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Efficient Wireless Power Transfer Techniques for Electric Vehicle Charging

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Abstract: The increased availability of charging stations has made EVs more accessible. However, as technology progresses, the demand problem on the electrical infrastructure becomes more pressing. One of the cutting-edge methods being explored to deal with the issue of rising power usage is vehicle-to-grid (V2G) technology. With the development of vehicle-to-grid (V2G) technology, electric vehicles may one day be able to sell any excess energy back to the grid, recouping some of the cost of their charging infrastructure. The use of renewable energy as a direct replacement for fossil fuels in transportation has become feasible because to advancements in V2G vehicle-to-grid technology. Recent developments in automation have made it possible to wirelessly charge electric automobiles. Electric vehicles' ability to connect to the grid is dependent on wireless networking due to transmission losses, misalignment, and security issues associated with electric power. In this paper a look can be taken at the pros and cons of several different wireless power transmission techniques

Index Terms- Wireless Power System, Battery Charging, Inductive Power Transfer.

I. INTRODUCTION

Electric vehicles (EVs) were first developed in 1830 to compete with internal combustion engine (ICE) cars worldwide [1]. Some of the major benefits of EVs are: Cleaner, better for the environment, quieter, and requiring less maintenance are just a few of the ways in which alternative fuel vehicles excel above their fossil fuel counterparts. To fill up the petrol tank is like recharging your phone. Installing charging stations for electric vehicles is less expensive up front than building gas stations. This further demonstrates the superiority of gas-free electric vehicles. Charging stations for electric vehicles must be placed in predetermined areas. In order to charge vehicles quickly, these stations typically require high-power transmission and auxiliary equipment. Wireless power could be the answer if using cables to charge devices is inefficient. Significant effort has been put into developing more efficient battery management systems and charging techniques for electric vehicles. Modern electric vehicles still rely heavily on batteries, though. The range of an electric car is dependent on how far a person drive it and how full the battery is. Long-distance power transmission without cables is theoretically possible according to Faraday's calculations of electromagnetic induction. Several methods exist for bettering inductive power transfer. High-quality batteries should be used in transmission and receiving coils, and charging procedures should be strictly followed to minimize electromagnetic interference. Several coil designs are optimized with the use of simulation software like ANSYS and COMSOL. The coils may be out of phase with one another due to improper installation or human error. Methods for preventing misalignment do this by combining well-established optimization techniques (such as phase angle optimization and balanced particle swarm optimization) with carefully positioned sensors. Wireless charging will improve if these adjustments are made.

II. EV Charging Methods

Improvements in the charging infrastructure are essential to the growth of EV mobility. Multiple options for charging electric vehicles are shown in Figure1, 2, 3 depicts the most popular types of EV charging infrastructure based on far field charging and near field charging methods. The charging stations for electric vehicles can be broken down into two distinct types. Conductive (plug-in) charging and wireless charging are the most prevalent methods. Charging a regular EV takes longer than a hybrid. Rapid charging can increase an electric car's battery life by as much as 50 percent in 3 minutes and 80 percent in 15 minutes. However, rapid charging methods reduce the battery pack's lifespan. As a result of the frustration caused by slow chargers, real-time, personalized fast chargers have been created.

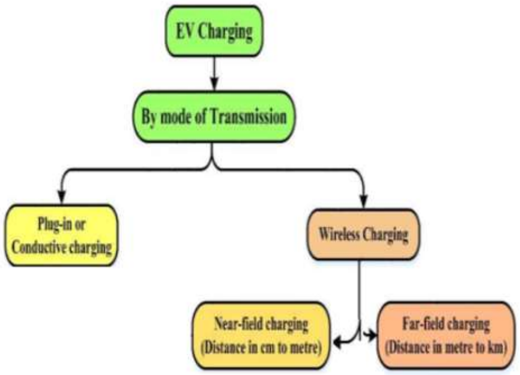

Figure 1. Classifications for charging EVs.

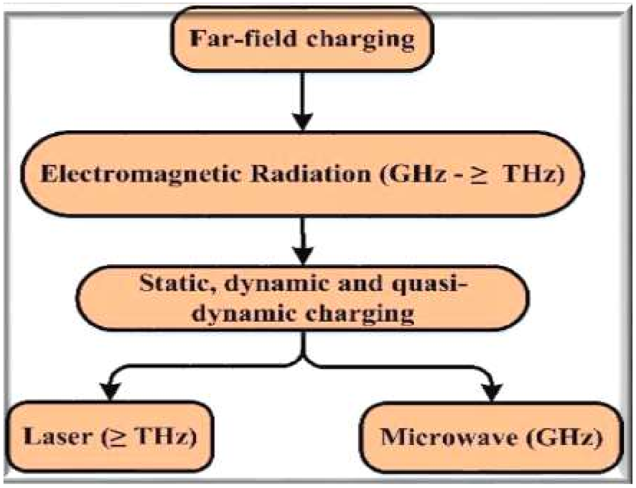

Figure 2 Typesof far-field charging.

Electric vehicles can also be charged by exchanging their batteries with a different one. This is also known as a "Battery Exchange System." The cost of the battery switching method is higher than the cost of fuel for internal combustion engines (ICE). Because of the wide range in battery size and cost needs, this approach would be prohibitively expensive.

Wireless Charging Technologies

WPT techniques are categorized as either far-field or near-field depending on the distance the inducing power must travel. Furthermore, the six variants of these two WPT systems are distinguished by the medium of transfer. Magnetic resonance, inductive power transfer, permanent magnet coupling, and capacitive coupling wireless power transmission are all examples of near-field charging methods, whereas microwave and laser are examples of far-field charging methods.

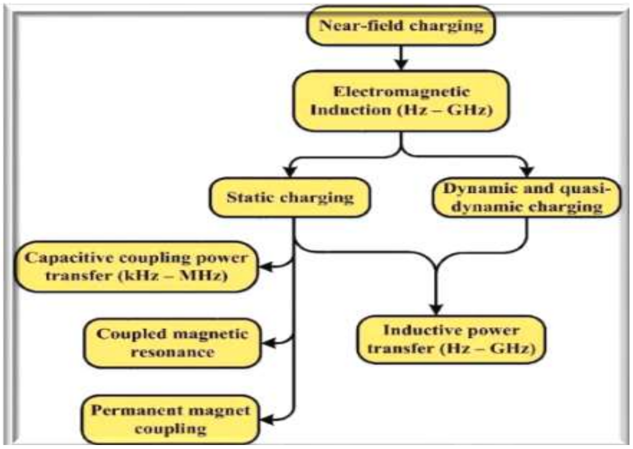

Figure 3 Types of near-field charging.

In contrast to microwave and laser, which cover much broader regions, near-field wireless technologies include IPT, CMR, and PMC. There are two ways to classify WPT, depending on whether or not they involve the use of personal autos. Static WPT is performed while the vehicle is stationary, in contrast to dynamic WPT which is performed while the vehicle is in motion. Several instances from the actual world illustrate how various WPT methods work. As a result, it is challenging to offer a solution that will work in a given context. CMR is better for low-power applications, while IPT can be used for high-power ones that don't need a resonant circuit. By employing WPT techniques, the air gap between the primary and secondary coils can be decreased, resulting in an efficiency boost of 85–96%. The larger the air gap, the less efficient the power flow will be. Increasing the airgap distance [2] between the transmitter and receiver coils is being considered by researchers as a means to improve efficiency. Maintaining peak performance in the presence of a sizable air gap calls for cautious management of the magnetic coupling coefficient. Efficiency levels above 90% are attainable with large values of the magnetic coupling coefficient.

Far-Field Charging

Long distances (from meters to kilometers) can be covered when transmitting electricity with far-field WPT. Figure 2 illustrates the correlation between far-field charging varieties and frequency bands. In the realm of far-field WPT, three main approaches exist. First step is to transform the electrical energy into a different form, such as a radio wave or a laser beam. The next step is to send the laser or radio wave to its final destination in outer space. All radiated energy is properly received and transformed into electrical current. The right transmission and reception channels make this method of power transfer straightforward to execute. Transmission frequency distinguishes between the two types of existing far-field WPT technology. Energy forms such as radio waves, lasers, and microwaves are utilized.

Microwave Power Transmission

The most cutting-edge improvement to the standard method of wireless power transfer is microwave power transmission. The first microwave ovens started appearing in homes in the 1960s. In 1964, William C. Brown attempted to power a helicopter with a "rectenna," which transforms microwaves into direct current (DC), and a microwave transmitter. A thin-film plastic rectenna was developed by NASA engineers in the 1980s using PCB technology, and it weighed just one tenth as much as regular rectennas. This is a significant step forward in the evolution of stationary high-altitude relay platforms (SHARPs), which are unmanned aircraft capable of transmitting power via microwaves. Microwaves are superior to other methods for long-distance energy transmission [2]. In 1968, the United States was the first to employ this method to transmit electricity internationally. However, there is a significantly broader frequency range (in GHz) that can be utilized for microwave power transmission. This method of transmission is successful only in areas devoid of humans (such as forests and deserts; ideally, there would be no terrestrial ecosystems at all) [94]. Only now, with the ability to convert solar energy into electricity in orbit and beam it back to Earth via microwaves, is the concept of satellites even possible. There is also a considerable effect of seasonal fluctuations and differences in the moisture content of the air on microwave performance. Microwaves, like radio waves, have difficulty passing through solid surfaces [2].

Laser Power Transmission

When compared to alternative methods, laser technology for long-distance power transmission is inefficient. The ability to charge an electric vehicle is disabled. The power transfer system for the laser is just as complex. In the realm of laser technology, high-frequency laser beams are the most effective means of transmitting energy. The photoelectric effect {2], first shown to exist in 1965, is fundamental to its functioning. Before the energy from a solar cell can be sent through a fiber optic cable, it must be converted into a high-frequency laser beam. This method of communication is referred to as "power beaming." The normal range for the wavelength of laser electromagnetic radiation is 180 to 400 nanometers, the same significance as the visible spectrum.

Having the laser point directly at the solar cell is crucial for this reason. Changing the type of electrical energy requires power converters once again. Because it may be utilized for mobile applications at distances up to one kilometer, laser power transmission is a versatile solution. But while working with lasers, additional precautions must be taken. The receiver's sweet spot is anywhere between 20% and 30%. The electro-chemical systems of live beings are vulnerable to the impacts of a poorly directed laser beam.

Near-Field Charging

According to the near-field power transmission idea, it is possible to send electricity across short distances without a medium or any kind of conversion. As its name implies, near-field WPT has a much smaller airgap between the primary and secondary coils. Both millimeters and meters can be used interchangeably. The performance of a near-field WPT is dependent on the materials used in the transmitter and receiver modules. Long-distance electrical transmission is possible with the appropriate arrangement of electrodes and coil-generated magnetic fields. Wireless power transfer (WPT) can be accomplished by either electric or magnetic fields. Large amounts of power can be transferred over relatively small distances because the electric field decays so quickly. In order to decrease the delivered power, the air gap between the primary and secondary coils must be widened, however this will decrease the coils' efficiency. When it comes to long-distance power transmission, magnetic fields are superior to electric currents.

Capacitive Coupling based Wireless Power Transfer

Including Capacitive Coupling Wireless Power Transfer (CCWPT) is crucial. Capacitive interaction between metal electrodes allows for this type of energy transmission. The transmission range is limited because the electric fields between the electrodes do not propagate. Figure 4 depicts the CCWPT equivalent circuit.

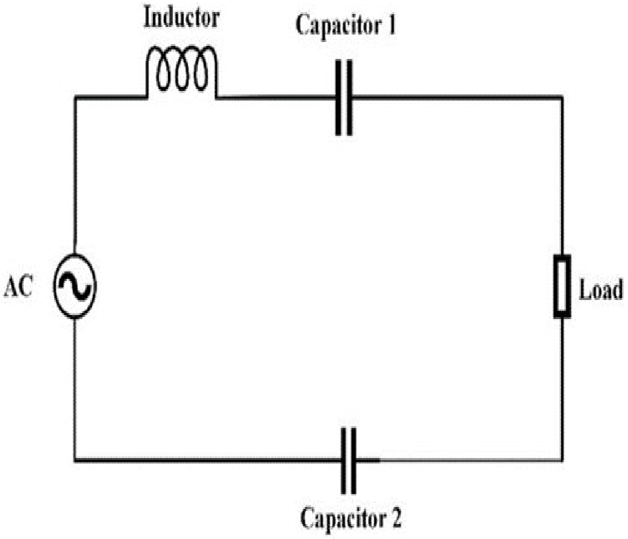

Figure 4 Equivalent circuit of CCWPT.

The domain of the electric transmission field can be reduced by lowering the distance between the electrodes, allowing the transmitter to transfer the electric field into an appropriate receiver or absorbing medium. Output voltage calculation equation depicted in equation 1:

$$V_{OUT} = \frac{V_{IN}}{j\omega L + \frac{2}{J\omega C_c} + R_L} R_L \qquad (1)$$

There are three strategies recommended by the aforementioned formula for increasing the system voltage. The impedance must be reduced before the operating frequency of the model may be raised. Alternatively, compensation can be used to similarly restrict capacitive impedance. Using a voltage booster circuit should only be done as a last resort. The low eddy current loss, low weight, and low cost of the approach are its primary selling points. CCWPT technology enables smaller airgap systems [2] due to the low-power needs of applications including medical instruments, mobile electronics, and LED lighting.

Coupled Magnetic Resonance Charging

Coupling theory is used by coupled magnetic resonance wireless charging to transmit power over such a large distance. The primary and secondary halves of this charging system are synchronized with each other via a pair of antennae. The MHz frequency range is optimal for this energy process. Numerous Japanese institutes, such as Nagano Japan Radio Co., Ltd. and Toyohashi University of Technology, are devoted to researching magnetic resonance and electric resonance couplings. Magnetic resonance charging was developed at the Massachusetts Institute of Technology in Cambridge, Massachusetts, USA. Power factor adjustment compensatory capacitors, secondary coils, and a resonant state all contribute to the system's ability to track power as efficiently as possible. South Koreans have embraced online electric vehicles with resolution-coupled Dynamic Wireless Charging (DWC). A dynamic WPT system can achieve an efficiency of 90% at a range of just 1 meter. The addition of magneto plate wires is a fantastic technique to increase power.

Permanent Magnet Coupling Charging

The University of British Columbia developed a WPT technique based on permanent magnet coupling, with neodymium permanent magnets serving as the magnetic coupler. Both the primary and secondary rotors are magnetic and rotate at the same frequency. The phrase "synchronous speed" is used to describe this rotational frequency. When there are a lot of moving parts, the charging process can be quite noisy, hot, and vibratory. One major drawback of the permanent magnet WPT system is the need for constant alignment and maintenance. In comparison to other EV charging methods, permanent magnet WPT has a number of downsides, such as its bulky size, low efficiency, moving mechanical parts, etc. The Covic et al. permanent magnet WPT model is 81% efficient at 150 Hz and 150 mm of air gap.

Inductive Power Transfer

Inductive power transfer relies on electromagnetic induction between places. However, power transfer via induction cannot occur without Lenz's law and Faraday's law. An electromagnetic field is produced close to a conductor (transmitter) when the current flowing through it varies with time. This provides power to the secondary coil, which is where the receiver is located. Subsequently, the power is transferred without the primary coil ever coming into direct contact with the battery or the load. With the right magnetic materials, electromotive force can be sent and received. A schematic of an inductive power transfer experiment is shown in Figure 5.

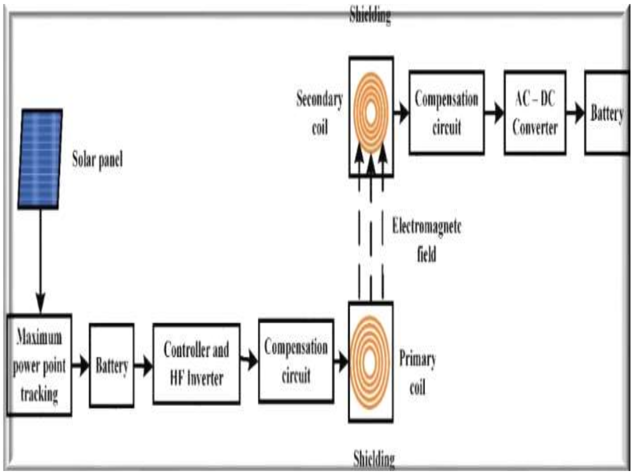

Figure 5. Block diagram of IPT.

In 1982, the Partner for Advanced Transit and Highways (PATH) finished a project to charge wirelessly using an airgap of 50-100 mm and a frequency of 400 Hz. It was in 1990 that the first IPT systems were established, one in France by Transport Urban Libre Individual Public (TULIP) and another in Germany by the Wampfler Company. In order to generate 30 kW of power at 22 kHz, the Showa Aircraft Company utilized an IPT system with an airgap of 14 cm and an efficiency of 92% [141]. In 1999, an innovative inductive coupler was constructed; it had an air gap of just 3 mm between its primary and secondary coils, generated 8.3 kW of power, and was 97% efficient. Radio-frequency identification (RFID) systems work wonderfully when used to lightweight portable technology (WPT) items. With the non-resonant IPT technique, power can be delivered consistently and effectively across a narrow air gap. The resonant IPT method is well-suited for large airgap power transmission since it runs at the same frequency.

Static Charging

The concepts behind IPT and static charging are conceptually similar. Static wireless charging is vastly superior to dynamic charging for recharging electric automobiles. Misalignment between the transmission and reception coils can reduce the effectiveness of static WPT. This issue can be fixed by employing suitable mechanical and compensating technology.Misalignment with static WPT has inspired investigation into potential remedies. Figure 6 [2] is a diagram showing the EV static WPT. Paying close attention to detail during the conversion process can help improve the system's efficiency. This block diagram depicts two different eras. First, electricity from a direct current or alternating current source is converted to a higher frequency using a high-frequency inverter.

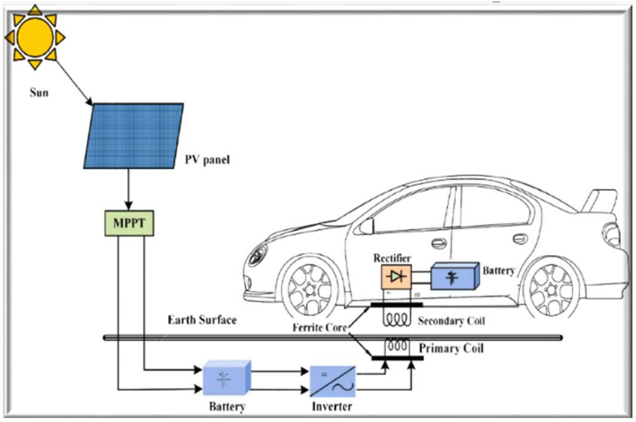

Figure 6. Static WPT [2].

Before the high-frequency inverter can function, the alternating current (AC) from the power source must be converted to direct current (DC), and the power factor must be corrected. High-frequency alternating current (AC) is all that's needed for energy transmission via induction. It is shown that the high-frequency inverter can be powered by either solar energy or a DC power source. The DC power is routed into an inverter, which converts it to extremely high-frequency AC current. The aforementioned strategy has the potential to increase production by as much as 97%.

Lastly, inductive coils, a compensating network, and an AC-to-DC converter round up the circuit. When the high-frequency inverter supplies the primary coil with alternating current (AC), an electromagnetic field is generated. The receiver coil creates an electromagnetic field using alternating current power and this field has a finite range. The battery charger is powered by DC current derived from the alternating current source. In the last stage, may achieve a success rate of 95% to 97%. Overall system efficiency is 85% gives effectiveness of the first two stages. Multiple automakers are working on static wireless charging for EVs.

V. CONCLUSION

Several nations have begun relying on renewable energy sources as a solution to the worldwide shortage of nonrenewable resources and the alarming increase in pollution. Companies are consequently hoarding more and more software that can run on renewable energy sources. The transportation sector consumes a disproportionate amount of renewable energy. As the automotive industry has grown and evolved at a rapid pace in recent years, wireless power transfer technologies in charging infrastructure have become increasingly significant. In coming years, various wireless charging techniques discussed in this paper should solve the problems that have hampered conventionally wired charging for EVs.

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