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Wireless Charging Technologies for Electric Vehicle: A Review

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ABSTRACT: The cost-effective and rapid adoption of electrified mobility necessitates a charging infrastructure that is quick, inexpensive, and dependable. This study presents a complete evaluation of all wireless charging technologies, characteristics, and standards known in the open literature for electric vehicles (EVs). Following a comparison of conductive and inductive wireless charging, a full explanation of different wireless charging technologies is provided. As a quick reference to the wireless important qualities and standards, research organizations, industry professionals, and investment agents will find this material incredibly beneficial.

KEYWORDS: Electric vehicle, wireless charging, wireless charging methods, charging technologies, compensation topologies.

NOMENCLATURE

AFE	Active Front End
AC	Alternating Current
BMS	Battery Management System
DWC	Dynamic Wireless Charging
EV	Electric Vehicle
IPT	Inductive Power Transfer
DC	Direct Current
MPT	Maximum Power Transfer
PV	Photovoltaic
PFC	Power Factor Correction
EREV	Extended Range Electric Vehicle
PS	Power Supply
HEV	Hybrid Electric Vehicle
PMC	Permanent Magnet Coupled Transfer
QWC	Quasi Dynamic Wireless Charging
RFID	Radio Frequency Identification
SWC	Static Wireless Charging
SOC	State of Charge
V2G	Vehicle to Grid
xEV	Electric Vehicle, Plug in Electric Vehicle or Plug- in Hybrid Electric Vehicle
WPT	Wireless Power Transfer

I. INTRODUCTION

With increase in global warming and depleting fossil fuels, there is a high demand for a shift to renewal resources. Transportation is one of the most important aspects of society, but traditional techniques pollute the environment. To address the aforementioned issue, electric vehicles (EVs) have emerged as one of the most cost effective and ecologically beneficial options. Normally, battery-bank based EVs are the most popular because to the quick decline in battery prices. When you use plug-in EV battery chargers, personal safety, convenience, current leakage, loss of connection, disconnection, and flexibility are all lost.



Plug-in Hybrid-Electric Vehicles (PHEVs), Electric Vehicles (EVs), and Plug-in Electric Vehicles (PEVs) have become increasingly popular as a way to decrease greenhouse gas emissions and air pollution. High-power storage devices, highly efficient electric motors, and electric trains are key features that make EVs more efficient.

Electric vehicles (EVs) have received increasing attention from customers and academic groups as a potential replacement for obsolete combustion engine autos. However, EV's biggest weakness has always been energy storage. With the battery's limited power, an electric vehicle can only drive a short distance. Wireless charging technology offers a promising solution to this problem.

Various concerns have emerged as a widespread human factor due to the advent of electric vehicles, combined with a lack of commercial charging infrastructure within the EV's fast-paced driving range. One of the major obstacles to the acquisition of EV is the lack of effective EV charging infrastructure compared to that found in modern ICE motor fuel stations. Ongoing charging and wireless charging, sometimes known as wireless charging, are two different ways of charging an electric car. The intermediate EV range, potential traffic congestion, the charging time and queue time at the charging station are all factors to consider with active charging systems. Wire free charging can solve the problem of EV charging infrastructure concerns.

Vehicles can be charged in three different modes using wireless charging: vertical, quasi-dynamic, and flexible charging. To mitigate the risk of electric shock by charging cables at residential garages or parking lots are only a few of the advantages of stable charging.

Whenever the electric vehicle is stopped for a short time, such as at traffic lights, quasi-dynamic wireless charging system allows to charge and this increases vehicle distance while on the road and reduces energy storage requirements. The wireless charging system keeps charging the EV while driving with fixed road charging channels, increasing the width and reducing the battery capacity.

Charging infrastructure design, installation, operation, and maintenance are all technological challenges we faced. Short-distance charging infrastructure that is efficient and dependable would allow EVs to travel without restriction. This article examines numerous aspects of electric vehicle wireless charging, including roadblocks, and compensation technologies.

II. PLUG - IN ELECTRIC VEHICLE IN CHARGING SYSTEM

Infrastructure of Electric vehicle charging is key to their improvement. As we know takes too much time to charge compare with gasoline-power based vehicles. So xEV charger must have higher efficiency and great power is essential to resolve these types of refuel issues.

We can charge the battery by the fast charger in three minutes and up to fifteen minutes, providing a 50% charge in three minutes and an 80% charge in fifteen minutes. Fast charging, on the other hand, causes high-voltage batteries to degrade. The control algorithm, which combines multiple microcontrollers and signal processors with specialized integrated circuits, is required conditional to the converter rating and charger cost. You can lengthen the battery's life by opting for the right current/voltage combination.

To remedy the issue of slow charging, fast chargers are required.

For the conductive charger, which is nearing completion, industry standards have been developed. Inductive charging has the potential to complement conductive charging, despite the fact that technology is still in its early phases.

A. Inductive Charging or Wireless Charging

Inductive charging is also called as wireless charging. It transmits electricity rather only a small distance and no contacts between the EV and PS. Scholars are attempting to expand the air gap distance to meters. For higher power levels, remote charging becomes more difficult but otherwise electricity can be easily delivered up to meters using simple equipment.

Some important examples of wireless power transfer techniques are coupled magnetic resonance (CMR), laser, Inductive power transfer (IPT), permanent magnet coupled transfer (PMC), radio wave and microwave are examples of wireless power transfer techniques.

Authors suggested that quasi-Dynamic wireless charging (QWC), Dynamic wireless charging (DWC), and Static wireless charging (SWC) are the three types of suitable wireless charging [2]. We have no means of determining which type of wireless power transmission is best for EV charging. As We Know Coupled Magnetic Resonance (CMR) is highly successful for low as well as medium-power wireless power transfer (WPT). however, due to there is no resonant circuit are needed in IPT is for high-voltage power transfer. Still, standardization of these WPT systems has an issue [1].

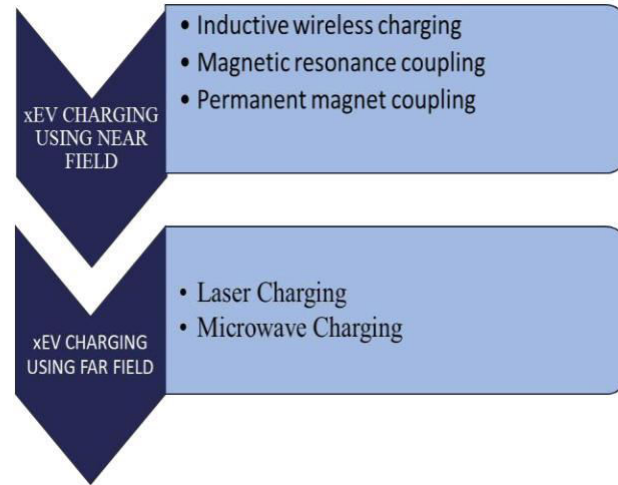


Fig. 1 Charging Methods and Wireless Charging Types

B. Conductive Charging for EVs

The electrical power supply is physically attached to the electric automobile in conductive charger. In conductive charging method both the converters and rectifiers such as DC-DC converter and AC-DC rectifier although using PFC, it can also convert low-frequency AC into high-frequency AC directly [2][8].

Because there is no evidence that conductive wireless charging improves system efficiency. High-frequency converters determine the system's efficiency.

On-board and off-board chargers are the two types of conductive chargers. Off-board chargers have battery current regulators and rectifiers on the inside of the vehicle. While on-board chargers have both on the outside.

III. WIRELESS CHARGING METHODS FOR EVS

Figure 1 depicts the categories of wireless charging. Non-radiative or near field electromagnetic fields are formed by a moving electric charge in an antenna device (transmitter), and radiative or far field electromagnetic fields are created by a moving electric charge in an antenna device (transmitter). This section only covers wireless power transfer systems for EV wireless charging.

A. Far Field Technologies for Wireless Charging

Laser energy, microwave & radio frequency are firstly converted from electrical energy; second, converted energy is transferred into space; and lastly, at the destination, power is composed and converted back to electrical energy. Far-field power transmission systems are divided into two categories: microwave or radio wave, and laser. A quick review of the literature on several wireless power transfer systems is provided below.

1) Use of Lasers for Wireless Charging

Despite the fact that laser technology can carry energy across large distances, its efficiency is limited. A laser cannot be used to charge an electric vehicle. Due to the challenges faced in transmitting/conducting laser power, electricity is replaced by a laser beam and then concentrated on the solar cell. The laser's electromagnetic output spectrum is more similar to visible light [12]. This necessitates the employment of high-quality photovoltaic laser power converters calibrated for monochrome light conversion. One needs to be very cautious while attempting to maximize efficiency. If there is any diversion of the laser beam, this could result in energy loss or even be life-threatening.



2) Use of Radio Wave and microwave for wireless charging

WPT is one of the oldest ways as it was designed for wireless communication. N. Shinohara's to making suitable wireless charging of EV, collaborate with Nissan Motors from 2003 to 2008 shows how to develop a 2.45 GHz road-to-vehicle WPT system that used slot antennas and magnetrons to save money and microwave to charge the battery at a high efficiency about 76%. For rectify the power, enhance the efficiency and minimize the charging period a GaN (Gallium Nitride) Schottky diode has been developed [11].

Microwave technology was used to supply and receive energy to Earth via a solarpowered spaceship. A laser is used in far-field technologies to send extremely high power to a specific place. As Microwaves have directed nature, these can be utilized for long-distance power beaming.

B. Near Field Technologies for Wireless Charging

The energy concentrated near the transmitter within a small radius is referred to as "near field". The electric field wireless power transfer (WPT) can only transfer power over a fractional distance due to its quick deterioration rate, however magnetic fields can. Magnetic fields can penetrate people, furniture, and wall this is the reason of using WPT which can carry power over longer distances than electric.

1) Wireless Charging Using Permanent Magnet Coupling

A permanent magnet WPT prototype with an efficiency of 81 percent at 150 Hz frequency was built at a distance of 150 mm. Due to the vibrations and noise of numerous mechanical components, this system has a number of issues. Other important limitations of this design include alignment and maintenance issues. This method is not suitable for EV charging because to its large system, low efficiency, mechanical rotation, and other difficulties. Three different forms of magnetic gear have been proposed for use in wireless power transmission and execution. Misalignment is a major problem with most wireless charging methods, but not with PMC wireless charging.

2) Wireless Charging Using Coupled Magnetic Resonance (CMR)

In this type of charging firstly we create Magnetic resonance which consists transmitting and receiving coils, as well as capacitances, that are used to compute compensation and power factor adjustments, and then to produce a resonant set-up for maximum power transfer [10] [17].

3) Wireless Charging Using Inductive Power Transfer (IPT)

The magnetic induction concept is employed to deliver energy without the necessity of a carrier in IPT-based wireless charging. As we know that according to faraday law and Lenz law current carrying conductor turns into a magnetic field that voltage generated by magnetic flux is received by a secondary loop (receiver).

IV. WIRELESS CHARGING TECHNOLOGIES AND ITS IMPLEMENTATION

While parked, SWC charges the vehicle. Dynamic wireless charging, also known as dynamic forthcoming charging, allows you to charge your car while it's on the road. QWC also known as static forthcoming charging, is beneficial to cars that stop for regular time period at any stop like traffic light. Thanks to equipment installed below, buses, for example, begin charging wirelessly as they approach a bus stop. Electromagnetic fields are the most widely used WPT approach for wirelessly charging electric vehicles. Wireless charging modes DWC, QDC, and SWC are described further down.

A. Static Wireless Charging

A Static Wireless Charging is that which marks the beginning of SWC maturity. Its power transfer efficacy has improved due to better-quality of alignment. We are describing here numerous stages of wireless charging system, each with its own competence and complication [7]. When supply is an AC signal we should use AFE that needs



conversion by PFC correction into DC. Translation steps, productivity distributions, and overall efficiency are depicted in the figure

2. Each conversion process must be tuned for optimal efficiency.

Subsequently, the DC to AC converter uses a compensation network to convert DC to high-frequency AC, which is required for high power transmission.

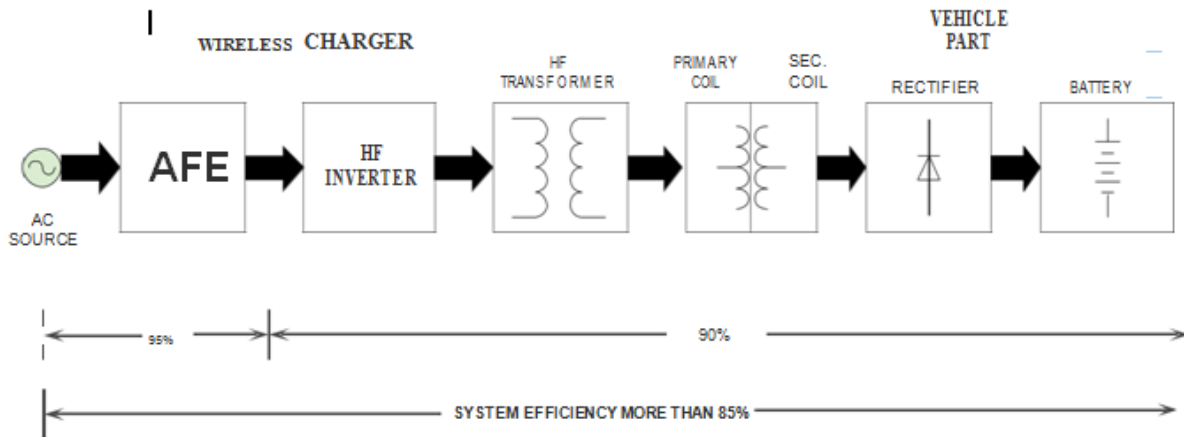


Fig. 2 Schematic Diagram of Wireless Charging System

Between this converter and the primary coil, a high frequency isolated transformer is installed to protect it from letdown. AC signal of high-frequency is generated in the secondary coil by applying Faraday's Law to the secondary coil, which then generates an alternating magnetic field, according to Ampere's Law. The resonant situation is matched utilizing the secondary compensation network to boost efficiency. Using a high-efficiency rectifier, AC electricity is converted and then battery is charged.

The main components of this charging system are, (a) the power electronics converters (b) the compensation network, and (c) primary and secondary coils are loosely connected and are separable; made of ferrite shielding.

B. Dynamic Wireless Charging

The EV is charged by dynamic wireless charging while driving. It is not compulsory to come to a complete stop while the battery is charging. This project faced several severe obstacles, including continuous power transmission, a high-frequency current regulated inverter, and a wide range of EMF characteristics. Range anxiety, battery size, battery expense, and other issues with electric vehicles are all solved with dynamic wireless charging. Current dynamic wireless charging models use inductive wireless power transmission. The coils put beneath the road surface has a magnetic link and supplied a high-frequency current to produce an electromagnetic field, as well as a pickup coil installed in the EV.

For DWC systems, stretched and lumped are the two types of track which is established, which differ in shape. A lumped track has a series of coils that are equivalent in size to the pickup coil while a stretched track has a transmitter coil that is considerably longer than the pickup coil.

The electricity captured by the on-road coils which form a pathway that continuously transmits power to the pickup coil that charges the EV battery when it is suitably conditioned. For a device with an implanted pickup coil low-power wireless system have also been created for delivering power and over a surface with a transmitter coil and many resonators, however these systems are inefficient for EVs because they travel in a straight line [7].

The OLEV was developed as a consequence of research on stretched tracks (On-Line Electric Vehicle). Only a part of the lumped track comprises the transmitter coil, which is linked and hence transfers power to the receiving coil. This supply segmentation technique improves DWC efficiency and reduces electromagnetic field radiation from non-coupled track components [21] [23].



C. Quasi-Dynamic Wireless Charging

QWC charging of electric vehicles (EVs) will be up-front to implement once both SWC and DWC are available. This mostly necessitates producing an auto-detective mechanism for charging situations. At traffic signals, use of Quasi wireless charging might be particularly beneficial because each stopping lane will have primary power pads which can be regulated by an isolated converter or in case of limited pads, it may be controlled by a single converter. In combination with traffic light controls, a controller could be used to activate and deactivate the pads. In the investigation, three different situations were used: (i) boosted driving range and economy by charging EVs at a predetermined power level at connectors. (ii) The charging profile is variable power, and V2G and G2V operations have been investigated. They have obtained outstanding outcomes as a result of its deployment. In bus networks, this charging solution would be really helpful. Because buses stop at regular intervals and these charging coils when placed inside the road will help charging on bus stops

V. EV WIRELESS CHARGING: ROAD BLOCKS

EV wireless charging has many benefits over the traditional contact charging, ease and galvanic separation are among topmost consumers advantages. The batteries of vehicles can be recharged, at a traffic light, at work, at shopping, at home, remove the need for charging points and wires. By incorporating charging lanes into highways and allowing cars to charge while driving, DWC may be able to eliminate the requirement for fast charging infrastructure.

The traditional charging has higher efficiency and power concentration as well as lower cost, size and manufacturing complexity whereas wireless charging is not that much efficient till now.

In order to transfer electricity efficiently, the challenges of EV wireless charging must be considered. Because wireless power transfer necessitates energy conversion, which limits conversion and transfer efficiency, it necessitates optimization and improvement in transfer efficiency. For all of these reasons, businesses find it difficult to switch from conductive to wireless charging. For the adoption of wireless chargers, each component is a significant study dimension. distance, compensation topology [2] [19], geometry, alignment, frequency and coil design are all factors that influence the effectiveness of the system, either directly or indirectly.

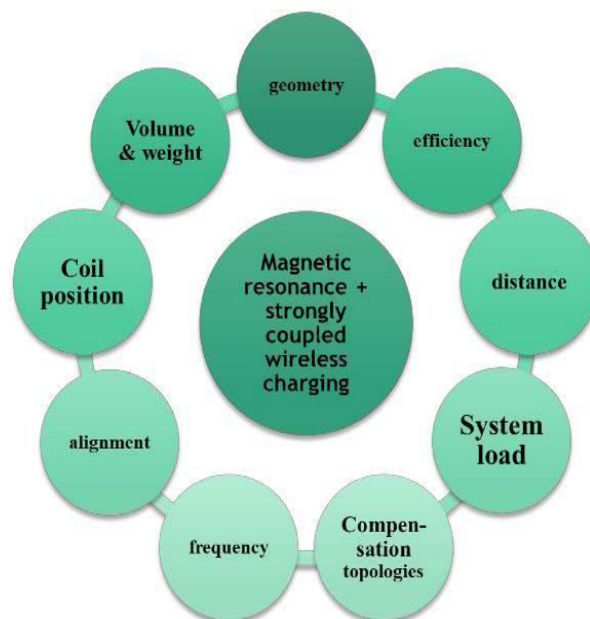


Fig. 3 Factors Influencing EV Wireless Charging

A resonant capacitance is required on both sides of an inductively linked power transmission. There are four alternative compensation topologies since the capacitor can be connected in parallel or series with the coil [2] [19].



A. SS TOPOLOGY

TOTAL IMPEDANCE

$$\bar{Z}_{total(SS)} = \left(R_1 + j \left(L_1 \omega - \frac{1}{C_1 \omega} \right) \right) + \left(\frac{\omega^2 M^2}{R_2 + R_L + j \left(L_2 \omega - \frac{1}{C_2 \omega} \right)} \right)$$

- SS compensation is meant to provide both a constant current and a constant voltage output.

- Operating frequency is unique for constant current operation as follows. $\omega = 1 / \sqrt{L_1 C_1}$
- Operating frequency is not unique for constant voltage operation

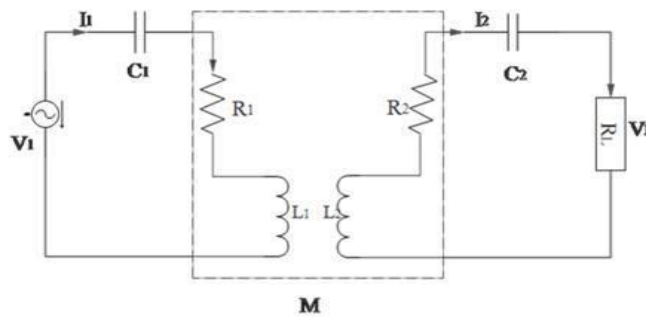


Fig. 4 Circuit Diagram of SS Topology

B. SP TOPOLOGY

TOTAL IMPEDANCE

$$\bar{Z}_{total(SP)} = \left(R_1 + j \left(L_1 \omega - \frac{1}{C_1 \omega} \right) \right) + \frac{\omega^2 M^2}{\left(R_2 + j L_2 \omega + \left(\frac{R_L}{1 + j R_L C_2 \omega} \right) \right)}$$

For high-power transmission, SP and SS are more cost-effective.

Because the resonance is assured, the SP and SS compensation topologies are better for shifting load situations

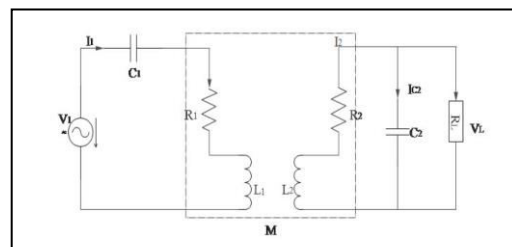


Fig. 5 Circuit Diagram of SP Topology



C. PS TOPOLOGY

TOTAL IMPEDANCE

$$\bar{z}_{total}(PS) = \frac{1}{(R_1 + jL_1\omega) + \frac{\omega^2 M^2}{R_2 + R_L + j(L_2\omega - \frac{1}{C_2\omega}) + jC_1\omega}}$$

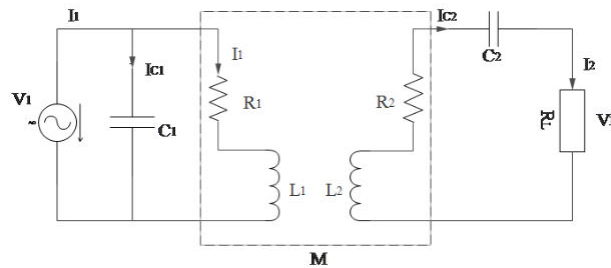


Fig. 7 Circuit Diagram of PP Topology

E. SPS COMPENSATION TOPOLOGY

TOTAL IMPEDANCE

$$\bar{Z}_{total} (SPS) = \frac{\bar{Z}_{11}}{1 + Z_{11}jC_3\omega}$$

Where, $\bar{z}_{11} = \bar{z}_1 + \bar{z}_r$

- It's a hybrid of SS and PS topology.
- Keeping K = 1, system act as PS topology
- Lower the value of Kc higher the possible rated misalignment rated power.

It can tolerate very high misalignment

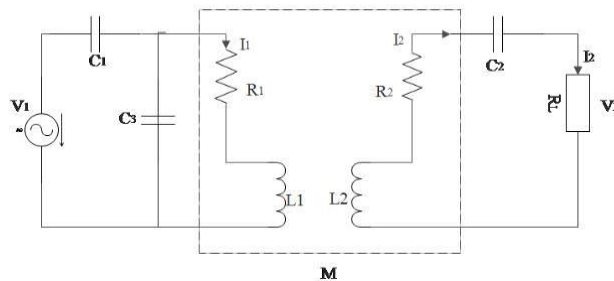


Fig. 8 Circuit Diagram of SPS Topology

F. LCC COMPENSATION TOPOLOGY

- The LCC topologis proposed by the Researchers from the University of Michigan, Dearborn.

$$P = \frac{8K\sqrt{L_1L_2}V_{in}V_{out}}{\pi^2\omega L_{f1}L_{f2}}$$



Where $k = \frac{M}{\sqrt{L_1 L_2}}$

- The input voltage of the inverter stage is V_{in}
The battery pack voltage is V_{out}

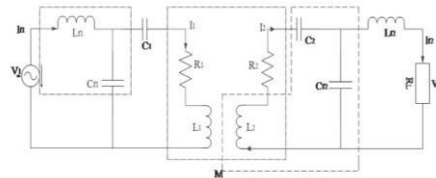


Fig. 9 Circuit Diagram of LCC Compensation

VII. CONCLUSION

The wireless charging system is reliable, efficient and also has more safety benefits. It is much better than the traditional wired charging system. In this paper we have studied about the various charging systems and different kind of wireless charging methods. The review on the static wireless charging, dynamic wireless charging and quasi dynamic wireless charging technologies is briefly described with their efficiency and dependency. To improve the charging technologies and increase the use of EV a summary made on compensation topologies in which we found LCC compensation for better future use.

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