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Wireless EV Charging System

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Abstract:Number of EVs present today in word is huge and the number is increasing day by day. In response to the surging global demand for electric vehicles (EVs), this report introduces an innovative wireless charging system designed to address key challenges hindering the widespread adoption of EVs. The proposed system leverages a variety of hardware components, including IR Proximity Sensors, LCD Displays, 5V Relay Modules, AT89S51 and PIC 16F877A Microcontrollers, Voltage Sensor Modules, and a 10W Solar Panel. At the heart of the solution is a transmitting coil that emits electromagnetic waves, serving as the primary medium for wireless energy transfer. The system is powered by a 12V battery, itself sustained through solar panel charging. Notably, the integration of an IR proximity sensor optimizes energy efficiency by activating the relay only when an EV is detected at the charging station, thereby minimizing unnecessary power consumption. To enhance user experience and streamline the charging process, the wireless EV charging station introduces a sensor-based approach. The presence of an EV is detected through the IR proximity sensor, triggering the relay to energize the charging coil. This eliminates the need for manual intervention by the driver, transforming the charging station into a hassle-free and user-friendly environment. Simultaneously, the EV itself incorporates a receiving coil, converting transmitted electromagnetic energy into direct current for efficient battery charging. Beyond reducing the reliance on traditional wired charging stations, this wireless solution embodies a forward-thinking paradigm in sustainable transportation, presenting a promising step towards the seamless integration of EVs into our daily lives.

Keywords: Auto charging system, EV, Inductive charging, Contactless EV charging, Wireless power transfer for EVs.

I. INTRODUCTION

The global presence of electric vehicles (EVs) has grown significantly, with numbers escalating daily. However, the expansion of EVs faces hurdles, primarily concerning the availability and wired nature of charging stations. Current charging methods require drivers to manually connect thick cables to their vehicles, select charging times, and handle payment, making the process cumbersome.

Wireless charging technology has been conceptualized since Tesla's era but lacked adequate technical support. In 2007, researchers achieved a breakthrough by controlling light from a wireless source up to two meters away. Wireless power transmission (WPT) finds diverse applications, with a pivotal focus on charging EVs. Traditional conductive charging systems, utilizing thick cables and manual connections, are environmentally unfriendly and pose risks like short circuits or electric shock. Additionally, battery solutions are costly, heavy, and have limited lifespans.

Wireless charging systems offer a promising solution by reducing initial costs and eliminating the need for bulky batteries. This study delves into the concepts, strategies, materials, and methods of EV wireless charging systems, providing comprehensive insights and analysis. It aims to address pertinent questions surrounding the efficacy and feasibility of WPT methods, particularly within the realm of EV charging systems.

II.LITERATURE SURVEY

English physicist Faraday was the first to show that a magnetic field can create an electric current. In one experiment, Faraday wrapped a thick iron ring with two coils of insulated wire. He connected one coil to a battery. When he closed the battery circuit, Faraday noticed a momentary movement in a galvanometer. When he opened the battery circuit, he observed a similar movement in the opposite direction. This experiment showed that a change in a magnetic field can generate an electric current in a nearby circuit, a phenomenon called electromagnetic induction. Maxwell later built on Faraday's work, developing the foundation of electromagnetic field theory. Faraday formulated a law stating that the amount of voltage induced in a coil is directly proportional to the rate of change of magnetic flux with respect to the coil and the number of turns of wire in the coil. Such idea we are introduce in our wireless EV Charging System.

Fossil fuels will run out one day, so India wants to switch to electric cars by 2030. Electric cars are powered by electricity and are cheaper and better for the environment. They can even drive themselves! But right now, electric cars have some problems. They cost a lot and can't go very far without needing to be charged again. To fix this, we either need to charge them a lot or put in bigger, heavier batteries, which costs even more. Charging them all the time is also expensive. Regular cars that run on gasoline or petrol make a lot of pollution and noise, and they're bad for the air. So, we're thinking of using a Wireless Charging System to charge electric cars without plugging them in. This could solve the problems of cost and range for electric cars in the future.

III. NEED OF THE STUDY.

The objectives and scope of the Wireless EV charging system encompass several key elements aimed at revolutionizing electric vehicle charging infrastructure. The primary goal is to develop a hassle-free wireless EV charging station specifically designed for electric cars. This entails creating a system entirely devoid of physical connections, ensuring seamless and convenient charging experiences for drivers. Additionally, the system provides comprehensive guidance to users, offering real-time updates on the charging process and ensuring transparency regarding payment requirements. While initially tailored for EV cars, the system is adaptable for Electric Bikes (E-bikes) in the future, demonstrating a forward-thinking approach to evolving mobility needs. Moreover, the reduction in physical components not only streamlines the charging process but also enhances the aesthetic appeal of the charging environment, contributing to cleaner urban landscapes. Lastly, the wireless nature of the charging station enhances scalability, facilitating its integration into existing urban infrastructure without the need for extensive construction or modifications, thereby promising a more sustainable and accessible future for electric vehicle charging.

IV.RESEARCH METHODOLOGY

In this system we are having two sections, one section will be placed on the charging station and other part will be in the EV. The charging station will be having a transmitting coil (primary) which will transmit the electrical energy in form of electromagnetic waves in the air. The system will be powered by a 12v battery. The battery will be charged using a solar panel. There is also a IR proximity sensor which will detect the presence of an EV on the charging place. If EV is parked there then it will switch on the relay which will energize the charging coil. This will save the energy wastage. All these things will be controlled by a microcontroller. On the other hand the system inside the EV will also have a coil. This coil will act as a receiver and it will receive the electrical power transmitted by the transmitting coil. The energy then converted into DC and can be used for EV battery charging. The EV driver will first receive a message on the LCD that the wireless charging is now available. The he has to select whether he wants to charge the EV or not. For this purpose the driver is provided with the switches to start and stop the charging. Depending upon the time he will be charged. And the total payment will e displayed on the LCD. The driver will get all the necessary information on the same LCD inside the EV. The LCD will show the battery voltage and the available charging voltage. The relays will connect the charging coil to the battery. There will be a PIC microcontroller which will control all these operations.

Inductive Coupling

Inductive coupling is the method of transferring energy between circuits by sharing a magnetic field**[9]**. It's also referred to as magnetic field coupling. Wireless power transfer (WPT) via inductive coupling involves transferring power between two coils using electromagnetic fields. One coil is located in the charging pad or base station, while the other is in the device being charged. Together, these coils form a transformer.

Resonant frequency in electronics occurs when a circuit exhibits its maximum oscillatory response at a specific frequency. This phenomenon is observed in circuits containing an inductor and capacitor. To grasp the concept of resonant frequency and its significance in electronics, consider a series RLC circuit powered by an AC source. Capacitive and inductive reactance vary with frequency, with capacitive reactance (Xc) expressed as 1/ (2πfC) and inductive reactance (XL) as 2πfL. The resonant frequency (fr) is determined by equating these reactances:

1. XL = XC
2. 2πfL = 1/ (2πfC)
3. fr = 1/ (2π √LC)

For effective wireless power transfer between two coils, both transmitting and receiving coils must be in resonance.

Formulas Referred:

1) Q(coil quality)= $2\pi fL/R$

2)ƛ$(LossFactor) = k(Couplingfactor).Q(CoilQuality)$.

3) Skin effect= $\sqrt{2\rho/\pi fu}$

4) Resonant frequency: Fr = $1/2\pi\sqrt{lc}$

Designing was based on following factors:

1) Output power (Expected): first step was to define expected output power so that all thecomponents can be selected as per required rating. In our case it was 5W.

2) Efficiency: We were expecting efficiency around 80-85% for 1 CM distance we got the sameas we got commercially made windings in our circuit.

3) Coil Quality: It was the part about material selection, we tried with different material like Singe strand copper wire, multistrand copper wire and litz wire. Also coupling factor (k) matters a lot while designing coils.

4) Distance: We were aiming for average distance of 1CM and max distance of 2CM system gives best efficiency at 10mm
5) Input voltage: Input voltage were needed for good efficiency was 12V at input side as our system is solar based we used a 24W panel for good efficiency.

Coil design specifications for WPT

Electric Vehicle	Battery Capacity (kWh)	Charging Time (10% to 80%)	Power (kW)
Tata Nexon	30.02 to 40.5	60 mins	50
Tata Tiago	19.2 to 24	58 mins	25
Tata Tigor	26	59 mins	25
MG Comet EV	17.3	3.5 hrs	7.4 AC
MG ZS EV	50.3	63 mins	50
Hyundai Ioniq 5	72.6	18 mins (350 kW DC)	350
		43 mins 30s (50 kW DC)	50
Kia EV6	77.4	63 mins (50 kW)	50
		16 mins (233 kW)	233
Mahindra XUV400 EV	34.5–39.4	50 mins	50

Table.1 Electric vehicles data

To decide the amount of transmitting power and battery storage for charging station, we need to analyse the data of various electric vehicles and acknowledge their charging time, battery capacity.

Development

We are studying past research to develop our own transmitter and receiver coils. We're figuring out the best distance between them to make them work better. Here's our result
The input voltage and current given to the transmitting coil are 12 V and 1.2 A, respectively. The output voltage and current obtained at the receiving coil are as follows:

Table. 2 Rx and Tx Efficiency

Sr.No	Distance between Tx and Rx Coil (Cm)	Output Voltage Rx (V)	Output Current Rx (A)	Efficiency (%)
1	0.25	5.20	2.60	93.88
2	0.5	5.19	2.32	83.61
3	0.75	5.19	1.90	64.47
4	1	5.19	1.14	41.08
5	1.25	5.19	0.84	30.27
6	1.5	5.18	0.20	7.20

V.HARDWARE COMPONENTS

- IR Proximity Sensor
- LCD Display (16x2)
- 5V Relay module (PCB Mounted)
- AT89S51 Microcontroller
- PIC 16F877A
- Voltage sensor module
- 7805 IC regulator
- Solar panel (10W)
- Batteries
- Rx and Tx Module

1. **IR Proximity Sensor**

Fig. 1 IR Proximity Sensor

An IR sensor is an electronic device that detects IR radiation falling on it. An IR sensor consists of two parts, the emitter circuit, and the receiver circuit. This is collectively known as a photo-coupler or an optocoupler. The emitter is an IR LED and the detector is an IR photodiode. The IR photodiode is sensitive to the IR light emitted by an IR LED. The photodiode's resistance and output voltage change in proportion to the IR light received. This is the underlying working principle of the IR sensor.

Specifications :

- Supply Voltage : 5V
- Output Voltage : 5V
- Range : 15 to 20 cm

2. **LCD Display (16x2)**

Fig. 2 LCD Display (16x2)

An LCD (Liquid Crystal Display) screen is an electronic display module and has a wide range of applications. A 16x2 LCD display is very basic module and is very commonly used in various devices and circuits. A 16x2 LCD means it can display 16 characters per line and there are 2 such lines. In this LCD each character is displayed in 5x7 pixel matrix. The 16 x 2 intelligent alphanumeric dot matrix display is capable of displaying 224 different characters and symbols. This LCD has two registers, namely, Command and Data.Command register stores various commands given to the display.

Data register stores data to be displayed. The process of controlling the display involves putting the data that form the image of what you want to display into the data registers, then putting instructions in the instruction register

Specifications :

- Operating Voltage: 4.7V to 5.3V
- Operating Current 1mA (without backlight)
- Can display (16x2) 32 Alphanumeric Characters
- Works in both 8-bit and 4-bit Mode

3. 5V Relay module (PCB Mounted)

Fig. 3 5V Relay module (PCB Mounted)

A relay is an electrically operated switch that uses electromagnetism to work. When the relay's circuit detects a fault current, it energizes the electromagnetic field. This creates a temporary magnetic field that moves the relay armature to open or close connections. In a relay, there are 3 terminals NO, NC and COM (common). A normally open (NO) contact connects a circuit when the relay is activated. A normally closed (NC) contact disconnects a circuit when the relay is activated.

Specifications :

- Trigger Voltage (Voltage across coil) : 5V DC
- Trigger Current (Nominal current) : 70mA
- Maximum DC load current: 10A @ 30/28V DC
- Operating time: 10msec Release time: 5msec

4.AT89S51 Microcontroller

Fig. 4 AT89S51 Microcontroller

The AT89C51 is a low-power, high-performance CMOS 8-bit microcomputer with 4K bytes of Flash programmable and erasable read only memory (PEROM). The device is manufactured using Atmel’s high-density nonvolatile memory technology and is compatible with the industry-standard MCS-51 instruction set and pinout. The on-chip Flash allows the program memory to be reprogrammed in system or by a conventional nonvolatile memory programmer. By combining a versatile 8-bit CPU with Flash on a monolithic chip, the Atmel AT89C51 is a powerful microcomputer which provides a highly-flexible and cost-effective solution to many embedded control applications.

Specifications :

- 8 bit Microcontroller
- Operating Frequency Max: 24MHz
- Program Memory Size: 4KB
- No. of Pins: 40Pins
- No. of I/O's: 32I/O's
- Interfaces: SPI, UART
- RAM Memory Size: 128Byte
- Supply Voltage : 4V to 5V

5.PIC 16F877A

Fig. 5 PIC 16F877A

PIC is a Peripheral Interface Microcontroller which was developed in the year 1993 by the General Instruments Microcontrollers. It is controlled by software and programmed in such a way that it performs different tasks and controls a generation line. PIC microcontrollers are used in different new applications such as smartphones, audio accessories, and advanced medical devices.
Specifications :

- 16 bit Microcontroller
- Operating Frequency Max: 20MHz
- Program Memory Size: 14KB
- Data Memory : 256 bytes
- No. of Pins: 40 Pins
- Operation Voltage : 2V to 5.5V
- 8 channels of 10 bit Analog-to-Digital Converter
- 2 Comparators
- SPI, I2C and UART Interfaces for Serial Communication

6.Voltage sensor module

Fig. 6 Voltage Sensor module.

The Voltage Sensor Module is a simple but very useful module that uses a potential divider to reduce an input voltage by a factor of 5. The 0-25V Voltage Sensor Module allows you to use the analog input of a microcontroller to monitor voltages much higher than it is capable of sensing. The Voltage Sensor is basically a Voltage Divider consisting of two resistors with resistances of 30KΩ and 7.5KΩ i.e. a 5 to 1 voltage divider. Hence the output voltage is reduced by a factor of 5 for any input voltage . The internal circuit diagram of the Voltage Sensor Module is given below.
Specifications :

- Range : 0 to 25V
- Output Voltage : 0 to 5V

7.Solar panel (10W)

Fig. 7 Solar panel (1.5 W)

A solar cell is basically a junction diode, although its construction it is little bit different from conventional p-n junction diodes. A very thin layer of p-type semiconductor is grown on a relatively thicker n-type semiconductor. We then apply a few finer electrodes on the top of the p-type semiconductor layer. When light reaches the p-n junction, the light photons can easily enter in the junction, through very thin p-type layer. The light energy, in the form of photons, supplies sufficient energy to the junction to create a number of electron-hole pairs. The incident light breaks the thermal equilibrium condition of the junction. The free electrons in the depletion region can quickly come to the n-type side of the junction. Similarly, the holes in the depletion can quickly come to the p-type side of the junction. Once, the newly created free electrons come to the n-type side, cannot further cross the junction because of barrier potential of the junction. Similarly, the newly created holes once come to the p-type side cannot further cross the junction became of same barrier potential of the junction. As the concentration of electrons becomes higher in one side, i.e. n-type side of the junction and concentration of holes becomes more in another side, i.e. the p-type side of the junction, the p-n junction will behave like a small battery cell. A voltage is set up which is known as photo voltage. If we connect a small load across the junction, there will be a tiny current flowing through it.

Specifications :

- Peak power (Wp): 2.37 W
- Open circuit voltage (Voc): 10.3 V
- Short circuit current (Isc): 0.42 A
- Dimensions: 147x80 mm
- Operating voltage: 6 V
- Power rating : 250 mA

8.Rx and Tx Module

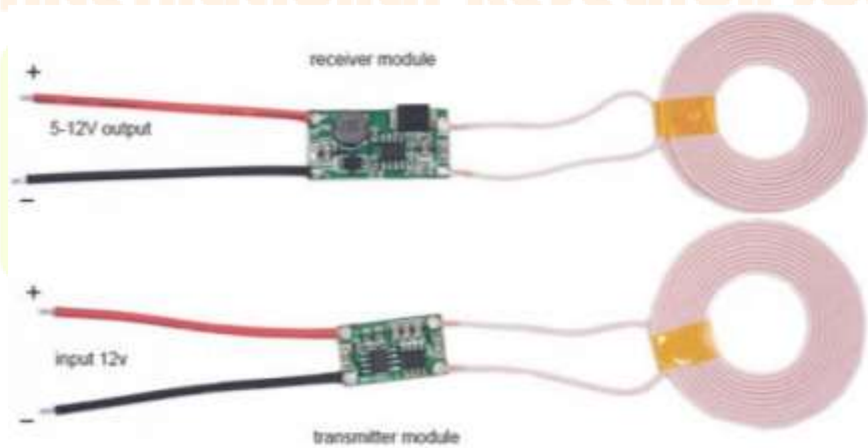

Fig.8 Transmitter and Receiver module

Table 3. Transmitter and Receiver module specifications

Sr No:	Parameter	Specification
1	Model	XKT-412.
2	Input Voltage	5-12VDC
3	Input Current	1.2-2 A
4	Output	5V / 700mA current
5	Normal Use Distance	2 ~ 10mm
6	Tx / Rx Coil Dimensions	Diameter 43mm, Inner diameter 20mm,
7	Coil Wire Thinkness	2.3mm
8	The transmitting module size	18mm*8.5mm*15mm
9	The receiving module size	10mm*25mm*3mm
10	Shipping Weight	0.035 kg
11	Shipping Dimensions	15 × 10 × 8 cm

VI. SYSTEM DIAGRAM

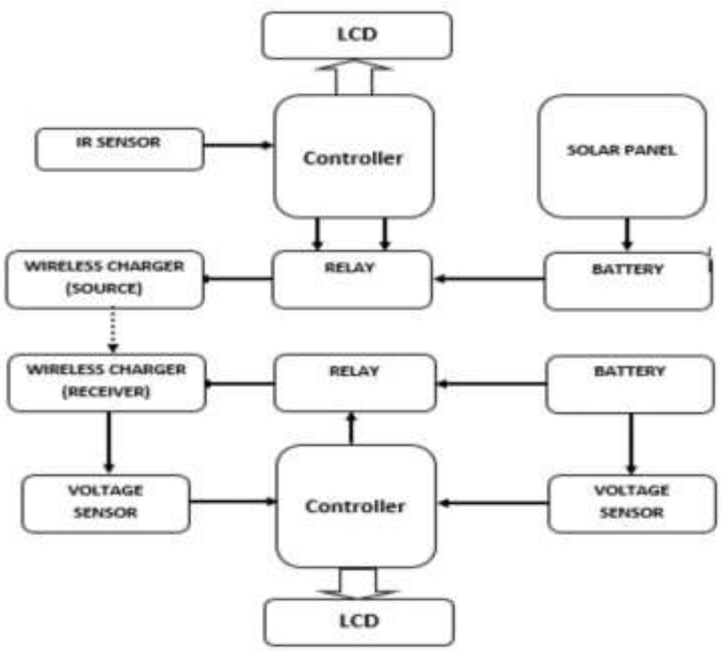

Fig. 9 System diagram

VII. CIRCUIT DIAGRAM

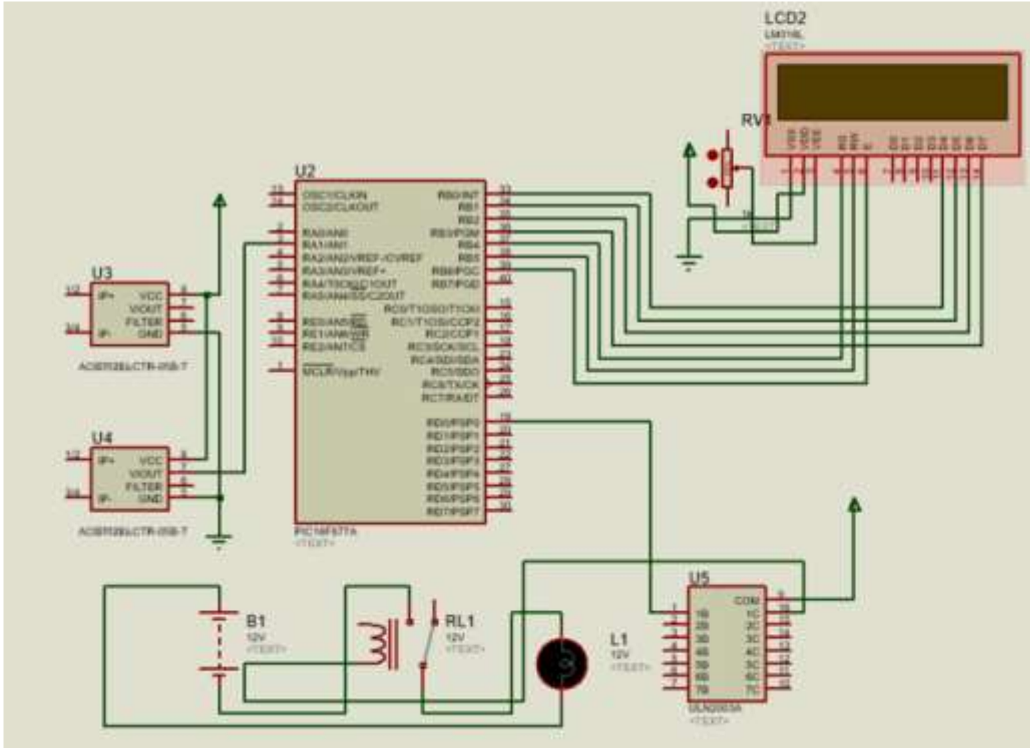

Fig. 10.Circuit Diagram of Receiver

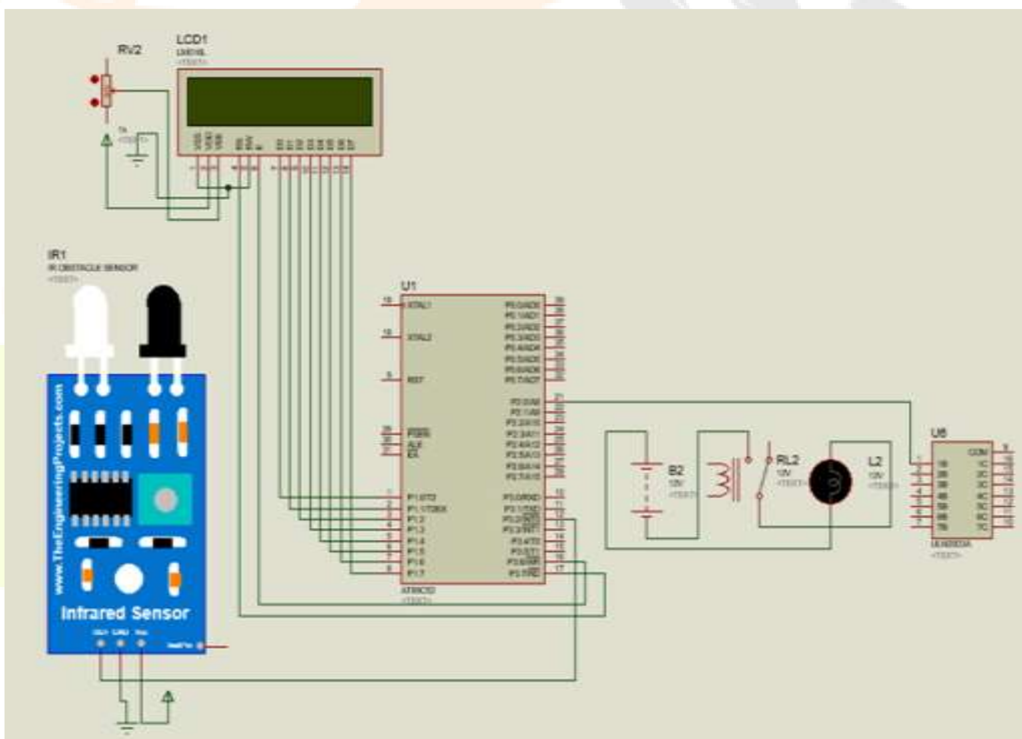

Fig. 11 Circuit Diagram of Transmitter

VIII. RESULT AND DISCUSSION

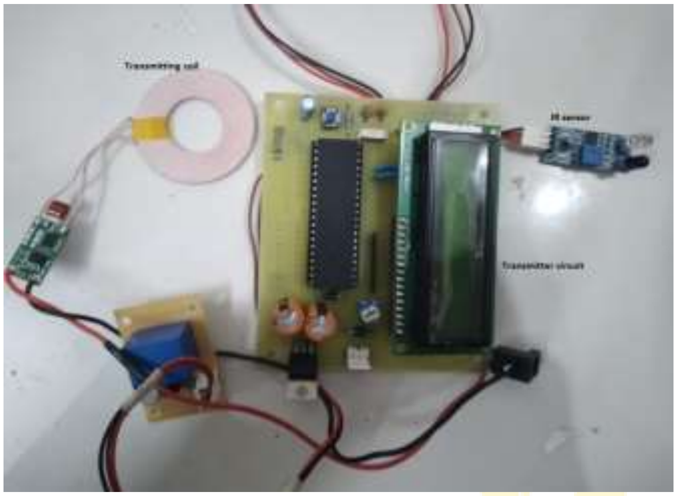

Fig 12. Transmitter Circuit

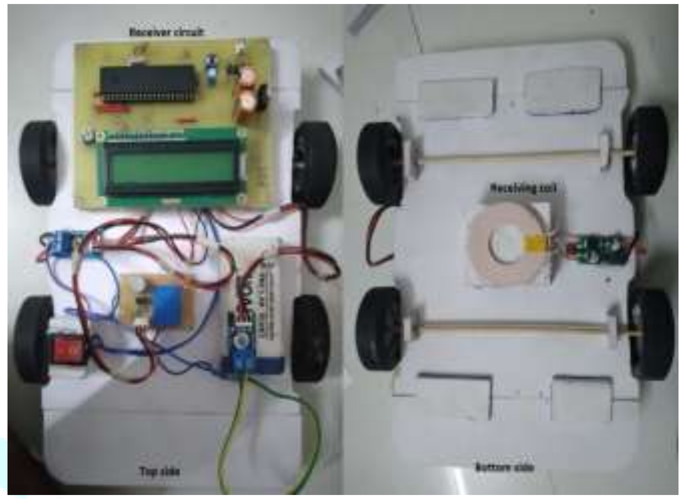

Fig 13. Receiver Circuit

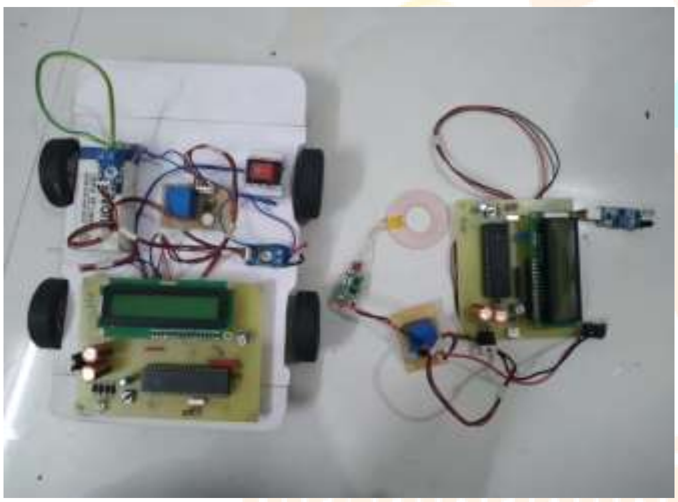

Fig 14. Transmitter and Receiver Circuit

Fig 15. Vehicle charging start

Fig 16. Vehicle is charged

In the figures above (Figures 12 to 16) the functioning of the entire system is delineated. The transmitter operates continuously to detect vehicles ahead using an IR sensor. Upon vehicle detection, power supply to the transmitting coil commences. Subsequently, when the receiving coil receives power, the battery initiates charging, and the LCD effectively displays the available power supply and the status of battery charging. Once the vehicle is fully charged and begins to move, the power supply automatically ceases. While this prototype demonstrates successful operation, the transition to real-world implementation necessitates the incorporation of various power transfer techniques to enhance efficiency.

In Fig. 12, the transmitter circuit contains an IR sensor, relay, and transmitting coil. Whenever the IR sensor detects a vehicle, the relay operates, and power is supplied to the transmitting coil. The receiving coil is attached to the base of the vehicle as shown in Fig. 13. The impedance of both transmitting and receiving coils matches, thus both are in resonance with each other. Due to this impedance matching, there is wireless power transfer between the coils. In Fig. 15, the vehicle shown is parked in the charging station, and the power transfer is initiated. Inside the vehicle, there is an LCD display that shows the available power for charging. With this data, the driver can position their vehicle for maximum power transfer. Afterward, if they wish to charge the vehicle, they will press the start button to initiate charging. This will also provide information about the battery's charging status. Finally, once the vehicle is fully charged, they will turn off the key and move. As soon as the vehicle is moved, the IR sensor stops detecting, and power supply to the transmitting coil is halted as shown in Fig. 16.

IX.APPLICATIONS

1. Residential Charging: Providing convenient and hassle-free charging solutions for EV owners at home, eliminating the need for plugging in cables.
2. Commercial and Workplace Charging: Offering wireless charging stations in parking lots and garages of offices, shopping malls, and public buildings to cater to the charging needs of employees, customers, and visitors.
3. Public Infrastructure: Installing wireless charging pads in public parking spaces, streets, and highways to enable EV drivers to charge their vehicles while shopping, dining, or traveling.
4. Fleet Management: Streamlining the charging process for electric vehicle fleets, such as taxis, delivery vehicles, and buses, by integrating wireless charging technology into depots and terminals.
5. Urban Transportation: Integrating wireless charging infrastructure into public transportation systems, such as electric buses and trams, to enable continuous charging while on routes, enhancing operational efficiency.
6. Automotive Industry: Integrating wireless charging systems into the design of electric vehicles during manufacturing, providing an additional charging option for consumers alongside traditional plug-in chargers.
7. Emerging Technologies: Exploring applications in emerging technologies, such as autonomous vehicles and electric drones, where wireless charging can enable continuous operation without human intervention.

X. FUTURE SCOPE:

1. Dynamic Electric Vehicle Charging (DEVC): Charging while in motion enhances EV range and eliminates the need for large energy storage, improving vehicle efficiency and compactness.
2. Integration with Smart Grids: Wireless EV charging will integrate with smart grids for dynamic management, optimized schedules, and bidirectional power flow, enabling vehicle-to-grid (V2G) capabilities.
3. Environmental Sustainability: Future trends prioritize reducing the environmental impact of charging infrastructure through recycled materials, energy-efficient designs, and renewable energy sources.

XI. CONCLUSION

This is the fundamental structure of the wireless EV charging system. It can automatically connect the vehicle to the wireless charging station, mitigating the shortcomings associated with wired or plug-in charging. Furthermore, it informs the driver about the total bill. However, despite its apparent ease and feasibility, this system faces several technical challenges, including issues such as the number of windings in the coil, required voltage, and the coil's shape for efficient power transfer. Research and experiments are being carried out to solve these issues.

XII. REFERENCES

[1] A. Kurs, A. Karalis, R. Moffatt, J. D. Joannopoulos, P. Fisher, M. Soljačić, Wireless power transfer via strongly coupled magnetic resonances, Science 317 (5834) (2007) 83–86. doi:10.1126/science. 1143254.
https://www.science.org/doi/10.1126/science.1143254

[2] S. Chhawchharia, S. K. Sahoo, M. Balamurugan, S. Sukchai, F. Yanine, Investigation of wireless power transfer applications with a focus on renewable energy, Renewable and Sustainable Energy Reviews 91 (2018) 888–902. doi:https://doi.org/10.1016/j.rser. 2018.04.101.
https://www.sciencedirect.com/science/article/abs/pii/S1364032118303162

[3] S. D. Barman, A. W. Reza, N. Kumar, M. E. Karim, A. B. Munir, Wireless powering by magnetic resonant coupling: Recent trends in wireless power transfer system and its applications, Renewable and Sustainable Energy Reviews 51 (2015) 1525–1552. doi:https: //doi.org/10.1016/j.rser.2015.07.031.
https://ideas.repec.org/a/eee/rensus/v51y2015icp1525-1552.html

[4] X. Zhang, Z. Yuan, Q. Yang, Y. Li, J. Zhu, Y. Li, Coil design and efficiency analysis for dynamic wireless charging system for electric vehicles, IEEE Transactions on Magnetics 52 (7) (2016) 1–4. doi: 10.1109/TMAG.2016.2529682.
https://ieeexplore.ieee.org/document/7406748

[5] A. N. Azad, A. Echols, V. A. Kulyukin, R. Zane, Z. Pantic, Analysis, optimization, and demonstration of a vehicular detection system intended for dynamic wireless charging applications, IEEE Transactions on Transportation Electrification 5 (1) (2019) 147–161. doi:10.1109/TTE.2018.2870339.
https://www.researchgate.net/publication/327714266_Analysis_Optimization_and_Demonstration_of_a_Vehicular_Detection_System_Intended_for_Dynamic_Wireless_Charging_Applications

[6] "Design of Magnetic Coupler for Wireless Power Transfer" HeqiXu ,Chunfang Wang *, Dongwei Xia and Yunrui Liu College of Electrical Engineering, Qingdao University, Qingdao 266071, China * Correspondence: qduwcf@qdu.edu.cn; Tel.: +86-158-9887-1588 Received: 13 July 2019; Accepted: 1 August 2019; Published: 3 August 2019.

[7] M. Zeng, A. S. Andrenko, X. Liu, Z. Li, and H. Tan, "A Compact Fractal Loop Rectenna for RF Energy Harvesting," IEEE Antennas Wirel. Propag. Lett., vol.16, pp. 2424-2427, 2017, doi: 10.1109/LAWP.2017.2722460.
[8] P. Lu, X. Yang, J. Li, and B. Wang,"A Compact Frequency Reconfigurable Rectenna for 5.2- and 5.8-GHz WirelessPower Transmission," IEEE Trans. PowerElectron., vol. 30, no. 11, pp. 6006-6010,2015, doi: 10.1109/TPEL.2014.2379588.
[9] S. Shen, C. Chiu, and R. D.Murch, "A Dual-Port Triple-BandL-Probe Microstrip Patch Rectennafor Ambient RF Energy Harvesting,"IEEE Antennas Wirel. Propag. Lett., vol.16, pp. 3071-3074, 2017, doi: 10.1109/LAWP.2017.2761397.
[10] P. Lu, X.-S. Yang, J.-L. Li, and B.-Z.Wang, "A dual-frequency quasi-pifarectenna with a robust voltage doubler for 2.45- and 5.8-GHz wireless power transmission," Microw. Opt. Technol.Lett., vol. 57, no. 2, pp. 319-322, Feb.2015, doi: https://doi.org/10.1002/mop.28841.
[11] M. Aboualalaa, A. B. Abdel-Rahman, A. Allam, H. Elsadek, and R. K. Pokharel, "Design of aDual-Band Microstrip Antenna With Enhanced Gain for EnergyHarvesting Applications," IEEEAntennas Wirel. Propag. Lett., vol.16, pp. 1622-1626, 2017, doi: 10.1109/LAWP.2017.2654353.
[12] M. Aboualalaa, I. Mansour, M.Mansour, A. Bedair, A. Allam, M. Abo-Zahhad, H. Elsadek, K. Yoshitomi, and R. K. Pokharel, "Dual-band RectennaUsing Voltage Doubler Rectifier andFour-Section Matching Network,"in 2018 IEEE Wireless Power Transfer Conference (WPTC), 2018, pp. 1-4, doi:10.1109/WPT.2018.8639451.
[13] M. Aboualalaa, I. Mansour, A.Bedair, A. Allam, M. Abo-Zahhad, H.Elsadek, and R. K. Pokharel "Dual-band CPW rectenna for low input power energy harvesting applications," IET Circuits, Devices Syst., vol. 14, no.6, pp. 892-897, 2020, doi: 10.1049/iet-cds.2020.0013.
[14] W. Zhou, Y. G. Su, L. Huang,X. D. Qing, and A. P. Hu, "Wirelesspower transfer across a metal barrierby combined capacitive and inductivecoupling," IEEE Trans. Ind. Electron.,vol. 66, no. 5, pp. 4031-4041, 2019, doi:10.1109/TIE.2018.2849991.
[15] V. Palazzi, M. Del Prete, and M.Fantuzzi, "Scavenging for Energy: ARectenna Design for Wireless Energy Harvesting in UHFMobile TelephonyBands," IEEE Microw. Mag., vol. 18,no. 1, pp. 91-99, 2017, doi: 10.1109/MMM.2016.2616189.
[16] E. Abramov and M. M. Peretz, "Multi-Loop Control for PowerTransfer Regulation in Capacitive Wireless Systems by Means of Variable Matching Networks," IEEE J. Emerg. Sel. Top. Power Electron., vol. 8, no.3, pp. 2095-2110, 2020, doi: 10.1109/JESTPE.2019.2935631.