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Model Based Implementation of Wireless Power Transfer System for Charging of E-Vehicles

Alok Kumar Mohanty*
Department of Electrical Engineering, Techno Main Salt Lake, Kolkata, India.
**Corresponding author*: alokmoh@gmail.com, *ORCiD*: 0000-0002-9882-6040
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***Abstract* — The popularity of electric vehicles has been increasing day by day due to the effect of the pollution caused by the fossil fuels. In the present scenario the difficulty arising in the use of the electric based transportation is the unavailability of the charging stations. So wireless charging system have emerged as one of the solutions for charging of electricity based vehicles. Wireless based electric vehicles come with an opportunity of charging those vehicles that can have the priority of not having charging plugs. Wireless charging technology comes with an option of spark free operation, reliable and user friendly as compared to the plug charging option. This technology makes use of a common charger that can be used for all types of electric operated vehicles. Wireless power transfer technology requires design of inductive coils which involves proper selection of inductances values. A high frequency full bridge converter has to be tuned for wireless power transfer between the transmitter and receiver coils. This paper presents an effective way of charging electric vehicles that has been implemented in Matlab/Simulink simulations. Rigorous simulations were carried out and analysis were conducted to evaluate the system's performance.**

Keywords— Wireless charging, Rectifier, Inverter, Mutual inductance, Li-ion battery.

I. INTRODUCTION

Electric vehicles have an important role to play in this present scenario to make a transition to a more user friendly and pollution free environment. As with the use of electric vehicles, carbon emissions are lowered and as traditional vehicles depends on fossil fuels. On the contrary electric vehicles reduces pollutants thereby improving power quality. Integrating electric vehicles with the present scenario requires intelligent charging systems which will ensure environment and economic stability.

As far as electric vehicles are concerned they use a motor instead of an internal combustion engine as used in traditional vehicle. The charging systems of an electric vehicle is one of the regions where the potential of wireless charging lies the most. The different charging methods can be broadly classified as inductive, conductive and wireless. Many on board and off board chargers have been developed as a conductive charging system using DC and AC systems. Electric vehicle charging depends upon the rate of power transfer from charging stations. The traditional methods of charging involve using a plug in charging systems also referred as a conductive charging stations. The traditional methods employ a heavy wire for charging and connectors as well. During occurrence of fault which may occur due to high temperature or in the charging itself, it may prove to be fatal of the personnel handling this. Also alternatively a person can use already charged batteries if the vehicle has to be driven for long distances but the batteries also have certain disadvantages such as heavy weight and not economical.

On the other hand, wireless power transfer and its practical implementations are widely investigated now-a-days for their potential applications in charging of electrical vehicles. Some of the advantages of wireless power transfer are safe operation, easier and flexible to use. The wireless power transfer system is considered easier to implement and safer as compared to traditional wired chargers due to absence of wire for transfer of energy from the source to the load. The charging system by wireless technology can be classified into fixed and dynamic charging. Electric vehicles are charged using wireless technology applying inductive coupling method. The input of the charger is connected to a power supply which is connected to a transmitter whereas the receiving end is connected to a load. The primary unit consists of a AC-DC converter followed by a high frequency inverter. The secondary segment consists of a diode rectifier and a chopper

In this paper, wireless power transfer technology involving mutual inductance with respect to a high frequency inverter have been implemented in Matlab/ Simulink Platform. The high frequency inverter operating at high resonant frequency is used to supply the primary coil of the transmitter. In the first part of the paper literature review carried out for implementing the model have been presented. In the subsequent parts the modelling, results and discussions have been presented

II. LITERATURE REVIEW

The wireless power transfer is more convenient, safe to use and more dependable as compared to conventional wired method of charging.as it uses no power to transfer electrical energy from source to load. The different types of charging involve magnetic charging, inductive charging and capacitive type charging. In an AC conductive charging the charger has to be directly connected to the battery management system and it does not require any extra mechanism for charging. On the other hand, DC charging also referred as fast charging involves extra mechanism. Dynamic inductive charging is another method of wirelessly powering an electric vehicle.

The following literature were undergone during the implementation of this work. Peter Joseph *et al.* [1] have presented a method of charging of low powered vehicles. The charger is optimized with current source inverter at the input end rather than voltage source inverter and series type compensation. Chathuranga M. *et al.* [2] has implemented a wireless power transfer technique which is strongly coupled magnetic resonance and is capable to transfer energy over short distance. Siqi Li *et al.* in [3] has presented a review of wireless power transfer for charging electric vehicles. A detailed analysis of different circuit components like power electronics converters and power control devices are presented in this paper. Songyan Niu *et al.* in [4] have discussed the background of wireless power technologies, its coupling configuration and also the various types of compensation topologies. Otchere Peter Kweku in [5] has presented one method that was being implemented for charging of mobile phones. The paper gives a fair idea about how to design an inductive coupling, microwave power transfer etc. Nandagopal S. *et al.* in [6] have designed and implemented a wireless method of power transfer in Matlab software. The system incorporates resonant magnetic coupling method for energy transfer. Xu Liu *et al.* in [7] has proposed a new approach for wireless power transfer which was considered more efficient as compared to series compensated wireless power transfer system.

Muhammad Amjada *et al.* [8] have reviewed the various methods and techniques used for charging electric vehicles. At first the generalised techniques used for wireless power transfer are discussed which comprises of capacitive and inductive power transfer and then he presented different wireless charging systems foe electric vehicles H. Feng *et al.* [9] have given a detailed review of wireless charging system for high power transfer application. Many high power wireless charging is presented and reviewed with respect to compensation network, power electronic converters and control strategies. R. González Ayestarán *et al.* [10] have presented that the electrical energy can be transferred from the source to the destination using near field and far field transmissions. For near field applications capacitive or inductive coupling medium are mostly used that is non radiative electric in magnetic or electromagnetic field. For far fields wireless power transfer system may be optical, acoustic or microwave. Abhishek Ranjan *et al.* [11] have presented a design of a high-frequency power converter based wireless battery charged for efficient transmission of electricity

III. METHODOLOGY FOR MODELLING OF WIRELESS POWER TRANSFER SYSTEM

The methodology to be carried out for implementing this model of wireless charging of electric vehicles employing high frequency inverter have been carried out as per the following steps.

A. Primary Side Topology

The source side rectifier consists of diode rectifier which is made up of snubber circuit resistance and capacitance. This diode is capable to conduct the values of current which changes from mA to a few kA and voltages up to a few kV.

A. *B. Secondary Side Topology*

The secondary side circuit consists of a transmitting coil with compensation capacitor, a vehicle side rectifier circuit with a smoothing capacitor and a battery to be used in the electric vehicle. The function of the smoothing capacitor is to reduce the ripples present on the load side. A diode rectifier is used to rectify the output from the transmission coil to DC which is used to charge the electric vehicle battery.

IV. CONFIGURATION OF THE WPT SYSTEM

A. Source Side Rectifier

The source side rectifier consists of diode rectifier which is made up of snubber circuit resistance and capacitance. This diode is capable to conduct the values of current which changes from mA to a few kA and voltages up to a few kV.

A. *B. High Frequency Inverter*

A high frequency inverter generates AC waveforms by the use of power devices at higher frequencies. The inverter bridge may be built up of

IGBTs or MOSFETs and these switches turn on and off to produce high frequency pulses. The LC filter smoothens the pulses into sinewave AC output. The output high frequency depends upon how fast the switches are turned on and off.

C. Resonant Inductive Charging

Electromagnetic induction forms the basis on which resonant inductive charging is done. After proper rectification and inversion, the ac current is fed to the transmitter coil. A magnetic field is created around the coil when ac voltage flows through the coil. Due to this there is an induced electromotive force in the receiver coil. A resonant inductive charging can transfer power for a longer distance as compared to an inductive power transfer.

D. Rectifier with Capacitor Filter

The function of rectifier is to convert the AC input to required DC. The DC that is obtained is not constant but varies with time and this fluctuating and DC cannot be used for charging the battery. To counter this difficulty to get a smooth DC a filter is used in the circuit.

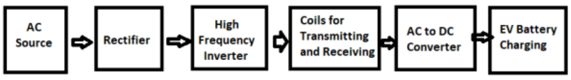

Fig.1. Block diagrammatic representation of wireless charging of electric vehicles.

V. MODELLING OF THE SYSTEM

The block diagrammatic representation of the wireless power transfer system is shown in Fig. 1. It consists of power electronics converters having an AC to DC rectifier and a high frequency DC to AC inverter. The system equations [11] used for implementing this model are as follows.

In this system let

V_1 = Source voltage, I_1 = Source side current, C_1 = DC capacitance, R_1 = Source resistance, L_1 = Source inductance

V_2 = Load voltage, I_2 = Load side current, C_2 = DC capacitance, R_2 = Load resistance, L_2 = Load inductance

K = Coefficient of coupling, M = Mutual inductance

As we know $K = \frac{M}{\sqrt{(L_1 + L_2}}$ (1)

Source side voltage, $V_1 = \left(\frac{1}{jwC_1} + jwL_1\ R_1\right) I_1 - jwMI_2$ (2)

Load side voltage, $V_2 = jwMI_1 \left(\frac{1}{jw\,C_2} + jwL_2\ R_2\right) I_2$ (3)

The input Impedance

$$Z_{in} = \frac{v_1}{I_1} = \left[\left(\frac{1}{jwC_1}\ jwL_1\ R_1\right) I_1 - jwMI_2\right] / I_1$$

$$= R_1 j\left(wL_1 - \frac{1}{wC_1}\right) + \frac{w^2 M^2}{(R_2 + R_l) + j(wL_2 - \frac{1}{wC_2}}$$ (4)

The resonant frequency is given as

$$w_0 = {}^{1}\!/\!\sqrt{L_1 C_1} = {}^{1}\!/\!\sqrt{L_2 C_2}$$ (5)

So, $V_1 = R_1 I_1 - jw_0 MI_2$ and $V_2 = jw_0 MI_1$-$R_2 I_2$ (6)

In this scheme of high frequency based wireless power transfer technique the power that will be delivered to the load. The simulation model has been developed in Matlab and is shown in Fig. 2. The model consists of an AC source which is connected to a source rectifier. The rectifier is implemented using diodes. The output of the source rectifier is fed to a high frequency inverter through an inductor coil and a parallel placed capacitor. A capacitor is connected to the source as well as the load side for impedance matching and to create a resonance effect. The AC voltage from the inverter is fed to the primary coil for wireless transmission. For transmitting maximum power, the high frequency inverter is switched on at resonance frequency. The output obtained from the secondary coil is fed to a vehicle rectifier. The vehicle rectifier constitutes of four diodes for rectification purpose. The output of the vehicle rectifier is being fed to Li-ion battery used in electric vehicles.

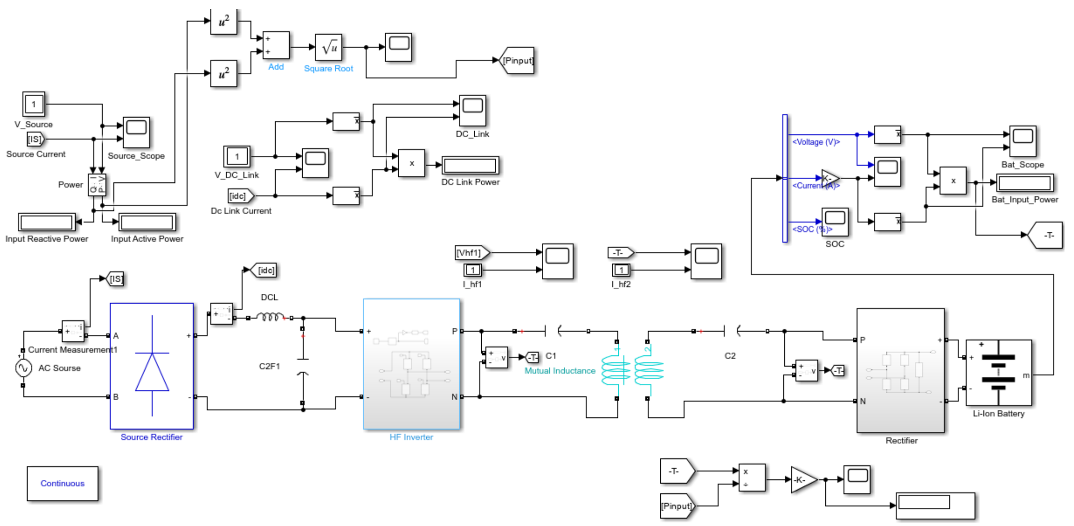

Fig. 2. Matlab simulation model of wireless charging system of electric vehicles.

VI. RESULTS and DISCUSSION

The Simulation model of wireless charging system of electric vehicles is run in order to verify the validity of the model and observe the results. The simulation model helps to ascertain power transferred using this design which will lead to a reliable wireless charging solutions of electric vehicles. The voltage of the input source is 380 V which is fed to the source side rectifier. The input AC voltage is rectified by the source side rectifier. The results obtained of the source side voltage and current is shown in Fig. 3.

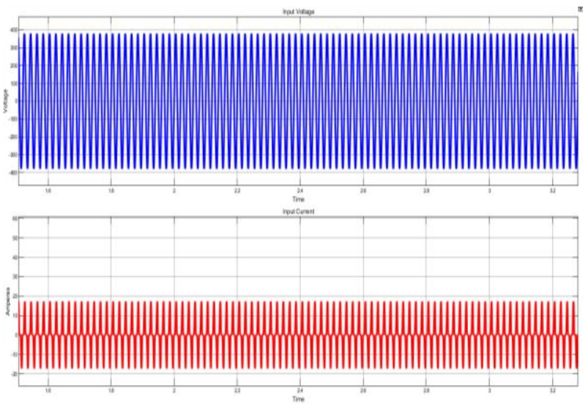

Fig. 3. Source voltage and current.

The waveform of the DC link voltage and current before it is being fed to the high frequency inverter are shown in Fig. 4.

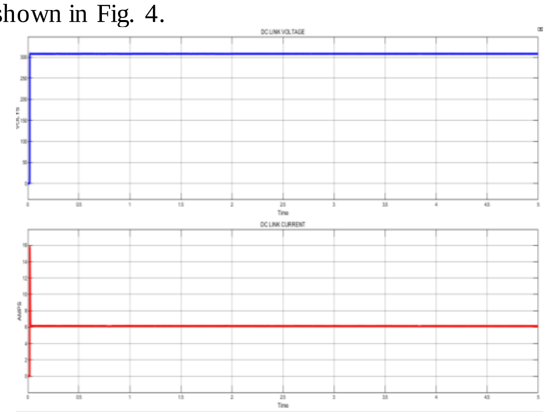

Fig. 4. DC link voltage and current.

The DC voltage obtained is connected to a high frequency inverter with a switching frequency of 35 kHz and it is operating under resonance condition. This high frequency inverter is a current source inverter which also contains filters. After proper compensation in the high frequency inverter it is fed to the transmitting coil. The AC voltage at the transmitting coil is nearly 380 V and the current is 27 A respectively as shown in Fig. 5.

Through the transmitting coil a high frequency current flows which produces a magnetic field which is oscillating which triggers the production of AC voltage in the receiving coil side. The receiving coil side voltage is around 380 Vand current is 28 A shown in Fig. 6. The AC voltage in the receiving coil side in again converted to DC voltage with the help of a diode rectifier. The DC voltage which is fed to the vehicle and the current is shown in Fig. 6.

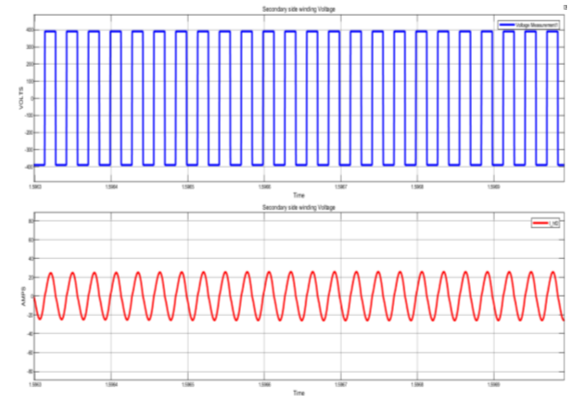

Fig. 5. Primary coil side voltage and current waveform.

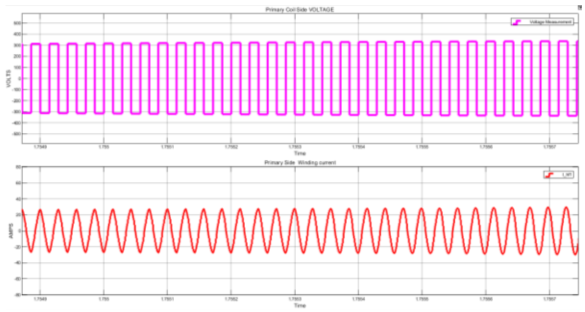

Fig. 6. Secondary coil voltage and current in the E-Vehicle side.

The voltage, current of the Li-ion battery is shown in Fig. 7. The voltage as shown in the results is 375 V and current is 5 A respectively.

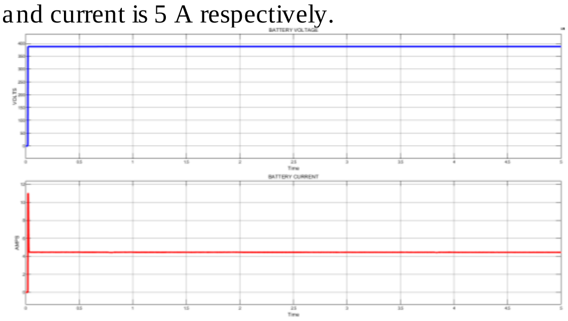

Fig. 7. Li-ion battery voltage and current used in E-Vehicle.

Fig. 8 depicts the state of charge of Li-ion battery of the electric vehicle that is being charged.

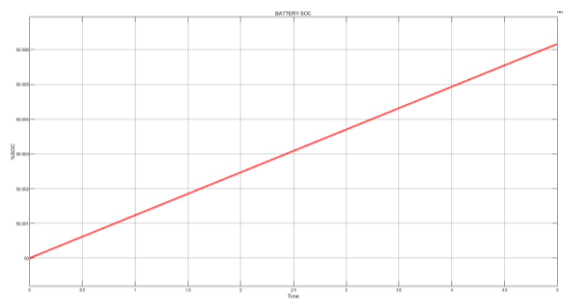

Fig 8. State of charge of Li-ion battery of the electric vehicle.

The variation of the system's efficiency with respect to changes in switching frequency of the high frequency inverter have been analysed and presented in Table I.

Table I. The variation of the system's efficiency.

Sl. No	Voltage (V)	Switching Frequency (kHz)	% Efficiency
1	380	30	87.59
2	380	31	88.08
3	380	32	88.46
4	380	33	89.11

VII. CONCLUSION

In this paper wireless power transfer technology for charging of electric vehicles has been implemented in Matlab / Simulink Platform. In the simulation a complete wireless power transfer system starting with the available AC source and ending with an equivalent load that represents a Li-ion battery of an Electrical Vehicle are analysed. The input power is being transferred with the help of a high frequency inverter through primary coil to the secondary coil through an air gap. Analysis were carried out considering an open loop system and the results were observed in the scope. The simulated results present a magnetic resonant wireless system and the results obtained were found to be satisfactory.

APPENDIX

IGBT	
Internal Resistance (Ω)	1e-03
Snubber Resistance (Ω)	1e-05
Source Rectifier	
No. of Bridge Arms	2
Snubber Resistance (Ω)	1e05
Resistance On (Ω)	1e-03
Transmitting Coil Parameters	
Primary Side Resistance (Ω)	1e-03
Primary Side Inductance (H)	266.16e-06
Secondary Side Resistance (Ω)	1e-03
Secondary Side Inductance (H)	257.79 e-06
Mutual Impedance (μH)	35
Vehicle Side Rectifier	
Resistance (Ω)	0.001
Snubber Resistance (Ω)	500
Snubber Capacitance (F)	250e09
Battery Parameters	
Battery	Lithium-ion
Initial State of Charge (%)	50
Battery Response Time (S)	10

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