Design of Wireless Charging of Electric Vehicles

Mohammed Waqas¹, Tanmayi M², Vaishali V³, Vandana N⁴ and Dr. Dhanalakshmi R⁵

¹²³⁴(BE students, Department of Electrical and Electronics, Dayananda Sagar College of Engineering Kumarswamy Layout, Bengaluru – 560078)
²³⁴(Professor, Department of Electrical and Electronics, Dayananda Sagar College of Engineering Kumarswamy Layout, Bengaluru – 560078)

Abstract: This paper presents the design and analysis of mutual induction based wireless charging for Electric Vehicles. Personal vehicles have become an inevitable part of our life. But most of these vehicles use petrol or diesel as fuel and hence there is immense emission of greenhouse gases which causes global warming which has become a major issue these days. Electric Vehicles are a very promising hope to reduce emissions of harmful gases. Charging of electric vehicles through rechargeable battery which can only be charged when the vehicle is parked has a greater mass thereby decreasing the efficiency of the vehicle. Thus, the concept of wireless power transfer is proposed, where a vehicle can be charged portably. The design calculations of transmitting and receiving coil in wireless charging is presented in the paper And also, performance analysis is carried out using experimental results.

Keywords: Electric Vehicles, wireless power transfer, charged portably, transmitting coil, receiving coil.

I. INTRODUCTION

To travel from one place to other humans have been using vehicles for transportation. Internal combustion (IC) engines are used to drive it. As the vehicle population is increased there is a vast increase in the environmental pollution rate.

In future days, the concept of pollution free transportation will be of focus. Due to increasing greenhouse gas radiation, and scarcity of petroleum products for upcoming year’s efficient use of electric vehicles and recharging them portably becomes important. Electric vehicle does not need petroleum products as fuel and the level of pollution caused is negligible when compared to regular vehicle. Hence, electric vehicles and efficient recharging process becomes the major concern. Main concern with electrical vehicles is its range and its charging time. At present state charging time is around 7-8 hours and Distance per full charge is about 200-250 km’s. Thus, the concept of wireless power transfer is proposed, where a vehicle can be charged portably. The reason for taking up this project is to make a model of wireless transfer of power for electric vehicle, which will enable dynamic charging in the electric vehicle, thereby increasing its range.

The proposed concept in our project is to have emitter coils on roads where the traffic moves really slow like toll gates, traffic signals, roundabout, traffic congested areas etc. A receiving coil attached to the belly of the vehicle will receive power from the transmitting coil and charge the battery. Electric vehicle consists of an electric motor, and generally a rechargeable battery which powers the motor.

II. LITERATURE SURVEY

The literature survey that we conducted helped us to understand different parameters and analysis to be made in order to carry out our project. It gave us information and parameters which had to be considered during our process of project.

Paper [1] emphasis mainly on, the need of wireless charging of vehicles. In addition to which it discusses about the charging stations of electric vehicles which include PV (Photovoltaic panels/Solar Panel) and wireless battery charger. It gives information about the QDQ (quad D quadrature) process of designing coil using JMEG FEM software.

Paper [2] mainly gives us the idea of various methods used to design the structure for wireless power transfer in electric vehicles. It discusses in detail about the analysis and simulation of various components involved in the design circuit of the model.

Various type of vehicles which work electrically like- manual Powered automobile (RPEVs) and Electric automobile (OEVs) are discussed, [3]. It also aims in discussing about the Solar Power Satellites (SPS) which are used in power transmission.

The available technologies of wireless transfer of power for electric vehicles are presented. [4]. It adds upon the information about wireless transformer structures with various ferrite shapes. This paper includes the...
investigation and stimulation made with the utilization of finite element method. It also gave us an idea of the latest developments in the area of wireless transfer of power and electric vehicles.

Paper [5] investigates the most recent development in functions and structure related studies of charging of wireless electric vehicles. This paper highlights on modeling, observations and procedure that is used to help and improve effectual and efficient working of transportation systems based on the wireless charging.

The changes brought about by the variety of the driving pace during remote charging and a thought regarding the electric vehicle charging number and the greatest driving rate on the scope of the framework are presented [6]. It is reasoned that the speed variety range can arrive at 20–60 km/h and charging power vacillation range can be inside 10–15%.

Paper [7] mainly talks about the various types of charging methods. The basic classification is done based on operating techniques into 4 types: Capacitive Wireless Charging System (CWCS), Permanent Magnet Gear Wireless Charging System (PMWC), Inductive Wireless Charging System (IWC), and Resonant Inductive Wireless Charging System (RIWC).

Analysis on “Wireless Charging Systems for Electric Vehicles”, according to Navigant Research there will be a growth by a compound annual growth rate (CAGR) of 108% from 2013 to 2022, achieving annual sales of slightly less than 302,000 units in 2022 in worldwide sales of equipment’s used to charge light duty electric vehicles are carried out [8].

III. PROPOSED PLAN

The figure 1 shows the block diagram of transmitter and receiver unit. The transmitting block consists of 12V SMPS, HF oscillator, MOSFET driver, and half bridge push pull inverter, HF transformer, transmitting coil. The receiver block consists of receiving coil, HF rectifier, filtering capacitor, buck boost converter, charge controller and DC motor.

COMPONENTS USED:
AC Power Supply
The supply for the wireless power transmitter is taken from AC220v source. SMPS AC-DC Converter Switching Mode power supply is used here to convert AC to DC. Here the input of the SMPS is 220v AC and output will be 12v DC.

HF Oscillator
High Frequency oscillator is designed using KA3525 IC. The IC circuit generates PWM switching pulses for driving the MOSFETs. Here the frequency of the oscillators set at 65KHz.

High Frequency Half Bridge Driver
High frequency converter consists of a high frequency oscillator which generates PWM pulses and drives the MOSFETs. Here two separate PWM pulses PWM1 and PWM2 are produced and supplied to the MOSFET gate.
HF Switching Transformer

Half bridge driver consists of a High frequency transformer which converts the DC current from the MOSFETs to a high frequency AC current. The primary of the HF transformer is connected to the MOSFETs and secondary connected to the transmitting coil.

Resonant Transmitter

The transmitter coil is designed with windings of copper coils which convert the high frequency oscillating electrical current into Electromagnetic waves resonating at a particular frequency.

Resonant Receiver

The receiver coil receives electromagnetic waves from the transmitter coil and converts into high frequency electrical output.

HF Rectifier

HF rectifier consists of fast switching rectifier diodes which converts HF voltage into DC voltage and filters the output voltage which is utilized by the vehicle motor.

Transmitting and receiver coil

A coupling circuit consists of a transmitting and receiving coils. The entire system processes through these coils. The efficiency of this coupling circuit gives the value of power in the receiver system.

IV. CIRCUIT DIAGRAM AND OPERATION

Power Transmitter block

The figure 2 shows the circuit diagram of transmitter block. It includes switching MOSFETs, HF transformer which converts low frequency into high frequency signals for an efficient induction. It consists of IC KA 3525 which produces the power switching pulses for the MOSFETs.

HF Transformer

The figure 3 shows a HF transformer it increases the input frequency into higher frequency signals and increases the voltage level for efficient induction.
Power Receiver block

fig.4. Receiver Block

The figure 4 shows the circuit diagram of the receiver block. It consists of a rectifier, buck boost converter and DC motor. The AC signals received by the receiver coil is converted to DC signals by the rectifier and it is fed to the DC motor the DC motor is mechanically coupled to the vehicle wheels which rotates making the vehicle accelerate.

HF rectifier

Fig.5. HF Rectifier

The figure 5 shows a HF rectifier which converts the AC signals received by the receiver coil into DC signals which is in turn coupled to the vehicle wheels through a DC motor.

OPERATION:

The system uses inductive coupling. The main factor to be considered while designing is the target of the power supplied to the system. The range of values of current and voltage and the frequency at which they operate depends on the power supplied to the system. Due to system being wireless and a public service system, the power transfer system is installed in a road with the use of resonant frequency. The frequency of operation of the wireless system is around 10-100KHz. In the system, the power supplied is 100KW and the resonance frequency is about 78KHz. The circuit is similar to that of the transformer model. The circuit has a high value of mutual inductance \( M \), which is more effective in the power transfer in the vehicle. The value is obtained by using \( L_1, L_2 \) inductances, the coefficient of coupling as given in the formula,

\[
M = k\sqrt{L_1 L_2}
\]  

(1)

The system comprises of a transmission and receiver part. Our project makes use of the following components: on the transmitting unit: 12V SMPS, HF oscillator, MOSFET driver, half bridge inverter, HF switching transformer, transmitting coil. On the receiver unit: receiving coil, HF full bridge inverter, filtering capacitor, buck boost converter, charge controller, DC motor. Initially 220v AC supply is converted into 12V DC by an adapter. This is fed to a push pull inverter through oscillator and MOSFET driver circuit later 12V DC is converter to 15V AC and is fed to the HF transformer. The transformer step-up the voltage level to 28.7AC, 192.8KHz pulsating AC waves.
V. DESIGN ANALYSIS

DISTANCE BETWEEN THE COILS

By changing distance between the two coils, two factors change, one the mutual inductance and other being coefficient of Coupling. Mutual Induction is the EMF induced in the second coil when current flows in the first coil. Coefficient of coupling is the ratio of flux linking in the second coil to the flux emitted from first coil.

Table I: Theoretical Values of coefficient of coupling and distance between the coils

<table>
<thead>
<tr>
<th>K</th>
<th>Distance between the coils</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>0.85</td>
<td>5</td>
</tr>
<tr>
<td>0.35</td>
<td>10</td>
</tr>
<tr>
<td>0.2</td>
<td>15</td>
</tr>
<tr>
<td>0.15</td>
<td>20</td>
</tr>
<tr>
<td>0.1</td>
<td>30</td>
</tr>
<tr>
<td>0.1</td>
<td>40</td>
</tr>
</tbody>
</table>

The Theoretical Values of coefficient of coupling and distance between the coils is tabulated in the above table I.

Fig.6: Graph between coupling coefficient k vs distance between the two coils using theoretical values. The figure 6 shows the graphical depiction between coupling coefficient k and distance between the two coils using theoretical values.

Table II: Practical values of coefficient of coupling and distance between the coils

<table>
<thead>
<tr>
<th>K</th>
<th>Distance between the coils</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.75</td>
<td>0</td>
</tr>
<tr>
<td>0.55</td>
<td>3</td>
</tr>
<tr>
<td>0.35</td>
<td>5</td>
</tr>
<tr>
<td>0.2</td>
<td>10</td>
</tr>
<tr>
<td>0.1</td>
<td>15</td>
</tr>
<tr>
<td>0.02</td>
<td>30</td>
</tr>
<tr>
<td>0.01</td>
<td>40</td>
</tr>
</tbody>
</table>

The practical Values of coefficient of coupling and distance between the coils is tabulated in the above table II.
The figure 7 shows the graphical depiction between coupling coefficient $k$ and distance between the two coils using practical values. It is generally thought that if coefficient of coupling is better, better output power is received, which is not the case. Depending upon the parameters like inductance of the two coils switching frequency and input voltage, an optimum coefficient of coupling can be found using the formula:

$$k_{opt} = \frac{R_1 (R_2 + R_L)}{\sqrt{w L_1 L_2}}$$  \hspace{1cm} (2)

Where, $R_1$ is resistance of transmitter coil, $R_2$ is resistance of receiving coil, $R_L$ is resistance of the load, $w$ is the switching frequency, $L_1$ is inductance of transmitter coil, $L_2$ is inductance of receiving coil.

Using optimum value of coupling coefficient, we can find the optimum distance between the two coils at which maximum power transfer will occur using the formula.

$$d_{opt} = \sqrt{\frac{k_{opt}^2}{r_1^2} - 1} r_1 r_2$$  \hspace{1cm} (3)

Where $r_1$ is radius of transmitter coil, $r_2$ is radius of receiving coil.

**SWITCHING FREQUENCY**

<table>
<thead>
<tr>
<th>Switching frequency (kHz)</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>40</td>
<td>35</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>60</td>
<td>72</td>
</tr>
<tr>
<td>70</td>
<td>67</td>
</tr>
<tr>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td>90</td>
<td>40</td>
</tr>
<tr>
<td>100</td>
<td>20</td>
</tr>
</tbody>
</table>

The values of switching frequency corresponding to its efficiency obtained during the analysis is tabulated in the table III.
COIL AND INDUCTANCE CALCULATIONS

- Inductance calculation of the transmitting coil:

\[
L = \frac{(d^2 + n^2)}{(18d + 40l)}
\]

(d = diameter (11.4 inches), L = length (1.2 inch), n = number of turns of the coil) 

\[d=11.4 \text{ inches}, l=1.2 \text{ inch}, n=40 \text{ turns 8 SWG copper wire} \]

\[L = 3014.01455 \mu \text{F} \]

- Frequency calculation of the transmitting coil:

\[
2\pi f = \frac{1}{\sqrt{LC}}
\]

(L = Inductance C = Capacitance) 

\[L=3014.01455\mu \text{F}, C=0.229\text{nF} \]

\[f = 192.8 \text{ KHz} \]

- Inductance calculation of the receiver coil:

\[
L = \frac{(d^2 + n^2)}{(18d + 40l)}
\]

(d = diameter (11.4 inches), L = length (1.2 inch), n = number of turns of the coil) 

\[d=11.4 \text{ inches}, l=1.2 \text{ inch}, n=40 \text{ turns 8 SWG copper wire} \]

\[L = 3014.01455 \mu \text{F} \]

- Frequency calculation of the receiver coil:

\[
2\pi f = \frac{1}{\sqrt{LC}}
\]

(L = Inductance C = Capacitance) 

\[L=3014.01455\mu \text{F}, C=2.1518\mu \text{F} \]

\[f = 63.3 \text{ KHz} \]
HARDWARE SETUP

Fig 9: Transmitting unit

The figure 9 depicts the transmission circuit unit. It consists of switching MOSFETs, HF transformer which converts low frequency into high frequency signals for an efficient induction. It consists of IC KA 3525 which produces the power switching pulses for the MOSFETs and HF oscillator.

Fig 10: Transmitting coil

The figure 10 shows the transmitting coil made up of 40 turns 8 SWG copper wire.

Fig 11: Receiver coil

The figure 11 shows the receiver coil made up of 40 turns 8 SWG copper wire.

Fig 12: Receiver unit

The figure 12 shows a receiver unit. The ac signal received by the receiving coil is fed to the dc motor after rectification process.
VI. CONCLUSION

This paper presents the design of transmitting and receiving coil in Wireless charging based Electric Vehicle. We conclude by saying that we have succeeded in fulfilling the objective of this project. We assure that wireless charging of electric vehicles is effective and it’ll greatly help in the reduction of greenhouse gases and global warming. This system enables the vehicle to be portably charged.

By making various combinations of different values of inductor coils, efficiency of wireless power transfer was studied. It was found that 3014.0145uH inductor coils as transmitter and receiver coil had the best efficiency of 72% and at frequency of 63.3Khz. It was found that circular co-axial coils give the best result as the transmitting and receiver coils. The project uses 8 SWG 40 turns copper coil for designing the transmitting and the receiver coil. The project concludes that mutual induction can efficiently be used to transfer power wirelessly. Thus, the model confirms the possibility of using wireless power transfer for realizing dynamic charging in electric vehicles.

VII. REFERENCES

5. Young Jae Jang, “Survey of the operation and system study on wireless charging electric vehicle systems.” Transportation Research, Department of Industrial and systems Engineering, KAIST.
7. Kiranmai Momidi, “Wireless electric vehicle charging system.” July 12, 2019