Smart Road Infrastructure for Wireless EV Charging.

Prof. Ganesh Sarmokaddam[1], Vikrant Karamore[2], Aman Lanjewar[3], Bhushan Charpe[4], Amar Warankar[5]
[1]Assistant Professor, PCE Nagpur, India.
[2,3,4,5]Student's PCE Nagpur, India.

Abstract: In recent years, electric mobility has become more popular in our daily lives. The rapid increase in demand for new EV charging solutions (according to the US Department of Energy, Statistics show that there will be 35 million new EVs on the road by 2030) is challenging people who charge EVs at home and on-the-go, providing additional challenges to those who have to wait for long period of time to charge their EV and may not always know where to find charging stations. Generally, charging stations that have traditional plug-in chargers/hybrid chargers come with disadvantages, such as very long charge times, limited staff and customer location for people needing to charge their EV, and persistent range anxiety for EV users. To address some of the ab ove- mentioned challenges, this research project proposes a new Smart Road Infrastructure (SRI) for the Wireless Electric Vehicle (EV) Charging, using advanced IPT (Inductive Power Transfer) technology to provide seamless energy transfer from the road to the vehicle. The SRI would be composed of transmitter coils, located underground beneath the roadway, which produce an electromagnetic alternating field (discussed later in this paper). The EV's receiver coils will allow the SRI to transmit energy to the battery of the EV, which can be used to recharge the battery of the vehicle and allow for limited or no downtime to recharge while the vehicle is in a static, or static state (however, while not parked) and while the vehicle is in motion. The infrastructure will also provide IoT sensors for system intelligence, providing the ability to monitor in real-time, in addition to the infrastructure utilizing V2I (Vehicle to Infrastructure) communication for improved efficiency. Automatically detecting EV vehicle connections, activating sections of the charging system selectively, optimizing the distribution of electrical power to EVs, and automating the billing process securely are all possible with these technologies. The integration of smart grids with renewable energy sources (e.g. solar, wind) allows for the sustainable use of energy and minimizes the impact on the environment. Also, the issues of safety and reliability are handled by using the methods of electromagnetic shielding, standardized procedures, and complex control systems. Further advances in power electronics, materials and communication technologies are rendering it far more practical to deploy massive wireless system, even though it is challenging to cope with the high costs of installations, modify the existing infrastructure and standardize systems. The Smart Road Infrastructure of Wireless EV Charging sets a new stage in the transportation industry offering a higher level of energy efficiency, convenience to users, decreased CO2 emissions, and helping to create smart, sustainable cities.

Keywords: Wireless Electric Vehicle (EV) Charging; Smart Road Infrastructure; Inductive Power Transfer (IPT); Dynamic Wireless Charging; Static Wireless Charging; Resonant Inductive coupling; Vehicle-to-Infrastructure (V2I) Communication; Internet of Things (IoT).

INTRODUCTION

The increasing demand to have more sustainable and eco-friendly transportation has resulted in a surging interest in the use of Electric Vehicles (EVs) worldwide. Governments, industries, and researchers are encouraging the use of EVs to curb the emission of greenhouse gases through transportation, decrease the use of oil in conventional vehicles, and decrease the total effect of transportation on climate change. Regardless of these advantages, there are still certain serious issues that do not allow mass use of EVs, including low range of movement, a long time to charge car, the lack of charging stations, and the inconvenience of an automobile attached to the charging station. Majority of conventional types of EV charging involve having parked vehicles hooked up to a physical charger using a fixed charge point. This can make the wait time in line with customers attempting to charge their vehicles extremely long and introduces a dependency on fixed infrastructure, which results in traffic jams at charging stations, decreased operational efficiency, and long-term impacts on the environment due to more vehicle weight, higher cost, and energy use to support large battery packs to support higher driving range.

In order to eradicate these constraints, the Smart Road Infrastructure of Wireless EV Charging project suggests a novel infrastructure by incorporating the use of Inductive Power Transfer (IPT) technology to transmit energy wirelessly to the electric vehicles (EVs) through a receiver in the car and energy is sent through a transmitter coil embedded in the ground. IPT operates based on electromagnetic induction; it does not establish any physical connection between the transmitter and the receiver, and direct energy transfers between the two can be provided. The other important aspect of this technology is that it allows static and dynamic forms of wireless charging systems. Also, through the use of energy-efficient III-V smart grid technology energy will be disseminated across the grid more effectively. Static charging occurs when an EV is stopped

(i.e., at a stop light, a parking lot, a busy street), while dynamic charging allows for charging to occur while moving. Dynamic charging technology is revolutionary because it minimizes the need for EV drivers to stop and recharge their vehicles during long-distance travel - helping alleviate range anxiety and allowing for smaller batteries to be put into the

vehicle, thus helping to create a more affordable and efficient electric vehicle.

By integrating advanced technologies such as the IoT, Vehicle-to-Infrastructure (V2I) communications, and smart grid systems into the Smart Road Infrastructure for Wireless EV Charging, the overall intelligence and quality of the charging infrastructure will be increased. Through the use of IoT sensors, vehicle detection, monitoring, and predictive maintenance occur in real time by the charging infrastructure. Through the exchange of secure data (or information) from a vehicle to a road, V2I communications will allow for the completion of automated billing and the optimization of energy management (or consumption). Additionally, by utilizing energy-efficient III-V smart grid technology, energy will be distributed throughout the grid more efficiently.

electricity, load balancing and integration of renewable energy sources such as solar and wind energy. Nevertheless, there are also challenges encountered during the implementation of smart road wireless charging systems, such as high installation costs, redesigning of infrastructure, standardization problems, energy losses, and safety issues associated with the exposure to electromagnetic fields. These issues need to be tackled through ongoing research, technological advancements, policy facilitation and partnership between governments, industries, and institutions. To sum up, Smart Road Infrastructure of Wireless EV Charging is a game-changer in terms of the next-generation transport systems. This technology can transform the electric mobility, increase the convenience of users, optimize traffic, and play a significant role in the creation of intelligent and sustainable cities by integrating wireless power transfer, intelligent communication, and sustainable energy.

I. RELATED WORK

The last ten years have seen significant research in the area of wireless electric vehicle (EV) charging and smart road infrastructure, the main aim of which is to enhance the inductive power transfer (IPT) technology, system efficiency and feasibility of large scale implementation. Initial research work was on resonant inductive coupling, optimization of coil design, compensation, and enhancement of power-transfer efficiency across the air gap. Parking-based charging pads, which are also known as the static wireless charging systems, were invented in order to enhance convenience and the absence of physical connectors. Based on these, scientists proposed dynamic wireless charging principles that allow cars to charge as they drive by using road coils, and pilot projects have shown the successful transfer of power at different speeds. Recent developments combine IoT sensors, vehicle to infrastructure (V2I) communication, smart grid connectivity, and renewable energy sources to allow intelligent energy management, real times monitoring, automated billing and cybersecurity protection. Together, these investigations confirm the technical viability, effectiveness, and scalability of smart road-based wireless charging systems, the basis of the new generation of sustainable transportation infrastructure. More recent research has added to the area with the introduction of smart grid systems, IoT-based monitoring, and vehicle-to-infrastructure (V2I) communications. Such innovations make it possible to control in real-time, auto-bill, predictive maintenance, and manage energy efficiently. Further, studies have been conducted on the effects of wireless charging on the power systems, which has shown that load balancing and grid stability is necessary because of the high power requirements

II. SYSTEM ARCHITECTURE

The wireless EV charging architecture of a smart road infrastructure system is designed in such a way that it enables effective, secure, and smart flow of energy wirelessly between the roads and the electric cars. It consists of several interconnected subsystems which work together to provide continuous charging.

1. Power Supply Unit

- Linked to the central electricity or renewable energy sources (solar/wind).
- AC power is fed which is converted and regulated to be transmitted wirelessly. Power Conversion System

2. Transmitter (Road-Embedded Coils)

- Coils installed under the road are the main winding.
- Produces an electromagnetic field to transfer wireless power.
- Separated into segments that turn on when EVs are sensed.

3. Receiver Unit (Vehicle Side)

- Fitted under the electric car.

- Traps magnetic energy and transforms it to electrical power.
- Installation of rectifier and battery management system (BMS) to charge.

4. Control and Communication System

- IotT sensors and Vehicle-to-Infrastructure (V2I) uses.
- Measures vehicle presence, controls the coils and regulates the power.
- Allows real time monitoring, diagnostics and automated billing.

5. Energy Management System (EMS)

- Maximizes the power allocation within several charging segments.
- Equalizes the demand of loads and incorporates renewable energy sources.
- Maintains a good and effective functioning of the system.

6. Safety and Protection Mechanisms

- Incorporates electromagnetic shielding and foreign object detection.
- Avoids overheating, overvoltage and leakage of energy.
- Maintains safety standards.

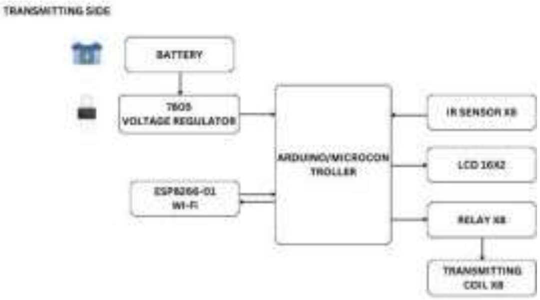
7. User Interface & Billing System

- Displays real-time charging information to users through mobile applications or dashboard.
- Allows the automatic payment in safe digital systems. Working Principle (Flow):

1. Electricity generated in the grid is fed to the conversion system.
2. High-frequency AC is sent to road-embedded transmitter coils.
3. On detecting an EV, particular coil sections are turned on.
4. Transfer of energy is through electromagnetic induction.
5. The battery is charged by the vehicle receiver that absorbs the energy.
6. Exchange of data is done in monitoring, control and billing.

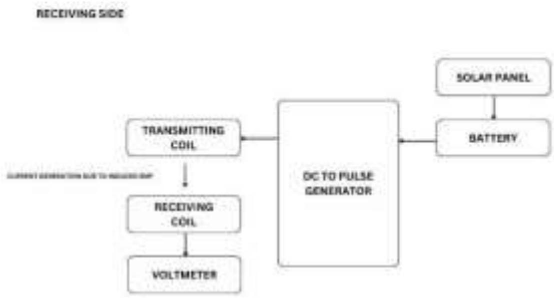
III. WORKING FLOW:

12V Battery Regulator (7805) to Arduino and sensors to relay activation to DC Pulse Generator to transmitting coil to magnetic field to receiving coil to output to voltage to voltmeter.



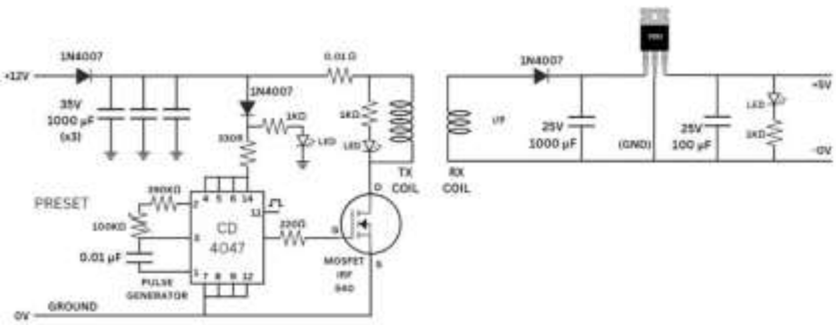
Transmitting Side:

A smart wireless EV charging system has its transmitting side tasked with the job of creating and managing the wireless power which is sent to the vehicle. The system starts with a battery, which serves as the primary power source. The 7805- voltage regulator is used to control this power and provide a constant supply of 5V to the sensitive electronic components such as microcontrollers and sensors. The main component of the system is the Arduino (microcontroller), which regulates the general work. It is fed by several IR sensors (8 units) that determine the presence of a vehicle and its location in a given section of the road. The microcontroller makes decisions based on this input on the charging segment to be activated. A 16x2 LCD is also included in the system that displays real-time information like system status, active coil, or vehicle detection response. The microcontroller uses relay modules (8 relays) in order to maintain the distribution of power. The Transmitting coils (8 coils) are embedded in the road and each relay is associated with a particular coil. When a vehicle is sensed by a given IR sensor, the respective relay is triggered and this powers the given transmitting coil. Lastly, the transmitting coils create an alternating magnetic field, which facilitates the wirelessly energy transfer to the receiver coil within the electric vehicle.



Receiving Side:

The wireless EV charging system has a receiver that captures the transmitted energy and converts it to useful electrical power to the vehicle or load. This is done in accordance with the principle of electromagnetic induction. The input stage requires a DC to pulse generator to convert the DC power available (charged in the battery by the solar panel) to high- frequency pulses. These pulses are needed to produce a fluctuating magnetic field in the transmitting coil that facilitates the process of wireless power transfer. The solar panel is a renewable energy source and charges the battery. Such stored energy helps to keep the system running even in situations when solar input is not present. The pulse generator is fed with power by the battery and keeps the system stable. The transmitting coil on the wireless transfer side produces an alternating electromagnetic field. When the receiving coil comes within this magnetic field, an electromotive force (EMF) is induced in it. This emf produces current in the receiving coil effectively transferring energy without physical contact. The receiving coil is then connected to a voltmeter to measure the output of the coil which shows the level of the induced voltage and establishes that power transfer was successful.



This circuit is a complete inductive wireless power transfer system, both transmitting and receiving. It exploits a pulse generator, power switching and coil coupling to transfer energy wirelessly.

1. Power Supply Section (Transmitter Side)

- The circuit starts with a +12V DC supply.
- A diode with reverse polarity protection is a 1N4007 diode.
- Filtering and smoothing of the input voltage are done with multiple 1000MuF capacitors (35V).
- A resistor with a small value of 0.01 ohms is used as a current limiting and stabilizer.

2. Pulse Generator (CD4047 IC)

- To produce square wave pulses the CD4047 IC is an astable multivibrator.
- Frequency is controlled using:
- Variable resistor (100kΩ) (preset)
- 390kΩ resistor
- 0.01µF capacitor
- This pulse signal is essential to create alternating current for inductive transmission.

3. MOSFET Switching Circuit

- The output from CD4047 is fed to the gate (G) of the IRF540 MOSFET through a 220Ω resistor.
- The MOSFET is a high-speed switch that switches ON and OFF in a short period of time. This switching action causes current to be taken through the transmitting coil.

4. Transmitting Coil (TX Coil)

- The TX coil linked to the drain of the MOSFET produces an alternating field of magnets as current passes through it.
- The operation status of the coil is indicated by LEDs.

5. Wireless Energy Transfer

- Electromagnetic induction - The varying magnetic field generated by the TX coil causes voltage to be induced in the adjacent RX coil.
- No physical contact is needed between the coils of TX and RX.

6. Receiving Side (RX Circuit)

- The AC voltage is induced on the RX coil.
- There is a 1N4007 diode that is an AC to DC converter.
- The output voltage is smoothed by capacitors (1000µF and 100µF).

7. Voltage Regulation (7805 IC)

- The DC voltage received is converted by a 7805-voltage regulator to a constant +5V output. This controlled output may be utilized to drive loads such as sensors, microcontrollers or batteries.
- An LED shows the existence of output voltage.

IV. METHODOLOGY

The proposed system is based on a systematic approach that integrates power electronics, embedded systems and wireless energy transfer to provide effective and intelligent EV charging. The process is broken down into several steps and its operation is controlled and optimized.

1. Power Startup and Control.

The circuit starts with a 12 V DC power supply which is fed into the circuit. A 1N4007 diode is used to provide reverse polarity protection to the voltage to provide safe and stable operation of electronic components. Noise filtering and stabilization of the voltage is done using capacitors (1000 uF and 100 uF). This is then fed through a 7805-voltage regulator to convert the 12V input to a controlled 5V output needed by the Arduino, IR sensors and a relay module among other control elements.

2. Sensor-Based Vehicle Detection

Numerous IR sensors (8 units) will be installed on various parts of the road. Such sensors are used to continuously check the existence of a vehicle. Passing a vehicle over a sensor, the sensor notices the breaking of the infrared signals and transmits a signal to the Arduino microcontroller. The sensors are a representation of each segment of charging.

3. Microcontroller Processing (Arduino)

The Arduino will be the core of control in the system. It interprets the indications of all the IR sensors and finds the prec ise location of the vehicle. Depending on the programmed logic, the Arduino determines which transmitting coil is to be turned on. This guarantees accurate and smart control of the charging procedure.

4. Relay-Based Switching Mechanism

The Arduino transmits the control signals to the relay module (8 relays). Relays are linked to certain transmitting coils. Upon detection of a vehicle by a certain IR sensor, the Arduino will enable the corresponding relay, preventing the current to pass through any other coil. This selective activity lowers the amount of energy wasted and makes it more efficient.

5. DC to Pulse Conversion

A DC to Pulse Generator converts the supplied DC power into high-frequency pulses. This is an essential step since the transfer of power wirelessly involves a constantly varying current to produce an alternating magnetic field. It is in the absence of this conversion that efficient inductive coupling would not be possible.

6. Wireless Power Transmission (Transmitting Coil)

The excited transmitting coil generates a fluctuating electromagnetic field surrounding it. In practice such coils are installed under the road. The intensity and frequency of the magnetic field varies with the input power and the feature of pulse.

7. Wireless Power Reception (Receiving Coil)

The electric vehicle has a receiving coil mounted on it. An electromagnetic induction causes an electromotive force (EMF) to be induced in it when it is in the magnetic field of the transmitting coil. This created EMF creates a current in the receiving coil, which essentially moves the energy wirelessly.

8. Output Power Utilization

The induced voltage on the receiving coil is turned into useful DC power (where applicable via rectifiers in practise). A 5 V output supply is shown and measured with a voltmeter in the prototype to ensure the energy transfer is successful.

9. Communication and Smart Features (Optional Enhancement)

The system can be connected to an ESP8266 Wi-Fi module to monitor using the IoT. This facilitates real-time information transfer, remote monitoring, system diagnostics, and automated billing using cloud services.

V. RESULT AND DISCUSSION

Experimental Result

The prototype was developed and tested under controlled conditions to analyze the performance of wireless power transfer in the case of inductive coupling. The system was able to regulate the 12V supply to 5V with the 7805 regulators and the system was able to maintain the stable operation of the Arduino, sensors and the control circuitry. The pulse generator CD4047 was used to generate a continuous square wave signal, which successfully powered the IRF540 MOSFET, providing the possibility to switch the transmitting coil with high frequency. When the transmitting coil was switched on, it created an alternating field of the magnet. An electromotive force (EMF) was induced when the receiving coil was put too closely together giving a measurable output voltage. The voltmeter measurements proved that it is possible to transfer energy wirelessly without any physical connection. Small loads like LEDs were driven in some test cases, which proved to be useful in practice. The IR sensor array (8 sensors) could effectively sense the existence of an object (a vehicle) at particular sections. Depending on the sensor signal, the Arduino would switch the respective relay so that the transmitting coil that was required was switched on. This confirmed the idea of segment based dynamic charging, where power is supplied only where it is required. Performance Analysis

a. Power Transfer Efficiency

The highest efficiency was found to be in the system where the transmitting and receiving coils were closely aligned and separated by a minimum distance. The larger the gap, the smaller the induced voltage. This underscores the need to have high accuracy of coils alignment in real-world applications.

b. Frequency Optimization

The performance of the system depended on the output of the CD4047 oscillator. The preset resistor was tuned properly to enhance the efficiency of energy transfer. The increased frequencies led to improved coupling and switching losses.

c. Stability of Output Voltage

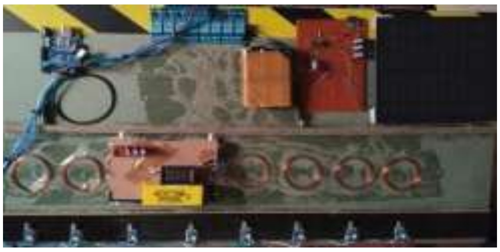
The circuit at the receiving end, which consisted of rectification and filtering, delivered a fairly stable DC output. The 78 05 regulators ensured a constant 5V output, suitable for low-power applications.

d. Precision of sensor and control.

The IR sensors were consistent in the range of detection. Arduino was able to process inputs in a short period of time and create relays without a perceivable delay, which allowed the system to respond to dynamic performance in real-time.

Discussion

The findings of the experiments confirm the possibility of wireless charging of EVs through inductive power transfer. A combination of Arduino-controlled functions, IR sensors, and relay switching proves an intelligent and energy-efficient solution to dynamic charging. The system is able to simulate the smart road infrastructure in the real world as it only lights up charging sections when vehicles are detected and when they are not, it manages energy consumption. But to scale this system to real world applications, there are several issues that will need to be resolved including the need to increase efficiency on large scales, deal with high levels of power, safety requirements, and create standardized protocols. The performance can be further increased by advanced technologies like resonant coupling, better coil materials and smart grid integration.



Hardware setup

VI. CONCLUSION

Smart road infrastructure of wireless EV charging systems is a great step in the development of the electric mobility sector as it eliminates some of the main shortcomings of the older charging systems. This project effectively proves the idea of the transfer of wireless energy of the inductive power transfer (IPT), with the inclusion of intelligent control systems Arduino - based automation, IR sensor detection, and relay-based segment activation. The prototype developed proves that it is possible to transmit electrical energy effectively with no physical connections which is convenient, safe and will not require a constant reliance on stationary charging stations. Among the greatest successes of this system is the introduction of dynamic charging functionality whereby the power is only delivered to the necessary part of the road depending on the vehicles detected. This will help cut down on energy wastage and enhance the efficiency of the system. The system is intelligent and flexible because it involves the use of numerous sensors and real-time control that provides the activation of the transmitting coils precisely. Also, a regulated power supply and pulse generation circuit is merged to guarantee stable operation and efficient generation of a magnetic field to transmit wirelessly. Experiments prove that under controlled conditions the system operates reliably and voltage is successfully induced at the receiving side. The generated output is good enough when there is low power usage, which proves that the concept is viable. Nevertheless, it is also evident that other factors like the coil alignment, coil separation, operating frequency and environmental factors influence system performance. These aspects need to be optimized efficiently to be deployed in the real world. Although it was successfully implemented, the project exposes several issues that should be tackled to be adopted on a large scale. They are: enhancing the efficiency of power transfer between distant locations, managing the large power levels needed in full-scale EV charging, meeting the electromagnetic safety requirements, lowering infrastructure costs, and providing standardization across vehicle platforms. Also, embedded road components sustainability and compatibility with existing transportation infrastructure are also key issues. In the future, the technology has a huge potential to transform the transportation industry. The system, integrating with smart grids, renewable energy sources, and IoT-based monitoring systems, may help to develop sustainable and energy-efficient smart cities. The future can involve application of new resonant coupling capabilities, AI based traffic and energy control and high-power wireless highway and public transport networks charging systems. In conclusion, the Smart Road Wireless EV Charging System provides a promising and innovative solution for the future of electric mobility. Not only does this improve the convenience of the user and minimizes charging time, but it can also enable environmental sustainability and the efficient use of energy. This system may have a significant role to play in the designing of the next generation of transportation systems and hasten the global shift towards clean and smart energy solutions with additional research and development of technology and infrastructure.

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