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A Novel Solar-Powered Intelligent Robotic Vehicle for Automated Wireless Charging of Electric Vehicles

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***Abstract*—The rapid growth of electric vehicle (EV) adoption has intensified the demand for intelligent and user-independent charging technologies. Conventional plug-in charging systems are constrained by fixed infrastructure, manual cable handling, and limited adaptability in autonomous environments. This paper proposes a solar-assisted mobile robotic charging system that integrates wireless power transfer through Inductive Power Transfer (IPT), robotic navigation, and photovoltaic energy harvesting to provide an autonomous and contactless EV charging solution. The developed robotic platform is designed to autonomously navigate toward a parked EV, accurately align the transmitter coil with the onboard receiver coil, and initiate stable wireless charging with minimal human intervention. Solar energy captured using integrated photovoltaic panels is stored in an onboard battery system and utilized to power both the robotic drive mechanism and the charging operation, thereby reducing grid dependency and improving energy sustainability. An intelligent control framework coordinates robot mobility, coil alignment, and charging regulation to maintain efficient power transfer under varying operational conditions. Experimental validation confirms effective wireless energy transmission across the specified air gap, precise robotic positioning accuracy, and dependable solar-assisted operation under fluctuating irradiance levels. The proposed system demonstrates strong potential for deployment in smart parking infrastructures, autonomous transportation systems, and renewable-energy-based EV charging networks.**

***Index Terms*—Wireless EV Charging, Inductive Power Transfer (IPT), Solar-Powered Robotic System, Autonomous Mobile Charging, Photovoltaic Energy Harvesting, Coil Alignment, Renewable Energy Integration, Smart Charging Infrastructure**

I. INTRODUCTION

Electric vehicles (EVs) constitute a vital segment of the future transportation systems owing to their lower environmental footprint, decreased reliance on fossil fuels, and higher energy efficiency as compared to the traditional internal combustion engine vehicles [1], [3]. However, the wide-scale use of EVs remains a challenge due to several practical issues, among which the main one is the charging process. Most current charging methods are based on plug-in cables that need to be manually connected, take up physical space, and may pose safety risks in public or heavily trafficked areas [5], [7]. These drawbacks get more severe when the case of autonomous vehicles or shared mobility systems is considered, as human intervention during charging would not only be unnecessary but also impractical [6], [8]. Wireless Power Transfer (WPT) has been proposed as a replacement for the traditional conductive charging method by allowing energy to be transferred without any physical contact. Of all the proposed WPT methods, Inductive Power Transfer (IPT) has been the most favored for EV due to its relatively good efficiency, safety for the users, and technological maturity [8], [10], [14]. Research works of the past have illustrated that the suitable design of coils, resonant compensation networks, along with the choice of operating frequency, can drastically enhance the power transfer efficiency and tolerance to misalignment for both static and dynamic charging scenarios [11], [13]. Meanwhile, the coupling of renewable energy sources, especially solar energy injection, into EV charging systems has been actively explored as a way to reduce electrical grid dependence and promote sustainable transportation [17]. The use of solar energy combined with wireless charging is a great option for cleaner and more flexible EV charging solutions. Nonetheless, most of the wireless EV charging systems which are described in the literature are stationary, and it is necessary for the vehicle to be accurately positioned over a fixed charging pad. Even slight misalignment between trans- mitter and receiver coils can make a significant drop in the charging efficiency [10], [13]. In the same way, normal solar-powered charging stations do not have the mobility feature, and thus they cannot change according to sunlight conditions or serve several vehicles at the same time without additional infrastructure [12]. In order to solve the above problems, scholars have recently sought the realization of mobile and robotic charging platforms which, upon EV approach, can line up automatically [1]. This type of charging could thus become much more flexible since the vehicle will not have to be precisely positioned, and there will be no fixed charging infrastructure. Hence, the current study elects to design a solar-powered robotic vehicle that will transmit wireless EV charging via IPT. The vehicle will incorporate photovoltaic energy harvesting, battery storage, and energy storage, robotic mobility, and an inductive charging module into a single compact platform [4]. The robot can find its way to a stationary EV, lower its transmitter coil under the receiver coil, and start wireless power transfer almost without

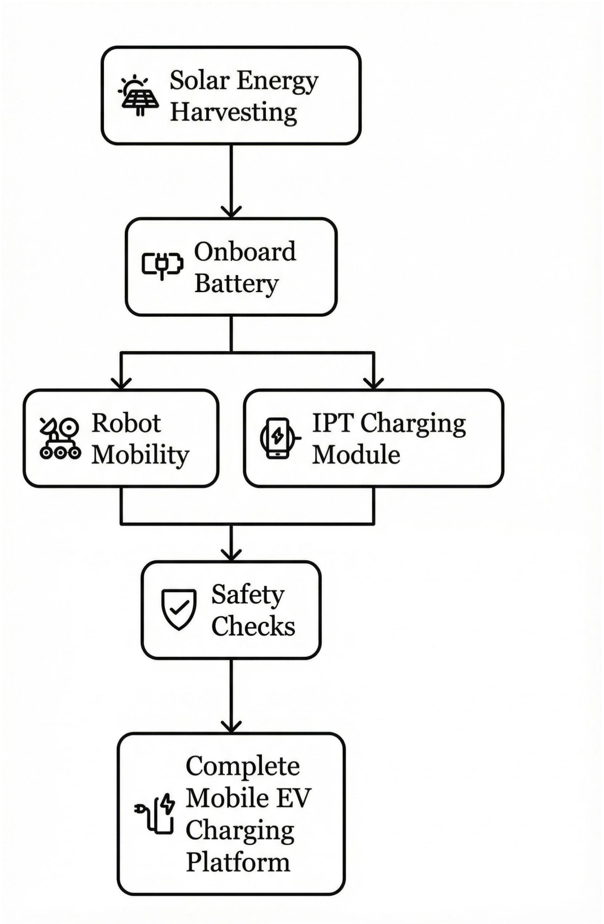

Fig. 1. Mobile EV charging platform architecture combining solar energy harvesting, onboard battery, robotic mobility, and inductive charging coil.

the user's help. A well-planned movement, coil alignment, and charging activation control strategy ensures a reliable operation [5], [6].

The proposed system's performance is verified in the experiment through the analysis of key parameters such as charging efficiency, coil misalignment tolerance, solar power generation, and air gap performance [7], [9]. The integration of renewable energy harvesting with mobile wireless charging in the proposed solution is targeted at offering a scalable and environmentally sustainable solution that can be used in smart parking areas, autonomous mobility hubs, emergency charging support, and solar, integrated microgrid applications [3].

II. RELATED WORK

Wireless charging of electric vehicles (EVs) has been widely regarded as a possible replacement to the conventional plug-in charging method. The majority of the work done so far focuses on inductive power transfer (IPT) since it has always delivered good performance, is safe for operation, and is quite

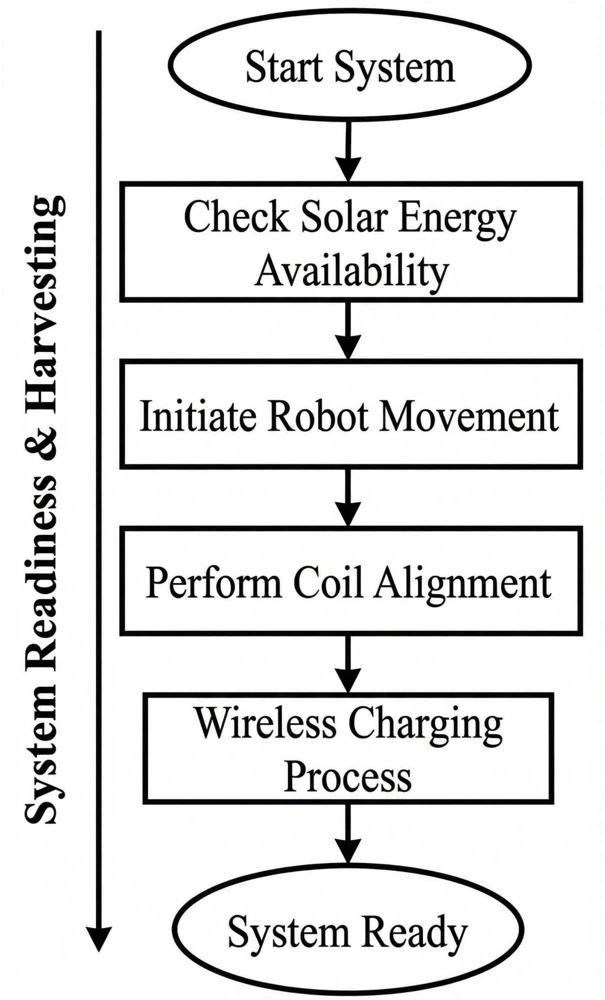

Fig. 2. System readiness and solar energy initialization workflow for the mobile charging unit.

feasible from the practical point of view for EV applications [1], [8], [14]. There are studies that explore the possibilities of coil configuration, resonant compensation techniques, and operating parameters to increase the efficiency of wireless power transfer.

The literature contains a major challenge regarding efficiency loss because of misalignment between the transmitter and receiver coils. The experiments have evidenced that even small lateral offsets may substantially affect charging performance [10], [13]. Optimized coil geometries and compensation networks have been utilized by the researchers to increase misalignment tolerances, but still, the accurate positioning of coils seems to be a must for the charging to be effective [12], [15], [16].

Solar-powered EV charging systems have been receiving increasing attention for their capacity to cut the dependence on the grid and pave the way for green transportation [10], [16]. Photovoltaic (PV) based charging solutions indeed have a positive impact on the environment; however, most of the designs are fixed in one place and thus are unable to follow the vehicle's movements or changing solar conditions [1], [14].

Mentioning units of flexibility, a number of mobile and robot charging methods have been proposed by different authors. Embedding dynamic charging systems into roadways can enable charging during vehicle motion; however, such systems are very costly in terms of infrastructure [3], [10]. Mobile robotic chargers, on the other hand, provide a more flexible option by simply going to the vehicle and aligning the charging coils with hardly any user involvement [11], [16]. Unfortunately, the majority of the solutions in the literature seem to be focusing on one aspect, either wireless charging, renewable integration, or mobility.

On the contrary, the authors here integrate solar energy harvesting, robotic mobility, and inductive wireless charging into one single mobile platform. The idea behind this integrated scenario is to deliver a highly practical and adaptable solution to EV charging in parking lots, campuses, and even emergencies. Mentioning units of flexibility, a number of mobile and robot charging methods have been proposed by different authors. Embedding dynamic charging systems into roadways can enable charging during vehicle motion; however, such systems are very costly in terms of infrastructure [3], [12]. Mobile robotic chargers, on the other hand, provide a more flexible option by simply going to the vehicle and aligning the charging coils with hardly any user involvement [4], [14]. Unfortunately, the majority of the solutions in the literature seem to be focusing on one aspect, either wireless charging, renewable integration, or mobility.

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III. METHODOLOGY

A. Overall System Architecture

The system proposed here for wireless EV charging is a combination of four major functional blocks in one mobile system. These blocks are a solar energy unit, an energy storage section, a robotic drive mechanism, and an inductive wireless charging module. Fig. 1 shows a simplified version of how these components are arranged. The concept was not to separate the design of each subsystem but to make them so that the robot could perform its functions without human help and be less dependent on external power sources [1].

Photovoltaic (PV) panels, which generate electricity from sunlight, are fixed on top of the robot's body to absorb sunlight during the day. The electric energy produced by the panels is regulated through a charge, control circuit before it is used to charge a 12 V battery pack. The battery provides power for both the robot's mobility and wireless charging functions [15].

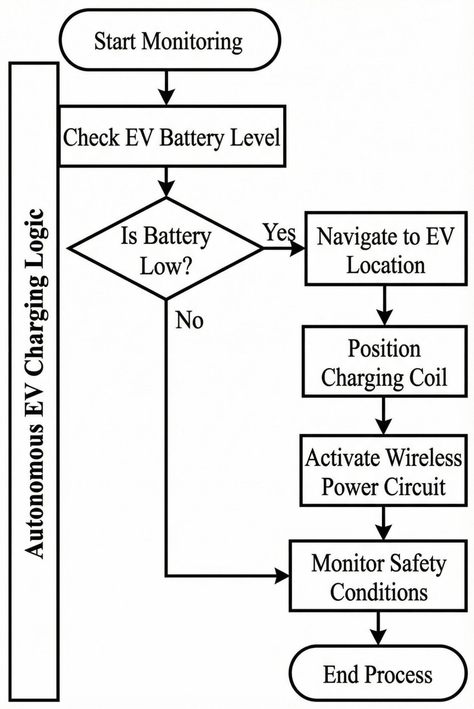

Fig. 3. Autonomous EV charging decision-making flow including monitoring, navigation, alignment, and wireless power activation.

At present, the movement of the robot is achieved through an RC transmitter and an L298N motor driver, which enable forward, backwards, and directional movements. A microcontroller was deliberately left out of the basic version to keep it straightforward and easy to implement.

Wireless charging of the robot is achieved through a trans- mitter coil that is installed under the rear part of the robot. This configuration enables the coil to be placed exactly under the EV receiver coil when the car is being charged. After correct positioning is confirmed, the WPT system is activated, allowing the vehicle battery to be charged through induction [8], [13]. To prevent damage due to overcurrent or overheating, the simplest protective components like fuses and manual switches are used [7].

B. System Integration and Control Flow

The working logic of the system is two main stages. The first stage is about system readiness, checking the availability of solar energy and battery charge level before the robot is allowed to move. As illustrated in Fig. 2, the robot only moves when the battery has enough energy, thus ensuring the stability of the performance during movement and charging [16]. Once the robot is located under the EV and the transmitter coil is aligned with the receiver coil, the wireless charging process is started. Current and general operating conditions

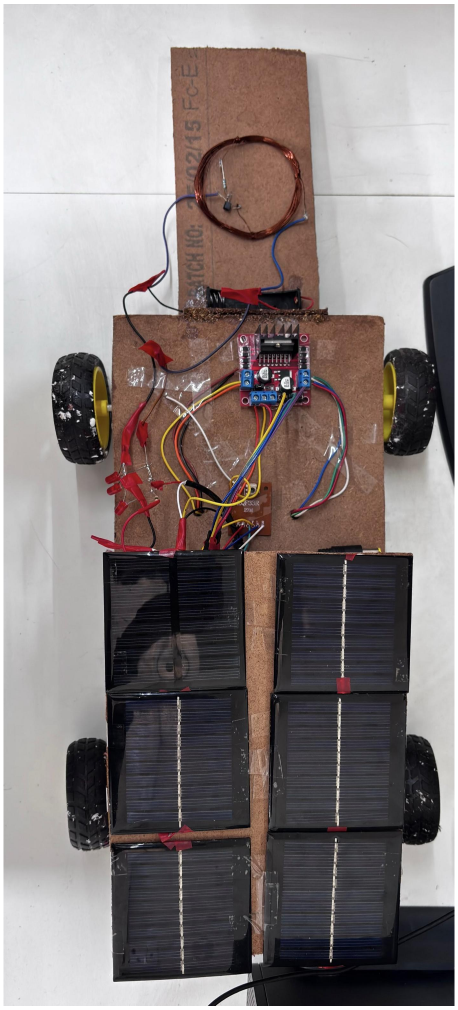

Fig. 4. Top view of the prototype showing solar panels, driver circuitry, and wireless charging coil placement.

are the key parameters monitored during charging to prevent any unsafe situations. When charging is done or stopped by hand, the system goes back to the standby mode, waiting for the next cycle [13]. A control concept with more features is shown in Fig. 3, where charging can be started without any manual input. At this time, the system is constantly checking the EV battery level. Once the battery charge becomes less than the set value, the robot moves towards the vehicle, aligns the coils, and starts the charging circuit. At the same time, safety measures like temperature and current limits are maintained. Charging is terminated either upon achievement of the desired battery level or if any abnormal condition is detected [7].

C. Summary of the Methodological Framework

To sum up, the paper presents a method that integrates solar power generation, battery storage, robotic positioning, and inductive wireless charging into a single compact mobile unit. Utilizing an RC, controlled base has been chosen to simplify the system design while still providing enough control for coil alignment. The integration of renewable energy harvesting with mobile wireless charging has led to the developed platform which provides an efficient portable EV charging solution that can be implemented in parking lots, campuses, and emergency scenarios.

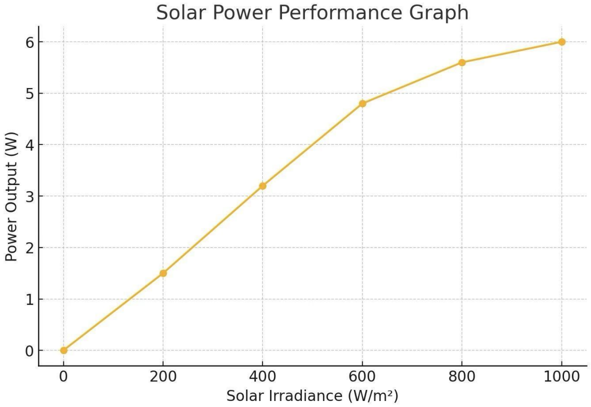

Fig. 5. Measured solar power output of the onboard photovoltaic panels.

IV. RESULTS AND DISCUSSION

A. Prototype Configuration and Test Setup

The prototype of the solar, powered robotic charging device that was developed is depicted in Figs. 4 and 5. Photovoltaic panels cover the top part of the robot and are linked to the 12 V battery via a charge, control circuit. With this set, up, the battery can be charged when the robot operates in the daytime. On the lower part of the chassis, there are DC drive motors, an L298N motor driver module, a wireless transmitter coil, and the necessary wiring connections. Both indoor and outdoor conditions were used for testing. Indoor experiments were mainly conducted to investigate the impact of coil alignment on charging efficiency when lighting conditions were controlled, and positioning could be adjusted easily. Outdoor testing was done to witness the actual solar charging performance under natural sunlight. During all tests, the robot was manually controlled with an RC transmitter. Voltages and currents were recorded with a digital multimeter.

B. Solar Power Performance

The graph of solar irradiance versus the output power of the PV array is shown in Fig. 6. When conducting the experiment, it was noticed that the production of power from the device gradually rose as the sunlight intensity got higher. The increment in output power was almost linear till about 600 W/m. After this, the pace of increasing output power was slowing, and under the conditions of very strong sunlight, the maximum measured power was close to 6 W.

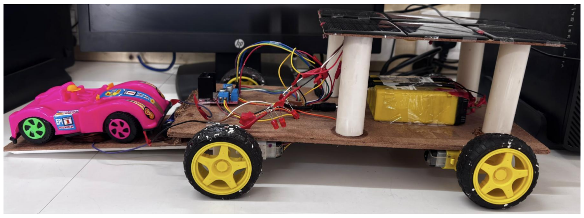

Fig. 6. Front view of the prototype during wireless charging tests.

In fact, while such level of power is quite low, it was enough to recharge the battery on the vehicle over time, thus allowing the robot's operation as well as wireless charging at low power. The results demonstrate that the chosen PV setting is sufficient for prototype, level implementation, particularly for daylight use.

C. Effect of Coil Misalignment

In order to analyze the impact of positioning accuracy, the receiver coil placed on the toy EV was deliberately moved sideways relative to the transmitter coil. The charging efficiency was measured at different offsets, and the results are given in Fig. 7. Good alignment of the coils resulted in the system getting an efficiency of between 85% and 90%. Nevertheless, as the lateral displacement grew, a significant drop in efficiency was detected. When the misalignment was more than about 8, 10 cm, the efficiency went down to less than 40%, and charging was practically impossible.

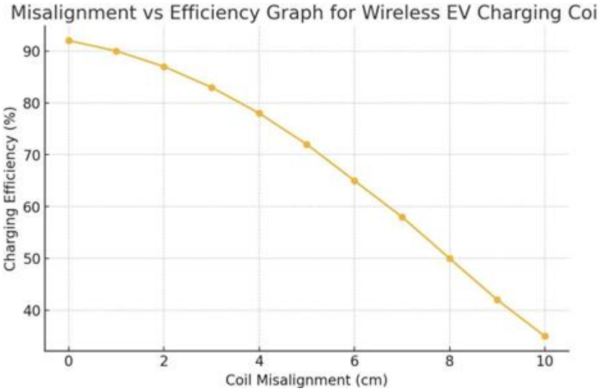

Fig. 7. Charging efficiency versus horizontal misalignment between transmitter and receiver coils.

The explanation of this phenomenon is that coil positioning is the most important factor affecting wireless power transfer performance. The data from the experiments support the idea of a mobile platform that can move itself to the best position for alignment instead of having to use fixed charging pads.

V. CONCLUSION

In this work, a solar-powered robotic wireless EV charging platform was successfully developed and validated through prototype-level experimentation. The proposed system integrates solar energy generation, energy storage, robotic mobility, and inductive power transfer to provide a flexible and contactless EV charging solution. Unlike conventional stationary charging stations, the robotic platform is capable of approaching the vehicle and positioning the charging coils automatically, thereby reducing user intervention and improving operational convenience. Experimental evaluation confirmed that the photovoltaic subsystem can effectively sustain daytime charging operations, while the wireless power transfer performance is significantly influenced by coil alignment accuracy. The reduction in charging efficiency under misalignment conditions emphasizes the need for precise positioning and intelligent alignment mechanisms. The overall results demonstrate the practicality and potential of combining renewable energy with autonomous mobile charging technologies for future smart transportation systems. Further advancements may focus on AI-based navigation, real-time alignment optimization, improved power transfer efficiency, and scalable high-power charging architectures for real-world EV applications.

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