“AI-Based Optimization and Control of Wireless Power Transfer Systems for Electric Vehicle Charging Applications”

[1]*Dr. Yogesh G S*, [2]*Prof.Satish Hegde*, [3]*Prof.Mangala Pyatishettar*,[4]*Mr.Raghu.R*
[1]*Professor & HOD, Department of Electronics and Communication, EPCET, Bangalore*
[2]*Assistant professor, Dept. of Electrical and Electronics, R R Institute of Technology, Bangalore*
[3]*Assistant professor, Dept. of Electronics and Communication, RGIT, Bangalore*
[4]*Service Engineer, Sanprocess Automation, Bangalore*

Abstract:

Wireless Power Transfer (WPT) systems are a rapidly developing technology with huge potential in consumer electronics, electric cars, biomedicine, and applications for smart grids such as Vehicle to Grid (V2G). With an emphasis on magnetic resonance WPT and its system designs, including coil construction, inputs, outputs, and compensatory topologies, this essay aims to give an overview of recent advancements in WPT. We examined and evaluated the benefits, drawbacks, and applications of fundamental compensations (SS, SP, PS, and PP) and hybrid compensations (LCC and LCL).Despite their strong performance at low mutual inductance, primary parallel compensations are rarely used because to their high impedance and load-dependent coefficient coupling. Consequently, hybrid topologies like as LCC and LCL, which are usually chosen for V2G or dynamic WPT applications, require extra compensations.

Keywords: *Artificial Intelligence, Wireless Power Transfer, Electric Vehicles, Machine Learning, Dynamic Wireless Charging, Vehicle-to-Grid, Power Transfer Efficiency, Smart Charging System.*

Introduction:

With an emphasis on developing the technologies for wireless power transfer (WPT) and applications like Vehicle to Grid (V2G), research trends on electric vehicles (EVs) have drawn increasing interest in recent years. It is challenging to discuss the future of Vehicle to Grid (V2G) without including an effective wireless power transfer system as the rise in WPT in electric cars opens up new opportunities. A bi-directional WPT system that permits energy transfer between the car and the electrical grid is necessary to create an efficient V2G that integrates electric vehicles into the power grids [1, 2].

In order to reduce the bottlenecks and problems associated with the use of wired battery charging, one of the main objectives of EV WPT research is the creation of alternate systems for powering battery-dependent gadgets. Some of the most notable advantages of the WPT system are increased device mobility and user-friendliness; by doing away with wires, devices may now be built with greater flexibility and less environmental design limitations, like in the case of underwater WiTricity and medical implantation.

The V2G concept is based on the idea that while EVs remain parked for the most of the day, the energy stored in their batteries may be used as long as the user restores the vehicle's original state of charge (SoC) before using it [2–4]. The system can be readily expanded to WPT even if the conventional V2G is intended for wired charging, as long as all of the unidirectional stages are swapped out with bidirectional stages that allow power to flow in both ways [1].

The V2G is referred to as Vehicle to Home (V2H) when the EV charging station is a home or house [5, 6]. In this scenario, the customer can either use the energy stored in the battery to power its own domestic loads or inject it into the grid if the loads are low-power [7–9]. A design process for a bi-directional WPT Vehicle to Home (BWV2H) application was provided, guaranteeing that the standard SAE J2954 for EV WPT and the regulations for low voltage utilities were met [3]. Demand response, the smart grid transition, and the smooth integration of renewable energy sources are anticipated to benefit from the widespread use of BWV2H technology.

In addition to compensating consumers for the services provided by the distribution system, the V2H approach also serves to decrease the total cost of electricity by stabilizing or lowering the variable power demand of residential loads [3]. Optimizing the system to enable load balancing, filling, and peak shaving is one of the study's potential outcomes [10, 11]. A 3.7 kW prototype was used to experimentally analyse and validate the WPT system, and a mathematical model for estimating the charge and discharge efficiency in an EV bidirectional ICPT wireless charger was given [12]. It was proposed that the operating mechanism, compliance, and control of V2G systems need to be improved.

Interesting advancements in wireless power transfer during the last several decades have spurred innovation and development in consumer electronics, electric cars, biomedical, and other disciplines. A new avenue for advancement in wireless power transmission was created in 2007 when an MIT researcher transferred 60 watts of electricity across a distance of two meters with an efficiency of 40% [13]. Researchers from Hong Kong Polytechnic University powered a 14-watt compact fluorescent lamp wirelessly in 2011 using a circular domino with repeater arrangement [14], and researchers from Utah State University transferred 5 kilowatts of power over a 20-cm gap at an efficiency of 90% in 2012 [15].

Additionally, in 2012, Wireless Advanced Vehicle Electrification (WAVE), a business located in Uttah, launched electric buses and put charging stations at bus stops [16]. The Korea Advanced Institute of Science and Technology (KAIST) developed and implemented Online Electric Vehicles (OLEV) in the public transportation system in 2013. When compared to a standard electric car, the OLEV's charging mechanism enables a one-third battery reduction [17]. It is an electric vehicle that can be charged both in motion and stationary.

An essential component of WPT research is the examination of the performance indices of wireless power systems [18–21], which is often carried out using equivalent circuit, coupled mode theory, or two port networks as modelling techniques with the aim of enhancing the system efficiency [22]. An study of the WPT coupling mechanism, coupling coils, and compensation topology was provided in order to create a stable and functioning WPT system for robots. This analysis was followed by research into further ways to improve coupling performance, such as multi-layer coil structure [23]. Another popular method is to model different system components and solve for performance indices using circuit theory and mutual inductance [18–21]. The link between maximum efficiency and air gap length in magnetic resonant coupling was examined using equivalent circuits and Neumann's formula [24], and the prerequisites for achieving maximum efficiency for a certain air gap were suggested. It was established that the coils' radius and number of turns had an impact on the air gap length. By determining the ideal characteristic impedances in each scenario, maximum efficiency is attained at different air gap lengths through mutual inductance, characteristic impedance, internal resistance, and resonance frequency. Theodoropoulos et al. developed a control technique for load balancing in wireless EV charging to increase WPT efficiency [25].

An overview and developments in wireless power transmission are presented in this article, with a focus on the use of magnetic resonant coupling for electric car charging. An overview of the WPT system categorization is provided in the preceding sections. The system designs were discussed with an emphasis on charging standards, coil design elements, and compensation topologies [76].

Classifications of the WPT system:

System characteristics including coupling strength, coupling type, transmission direction, and transmission distance are typically used to categorize WPT systems. When it comes to transmission distance, it can be either near-field (non-radiative) or far-field (radiative) depending on proximity. The preferred type of WPT is mostly determined by the needs of the intended application.

1. Classification Based on Transmission Distance

Depending on the transmission distance between the transmitter and receiver, wireless power transfer (WPT) systems are primarily divided into near-field (non-radiative) and far-field (radiative) systems. While far-field WPT systems use electromagnetic radiation to transfer power over vast distances, near-field WPT systems use magnetic or electric field coupling to work over small distances [76].

A. Near-Field (non-radiative) WPT:

Near-field WPT transmits energy using magnetic or electric fields without emitting electromagnetic waves into space. These technologies are highly efficient and are frequently employed for short-distance applications. Transmission distance ranges from a few millimetres to roughly 1 meter.

Mathematical Equation

For inductive coupling:

$$V_2 = M\frac{dI1}{dt} \qquad (1)$$

Where:

- V_2 = Induced voltage
- M = Mutual inductance
- I_1 = Primary current

Types of Near Field WPT

1. Inductive coupling (IC).

Inductive coupling transfers power by magnetic flux connection between main and secondary coils. Efficiency is determined by the coupling coefficient and coil alignment. Applications include distances up to 10 in mobile chargers' Electric toothbrushes Biomedical Implants

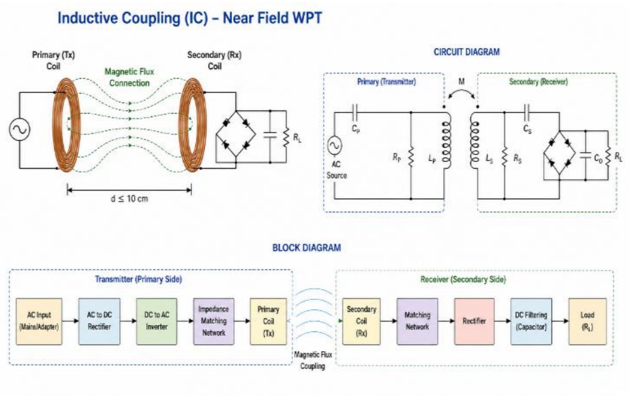


Figure 1: Inductive Coupling

2. Resonant inductive coupling (RIC)

Resonant inductive coupling increases transmission distance and efficiency by keeping both coils at the same resonant frequency. Applications range from 10 cm to 1 meter. Charge electric vehicles, use consumer devices, and automate industrial processes.

Resonant Frequency Equation $f_r = \frac{1}{2\pi\sqrt{LC}}$ (2)

Where:

- fr = Resonant frequency
- L = Inductance
- C = Capacitance

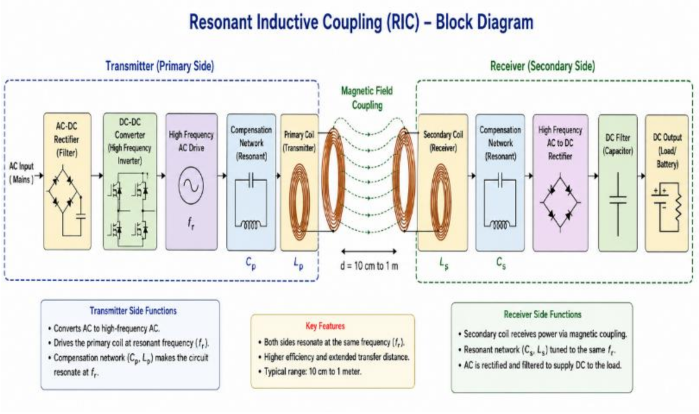


Figure 2: Resonant Inductive coupling

3. Capacitive coupling (C).

Capacitive coupling uses electric fields to transmit energy between conductive surfaces. Distance ranges from a few millimetres to many centimetres. Applications Low-power sensors. Portable Electronic Devices

$$X_c = \frac{1}{2\pi f c} \tag{3}$$

Where:

- X_C = Capacitive reactance
- f= Operating frequency
- C = Capacitance

B. Radiative (Far-Field) WPT

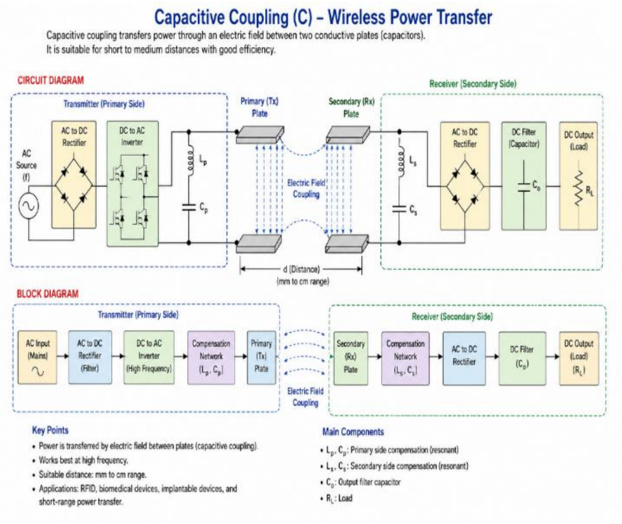
Far-field WPT systems transmit power over great distances using electromagnetic radiation such as microwaves or laser beams. Transmission Distance: Several meters to kilometres.

Friis Transmission Equation

$$p_r = \left(\frac{\lambda}{4\pi R}\right)^2 G_r G_t p_t \tag{4}$$

Where:

- Pr = Received power
- Pt = Transmitted power
- Gt,Gr = Antenna gains
- λ = Wavelength
- R = Transmission distance


Capacitive Coupling (C) – Wireless Power Transfer

Capacitive coupling transfers power through an electric field between two conductive plates (capacitors). It is suitable for short to medium distances with good efficiency.

Key Points

- Power is transferred by electric field between plates (capacitive coupling).
- Works best at high frequency.
- Suitable distance: mm to cm range.
- Applications: RFID, biomedical devices, implantable devices, and short-range power transfer.

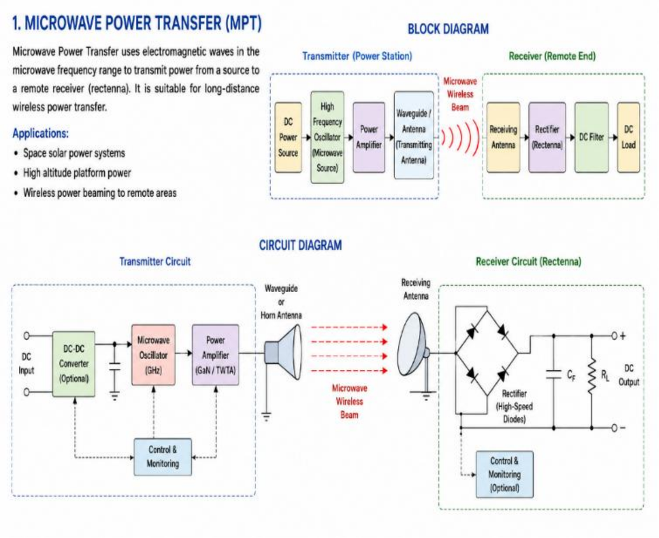
Main Components

- L_p, C_p: Primary side compensation (resonant)
- L_s, C_s: Secondary side compensation (resonant)
- C_o: Output filter capacitor
- R_L: Load

Figure 3: Capacitive coupling

1.Microwave Power Transfer (MPT).

Microwave power transfer is the conversion of electrical energy into microwave radiation, which is then transmitted by antennas. Distance: many meters to many kilometres. Applications Satellite power transmission Drone charging, remote power delivery


1. MICROWAVE POWER TRANSFER (MPT)

Microwave Power Transfer uses electromagnetic waves in the microwave frequency range to transmit power from a source to a remote receiver (rectenna). It is suitable for long-distance wireless power transfer.

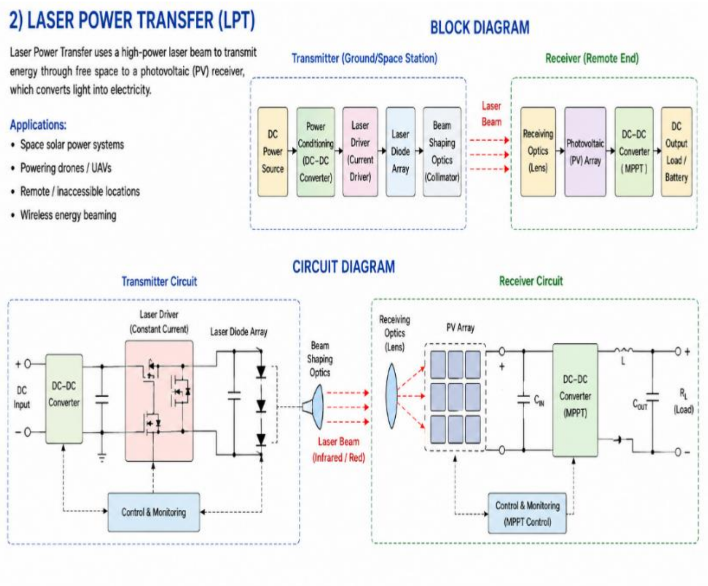
Applications:

- Space solar power systems
- High altitude platform power
- Wireless power beaming to remote areas

Figure 4: Micro Wave Power transfer

2) Laser Power Transfer (LPT)

Laser power transfer is the process of delivering energy to photovoltaic receivers via focussed laser beams. Distance: Several meters to kilometres. Applications Space applications Military systems use remote sensing.


2) LASER POWER TRANSFER (LPT)

Laser Power Transfer uses a high-power laser beam to transmit energy through free space to a photovoltaic (PV) receiver, which converts light into electricity.

Applications:

- Space solar power systems
- Powering drones / UAVs
- Remote / inaccessible locations
- Wireless energy beaming

Figure 5: laser power transfer

2. Classification by Coupling Strength

WPT systems are also classed based on the degree of magnetic coupling between the transmitter and reception coils.

A. Tight coupling.

Tightly linked systems have a high mutual inductance and need coils to be closely aligned. The distance is quite short (a few millimetres to centimetres).
Applications: wireless phone chargers, RFID systems.

Coupling Coefficient Equation

$$\boldsymbol{K = \frac{M}{\sqrt{L_1 L_2}}} \qquad (5)$$

Where:

- k = Coupling coefficient
- M = Mutual inductance
- L_1, L_2 = Self-inductances

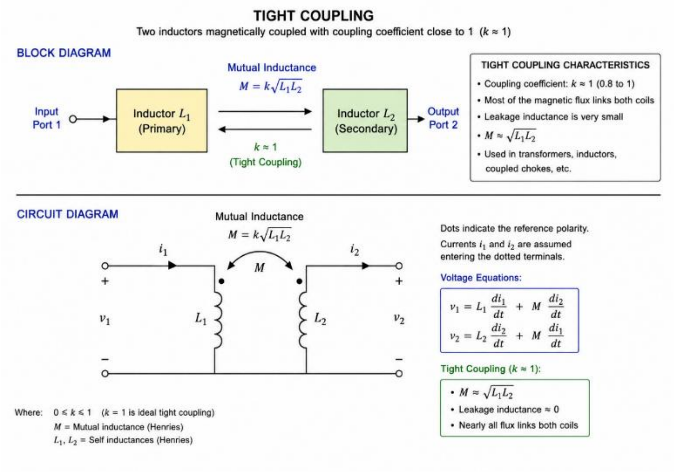


Figure 6: Tightly Coupled

B. Loose coupling

Loosely connected systems allow for greater air gaps and mild misalignment, but have a lower efficiency. Applications range from a few centimetres to one meter. Automatic charging methods for electric vehicles

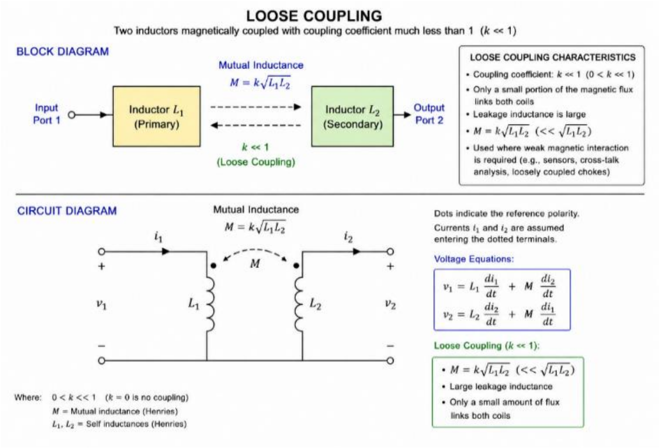


Figure 7: Loose coupled

3. Classification Based on Transmission Direction

A. Unidirectional WPT.

In unidirectional systems, electricity is only sent from the transmitter to the receiver.

Distance depends on the WPT technology utilized in applications. Consumer electronics

Industrial Charging Systems

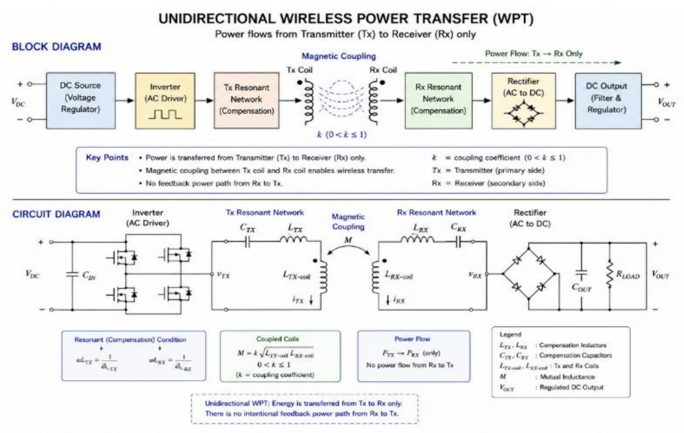


Figure 8: Unidirectional WPT

B. Bidirectional WPT.

Bidirectional WPT systems provide energy transmission in both directions. Distance is usually short to medium range applications. Vehicle-to-grid (V2G) systems, smart grid applications

Power Equation

$$P = VI\cos\phi \qquad (6)$$

Where:

- P = Power transferred
- V = Voltage
- I = Current
- ϕ = Phase angle

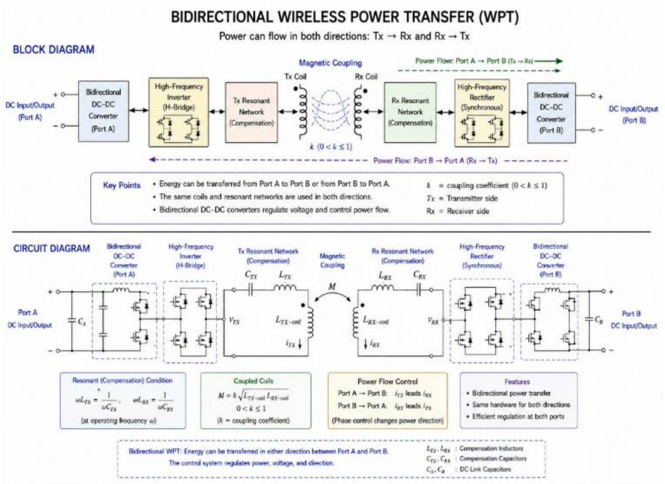


Figure 9: Bi directional WPT

4. Classification Based on Mobility

A. Static WPT.

Static WPT transmits power while the receiver stays stationary.

Distance: a few millimetres to many centimetres. Applications Stationary electric vehicle charging Wireless charging pads

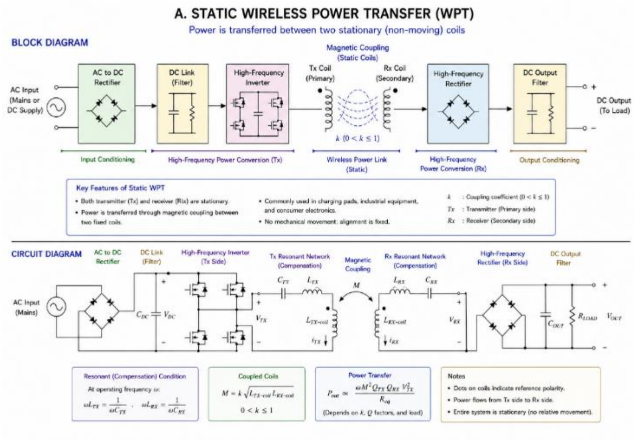


Figure 10: Static WPT

B. WPT dynamic

Power is transferred via dynamic WPT while the receiver is in motion. Applications for a distance of few centimetres to meters Roadways for dynamic EV charging Vehicles with automated guidance

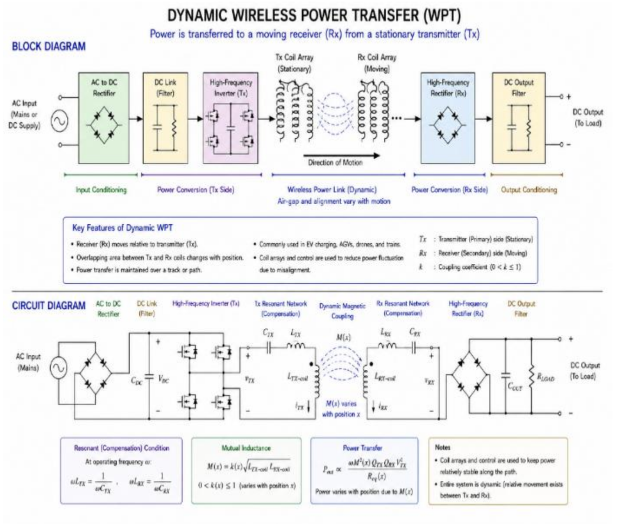


Figure 11: Dynamic WPT

5. Classification Based on Power Level

A. WPT with Low Power

Sensors and wearable electronics with a power range of milliwatts to a few watts

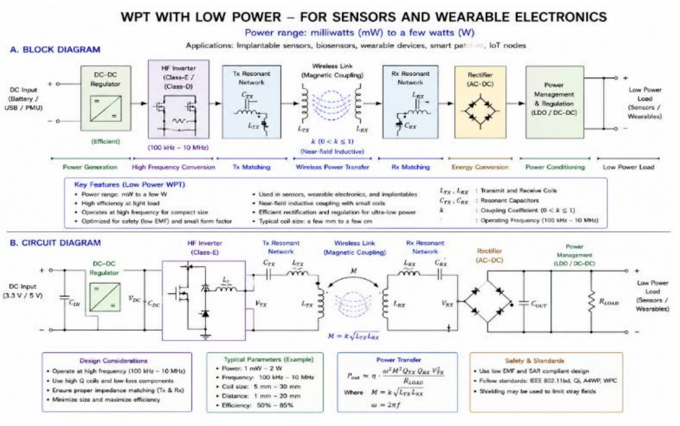


Figure 12: WPT with Low power

B. WPT Power Range for Medium-Power

Applications: tens to hundreds of watts Medical equipment and consumer electronics

C.

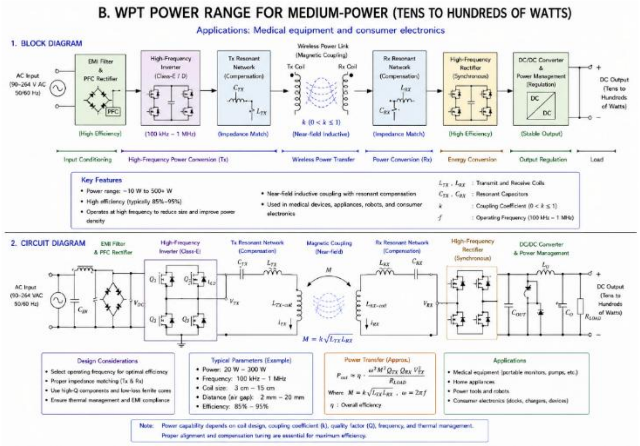


Figure 13: WPT for Medium Range

D. High-Power WPT

Power Range Kilowatts and Higher Applications: Industrial systems, electric cars

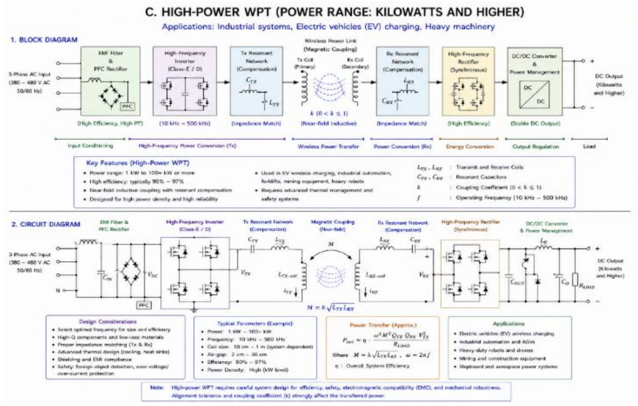


Figure 14: WPT for High power WPT

Transmission Distance:

Loosely coupled, firmly coupled, inductively coupled, capacitively coupled, and any other coupling whose transmission distance falls within the nearfield area are all included in the near field WPT. The far-field zone is where microwave-coupled WPTs function. Because of the

Magnetic resonance coupling is becoming more popular in applications like electric vehicle (EV) charging due to its potential for transmission distance to satisfy design criteria. Examples of near-fields include inductive and capacitive coupling, when the power transmission distance is less than the working wavelengths. Although the power transfer efficiency is significantly better than that of far-field approaches and has a larger misalignment tolerance, the efficiency decreases with increasing distance and the transfer distance is modest. Far-field WPT can power devices tens of thousands of kilometres away and is characterized by a transfer distance far greater than the electromagnetic wavelength. Wireless power transfer from solar satellites to terrestrial rectennas is one example. The poor efficiency and directivity limitations, however, are a significant disadvantage; high alignment is necessary for effective power transmission since the misalignment tolerance is too low. Analysis of dipole transmitter elements for WPT was done in order to enhance the transmission properties of wire antennas for wireless power transfer, such as directivity [34]. The current distribution and radiated fields were calculated using the half-wave dipole and the Method of Moment method (MoM). Design and analysis of broadside and end fire arrays with five, six, seven, ten, twenty, and thirty elements at 0.3, 0.4, and 0.5. electric cars, medicinal equipment, electronics, and other fields [20, 38, 39]. This is because the efficiency of wireless power transfer drastically decreases when using the radiative strategy.

System architectures:

Certain design goals must be met while creating the circuit architecture of the WPT system since system losses rise as reactive power increases. Capacitors are used to adjust the circuit in order to meet one or more of the following conditions [17, 41, 42]:

Power transmission: The main goal is to increase power transmission, which may be done by eliminating leakage inductances on both the primary and secondary sides [17].

VA rating: By supplying the controlled reactive power required to create and maintain the magnetic field, it is often sought to reduce the power supply's VA rating [17, 76]. Reactive currents raise conduction and semiconductor losses, particularly in diodes. To raise the power factor to almost unity, primary resonance cancels out the primary leakage inductance.

Phase Angle and Soft Switching: Since the phase angle between the input voltage and the current determines the VA rating on the power supply, a phase angle of zero is required for the minimal VA rating, however a phase angle greater than zero is required for MOSFET switching. Phase angle is therefore often chosen to be both low enough for a satisfactory VA rating and somewhat more than zero to accomplish soft-switching.

Constant Voltage (CV) or Constant Current (CC): Providing constant voltage or constant current at the output is occasionally requested. A battery is often the end load for a wireless power transfer system, and it needs constant voltage throughout the charging stage and constant current at low states (0–85%) [17]. In certain applications, compensation networks are specifically made to maintain a constant output voltage or output current in order to satisfy battery charging requirements [17]. Voltage sources need primary series compensation, whereas current source drives employ parallel compensation.

Bifurcation Tolerance: The goal was to increase the system's bifurcation tolerance. This is accomplished by creating a compensation network for a single zero phase angle while maintaining system stability under various loading scenarios and controlling frequency fluctuation [17].

Misalignment Tolerance: The sensitivity of each compensatory topology to changing location (misalignment) varies. In order to maintain the resonance frequency on both sides, a more intricate control system is required.

Compensation Topology:

When the coupling coefficient drops to less than 0.3, compensations are added to achieve the desired properties. A compensation network is required to reduce the excessive leakage inductance and loose coupling of the WPT pads. To improve the system's power transmission metrics, such as power delivered to the load (PDL) and power transfer efficiency (PTE), compensation circuits are usually necessary for both TX and RX. Two essential features of WPT technology that affect the power transmission range and interference with other devices are PTE and PDL.Lowering the power supply's volt-ampere (VA) rating and more effectively modifying the supply loop's current and receiving loop's voltage are just two benefits of a compensation circuit. Adding a capacitor to either side of the system is the simplest approach to provide compensation, and this results in either basic topology or hybrid topology. The main or secondary topology, the quality factor, and the magnetic coupling coefficient value are some of the factors that affect the choice of the resonant circuit is L and C values.

MRC WPT has several hybrid compensation circuits in addition to four standard compensation circuits. Series–Series (SS), Series–Parallel (SP), Parallel–Series (PS), and Parallel–Parallel (PP) are the four fundamental compensation schemes. The circuit schematics of the four fundamental compensation networks are displayed in the image below[76].

Series–Series (SS) Compensation: In SS, unity power factor occurs at resonant frequency, making the compensation desired where high efficiency and high-power factor (PF ≈ 1) are required. The significance of these two metrics depends on how they fluctuate with coupling and load variation. One of the advantages of the SS compensation is the independence of the primary capacitance value on coupling coefficient and load. It finds application in dynamic WPT where the coupling coefficient changes as the device moves, such as segmented dynamic WPT charging in electric vehicles. The way these two parameters change with coupling and load fluctuation determines how important they are [42]. The independence of the main capacitance value from the coupling coefficient and load is one of the benefits of the SS compensation [45]. It is used in dynamic WPT, such as segmented dynamic WPT charging in electric vehicles, where the coupling coefficient varies as the device moves. Systems with long primary tracks are best suited for series compensation, in which the compensation capacitors are linked in series along the primary track. This makes it possible to maintain the track voltages within reasonable bounds. Parallel compensation is more appropriate for concentrated windings as they are frequently high-current systems. The light load condition, which happens when the receiver is absent and results in a zero impedance at the principal resonance frequency, is a significant disadvantage. As a result, under these circumstances, a very high voltage is delivered to the load. In this case, the parasitic impedances of the coil and capacitor are the sole factors limiting the current[76].

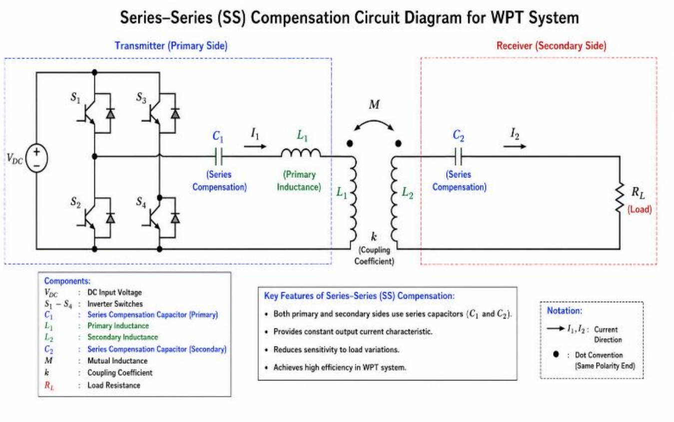
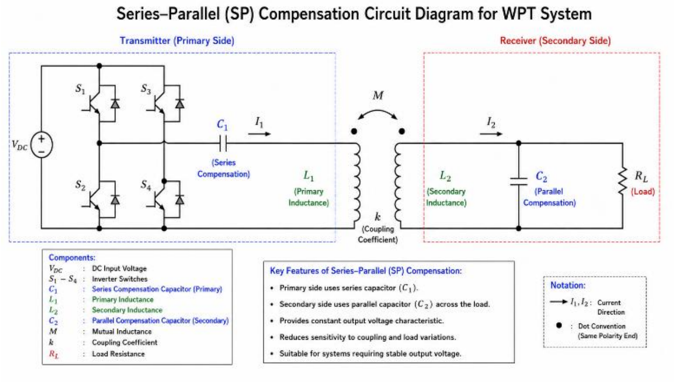


Figure 15: ***Series–Series (SS) Compensation***

Series-Parallel (SP) Compensation: In SP, some impedances are transmitted to the main independent of the load. If the load is missing at resonance, there would still be a short circuit, which makes a current limiting control necessary. Additionally, changes in mutual inductance affect system dynamics and power factor, making power factor more difficult [42]. Additionally, when the mutual inductance varies, so does the resonant frequency and, as a result, the capacitance value. With efficiencies above 93 percent and nearing 97 percent at different transmission power levels, the SS and SP compensation are most frequently used in real applications and implementation [56,76].



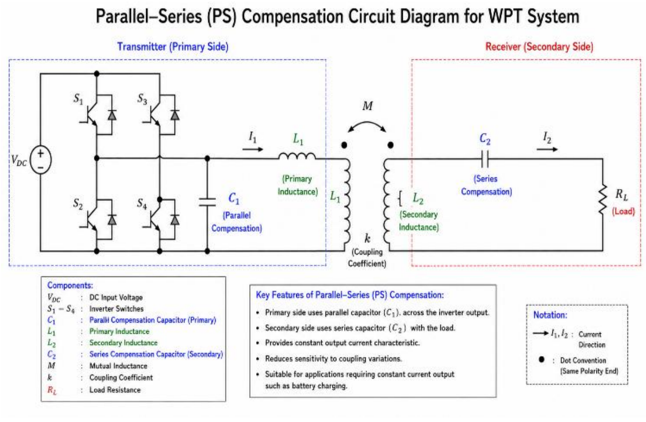
Components:
V_{DC} : DC Input Voltage
$S_1 - S_4$: Inverter Switches
C_1 : Series Compensation Capacitor (Primary)
L_1 : Primary Inductance
L_2 : Secondary Inductance
C_2 : Parallel Compensation Capacitor (Secondary)
M : Mutual Inductance
k : Coupling Coefficient
R_L : Load Resistance

Key Features of Series–Parallel (SP) Compensation:

- Primary side uses series capacitor (C_1).
- Secondary side uses parallel capacitor (C_2) across the load.
- Provides constant output voltage characteristic.
- Reduces sensitivity to coupling and load variations.
- Suitable for systems requiring stable output voltage.

Figure 16: ***Series-Parallel (SP) Compensation***

Parallel-Series (PS) Compensation: Both series-series and parallel-series topologies have the same reflected impedance to the main. The efficiency and power factor are strong for comparatively low mutual inductances and a wide range of load and mutual inductance variations. Additionally, the P-S is adjusted by adding an inductor to generate an LCL resonant task since the system requires current source input to prevent abrupt voltage fluctuations. Research reveals that the compensating capacitance used in secondary parallel circuits is influenced by coupling fluctuation. In order to attain SPS constant output power without modifying the power source, it is also feasible to combine the features of SS and PS [11]. Despite PS's ability to provide smooth switching in semiconductors, main side compensations are rarely used because of a number of issues, including high impedance, calculation complexity, and coupling coefficient dependency on load. To transmit enough power in PS and PP, a high driving voltage is required due to the higher input impedance.



Components:
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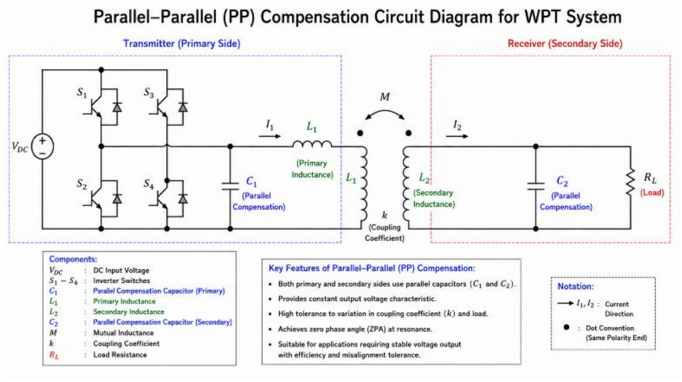
$S_1 - S_4$: Inverter Switches
C_1 : Paralll Compensation Capacitor (Primary)
L_1 : Primary Inductance
L_2 : Secondary Inductance
C_2 : Series Compensation Capacitor (Secondary)
M : Mutual Inductance
k : Coupling Coefficient
R_L : Load Resistance

Key Features of Parallel–Series (PS) Compensation:

- Primary side uses parallel capacitor (C_1). across the inverter output.
- Secondary side uses series capacitor (C_2) with the load.
- Provides constant output current characteristic.
- Reduces sensitivity to coupling variations.
- Suitable for applications requiring constant current output such as battery charging.

Figure 17: ***Parallel-Series (PS) Compensation:***

Parallel–Parallel (PP) Compensation: To get the necessary capacitance to accomplish the specified voltage and current ratings, a combination of both series and parallel compensation is utilized, as series compensation needs more voltage and current than parallel compensation. Additionally, a series-parallel-series topology combination is suggested to mitigate the impact of misalignment. Analysis of the four fundamental compensation circuit topologies generally reveals that lowering the reactive power flow by changing the operating frequency achieves the maximum power transfer capability; however, control complexity brought on by frequency bifurcation happens and causes system instability.



Components:
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$S_1 - S_4$: Inverter Switches
C_1 : Parallel Compensation Capacitor (Primary)
L_1 : Primary Inductance
L_2 : Secondary Inductance
C_2 : Parallel Compensation Capacitor (Secondary)
M : Mutual Inductance
k : Coupling Coefficient
R_L : Load Resistance

Key Features of Parallel–Parallel (PP) Compensation:

- Both primary and secondary sides use parallel capacitors (C_1 and C_2).
- Provides constant output voltage characteristic.
- High tolerance to variation in coupling coefficient (k) and load.
- Achieves zero phase angle (ZPA) at resonance.
- Suitable for applications requiring stable voltage output with efficiency and misalignment tolerance.

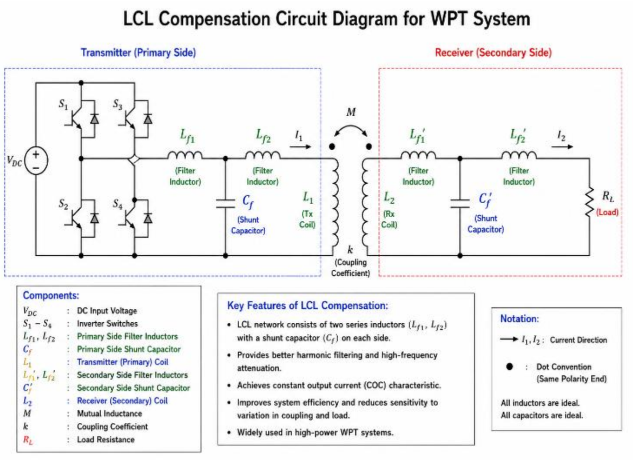
Figure 18: ***Parallel–Parallel (PP) Compensation***

Hybrid Compensation Topologies:

For the MR WPT circuit, designs of hybrid capacitor and inductor topologies, such as LCL, LCC, LCCL, etc., have been investigated in order to obtain further improvements, such as constant current/voltage and increased efficiency. The LCC and LCL are taken into

In short, below:

1. LCL Compensation: This can solve the issues with series and parallel compensations and is created by adding an inductor to a parallel resonance network [44]. A mathematical model of a bidirectional power flow was developed, and a phase-angle control approach was established to efficiently govern the direction and amount of power flow in a WPT device using an LCL compensation [1]. As a strength, a complete bridge converter with a low VA rating makes it simple to adjust the source current of LCL for changes in the coupling coefficient and load circumstances. The secondary side may be a hybrid, series, or parallel compensation. LSL-S, LCL-P, and LCL-LCL are common secondary combinations of LCL primary compensation. A dynamic LCL-S/LCL architecture was suggested in order to get constant voltage and current in the transmitting coil [68]. Due to its ability to adapt to changes in load, parallel compensation is widely used [69]. Reactive power is increased by the real and imaginary components of the load in the reflected impedance on the primary. A large dc inductor is needed to guarantee continuous conduction across the rectifier, which raises the system's cost and loss. When comparing LCL-S and LC/S, their structures are the same, but their tuning techniques differ. But compared to LCL-S, the LC offers a stronger capacity for high voltage suppression and a superior load-independent voltage output [70,76].



Components:

V_{DC}	:	DC Input Voltage
$S_1 - S_4$	:	Inverter Switches
L_{f1}, L_{f2}	:	Primary Side Filter Inductors
C_f	:	Primary Side Shunt Capacitor
L_1	:	Transmitter (Primary) Coil
L_{f1}', L_{f2}'	:	Secondary Side Filter Inductors
C_f'	:	Secondary Side Shunt Capacitor
L_2	:	Receiver (Secondary) Coil
M	:	Mutual Inductance
k	:	Coupling Coefficient
R_L	:	Load Resistance

Key Features of LCL Compensation:

- LCL network consists of two series inductors (L_{f1}, L_{f2}) with a shunt capacitor (C_f) on each side.
- Provides better harmonic filtering and high-frequency attenuation.
- Achieves constant output current (COC) characteristic.
- Improves system efficiency and reduces sensitivity to variation in coupling and load.
- Widely used in high-power WPT systems.

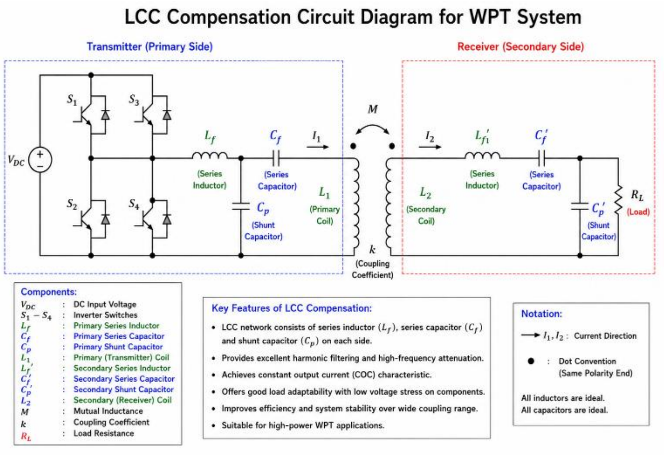
Notation:

$\rightarrow I_1, I_2$: Current Direction
● : Dot Convention (Same Polarity End)

All inductors are ideal.
All capacitors are ideal.

Figure 19: ***LCL Compensation***

2. LCC Compensation: A parallel resonant circuit is combined with an inductor and a capacitor in series to create the LCC. The double-sided LCC has been the subject of several studies [73–77]. It may be utilized as a strength to get unity power factor by compensating the power factor at the secondary side. Additionally, it guarantees Zero Volt Switching (ZVS) for MOSFETs regardless of the coupling coefficient and load circumstances [76]. Due to its high misalignment tolerance, load independence, lower inverter current stress, and increased efficiency, double-sided LCC is often preferred by researchers [73]. In EV WPT, a comparison of S-S and LCC-LCC topologies reveals that LCCLCC performs better than S-S topology in terms of efficiency stability with regard to fluctuations in self-inductance caused by lateral displacement of receiving and transmitting coils [76]. However, LCCL has a bigger coupling coefficient, a higher power transfer level, and a higher efficiency than the LCCL compensation topology. The efficiency of LC-S is 2.5% higher than that of LC-S [76].



Components:

V_{DC}	:	DC Input Voltage
$S_1 - S_4$	:	Inverter Switches
L_f	:	Primary Series Inductor
C_f	:	Primary Series Capacitor
C_p	:	Primary Shunt Capacitor
L_1	:	Primary (Transmitter) Coil
L_f'	:	Secondary Series Inductor
C_f'	:	Secondary Series Capacitor
C_p'	:	Secondary Shunt Capacitor
L_2	:	Secondary (Receiver) Coil
M	:	Mutual Inductance
k	:	Coupling Coefficient
R_L	:	Load Resistance

Key Features of LCC Compensation:

- LCC network consists of series inductor (L_f), series capacitor (C_f) and shunt capacitor (C_p) on each side.
- Provides excellent harmonic filtering and high-frequency attenuation.
- Achieves constant output current (COC) characteristic.
- Offers good load adaptability with low voltage stress on components.
- Improves efficiency and system stability over wide coupling range.
- Suitable for high-power WPT applications.

Notation:

$\rightarrow I_1, I_2$: Current Direction
● : Dot Convention (Same Polarity End)

All inductors are ideal.
All capacitors are ideal.

Figure 20: *LCC Compensation*

Optimization and Control for Wireless EV Charging Using AI:

Due to its ability to transfer energy safely, conveniently, and without the need for cables, Wireless Power Transfer (WPT) systems are emerging as a key technology for EV charging. A significant issue in EV charging applications is maintaining high power transfer efficiency across a variety of operating situations, including air-gap changes, load changes, and coil alignment. The implementation of artificial intelligence (AI)-based optimization and intelligent control strategies for WPT systems that are is the main emphasis of our study in order to overcome these problems. To increase charging efficiency, power control, and system stability, the suggested system combines AI methods such Artificial Neural Networks (ANN), Fuzzy Logic Controllers (FLC), and Reinforcement Learning (RL) with power electronic converters and compensation networks. The AI regulator dynamically modifies the operating settings for best results by continually monitoring variables such as coupling coefficient, output voltage, current, switching frequency, and battery charging conditions. To improve resonance and lower power losses, advanced compensation topologies including Series-Series (SS), Series-Parallel (SP), and LCC compensation are taken into consideration. The suggested system is assessed under various alignment and loading scenarios using MATLAB/Simulink modelling and analysis. The findings show that AI-based control greatly increases efficiency, lowers transmission and switching losses, improves misalignment tolerance, and offers dependable real-time wireless charging performance. The construction of effective, intelligent, and autonomous EV charging infrastructure for next transportation systems may be greatly aided by the suggested intelligent WPT system.

Conclusion:

WPT is a technology that is evolving quickly and has a lot of potential. An overview of WPT developments was given in this article, with particular attention on magnetic resonance WPT and its system designs, including coil shape, outputs and inputs, and compensatory topologies. The advantages, disadvantages, and uses of basic compensations (SS, SP, PS, and PP) and hybrid compensations (LCC and LCL) are discussed. Primary parallel reimbursements work well at low mutual inductance, but because of their high impedance and load-dependent coefficients coupling, they are rarely used. Consequently, additional compensations are needed, leading to hybrid topologies like LCC and LCL, which are frequently employed for V2G or dynamic WPT applications. In the future, creative approaches to accomplishing the enhanced design goals will receive a lot of attention. and incorporating the AI optimization control

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