Journal of Energy Storage 16 (2018) 145–155

Contents lists available at ScienceDirect

Journal of Energy Storage

journal homepage: www.elsevier.com/locate/est

A review on renewable energy powered wireless power transmission techniques for light electric vehicle charging applications

Peter K. Joseph*, D. Elangovan

Department of Electrical Engineering, VIT, India

ARTICLE INFO

Article history:
Received 4 September 2017
Received in revised form 13 November 2017
Accepted 29 December 2017
Available online xxx

Keywords:
Plugged in hybrid electric vehicles
Wireless power transfer
Inductive power transfer
Strongly coupled magnetic resonance
Inductively coupled power transfer
Renewable energy

ABSTRACT

Magnetic resonance technology set a new course in the wireless power transfer (WPT) sector. WPT is derived from inductive power transfer (IPT) which is developed many decades back. After this much time, the transfer efficiency increased from 70% to more than 95% and transfer distance from few centimeters to several meters. A converging pattern in the trade off between transfer efficiency and the air gap distance is visible in every novel designs. This pattern is achieved through the optimum selection and design of compensator, wireless transformer and the battery packs. As the conservation of energy and exploration of renewable energy resources became a common aspect in every novel technological entities, solar power and fuel cells made its debut to wireless charging. A detailed analysis of different types of wireless charger topologies implemented and proposed in plugged in hybrid electric vehicle (PHEV) charging applications are presented in this paper. The recent attempts to integrate the renewable energy sources to the wireless charging is covered. Two winding model is taken for the analysis of the state of art efficiency. For enhancing the performance of wireless charging system, various compensation techniques are validated based on different topologies. Maximum efficiency and charging condition for a given impedance is explained and derived comprehensively. Different winding designs for wireless transformer is described with comparison. Magnetic coupler selection, battery selection and different safety standards for WPT design are mentioned in this paper.

1. Introduction

Wireless power transfer is always being an interesting riddle to every aspiring engineers. It cannot only solve the energy crisis in several sectors but also can simplify numerous day today activities in this century. World renowned scientist Nikola Tesla started this quest in 1889 by inventing Tesla coils which is able to transfer power wirelessly. The pursuit of wireless power transfer started from there [1]. William C. Brown suggested a microwave beam based wireless power transfer in 1964 [2]. American Engineer Peter Glaser proposed a concept of transmitting solar energy from solar power station to earth station in the form of microwave beams [3].

In 2007, the research team of MIT leaded by Professor Marin Soljacic started a new era in wireless power transmission by demonstrating strongly coupled magnetic resonance (SCMR) which is able to transfer a 60 W power for more than 2 m with 40% efficiency [4]. After the 2007 breakthrough, several advancements took place in wireless power transfer history. And the technology so used can be broadly classified based on the working principle into electromagnetic radiation mode, electric field coupling mode and magnetic field coupling mode. Because of the higher power density and features, electromagnetic radiation mode is only used for large distance applications. The electric field coupling mode is basically transfer of charges accumulated on the object surface. A voltage source with higher frequency and higher voltage resonate the transmitter for developing an alternating electric field which can couple with receiver to transfer energy. As the efficiency of transfer is severely affected with objects in the path and nearby environment, this method is neither suitable for commercial applications [5,6]. For commercial use, the most suitable wireless power transfer method is magnetic field coupling. Based on the distance of power transfer, this electromagnetic coupling is divided into two. For short range (centimeters) with higher efficiency, electromagnetic induction coupling is used whereas strongly coupled magnetic resonance (SCMR) is

* Corresponding author.
E-mail addresses: peterk.joseph@vit.ac.in (P.K. Joseph), elangovan.devaraj@vit.ac.in (D. Elangovan).

https://doi.org/10.1016/j.est.2017.12.019
2352-152X/

used for medium range (meters) relatively less efficient power transmission [7,8].

For inductive and SCMR power transmission, MHz frequency is usually used for better performance and resonance. When wireless power transfer (WPT) is used for charging electric vehicles (EV), this MHz criterion is difficult to follow as transferring few kW power with state of art power electronic devices in MHz is inefficient. The air cored coils have to be replaced with ferrites cores in EV charging, as air cored coils are very much sensitive to nearby magnetic objects. Also air cored coils will cause high eddy current loss in vehicle chassis, as magnetic flux will spread over it [9]. By making the above mentioned changes like reducing the frequency to KHz range and using ferrite core will result in the inductive power transfer (IPT) which has been a part of research for more than few decades [10–26]. Since WPT is evolved to electromagnetic short/mid-range technology, the difference between traditional IPT become negligible which is based on the magnetic field coupling with or without resonance between the transmitter and receiver windings. The IPT technology has already been applied and proposed to numerous applications, like mining systems [13], under water vehicles [19–21], cordless robots in automated production sector [23–26] and charging of EV [10,11,14–16].

Presently most commercially available EVs are powered by plugging them to the charging station. Those conductive type of recharging causes several problems as physical plugging of the wire, high stating current, insulation damage and related safety concerns. Manual charging is undesirable with caution of electric shock or hazard. So, there is an inclining requirement for convenient, safe and still effective way to recharging vehicles. Lately, the technologies in EV sector as well as the charging of EV is booming to the next level. The power transfer distance for charging is increased from few millimeters to several hundred millimeters at kW power range [9,11,26]. As a proof of IPT technology, at UC Berkeley, the PATH (Partners for Advance Transit and Highways) program was conducted to build a roadway with EV powered inductively in the end of 70s [11]. A 60 kW, 35-passanger bus was driven along a 213 m distance road with 2 powered rails. The integration of renewable energy with wireless charging became real only after 2015 [65–67]. Delft University implemented world's first solar powered wireless charger for electric bicycle in 2016 [67].

In the following sections, a comprehensive literature review of different wireless charger topologies, transformer design methods, battery selection criteria and integration with renewable energy are performed. Moreover, the maximum efficiency condition for a given system is explained.

2. Magnetic resonance concept

Resonance [15] indicate the oscillation of energy between two distinct forms.

If a system is in resonance, a large quantity of energy can be stored with less excitation. If loss of energy is lesser than intake of energy, it accumulates. One example of basic electro-magnetic resonator with an inductor, capacitor and resistor is shown in Fig. 1. Here the energy oscillates between inductor (in the form of magnetic field) and capacitor (in the form of electric field) at a resonant frequency.

$$\omega_o = \frac{1}{\sqrt{LC}} \tag{1}$$

From (1) quality factor of the coil can be derived.

$$Q = \sqrt{\frac{L}{C}} \cdot \frac{1}{R} = \frac{\omega_o L}{R} \tag{2}$$

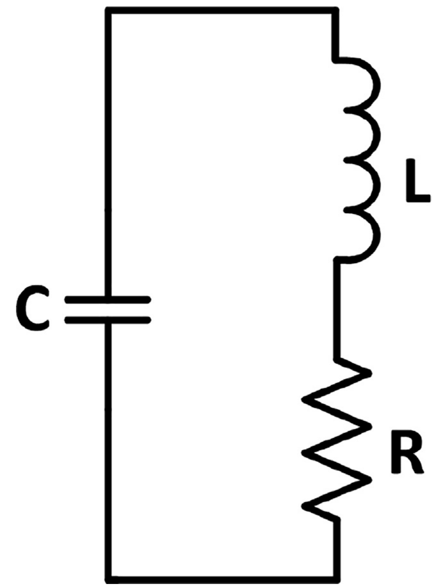

Fig. 1. Electrical resonator.

From (2), it can be seen that the quality factor and the circuit loss are in inverse proportional. So in a wireless power transfer system, quality factor should be maximum for maximum system efficiency. If two resonators are placed in the vicinity to each, the coils can establish a link and will be able to transfer energy. And the efficiency of energy transferred depends on the coupling coefficient k of two coils. The equivalent circuit of coupled resonant coils are shown in Fig. 2.

In Fig. 2, V_g is the input voltage amplitude, R_g is the internal resistance of the source and R_L is the load resistance. C_s, C_d, L_s and L_d are the source and device resonant capacitor and inductor respectively. R_s and R_d is the unwanted ohmic resistance of inductor and/or capacitor of respective circuit. The mutual inductance of the circuit is denoted by $L_m = k\sqrt{L_s \cdot L_d}$. The efficiency of the resonant circuit is determined from the ratio of transmitted power at the load side to the maximum delivered power from the source, while both coils are coupled.

$$\frac{P_L}{P_{g,\max}} = \frac{4U^2 \frac{R_g R_L}{R_s R_d}}{\left[\left(1+\frac{R_g}{R_s}\right)\left(1+\frac{R_L}{R_d}\right)+U^2\right]^2} \tag{3}$$

$$U = \frac{\omega M}{\sqrt{R_s R_d}} = k\sqrt{Q_s Q_d} \tag{4}$$

To ensure the best performance of the system, from (3) and (4) we have to choose load resistance to give maximum quality factor.

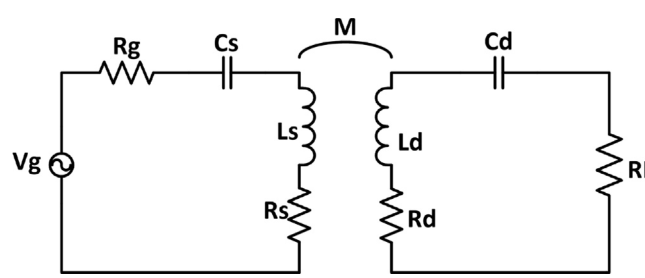

Fig. 2. Two coil coupled resonant circuit.