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Wireless Charging System for Electric Vehicles

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ABSTRACT

Due to the significant fuel emissions and relative benefits of electric vehicles, the majority of automotive industries are currently producing electric vehicles. The complexity and weight of the vehicle are reduced when batteries are used. The batteries used in cars should be highly efficient, but doing so adds weight to both the battery and the car, which causes the batteries to overheat. Wireless power transfer, a technique created to charge the battery, is used to solve this issue. The wireless power transfer method's basic operating idea is based on mutual inductance, in which the receiver charges the transmitter while the transmitter charges the vehicle. Receiver coils have been added to the previously mentioned system to increase charging power and track source-to-vehicle power transmission. The performance of the wireless recharge system and the impact of parameters on the vehicle while charging is both improved using the novel technique presented in this paper.

Keywords: Electric vehicles, Mutual inductance, Wireless charging system, Inductive charging, Dynamic charging, Static charging, Contact less charging.

INTRODUCTION:

Fuel is required by all modes of transportation in the modern world, primarily gasoline and diesel. However, at the moment, more vehicles are being produced than fuel. The automotive industry is significantly impacted by these enormous fuel emissions. Resulting Electric vehicles, which run on batteries and don't require fuel, are being introduced to the market in response to the fuel emissions. However, the main disadvantage of these electric cars is the energy storage in the batteries.[14]

Many automotive industries developed batteries that can store the energy needed by the user, but doing so increased the weight of the car and made the batteries overheat, which led to car fires. In order to increase energy efficiency, numerous experiments were carried out. Some of these experiments concentrated on the hybrid recharge system, which uses two power sources inside the vehicle—a battery and a photovoltaic system that converts light energy into electrical energy. However, this model also has some drawbacks, including the vehicle's structure, increased vehicle weight, and the shading effect (shadows falling on solar panels reduce output power). Researchers have developed a new technique, wireless charging, which is more reliable and advantageous, while keeping in mind the aforementioned drawbacks. The vehicle battery will be smaller and more effective thanks to wireless charging. Inductive power transfer, magnetic gear wireless power transfer, capacitive wireless power transfer, and inductive coupling link wireless power transfer are just a few of the techniques that have been developed for wireless energy transfer. Inductive coupling link wireless power transfer is a widely used and effective technique from the list of techniques above for charging EVs. The mutual inductance between the primary and secondary coils has been the foundation of this technique. The primary coil, also known as the transmitter, is installed on the road, and the secondary coil, also known as the receiver, is installed inside the car. To charge the vehicle, the appropriate number of wireless coils should be positioned in the road.[14]

To install the appropriate number of coils in the road, factors including resistance, inductance, pitch angle, coil dimensions, spacing between coils, and receiver coil displacement speed were taken into account. Wireless charging technology is already in use in other nations, including Sweden, Norway, and others. We can better understand the wireless charging system by reading the sections below.[14]

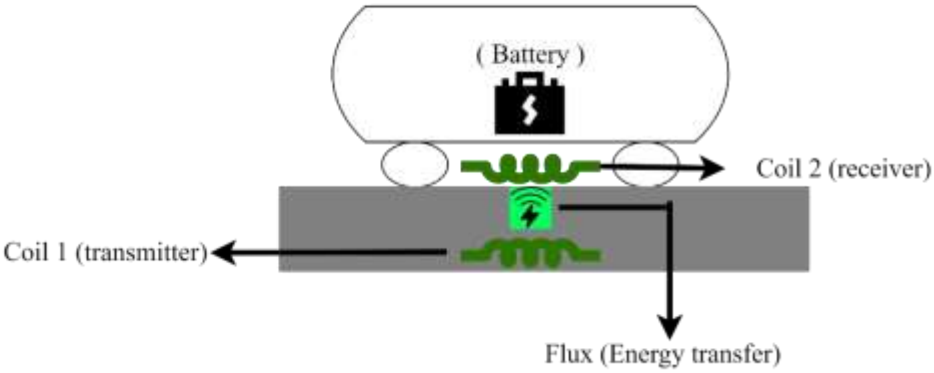

Fig. 1. Wireless Charging System

1. WORKING PRINCIPLE OF WIRELESS CHARGING

The wireless charging system is based on the principle of mutual induction, which essentially states that whenever the current in coil 1 changes, it also generates a changing magnetic field (according to Ampere's Law). According to Faraday's Law, a changing magnetic field induces an emf in coil 1, and because the magnetic flux through coil 2 also changes as a result of the changing magnetic field in coil 1, an emf is also induced in coil 2. Here, we must note that the primary coil's changing current causes an emf to be induced in the secondary coil. As a result, the coil 2 will have a changing current after producing emf, and because of the coil 2's changing current, the coil 1 will also produce emf. Mutual induction is used here because emf is induced in both coils. Mutual induction is nothing more than the transfer of energy between coils 1 and 2 without the use of wire contact. Due to the fact that energy transfer is dependent on the distance between the coils, mutual induction is primarily dependent on the number of turns in the coils, conductor cross sectional area, and distance between the primary and secondary coil. Smaller distances between coils result in greater energy transfer efficiency, whereas larger distances between coils result in greater efficiency.

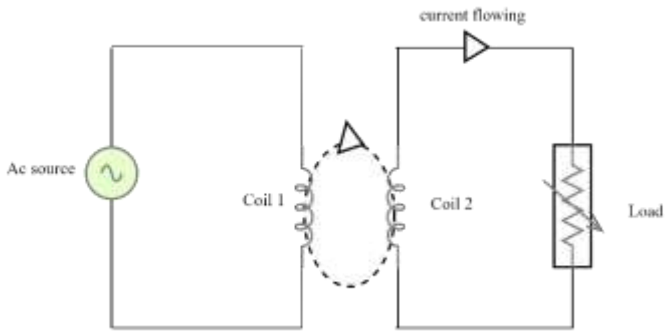

Fig. 2. Mutual Induction

2. WORKING OF WIRELESS CHARGING SYSTEM

We'll start by talking about the components of the system. Three main parts are used on the primary or transmitter side: a power source, an AFE, and an inverter. On the secondary or receiver side, we use a battery and a rectifier.

2.1. AFE

It is the best technology for overcoming harmonic challenges because AFE, or Active Front End, is a bidirectional rectifier that switches from AC to DC and vice versa.

2.2. INVERTER

It is a piece of technology that changes DC into AC. These are employed both in domestic and commercial settings. ***2.3. 2.3. RECTIFIERS***

Only DC power is stored in batteries. In order to convert AC power to DC, a rectifier is used.

The mutual induction principle underlies how the wireless charging system operates. Coil 1 is installed in the road as a transmitter for this, and coil 2 is installed underneath the vehicle as a receiver. The two coils are separated by a vacuum, and each part has an electronic system that ensures compatibility between the transmitter and receiver. Initially, an active front end (AFE) converter that produces a controllable DC voltage is connected to an AC power source. In order to maintain grid stability, this portion of the transmitter block is modified by a power factor corrector (PFC) block, which monitors the reactive power flowing from the source to the transmitter.[14]

A full bridge high frequency inverter transforms the converted DC from AFE into high frequency AC after being flown there (here we are giving AC to transmitter i.e., coil 1 because as earlier said an emf is induced in the secondary coil only if there is a changing current in the primary coil). Since the direction of current flow in AC can change while it remains constant in DC, we use AC. The induced emf will take on a sinusoidal shape after being induced in coil 2 (on the receiver side). Because batteries are unable to store AC power, we use a rectifier on the receiver side to convert the AC to DC, which is then supplied to the battery.

The two factors are what this wireless charging system primarily depends on. The power transfer efficiency is guaranteed by the compensation topologies, which are the first factor. The design of the coils used on the primary and secondary sides is the second factor. These two factors will be very clearly understood by the end of the following sections.

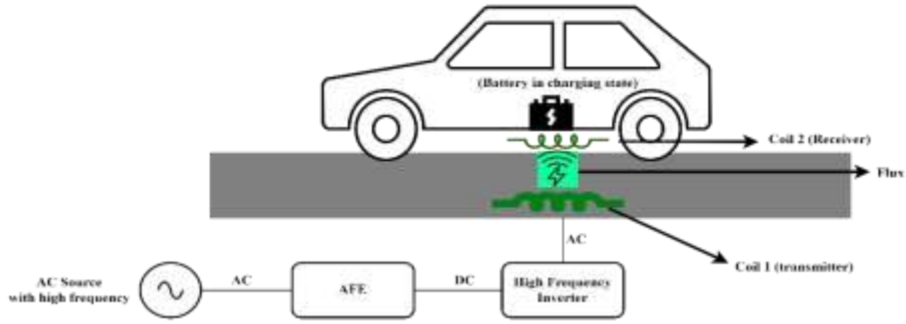

Fig. 3. Working of WPT System

COMPENSATION TOPOLOGIES

This is the primary element that has an impact on the wireless charging system. First, it is important to understand what is a topology is. A topology is nothing more than a network of connections between circuit components.

CAPACITOR

The capacitor stores energy and releases it back into the system once every half cycle. When a load has a low power factor, capacitors supply the stored energy. Capacitors are therefore referred to as temporary batteries.

The capacitor is connected across the inductor to improve power transfer and reduce apparent power from the input source. Therefore, in order to make the concept clear, we discussed the capacitor above. There are four topologies for resonant circuits, which have very low impedance at specific frequencies. Both parallel and series connections are possible for the capacitor and inductor. Assume that the values of the primary, secondary, and inductors are (C 1, C 2) and (L 1, L2), respectively. The four topologies are:

1) Series-Series (SS)
2) Series-Parallel (SP)
3) Parallel-Series (PS)
4) Parallel-Parallel (PP)

Fig. 4. Series-Series Topology

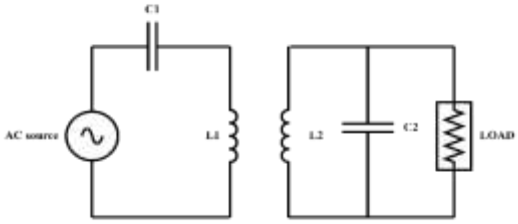

Fig. 5. Series-Parallel Topology

Fig. 6. Parallel-Series Topology

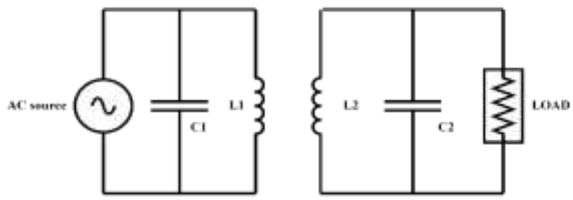

Fig. 7. Parallel-Parallel Topology

The characteristics of the topologies are listed in table 1 below for the selection of an appropriate topology for maximum power transfer.

Table 1

Topology Specifications

FEAUTURES	SS	SP	PS	PP
Sensitivity of power factor over distance	Low	Low	Moderate	Moderate
Impedance at resonant state	Low	Low	High	High
Suitability for EV applications	High	High	Moderate	Moderate
Power transferred at constant source	Low	High	Low	Low
Alignment tolerance	High	High	Moderate	Low
Frequency tolerance	Low	High	Low	High
Type of source to be applied to transfer maximum power	Voltage source	Voltage source	Voltage/Current source	Voltage/Current source

From the above table we conclude that topologies with the series primary compensating are the most effective in the IPT (Inductive power transfer) for charging devices among the four classical schemes.

COIL DESIGN

The WPT system is influenced by this second factor. Since there would be no energy transfer without coil, coil can be thought of as the beating heart of the WPT system. The coil's design is crucial for energy transfer because the efficiency of power transfer depends on the coil's design and some coil designs also help to minimize misalignment issues. The power transfer will be lessened if the coils of the transmitter and receiver are not aligned. There are numerous coil designs available on the market that can be used with the WPT system, but they fall short of user expectations in terms of increased power transfer, quick charging, etc. With these coil designs, their main challenge was maintaining proper alignment between coils 1 and 2, as even a small difference in distance reduced power transfer. It is essential to have the highest misalignment tolerance between the coils in order to solve these issues. Researchers have therefore created three different coil designs that virtually eliminate the positional dependence of the receiving coil's receiving power.

The three different coil configurations are 1

1) Spiral coil design
2) Planar coil design
3) SAP

Fig. 8. Spiral coil design[1]

Fig. 9. Planar coil design

Fig. 10. SAP coil design [1]

To enhance performance and address misalignment issues, the aforementioned three coil designs can be created in either of two possible configurations, namely simple forms or combinational forms.

Simple Forms

Simple forms come in three different varieties: square, circle, and rectangle. The coils are wound in these shapes in case of single transmitter and receiver. It is also known as the two-coil type.

Fig. 11. Rectangular form

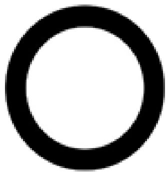

Fig. 12. Circle form

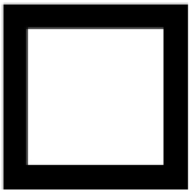

Fig. 13. Square form

Combinational forms

Combinational forms come in four different categories. The coils are wound in these shapes when there are multiple transmitters and receivers. This type is additionally known as the multiple coil type. Below is a list of the various types of combinational forms.

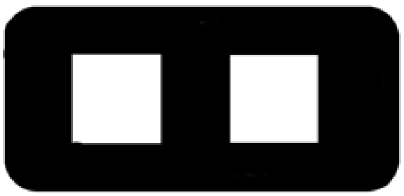

Fig. 14. Double-D

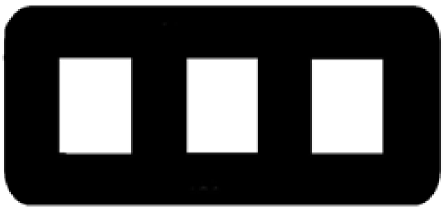

Fig. 15. Bi-polar form

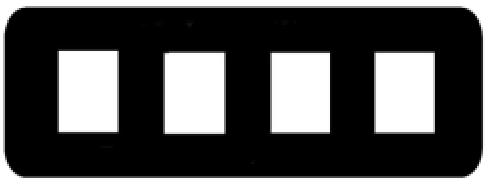

Fig. 16. Double D-quadrature

Fig. 17. Quad-D quadrature

Note: In the aforementioned forms, the black colour stands in for the coils, and the white colour represents empty space. The circular planar structure has the lowest null zone when compared to the other models when all the aforementioned coil design types are tested for a 2KW inductive power transfer.[14]

CHARGING EFFICIENCY IN VARIOUS CONDITIONS

Many factors influence charging efficiency, including distance between transmitter and receiver, coil design, kind of correction, and so on. Among the previously stated considerations are coil design and different compensation strategies, which are described in the preceding sections. This section will go through the influence of distance on charging efficiency. This aspect has a significant impact on charging efficiency. The car is charged in two ways: when it is moving and while it is still. To better explain these two circumstances, we shall utilise two non-technical terms: static and dynamic.

Static Charging

When the car battery remains static, it charges, as the name implies. So we could just park the vehicle at the charging location, which is the receiver coil in the road. Because of the parallel alignment of the transmitter and receiver, the efficiency of energy transmission is higher in this scenario. Figure 6.2 depicts the change in energy transfer efficiency with time in a static charging state.

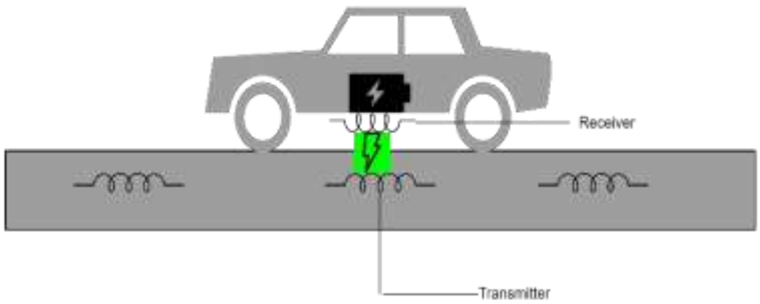

Fig. 18. Battery Charging in Static Mode

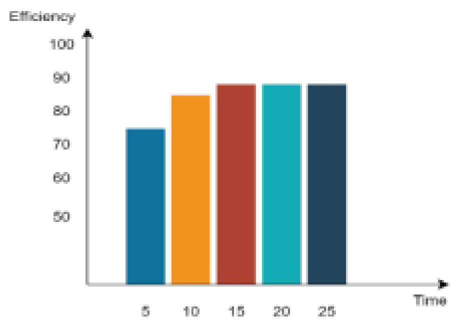

Fig. 19. Efficiency of Energy Transfer vs Time

Dynamic Charging

The battery is charged while the vehicle is in motion, as the name indicates. The energy transmission in this situation varies with distance and time because the transmitter and receiver coils never align parallelly for more than a minute due to the vehicle's speed. As a result, the energy transfer efficiency in this situation is lower than in the previous example, i.e., in static mode.

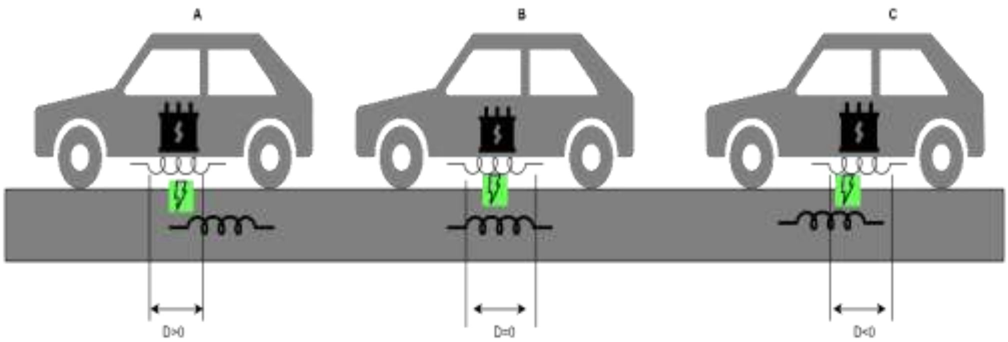

Fig. 20. Dynamic Charging

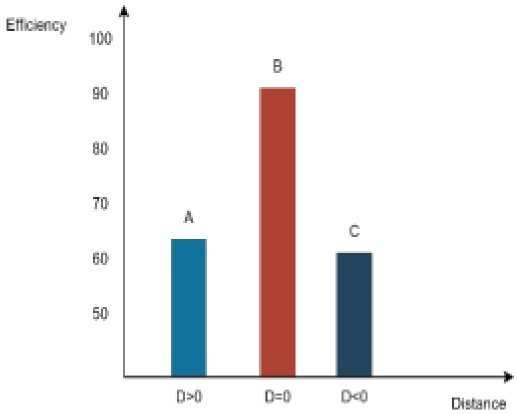

Fig. 21. Efficiency of Energy Transfer vs Distance

For clarity, we will assume three scenarios: first, the receiver is approaching the transmitter (D<0), second, the receiver and transmitter are aligned parallelly (D=0), and third, the receiver is leaving the transmitter (D>0). According to the graph, the second case, with D=0, has the highest efficiency of the three cases. When the automobile approaches the transmitter, power transfer begins; when the car is parallel to the transmitter, efficiency increases; and when the car leaves the transmitter, efficiency decreases.

The energy transfer is greater at D=0. This is what we mentioned in the static charging section. We may wonder why we have broken things into two groups if both are the same. The answer is to demonstrate and comprehend that power transmission efficiency will vary with distance (within the certain limits).

METHODS TO IMPROVE THE EFFICIENCY OF POWER TRANSFER

A longer coil length may also aid enhance inductance and magnetic field, which may result in greater transfer efficiency. Aligning the transmitter and receiver coils in parallel may also help boost power transfer efficiency. By employing more receiver coils in the vehicle and more transmitter coils for every one metre on the road increases the efficiency.

Conclusions

The major goal of this article was to improve the efficiency of power transfer. The essential components of the WPT were explored in terms of compensation topology, coil design, and functioning principle. The efficiency is determined by the mutual inductance value. Having extra coil receivers under the EV is also an improvement to the process. In the WPT system, mutual inductance is a significant characteristic. The development of a new type of WPT gadget to assure high-efficiency EV battery charging is now underway. The laboratory results reveal that increasing the number of turns in the coil can boost the efficiency of the wireless recharging system by 100%.

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