National Institute of Technology Delhi

Electrical and Electronics Engineering

Dynamic Charging of Electric Vehicles

Project Report

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ABSTRACT

The global shift towards electrified transportation is integral to curbing greenhouse gas emissions and mitigating the impact of rising petrol prices. This paper provides a comprehensive review of wireless electric vehicle charging systems (WEVCS), offering insights into both existing and emerging technologies. WEVCS have the potential to charge electric vehicles (EVs) without encountering plug-in problems, fostering greater convenience and ease of adoption.

The study compares four wireless power transfer methods—capacitive, magnetic gear, inductive, and resonant inductive—highlighting their respective advantages, disadvantages, challenges, and applications for EVs.

A significant focus is dedicated to wireless transformer structures, encompassing the design and optimization of coils, ferrite shapes, and protective/supportive layers. These elements constitute the fundamental components of WEVCS, and the paper scrutinizes their intricacies. Moreover, it addresses health and safety considerations, emphasizing compliance with electromagnetic compatibility and interference standards.

The study also provides a detailed exploration of static and dynamic WEVCS, elucidating their current progress and features. Static systems cater to EVs during parking, while dynamic systems extend charging capabilities while in motion

This study underscores the significance of wireless charging systems in advancing the accessibility and adoption of EVs. By exploring the intricacies of wireless power transfer methods, transformer structures, and the progression of static and dynamic WEVCS, the paper contributes to a comprehensive understanding of the evolving field, laying the groundwork for sustainable and efficient mobility solutions.

1.INTRODUCTION

Wireless Charging Systems (WCS) are proposed for high-power applications like Electric Vehicles (EVs) [1], and plug-in electric vehicles (PEVs) [2] in stationary [3] settings. Compared to plug-in systems, WCS offers simplicity, reliability, and user-friendliness [4]. However, they are limited to usage when the vehicle is parked [3], presenting challenges like electromagnetic compatibility issues, limited power transfer, bulkiness, shorter range, and higher efficiency concerns [5-7].Dynamic mode of WCS for EVs approach enables charging while the vehicle is in motion, reducing the need for expensive battery storage and extending transportation range [8,9,10]. Yet, dynamic WCS faces hurdles, particularly large air gaps, and coil misalignment, impacting power transfer efficiency, which relies on optimal coil alignment and the distance between the source and receiver [5,11]. For smaller passenger vehicles, the average air-gap ranges from 150 to 300 mm (about 11.81 in), potentially increasing for larger vehicles.Aligning the transmitter coil's optimal driving position is feasible in dynamic mode as the vehicle is automatically driven. Additionally, compensation methods—such as series and parallel combinations—are used on both transmission and reception ends to minimize losses and enhance system efficiency [12,13].Dynamic inductive power transfer systems (DIPTs) technology is intended to support long-trip travel on freeways, which is one of the main obstacles for EV technology. In addition, DIPT technology has the potential to significantly increase driving range while using a smaller onboard battery. Therefore, DIPTs offer a promising solution for self-driving vehicles as well as heavy-duty vehicle electrification. Dynamic charging is achieved by burying the transmitter coil into the ground and attaching the receiving coil at the bottom of the vehicle. These coils are supplied by high voltage and high frequency from an ac source. They are coupled with each other by the magnetic field when the vehicle passes over the transmitter coil to transmit the nominal power with maximum efficiency.

As outlined by the data sourced from the International Energy Agency's Global EV Policy Explorer [41], China, a leader in the EV market, announced its ambition in 2022 to establish charging infrastructure to accommodate 20 million Non-Emission Vehicles (NEVs) by 2025. These NEVs encompass Battery Electric Vehicles (BEVs), Plug-in Hybrid Electric Vehicles (PHEVs), and Fuel Cell Electric Vehicles (FCEVs) [4]. China also aims to bolster its lithium-ion battery industry due to its dominance in automotive applications. The United States federal government set targets in 2022 to achieve a 50% EV sales share and develop 500,000 public chargers by 2030. Canada adjusted its federal government target for 100% zero-emission light-duty vehicle sales from 2035 to 2040, while the European Union's "Fit-for-55" package includes measures aiming for 100% zero-emission vehicles by 2035 and charging infrastructure targets [41,42].

Positive policies, advancements in electric battery technology, increased EV models, and expanded charging infrastructure have spurred a surge in global EV sales. By 2021, over 16.5 million NEVs were on the roads globally, primarily BEVs and PHEVs [5]. However, challenges persist; high EV prices, chiefly due to expensive electric batteries, remain a barrier [5,6]. Battery capacity limitations to control costs and concerns about battery lifespan add complexity [7,43,9].

Recent studies have explored various EV charging technologies, including integrating renewables, charging levels, and smart charging concepts [21,22]. However, comprehensive research on innovative wireless charging technologies, smart charging infrastructure, and control systems remains limited. This study aims to provide a comprehensive overview of EV charging schemes, emphasizing inductive charging concepts categorized as static, dynamic, and quasi-dynamic. Additionally, it will delve into smart charging features and their integration with modern technologies, exploring the implications and benefits of widespread EV integration into the electricity network [21,22].

Our project, centered on the theoretical exploration of dynamic charging for electric vehicles (EVs), is driven by a meticulous study of diverse wireless power transfer methods and an in-depth analysis of factors influencing this innovative charging prototype.

The main objectives of the project are:

Wireless Power Transfer Methods:

- Investigate and assess various wireless power transfer methodologies, including inductive and resonant systems, to identify the most suitable approach for dynamic charging of electric vehicles.

Coil Placement Optimization:

- Explore and refine theoretical models for optimal coil placement on both the vehicle and the charging infrastructure. Evaluate the impact of different coil configurations on energy transfer efficiency and charging performance.

Identification of Limiting Factors:

- Systematically analyze the factors limiting the practical implementation of dynamic charging. This involves a comprehensive examination of challenges such as electromagnetic interference, energy losses, as well as safety and economic considerations

2.WIRELESS CHARGING OF ELECTRIC VEHICLES

2.1 BASIC OPERATING PRINCIPLE: - The system functions by converting AC mains power from the grid into high-frequency (HF) AC via AC/DC and DC/AC converters. To enhance the overall efficiency, compensation topologies employing series and parallel combinations are integrated into both the transmitting and receiving ends [14,15].

The receiving coil, typically positioned beneath the vehicle, transforms the oscillating magnetic flux fields into HF AC. This high-frequency AC is then converted into a stable DC supply, utilized by the onboard batteries. To ensure safety and stable operation, the system incorporates power control, communication functionalities, and a Battery Management System (BMS).

In this setup, magnetic planar ferrite plates are utilized on both the transmitter and receiver sides. These plates serve to diminish any detrimental leakage fluxes and enhance the distribution of magnetic flux, thereby optimizing the charging process.

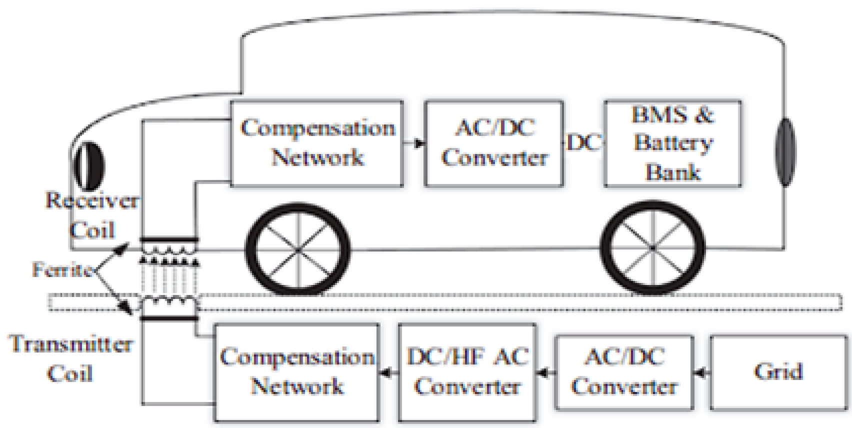


Fig. 1 Basic block diagram of static wireless charging system for EVs.

2.2 WIRELESS POWER TRANSFER METHODS: -

Since the inception of wireless charging systems for Electric Vehicles (EVs), four design methods have been employed:

1. Capacitive Wireless Power Transfer (CWPT)
2. Magnetic Gear Wireless Power Transfer (MGWPT)
3. Traditional Inductive Power Transfer (IPT)
4. Resonant Inductive Power Transfer (RIPT)

1.Capacitive Wireless Power Transfer: -

The affordability and simplicity of Capacitive Wireless Power Transfer (CWPT) technology, achieved through innovative geometric and mechanical designs of coupling capacitors [19,20], make it highly suitable for low-power applications like portable electronic devices [7], cellular phone chargers [8], and rotating machines [9]. Unlike systems using coils or magnets, CWPT utilizes coupling capacitors to transmit power from the source to the receiver.

In CWPT, the primary AC voltage is directed through an H-bridge converter, incorporating power factor correction circuitry. This generates high-frequency AC that passes through coupling capacitors at the receiver side. CWPT operates effectively with both high voltage and low current scenarios. To reduce impedance between transmitter and receiver sides in the resonant arrangement, additional inductors are added in series with the coupling capacitors, enabling soft switching within the circuitry.

The received AC voltage is converted to DC for the battery bank or load using rectifier and filter circuitry [10]. The efficiency of power transfer hinges on the size of the coupling capacitor and the distance between the two plates. CWPT performs exceptionally well with small air gaps, establishing superior field constraints between the capacitor plates [11].

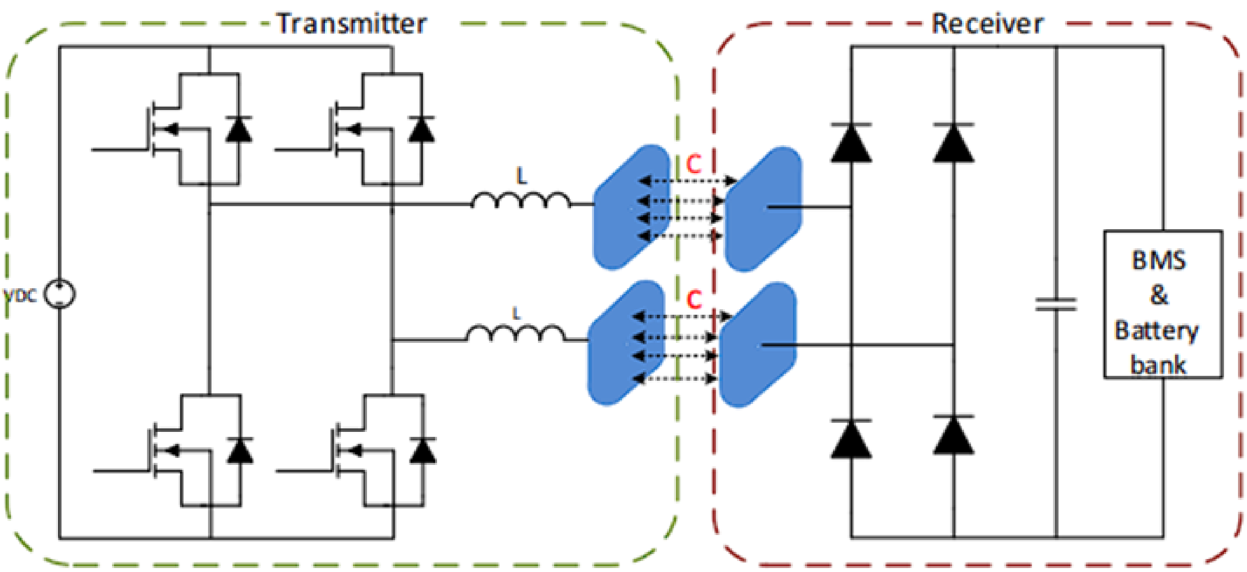


Fig. 2 Schematic Diagram of Capacitive Wireless Power Transfer

However, its application in Electric Vehicles (EVs) has been restricted due to the requirement for large air gap reductions and high-power levels. Some suggestions for improvement include reducing air gaps [12] and employing high capacitance coupling designs. For instance, proposals [6] to use a car's bumper bar as a receiver were made to minimize the air gap between coupling plates. A stationary laboratory prototype demonstrated over 1 kW with approximately 83% efficiency from the DC source to the battery bank, operating at 540 kHz frequency.

2.Magnetic Gear Wireless Power Transfer: -

Magnetic Gear Wireless Power Transfer (MGWPT) sets itself apart from both CWPT and IPT, this approach involves positioning two synchronized permanent magnets (PM) side-by-side, differing from the coaxial cable-based WEVCS systems.

The primary power, acting as the current source, is applied to the transmitter winding, generating mechanical torque on the primary PM. This torque causes the primary PM to rotate, inducing a similar torque on the secondary PM through mechanical interaction. In this synchronized setup, the primary PM functions in generator mode, while the secondary PM receives and transmits power to the battery via the power converter and Battery Management System (BMS) [3].

A laboratory prototype of MGWPT, capable of delivering around a 150 mm air gap distance and producing 1.6 kW, has been developed. However, integrating this technology into both static and dynamic applications poses numerous challenges. Reports [13] indicate that at 150 Hz, the rotators lost synchronization speed, significantly impacting the transmitted power. Constant speed adjustments are required, utilizing advanced feedback systems from the battery side to the primary side, to avoid exceeding the upper power limit.

The power transfer capability is influenced by the axis-to-axis separation between the primary and secondary PMs. As this distance increases, the coupling between the synchronized windings decreases abruptly. Consequently, while suitable for stationary Wireless Electric Vehicle Charging Systems (WEVCS), employing MGWPT in dynamic applications proves considerably challenging [14].

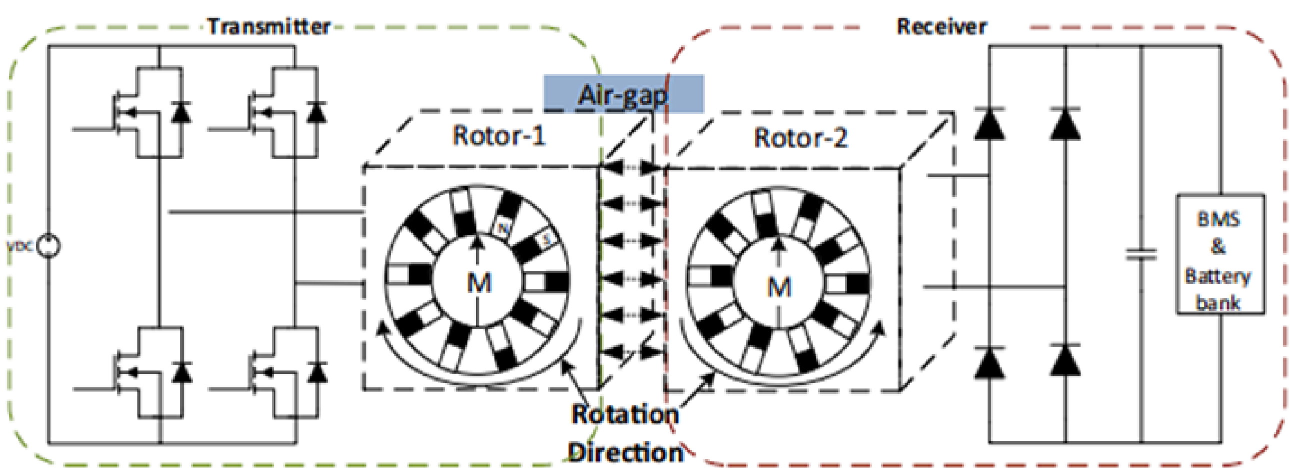


Fig. 3 Schematic diagram of magnetic gear based WPT

3.Inductive Power Transfer: -

The inception of the Traditional Inductive Power Transfer (IPT) dates to Nikola Tesla in 1914, marking an innovative method for wireless power transmission. Fig. 4 illustrates the fundamental block diagram of this traditional IPT, which has become a foundation for various EV charging structures.

IPT technology has undergone extensive testing and application across a broad spectrum, handling power transfer from milliwatts to kilowatts without physical contact between the source and the receiver. In a notable instance in 1996, General Motors (GM) introduced the Chevrolet S10 EV, utilizing the Magne-charge IPT (J1773) system. This system facilitated both level 2 (6.6 kW) slow and level 3 (50 kW) fast charges for the vehicle [3].

The Magne-charge system operated through a primary coil, often referred to as a charging paddle or inductive coupler, inserted into the vehicle's charging port. This primary coil transmitted power to the secondary coil, enabling the EV to charge. Additionally, the University of Georgia showcased a 6.6 kW Level 2 EV charger that could charge batteries ranging from 200 to 400 V at an operating frequency of 77 kHz. This universal IPT system utilized a 10 KVA coaxial winding transformer, offering substantial benefits such as adaptable power ranges and a flexible inductive coupling design.

Through these demonstrations and applications, IPT has proven its efficacy and adaptability in the realm of Electric Vehicle charging, highlighting its potential for scalable and versatile wireless power transfer [29,30].

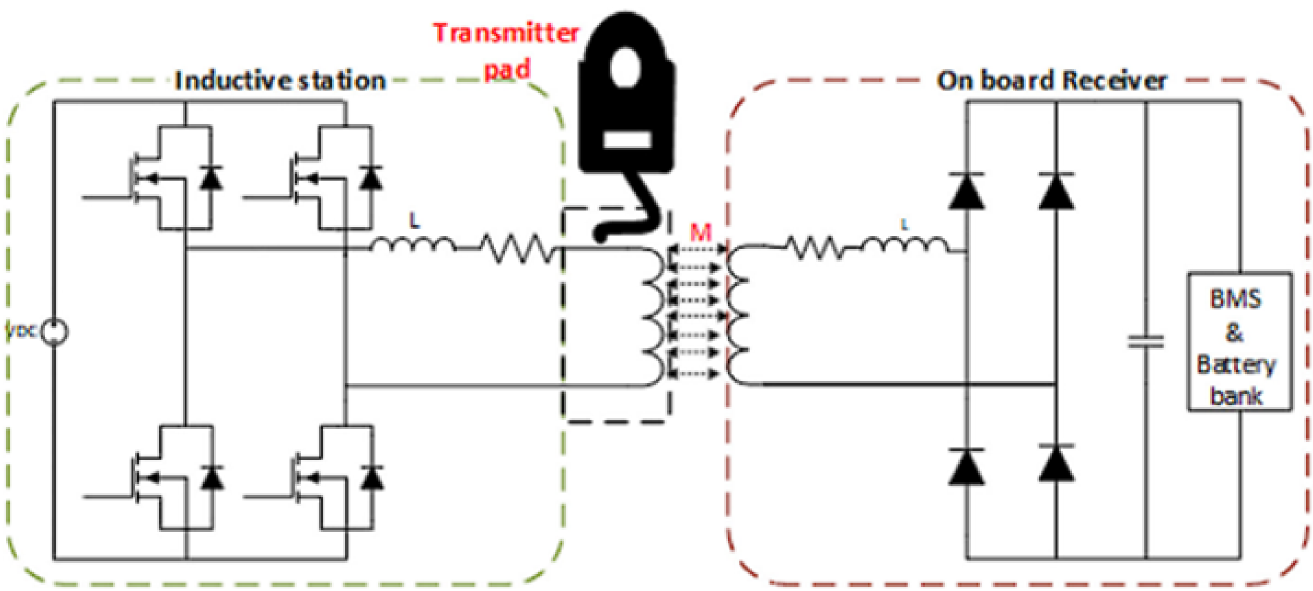


Fig. 4 Schematic diagram of Traditional Inductive Power Transfer

4.Resonant Inductive Power Transfer: -

The RIPT is one of the most well-known and advanced versions of the traditional IPT, in terms of designing power electronics and wireless transformer coils. Like other WPTs, the main AC voltage is converted into the HF AC source and supplied to the transmitter or primary winding. The receiver or secondary coil receives power via varying magnetic fields. The received power is converted to DC for the battery bank of the EVs through additional power electronics and filter circuitry. In comparison to the traditional IPT, additional compensation networks in the series and/or parallel configurations are added to both the primary and secondary windings not only to create the resonant case as presented in (1) but also to reduce additional losses.

$$f_{r(p,s)} = \frac{1}{2\pi\sqrt{L_{p,s} \cdot C_{p,s}}} \qquad (1)$$

where f r is the resonant frequency of the primary and secondary coils, and L and C are the self-inductance and resonant capacitor values of the transmitter and receiver coils, respectively.

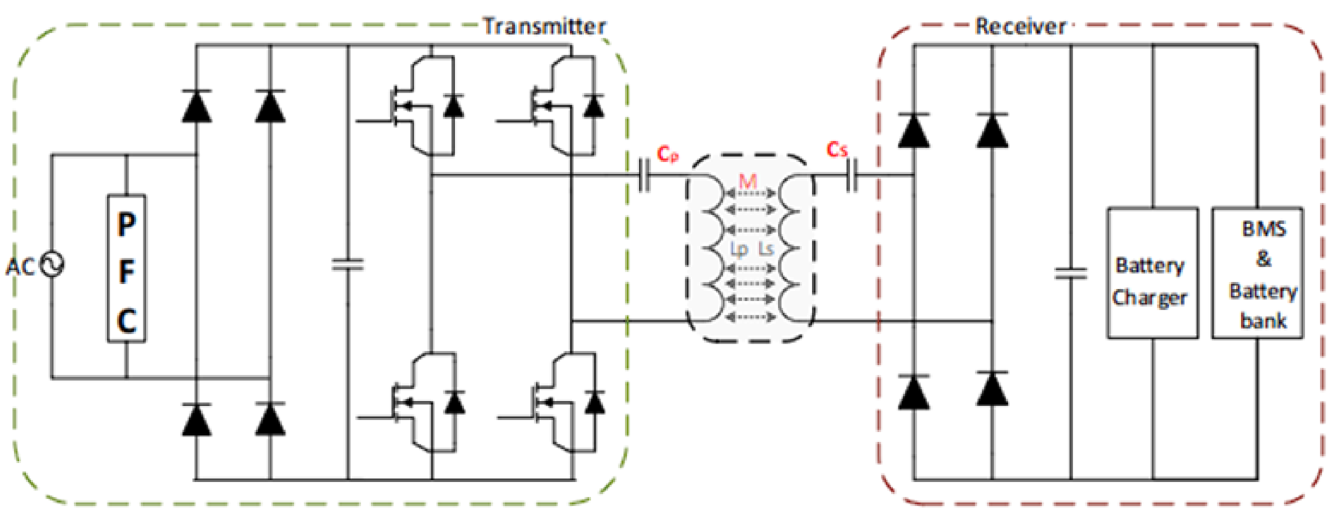


Fig. 5 Schematic diagram of Resonant Inductive Power Transfer

When the resonant frequencies of the primary and secondary coils are matched together, efficient power transfer is possible. The operating frequency of the RIPT ranges from tens of kilohertz to several hundred kilohertz. The magnetic flux generated at this frequency range, without any magnetic core, has a significantly adverse effect on the mutual inductance and hence the reduction of the coupling coefficient (k). The value of the coupling coefficient in the RIPT varies from 0.2 to 0.3 due to the minimum height clearance requirement of the EVs, which is 150–300 mm [31,32]. L_p and L_s are the self-inductance of the transmitter and receiver coils, respectively. L_m is the mutual inductance between the two coils. If the primary and secondary coils are strongly coupled, the mutual inductance value would be higher, and vice versa.

$$k = \frac{L_m}{\sqrt{L_p L_s}} \qquad (2)$$

2.3 COMPENSATION NETWORKS: -

Four types of compensation network topologies, namely series-series (SS), series–parallel (SP), parallel-series (PS) and parallel-parallel (PP), are shown in Fig. 6. The source compensation is required to eliminate phase difference between current and voltage and to minimize the reactive power in the source [32,33]. The installation of a secondary compensation network maximizes the load power transfer and efficiency [3,34]. Additionally, the selection of the network topologies relies on the specific application requirements in the WPT. The PS- and PP-compensated WCS are protected so that the source coil does not operate without the receiver coil. Even though it offers a safe environment, the system is unable to transfer sufficient power in the case of misalignment between the source and the receiver [5].

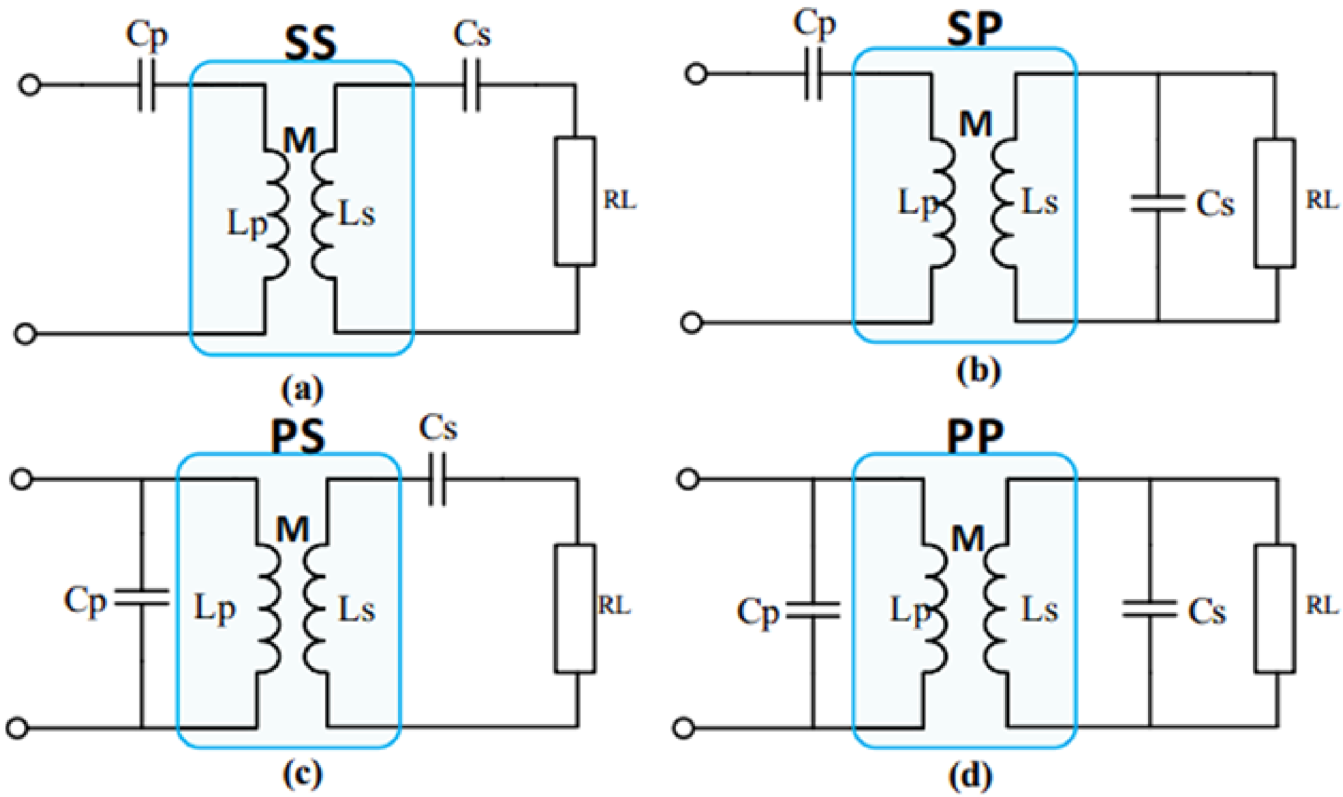


Fig. 6 Compensation topology (a) Series-Series (b) Series-Parallel (c) Parallel-Series (d) Parallel-Parallel

It also requires additional series inductors to regulate the source current to flow in parallel in the resonant circuit. The value of the capacitor is its reliance on the magnetic coupling and quality factor. The primary compensation capacitor value is not dependent on mutual inductance in SP-based compensated WCS and can offer higher power transfer than the graded system. However, it is critically dependent on variation of load [15].

SS compensated topology is the most suitable for EV applications because it offers two significant advantages [38,39]. The first advantage is that the value of the capacitor in the source and receiver sides is independent from the load conditions and mutual inductance. As a result, the resonant frequencies of the source and receiver sides are not reliant upon the mutual inductance and loads but depend on self-inductance of the primary and secondary coils [35,33].

The second advantage is that such systems maintain a unity power factor by drawing active power at the resonant frequency as the reflected impedance from the receiver coil does not add an imaginary part in the transmitter coil [16].

3.WIRELESS TRANSFORMER TOPOLOGIES

In wireless charging systems, the transmitter and receiver pads consist of multiple layers of components to achieve maximum power transfer efficiency while minimizing electromagnetic interference with cost-effectiveness. The key elements of the wireless transformer pads include the coil, shielding materials (such as ferrite and aluminum plate), and protective and supportive layers.

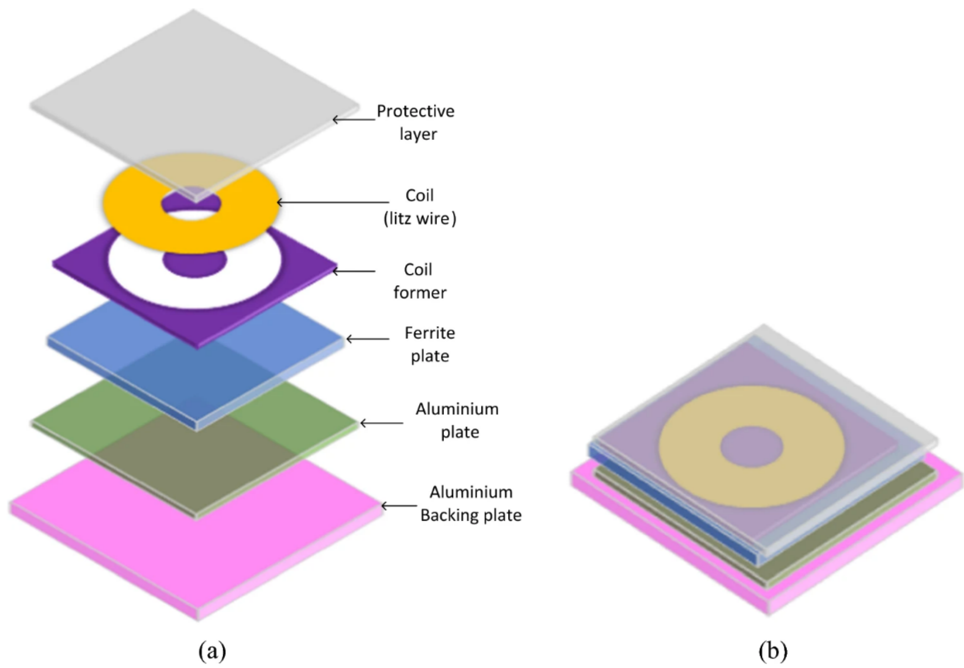


Fig.7 (a) Exploded View (b) Top View

i. **Protective layer**: - Used for the protection of the pad.
ii. **Coil and Coil Former**: - Responsible for generating a magnetic field.
iii. **Ferrite Plate**: - To align the magnetic field.
iv. **Aluminum Plate**: - To hold the power pad.
v. **Aluminum Backing Plate**: - To hold the entire system.

The coupling pads' effectiveness is determined by the quality factor, coefficient of coupling and alignment between the coupling pads. Litz wires are often used in magnetic coupler construction to minimize losses from the skin effect. It is important to employ ferrite cores for effective flux guiding because they reduce leakage inductance, raise mutual inductance, and offer shielding. The coil's design, the core's composition, and the spacing between two coils affect the coupling coefficient and quality factor.

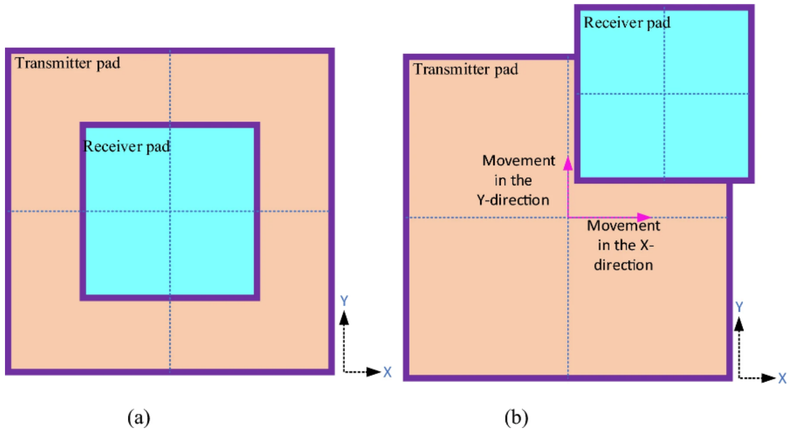


Fig.8 (a) Perfectly Aligned (b) Misaligned

As essential characteristics of a WPT system, the core, coil, and shield in these structures are designed and placed to reduce the weight and volume of the pad while having misalignment tolerance in all directions. According to the linked flux component's orientation, planner pads may be non-polarized or polarized.

An intermediate coil, also known as a coplanar coil, might be positioned in the same plane as the primary-side coil to increase efficiency, load function variations, misalignment tolerance, and coupling factor.

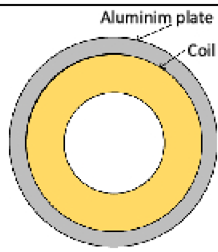
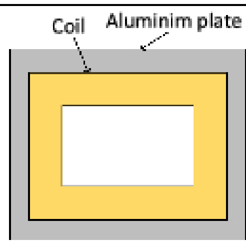
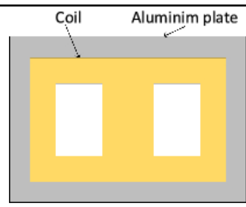
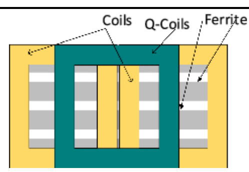
A third coil was added in a transmitter and receiver set to improve the system efficiency and resilience to variations in load. If the source coil is kept nearer to the transmitter coil, the coil's efficiency will be less. Adding a coil in the receiver section improves the coefficient of coupling and enhances the transmission distance and efficiency of the system.

3.2 COMPONENTS OF TRANSFORMER PADS: -

3.2.1 COIL SHAPES: - In Wireless Charging Systems for EVs, an air-core wireless transformer concept is used to transfer several watts to kilowatts of power from the source to receiver sides. A variety of planar coil shapes such as circular, rectangular, and hybrid arrangements have been utilized in the wireless transformer designs to improve performance and to solve misalignment problems between the transmitter and receiver pads [18]. Wireless charging coils are categorized in two primary areas: polarized pads (PPs) and non-polarized pads (NPPs).

a. Polarized Pads: - These are created from multiple coils and shapes to generate perpendicular (vertical) and parallel (horizontal) components of the flux.
b. Non-Polarized Pad: - These are the traditional shaped coils, such as circular, square, rectangular and hexagonal.

Table 1:-

Type of Pad	Pad Structure	Flux Distribution	Colis	Features
Non-polarized		Single sided	1	▫ Poor misalignment tolerance. ▫ Lower coupling coefficient. ▫ More flux leakage.
Non-polarized		Single sided	1	▫ Better misalignment tolerance. ▫ Reduced flux leakage. ▫ More efficient and better at transferring power.
Polarized		Single sided	2	▫ Higher misalignment tolerance. ▫ Flux leakage is extremely low. ▫ It is suitable for DWC.
Polarized		Double sided	3	▫ Flexible center coil design to accommodate the air gap ▫ Multiple modes of excitation ▫ Frequently used in secondary

3.2.2 MAGNETIC FERRITE SHAPES: -

In the WEVCS, the magnetic flux is generated in medium to high power ranges. In addition, it affects coupling efficiency between two windings, particularly if there is no shielding to reduce the leakage fluxes. Proper design of magnetic ferrite cores can help redirect path to magnetic fluxes from primary to secondary and improve mutual inductance and self-inductance of the coils [23]. The selection of ferrite core depends on multiple factors including size, shape, permeability, operating frequency, and cost.

Basic ferrite shapes such as circular, square, and rectangular (as demonstrated in E-core and U-core) have been utilized in the source pad as well as on the receiver side to reduce leakage fluxes in the WCS for EVs [25].

In WEVCS, aluminum plating offers two significant functions: shielding material and structure integrity. Aluminum construction reduces flux leakages and improves the coupling coefficient in the WCS for EVs through means of eddy currents [3].

Aluminum plates are mostly placed underneath the ferrite structures because without the ferrite the mutual inductance of the coils is reduced [17].

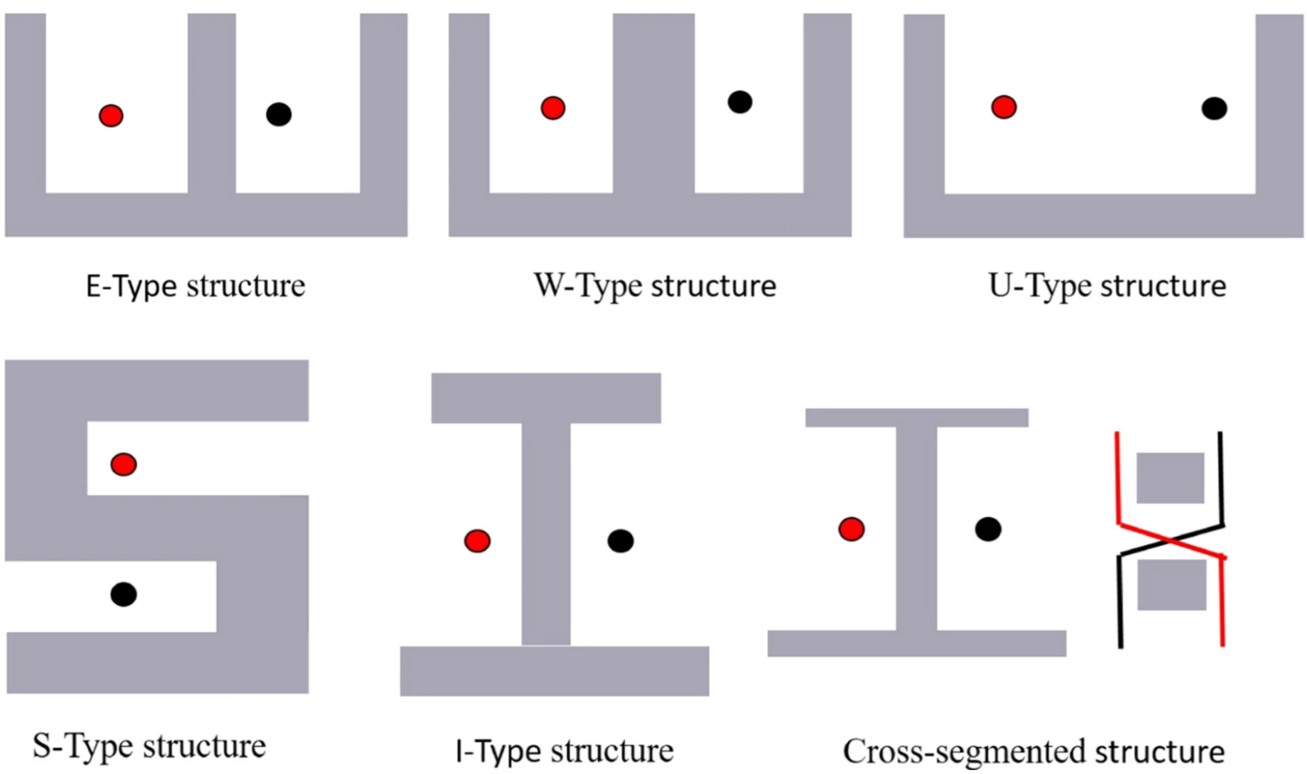


Fig. 9 Ferrite Core Structures

3.2.3 PROTECTIVE AND SUPPORTIVE STRUCTURE: -

Wireless electric vehicle (EV) charging systems require various protective and supportive structures to ensure safe and efficient operation. These structures are designed to address challenges such as electrical safety, environmental exposure, and mechanical durability.

In WEVCS the transmitter pad is mounted underneath the concrete structure of the road and can handle a car's weight and additional vibration of the vehicle. To improve structure stability, the top and bottom players of the charging pads are manufactured from a PVC plastic sheet. The length and width are dependent on the charging pad size and thickness and vary in size from 5 mm (about 0.2 in) to 20 mm (about 0.79 in). Sometimes transparent acrylics are also added around the coil for support and to enhance the appearance of the charging pad.

3.3 HEALTH AND SAFETY CONCERNS

Wireless Electric Vehicle Charging System (WEVCS) comes with three major potential health and safety issues— electrical, magnetic, and fire hazards. WEVCS operates at high current and voltage levels. This can create electrical shock risk due to malfunction or accidental damage to the device, resulting from environmental conditions (hot or cold) and physical damage.

3.3.1 MAGNETIC HAZARDS: - Magnetic fluxes generated at high power levels may surpass the minimum standards and regulations set by the standards agencies and be harmful to the general community. High power transfer from the transmitter to the receiver's charging pads happens at large air gaps from 150 mm (about 5.91 in) to 300 mm (about 11.81 in) at some kilohertz to a few megahertz. As a result, high frequency leakage fluxes are generated due to large air gaps. The level of such exposure fluxes must be below or meet the human exposure guidelines (IEEE C.95.1 2005 [26], ICNIRP 1998 (0 Hz-300 GHz), and ICNIRP 2010 (0 Hz-100 kHz) [27]) for a variety of human body parts. Furthermore, these electromagnetic fields may have the potential to discontinue operation of the implantable medical devices that are found in the vicinity of the system

3.3.2 FIRE HAZARDS: - High power level devices always pose a fire risk due to faults or breakdowns in the electronic or mechanical components. This can create life threatening conditions in houses or parking spaces. Cable insulation or failure of the switch devices can short circuit and cause a fire. To avoid such performance issues, rules, regulations, and manufactured standards must be in place. This includes weather conditions because temperatures in some countries vary from extremely cold to hot during a year.

3.4 HEALTH AND SAFETY STANDARDS

To create a user-friendly environment for the WEVCS, it is vital to define standards for efficiency, power level, operating frequency, EMI, EMC, and safety and testing for the research and commercialization of the technology.

To address safety issues related to EMFs, EMF shielding solutions are proposed. EMF shielding is typically used in IPT systems to minimize these leakage EMFs, thus improving the coupling performance and leading to a better efficiency and quality factor.

Table 2 :- List of international standards for WEVCS.

Organization	Relevant Standard/s	Standard Definition	Year
Society for Automobile Engineers (SAE)	J2954 [19] J1772 [20] J2847/6 [21]	• Wireless Power Transfer for Light-Duty Plug-In EVs and Alignment Methodology. • EV/PHEV Conductive Charge Coupler (CCC). • Communication Between Wireless Charged Vehicles and Wireless EV Chargers	2017 2017 2015
Institute of Electrical and Electronic Engineers (IEEE)	P2100.1 [22] C95.1 [60,61]	• Wireless Power and Charging Systems. • Respect to Human Exposure to Radio Frequency (3 kHz – 300 GHz) Electromagnetic Fields.	2017 2006
International Electro-mechanical Commission (IEC)	61980-1 Cor.1 Ed.1.0 [3,51] 62827-2 Ed.1.0 [3,51]	• EV WPT Systems Part -1: General Requirements. • EV WPT Systems Part -1: General Requirements	2017 2017
International Organization for Standardization (ISO)	19,363 [24]	• Electrically Propelled Road Vehicles – Magnetic Field WPT – Safety and Interoperability Requirements	2017

Table 3 :- SAE Internal Standards (J2954) for PHEV/EV Wireless Charging

Features	Wireless Power Transfer Classes			
Maximum Input Power (kW)	WPT-1 3.7	WPT-2 7.7	WPT-3 11	WPT-4 22
Minimum Target Efficiency (%)	>85% Aligned			
Operating Frequency (kHz)	85 (Band: 81.39–90)			

4.ADVANCEMENTS IN DYNAMIC WIRELESS ELECTRIC VEHICLE CHARGING SYSTEMS (D-WECS)

4.1 WORKING

Electric vehicles (EVs), especially Plug-in or Battery Electric Vehicles (BEVs), face formidable challenges in terms of cost and limited range. Addressing these challenges traditionally involves either frequent charging or augmenting the battery pack size, which introduces additional complications such as increased costs and weight. A potential breakthrough technology that mitigates these challenges is the Dynamic Wireless Electric Vehicle Charging System (D-WEVCS). Also referred to as "roadway powered" [30], "on-line," or "in-motion" [31] Wireless Electric Vehicle Charging System (WEVCS), it emerges as a promising solution for the future of automated EVs. To eliminate this charging downtime, dynamic wireless charging (DWC) systems allow EV drivers to charge their EV batteries continuously while in motion, to compensate for the energy consumed by the EVs without depleting the batteries. An outline of the placement of primary charging pads on a road is shown in Fig. 10 to demonstrate a dynamic wireless charging system.

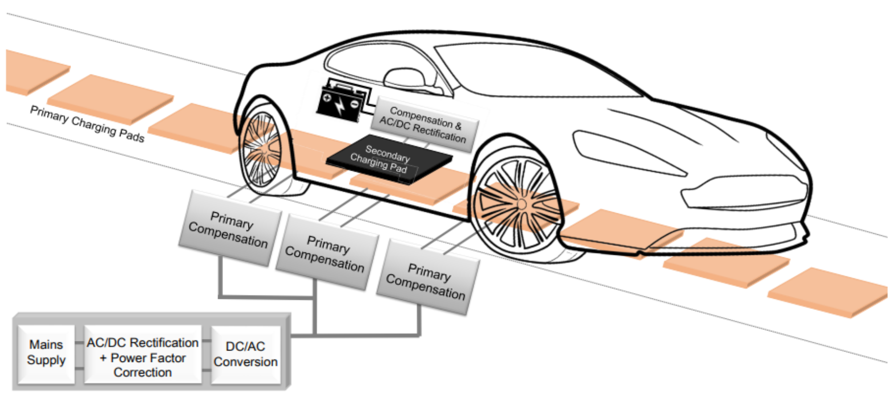
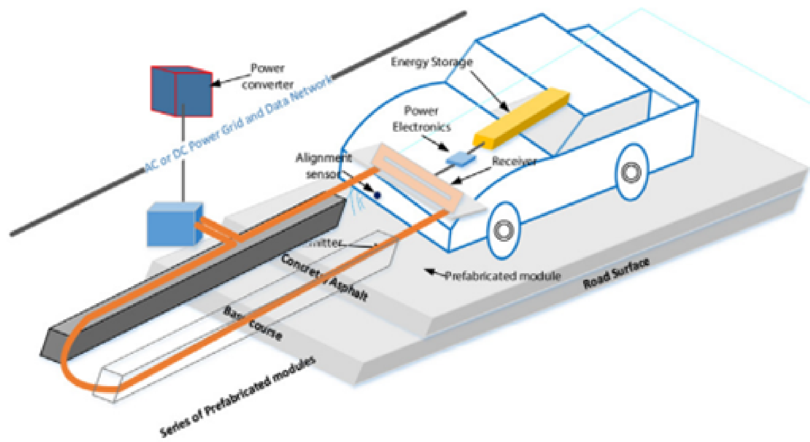


Fig.10 Outline of dynamic charging system

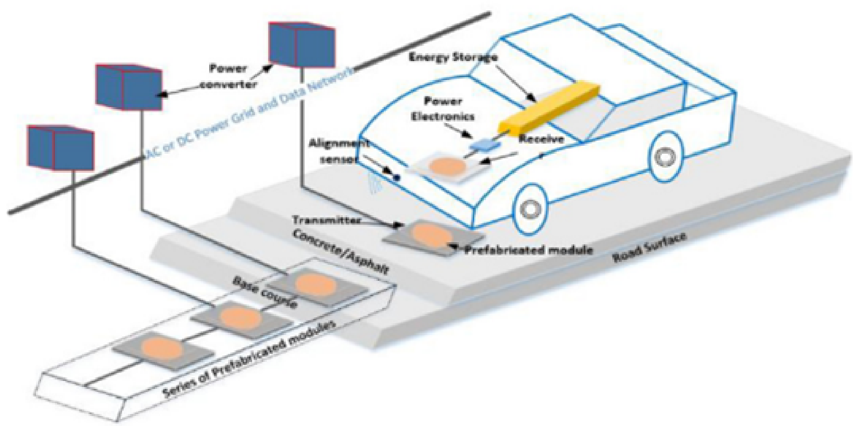
In the schematic representation depicted in Figure, primary coils are strategically embedded into the road's concrete surface at specific intervals, powered by a high voltage, high-frequency AC source, and accompanied by compensation circuits linked to the microgrid and/or Renewable Energy Sources (RES).

Like its static counterpart, the secondary coil is positioned beneath the vehicles. As electric vehicles traverse over the embedded transmitters, they intercept a magnetic field through a receiver coil. This magnetic energy is then converted into Direct Current (DC) to replenish the battery bank, facilitated by power converters and Battery Management Systems (BMS). An advantageous outcome of the D-WEVCS is a substantial reduction, approximately 20%, in the overall battery requirements compared to current EVs [8].

For the dynamic variant of WEVCS, specific locations and predefined routes necessitate the installation of transmitter pads and power supply segments [36]. The power supply segments are typically categorized into centralized and individual power frequency schemes, as illustrated in Fig. 11(a) and (b). In the centralized power supply scheme, a large coil spanning 5–10 meters is embedded in the road surface, deploying multiple smaller charging pads. However, this scheme exhibits higher losses, reduced efficiency, and increased installation and maintenance costs in comparison to the segmented scheme.



(a)



(b)

Fig.11 Basic diagram of dynamic wireless electric vehicle charging system

The initial infrastructure installation for this technology is undeniably costly. However, the integration of self-driving cars in the future presents a compelling opportunity to enhance the alignment between transmitter and receiver coils, significantly improving overall power transfer efficiency. The versatility of Dynamic-WEVCS extends to various EV transportation applications, including light-duty vehicles, buses, railways, and rapid transport. Table 6 [3,10,33,37–40] provides a comprehensive development summary of D-WEVCS, highlighting its potential applications and advancements.

Table 4 :-

Summary of research and development of Dynamic WEVCS.

Research and Development	Pick-up Power (kW)	Operating Frequency (kHz)	Air-gap (mm)	Efficiency (%)
Oak Ridge National Laboratory (ORNL) [85]	20	22–23	125–175	90
University of Auckland, New Zealand [6,7,98]	20–30	12.9	500	85
Japan Railway Technical Research Institute [99]	50	10	7.5	TBA
KAIST University, Korea [100–110]	3	20	10	72–80
	6		170	71
	15		120–200	74–83
	25–100		200	85
Flanders Drive with industries and universities [111]	80	20	100	88–90
EV System Lab & Nissan Research Centre [112]	1	90	100	>90
North Carolina State University, USA [8,113,114]	0.3	100	170	77–90

4.2 ADVANTAGES

The following are the major benefits of dynamic charging technology:

- Increase driving range: Because vehicles are continuously charged in moving status, the mileage-anxiety concern is completely eliminated, which cannot be achieved by any other existing technology and infrastructure. As a result, the adoption of green transportation is expected to increase dramatically.
- Improve transportation efficiency: Dynamic charging overcomes the limitation of the slow-charging rate. The extra transportation time caused by using the charging station and the waiting time during charging are both saved. During rush hour especially, it contributes to alleviating traffic congestion. The construction of fast-charging stations along the highway is reduced, and the possible waiting line around the stations is, therefore, lessened.
- Improve transportation safety: Because the vehicles could be charged more frequently, the size of the on-board battery pack is significantly reduced, resulting in less risk of explosion in accident scenarios. Furthermore, electric vehicles are conveniently connected and share traffic information, which contributes to avoiding potential accidents.
- Alleviate the demand response from power grid: The dynamic charging system is built along the roadway and the load is evenly distributed. Compared to a fast-charging station, the transient power requirement from the power system is reduced. It is convenient to have distributed energy resources along the roadway to reduce power demand from the grid.

Category	Fast Station	Dynamic
Waiting time	Long (>20 mins)	Zero
Battery size	Large	Small
Vehicle cost	High	Low
Infrastructure cost	High	High
Power grid effect	Negative	Positive
Traffic management	Negative	Positive

Table 5:- comparison of stationary and dynamic charging.

5.CHALLENGES HINDERING DYNAMIC CHARGING

The deployment of dynamic charging infrastructure on a large scale requires substantial investment and planning, presenting logistical and financial challenges. Furthermore, the optimization of power transfer without causing excessive electromagnetic interference and ensuring safety standards remain high are critical aspects that demand careful consideration.

A critical impediment to the broader acceptance of WEVCS is the power range limitations when compared to traditional plug-in chargers. The charging capabilities of AC Level 1 (1.4–1.9 kW) and Level 2 (3.3 to 20 kW) on-board charging systems offer a charging rate ranging from 2 to 20 miles per hour. In contrast, DC fast charging (up to 100 kW) can contribute 60 to 80 miles of range in just 20 minutes [3]. Presently, Wireless Power Transfer (WPT) standards for static modes can reach up to 22 kW, as outlined in the emerging J2954 standards, which are still in the research and development phase.

To address these challenges, an advanced network of static and dynamic wireless charging stations must be strategically installed on roads. However, this presents a substantial hurdle due to incompatibility with existing infrastructure arrangements, necessitating new infrastructure development. Such initiatives result in additional financial requirements, with the starting cost of WEVCS Level 1 (3.3 kW) estimated at approximately $2470 [27]. The dynamic variant, with a charging power level of 200 kW, incurs a considerable cost of approximately A$2M/km/lane [28], making it economically challenging for developing and underdeveloped countries. Furthermore, the substantial investment in WEVCS requires meticulous maintenance to prevent major losses due to improper handling, wear and tear, and the identification limitations of foreign objects (FOI) [29].

1. **Large cost of the installation:** The complexity of integrating dynamic charging with existing road networks and ensuring compatibility across diverse vehicle types adds an extra layer of cost. The costs involve not only the development and installation of the charging technology itself but also the implementation of supporting infrastructure, such as power grid enhancements and communication systems.
2. **Necessity to have a separate lane for charging:** The concept of a separate lane for dynamic charging of electric vehicles addresses the need for efficient and continuous power supply while minimizing disruptions to regular traffic flow. This separation not only enhances the overall reliability of the charging system but also reduces the impact on existing road infrastructure, as the charging process occurs independently in a designated lane.
3. **Necessity for perfect alignment:** This is paramount for efficient and effective power transfer. For optimal energy transfer, precise alignment between these coils is crucial. Any misalignment can result in reduced charging efficiency, energy loss, and potential safety concerns. Ensuring perfect alignment is especially critical for dynamic charging scenarios, where vehicles are in motion.

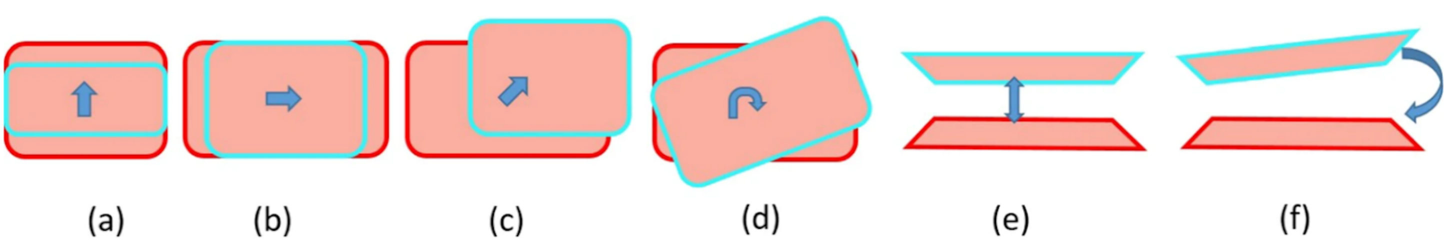
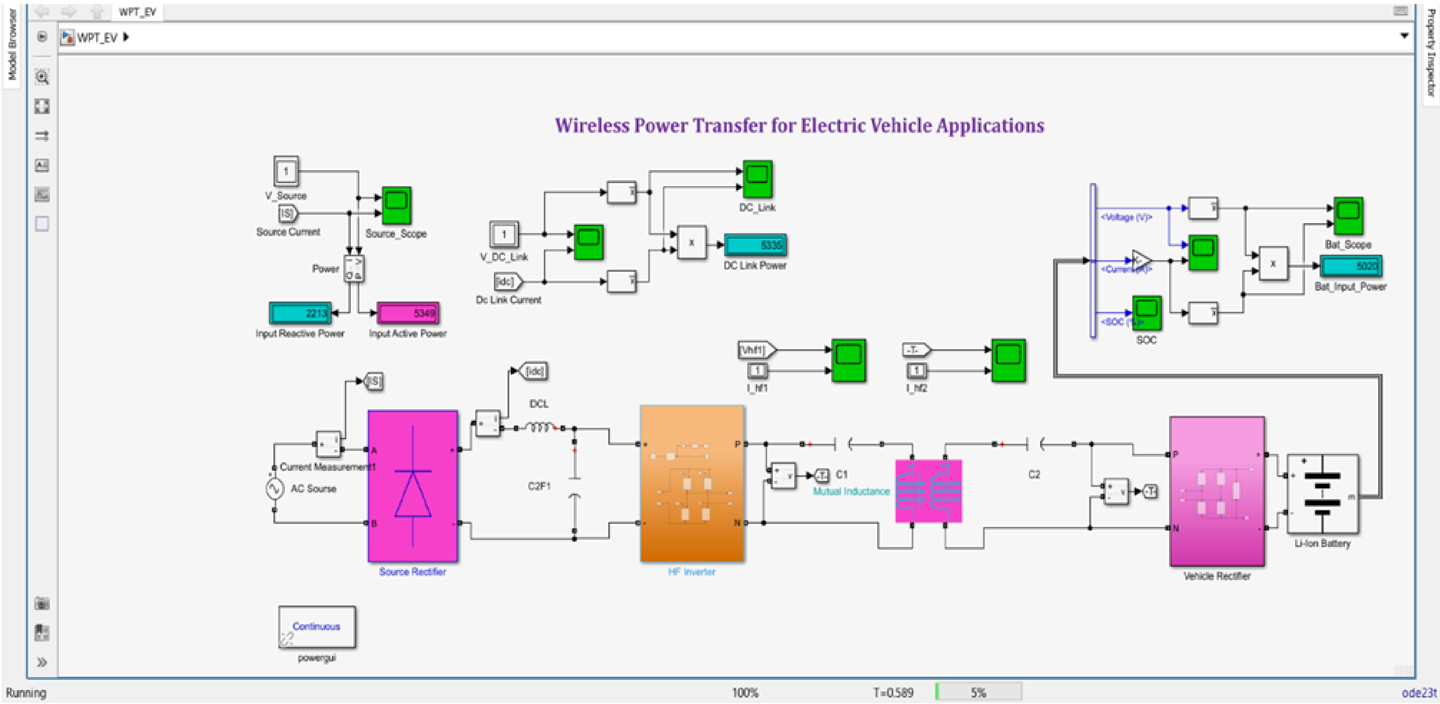
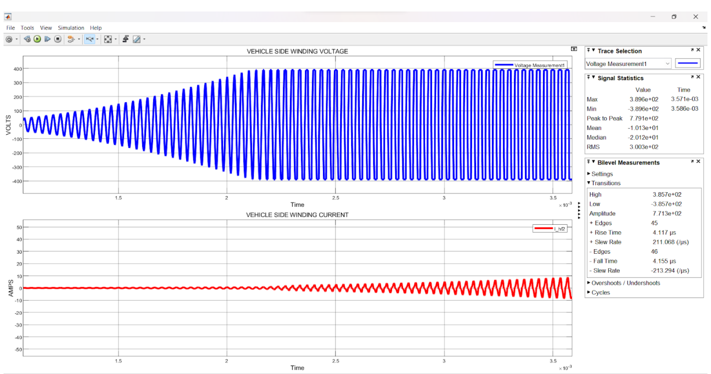


Fig. 12 Pads misalignment positions

6.SIMULATION





Fig(a)

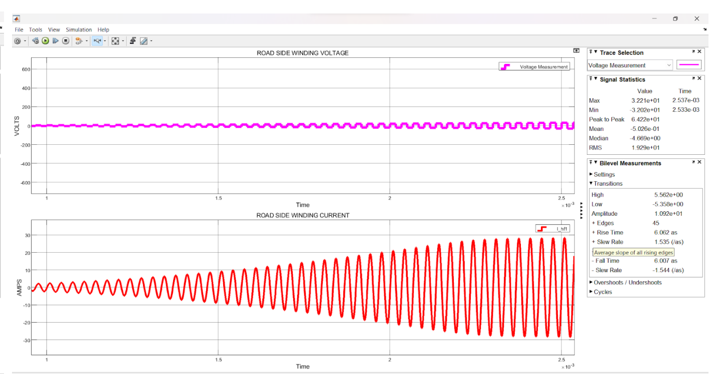


Fig (b)

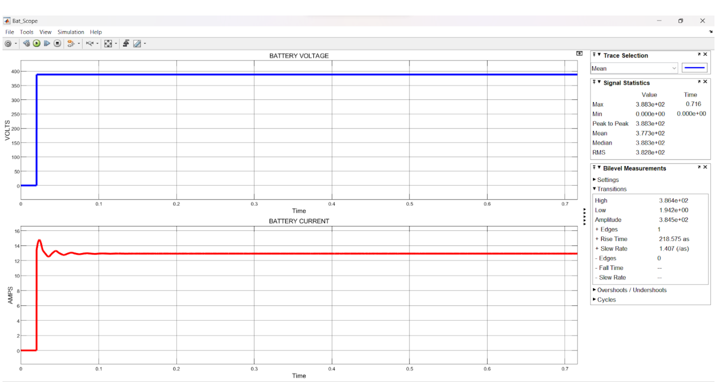


Fig (c)

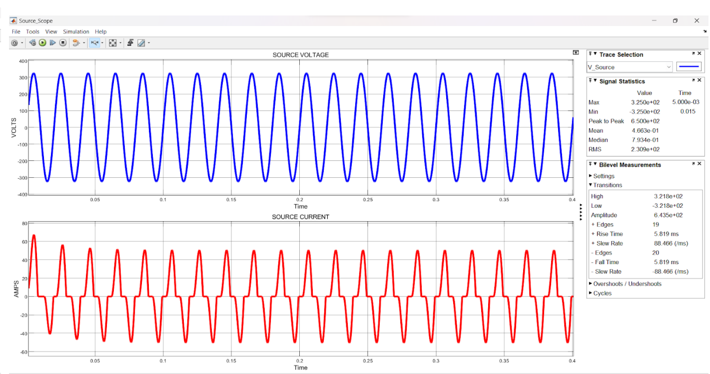


Fig (d)

7.RESULT

In Fig.(d) we observe source voltage and source current accordingly. Source voltage is about 325 V and source current is about 50 A.

In Fig.(c) we observe the waveform of the converted DC voltage and DC current from the AC signal. Initially the DC signal fluctuates and then it settles down to a constant value.Here Battery voltage is about 380V and Battery current is about 13A.

In Fig.(b) we observe the roadside winding voltage and current which is alternating in nature.Roadside voltage is of constant amplitude while amplitude roadside current increases with time.RMS value of voltage here is 19.29V.

In Fig.(a) we observe vehicle side winding voltage and current which is of alternating nature.RMS value of voltage here is about 300V.

8.CONCLUSION: Paving the Way for the Future of Electric Vehicle Charging

In conclusion, our comprehensive exploration of dynamic charging systems for electric vehicles has unveiled a promising avenue towards revolutionizing the way we power our vehicles. The incorporation of wireless charging technology underscores the commitment to user-friendly, hands-free charging experiences. The convenience and flexibility provided by wireless charging pads positioned strategically along road networks or in urban environments have the potential to redefine the landscape of electric mobility. As electric vehicles become more ubiquitous, the implementation of such wireless charging infrastructure can foster greater adoption and ease of use.

In the context of sustainability and environmental impact, dynamic charging systems showcase the potential to minimize the carbon footprint associated with traditional charging stations. By reducing the need for stationary charging points and encouraging a continuous, on-the-go charging model, we are contributing to a more sustainable and eco-friendly future.

Despite the remarkable strides made in the dynamic charging arena, challenges remain, including standardization, regulatory frameworks, and widespread infrastructure deployment. Addressing these challenges will be pivotal in realizing the full potential of dynamic charging and ensuring its seamless integration into mainstream electric vehicle usage.

One of the pivotal aspects of our research revolves around the optimization of wireless power transfer efficiency and the extension of charging range. By addressing challenges related to energy loss and distance limitations, our project contributes to the ongoing efforts to make wireless charging more practical and effective. The innovative approaches employed to enhance the range of wireless charging underscore the adaptability and potential of these technologies in real-world scenarios.

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