DEDAN KIMATHI UNIVERSITY OF TECHNOLOGY

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

FINAL YEAR PROJECT PROPOSAL

SMART EV WIRELESS CHARGING SYSTEM

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A proposal submitted to the Department of Electrical and Electronic Engineering in partial fulfillment of the Award of Degree of Bachelor of Science in Electrical and Electronics Engineering.

JULY 2023.

Declaration

This project is our original work, except where due acknowledgement is made in the text, and to the best of our knowledge has not been previously submitted to Dedan Kimathi University of Technology or any other institution for award of degree or diploma.

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SUPERVISOR'S CONFIRMATION

This project has been submitted to the department of Electrical and Electronics Engineering, Dedan Kimathi University of Technology with my approval as the university supervisor.

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Eric, Esther & Tom

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Abbreviations

AC	Alternating Current	RC	Resistor capacitor
CC	Constant current	RF	Radio frequency
CP	Circular pad	Rx	Receiver
CPT	Capacitive power transfer	SAE	Society of automotive engineers
CV	Constant voltage	SEVWCS	Smart Electric Vehicle Wireless Charging System
DC	Direct current	SoC	State of charge
EV	Electric vehicle	SP	Series-parallel
GHz	Giga Hertz	SS	Series-series
IPT	Inductive power transfer	SWCS	Stationary wireless charging system
kW	Kilowatt	SWPT	Stationary wireless power transfer
LCC	Inductor-capacitor-capacitor	Tx	Transmitter
LCLC	Inductor-capacitor-inductor-capacitor	USB	Universal serial bus
LED	Light emitting diode	WC	Wireless Charging
Li-ion	Lithium ion	WCS	Wireless charging system
LPF	Low pass filter	WPT	Wireless power transfer
NiCad	Nickel cadmium	ZCS	Zero current switching
NiMH	Nickel metal hydride	ZPA	Zero phase angle
OLEV	Online electric vehicle	ZVS	Zero Voltabe Switching
PFM	Pulse frequency modulation		
PP	Parallel-parallel		
PS	Parallel-series		
PTE	Power Transfer Efficiency		
PWM	Pulse width modulator		

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Abstract

Electric vehicles provide a lot of convenience compared to fuel-engine vehicles. They move quietly and are not as heavy as the latter. This is because they are powered by a battery-operated motor instead of an engine. The vehicles are controlled and managed by microcontrollers, which make it easy to automate almost all of their functionalities. As a result, these vehicles require power supply from batteries with high specific energy. Li-ion batteries have been shown to be the most effective batteries in terms of energy per cell and lifespan. These types of batteries are lighter compared to lead-acid batteries or nickel-metal hydride batteries, making them suitable for EVs. Charging the batteries can be completed through two main methods of charging, namely wired and wireless charging. This project proposal explores the latter through an innovative Smart EV Wireless Charging System, which applies automatic wireless charging controlled by an STM32 microcontroller on the transmitter side of the system. The first chapter of the proposal covers the background of wireless charging, the problem statement, justification of the project, main and specific objectives, and the scope of the study. The second chapter of the paper covers a comprehensive literature review regarding wireless charging. It also explains in detail what wireless power transfer (WPT) is, its design and engineering, and all the safety standards associated with it. The third chapter covers the implementation methodology of the Smart EV Wireless Charging System, a Gantt chart of the project, and the proposed prototype implementation budget.

Chapter 1: Introduction

Transmission of power wirelessly for charging different electronic devices has been there since the times of Nikola Tesla. However, the technology was limited back then because it was not feasible with the technology of the time. The field of wireless charging, however, experienced a major breakthrough when researchers were able to light up a bulb from a wireless power source at a separation distance of 2m [3]. Much has been done since then, with a lot of studies and research directed towards smart wireless charging. Electric vehicle charging is one of the major areas of application for wireless charging. Following the urgent demand imposed by the climate conditions to go green, WPT and its practical applications are being widely investigated [4]. The main two methods of wireless charging are Inductive Power Transfer (IPT) and Capacitive Power Transfer (CPT) [5]. The former has applications in EVs since it is capable of delivering more power at high efficiency compared to the latter, which currently can only be applied in universal serial bus (USB) devices, lamps, and small robots.

The CPT method is still being investigated for EV charging due to its simpler structures, which only require plates and foils. The resulting charging system from the CPT is not only lighter but also cost-effective. The main disadvantage of CPT is that power transfer levels are lower, and the air gap is also quite small (1mm) [6]. However, research is underway to overcome these shortcomings [7]. As a result, the Smart EV Wireless Charging System is based on IPT since IPT is well-researched and successfully applied in EVs. The SEVWCS is an innovative solution designed to provide efficient and convenient charging for electric vehicles (EVs). It will be controlled wirelessly using GSM AT commands. That is, it will be able to move up when it's charging and down after the vehicle is fully charged. All these controls will be issued by the parking lot attendant through a phone message. The EV will be connected to charge after the owner makes payment or scans their RFID tag. The attendant will issue the command "charge" and send it to the system via a mobile phone, which will then command the microcontroller to connect the 3-phase power and adjust the air gap to a minimum between the car and the system to reduce power losses through leakage flux. By mitigating the power loss issues with the current wireless charging systems, the Smart EV Wireless Charging System will be more efficient and economical.

1.1 Background

Wireless power transfer dates back to the Wardenclyffe Tower where Nikola Tesla tried to transmit electricity wirelessly over long distances [8]. He envisioned to harness the Earth's electrical energy and transmit it wirelessly to power various devices. The tower acted as a transmitter which resonated at a specific frequency to transfer energy to a receiver. Many researchers and Ph.D. students have dived into wireless power transfer and made significant breakthroughs since Tesla's Wardenclyffe Tower was demolished [9] [10]. Wireless Power Transfer systems employ the principle of inductive coupling to transfer power wirelessly [9]. This method relies on magnetic fields generated by an alternating current in a transmitter coil to induce a voltage in a receiver coil. This method is widely used in charging electric vehicles and electronic devices. Resonant coupling is another important technique in wireless power transfer where both the transmitter and receiver coils are tuned to the same resonant frequency [3]. This approach enables efficient power transfer over longer distances and is suitable for applications like wireless EV charging. Wireless power transfer has found particular relevance in the field of electric vehicles. It offers the convenience of charging EVs without the need for physical connections which reduces the infrastructure requirements for widespread EV adoption [11]. Wireless power transfer is a rapidly evolving technology with a wide range of applications [12]. The development and implementation of WPT systems hold promising prospects for a wirelessly powered future.

1.2 Problem Statement

Wireless charging of electric vehicles eliminates the need for physical connections, where electric vehicle owners can simply park over a charging pad and have their vehicles connected to power [4]. It accommodates slight misalignments and promotes safety by eliminating the risk of electrical shock. The wireless charging systems for EVs currently available on the market use only one charging pad, which is fixed on solid ground [13]. The Smart EV Wireless Charging System provides an innovative solution to these limitations. It incorporates two pairs of transceiver coils that deliver more power and shorten the charging time. It also introduces a flexible mechanism for the pads, allowing them to automatically adjust the airgap between them and achieve maximum power transfer. The system will be controlled wirelessly using GSM AT Commands to enhance convenience and allow easy authorized access. An RFID mechanism will also be included for regular customers who have weekly or monthly subscriptions.

1.3 Justification

The world of technology is developing towards complete automation. Following the cumbersome nature associated with wired charging, such as the risk of electric shock during rainy seasons, wireless charging is a better option [4]. The Smart EV Wireless Charging System will provide EV owners with a lot of convenience and flexibility. It will eliminate the need for physically plugging and unplugging the charging cable, making it more convenient and user-friendly. EV users will simply park over a charging pad, and the charging process will be initiated automatically. The Smart EV Wireless Charging System will also eliminate the exposure to live electrical connections thereby reducing the risk of electric shock and damage caused by improper handling of cables and connectors [14]. The system also aligns well with the concept of self-driving vehicles. As autonomous vehicles become more prevalent, Smart EV Wireless Charging Systems will be a necessity to achieve complete automation of the vehicles. This will allow the autonomous vehicles to charge automatically while waiting without human intervention. The underground operation nature of the system also maintains the aesthetics of the parking lot and the surrounding by reducing visual clutter. However, the field of wireless charging is still under research. As wireless charging technology continues to develop, standardization efforts are underway to ensure interoperability among different vehicle manufacturers and charging infrastructure providers [15]. This will promote compatibility and scalability thereby enabling a broader network of charging stations and supporting the growth of electric vehicle adoption.

1.4 Objectives

1.4.1 Main Objectives

To design and implement a Smart Electric Vehicle Wireless Charging System.

1.4.2 Specific Objectives

i. To implement two transceiver coil sets to deliver more power for fast charging.
ii. To design auto-adjustable coil separation distance mechanism that maximizes flux linkage.
iii. To incorporate wireless control using GSM communication protocol.
iv. Incorporate RFID mechanism for easy authorized access to regular customers.

1.5 Scope of the Study

The project is limited to automating the wireless power transfer section of the existing wireless charging systems. The power supply section, rectification process, and battery management systems are not covered within the scope of the project. The Smart EV Wireless Charging System utilizes the existing power supply block diagram, battery management and charging mechanisms to charge EV batteries. The core concept of the system is to achieve wireless control and automate the WPT section of wireless charging systems. To achieve this, the system uses a programmable microcontroller. The microcontroller will be programmed to rotate the motor connected to the two flexible transmitter coils clockwise when an interrupt command is received from the attendant side or counterclockwise when an interrupt command is received from the receiver section of the system. A section of the project will be simulated in Proteus 8 Professional to evaluate the performance before implementation. This will include the STM32F103C8T6 Blue Pill Microcontroller, transceiver coils, Three-phase power, RFID, Motor mechanism and the IR proximity mechanism. The wireless communication protocol using GSM SIM7600CE will be realized in the system prototype since no software can simulate the set up. The entire system prototype will then be designed and tested physically. To confirm its functionality, a model car will be converted into an electric car prototype and it will be charged using the system. The charging voltage and the remaining time to full charge will be displayed in a segment display connected to the model car. When the model car is fully charged, it will communicate back to the system and power will be disconnected.

Chapter 2: Literature Review

2.1 Introduction

EVs wireless charging technology is gaining a lot of popularity recently. Following the United Nations' 17 development goals, EVs will see the transport industry go green completely and achieve sustainability [16]. WPT technology provides unquestionable hope for the future of the transport industry and electronic devices [4]. However, there are several safety concerns in wireless charging systems for EVs as noted in previous works [17]. Wireless charging is associated with electromagnetic interference and thermal effects [18]. Therefore, proper design and shielding techniques are essential to mitigate these risks. The International Commission on Non-Ionizing Radiation Protection has a guideline that the leakage magnetic flux density should not be more than 27 micro-Tesla when exposed to human beings as it is harmful beyond this threshold [19]. One main consideration in wireless charging of EVs is charger placement and power allocation. The charging pads should be optimally placed to maximize charging quality [20]. The authors also propose an algorithm to determine the optimal charger locations and power allocation by considering factors such as the charging rate and charging distance.

With the limitation of only one receiver coil in terms of charging time, a novel wireless charging system topology is proposed which utilizes two receiver coils to improve charging efficiency [21]. This approach mitigates power losses due to misalignment between the transmitter and receiver coils and also delivers more power within a short time span. EVs' wireless charging can also be realized with pure solar power. Kashani explores the integration of solar energy into wireless charging systems for EVs [21]. The author reviews state-of-the-art research on combining wireless charging technology with solar panels with a sole aim of enhancing the sustainability of EV charging infrastructure. Some of the current trends and challenges in wireless charging systems for EVs include standardization, interoperability, and infrastructure deployment [4, 15]. The authors emphasize the need for further research and development to overcome these challenges and realize the full potential of wireless charging technology.

2.2 Wireless Power Transfer

2.2.1 Principles of Inductive Charging and WPT

Wireless Power Transfer Systems transfer electric energy from source to load without any wired connections. The schematic of the WPT for electric battery charging is as shown below;

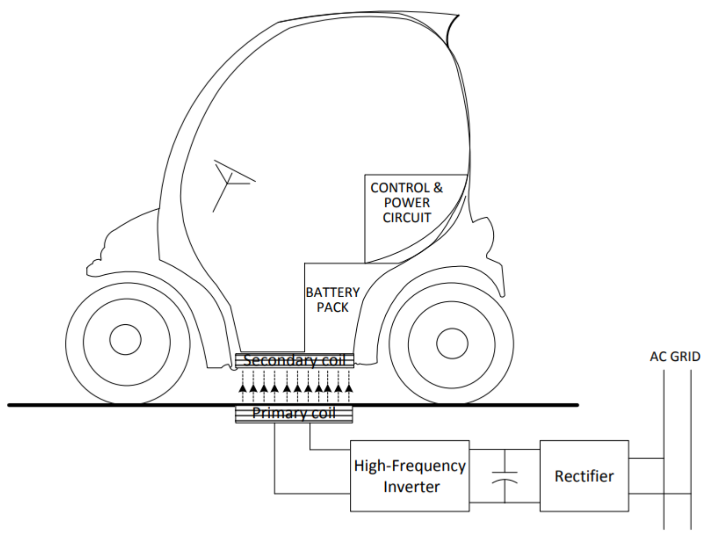


Figure 1WPT Schematic [9]

They are made up of two power sections electrically insulated transmitter and receiver. The transmitter is buried into the pavement and fed by the mains. The receiver is embedded into the electric vehicle and delivers power direct to the battery on the vehicle.

Each section of the WPTS consists of two sections, coupling device and power converter [9].

Coupling device of the Transmitter

The coupling device generates an alternating field which can be electric, magnetic or a combination of both (electromagnetic). Any alternating electric field is associated to an alternating magnetic field. The vice versa is also true, such that when the frequency of oscillations is relatively low, the quasi – static field conditions prevail and the field can be either electric or magnetic depending on the transmitting device [10]

Coupling device of the Receiver

The coupling device of receiver is intersected by the alternating field generated by the transmitting device. It takes the energy transported by the field.

The Power converter of the Transmitter

Consists of front-end Power Factor Correction rectifier cascaded by an inverter that feeds the transmitting device with an alternating voltage.

The Power converter of the Transmitter

Draws energy from the receiving device, working as a rectifier that recharges the batteries with the required values of voltage and current.

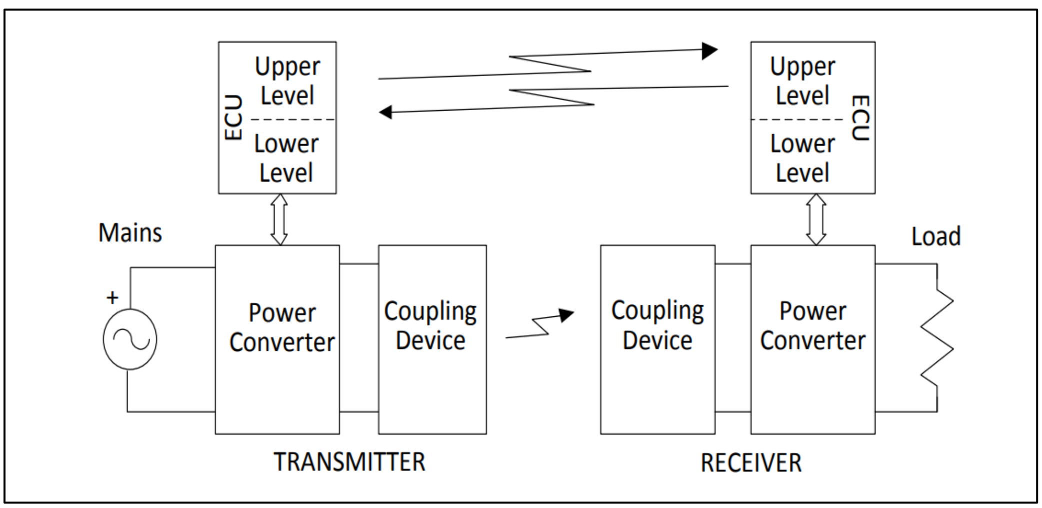


Figure 2 Power Converter [9]

Wireless Power Transfer Technologies [9, 10]

The technologies include

- Capacitive

- Radiant
- Inductive

Capacitive Wireless Power Transfer

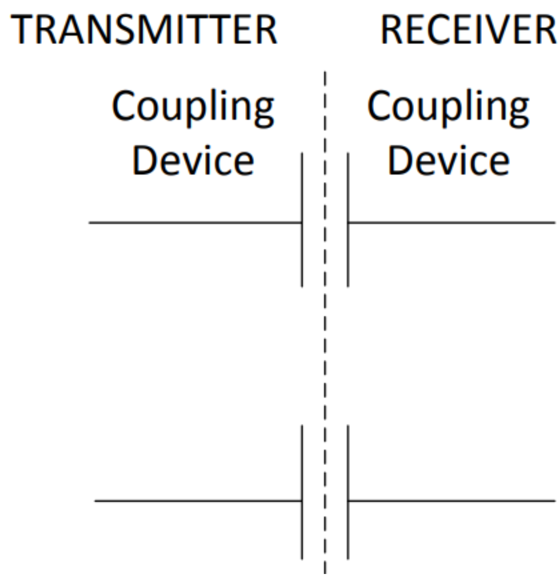


Figure 3 Capacitive Wireless Power Transfer [9]

The coupling devices are two plane capacitors, plates on transmitter face plates on receiver.

Main advantages include;

- Losses are low
- Electromagnetic emissions are insignificant
- Can transfer power through metal without producing eddy currents

Disadvantage

- Energy density stored in between the plates is low; the technology is therefore limited to low power applications [7].

Radiant Wireless Power Transfer

Here, size of coupling device is proportional to wavelength of the electromagnetic waves. So, to maintain it within practical limits, high frequency waves are used e.g., microwaves and lasers. The main advantage is that it is capable of transferring power with high efficiency over longer distances [3].

Inductive Wireless Power Transfer (Principles of Inductive Charging)

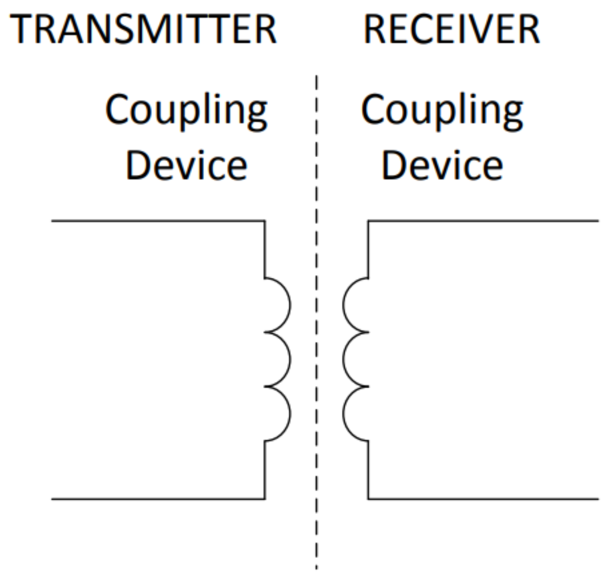


Figure 4 Inductive Wireless Power Transfer [10]

It is based on the principle of electromagnetic induction. Coupling device are 2 coils (Transmitter and Receiver) which are mutually coupled. The transmitting coil is excited by an alternating current (AC) at high frequency between 10KHz – 150KHz [5]. This generates a magnetic field that induces voltage in the receiver coil. The efficiency depends on coupling between the coils and their quality [22]. Coupling is determined by

- Distance between the coils
- Shape of coils
- Angle between the coils

Advantage

- Has greater energy density thus able to handle higher power than capacitive WPT.

Disadvantage

- Losses in coil resistances
- Cannot operate if a metallic body is between the coils.

2.2.2 Electromagnetic Fields and their Applications in Wireless Charging

Electric field is a vector field that quantifies the force exerted on a charged particle per unit charge by the presence of other charged particles or by an electric potential gradient while magnetic field is a vector field that represents the distribution of magnetic forces and influences in the space. It arises from the moving electric charges permanent magnets and exerts a force on the other moving charges and magnets. Wireless charging is based on principle of Magnetic Resonance (MR) or Inductive Power Transfer (IPT) [12].

Applications [9]

Induction Based Charging

This utilizes electromagnetic fields to transfer energy from charging pad (transmitter) and charging devices (receiver). Alternating current is passed through transmitter which generates a magnetic field that induces an alternating voltage in receiver.

Magnetic resonance coupling

Involves resonant transfer of energy between two coils tuned to same frequency. The transmitter generates an oscillating magnetic field, the receiver coil resonates with this field.

Electromagnetic radiation

Used in technologies like Radio Frequency and microwave wireless power transfer.

2.2.3 Efficiency and Limitations of Wireless charging compared to Wired Charging

Wireless EV charging technology is still evolving. Ongoing research can improve its efficiency, convenience and practicability [13]. Comparing the efficiency between the wireless and wired charging, the following factors were considered:

Losses during conversion

Wireless charging involves converting electrical energy into an electromagnetic field which is then converted back to electrical energy at receiving coil [11]. This introduces energy losses which may lower the overall efficiency compared to wired or plug-in charging.

Alignment

The efficiency of the wireless charging decreases with increase in distance between the coils and misalignment [14]. For high efficiency, proper alignment and closeness of the charging device should be considered as compared to wired charging which is not affected by the factor of separation distance and alignment.

Heat generation

Wireless charging generates more heat compared to wired charging. The heat reduces charging efficiency and affects the longevity of the charging system. Energy losses in form of heat also occurs in wired charging from the grid to battery.

Speed of charging

Wired charging offers higher power transfer rates [11].

State of Charge (SOC)

When an individual parks to charge a wireless EV, they more likely to be operating in the 20-80% SOC range. This is more efficient since in wired charging, the 20-80% SOC range is less likely to be maintained, thus less efficient. The overall efficiency of the wired charging system is about 80-94% while for the wireless charging system, is about 88-93% [11].

Advantages of wireless charging over wired charging

- Convenience and Ease of Use – It does not require plugging or connections to enable charging.

- Enhanced Durability – It has a long lifespan since there are no manual operations involved which reduces wear and tear.
- Flexibility and Freedom of Movement – It allows for easier charge connection and disconnection without having to manually interfere with the system.
- Reduction in Cable Clutter – it involves few cable connections which saves on space and it is more aesthetic.
- Future Integration and Standardization – Wireless charging is a developing technology which allows for future improvement and optimization.

2.3 Design and Engineering

2.3.1 Principles of Wireless Charging Pad Design and Optimization

Through the inductive charging technology, power is transferred wirelessly from one magnetic coil in the charging pad to another one installed on the vehicle [9].

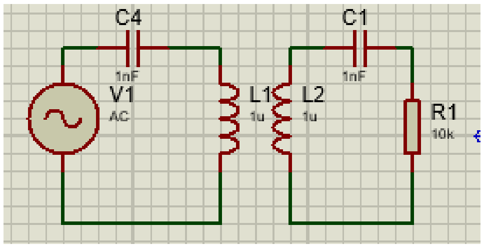


Figure 5 Series-series Topology

It is necessary to maximize efficiency and reduce the reactive power of the WPT system to achieve the resonant condition for both transmitter and receiver sides. Resonance is a condition where the natural frequencies of the transmitter and receiver circuits are matched [22]. There are four types of resonant topologies using a capacitor compensated coil on one side as series-series (S-S), Series-Parallel (S-P), Parallel-Series (P-S), Parallel-Parallel (P-P) [10]. The Series-Series (SS), has suitability for EV application, high power transfer capability and high alignment tolerance and good compact design [19].

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

Coil designs (receiver & transmitter)

Coil size and shape

The planar spiral spring coil shape is preferred as for WPT due to its compact shape which makes it easy to incorporate [23].

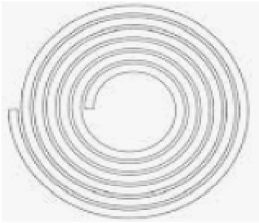


Figure 6 Planar spiral spring coil shape [23]

Spiral coil types offer higher coupling coefficient which measures the efficiency of energy transfer between the transmitter and receiver coils. This means that more energy can be transferred from the transmitter to the receiver, resulting in better overall performance [24]. It also has a good compact size enabling perfect incorporation to the vehicle since it is designed to be more compact than helical coils. This is beneficial as space is limited. Spiral coils are also relatively easier to fabricate compared to helical coils. The manufacturing process for spiral coils is typically simpler and more straightforward and results in cost savings and increased production efficiency [23].

Coil Material selection and choice of materials

Copper is used for coil as it is readily available and less expensive than silver, aluminum and Copper-clad Aluminum (CCA) [23]. Copper also has excellent electrical conductivity which reduces power losses hence maximizing the efficiency of power transfer. Copper also has good mechanical properties and has good thermal conductivity which makes it suitable for handling high power levels in EV wireless charging applications [22].

Alignment angle (θ)

This is the angular deviation between the transmitter and receiver coils and mostly affects the coupling efficiency. When the coils are well aligned, the angle (θ) between their axes is zero degrees, hence maximum coupling. As the angle increases from zero, the coupling efficiency decreases. The charging station with the transmitter coil incorporated at a spacious place where the vehicle with the receiver coil integrated into its undercarriage will be parked at the center with perfect positioning to avoid misalignment. Precise alignment and positioning mechanisms are employed to ensure proper coil matching and alignment [3]. Coupling coefficient (k) quantifies the degree of magnetic coupling between the coils. It is a measure of how well the magnetic field generated by the transmitter coil couples with the receiver coil [24]. The coupling coefficient (k) can be expressed as;

$$K = \frac{M}{L1 * L2} \tag{2}$$

Where;

M – mutual inductance between the coils.

L1 and L2 – self-inductances of the transmitter and receiver coils respectively.

Self-inductance is a phenomenon in which a changing current in a circuit induces an electromotive force (EMF) in the same circuit.

$$V(induced) = L\left(\frac{di}{dt}\right) \tag{3}$$

$\mathrm{L} = \frac{\mathrm{N}^2}{S}$ N is the number of turns and S is the reluctance of the coil (A/Wb)

It also depends on permeability.

$\mathrm{L} = \mathrm{N\emptyset M}/S$

Mutual inductance is the opposition to the change in current in one coil due to the presence of a second coil,

$$M_{12} = \sqrt{L_1 L_2} \tag{4}$$

Induction & impedance matching

Impedance matching is the balance between the source and load impedance to ensure the load receives maximized power. Induction is the efficient transfer of electrical energy through magnetic fields between the transmitter and receiver coils. Spiral coils, with their tightly wound conductive wire in a spiral pattern, enhances magnetic coupling thereby improving induction efficiency and facilitating better power transfer. Impedance matching optimizes power transfer by minimizing signal reflections [23]. Properly designing the dimensions and parameters of spiral coils, including the number of turns, diameter, and spacing between windings, allows for impedance tuning to match the source and load impedances [9]. Additionally, impedance matching networks can be utilized to further enhanced matching [25]. The findings of this study emphasize the vital role of induction and impedance matching in achieving efficient wireless power transfer using spiral coils which contributes towards advancing the WPT technology.

The basics of electromagnetic are derived from the Maxwell equations, both in time independent and time dependent cases [26]. The four Maxwell equations are as follows,

Gauss's law for electric fields

$$\oint \vec{E} \,.\, dA = \varepsilon_0 \int \rho \, dVt \tag{5}$$

Gauss's law for magnetic fields

$$\oint \vec{B} \,.\, dA = 0 \tag{6}$$

Faraday's law of electromagnetic induction

$$\oint \vec{E}\,.\,dS = -\frac{d\emptyset B}{dt} \tag{7}$$

Ampere’s circuital law (with Maxwell’s addition)

$$\oint \vec{B}\,.\,dS = \mu_0 \left(I + \varepsilon_0 d\emptyset \frac{E}{dt} \right) \tag{8}$$

These four equations together, along with appropriate boundary conditions, form Maxwell’s equations and describe the behavior of electromagnetic fields in terms of electric and magnetic fields, charges, currents, and their interactions.

2.3.2 Exploring Different Charging Pad Materials, Coils configuration and Resonant Frequency Tuning

Tuning the resonant frequency involves adjusting electrical properties of the coils and all the component of the charging pad to ensure resonance between the transmitter and receiver coils for optimization of power transfer & efficiency. This resonant frequency refers to the frequency at which the transmitter and receiver coils exhibit maximum energy transfer efficiency [3]. When the coils are operated at their resonant frequency, the impedance of the coils is matched, resulting in efficient power transfer [9]. The resonant frequency of the coils also depends on the combination of their capacitance and inductance values. Increasing the capacitance or decreasing the inductance lowers the resonant frequency, while decreasing the capacitance or increasing the inductance raises the resonant frequency [10]. In order to tune the resonant frequency, capacitors and inductors can be added in series or parallel with the coils. These components are selected to achieve the desired resonant frequency. Capacitors adjusting the capacitance, while the inductors adjusting inductance of the coils [14]. In some special cases, variable capacitors and inductors are utilized to allow for fine-tuning of the resonant frequency providing flexibility in adjusting the resonant frequency to compensate for variations such as environmental or load changes in the system [3]. In advanced EV WPT, the charging pads are incorporated with adaptive control systems that monitor the resonant frequency and automatically adjust the tuning in real-time [20]. This ensures optimal power transfer efficiency, even when the system experiences dynamic conditions. Resonant frequency is given as;

$$f_r = \frac{1}{\sqrt{LC}} \tag{9}$$

2.3.3 Hands-on Activities involving designing and building a small-scale SEVWCS

This involves designing and building a prototype of the Smart EV Wireless Charging System. The following list of tasks will be completed at the prototype stage of the project.

- Circuit design in proteus
- Program development in the STM32CubeIDE.
- Uploading the program to the STM32F103CEU6 microcontroller.
- Connecting the L298 H-Bridge driver with the microcontroller.
- Connecting the motor to the L298 driver.
- Connecting the transmitter coils on the motor shaft via gears.
- Connecting the GSM SIM7600CE Module to the microcontroller.
- Connecting the RC522 RFID Module to the microcontroller.
- Connecting the high-frequency switching circuit using the MOSFET Transistor.
- Powering the transmitter coils from a single-phase power supply using the 12V DC power supply adapter.
- Powering the two transmitter coils.
- Powering receiver side controller and charging a 3.7 Li-ion battery.

2.4 Safety and Standards

2.4.1 International and Regional Standards for Wireless Charging Infrastructure

- **International Electrotechnical Commission (IEC)** – This organization has developed several standards related to wireless power transfer. The IEC 61980 series of standards covers safety, electromagnetic compatibility, and performance requirements for WPT systems [27].
- **Federal Communications Commission (FCC)** – The FCC regulates the use of wireless power transfer devices. It has established guidelines for electromagnetic compatibility and Specific Absorption Rate (SAR) limits to ensure that WPT systems do not cause harmful interference or exceed safe levels of human exposure to electromagnetic fields.
- **International Organization for Standardization (ISO)** – The ISO has developed standards related to WPT systems, such as ISO/IEC 14543-3-10. This series specifies the communication protocols for wireless power transfer devices [28].
- **Institute of Electrical and Electronics Engineers (IEEE)** – The IEEE has developed standards for WPT which include IEEE 802.15.4, which specifies the physical and media access control layers for low-rate wireless personal area networks (LR-WPANs), including WPT devices [29].
- **National Electrical Manufacturers Association (NEMA)** – This is an organization that develops standards for the electrical manufacturing industry. NEMA has published standards related to wireless power transfer, such as NEMA WPT 1, which addresses safety requirements and test methods for WPT systems [30].

- **SAE (Society of Automotive Engineers) International** – It develops standards and guidelines for various automotive technologies, including wireless power transfer in the context of electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs).

SAE J2954 is another standard for wireless power transfer (WPT) for electric vehicles.

It is led by SAE (Society of Automotive Engineers) International. It classifies products in terms of charging levels, vehicle ground clearance and systems interoperability [31]. The three power levels are:

- WPT1 (3.7 kW)
- WPT2 (7 kW)
- WPT3 (11 kW)

The J2954 system consists of two entities

- Vehicle Assembly (VA) – This is the vehicle-mounted section
- Ground Assembly – This connects to grid. Changes AC to DC. The DC output of rectifier drives a power inverter outputting AC of 85KHz.

SAE J2954 establishes a universal Ground Assembly for WPT3, critical especially for public infrastructures. It is downward-compatible to charge vehicles also at WPT1 and WPT2. The goal is to install WPT-GAs in publicly available parking spaces, per the setup in today's plug-in charging infrastructure. Installation with WPT3 will allow downward compatibility. SAE J2954 specifies the requirements to make the GAs and VAs fully interoperable that is, characteristic of a system to work with other systems. So that any vehicle will be able to charge when it is parked in an SAE J2954 GA-equipped parking location. The SAE J2954 standard includes parameters like minimum efficiency, EMI and EMF (electromagnetic interference and field) limits as well as foreign object detection. There are three overlapping ranges of vehicle ground clearances from

100 to 250 mm (3.9 to 9.8 in.) and three levels of grid input to the GA up to 11.1 kVA. Parking tolerances are ±75 mm (3.0 in.) in the direction of travel and ±100 mm (3.9 in.) in the lateral direction. The SAE J2954 task force came to a conclusion that to ensure interoperability, the ability of systems to transfer power, as designed by different manufacturers, it must be validated in both bench and vehicle testing. SAE J2954 standardizes a WPT GA/VA test station, along with coil specifications to evaluate the requirements for safety, interoperability and performance [31].

Chapter 3: Methodology

3.1 Simulation

Sections of the main and the prototype of the Smart EV Wireless Charging System have been simulated in Proteus 8 Professional to evaluate the system's performance before implementation. These simulations only cover the STM32F103C8T6 Blue Pill Microcontroller, transceiver coils, Three-phase and single-phase power, Motor mechanism and the IR proximity mechanism. The GSM SIM7600CE communication protocol has been simulated using a switch which triggers a particular section of the program same case with the RFID communication protocol. The real wireless communication protocol using GSM SIM7600CE will be realized in the system prototype as well as the swiping tags for the RFID communication protocol. The following is the Proteus simulation block of the prototype design.

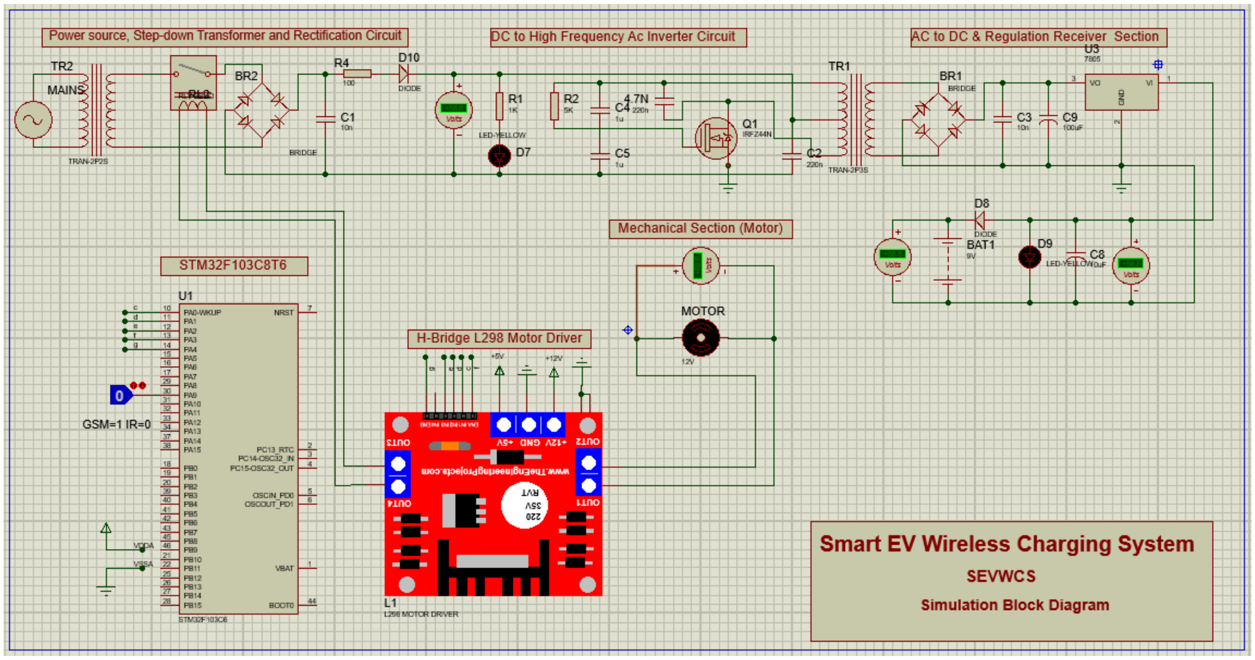


Figure 7 SEVWCS Prototype Simulation Block

The Main Smart EV Wireless Charging System utilizes three-phase power supply. The rectification is based on the Graetz circuit using diodes but the real system will utilize SCRs for the Graetz circuit. The simulation block is as shown below.

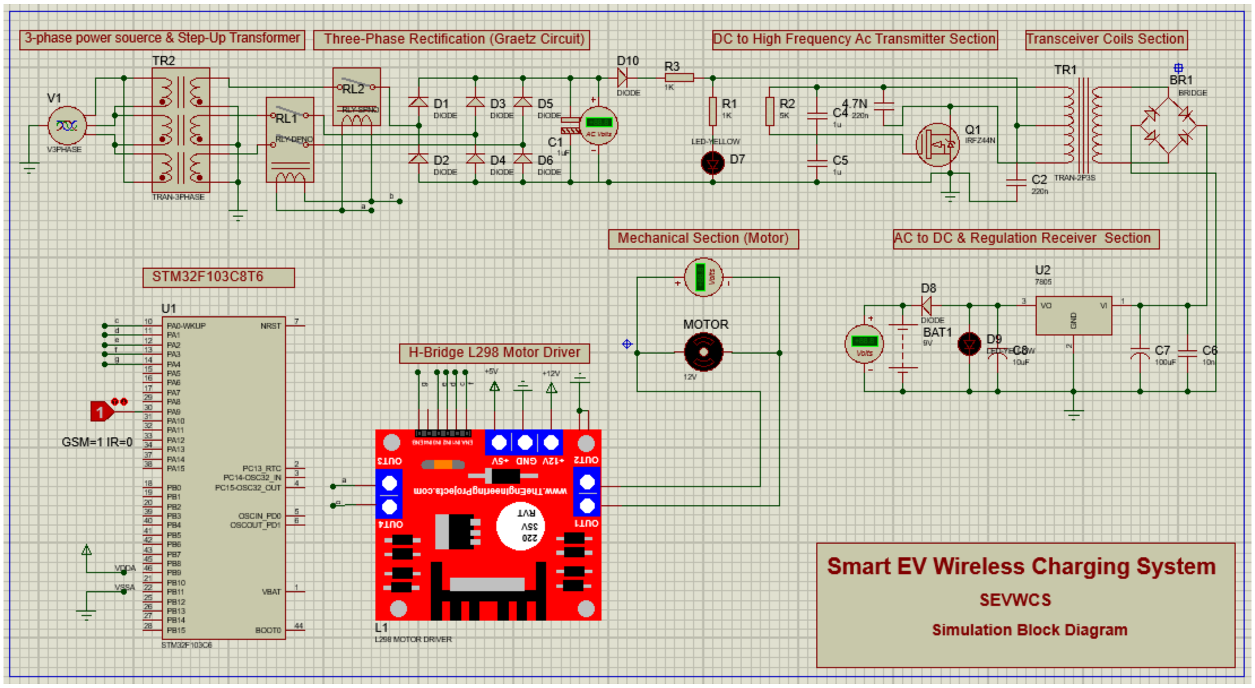


Figure 8 SEVWCS Main System Simulation Block

Both setups have been simulated and produced conclusive results. The program was able to rotate the motor in clockwise direction for one second and power the relay(s) to connect the power supply. After connecting power, the program delays for three seconds (charging time) and disconnects power supply. After power supply is disconnected, the system delays for a second before the motor rotates anti-clockwise. The rotation of the motor in the clockwise direction and anti-clockwise direction implies the movement of the system up and down respectively.

3.2 System Modelling

The entire system prototype will be designed according to figure 9 below and tested physically. To showcase the functionality, a model EV Bus will be charged using the system. The charging voltage and the remaining time to full-charge will be displayed in a segment display connected to the model car via a microcontroller. When the model car is fully charged, it will communicate back to the system and power will be disconnected. The two block diagrams of the main system are as shown below.

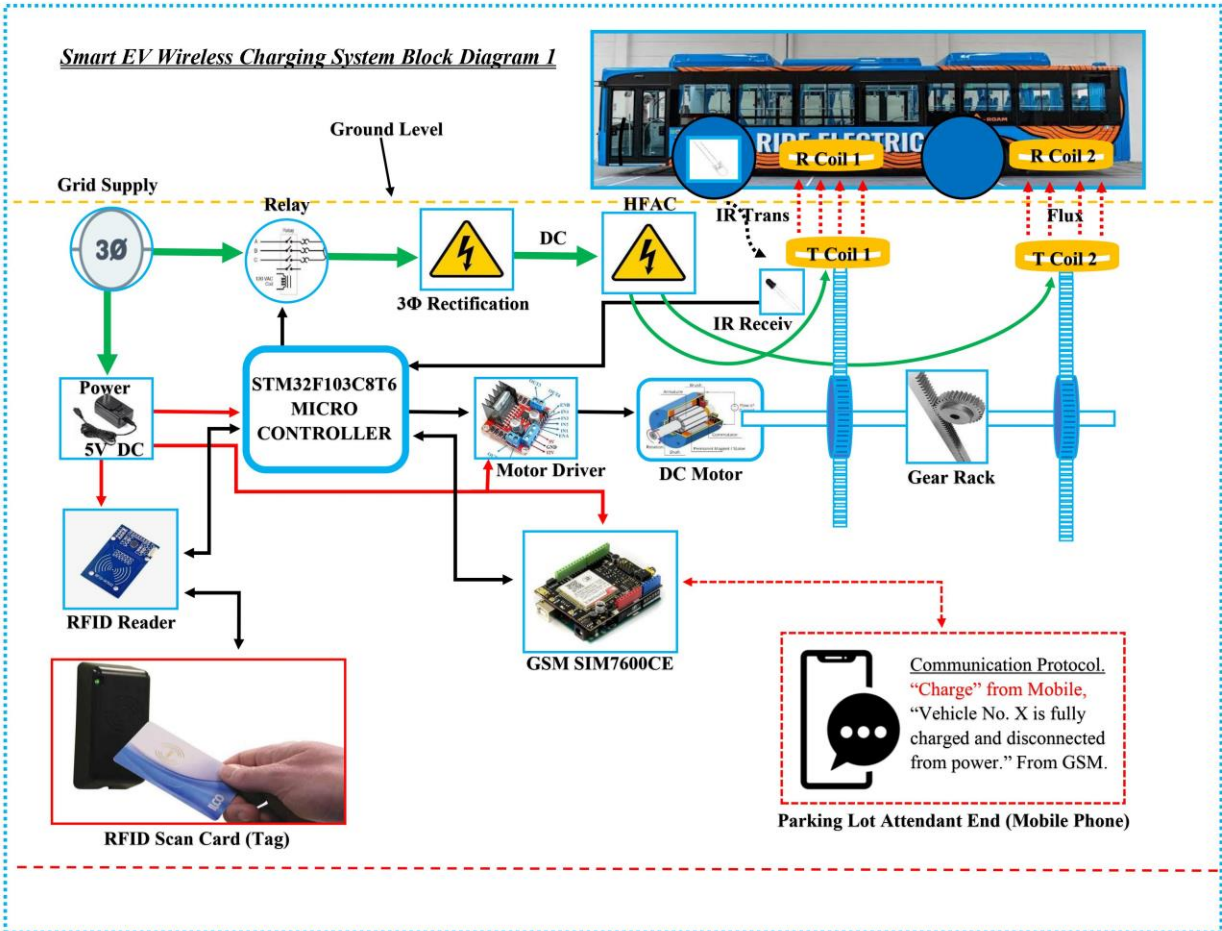


Figure 9 SEVWCS External Block Diagram

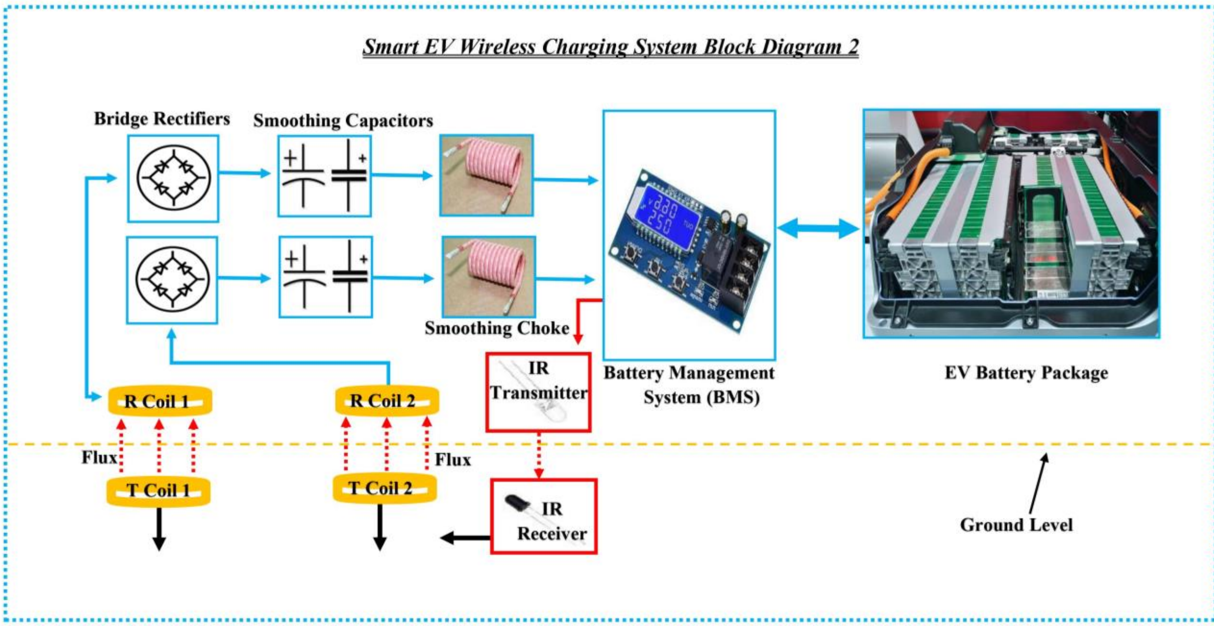


Figure 10 SEVWCS Inside EV Block Diagram

3.2.1 Objective Functions

An inductive WPT can be modelled using the following equivalent circuit [11],

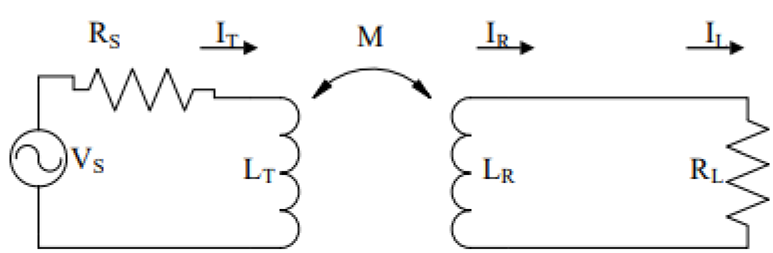


Figure 11 WPT Equivalent Circuit [11]

The L_T is the self-inductance of the transmitter side while L_R is the self-inductance of the receiver side. M is the mutual inductance and the resistance of the source and the receiver are denoted by R_S and R_L respectively. The coefficient of coupling between the transmitter and the receiver is given by;

$$k = \frac{M}{\sqrt{L_T L_R}} \tag{10}$$

The voltage equations of the transmitting and the receiving coils are given by,

$$V_S = Z_T I_T + j\omega M I_R \tag{11}$$

$$0 = j\omega M I_T + Z_R I_R \tag{12}$$

Where, Z_T and Z_R are the transmitting and the receiving impedances respectively.

The describing equations of Z_T and Z_R are as follows,

$$Z_T = R_S + j\omega L_T \tag{13}$$

$$Z_R = R_L + j\omega L_R \tag{14}$$

Where, $\omega = 2\pi f$ is the angular frequency of the source voltage.

The quality factors of the transmitter and the receiver are given by,

$$Q_T = \frac{\omega L_T}{R_S} \tag{15}$$

$$Q_R = \frac{\omega L_R}{R_L} \tag{16}$$

From Faraday`s law, the induced emf in the receiver is given by

$$emf = -\frac{d\phi}{dt} \tag{17}$$

WPT system performance can be estimated by the power transfer efficiency (PTE) which is dependent on the product of the coupling coefficient (k) and the quality factor. K is the coupling coeffect between transmitter and receiver and it is a ratio and varies from 0 to 1 as a maximum value at totally power coupling. Q is the unloaded quality factor of the transmitter or receiver coil. The PTE is calculated as follows,

$$PTE = \frac{k_2 Q_t Q_r}{\left(1 + \sqrt{1 + k^2 Q_t Q_r}\right)^2} * 100\% \tag{18}$$

From the equation, it is clear that increasing the transfer efficiency needs a high value of the KQ product.

3.3 Validation and Performance Analysis of the Proposed Method

The prototype will be able to adjust itself to achieve a maximum separation distance of 10mm. The coupling coefficient will be calculated according to equation (10),

where the mutual inductance is given by,

$$M = \frac{N_1 N_2}{S} \tag{19}$$

And self-inductances are given by (15) and (16),

S is reluctance and it is calculated as follows,

$$S = \frac{l}{\mu_0 \mu_r A} \tag{20}$$

Where, l is the separation distance of the Tx and the Rx and A is the effective area. The effective area is calculated as shown below. R is the radius of the larger circle and r is the radius of the null circle.

$$A = \pi R^2 - \pi r^2 \tag{21}$$

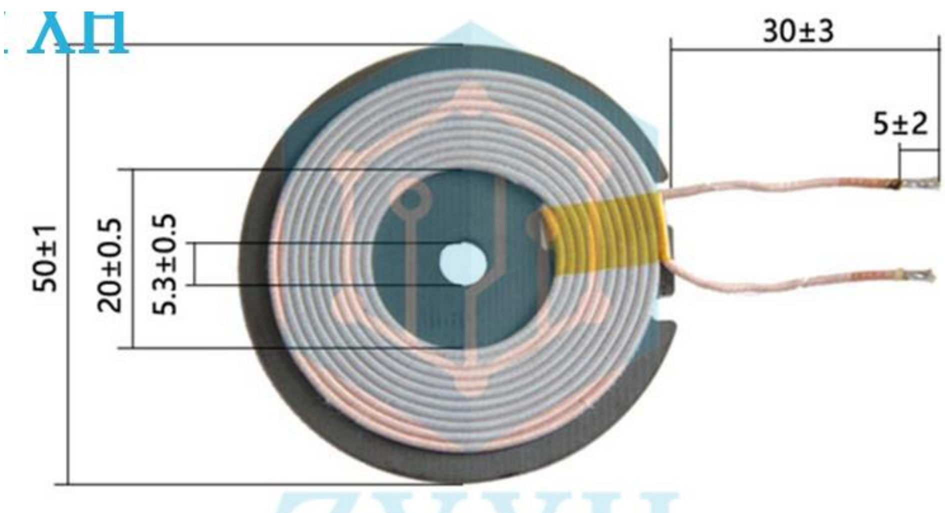


Figure 12 Coil dimensions and Area

3.31 Evaluating Mutual inductance for different Coil-Separation Distances

- **0.01m coil-separation distance**

From equation (21) and Figure (12), the effective area is calculated as follows,

$$A = \pi R^2 - \pi r^2 = (\pi * 0.025^2 m) - (\pi * 0.01^2) = 0.00165 m^2 \tag{22}$$

The separation distance will be 10mm (0.01m). Therefore, the reluctance of the coil will be,

$$S = \frac{l}{\mu_0 \mu_r A} = \frac{0.01}{4\pi * 10^{-7} N/A^2 * 1 * 0.00165 m^2} = 4.8229 * 10^6 \frac{AT}{wb} \tag{23}$$

The self-inductances of the transmitter and the receiver will be the same since the system seeks to transmit power in the ratio of 1:1. Therefore, the number of turns in the transmitter coil will be the same as the receiver coil.

$$L_T = L_R = \frac{N_1^2}{S} = \frac{10^2}{4.8229.1 * 10^6} = 2.0735 * 10^{-5} H \tag{24}$$

The mutual inductance of the prototype will be,

$$M = \frac{N_1 N_2}{S} = \frac{10 * 10}{4.8229.1 * 10^6} = 2.0735 * 10^{-5} H \tag{25}$$

Therefore, the coupling coefficient will be,

$$k = \frac{M}{\sqrt{L_T L_R}} = \frac{2.0735 * 10^{-5}}{\sqrt{(2.0735 * 10^{-5})^2}} = 1 \tag{26}$$

The coupling capacitors for the LC tank in Tx and Rx sections based on the SS compensation topology are calculated as follows. The desired resonating frequency of the prototype is 150kHz.

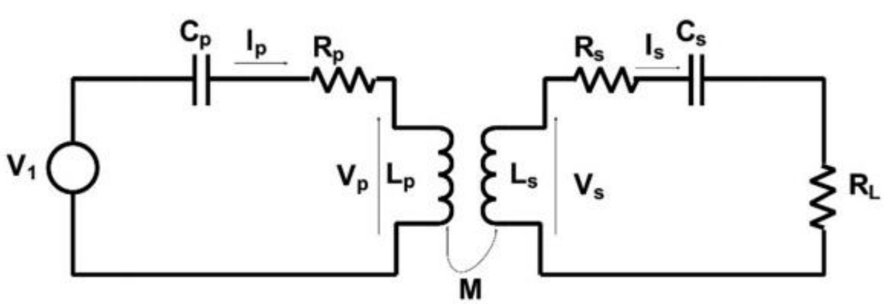


Figure 13 SS Compensation Topology [11]

$$C_p = C_r = \frac{1}{4\pi^2 f^2 (L_p + M)} \tag{27}$$

$$C_p = C_r = \frac{1}{4\pi^2 * 150000 * (2.0735 * 10^{-5} + 2.0735 * 10^{-5})} = 4.0721 * 10^{-3} F \tag{28}$$

- **0.1m coil-separation distance**

From equation (21) and Figure 12, the effective area is calculated as follows,

$$A = \pi R^2 - \pi r^2 = (\pi * 0.025^2 m) - (\pi * 0.01^2) = 0.00165 m^2 \tag{29}$$

The separation distance for this case will be 100mm (0.1m). Therefore, the reluctance of the coil will be,

$$S = \frac{l}{\mu_0 \mu_r A} = \frac{0.1}{4\pi * 10^{-7} N/A^2 * 1 * 0.00165 m^2} = 4.823 * 10^7 \frac{AT}{wb} \tag{30}$$

The self-inductances of the transmitter and the receiver will be the same since the system seeks to transmit power in the ratio of 1:1. Therefore, the number of turns in the transmitter coil will be the same as the receiver coil.

$$L_T = L_R = \frac{N_1^2}{S} = \frac{10^2}{4.823 * 10^7} = 2.0735 * 10^{-6} H \tag{31}$$

The mutual inductance of the prototype will be,

$$M = \frac{N_1 N_2}{S} = \frac{10 * 10}{4.823 * 10^7} = 2.0735 * 10^{-6} H \tag{32}$$

Therefore, the coupling coefficient will be,

$$k = \frac{M}{\sqrt{L_T L_R}} = \frac{2.0735 * 10^{-6} H}{\sqrt{(2.0735 * 10^{-6} H)^2}} = 1 \tag{33}$$

The coupling capacitors for the LC tank in Tx and Rx sections based on the SS compensation topology are calculated as follows. The desired resonating frequency of the prototype is 150kHz.

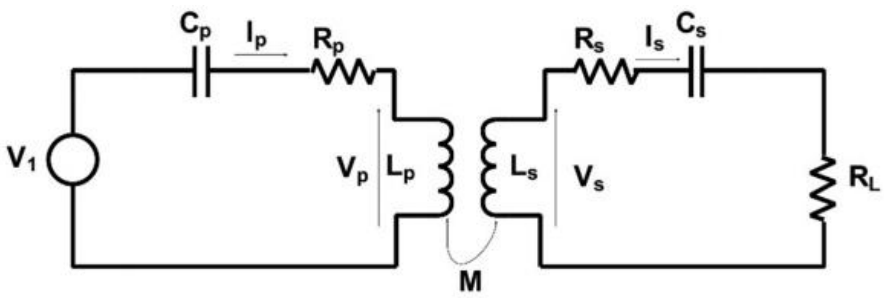


Figure 14 SS Compensation Topology [11]

$$C_p = C_r = \frac{1}{4\pi^2 f^2 (L_p + M)} \tag{34}$$

$$C_p = C_r = \frac{1}{4\pi^2 * 150000 * (2.0735 * 10^{-6} + 2.0735 * 10^{-6})} = 4.0722 * 10^{-2} F \tag{35}$$

- **1m coil-separation distance**

From equation (21) and Figure 12, the effective area is calculated as follows,

$$A = \pi R^2 - \pi r^2 = (\pi * 0.025^2 m) - (\pi * 0.01^2) = 0.00165 m^2 \tag{36}$$

The separation distance will be 10mm (0.01m). Therefore, the reluctance of the coil will be,

$$S = \frac{l}{\mu_0 \mu_r A} = \frac{1}{4\pi * 10^{-7} N/A^2 * 1 * 0.00165 m^2} = 4.8229 * 10^8 \frac{AT}{wb} \tag{37}$$

The self-inductances of the transmitter and the receiver will be the same since the system seeks to transmit power in the ratio of 1:1. Therefore, the number of turns in the transmitter coil will be the same as the receiver coil.

$$L_T = L_R = \frac{N_1^2}{S} = \frac{10^2}{4.8229 * 10^8} = 2.0735 * 10^{-7} H \tag{38}$$

The mutual inductance of the prototype will be,

$$M = \frac{N_1 N_2}{S} = \frac{10 * 10}{4.8229 * 10^8} = 2.0735 * 10^{-7} H \tag{39}$$

Therefore, the coupling coefficient will be,

$$k = \frac{M}{\sqrt{L_T L_R}} = \frac{2.0735 * 10^{-7}}{\sqrt{(2.0735 * 10^{-7})^2}} = 1 \tag{40}$$

The coupling capacitors for the LC tank in Tx and Rx sections based on the SS compensation topology are calculated as follows. The desired resonating frequency of the prototype is 150kHz.

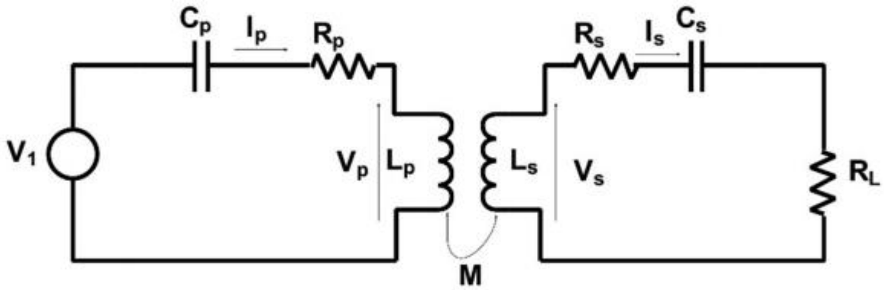


Figure 15 SS Compensation Topology [11]

$$C_p = C_r = \frac{1}{4\pi^2 f^2 (L_p + M)} \tag{41}$$

$$C_p = C_r = \frac{1}{4\pi^2 * 150000 * (2.0735 * 10^{-7} + 2.0735 * 10^{-7})} = 4.0722 * 10^{-1} F \tag{42}$$

- **10m coil-cseparation distance**

From equation (21) and Figure 12, the effective area is calculated as follows,

$$A = \pi R^2 - \pi r^2 = (\pi * 0.025^2 m) - (\pi * 0.01^2) = 0.00165 m^2 \tag{43}$$

The separation distance will be 10mm (0.01m). Therefore, the reluctance of the coil will be,

$$S = \frac{l}{\mu_0 \mu_r A} = \frac{10}{4\pi * 10^{-7} N/A^2 * 1 * 0.00165 m^2} = 4.8229 * 10^9 \frac{AT}{wb} \tag{44}$$

The self-inductances of the transmitter and the receiver will be the same since the system seeks to transmit power in the ratio of 1:1. Therefore, the number of turns in the transmitter coil will be the same as the receiver coil.

$$L_T = L_R = \frac{N_1^2}{S} = \frac{10^2}{4.8229 * 10^9} = 2.0735 * 10^{-8} H \tag{45}$$

The mutual inductance of the prototype will be,

$$M = \frac{N_1 N_2}{S} = \frac{10 * 10}{4.8229 * 10^9} = 2.0735 * 10^{-8} H \tag{46}$$

Therefore, the coupling coefficient will be,

$$k = \frac{M}{\sqrt{L_T L_R}} = \frac{2.0735 * 10^{-8}}{\sqrt{(2.0735 * 10^{-8})^2}} = 1 \tag{47}$$

The coupling capacitors for the LC tank in Tx and Rx sections based on the SS compensation topology are calculated as follows. The desired resonating frequency of the prototype is 150kHz.

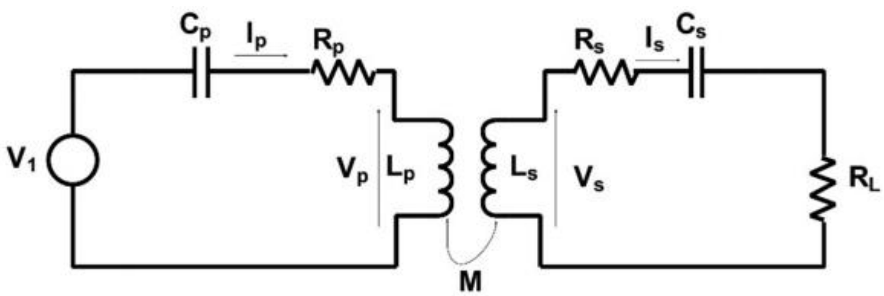


Figure 16 SS Compensation Topology [11]

$$C_p = C_r = \frac{1}{4\pi^2 f^2 (L_p + M)} \tag{48}$$

$$C_p = C_r = \frac{1}{4\pi^2 * 150000 * (2.0735 * 10^{-8} + 2.0735 * 10^{-8})} = 4.0722F \tag{49}$$

3.32 Comparing the performance of the different coil-separation distances (0.01m, 0.1m, 1m & 10m)

The mutual inductance for a 0.01m separation distance is the highest as compared to that of 0.1m, 1m or 10m separation distances. The mutual inductance is inversely proportional to the separation which implies that the smaller the separation distance between the transmitter and the receiver coils, the higher the power efficiency.

3.4 Proposed Method

The prototype of the system will be powered by a single-phase power supply (240V, 50Hz). The 12V DC Power Supply adapter will be used to deliver 12V direct current to the transmitter circuit at 24W. The transmitter circuit will utilize the high-frequency switching capability of a IRFZ44N MOSFET to complete the inverter operation. The following is the transmitter circuit diagram,

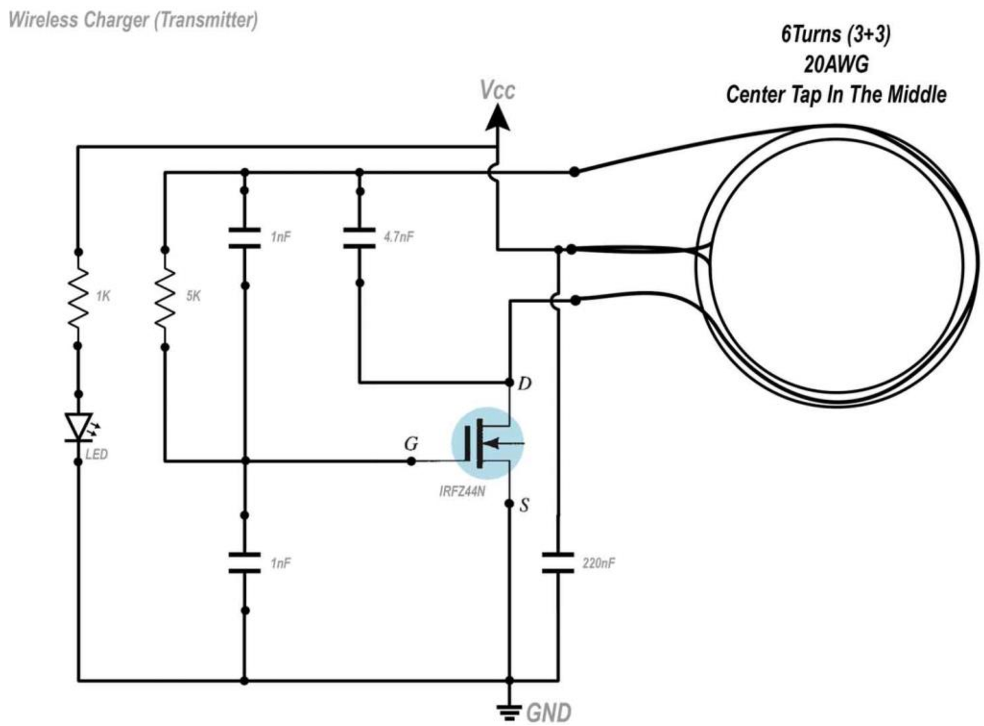


Figure 17 Transmitter (Tx) [30]

The receiver circuit will be as shown in the figure 15 below. The turns ratio of the receiver to the transmitter will determine the amount of voltage that will be delivered to the battery. The 5V output from the receiver will be connected to a battery and a microcontroller setup with IR Sensor and segment display. The microcontroller will be used to monitor the charging of the battery and display the charging time and power delivered to the battery in real time. When the battery is fully charged, the microcontroller will interrupt and command the IR transmitter to produce a signal which will be received by the IR Receiver connected to the STM32F103C6T8. This will trigger an interrupt program in the STM32 microcontroller to shut down power and move the system down after one second delay.

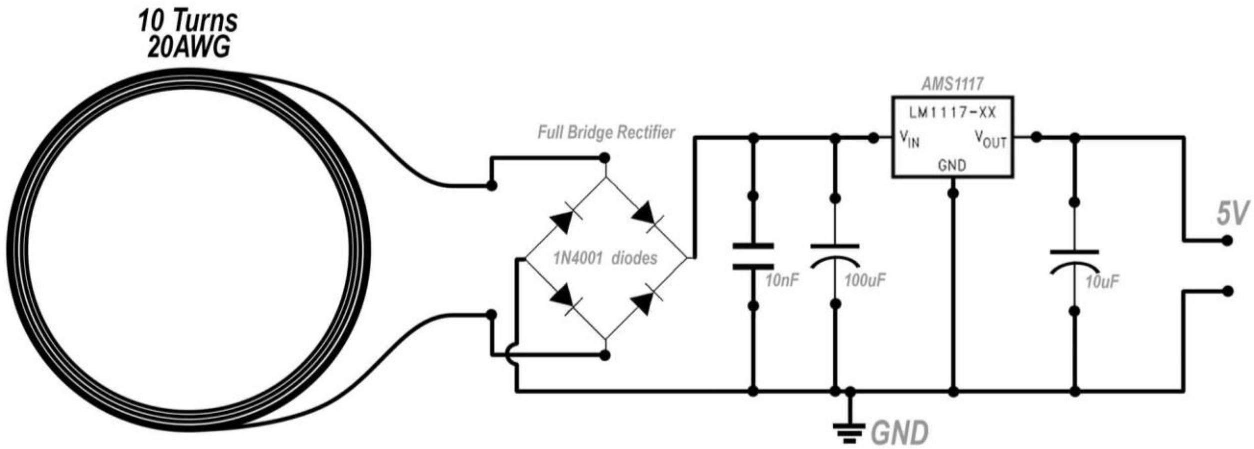


Figure 18 Receiver (Rx) [30]

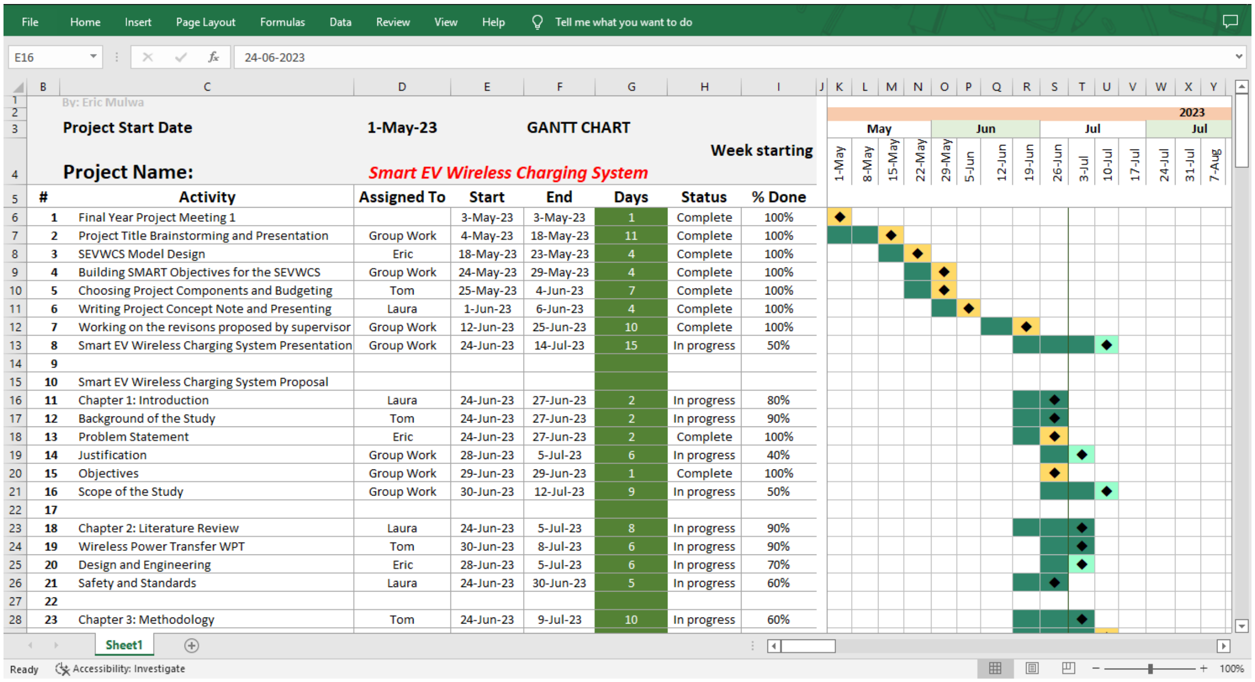
Budget

The following is a list of the components to be used with their respective prices and quantity.

No.	Component Name	Quantity	Total (Ksh)
1	STM32F103C8T6 Microcontroller + ST-Link V2	1	1600
2	Motor Driver L298N H-Bridge 12V 2A	1	500
3	12V DC Power Supply Adapter AC 100-240V (5.5*2.5mm)	1	500
4	RC522 RFID Reader and Tags (MFRC - RC522)	1	150
5	5-wire gear step 12V DC Motor	1	250
6	GSM SIM7600CE Module (4G)	1	7200
7	38kHz IR Sensor (Transmitter and Receiver separated)	1	110
8	Jumper wire DuPoint Line (5 male, 5 Female and 5 Male-Female)	3	100
9	12V 2A wireless charger Transmitter and Receiver coils	4	400
10	IRFZ44N MOSFET Transistor	1	200
11	LCD 1602 Module Green	1	160
12	Resistors (1k, 5k, 220 and 10k) two each	2	50
13	Capacitors (10u, 100n, 1n, 4.7n and 220n) two each	2	50
14	5V LEDs (Green, Blue, Yellow and Red) two each	2	50
15	7805 Voltage Regulator Chip	1	30
16	Diodes (Bridge rectifier)	4	20
17	Electric Bus Model	1	200
Total			**11,570**

Table 1 Budget

Gantt Chart


By: Eric Mulwa

Project Start Date **1-May-23** **GANTT CHART**

Week starting

Project Name: ***Smart EV Wireless Charging System***

#	Activity	Assigned To	Start	End	Days	Status	% Done
1	Final Year Project Meeting 1		3-May-23	3-May-23	1	Complete	100%
2	Project Title Brainstorming and Presentation	Group Work	4-May-23	18-May-23	11	Complete	100%
3	SEVWCS Model Design	Eric	18-May-23	23-May-23	4	Complete	100%
4	Building SMART Objectives for the SEVWCS	Group Work	24-May-23	29-May-23	4	Complete	100%
5	Choosing Project Components and Budgeting	Tom	25-May-23	4-Jun-23	7	Complete	100%
6	Writing Project Concept Note and Presenting	Laura	1-Jun-23	6-Jun-23	4	Complete	100%
7	Working on the revisons proposed by supervisor	Group Work	12-Jun-23	25-Jun-23	10	Complete	100%
8	Smart EV Wireless Charging System Presentation	Group Work	24-Jun-23	14-Jul-23	15	In progress	50%
9							
10	Smart EV Wireless Charging System Proposal						
11	Chapter 1: Introduction	Laura	24-Jun-23	27-Jun-23	2	In progress	80%
12	Background of the Study	Tom	24-Jun-23	27-Jun-23	2	In progress	90%
13	Problem Statement	Eric	24-Jun-23	27-Jun-23	2	Complete	100%
14	Justification	Group Work	28-Jun-23	5-Jul-23	6	In progress	40%
15	Objectives	Group Work	29-Jun-23	29-Jun-23	1	Complete	100%
16	Scope of the Study	Group Work	30-Jun-23	12-Jul-23	9	In progress	50%
17							
18	Chapter 2: Literature Review	Laura	24-Jun-23	5-Jul-23	8	In progress	90%
19	Wireless Power Transfer WPT	Tom	30-Jun-23	8-Jul-23	6	In progress	90%
20	Design and Engineering	Eric	28-Jun-23	5-Jul-23	6	In progress	70%
21	Safety and Standards	Laura	24-Jun-23	30-Jun-23	5	In progress	60%
22							
23	Chapter 3: Methodology	Tom	24-Jun-23	9-Jul-23	10	In progress	60%

Figure 19 SEVWCS Gantt Chart

Link to view the Gantt Chart:

https://docs.google.com/spreadsheets/d/1OwKE61lzK0xsAF-tuYIkcsnJG28TEDKOmG-Nxwoc0-8/edit?usp=sharing

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