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# MEMOIRE

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**Par** : DRICI Ismail Anwar & DERKAOUI Yacine

**Sujet**

# Study of different wireless charging techniques for electric cars

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# Dedication 1

With the help of Almighty God, we have completed this modest work, which I dedicate:

To my dear parents, this dedication is a humble testament of my love, gratitude, and eternal appreciation towards you. You are my pillars, my guides, and my sources of inspiration. Every success I have achieved is a reflection of your values, your upbringing, and your teachings. You instilled in me solid principles, a strong work ethic, and a confidence that allowed me to overcome challenges and persevere. May God bless you abundantly, grant you flourishing health, and a life filled with happiness and serenity.

I also dedicate this work to my beloved extended family, to my brother Adel, to my sisters Aya and Hadjer. May our family bond remain strong. May our bonds of love continue to grow, and may we share many more happy moments together.

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Yassine DERKAOUI
Tlemcen, June 08th, 2024

# Dedication 2

With the help of Almighty God, We have completed this thesis, which I dedicate to my beloved family and friends who have supported me throughout this journey.

First and foremost, to my dear parents. Your unwavering love, support, and encouragement have been the bedrock of my life. You have been my pillars, steadfast and strong, guiding me with your wisdom and strength at every step. This achievement is a tribute to the countless sacrifices you have made and the enduring values you have instilled in me. Your dedication and belief in my potential have driven me to succeed. I am eternally grateful for all you have done and continue to do for me.

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ismail anwar DRICI
Tlemcen, June 08th, 2024

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***Yassine DERKAOUI Ismail Anwar DRICI***
***Tlemcen, June 08th, 2024***

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# List of Figures

# List of acronyms

The main notations and abbreviations used in this thesis are explained below, in their most commonly used form in the field electrical engineering.

**Electrical quantities**

| **Name** | **Symbol** | **Unit** |
|---|---|---|
| Time | $t$ | s |
| Voltage | $U$ | V |
| Current | $I$ | A |
| Power | $P$ | W |
| Sizing power ratio | $S_{PR}$ | kW ,kVA |
| Electromagnetic induction | $L$ | H |
| Capacitance | $C$ | F |
| Frequency | $f$ | Hz |
| Electric pulse | $\omega$ | rad/s |
| Mutual induction | $M$ | H |
| Coupling coeffient | $K$ | / |
| Efficiency | $\eta$ | % |
| Quality factor | $Q$ | SI |
| Impedance | $Z$ | Ω |
| Reactance | $X$ | Ω |
| Resistance | $R$ | Ω |

# Glossary

| **Acronyme** | **Signification** |
|---|---|
| EVs | Electrical vehicles |
| PHEV | Plug-in hybrid electric vehicles |
| HEV | Hybrid electric vehicles |
| BEV | Battery electric vehicles |
| FCEV | Fuel cell electric vehicles |
| ICE | Internal combustion engine |
| RWD | Rear-wheel drive |
| EM | Electrical machines |
| PE | Power electronics |
| TRN | Transmission |
| DCT | Double clutch transmission |
| REEV | Range extended electrical vehicles |
| CVT | Continuously variable transmission |
| PG | Planetary gear. |
| 4WD | Four wheel drive |
| HVAC | Heating, ventilation and cooling |
| DC | Direct current |
| AC | Alternative current |
| DWC | Dynamic wireless charging |
| SWC | Stationary wireless charging |
| OBC | On-board charger |
| BMS | Battery management system |
| IPT | Inductive power transfer |
| WPT | Wireless power transfer |
| MPT | Microwave power transfer |
| LPT | Laser power transfer |
| MRPT | Magnetic Resonance power transfer |
| RIPT | Resonance inductive power transfer |

| **Acronyme** | **Signification** |
|---|---|
| EMC | Electromagnetic compatibility |
| FOD | Foreign object detection |
| SAE | Society of automotive engineers |
| A4WP | Alliance for wirelees power |
| ISO | International standards organization |
| CHAdeMO | charge de move |
| CCS | Combined charging system |
| SS | Series-Series |
| SP | Series-Parallel |
| PS | Parallel-Series |
| PP | Parallel-Parallel |
| SOC | state of charge |
| WCS | wireless charging system |

# General Introduction

As nations undergo continuous progress and advancement in infrastructure, automation, transportation, and technology, a substantial volume of detrimental emissions is released into the environment. The expansion of these sectors, particularly in developing countries, has been linked to an increase in greenhouse gas emissions, exacerbating climate change and contributing to the ongoing global warming phenomenon. This environmental impact is not solely attributed to industrial pollutants, but also vehicular traffic emerges as a significant contributor to the release of harmful emissions, further intensifying the challenges associated with climate change [1].

The imperative to address climate change and mitigate pollution has prompted a shift away from petroleum as the predominant energy source for the transportation systems. Embracing electricity as a power source in transportation offers a sustainable alternative. Electric vehicles (EVs), particularly battery electric vehicles(BEVs), play a pivotal role in this transition. These vehicles are designed to be connected to the electrical grid, enabling their on-board battery systems to be replenished using clean and renewable electricity sources. By adopting electric transportation, the aim isto curtail reliance on petroleum, reduce emissions, and contribute to a more environmentally sustainable future [2].

The widespread adoption of BEVs has the potential to act as a catalyst for achieving 100 percent renewable power systems. This positive impact stems from the flexibility introduced by BEVs, enabling their integration into renewable energy ecosystems. The flexibility is particularly highlighted in the charging technology employed. The success of this transition relies on strategic choices in charging infrastructure and technologies[3], EVs undergo charging through dedicated chargers, utilizing two predominant techniques: wired and wireless charging. In the wireless charging method, no direct physical connection exists between the EV and the charging system. Currently in the developmental phase, wireless charging techniques demand substantial research efforts to potentially replace traditional wired chargers. Meanwhile, contact-type chargers involve a direct connection, with EVs linked to the charging system through interconnecting cables or wires [4].

In this thesis we are going to discuss the generalities about electric vehicles in the first chapter, such as the different types, the components, the history behind it and the principal of operating an EV. For the second chapter, we are going to elaborate on the basic principals of charging which can be divided in two main categories: wired charging and wireless charging, for the first one we are going to mention the three levels of wired charging and for the second one we are going to talk about different wireless charging techniques and their principle of operating. In the last chapter, our study is going to be focusing on the magnetic resonance power transfer (RIPT).

# Chapter I

# General about the electric vehicles

CONTENTS

## I.1 Introduction

Electric vehicles (EVs) are driving a monumental revolution in the automotive industry, heralding the era of electric propulsion technology. This transformative wave encompasses two distinct variants: all-electric vehicles, which rely solely on batteries for power, and plug-in hybrid electric vehicles (PHEVs), combining electric motors with internal combustion engines (ICE) for added versatility. By championing emission-free transportation and reducing dependence on fossil fuels, EVs are pivotal in spearheading sustainable mobility solutions. As breakthroughs in technology surge and charging infrastructure expands exponentially, Electrical vehicles (EVs) are positioned to emerge as the foundation of a more environmentally sustainable and robust transportation system, paving the way for a brighter future for future generations [5-6].

## I.2 History of the electric vehicle

While the perception may be that electric vehicles are a relatively recent innovation, their origins can be traced back to the 1830s. Scottish inventor Robert Anderson is commonly acknowledged for conceptualizing an early electric carriage between 1832 and 1839. This marked a departure from the reliance on horses as the primary propellant for carriages, laying the foundation for the contemporary vehicle, a transformation not exclusive to electric vehicles alone [7].

In the 1830s, the initial electric vehicles utilized non-rechargeable batteries. However, it took around 50 years for batteries to advance enough to be practical for use in commercial electric vehicles. By the end of the 19th century, rechargeable batteries were being mass-produced, which led to the widespread adoption of electric vehicles [8].

Figure I.1: New York Taxi Cab in about 1901, a battery electric vehicle (Photograph reproduced by permission of National Motor Museum Beaulieu [8])

At the early 20th century, electric vehicles seemed to be a promising option for future road transport. They were relatively reliable and started instantly. However, with the widespread availability of cheap oil and the invention of the self-starter for internal combustion engines in 1911,also the high cost ,low speed and limited range compared to the internal combustion engine (ICE) vehicles led to decline in their use as a privet vehicles which made the ICE a more attractive option for powering vehicles. Ironically, the main market for rechargeable batteries has since been for starting ICE engines [8].And by the end of the 1920s, electric vehicles (EVs) had lost prominence to internal combustion engine (ICE) automobiles in terms of market share [9].

During the end of the 20th century, significant changes have emerged that could enhance the appeal of electric vehicles. Growing environmental apprehensions regarding carbon dioxide emissions and local exhaust fumes have made urban areas less habitable. Furthermore, advancements in vehicle design and enhancements in rechargeable batteries, motors, and controllers have been pivotal. Additionally, rechargeable batteries and fuel cells, initially conceptualized by William Grove in 1840, have undergone substantial development to the extent that they are now integrated into electric vehicles [8].

From the early 2000s to 2021, there has been a noticeable escalation in competition, with an increasing number of electric vehicle (EV) models entering the market annually. Advancements in battery technology have facilitated the development of lighter vehicles with enhanced battery efficiency and cost-effectiveness. Consequently, there has been a notable rise in public acceptance of alternative fuel vehicles. In 2020, global EV sales surged by 39 percent to reach 3.1 million units, despite a 14 percent decline in the overall passenger car market (inclusive of traditional internal combustion engine vehicles) attributed to the global COVID-19 pandemic [7].

Figure I.2: The classic electric car, a battery powered city car (Picture of a Ford Think kindly supplied by the Ford Motor Co. Ltd [8])

## I.3 Types of electric vehicles

Electric vehicles are classified into four main types: Battery Electric Vehicles (BEV), Hybrid Electric Vehicles (HEV), Fuel Cell Electric Vehicles (FCEV)and Plug-in Hybrid Electric Vehicles (PHEV). BEVs operate solely on electric power, producing zero carbon emissions. On the other hand, HEVs feature both an engine and an electric motor, employing a regenerative braking system. PHEVs face a significant drawback related to battery limitations. FCEVs, on the other hand, utilize electricity generated by a fuel cell to propel the electric motor [10-11].

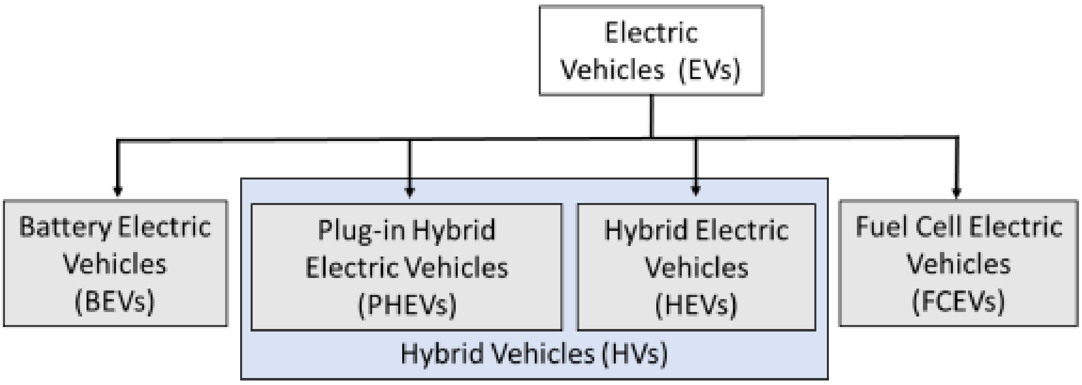

Figure I.3: Electric vehicles classification according to their engine technologies and settings [13].

### I.3.1 Battery Electric Vehicles

Electric vehicles that are 100 percent propelled by electric power are known as Battery Electric Vehicles (BEVs). Unlike traditional vehicles, BEVs are distinguished by their absence of internal combustion engines and their independence from any liquid fuel reliance. Instead, they utilize large packs of batteries. Instead, they utilize large packs of batteries to store and provide electric power for the vehicle, ensuring an acceptable level of autonomy. BEVs provide several advantages, including their simple construction, easy operability, and overall convenience. One of the key environmental benefits is that BEVs do not produce GHG emissions during operation. Additionally, they operate quietly, contributing to a reduction in noise pollution. These characteristics make BEVs not only user-friendly but also environmentally friendly, aligning with sustainable and eco-conscious transportation solutions [12-13].

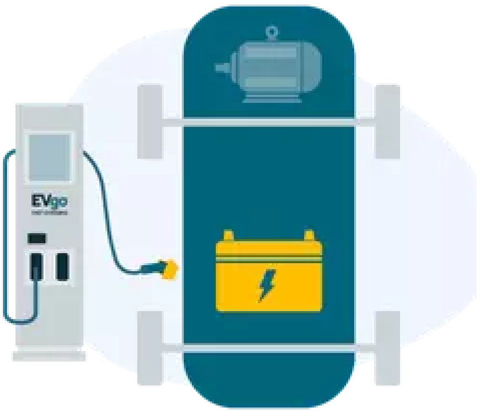

Figure I.4: Model of a battery electric vehicle [60].

### I.3.2 Fuel Cell Electric Vehicles

FCEVs are equipped with an electric engine powered by a combination of compressed hydrogen and oxygen sourced from the air, resulting in water as the sole emission generated by this process, leading to the classification of these vehicles as presenting "zero emissions." However, it's essential to note that despite the existence of green hydrogen, a considerable portion of the hydrogen used in FCEVs is derived from natural gas, impacting the overall environmental sustainability of these vehicles [13].

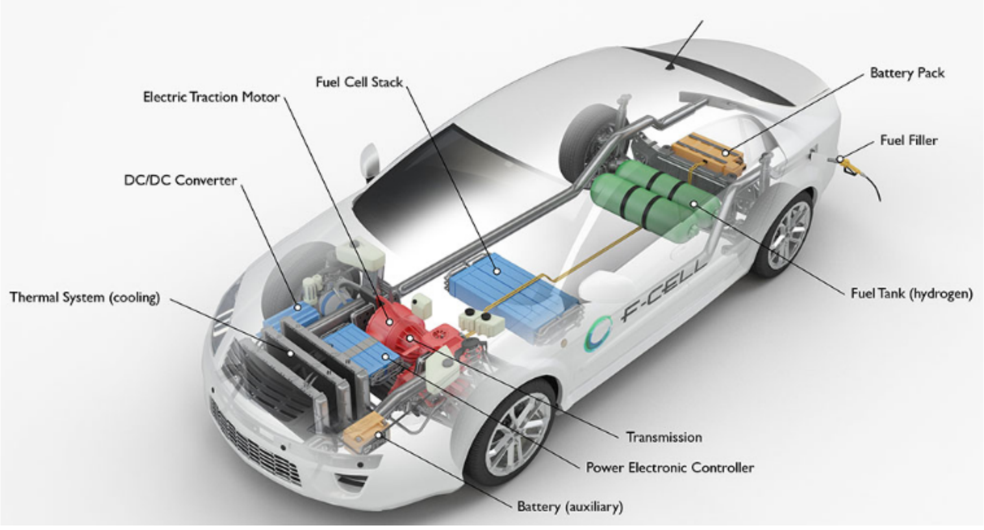

Figure I.5: Model of a Fuel Cell Electric Vehicle [21]

### I.3.3 Plug-in Hybrid Electric Vehicles

Plug-in Hybrid Electric Vehicles have the unique capability of being charged by a pluggable external electric source. This feature allows PHEVs to store sufficient electricity from the grid, enabling them to operate in electric-only mode for a certain distance. The ability to rely on stored electricity significantly reduces fuel consumption during regular driving conditions, making PHEVs a more environmentally friendly and fuel-efficient option [13].

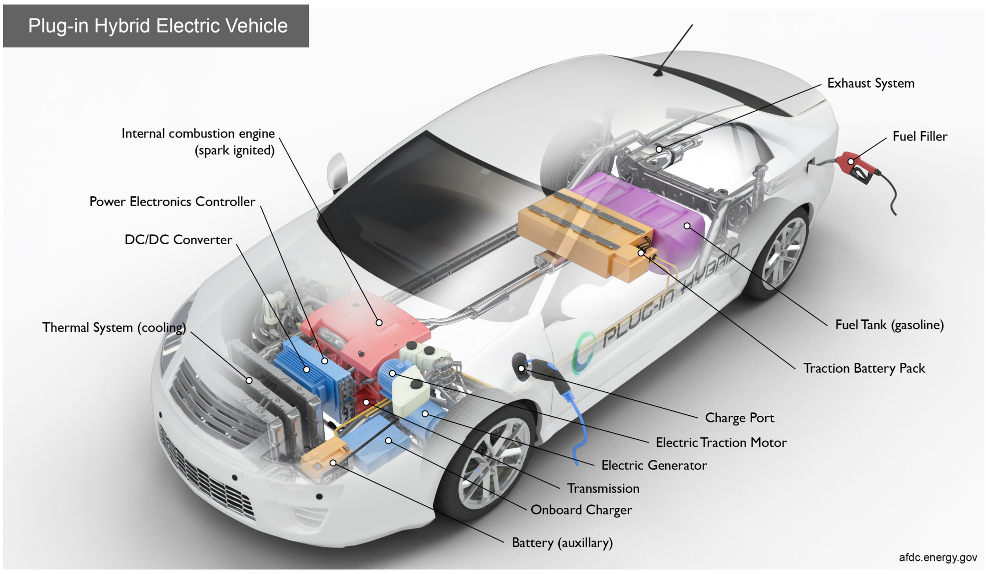

Figure I.6: Model of a Plug-in Hybrid Electric Vehicles [21]

### I.3.4 Hybrid Electric Vehicles

Hybrid vehicles exhibit a dual nature, combining features of conventional internal combustion engines fueled by gasoline with electric motors powered by stored electrical energy. These vehicles operate on a hybrid system, leveraging both fuel and electricity to propel the car. The conventional engine utilizes gasoline as its energy source, while electric motors draw power from batteries within the vehicle. This dual setup enables hybrid vehicles to enhance fuel efficiency and reduce emissions by seamlessly transitioning between the conventional engine and electric propulsion, optimizing energy usage based on driving conditions [14].

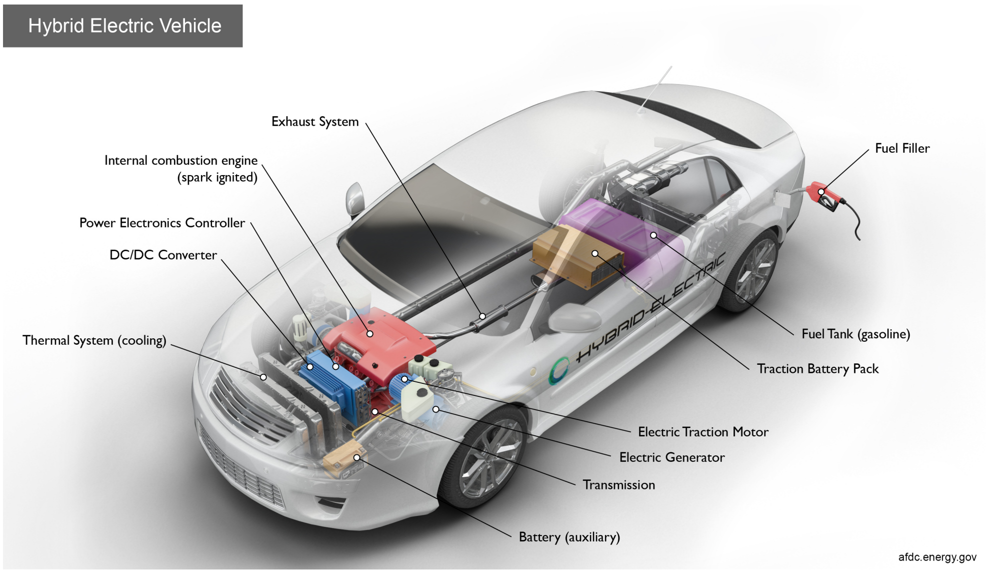

Figure I.7: Model of a Hybrid Electric Vehicles [21]

### I.3.4-a Parallel hybrid electric vehicle with two clutches

In a parallel hybrid powertrain configuration, both the internal combustion engine and electric motor have the capability to transfer torque to the driving wheels, either sequentially or simultaneously. In the context of a rear-wheel drive (RWD) vehicle, a prevalent hybrid powertrain design involves the integration of an electric machine positioned between two clutches [54].

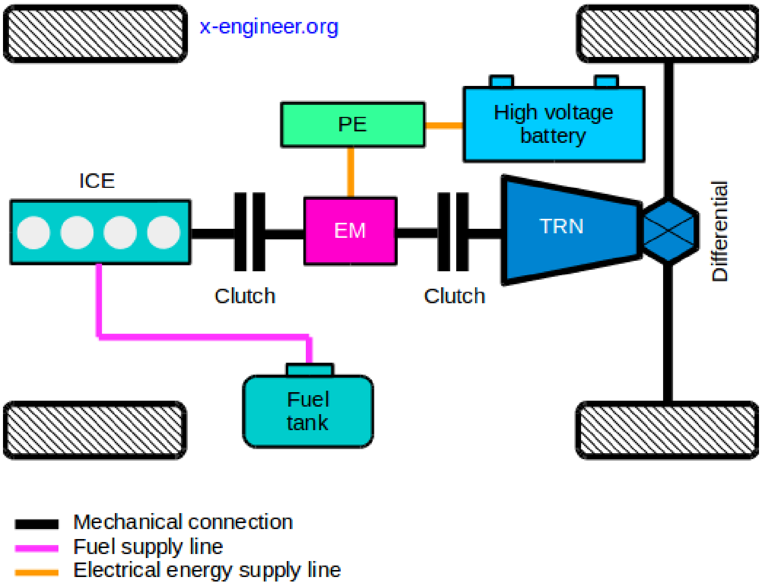

Figure I.8: Model of parallel hybrid Ev with two clutches [54]

where:

- ICE : internal combustion engine

Table I.1: States of the clutches during each mode of the hybrid powertrain [54]

| Mode | Clutch before EM state | Clutch after EM state |
|---|---|---|
| Engine stop and start | Open | Open/Closed |
| Energy recuperation | Open | Closed |
| Torque assist/boost | Closed | Closed |
| Electric driving | Open | Closed |
| Coasting | Open | Open |
| Charge at standstill | Closed | Open |

- EM : electric machine
- TRN : transmission
- PE : power electronics

The initial clutch, situated between the engine and electric motor, permits disconnection of the engine from the drivetrain, enabling operation in pure EV mode. Additionally, by disengaging the engine during deceleration, its braking effect is eliminated, resulting in enhanced efficiency for kinetic energy recuperation [54-55].

The secondary clutch facilitates the disconnection of the electric machine from the drivetrain, enabling the vehicle to coast during deceleration. Notably, from an implementation standpoint, the secondary clutch is integrated within the transmission rather than being a separate component [54].

The states of the clutches during each mode of the hybrid powertrain can be summarised in a table I.1:

#### I.3.4-b Parallel hybrid electric vehicle with double-clutch transmission:

In certain vehicle configurations, particularly those featuring a front engine and front-wheel drive, space constraints pose a significant challenge for component packaging. The installation of a clutch between the engine and electric machine may not be feasible due to limited available space [54].

In such scenarios, it becomes advantageous to adapt an existing powertrain solution to incorporate hybrid technology. One approach involves utilizing a double clutch transmission (DCT) and integrating an electric machine onto one of the input shafts, positioned after the clutch. This modification allows for the hybridization of the powertrain without requiring additional space, making it a practical solution for vehicles with restricted packaging options [54][56].

In this design, the electric machine is incorporated within a sub-unit of the transmission, typically situated on either the odd or even gears. Utilizing two input shafts and output shafts for both odd and even gears allows for the internal combustion engine's input torque to be conveyed to the output via a distinct mechanical pathway from that of

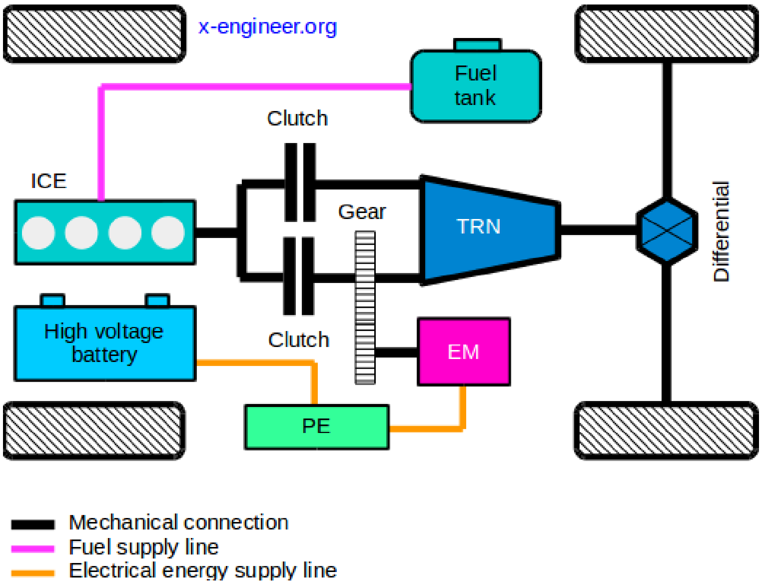

Figure I.9: Model of Parallel hybrid electric vehicle with double-clutch transmission [54]

the electric machine. The combination of torques occurs at the ring gear, which is linked to the differential [54][56].

For instance, Getrag has adapted its own 7-speed dual-clutch transmission, known as the 7DCT300, into a hybrid configuration by integrating an electric machine onto the shaft corresponding to the even-numbered gears. This transmission, designed for front-transverse applications, features seven forward gears and one reverse gear. The gear ratios are divided between the even (2, 4, 6, R) and odd-numbered gears (1, 3, 5, 7), each forming a separate sub-transmission. Connection between the engine and the two partial transmissions is facilitated by a wet dual clutch [54].

The resulting hybrid transmission, designated as the 7HDT300, offers flexibility suitable for integration into mild, full, and plug-in hybrid electric vehicles. In its full hybrid configuration, the transmission incorporates a 40 kW electric machine, enabling electric-only driving at speeds of up to 50-60 kph, depending on the specific application [54][56].

This approach enables the engine to be disconnected by opening both clutches, ensuring purely electric operation. EV driving. It's also feasible to disconnect the electric machine from the rest of the drivetrain by disengaging the gear synchronizers within the transmission [54].

### I.3.4-c Series hybrid Electric vehicle:

In a series hybrid powertrain, the internal combustion engine doesn't directly transmit torque to the drive wheels. Instead, it drives an electrical generator, which in turn powers the traction electric motor. Unlike parallel hybrids, series hybrids employ two electric machines: a generator linked to the engine and a motor connected to the wheels via a single-step gearbox and a differential. One notable distinction is the absence of a transmission due

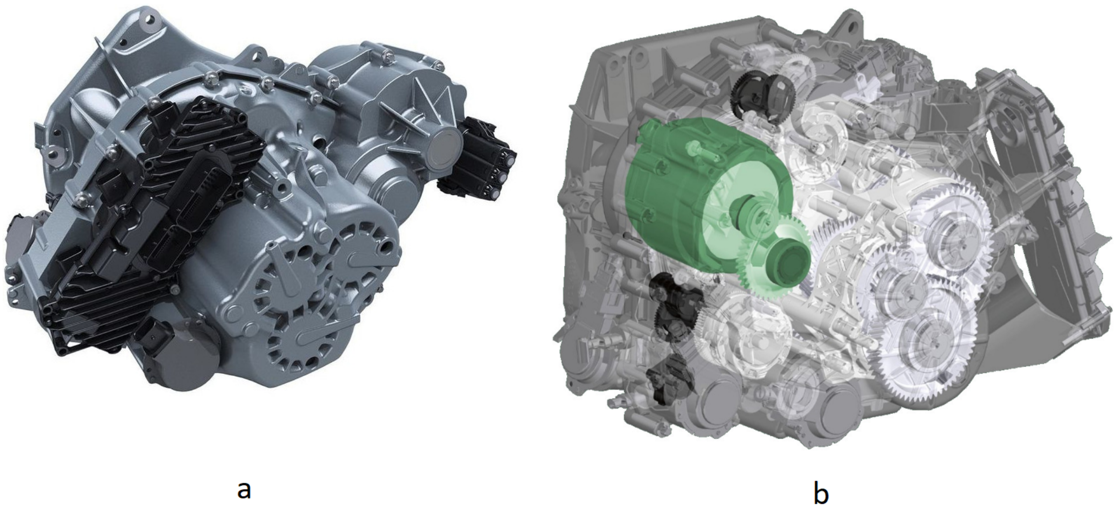

Figure I.10: Difference between a dual-clutch transmission and dual clutch transmission with electric machine [54] : a) hybrid dual-clutch transmission , b) hybrid dual-clutch transmission with electric machine integration

to the lack of direct mechanical linkage between the engine and the drive wheels, leading to space efficiency gains in packaging with reduced engine and generator footprint [15][54].

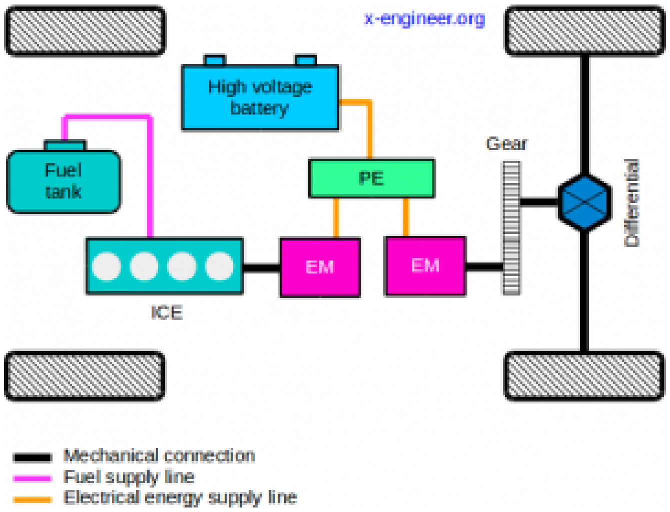

Figure I.11: model of series Hybrid EV [54]

Additionally, there's no clutch linking the electric motor to the drive wheels. This is an advantage in terms of packaging but it doesn't allow the vehicle to Coast since the electric motor will be always connected to the drive wheels [54].

When it comes to powertrain functions, a series hybrid can only :

- Engine stop & start
- Energy recuperation

- Electric driving
- Charge at standstill

Both electric machines must possess a power rating similar to that of the internal combustion engine. Since the vehicle speed does not depend on the engine speed, the operating point of the engine's speed and torque can be adjusted to maximize fuel efficiency. This is it's advantageous at low vehicle speeds but becomes a disadvantage at higher speeds [54].

Another disadvantage of the series hybrid is the double energy conversion. If the battery is depleted, the energy required at the wheel is coming from the internal combustion engine, after it is converted into electrical energy. This further reduces the overall efficiency of the powertrain when the engine is providing the main energy source [54].

Because a series hybrid lacks flexibility in terms of power output across a broad range of vehicle speeds, it is not suitable as hybrid powertrain architecture for road vehicles. Nevertheless, by fitting a smaller engine, with a smaller rated power than the traction electric motor, a series hybrid becomes a Range Extended Electric Vehicle (REEV) [54][15].

#### I.3.4-d Serie-parallel HEVs:

Series-parallel hybrid vehicles, commonly known as power-split hybrids, feature parallel configurations with integrated power-split devices. This design enables power to travel from the Internal Combustion Engine (ICE) to the wheels through either mechanical or electrical pathways. The configuration seamlessly blends the advantages of both series and parallel hybrids, resulting in an exceptionally efficient system. However, compared to these technologies, power-split hybrids demand additional components and a more intricate control algorithm, making their setup more complex [54].

Transforming a series hybrid into a series-parallel hybrid involves introducing a mechanical connection, typically a clutch, between the two electric machines. This architectural modification offers distinct advantages: at low speeds, with the clutch disengaged, the powertrain operates akin to a series hybrid, optimizing engine efficiency. As vehicle speed increases, the clutch engages, allowing the engine to directly deliver torque to the driving wheels, effectively transitioning the powertrain into a parallel hybrid configuration [54][57].

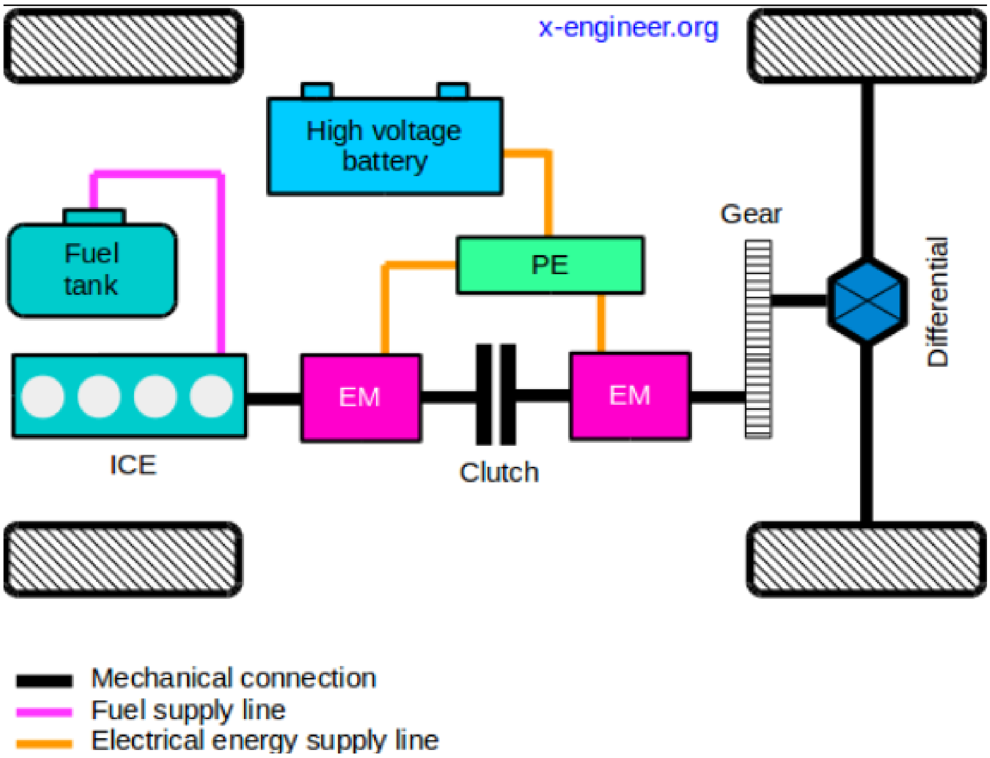

Figure I.12: Model of a series-parallel HEV [54]

In contrast to the series hybrid, the series-parallel hybrid offers the advantage of requiring a smaller generator power rating, as surplus engine power can be directly transmitted to the drive wheels. However, the incorporation of a mechanical connection, such as a clutch, sacrifices packaging flexibility [54].

In terms of powertrain capabilities, a series-parallel hybrid can perform various functions including engine stop and start, energy recuperation, torque assist/boost, electric driving, and charging while stationary. This architecture employs two electric machines, similar to a parallel hybrid, to execute these tasks efficiently [57].

Despite its capabilities, the series-parallel hybrid with a clutch connection between electric machines is not widely adopted by automotive manufacturers. This is due to concerns regarding its packaging constraints and the availability of alternative hybrid architectures that offer comparable functionality with simpler designs [54][16].

### I.3.4-e complex HEVs:

In contrast to the simpler series-parallel system, the complex hybrid system enables bidirectional power flow, commonly referred to as a series-parallel configuration in current terminology. However, this system is characterized by high costs and complexity. Within complex hybrid systems, continuously variable transmissions (CVTs) play a crucial role in facilitating power splitting or selecting power sources for wheel propulsion. Toyota Motor

Co. introduced the concept of e-CVTs, which employ electric arrangements for these functions [17].

CVTs come in various forms, including hydraulic, mechanical, hydromechanical, and electromechanical, and utilize either input splitting or complicated splitting methods for power distribution. For input splitting, a power-splitting mechanism is employed at the transmission input, with certain Toyota and Ford vehicles incorporating this mechanism. Different manufacturers employ various modes for both splitting methods. Hybrid electric vehicles (HEVs) utilizing power-splitting mechanisms typically consist of an engine, wheels, two electric machines, and a planetary gear (PG), offering numerous combinations—up to twenty-four—with potential for over one thousand configurations when considering alternative PGs. An optimal design incorporating a single PG has been proposed to streamline efficiency [54].

In four-wheel drive (4WD) systems, power transfer to the rear wheels is unnecessary as they are equipped with their own motor. Consequently, a two-motor hybrid configuration can be implemented, facilitating energy regeneration through regenerative braking. Figure I.13 illustrates the structure of a 4WD HEV, with stability enhancement schemes available for these configurations through rear motor control [54].

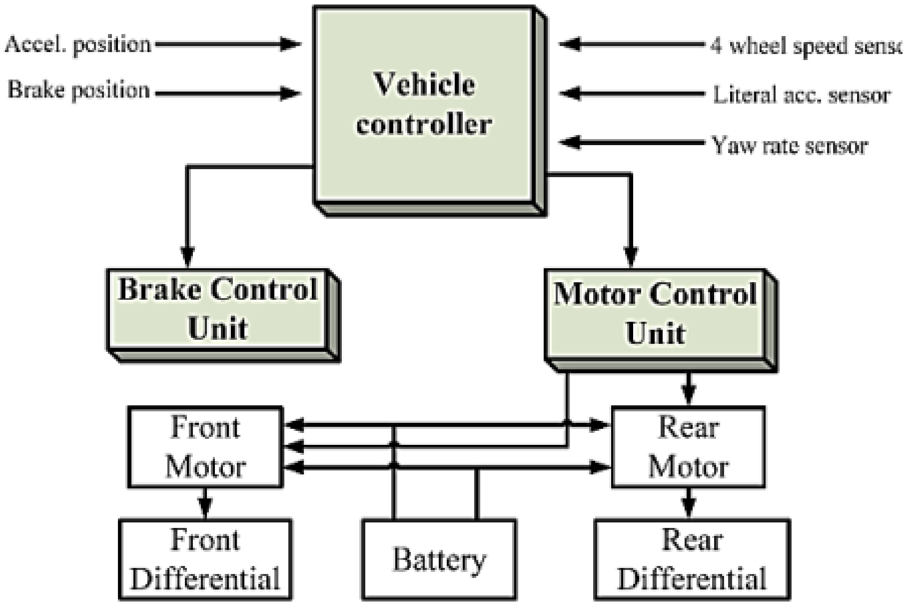

Figure I.13: Structure of a complex HEV [17]

## I.4 The components of an electric vehicle

All-electric vehicles, commonly known as battery electric vehicles (BEVs), are equipped with an electric motor instead of an internal combustion engine. These vehicles rely on a sizable traction battery pack to supply power to the electric motor, necessitating regular charging via a wall outlet or dedicated charging equipment, often referred to as electric vehicle supply equipment (EVSE) [18]. By operating solely on electricity, BEVs produce zero emissions from a tailpipe and do not incorporate traditional liquid fuel components like fuel pumps, fuel lines, or fuel tanks. the main components of an electrical vehicle can be explained in a few points [21]:

### I.4.1 The battery :

In electric drive vehicles, the auxiliary battery plays a pivotal role by supplying power to a range of essential vehicle accessories and systems. These systems encompass lighting, windshield wipers, infotainment units, HVAC systems, power steering, brakes, and various safety features. Serving as a backup power source, the auxiliary battery ensures the continuous operation of critical functions, particularly when the main traction battery is depleted or disconnected. Its reliability and ability to sustain essential vehicle operations contribute significantly to the overall functionality and safety of electric drive vehicles, enhancing user confidence in their reliability and usability [58][21].

While the main traction battery is primarily responsible for powering the electric motor for propulsion, the auxiliary battery complements this role by supporting ancillary functions and maintaining vehicle functionality, even during periods of low traction battery charge or when the vehicle is stationary. Manufacturers employ advanced power management systems and efficient charging mechanisms to optimize the performance and longevity of auxiliary batteries in electric drive vehicles. As electric vehicles continue to advance and integrate new technologies, the importance of the auxiliary battery in sustaining critical vehicle operations remains paramount, ensuring the seamless operation and reliability of electric drive systems [21].

### I.4.2 The charge port:

The charge port serves as the gateway for electric vehicles to connect with external power sources for recharging the traction battery pack. Through this port, the vehicle establishes a link with charging infrastructure, facilitating the replenishment of its energy reserves. This essential component enables seamless integration with various charging stations and outlets, ensuring the vehicle remains operational. By providing a convenient interface for charging, the charge port enhances the practicality and versatility of electric vehicles. Its accessibility empowers drivers to replenish their vehicle's energy reserves at home, work, or public charging stations. With the charge port's functionality, electric vehicles offer a sustainable and convenient alternative to traditional gasoline-powered vehicles [21].

### I.4.3 DC/DC converter:

This device transforms higher-voltage DC power from the traction battery pack into the lower-voltage DC power essential for operating vehicle accessories and recharging the auxiliary battery. It serves as a vital component in regulating and distributing electrical power within the vehicle's system. By converting power efficiently, it ensures the smooth operation of essential accessories and systems while maintaining optimal battery performance [21].

The device facilitates the seamless integration of various electrical components, enhancing the overall functionality of the vehicle. Its role in managing power flow contributes to the efficiency and reliability of electric drive systems. With its capability to regulate voltage levels, it enables the efficient operation of vehicle accessories and ensures the continuous availability of power for essential functions [21].

### I.4.4 The electric traction motor:

Utilizing energy from the traction battery pack, this motor propels the vehicle's wheels, enabling motion. Certain vehicles employ motor generators, fulfilling dual roles of driving and regenerating energy. This motor serves as the primary source of propulsion in electric vehicles, translating electrical energy into mechanical motion. By harnessing power from the battery pack, it facilitates efficient and eco-friendly transportation. The motor's dual functionality allows for seamless transition between driving and regenerative braking, enhancing energy efficiency. Its integration into the vehicle's drivetrain ensures smooth acceleration and responsive performance. The motor's versatility optimizes energy usage, contributing to extended battery life and increased driving range [21].

### I.4.5 The onboard charger:

This component receives AC electricity from the charge port and transforms it into DC power, facilitating the charging of the traction battery. It engages in communication with the charging equipment, ensuring efficient charging operations. Additionally, it monitors various battery parameters, including voltage, current, temperature, and state of charge, to optimize charging performance. By managing these characteristics, it safeguards the health and longevity of the traction battery. Its role in regulating the charging process ensures safe and effective energy replenishment. Through continuous monitoring and adjustment, it maintains optimal charging conditions, maximizing battery efficiency and lifespan. Its integration into the charging system enhances reliability and safety during the charging process [21].

### I.4.6 The power electronics controller:

This unit regulates the distribution of electrical energy from the traction battery, governing both the speed and torque output of the electric traction motor. It plays a crucial role in optimizing the vehicle's performance and efficiency by adjusting power delivery to the motor. Through precise control, it ensures smooth acceleration and responsive driving dynamics. By managing the flow of energy, it enhances traction and stability under varying driving conditions. Its integration into the vehicle's powertrain system allows for seamless coordination between the traction battery and electric motor. With its ability to modulate power output, it enhances overall driving experience and efficiency. The unit's control over energy flow contributes to improved range and battery utilization in electric vehicles. Its sophisticated management capabilities enable precise control over motor speed and torque, enhancing both performance and efficiency [21].

### I.4.7 The thermal system:

This system ensures optimal operating temperatures for the engine, electric motor, power electronics, and other critical components. It regulates the temperature range to safeguard against overheating and ensure efficient performance. By managing heat dissipation, it prolongs the lifespan and reliability of vehicle systems. The traction battery pack stores electrical energy, serving as the primary power source for the electric motor. It stores energy generated from external sources such as regenerative braking and charging stations. This battery pack enables sustained operation of the electric motor, facilitating propulsion. Its efficient storage and discharge capabilities contribute to extended driving range and enhanced vehicle performance. The traction battery pack's reliability and capacity are crucial factors in the overall efficiency and functionality of electric vehicles [21].

### I.4.8 The traction battery pack:

This component stores electricity to power the electric traction motor, serving as its energy source. It accumulates electrical energy from various sources, including charging stations and regenerative braking. The stored energy enables the electric traction motor to propel the vehicle, facilitating movement. Its capacity and efficiency are essential for ensuring prolonged driving range and optimal performance. As the primary energy reservoir, it plays a vital role in the operation of electric vehicles. The stored electricity is utilized to drive the motor, translating electrical energy into mechanical motion. Its reliable performance is crucial for the overall functionality and efficiency of the vehicle. The battery's ability to store and discharge electricity efficiently contributes to enhanced driving dynamics and sustainability [21].

### I.4.9 The transmission (electric):

The transmission facilitates the transfer of mechanical power generated by the electric traction motor to propel the vehicle's wheels. It serves as a critical intermediary component in the powertrain system, enabling efficient energy conversion. By transmitting torque from the motor to the wheels, it facilitates vehicle movement and acceleration. The transmission's design and functionality optimize power delivery for various driving conditions, enhancing performance and efficiency. Its role in regulating torque output ensures smooth and responsive driving dynamics. Through its operation, the transmission enables precise control over vehicle speed and acceleration. Its integration into the powertrain system contributes to the vehicle's overall drivability and performance. The transmission's efficiency and reliability are paramount for ensuring seamless power transfer and optimized driving experience [21].

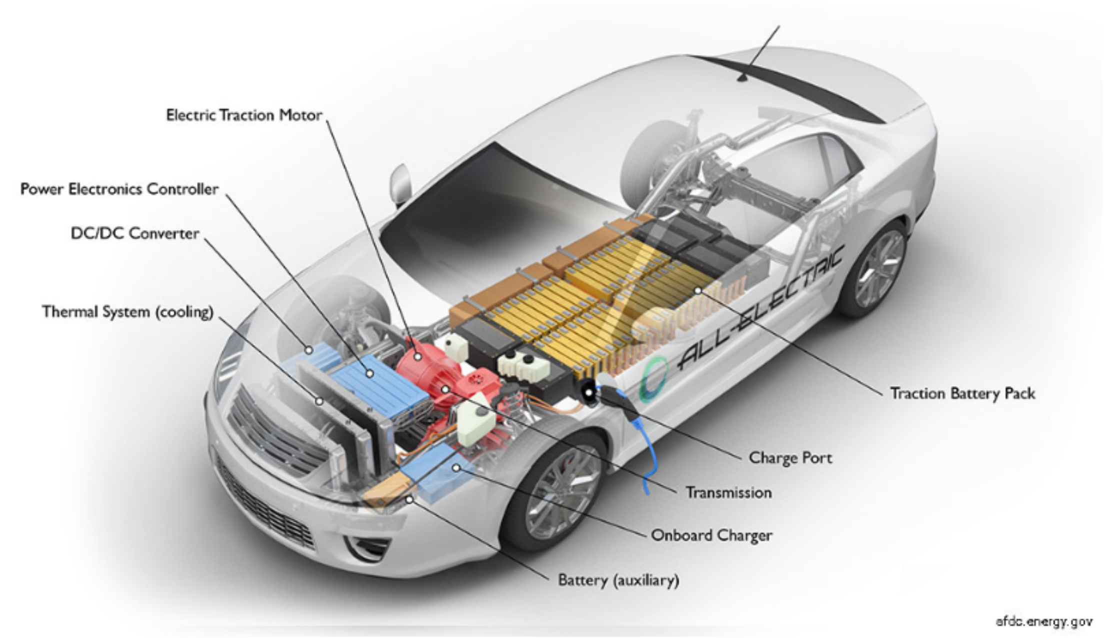

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Figure I.14: key components of an electric vehicle [21].

## I.5 Principle of operation of an electric vehicle

Electric vehicles (EVs) function by employing an electric motor to propel the wheels, Utilizing energy from a stored battery pack, the motor converts power into rotational force when the accelerator pedal is engaged. to drive the wheels. Charging the battery pack is achieved by connecting the vehicle to an electric power source, whether it be a wall outlet or a public charging station. The battery stores energy in a chemical state, which is later converted into electrical energy to drive the motor. In addition to the motor and battery pack, the electric vehicle (EV) includes a controller tasked with overseeing the power transfer from the battery to the motor. This controller adjusts the motor's speed based on input from the accelerator pedal and various sensors, including the speedometer and brake pedal [18].

## I.6 The advantages and drawbacks of electric vehicles

Various types of electric vehicles (EVs) come with their own sets of pros and cons. Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicles (FCEVs) are lauded for producing zero tailpipe emissions, promoting environmental friendliness. However, their drawbacks include limited range and potential challenges due to infrastructure gaps. On the other hand, Hybrid Electric Vehicles (HEVs) and Plug-in Hybrid Electric Vehicles (PHEVs) provide increased flexibility and don't necessitate new infrastructure. Nevertheless, they still emit some pollutants and fall short in terms of environmental friendliness when compared to the emissions-free BEVs and FCEVs [19].

Table I.2: Advantages and drawbacks of each type of vehicle [20]

| Vehicle Type | Description | Advantages | Drawbacks |
|---|---|---|---|
| Battery Electric Vehicle (BEV) | Runs on electricity alone with a large battery. | Zero emissions, reduced reliance on fossil fuels, widely available. | Limited driving range, charging time, charging stations. |
| Fuel Cell Electric Vehicle (FCEV) | Uses hydrogen fuel cell technology for power generation. | No emission, high efficiency, electricity-free. | Limited hydrogen refuelling infrastructure, fuel cell cost. |
| Plug-in Hybrid Electric Vehicle (PHEV) | Integrates electric power and combustion engine. | Range depends on batteries used, no emission, reduced fuel consumption. | Limited electric range, reliance on fossil fuels. |
| Hybrid Electric Vehicle (HEV) | Operates with both a combustion engine and an electric motor | Receive power from both fuel and electrical supply, reduced emissions | Limited electric range, reliance on fossil fuels. |

## I.7 Recharging techniques for EVs

The success of electric vehicles (EVs) is closely linked to factors such as driving range, refueling convenience, and cost, all of which are heavily influenced by the availability and quality of EV charging infrastructure [22].

There are two primary options when it comes to EV chargers: wired and wireless EV chargers. Wired charging solutions necessitate a physical connection through a cable to initiate the charging process for the vehicle. In contrast, wireless charging solutions, often referred to as inductive chargers, eliminate the need for a physical cable. These systems utilize electromagnetic induction, transferring energy from the charging pad on the ground to a corresponding receiver on the vehicle [23].

## I.8 Conclusion

This chapter has delved into the evolution, types, components, operation principles, and pros and cons of electric vehicles (EVs). From tracing their historical journey to dissecting their intricate components and operational mechanisms, we've explored the diverse landscape of EV technology. Understanding the advantages and drawbacks of EVs is crucial for navigating the transition towards a sustainable and efficient transportation ecosystem. The next chapter ,lists types of charging ( wired and wireless charging ).

## Chapter II

# Charging of electric vehicles

CONTENTS

## II.1 Introduction

Wireless Electric Vehicle (EV) charging has gained popularity as an alternative to traditional plug-in charging. While plug-in charging involves a physical connection between the EV and the socket, it poses challenges such as expensive electrical isolation solutions and compatibility issues, leading to user inconvenience and range anxiety. In response to these issues, wireless EV charging solutions are on the rise, transferring power wirelessly through inductive coupling between a ground-based primary pad and a receiver pad beneath the EV. Despite this advancement, stationary wireless systems (SWC) still face range anxiety concerns. Dynamic Wireless Charging (DWC) addresses this by installing charging segments along roadways, allowing EVs to charge while in motion. This approach reduces range anxiety during extended journeys, eliminates delays from charging downtime, and supports large-scale deployment in cities, enabling EV battery downsizing and cost reduction through increased reliance on energy received during vehicle motion. Additionally, wireless energy exchange between vehicles becomes possible with direct vehicle-to-vehicle wireless transfer, contingent on effective coordination and alignment between EVs [24][25].

## II.2 Basic principals of charging

There are two main types of electric vehicle charging which are wired and wireless charging technologies, these two types have risen to prominence, providing unique benefits and catering to diverse requirements within the electric vehicle (EV) ecosystem.

### II.2.1 wired charging

Wired charging methods for electric vehicles (EVs) necessitate a direct link between the EV and the charging system using cables. These technologies can be divided into AC charging and DC charging. AC charging involves charging the battery via the on-board charger (OBC) inside the vehicle, which increases the system's weight (the conversion unit that converting AC into DC is placed inside the vehicle). AC charging can be slow (single-phase) or fast (three-phase). In contrast, DC charging directly charges the battery, offering faster charging capabilities. DC charging can be off-board fast or rapid charging systems, with a separate conversion unit reducing the vehicle's weight. However, DC charging lacks flexibility in charging locations, and its battery management system (BMS) installation is costlier. Despite advancements, the main drawbacks of wired charging are its limited flexibility and safety concerns related to the BMS [26].

Figure II.1: The wired charging station [61].

In a nutshell, electric vehicle charging is classified into three levels.

### II.2.1-a Level one

Level 1 charging is the most accessible and cost-effective option, utilizing standard 120-volt household outlets. Despite its affordability, it is the slowest charging method,with a low power output of 1.4 kw, which providing only three to five miles of range per hour. This level of charging is suitable for overnight charging at home, ensuring a gradual replenishment of battery capacity. While it may not be suitable for rapid recharging needs, it offers a convenient solution for daily commuting and overnight charging routines. Its simplicity and accessibility make it a popular choice for electric vehicle owners with residential charging capabilities [27].

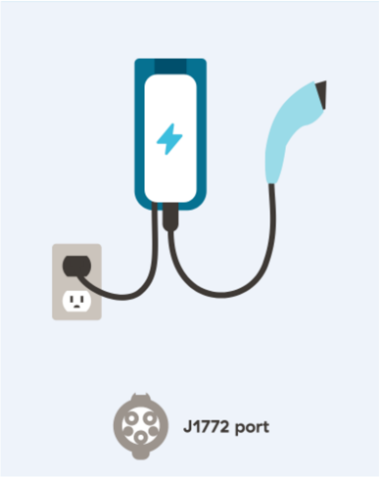

Figure II.2: wired charging level one [62]

### II.2.1-b Level two

Level 2 charging, enabled by a 240-volt outlet, offers significantly faster charging compared to Level 1, with a power output of 3.9-19.2 kw, delivering between 12 and 80 miles of range per hour. Widely used in residential settings, workplaces, and public charging stations, it provides a convenient and efficient charging solution for electric vehicles. Its versatility and faster charging speeds make it a preferred option for Electric Vehicles owners seeking quicker replenishment of battery capacity [27].

Figure II.3: wired charging level two [62] .

### II.2.1-c Level three

With a rate of 3–20 miles per minute, Level 3 charging stands as the quickest charging option, using 400 volt to 900 volt, with a power output of 24-300 kw commonly found in public stations along busy routes and utilized by commercial fleets. Unlike Levels 1 and 2, Level 3 charging employs direct current (DC), enabling rapid energy transfer for reduced downtime and increased convenience [27].

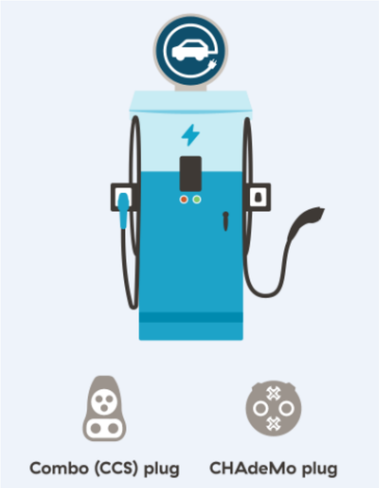

Figure II.4: wired charging level three [62]

### II.2.2 wireless charging

Wireless charging for electric vehicles (EVs) is based on Inductive Power Transfer (IPT), which we can categorize into three groups: near-field, medium-field, and far-field charging. Near-field and medium-field charging, also known as mechanical charging are currently the most prevalent methods used for EV charging. The demand for wireless charging technologies is increasing due to their lower cost compared to wire charging and their ability to charge EV batteries without a direct connection. These technologies transmit high-frequency AC (to 600 kHz) power from a transmitter pad to a receiver pad attached to the EV. Far-field charging is considered the future of EV charging. However, a major drawback of wireless charging is the risk of losing connection between the transmitter and receiver, which can disrupt the charging process [26].Primarily, there exist two wireless charging types:

Figure II.5: The Wireless EVs Charging Station [63]

### II.2.2-a Static WPT charging

Wireless inductive EV charging is activated when a vehicle is parked in a designated area. This technology utilizes a charging plate embedded with a coil that generates an alternating current (AC) magnetic field, which is then transmitted to the vehicle's inductive pick-up. Upon receiving the AC current, a voltage converter in the vehicle converts it to direct current (DC), which subsequently charges the battery pack. The charging pad, connected to a wall-mounted power adapter, is placed on the ground, while the vehicle is parked over it. A receiver at the backside of the vehicle detects the charger within range, triggering automatic charging [28].

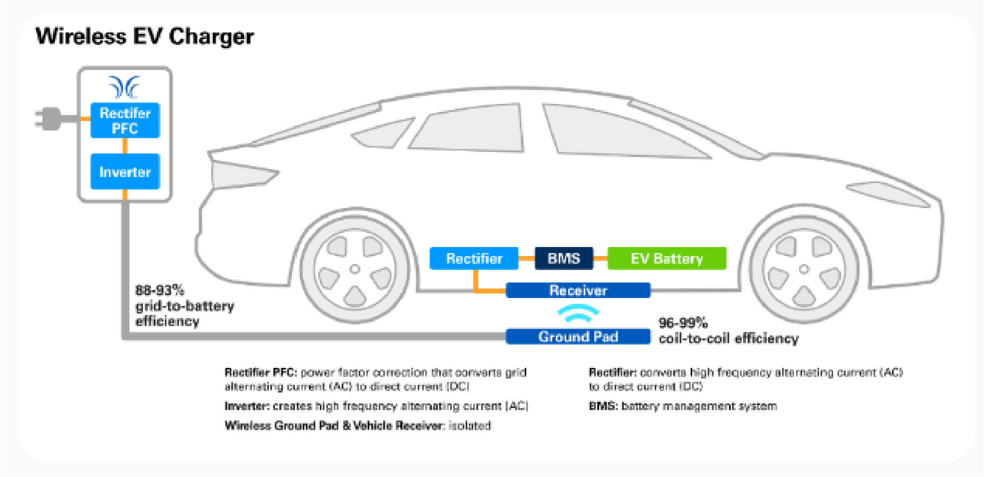

Figure II.6: static wireless EV charger [64]

### II.2.2-b Dynamic WPT charging

In motion or during brief stops, such as at red lights, dynamic charging systems are utilized for electric vehicles (EVs). These systems enable vehicles to charge while on the move, akin to stationary charging setups where EVs are charged via resonant coils. To facilitate this, charging lanes are designated alongside roads, allowing drivers to charge their vehicles while driving. Dynamic charging systems cannot be achieved through wired setups, necessitating the use of Wireless Power Transfer (WPT) technology to enable this method of charging [29].

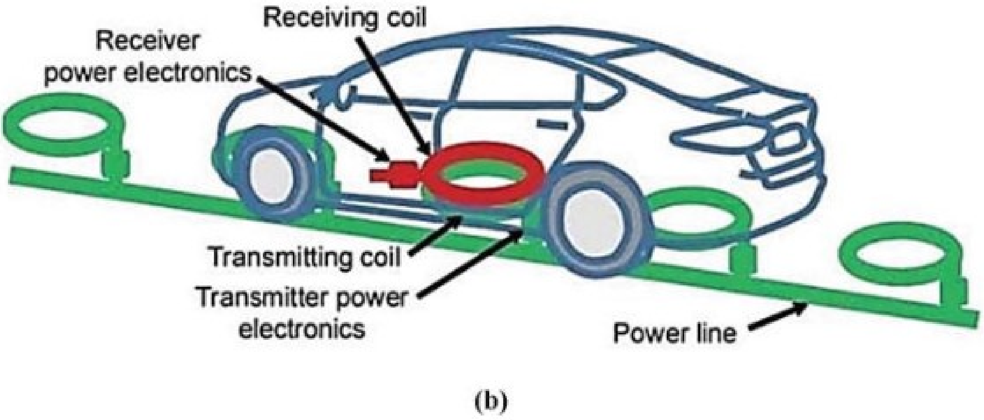

Figure II.7: block diagram of dynamic wireless charging [65]

### II.2.3 Comparison between wired and wireless charging

Table II.1: Difference between wired and wireless charging [30][31][32][33]

| | Wireless Charging | Wired Charging |
|---|---|---|
| Efficiency | Efficiency may vary depending on wireless charging technology, with potential energy loss due to induction or electromagnetic radiation | Generally high efficiency due to direct connection and minimal energy loss |
| Cost | Cost Initial infrastructure costs for charging pads or equipment, which may vary depending on technology Initial infrastructure costs for charging stations and cables | Initial infrastructure costs for charging stations and cables |
| Mobility | Offers greater mobility as EVs can be charged without being tethered to a cable | Limited mobility due to cable length and connection requirements |
| Charging Speed | Charging speeds may vary depending on technology and distance from the charging source | Can provide high charging speeds, especially with fast charging stations |
| Installation | May require installation of charging pads or infrastructure, but eliminates need for cables | Typically requires installation of charging stations with cables |
| Convenience | No physical connection required, offering convenience and ease of use | Requires physical connection with cable |
| Alignment | May require alignment between charging pads or transmitter/receiver coils, but generally less stringent | Requires precise alignment between charging plug and vehicle port |
| Adaptability | Developing infrastructure with limited compatibility, but offers potential for future integration and advancement | Well-established infrastructure and compatibility with most EV models |
| Safety | Requires adherence to safety protocols to mitigate risks such as electromagnetic radiation exposure | Minimal safety risks associated with proper installation and operation |

## II.3 wireless charging techniques

Wireless charging technologies have emerged as promising solutions for electric vehicle (EV) charging, offering convenience and ease of use. Among these technologies are inductive power transfer (IPT), resonant inductive power transfer (RIPT), microwave power transfer (MPT) and lazer or infrared power transfer (LPT) technologies. Each method utilizes unique principles to wirelessly transfer power to EVs, contributing to the evolution of electric mobility.

### II.3.1 Microwave power transfer

Microwave Power Transfer (MPT) is a far-field Wireless Power Transfer (WPT) technique that operates using electromagnetic radiation [34].

#### II.3.1-a Principal of operating an MPT technology

The underlying principle of this technology is as follows: a magnetron, powered by a high-voltage DC generator, generates microwaves that pass through a waveguide and are then radiated by the transmitting antenna. The antenna can be designed to direct the radiated power to the collection region by utilizing a phase-shifter array in the transmitter. On the receiving end, a rectenna converts the microwave signal into a DC signal, which is then connected to the electric vehicle's battery for charging. MPT typically operates at frequencies of 2.4 GHz or 5.8 GHz, with recent works also exploring the use of 28-GHz signals [34][35].

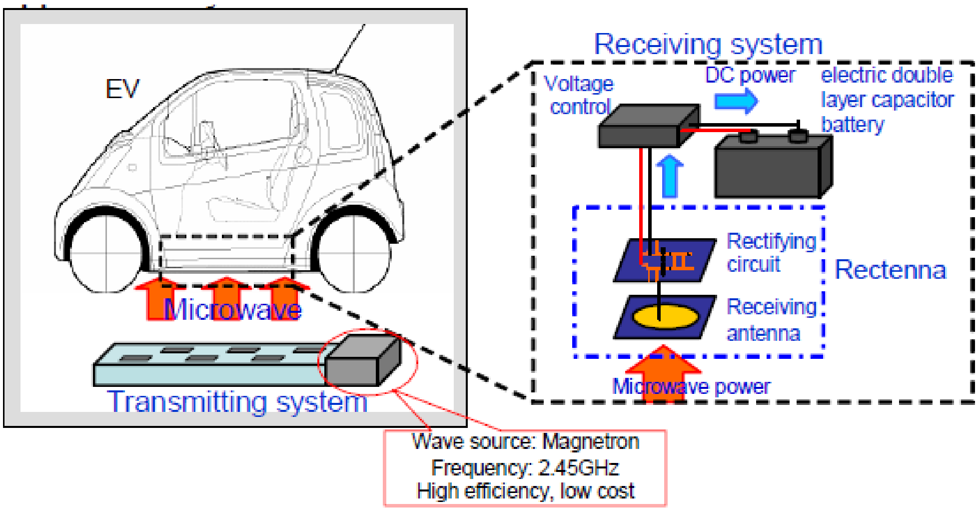

Figure II.8: Diagram of MPT charging system for EV from road [38]

#### II.3.1-b Advanteges

The advantages of Microwave Power Transfer (MPT) technology include:

- The ability to charge electric vehicles (EVs) while parked or running using the same MPT system.

- Long-distance wireless charging capabilities, extending over several meters.
- A single power transmitter capable of charging multiple receivers through beam steering technology.
- Lower establishment costs for transmitter systems compared to traditional charging methods.
- Simultaneous transmission of power and information through microwave frequency, enhancing the efficiency and functionality of the charging process [36-37]

#### II.3.1-c Drawbacks

MPT technology in the EV context faces three main limitations:

- The transmitter and receiver are designed for unidirectional power flow, requiring the duplication of a dual system for V2G operations.
- High power levels necessitate bulky antennas, potentially limiting its applicability in certain scenarios.
- The efficiency of MPT is lower than that of inductive or capacitive coupling, often referred to as beam collection efficiency. This lower efficiency may impact the overall performance and efficiency of the charging process.
- Also The MPT has a low charging efficiency, and microwaves become less health-safe when exposure to radiofrequency density increases [37-38]

### II.3.2 Laser Power transfer (Infrared)

Laser Power Transfer (LPT) has the potential to become a leading technology in the long-range Wireless Power Transfer (WPT) field, thanks to its monochromaticity, coherence, and directionality. LPT utilizes a narrow, high-power collimated beam created by a resonator, which can cross long distances due to its low divergence [37].

#### II.3.2-a Principal of operating an LPT technology

The optical wave is produced by a laser diode, which is fueled by the framework within the transmitter. A laser produces a concentrated bar of light of a specific wavelength and control. To alter the course of the light, a bar executive is joined into these frameworks so that the light can reach the recipient. The collector is prepared with photovoltaic cells which change over the gotten laser light into control. This control is exchanged to the battery by control converters. The transmitter or the recipient can depend on a most extreme control point following gadget to maximize the gotten control pillar and, thus, the effectiveness of the control exchange. The bar chief is an essential component as within the run of wavelengths the control transmitter and its collector must keep the line-of-sight and no middle objects ought to be permitted. Beneath this circumstance, the recipient may be up [34].

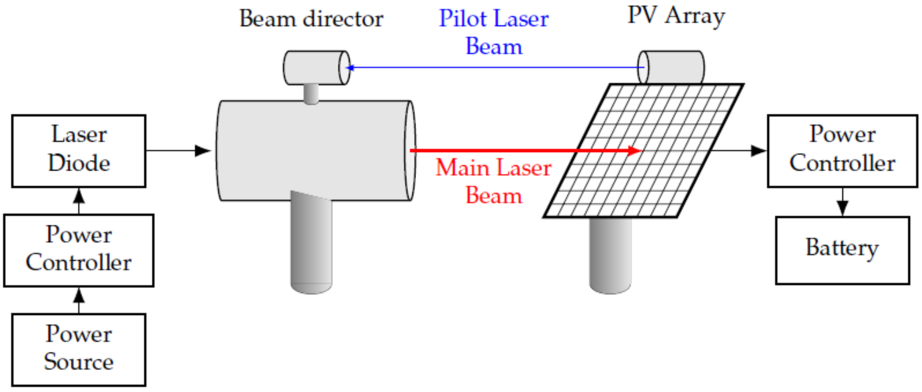

Figure II.9: Diagram of LPT charging system [34]

### II.3.2-b Discription of LPT systems

LPT systems can be classified into space-based, ground-based, and underwater categories, depending on their intended applications. Despite the differences, all systems share common subsystems, such as the laser emission, transmission control, and receiving subsystems. The laser emission subsystem comprises three main components: the laser source, which generates the laser, an aiming rotary table that directs the laser, and a cooling mechanism to prevent overheating. These components must work together to ensure safe and efficient laser operation. During wireless laser transmission, various types of losses can occur, including absorption, reflection, and scattering. The laser receiving subsystem includes several key elements, such as laser power conversion, thermal management, and energy management, which are critical for efficient energy transfer and utilization [39].

### II.3.2-c Advanteges

This technology offers several advantages:

- **Long-range power transmission:** LPT can cover long distances with power transmission, making it a viable option for charging electric vehicles (EVs) while in motion.
- **High precision:** LPT can precisely target the receiver, ensuring efficient energy transfer.
- **Compact size:** LPT devices can be compact and lightweight, making them easy to install and use.
- **Minimal interference:** LPT can operate at frequencies that do not interfere with other wireless communication systems, reducing the risk of interference [39-40]

### II.3.2-d Drawbacks

- Safety concerns: High-powered lasers can be dangerous to humans and animals, requiring safety measures to prevent accidental exposure.
- Atmospheric conditions: Weather conditions, such as fog, rain, or snow, can affect the efficiency of LPT, reducing its effectiveness in adverse weather conditions.

- Cost: LPT technology is still in development, and the cost of implementing it can be high, making it less accessible to the general public.
- Regulatory challenges: LPT technology operates at high power levels, requiring regulatory compliance and approval, which can be a lengthy and complex process [40-41].

### II.3.3 Inductive power transfer

Induction power transfer (IPT) is near-field power transmission in the range of Hz to GHz, based on the principle of electromagnetic induction, where power is transmitted between two coils: one in the charging pad (transmitter) and one in the device (receiver). The transmitter coil, when carrying an alternating current, generates a magnetic field that then induces a voltage in the receiver coil, which in turn charges the device. This process occurs when the two coils are in close proximity to each other [42].

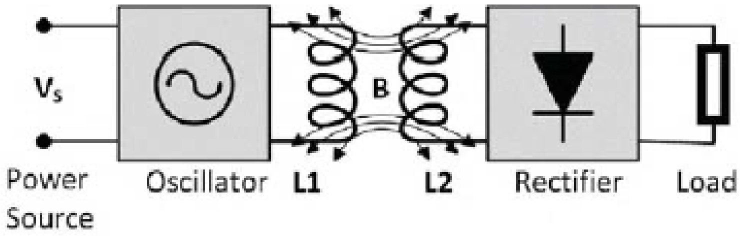

Figure II.10: inductive coupling method [46]

#### II.3.3-a Principle of operation IPT technology

The system comprises two electrically insulated components: the ground side, which includes the transmitter, grid, or primary components, and the vehicle side, which includes the receiver or secondary components. The ground side is integrated into the road to receive low-frequency power from the grid, convert it to high-frequency power, and supply it to the transmitter coil. The electromagnetic fields (EMFs) produced by the transmitter coil are coupled with the receiver coil in the vehicle to generate high-frequency voltages and currents in the secondary circuit. The high-frequency secondary power is then recertified to charge the vehicle's energy storage system, such as a battery. The two sides communicate wirelessly through a high-frequency link. The system operates at a frequency of 80-90 kHz, which reduces its size and enhances its power transfer capability. To achieve high-power and For optimal efficiency, resonance capacitors are linked to both the transmitter and receiver coils, compensating for large leakage inductances due to the large air gap and providing the necessary reactive power for magnetizing the air gap. These capacitors can be connected in series or parallel and can be a combination of LC circuits [43].

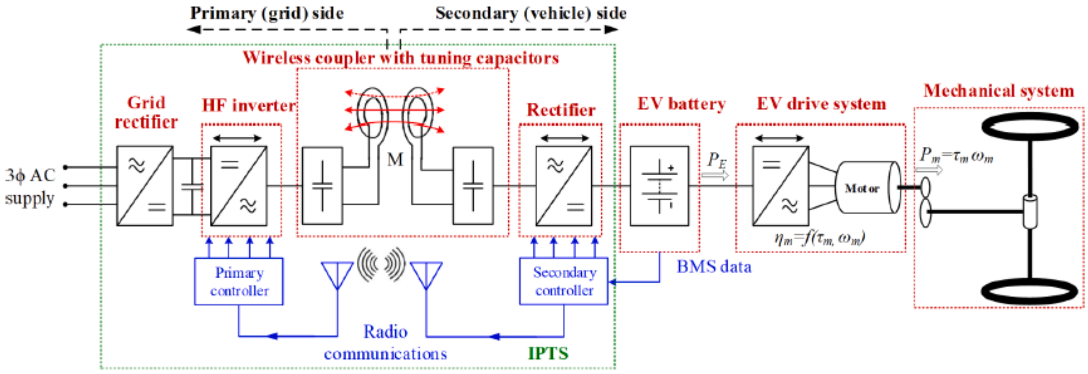

Figure II.11: Schematic diagram of an IPT system for EV charging [43]

### II.3.3-b Advanteges

- Convenience: IPT charging eliminates the need for physical connectors, making the charging process as simple as parking the vehicle over a charging pad. This convenience can encourage more frequent charging and increase EV adoption.

- Safety: With no exposed electrical contacts, IPT charging can be safer, especially in wet or outdoor environments. There's also a reduced risk of electrical shock or short circuits compared to traditional plug-in chargers.

- Durability: Since there are no physical connectors to wear out, IPT charging systems can have longer lifespans and lower maintenance requirements, leading to potentially lower operating costs over time.

- Flexibility: IPT charging pads can be integrated into various locations, such as parking lots, streets, or garages, enabling seamless charging experiences without the need for dedicated charging stations [44][37].

### II.3.3-c Drawbacks

- Efficiency: Inductive power transfer systems can suffer from lower efficiency compared to wired charging systems. Energy losses can occur during the transfer of power wirelessly, leading to longer charging times and higher energy consumption.

- Cost: Installation of IPT charging infrastructure can be expensive, especially for widespread adoption. This includes the cost of manufacturing and installing the charging pads, as well as any necessary upgrades to power grid infrastructure.

- Limited Range and Power: IPT charging systems typically have a limited range over which power can be transferred efficiently. Additionally, transferring higher power levels wirelessly can be more challenging and less efficient compared to wired connections, which may limit the practicality of IPT charging for fast charging of EVs.

- Standardization: There's a need for standardization to ensure interoperability between different IPT charging systems and EV models. Without standardized protocols and specifications, compatibility issues could arise, hindering the widespread adoption of IPT charging technology [43-44]

### II.3.4 Resonant inductive power transfer

Resonance inductive charging technology is based on the principle of a vibrating tuning fork, which is an application of sound resonance. When a coil vibrates at its natural frequency, it excites a nearby coil with the same resonant frequency, generating energy for charging the electric vehicle [45].

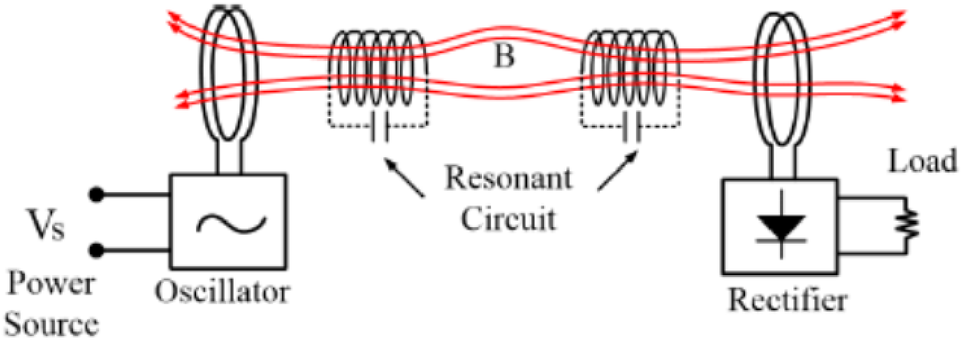

Figure II.12: magnetic resonant coupling method [66]

#### II.3.4-a Principle of operation RIPT technology

Magnetic components are used to facilitate the transfer of power between two resonant circuits, one at the transmitter and another at the receiver. Each resonant circuit is made up of a coil of wire, which can be connected to a self-resonant coil, a capacitor, or another resonator with internal capacitance. These two circuits are tuned to resonate at the same frequency, enhancing the power transfer and coupling between them. The generated energy transfer occurs through the magnetic field created by the vibrating coil, which induces a voltage in the receiving coil, allowing for the transfer of electrical energy. This technology has the potential to enable efficient and convenient charging of electric vehicles.

This resonance is similar to how a vibrating tuning fork can cause sympathetic vibration in a remote branch that is tuned to the exact same pitch, highlighting the principle of resonance inductive power transfer for electric vehicles [46].

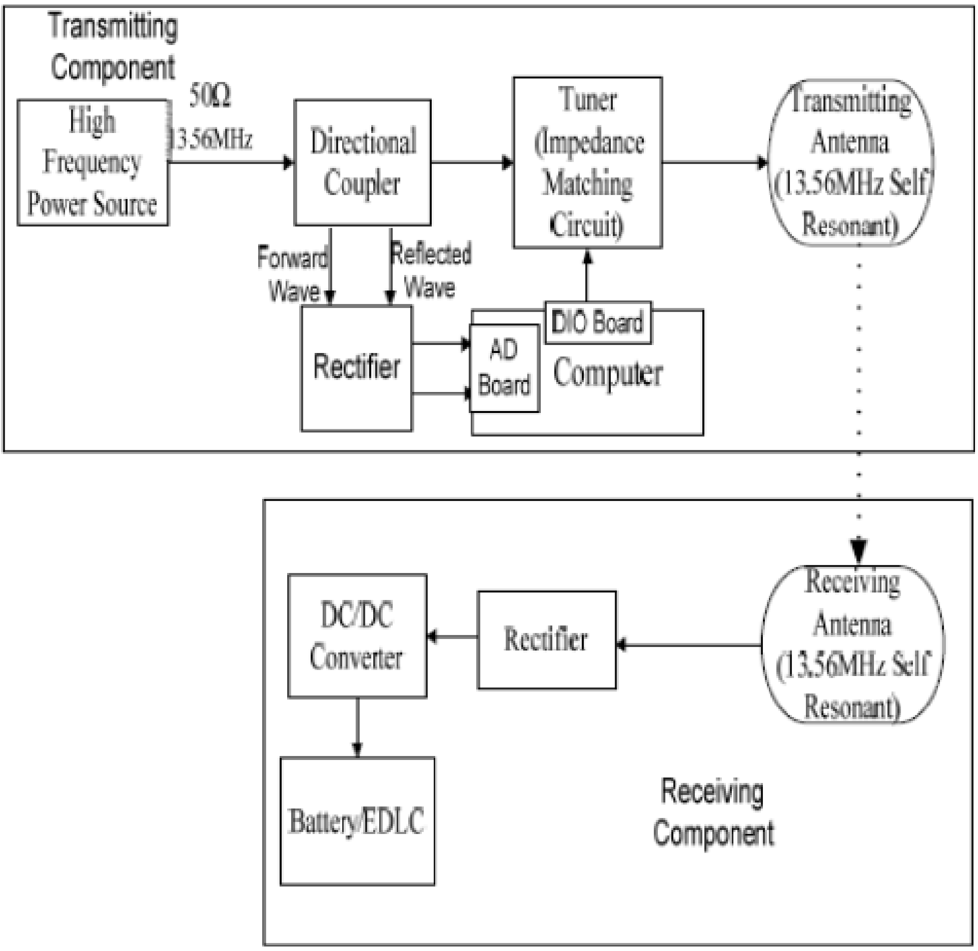

Figure II.13: Wireless power transfer system with tuning [67]

#### II.3.4-b Advanteges

- Safety and high power transfer efficiency over a long transmit distance, making it suitable for EV charging applications.
- Improvement in efficiency of wireless power transfer of resonance inductive coupling using magnetoplated wire.
- High-efficiency wireless power transmission at low frequency using permanent magnet coupling.
- The ability to overcome problems such as coil misalignment, improper compensation topologies, and magnetic materials, which can reduce the efficacy of the power transfer.
- Provides galvanic isolation [47-48].

#### II.3.4-c Drawbacks

- The need for precise alignment between the transmitter and receiver coils to maintain high efficiency and power transfer .

- Extremely sensitive to the obstacles in between coupler coils. (Especially the metallic ones) .
- Cost of the system increases with power .
- The circuit can be affected by eddy current losses that overheat the circuit, causing damage [47-48].

## II.4 Safety of WPT Systems and Related Standards

Wireless charging for Electric Vehicles (EVs) requires adherence to standards to ensure interoperability, safety, and efficiency across different charging systems and vehicle models.The key considerations and preventive measures concerning the safety of Wireless Power Transfer (WPT) systems for Electric Vehicles (EVs) are outlined as follows:

1. Electromagnetic Compatibility (EMC): Ensuring compliance with electromagnetic compatibility standards is essential for WPT systems. This ensures seamless operation alongside other electronic devices while minimizing electromagnetic interference [68]
2. Foreign Object Detection (FOD): Wireless chargers should possess the capability to identify foreign objects positioned beneath the vehicle during charging. This feature prevents inadvertent operation on foreign objects, thereby enhancing safety [69]
3. Temperature Regulation: Employing temperature sensors and control mechanisms is crucial to mitigate the risk of overheating during wireless charging sessions [70]
4. User Safety: Wireless chargers should incorporate protective features to ensure the safety of the user [71]
5. Adherence to Standards: WPT systems must meet industry standards and regulations to ensure both security and performance. The prescribed standards for WPT systems include:
    - SAE J2954, overseen by the Society of Automotive Engineers (SAE) International, sets the standard for Wireless Power Transfer (WPT) systems for Electric Vehicles (EVs). It provides a structured approach for the design and testing of WPT systems catering to power levels of up to 11 kW. This standard encompasses the powering frequency, electrical specifications, testing procedures, and various factors to be assessed. Furthermore, SAE J2954 delineates the precise dimensions for components such as the power transmitting coil (ground assembly - GA) and receiving coil (vehicle assembly - VA), ensuring uniformity and efficacy in their assembly [49][72]
    - IEC 61980-1 outlines general requirements for EV Wireless Power Transfer (WPT) systems, including efficiency, safety, EMC, and EMF definitions. IEC 61980-2 details MF WPT system operations and communication. IEC 61980-3 covers power transfer specifics for off-board components in MF-WPT systems [73]

- ISO 19363:2020 specifies the criteria and function of on-board vehicle gear facilitating Magnetic Field (MF) WPT for charging EV traction batteries. Primarily designed for passenger cars and light-duty vehicles, it ensures standardized operations [74]
- Alliance for Wireless Power (A4WP): A4WP is a major wireless charging camp that focuses on advancing wireless charging technologies, including high-power applications for devices like laptops and tablets [51].
- ISO 15118: This International Organization for Standardization (ISO) standard specifies communication protocols for wireless charging of EVs, defining the Vehicle-to-Grid (V2G) communication interface for bi-directional power flow control, authentication, and billing purposes [50].

It exists as well other standards such as combined charging system (CCS),CHAdeMO (CHArge de MOve, meaning: "move by charge") and supercharge (Tesla vehicles) and many other standards.

Adherence to these standards ensures the safe, reliable, and compatible operation of wireless charging systems for EVs with various vehicle models and charging infrastructure, promoting interoperability and facilitating the widespread adoption of wireless charging technology in the electric vehicle ecosystem.

## II.5 Comparison between different techniques of wireless charging

Table II.2: Advantages and drawbacks of wireless charging technology [34][59]

| Technology | Power Level | Efficiency | Bi-Directional Flow | Gap | Intermediate Objects | Motion | Cost |
|---|---|---|---|---|---|---|---|
| Resonant | High (Up to 100kW) | 90–95 % | Yes | $<$ 30 cm | Yes | Yes | Medium |
| Inductive | Medium (Up to 7kW) | 80-85 % | Yes | $<$ 30 cm | Yes | Yes | Low . |
| Microwave | Low ($<$ 250 W) | 40-50 % | No | up to 1 km | No | No | High |
| Laser | Low ($<$ 500 W) | 1-15 % | No | up to 1 km | No | No | High |

## II.6 Conclusion

This chapter has covered the basics of both wired and wireless charging for electric vehicles (EVs), exploring various techniques such as microwave, laser, inductive, and resonance inductive power transfer. We've also discussed the standards and norms governing wireless charging and compared the different techniques, providing insights into their advantages and limitations. Understanding these aspects is crucial for stakeholders in advancing the development and adoption of efficient and sustainable charging infrastructure for EVs.

In the next chapter, there will be a simulation and a discussion about the most commonly used technologies nowadays, which are Inductive power transfer (IPT) and Resonance inductive power transfer (RIPT) or Magnetic resonance power transfer (MRPT). The focus of the discussion will be on (RIPT) technology because of it's high efficiency in charging electric vehicles wirelessly.

## Chapter III

# Wireless charging techniques simulaions and modelizations

CONTENTS

## III.1 Introduction

The inductive power transfer (IPT) technique has gained significant interest and widespread use. Reactive compensation of the primary and secondary windings is essential to reduce the VA rating of the input power supply and increase power transfer capability. Compensation capacitors can be connected in series (S) or parallel (P) to the primary coil, secondary coil, or both, resulting in four common compensation topologies: series-series (SS), series-parallel (SP), parallel-series (PS), and parallel-parallel (PP). The choice of topology depends on the specific application and design specifications. In this chapter we are going to try to identify the most efficient compensation topology used in wireless power transfer systems for Electrical Vehicles (EVs) charging between series-series topology and series-parallel topology considering that they are the most suitable compensation topologies for (EVs).

## III.2 Inductive Power Transfer

### III.2.1 Electrical equivalent circuit analysis

The electrical model of the inductive charging is illustrated in figureIII.1 where $R_1$, $R_2$ and $L_1$, $L_2$ are the resistances and the inductance of the transmitting and receiving coils, respectively, M is the mutual inductance between the two coils, and $R_L$ is the equivalent AC load resistance.

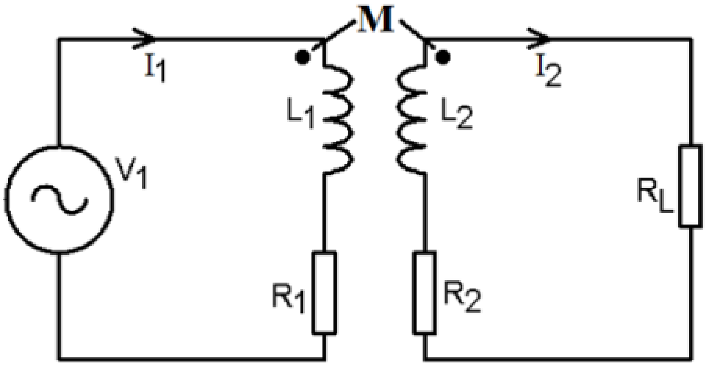

Figure III.1: Equivalent circuit of inductive charging [75]

Suppose the transmitting coil receives a sinusoidal voltage $\bar{V}_1$ with an angular frequency of $\omega$ . Using the electrical equivalent circuit model, we can establish steady-state equations for both the transmitter and receiver sides.

$$\bar{V}_1 = \bar{I}_1 R_1 + j\omega L_1 \bar{I}_1 - j\omega M \bar{I}_2 \tag{III.1}$$

$$j\omega M \overline{I}_1 = j\omega L_2 \overline{I}_2 + \overline{I}_2 R_2 + \overline{I}_2 R_L \tag{III.2}$$

where $\bar{I}_1$,$\bar{I}_2$ are the currents flowing in the transmitting and receiving coils. From equation III.2 the current $\bar{I}_2$ is:

$$\overline{I_2} = \frac{j\omega M\overline{I_1}}{j\omega L_2 + R_2 + R_L} = \frac{j\omega M\overline{I_1}}{Z_2} \tag{III.3}$$

$Z_2$ signifies the equivalent impedance on the receiving end. When equation III.3 is substituted into equation III.1, gives:

$$\overline{V_1} = R_1\overline{I_1} + j\omega L_1\overline{I_1} + \frac{\omega^2 M^2}{Z_2}\overline{I_1} \tag{III.4}$$

Total impedance $Z_t$ seen from the transmitter side is given by:

$$Z_t = R_1 + j\omega L_1 + \frac{\omega^2 M^2}{Z_2} \tag{III.5}$$

From equation III.5 reflected impedance $Z_r$ at transmitter side is given by:

$$Z_r = \frac{\omega^2 M^2}{Z_2} \tag{III.6}$$

Observing equations III.2 through III.6, it's apparent that both the induced and reflected impedance are influenced by the mutual inductance (M) between the transmitting and receiving coils. This mutual inductance, in turn, is determined by the coupling coefficient (k), expressed as:

$$\mathrm{k} = \frac{M}{\sqrt{L_1 L_2}} \tag{III.7}$$

In contactless charging scenarios, the mutual inductance (M) tends to be small, while both $L_1$ and $L_2$ are typically large, resulting in a small value for the coupling coefficient (k). This leads to a range for k typically falling between 0.1 and 1:

$$\frac{\overline{I_2}}{\overline{I_1}} = \frac{j\omega M}{j\omega L_2 + R_2 + R_L} = \frac{j\omega M\overline{I_1}}{Z_2} \tag{III.8}$$

The primary performance metrics for inductive power transfer include efficiency, maximum load power, and the sizing power ratio of the voltage source. They are defined as follows:

Efficiency, as derived from equations III.5 and III.8, is expressed as:

$$\eta = \frac{\bar{I_2}^2 R_L}{\bar{I_1}^2 Re\{Z_t\}} = \frac{R_L}{R_1\frac{L_2^2}{M^2} + (R_2 + R_L)\left[1 + \frac{R_1(R_2+R_L)}{\omega^2 M^2}\right]} \tag{III.9}$$

Re $Z_t$ represents the real component of the total impedance observed from the transmitting end.

Maximum load power $P_{Lmax}$ can be computed from the short-circuit power $S_{sc}$ , which is the result of multiplying the open-circuit voltage by the short-circuit current:

$$S_{SC} = \frac{(\omega M I_1)^2}{\omega L_2} \tag{III.10}$$

In adherence to the maximum power transfer theorem,$P_{Lmax}$ is achieved when $R_L = \omega L_2$, disregarding the coil's resistance, and is expressed as:

$$P_{Limax} = \frac{1}{2}\frac{(\omega M I_1)^2}{\omega L_2} \tag{III.11}$$

In an uncompensated system,$P_{Li,max}$represents the maximum load power. The Sizing Power Ratio (SPR) is defined as the ratio between the nominal apparent power and the nominal load power. To safeguard the source, SPR should approach unity. Simplifying matters, we can disregard resistance, and the resulting expression is outlined in equation III.12:

$$SPR_i = \frac{\sqrt{{R_L}^2 + (\omega L_2)^2}\sqrt{(L_1 R_L)^2 + [\omega(L_1 L_2 - M^2)]^2}}{\omega M^2 R_L} \tag{III.12}$$

In the context of the uncompensated system, SPRi represents the sizing power ratio of the voltage source. As depicted in equation III.9, it's evident that to attain maximum efficiency, either $\omega$ and M need to be increased or resistance should be decreased.

Studies suggest that maximum efficiency is attained at higher frequencies [78], as indicated by the condition:

$$\omega \gg \frac{\sqrt{R_1(R_L + R_2)}}{M} \tag{III.13}$$

As indicated by equation III.5, it's noticeable that at higher frequencies, the total impedance perceived by the source becomes increasingly inductive, leading to a decrease in the input power factor. Consequently, to accommodate higher frequencies, the inverter on the source side should possess a higher apparent power rating. This underscores the necessity for compensation in Inductive Power Transfer.

### III.2.2 Matlab simulation of the system

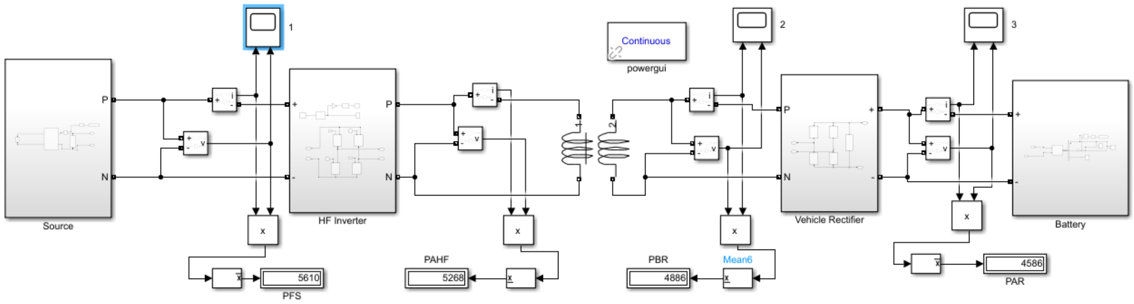

Figure III.2: Matlab simulation of an IPT system

Observing III.2, the simulation involves multiple subsystems. The initial stage is the source, which contain a grid power rectified followed by high-frequency inversion before transmitting it to the primary coil. The resulting output is obtained from the secondary coil after undergoing another rectification process. Internal circuit diagrams of the subsystems depicted in figureIII.2 are illustrated from figure III.3 to figure III.5.

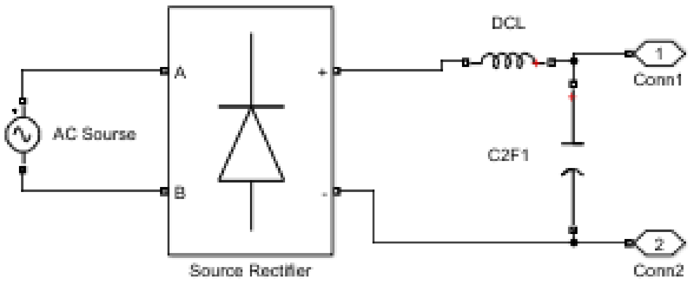

Figure III.3: The source of the IPT system

In figure III.2, the source subsystem is shown. It includes an AC/DC Rectifier, it is a full bridge rectifier. Although two rectifiers are utilized in the simulation , they are identical, hence not separately illustrated. The primary rectifier is linked to the grid, transforming grid power into pulse settings before feeding it to the inverter. The secondary rectifier rectifies the voltage from the secondary coil, providing power to loads.

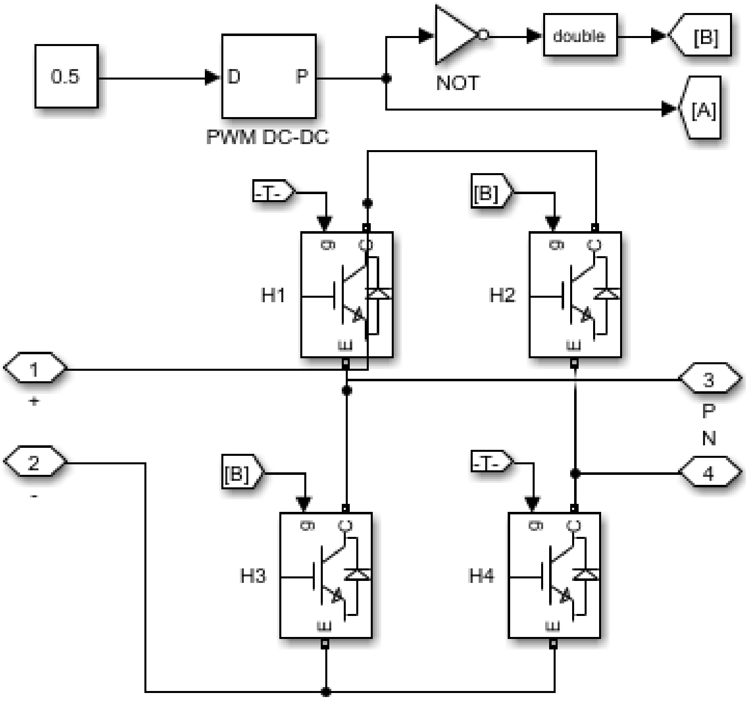

Figure III.4: HF inverter subsystem

Figure III.4 illustrates the High-Frequency DC/AC Inverter subsystem. It comprises a full bridge inverter constructed with IGBT components. The rectified grid power is supplied to the inverter, and subsequently, the inverted signal is transmitted across the primary coil. The operation of the inverter section requires two gate pulses.

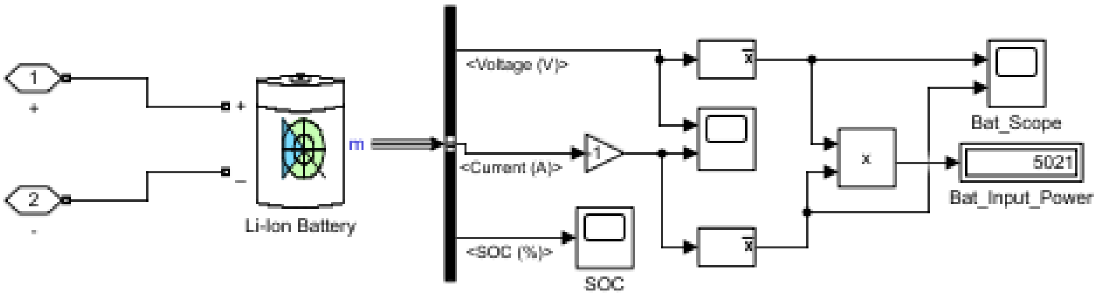

Figure III.5: Battery subsystem

The figureIII.5 ,the battery is shown which is a Lithium-Ion (Li-Ion) battery model represents the behavior of a lithium-ion battery within a simulation environment .This model typically encompasses various components and parameters to simulate the dynamic behavior of Li-Ion batteries accurately . The characteristics of Li-Ion battery is shown in table III.1 .

Table III.1: characteristics of Li-Ion battery

| | |
|---|---|
| Nominal voltage (V) | 360 |
| Rated capacity (Ah) | 100 |
| Initial state-of-charge (%) | 30 |
| Battery response time (s) | 10 |

Inductive power transfer (IPT) technology, utilized in electric vehicle charging, encounters significant challenges. Firstly, efficiency decreases as the gap widens between the charging coils, resulting in extended charging durations. Secondly, maintaining precise alignment between the coils is essential for optimal functionality, which presents practical difficulties. Furthermore, power losses stemming from resistance and electromagnetic interference can further diminish the overall charging efficiency [79][42].

Resonance inductive power transfer (RIPT) presents distinct advantages compared to traditional inductive power transfer (IPT) in the realm of electric vehicles (EVs).

RIPT generally achieves superior efficiency across extended distances, facilitating efficient charging despite potential gaps between the coils. Moreover, RIPT systems commonly demonstrate lower susceptibility to electromagnetic interference and offer enhanced flexibility in coil alignment, streamlining the charging experience for users [80][81].

## III.3 RIPT model and simulation

The resonance inductive power transfer (RIPT) or inductive coupled power transfer (ICPT) technique is renowned for its ability to efficiently transfer high power in various applications, particularly in electric vehicles . It facilitates swift charging and optimizes power transmission through frequency modulation and control to mitigate losses stemming from insufficient magnetic coupling. RIPT has found utility in both stationary and mobile electric vehicle scenarios .

Investigating the model involves categorizing resonant circuits and establishing their equivalent circuits to gain a comprehensive understanding of their operational behavior. There are two types of resonance circuits which are : Series Resonance and Parallel Resonance.

The configuration of capacitor connections for compensation on both sides, whether in series or parallel, results in four distinct topologies: series-series (SS), series-parallel (SP), parallel-series (PS), and parallel-parallel (PP), as illustrated in figureIII.6.

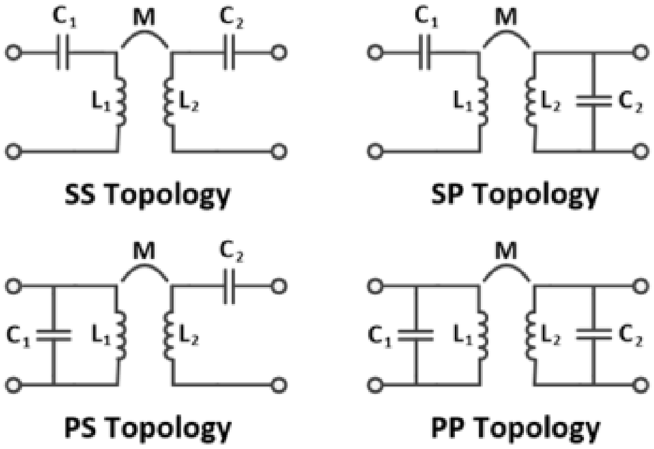

Figure III.6: Compensation topologies (a) SS, (b) SP, (c) PS, (d) PP [77]

In this context, the letters "P" and "S" represent the manner in which the capacitor (either compensation or resonant capacitor) is linked to the coil. Specifically, "P" denotes a parallel connection of the compensation capacitor with the coil, while "S" indicates a series connection of the compensation capacitor with the coil.

## III.4 Compensation topologies

Among the compensation topologies of the MRPT illustrated in figureIII.6, the two primary configurations renowned for their efficiency and suitability for electric vehicles are the series-series and series-parallel compensations [79]. In this section, we will delve into a detailed discussion of these two topologies.

### III.4.1 Series-series topology

#### III.4.1-a System modeling

From figureIII.7, it's evident that the Wireless Power Transfer (WPT) in general is divided into two main parts: the transmitter, which includes the primary coil, and the receiver, housing the secondary coil. While the transmitter consists of both a rectifier and an inverter section, the receiver only contains a rectifier section. The transmitter is powered by the grid and can be installed in the EV parking area, whereas the receiver, situated within the EV, needs to be compact and lightweight for ease of use.

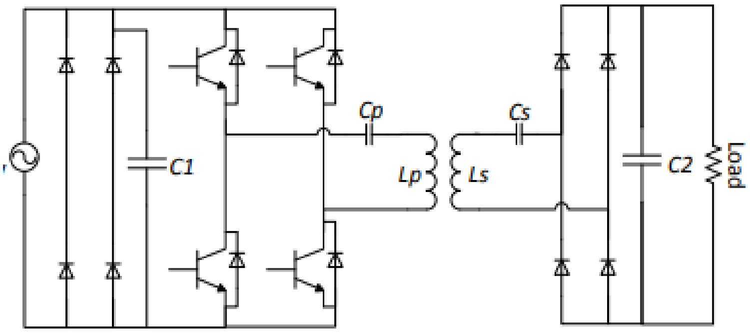

Figure III.7: Series-series (SS) topology circuit diagram [76]

To optimize power transfer from the primary to the secondary coil, the system should operate at its resonance frequency. Capacitors C$_p$ and C$_s$ play a crucial role in achieving this resonance condition and in compensating for losses in both the primary and secondary coils.

Based on the theory of magnetic coupling between two coils, the resonance frequency for all the compensation topologies can be formulated as:

$$\omega_0 = \frac{1}{\sqrt{L_p C_p}} = \frac{1}{\sqrt{L_s C_s}} \tag{III.14}$$

$$f_{0(p,s)} = \frac{1}{2\pi\sqrt{L_{p,s} C_{p,s}}} \tag{III.15}$$

where L$_p$ = L$_s$ is the self-inductance of transmitting and receiving coil, C$_p$ = C$_s$ is the series compensation capacitance of transmitting and receiving coil.
The coefficient of magnetic coupling between two coils can be expressed as ;

$$k = \frac{M}{\sqrt{L_p L_s}} \tag{III.16}$$

where M is the mutual inductance between transmitting and receiving coil.

In series-series compensation, you can calculate the values of the transmitter and receiver capacitors using equations III.17 and III.18. Moreover, you can determine the quality coefficients of the transmitter and receiver coils (Q) using equations III.19 and III.20

$$C_p = \frac{L_s C_s}{L_p} \tag{III.17}$$

$$C_s = \frac{1}{w_0^2 L_s} \tag{III.18}$$

$$Q_p = \frac{R_L L_p}{w_0 M^2} \tag{III.19}$$

$$Q_s = \frac{w_0 L_2}{R_L} \tag{III.20}$$

where $R_L$ is the load resistance.

In series-series (SS) topology total impedance, at resonance,and the reflected impedance seen by secondary can be formulated as:

$$Z_{T,r} = \frac{w_0^2 M^2}{R_L} \tag{III.21}$$

### III.4.1-b Matlab simulation of the system

This simulation is designed with the goal of charging a battery that has the capacity to store a total of 36 kW of energy. To achieve that, a power source that delivers a total of 5.3 kW of energy is used. The simulation will explore the efficiency and effectiveness of the charging process, ensuring that the power from the source is optimally utilized to fully charge the battery.

Table III.2,contains parameters that are utilized in both series-series and series-parallel simulations.

Table III.2: Parameter values used in the simulations

| Parameter | Value |
|---|---|
| Input voltage | 325 v |
| Resonance frequency | 30 kHz |
| Primary side self-inductance | 266.16 $\mu H$ |
| Secondary side self-inductance | 256.76 $\mu H$ |
| Mutual inductance | 85.46 $\mu H$ |
| Primary side capacitance | 105.74 nF |
| secondary side capacitance | 109.69 nF |
| coefficient of magnetic coupling | 0.3 |
| System input power | 5.3 kW |

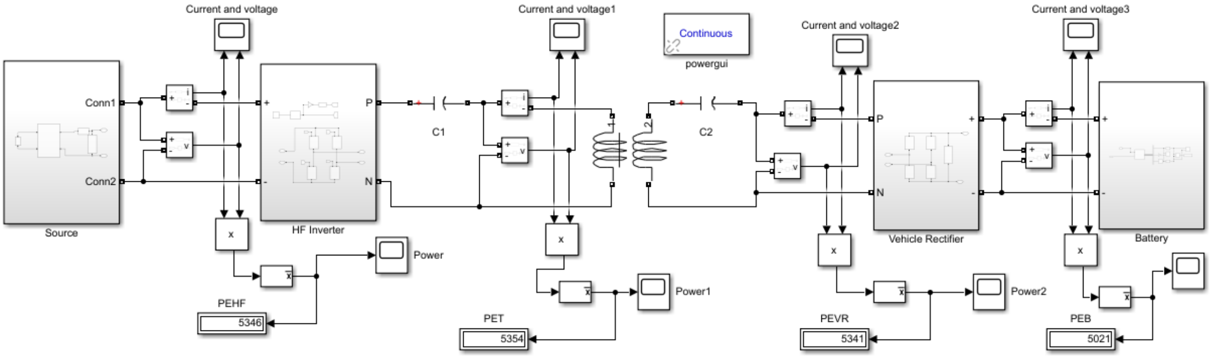

Figure III.8: Matlab simulation of the SS resonance system

- **Source voltage**

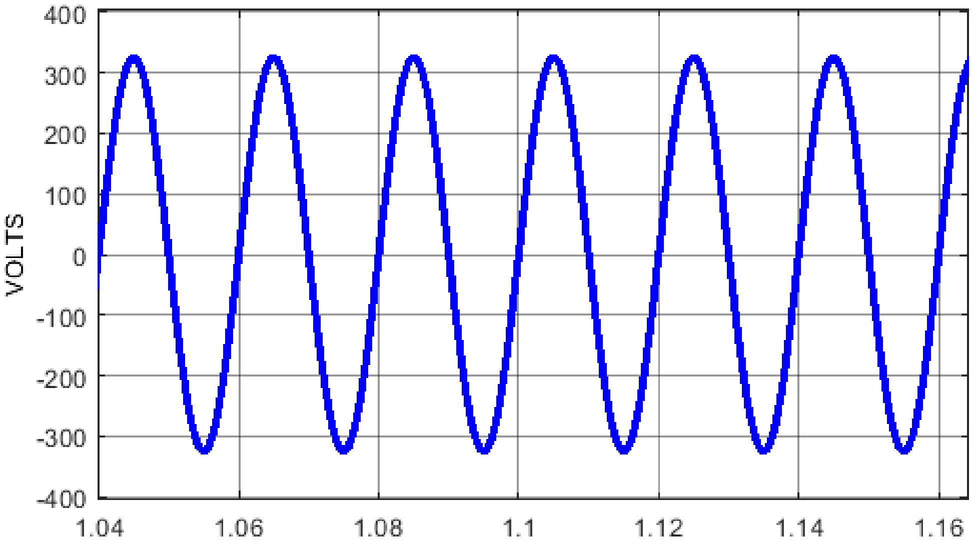

Figure III.9: The AC Source voltage of SS system

Figure III.9,shows the voltage of the alternative voltage source (AC) curve reaching 325 volts as mentioned in table III.2 before it was rectified.

- **Source Current**

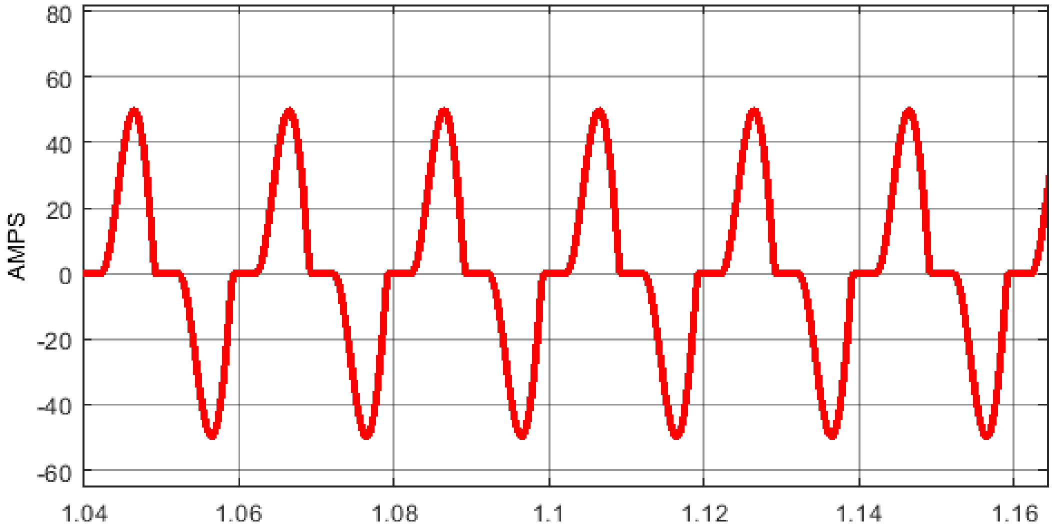

Figure III.10: The AC Source Current of SS system

Figure III.10, shows the current curve of the alternative current source (AC) ,before it was rectified .The current value settles at positive peak of a 50 amperes.

- **DC link voltage**

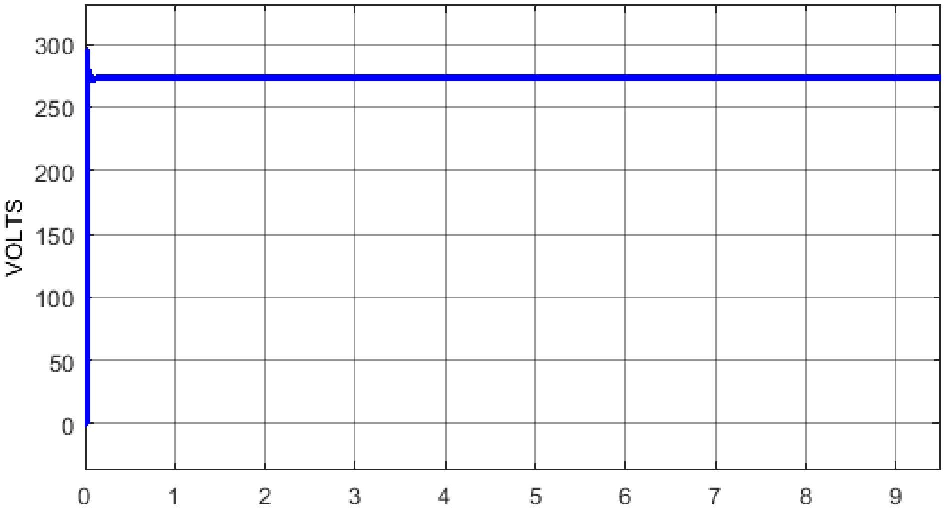

Figure III.11: The DC link voltage of SS system

Figure III.11, represents the rectified voltage of the AC source. As we can see, the curve peaks at 295 volts and then drops to 272 volts, which is 16 % less than the AC source before it was rectified.

- **DC link current**

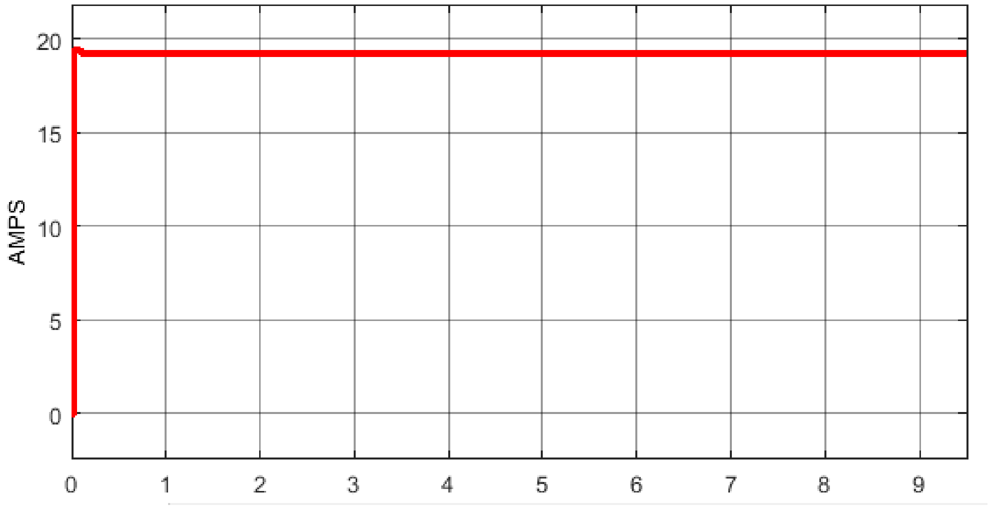

Figure III.12: The DC link current of SS system

Figure III.12, shows the rectified current .After filtering the current, it is displayed in the figure III.12 as a direct current with a value of 19 amps. .This value has decreased significantly since it was rectified.the value of the AC current decreases after rectification due to the pulsating nature of the rectified current and the effect of filtering components.The average value of the rectified DC current increase slightly after filtering.

- **battery voltage**

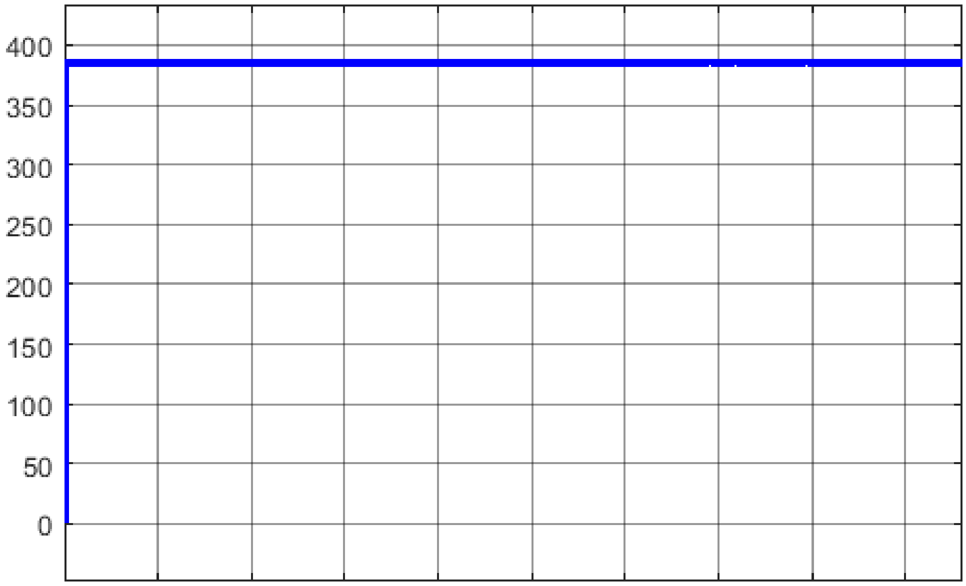

Figure III.13: The Battery voltage of SS system

As we can see in figure III.13, the battery voltage have a fixed value at 385 volts and this value is higher than the input voltage value.

It's common for the battery voltage of the electrical vehicles to be higher than the source voltage from the charging infrastructure,considering the efficiency,the battery Charging requirements and configuration which is mentioned in table III.1 and the Voltage Step-Up Conversion by using the DC-DC converter that allows the EV battery to be charged at a higher voltage than the source voltage.

- **Battery State of charge**

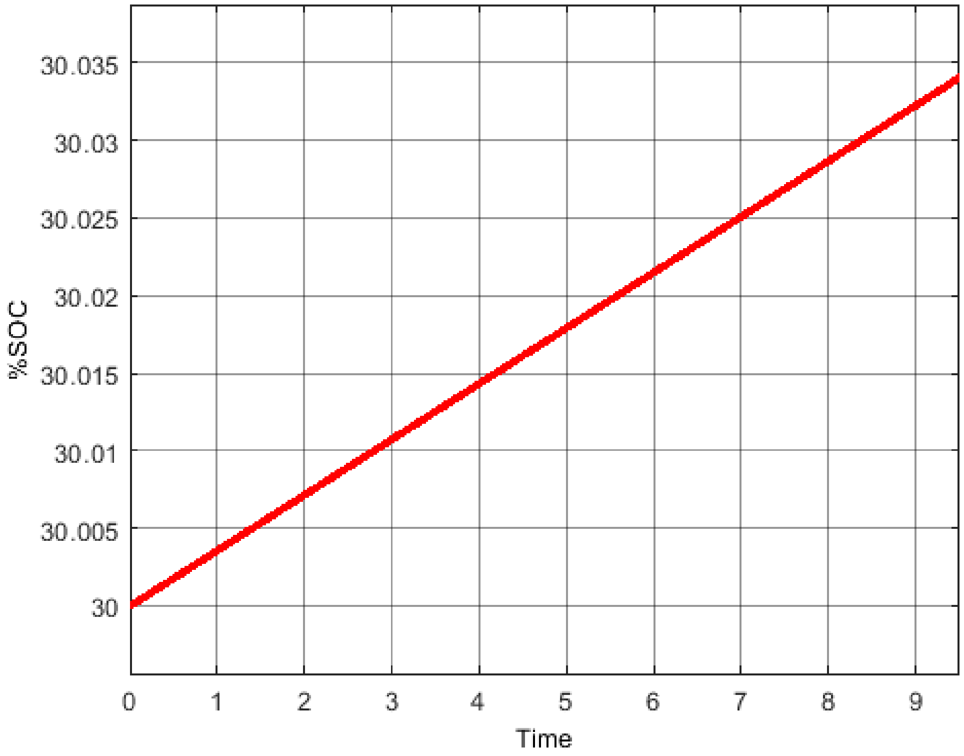

Figure III.14: State of charge of the battery of SS system

From table III.1 which shows the characteristics of the Lithium-Ion (Li-ion) battery used in the simulation ,the initial state of charge is 30%.We have observed from figure III.14 and our calculation that this percentage is rising by 1% every 5 min.

- **Road side winding voltage**

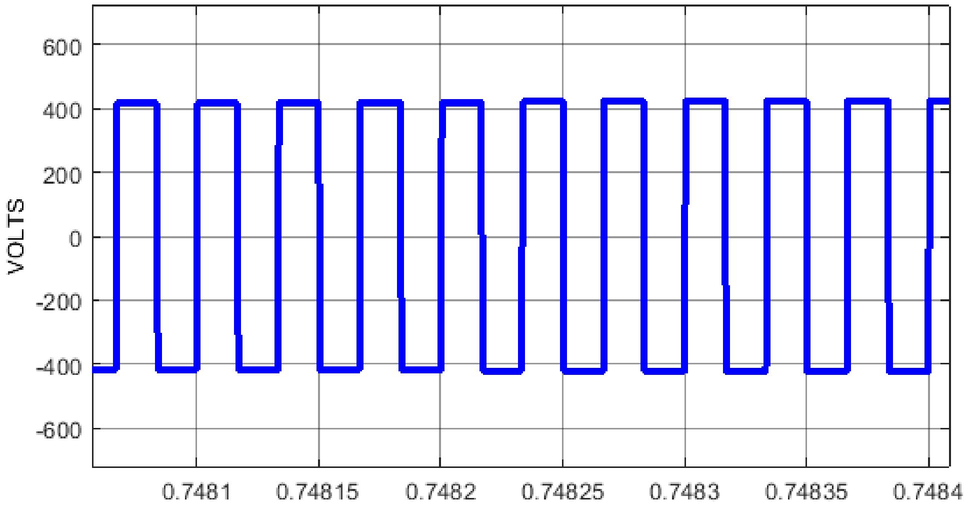

Figure III.15: The Road side winding voltage of SS system

Figure III.15,shows the road side winding voltage which represent the side winding voltage of the primary side inductor.In this figure III.15,we can observed that the voltage it alternating with a positive amplitude 424 volts.

- **Road side winding current**

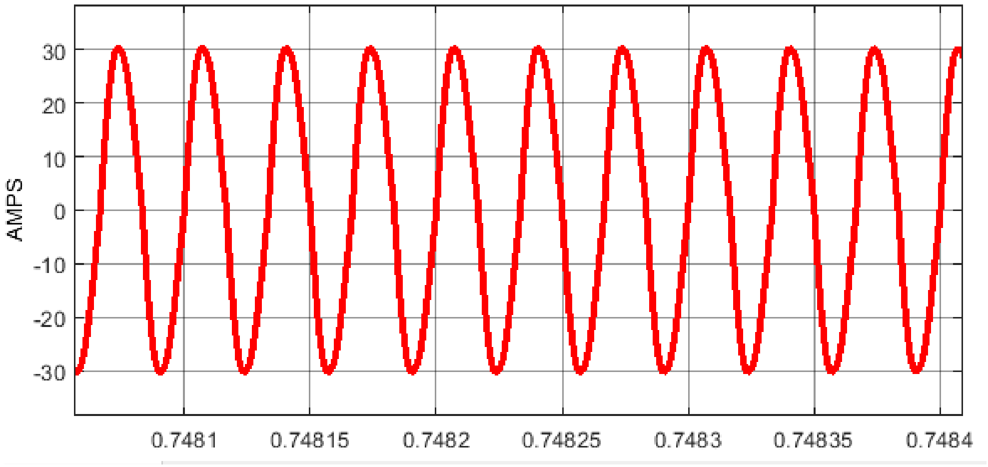

Figure III.16: Road side winding current of SS system

In figure III.16, the road side winding current represent the side winding current of the primary side inductor,as it shows the figure III.16,the current in this side winding alternate at a fixed positive peak value of 30 amperes.

- **Vehicle side winding voltage**

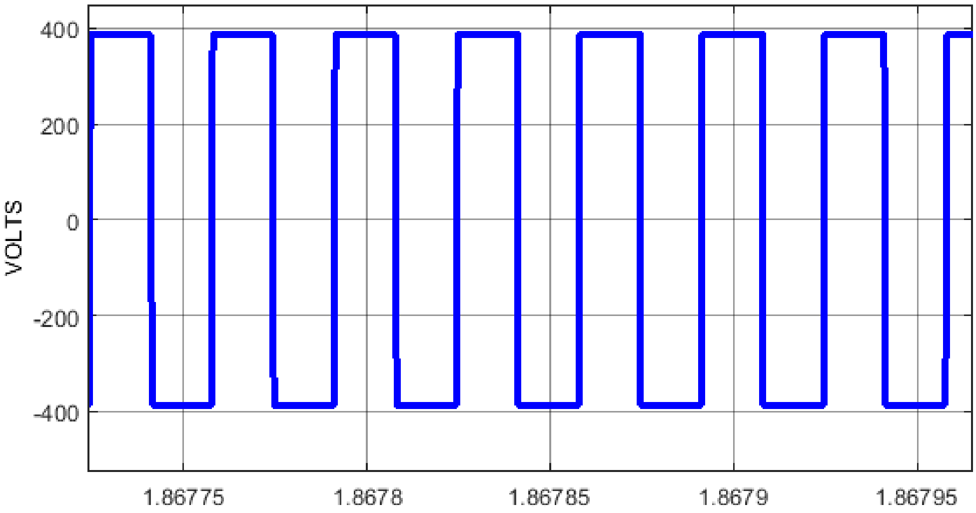

Figure III.17: The Vehicle side winding voltage of SS system

In figure III.17, the vehicle side winding voltage represent the side winding voltage of the secondary side inductor,as it shows in figure III.17,the voltage in this side winding is alternating at a fixed peak value 387 volts.

- **Vehicle side winding current**

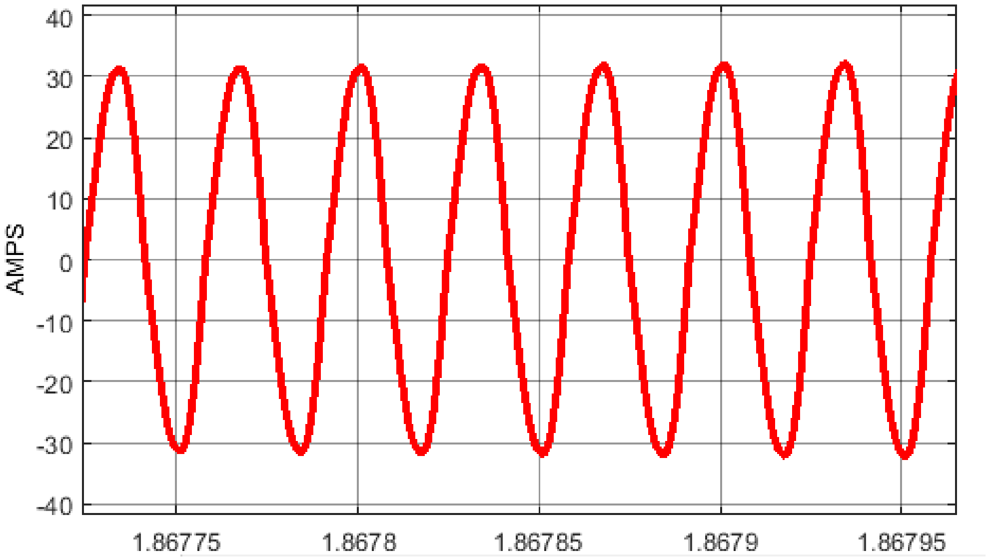

Figure III.18: The Vehicle side winding current of SS system

Figure III.18,shows the vehicle side winding current which represent the side winding current of the secondary side inductor.In this figure III.18,we observed that the current is alternating with a positive peak of 31 amperes.

From figure III.15 to figure III.18, the road and vehicle side winding play a crucial role in the entire charging process, as can be said. Also from figure III.17 and figure III.13 we can see that the vehicle side winding has effected the battery voltage.

## III.4.2 Series-parallel topology

### III.4.2-a System modeling

The subsequent circuit of Wireless Power Transfer (WPT) was constructed using the Sereis-Parallel (SP)compensation topology, depicted in figure III.19. In this setup, the initial capacitor is in series with the primary-side inductance, while the second compensation capacitor is connected in parallel with the secondary side.

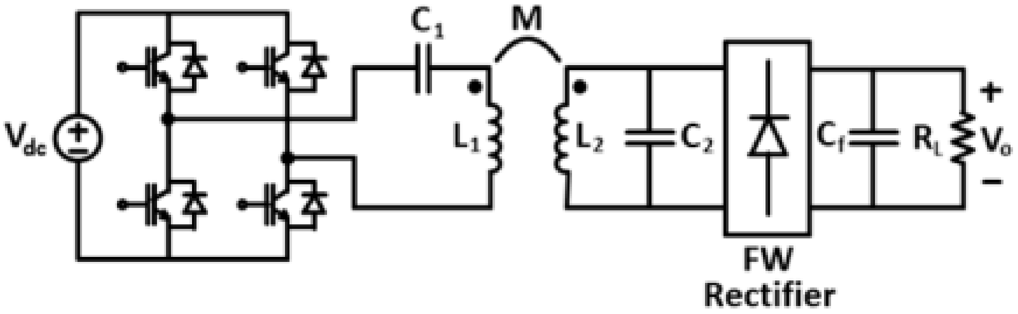

Figure III.19: Series-Parallel (SP) topology circuit diagram [77]

The sereis-parallel (SP) topology have the same power transfer optimization as the series-series (SS) topology which gives the same resonance frequency mentioned in equation III.15 ,as well for the coefficient of magnetic coupling between two coils in the equation III.16.

In series-parallel (SP) compensation, you can calculate the value of the primary side (transmitter) capasitor using equation III.22 and determine the quality coefficient with the same equation III.19 that is used in series-series compensation.

$$C_1 = \frac{1}{\omega_o^2\left(L_1 - \frac{M^2}{L_2}\right)} \tag{III.22}$$

For the secondary side (receiver),you can calculate the value of the capacitor using equation III.18,and the quality coefficient using equation III.23.

$$Q_2 = \frac{R_l}{\omega_o L_2} \tag{III.23}$$

For series-parallel (SP) topology total impedance, at resonance is calculated using equation III.24.

$$Z_T = \frac{M^2 R_L}{L_2^2} \tag{III.24}$$

We can calculate the secondary reflected impedance using equation III.25

$$Z_r = \frac{M^2 R_L}{L_2^2} - \frac{j\omega_o M^2}{L_2} \tag{III.25}$$

### III.4.2-b Matlab simulation of the system

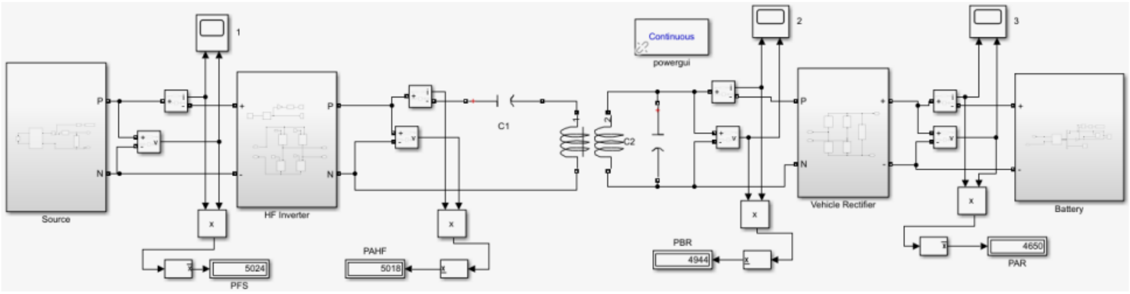

Figure III.20: Matlab simulation of the SP resonance system

### III.4.2-c Matlab simulation results

- **Source voltage**

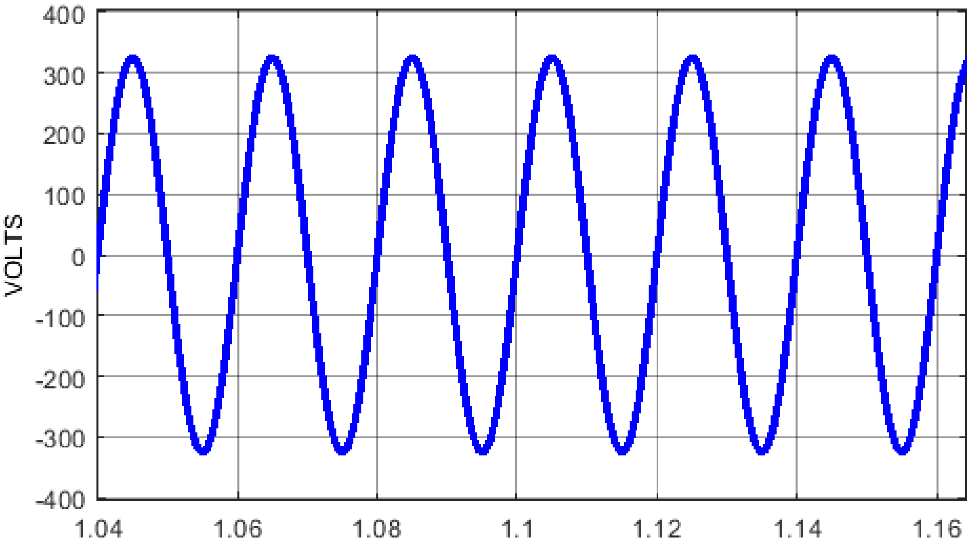

Figure III.21: The AC Source voltage

This figure III.21, shows the voltage of the source (Alternative current) which is the same that was used for the series-series simulation.

- **Source Current**

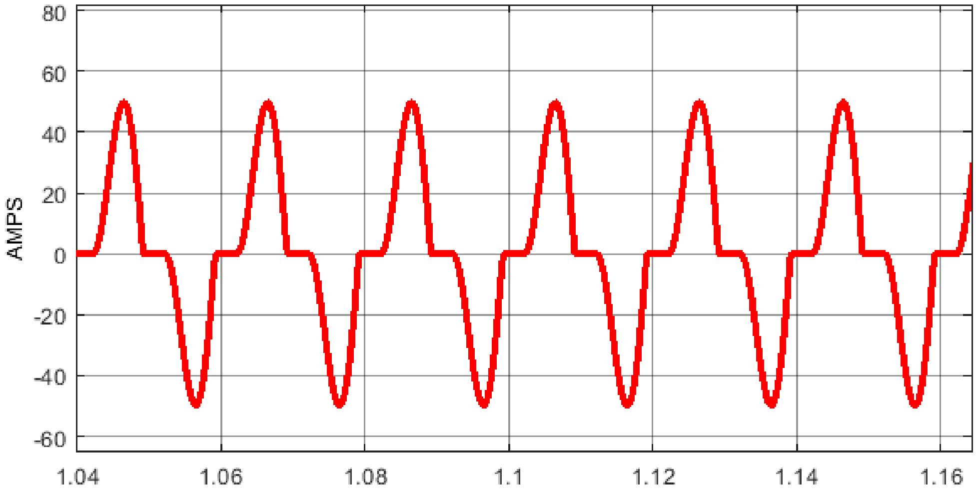

Figure III.22: The AC Source Current

The III.22 shows the current curve, As it was mentioned before in the simulation of the series-series the current value settles at 50 amperes.

- **DC link Voltage**

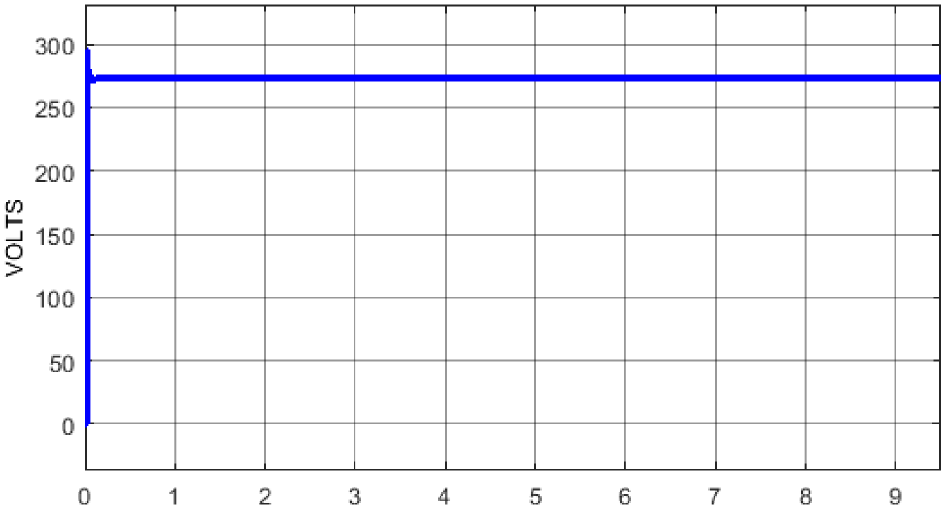

Figure III.23: The DC link Voltage

We notice from III.23 that the maximum value reached is 290 volts and then it settles down to the final fixed value of 269 Volts

- **DC link Current**

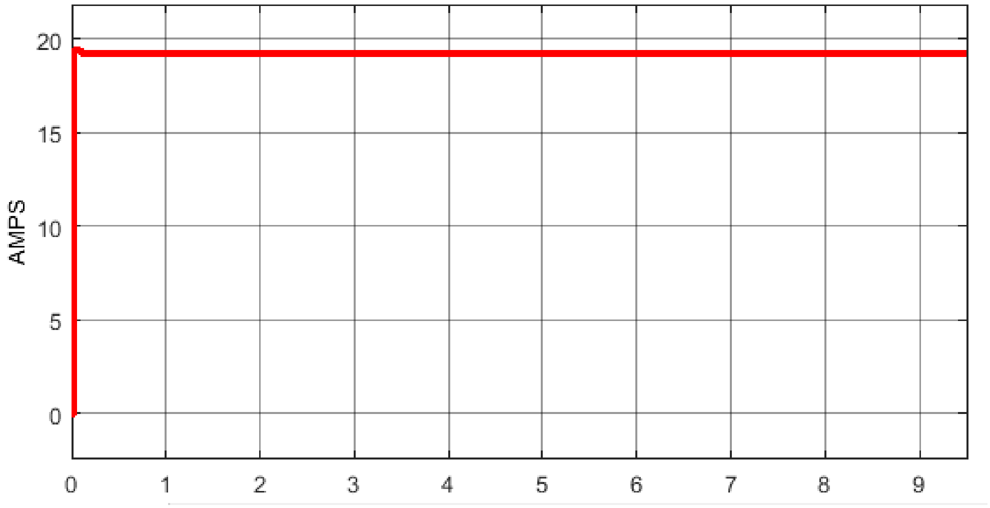

Figure III.24: The DC link current

We notice in III.24 that there is a slight difference between the series-series and the series-parallel results, The SP result has a current value of 18 amps after filtering.

- **Battery voltage**

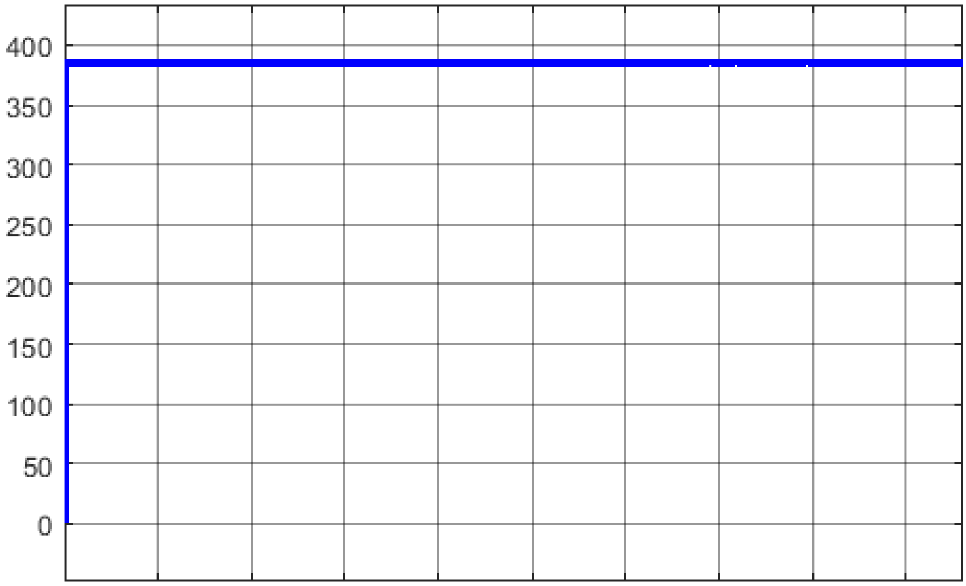

Figure III.25: The Battery voltage for SP

As we can see in the figure III.25 we have the same voltage as the one we had in series-series simulation which is a constant value of 385 volts.

- **State of charge of the battery**

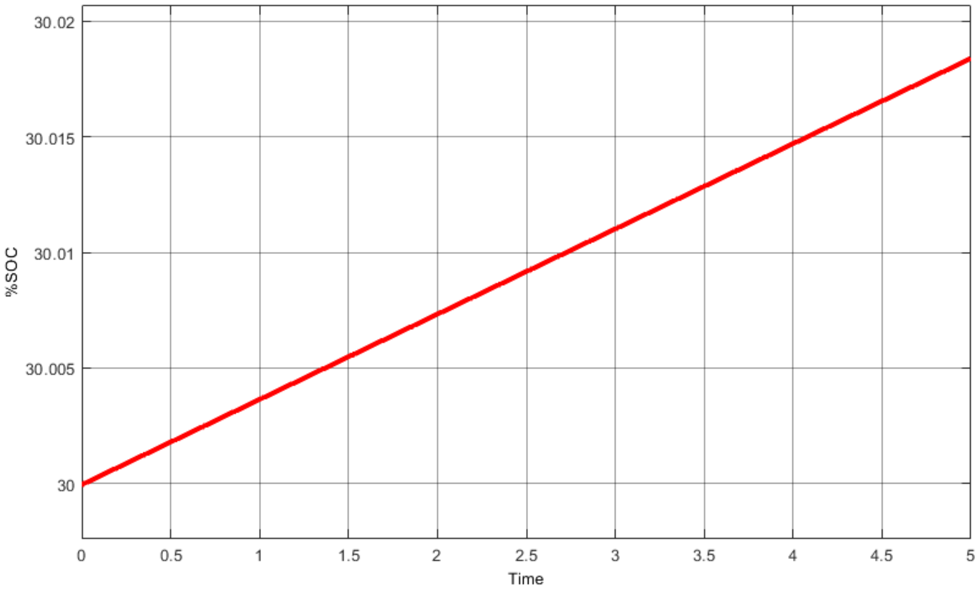

Figure III.26: State of charge of the battery in SP

From Table III.1, which outlines the characteristics of the Lithium-Ion (Li-ion) battery used in the simulation, we note that the initial state of charge is 30%. As observed in Figure III.26, this percentage increases by 0.8% every 5 min.

- **Road side winding voltage**

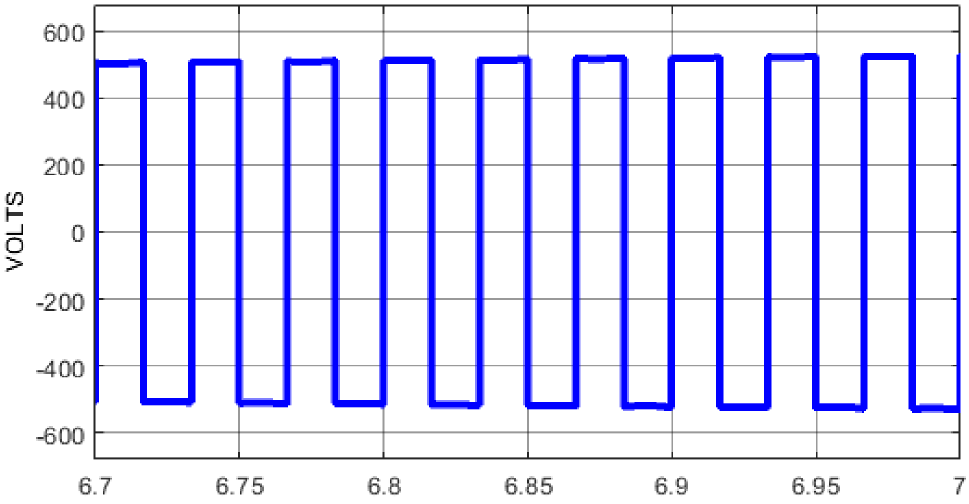

Figure III.27: Road side winding voltage SP

In figure III.27, the vehicle side winding voltage represent the side winding voltage of the primary side inductor.In this figure III.27,we observed that the voltage has a positive peak value of 500 volts, then continues alternating the positive peak value and the negative peak value which is -500 volts.

- **Road side winding current**

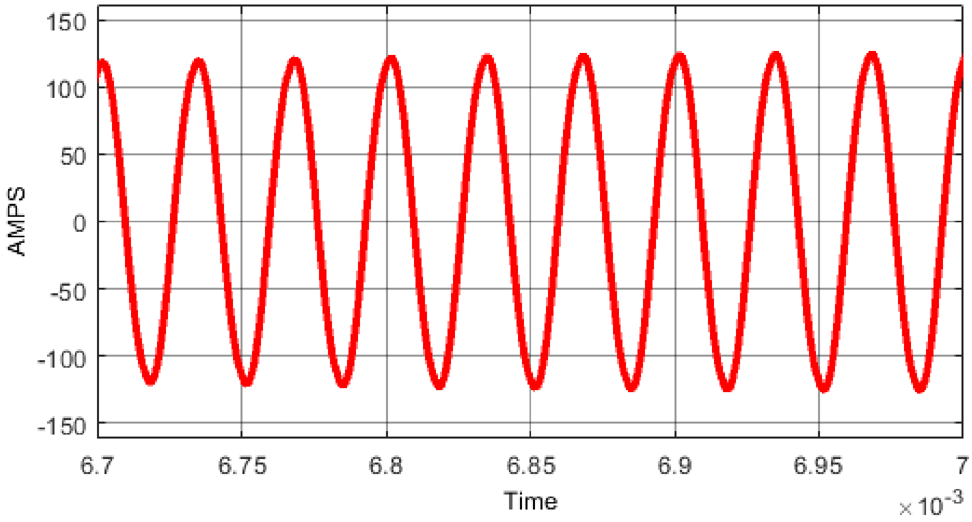

Figure III.28: Road side winding current for the SP

In figure III.28, the road side winding current represent the side winding current of the primary side inductor,as it shows the figure III.28,the current in this side winding is alternating with a positive peak value of 126.7 amperes.

- **Vehicle side winding voltage**

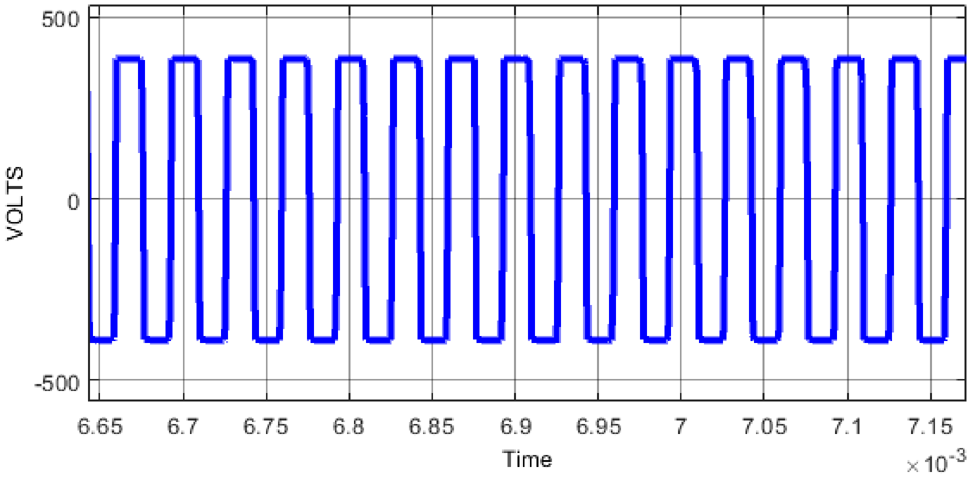

Figure III.29: Vehicle side winding voltage SP

In figure III.29, the vehicle side winding voltage represent the side winding voltage of the secondary side inductor,as it shows the figure III.29,the voltage in this side winding is alternating a positive peak value 386.5 volts.

- **Vehicle side winding current**

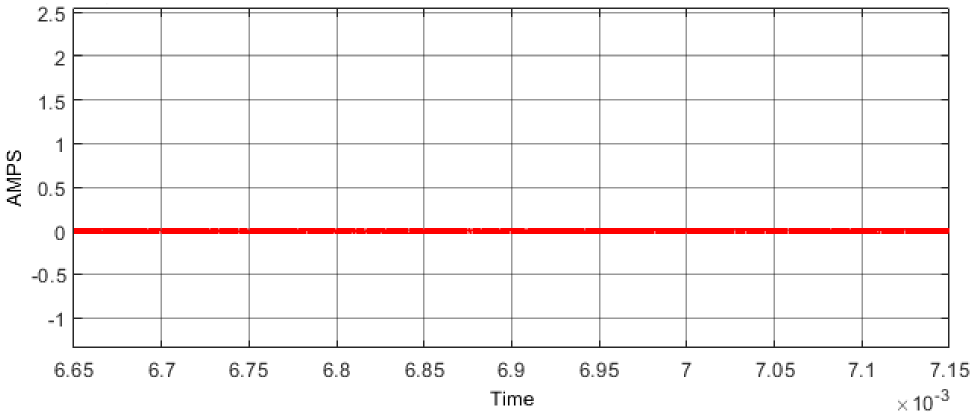

Figure III.30: Vehicle side winding current SP

In figure III.30, the road side winding current represent the side winding current of the secondary side inductor, the current in this side winding is 0 because we have a parallel capacity which is basically a voltage load (second battery).

## III.5 Comparison between typologies

As a results of the two simulation,we observed that the two simulation have a common primary side structure,but a different secondary side compensation, as we can say also on the simulation results that have a slightly different in values between the primary and the secondary side on both simulation.

Additionally,in context of power transfer efficiency,the series-series topology seems to be a more ideal compensation with 95%,than the series-parallel topology which has a slightly decrease of 4% then the series-series efficiency of power transfer.

Table III.3: The simulation results of S-S and S-P topologies comparison.

| | series-series topology | series-parallel topology |
|---|---|---|
| Efficiency | 95% | 91% |
| output Power | 5 KW | 4.8 KW |
| EV application | suitable for EV | suitable for EV |
| output voltage | 385 Volts | 385 Volts |

The efficiency of the SS topology system depends on several factors, including the choice of electronic components for converters and regulators, the frequency range, control techniques, battery type, etc. Enhancing the efficiency of the charging system must also comply with safety regulations.

Moreover, the peak efficiency of the SS topology is higher than that of the SP topology, further supporting the preference for SS topology. Therefore, theoretically, SS topology is the best choice for EV battery charging.

## III.6 Conclusion

In this chapter, we studied both the SS topology and the Sp topology. However, the SS topology has two distinct advantages that make it particularly valuable for use in the IPT platform. Firstly, the primary capacitance in SS topology is independent of both magnetic coupling and load, ensuring it remains perfectly tuned in dynamic charging conditions where mutual inductance constantly varies. Secondly, the reflected impedance of the secondary winding onto the primary winding has only a real reflected component, with no reactive component. This means the secondary winding draws only active power when operating at the secondary resonance frequency, resulting in a unity power factor.

# General conclusion and perspectives

This thesis has investigated various wireless power charging techniques for electric vehicles (EVs), including microwave power transfer, laser power transfer, inductive power transfer, and resonance power transfer. Through a comprehensive analysis of each technique, we have aimed to illuminate their strengths, limitations, and practical applications in the context of electric transportation.

Our research journey began with an extensive literature review, laying the groundwork for our exploration of wireless power charging technologies. From there, we delved into the intricacies of microwave, laser, inductive, and resonance power transfer methods, examining their underlying principles, operational characteristics, and EVs implementations. By evaluating the performance metrics, efficiency, and feasibility of each technique, we have provided valuable insights into the diverse landscape of wireless charging for EVs.

Furthermore, this thesis has not only focused on theoretical analysis. A simulation study was conducted using MATLAB to investigate the series-series and series-parallel topologies of the Resonant Inductive Power Transfer (RIPT) system. By simulating these topologies, we were able to assess their performance, efficiency, and suitability for EVs applications. The simulation results have contributed valuable empirical evidence to complement our theoretical findings, providing a holistic understanding of RIPT system configurations.Also, the results of the simulations helped up understand which one of the topologies is better regarding the efficiency while charging an electric vehicle (EV) which is a major factor in choosing the desired topology so we can confidently say that the SS topology is more reliable than the SP topology.

In light of our findings, several avenues for future research and development have been identified. These include further optimization of wireless power transfer techniques, exploration of new materials and technologies, and integration with emerging smart grid systems. By addressing these research gaps, we can unlock the full potential of wireless charging and accelerate the adoption of electric vehicles on a global scale.

In summary, this thesis represents a significant contribution to the field of wireless power charging for electric vehicles. By synthesizing existing knowledge, conducting empirical studies, and proposing future research directions, we hope to inspire continued innovation and advancement in this critical area of sustainable transportation. As we move forward, let us remain committed to harnessing the power of wireless charging to drive positive change and create a greener, more efficient transportation ecosystem for generations to come.

# Bibliography

# Bibliography

[1] Barman, P., Dutta, L., Bordoloi, S., Kalita, A., Buragohain, P., Bharali, S., & Azzopardi, B, Renewable energy integration with electric vehicle technology: A review of the existing smart charging approaches, Elsevier BV, 2023, https://doi.org/10.1016/j.rser.2023.113518

[2] Tu, H., Feng, H., Srdic, S., & Lukic, S, Extreme Fast Charging of Electric Vehicles: A Technology Overview, Institute of Electrical and Electronics Engineers (IEEE), 2019, https://doi.org/10.1109/tte.2019.2958709

[3] Horak, D., Hainoun, A., Neugebauer, G., & Stoeglehner, G, Battery electric vehicle energy demand in urban energy system modeling: A stochastic analysis of added flexibility for home charging and battery swapping stations, Elsevier BV, 2024, https://doi.org/10.1016/j.segan.2023.101260

[4] Islam, S., Iqbal, A., Marzband, M., Khan, I., & Al-Wahedi, A. M. A. B, State-of-the-art vehicle-to-everything mode of operation of electric vehicles and its future perspectives, Elsevier BV, 2022, https://doi.org/10.1016/j.rser.2022.112574

[5] Morgan, J, Electric vehicles: the future we made and the problem of unmaking it, Oxford University Press (OUP), 2020, https://doi.org/10.1093/cje/beaa022

[6] Alternative Fuels Data Center: Electric Vehicle (EV) definition, The Vermont Statutes Online, 2021,Jun 3rd, https://afdc.energy.gov/laws/12660

[7] Autocrypt Co., Ltd, Basics Guide to EV Technology & Trends, AUTOCRYPT, 2023, May 9th, https://autocrypt.io/downloads/abstract-ebook-basics-guide-ev-tech-and-trends/

[8] Larminie, J., & Lowry, J, Electric vehicle technology explained, John Wiley & Sons, 2012https://onlinelibrary.wiley.com/doi/book/10.1002/9781118361146

[9] Nationalgrid, The (surprisingly long) history of electric vehicles Nationalgrid, 2021,January 26th, https://www.nationalgrid.com/stories/journey-to-net-zero-stories/surprisingly-long-history-electric-vehicles

[10] Adedeji, B. P, Electric vehicles survey and a multifunctional artificial neural network for predicting energy consumption in all-electric vehicles, Elsevier BV, 2023, `https://doi.org/10.1016/j.rineng.2023.101283`

[11] Subramanian, G., & Thampy, A. S, Implementation of Hybrid Blockchain in a Pre-Owned Electric Vehicle Supply Chain, Institute of Electrical and Electronics Engineers (IEEE), 2021, `https://doi.org/10.1109/access.2021.3084942`

[12] Halim, A. A. E. B. A. E., Bayoumi, E. H. E., El-Khattam, W., & Ibrahim, A. M, Electric vehicles: a review of their components and technologies, Institute of Advanced Engineering and Science, 2022, `https://doi.org/10.11591/ijpeds.v13.i4.pp2041-2061`

[13] Sanguesa, J. A., Torres-Sanz, V., Garrido, P., Martinez, F. J., & Marquez-Barja, J. M, A Review on Electric Vehicles: Technologies and Challenges, MDPI AG, 2021, `https://doi.org/10.3390/smartcities4010022`

[14] V, T. K. G., Bejgam, R., Sunkari, S., Keshipeddi, S. B., Rangaraju, M. R., & Dunde, V, A Brief Study on Hybrid Electric Vehicles, Presented at the 2021 Third International Conference on Inventive Research in Computing Applications (ICIRCA), 2021, `https://doi.org/10.1109/icirca51532.2021.9544968`

[15] Pan, W., Wu, Y., Tong, Y., Li, J., & Liu, Y, Optimal rule extraction-based real-time energy management strategy for series-parallel hybrid electric vehicles, Elsevier BV, 2023, `https://doi.org/10.1016/j.enconman.2023.117474`

[16] Keldiyararova Malika Shukhrat Qizi, HYBRID ELECTRICAL VEHICLE TECHNOLOGIES. Zenodo, Zenodo, 2022, `https://doi.org/10.5281/ZENODO.7189189`

[17] Halim, A. A. E. B. A. E., Bayoumi, E. H. E., El-Khattam, W., & Ibrahim, A. M, Electric vehicles: a review of their components and technologies, Institute of Advanced Engineering and Science, 2022, `https://doi.org/10.11591/ijpeds.v13.i4.pp2041-2061`

[18] Verma, S, EV and its History, Indospace Publications, 2023, `https://doi.org/10.55041/ijsrem18882`

[19] Alanazi, F, Electric Vehicles: Benefits, Challenges, and Potential Solutions for Widespread Adaptation, MDPI AG, 2023, `https://doi.org/10.3390/app13106016`

[20] Nouri, A., Lachheb, A., & El Amraoui, L, Optimizing efficiency of Vehicle-to-Grid system with intelligent management and ANN-PSO algorithm for battery electric vehicles, Elsevier BV, 2024, `https://doi.org/10.1016/j.epsr.2023.109936`

[21] Alternative Fuel data center, Alternative Fuels Data Center: How do All-Electric Cars work? , Energy Efficiency & Renewable Energy, 2023, `https://afdc.energy.gov/vehicles/how-do-all-electric-cars-work`

[22] Das, H., Rahman, M., Li, S., & Tan, C, Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review? , Renewable &

Sustainable Energy Reviews, 120, 109618, 2020, https://doi.org/10.1016/j.rser.2019.109618

[23] Resilient Electrical, Wired vs Wireless EV Chargers, Resilient Electrical, 2023, April 9th, https://resilientelectricalco.com/wireless-vs-wired-ev-chargers

[24] Bouanou, T., El Fadil, H., Lassioui, A., Bentalhik, I., Koundi, M., & El Jeilani, S, Resilient Electrical, MDPI AGl, 2023, https://doi.org/10.3390/wevj14050117

[25] ElGhanam, E., Ahmed, I., Hassan, M., & Osman, A, Authentication and Billing for Dynamic Wireless EV Charging in an Internet of Electric Vehicles, MDPI AGl, 2021, https://doi.org/10.3390/fi13100257

[26] Mohammed, S. A. Q., & Jung, J.-W, A Comprehensive State-of-the-Art Review of Wired/Wireless Charging Technologies for Battery Electric Vehicles: Classification/-Common Topologies/Future Research Issues, Institute of Electrical and Electronics Engineers (IEEE), 2021, https://doi.org/10.1109/access.2021.3055027

[27] EVBox, EV charging levels explained , EVBox, 2023, https://blog.evbox.com/ev-charging-levels#Level-1

[28] Farnell, Wireless power transfer: a convenient and efficient solution for EV charging , Farnell, 2024

[29] Sathe, M. D., Nikam, P. S., & Khapre, G, Wireless Charging Control for Electric Vehicles, International Journal for Research in Applied Science and Engineering Technology (IJRASET), 2023, https://doi.org/10.22214/ijraset.2023.52478

[30] Bai, H. K., Costinett, D., Tolbert, L. M., Qin, R., Zhu, L., Liang, Z., & Huang, Y, Charging Electric Vehicle Batteries: Wired and Wireless Power Transfer: Exploring EV charging technologies , Institute of Electrical and Electronics Engineers (IEEE), 2022, https://doi.org/10.1109/mpel.2022.3173543

[31] Palani, G., Sengamalai, U., Vishnuram, P., & Nastasi, B, Challenges and Barriers of Wireless Charging Technologies for Electric Vehicles , MDPI AG, 2023, https://doi.org/10.3390/en16052138

[32] Sathe, M. D., Nikam, P. S., & Khapre, G, Wireless Charging Control for Electric Vehicles , International Journal for Research in Applied Science and Engineering Technology (IJRASET), 2023, https://doi.org/10.22214/ijraset.2023.52478

[33] Dimitriadou, K., Rigogiannis, N., Fountoukidis, S., Kotarela, F., Kyritsis, A., & Papanikolaou, N, Current Trends in Electric Vehicle Charging Infrastructure; Opportunities and Challenges in Wireless Charging Integration , MDPI AG, 2023, https://doi.org/10.3390/en16042057

[34] Triviño, A., González-González, J. M., & Aguado, J. A, Wireless Power Transfer Technologies Applied to Electric Vehicles: A Review , MDPI AG, 2021, https://doi.org/10.3390/en14061547

[35] Hossain, Md. S., & Barua, A, Charging electric vehicles via microwave energy transmission and analysis of advanced energy storage system , Presented at the 2013 2nd International Conference on Informatics, Electronics and Vision (ICIEV), 2021, https://doi.org/10.1109/iciev.2013.6572702

[36] Toromura, H., Yong Huang, Koyama, S., Miyakoshi, J., & Shinohara, N, Biological effects of high-power microwave power transfer for electric vehicle. , Presented at the 2016 IEEE Wireless Power Transfer Conference (WPTC), 2016, https://doi.org/10.1109/wpt.2016.7498870

[37] Colombo, C. G., Miraftabzadeh, S. M., Saldarini, A., Longo, M., Brenna, M., & Yaici, W, Literature Review on Wireless Charging Technologies: Future Trend for Electric Vehicle? , Presented at the 2022 Second International Conference on Sustainable Mobility Applications, Renewables and Technology (SMART), 2022, https://doi.org/10.1109/smart55236.2022.9990331

[38] Shinohara, N., Kubo, Y., & Tonomura, H. , Wireless charging for electric vehicle with microwaves , Presented at the 2013 3rd International Electric Drives Production Conference (EDPC), 2013, https://doi.org/10.1109/edpc.2013.6689750

[39] Jian Li & Naoki Shinohara, Space solar power and wireless transmission , KeAi, 2023, https://www.keaipublishing.com/en/journals/space-solar-power-and-wireless-transmission

[40] Rathod, Y., & Hughes, L, Simulating the charging of electric vehicles by lase , Procedia Computer Science, 155, 527–534, 2019, https://doi.org/10.1016/j.procs.2019.08.073

[41] Yigit, H., & Boynuegri, A. R, Pulsed Laser Diode Based Wireless Power Transmission Application: Determination of Voltage Amplitude, Frequency, and Duty Cycle , Institute of Electrical and Electronics Engineers (IEEE), 2023, https://doi.org/10.1109/access.2023.3281656

[42] Mishra, P., Bhakta, A., Sarkar, R., & Jasmin, F, A model of inductive charging technique in battery electric vehicles(BEVs) , IOP Publishing ,2021, https://doi.org/10.1088/1757-899x/1080/1/012005

[43] Mohamed, A. A. S., Shaier, A. A., Metwally, H., & Selem, S. I, A comprehensive overview of inductive pad in electric vehicles stationary charging , Elsevier BV , 2020, https://doi.org/10.1016/j.apenergy.2020.114584

[44] Zucca, M., Bottauscio, O., Harmon, S., Guilizzoni, R., Schilling, F., Schmidt, M., . . . Liorni, I., Metrology for Inductive Charging of Electric Vehicles (MICEV) , Presented at the 2019 AEIT International Conference of Electrical and Electronic Technologies for Automotive (AEIT AUTOMOTIVE) , 2019, https://doi.org/10.23919/eeta.2019.8804498

[45] Ayisire, E., El-Shahat, A., & Sharaf, A, Magnetic Resonance Coupling Modelling for Electric Vehicles Wireless Charging , Presented at the 2018 IEEE Global Humanitar-

ian Technology Conference (GHTC), 2018, https://doi.org/10.1109/ghtc.2018.8601806

[46] Yousuf, Md. A., Das, T. K., Khallil, Md. E., Aziz, N. A. Ab., Rana, Md. J., & Hossain, S, Comparison Study of Inductive Coupling and Magnetic Resonant Coupling Method for Wireless Power Transmission of Electric Vehicles, Presented at the 2021 2nd International Conference on Robotics, Electrical and Signal Processing Techniques (ICREST) , 2021, https://doi.org/10.1109/icrest51555.2021.9331096

[47] Mahesh, A., Chokkalingam, B., & Mihet-Popa, L, Inductive Wireless Power Transfer Charging for Electric Vehicles–A Review , Institute of Electrical and Electronics Engineers (IEEE) , 2021, https://doi.org/10.1109/access.2021.3116678

[48] Kesler, M, Wireless Charging of Electric Vehicles , Presented at the 2018 IEEE Wireless Power Transfer Conference (WPTC) , 2018, https://doi.org/10.1109/wpt.2018.8639303

[49] Sulejmani, E., Beltle, M., & Tenbohlen, S, EMC of Inductive Automotive Charging Systems According to Standard SAE J2954 , MDPI AG , 2023, https://doi.org/10.3390/vehicles5040083

[50] Multin, M, ISO 15118 as the Enabler of Vehicle-to-Grid Applications , Presented at the 2018 International Conference of Electrical and Electronic Technologies for Automotive , 2018, https://doi.org/10.23919/eeta.2018.8493213

[51] Tseng, R., von Novak, B., Shevde, S., & Grajski, K. A , Introduction to the alliance for wireless power loosely-coupled wireless power transfer system specification version 1.0 , Presented at the 2013 IEEE Wireless Power Transfer Conference (WPTC) , 2013, https://doi.org/10.1109/wpt.2013.6556887

[52] TGrazian, F., Shi, W., Dong, J., van Duijsen, P., Soeiro, T. B., & Bauer, P, Survey on Standards and Regulations for Wireless Charging of Electric Vehicles , Presented at the 2019 AEIT International Conference of Electrical and Electronic Technologies for Automotive (AEIT AUTOMOTIVE) , 2019, https://doi.org/10.23919/eeta.2019.8804573

[53] Survey on Standards and Regulations for Wireless Charging of Electric Vehicles , Infineon Technologies AG , 2019, https://www.infineon.com/dgdl/Infineon-Infineon-Whitepaper-OPTIGA-Trust_Charge-Whitepaper-v01-00-EN.pdf?da=t&fileId=8ac78c8c8929aa4d0189966608227abe

[54] Types of Hybrid Electric Vehicles (HEV) , X-engineer , 2013, https://x-engineer.org/types-hybrid-electric-vehicles-hev/

[55] Joshi, A. S., Shah, N. P., & Mi, C, Modeling and simulation of a dual clutch hybrid vehicle powertrain , 2009 IEEE Vehicle Power and Propulsion Conference , 2009, doi:10.1109/vppc.2009.5289682/

[56] Szumanowski, A., Chang, Y., Liu, Z., & Krawczyk, P, MHybrid powertrain efficiency improvement by using electromagnetically controlled double-clutch transmission, International Journal of Vehicle Design, 76(1/2/3/4), 1 , 2018, doi:10.1504/ijvd.2018.096094

[57] SLi Chen, Futang Zhu, Minmin Zhang, Yi Huo, Chengliang Yin, & Huei Peng, Design and Analysis of an Electrical Variable Transmission for a Series–Parallel Hybrid Electric Vehicle, IEEE Transactions on Vehicular Technology, 60(5), 2354–2363, 2011, doi:10.1109/tvt.2011.2134876

[58] Sergio Manzetti and Florin Mariasiu, Electric vehicle battery technologies: From present state to future systems, Renewable and Sustainable Energy Reviews, vol 51, pages 1004-1012, 2015, issn 1364-0321, https://www.sciencedirect.com/science/article/pii/S1364032115006577

[59] Liu, Hongzuo and Zhang, Yixuan and Hu, Yihua and Tse, Zion and Wu, Jing, Laser Power Transmission and Its Application in Laser-Powered Electrical Motor Drive: A Review, volume 6, number 41, Power Electronics and Drives, Politechnika Wrocławska. Oficyna Wydawnicza Politechniki Wrocławskiej, 2021 , pages 167–184 , https://bibliotekanauki.pl/articles/1955981

[60] Types of Electric Vehicles A brief overview of EV options , EV go , 2024, https://www.evgo.com/ev-drivers/types-of-evs/

[61] Tom Moloughney, What Are The Different Levels Of Electric Vehicle Charging? , Forbes wheels , 2021,October 4th, https://www.forbes.com/wheels/advice/ev-charging-levels/

[62] Carlos Huerta, EV Charging Levels Explained , revcharge , 2024, https://www.revcharge.com.au/blog/what-is-level-1-level-2-and-level-3-charging

[63] Pratyush, Wireless EV Charging: Types, Benefits, Challenges , 1charging , 2024, January 1st, https://1charging.com/wireless-ev-charging-types-benefits-challenges/

[64] Amy Barzdukas, Wired vs wireless charging efficiency for EVs: A comparison, witricity , 2022,February 23rd, https://witricity.com/media/blog/what-is-efficiency-how-do-you-measure-it-and-why-should-you-care

[65] Nassim Iqteit, Khalid Yahya & Sajjad Ahmad Khan, Wireless Power Charging in Electrical Vehicles , intechopen , 2021,February 15th, https://www.intechopen.com/chapters/75267

[66] Tresna Dewi, Tilt Angle Effect Analysis on Nodes of Inductive Resonance Wireless Power Transfer , ResearchGate, 2024,May 17th, https://www.researchgate.net/figure/Wireless-power-transfer-with-resonance-inductive-coupling-fig1-339101136

[67] Logesh Kumar, NON-RADIATIVE WIRELESS POWER TRANSFER USING MAGNETIC RESONANCE COUPLING, International Journal Of Engineering Research and Technology (IJERT ), 2014

[68] Obayashi, S.; Tsukahara, H., TEMC issues on wireless power transfer , In Proceedings of the 2014 International Symposium on Electromagnetic Compatibility, Tokyo, Japan, 2014,May 12–16

[69] Hentschel, U.; Helwig, M.; Winkler, A.; Modler, N, Simulation of Foreign Object Detection Using Passive Inductive Sensors in a Wireless Charging System for Electric Vehicles , World Electr. Veh. J. , 2023 , https://www.mdpi.com/2032-6653/14/9/241

[70] Zimmer, S.; Helwig, M.; Lucas, P.; Winkler, A.; Modler, N, Investigation of Thermal Effects in Different Lightweight Constructions for Vehicular Wireless Power Transfer Modules , World Electr. Veh. J , 2020 , https://www.mdpi.com/2032-6653/11/4/67

[71] Lin, J.C, Safety of Wireless Power Transfer , IEEE Access , 2021 , https://ieeexplore.ieee.org/document/9535368

[72] Kim, D.; Kim, H.; Huang, A.; He, Q.; Zhang, H.; Ahn, S.; Zhu, Y.; Fan, J, Analysis and Introduction of Effective Permeability with Additional Air-gaps on Wireless Power Transfer Coils for Electric Vehicle Based on SAE J2954 Recommended Practice , Energies, 2019 , https://www.mdpi.com/1996-1073/12/24/4797

[73] International Electrotechnical Commission, IEC 61980-1 EV WPT Systems , Available online, 2024, March 5 , https://webstore.iec.ch/preview/info-iec61980-1%7Bed1.0%7Den.pdf

[74] International Organization for Standardization: Geneva, Switzerland, IISO 19363:2020; Electrically Propelled Road Vehicles, Magnetic Field Wireless Power Transfer, Safety and Interoperability Requirements, Available online, 2020 , https://www.iso.org/standard/73547.html

[75] Sari, V, Design and Implementation of a Wireless Power Transfer System for Electric Vehicles , World Electr. Veh. J, 2024 , https://doi.org/10.3390/wevj15030110

[76] Saikot Baroi, Md. Shahidul Islam & Shawon Baroi, Design and Simulation of a Wireless Charging System for Electric Vehicles , 2nd International Conference on Electrical & Electronic Engineering (ICEEE), 2017 , https://doi:10.1109/CEEE.2017.8412915

[77] Nutwong, Supapong and Sangswang, Anawach and Naetiladdanon, Sumate, Output voltage control of the SP topology IPT system using a primary side controller, 2016 13th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), 2016, pages 1-5, https://doi.org/10.1109/ECTICon.2016.7561393

[78] Juan Luis Villa and Jesus Sallan and Andres Llombart and Jose Fco Sanz, Design of a high frequency Inductively Coupled Power Transfer system for electric vehicle

battery charge, Applied Energy, volume 86, N3, pages 355-363, 2009, issn 0306-2619, = https://www.sciencedirect.com/science/article/pii/S0306261908001359

[79] Zamani, Mohammad and Nagrial, Mahmood and Rizk, Jamal and Hellany, Ali, A review of inductive power transfer for electric vehicles, 2019 International Conference on Electrical Engineering Research & Practice (ICEERP), 2019, pages 1-5, `https://ieeexplore.ieee.org/document/8956971`

[80] Biswal, S. S., Kar, D. P., & Bhuyan, S, Consideration of Series-Series and Series-Parallel Topology in Perspective of Dynamic Resonant Inductive Coupling Based Wireless Charging, 2021 1st Odisha International Conference on Electrical Power Engineering, Communication and Computing Technology (ODICON), 2021, 10.1109/odicon50556.2021.9428, `https://ieeexplore.ieee.org/document/9428953`

[81] Roslan, M. A. A., Nanda, N. N., & Yusoff, S. H, SERIES-SERIES AND SERIES-PARALLEL COMPENSATION TOPOLOGIES FOR DYNAMIC WIRELESS CHARGING, IIUM Engineering Journal, 22(2), 199–209, 2021, `https://doi.org/10.31436/iiumej.v22i2.1660`

## Résumé

Les véhicules électriques (VE) sont largement considérés comme essentiels pour l'avenir des transports intelligents. Leur principal avantage réside dans leur capacité à réduire considérablement les émissions de carbone. Les VE offrent de nombreux avantages, notamment la réduction du bruit, des coûts de maintenance plus faibles et une pollution nulle. Cependant, des défis tels que l'autonomie limitée et les temps de recharge prolongés restent des préoccupations importantes. Pour relever ces défis, le transfert d'énergie sans fil (WPT) émerge comme une solution pratique. En utilisant le WPT, les VE peuvent calculer les distances de trajet plus précisément et réduire le temps nécessaire pour recharger les batteries. Dans le système proposé, les dispositifs de recharge sans fil utilisent l'induction électromagnétique pour transférer l'énergie électrique entre deux circuits. Lorsque l'alimentation principale en courant alternatif est fournie à la bobine émettrice, elle génère un champ électromagnétique qui induit de l'énergie électrique dans la bobine réceptrice par induction mutuelle. L'énergie électrique est ensuite transférée à la batterie du véhicule avec l'aide de convertisseurs. Un système de simulation a été créé en utilisant MATLAB/SIMULINK, et les performances du système ont été validées par les résultats obtenus de la simulation.

Mots clés : Transfert d'énergie sans fil ; Véhicules électriques ; Technologies de charge sans fil ; Normes de charge sans fil ; Histoire des véhicules électriques ; Composants des véhicules électriques ; Types de véhicules électriques

## Abstract

Electric vehicles (EVs) are widely regarded as essential for the future of smart transportation. Their primary advantage lies in their ability to significantly reduce carbon emissions.The EVs offer numerous benefits, including reduced noise, lower maintenance costs, and zero pollution. However, challenges such as limited travel range and lengthy charging times remain significant concerns.In addressing these challenges, wireless power transfer (WPT) emerges as a practical solution. By employing WPT, EVs can calculate trip distances more accurately and reduce the time required for battery charging. In this proposed system. Wireless charging devices utilize electromagnetic induction to transfer electrical energy between two circuits. When the main AC supply is provided to the transmitter coil, it generates an electromagnetic field that induces electrical energy in the receiver coil through mutual induction. The electric energy is then transferred to the vehicle's battery with the assistance of converters. A simulation system has been created using MATLAB/SIMULINK, and the system's performance has been validated through the obtained simulation results.

Keywords : Wireless power transfer; Electric vehicles ; Wireless charging technologies; wireless charging standards; history of EVs ; Electric vehicles components; Types of electric vehicles}

## ملخص

تُعتبر المركبات الكهربائية ضرورية لمستقبل النقل الذكي. تكمن ميزتها الأساسية في قدرتها على تقليل انبعاثات الكربون بشكل كبير. تقدم المركبات الكهربائية العديد من الفوائد، بما في ذلك تقليل الضوضاء، وخفض تكاليف الصيانة، وانعدام التلوث. ومع ذلك، تظل تحديات مثل مدى السفر المحدود وأوقات الشحن الطويلة مصدر قلق كبير. لمواجهة هذه التحديات، يظهر نقل الطاقة اللاسلكي كحل عملي. باستخدام نقل الطاقة اللاسلكي، يمكن للمركبات الكهربائية حساب مسافات الرحلات بدقة أكبر وتقليل الوقت المطلوب لشحن البطارية. في هذا النظام المقترح، تستخدم أجهزة الشحن اللاسلكي الحث الكهرومغناطيسي لنقل الطاقة الكهربائية بين دائرتين. عند تزويد الملف المرسل بالطاقة من مصدر التيار المتردد الرئيسي، يولد مجالاً كهرومغناطيسيًا يحث الطاقة الكهربائية في الملف المستقبل من خلال الحث المتبادل. ثم يتم نقل الطاقة الكهربائية إلى بطارية المركبة بمساعدة المحولات. تم إنشاء نظام محاكاة باستخدام برنامج MATLAB/SIMULINK، وتم التحقق من أداء النظام من خلال النتائج المستخلصة من المحاكاة.

الكلمات المفتاحية

نقل الطاقة اللاسلكي; المركبات الكهربائية; تقنيات الشحن اللاسلكي; معايير الشحن اللاسلكي; تاريخ المركبات الكهربائية; مكونات المركبات الكهربائية; أنواع المركبات الكهربائية