(Research Article)

Implementation of EV Battery Charging by Wireless Power Transfer

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Abstract

The transmission of electric power from a source point (front-end) to the load point (rear-end) destination offers to be a challenging one without any intermediate physical substance or either the annoying wires between them. As this originates from the experimentation of Tesla in the year 1899 which is meant to be called as “World Wireless System”, his experiment was done in the concept of microwave power generation which is most suitable for long distance and high frequency applications. Apart from the methods developed the promising wireless charging technology used is the ICPT by analyzing the design of charging coils, coupler, compensation network, power level enhancement and efficiency into major criteria. WPT is the technology that reduces the troubles in usages of wires and mainly long period charging of batteries. The objective of this paper aims in dynamically charging the online electric vehicle with the transmitter embedded inside the roads and the vehicle chassis as the receiver.

Keywords: Current magnification network, Loosely coupled coils, Dynamic charging, Magnetic resonance coupling.

1. Introduction

The wireless power transfer history began with the experiment of Tesla coils and it has been categorized into two field techniques far-field technique and near-field technique. Electromagnetic waves was the transfer medium, the radiations emitted are hazardous to human beings. Magnetic resonance is the near field technique where an air-gap can be used as a transfer medium. Magnetic coupled waves are similar to magnetic field induction of the transformer principle. Some of the technologies used are: Microwave Power Transfer (MPT), Inductive Power Transfer, and Inductively Coupled Power Transfer (ICPT). Apart from the methods developed the promising wireless charging technology used is the ICPT by analyzing the design of charging coils, coupler, compensation network, power level enhancement and efficiency into major criteria. WPT is the technology that reduces the troubles in usages of wires and mainly long period charging of batteries [1]-[4].

Conductive charging method is replaced by the novel wireless power transfer (WPT) technology by maintaining a comparable power level and efficiency. The focus of this paper leads the way to dynamically power the moving vehicles on road with reduced battery pack and extending the charging distance. The charging troublesome in both the stationary and dynamic state of the electrical vehicle is discussed and addressed by some solutions presented below.

In Inductive Power Transfer (IPT) the coil structure is formed such that the two separated coupled coils or can be termed as a loosely coupled coils, they resonate at a frequency termed as resonant frequency hence this technology involves the resonant condition. The coils tend to operate at this resonance and, once tuned by either auto-tuning method or manual tuning method also to transfer power efficiently in spite of the air gap between the coils, efficiency, magnetic weak linkage and power transfer capability [5]-[9].

The prototype presented here is for small power range charging applications. The AC source comprises of additional power factor correction (PFC) circuit at the primary and secondary side. The front-end is provided here by the DC source and rear-end of the WPT circuit is provided with the battery regulatory system boost converter. The proposed WPT converter section is provided such that the induced primary and secondary voltage and its corresponding primary current are analyzed with the mutual inductor principle. Controlling power flow in IPT systems are available with two types of control the first one is either primary or secondary control or the other one is to provide the combination controller affecting both the primary and the secondary.

2. Simulation of circuit and results

The proposed WPT converter here is of capacitive DC load which can be assumed as a resistive load. The primary side is provided with high frequency power source which is responsible for the connection between the power grid and the magnetic link. It is usually composed by and rectifier followed by an inverter. The high frequency (HF) inverter AC output aids the inductive link to carry and induce current to the receiving coil. The HF inverter topology is a simple full-bridge circuit as shown in Figure 1. PWM technique was applied for the switches, the operation of the inverter is the same as the working of single phase full bridge inverter and the high frequency inverter implies not the switching frequency, the output of the inverter must provide as a high frequency inductive link to the primary transmitter coil.

Figure 1. Full-Bridge HF inverter: Simulation circuit

The secondary side can be mentioned as the battery charger control circuit allows to control the charging process and to control the changing voltage to the levels accepted by each type of battery. It is also responsible by making the connection between the WPT system and the battery set to be charged which is on-board of the car. For a battery charging system a simple diode rectifier is used. The paper is proposed with the secondary side power converter with PFC [1] with power factor (pf) of 0.97 obtained from the simulation results (Figure 2).

Figure 2. Secondary PFC circuit with pf value

As the value of power factor is approached to unity and the secondary side load is assumed here as a resistive load which is provided along with a battery charging regulatory circuit. The loosely coupled coils generally need to be compensated with a capacitor to obtain the current magnification; this network can be called as compensation network. For $k < 0.3$, a compensation network is required on both sides for primary and secondary coils. The series-series compensation network is adopted in [1]. The frequency response is simulated in PSpice (Figure 3) and the response is shown in Figure 4.

Figure 3. Compensation for $k < 0.3$

Figure 4. Frequency response characteristics

3. Analysis of coils designed with coupling coefficient, $k < 0.5$

The coils here is not wound on the same common magnetic core as they are separated at a distance from each other with $k < 0.5$, the leakage flux and the induced magnetic effect is reduced and become weaker. For weak flux linkage the compensation network is provided as seen in the previous

section. The parameters need to be optimized for the coils to improve the efficiency between the coils are: .

- Quality factor (Q_{L1}, Q_{L2}) for each coil
- Inductances of primary and secondary coils (L_1, L_2)
- Tuning capacitance of primary side and secondary side (C_1, C_2)
- coupling coefficient (k)
- resonant frequency response (f_0)

The circuit for the optimization shown in Figure 5 and the equations are given through (1) to (5).

Figure 5. Circuit for optimization of parameters of the coils

$$Q_{L1} = \frac{\omega_0 C_1}{g_{t1}} = \frac{1}{g_{t1} \omega_0 L_1} \quad (1)$$

$$Q_{L2} = \frac{\omega_0 C_2}{g_{t2}} = \frac{1}{g_{t2} \omega_0 L_2} \quad (2)$$

$$Q_L = \sqrt{Q_{L1} Q_{L2}} \quad (3)$$

$$K = \sqrt{Q_{L1} Q_{L2}} = \sqrt{Q_L} \quad (4)$$

$$\omega_0 = 2\pi f_0 = \frac{1}{\sqrt{L_1 C_1}} = \frac{1}{L_2 C_2} \quad (5)$$

where ω_0 – resonant frequency

The coils have been simulated based on the critical parameters and from the previous analysis made with the help of coding in MATLAB including the distance between the coils and 3-D design of the coils is done in MAXWELL as in [1].

4. Proposed Hardware Prototype

Hardware prototype of WPT configuration was realized in Hylam sheet with all the components drilled with the terminal connections (banana terminals). Single phase inverter supply was given as a DC directly from the regulated power supply (RPS) 12V and the pulses to the inverter were done using programming in ARDUINO controller interfaced with along with optocoupler; it isolates low voltage gate circuit from high voltage power circuit. To use a photo coupler to drive

the high side of a bridge circuit, a floating power supply is required as shown in Figure 6.

The existing electric vehicle (EV) WPT designs are either too complex, uneconomical to implement with the higher frequency resonance operation hence for the small prototype the frequency operation is chosen in kHz operation. As per the simulation results, the prototype was done (Figure 7).

Figure 6. Optocoupler MCT2E Circuit

Figure 7. Hardware Prototype of Typical WPT Circuit

Figure 8. Litz wire: loosely coupled coils

The spiral shaped coils can transmit power more efficiently than the other geometry of the coils used in the literature. The number of turns and based on the optimization parameters as discussed in the previous topic the coil can be designed.

Litz wire is used to reduce the skin proximity effect and the coils are provided along with the transmitter and receiver chip as we require a driver circuit to implement the coupled coils. The coils are shown in Figure 8. The primary side switched between the full bridge single phase inverter was done with the switching frequency and the PWM signals (Figure 9) and the high frequency output single phase voltage is with 20 kHz frequency range is implemented and shown in Figure 10.

Figure 9. Switching pulses of high frequency inverter

Figure 10. Output of single phase inverter high frequency signal

5. Conclusion

The wireless power transfer system for EV charging both primary control and secondary control can be enhanced and the loosely coupled coils challenges can be rectified with respect to increasing the distance and misalignment between the coils. Higher frequency resonating coils can be implemented with increasing beyond 20 kHz that is done in this work. Power transfer and efficiency can be improved with complex and efficient coil design with a reasonably larger air gap. To maintain a normal operation of power transfer dual control has been adopted in this paper. The

implementation was found to be contingent upon the leakage flux compensation topology, charging distance and proper alignment. The detailed of spiral coils has been presented in [1] by the authors. A trade-off between distance, charging pad size and efficiency is necessary for EV charging application.

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Biographical notes

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