Wireless Power Transfer Technologies for Electric Vehicle Battery Charging – A State Of The Art

Dharavath Kishan
Research Scholar
Dept. of EEE
National Institute of Technology, Trichy,
Tamilnadu, India.
dharavathkishan4@gmail.com

P Srinivasa Rao Nayak
Asst. Professor
Dept. of EEE
National Institute of Technology, Trichy,
Tamilnadu, India.
psnayak@nitt.edu

***Abstract*— This paper presents a state of the art on different wireless power transfer (WPT) techniques for electric vehicle (EV) battery charging. The principle of operation and advantages of WPT techniques are discussed. In addition, the limitations and challenges associated with the WPT techniques are explored. A meticulous comparison has been done to identify the better WPT for EV battery charging.**

Keywords— Wireless power transfer (WPT), Electric vehicle (EV), Resonance, Inductive power transfer.

I. INTRODUCTION

The popularity of Electric vehicle (EV) in automobile industry sector has always been increasing due to various advantages offered by EV of increased energy security, improved fuel economy, reduced fuel costs, and reduced emissions. EV run on electricity and are propelled by one or more electric motors powered by rechargeable battery packs. EV has many positive aspects of energy efficiency, environment friendliness, performance, and reduced energy dependence on fossil fuels. However, the use of Electric vehicle faces some challenges like driving range, recharge time, battery cost, more bulk, and weight. Thus with growing EV market, we need to overcome the problems by stimulation new ideas and developments in this area. One such major concern of EV is the conductive battery charging application which introduces the inconvenience and risk of hazards. This can be overcome by the simple concept of wireless power transfer battery charging [1],[3],[4].

Wireless battery charging of EV does not require power cable connection for charging like plug-in EV. The contemporary development in the area of power electronics in wireless power transfer for EV are considered for the relief of fuel powered internal oxidization engine driven vehicles [14],[15],[17]. The development of electric vehicle had gained more attention from both consumers and research community since it is an alternate. Wireless power transfer provides on inherent electrical isolation and reduces on board charging cost, weight & volume, wireless Power Transfer completely eliminates the existing high tension power transmission lines cables, towers and substation between the generating stations and consumers to facilitates the interconnection of electrical generation plants on a global scale [2].

Nikolas tesla was a profile inventor of wireless power transfer, the proposed electric power transmission through the air as a medium [2]. The electrical energy transfer is by the time-varying magnetic field or electric fields or by microwaves and not by wires. Nikolas Tesla was inventor indeed “father of wireless” was the first person to conceived the idea wireless power transmission and demonstrated the transmission of electricity using wires, that depends on electrical conductivity, even for charging of electric vehicles [13]. The electric vehicle provides smoke-free transportation and offers a solution for the adverse environment.

Different methods have been developed for EV battery charging technologies [5],[11],[14],19]. The different method has approached the capability in terms of power level, efficiency and distance. This paper reviews the development for wireless charging methods of electric vehicles, the impact of an electric vehicle. The basic block diagram of wireless power transfer system is shown in fig.1.

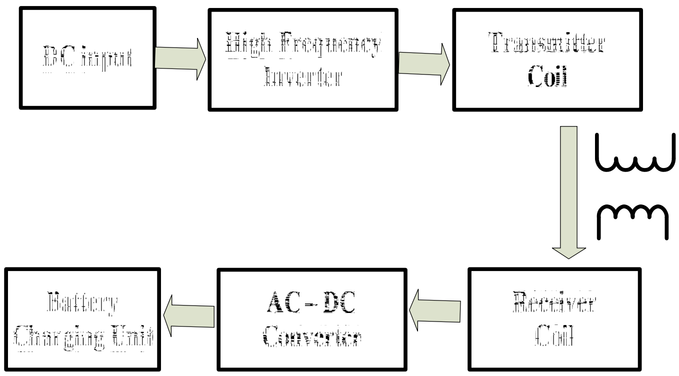

Fig. 1 Block diagram of WPT technology.

II. A STATE-OF- THE ART ON WIRELESS POWER TRANSFER TECHNOLOGIES

Wireless Power Transfer is the method of transmitting the electrical power from one source to consuming device without conductors. It can be categorized into

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i. Radiative (far field) or Microwave power transfer
ii. Non-radiative (near field) WPT

a. Microwave power transfer:

Radiative(far field) techniques is also called as Microwave Power Transfer, in this power transmission method; power transmission and information are carried by using radio waves whose wavelength abatement into the category of microwaves. Microwave power transfer consists of a microwave generator, receiving and transmitting antenna [5],[6],[8]. The transmitting and receiving antennas of microwave wireless power transfer are not magnetically coupled. The major disadvantage of microwave power transfer is high power transmission which is not safe for humans and it does not acquiesce for radio wave regulation for high power.

In non-radiative technique power transferred for short distances by magnetic fields between the coils using an inductive coupling and by electric fields using capacitive coupling between electrodes.

b. Capacitive WPT

It is an alternate wireless power transfer system. The basic block diagram of capacitive wireless power transfer system is shown in fig.2. The coupling medium consists of two pair metal plates that constitute the transmitter and receiver coil. The coupling plates are coated with suitable insulator/dielectric. The plates resemble a loosely coupled capacitor. The two types of capacitive interface are unipolar and bipolar [11],[12]. When electrical energy supplied to the transmitter plate of the capacitor an electric field set up between the transmitter and receiver side plate. The electric field causes a displacement current to flow in between the transmitter and receiver. The capacitive interface consists of an equivalent series resistance and equivalent series inductance. At particular frequency, the equivalent internal series inductance forms a series resonant circuit and it is termed as self-resonant frequency of coupling capacitor [10],[13]. The advantage of resonance is enabled maximum power flow (behavior is resistive network) and resonating elements allow the flow of fundamental component behaves as a filter which discards higher order harmonics. The major advantage of capacitive power transfer over inductive power transfer system reduces the electromagnetic interference (EMI) produced by the system and the capacitive power transfer system are resonant in nature, therefore, the converters operated in either in zero voltage switching (ZVS) or zero current switching (ZCS) making the capacitive power transfer system extremely efficient.

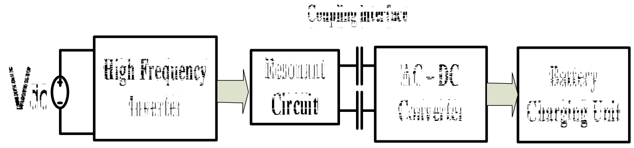


Fig. 2 Capacitive wireless power transfer system

c. Resonant Inductive WPT

Resonant Inductive Power Transfer is the most fashionable current WPT technology [1],[2],[3],[14]. This technique uses two or more tuned resonant tanks operating at the resonance frequency. A typical RIPT system consists of resonant transmitter and receiver. The receiver and transmitter contain resonant capacitors, Cp and Cs. Various resonant compensation topologies are proposed in [17]. As noted in [17] the primary functions of the resonant circuits include: improves transferred power, transmitted power frequency variation controlling, providing certain source characteristics(current or voltage source), transmission efficiency optimization, magnetic coupling variation compensation, matching the transmitter coil impedance to the source, magnetizing current compensation in transmitter coil[14].

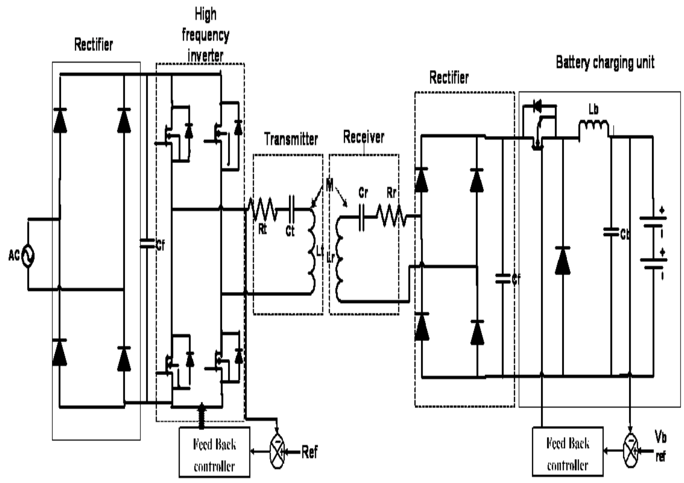
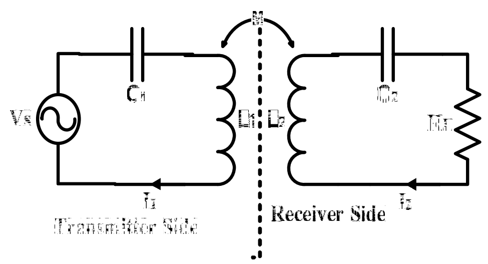
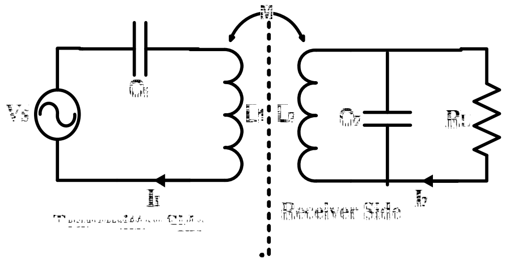


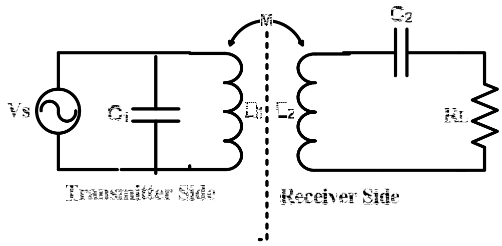
Fig 3: A Schematic diagram of resonant inductive Wireless power transfer System for a single transmitter and receiver.



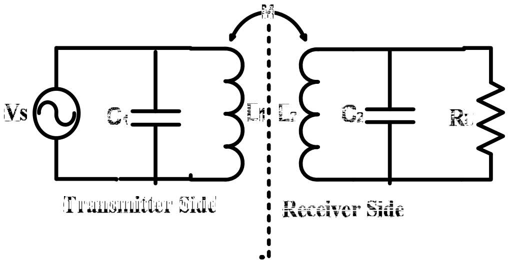
a) S/S Compensation



b) S/P Compensation



c) P/S Compensation



d) P/P Compensation

Fig.4. Four basic compensation topologies.

When coupling coefficient is reduced to less than 0.3 in the EV WPT, compensation at both the primary and secondary side is recommended to have more flexible characteristics [15],[16]. Various basic resonance circuit configurations are in Fig.4.

i. Modeling of Resonant Inductive WPT:

The equivalent circuit diagram for S-S compensation resonant inductive wireless power transmission is shown in fig.4. The power transfer efficiency can be calculated as fallows.

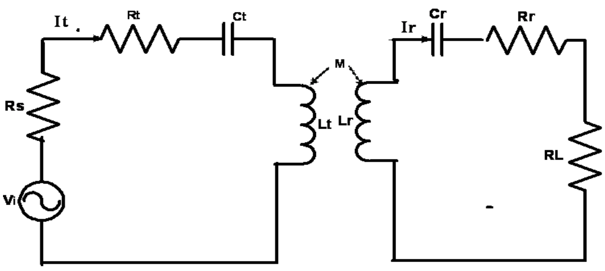
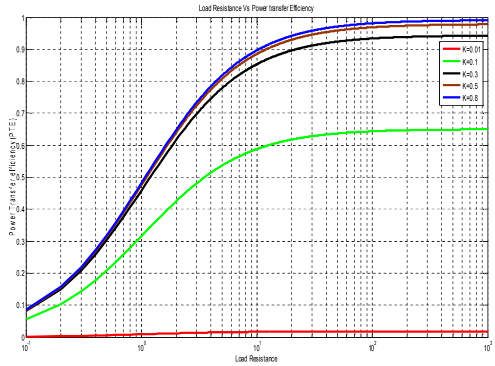
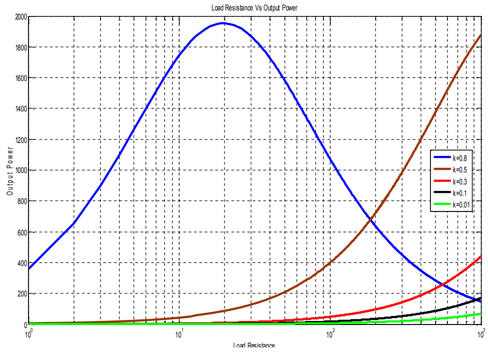


Fig 5. Equivalent circuit of S-S compensation Topology



(a)



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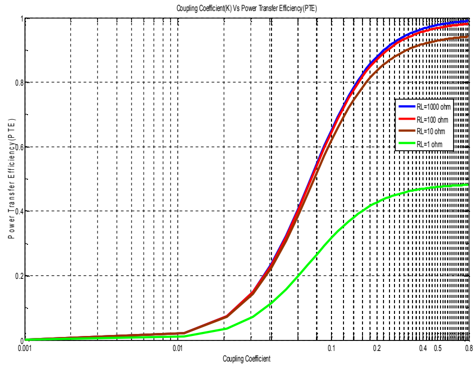
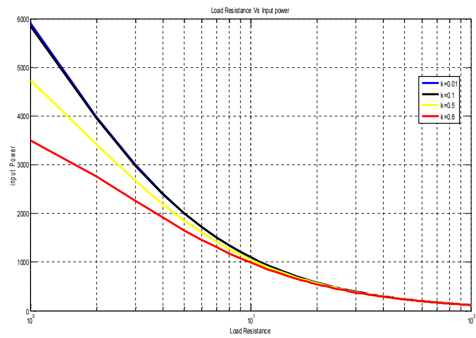


(c)



(d)

Fig.6. Performance characteristics of resonant inductive power transfer system a) Load resistance Vs Power transfer Efficiency b) Load resistance Vs Output Power c) Coupling coefficient Vs Power transfer Efficiency d) Load resistance Vs Input Power

Transmitter and receiver impedances are given by respectively as Z_{Tr} , Z_r

$$Z_{Tr} = R_t + j\omega L_t + \frac{1}{j\omega C_t} \quad (1)$$

$$Z_r = R_r + j\omega L_r + \frac{1}{j\omega C_r} \quad (2)$$

$$I_t = \frac{V_s(Z_r + R_L)}{(Z_{Tr} + R_s)(Z_r + R_L) + (\omega M)^2} \quad (3)$$

$$I_r = \frac{V_s * \omega M}{(Z_{Tr} + R_s)(Z_r + R_L) + (\omega M)^2} \quad (4)$$

At the resonance condition, reactive impedance of the coil becomes zero.

Output power $P_{output} = |I_L|^2 R_L = |I_r|^2 R_L,$ (5)

Input power $P_{input} = |I_t|^2 R_t + |I_L|^2 (R_L + R_t)$ (6)

Power transfer efficiency (PTE) $= P_{output} / P_{input}$ (7)

$$PTE = \frac{R_L * (\omega_0 M)^2}{\{(R_t + R_s)(R_r + R_L) + (\omega M)^2\}(R_r + R_L)} \quad (8)$$

2.4. Dynamic / On-Line Road WPT

Dynamic wireless charging system (OLEV), which was one of the crucial obstacles in commercializing EVs. Three models of dynamic wireless charging have been developed since 2009. The first Dynamic wireless charging version was a golf car with 3kW to the vehicle with 80% power transferred efficiency through a 1-cm air gap between the transmitter and receiver coil [18]. The second version was developed bus with IPTS can transfer 52kW via ten transmitters at each of 5.2kW through a distance of 17-cm distance between coils and efficiency achieved is 72%. The third version is a dynamic wireless charging sports utility vehicle (SUV) [19].

TABLE I: Comparison of various WPT Techniques.

	Microwave Power Transfer (MPT)	Capacitive Power Transfer (CPT)	Resonant Inductive Power Transfer (RIPT)	Dynamic Wireless Power Transfer (DWPT)
Distance	Long	Low	Low	Low
Frequency	(1-30) MHz	(1KHz–20 MHz)	(20-200) KHz	(20-200) KHz
Transmitter & Receiver Devices	Rectennas	Electrodes	Tuned wire coils, Lumped element Resonators	Tuned wire coils, Lumped element resonators
Power level	Low / Medium	Low	High	High
Cost	Medium	Low	Medium	Medium
Application	Solar Power Satellites. Powering drone aircrafts	Tooth brush and Cellular phone charger	Electric Vehicle Battery Charging, Powering Busses, Trains, MAGLEV, RFID, Smart cards.	Online Electric Vehicle Battery Charging
Efficiency	Medium	Low	Medium	Medium

To pick up more power, a slim type multi-winding pickup was developed to provide 15 kW per pickup through a 20-cm air gap and power transfer efficiency was 74%. The main components employed in dynamic charging are a transmitter (primary) and receiver (secondary). The secondary consist of a receiver coil, resonant tank, rectifier, DC-DC converter and electric vehicle battery [19],[20],. The receiver coil installed under the vehicle can receive electric power. The receiver coil loosely coupled with the magnetic field from the primary end and it is tuned with a capacitor to the operating frequency. The capacitor forms a resonant tank with the inductance of receiver coil, while the rectifier converts AC-DC and DC-DC converter is used to maintain the constant voltage for battery charging applications.

III. CONCLUSION

A state of the art of existing WPT techniques used for electrical vehicle battery charging has been described. A through comparison of various WPT techniques has been carried in terms of distance, cost, power level, operating frequency, efficiency, and application. From the comparison resonant inductive WPT is better than that of other WPT techniques. However, the design of receiver coil and controlling of transmitter and receiver converters of dynamic charging is an area of concern.

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