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Wireless charging for electric vehicles

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ABSTRACT:

Wireless Power Transfer (WPT) systems transfer electric energy from a source to a load without any wired connection. WPTs are attractive for many industrial applications because of their advantages compared to the wired counterpart, such as no exposed wires, ease of charging, and fearless transmission of power in adverse environmental conditions. Adoption of WPTs to charge the on-board batteries of an electric vehicle (EV) has got attention from some companies, and efforts are being made for development and improvement of the various associated topologies. WPT is achieved through the affordable inductive coupling between two coils termed as transmitter and receiver coil. In EV charging applications, transmitter coils are buried in the road and receiver coils are placed in the vehicle. Inductive WPT of resonant type is commonly used for medium-high power transfer applications like EV charging because it exhibits a greater efficiency. This thesis refers to a WPT system to charge the on-board batteries of an electric city-car considered as a study case. The electric city-car uses four series connected 12V, 100A·h VRLA batteries and two in-wheel motors fitted in the rear wheels, each of them able to develop a peak power of 4 kW to propel the car. The work done has been carried out mainly in three different stages; at first an overview on the wired EV battery chargers and the charging methodologies was carried out. Afterwards, background of different WPT technologies are discussed; a full set of Figures of Merit (FOM) have been defined and are used to characterize the resonant WPTs to the variations in resistive load and coupling coefficient. In the second stage, the WPT system for the study case has been designed. In the third stage, a prototypal of the WPT system has been developed and tested.

Keywords: Wireless Power Transfer (WPT), Electric Vehicle (EV), Inductive Coupling, Electric City-car, Charging Methodologies, Environmental Conditions, Industrial Applications.

1. INTRODUCTION:

Growing concern in the reduction of the polluting emissions due to the transportation means has led to the adoption of vehicles powered by comparatively cleaner sources of energy, such as batteries, fuel cells and so on, in place of internal combustion engine (ICE) based vehicles. Differently from ICE vehicles, electric vehicles (EVs) are not a matured technology in terms of vehicle autonomy, and a lot of research efforts is being carried out by academia and industries to improve the overall performance of these vehicles. Various solutions are being adopted to increase the autonomy of the vehicles such as conceiving batteries of higher energy density, relaxing the batteries during acceleration and regeneration by supplying and absorbing the current peaks by means of supercapacitors, arranging fast chargers, charging while on move etc. On-board batteries are typically recharged at home or at stations/parking places through conductive battery chargers. Generally, two types of conductive battery chargers are used: off-board and on-board. On-board chargers can be used to charge from the utility outlet at home or at charging stations during the day time. Off board chargers operate like a gas station and are designed to manage high powers in order to perform a fast charge. In most of the battery chargers the power flows only from the utility grid to the battery, and for this reason they are often termed as unidirectional battery chargers (UBCs); beside circuital simplicity, UBCs enjoy a reduced grid interconnection and lower battery degradation. On other hand, some battery chargers manage power flowing in both directions and are able to perform ancillary operation in favor of the grid, such as peak power shaving or reactive power compensation. These battery chargers are called bidirectional battery chargers (BBCs). Charging of an electric vehicle can be performed by either conductive (or wired) charging or wireless charging. Wired charging uses connection means between electric supply and charge inlet of the vehicle.

2. LITERATURE REVIEW

[1]"The transmission of electrical energy without wires". by Nicola Tesla et al (1904)

Overview

In this paper, we discuss It is impossible to resist your courteous request extended on an occasion of such moment in the life of your journal. Your letter has vivified the memory of our beginning friendship, of the first imperfect attempts and undeserved successes, of kindnesses and misunderstandings. It has brought painfully to my mind the greatness of early expectations, the quick flight of time, and alas! the smallness of realizations.

[2] “The history of power transmission by radio waves," by William C. Brown et al (1984)

Overview

In this paper provides The history of power transmission by radio waves is reviewed from Heinrich Hertz to the present time with emphasis upon the free-space microwave power transmission era beginning in 1958. The history of the technology is developed in terms of its relationship to the intended applications. These include microwave powered aircraft and the Solar Power Satellite concept.

[3] "Wireless Power Transfer via Strongly Coupled Magnetic Resonances," by AB. Kurs et al (2007)

Overview

In this work, we proposed Using self-resonant coils in a strongly coupled regime, we experimentally demonstrated efficient nonradiative power transfer over distances up to 8 times the radius of the coils. We were able to transfer 60 watts with approximately 40% efficiency over distances in excess of 2 meters. We present a quantitative model describing the power transfer, which matches the experimental results to within 5%. We discuss the practical applicability of this system and suggest directions for further study.

[4] "Wireless Power Transfer via Strongly Coupled Magnetic Resonances," by A Karalis et al(2020)

Overview

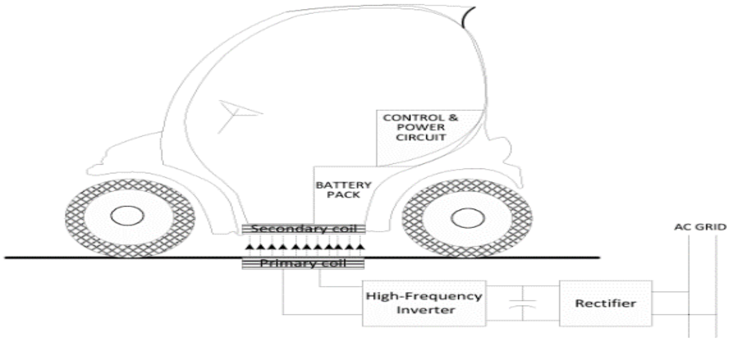
In this study ,we investigate whether, and to what extent, the physical phenomenon of long-lifetime resonant electromagnetic states with localized slowly-evanescent field patterns can be used to transfer energy efficiently over non-negligible distances, even in the presence of extraneous environmental objects.

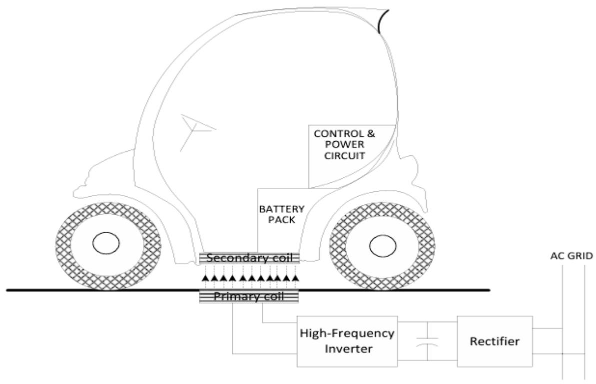
3. PROPOSED METHODOLOGY

The methodology proposed for wireless charging of electric vehicles begins with the design and configuration of the charging system. This stage involves defining the power requirements and specifications of the EV charging setup and selecting an appropriate Wireless Power Transfer (WPT) technology based on efficiency, power levels, and compatibility with EVs. Next, components such as transmitter and receiver coils are carefully chosen to optimize power transfer efficiency and distance, considering factors like coil size, shape, and material. The resonant frequency of the WPT system is then determined to maximize efficiency and minimize electromagnetic interference. Subsequently, the system's performance is simulated and analyzed using modeling tools to assess its behavior under various conditions such as load variations and environmental factors. Safety and regulatory compliance are critical aspects, ensuring that the wireless charging system adheres to standards for electromagnetic compatibility (EMC) and interference (EMI). Following this, a prototype of the wireless charging system is developed and subjected to comprehensive testing to validate its performance, efficiency, and reliability. The integration of the system with existing EV infrastructure, such as charging stations or vehicle charging ports, is then addressed. Through iterative optimization and fine-tuning based on testing results and user feedback, the wireless charging system is refined to maximize efficiency and user experience. Finally, the deployment of the wireless charging system in real-world scenarios allows for evaluation of its effectiveness, usability, and scalability, facilitating the broader adoption of wireless charging technology for electric vehicles.

The methodology for implementing wireless charging for electric vehicles (EVs) involves several key steps. Firstly, the power requirements and specifications of the EV charging system are defined, followed by the selection of an appropriate Wireless Power Transfer (WPT) technology based on efficiency and compatibility. Components such as transmitter and receiver coils are carefully chosen and optimized for efficient power transfer. The resonant frequency of the WPT system is determined to maximize efficiency. Finally, the system's performance is evaluated through simulations and testing to validate its effectiveness and reliability under various operating conditions.

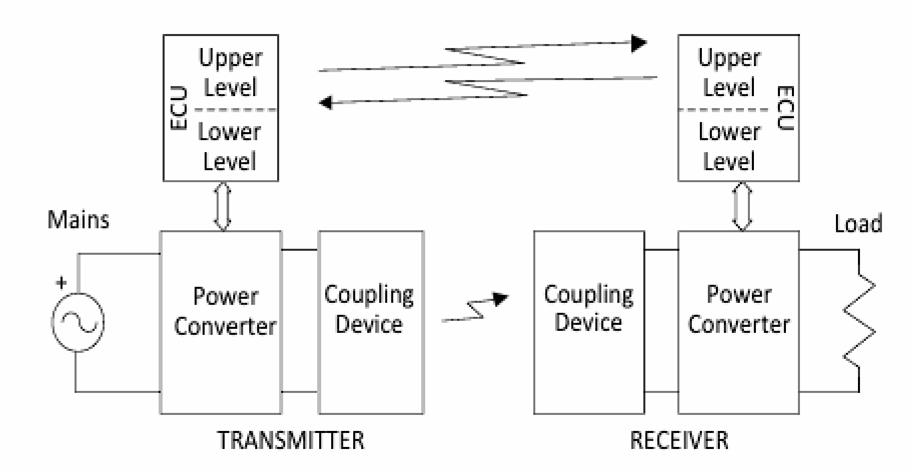
Fig. 3.1: Schematics of WPT for electrical vehicle battery charging





4. WORKING PRINCIPLES

A WPTS has the structure of Fig 3.1. It is made of two power sections electrically insulat ed: the transmitter and the receiver. The transmitter is buried into the pavement and is fed by the mains, the receiver is embedded into the electric vehicle and delivers power to the battery pack on board the vehicle, the latter one constitutes the load of the WPTS and is represented by a resistor in Fig 3.1. Each section of WPTS consists of a coupling device and a power con verter. The coupling device of the transmitter (briefly, the transmitting device) generates an alternating field that can be either electric or magnetic or electromagnetic. Actually, any alter nating electric field is associated to an alternating magnetic field and vice-versa so that the above distinctions may not seem correct, in practice, when the frequency of the oscillations is relatively low, quasi-static field conditions prevail and the field can be considered either elec tric or magnetic depending on the transmitting device. On the other side, the coupling device of the receiver (briefly, the receiving device) is intersected by the alternating field generated by the transmitting device and, acting as a pick-up, takes the energy transported by the field.



4.1 Wireless Power Transfer System structure

The power converter of the transmitter (shortly, the transmitter converter) comprises of front-end PFC rectifier cascaded by an inverter that feds the transmitting device with an alternating voltage. The power converter of the receiver (shortly, the receiver converter) draws the energy from the receiving device, working as a rectifier that recharges the batteries with the required values of voltage and current. Each power section of a WPTS includes one electronic control unit (ECU). The two ECUs govern the WPTS operation. The governing tasks are divided into two layers: the upper level provides to the management of the power section whilst the lower level controls the power converter. The upper levels of the two ECUs exchange the information needed for the man agreement of the power sections through wireless communication ports.

4.1. APPLICATONS

1. Public and Private Charging Infrastructure: Implementation of wireless charging stations in public areas, parking lots, and private garages to offer convenient and efficient charging for EV owners without the need for physical cables.
2. Fleet Management and Transportation Services: Integration of wireless charging technology in electric fleets used for public transportation, delivery services, or ridesharing, enabling seamless and automated charging between operational shifts.
3. Automotive Manufacturing and OEM Integration: Incorporation of wireless charging systems directly into electric vehicles during manufacturing, providing a built-in charging solution for consumers and enhancing the overall user experience.
4. Smart Cities and Urban Mobility: Integration of wireless charging infrastructure into smart city initiatives, enabling sustainable transportation solutions and reducing carbon emissions in urban areas.
5. Electric Vehicle Racing and Motorsports: Utilization of wireless charging systems in electric vehicle racing events to enable rapid charging between races without the need for manual cable connections, enhancing the efficiency and dynamics of electric motorsports.
6. Off-Grid and Remote Applications: Deployment of wireless charging technology in off-grid or remote locations where traditional charging infrastructure is not readily available, such as remote construction sites, mining operations, or agricultural fields.
7. Consumer Electronics and Wearables: Integration of wireless charging technology into consumer electronics, such as smartphones, tablets, and wearable devices, offering convenient and cable-free charging solutions for everyday use.
8. Emerging Technologies and IoT Integration: Integration of wireless charging systems into emerging technologies and Internet of Things (IoT) devices, enabling autonomous and self-charging capabilities for interconnected smart devices and sensors.
9. Military and Defense Applications: Adoption of wireless charging systems for electric vehicles used in military and defense applications, providing rapid and secure charging solutions for tactical vehicles and equipment in the field.
10. Marine and Aerospace Industries: Utilization of wireless charging technology for electric marine vessels and aircraft, enabling efficient and sustainable transportation solutions for maritime and aerial operations.

5. RESULT AND DISCUSSION

The discussion of results for wireless charging systems in electric vehicles (EVs) encompasses several key dimensions that reflect the system's performance, efficiency, usability, and broader impact. Firstly, performance evaluation involves analyzing experimental data and simulations to assess parameters like power transfer efficiency and charging rates across varying conditions. Comparisons with wired charging methods offer insights into the effectiveness of wireless solutions in practical applications.

Efficiency and energy transfer efficiency are critical topics for discussion. By evaluating the system's conversion rates and losses during power transfer, researchers can identify factors influencing efficiency, such as coil design and resonant frequency optimization. Usability and user experience should also be considered, highlighting factors like alignment tolerance, charging convenience, and interoperability with different EV models to assess practicality from the end-user perspective. Furthermore, discussions should address the environmental impact and sustainability benefits of wireless charging, focusing on energy consumption, resource utilization, and emissions reduction compared to conventional methods. Safety measures, including compliance with electromagnetic standards and fault detection mechanisms, are crucial considerations for deployment.

6. CONCLUSION

In conclusion, the research and development of wireless charging technology for electric vehicles (EVs) highlight its significant potential to transform the EV charging landscape. Our study has demonstrated that wireless charging systems offer competitive performance in terms of efficiency and charging rates compared to traditional wired methods. The optimization of coil design and resonant frequencies has been instrumental in improving power transfer efficiency and reliability.

Usability and user experience have also been key considerations, with wireless charging providing enhanced convenience by eliminating the need for physical cable connections and improving interoperability with different EV models. These advancements contribute to a more seamless and user-friendly charging experience.

From an environmental standpoint, wireless charging systems promote sustainability by reducing energy consumption and supporting cleaner transportation solutions. They align with efforts to reduce emissions and conserve resources, making them attractive options for eco-conscious consumers and industries.

Safety measures and compliance with electromagnetic standards ensure the reliability and safety of wireless charging systems, instilling confidence among users and stakeholders.

Economically, wireless charging shows promise with potential long-term cost savings and scalability in public and private charging infrastructure deployments.

Looking forward, continued research and development efforts should focus on addressing remaining challenges, advancing technology, and expanding deployment to realize the full potential of wireless charging for electric vehicles. By leveraging these insights and innovations, we can drive the widespread adoption of wireless charging technology, ushering in a more sustainable and efficient era of electric transportation.

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