NEXT GENERATION DYNAMIC WIRELESS CHARGING FOR ELECTRIC VEHICLE

A PROJECT REPORT

Submitted by

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BONAFIDE CERTIFICATE

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ABSTRACT

This project aims to develop an in-motion wireless charging infrastructure for electric vehicles (EVs) using resonant inductive coupling tuned at 85 kHz. It introduces a next-generation dynamic wireless charging system designed to enable seamless energy transfer to EVs while in motion, thereby eliminating the need for physical connections between EVs and charging stations. While static charging methods in wireless power transfer technology also eliminate physical connections, they come with significant limitations, including long charging times, limited driving range, and the need for frequent stops. To overcome these challenges, our proposed system employs resonant inductive coupling technology embedded within road infrastructure to wirelessly transmit power to receiver coils mounted on moving vehicles. The system features a primary coil embedded in the road surface, which is magnetized only when a vehicle approaches the transmitter coils. When no vehicle is present, the coils are automatically demagnetized through the integration of IoT sensors embedded in the road. This smart activation mechanism conserves energy and enhances safety. The ultimate goal of this project is to develop a sustainable, on-the-go charging infrastructure that eliminates range anxiety, promotes uninterrupted mobility, and supports the widespread adoption of electric vehicles. Beyond green transportation, this project also lays the foundation for smart road ecosystems of the future.

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LIST OF ABBREVIATIONS

ABBREVIATIONS	EXPANSION
EV	Electric Vehicle
DWPT	Dynamic Wireless Power Transfer
WPT	Wireless Power Transfer
IoT	Internet of Things
ITS	Intelligent Transportation Systems
V2I	Vehicle-to-Infrastructure
V2G	Vehicle-to-Grid
BMS	Battery Management System
LI-ION	Lithium-ion
PCB	Printed Circuit Board
DC	Direct Current
AC	Alternating Current
PWM	Pulse Width Modulation
IC	Integrated Circuit
ESP32	A microcontroller with integrated Wi-Fi and Bluetooth
MIT	Massachusetts Institute of Technology
SPI	Serial Peripheral Interface
ADC	Analog-to-Digital Converter
UART	Universal Asynchronous Receiver-Transmitter
I2C	Inter-Integrated Circuit
DAC	Digital-to-Analog Converter
IRFZ44N	A model of N-channel MOSFET
FET	Field Effect Transistor
JSON	JavaScript Object Notation
GUI	Graphical User Interface
DC-DC	Direct Current to Direct Current
EMF	Electromagnetic field

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND AND MOTIVATION

The rapid adoption of electric vehicles (EVs) is a significant step toward achieving sustainable and eco-friendly transportation. However, the limited driving range and lengthy charging times remain key obstacles to their widespread adoption. Traditional stationary charging systems require vehicles to stop and connect to a charging station, leading to downtime and inefficiencies. To address these challenges, dynamic wireless power transfer (DWPT) via charging roads is emerging as a promising solution.

1.2 CONCEPT OF WIRELESS CHARGING ROADS

Wireless Charging Roads are embedded with electromagnetic coils that enable energy transfer to EVs in motion using inductive or resonant coupling technologies. This allows vehicles to charge while driving, eliminating the need for frequent stops. These roads represent a convergence of smart infrastructure, transportation electrification, and wireless communication technologies.

1.3 CHALLENGES IN EV CHARGING AND THE NEED FOR DYNAMIC SOLUTIONS

While static charging infrastructure is growing, it cannot fully accommodate the projected demand of future EV markets. Key limitations include long charging durations, peak load issues, and space constraints. Dynamic wireless charging mitigates these problems by decentralizing the charging process and distributing the load more evenly across the transportation network.

1.4 EXISTING SYSTEM

- Focuses primarily on **stationary or low-speed dynamic charging**.
- Often implemented in **pilot projects** or limited-scale test tracks (e.g., OLEV in South Korea, Electreon in Sweden).
- Uses **conventional inductive power transfer (IPT)** with moderate tolerance for misalignment.
- **Limited IoT or smart communication integration**.
- Infrastructure deployment is **cost-intensive and slow**, especially for urban retrofitting.
- Often lacks real-time **adaptive power control** or multi-vehicle optimization.

1.5 PROPOSED SYSTEM

- Designed for **next-generation dynamic charging** at both urban and highway speeds.
- Utilizes **enhanced coil structures** with better misalignment tolerance and higher efficiency.
- Integrates **IoT and AI-based smart control** for adaptive power transfer based on vehicle type, battery level, and traffic conditions.
- Includes **modular road segments** for easier deployment and maintenance.
- Enables **Vehicle-to-Infrastructure (V2I)** and **Vehicle-to-Grid (V2G)** communication.
- Aims for **cost optimization** through scalable deployment models and renewable integration.

1.6 EXISTING SYSTEM VS PROPOSED SYSTEM

Existing systems have demonstrated technical feasibility, they still face challenges related to energy efficiency, system cost, scalability, and adaptability to various road conditions. Comparison table of both existing and proposed systems are discussed in Table 1.1. The proposed system aims to address these limitations by introducing enhancements in design, control, and integration.

TABLE 1.1 COMPARISON TABLE: EXISTING VS PROPOSED SYSTEM

Feature / Parameter	Existing System	Proposed System
Charging Type	Stationary / Low-Speed Dynamic	Full-Speed Dynamic Wireless Charging
Power Transfer Efficiency	Moderate (60–80%)	High (85–95%) with improved coil design
Misalignment Tolerance	Low to Moderate	High (enhanced lateral/longitudinal tolerance)
Control System	Basic / Manual	IoT-enabled Smart Control (AI-based)
Infrastructure Cost	High	Optimized via modular design
Communication Capabilities	Limited	Full V2I and V2G Integration
Energy Management	Static	Adaptive and Real-Time Based on Demand
Scalability	Pilot-Level or Specific Routes	Scalable to Urban & Highway Networks
Renewable Integration	Not standard	Supported

1.7 OBJECTIVES

The primary objectives of the project titled Next Generation Dynamic Wireless Charging For Electric Vehicles are as follows:

1. **To study** the current state-of-the-art in wireless power transfer (WPT) technologies, specifically focusing on dynamic charging systems.
2. **To design** a high-efficiency coil system optimized for dynamic charging under varying road and vehicle conditions.
3. **To simulate** the proposed system using tools such as MATLAB/Simulink and COMSOL to analyze power transfer efficiency, alignment sensitivity, and thermal behavior.
4. **To evaluate** the economic feasibility and environmental benefits of implementing DWC infrastructure on urban roads and highways.
5. **To integrate** smart control systems and communication protocols (V2I, V2G) to optimize energy delivery based on vehicle demand and grid status.
6. **To propose** a scalable deployment model suitable for urban transportation networks and long-distance highways.

1.8 ORGANIZATION OF THE THESIS

The thesis is organized as follows:

- **Chapter 1** Introduces the background, motivation, objectives, and scope of the project on dynamic wireless charging using inductive coupling.
- **Chapter 2** Reviews existing research, technologies, and methods related to wireless power transfer, inductive charging, and battery management systems.
- **Chapter 3** Presents the proposed design methodology, working principle, and system architecture for dynamic wireless charging integrated with IoT.

- **Chapter 4** Describes the hardware components such as ESP32, coils, sensors, BMS, and power circuitry used to build the prototype system.
- **Chapter 5** Explains the software tools, mobile app design (MIT App Inventor), Arduino coding, Firebase cloud integration, and simulation environment.
- **Chapter 6** Provides waveforms, output signals, experimental data, and validation results of wireless charging performance and real-time monitoring.
- **Chapter 7** Summarizes the work done, highlights the outcomes, and suggests possible improvements and extensions for future developments.

The report also includes references and an appendix for supporting materials.

CHAPTER 2

LITERATURE SURVEY

Dynamic Wireless Charging (DWC) has emerged as a transformative technology to support sustainable electric mobility by allowing EVs to charge while in motion. The following literature provides insights into the progress, design optimization, control systems, and deployment challenges of DWC systems.

2.1 TECHNOLOGICAL OVERVIEW AND EVOLUTION OF WIRELESS CHARGING SYSTEMS

- Bi et al. (2016) provided a review of wireless power transfer for electric vehicles, exploring the prospects of dynamic wireless charging (DWC) in enhancing sustainable mobility. Their work discussed energy efficiency, system architecture, and the integration of renewable energy sources into wireless power systems. *(Bi et al., 2016)*
- Jang (2018) conducted a comprehensive survey on the operation and system study of wireless charging electric vehicle systems. He explored various control strategies and infrastructure deployment challenges, providing insights into the scalability of these systems. *(Jang, 2018)*

2.2 WIRELESS POWER TRANSFER SYSTEM DESIGN AND OPTIMIZATION

- Li and Mi (2014) focused on wireless power transfer technologies for electric vehicle applications, detailing circuit design, power levels, and magnetic field modeling. Their findings provide a technical baseline for both static and dynamic charging systems. (Li & Mi, 2014)

- Tavakoli and Pantic (2017) demonstrated a 25 kW dynamic wireless charging (DWC) prototype for electric vehicles. Their experimental validation bridged the gap between theoretical modeling and practical system deployment, focusing on dynamic load conditions. (Tavakoli & Pantic, 2017)

2.3 BATTERY TECHNOLOGIES AND CHALLENGES FOR EV CHARGING

- Etacheri et al. (2011) reviewed the challenges in developing advanced Li-ion batteries, discussing performance limitations and future opportunities for improving battery technologies to support electric vehicle applications. (Etacheri et al., 2011)
- Zhang and Mi (2015) explored compensation topologies in high-power wireless power transfer systems, highlighting the need for effective compensation mechanisms to optimize energy transfer efficiency in DWC systems. (Zhang & Mi, 2015)

2.4 POWER CONVERSION AND CONTROL STRATEGIES

- Li, Hu, and Covic (2011) proposed a direct AC-AC converter for inductive power-transfer systems, addressing the need for efficient energy conversion in dynamic wireless charging systems for electric vehicles. (Li, Hu, & Covic, 2011)
- Choi et al. (2014) provided an overview of advancements in wireless power transfer systems for roadway-powered electric vehicles, highlighting key challenges in system control, power delivery, and integration into transportation networks. (Choi et al., 2014)

2.5 FUTURE OF FAST AND DYNAMIC CHARGING FOR ELECTRIC VEHICLES

- Tu et al. (2019) presented a technology overview of extreme fast charging for electric vehicles, exploring the technical requirements and future potential of high-power wireless charging systems. (Tu et al., 2019)
- Chawla et al. (2022) conducted a comparative analysis of power distribution architectures for large-scale electric vehicle in-motion wireless charging infrastructures, focusing on system scalability and performance optimization. (Chawla et al., 2022)

2.6 DESIGN CONSIDERATIONS FOR EFFICIENT CHARGING SYSTEMS

- Aditya and Williamson (2014) reviewed design considerations for loosely coupled inductive power transfer (IPT) systems, focusing on the challenges of designing efficient systems for EV battery charging.
- Wang et al. (2021) studied dynamic wireless charging for medium power and speed electric vehicles, examining performance characteristics and technical requirements for implementing such systems on roadways.

2.7 CONCLUSION

This chapter explored the evolution, design stretegies, control mechanisms, and research gaps in wireless ev charging. It established the theoretical foundation for proposed an improved dynamic system.

With these insights, the next chapter introduces the proposed solution tailored to enhance wireless power transfer efficiency and real-time control.

CHAPTER 3

PROPOSED SYSTEM

3.1 OVERVIEW

The proposed system introduces an innovative **Wireless Charging Road (WCR)** setup that enables **Dynamic Wireless Power Transfer (DWPT)** to electric vehicles (EVs) while they are in motion. This eliminates the need for frequent stops for charging, reduces battery size requirements, and enhances the practicality and efficiency of EV transportation.

3.2 OBJECTIVE

To design and implement a smart road infrastructure capable of wirelessly transferring power to EVs in motion, using **resonant inductive coupling**, with smart control systems for real-time energy management and communication between the vehicle and the infrastructure.

3.3 SYSTEM COMPONENTS

The proposed system consists of the following key components:

3.3.1 TRANSMITTING SIDE (ROAD INFRASTRUCTURE)

- **Primary Coils**: Embedded under the road surface; transmit electromagnetic energy.
- **Power Supply Unit**: Converts grid AC to high-frequency AC suitable for WPT.
- **Controller & Switching Unit**: Activates coil segments only when a vehicle is detected above.
- **Sensor System**: Detects vehicle position and speed to synchronize charging.

3.3.2 RECEIVING SIDE (ON-BOARD VEHICLE SYSTEM)

- **Secondary Coil**: Mounted on the underside of the vehicle to receive transmitted power.
- **Rectifier & Converter**: Converts received AC into regulated DC for charging.
- **Battery Management System (BMS)**: Monitors the battery's charging state and health.

3.4 WORKING PRINCIPLE

1. An EV enters a wireless charging lane.
2. Roadside sensors detect the EV and activate relevant coil segments beneath it.
3. High-frequency AC power is transmitted wirelessly through magnetic fields.
4. The vehicle's receiver coil collects the energy and converts it to DC for charging the battery.
5. The charging session is monitored and managed via the cloud and smart grid.

3.5 FEATURES AND BENEFITS

- **Continuous charging** during movement.
- **Reduced need** for large onboard batteries.
- **Lower downtime** due to real-time charging.
- **Smart control** for efficient energy use.
- **Eco-friendly** with smart grid and renewable integration

3.6 BLOCK DIAGRAM

Block diagram of our entire project should present in Fig 3.1.

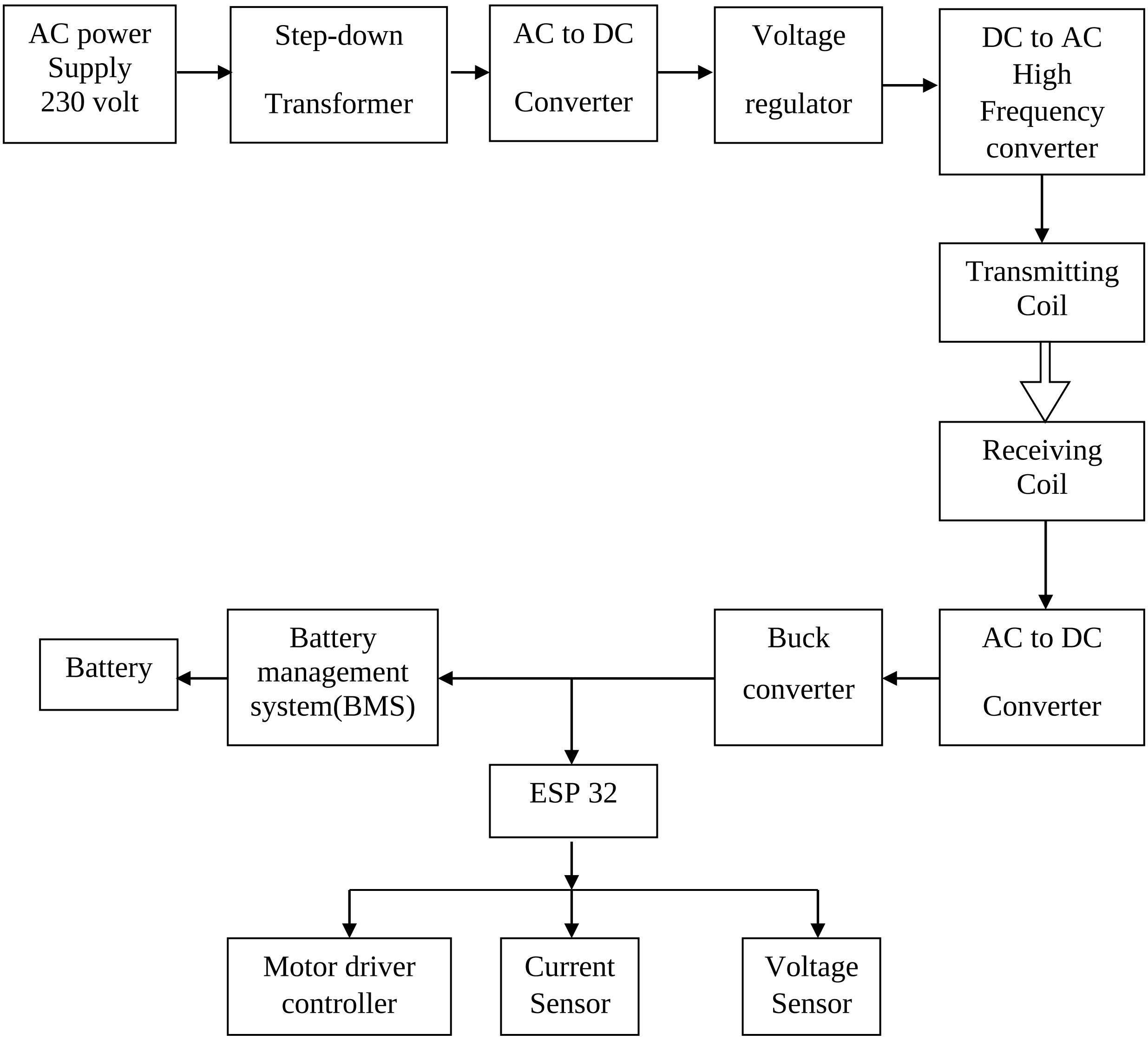

Fig 3.1 BLOCK DIAGRAM

POWER INPUT AND TRANSMISSION SIDE:

AC Power Supply (230V): This is the standard mains power supply that serves as the input source.

Step-down Transformer: Reduces the 230V AC to a lower AC voltage suitable for conversion and wireless transmission.

AC to DC Converter: Converts the lower-voltage AC to DC power for use in further electronic circuits.

Voltage Regulator: Stabilizes the DC voltage to a fixed level to ensure consistent performance.

DC to AC High Frequency Converter: Converts regulated DC into high-frequency AC. High-frequency AC is more efficient for inductive wireless power transfer.

Transmitting Coil: Generates an alternating magnetic field using the high-frequency AC. This field transmits power wirelessly.

POWER OUTPUT AND RECEIVING SIDE:

Receiving Coil: Placed in the electric vehicle (EV), this coil receives the electromagnetic energy from the transmitting coil.

AC to DC Converter (in vehicle): Converts the received AC back into DC to charge the battery.

Buck Converter: Steps down the received DC voltage to a level suitable for charging the EV battery.

Battery Management System (BMS): Manages the charging of the battery, prevents overcharging, balances the cells, and ensures battery health and safety.

Battery: Stores the energy wirelessly received and regulated through the BMS for powering the EV.

ESP32 Microcontroller:

- Acts as the central controller.
- Interfaces with sensors and the BMS.
- Sends data to the cloud or mobile app for real-time monitoring.

Voltage Sensor: Measures the voltage received by the battery and sends it to ESP32.

Current Sensor: Measures the charging current and sends the data to ESP32.

Motor Driver Controller: Controls the EV motor, possibly enabling or disabling movement based on battery status or charging condition.

3.7 CONCLUSION

The system was designed using an ESP32 controller integrated with sensors and a motor driver, enabling real-time monitoring and actuation.

With the design finalized, the next chapter details the hardware implementation and integration of the system components.

CHAPTER 4

HARDWARE DESCRIPTION

4.1 ESP32 MICROCONTROLLER

The **ESP32** is a low-cost, low-power system-on-a-chip (SoC) microcontroller developed by **Espressif Systems**, a technology company based in Shanghai, China. It is designed for a wide range of applications, particularly in the **Internet of Things (IoT)** domain, thanks to its integrated **Wi-Fi** and **dual-mode Bluetooth** capabilities. The ESP32 is built around a **Tensilica Xtensa LX6 microprocessor**, available in both **dual-core** and **single-core** configurations, or alternatively, it can feature an **Xtensa LX7 dual-core processor** or a **single-core RISC-V microprocessor**. This variety allows the ESP32 to cater to diverse processing needs, from simple tasks to more complex applications requiring significant computational power.

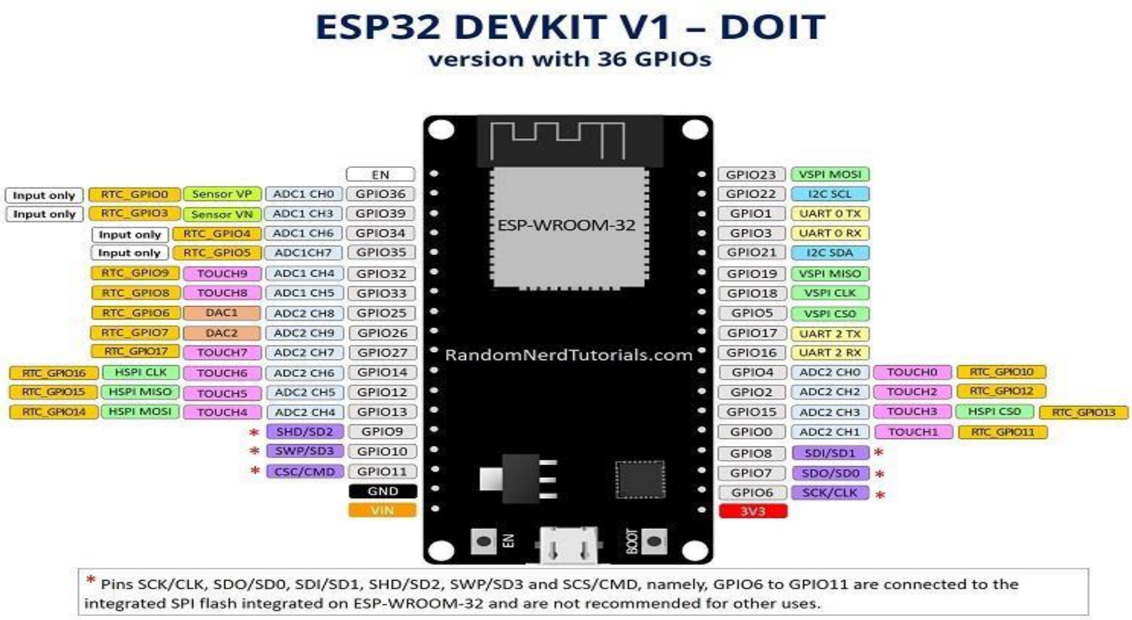

Fig 4.1 ESP32 MICROCONTROLLER PIN CONFIGURATION

In addition to its powerful processor, the ESP32 integrates essential components like **antenna switches**, **RF baluns**, **power amplifiers**, **low-noise receive amplifiers**, and **filters**, all of which help in enhancing wireless performance and reducing power consumption. The microcontroller also includes **power management modules**, making it ideal for battery-operated devices that require energy efficiency. Manufactured by **TSMC** using their **40 nm process technology**, the ESP32 offers a combination of performance, connectivity, and low power consumption, positioning it as an excellent solution for a variety of embedded and wireless communication projects. It serves as a direct successor to the **ESP8266** microcontroller, offering improved capabilities and broader use cases. Pin configuration of esp32 microcontroller should explained in Fig 4.1.

Pin configuration

The ESP32 peripherals include:

- 18 Analog-to-Digital Converter(ADC) channels
- 3 SPI interfaces
- 3 UART interfaces
- 2 I2C interfaces
- 16 PWM output channels
- 2 Digital-to-Analog Converters(DAC)
- 2 I2S interfaces
- 10 Capacitive sensing GPIOs

Applications of ESP32

- Used in **IoT (Internet of Things)** applications for real-time data monitoring and control.

- Commonly applied in **home automation systems** (e.g., smart lights, alarms, door locks).
- Utilized in **industrial automation** for remote monitoring, machine control, and data logging.
- Integrated into **wearable devices** and **portable gadgets** due to its low power consumption.
- Employed in **wireless sensor networks** for environmental monitoring and smart agriculture.
- Suitable for **health monitoring systems** such as pulse oximeters and fitness trackers.
- Used in **educational kits** and **prototyping platforms** for learning embedded systems and IoT.
- Ideal for **robotics applications** involving wireless control and sensor interfacing.
- Plays a role in **dynamic wireless charging systems** for electric vehicles by managing sensors, power flow, and communication.

4.2 COIL

Transmitting Coil

The **transmitting coil** is a crucial component in a dynamic wireless charging system, typically embedded under the surface of the road or mounted in a stationary charging pad. It is connected to a high-frequency AC power source, which creates a **time-varying magnetic field** when current flows through the coil. This magnetic field is used to wirelessly transfer energy. The transmitting coil is usually made of **copper wire** due to its high electrical conductivity and is often paired with **ferrite cores** to enhance magnetic coupling and reduce energy loss. The coil operates on the principle of **electromagnetic induction**, and its efficiency is influenced by its shape, number of turns, material, and operating frequency.

Receiving Coil

The **receiving coil** is installed underneath the electric vehicle and is aligned to the position of the transmitting coil. When the vehicle passes over or stops above the transmitting coil, the changing magnetic field induces an electromotive force (EMF) in the receiving coil. This induced AC voltage is then converted to DC using rectifier circuits and used to charge the vehicle's **battery**. Like the transmitting coil, the receiving coil is also made of copper wire and may include a ferrite backing to improve magnetic flux concentration. The efficiency of energy transfer depends heavily on the **alignment**, **distance**, and **resonance** between the receiving and transmitting coils. Below Fig 4.2 describe the transmitting and receiving coil structure.

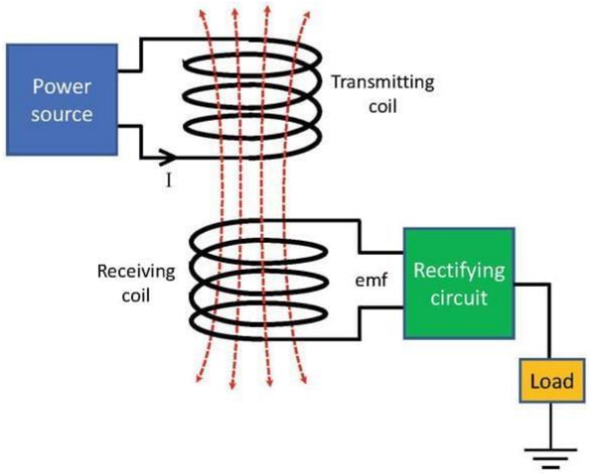

Fig 4.2 TRANSMITTING AND RECEIVING COIL

Applications of Coil in Wireless Charging

- Used for **wireless power transfer** through electromagnetic induction.
- The **transmitter coil** is embedded in the road infrastructure.
- The **receiver coil** is installed in the electric vehicle.
- Transfers energy from the road to the vehicle **without physical connectors**.

- Made of **high-conductivity copper wire**, often with a ferrite core to focus the magnetic field.
- Enables **charging while the vehicle is moving** (in dynamic systems) or stationary (in static systems).
- Works efficiently at **high frequencies** to reduce energy loss.
- Plays a key role in **safe, contactless energy delivery** in smart transportation infrastructure.

4.3 CURRENT SENSOR

A **current sensor** is an essential component in a dynamic wireless charging system, used to **measure the flow of electric current** through the circuit in real time. It plays a critical role in **monitoring and controlling the charging process** to ensure safe and efficient power transfer. Current sensors can detect both **AC (alternating current)** and **DC (direct current)** and convert the current into a measurable voltage signal, which can then be read by a microcontroller like the **ESP32**. Fig 4.3 Illustrates the current sensor module used for real-time monitoring of current flow in the system. This data helps in determining how much current is being transferred to the electric vehicle and whether it is within the safe operating limits.

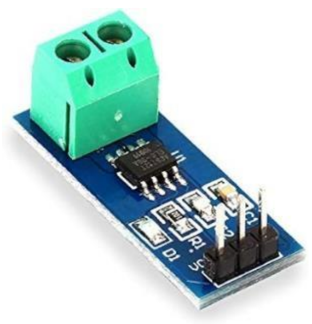

Fig 4.3 CURRENT SENSOR

In wireless charging applications, current sensors are used to **detect anomalies**, such as overloads or short circuits, and can trigger protective actions to avoid damage to the system. They also help in **calculating power consumption** when used alongside voltage sensors. Common types of current sensors include **Hall-effect sensors** and **shunt resistors**, both offering reliable performance in embedded systems. Accurate current sensing is vital for **efficiency monitoring**, **load management**, and **system diagnostics** in smart energy transfer systems.

4.4 VOLTAGE SENSOR

A **voltage sensor** is a critical component in dynamic wireless charging systems, used to **measure the electrical potential difference (voltage)** in the circuit. It helps monitor the voltage supplied to and received by various components, especially the **battery** of the electric vehicle, ensuring that the system operates within safe and optimal voltage levels. The sensor converts the voltage into a proportional analog or digital signal, which is then read by a microcontroller such as the **ESP32** for real-time monitoring and control. Fig 4.4 Displays the voltage sensing module that tracks voltage levels across different parts of the system for safety and performance.

Fig 4.4 VOLTAGE SENSOR

In wireless power transfer, voltage sensors work alongside **current sensors** to calculate the total **power delivered** ($P = V \times I$), helping in **efficiency tracking**, **fault detection**, and **battery protection**. They are also essential for implementing **feedback control** in power electronics circuits, allowing the system to adjust the power output based on real-time voltage readings. Common types of voltage sensors include **resistive voltage dividers** and **op-amp-based isolation circuits**. Accurate voltage sensing ensures **safe charging**, prevents **overvoltage conditions**, and contributes to the overall **reliability and stability** of the system.

4.5 MOTOR DRIVER

The **L298N motor driver** is a high-performance, dual full-bridge driver IC widely used in robotics and embedded systems to control **DC motors** and **stepper motors**. It allows for independent control of the **direction and speed** of two motors, making it ideal for applications such as **automated vehicles**, **robotic arms**, and **conveyor systems**. The L298N can operate motors with **voltages from 5V to 35V** and current up to **2A per channel**, and it supports both **PWM (Pulse Width Modulation)** and **digital control signals** for precise motor control. Fig 4.5 Shows the dual H-bridge motor driver used to control mechanical components or motor simulations within the setup.

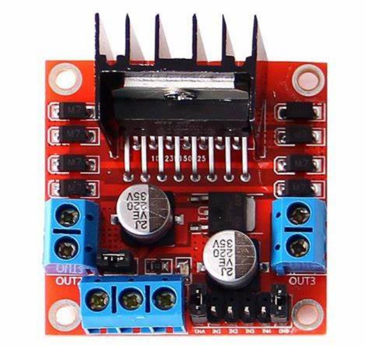

Fig 4.5 L298N MOTOR DRIVER

In dynamic wireless charging systems, the L298N can be used to **control the movement of mechanical components** such as sliding coils, positioning systems, or alignment mechanisms in test prototypes. The module includes built-in **protection diodes**, **heat sink**, and logic-level inputs compatible with microcontrollers like **ESP32** or **Arduino**. Its simple interface, affordability, and reliable performance make it a popular choice for motor control in educational and industrial projects alike.

4.6 MOTOR

A **motor** is an electromechanical device that converts **electrical energy into mechanical motion**. In embedded systems and automation projects, motors are used to perform physical actions such as rotation, movement, or positioning of components. There are different types of motors, including **DC motors**, **stepper motors**, and **servo motors**, each suitable for specific applications based on precision, speed, and control requirements. Fig 4.6 Illustrates the DC motor used for simulating or controlling vehicle prototype movements. In a **dynamic wireless charging system**, motors can be used to **adjust or align the position of the receiver coil** or to simulate vehicle movement in prototype models. When paired with a **motor driver module** like the **L298N**, motors can be controlled for both **direction and speed** using signals from microcontrollers such as the **ESP32** or **Arduino**.

Fig 4.6 5V DC MOTOR

4.7 RELAY

A **relay** is an electrically operated switch that controls the flow of current in a circuit using an electromagnet. When the relay coil is energized, it creates a magnetic field that attracts or repels a movable contact, thereby opening or closing the circuit. Relays are widely used in automation systems, home appliances, industrial machinery, and automotive applications. They come in various types, including electromagnetic relays, solid-state relays, thermal relays, and latching relays, each suited for different functions. Their key advantages include providing isolation between control and load circuits, ensuring reliable switching, and enabling remote operation. Due to their versatility, relays play a crucial role in electrical and electronic systems where automatic switching is required. Fig 4.7 Displays the relay circuit used for switching between different operating modes or controlling power delivery.

Fig 4.7 RELAY MODULE

4.8 555 TIMER IC

The 555 timer IC was introduced in the year 1970 by Stigmatic Corporation and gave the name SE/NE 555 timer. It is basically a monolithic timing circuit that produces accurate and highly stable time delays or oscillation. When compared to the applications of an op-amp in the same areas, the 555 IC is also equally reliable and is cheap in cost.

Apart from its application as a mono stable multivibrator and astable multivibrator, a 555 timer can also be used in dc-dc converters, digital logic probes, waveform generators, analog frequency meters and tachometers, temperature measurement and control devices, voltage regulators etc. Fig 4.8 Shows the widely-used 555 timer chip employed here for generating high-frequency pulses to drive the transmitter.

The timer IC is set up to work in either of the two modes – one-shot or monostable or as a free-running or astable multivibrator. The SE 555 can be used for temperature ranges between – 55°C to 125 °. The NE 555 can be used for a temperature range between 0° to 70°C.

Fig 4.8 555 TIMER IC

4.9 TRANSFORMER

The transformer is a static device (means that has no moving parts) that consists of one, two or more windings which are magnetically coupled and electrically separated with or without a magnetic core. It transfers the electrical energy from one circuit to the other by electromagnetic induction principle.

The winding connected to the AC main supply is called primary winding and the winding connected to the load or from which energy is drawn out is called as secondary winding. These two windings with proper insulation are wound on a laminated core which provides a magnetic path between windings.

STEP – UP AND STEP – DOWN TRANSFORMERS

So far, we've observed simulations of transformers where the primary and secondary windings were of identical inductance, giving approximately equal voltage and current levels in both circuits. Equality of voltage and current between the primary and secondary sides of a transformer, however, is not the norm for all transformers. If the inductances of the two windings are not equal, something interesting happens. Fig 4.9 Depicts the step-down transformer used in the power conditioning stage of the transmitter.

Fig 4.9 TRANSFORMER

4.10 HALL EFFECT SENSOR

The hall effect sensor is a type of magnetic sensor which can be used for detecting the strength and direction of a magnetic field produced from a permanent magnet or an electromagnet with its output varying in proportion to the strength of the magnetic field being detected. Magnetic sensors convert magnetic or magnetically encoded information into electrical signals for processing by electronic circuits, and in the Sensors and Transducers tutorials we looked at inductive proximity sensors and the LDVT as well as solenoid and relay output actuators.

Magnetic sensors are solid state devices that are becoming more and more popular because they can be used in many different types of application such as sensing position, velocity or directional movement. Fig 4.10 Illustrates the magnetic field sensor used to detect vehicle presence or alignment over the transmitting coil.

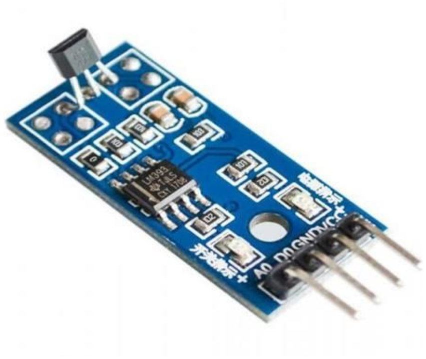

Fig 4.10 HALL EFFECT SENSOR

4.11 BATTERY

The lithium-ion (Li-ion) battery is the predominant commercial form of rechargeable battery, widely used in portable electronics and electrified transportation. The rechargeable battery was invented in 1859, while the research underpinning the Li-ion battery was published in the 1970s and the first commercial Li-ion cell was made available in 1991.

During a discharge cycle, lithium atoms in the anode are ionized and separated from their electrons. The lithium ions move from the anode and pass through the electrolyte until they reach the cathode, where they recombine with their electrons and electrically neutralize. The lithium ions are small enough to be able to move through a micro-permeable separator between the anode and cathode. In part because of lithium’s small atomic weight and radius (third only to hydrogen and helium), Li-ion batteries are capable of having a very high voltage and charge storage per unit mass and unit volume.

Li-ion batteries can use a number of different materials as electrodes. The most common combination is that of lithium cobalt oxide (cathode) and graphite (anode), which is used in commercial portable electronic devices such as cellphones and laptops. Other common cathode materials include lithium manganese oxide (used in hybrid electric and electric automobiles) and lithium iron phosphate. Li-ion batteries typically use ether (a class of organic compounds) as an electrolyte. Below Fig 4.11 Shows the battery cell used for energy storage in the vehicle prototype.

Fig 4.11 LITHIUM-ION BATTERY CELL

Compared to other high-quality rechargeable battery technologies (nickel-cadmium, nickel-metal-hydride, or lead-acid), Li-ion batteries have a number of advantages. They have some of the highest energy densities of any commercial battery technology, as high as 330 watt-hours per kilogram (Wh/kg), compared to roughly 75 Wh/kg for lead-acid batteries. In addition, Li-ion cells can deliver up to 3.6 volts, 1.5–3 times the voltage of alternatives, which makes them suitable for high-power applications like transportation. Li-ion batteries are comparatively low maintenance, and do not require scheduled cycling to maintain their battery life. Li-ion batteries have no memory effect, a detrimental process where repeated partial discharge/charge cycles can cause a battery to ‘remember’ a lower capacity. Li-ion batteries also have a low self-discharge rate of around 1.5–2% per month, and do not contain toxic lead or cadmium.

High energy densities and long lifespans have made Li-ion batteries the market leader in portable electronic devices and electrified transportation, including electric vehicles (EVs) like the Nissan Leaf and the Tesla Model S as well as the hybrid-electric Boeing 787. In terms of decarbonizing our economy’s energy use, Li-ion technology has its greatest potential in EVs and electrified aviation.

4.12 BMS (BATTERY MANAGEMENT SYSTEM)

A battery management system (BMS) monitors and controls the state of a battery, thereby allowing the battery to work safely for a long period. A battery (lithium-ion battery) used in an EV deteriorates every time the battery discharges or is charged. These cycles of battery deterioration may lead to a drop in the vehicle performance. The BMS is an important solution to this problem. It monitors the state of the entire battery cells on a cell-by-cell basis and allows them to work uniformly by eliminating variations in individual batteries' performance.

A large-capacity battery pack consists of a number of battery cells. These cells vary in performance and deteriorate at different rates. For example, when a specific cell deteriorates faster than other cells do, it may affect the overall performance or service life of the battery pack. Such variations in performance or deterioration rate are eliminated by a function called "balancing."

Voltage measurement:

The BMS measures the voltage of each battery cell or the overall voltage of the battery pack, thereby preventing an overcharging or excessive discharging.

Current measurement:

The BMS measures the discharge current from the battery or the charge current to the battery. It checks the use status or the charged state of the battery and performs proper control.

Temperature measurement:

The BMS constantly monitors the temperature of the battery through a temperature sensor. Using the battery within a proper temperature range ensures the safety of the battery and longer service life. Fig 4.12 Displays the BMS module responsible for monitoring and balancing the battery's charging cycles and safety parameters.

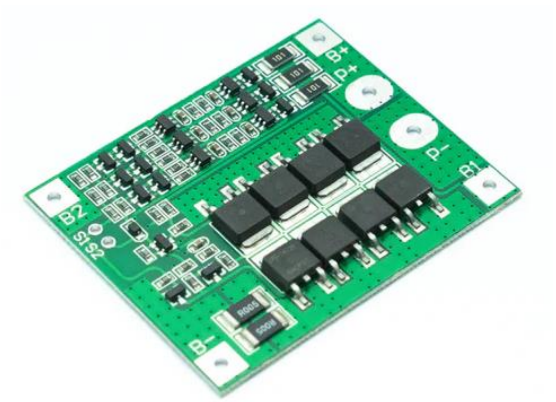

Fig 4.12 Battery management system

4.13 CONCLUSION

Hardware components such as sensors, power circuits, and wireless modules were successfully interfaced and tested for functional accuracy.

After assembling the hardware, the focus shifts to software development and control logic, which is discussed in the next chapter.

CHAPTER 5

SOFTWARE DESCRIPTION

5.1 ARDUINO IDE

Arduino IDE is an open-source software, designed by Arduino.cc and mainly used for writing, compiling & uploading code to almost all Arduino Modules. It is an official Arduino software, making code compilation too easy that even a common person with no prior technical knowledge can get their feet wet with the learning process. It is available for all operating systems i.e. MAC, Windows, Linux and runs on the Java Platform that comes with inbuilt functions and commands that play a vital role in debugging, editing and compiling the code. A range of Arduino modules available including Arduino Uno, Arduino Mega, Arduino Leonardo, Arduino Micro and many more. Each of them contains a microcontroller on the board that is actually programmed and accepts the information in the form of code. The main code, also known as a sketch, created on the IDE platform will ultimately generate a Hex File which is then transferred and uploaded in the controller on the board. The IDE environment mainly contains two basic parts: Editor and Compiler where former is used for writing the required code and later is used for compiling and uploading the code into the given Arduino Module. This environment supports both C and C++ languages. Fig 5.1 Screenshot of the Arduino Integrated Development Environment used to code and upload software to the ESP32.

Sketch: The first new terminology is the Arduino program called “sketch”.

Structure: Arduino programs can be divided in three main parts: Structure, Values (variables and constants), and Functions. In this tutorial, we will learn about the Arduino software program, step by step, and how we can write the program without any syntax or compilation error.

Let us start with the **Structure**. Software structure consist of two main functions:

- Setup() function
- Loop() function

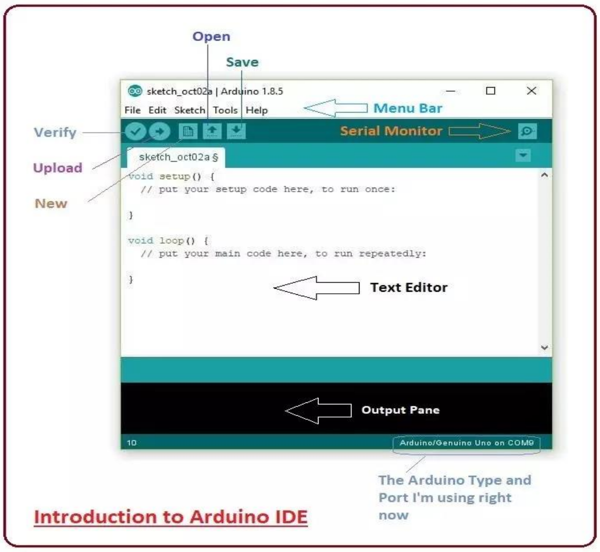

Fig 5.1 ARDUINO IDE

Arduino – Program Structure:

Void setup ( )

{

}

PURPOSE: The setup () function is called when a sketch starts. Use it to initialize the variables, pin modes, start using libraries, etc. The setup function will only run once, after each power up or reset of the Arduino board.

- INPUT: -
- OUTPUT: -

● RETURN: -

Void Loop ( )

{

}

PURPOSE: After creating a setup () function, which initializes and sets the initial values, the loop () function does precisely what its name suggests, and loops consecutively, allowing your program to change and respond. Use it to actively control the Arduino board.

● INPUT: -

● OUTPUT: -

● RETURN:

Serial Monitor - A separate pop-up window that acts as an independent terminal and plays a vital role in sending and receiving the Serial Data. You can also go to the Tools panel and select Serial Monitor, or pressing Ctrl+Shift+M all at once will open it instantly. The Serial Monitor will actually help to debug the written Sketches where you can get a hold of how your program is operating. Your Arduino Module should be connected to your computer by USB cable in order to activate the Serial Monitor. Fig 5.2 Illustrates the output console of Arduino IDE used to debug and view real-time system responses. below Fig 5.3 Shows the main code editing window in the Arduino IDE where the logic is written and Fig 5.4 Displays the section of the IDE that shows compilation status, memory usage, and errors.

- You need to select the baud rate of the ESP32 Board you are using right now. For my ESP32 Baud Rate is 9600, as you write the following code and click the Serial Monitor, the output will show as the image below.

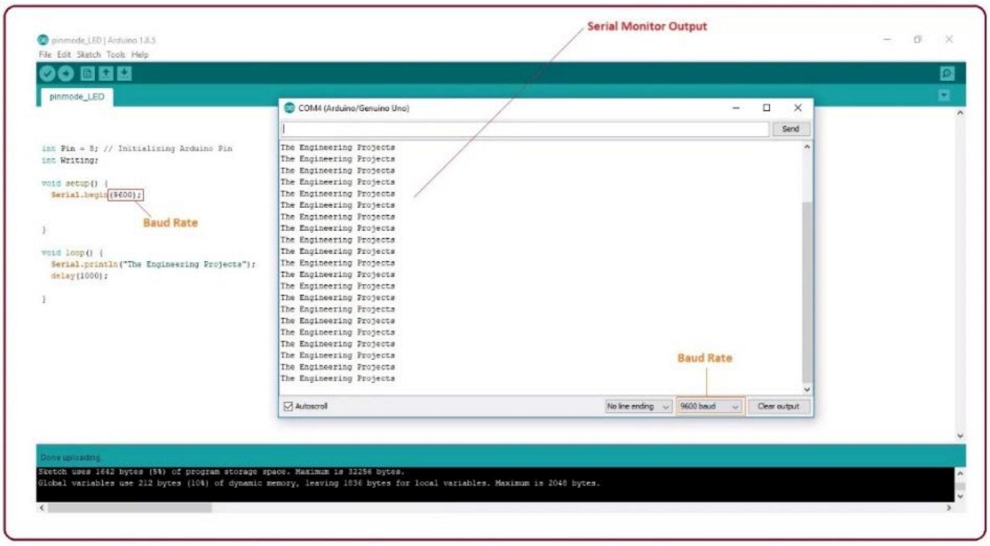

Fig 5.2 SERIAL MONITOR

- The main screen below the Menu bard is known as a simple text editor used for writing the required code.

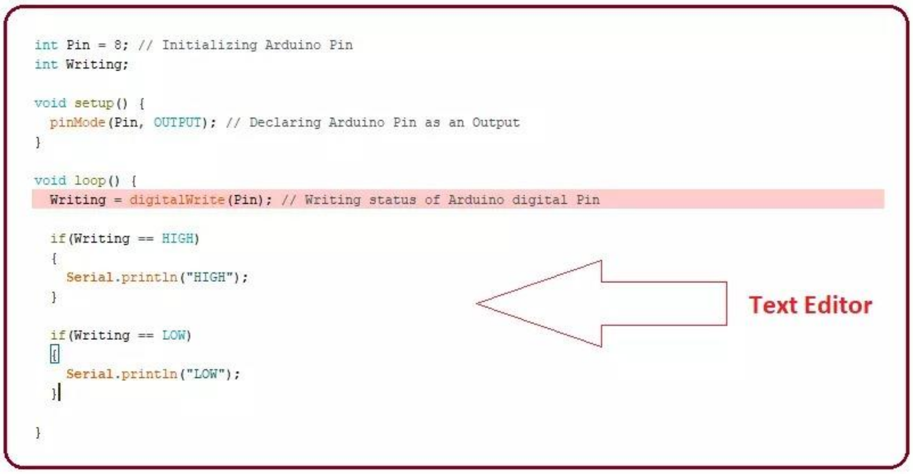

Fig 5.3 SERIAL MONITOR TEXT EDITOR

- The bottom of the main screen is described as an Output Pane that mainly highlights the compilation status of the running code: the memory used by the code, and errors that occurred in the program. You need to fix those errors before you intend to upload the hex file into your Arduino Module.

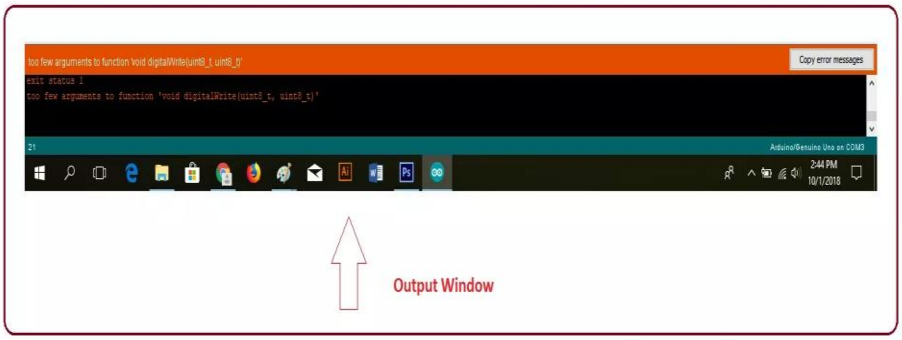

Fig 5.4 SERIAL MONITOR OUTPUT WINDOW

5.2 MIT APP INVENTOR

MIT App Inventor is a visual programming environment that allows users to create mobile applications for Android devices using a block-based coding system. Developed by the Massachusetts Institute of Technology (MIT), it is designed to make app development accessible to beginners, educators, and students without requiring prior programming experience.

With MIT App Inventor users can design their app's layout and functionality using pre-built components. This consists of two main parts:

- Used to create the user interface by adding buttons, labels, images, and other elements. Fig 5.5 Screenshot of the drag-and-drop GUI design for the mobile app's layout.

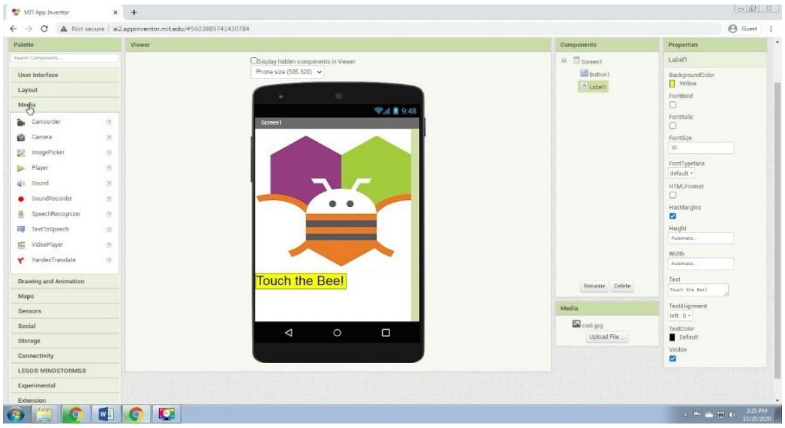

Fig 5.5 USER INTERFACE WINDOW

- Allows users to define the app's behavior using a visual programming language based on logic blocks. Fig 5.6 Visual representation of the code blocks used in MIT App Inventor to handle app logic and database integration.

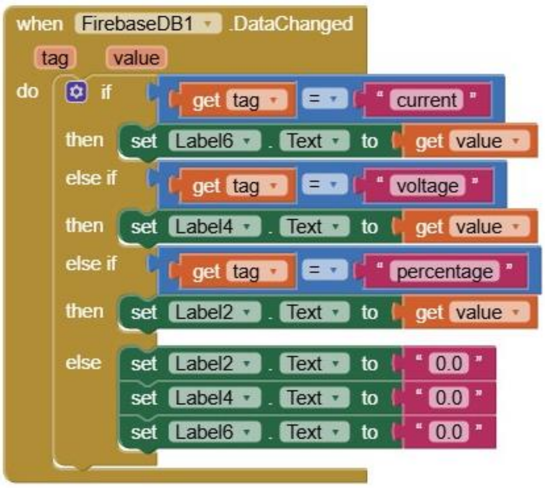

Fig 5.6 FIREBASE LOGIC BLOCKS

5.3 FIREBASE REALTIME DATABASE

The Firebase Realtime Database is a cloud-hosted database in which data is stored as JSON. The data is synchronized in real-time to every connected client. All of our clients share one Realtime Database instances and automatically receive updates with the newest data, when we build cross-platform applications with our iOS, and JavaScript SDKs.

The Firebase Realtime Database is a NoSQL database from which we can store and sync the data between our users in real-time. It is a big JSON object which the developers can manage in real-time. By using a single API, the Firebase database provides the application with the current value of the data and updates to that data. Real-time syncing makes it easy for our users to access their data from any device, be it web or mobile.

The Realtime database helps our users collaborate with one another. It ships with mobile and web SDKs, which allow us to build our app without the need for servers. When our users go offline, the Real-time Database SDKs use local cache on the device for serving and storing changes. The local data is automatically synchronized, when the device comes online. Fig 5.7 Depicts the Firebase Realtime Database panel showing live data used in the project.

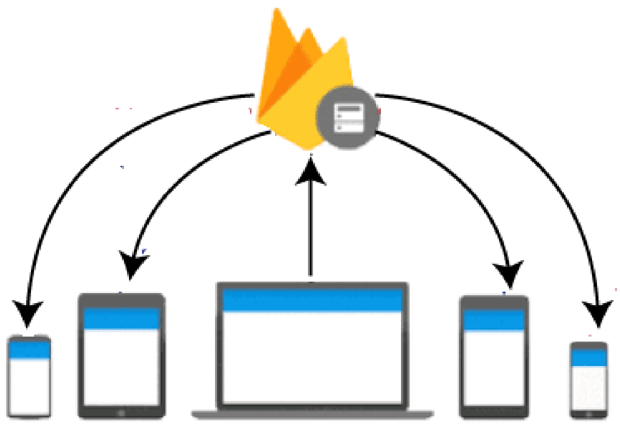

Fig 5.7 FIREBASE DATABASE

The database uses key-value pairs to store data. The keys are strings while the values can be primitive types like numbers, strings, booleans or complex nested objects.

Data is organized into hierarchical JSON documents similar to below Fig 5.8.

```
{
  "users": {
    "alovelace": {
      "name": "Ada Lovelace",
      "email": "alovelace@gmail.com"
    },
    "ghopper": {
      "name": "Grace Hopper",
      "email": "ghopper@gmail.com"
    }
  }
}
```

Fig 5.8 JSON BODY FORMAT

With this structure, related data is grouped into collections called nodes. For our user's data, "users" is the root node while "alovelace" and "ghopper" are child nodes.

5.4 PROTEUS

Proteus 8 Professional is a software package that allows users to design and simulate electronic circuits. It was developed by Labcenter Electronics and is widely used in the electronics industry.

Schematic Capture: The schematic capture module allows users to create electronic circuit diagrams. It includes a library of pre-built components, such as resistors, capacitors, and transistors, which can be easily added to the diagram. Users can also create their own components and save them to the library. Below Fig 5.9 is the Screenshot of the Proteus environment used to simulate circuit designs.

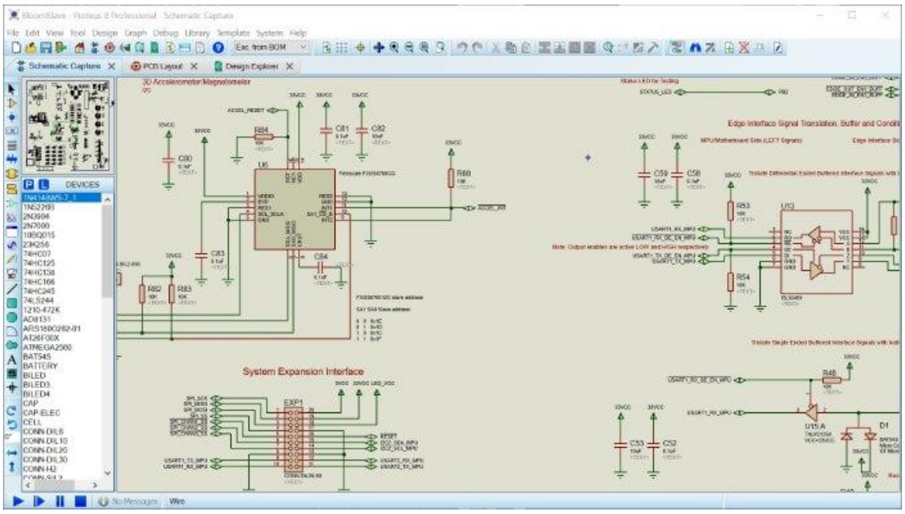

Fig 5.9 PROTEUS SIMULATION SOFTWARE

PCB layout: The PCB layout module allows users to design the physical layout of the circuit board. It includes a variety of design tools, such as a component placer, a track editor, and a copper pour tool. Users can also generate a 3D rendering of the circuit board to visualize how it will look in real life. Below Fig 5.10 Displays the PCB layout view used for designing the hardware circuits.

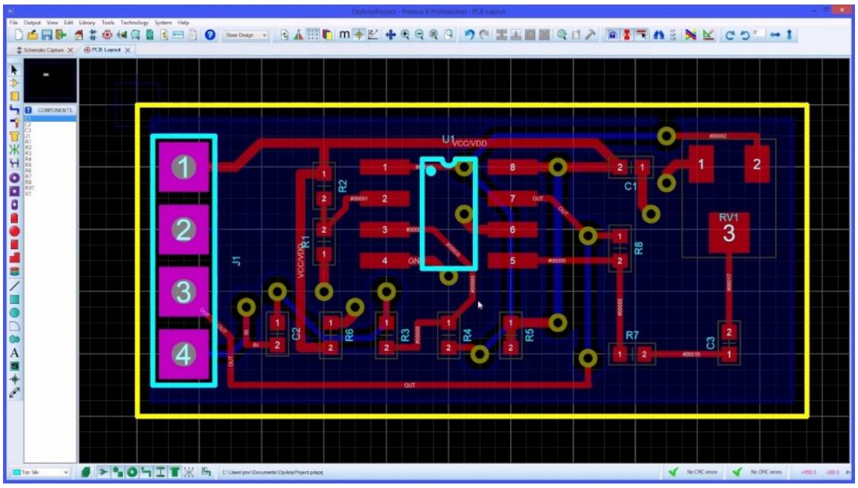

Fig 5.10 PCB LAYOUT

Simulation: The simulation module allows users to test and troubleshoot their circuit designs before building them in real life. It includes a variety of simulation tools, such as a logic analyzer, a waveform viewer, and a virtual oscilloscope. Users can also simulate real-world conditions, such as temperature and voltage fluctuations, to ensure their circuit design is robust.

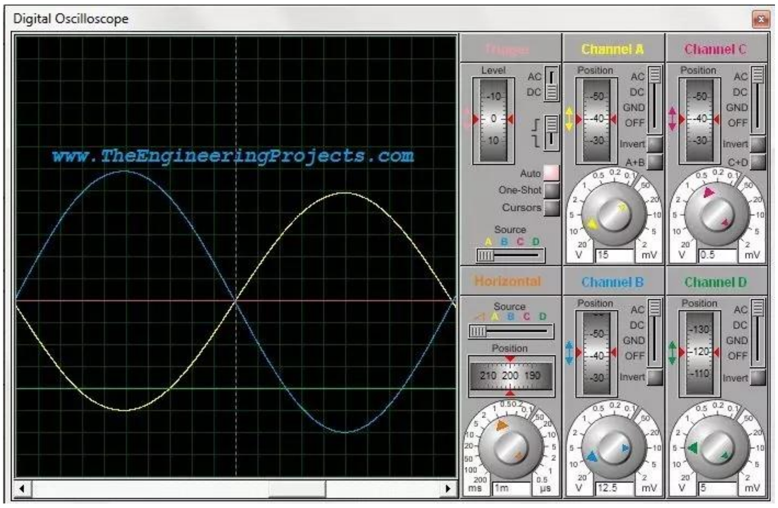

Fig 5.11 DIGITAL OSCILLOSCOPE

Fig 5.11 Shows the Proteus digital oscilloscope used to monitor and analyze signal behavior in the simulation. Proteus 8 Professional is a powerful software package for circuit design and simulation. It includes a variety of modules, including schematic capture, PCB layout, simulation, 3D visualization, and microcontroller simulation. The software is widely used in the electronics industry and is a valuable tool for anyone involved in circuit design.

5.5 CONCLUSION

The software, written for the ESP32 and integrated with Firebase/cloud services, successfully manages data acquisition, Bluetooth control, and decision logic.

With both hardware and software operational, the next chapter presents results, performance analysis, and testing outcomes.

CHAPTER 6

SIMULATION AND RESULTS

6.1 PROTEUS SIMULATION

6.1.1 SIMULATION OBJECTIVE

The objective of the simulation is to verify the functionality of the transmitter side of the dynamic wireless charging system. This includes generating a high-frequency AC signal using a 555 Timer IC in astable mode to drive a power MOSFET, which in turn switches current through a transmitting coil.

6.1.2 SIMULATION ENVIRONMENT

Components Simulated:

- 555 Timer IC (U1)
- IRFZ44N Power MOSFET (Q1)
- Step-down Transformer (TR1)
- Full-bridge Rectifier (BR1)
- Capacitors (C1: 1nF, C2: 2200μF)
- Resistors (R1: 1kΩ, R2: 10kΩ)
- Oscilloscope (to measure output waveform)

6.1.3 CIRCUIT DESCRIPTION

The simulation circuit consists of:

- An AC source converted to DC using a and bridge rectifier. The frequency and duty cycle are controlled by R1, R2, and C1.
- A 555 Timer IC configured in astable mode, generating a square wave signal.

- The timer's output is used to drive an IRFZ44N N-channel MOSFET, which switches a high-frequency current through a simulated wireless power transmitter coil. Refer to Fig. 6.2 for the complete simulation schematic.

6.1.4 OUTPUT WAVEFORM ANALYSIS

6.1.4.1 TIMER OUTPUT SIGNAL

The output from pin 3 of the 555 timer produces a square wave signal. Refer to Fig. 6.1 for the timer Circuit output. Refer Table 6.1 for output parameters.

- Based on the oscilloscope trace:
  - Frequency: ~65 kHz (depending on R1, R2, C1 values)
  - Duty Cycle: ~50-60%

6.1.4.2 MOSFET SWITCHING SIGNAL

The MOSFET gate is driven by the timer output, allowing it to switch the coil on/off. Oscilloscope Channel C and D show the drain voltage of the MOSFET and the waveform across the coil. Refer to Fig. 6.3 for the switching waveform.

6.1.5 SIMULATION RESULTS SUMMARY

TABLE 6.1 KEY ELECTRICAL PARAMETERS

Parameter	Observed Value	Notes
Output Frequency	~65 kHz	Suitable for inductive power transfer
Signal Type	Square wave	Ideal for fast switching
MOSFET switching	Confirmed	Proper response to timer pulses
Voltage across coil	Pulsed waveform	Required for resonant inductive coupling

6.1.6 INTERPRETATION

The simulation successfully demonstrates that the designed circuit can:

- Generate a consistent high-frequency signal.
- Switch the coil effectively via the MOSFET.
- Serve as a working prototype for wireless power transmission.

This validates the transmitter side of the dynamic wireless charging system, which will be connected to the primary coil embedded in the road infrastructure.

6.1.7 SIMULATION OUTPUTS

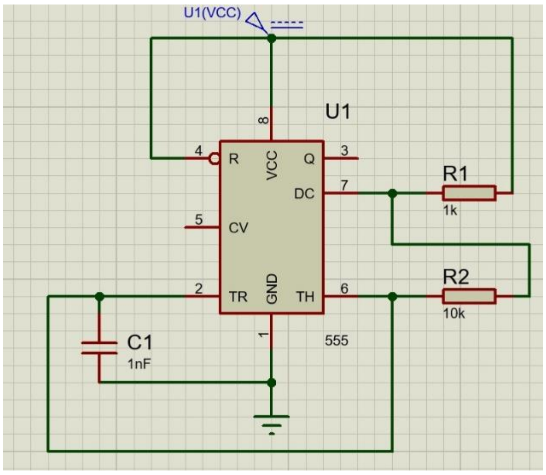

Fig 6.1 555 TIMER CIRCUIT DIAGRAM

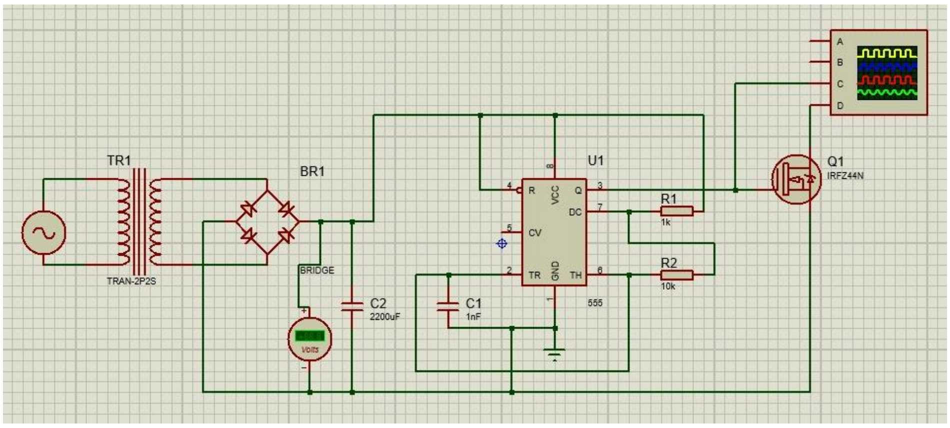

Fig 6.2 FULL SIMULATION CIRCUIT DIAGRAM

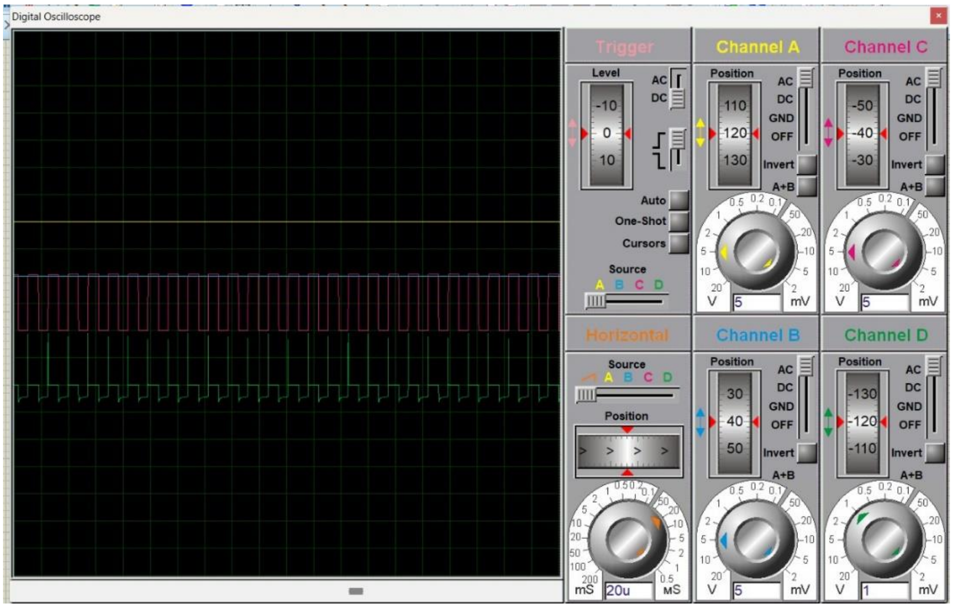

Fig 6.3 MOSFET GATE AND DRAIN WAVEFORM

6.2 MOBILE APPLICATION INTERFACE

6.2.1 OVERVIEW

To enhance the usability and monitoring capability of the dynamic wireless charging system, a dedicated mobile application was developed using MIT App Inventor. This application allows users to monitor real-time data such as battery percentage, voltage, and current. It also enables basic control functionality for interfacing with the vehicle's charging system.

6.2.2 PLATFORM USED

The mobile application was created using:

- MIT App Inventor: A visual programming environment for building fully functional Android applications.
- WiFi connectivity was used to interface with the ESP32 microcontroller onboard the vehicle.

6.2.3 APPLICATION FEATURES

The mobile app includes the following features:

- Real-time monitoring of battery percentage, voltage, and current.
- Visualization of wireless charging operation through graphical interface.
- CONTROL button: Allows manual override or initiation of charging process.
- MONITOR button: Displays current system status and data received from the vehicle sensors.

6.2.4 OUTPUT SCREENS

This image displays a mobile application's user interface for a wireless EV charging system. It features two main buttons: CONTROL to turn the charging system on/off, and MONITOR to track battery parameters in real-time. The background visual shows an electric vehicle receiving power wirelessly from a ground-based charging pad. The app is part of the IoT-based system using ESP32 and Bluetooth for communication and monitoring. Fig 6.4 is the main screen of the custom mobile application showing monitoring and control options.

Fig 6.4 HOME SCREEN

The image shows a wireless EV charging system where a car charges in a designated charging lane using embedded coils. Real-time battery data like percentage (49.42%), voltage (10.78V), and current (0.66A) are displayed. This data is monitored using an ESP32 connected to sensors and a BMS. It visually represents the output of the block diagram shown in the project. Fig 6.5 Screen showing real-time data such as battery voltage, current, and percentage.

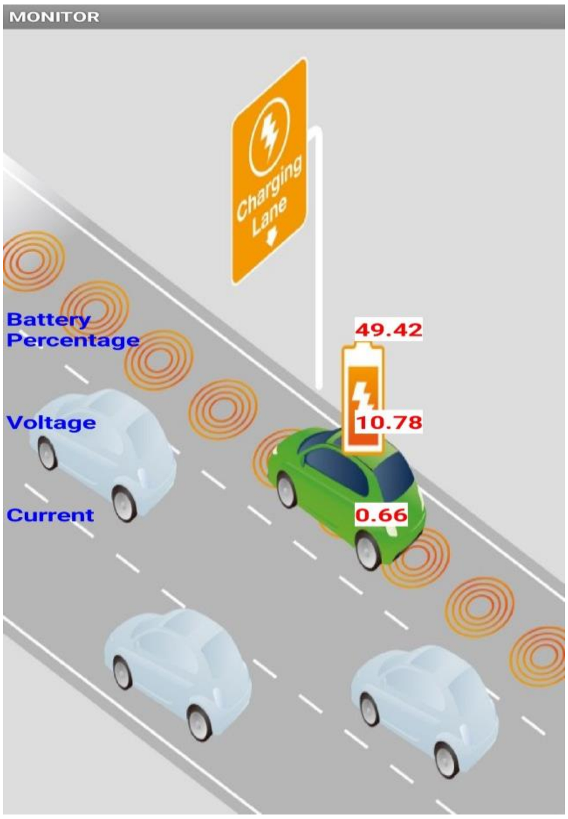

Fig 6.5 - MONITOR SCREEN

6.3 HARDWARE RESULT

This image shows an electronic project mounted on a board. It includes an ESP32 microcontroller, which is used to control the system. A custom circuit board with capacitors, transistors, and heat sinks manages power or signal control. An 8-channel relay module is used to switch devices on and off. A large transformer provides different voltage outputs for the system.

Wires and terminal blocks connect all components together. The setup likely functions as a smart power control or automation system. Fig 6.6 shows Hardware setup of the inverter circuit used to manage the charging input with relay integration.

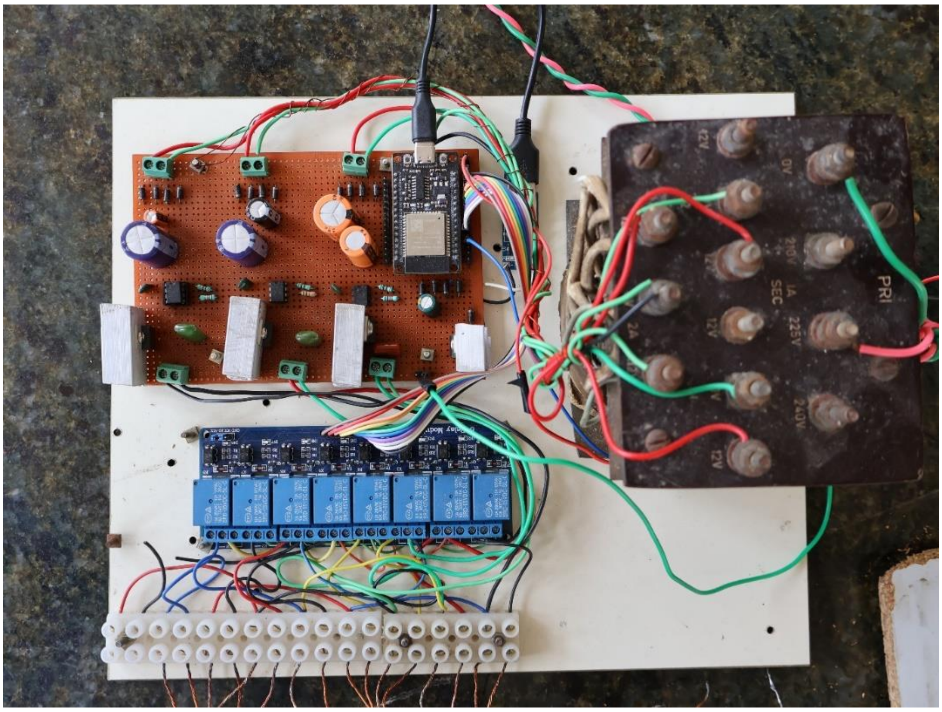

Fig 6.6 INVERTER CIRCUIT WITH RELAY MODULE

This image shows the bottom view of a four-wheel robotic car chassis. It is made from an acrylic or MDF sheet with cut outs for mounting components. The car has four rubber wheels attached to yellow gear motors. A copper coil is fixed to the base, likely for wireless power transfer or charging. The coil is neatly wound and secured with red tape. This setup is likely part of a dynamic wireless charging project for electric vehicles or robots. Fig 6.7 Shows Physical model showing the EV prototype with mounted receiving coil.

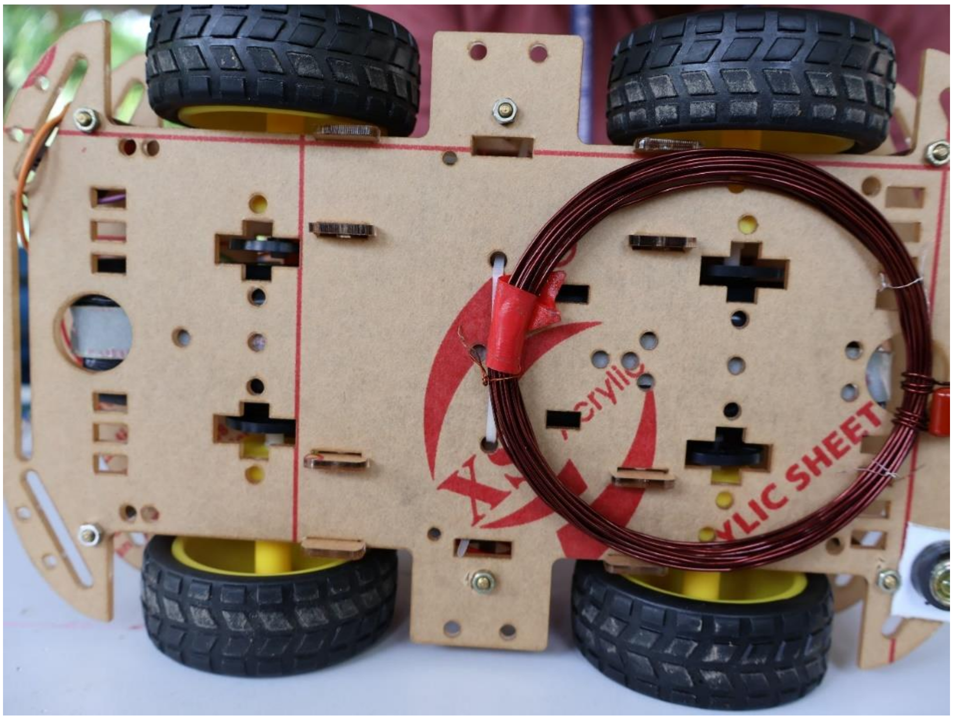

Fig 6.7 RECEIVER COIL WITH CAR PROTOTYPE

This image shows the top view of an electronic control circuit for a robotic car. At the center is an ESP32 microcontroller, which controls the entire system. On the left, there's an L298N motor driver used to control the car's motors. Below that, a DC-DC buck converter adjusts voltage levels to power different components. Multiple wires connect the circuit, carrying signals and power. Sensors and connectors are also visible, likely used for input and communication. This setup enables the robotic car to move and possibly respond to wireless commands. Fig 6.8 Depicts the onboard receiver circuit including rectifier and DC conditioning for the battery.

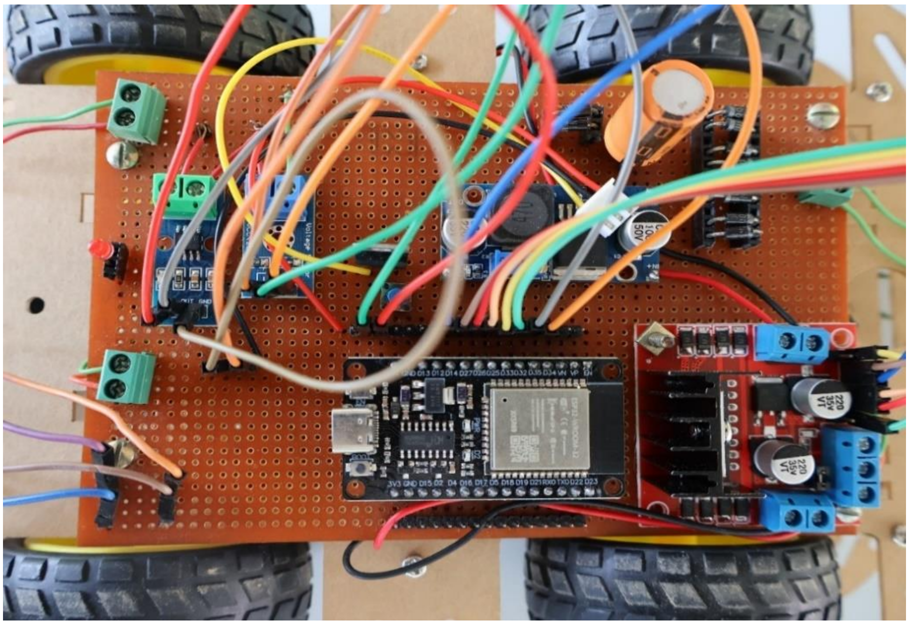

Fig 6.8 RECEIVER MODULE CIRCUIT

These coils are part of a dynamic wireless power transfer system, likely used for charging a moving electric vehicle or robot. When current flows through the coils, they create a magnetic field that can transfer power wirelessly to a receiver coil. The coils are connected to a terminal block at the bottom, distributing power to each loop. As a vehicle moves over the coils, it receives continuous charging. This setup demonstrates the working of multiple transmitter coils for uninterrupted wireless charging. Fig 6.9 Demonstrates scalability with multiple transmitting coils embedded into the road infrastructure.

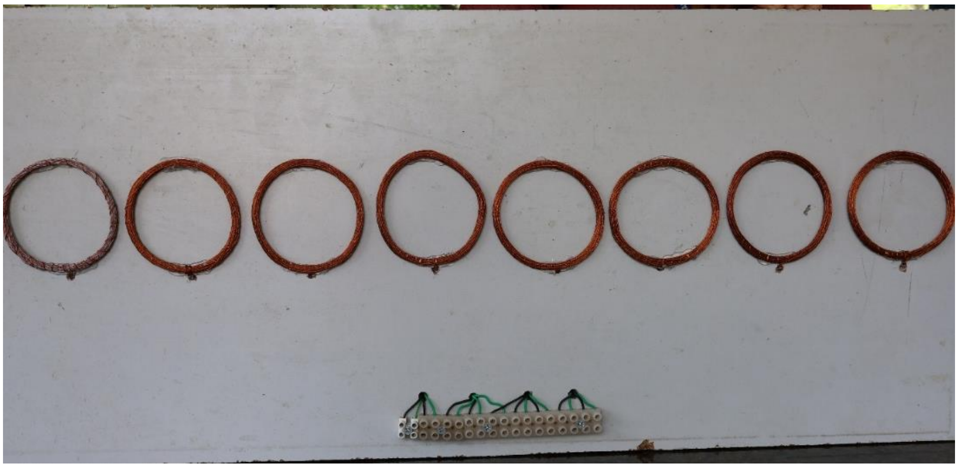

Fig 6.9 MULTIPLE TRANSMITTING COILS

The board at the top contains the power supply, relay module, and control circuits, which manage the activation of transmitter coils. The white panel below has multiple copper coils acting as wireless power transmitters. These coils are energized in sequence as the vehicle moves over them. The robotic car at the bottom right has a receiver coil and an ESP32 microcontroller to receive power wirelessly and control movement. The system demonstrates how a vehicle can charge continuously while in motion over embedded coils. Fig 6.10 Photo or schematic representing the complete system concept as a futuristic wireless EV charging platform.

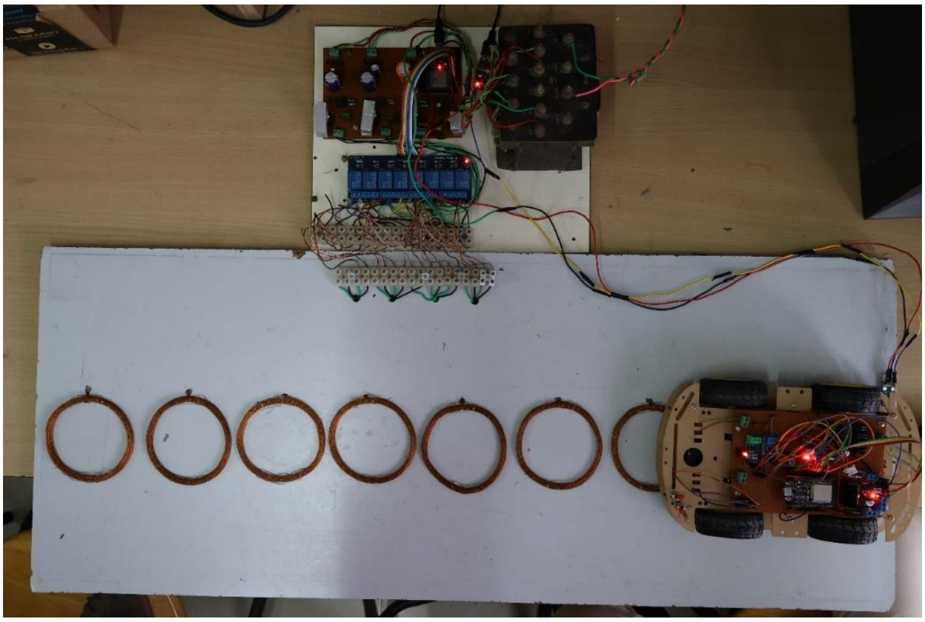

Fig 6.10 NEXT GENERATION DYNAMIC WIRELESS CHARGING

6.4 CONCLUSION

The system was tested under various conditions and showed reliable performance in wireless charging, smart irrigation, and real-time monitoring.

These results validate the system’s effectiveness, leading to the final chapter which summarizes the project and suggests future enhancements.

CHAPTER 7

CONCLUSION & FUTURE WORK

7.1 CONCLUSION

This project successfully demonstrates a prototype of a dynamic wireless charging system for electric vehicles using resonant inductive coupling. The design incorporates a high-frequency signal generator using a 555 timer, MOSFET-based switching, and transmitting coils embedded within a simulated road infrastructure. The receiving end consists of a compatible coil, rectification unit, and battery management system (BMS), integrated with an ESP32 microcontroller for data monitoring and wireless communication.

The simulation validated the ability of the circuit to produce high-frequency switching signals appropriate for wireless power transmission. Furthermore, a mobile app developed using MIT App Inventor provided real-time monitoring of battery parameters such as voltage, current, and state of charge. This project supports the vision of uninterrupted, smart, and sustainable transportation by addressing the limitations of stationary charging systems.

7.2 FUTURE WORK

To enhance the capabilities, efficiency, and scalability of this inductive power transfer system, future work may include:

- Integration of Artificial Intelligence for adaptive charging based on traffic patterns, vehicle type, battery status, and usage history.
- Development of a multi-vehicle load balancing algorithm to support safe, efficient simultaneous charging without overloading the system.
- Field testing with larger-scale hardware on moving vehicles and embedded coils in controlled test tracks to validate real-world performance.

- Incorporation of renewable energy sources such as solar or wind power into the primary power supply, making the system more sustainable and environmentally friendly.
- Implementation of V2G (Vehicle-to-Grid) technology to allow electric vehicles to discharge energy back into the grid during peak load conditions.
- Improvement of the mobile application with advanced diagnostics, predictive maintenance, real-time alerts, and remote control capabilities.
- Designing modular road segments for easier deployment, maintenance, and integration in diverse urban and rural infrastructures.
- Use of advanced materials and thermal management systems to improve coil durability, efficiency, and safety under continuous operation.
- Integration with smart traffic infrastructure (e.g., traffic lights, sensors, and vehicle-to-infrastructure communication) to optimize charging during idle periods.
- Standardization and compliance testing to ensure compatibility across different EV models and international regulatory requirements.
- Real-time billing and authentication system using blockchain or secure digital ledgers for transparent energy usage tracking and payments.
- Adaptive frequency tuning systems to dynamically match coil resonant frequencies with load variations for higher efficiency.
- Incorporation of safety mechanisms like foreign object detection, over-temperature protection, and electromagnetic field shielding.
- Optimization of coil alignment detection and guidance using computer vision or magnetic sensors for better energy transfer even when vehicles are misaligned.

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APPENDIX

CONFERENCE CERTIFICATES


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