COLLEGE OF SCIENCE AND TECHNOLOGY

University of Rwanda, College of Science and Technology

"ADOPTING E-BIKES IN RWANDA USING WIRELESS CHARGING SYSTEM, CHALLENGES AND OPPORTUNITIES"

By

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Reference Number: 220000540

A Thesis submitted to the African Center of Excellence in Energy studies for sustainable development (ACE-ESD)

In partial fulfillment of the requirement for the degree of Master of Science In Electrical power systems

Project ID: ACEESD/REE/21/20

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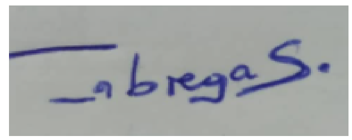
November ,2021

Kigali-Rwanda

DECLARATION

I, the undersigned, declare that this thesis work is my original work and that it has not previously been presented or submitted for a degree at the University of Rwanda or any other college. All sources of materials used in the thesis work have been properly acknowledged.



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APPROVAL

Submission Date 12/11/2021

This research has been submitted for examination with my approval as a university supervisor.

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ACKNOWLEDGEMENTS

This thesis work illustrates the conclusion of my level in electrical power system at the University of Rwanda, which was funded by the African Center of Excellence for Energy Sustainability Development. My heartfelt thanks to everyone who helped me complete this thesis. This assignment undoubtedly tested my creative abilities.

I would like to express my sincere gratitude and appreciation to my primary supervisor Prof. Dr. Ir Etienne Ntagwirumugara and my Co-supervisor Dr.Ir. Mulugeta Gebrehiwot Gebremichael For the enormous and valuable intervention during the scheduling and execution thesis. Their readiness to give their time has been humbly much appreciated, also i would like to appreciate my Lab engineer Aphrodice for his patient guidance and enthusiastic encouragement and constructive useful critics for this research work. I would like also to thank Eng. Simba Charles for his great input on the execution of this work. Finally, I would like to thank my wife Evelyne for her kind support in this journey, my teacher and mother for her great impact, my sisters and brother, the support from family and friends to achieve this master's level.

''*ask, and it shall be given you; seek and ye shall find; knock, and it shall be opened unto you: for every one that asketh receiveth''*

__ Jesus Christ

Abstract

In developed cities and countries, electric bikes, also known as e-bikes, are well known and common mode of transport. There is a huge demand for modern technological infrastructures, and a new demand for wireless charging systems (WCS), because of the growth and need for integration of electric mobility, particularly in e-bikes. The contactless charging technology is quickly gaining traction as a novel way to charge the supply of electric vehicles, including, of course, e-bikes. IPT is the main technology that makes wireless EV battery charging possible (IPT). The following are the main advantages of inductive power transmission over wired methods on e-bikes: the absence of a plug-in procedure, the elimination of obtrusive cables, the deletion of open connections, and a simple air gap closure, safety, and comfort. In this thesis we evaluate the opportunity and challenges of e-bikes integration in Rwanda and explore different possibilities of WCS on e-bikes. The goal is to describe this wireless charging system and suggest a new framework for a wireless charging prototype application that is both possible and efficient. Initially, this research focuses on evaluating and comparing various studies on related wireless charging systems for e-bikes in general. Following a thorough review of the literature, various factors have been developed that can have an impact on the system. These variables are assessed to gain a thorough grasp of their impact on the wireless charging phenomenon. Using these factors as design criteria, new recommended prototypes are created based on the collection of current standards. Finally, a business integration analysis using the Potential Weakness Opportunity and Challenges (PWOC) method is performed to establish a strategic planning system for wholesale e-bike companies or government policymakers to categorize potentials, weaknesses, opportunities, and constraints. The prototype displays and provides a clear direction with the framework and project commencement; the framework is designed and evaluated with feasibility and execution in mind. According to the research, Rwanda will gain from the use of e-bikes in an electric mobility program. The WCS is a good and promising profitable future industry that appeals to any e-mobility business start-ups in Rwanda. The prototype displays and provides a clear direction with the framework and project commencement; the framework is designed and evaluated with feasibility and execution. According to the research, Rwanda will gain from the use of e-bikes in an electric mobility program. The WCS is a good and promising profitable future industry that appeals to any e-mobility business start-ups in Rwanda.

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LIST OF ABREVIATIONS

EDLC	Electrical Double-Layer Capacitor
EV	Electric Vehicle
FHA	First Harmonic Analysis
BMC	Business Model Canvas
DERs	Distributed Energy Resources
Rx	Receiver
DSE	Design Space Exploration
E-Bike	Electric Bike
EMF	Electromagnetic Field
WCS	Wireless Charging System
FHA	First harmonic analysis
Tx	Transmitter
IPT	Inductive Power Transfer
ICPT	Inductive coupled power Transfer
MCT	Magnetic Coupling Transfer
MPT	Microwave power transfer
COVID-19	Corona virus Infection Disease 19
PPc	Parallel-Parallel compensation
PSc	Parallel-Series compensation
PWCO	Potential weakness constraints and opportunity
Rx	Receiver (on the secondary side)
SPc	Series-Parallel compensation
SSc	

Chapter 1. INTRODUCTION

1.1 Background

The bicycles play most practical ways of transportation. They are effective, cost-effective, environmentally friendly, and riding leads to a long and healthy life. Recent statistics indicate that [1].The electric bicycle, a new model of bicycle has transformed the cycling business. The electric bicycle enhances and expands the human-powered lifestyle. This innovative mode of transportation, along with electric automobiles, trains, and other electric vehicles, is classified as an EV. Traditionally, electric bike battery charging systems have been plugged in indoors. This wired charger could only be used indoors or in a supervised and secured area to prevent misuse, incorrect operation, vandalism, or even injury

The e-bike allows for the comfort of relaxation and contentment while also generating a profit. Over the last few years, it has been clear that Rwanda's integration and demand for electric mobility has expanded. Novel market demands necessitate the development of new charging facility schemes, including the use of wireless charging systems (WCS) technology to e-bikes. Serious issues can arise with wireless charging, such as the user's requirement for comfort when it comes to wireless charging equipment and the promise of charging efficiency. The prediction for electrical wireless charging capability is becoming more hopeful as the technology advances. Current research and discoveries have resulted in several technologies that enable an electrical wireless charging system for e-bikes. Many of these solutions, however, are only applicable to specific schemes and have restricted uses. To improve this, a space expedition called Effective Design will be required (EDNE) [2].

1.2 The goals and Research question

The principal Research goals

The specific goal of this project work is to examine the wireless charging system WCS for electric-bikes and propose a new prototype feasible, efficient, and secured electrical wireless charging operational for the electric-bike. This will be achieved by carrying out an Effective Design space exploration EDNE to discover a positive design amidst all the designs in related works. Based on the similar works, definite parameters will be recorded and investigated.

This parameter can have a variety of effects on charging concerns, including feasibility, efficiency, and security of electrical wireless charging. Here, market and manufacturer leaders' input will be used as well. In addition, a case implementation analysis using the PWOC (Potential weakness, opportunity, and challenge) method is carried out to develop a strategic integration system for wholesale e-bike companies or government policymakers to categorize potentials, weaknesses, opportunities, and constraints. The next paragraph comprises the primary research questions, followed by four sub questions that this thesis will investigate to fulfill the major study goal.

1.3 Research Questions

The goal of this study is to find solution for question identified in this research**: in which parameters of electric wireless charging system model be achieved in such a way that is practical, efficient, and secure for an e-bike battery charging system and e-bikes transport integration**?

Connected questions:

1. *What are the resolutions among different investigated and analyzed electrical wireless electric-bike charging methods?*

Outstanding features used in research or related studies on electrical wireless charging systems are studied to discover a solution to this problem. These analyses are compared and studied to detect any significant deviations or resemblances. (This is covered in Chapter 3)

2. *What are the most essential parameters that affect the electrical wireless charging mechanism's efficiency, practicality, and security?*

   Several characteristics should be set to determine what develops the feasibility, efficiency, and security of WCS in e-bikes. The consequences of these will be studied to determine how they affect the condition and quality of the e-bike charging system. (This is covered in Chapters 4&5)

3. *How can e-bike transport integration in Rwanda can be achieved and put in service with WCS electric-bikes*

An integration strategy is developed to determine whether the concept of the WCS electric bike can function as a standalone well-operating system. (This will be covered in Chapter 6)

1.4 Intervention

The purpose of this project is to study the integration of electric bikes in Rwanda, to investigate WCS for electric bikes, and to provide a framework for a new practical, efficient, operational, and secure prototype. The factors that guide the electric-bike wireless charging system are the specific criteria considered in this research.

The foundation for building the prototype proposed in this research work can be used in future studies where motivated scientists and engineers can design, build, and optimize it. Driven and motivated with the new Rwandan government policy of starting e-mobility campaign to reduce greenhouse gases emissions.

1.5 Methodology

For this thesis, the hierarchical order of system engineering has been used. According to engineering system, we have a definite set of steps used to design, analyze, and validate a working system. This is known as system life-cycle engineering as represented in Figure.1. This thesis is centered on two main pioneer parts in the acquisition phase: conceptual design and & the preliminary design phase and definite design & development phase.

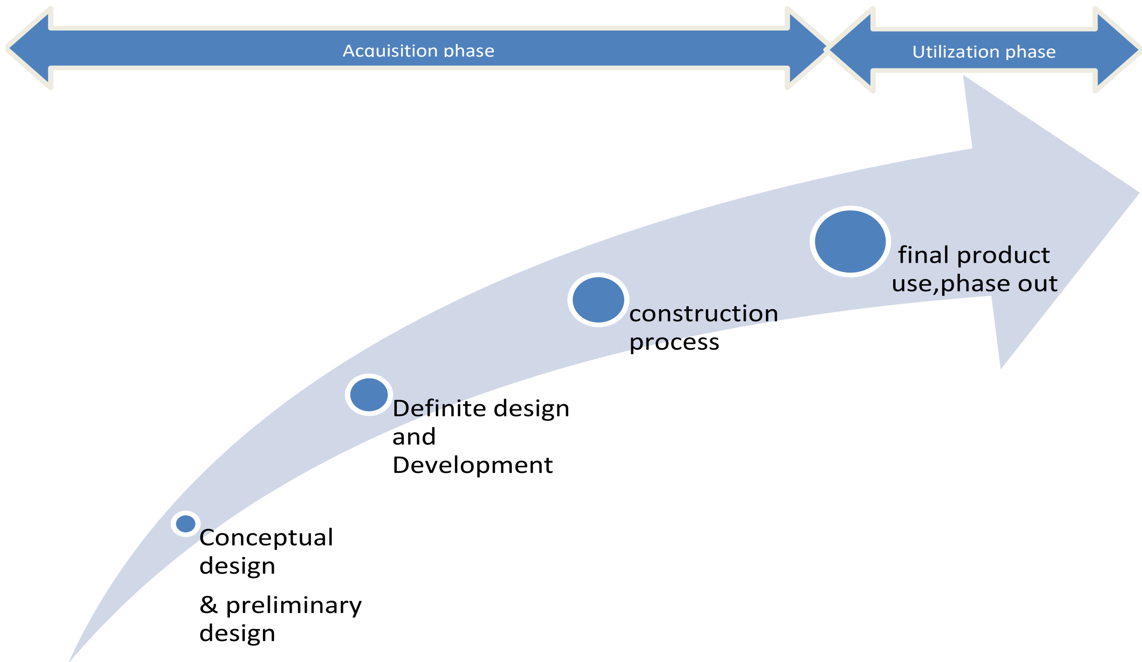

Figure1. 1 Engineering Life Cyle System

Conceptual design (what?) **-Chapter2**

A literature review is conducted in this step to learn more about the technology underpinning WCS in e-bikes and IPT. Identifying several parameters that influence the quality of system charging is also a goal. The design will be discussed in chapter three and four.

For the following phase, all the necessary parameters that have a positive influence on feasibility, efficiency, and security of WCS e-bike are recorded and analyzed. These are recommended for the new prototype.

Concept design and development –Chapter 5 and Chapter 6

The prototype can be built in the laboratory at the University of Rwanda's African center of excellence in energy sustainable development, using the current facilities. The primary goal is to establish a fundamental product guideline as well as future recommendations.

The means, conduct, and materials adopted to collect data and performing research are:

- Analysis of current data using documents
    - Books
    - Webinars
    - Master's thesis works
    - Research papers
- Interviews with domain engineers
- Survey regarding integration opportunities and challenges

Limitations

Several obstacles were encountered throughout this project's structured design and development phase, producing a change in the original plan. The laboratories facilities at the African center of excellence in energy sustainable development were inaccessible until the thesis conduct period due to COVID-19 actions adopted simultaneously by the government.

As a result, the expected concept prototype that was supposed to be built in the lab never got off the ground. Nonetheless, because of this conversation, a foundation for future dedicated and committed field engineers to pursue has been established.

1.6 Arrangement of theses

The core of this thesis is divided into chapters. Chapter 2 contributes to the e-bike literature review by including consistent details to comprehend wireless charging systems WCS in electric cars (EVs) and induction power transfer. This section continues in chapter 3, with three of the most important and fundamental existing electrical wireless charging solutions for e-bikes presented and contrasted. The resolves among the highlighted metrics from the previous chapter that suggest a difference in different electrical charging techniques for e-bikes are investigated in chapter 4.

The framework for concept prototypes is described and proposed in chapter 5. The integration plan for a WCS e-bike opportunity and difficulties are presented in chapter 6. Finally, chapter 7 contains a review of the prior chapters' thorough conclusions as well as future recommendations. Additional information can be found in the appendix.

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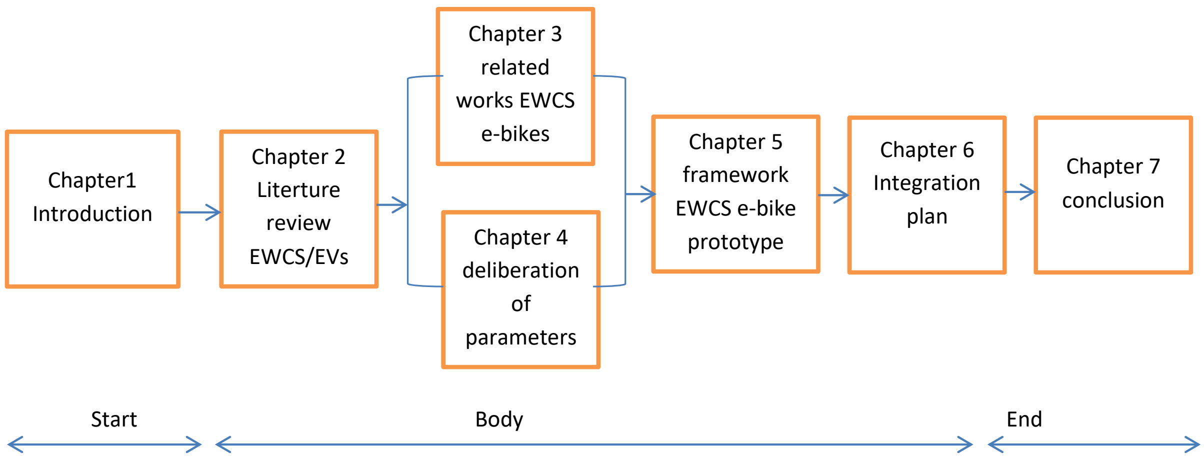

Figure 1. 2 Thesis structure overview

Chapter2. Literature review

This chapter contains words, definitions, and technological advancements for electric vehicle wireless charging systems. In paragraphs of part 2.1 and 2.2 discusses the basic characteristics that a working system should have to construct an electric wireless charging system. In Section 2.3 of this chapter, we'll go over the notion of inductive power transfer (ITP) and how it's used. Finally, in section 2.4, the second half of this chapter focuses on the e-general bike's operating mechanism. Section 2.5 concludes with a discussion.

2.1 Introduction

An electromagnetic field is utilized in an electrical wireless charging system to transport electric energy from a primary power supply to a secondary load over space without the usage of physical connections[3]. A century ago Nicolas Tesla conducted a research experiment on the transfer of the electrical power transfer wirelessly [4]. With the formulation of Maxwell's equations in 1862, the concept of wireless power transfer was born and WCS is already well recognized as a way for charging electric vehicle batteries (EVs) [5]. Global ambition, development, and exploitation of clean green energy resulted in a significant growth in the use of renewable energies [6]. This has resulted to a reduction of the use of fossil fuels such as coal, peat, oil, and natural gases, based on recent research highlights, the use of clean and efficient energy innovative technologies is one of the promising initiatives. WCS for EVs has the ultimate potential to overcome the inconveniences of wired chargers. And remove some hindrances toward the sustainability of electric mobility.

According to the application, such as mobile phones, implanted medical equipment, household electronic appliances, robotics, laptops, television, electric bicycles, and robust electric cars, the frequency of wireless battery charging systems vary from low to high. When compared to most electronic equipment, EV charging appears to be at extraordinarily high degree, ranging from a few hundred watts (as in the case of e-bikes) to many kilowatts.

The electrical wireless charging systems (WCS) is not yet fully commercialized and given a standard. However, implementation using Inductive Power transfer (ITP) between two coils. It offers in terms of feasibility, efficiency and security to the operators and users. Further on this is described in section 2.3.

The main difference between wired and wireless power transfer is that wireless charging employs an air core in the transformer, whereas wired charging uses an iron core.

By putting the bicycle on the charging platform, the charging of e bike does not requires removing battery charging equipment or plugging it in with a cord. WCS technology can be utilized to eliminate many of the risks and limitations associated with traditional charging techniques.

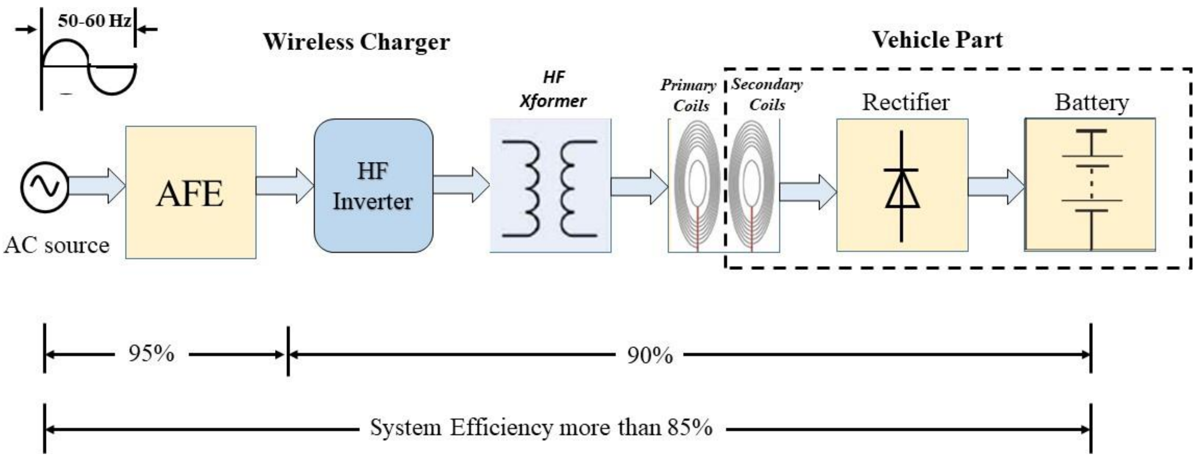

Figure2. 1.Block Diagram of a Wireless Charging System[6]

2.2 Wireless power transfer Components

The following are the components of wireless charging electric vehicles, according to the author [7].

The power supply links the bike to the power source, allowing it to gain electricity.

Charging infrastructure is made up of the main energy transmitter and the charging unit, which transfers electricity from the grid via an electromagnetic field.

Pickup: A supplementary equipment is a component that link energy from the power transmitter unit and consists of a pickup unit mounted to the vehicle's bottom surface to receive energy.

Load: equipment to be charged.

2.3 Inductive power Transfer (IPT)

The current technology that enables WCS in electric bike is Inductive Power Transfer (IPT). IPT deliver electric power from their air-cored primary and secondary coils to a consuming device via a high-frequency magnetic field (load)[9].

Due to the elimination of plug T in/out operations, the IPT delivers various benefits to the driver in terms of safety and comfort. When using the power cord is problematic or impossible, the suppression of wire cables can be advantageous. IPT systems generate electricity without requiring any physical touch, therefore they are unaffected by dirt, ice, water, or chemicals, making them both ecologically benign and low-maintenance cost.

Electric vehicles are charged through IPT in 3 main common modes according to [12]

Static mode: when an electric vehicle (EV) is stationary and the driver or operator is not using it, such as when an e-bike is being charged

Contactless mode: the charging process occurs when the EV is stationary, but the driver or operator must be inside the EV.

Dynamic mode: the vehicle is charged while it is in motion, such as a moving train.

Today's R&D academic experts have proposed numerous possibilities for the location and attributes of the coupled coils. While this technology is still in its infancy, IPT charging is preferred for use with a stationary e-bike.

2.3.1 IPT Working principle

The induction power transfer system is divided into two components. There are two sections: the first part, which houses the power source, and the second section, which houses the charging batteries. The first and second parts connected electric circuits are in the shape of coils to increase the magnetic field of the circuits. A magnetic field is formed when a current flows through the sending or transmitter coil (primary/charging part/Tx).

The receiving coil (secondary/pick up/Rx) is magnetically connected to this. The secondary coil generates a voltage when the transmitter current varies. The battery charger can also be driven by the magnitude voltage created in the secondary coil. Figure 2.2 depicts a basic IPT WTP setup.

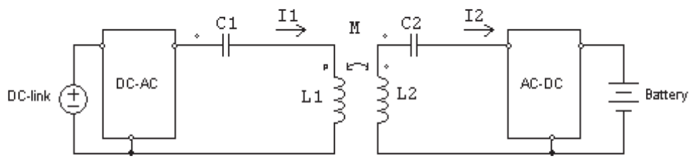

Figure2. 2. Circuit diagram of the IPT system [13]

C1= primary compensation capacitor, C2= secondary compensation capacitor
and L1= self-inductance primary coil, L2= self-inductance secondary coil
M= The mutual inductance, I1= current primary and I2= current secondary

For above-mentioned circuit is described in part 5. IPT happens between two magnetically connected coils, as previously explained. Their self-inductance is L1 and L2, and their mutual inductance is M. Coefficient for coupling is mathematically defined as:

$$k = \frac{M}{\sqrt{L_1 L_2}}$$

Equation 1. coupling coefficient [7]

2.3.2 IPT Compensation circuits

In system of two-coil, a weakly transformer linked with leakage inductances needs the use of compensating methods. On the first part (or transmitter) side, the compensation topology is used to reduce the power supply's VA rating and achieve zero phase angle (ZPA), implying that no phase shifter is required.

For the power source to create reactive power, ensuring that apparent and true power are equal. The compensation topology tunes the circuit on the secondary (or receiver) side to have the same resonance frequency as the circuit on the transmitter side in order to maximize power transfer[3]. Adjustment topologies also aid in the smooth switching of power transistors as well as the reduction of switching losses. Another advantage of compensation topologies is that they can accomplish constant current or constant voltage charging, which implies that if the root mean square value of the input voltage is fixed, the output DC current or DC voltage will be as well. The four primary compensation topologies are depicted in Figure 2.3: SS, SP, PS, and PP. The letters "S" or "P" indicate whether the compensation capacitors are connected in series or parallel to the coils. The first letter denotes the transmitter side, while the second denotes the receiving side. First harmonic analysis (FHA) is a fundamental analysis method used to examine circuits, and vac is the fundamental component of the inverter stage's input voltage.

Although the battery is a voltage-source-based load whose voltage varies with its state of charge, the battery voltage value must be fixed as a criterion for constructing a wireless charging system at the specified power level. As a result, the battery is regarded as a resistive load, and Req is the equivalent resistance at the rectifier stage's input.

Compensation topologies

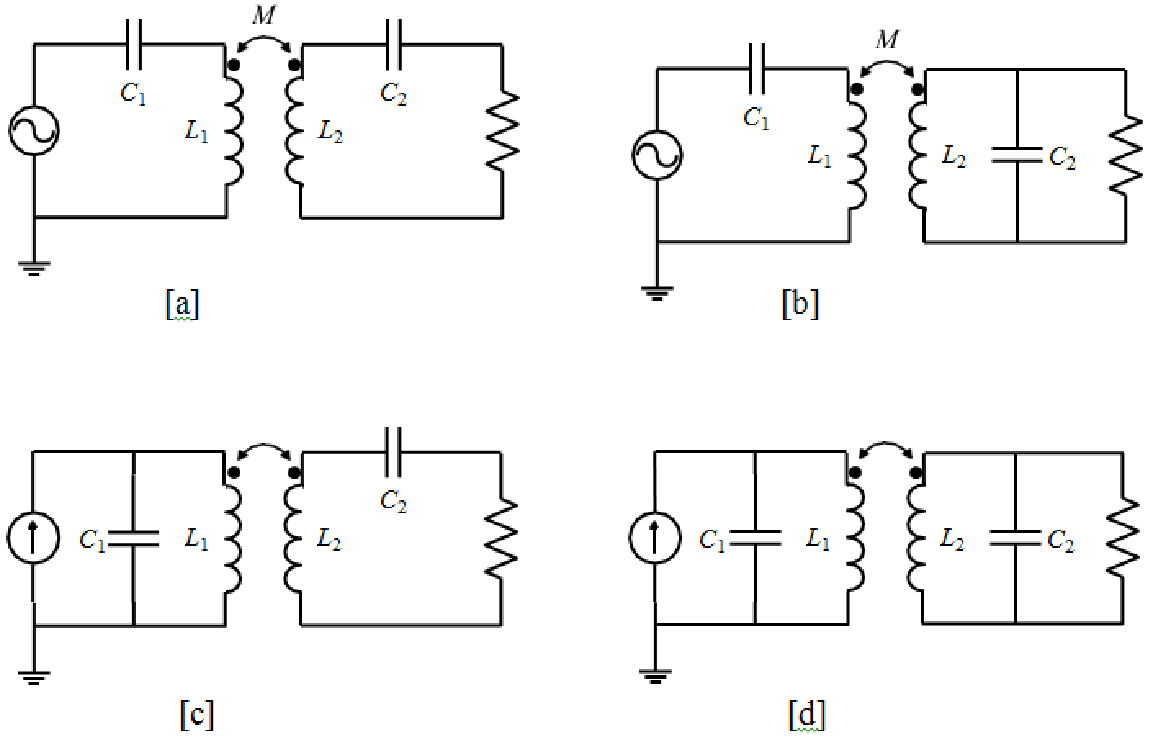

Figure2. 3.Topologies for compensation

(a) SS, (b) SP, (c) PS, and (d) PP.

L1 and L2 are inductor coils, C1 and C2 are capacitors; Vac is alternating voltage; ac is alternating current; M is mutual inductance between the primary and secondary coils; Req is equivalent resistance.

2.3.3 IPT- Power electronics converters and control technics

The electronics converters on the transmitter side convert 60 Hz utility AC current into high frequency AC power at the desired power level. The conversion can be accomplished in two ways: first, the dominant method is indirect two-stage power conversion, in which 60 Hz utility power is rectified into DC power and then inverted into high frequency AC power using a full-bridge inverter; second, a less commonly used method is direct power conversion, in which 60 Hz utility AC/AC converters known as power inverters convert AC power to another high frequency AC power; and third, direct power conversion, in which 60 Hz utility AC/AC converter is proposed .

To charge battery bank, high frequency AC power is transformed to DC power on the receiver side by a full-bridge rectifier. The resonant frequency is determined by the compensation networks and realized by the inverter. The inverter's resonant frequency, or switching frequency, in wireless charging systems for electric vehicles ranges from 20 kHz to 100 kHz. Modern silicon carbide MOSFETs, on the other hand, can have resonance frequencies as high as 1 MHz [14]. Higher frequencies makethe wireless charging system more compact, but other issues introduced by high frequency AC, such as EMF emissions, need to be further studied.

2.4 Electric bicycles

The market for e bike is rapidly increasing, resulting in strong increases in demand for e-bike manufacturers around the world, and electric bikes are becoming more affordable and less expensive. The constant advancements in battery technology demonstrate that using an E-bike is quite viable and offers substantial advantages, particularly in terms of reducing the driver's mechanical energy when compared to a regular bike. The e-bikes are powered by a battery that lasts roughly 75 kilometers. Despite its flaws, it is functional and requires less maintenance than a gasoline-powered motorcycle. An electric bicycle is a form of electric vehicle that is based on a standard bicycle with the addition of an electric motor to assist with propulsion [7].

The design and efficacity of e-bike adoption promotion campaigns necessitates an understanding of user characteristics and motivations, as well as e-bike use for work, shopping, and leisure journeys. Many studies integrate technology adoption principles with aspects obtained from mobility behavior research. People in their 60s and older are the most common early adopters, who mostly utilize the e-bike for leisure outings. Adopters are frequently pro-environmental and technophile. E-bike usage is primarily influenced by perceived utility, which is dependent on ease of use, adequate infrastructure, as well as user norms and attitudes toward the environment [7].

Main components

There are three primary components in an electric bicycle. The engine is the first, followed by the battery, and then the sensor. To function properly, an e-bike requires all its components to work together.

2.4.1 Motor

The basic function of the motor is to manage torque. An e-motor bike's placement can vary, with each location (mid-drive, front hub and rear hub having its own advantages.

Motor hub in front is mounted on the front tire and spin the tire to create power. The motor makes the bike feel like it's being "dragged" ahead**.**

Propulsion: Near hub motors rotate the back tire to create power. It “push" the rider forward, which may feel more natural to traditional bike riders than front hub motors.

Drive motors in mid Instead of a hub, drive motors in midi transmit power to the bike's drivetrain. It has a more natural riding sensation than hub motors because of its center location.

2.4.2 Battery

Battery technologies play an important part in the increasing market of electric vehicles due to their qualities in terms of power and energy density (EVs). The aging of the batteries, as well as their expected lifetime, are being researched as two more crucial parameters for their utilization. Because of its increased gravimetric energy density [Wh/kg], volumetric energy density [Wh/l], and power density [W/kg], lithium-ion (Li-ion) batteries play a vital role, resulting in smaller and lighter batteries, as demonstrated in Fig2.4. They also have a longer lifespan and no memory effect as compared to other battery technologies[15].

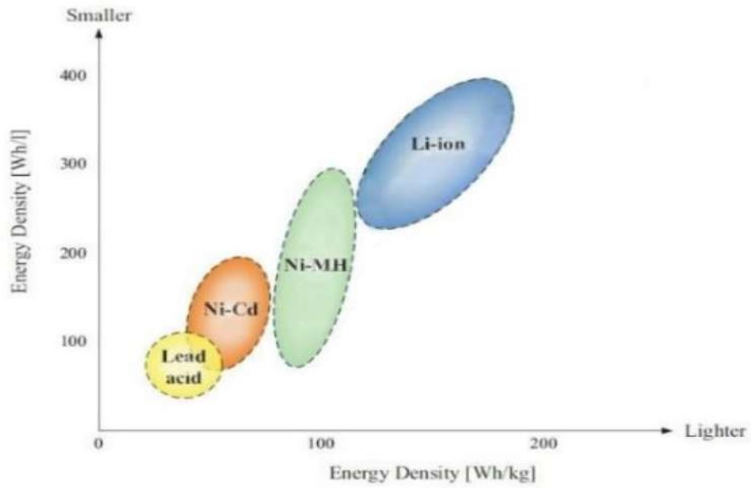

Figure 2. 4. different lithium-ion (Li-ion) batteries and their volumetric energy density[15]

2.4.3 Sensors

The sensor architecture of a user-assisted electric bicycle enables it to optimize a commonly traveled route. The two most prevalent types of sensors in use today are speed sensor and torque sensor.

When you start pedaling, the speed sensor instantly turns on the motor. This allows the cyclist to receive assistance while on the road. When the rider moves, the sensor for torque responds with slowly from the speed match and this improves speed and maneuverability[15].

2.5 Discussions

The following are the reasons for the adoption of wireless charging technology in an e-bike:

- **Comfortability for the user**: When comparing a standard bicycle to an e bicycle, it gives the user with more comfort when traveling, regardless of the distance or slope of the road. Wireless charging systems can also be more convenient because they are contactless.
- **Overcrowding and traffic congestion:** According to research, when e-bikes are available at high level and they are used; a ratio of e-bike journeys normally can be taken in spite of car; and many people will be used.

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- **Integration**: Despite the modest quantity of electric bicycles supplied on the market, e-bikes are on their way to becoming a viable mode of alternative transportation.

- The bike is undoubtedly the most energy-efficient and cost-effective option, but it is only practical for short distances (whether on a mountain, road, or city cycle) and only on flat surfaces. Compared to regular automobiles, an electric bicycle consumes significantly less energy[16].
- **Health**: Cycling promotes physical activity, which helps to combat obesity and other health problems.
- **Social impact** : The employment of moderate-speed vehicles in transportation can make major cities more livable and social, benefiting inhabitants' mental and social health.
- **Environment**: They serve as a motivator to move to a less polluting mode. According to studies, e-bikes generate 30 to 40 times less CO2 than cars, hence helping to lower energy usage and CO2 emissions.
- **Durability**: When power is transferred using IPT, the entire electric circuit is sealed from moisture.
- **Obstruction**: the transmitting source is positioned to have the least amount of impact on the cityscape. If necessary, it could cohabit with existing locking systems as well as other electrical equipment in its immediate vicinity. However, there are certain disadvantages:

User comfort: e-bike weight can rise depending on coil design (size, weight, etc.) and positioning, which might disrupt the working level.

Costs: Depending on the device/equipment type, the design and implementation might be costly.

Speed: many studies show that speed and braking issues remain critical; as a result, many countries have enacted laws prohibiting the use of e-bikes; for example, in Spain, Finland, and the United Kingdom, the top speed is limited to 25 km/h, and the motor's maximum power output is limited to 250 Wh [15].

- **Efficiency**: energy loss between coil gaps is unavoidable.
- **Time**: When compared to wired charging, wireless charging takes longer.
- **Environment**: Battery disposal can be extremely dangerous and polluting.[17].

Chapter 3. Similar Work Analysis

In theory, e-bike wireless charging systems can be designed in a variety of ways. This chapter, on the other hand, investigates and compares the three most important electrical wireless charging technologies. In Section 3.1, which serves as an introduction, the main fundamental crucial parameters are illustrated with their basic demands and restrictions. Part 3.2 examines three key wireless e-bike charging technologies that have been successfully deployed by a variety of researchers.

3.1 Brief Introduction

Following the investigation, a table of parameters was created to show the differences and similarities between the wireless e-bike charging techniques. Every setting has a different effect on the wireless charging quality. Finally, the implementation of DSE can be done using the received list of parameters. Explaining the efficient parameters that can be used to determine the EWCS mechanism's feasibility, efficiency, and security.

The following are the main parameters to be explored for electrical IPT e-bikes working as wireless:

1. *Type of energy resource*

- ✓ Distributed Energy Resources (DERs
- ✓ The Grid-connected
- ✓ Stand alone
- ✓ Energy from Renewable sources

2. *Parameter description of transmitters (Tx) and receivers (Rx)*
    - ✓ Property of used Material
    - ✓ Physical characteristics
3. Location and installation of the receivers (Rx)
    - ✓ Front area
    - ✓ Middle area
    - ✓ Kickstand
    - ✓ Back area

4. Battery technology description
   - ✓ Lithium-ion
   - ✓ Nickel metal

5. Acceptable airgap
6. Efficiency
7. Safety implications

The seven design elements listed above are the most critical, and the main goal is to match these parameters so that WCS in e-bikes is practical, efficient, and secure.

The first sub-research topic is "What are the resolutions among different investigated and studied electrical wireless e-bike charging methods?" To provide an appropriate solution to this topic, the first sub-chapter will present a synopsis of three main studied approaches, followed by the question being answered in the last sub-chapter. The "identification of the numerous characteristics" that might affect the quality of an e-electrical bike's wireless charging is the initial part of the second sub-research topic. These criteria will be thoroughly explored in this chapter and Chapter 4 as can be seen in this part.

Basic demands and constraints

The relevant work considered and constructing the new EWCS e-bike prototype, several crucial fundamental demands and constraints for the presented parameters should be considered.

Energy resource type: The grid, PV, geothermal power generators, clean diesel generators, electric vehicles (EVs), and other forms of energy sources can all be used to power the e-bike electric primary side circuit. Each source will bring multiple network benefits, but we will not focus on that for the time being because it is outside of our scope. With the current global worming crisis and worldwide green environmental campaign, the efficiency, flexibility, and impending market penetration of Distributed Energy Resources (DERs) composed of a combination of many renewable energy sources can be preferred because they are "sustainable" in the sense that they will not run out and are environmentally friendly.

The receivers' location and installation (Rx): The Rx can be installed in a variety of locations on the bike. However, it should be tightened carefully on the bicycle to avoid loosening due to vibration. The long-term alignment of the Rx must be evaluated. It would be configured so that it does not interrupt the use of an electric-bike.

Type of batteries: Various battery kinds can be found in various literatures. The prototype battery should strengthen the power mechanism, be able to survive a long period with a low charging time interval and light.

Acceptable airgap: This value should be kept as low as possible to enable for more strong and continuous magnetic coupling and to prevent electromagnetic interruption and other receiver and transmitter contact disruptions.

Power efficiency: The practical power efficiency ranges from 70 to 90%.

Bibliometric research

As previously stated, there have been numerous notable research on the WCS in the e-bike, also known as wireless power transfer (WPT). The bibliometric studies provide a broad overview of the outstanding e-bike publications that have been published for two objectives yearly evaluation and global distribution. Design space exploitation refers to the process of evaluating a system's performance because of various parameter combinations to find which parameter combinations are optimal. The parts for an effective DSE are listed in the three EWCS e-bike approaches[17].

3.2Analysis of Related Work

3.2.1Case Study one: Resonant IPT and E-bike Charging station

In paper [18] The authors presented the design of an E-bike for a 300-W Battery charger for a cyclo-station based on wireless charging technology, as well as experimental results. The following are the findings of the study: [19] [18].

- ✓ Overview on the RIPT technology
- ✓ Series resonant inductive power converter
- ✓ Mathematical model development and performance analysis

The Dc-Dc boost-type converter was found to be the most compact in terms of e-bike power capacity, and their proposed system was experimentally tested as a prototype.

The maximum frequency points of active input power differ from the maximum frequency points of efficiency and the zero-frequency points of reactive input power, according to the results of the investigations.

The on-board charging system consists of a rectifier converter connected to the battery; however, the upstream circuit of the RIPT

When the yields of the upstream conversion structure were considered, the efficiency was dropped to 85 percent.

Location and positioning inductors on E-bike charging station**:** A stationary inductive charging system for an E-bike cycle station is given as part of the IECO (Inductive Charging Station for an E-bike) is part for this research project. An imaginative mobility and decision to utilize an inductive charging system because of the need for an autonomous charging system that does not require the users' participation.

Figure3. 1: types of e-bike Cyclo-station topologies[18]

Figure 3.1 depicts two representative cycling stations that might benefit from the suggested changes. The first and second windings' geometrical solutions are co-planar and rectangular in shape, which reduces the air gap between the coils and ensures that misalignment is minimized.

This is accomplished by matching the geometry and location of the charging device (primary and secondary) to the geometry of the bike and the pedestal, allowing the system to properly couple the bike to the power source and release it when the charge is complete.

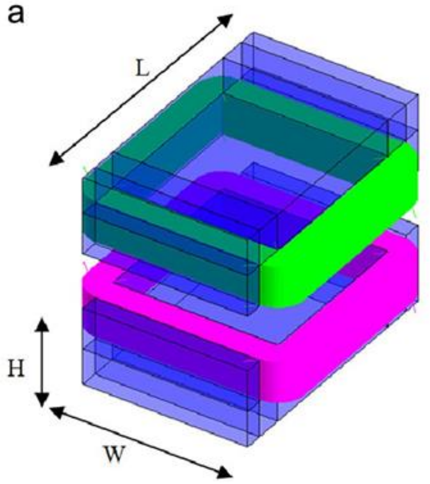
The secondary winding (integral with the bicycle frame) is situated between the center tube of the seat and the diagonal tube in Fig3.1a, while the primary winding is fixed to a column. The secondary is mounted on a support in front of the wheel in Fig3.1b, while the main is fixed to a U-type column with a single stand.

3.1.1 Characteristics of RIPTs

Resonant inductive power transfer (RIPT) is now the most widely used technology in the field of WPT [18]. It uses two or more resonant circuits that resonate at the same frequency to transmit electrical energy as efficiently as possible.

The losses in the ferrite cores are directly proportional to the frequency, and the losses grow as the frequency rises. A Litz wire must be utilized to minimize the resistance of the windings at high frequencies [20]. With today's electrical technology for power generation, the most cost-effective power transfer frequencies for multi-kilowatt systems are on the order of l0–l00 kHz. The SAE Hybrid J2954 standard is currently in use [25]. In EV applications, the Frequency Selection Task Force must be employed to choose an operating frequency of 85 kHz for the maximum input WPT power rating of 3.7 kW. However, due to the SAE resolutions, various obstacles must be addressed, such as the absence of semiconductor switches capable of running efficiently at these power levels and at such high operating frequencies. As a result, many various WPT EV charging prototypes have been built to function at a significantly lower frequency now. KAIST (Korea Advanced Institute of Science and Technology) has chosen 20 kHz for high-power (>50 kW) IGBT devices; University of Michigan-Dearborn has chosen 80 kHz for medium power (10 kW); and MOSFET for high-power, numerous WPT devices in parallel (>50 kW) [21].

a



b

Size	
Length (L)xWidth (W)xHeight (H)	93x60x28 mm
Core Parameters	
Primary, Secondary self-inductance L_P, L_S	91.3 H
Mutual inductance M	30 H
Primary, Secondary winding resistance	19.8$m\Omega$
Capacitor Parameters	
Primary, Secondary Capacitance C_P, C_S	180 nF
Primary, Secondary ESR	42 $m\Omega$
Equivalent Resistance parameters(*)	
Primary, Secondary Resistance R_p, R_s	61.8$m\Omega$

Figure 3. 2: Magnetic core of the RIPT device and parameter dimension of magnetic core [18]

3.1.2 Case Study Two: Resonant IPT located in bicycle kickstand

The papers [22] ,and [23], WPT in e-bikes being investigated ,The authors investigate the WCS with linked lumped magnetic coupler designs that might be put within or around an electric bicycle kickstand to provide wireless charging capability to the on-board battery pack.

Preferences design for a Tx subterrestrial kit and Comparison of several geometrically formed IPT coils either cylindrical or solenoid and more information is provided in table3.1.

The study found that a solenoid bar pickup with a Double-D gave the best coupling, while a solenoid bar pickup and primary looks to be the most cost-effective choice, requiring the least amount of ferrite and copper. In a prototype system, the developed magnetic coupler was able to create an output of 200W with an efficiency of 86 percent.

Type of power source: An alternating current (AC) generator makes up a stand-alone system. The primary receives a track current of 13A from the power supply at a frequency of 38.4 kHz.

Type of transmitter circuits (Tx) and receiver circuits (Rx): The geometrical construction of most IPT coils differs from that seen in Figure 3.2. Copper and ferrite are the most used wiring materials .

Table 3. 1 Characteristics of the magnetic couplers [24]

Magnetic Structure	Primary	Cylindrical Solenoid	Circular	Solenoidal Bar	Double-D
	Pickup	Cylindrical Solenoid	Cylindrical Solenoid	Solenoidal Bar	Solenoidal Bar
Ferrite volume in primary		79.26 cm^3	54.72 cm^3	13.2 cm^3	13.2 cm^3
Ferrite volume in pickup		31.86 cm^3	31.86 cm^3	13.2 cm^3	13.2 cm^3
Copper volume in primary		36.19 cm^3	32.57 cm^3	10.44 cm^3	41.4 cm^3
Copper volume in pickup		10.56 cm^3	10.56 cm^3	6.48 cm^3	6.48 cm^3
Total ferrite volume		111.12 cm^3	86.58 cm^3	26.4 cm^3	26.4 cm^3
Total copper volume		46.75 cm^3	43.13 cm^3	16.92 cm^3	47.88 cm^3
P_{su}/ Ferrite Volume (centred)		0.5453 VA/cm^3	0.6803 VA/cm^3	2.5795 VA/cm^3	2.9621 VA/cm^3
P_{SU}/ Copper Volume (centred)		1.2962 VA/cm^3	1.3656 VA/cm^3	4.0248 VA/cm^3	1.6332 VA/cm^3
P_{su}/ Ferrite Volume (20 mm X offset)		0.3891 VA/cm^3	0.5290 VA/cm^3	1.6363 VA/cm^3	1.8447 VA/cm^3
P_{SU}/ Copper Volume (20 mm X offset)		0.9249 VA/cm^3	1.0619 VA/cm^3	1.6363 VA/cm^3	1.0171 VA/cm^3

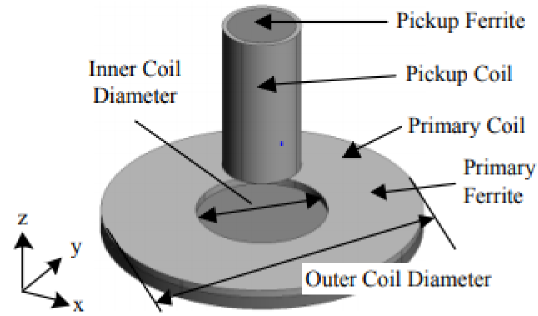
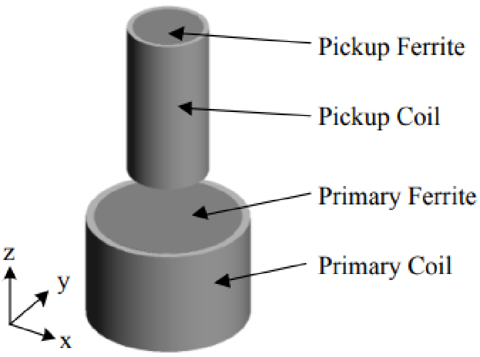


Figure3. 3 circular primary with different ferrite configuration Tx and Rx(



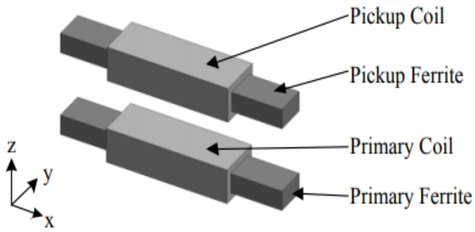


Figure3. 4 solenoid Tx and Rx in cylindrical form

Figure3. 5 solenoidal bar Tx and Rx

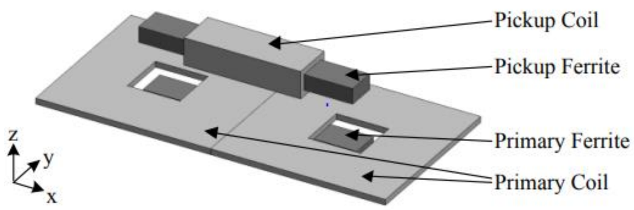


Figure 3. 6 double D Tx with solenoidal bar Rx

Location and installation of the receivers (Rx*)* : Because of the benefits it gives when compared to other positions on the electric bicycle, the Rx is recommended to be placed in or near the kickstand (to be discussed in Chapter 4). If the receiving coil Rx is mounted at a different position, a mechanism is necessary to keep the primary coil near to the pickup during working mode.

Rated power efficiency: The prototype can deliver up to 250W at the output, with an 85 percent pickup efficiency at 200W [25]. Most electric bicycles on the market are powered by 36 V 10-Ah on-board batteries, and the charging mechanism must provide a reasonable charging rate.

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) addressed all basic measurement techniques based on the International Commission of Non-Ionizing Radiation Protection (ICNIRP) guidelines and advised taking average exposure levels at four points on the human body: the head, chest, groin, and knee [30]. Figure 3.6 depicts the simulated magnetic flux densities at the knee, groin, chest, and head based on the author's mathematical calculations, assuming a 1.5m tall female user stands 150mm away from the center of the magnetic couplers.

Table 3. 2 properties of magnetic couplers with air pap of 20mm[25]

Magnetic Structure					
Magnetic Structure	Primary	Cylindrical Solenoid	Circular with ferrite bars	Solenoidal Bar	Double-D
	Pickup	Cylindrical Solenoid	Cylindrical Solenoid	Solenoidal Bar	Solenoidal Bar
Primary turns		20	12	20	10 + 10
Pickup turns		30	30	30	30
Primary size		Diameter: 60 mm Height: 60 mm	Diameter: 142 mm Height: 8 mm	Length: 110 mm Width: 21 mm Height: 14 mm	Length: 180 mm Width: 85 mm Height: 11 mm
Pickup size		Diameter: 30 mm Height: 60 mm	Diameter: 30 mm Height: 60 mm	Length: 110 mm Width: 19 mm Height: 12 mm	Length: 110 mm Width: 19 mm Height: 12 mm
Aluminium shield		None	None	None	None
Psu (centred @ 20mm)		60.6 VA	58.9 VA	68.1 VA	78.2 VA
Psu (X offset = 20mm)		43.24 VA	45.8 VA	43.2 VA	48.7 VA
Psu (Y offset = 20mm)		43.24 VA	45.8 VA	44.0 VA	48.8 VA
Coupling (centred @ 20mm)		0.1646	0.2420	0.2130	0.3236
Primary inductance (centred @ 20mm)		55.80 μH	24.65 μH	37.89 μH	18.72 μH
Pickup inductance (centred @ 20mm)		67.89 μH	69.04 μH	85.80 μH	83.70 μH

3.2 Case Study

IPT Case One: *Front Kit Tx and Rx patch Antenna for the IPT Case 1: Electric double layer capacitors (EDCLs), Batteries, and Front Kit Tx and Rx patch Antenna for the IPT*

In publication [22] Front Kit Tx and Rx patch Antenna for the IPT Case 1: Electric double layer capacitors (EDCLs), Batteries, and Front Kit Transmitter and Reciver patch Antenna for the IPT. The research demonstrates that

- ✓ Main features on the induction power transfer.
- ✓ Study of the characteristics of WPT antenna.
- ✓ Design of the EDLCs capability.
- ✓ Comparison of Dc-Dc converters used in wireless charging technologies.

The overall findings showed that the chopper or boost-type converter is the most practicable and efficient at the e-power bike's capacity level, and they proposed a prototype system with experimental.

Type of power source; Electric double layer capacitors (EDCLs) are used as a power source in this stand-alone circuit made up of a direct current (DC) generator. Wireless power transmission is used to charge EDLCs using a quick charger.

Type of transmitter circuits (Tx) and receiver circuits (Rx): Microstrip patch antennas are utilized in both the receiving and transmitting circuits. Microstrip antennas are wireless transmitters and receivers of frequency signals.

The patch antenna is the most commonly used microstrip antenna because it has a number of technological advantages, including ease of manufacture, a simple structure, and easy integration with microwave integrated circuits [23].

Copper is used for the wiring, and the geometrical shape is a planar octagon. Because the coils are loosely connected, a reactive network (SS compensation circuit, chapter 2.3.1) is required to increase power transfer efficiency and optimize the power factor [26].

Location and positioning inductors on E-bike charging station: The e-front bike's structure. As shown in Figure 12, the receiver is mounted in front of the bicycle basket, while the transmitter Tx is mounted on the straight wall. In the publication, a comparable placement approach is also developed and described [22].

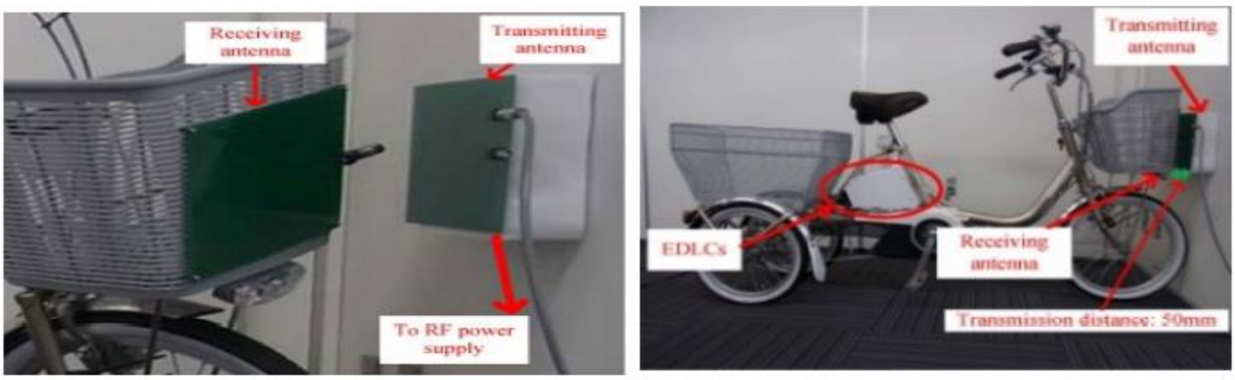


Figure3. 7:methods of wireless charging of the electric[22]

Type of battery: Instead of Lithium-ion, EDLCs are used. Because of its high energy density, the lithium-ion battery is ideal for extended assist times. The battery in lithium ion however, has a short lifespan and requires a considerable charging period, according to the authors.

Parameter characteristics of EDLCs

The EDLCs is defined by the author [26] as a equipment that employs induced ions between an electrical conductor such as activated carbon and an ionic conductor such as an organic or aqueous electrolyte. EDLCs have a higher capacity than aluminum electrolytic capacitors, but their higher internal resistance prevents them from being used as ripple absorption in alternating current circuits [23].**Accepted airgap: 50mm**

Items	Values	Remarks
Outline (Length)	250 mm	
Outline (Side)	200 mm	
Number of turns (surface)	10 turn	Short type
Number of turns (reverse face)	10 turn	Short type
Space between copper trace	5 mm	
Width of copper trace	3 mm	
Thickness of PCB	2 mm	FR-4
Thickness of copper trace	70 µm	
Self-inductance L_1	58.27 µH	
Self-inductance L_2	58.70 µH	
Mutual inductance M	21.95 µH	
Designed coupling factor k_0	0.375	
Primary capacitance C_1	586 pF	
Secondary capacitance C_2	500 pF	

Figure3. 8.Experiment parameters[22]

Items	Values
Frequency of the FG	929 kHz
Resonant frequency	929 kHz
Voltage of the FG	450 mVrms
Gain of the RF power source	100
Transmission distance	50 mm

Figure3. 9.Parameters of the Antenna parameters [22]

Case Study 2 According to ICNIRP and ARPANSA recommendations, the proposed magnetic couplers would readily meet the requirements. They looked at methods for calculating average exposure levels at four different sites on the human body [35].

The charging station discussed in [24] that the proposed magnetic couplers would readily meet the criteria if a 1.5m tall user stood 150mm away from the center of the magnetic couplers However, if the charging station will charge numerous bikes at the same time, these calculations must be performed for the unique circumstance. Also in paper [26] They demonstrated that, based on both modeling and actual data acquired during their trials, a 25 cm safety gap from the system's center is recommended for bikers and pedestrians during charging operations. As a result, suitable care must be made in the construction of parking places for the e-bike wireless charging operation. Nonetheless, no experimental results on EMC radiation are offered in this pipe. Operators and passengers should not be subjected to excessive magnetic radiation if IPT uses electromagnetic fields to transfer electricity across an air gap. This can be achieved by constructing the pads in such a way that stray magnetic field emissions are minimized. the magnetic forces at ground level can be contained for limiting the magnitude. As a result, the magnetic radiation directed at users and passengers is reduced.

Case Study 3: EDLC batteries should be used instead of Lithium-ion batteries. On the other hand, employing EDLCs necessitates the inclusion of an additional DC-Dc converter in the electrical circuit, as well as a reduction in lifespan due to the use of electrolyte. When numerous parallel stacks are required, the energy content of the EDLCs may not be sufficient. In this perspective, lithium-ion capacitors could be a promising solution for electric vehicle applications that require greater peak outputs and larger energy[26]. When compared to the other pad configurations, the double-d-Sol design has the highest coupling and the lowest magnetic leakage in terms of coil geometrical shapes and coupling. When other parameters (size constraint, pricing, wire and shielding material availability, etc.) are known, an appropriate shape decision can be made and tested or simulated.

Discussion

The bibliometric investigation discovered that there is now a growth for electric-bike trend when it comes to investigating various techniques for WPT. Throughout the chapter, the most three prevalent design possibilities for a WPT e-bike charger are explored and compared. The response to the first sub-research question, "What are the tradeoffs between the researched wireless e-bike charging methods? Is shown in Table 3.3.

Table 3. 3 Difference between the analyzed wireless e-bike charging

Case Study 1	Technology for WPT:Source:	Resonant IPT
	Airgap:	Battery
	Characteristics coils:	40mm
		Tx/Rx: Two identical planar circular coils have been used
		Wire coil: copper
		Geometrical shape: U-type column with a single stand.
	Positioning coils:	Rx: front section of e-bike, on the front wheel.
Case Study 2	Technology for WPT:Source:	IPT Closed circuit-Ac Lithium-ion
	Battery:	20mm
	Airgap:	Solenoid bar (Tx)
	Characteristics coils:	Rx: dual-D and solenoidal bar Copper wire coil
		Ferrite as a shield
		Geometric shapes include Cylindrical Solenoid, Circular,
		Solenoidal Bar, and Double-D. (side stand)
	Positioning coils:	
Study 3	Technology for WPT:Source:	Loosely coupled -IPTOwn circuit- Dc EDLC
	Battery:Airgap:	50mm
	Characteristics coils:	Tx/Rx: microstrip patch antennas (identical withRx).
		Wire coil: copper
		Geometrical shape: planar octagonTx: vertical wall.
	Positioning coils:	Rx: front section of e-bike, on the basket .

Case Study 1 created a stationary inductive charging system employing wireless power technology and a series resonant inductive power converter with an E-geometry magnetic core architecture. The analytical and experimental results demonstrated how the lowest and maximum relative frequency points of active input power and efficiency altered as the resistance load fluctuated. The analyses found that the maximum frequency points of active input power, efficiency, and zero-frequency sites of reactive input power are not the same.

This shows that the resonance frequency does not correlate to highest power transfer and the conversion of efficiency [18] found that a wide frequency characterization of 30–50 kHz around the specified resonant frequency of 40 kHz was possible. For various air-gap configurations, the design of the E-bike wireless battery charging system is validated in terms of rated input voltage and output power.

Chapter 4. Deliberation of Parameters

The fundamental three typical wireless charging techniques for e-bikes are examined in Chapter 3. DSE was re-defined as a systematic method for determining the best putting into action (parameter) modifications. When all the methods are put side by side, resolution possible reached using the specifications described in this chapter. The examination of the types of resources accessible in relation to the WPT e-bike is detailed in 4.1 section. The numerous considerations in the magnetic coils Rx and Tx in the WPT e-bike technologies are detailed in 4.2 section and part4.3 discusses the numerous batteries options and the most used batteries. The second sub-research topic is addressed in Section 4.4's discussion. The prototypes in Chapter 5 are based on the results obtained here.

4.1 Type of Resource

The first component is source of power, which links the other three components to the power source for them to receive power. The power source is situated on the primary side of the circuit, not on the e-bike side. The main grid or a stand-alone generating system can be used to produce energy. The preferred power sources, as discussed in Chapter 3, are primarily derived from nature: conventional and nonconventional sources. Most of the authors of WPT e-bike-related studies have frequently based on a simple power source circuit rather than the full combination with a renewable resource. There were two power sources available here: primarily alternating current (AC) and direct current (DC). Rwanda, as a signer to the Paris Agreement, is committed to establishing the ambitious targets required to effect change. Rwanda's firm commitment to climate action increases ambition in all components.
Currently Renewable resources are the first option for power source type in today's emerging green energy initiatives. When comparing the three studied renewable sources from Table3, the solar energy source is the best option once evaluating the required input power and the ease of use for an e-bike.

4.2 Structure of Coils that are magnetic

The main elements of an electrical wireless charging system are thoroughly discussed here. The first is the charging infrastructure Transmitter Tx, which is the unit that sends power via electromagnetic induction. The second is the pickup receiver Rx, which intercepts power from the primary side. WPT coils have various users which include robotics, medicine, automotive, infrastructure, aviation as well as medical technology.

Technical performance (shielding, efficiency, k-factor): The main issue with WCS via IPT is the poor performance of magnetic coupling, which has a significant influence on overall efficiency. Factors that play a significant role are listed**:**

- The positioning of the coils and the air gap could have a negative impact on the coupling factor (k).
- The performance of the coils, due to their characteristics, can improve the quality factor (Q).
- Electromagnetic field leakage, which can be lowered with shielding

To improve overall performance, the three main points mentioned above should be strictly followed (efficiency).

Way for installation on the bike: The coils should not be a hindrance or cause discomfort for the user, as well as the overall electrical system and bike structure.

Interference of electromagnetic fields with other electrical components: As discussed in section 2.3.5, the EM field has little effect on humans. Even if the coils are radiated in response to unwanted heat flows, the unwanted temperature increase should not have a negative impact on the other components of the WCS system.

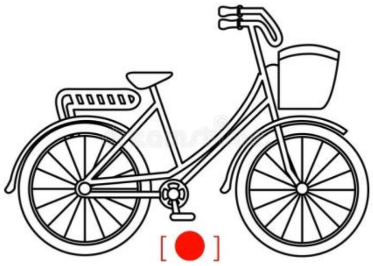
Flexibility about Rx location

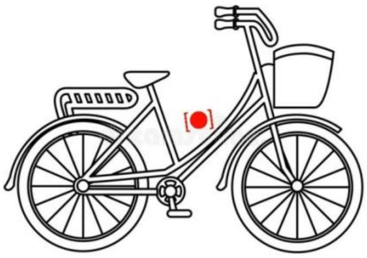
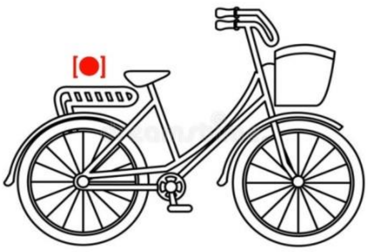
The Tx and Rx can be fixed in different locations, as discussed in Chapter 3. The Transmitter must be mounted on a distinct separate structure. However, it is recommended that the Rx be fixed (not detachable) to the bicycle's metal frame. It can provide enormous benefits by keeping the Receiver in a fixed position, such as:

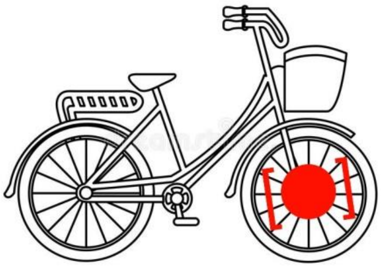
- Reduce material wear affected by user and e-bike displacements.
- Reduce the number of misalignments with the Tx.
- Reduce the possibility of electromagnetic leakage caused by large air gaps or misalignments.

The coming possibilities for the Receiver Rx fixing on e-bike framework are discussed in the following table

Table 4. 1 comparative analysis of Advantages and disadvantages of Tx & Rx[23]

Lactation of RX	Advantages	Disadvantages
Under the bike Kickstand 	**Feasible**: The coils can be mounted in a simple way single or kickstands with two supports (side stand and two-legged stand). When a flat tile is used for the primary coil, a magnetic circuit with a double stand can form a closed circuit. **Safety** According to the type of coils used on the ground level, electromagnetic radiation radiation has no negative impact on the user. **Efficiency**: according to the airgap between the Tx and Rx is definitively low due to the placement of the kickstand on the ground, that can boost the magnetic coupling ratio.	according position of angle for the kickstand there is a high percentage risk misalignment occurs when the TX and kickstand are not perpendicular to each other. Because the device may encounter friction because of this approach Rx is fixed on the Tx device. Many bicycles have different types of kickstands structure therefore it is not directly
Front Basket of the bike 	**Safety:** It is completely safe. The magnetic field has no effect on people's lives or the devices around them. And the coils are placed a little further away from the other apparatus. Paying attention to the coil parameters, this could be a low-efficiency system (see 3.2.1 section).	Feasibility: this no totally applicable, because Baskets are not standard on all bikes. The reason why, it is not directly applicable to many e-bikes. Unequal Heights Misalignments between the receiving unit Rx and the transmitting unit Tx can happen when the bike's basket is being used.

Between bike middle frame 	Normally it could be easily fixed Because it is supported between the images, it is attached to the frame.	**Feasibility** It is not feasible: Because of the presence of other e-bike components and electric wiring, it is not recommended to keep more components in this area, which is also known as the Bermuda triangle. Only applicable with a specific type of bike frame. Many female bike frames are unique.
Under the back carrier 	The horizontal supports the receiving coil Rx coil strongly. framework of the carrier.	**Feasibility**: It is not practical: most e-bikes lack a backrest. carrier. Furthermore, there is a higher risk of danger due to vibration and passengers who may use the back carrier. The coil is attached to the carrier, which must be placed backwards in the charging station. In comparison to the others, assembling the Tx will be more difficult. Most batteries used in e-bike technology are fixed near the carrier, which may result in the creation of interference.
In Front wheel (around the rim or between spokes)	The position of the receiver Rx has been installed and locked. It has a lower maintenance.	The Tx must be designed in such a way that misalignments change only slightly. Because of the Rx circumference

	When the Tx is on a different stellation that supports it, the bike can be secured with a padlock.	around the spokes, the Tx coil assembly could be quite large. Because of the large coils and metal inside the wheel, it is not practical around the rim. Spokes: The magnetic field can cause heat to be generated by the metal spokes and rim. It is recommended that the wheel radius be carefully designed because the primary system must adapt to the height to ensure a high coupling.

Discussion on Fixing Transmitter and Receiver on the bike:

- **The Coils design should be ultimately practical**
- The e-physical bike's appearance should remain unchanged because of the addition of a new Rx unit.

Rx should be installed on the bike and not detachable to reduce material wear and sudden misalignments.

Rx should be set up in such a way that it does not interfere with the user's riding (location, size, and weight).

It should be feasible and applicable to most different types of e-bikes and users.

The Tx and Rx should be resistant to weather and season changes while still operating within their operating range.

- **Effective:**
  - To reduce EM field leakages, a special shielding medium must be used.
  - It should have a very small air gap to increase the magnetic coupling ratio and reduce EM rays.
  - It should be properly fixed so that it does not interfere with other devices.
  - Because the performance of the coils can be upgraded by its parameter characteristics, the quality factor must be carefully chosen.

Next systematic review in books, literatures and visits of some e-bikes manufacture through online platforms, the following necessities, and considerations the following coils have been proposed for the transmitter and Receiver coils:

• The weight of the Rx coil should not exceed 3 kg to avoid overweight and deformation.

• The Rx should not be installed in the middle (triangle area) frame to avoid unwanted loose and damage as a result of a sudden fall and interference with other electronic devices on the e-bike (e.g. motor, battery-pack etc).

• The Rx size should not be oversized and should be approximately 5cm*5cm*5cm (length, width, and height). Alignment is classified into three types: lateral misalignment, angular misalignment, and vertical misalignment. The size of the effective area of the receiver coil in the magnetic field and the width between the two coils in the vertical direction determine perfect coupling and maximum energy transfer. As a result, depending on the position of the Rx, the transmitter coil is either placed in a separate structure construction block or in the ground under a tile when it comes to the place to fix and install the Tx and the Rx. According to Table4, the Rx can be placed in one of two locations: the front frame or the kickstand.

4.3 Coil parameter features

The performance of the coils can improve the quality factor (Q). They can be arranged in metrics listed below:

- Geometrical form
- Transmitter and Receiver dimensions (number of turns; diameter of the coil; wire length etc.)
- Wire material of high quality
- Wire material of high quality

Number of turns: as the number of turns increases, so does the length of the coil wire, which results in an increase in the amount of current flow, which leads to an increase in the magnetic field. Permeability * (number of turns / solenoid length) * current = magnetic field $B = u \times \frac{N}{L} \times I$ However, an increased number of coil turns may result in unwanted losses in the coil-system due to rapidly increased parasitic resistance, reducing coil-system efficiency dramatically. When compared to tightly wound coils, loosely wound coils can improve coil-system efficiency.

Shield Material characteristics*:* Ferrite or aluminum? In paper-reviewed studies [27] It has been demonstrated that material for shielding, guiding, and confining magnetic flux is required to ensure good coupling and to meet the magnetic field absorption limits set by ICNIRP [28]. The size of ferrite and aluminum has been shown to have a significant impact on the coupling factor and magnetic field.

Edge effects have a significant impact on magnetic field behavior.

The two main functions of shield are:

- Offering a "short path" for the magnetic flux to reduce and limit the heating of other outside of the shield.
- Amelioration of inductance so that windings coils are reduced, saving excessive resistance.

Acceptable air gap: To avoid magnetic leakage, the air gap should be very small. Tx and Rx contact disruption may occur in the future. Many e-bike studies for wireless applications have air gap ranges ranging from 1mm to 5mm. The air gap for this prototype should be between the acceptable range.

Considerations for Magnetic Field Safety

To ensure the safety of users and passengers, the charging system should adhere to the guidelines of the International Commission on Non-Ionizing Radiation Protection (ICNIRP). Typically, the magnetic flux density in the entire system should be less than 27 T at 3 kHz 10 MHz (Ubiquitous IPT zone) Zone U-IPT [28].

4.4 Battery technology Types

The last and critical part of electrical the wireless charging system is examined in this article. The primary load; the one being charged. E-bike batteries will undoubtedly determine the distance that an e-bike can travel while riding. The two main things that the user shouldpay attention on, is to determine the need and affordability. Following that, a decision can be made based on:

1. Practicability of proposed storage battery technology
   - Dimensions & Weight
   - Form
2. Battery effectiveness
   - Specific storage Battery type (Lithium-ion Lead-Acid, NIMH, etc.)
   - Rated power
   - Charging time
   - Battery life spam

4.5 Practicability

Worldwide it is recommended to keep the e-weight bikes under control in a range of 100-140 kg. Where the battery Wight must not be beyond 1 kg. Also, the battery must possess a good size and shape.

Example from Daymak most e-bike batteries are mounted on an e-bike carrier so that their weight is fixed and supported by the carrier frame and their size must fit easily to avoid inconveniences for the user and other bike main components.

4.6 Battery Efficiency

Paratactically the most adopted the following batteries have been used in electric bycle:

1. Lithium-based
2. NIMH-based
3. Lead Acid-based

4.6.1 Lithium-based battery

The lithium-ion (Li-ion) battery technology has a main role due to its characteristics in terms of power and energy density. However, the aging of the batteries and their expected lifetime, which are other two key parameters for their utilization, are still under investigation.
Pros and cons are presented in table5. Below

Table 4. 2 Pros and cons lithium-ion (Li-ion) battery[26]

Pros	Cons
❖ High power density [W/kg], ❖ volumetric energy density [Wh/l] ❖ smaller and lighter batteries ❖ higher gravimetric energy density [Wh/kg], ❖ have no memory effect compared to other battery technologies ❖ fast recharge time ❖ high storage capability	❖ Very expensive. ❖ Additional protection mechanism ❖ necessitate special handling ❖ Only a few Li-ion battery recycling programs have been established.

4.6.2 NI-MH

The memory effect has a significant impact on Nickel Metal Hydride batteries. the battery does not recognize that it can be discharged further depending on the status either recharge or discharge.

Table 4. 3 Nickel-metal-hydride battery

Pros	Cons
➢ Its composition has no toxic metals. It is considered as environmentally friendly. ➢ Recycling capability	➢ provides enormously more heat during charge process ➢ service life limited ➢ High maintenance cost

4.6.3 Lead Acid-based Battery

These type of batteries were adopted by users due to its use and availability on a low cost Now, most electric electric mobility such as e-scooters e-bikes and e-motorcycle still chose to use SLAbatteries. On the other side.

Table 4. 4 Lead Acid battery

Pros	Cons
➢ Low cost ➢ Manufacturing and process are not difficult ➢ Reduced self-discharge	➢ The weight is too high ➢ Lifespan reduced were shorter life ➢ Susceptible to poor treatment ➢ Unfriendly to the environment

It is observed that a lithium battery has roughly 2-3 times the lifespan of a SLA batteries in lithium ion produce the same amount of energy as NiMH batteries but weigh approximately 20% to 35% less due to their high energy densities.

Table 4. 5Analytical Comparison between 3 types of batteries for e-[23]

Parameters	***NiMH***	***Lead Acid***	***Li-ion***
Density of Gravimetric Energy	from60-120	from30-50	from110-160
(Wh /kg)			
Internal Resistance (m Ω)	from200 to 300	<100	from150 to 250
	6V pack	12V pack	7.2V pack
Life of a Cycle (to 80 percent IC)	from300 to 500[2]	from200 to 300[2]	from500 to 1000
Quick Charging	2-4h	8-16h	2-4h
Tolerance for Overcharging	low	High	very low
Month /Self-discharge	30%	5%	10%
Voltage of the Cell (nominal)	1.25V	2V	3.6V
Load Current Maximum	5C	5C[7]	>2C
best outcome	0.5C or lower	0.2C	1C or lower
Temperature at Work	from-20 to 60°C	from-20 to 60°C	from-20 to 60°C
Maintenance is required.	from60 to 90 days	from3 to 6 months	not required

Why choose the Lithium based batteries?

The author [49] illustrate the main advantages that set Lithium-ion batteries apart:

- Lithium batteries have an appropriate weight-to-capacity ratio.
- have no memory effect compared to other battery technologies
- lithium-ion batteries in terms of Specific capacity, it becomes the highest among all existing battery types.
- Lithium-ion battery has a fast recharge time in comparison to the other three

As covered Lithium batteries have an appropriate weight-to-capacity ratio. According to current e-bikes manufacturers, they prefer to use lithium-ion battery cells.

4.7 Rated Power

The power of e-bikes is restricted in Europe to the maximum rated power of 250W and the maximum speed of the speed 25Km/h [29] . If the power and if the e-speed bike's exceeds 250W or 25Km/h, it must first apply for registration, insurance, a license plate, and so on.

E-bike batteries can come in different voltage levels of 24V, 36V, 48V, and 72V batteries. And the current Amps-hours (Ah), which determine the capacity, shows the battery's life and is found in the 10-20Ah range. As discussed in Chapter 3, the maximum output ideal for the basic requirements is 100 percent. But practically we find that losses are inevitable and t that are always present many studies said that they achieved a power output efficiency of 70% or higher. As a result, our maximum target for the new prototype's output power efficiency should be greater than or equal to 70% of the supplied input power, Efficiency = Pout / (Pout-Ploss[30].

4.8 Time to Charge

Normally, it takes 3.5 to 6 hours to fully recharge battery kit for an e bike that has been fully depleted. Batteries that are still partially charged will take less time to charge. When the battery is not fully charged and is used when it is half charged, there is a risk that the battery's life expectancy will be reduced. However, some fast-charging mechanisms can also be used.

4.9 security

E-bikes are considered zero-emission vehicles because they produce no combustion gases. E-bikes are said to have a significantly lower environmental impact than conventional automobiles and are generally regarded as environmentally friendly in cities [31]. The consequences of manufacturing and disposing of batteries must be carefully considered. It is recommended that batteries be recycled once they have reached the end of their useful life.

4.10 Discussion

The analytical investigation of possible optimal parameter options is addressed in this chapter. The parameters that can affect the efficiency, feasibility, and security of an electrical wireless charging mechanism?' The following factors influence the WCS in an e-bike: the type of power source, the characteristics of transmitter parameters (Tx) and receiver parameters (Rx), the positioning and placement of coils, and the type of batteries.

From this chapter we can make a brief summarize as:

- Following theoretical deliberation, the coils can be placed as follows: Transmitter coil can be placed in a different construction block or in the ground beneath a tile. This will be a permanent fixed system mounted to the ground, into which the bike will eventually be locked and secured.

The Rx can be found in one of two locations: the front frame or the kickstand. The coil design of the Tx and Rx should be such that it can be used for various types and sizes of e-bikes.

- The coil receiver weight should not exceed 2.5 kg. The Rx area should be larger than 5 cm, 5cm *5cm* 5cm (height, length, and width).
- The surface of the receiver coil should be equal to or less than 80% of the surface of the Tx coil. The coil can be made of litz or copper with a ferrite or aluminum shielding. Geometrical shapes that coils can take: Circular planar; U&I-core; Cylindrical solenoid.
- To have an efficient WCS, the k and Q studies should be carefully chosen because the coupling factor (k) can be influenced by coil poisoning and the quality factor (Q) can be improved by coil performance.
- A lithium-ion battery was chosen as the best battery option for the e-bike. The battery should be in a shape and size that allows it to be easily adjusted on the bike while adding as little unnecessary weight as possible. Fast chargers to charge a battery to 50% capacity or an advanced variable amperage charger that can either slow charge or fast charge as needed can be used for a faster charging process of a battery. However, depending on the chemistry and care, all e-bike batteries have a specific lifespan.

Chapter5. Design of WCS E-bike Prototype

Previously, many design scopes of wireless charging technologies were evaluated, and some new possibilities and choices are now proposed prototype. In this part, a new conceptual framework for new WCS e-bike prototypes will be developed by focusing on magnetic coupling capability and electronic design factors. Section 5.1 presents an overview of the three primary expected prototypes. Section 5.2 provides a conceptual framework for the prototype's magnetic coupling coils.

5.1 Introduction

This chapter provides a framework for dealing with this. The framework, defined as a set of principles, ideas, or beliefs used to plan or decide something, gives a definite impending foundation that future developers can use to build the intended WPT e-bike prototypes or as a starting point for creating their own prototype. The studies and recommendations offered here are based on current information, related research, observations, and AMPERSAND interviews. The following parameters must be fulfilled in the new prototype

1. **Feasibility**

- All the main segments should be joined all together with the e-bike frame without changing the normal usefulness of the e-bike and user.
- Smooth operation for the receiver coil(s) on the e-bike
- Smooth operation of the Tx coil(s) on the ground

2. **Efficiency in rated output power**
3. **Security**
    - Safety for surrounded beings with respect to EMI radiation.
    - Safety and impact for the environment according to the used materials.

As proposed in Chapter 4. Theoretical Deliberation of Parameters, the three main current prototypes are discussed:

1. **Circular planar spiral coils**

   Tx: Circular planar; Location of fixing: independent construction section block,

   Rx: Circular planar; Location of fixing: front frame of e-bike.

2. **Cylindrical circular solenoid coils**

   Tx: Cylindrical solenoid; Location of fixing: Tile, sub terrestrial.

   Rx: Cylindrical solenoid; Location of fixing : Kickstand.

3. **U-core; I-core coils**

   Tx: I-core; Location of fixing: Front frame of e-bike.

   Rx: U-core; Location of fixing: independent standing construction section

Each parameter should be chosen and designed in accordance with the explanation in Chapter.3. The information provided here can aid in the construction or simulation of coils. To increase the power flow, efficiency, and power factor of the power system, the IPT coils in the suggested prototypes have been regulated with SS capacitors. This arrangement can function on the resonance frequency of the adjusted system. The IPT prototype is based on intimate magnetic coupling, with coil separation of little more than 5 mm. The power in the circuit can be changed by adjusting the frequency of the coil current.

5.2 Magnetic coils with its characteristics

The primary goal of the WCS coils is to transfer as much power as possible as efficiently as feasible. This can be hampered by the following factors:

When the distance between Tx and Rx is minimal, the magnetic coupling coefficient ratio (k) increases; otherwise, it becomes contrary.

Parasitic resistances: which can result in losses and a low efficiency?

Q-factor is mostly impacted by coil performance.

As previously stated, the placement of the receiver and the properties of the coil have a significant impact on WCS efficiency. that is why they must be properly chosen and implemented.In Figure 5.1 the flowchart is provided to design different types of WCS coils for e-bikes. The framework can also be used to the three proposed prototypes.

The identification design goals of the specific prototype need to be done. In this scenario, the main design goal is that the three different coil types proposed must be feasible and sacured as considered in part 5.1. During the process on the design goals, a certain number of limiting factors are. these constraints include application domain, the applicationarea, size, weight, and working frequency.

As previously stated in Chapter 4, you cannot put the Rx coil wherever on the e-bike since various aspects (feasibility, safety, interference, aerodynamics, etc.) must be considered. Practically, the coils should be small. The weight of the coil must also be minimal, as it may cause discomfort to the rider. The Rx must be small, being around 5 cm in length, 5 cm in width, and 5 cm in height. The surface of the receiver coil should be equal to or more than 80% of the surface of the Tx coil (see 4.2). The weight is proportional to the geometrical shape of the coils chosen, the coil material, and the shielding material utilized. It is not advisable to add additional devices to the bicycle that increase its weight. It is very recommended to keep the weight as light as possible. According to an interview with local e-vehicle makers AMPERSAND and GURA RIDE, the weight should be kept around 2.5kg (see 4.2.) The working frequency is critical in this case since it is affected by many circuit characteristics.

The next stage is to include various inputs such as wire parameters, number of turns, inner and outer radius, wire material, shielding material, geometrical pattern, air gap, and lateral misalignment. The number of turns in each coil is also affected by many factors such as coupling coefficiency, power losses owing to wire length, and the skin effect[32] .The diameter of each coil should be chosen based on the space limits of the e-particular bike's position. To resist skin effect, the wire that can be used for coils is litz. Three geometrical prototypes are proposed. As previously stated, the air gap should be kept as small as possible to improve magnetic coupling (k). When connecting the two coils (Tx and Rx), lateral misalignment is possible. This should be carefully evaluated and computed when the input compromises the limits for design, should be examined again, and the input parameters should be modified based on those variables. If the input agrees with the coils' design limits, we examine the output rated power circumstances. The coefficient (k) between the primary and secondary circuits must be strong to achieve the best efficiency and power transfer in the WCS. This indicates that the coils must be near together (with a tiny air gap). In the kickstand and front tile, putting the coils near together is not a possibility. To fill the kickstand with ferrite material and construct a u-shape core in the tile on the primary side, resulting in a tiny air gap and a high permeability route should be the best method.

A validation process must be carried out when the coils are built in a test laboratory or a simulation software. The WCS coils are ready for use on the e-bike. If not, the needed output power should be double-checked.

Magnetic coils can be designed and validated using the EMWORKS magnetic and electric field modeling program, a true Multiphysics software that lets to combine the magnetic, and electrical design circuit, motion, thermal, and structural analysis. Begin with a new model wizard in the user interface. The precise space dimensions can be used. A comprehensive 3D electromagnetic simulation of the coils can be performed utilizing entire 3D geometry to confirm the design's accuracy and integrity. EMS also allows for 2D planar and axis-symmetry simulations for designs, resulting in greatly decreased solution time with no loss of accuracy. When deciding on the physics for this application, it is advisable to go to the Ac/Dc tab and pick magnetic fields (mf). The research type can be chosen based on the measurement goals, however the stationary study is a good place to start (field variable parameters do not change over time). The coil model geometry will then be built, an infinite element domain will be created, material properties will be added, the Magnetic Fields interface will be executed, appropriate boundary conditions will be set up, mesh settings will be adjusted, simulation results will be post-processed, a parametric sweep will be performed. Finally, the parameters from the graph in Figure 5.1 using software can be changed to provide the desired acceptable result. As a result, it is recommended that the applications be built alongside the software after simulation. After determining the magnetic properties, the following step is to incorporate them into the electrical circuit

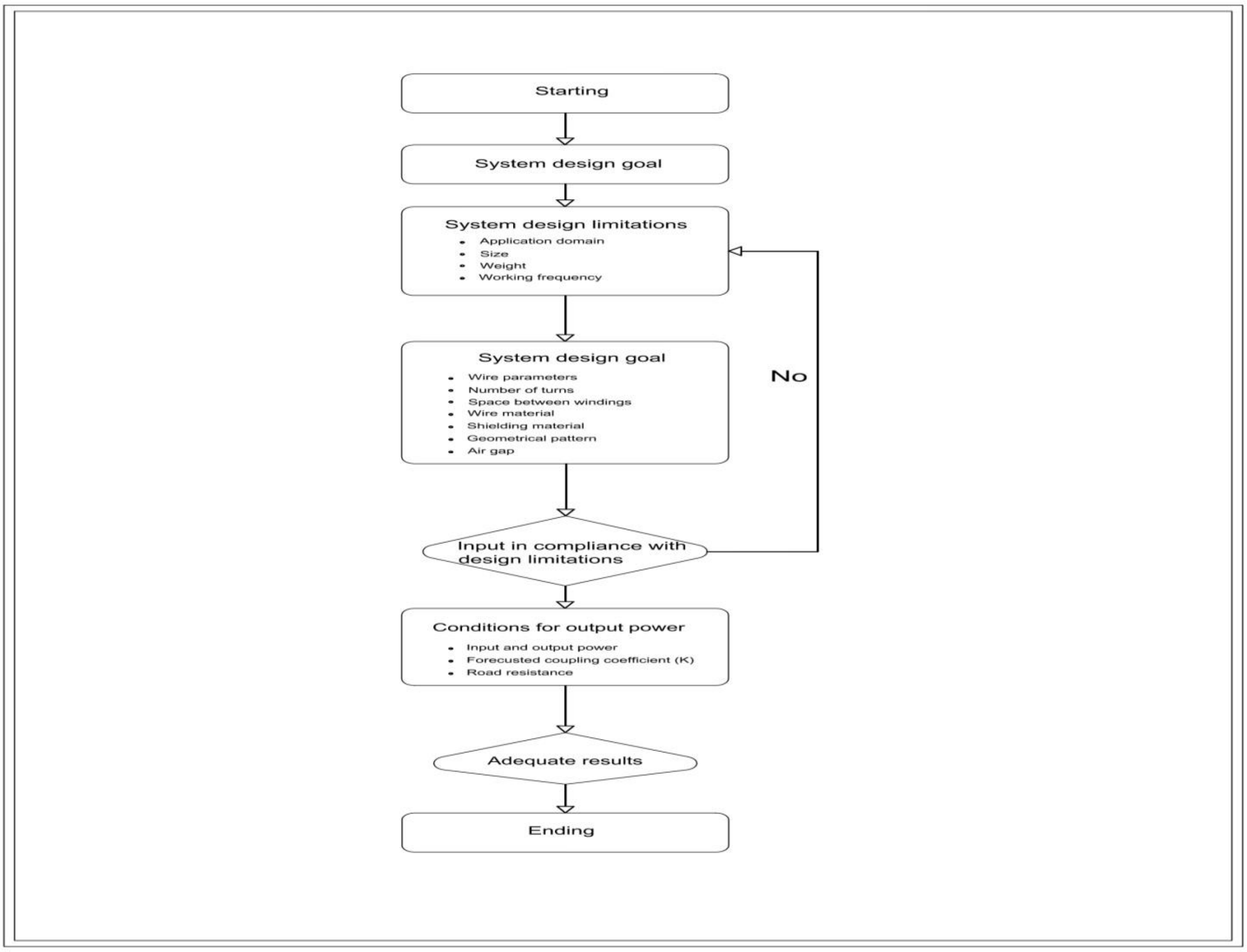


Figure5. 1:Flowchart design of wireless charging system (WCS) of Ebike

5.3 Electrical attributes

When we check inside the charging station, we can see that many different forms of electric consumer should be powered, but the e-bikes are the primary loads. Other loads include command and control systems, as well as illumination, communication, and other user devices. As a result, the calculations for energy estimation are divided into two different loads: e-bikes and supplementary device.

5.3.1 E-bikes

In this scenario, a charging station is proposed where several small e-bikes can be charged at the same time. The proposed station's primary objective is to charge the electric bike. The station can be set up in a variety of locations. The University of Rwanda is assumed to be the station's test site (college of science and Technology).

Once the traveled distances are considered, the computed figure of 794 Wh in Table 5.1 is an assumed approximation of the least necessary energy for one WCS e-bike. For the time being, The accessible battery size of the makers and dealers in Rwanda and East Africa, which is the 794 Wh (14 Ah x 36V) battery, will be considered. This means that the charging station must have a minimum of 794 Wh of power available to charge one e-bike. Assuming the charging station has five open charging places, the total required energy is 3970Wh (794 Wh *5).

Table 5. 1 Electric-Bike energy use per kilometer for GIANT Global manufacturer

Design company	***Energy use (Wh/Km)***				
	ECO mode	Basic mode	Active mode	Sport mode	Power mode
GIANT Global	5	9	13	15	18

Table 5. 2 e-bike energy estimation for University of Rwanda (CST).

Distance to university of Rwanda	***Energy use (wh)***				
	ECO mode	Basic mode	Active mode	Sport mode	Power mode
From Nyamirambo (5km)	25				
From kimihurura (6km)		54			
From Kacyiru (10km)			130		
From Remera (15km)				225	
From Kimironko (20km)					360
TOTAL	794				

5.3.2 Auxiliary devices consumption

The auxiliary devices of the electric bike will require power for control and monitoring of the entire system. This is computerized command center that will ergonomically perform controls and adjustments of riding modes (Eco mode, basic mode, active mode, sport mode, and power mode), view data including speed, distance, and battery use and charging level, and most importantly and makes the charging of the bikes visible. This computerized command center and screen will approximately have a power of 200 W and is running 24 hours, in total 4800Wh (200*24) and the lighting is also necessary.

5.3.3 Total load energy

By adding up all the required energies using the approximated values the total comes to 8770 Wh

Compensation for series-series capacitors should have :

Input converter: Voltage source.

Converter output: Current source

Primary compensation capacitor relays on: Primary inductance

Notice: This compensation circuit is validated if the number of turns on the primary andsecondary side is both equal. There could be parasitic resistance losses in the circuit. Reduced absolute coil resistance may enhance overall efficiency; but, materials and isolation that can withstand stresses are difficult to find and may increase prices; so, minimizing voltage and current stresses is a critical criterion of a realistic design.

If the resonance frequency in the circuit is high, the losses in the switching components of the converter side are also high; or the modern power electronic switches are too slow to respond to system resonance frequency rising difficulties. To address this issue, a lower frequency resonance wave can be employed.

Communication

Current study is focusing on the possibility of data transmission while the e-bike is charging. The data contains information for the user about the charging process's status. This communication can be accomplished via a variety of techniques, including Bluetooth, zigbae, Wi-Fi, or Power Line Communication (PLC), IR, and coil communication.

Human Safety

In accordance with the safety of users near WCS e-bike charging station, it can be confirmed that the EM field does not have too much negative effects. Author [2] According to their findings, a 25 centimeter safety gap from the system's center is recommended for bikers and pedestrians during charging operations. When numerous charging stations are used in proximity, fresh measurements must be taken to ensure that they meet the INCGS standards. These can be determined using the APRANSA method, which uses measurement techniques that take the average exposure level at four sites on the human body.: the head,chest, groin, and knee are addressed.

In the framework from [33] the iterative procedure for the electrical design can be implemented

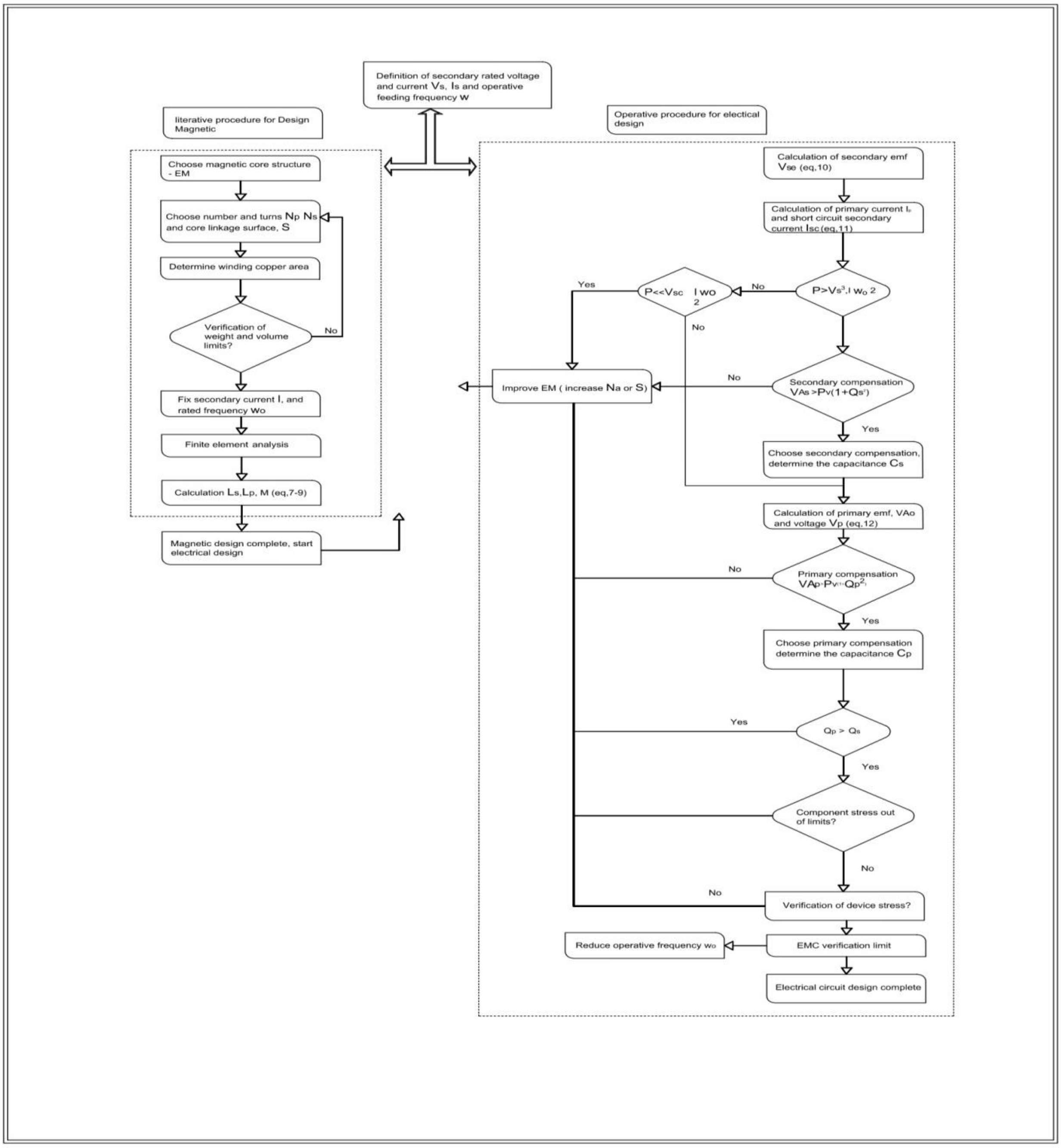


Figure5. 2 Framework of WCS coil structure setup [33]

5.4 Conceptual Prototypes Experiment

The conceptual prototypes are discussed in this section. First and foremost, by designing the reel circuits and coils, the major purpose was to create a prototype for a Wireless charging system (WCS) in a single workable magnetic structure. This, however, did not occur due to the COVID-19 pandemic. Students were unable to access the campus until the end of the school year. However, the recommended prototypes can be built using the conceptual framework from Section 5.2 and the crucial critical elements from parts5.3. Figure5.3 depicts the electrical circuit layout for IPT, as detailed in Section 2.3. This circuit is used to represent the three notions. Figure 5.3 depicts a common electromagnetic resonator circuit consisting of a coil, a capacitor, and a resistor. At a specific resonance frequency, energy oscillates between the coil (energy stored in the form of a magnetic field) and the capacitors (energy stored in the form of an electric field) in this circuit.

According to Equation below, increasing the system's quality factor minimizes losses in the circuit (R is lowered) .The resonator circuit in a high-resonance wireless power transfer system must have a very high-quality factor for efficient power transfer. When two resonators are put near together, they establish a link and can exchange energy. The energy exchange efficiency varies depending on the resonator and the coupling coefficient (K).

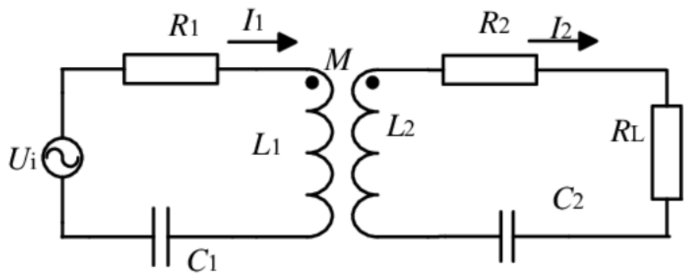


Figure5. 3 Equivalent circuit of a coupled resonator system

Source and device resonator coils are L1 and L2

R internal resistance

W frequency (2πf)

Ui Amplitude of input voltage

Mutual inductance (M equal k$\sqrt{L1 * L2}$)

AC Load resistance is RL

Each coil in the circuit is equipped with a series capacitor that acts as a resonator. R1 and R2 resistors indicate unwanted resistances (including ohmic and radiation losses) in the coil and resonance capacitor of each resonator. The resonance frequency is a crucial critical element in system design, and its reading may be changed by adjusting the gap length between Rx and Tx as well as the impedance elements in the circuit.

5.4.1 Concept 1: Circular planar coils located between two Transmitters

The magnetic circular planar receiving coil in this design is situated between two transmit resonators, which provide the uniform charging area. The E-bike is equipped with a receive resonator and a receiver. The receiver is situated on the rear wheel, while the receive resonator is mounted on the front wheel. The coaxial cable connects the receiver to the receive resonator. Figure 5.4 depicts the proposed prototype setup developed by researchers at the Electronics and Telecommunication Research Institute Daejeon, KOREA. Seong-Min Kim, Sang-Won Kim, Jung-Ick Moon, and In-Kui Cho designed this configuration. The coaxial cable is used to connect the receive resonator and the receiver.

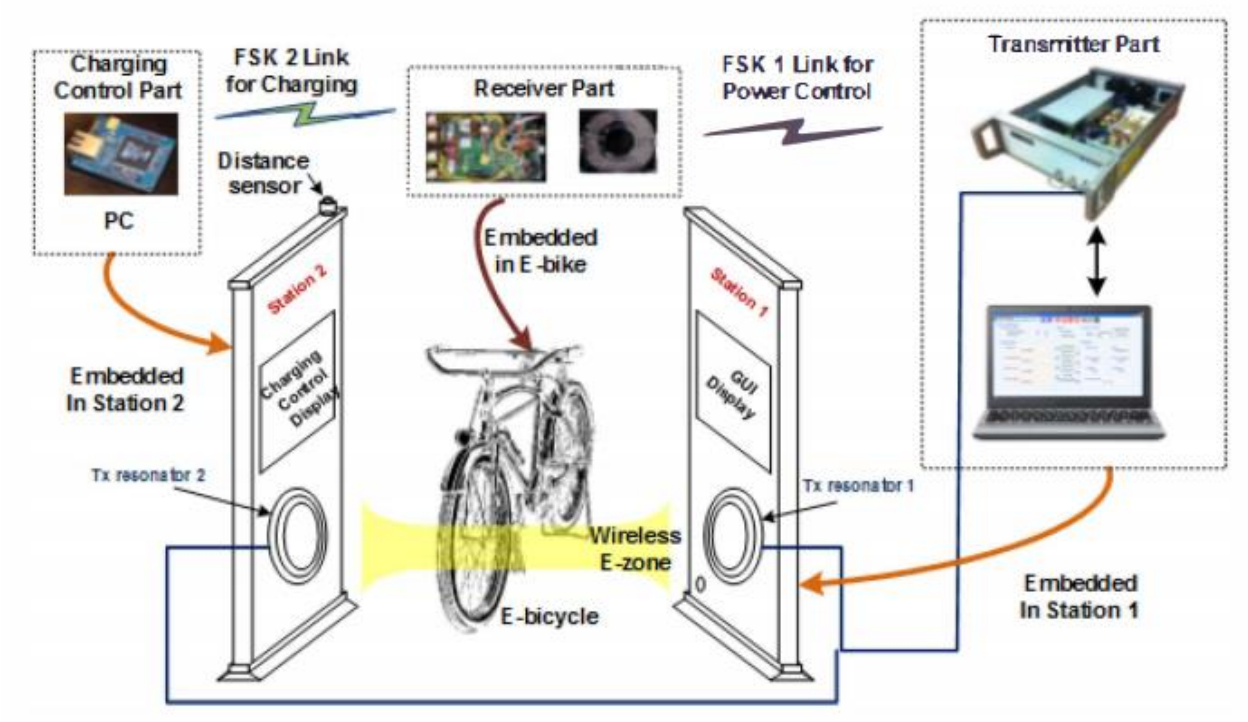


Figure5. 4 Configuration of the entire wireless charging system with two charging stations for E-bike [32]

A magnetic resonance (MR) method was used in this concept to wirelessly charge an electric bicycle (E-bike). The system is made up of two charging stations that serve as transmitters and an E-bike that houses the receive resonator and receiver. The operating frequency band of these two charging stations is 1.7 MHz, and the average transmit power is around 100 W.

The suggested system's unique characteristic is the uniform transmission efficiency in a specific one-dimensional area employing two transmit resonators positioned at two charging stations. The suggested technique creates a one-dimensional uniform charging zone up to 80 cm in length.

The transmitter generates a RF power signal in the 1.7 MHz frequency band and controls the output power according to the communication messages from the receiver [34]. The block diagram of the transmitter is shown in Fig.17. The transmitter is made up of the following components: 'Signal Generator,' 'Power Amplifier,' 'Return Loss Measurement,' 'AC/DC Converter,' and 'Control & Communication.' The 'Signal Generator' employs a direct digital synthesizer (DDS) to generate a 1.7 MHz band RF signal with precision frequency step and fast locking time. In the output matching circuits, two series LC resonators are used for third harmonic peaking. The bias voltage control is also utilized to provide power control. The output power is adjustable from 1 to 130 W in 2 W steps. The bias voltage is adjusted in the range of 30 to 105 V for this power control. The control voltage signal from the 'Control & Communication' controls the bias voltage in the 'AC/DC Converter.

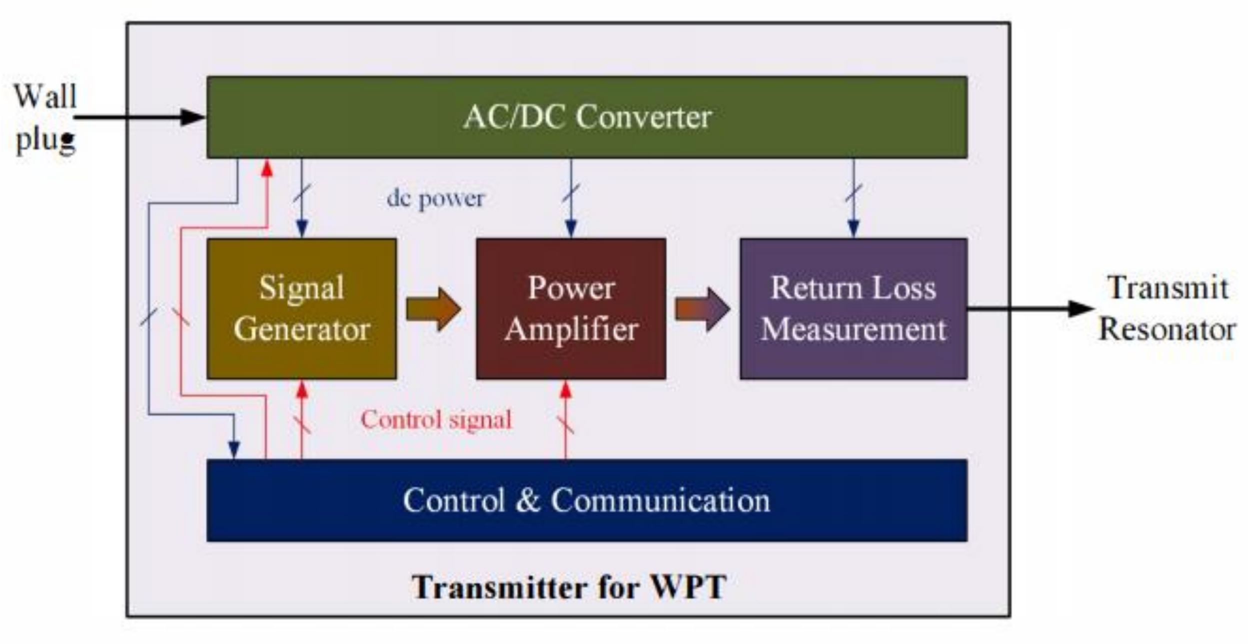


Figure5. 5 The block diagram of the power transmitting unit[34]

Receiver converts the input RF signal to constant current dc signal to charge the battery [35]. It is made up of two major components: a full-bridge rectifier and a constant current charger. A constant-current converter, a controller, and two FSK communication modules, FSK 1 and FSK 2, are included in the charger unit. To charge a battery, the constant-current converter generates a varied constant-current signal ranging from 0.1 to 1 A. The controller collects all measured information and communication messages and regulates the receiver based on the data. FSK 1 connects with the transmitter housed within the 'charging station.' The 'charging station 2' communicates with FSK 2.These two FSK modules use the different channel at 400 MHz frequency band.

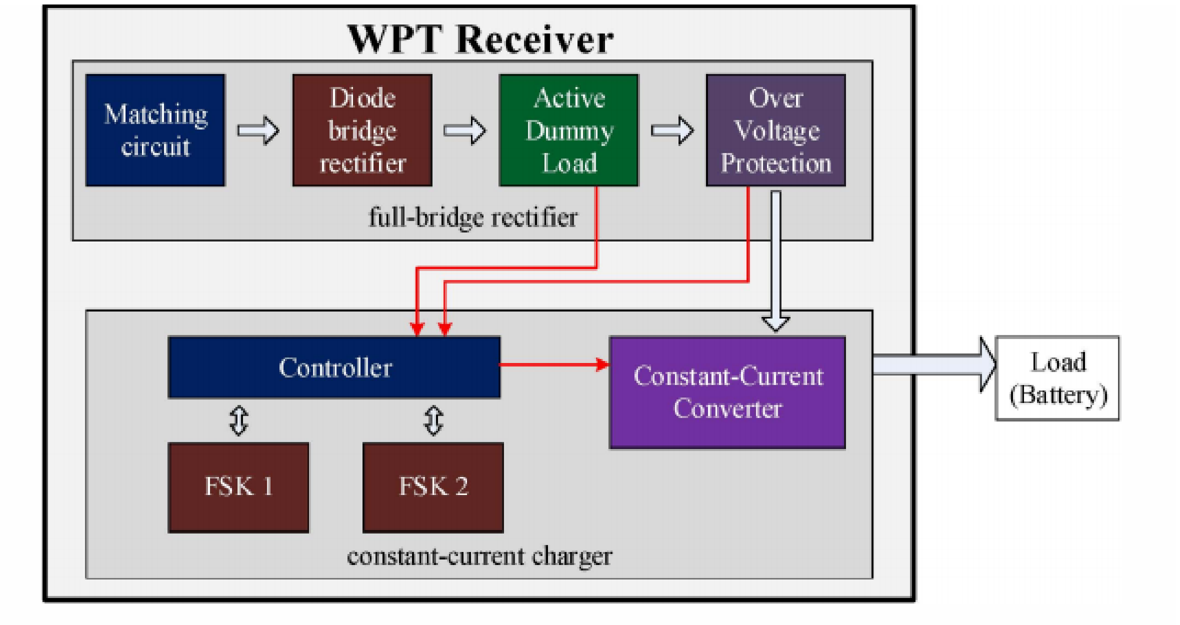


Figure5. 6 The block diagram of the receiving unit [32]

To ensure that the one-dimensional charging area is secure, the system efficiency is computed by the position of the e- bike. According to the measurement results, the average output power of the transmitter is approximately 90 to 100 W depending on the E-bike position, and the received dc power is 48 to 54 W depending on the battery status. The average system efficiency is around 54%, and the variance in efficiency due to the position of the e-bike is less than 10%. The results of this measurement show that the system efficiency is relatively well maintained in the 80cm area.

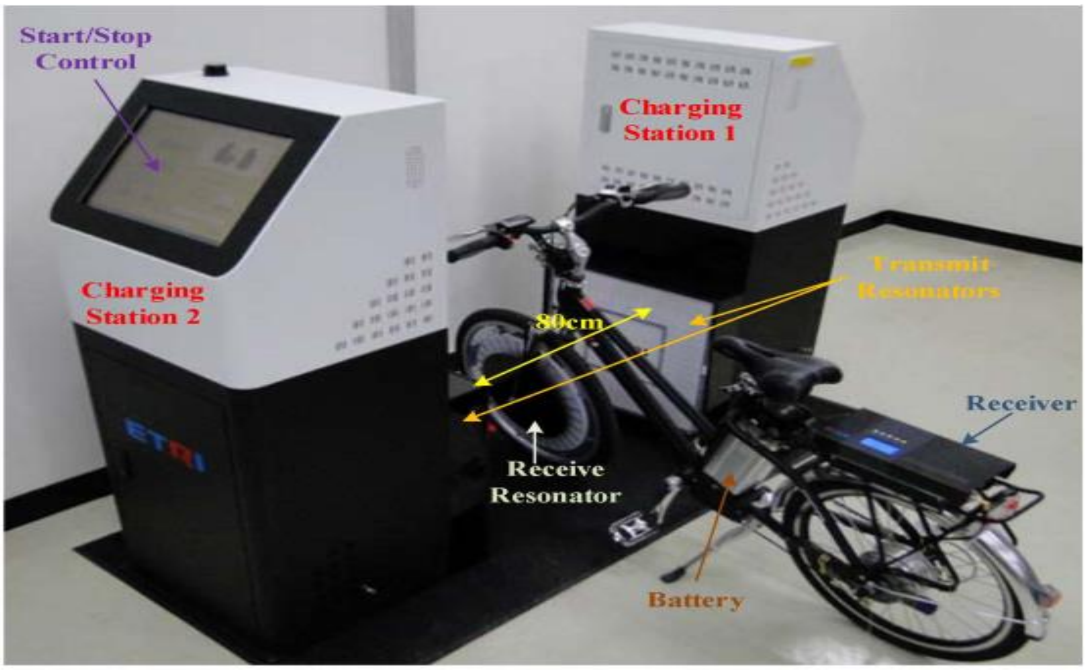


Figure5. 7 constructed Electrical wireless charging system for E-bike [32]

As mentioned before, transmission efficiency is the main constraints when this the proposed Electrical wireless charging system .To maintain the transmission efficiency constant, three main key features to rectifier the effectiveness and performance of existing systems has to be done:

- The first is to create a one-dimensional uniform charging area up to 80 cm distance
- To construct a uniform charging area, two transmit resonators and in-phase feeding
- power control function to protect the approaching human body.

Concept 2: U-; I-Core coils

Magnetic coils are used in this design, with the primary side fashioned like a U-coil and the secondary side shaped like an I-coil. The prototype was produced by at the University of Delft as research done. This configuration was created by Bart Roodenburg and Prof. J.A.Ferreira. Figure 20 displays the power transfer, which in both situations is based on magnetic coupling. L1 (U-core) and L2 transistors are used in the magnetic power transfer circuit (I-core).
Magnetic coils are included in this proposal, with the primary side resembling a solenoid coil (Tx) and the secondary side resembling a solenoid coil as well (Rx).

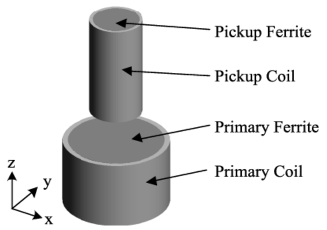


Figure5. 8 Magnetic coil second concept : solenoid coils [6]

A DC-generator (as defined in section 4.1 Type of Resource) uses an H-bridge (inverter) to convert DC power to AC power (S1, S2, S3, S4). It is then transferred to the secondary side, where it is rectified by a four-diode diode bridge. The resonant power transmission frequency used is 85kHz.
The data transmission circuit, on the other hand, contains two more communications windings, Lx (u-core) and Ly (i-core), which are both integrated into the same magnetic power transfer structure. This data transfer circuit establishes a communication link between the primary and secondary coils. The primary serial input data is sent to two different sinusoidal frequencies 1MHz and 2MHz representing the "0" and "1" digital statuses, respectively (i.e. so-called Frequency Shift Keying FSK- modulation). An FSK demodulator on the secondary side can recover the serial data.

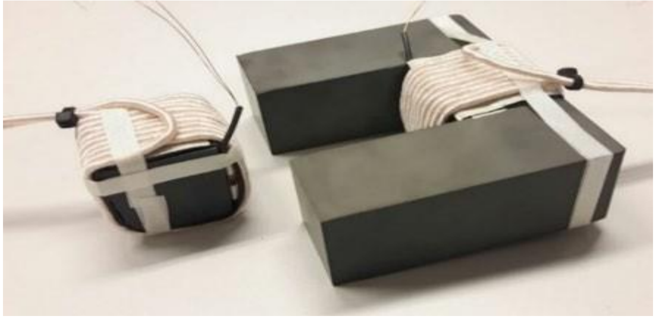


Figure5. 9 Magnetic coil concept 1: U-core and I-core [50]

Concurrently, fluxes are produced by the coils transporting power (L1, L2) and the windings transferring data (Lx, Ly). In this scenario, the axis of the data transmission flux created by Lx is perpendicular to the axis of the power inductor. As a result, the coupling factor between L1 and L2, as well as Lx and Ly, is adequate for power and data transfer.

There are just a few suggestions about where to install the Rx and Tx coils. The Rx coil, for example, is integrated into the bicycle frame and is fixed on a support in front of the wheel, whereas the primary is permanently attached to a U-type column with a single stand.

Figure5. 10 Daymaks new wireless charging stations [36]

As previously explained, the key limits when using this WPDT device in a final produced product is the mechanical coupling's freedom of movement. As a result, the following critical measures can be taken into consideration when implementing this WPDT device:

- Analyze winding size, and assembling process.
- Ameliorate the coupling capability between the windings Lx and Ly.
- Reduce the coupling between the “power-flux” and “communication flux”;(reduce the size, flatness, and shape of the send- and receive windings)
- Analyze the filtering methods for the FSK-receive signal; (The power communicationfrequency at 85kHz and FSK frequencies 1-2MHz are separated significantly).

Concept 3: Solenoid coils

This concept is made up of magnetic coils, with the primary side resembling a solenoid coil (Tx) and the secondary side resembling a solenoid coil as well (Rx).

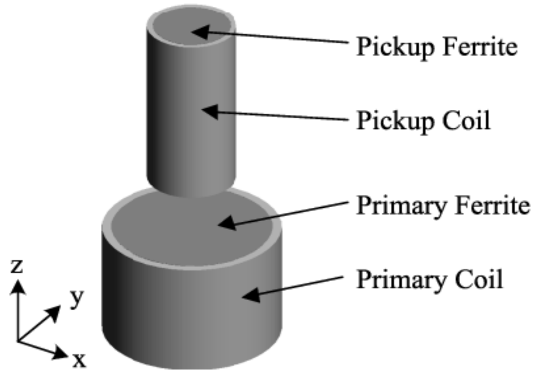


Figure5. 11 structure of coil concept 2, solenoid coils [33]

In this situation, it is impractical to mount the pickup (Rx) on the bike's kickstand and the primary in subterranean as a tile. Magnetic and Internet of things IoT data transport technologies like as zigbae can be examined for this prototype. However, most e-bike kickstands have a minor angular misalignment since they do not reach the ground perpendicularly. As a result, the Tx's repair process should be conducted seriously and with care. To determine the best practicable magnetic coupling coefficient.

5.3 Discussion

Previously three WCS coil topologies for e-bike have been suggested. According to the theoretical analysis and manufactures data. In Chapter 5, a framework for building the three prototypes in the lab was developed. The technique for the whole possible electrical circuit is shown in flowchart provided early.

With respect to the design procedure, the prototypes can comply with the following requirements:

1. **Practicality**

   - The results in Section 5.2 revealed that the ideal places for the receiving coils to be installed in the front frame had been found. Each prototype's Rx coil has been analyzed so that it may be positioned in the best possible positions.
   - The Tx coils will be put based on the optimality of the site. The suggested technique uses two transmit resonators positioned at two charging stations to achieve uniform transmission efficiency in a certain one-dimensional area using the magnetic resonance (MR) technique. The transmitter for the U and I core Solenoid prototypes can be fixed under tiles in the ground (Rx is in the floor) or in a building erected in front of the frame (Rx is placed on the front frame), with the latter being the most common.

2. **Power output efficiency**
   - The transmission efficiency can be maintained constant by using both the two proposed methods
   - The parameters that impact power efficiency (the magnetic coupling coefficient, Q-factor, and parasitic resistances) have also been reviewed and considered in the framework for the prototypes and are displayed.
   - the validation process occurred for both magnetic resonance (MR)with the U and I core (Bart Roodenburg [37]), it canbe said that it both achieved maximum productivity at a low cost

3. **Safety**
   - Secured and safe to surrounding of human beings
   - the average EM field exposure is minimum and reduced.

Based on the theoretical analysis and the key points requirements outlined in Section 5.2, it is possible to conclude that the U and I coil and solenoid coil prototypes are the most likely to be built. The U and I coils have been validated, and the maximum productivity with the least amount of waste has been achieved at a cheap cost.

Chapter 6: E-bike integration

This chapter outlines a basic integration plan for e-bikes in existing transportation as well as their suitability for urban and touristy regions. To answer the third research question, an integration plan for the WCS e-bike technology was proposed using the Business Model Canvas tool. Section 6.1 discusses the primary concept underlying the WCS and e-bike businesses. Section 6.2 provides an overview and explanation of the Business Canvas Model and its nine interconnected essential parts. Section 6.3 provides a brief overview of the feasibility analysis framework. The PWOC analysis for the e-bike integration plan is summarized in Section 6.4. The chapter concludes with a conclusion based on the outcomes of the Business Canvas Model section 6.5.

6.1 Introduction

Globally the automobile industry is rapidly moving towards electric vehicle integration. Transport industries are dominated by the internal combustion engine which is now being rapidly replaced by the electric vehicles. Basically, three types of EVs are available in the world i.e. Hybrid electric vehicle (HEV), Plug-in-Hybrid Electric Vehicle (PHEV), and Battery Electric Vehicle (BEV). Among of these EVs BEV is being used in Rwanda.

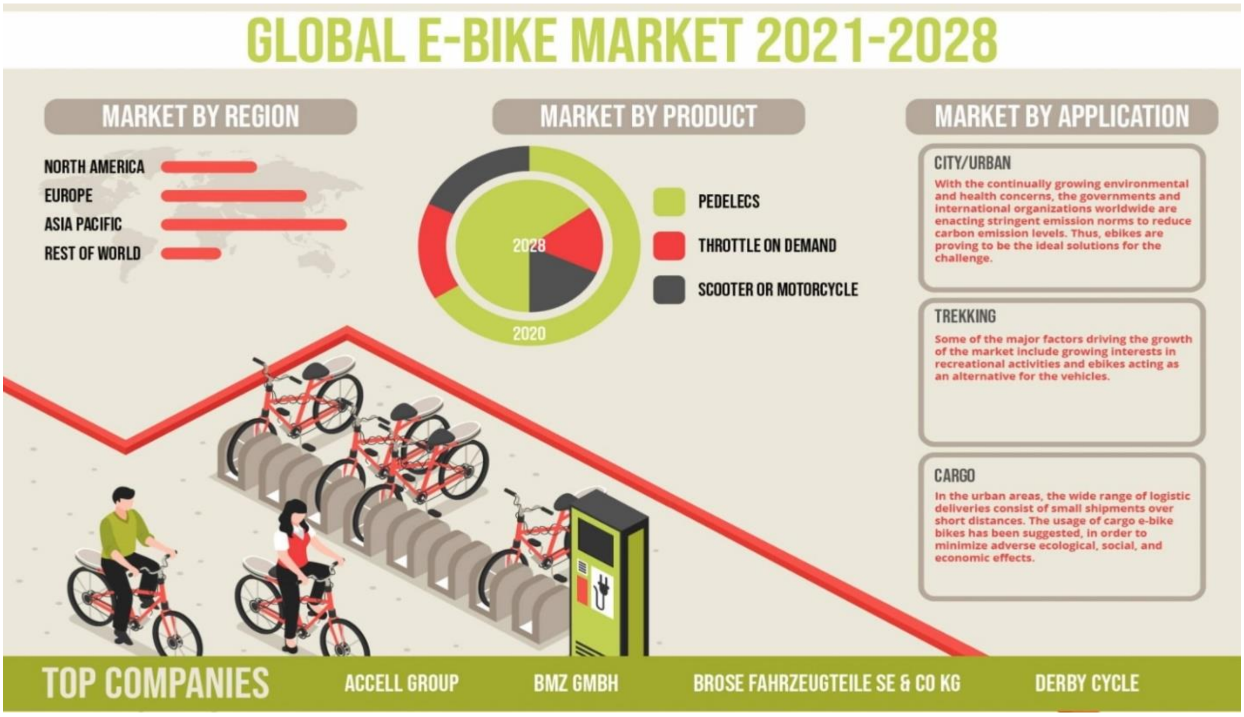


Figure6. 1 Global E-bike market Growth, Trends, share, opportunity and size [38]

A few factors which are pushing this integration increase are:

- desire to meet goals for a sustainable transportation to replace the fossil fuel & the GHG emissions control
- The necessity of an upgrade of smart city transport upgrade platform
- Increased quantity of electric power generation leading to a demand of load increase also.

Generally electric bike consumes 1-2 kWh for 30-50 km. The battery being used in motorcycles being used in commercial transport takes 6-8 hours for full charging whereas electric bike battery takes 3-5 hours for full charging. Almost all the cases, the EV uses lead acid battery for operation.
The third component introduces the concept of increasing demand for e-vehicle penetration, which includes e-bikes in our study. All of this has created an incentive for integration to be applied to e-bikes, which has the potential to grow into a major and profitable company.

Building a successful integration strategy necessitates extensive planning, financial resources, specialists or engineers from the specialized industry, and a strong commitment. One such strategy could be to begin with an electric bike sales and servicing shop.

As mentioned in Chapter 2.4 Electric bicycles, an electric bike is essentially a regular bike with an integrated electric motor and other electromechanical components that can be utilized for propulsion. In Chapter 3.1 Introduction, it is stated that many countries throughout the world are interested in electric bicycles (eg. United States, China, Germany, Japan, Taiwan, Italy, South Korea, the United Kingdom, Australia, Canada, Portugal, India, Netherlands, etc.). However, due to the knowledge of the working environment in Rwanda, this integration strategy will concentrate on application in Rwanda.
Rwanda is active when it comes to technological progress e-bikes, and the government has recently recognized that there is a promising potential in this sector thanks to the devotion of government authorities and private business growth. If it is launched and implemented in a densely populated area with a mix of locals, students, and visitors, e-bike integration can be quite profitable. Even though revenue for electric bike rental services has increased over the years, many new initiatives failed to stay in business during the COVID-19 outbreak. Nonetheless, good projects must continue to be implemented.
In brief, Rwanda's electric bike integration plan is a profitable sector that is available to any ambitious entrepreneur to come in and create his or her firm; it is an open decision one can choose to start on a small scale or start on a large one with many outlets in important through cities .

To begin the integration, ensure that a business plan, feasibility study, and a PWOC analysis are completed, which should not be taken for granted. In the next sub-chapters, a framework for an e-bike hire shop integration strategy that can help to launch a successful business in Rwanda will be provided.

6.2 Integration Business Plan Model

The business Model Canvas (BMC) architectural template is utilized for the e-bike integration business plan. This design tool was devised and developed by Alexander Osterwalder, a Swiss economic theorist, and Yves Pigneurin, a computer scientist (2005). The technical phrase "business model canvas" also refers to the ability of a business plan to be clearly portrayed on a piece of paper. This allows visualizing, detecting weaknesses and testing whether a business can work or not. The Business Model Canvas (BMC) provides a common language through which they can evaluate traditional processes and bring innovations into their business models. The Business Model Canvas helps visualize what is important and forces users to address key areas. It can also be used by a team (employees and/or advisors) to understand relationships and reach agreements.

The execution of BMC has 5 main advantages

- **Easy structured discussions:** it helps entrepreneurs to present and use the building blocks to guide brainstorming, grouping comments and ideas under the nine headings quickly gives ideas shape
- **Fastness:** it allows to write a one-page business model to see if the idea has clearance, and take a lean entrepreneurship approach where you discover customers and the best business model in real time in the market
- **Great for developing a portfolio of ideas:** long time ago in business-plan thinking, weeks or months were spent just writing one business plan for one idea. Using the Business Model Canvas, only minutes or hours sketching business models for multiple ideas can be achieved.
- **Credibility:** I find it quickly clarifies thinking on the business model and that one building block naturally leads to the next.
- in the design there are 9 steps, together these steps provide a coherent view of a business key drivers:
- Step1. **Customer Segments**: this first step is to find out what type of customers your organization is targeting.
- **Step2**. **Value Propositions:** This second step part goes further than just stating your

product/service, by expressing why your product/service is valuable

- **Step3. Channels:** deals with Methods to reach out to prospective customers. These channels include communication, distribution, and sales.
- **Step4**. **Customer Relationships**: this goes with Acquiring, retaining, and growing customers which is very important in keeping your reputation as a caring organization.
- **Step5**. **Revenue Streams:** this step finds out how exactly your customers buy your product/service. through choosing good methods which the income will grow.
- **Step6**. **Key Activities:** This step describes the most important assets required to make a business model work.
- **Step7. Key Resources:** this step, discuss the most important actions a company must take to operate successfully
- Step8. **Key Partnerships:** This step describes the external resources that help the business.
- Step9. **Cost Structure:** In this step, the company views costs and what costs it requires to operate.

The concept discussed here is a master plan that clearly outlines your business at first and then expands on it. The BMC is used for the e-bike integration business in the Rwandan transport sector, as shown in Figure 6.2; further details on this per segment are provided in the following sections.

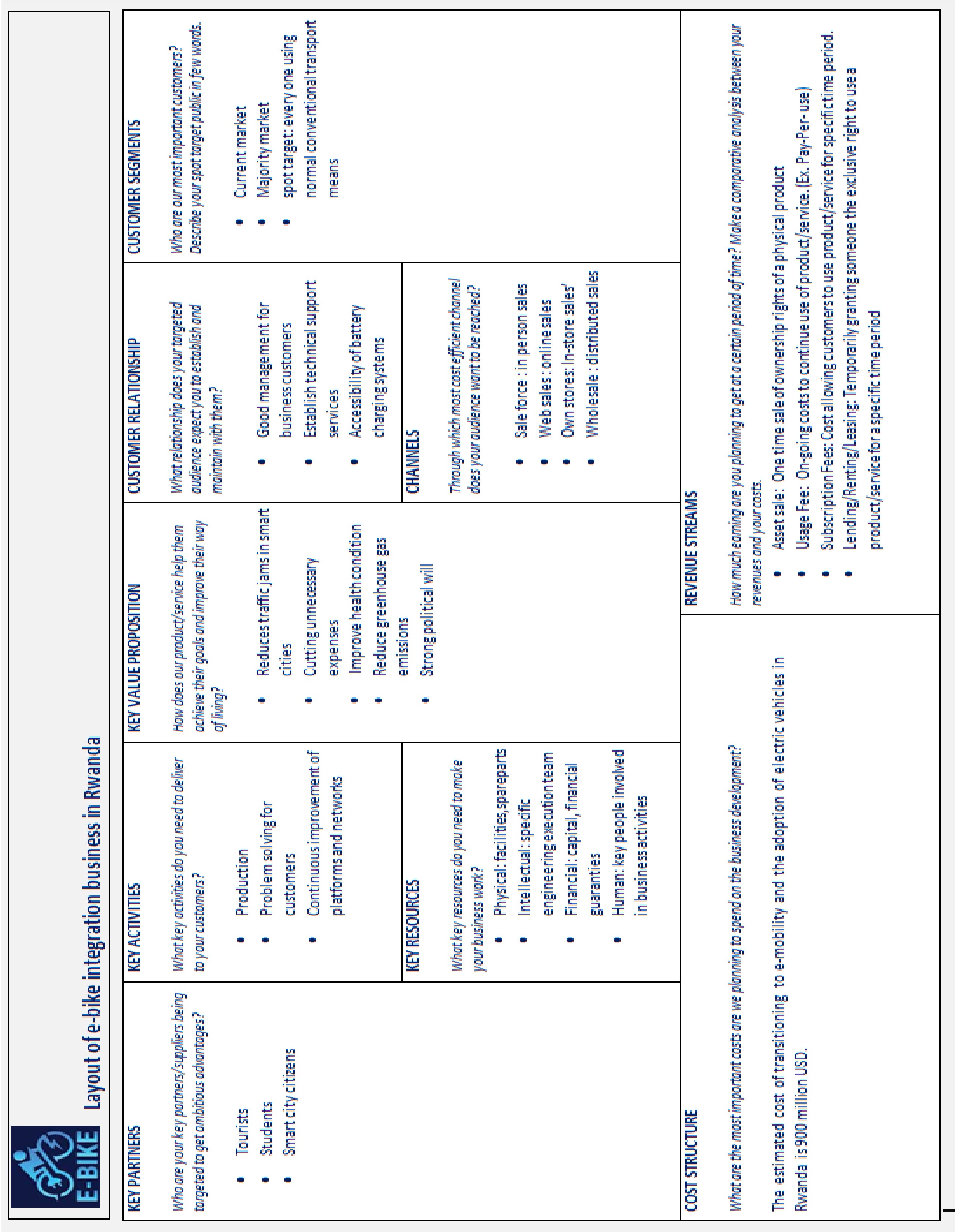
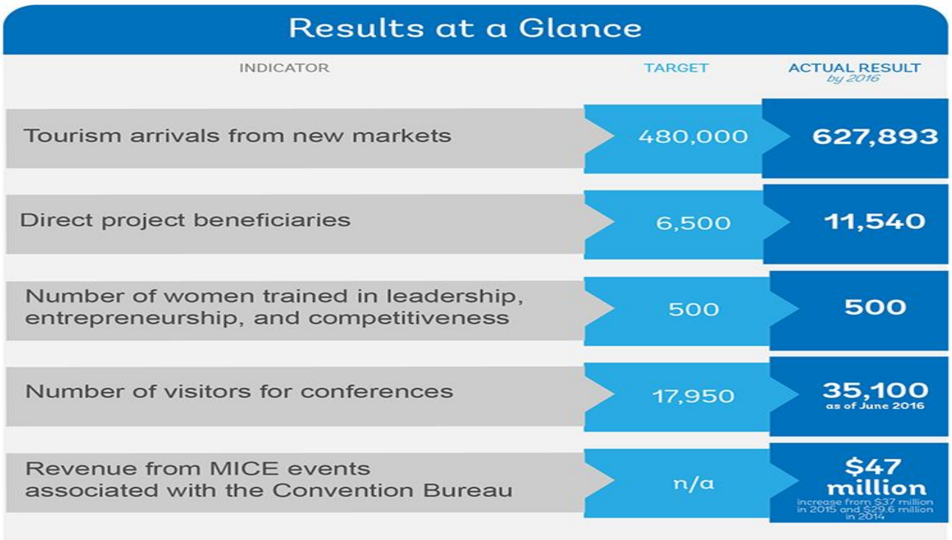


Figure6. 2 Block diagram Business Model Canvas e-bikes business integration

6.2.1 Customer behavior

The customer behavior that gives the income include users and paying customers

1. Tourists: Rwanda is becoming one of Africa's leading business tourism destinations; E-bikes integration can help attract new tourist's customers who might need to enjoy riding using electric bikes. Following the launch of mountain biking and cycle tourism, RDB (Rwanda Development Board) invites cyclists, both local and foreign; to enjoy the world class trails across the country [39]. The famous Congo-Nile Trail, borders the scenic Lake Kivu, now attracts over 5,000 tourists annually. Commenting on the launch of mountain biking across the country, the Chief Tourism Officer, Rwanda Development Board, Belise Kariza said, "Rwanda is the best destination for adventurers seeking memorable, sustainable tourism experiences in Africa. We are happy to unveil mountain biking, our new tourism experience. Visitors can now experience the vibrancy and beauty of our country in a fresh way. Visit Rwanda and discover just why our country is the new cycling mecca of Africa" In order to further the growth of cycling as both a sport and a tourism experience, the Government of Rwanda has announced a 25% tax waiver on the importation of mountain and racing bicycles [40]. This shows that though tourism this e-bikes integration business can boost and help the existing sport bikes.



Results at a Glance

INDICATOR	TARGET	ACTUAL RESULT by 2016
Tourism arrivals from new markets	480,000	627,893
Direct project beneficiaries	6,500	11,540
Number of women trained in leadership, entrepreneurship, and competitiveness	500	500
Number of visitors for conferences	17,950	35,100 as of June 2016
Revenue from MICE events associated with the Convention Bureau	n/a	$47 million increase from $37 million in 2015 and $29.6 million in 2014

Figure6. 3 Rwanda private sector scare in the meetings, incentives, conferences, and events (MICE) conferences, and events (MICE) market [41]

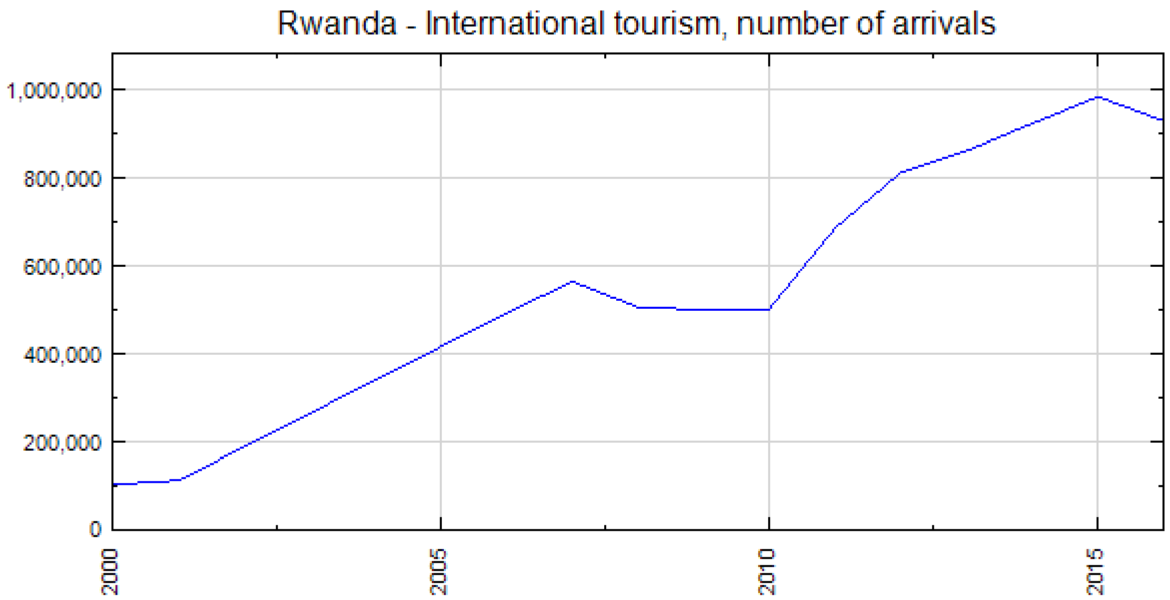


Figure6. 4 Rwanda - International tourism, number of arrivals [42]

2. Students; The bike is the cheapest and favored mode of transportation for most students, based on their financial situation. once the pricing range is convenient for them or if there is a particular package deal for them, they can bring in a lot of money for the company.

3. Smart cities citizens. The integration and use of e-bikes as new mode of transport in the city of Kigali will contribute to the promotion of smart and green city. The e-bike transport system within the city will make movements from one point to another more convenient and affordable. the Rwandan government is encouraging and promoting carbon-free mobility in the country's growing cities and urban centers [43].

4. E-bikes wholesale stakeholders; Wholesale dealers (such as GURARIDE) should be easily sell or rent their wares. They can sell or rent essential e-bikes to small merchants, allowing them to earn a profit. The wholesaler benefits by being able to sell more through the small vendors who have established themselves around Kigali and other smart towns. The primary stakeholders may not be able to settle everywhere, but small businesses can, and they can have a higher profit margin because they are more approachable to the entire community than the larger stakeholders. They can both profit in this manner.

These previously mentioned customer segments are the most important customers for the e-bike integration company. It is advantageous that more can be added to this when this company plan is implemented. Each of the four client segments is associated with one or more major value propositions. All parameters on the canvas's left side, as shown in Figure 25, must support the canvas's right side.

6.2.2 Main propositions

The main propositions, also known as value propositions, essentially outline the potential items and services that will be supplied to clients. The purpose of the e-bike business is to service a diverse clientele while earning a profit. To fulfill the primary goal of establishing a profitable e-bike business, the start-up must ensure that everything they do and provide is legal in Rwanda.
The main product and services should include:

- Electric-bike rental services with perspective charging facilities.
- Establish retail services for the newest and most unique brands of e-bikes, e-bike parts, and accessories.
- Establish repair and maintenance services (either at the shop or at another designated place, such as a home or a road).
- Establish repair and maintenance services (either at the shop or at another specific place, such as a home or a road).
- Adopt Price reduction technics for particular groups (e.g. students).

For the business to achieve its core purpose, each major proposition stated below must be linked to a consumer category and a revenue stream.

6.2.3 Channels

Basically channels refers on How do our Customer Segments want to be reached? These channels include communication, distribution and sales. To reach the customers, below are the main 5 channel types to be selected and implemented

- Sales Force; engage In-person sales strategies:
- Web Sales: build and Online sales platforms.
- Own Stores: by starting local In-store sales.
- Partner Stores: through In-partner-store sales.
- Wholesaler: by performing distributed sales.

Also to reach the customers, the marketing strategic approach can beimplemented accordingly

- Introduce the usage of eye-catching handbills to raise awareness and direct people to the business location.

- Install business signage and flexi banners in strategic locations across the property.

- Use radio and television platforms to interact with the big community where your marketing team cannot reach.

6.2.4 Customer Relationships

Customer connections solve the question of how a business gain, retains, and grows by interacting with customers in a variety of ways:

The client relationship can be maintained by doing the following:

- Making strategic advertisements through online platforms and hardcopy brochures
- Use social media information updates and Q&A sessions
- Perform Technical support services
- Use available modern newsletters platforms
- Adopt personal assistance and information distribution.

6.2.5 Revenue streams

This structured diagram depicts the states where the business's revenue is generated. Renting e-bikes, selling e-bikes, and providing spare parts are all part of the Electric Bike company. The availability of charging stations, as well as maintenance and repair services, is critical. The company's objectives are to maximize earnings while minimizing costs because of the new unique e-bike technology choice. You can find the facilities for electric bike integration from the following sectors

- Renting fees on e-bikes
- Retail fees on different type and brands of e-bikes, parts and accessories (motor, battery)
- Service and maintenance by providing repair and maintenance services
- Introducing charging equipment and battery exchange in surrounding area.

The pricing mechanism should be based on what the industry offers. Students get a significant discount. Payment rules that might be implemented by a firm can differ. Different payment alternatives are available to clients based on their preferences. As a result, clients can pay a one-time cost or, in some cases (students and middle-income persons), a monthly subscription price. It is necessary to develop a payment option via internet platforms.

6.2.6 Key activities

This refers to the most crucial key actions to take for the business model to work. To be guaranteed of delivering any value to clients, key activities should be closely related to the value offer.
The Key activities is described in 3 main categories

Production: Provide the product at low cost at high quality and enough

Problem Solving for customers: provide Consultancies and other related service with new adequate solutions to individuals or group customers problems.

Continuous improvement Platform and Network: Networks, software platforms can function as a platform. For example, a key activity for instagram is updating the platform.

6.2.7 Important Resources

This area of the building discusses the most critical strategic assets required to make your company model successful. In general, resources can be classified into four types:

- **Physical** (example buildings, vehicles, machines, and distribution networks)
- **Intellectual** (example specialist knowledge, patents and copyrights, partnerships, and customer databases.)
- **Financial** (example lines of credit, cash balance etc.)
- **Human** (example people can be the most key resource, this is particularly true in creativeand knowledge-intensive industries.

6.2.8 Key Partners

The main parameters to get competitive advantage are:

- Wholesaler companies (e.g. GURARIDE) for providing the different type of e-bikes
- Advanced Technical companies to supply spare parts and accessories.

- Government e-mobility initiative funds
- Other e-mobility firms that can form a possible partnership

6.2.9 Cost structure

The cost structure section's primary purpose is to ensure that costs are in line with the value offer. After demonstrating the main resources, key activities, and key relationships, it should be easy to determine the most important expenses.

The following list shows the main costs by looking at activities and resources:

- Business team development
- Charging station infrastructures
- Operations support
- Sales and marketing
- Sales and marketing

6.3 Discussion

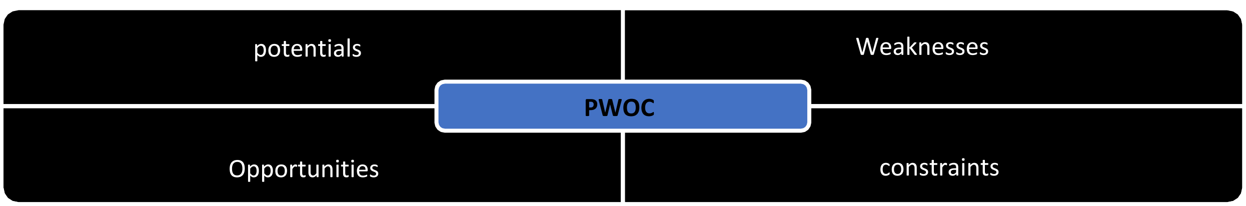
The nine factors discussed above serve as the foundation for the electric-bike business integration. These can be tailored to the needs of the business owner. As previously said, the nine elements should collaborate with one another to provide a holistic image of a firm.

Each client category is connected to a core value offer and a revenue source. Everything on the canvas's left side is required to support the canvas's right side. To ensure that you are providing value to your clients, all Key Activities should be directly related to your value proposition. It is required to make sure that all the costs are aligned with the value proposition

The position of the company is important since it decides who the primary target market is, what products and services must be provided, and provides an overview of prospective competition. Prior to beginning, it is necessary to gather information about the area's diverse demographics. Many towns and smart cities have strong cycling cultures, and many government initiatives are focusing on boosting e-cycling.

6.4 PWOC analysis for e-bike business integration

PWOC is an acronym standing for *Potentials*, *weaknesses*, *opportunities*, and *constraints*. PWOC analysis is a strategic planning system that can be used for categorizing potentials, weakness, opportunities, and challenges. It is an important tool for determining the barriers existing in Rwanda for e-bike adoption. Fig 28 shows the PWOC analysis for e-bike adoption and determines the barriers of EV acceptance in Rwanda. A two-by-two matrix is used to examine these four elements. To determine the worthiness of a stated opportunity, the matrix considers both internal elements (potentials and weaknesses) and external factors (opportunities and restrictions). This is a commercial analytical tool. The tool is simple to use and comprehend, and it can be applied to any business circumstance, including e-bike business integration. The primary goal of PWOC analysis is to identify and capitalize on potentials as well as opportunities, to comprehend weaknesses, and to manage and eliminate limitations.



POTENTIALS	WEAKNESSES
Environemental friendly&less GHG emission	Limited resources
Large market opportunities	Frequenty road accident
Affordable prices for customers	Low consumer awareness
Easy to drive	Technology still in development
OPPORTUNITIES	CONSTRAINTS
Integration for renewable resources for charging	Lack of charging facilities
Greater opportunities for research development	Questionable market demand
Expansions in business partners	Unpredictable costs
Low cost labour	Poor road facilities

Figure6. 5 PWOC analysis for e-bike adoption

- ***Strengths factor in the PWOC table for e-bike integration*:** Worldwide e-bike transportation is a revolutionary and unique business concept with numerous advantages. Because of the exponential development in demand for e-bikes, their acceptance in many nations has the potential to create enormous market opportunities. Adoption of e-bikes and e-mobility in general is part of the government's push for sustainable transportation to replace fossil fuels and reduce GHG emissions.
- ***Opportunities factors*:** The Rwandan e-mobility market is a starting business dominated by electric motorcycles, and their target markets may expand in tandem with the increasing demand for e-bikes.

- With e-bike integration comes the introduction of new technologies, particularly in charging systems such as WCS and other charging technologies. That means that the e-bike industry can be embraced and expanded, perhaps leading to an increase in business partners in the new lease or rental e-bike sector.
- ***Weakness factors*:** Because e-bikes are still in their early stages, and the e-mobility technology that powers them is still in its early stages, limited resources will be available during this phase. Despite increased demand, practically all e-vehicle charging stations are private, and they have charged higher rates for EV charging. And it is projected that the national grid will be stressed because of such EV charging demand, particularly during peak hours.
- *Constraints factors*: As mentioned above, at this time the private sector and the government cannot take proper action regarding this issue. There are different types of elements associated with the EV adoption in Rwanda. Mainly these constraints are insufficient EV charging station (EVCS), modern battery technology, insufficient power supply, high cost of electricity, environmental pollution etc. Several studies were performed on barriers of EV penetration in different regions. However, there is no study is observed in the context of Rwanda for e-bike adoption and e-mobility in general. It is the reason why authors and researchers should be motivated to do the research for starting integration of ebike.

6.5 POLICY RECOMENDAION FOR E-BIKE ADOPTION

Generally electric vehicle has a huge demand of electricity and most of the times many energy utilities fall into a problem with shortcomings of profit. In other cases, the electric vehicle has numerous positive impacts on environment, fossil fuel reduction, improved socio-economic status of EV owner and a reduction of unemployment. To have a reliable and sustainable in energy sector, It is critical to expand EV penetration in Rwanda. Various academics and authors propose a few recommendations for feasibility after analyzing the challenges of e-bike adoption and e-mobility integration in general. The following are the primary recommendations:

- ❖ First of all, electric vehicle i.e. electric bike, electric moto-cycle, electric cars needs registration in the government transport regulation authorities. When it is finished then the total number of charging station required in different corners of Rwanda can be easily calculated. Charging rate of EVs should be chosen according to the total energy consumption.
- ❖ As it is worldwide known that this vehicle is environmentally friendly vehicle and a cheapest mode of transportation, the government should mainly prioritize this vehicle. It can be achieved by applying no tax on accessories of the electric vehicles, putting in place more charging infrastructures. The placement of charging stations needs to be located at favorable places where transportation is easy.
- ❖ As the possible number of EV charging systems are connected at grid simultaneously, it disturbs the power quality by introducing harmonics, voltage fluctuation etc. Coordinate charging scheme must be established, and it can be helpful for a good and efficient charging process for EVs to reduce power quality problems.
- ❖ To reduce problems that can be present on the national grid caused by big new EV charging systems, the abundant potentiality of renewable resources such as solar, biogas and wind should be adopted too. Practically Solar based Charging stations can firstly be established in different corners of Rwanda by the government. The Government can set favorable tariffs for an easy and low-cost recharging e-bikes and e-motorcycles respectively. As the solar can generate power only at day time and is not available in cloudy& night time, thus hybrid system (such as solar, biogas) is mandatory for sustainable production of electricity for EV charging [44].

- A new technology of Vehicle to Grid (V2G) integration is also required for an efficient EV management for proper utilization of renewable resources and also for improving the whole power system efficiency [45]. Thus, excess energy will be used effectively.
- The secondhand batteries (used batteries) of EVs can be further used for backup purposes. The used batteries when no longer usable in EVs, their residual capacity still has significant value. in off-peak hours, the excess electricity generation can be stored using these batteries. In addition, the EV owners can generate and earns some extra money by selling these batteries. The new battery recycling plants constructed, and good policy developed made by the government will help environmentally and financially.
- The government should mobilize, encourage put in place many research and development centers on these new types of transportation vehicle for improving technology. this type of research center can facilitate to extend ne range of electric vehicles as well as enhancing battery capacity and technology.
- Finally, the awareness program should be done by publishing the environmental benefits of using electric vehicles can help more adoption in Rwanda.

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