Resonant Coupling Topologies used for EV Batteries

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Abstract

Both simulation and experimental investigations have been conducted to obtain an appropriate elucidation for improving the power transfer efficiency of a resonant inductive coupling based wireless system for electric vehicle charging. It is seen that the optimum power transfer efficiency of the wireless system depends on the driving frequency, charging coil structure, configuration, vertical spacing and misalignment between the charging coils. Under the strong magnetic coupled condition, theefficiency is found to be maximum. In order to make the charging system more viable, the effects of the operating parameters on the performance of wireless power transfer system are analyzed using electromagnetic simulation and experiments. The analysis may provide the design guidelines for efficient charging of Evs even under non-ideal scenarios.

Keyword: *wireless charging system; magnetic resonance;electric vehicle; eletromagnetic coupling.*

1. INTRODUCTION

There is an evolving paradigm shift in transportation industry towards electrified vehicles. The greatest benefit for switching to electricity from hydrocarbon for driving vehicles is certainly the positive effect on the environment. But there is another advantage of using electricity that it can be transferred over-the-air without the use of a conduit, which is something not possible for hydrocarbon fuels. Therefore, the inductive coupling based wireless charging systems have been intended for more than two decades for applications of electric vehicles[1-3]. Although the inductive coupling has the high potential for EV charging but the prevalent difficulties of poor efficiency and inconvenience limits the commercial development. Providentially, there is a solution in the form of resonant inductive coupling based wireless charging for widespread adoption. The idea of wireless charging for EVs through resonant inductive coupling so called magnetic resonancecoupling has now become popular with some industry and academic groups [4-8]. So, the scheme of wireless charging is certainly catching on. But in order to build a practical wireless charging system for an EV, it is not good enough to just show the electrical power being transmitted from the charging station to the on-board battery. To make the charging system doable, it is essentially required to delineate the effects of design parameters on the wireless efficiency characteristics. In this work, the effects operational frequency, coil configuration, horizontal & vertical offsets between transmitting and receiving charging coils on the system efficiency have been investigated by using electromagnetic simulation and experimental measurements. The simulation and experimental analyses can provide guidelines to obtain a suitable or validating efficient wireless charging system for EVs.

II. EXPERIMENTAL SETUP AND MECHNISM OF WIRELESSCHARGING SYSTEM

The method associated in the resonant wireless EV charging system is illustrated schematically in Fig.1.

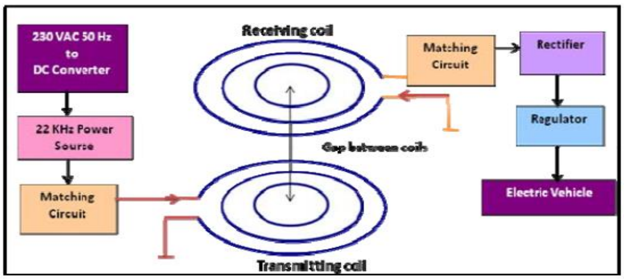

Fig.1. Method implicated in the resonance based wireless EV charging system.

ISSN: 2233-7857 IJFGCN

The setup (experimental) of magnetic resonant inductive coupling based wireless power transfer system (WPT) In the investigated system, a power source with high frequency is applied to energize the transmitting coil perfectly tuned by an external capacitor for a particular resonant frequency. The generated magnetic field is captured by a receiving resonant coil placed away from the transmitting resonant coil. The received power is then rectified and fed to the battery of EV. The performance of this WPT system is analyzed through the designed EM simulation model. The basic principle behind this WPT is magnetic resonant inductive coupling. If the charging coils of the system are physically separated over a far distance (in the order of the coil size) their magnetic near fields will couple strongly under tuned condition. This means that at resonance the magnetic coupling enables to transfer energy from the transmitter to the receiver coils efficiently.

III. THEORETICAL ANALYSIS

In this WPT system, the wireless power transfer involves electromagnetic resonance coupling creating an LC at the resonant frequency. By using the Coupled- Mode theory [9-10], the energy exchange between the two resonant coils of a strongly coupled wireless power transfer system can be analyzed. The power transfer efficiency depends on the power absorbed by the transmitting coil (P1), the power received by the receiving coil (P2) and the power delivered to the electric load resistance connected to the receiving coil (PL).Hence the efficiency of the wireless power transfer (WPT) system will be the ratio of the output power (power delivered to the load resistor connected across receiving coil) and the total source power of the system (the total power delivered to the transmission system from the source in accordance with the energy conservation theory). The power transfer efficiency can be expressed as follows:

$$\eta_{12} = \frac{P_L}{P_1 + P_2 + P_L} \qquad \text{(i)}$$

If the coupling coefficient between the transmitting and receiving coils is k12, T1 is the intrinsic decay rate due to absorption loss, T2 is the rate of intrinsic decay due to the radiative losses and TL is the resonance width due to load resistance connected to the receiver coil, then the power transferefficiency can be expressed as follows:

$$\eta_{12} = \frac{\left(\frac{\Gamma_L}{\Gamma_2}\right)\frac{k_{12}^{\;2}}{\Gamma_1\Gamma_2}}{\left(1+\frac{\Gamma_L}{\Gamma_2}\right)\frac{k_{12}^{\;2}}{\Gamma_1\Gamma_2} + \left(1+\frac{\Gamma_L}{\Gamma_2}\right)} \qquad \text{(ii)}$$

For identical transmitting and receiving coils,
Γ1 = Γ 2 = Γ and k = k 12 Thus, the power transfer ef ficiency of the WPT system comprised of identical transmitting and receiving coils will be as follows:

$$\eta = \frac{\frac{k^2}{\Gamma^2}\sqrt{1+\frac{k^2}{\Gamma^2}}}{\left(1+\sqrt{1+\frac{k^2}{\Gamma^2}}\right)\frac{k^2}{\Gamma^2} + \left(1+\sqrt{1+\frac{k^2}{\Gamma^2}}\right)^2} \qquad \text{(iii)}$$

Therefore, for efficient wireless energy transfer the system must operate in the strongly coupled region means k Γ >>1 and as large as possible. By maximizing coupling to loss ratio (k Γ), the efficiency can be maximum. If the coils are wound to make circular spiral loops of similar dimensions (radius R1= R2=R; Inductance L1= L2= L) and resonate at the same frequency, then the coupling to loss ratio can be calculated can be calculated using the Biot-Savart’s law and the concept of mutual coupling as follows:

$$\frac{k}{\Gamma} = \frac{\mu_0 \pi^2 f N R^3}{\left(R^2 + D^2\right)^{3/2}}\left[\frac{1}{\frac{1}{2a}\sqrt{\frac{\mu_0 \pi f}{\sigma}} + \sqrt{\frac{\mu_0}{\varepsilon_0}}\frac{4\pi^5 N R^3}{3}\left(\frac{f}{c}\right)^4}\right] \qquad \text{(iv)}$$

ISSN: 2233-7857 IJFGCN

From equation (iii) and (iv), it is seen that the power transfer efficiency depends on the frequency, radius of the coil, number of turns of the coil structure, physical spacing between the coils, and the coil's material property.

IV. RESULTS AND DISCUSSION

The theoretically calculated power transfer efficiency characteristics vs frequency at different vertical separationdistance are illustrated. It reveals that the maximum efficiency is achieved for a certain frequency region called optimum frequency band. The efficiency falls off significantly outside that frequency band. This is because at the resonant frequency band both the charging coils are coupled very strongly. Also, the coupling w.r.t power loss ratio is higher at the optimum resonant frequency band which is evident from the results depicted. Hence it can be presumed that each system will have its own optimum frequency band at which maximum efficiency can be achieved.

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ISSN: 2233-7857 IJFGCN