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Smart Solar-Powered Dynamic Wireless Charging and Access Control System for Electric Vehicles

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Abstract— ***As the importance of electric cars (EVs) in lowering pollution levels in the environment increases, so does the need for easily accessible, environmentally friendly, and effective charging infrastructure. In order to make EV charging infrastructure more convenient and environmentally friendly, this project installs a solar-powered Wireless Power Transfer (WPT) system. The goal is to lessen reliance on the electrical grid by using solar energy harvesting to wirelessly charge electric automobiles. Integrating solar monitoring devices and energy forecasting algorithms is a crucial part of this solution since it maximizes solar power availability and utilization all day long. The device guarantees effective energy conversion in a range of solar circumstances by utilizing Maximum Power Point Tracking (MPPT) methodologies. Furthermore, to facilitate effective wireless energy transfer from the charging station to the car, resonant inductive coupling is used. A monitoring system that shows energy generation, storage, and transfer parameters in real time is also part of the project. The ultimate goal is to create a clean energy-based, affordable wireless charging prototype that promotes the wider use of EVs by lowering user intervention, increasing dependability, and reducing carbon emissions. This application demonstrates how cutting-edge power transmission technology and renewable energy may be combined to create a sustainable transportation ecology.***

Keywords— Wireless Power Transfer (WPT), Solar energy, Electric vehicles (EVs), utilizing Maximum Power Point Tracking (MPPT)

I. INTRODUCTION

The rapid adoption of electric vehicles (EVs) is a watershed moment in the global transportation sector, driven by the critical need to combat climate change, cut greenhouse gas emissions, and reduce reliance on fossil fuels. As urbanization accelerates and vehicle usage rises, creative and sustainable charging options are critical to the mainstream adoption of EVs. One such potential breakthrough is wireless power transfer (WPT), which allows for efficient, contactless energy transmission to EVs, minimizing the annoyance of plug-in systems and improving the user experience.

Dynamic wireless charging, in which EVs get electricity while in motion using inductive power transfer devices integrated in road infrastructure, provides a novel approach for reducing range anxiety and increasing energy efficiency. However, the environmental advantages of such systems are negated when they are powered by traditional energy sources. The carbon footprint associated with EV use can be further decreased by incorporating renewable energy, especially solar electricity, into WPT systems.

Road-integrated, wireless, solar-powered technology has the potential to significantly improve EV viability and promote eco-friendly mobility [2]. This is a workable solution to meet the energy requirements of electric vehicles while lowering carbon emissions. By creating a system that can satisfy EV charging requirements, the solar-powered EV charging system can significantly lessen EVs' reliance on traditional energy sources and provide a more ecologically friendly form of transportation. Remote force move technology is integrated into the process of transferring solar energy from the photovoltaic (PV) cell to the battery of the electric car [1]. The lowering the requirement for shared energy sources. The sun-oriented boards generate electrical energy by harnessing the light energy generated by the sun. The force yield of the photovoltaic cell is increased by transferring the energy from the board to a battery via a solar-powered charge regulator. DC current is introduced into the battery as a result of the wireless connection between the transmitting and receiving coils. When the battery is full, solar power is immediately cut off.

The goal is to create an economical and ecologically sustainable prototype that ensures seamless wireless energy distribution and supports scalable infrastructure for future smart transportation systems.

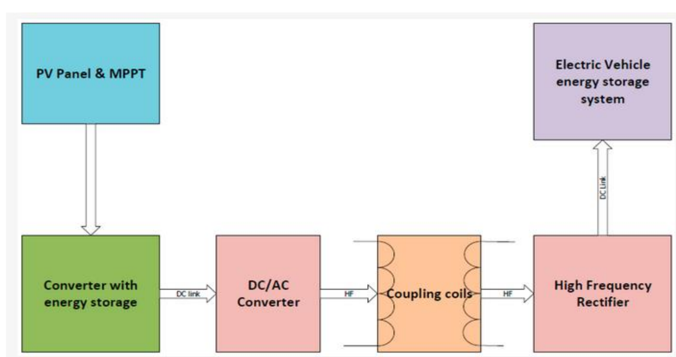


Fig 1.1. Overview of wireless charging powered by a solar panel.[1]

This work focuses on evaluating several solar-integrated WPT designs. The goal of this study is to balance transmission reliability, energy efficiency, and environmental sustainability in order to suggest the best implementation strategy for wireless EV charging. Dynamic wireless charging—charging while moving—using solar-powered inductive transfer systems integrated into road infrastructure is given special attention. In order to improve solar usage and guarantee constant energy supply for automobiles, the study also investigates energy forecasting models.

When properly adjusted, wireless charging systems can provide scalable, sustainable, and seamless solutions for electric mobility in the future. This project promotes the shift to cleaner energy sources and advances the field of green mobility by creating an intelligent control framework that combines wireless communication protocols, solar energy collecting, and predictive algorithms.

Wireless power transfer (WPT) is a game-changing technology that improves convenience, safety, and automation by doing away with the need for physical connectors in EV charging. Delivering power consistently is still difficult, particularly when depending on sporadic solar energy. A number of factors, including as sunlight intensity, vehicle placement, coil alignment, and energy storage efficiency, significantly affect how well solar-based WPT systems function.

This research combines resonant inductive coupling, dynamic power management, and solar prediction algorithms to overcome these obstacles and preserve steady charging conditions. While adaptive control systems modify transmission parameters in real time based on operational and environmental conditions, energy forecasting makes sure that EVs receive enough power during the best times of the day.
This work illustrates a scalable and effective method of integrating wireless energy distribution with renewable energy forecasting.

I. LITERATURE REVIEW

Umair et al. (2024) [2] integrated solar energy storage systems to provide a renewable method of EV charging. Their research highlighted the value of energy storage in reducing solar power's erratic nature and guaranteeing a steady and dependable EV charging source. The study emphasized how these systems may lessen reliance on traditional electricity networks and encourage environmentally friendly modes of mobility. According to the researchers, techniques are essential for optimizing computing efficiency without compromising visual accuracy.

Kashani et al. (2023) [3]. They talked about the difficulties in integrating these systems with solar power sources and investigated several WPT techniques, such as capacitive and inductive coupling. In order to maximize the performance of wireless solar charging systems, the study emphasized the necessity of effective power management and control mechanisms.

Nguyen (2023) [5]. Dynamic optical wireless power transfer (OWPT) for EVs This novel method offers a potential answer for on-the-go charging by using laser beams to convey electricity wirelessly. The study addressed safety issues and alignment difficulties in addition to discussing the benefits of OWPT, such as its high power density and directional energy transmission.

Mwasilu et al. (2014) [6] investigated the relationship between EVs and smart networks. Their analysis emphasized how EVs can function as energy storage devices because of the two-way energy flow between them and the grid. The study highlighted how smart grid infrastructure supports the widespread use of EVs and enables efficient energy distribution.

Khan et al. (2018) [7]. They talked about the financial and environmental advantages of solar charging and examined different system configurations, such as independent and grid-connected systems. The study also looked at issues like the necessity for efficient energy storage technologies and variations in solar irradiance

Sain et al. (2020) [8] concentrated on creating energy-efficient permanent magnet synchronous motor (PMSM) drive systems for solar-powered smart electric cars. Their study made clear how crucial it is to maximize motor performance in order to raise the overall efficiency of solar-powered EVs. The incorporation of sophisticated control techniques for efficient energy management was also included in the study.

Beniwal et al. (2025) [9] suggested a wireless solar-powered system for energy control and EV charging. Their study highlighted how crucial it is to combine sophisticated energy management with renewable energy sources in order to build effective and environmentally responsible EV charging infrastructures.

Mou et al. (2023) [10] researched how to incorporate renewable energy sources into dynamic EV charging systems in order to reduce carbon emissions. Their research demonstrated how solar energy and dynamic charging technologies might be combined to lessen EVs' negative environmental effects and support sustainable urban transportation.

Subudhi and Krithiga[11] conducted a thorough analysis of the several wireless power transfer (WPT) topologies used in both static and dynamic EV charging situations. Their study examined the working principles, energy transfer efficiency, and suitability for dynamic charging requirements of inductive, capacitive, and resonant power transfer techniques. The study underlined how crucial coil design, alignment tolerance, and compensation strategies are to the successful deployment of WPT systems.

Bukhari et al. (2024) [12] planned and examined a wireless charging infrastructure for EVs on the road that is powered by renewable energy in smart cities. Their prototype provided a sustainable way to continuously charge EVs in urban settings by proving that solar energy integration with on-road WPT systems is feasible.

Sundaramoorthi and Chitraselvi (2025) [13] investigated the application of deep learning to EV charging systems, particularly for monitoring and optimizing renewable energy use. According to their research, deep learning models greatly enhance predictive analytics in renewable energy management, allowing for more intelligent and flexible charging practices that are dependent on demand and energy availability.

Adil et al. (2020) [14] used machine learning to enable dynamic wireless charging in their construction of a dependable sensor network infrastructure for EVs. This infrastructure ensures smooth charging without user involvement by supporting real-time decision-making based on vehicle position, speed, and energy requirements.

I. PROPOSED MODEL

For the purpose of to provide smooth dynamic charging while vehicles travel over designated charging highways, the suggested model offers a smart, solar-powered, wireless electric vehicle (EV) charging system that is connected with automated billing and access control. In the end, this technology hopes to contribute to cleaner, more intelligent transportation infrastructure by doing away with the need for manual plug-in charging, cutting down on charging downtime, and offering a seamless mobile platform payment experience.

To automate gate control and wireless dynamic charging of electric vehicles (EVs). The main power supply, which provides high-voltage AC current, starts the entire process. The AC power is initially routed to a step-down transformer since the majority of electronic components need low-voltage DC current to function effectively. Before sending the voltage to the rectifier bridge and filter, this transformer lowers it to a level that is safer and useable. To guarantee a steady power source, the AC current is transformed into DC here, and any output ripples are smoothed out.

A transistor section, which is crucial in transforming the steady DC signal into high-frequency pulses, receives the filtered DC power after that. The electromagnetic induction method of energy transfer requires these pulses. The transmitter coil (TX coil), which is integrated into the road infrastructure, receives the output from the transistor portion. The TX coil creates a magnetic field when it is powered, which acts as a conduit for wireless energy transfer.

The reception coil (RX coil), which is installed on the EV's underside, detects the magnetic field created when an electric vehicle passes over this embedded TX coil. This causes a current to flow through the RX coil via the electromagnetic induction concept. However, the induced current is routed through an additional rectifier bridge and filter on the EV because it is alternating and not appropriate for direct battery storage. This guarantees that AC power is converted to DC power, allowing for the onboard battery to be charged safely and efficiently. Above the charging pad, a strategically placed infrared sensor detects the presence of a vehicle. The microcontroller, the system's main control unit, receives a signal from it upon detection.

The several modules are coordinated by the microcontroller, which makes sure that every part operates in the right order. It controls the IR sensor's inputs, analyzes the data, and decides whether to start the charging process. In order to convey important information to the user, the microcontroller also interfaces with an LCD display module. Real-time information is displayed on this screen, including the IP address linked to the IoT module, the charging status, and any user prompts required for authorization and payment. The IoT module, which links the system to the internet, is another device that the microcontroller controls communication with. The system as a whole becomes smarter and more user-centric because to this connectivity, which enables real-time data logging, online payment integration, and remote monitoring.

The microprocessor signals a motor driver, which in turn turns on the gate motor, after payment or user authentication is successfully accomplished. By serving as a mediator, the motor driver converts the microcontroller's low-power impulses into the higher-power signals needed to run the gate motor. The gate ensures seamless vehicle movement without the need for physical intervention by opening or closing in response to the charging and payment process's state. Through a network-enabled embedded environment, this integrated system essentially offers a smooth solution for dynamic wireless charging of electric vehicles while automating gate control and user interaction. It supports the goal of smart urban mobility infrastructure, encourages energy efficiency, and improves EV users' convenience.

When supply power is applied to a transistor-based switching circuit, a high-frequency alternating current is started, starting the process. As a component of an inductive power transmission system, this AC is utilized to create wireless power via a copper coil on the transmitter side.

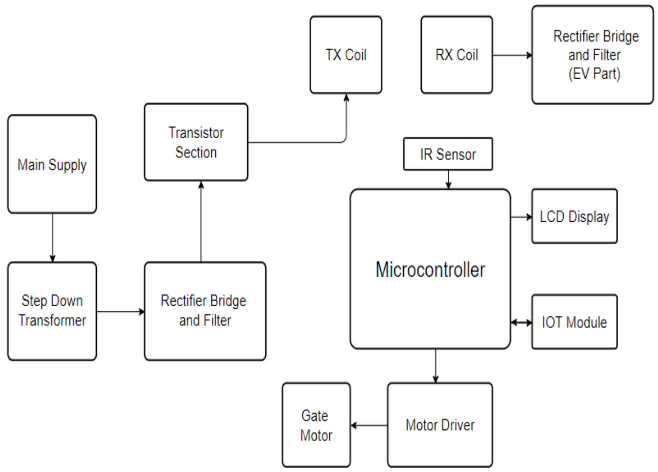


Fig 3.1: Block Diagram of Wireless Dynamic EV Charging and Automated Gate Control System Using Microcontroller

Continuous power transfer to moving vehicles is made possible by the linear array of transmitter coils implanted beneath the charging road surface. Smart detecting methods like RFID, infrared sensors, or vehicular communication systems activate a series of embedded transmitter copper coils beneath the road surface in real-time when the electric vehicle (EV) approaches and passes over the specifically built charging lane. In order to minimize energy loss and maximize magnetic field alignment, these coils are positioned and powered in a sequential manner to correspond with the vehicle's position and speed. The EV's receiver copper coil is built into the chassis' bottom and is oriented exactly to pick up the alternating magnetic field produced by the transmitter coils embedded in the road. The magnetic field induces a storage in the vehicle's onboard battery management system (BMS) by using the concepts of resonant inductive coupling.

Hardware & Software Used

Microcontroller Nodemcu, LCD Display (16X2), Object Sensor, Transformer, Rectifier and filter, Motor, Transistor, Cooper Coil, PCB Board, LED, Connecting wire, Arduino IDE

Fig 3.2: 1N4007 Pinout

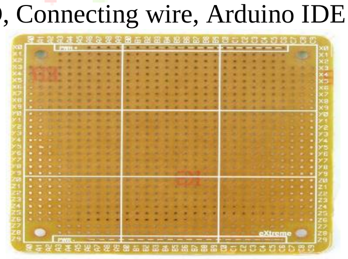


Fig 3.3: PCB board

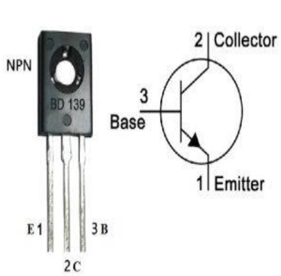


Fig 3.4: BD139 Transistor Pin

Fig 3.5: LCD Display

Fig 3.6: IOT Esp8266 Node MCU

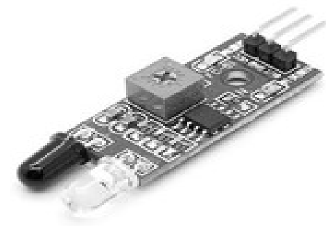


Fig 3.7: Infrared Sensor

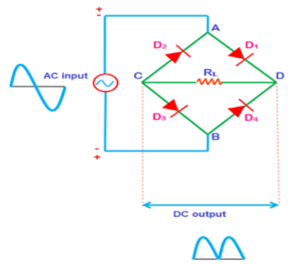


Fig 3.8: Bridge Rectifier

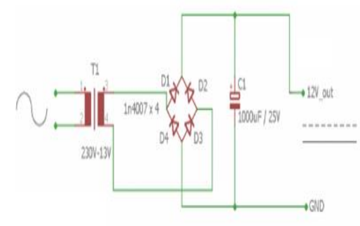
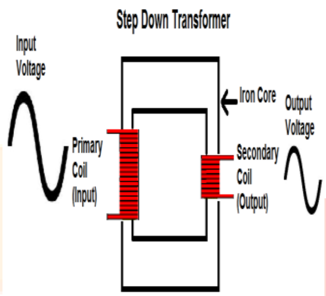


Fig 3.9: Power Supply section



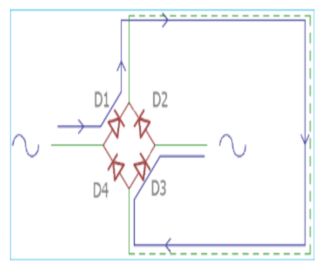


Fig 3.10: Step Down Transformer

Fig 3.11: Diodes in Bridge

Fig 3.12: Arduino IDE

Proposed Workflow

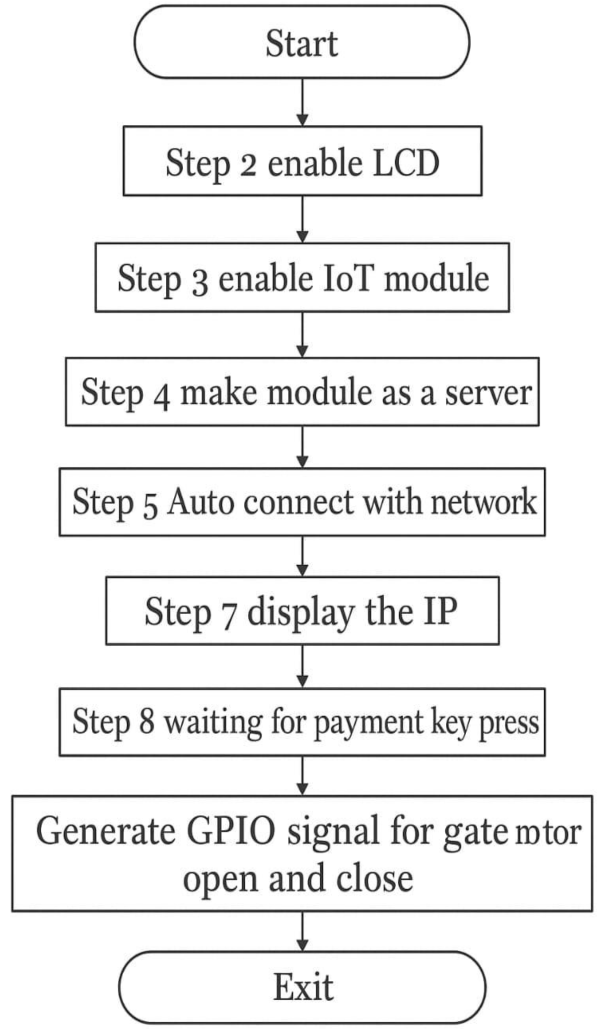


Fig 3.13: Proposed Workflow

When supply power is applied to a transistor-based switching circuit, a high-frequency alternating current is started, starting the process. As a component of an inductive power transmission system, this AC is utilized to create wireless power via a copper coil on the transmitter side. Continuous power transfer to moving vehicles is made possible by the linear array of transmitter coils implanted beneath the charging road surface.The receiver copper coil, which is inside the EV's underbelly, detects the magnetic field created by the transmitter coils as the EV approaches and passes over the charging lane. Energy is wirelessly transferred from the road infrastructure to the car's onboard battery using electromagnetic induction. creating an atmosphere that is dynamic for charging.

The car comes across a smart checkpoint system at the conclusion of the charging section. The sensors and communication modules on this node determine how much energy was used overall while the car was traveling over the charging road. Based on energy use, time spent in the charging lane, and current tariff rates, the system calculates the cost of charging. An LCD interface placed next to the exit barrier shows this data instantly for the user's reference. Users can use a smartphone-based UPI or digital wallet system to finish the payment at the same time that a secure payment interface is launched. Contactless transactions are ensured by integration with mobile payment apps, improving security and convenience. A motorized gate mechanism receives a signal from the system upon successful transaction confirmation, and it opens automatically to let the car out. This promotes accountability and facilitates effective revenue collection by guaranteeing that cars can only depart once the billing procedure is finished.

An embedded microcontroller unit (MCU) controls the whole system, coordinating gate control, billing calculations, power transfer timing, and display functions. IoT modules for data logging, performance tracking, and remote diagnostics can also be used to incorporate real-time monitoring and control functionalities. Through the integration of wireless dynamic charging, automated billing, and renewable energy, the model offers a scalable and self-sufficient solution for future smart transportation networks. By using solar energy as its main energy source, it enhances user experience, lessens reliance on static charging infrastructure, and supports sustainability objectives. By enabling on-the-go charging and automated user engagement, Our method gets over conventional EV charging constraints including lengthy wait periods and permanent plug-in stations. By integrating payment and control technologies, it establishes the framework for smart highways that not only provide power to automobiles but also guarantee operational transparency and user-friendliness.

IV. RESULTS

The suggested technology has been successfully put into practice and tested to show a functional prototype of an electromagnetic induction-based wireless charging infrastructure for electric cars (EVs). The main goal of facilitating wireless energy transmission from a fixed transmitter buried in the road surface to a mobile receiver coil placed underneath the EV is validated by the experimental configuration.

A magnetic field is produced by the transmitter coil when it is powered by alternating current. The receiver coil absorbs this magnetic flux as the car passes over the charging lane and creates an AC voltage. The EV's rectifier bridge and filter circuit transforms this generated energy into a steady DC output that may be used to charge the battery.

The device has an LCD display module to enable user interaction and energy monitoring. The energy consumption and associated charge cost are shown in real-time on the display. This makes it easy for consumers to monitor how much they use when charging. Online payment and remote connectivity are made possible in large part by an IoT-enabled NodeMCU module. The NodeMCU module, which is set up as a server, shows the payment amount via a web interface that can be accessed using a smartphone once charging is complete. The efficiency of the online transaction function is confirmed by the system's successful processing of digital payments.

Following the confirmation of payment, a GPIO-triggered signal is generated to activate a gate motor. The microcontroller sends this signal to a motor driver circuit, which in turn opens the exit gate automatically, allowing the vehicle to proceed. This end-to-end automation, from charging to payment to gate control, has been verified to function seamlessly. Throughout testing, the integrated subsystems including the wireless charging module, IR-based object detection, LCD monitoring, IoT payment gateway, and gate automation performed as expected. The results confirm that the design is viable for smart EV charging environments. The system provides a promising foundation for real-world implementation in smart cities, supporting sustainable transportation infrastructure with user convenience, automation, and real-time energy management.

The Working Model

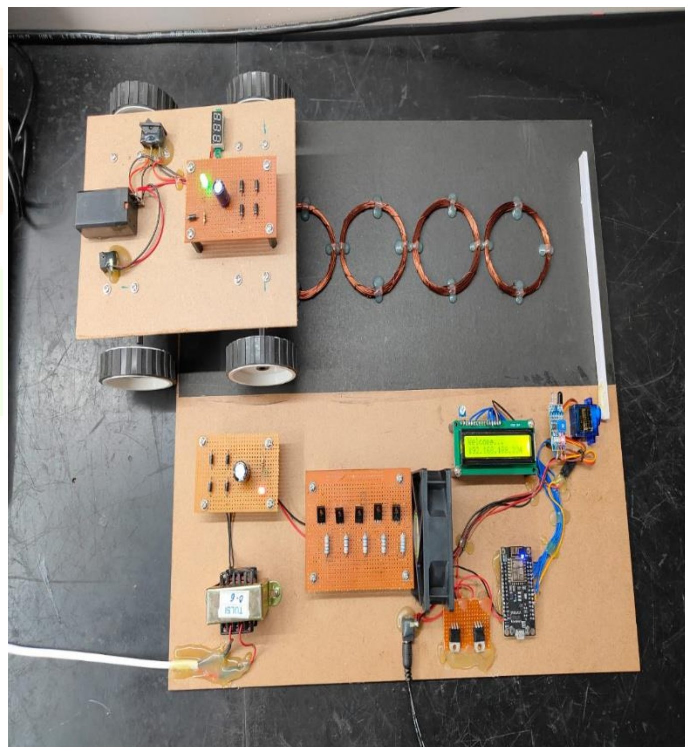


Fig 4.1: The Working Prototype

V. CONCLUSION

The project's successful completion amply demonstrates that wireless electric vehicle (EV) charging is not only technically feasible but also provides a number of benefits in terms of user experience, efficiency, and convenience. The method improves safety by removing the need for physical connectors and human plugging, which lowers the possibility of mechanical failures, electric shocks, or accidents brought on by tangled cables. Furthermore, it reduces maintenance expenses associated with connector wear and tear, which is normally typical in traditional charging infrastructure.

Through electromagnetic induction, smooth, contactless power transfer is made possible by the integration of the transmitter coil in the road infrastructure and the receiver coil in the EV itself. This method simplifies the charging procedure, making it quicker and less obtrusive, particularly in public and busy areas like smart parking lots, highways, and metropolitan roadways. The project adds to the convenience of use by showing that a car can start accepting energy without the driver's help once it lines up with the charging channel.

More significantly, this technique establishes the foundation for dynamic wireless charging, which allows EVs to be charged while moving. By tackling range anxiety and lengthy charging periods, two of the biggest obstacles to EV adoption, this invention has the potential to completely transform electric mobility. Having the capacity to continuously recharge while traveling.

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