Design and Implementation of Wireless Charging for Electric Vehicle

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Abstract:

Nowadays, electric vehicles are becoming more popular due to the consideration of fossil fuels and pollution caused by conventional vehicles. One of the problems associated with electric vehicles is the availability of charging stations. At present, the electric vehicle has been charged at home or in the fleet at the owner's place of business. In the future, the vehicle will be charged at a variety of places, like stores, streets, etc., and in places of interest. The wireless charger for an electric vehicle can attract new customers and encourage people to buy an electric vehicle. Wireless charging technology is the most convenient, reliable, robust, spark-free, and user-friendly. This technology makes a common charger for all types of electric vehicles. It is also helpful for the future technology of self-driving vehicles. In wireless charging, the vehicle is charged by just parking it over the charging pad.

In this paper a detailed description of the theory behind the inductive power transfer was discussed. The proposed model circuit was designed using the MATLAB software. The power obtained from the system is 967.5W. The coil was designed with the help of ANSYS software. The need for the compensation capacitor and high frequency was explained.

Keywords: Wireless Charging, Inductive coupling, Electric vehicle, Transmitter Coil, Receiver Coil, Electromagnetic Induction, Magnetic field

1.Introduction:

An electric vehicle operates with the help of an electric motor instead of an internal combustion engine. The power supply for the electric motor is supplied by the battery. The design of the battery is not easy; many aspects like high energy density, high power density, affordable cost, safety, and reliability have to be achieved simultaneously. The lithium-ion battery is considered to be the solution for an electric vehicle. The battery capacity of an EV with wireless charging could be reduced by about 20% or less than that of EV today. Inductive coupling is a method by which power is transferred from the transmitter coil to the receiver coil with the help of a magnetic field. It is the technology of transferring power from one device to another without any physical contact. This enables an automated charging process for the vehicle without the intervention of the driver by eliminating the charging cable. There are two types of inductive charging: static and dynamic. The goal of static charging is to charge the vehicle when it is parked in the charging slot. The receiver has to be properly aligned with the transmitter to achieve maximum efficiency.

2. Related Works:

The transfer of wireless power was discovered by Nikola Tesla. He was the person who invented the concept of WPT. This technology was improved by other scientists and was applied in many applications, like wireless mobile charging, electric toothbrushes, electric vehicles, etc [1].

The authors in [2] describe the basic components involved in inductive charging. It also gives a theoretical background on inductive coupling, and experimental work on the coupling is performed and an efficiency of 72% is achieved. The paper also illustrated the theory of WPT. The design involved in inductive charging and the concept of electromagnetic induction are explained, and a miniature model of inductive charging for electric vehicles is demonstrated. The model explains that there is a transmitter and a receiver coil for transmitting power wirelessly. The ac supply from the grid is fed to the primary coil and fed to the rectifier to rectify it to dc, which is regulated and used for charging the lithium-ion battery [3].

The computational theory behind the electromagnetic is applied to the analysis and design of the inductive power transfer (IPT) system for stationary charging of an electric vehicle. The output dc power obtained from the system is 1500W and the frequency applied to the system is 22 kHz. The author simulated the coupled coil with the help of 3D FEA ANSYS Maxwell software. The components used for simulating the system are a high frequency inverter on the transmitter side, a resonant capacitor, a bridge rectifier on the receiver side. The difference in efficiency is due to the loss occurring in the coil [4].

3.ELECTRIC VEHICLE CHARGER

The electric vehicle is a vehicle that uses one or more electric motors for propulsion. The electric motor can be powered by a battery or fuel cell. The battery is charged from the external source using wired or wireless charging. The fundamental unit involved in the electric vehicle charger is shown in figure 1.

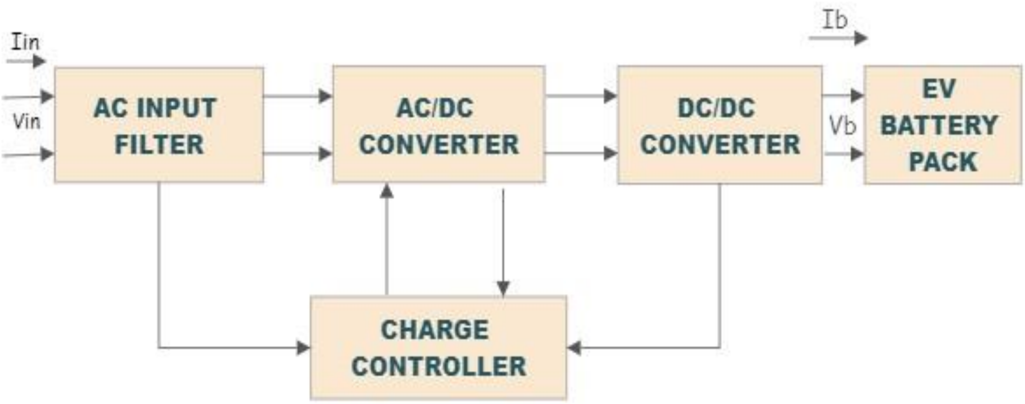

Figure 1 Fundamental Unit of Electric Charger

RESONANT INDUCTIVE POWER TRANSMISSION

The basic principle involved is electromagnetic induction. The ac current flows through the transmitter coil. The ac voltage flowing creates a magnetic field around the coil. This induces an emf voltage in the receiver coil. The resonant inductive power transfer can transfer power for a longer distance than inductive power transfer. The schematic circuit diagram of the inductive power transfer circuit is shown in figure 2.

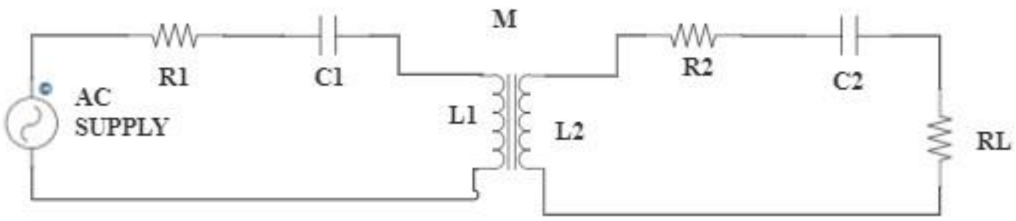

Figure 2 Inductive Power Transfer Schematic Circuit Diagram

C1=Compensation capacitor on primary side
C2=Compensation capacitor on secondary side
L1=Self inductance of coil on primary side
L2=Self inductance of coil on secondary side
M=Mutual inductance between two coils

4.SYSTEM DESCRIPTION

The block diagram in Figure 3 shows a complete circuit diagram that is simulated with the help of MATLAB/SIMULINK.AC supply from the grid is obtained as input, and the AC is converted to DC with the help of a rectifier. The wireless power transfer has to be done at a high frequency. The rectified DC supply will be fed into the high-frequency inverter. The LC circuit is designed in such a way that it oscillates at a high frequency. The maximum power transfer can be achieved using this method. The output from the secondary coil is fed into a rectifier and converted into DC. This DC voltage is stepped down with the help of a buck converter. The DC voltage obtained from the buck converter is used to charge the battery.

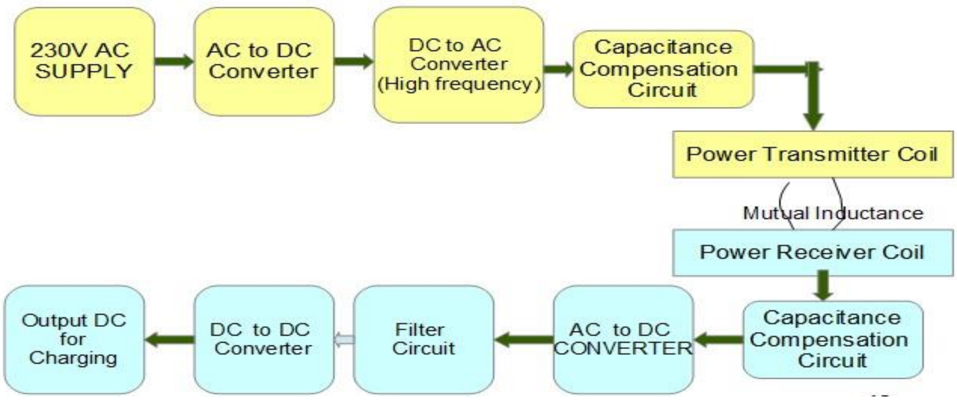

Figure 3 Proposed Model of Resonant Inductive Power Transfer System

The important parameters involved in this model are compensation capacitors,inductance of the coil,excitation current for the coil, and voltage needed at the output. The parameters needed for designing a resonant inductive power transfer were calculated using the formula given in the equation.
The inductance of the transmitter and receiver coils is calculated using equations (1) and (2), where L1 is the inductance of the transmitter coil and L2 is the inductance of the receiver coil. The self-inductance of

each coil is an important parameter in designing the model. The inductance value that offers power transfer between the coils is denoted by M, which is known as the mutual inductance. The mutual inductance is calculated using the equation (3).

$$L1=\frac{M^2}{L2k^2} \quad (1)$$

$$L2=\frac{QsRl}{wo} \quad (2)$$

$$M=\frac{I2Rl}{I1wo} \quad (3)$$

The other parameters used in the proposed model are the quality factor,coupling coefficient, and primary and secondary currents. The coupling coefficient is one of the important factors in determining the mutual inductance of the coil, denoted by k, whereas Qs is the quality factor of the receiver coil. The coupling coefficient should be less than the critical coefficient, which is calculated using the equation (4). The RMS values of current in the transmitter and receiver coils can be calculated with the help of equations (5) and (6). The load resistance Rl is calculated using the equation (7).

$$kc < \frac{1}{Qs\sqrt{1-\frac{1}{4Qs^2}}} \quad (4)$$

$$I1=\frac{Po}{V1} \quad (5)$$

$$I2=\frac{V2}{Rl} \quad (6)$$

$$Rl=\frac{Vo^2}{Po} \quad (7)$$

The capacitor is required to maintain a resonance frequency between the coils. The capacitor act as a compensation for a low power factor which is caused due to the high frequency. The value of compensation capacitor needed in the transmitter and receiver side can be found using the equation (8) and (9).

$$C1=\frac{1}{wo^2 L1} \quad (8)$$

$$C2=\frac{1}{wo^2 L2} \quad (9)$$

The WPT principle is based on two coils isolated by air gap. They are many design available for the coil and the coil design of the transmitter and receiver improves the system performance. The system performance is impacted by the coil-to-coil relative motion,addition of materials and coil structure parameters. In this circular coil is designed using Ansys electronic software. The circular coil has the advantage of having uniform flux distribution. This uniform power transfer reduces the stress on the power electronics part of the secondary side of the system

Self inductance of the coil is as follows

$L=N^2(Dout+Din)^2/8(15Dout-7Din)2.54$

N=Number of turns

Dout=Outer diameter in mm

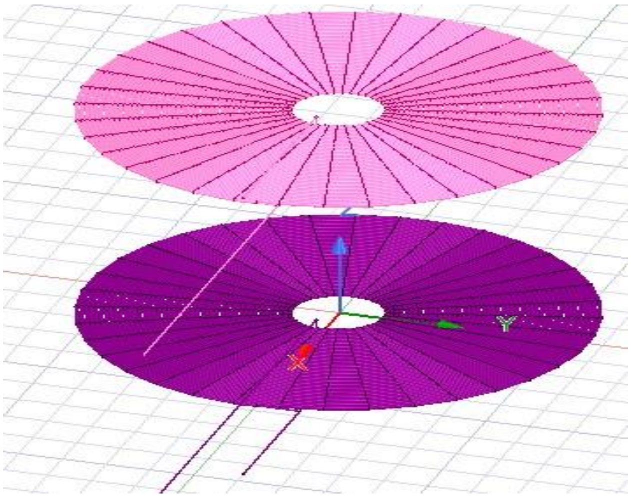

Figure 4 Coil design in ANSYS

Din=Inner diameter in mm

5.SIMULATION AND EXPERIMENTAL RESULTS

In the supply side there are rectifier with filter,inverter, compensation capacitor and primary coil. The AC supply applied in this model is 230Vac. The 230 V AC is supplied from the grid. Then this AC Supply is converted into DC waveform using rectifier. The DC waveform is then converted into high frequency AC square waveform. The compensation capacitor is to attain maximum efficiency by improving the low power factor which is caused by high frequency.

The vehicle side IPT consists of rectifier with filter, compensation capacitor,Dc-Dc converter, battery and Secondary coil. The magnetic field formed by the AC in primary coil induces a voltage in the secondary coil. The AC voltage obtained in the secondary coil is converted into DC using rectifier. The DC Voltage is then stepped down to the DC voltage needed by the battery. The DC voltage is then subjected to the battery. The output power obtained is less than input power because a loss occurs in the coil and inverter due to high frequency.

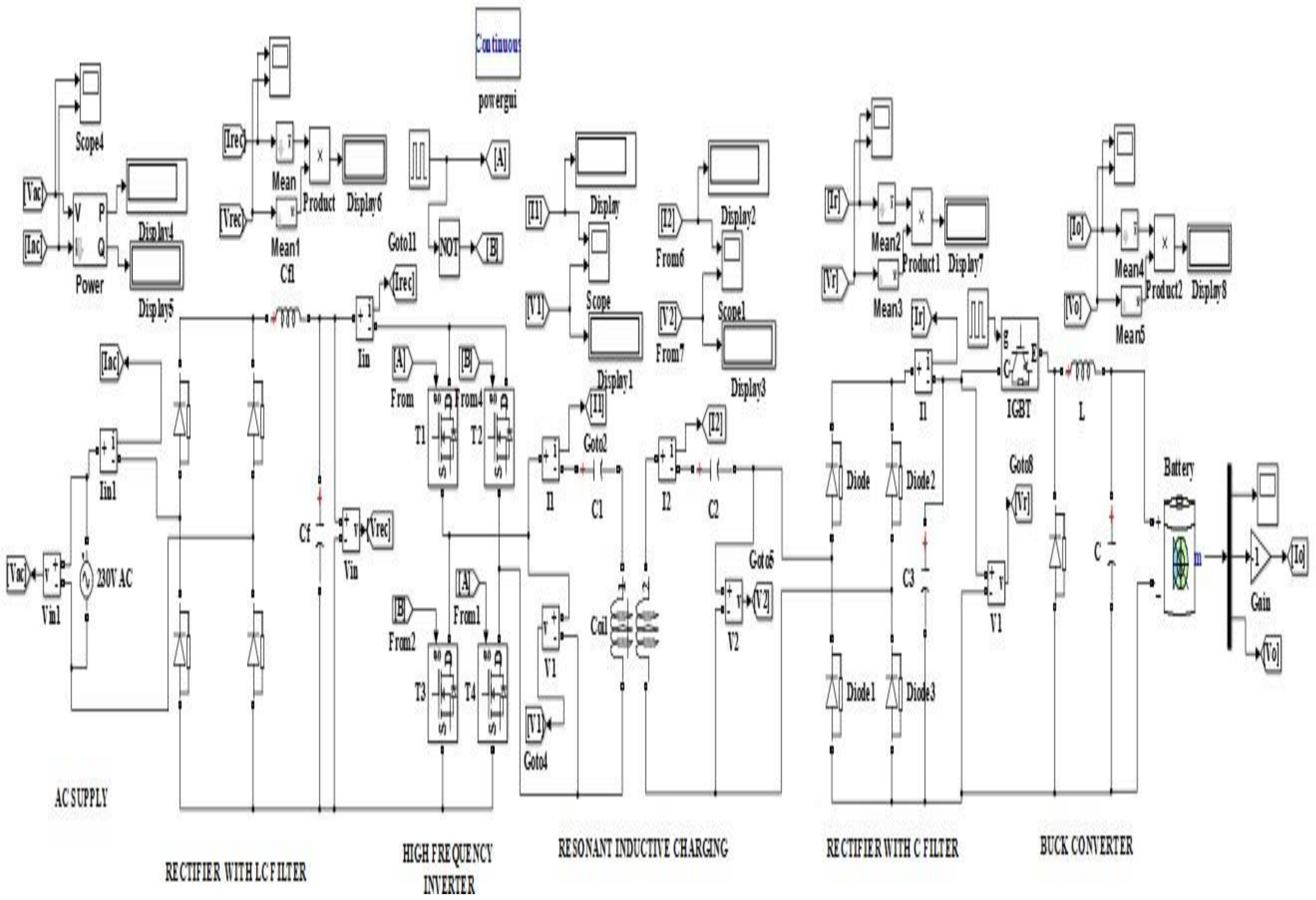

Figure 5 Simulation diagram of designed resonant IPT

The list of parameters obtained from the equation are summarized in the Table 1

Table 1 Design Parameter Value of the Proposed System

PARAMETER	VALUES
L1(uH)	420.96
L2(uH)	420.96
M(uH)	210.48
C1(nF)	37.61
C2(nF)	37.61
Resonant frequency f(kHz)	40
K,coupling coefficient	0.5
Qs,Quality factor	1.5
D	0.29
L(uH)	500

C(uF)	170

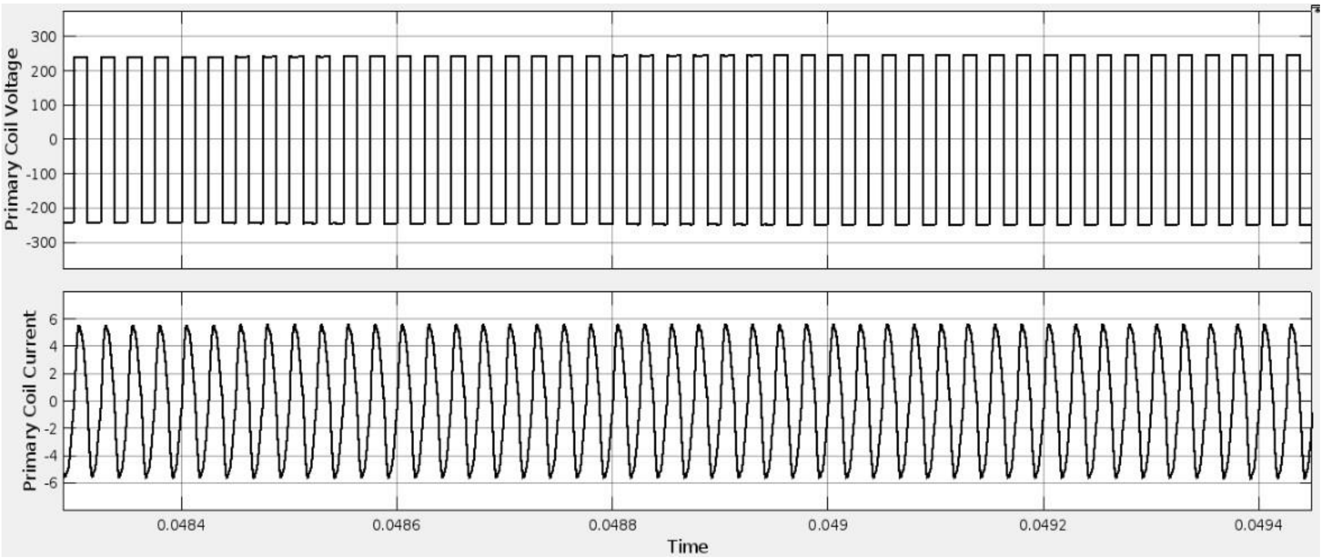

Figure 6 Primary Side Voltage and Current Waveform

The transmitter side voltage and current waveform is shown in the figure 6.

The voltage transmitted by the transmitter approximately 230V and 4.347A respectively. The voltage waveform is square and the current waveform is sinusoidal. The power transmitted is 999.81W.The

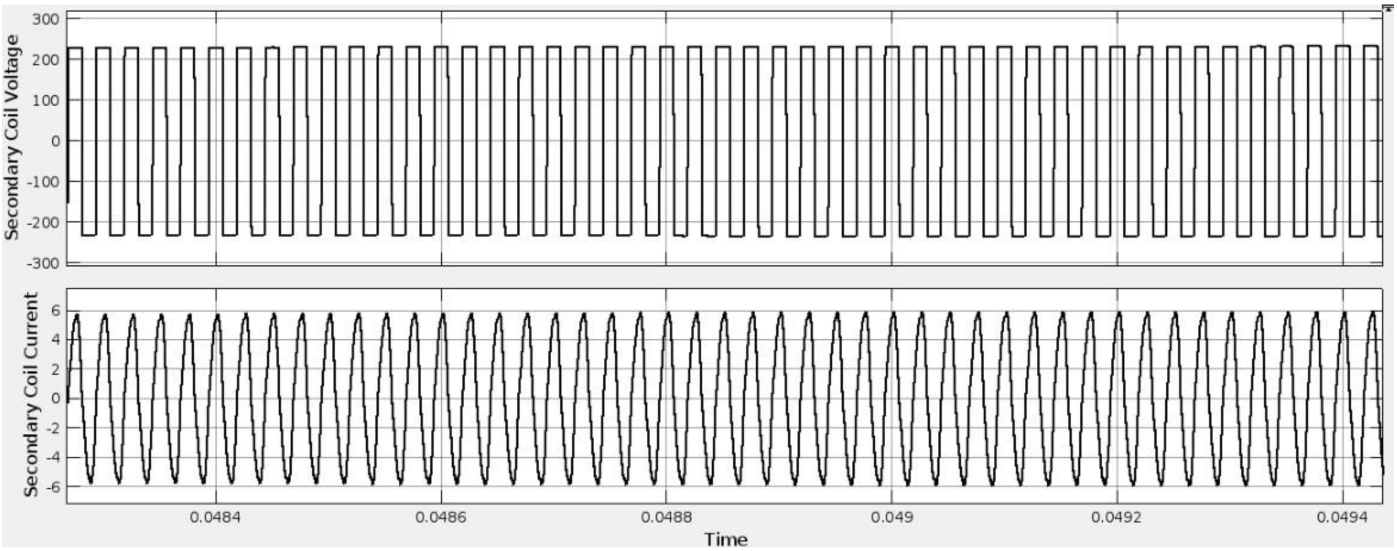

Figure 7 Secondary side Voltage and Current Waveform

receiver side voltage and current waveform is shown in the figure 7.

The voltage transmitted by the transmitter approximately 226V and 4.347A respectively. The voltage waveform is square and the current waveform is sinusoidal. The power transmitted is 982.422W.The output voltage and current obtained from the buck converter is shown in the figure 8.

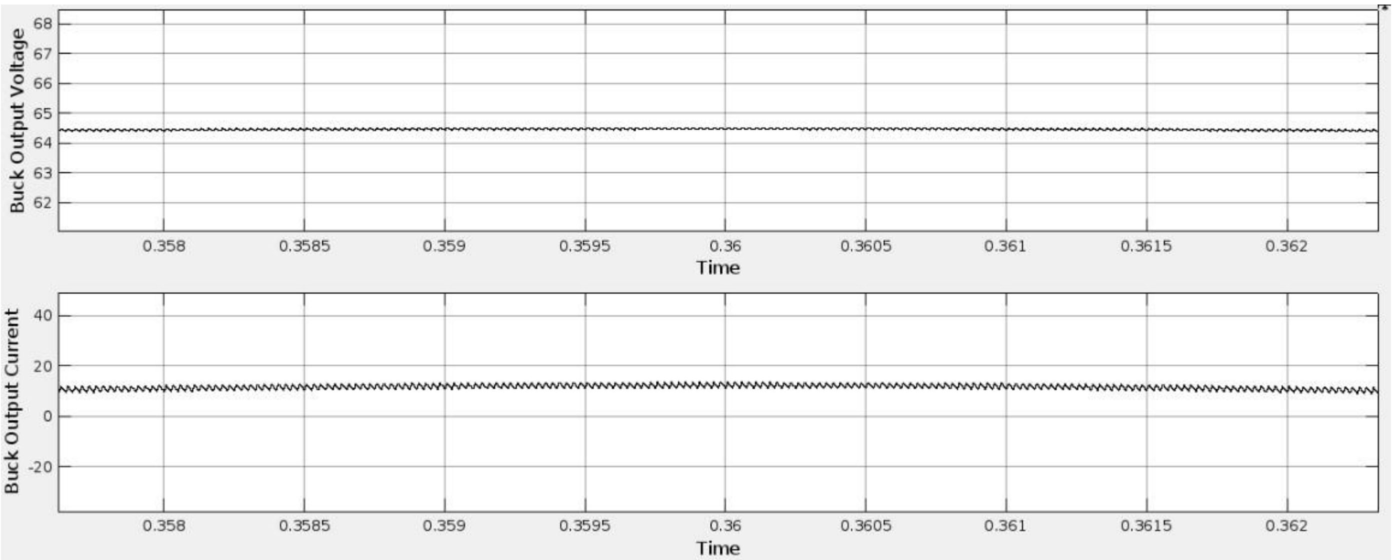

Figure 8 Buck converter output waveform

The output obtained from the buck converter is used to charge the battery. In the buck converter the DC voltage is stepped down from 226V to 64.5V. The figure 9 shows the state of charge of the battery. The table 2 shows the specification of battery

Table 2 Battery specification

Battery type	Lithium-ion battery
Battery Voltage	60V
Battery Capacity	20AH
Battery SOC	30.00%

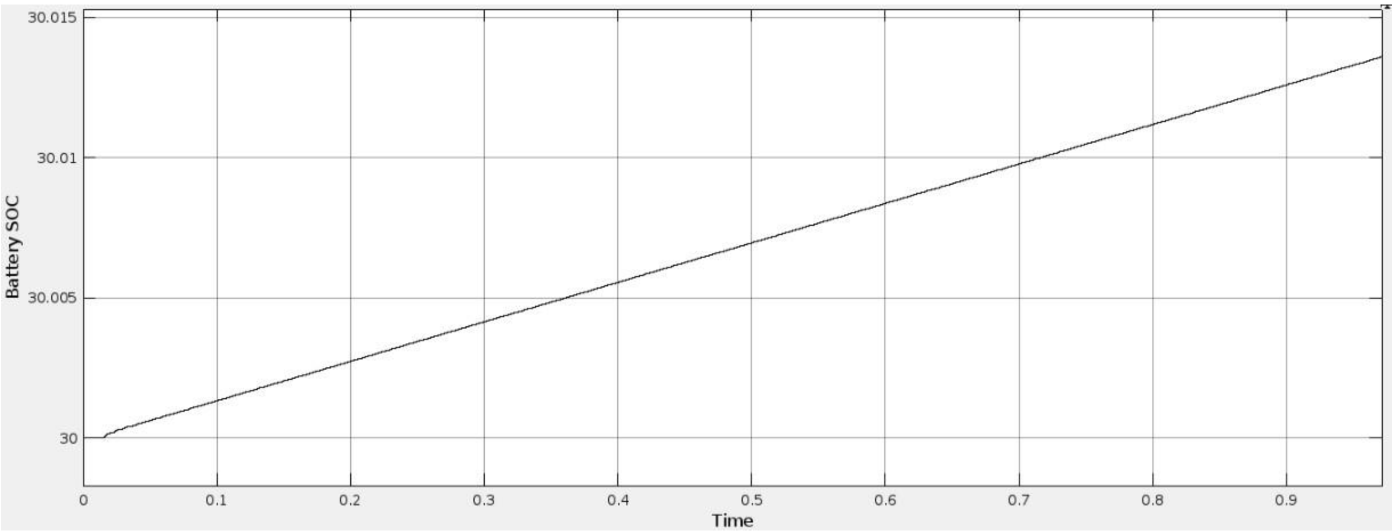

Figure 9 SOC of the battery

It is clearly seen that the SOC of the battery increases,this indicate the charging state of the battery. So by using resonant inductive charging the battery can be charged by just parking in a parking lot.

CONCLUSION

The coil was simulated using ANSYS software, and the calculation of the inductance was carried out. The proposed system was implemented with the help of a MATLAB/SIMULINK software diagram. A power of 982.44 W is transferred from the primary to the secondary coil. A power loss of 17.388 W occurred in the coil. According to the results, the transmitted power efficiency from the primary coil to the secondary coil is around 98.26%. There is a loss of 1.74%. The power received by the battery is 967.5W. The overall efficiency of the system is 87.95%.

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