

Circuitry included the following components (including their specifications):

1. Tata Solar TS-12-20:
    a. 20 Watt-peak
    b. 19.6 Volt
    c. 0.59Amp
2. Inverter: Boost Power Convertor
    a. 12/220 volt
    b. 150 Watt, 20KHZ
3. Battery Bank:
    a. 12 Volt
4. amp-hour
5. Transmitting Coils: Copper Plated Aluminium Coil
    a. No of Turns: 100
    b. Circumference of 1 Turn: 23.876 cm
    c. Mean Diameter of 1 Turn: 7.6 cm
6. Receiving Coils: Copper Plated Aluminium Coil
    a. No of Turns: 100
    b. Circumference of 1 Turn: 23.876 cm
    c. Mean Diameter of 1 Turn: 7.6 cm
7. Copper Plated Aluminium wire of diameter of 0.61 mm.
8. Switch
9. Red LEDs
10. Bread board
11. Diode
    a. 1N4007

12. Resistors
    a. 1k, 2.2k, 10k ohms
    b. 100 ohms
    c. 10 ohms
13. Capacitors (Electrostatic-type)
    a. 20 micro-farad
14. Capacitors (Polyester-type)
    a. 0.2A rating
    b. 22 nana-farad
15. Inductors (Drum-type)
    a. 0.1A rating
    b. 3 milli-henry
16. Rectifiers
    a. BR-61
17. Op-Amps
    a. LM741
    b. LM3886
18. Fuse
    a. 1 Ampere
    b. 2 Ampere

5.2 Focus of Work Last Semester

- Conducted a thorough literature review to gather information about the current state of wireless EV charging and related technologies.
- Developed a detailed technical specification for the dynamic wireless EV charging system.
- Designed and built a prototype of the dynamic wireless EV charging system, including the charging pad and the control unit.
- Conducted initial tests on the prototype to evaluate its performance and to identify any areas for improvement

5.2.1 Steps Involved

- **Step 1: <u>Inverter verification</u>**

Using an almost resistive load produces an sine wave with a power factor of 0.80

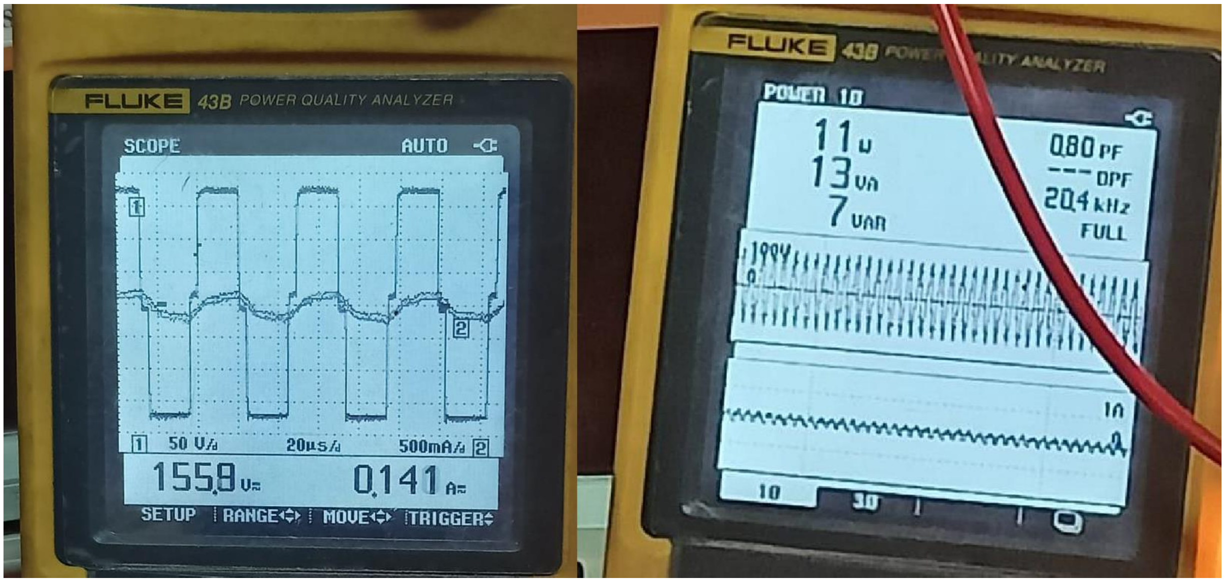


Figure 5.1 Inverter output from oscilloscope

- **<u>Circuit Model of Transmitter Coil</u>**

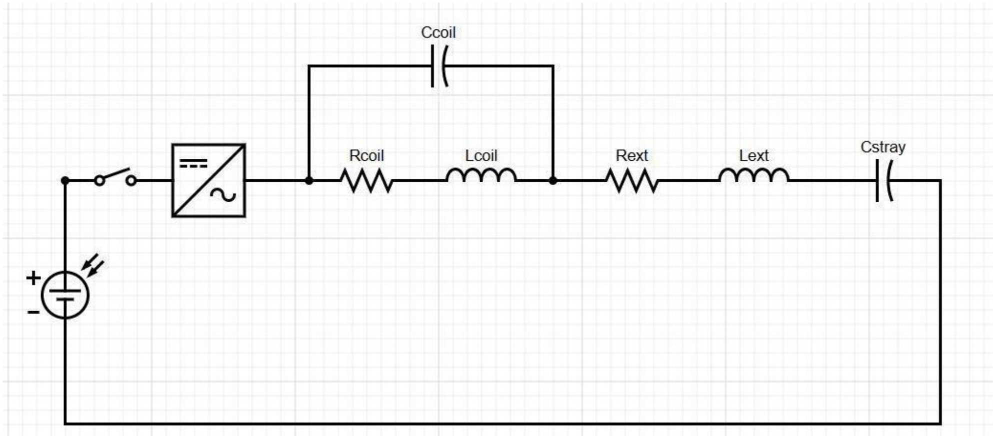


Figure 5.2 Charging Circuitry

- **<u>Measurement of Impendences</u>**

a. $L_{coil} = 2 * \pi * f * lcoil$ Henry

b. $l_{coil} = 36.73 * 10^{-12} * N^2$ Henry

First the inductance of coil is calculated., where it depends upon the square of number of turns. Whereas the inductive impedance depends on the frequency of operation.

c. $R_{coil(Calculated)} = 253.36 * N * 10^{-3}$ ohm

d. $R_{coil\ (\ measured)} = 26.5$ ohm (N = 100 turns)

Then the coil resistance is calculated and then verified with the actual constructed coil. It shows that for the 100 turns coil the coil resistance is almost equal to the measured coil resistance.

Note that the resistance of cables/wires increases with AC frequencies due to **skin effect**, as the effective cross section of conduction decreases. And as the frequency of operation increases so does the AC resistance. But here we ignore the effect.

e. $C_{coil} = 1 / 2 * \pi * f * c.coil$ pF

f. $c_{coil} = H*D$ pF (H = Factor corresponding to coil length/diameter ratio , D = Coil diameter in cm)

For higher frequency operations the coil self-capacitance becomes a substantial part of the coil model.

g. $X_{Total} = X_1 - jX_2$

$$\frac{RLC - RC(L-C)}{R^2 + (L-C)^2} - \left[\frac{R^2C + LC(L-C)}{R^2 + (L-C)^2} + C_{stray\ (ext)}\right]$$

Thus, the total impedance phasor is calculated.

- **Step 3. Material Used is of Aluminium**
    a. According to American wire gauge Standard 21 Gauge of copper is equivalent to 23 gauge of aluminium
    b. Current rating of wire = 1.2 Amps

- **Step 4. Inequality Formation**
    a. Max (X_{total}) > V / I
    b. I is taken as 0.4 / 0.5 amps
    c. So, number of turns in coils optimized to increase impedance and flux linkage.
    d. For I =0.5A, L_{ext} = 3.18 mH and R_{ext} = 10 ohm
    e. For I =0.4A, L_{ext} = 3.977 mH and R_{ext} = 10 ohms.

- **Step 5. Now check for resonance**
    a. Checking of resonating frequencies verified in MHz way above range of operation (20 kHz).

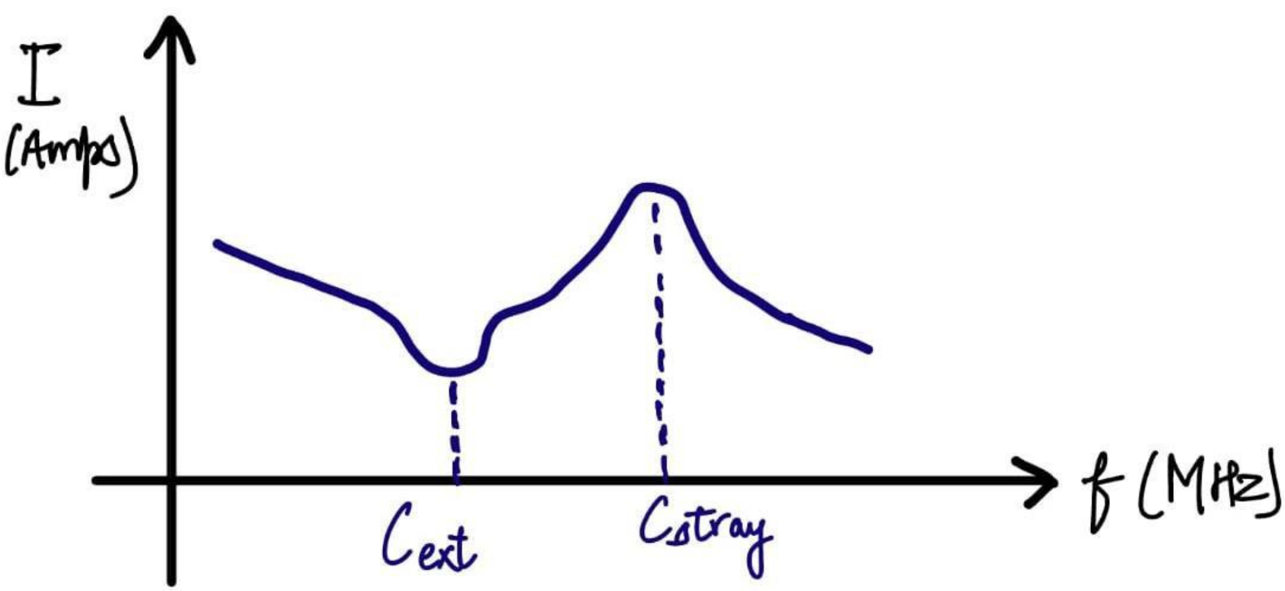


Figure 5.3 Current Vs Resonant Frequency

- **<u>Step 6. Construction of Coils</u>**
    a. No of turns = 100
    b. D_{mean} of 1 Turn = 7.6 cm
    c. No of Receiving Coils = 1
    d. No of Transmitting Coils = 3

- **<u>Step 7. Protection of Coil</u>**
    a. Fuse and Flyback diodes are used from overcurrent protection

5.3 Focus of Work This semester:

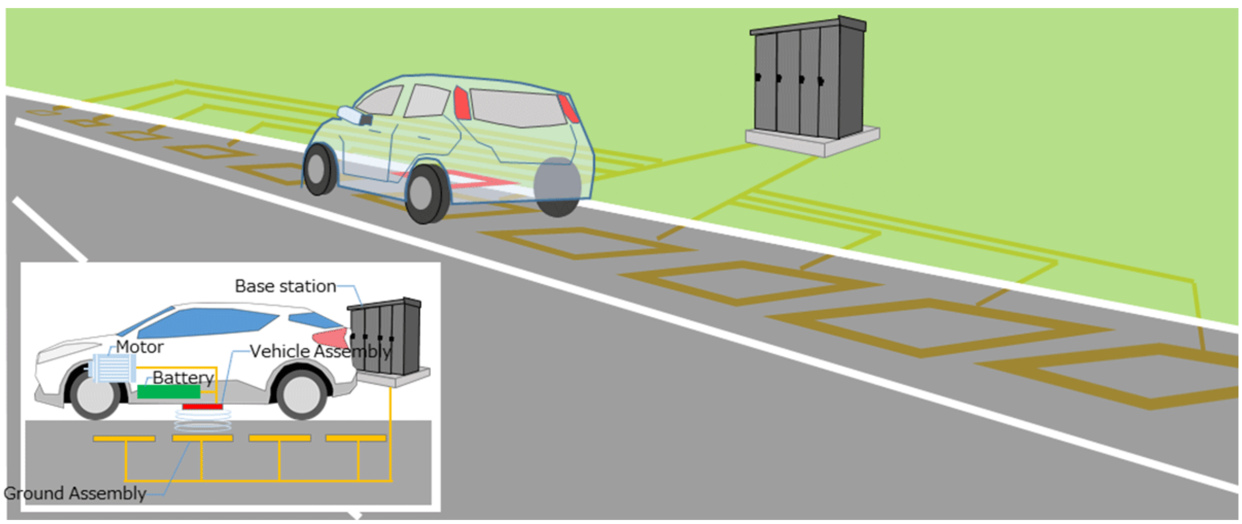
- Implement a system of **distributed charging pads** instead of lump charging pads to reduce power wastage and increase efficiency, with the pads activated according to the car's position.
- Provide a unified interface for users to monitor **power consumption** and view generated bills.
- Refine the working of the wireless EV charging system by improving the **efficiency of the power transfer** and tackling the issues of DC Gain and Inverter Impedance
- Study and address potential health hazards of high-frequency magnetic fields, as well as interference issues with communication wires and systems.

5.3.1 Smart Distributed Charging Pads

Smart charging pads are a key component in dynamic wireless EV (electric vehicle) charging. They are designed to transfer energy wirelessly from a charging pad on the ground to a receiver on the underside of an EV while it is in motion.

The smart charging pads incorporate a variety of features that help to optimize the charging process and make it more efficient. It uses charging pads embedded in the road surface to transmit power wirelessly to the vehicle's battery through inductive charging.

The charging pads used are typically made up of a series of copper coils that generate a magnetic field. When an electric vehicle equipped with a compatible receiver drives over the charging pad, the magnetic field induces an electrical current in the receiver, which is then used to charge the vehicle's battery.



So, we can see there are numerous charging pads installed in the road.

Why do we have to on the all-charging pads even if vehicle is not passing over them. We can optimize power transfer and reduce the power wastage by switching that charging pad only which is under the vicinity of the vehicle.

We can fix this problem by using an ultrasonic sensor. Each receiver coil is positioned in front of an ultrasonic sensor. Along with the infrastructure for the receiver coils, the sensors will be deployed on the road. They will frequently send sound wave signals, and as soon as they get a response, they will know that a car is nearby. Consequently, it will trigger the relay coil and turn off the charging pad to which it is connected.

HC-SR04 Sensor Features

- Theoretical Measuring Distance: 2cm to 450cm
- Operating voltage: +5V
- Practical Measuring Distance: 2cm to 80cm
- Accuracy: 3mm
- Measuring angle covered: <15°
- Operating Current: <15mA
- Operating Frequency: 40Hz

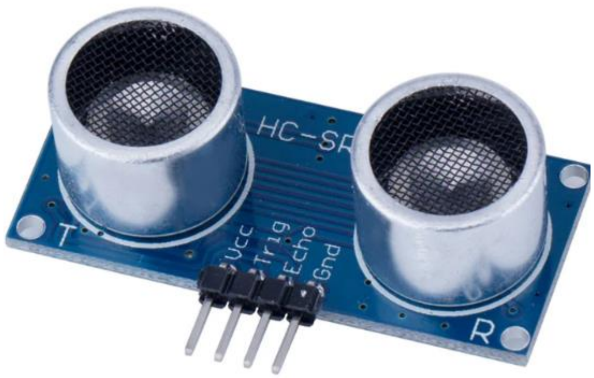


Fig: HC-SR04 Ultrasonic Sensor

Working of Ultrasonic Senor

- The HC-SR04 is an ultrasonic sensor module that uses sound waves to measure distances. It has two main components: a transmitter and a receiver.

- When you trigger the sensor by sending a high signal to its trigger pin, the transmitter sends out a burst of high-frequency sound waves, typically at 40 kHz. These sound waves travel through the air and bounce off any objects in their path.

- The receiver then picks up the echoes of these sound waves and sends a signal back to the sensor module.
- The sensor calculates the time it took for the sound waves to travel to the object and back, and uses this information to determine the distance to the object.

<u>Ultrasonic Sensor Pinout Configuration</u>

The HC-SR04 sensor module has four pins: VCC, GND, Trigger, and Echo. The VCC and GND pins provide power to the sensor, and the Trigger and Echo pins are used to trigger the sensor and receive the echo signal, respectively.

Pin Number	**Pin Name**	**Description**
1	V_{cc}	The V_{cc} pin powers the sensor, typically with +5V
2	Trigger	Trigger pin is an Input pin. This pin must be kept high for 10us to initialize measurement by sending US wave.
3	Echo	Echo pin is an Output pin. This pin goes high for a period of time, which will be equal to the time taken for the US wave to return back to the sensor.
4	Ground	This pin is connected to the Ground of the system.

To use the sensor, you typically connect the VCC pin to a 5V power source, the GND pin to ground, the Trigger pin to a digital output pin on your microcontroller, and the Echo pin to a digital input pin on your microcontroller. You can then send a trigger signal to the sensor using the Trigger pin, and read the distance measurement from the sensor using the Echo pin.

Let us understand how power wastage can be reduced using ultrasonic sensor.
Two pins ECHO and Trig from sensor is feeding the data to Arduino. The output from the control unit is fed to relay coil. These relay coils are normally open which means the circuit is open. There is no current flowing through the transmitting coils. When the vehicle is in range of sensor it will be activated and relay ends will be closed which in turn activate the transmitting coil due to which current will start flowing through it. Now these transmitting coils can feed the receiver coil which is placed inside the EV through which battery of EV can be charged. Thus, in this way circuit is complete and we can see there is wireless power transfer.

Code Snippet for Initial Setup

```
// C++ code
// variable declaration
float distance1 = 0;
float distance2 = 0;
float distance3 = 0;
float distance4 = 0;

float duration1 = 0;
float duration2 = 0;
float duration3 = 0;
float duration4 = 0;

// initial setup
void setup()
{
  Serial.begin(9600);
  pinMode(2, OUTPUT);
  pinMode(13, OUTPUT);
  pinMode(12, INPUT);

  pinMode(3, OUTPUT);
  pinMode(11, OUTPUT);
  pinMode(10, INPUT);

  pinMode(4, OUTPUT);
  pinMode(9, OUTPUT);
  pinMode(8, INPUT);

  pinMode(5, OUTPUT);
  pinMode(7, OUTPUT);
  pinMode(6, INPUT);

  digitalWrite(2, HIGH);
  digitalWrite(13, LOW);

  digitalWrite(3, HIGH);
  digitalWrite(11, LOW);

  digitalWrite(4, HIGH);
  digitalWrite(9, LOW);

  digitalWrite(5, HIGH);
  digitalWrite(7, LOW);

}
```

Code Snippet for Control Logic

```
// control logic
void loop()
{
  delayMicroseconds(2);

  digitalWrite(13, HIGH);
  delay(0.001); // Wait for 0.001 millisecond(s)
  digitalWrite(13, LOW);
  duration1 = pulseIn(12,HIGH);
  distance1 = microsecondsToCentimeters(duration1);
  Serial.print("distance1: ");
  Serial.println(distance1);

  digitalWrite(11, HIGH);
  delay(0.001); // Wait for 0.001 millisecond(s)
  digitalWrite(11, LOW);
  duration2 = pulseIn(10,HIGH);
  distance2 = microsecondsToCentimeters(duration2);
  Serial.print("distance2: ");
  Serial.println(distance2);

  digitalWrite(9, HIGH);
  delay(0.001); // Wait for 0.001 millisecond(s)
  digitalWrite(9, LOW);
  duration3 = pulseIn(8,HIGH);
  distance3 = microsecondsToCentimeters(duration3);
  Serial.print("distance3: ");
  Serial.println(distance3);

  digitalWrite(7, HIGH);
  delay(0.001); // Wait for 0.001 millisecond(s)
  digitalWrite(7, LOW);
  duration4 = pulseIn(6,HIGH);
  distance4 = microsecondsToCentimeters(duration4);
  Serial.print("distance4: ");
  Serial.println(distance4);
  // delay(1000);
  if(distance1 < 15) {
    digitalWrite(5, LOW);
      digitalWrite(3, HIGH);
      digitalWrite(4, HIGH);
      digitalWrite(2, HIGH);
  }

  if(distance2 < 15) {
    digitalWrite(4, LOW);
      digitalWrite(2, HIGH);
      digitalWrite(3, HIGH);
      digitalWrite(5, HIGH);
  }

  if(distance3 < 15) {
    digitalWrite(3, LOW);
      digitalWrite(4, HIGH);
      digitalWrite(2, HIGH);
      digitalWrite(5, HIGH);
  }

  if(distance4 < 15) {
    digitalWrite(2, LOW);
      digitalWrite(3, HIGH);
      digitalWrite(4, HIGH);
      digitalWrite(5, HIGH);
  }

}

float microsecondsToCentimeters(float microseconds) {
   return microseconds / 29 / 2;
}
```

5.3.2 Measurement of Power Transferred

Let's first comprehend the significance of this feature. If the infrastructure is put in place, how will a user be billed? The amount a user is charged depends on how much energy their car uses overall. A voltage sensor able to output the total voltage detected at the vehicle side can assist with this. With the help of this voltage, power may be computed, and the user is charged according to the amount of energy used.

The Voltage sensor is installed inside the car and is feeding it’s data to ESP8266 Wi-Fi module. Wi-Fi Module is physically present inside the car and is programmed to display the data on a live web page.

Fig : ESP8266 WI-FI Module

This is how voltage is measured using the EC-2173 sensor and displayed live on a web page using an ESP8266 Wi-Fi module:

1. Connect the EC-2173 sensor to the ESP8266 module. The EC-2173 sensor has three pins: VCC, GND, and OUT. Connect the VCC pin to the 3.3V output of the ESP8266 module, the GND pin to the ground of the module, and the OUT pin to an analog input pin of the module, such as A0.

2. Set up the Arduino IDE and the ESP8266 board. Install the appropriate libraries such as the ESP8266WiFi and ESPAsyncTCP libraries.

3. Write a program to read the voltage values from the sensor and transmit them to a web server. The **analogRead()** function to read the voltage values from the sensor and the **ESPAsyncWebServer** library to create a web server on the ESP8266 module.

4. Upload the program to the ESP8266 module using the Arduino IDE. Select the ESP8266 board and the appropriate port in the Arduino IDE and then upload the program to the module.

5. Connect the ESP8266 module to the same Wi-Fi network on which web page is connected.

6. Open a web browser and enter the IP address of the ESP8266 module. You should see the voltage value displayed on the web page.

7. Power transferred can be calculated as Power = V*V / R

```
#include <Arduino.h>
#include <ESP8266WiFi.h>
#include <Firebase_ESP_Client.h>

//Provide the token generation process info.
#include "addons/TokenHelper.h"
//Provide the RTDB payload printing info and other helper functions.
#include "addons/RTDBHelper.h"

// Insert your network credentials
#define WIFI_SSID "Hotspot"
#define WIFI_PASSWORD "12345678"

// Insert Firebase project API Key
#define API_KEY "AIzaSyBiiyYsw6ccF5YY-Fgm30EFDM0HknqYn9U"

// Insert RTDB URLefine the RTDB URL */
#define DATABASE_URL "https://majorprojectapp-0-default-rtdb.firebaseio.com/"

//Define Firebase Data object
FirebaseData fbdo;

FirebaseAuth auth;
FirebaseConfig config;

unsigned long sendDataPrevMillis = 0;
int count = 0;
bool signupOK = false;

const int ADC_pin = A0;
float sensor_reading = 0;

void setup(){
  Serial.begin(115200);
  WiFi.begin(WIFI_SSID, WIFI_PASSWORD);
  Serial.print("Connecting to Wi-Fi");
  while (WiFi.status() != WL_CONNECTED){
    Serial.print(".");
    delay(300);
  }
  Serial.println();
  Serial.print("Connected with IP: ");
  Serial.println(WiFi.localIP());
  Serial.println();

  /* Assign the api key (required) */
  config.api_key = API_KEY;

  /* Assign the RTDB URL (required) */
  config.database_url = DATABASE_URL;

  /* Sign up */
  if (Firebase.signUp(&config, &auth, "", "")){
    Serial.println("ok");
    signupOK = true;
  }
  else{
    Serial.printf("%s\n", config.signer.signupError.message.c_str());
  }

  /* Assign the callback function for the long running token generation task */
  config.token_status_callback = tokenStatusCallback; //see addons/TokenHelper.h

  Firebase.begin(&config, &auth);
  Firebase.reconnectWiFi(true);
}

void readVoltage() {
  sensor_reading  = analogRead(ADC_pin);
  float R1 = 30000.0;
  float R2 = 7500.0;
  float vOUT = (sensor_reading * 3.3) / 1023.0;
  sensor_reading = vOUT / (R2/(R1+R2));

  Serial.print("ADC reading = ");
  Serial.println(sensor_reading);

  // delay(1000);
}

void loop(){

  if (Firebase.ready() && signupOK && (millis() - sendDataPrevMillis > 500 ||
sendDataPrevMillis == 0)){
    sendDataPrevMillis = millis();
    readVoltage();
    // Write an Float number on the database path test/float
    if (Firebase.RTDB.setFloat(&fbdo, "voltage/float", sensor_reading)){
      Serial.println("PASSED");
      Serial.println("PATH: " + fbdo.dataPath());
      Serial.println("TYPE: " + fbdo.dataType());
    }
    else {
      Serial.println("FAILED");
      Serial.println("REASON: " + fbdo.errorReason());
    }
  }
}
```

5.3.3 Concept of Power Unit and Control Unit:

Distributed Charging Pads:

Distributed charging pads are the physical devices that allow wireless charging of electric vehicles (EVs). These pads are designed to be placed on the ground or embedded in the road surface. The charging pads use induction technology to transfer power wirelessly to the EV's battery.

Power Unit:

The power unit is responsible for supplying power to the charging coils in the distributed charging pads. This unit is usually located at a central location, such as a charging station, and is connected to the power grid. The power unit converts the AC power from the grid into a DC voltage that can be used to charge the EV's battery. The power unit typically uses power electronics, such as inverters and rectifiers, to manage the power flow between the grid or a solar farm, and the charging pads.

Control Unit:

The control unit is responsible for managing the charging process by turning on and off the charging pads based on the position of the EV. The control unit uses a range of sensors, such as cameras, lidar, and ultrasonic sensors (we use US sensors in our case), to detect the location of the EV. Once the EV is detected, the control unit activates the nearest charging pad, and the EV begins to charge wirelessly. The control unit also monitors the charging process and can adjust the power flow to optimize the charging rate and protect the EV's battery.

5.4 WPT Efficiency:

We have come up with two ways to improve efficiency of our WPT system:

5.4.1 Switching from Inductive WPT to resonant WPT:

<u>Inductive WPT Technique:</u>

Inductive wireless power transfer (WPT) is a method of transferring electrical power from a charging pad to an electric vehicle (EV) wirelessly using magnetic fields. In an inductive WPT system, the charging pad and the EV have separate coils that are coupled through a magnetic field. When the charging pad is connected to an AC power source, it generates a magnetic field, which induces an electric current in the coil of the EV. The electric current then charges the battery of the EV.

<u>Resonant WPT Technique:</u>

Resonant WPT is an advanced wireless power transfer technique that uses resonant circuits to establish a magnetic coupling between the charging pad and the

EV. In a resonant WPT system, the charging pad and the EV have resonant circuits that are tuned to the same frequency. When the charging pad is connected to an AC power source, it generates an oscillating magnetic field, which resonates with the resonant circuit of the EV. This resonance leads to a stronger magnetic coupling between the charging pad and the EV, which improves the power transfer efficiency.

Shortcomings of Inductive WPT System:

The inductive WPT system has several limitations that affect its efficiency. Firstly, the distance between the charging pad and the EV affects the efficiency of power transfer. As the distance increases, the magnetic field generated by the charging pad weakens, leading to a decrease in power transfer efficiency. This limitation often requires EVs to be parked in a precise location over the charging pad, which can be inconvenient for drivers.

Secondly, the inductive WPT system has a low power transfer efficiency due to the large air gap between the charging pad and the EV. The air gap reduces the magnetic coupling between the charging pad and the EV, leading to significant energy losses during power transfer. This limitation can lead to longer charging times and reduced charging range for EVs.
Improving Efficiency by Switching from Inductive WPT System:
To improve the efficiency of the WPT system, one approach is to switch from an inductive WPT system to a resonant WPT system. A resonant WPT system uses resonant circuits to establish a magnetic coupling between the charging pad and the EV. This system allows for higher power transfer efficiency and a larger operating range. Additionally, a resonant WPT system can be designed to operate at a resonant frequency, which allows for better power transfer efficiency and reduced energy losses.

In our application, we calculate the specific values of L, and C and an external resistive load, at the resonant frequency of 20Hz (which is the output of the power unit). We made a hefty calculating model of the transmitting coil that helps us to find the specific values at different resonant frequency and current requirements):

$$
\begin{aligned}
y+\frac{V}{x} = \Bigg(\Bigg(&\frac{\left(\frac{26.5\cdot N}{100}+R_{ext}\right)\left(2\pi\cdot f\cdot\left(36.73\cdot 10^{-12}\cdot N^{2}+L_{ext}\cdot 10^{-3}\right)\right)\left(\frac{c_{coilon}}{2\pi\cdot f\cdot C_{coil}\cdot 10^{-12}}\right)-\left(\frac{26.5\cdot N}{100}+R_{ext}\right)\left(\frac{c_{coilon}}{2\pi\cdot f\cdot C_{coil}\cdot 10^{-12}}\right)\left(\left(2\pi\cdot f\cdot\left(36.73\cdot 10^{-12}\cdot N^{2}+L_{ext}\cdot 10^{-3}\right)\right)-\left(\frac{c_{coilon}}{2\pi\cdot f\cdot C_{coil}\cdot 10^{-12}}\right)\right)}{\left(\frac{26.5\cdot N}{100}+R_{ext}\right)^{2}+\left(\left(2\pi\cdot f\cdot\left(36.73\cdot 10^{-12}\cdot N^{2}+L_{ext}\cdot 10^{-3}\right)\right)-\left(\frac{c_{coilon}}{2\pi\cdot f\cdot C_{coil}\cdot 10^{-12}}\right)\right)^{2}}\Bigg)^{2} \\
&+\left(\frac{\left(\left(\frac{26.5\cdot N}{100}+R_{ext}\right)^{2}\left(\frac{c_{coilon}}{2\pi\cdot f\cdot C_{coil}\cdot 10^{-12}}\right)+\left(2\pi\cdot f\cdot\left(36.73\cdot 10^{-12}\cdot N^{2}+L_{ext}\cdot 10^{-3}\right)\right)\left(\frac{c_{coilon}}{2\pi\cdot f\cdot C_{coil}\cdot 10^{-12}}\right)\left(\left(2\pi\cdot f\cdot\left(36.73\cdot 10^{-12}\cdot N^{2}+L_{ext}\cdot 10^{-3}\right)\right)-\left(\frac{c_{coilon}}{2\pi\cdot f\cdot C_{coil}\cdot 10^{-12}}\right)\right)\right)}{\left(\frac{26.5\cdot N}{100}+R_{ext}\right)^{2}+\left(\left(2\pi\cdot f\cdot\left(36.73\cdot 10^{-12}\cdot N^{2}+L_{ext}\cdot 10^{-3}\right)\right)-\left(\frac{c_{coilon}}{2\pi\cdot f\cdot C_{coil}\cdot 10^{-12}}\right)\right)^{2}}+\left(\frac{c_{exton}}{2\pi\cdot f\cdot C_{ext}\cdot 10^{-9}}\right)\right)^{2}\Bigg)^{\frac{1}{2}}
\end{aligned}
$$

Where x-output coil current

V- supply voltage to the transmitting circuit

R_{ext}- external load resistance

N- number of cylindrical coils

f- power unit output frequency

L_{ext}- external resonant inductance value

C_{coil}- Transmitting coil's self capacitance

C_{ext}- external resonant capacitor value

Optimization of L and C and approximation:

- Current limitations: As priorly mentioned, the current rating of the gauge wire is capped to a 1.2A limit. We keep it way down because of the AC resistance of wire increases with a power frequency of 20kHz due to the skin effect.

- We fix the output frequency to a range of 19kHz to 21kHz. This is due to the variability of the power unit inverter.

- The voltage of operation is fixed, and the calculation is performed.

- We try to find real solutions for a variety of operating voltages, and lesser values of output current, and that too by keeping the external load resistance as zero. This is because the external resistance induces a lot of active power losses in the transmitting circuit, thus bringing down the overall power transfer efficiency down. Only if we are unable to find real solutions for both L and C, only then introducing an external load will be justifiable.

5.4.2 Replacing the power unit transformer with a power amplifier, or inserting a power buffer after the power unit transformer.

First, we need to understand the key differences between them.

A transformer and an amplifier are two different types of devices used for manipulating electrical signals. A transformer is a passive device that uses magnetic coupling to transfer electrical energy from one circuit to another. It is used primarily for voltage and current transformation, isolation, and impedance matching. On the other hand, an amplifier is an active device that takes an input signal and increases its amplitude, power, or current.

Here are some key differences between transformers and amplifiers:

- **Function**: The primary function of a transformer is to transfer electrical energy from one circuit to another without any electrical connection between them. It does not amplify or modify the signal in any way. In contrast, an amplifier takes an input signal and amplifies it to produce a higher output signal.

- **Operation**: A transformer works based on the principles of electromagnetic induction. When an alternating current (AC) flows through the primary coil, it creates a magnetic field that induces a current in the secondary coil. The magnitude of the induced current depends on the turn's ratio of the transformer. In contrast, an amplifier operates by applying a power source to a control element such as a transistor, tube, or op-amp, to amplify the input signal.

- **Frequency range**: A transformer can operate over a wide range of frequencies, from a few hertz to several kilohertz. The frequency response of a transformer is limited by its core material and construction. Amplifiers, on the other hand, have a limited frequency range and are designed to work within a specific frequency range.

- **Power handling**: Transformers are designed to handle large amounts of electrical power, making them suitable for high voltage and current applications. Amplifiers, on the other hand, are designed to handle low to moderate amounts of power.

When using a high frequency inverter with a voltage transformer, to drive high inductance loads (such as motors, coils, etc.), it causes asymmetrical output current, while the symmetrical voltage is maintained. This is due a DC gain being introduced, and the total power being transmitted is greatly reduced.

In a half H bridge inverter, the output voltage is generated by switching the DC voltage across the inductive load using two switches. The switches are controlled by a pulse width modulated (PWM) signal, which varies the duty cycle to control the output voltage. The inductive load is typically a motor, which generates a back EMF that opposes the current flow through the motor. This back EMF is a source of energy that needs to be absorbed by the inverter to maintain the current flow.

When a transformer is used after the half H bridge inverter to drive a high inductive load, such as a motor, it can cause input impedance issues due to the transformer's characteristics. A transformer has a finite inductance and resistance, which can affect the inverter's ability to drive the motor efficiently.

Here are some reasons why:

- **Reactive Power**: A transformer has reactive power, which is the power that oscillates between the transformer's primary and secondary coils. This reactive power can cause a phase shift between the voltage and current, leading to poor power factor and reduced efficiency. The inductive load, such as a motor, also has reactive power, which can compound the problem.

- **Impedance Mismatch**: The transformer's impedance can be mismatched with the inductive load, causing reflected waves and standing waves. This can lead to voltage spikes and current surges, which can damage the inverter and the load. The reflected waves can also cause ringing and oscillations, leading to noise and instability in the system.

- **Saturation**: A transformer can saturate when it is driven with a high current, causing a reduction in the transformer's inductance. This can lead to a loss of voltage regulation and increased distortion in the output waveform.

To address these issues, a power buffer or a power amplifier can be used after the transformer to drive the inductive load. A power buffer is an active device that can buffer the current and voltage signals, improving the inverter's ability to drive the load. A power amplifier is an active device that can amplify the current and voltage signals, providing a higher output power and improved efficiency.

We tackle these problems by either using a power buffer or a power amplifier.

- The transformer input impedance issues can be minimized by using a power buffer after the transformer.
- Or, the transformer can be removed, and replaced by a power amplifier. This is finishing any input impedance issues, as the transformer was directly removed.
    - NOTE: this is not possible when using a H-bridge inverter, because it fundamentally uses a center-tap transformer to operate.

Thus, the inverter can efficiently drive the inductive load without damaging the transformer or the load.

5.5 Challenges Faced

1. **Availability of Inverter:**
   Non availability of high frequency inverters in the local market.
   Proposed solutions:
   - To extract from a UPS: This solution proposes to extract an inverter circuitry from a UPS, which provides us with a power frequency inverter (50 Hz). But as in literature review, the optimal frequencies for wireless power transfer is in megahertz. Thus, this solution was infeasible for our application.
   - Simple Full H-bridge inverter circuit: A full H-bridge inverter gives a square wave output, which presents us with various problems presented below.

2. **Configuration of Inverter:**
   All the inverters available were with square wave output only. Square wave output is not suitable for inductive load hence not suitable for WPT. Proposed solutions:
   - Optimization of coil L/R: It can be noted for a certain frequency, the transient time period greatly reduces with a decrease in L/R value of transmitting coil. Also it is noted that the RMS current increases with an increase in L/R value. Both RMS values and transient time period vary with operational frequency. Thus, optimization of L/R value of coil and operational frequency needed.

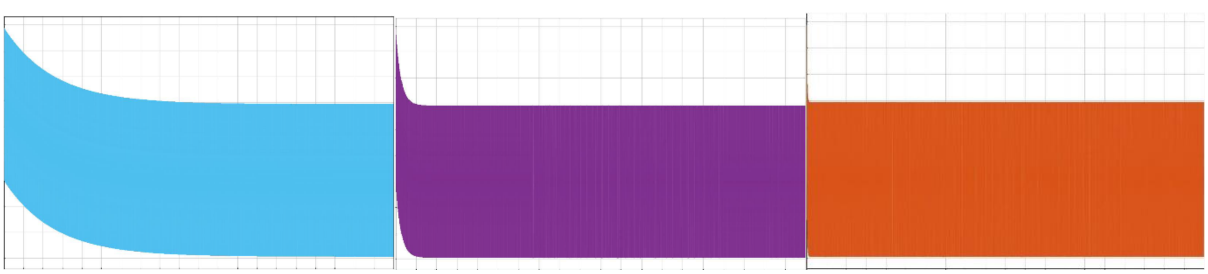


Figure 5.4 Decreasing L/R Ratio (left to right)

- <u>Multilevel Inverter using IC 4047 and 555 timer IC's:</u> Comprises of IC 4047 and Timer 555. It requires 2 inverters with separate transformers having different turn ratios at the secondary winding. Multiple lower-level DC voltage at the input. Disadvantage: complicated design.

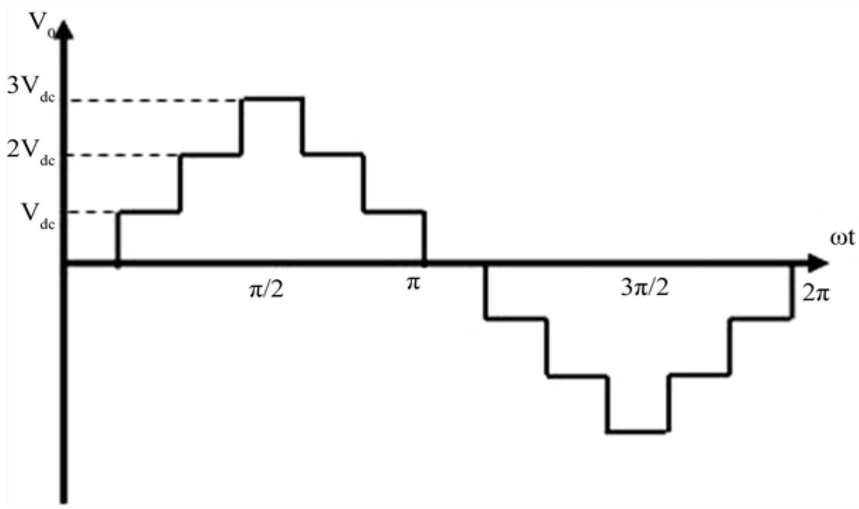


Figure 5.5 Multilevel inverter waveform

- <u>Using Harmonic Traps:</u> Combination of inductance and capacitors. It's a notch filter with added protection. Disadvantages: Finding the specific value of the capacitor is quite complicated. The filter can become bulky and can bring waveform down to 10% at best.

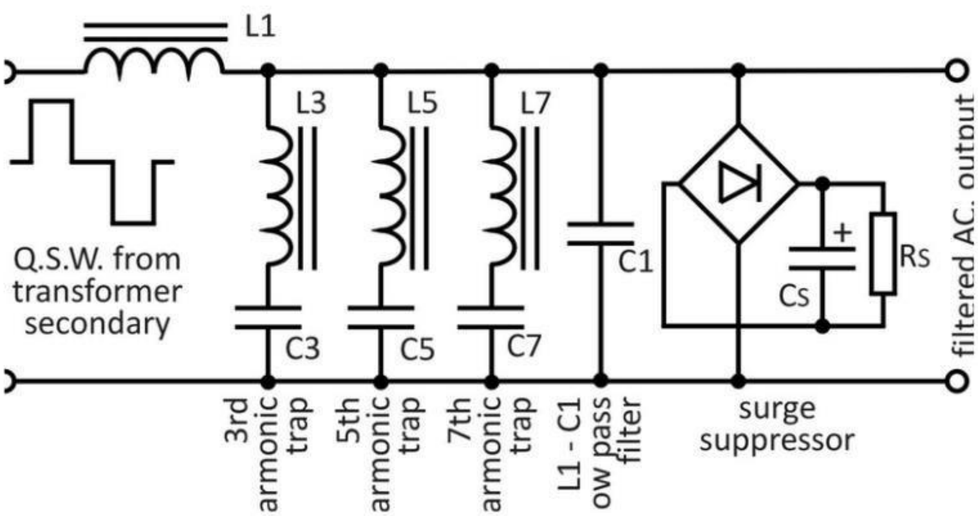


Figure 5.6 Harmonic Trap Circuit

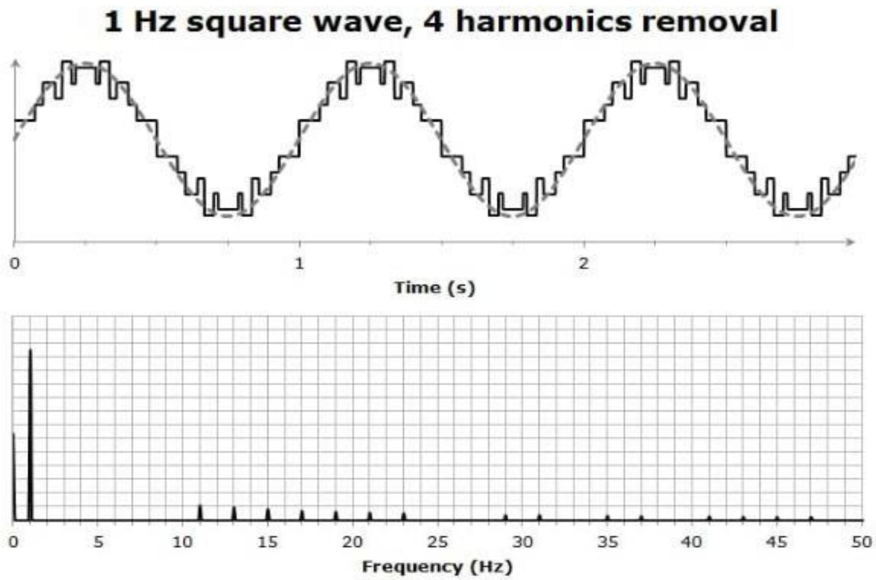


Figure 5.7 Harmonic trap circuit output waveform

- Passing with High Cut/Low Pass filter: Carries low-frequency signals. Discards signals higher than cutoff-frequency signals. Filtering is done by RC circuit Disadvantages: Finding the specific value of the capacitor is quite complicated. The filter can become bulky and can bring waveform down to 10% at best.

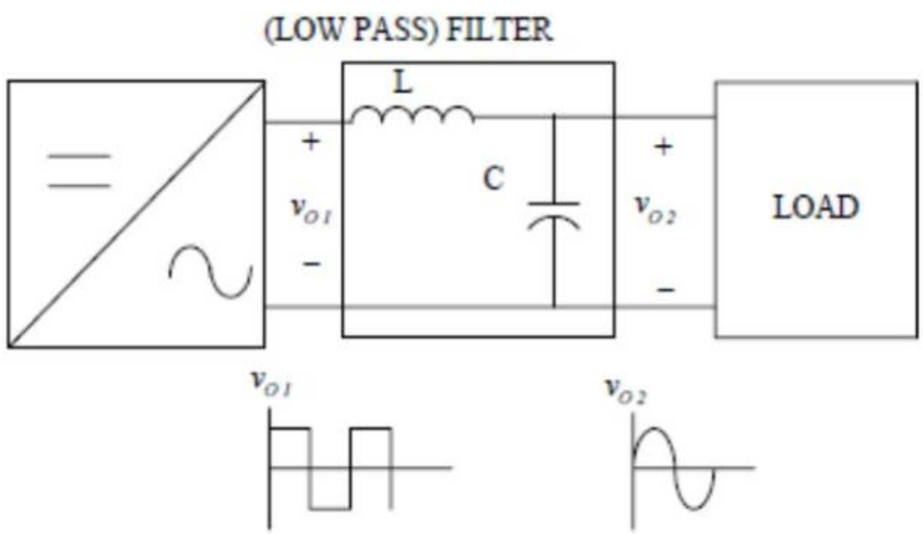


Figure 5.8 Low pass filter circuit

3. **Power ratings of Op-amps, L and C** available in the market are very low and are impractical for smaller scale dynamic charging systems.

4. **Specific Values of L and C** that have been calculated for the resonant frequency of 20kHz are hard to find in the market.

5. **High leakage and stray reactance of coil:** There are way too many unknown and unaccounted variables not used in calculating the values of passive elements required. Also many simple measuring equipment fail to measure with good clarity due to high interference of magnetic signals produced in the coil.

6. **Half-H bridge and Power Amplifier:** As previously mentioned, removing the transformer from the power unit is not possible when using a H-bridge inverter, because it fundamentally uses a center-tap transformer to operate. Thus a power amplifier can not be utilized in a half-H bridge inverter based power unit.

7. **Coil Design:**

   Analyzing which coil shape or design would be efficient for WPT. This involved simulations and research study for various coil designs, as was discussed in the methodology section.

6 FUTURE CHALLENGES AND OPPORTUNITIES

- **Implementation:**

Road infrastructure: Road infrastructure is one of the most important factors which facilitate EVs to penetrate the universal market and to be more widespread. Good road infrastructure permits easy installation and maintenance and decreases the implementation cost of wireless charging systems. As a result, governments and commercial organizations are encouraged to set up charging stations in order to popularize the use of electric cars. Most countries do not have the suitable infrastructure; therefore, these countries are developing short-term plans to enhance the road infrastructure to help spread the wireless charging of EVs.

In Germany, it is expected that the road infrastructure would need to be replaced during the next twenty years in order to be able to use wireless charging on a large scale, and this would help to develop electric vehicles and access to automatic vehicles. Project Forever Open Road is developing the next generation of optimized, adaptive roads for wireless charging designs and communication systems merged with them. Coils buried inside roads must meet the same regulations relating to the road incorporating them. There are two types of suitable roads for installing inductive charging pads. One of them is the traditional solid style road which is made up of a concrete section with 4 cm gradient overlaps instead of the base and binder courses which are available in the typical roads that are being constructed and developed these days. This typical road consists of a number of layers of rubble and a flexible structure consisting of a membrane, sub-layer, sub-base, main track, binding cycle, and 4 cm surface course. The transmitter coils are buried inside the main path of modern flexible road and inside the sub-base of the traditional solid road, and this ultimately affects the depth of the charging pad; in the traditional solid roads, the pad is placed at a lower depth. The air gap with the buried depth of the charging pad on the transmitter side represents the distance over which the power is transported. Thus, increasing the pad depth inside the concrete parts may cause problems in the power transmission process.

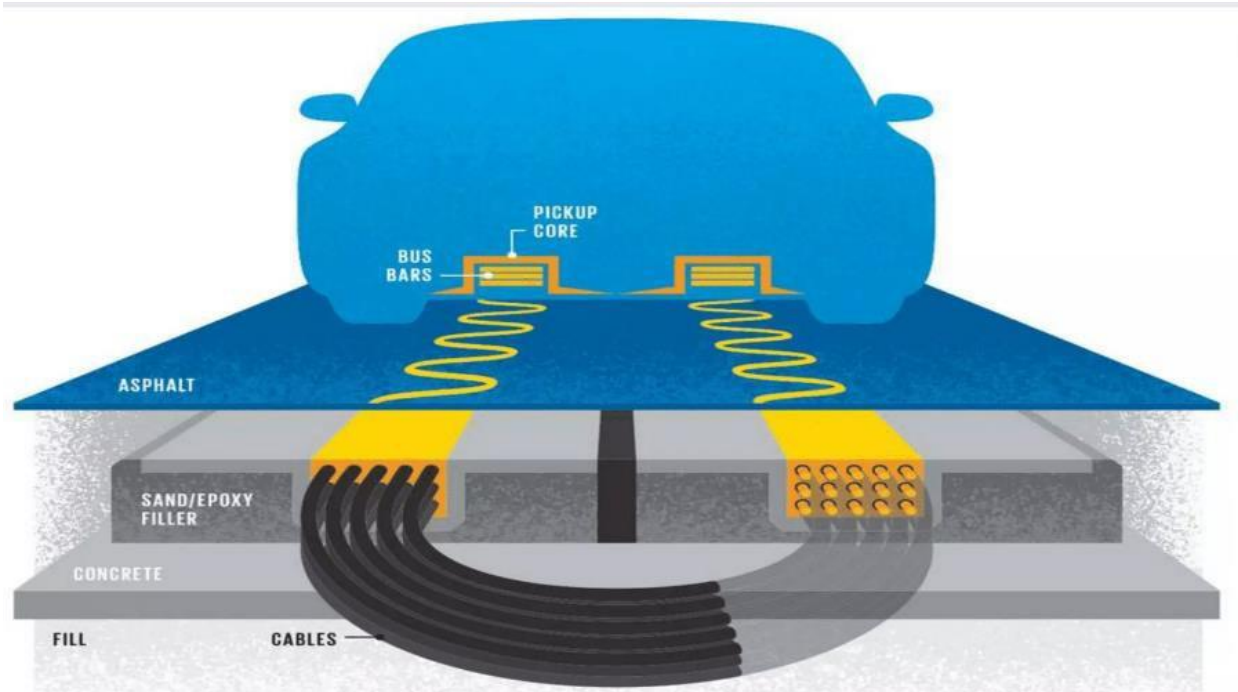


Figure 6.1 Road infrastructure

Interoperability: Additional efforts are needed to investigate the interoperable operation among various kinds of pad designs. How can the interoperability options be tested and estimated? Which models achieve interoperability principles with others? The effect of various implementation conditions for the transmitter pad (above-, flush-, and under-ground) on the interoperability concept of the IPT system must be explored, and the interoperability of different types of receiver pads with a static and dynamic transmitter considering the different integrations with the road must be investigated.

Durability: WPT systems will be implemented outdoors for general use, so they need to be robust enough to withstand the harsh environmental and extreme operating conditions. In addition, the method of pad integration with both the vehicle and road is an open question that requires extensive engineering effort.

- **Safety Concerns:**

There are concerns associated with the safety of the system. The first safety concern is related to EMFs; extra effort is required to investigate novel shielding designs, especially active and reactive shielding. Another safety concern is related to the heat produced in metallic objects next to the system, which requires an effective foreign metal object detection method. In addition, a living object detection method is necessary to prevent pets and animals accessing the hot region during operation. All the current foreign object detection techniques are exploring ways to detect the object and shut down the system. However, it is important to investigate what needs to be done after shutting the system down.

Wireless charging for EVs demands high electric power to transmit through a large air gap by magnetic induction. Accordingly, powerful EMFs are generated around the charging system while it is operating. These fields may exceed the maximum permissible limits established by the international standards and guidelines. These magnetic fields may have the potential to induce high field strengths in human tissues and organisms located in the vicinity of the WPT charging system. This increases the important safety issues such as the heat stress on the whole body, redundant heating of localized tissues, and damage to public health. Furthermore, these electromagnetic fields may have the potential to discontinue operation of the implantable medical devices that are found in the vicinity of the system. Therefore, all precautions must be taken into account when conducting the design and manufacturing steps to guarantee electromagnetic compatibility (EMC) with global standards. In addition, EMFs must undergo mandatory testing after manufacturing and installing the charging system inside the EV to ensure EMC before being put on the market.

- **Technologies:**

Cost: Extra efforts are needed to keep the system's cost low by using cost- effective materials (wires, magnetic cores, and shielding materials), manufacturing, and implementation processes. DIPT can mitigate the high cost of EVs by substantially reducing the onboard battery size. The lack of a charging infrastructure is currently the main impediment to DIPT. Therefore, efforts from the private sector and also from the government are required to work on improving the infrastructure in the hope of reducing the total cost of the dynamic charging system.

Communication system: Communication is essential in DIPT to ensure that the power transfers to the battery charging system in time or else the charging system is likely to fail. Therefore, the data exchange between the transmitter and the receiver must take place in actual time. In the ideal scenario, a real-time control system would be established to implement the control loop of the battery charging system. However, the control in DIPT systems gives good performance despite the delay caused by wireless communications. The wireless communication system needs to be improved to transmit data of the coupling factor between the receiver and transmitter sides for better charging, accuracy, security, and reduced delay time.

Fast Charging: There is a current need to design chargers that are able to bring the charging time down to less than 15 min. Therefore, investigating high-power wireless chargers (>200 kW) is a gap that needs to be filled. Novel pad designs with new magnetic materials, wires, and shielding are crucial so that the system can transfer high power efficiently at a reasonable cost and work at high misalignment conditions and with a larger air gap.

Sensor systems: It is necessary to achieve the development of the sensor systems and controllers that are used to detect EVs on the highways in DIPT with segmented coils to charge batteries without errors to increase total system efficiency.

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