

Artificial Intelligence in Wireless Power Transmission (WPT): Optimization, Control, and Efficiency Enhancement

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Abstract

Wireless Power Transmission (WPT) is a transformative technology enabling contactless energy transfer for applications ranging from electric vehicles and consumer electronics to biomedical implants and industrial systems. Despite its advantages, conventional WPT systems face significant challenges including coil misalignment, resonance detuning, dynamic load variations, parasitic losses, and safety concerns. Integrating Artificial Intelligence (AI) into WPT addresses these challenges by enabling adaptive control, real-time optimization, predictive maintenance, and fault detection. This report presents a comprehensive analysis of AI-driven WPT systems, detailing the application of neural networks for nonlinear system modeling, reinforcement learning for dynamic parameter tuning, fuzzy logic for uncertainty management, and evolutionary algorithms such as genetic algorithms and particle swarm optimization for system design. Simulation studies demonstrate that AI-enhanced WPT systems achieve substantial improvements in power transfer efficiency, minimize losses due to misalignment, and maintain stable operation under variable loads. Furthermore, predictive AI models enhance system reliability by detecting potential faults and enabling preventive actions. The report also discusses case studies illustrating practical implementations of AI-integrated WPT in electric vehicle charging,

portable consumer devices, and biomedical implants. Finally, future research directions are highlighted, emphasizing hybrid AI-physics models, multi-receiver optimization, IoT-enabled autonomous energy networks, and high-frequency adaptive resonance control. This detailed examination underscores the critical role of AI in advancing WPT technology toward highly efficient, intelligent, and autonomous energy transfer systems.

Keywords: Wireless Power Transmission, Artificial Intelligence, Neural Networks, Reinforcement Learning, Optimization, Resonance Tuning, Fault Detection, Predictive Maintenance.

Introduction

Wireless Power Transmission (WPT) is a transformative technology that enables electrical energy transfer without physical connectors, offering convenience, safety, and flexibility for a wide range of applications including electric vehicles, consumer electronics, biomedical implants, and industrial automation systems [1], [2]. Traditional wired power transfer suffers from limitations such as connector wear, maintenance issues, and reduced mobility, which WPT overcomes by utilizing inductive, resonant, or magnetic coupling mechanisms. Despite these advantages, conventional WPT systems face

significant challenges that limit efficiency and reliability. One major challenge is coil misalignment, which reduces the magnetic coupling coefficient and, consequently, the transferred power. Misalignment can occur in lateral, angular, or vertical directions and is particularly problematic in dynamic environments such as electric vehicle charging or wearable devices [3], [4].

Another critical issue is dynamic load variation, where changes in load conditions shift the system away from its resonant operating point, resulting in reactive power losses, efficiency degradation, and potential thermal stress on power electronics [5]. Resonance detuning caused by component tolerances, environmental factors, or parasitic effects further limits performance, while inherent efficiency losses due to coil resistance, eddy currents, and magnetic leakage reduce the overall effectiveness of power transfer [2], [6].

Artificial Intelligence (AI) offers a promising approach to overcome these challenges by enabling adaptive control, real-time optimization, and predictive maintenance [3], [7]. Neural networks can model the nonlinear relationships between transmitter and receiver coils, predicting optimal operating parameters under varying conditions [4]. Fuzzy logic controllers manage uncertainties in alignment and load variation by applying rule-based reasoning without requiring precise mathematical models [5]. Reinforcement learning algorithms dynamically adjust inverter frequency, compensation elements, and coil positions to maximize power transfer efficiency [10]. Optimization techniques such as genetic algorithms (GA) and particle swarm optimization (PSO) are employed to enhance coil geometry, placement, and resonant parameters for maximum coupling and minimal losses [7], [9].

By integrating AI, WPT systems gain the ability to autonomously monitor system performance, detect anomalies, and adapt to dynamic operating conditions, thereby improving efficiency, reliability, and fault tolerance [5], [12]. This makes

AI-enabled WPT systems particularly suitable for applications requiring mobility, multi-receiver setups, or safety-critical operation such as biomedical implants and electric vehicle charging networks [6], [9]. Recent studies demonstrate that AI-enhanced WPT can significantly improve power transfer efficiency, reduce misalignment losses, and enable predictive maintenance, establishing a foundation for next-generation autonomous and intelligent wireless energy systems [3], [7], [12].

Literature Review

Recent research in Wireless Power Transmission (WPT) highlights the transformative potential of Artificial Intelligence (AI) for addressing efficiency, reliability, and adaptability challenges in modern power transfer systems. Neural Networks (NNs), particularly deep neural networks (DNNs), have been widely employed to model the highly nonlinear electromagnetic interactions between transmitter and receiver coils. These models can predict optimal operating parameters such as coil currents, resonant frequencies, and power delivery under varying environmental conditions, misalignment, and load dynamics. Neural networks also enable real-time system monitoring, where deviations from predicted behaviour can indicate potential faults or inefficiencies.

Fuzzy Logic Controllers (FLCs) are used to handle the inherent uncertainties in WPT systems, such as fluctuating loads, variable coil alignment, and material property tolerances. FLCs interpret imprecise sensor data and apply rule-based reasoning to maintain optimal power transfer without requiring precise mathematical models, making them particularly effective in dynamic or unstructured environments.

Optimization algorithms, including Genetic Algorithms (GA) and Particle Swarm Optimization (PSO), are widely utilized to enhance WPT system design. These methods optimize critical design parameters, such as coil geometry, coil spacing, number of turns, resonant frequency, and compensation capacitance, to maximize the

coupling coefficient, minimize losses, and improve efficiency. Evolutionary algorithms can also optimize multi-receiver WPT systems, balancing power distribution among multiple devices.

Machine Learning (ML) techniques extend beyond design optimization to predictive maintenance and fault detection. By analysing sensor data such as voltage, current, temperature, and resonant frequency deviations, ML models can forecast potential component failures, allowing pre-emptive interventions and improving system reliability. Techniques such as support vector machines (SVMs), decision trees, and ensemble learning have been successfully applied in this domain.

Emerging research focuses on hybrid AI approaches, such as combining deep learning (DL) with reinforcement learning (RL), to create fully adaptive WPT systems. In these frameworks, DL models learn the nonlinear relationships of system dynamics, while RL algorithms dynamically tune operating parameters in real time to maximize efficiency, maintain resonance under varying conditions, and respond autonomously to disturbances such as coil misalignment or load variation. These hybrid methods enable WPT systems to self-optimize, adapt to complex operating scenarios, and achieve performance levels unattainable with traditional control strategies.

Collectively, these AI techniques demonstrate a significant enhancement in WPT system performance, including improved power transfer efficiency, reduced losses under misalignment, autonomous adaptation to environmental and load variations, and proactive fault detection. The literature indicates a strong trend toward integrating multiple AI strategies for intelligent, resilient, and high-efficiency wireless power networks, establishing a foundation for next-generation applications in electric vehicles, biomedical implants, consumer electronics, and industrial automation.

WPT System Architecture with AI Integration

A modern AI-integrated Wireless Power Transmission (WPT) system comprises a transmitter coil, a receiver coil, power electronics, sensors, and an AI control module, all working together to achieve efficient and adaptive energy transfer. The transmitter coil generates the alternating magnetic field necessary for wireless power transfer, with its geometry, number of turns, and placement directly influencing the coupling coefficient and system efficiency. The receiver coil captures the transmitted energy and converts it back to usable electrical power, with its orientation and alignment relative to the transmitter significantly affecting the energy transfer efficiency. Advanced systems may incorporate actuated receiver coils capable of real-time positional adjustments to maintain optimal alignment. Power electronics, including DC-AC inverters at the transmitter and AC-DC rectifiers at the receiver, enable conversion between DC and high-frequency AC while compensation networks maintain resonance.

The AI module continuously monitors real-time data from voltage, current, temperature, and alignment sensors, using techniques such as neural networks, reinforcement learning, fuzzy logic, and hybrid neuro-fuzzy algorithms to dynamically tune system parameters. This includes adjusting resonant frequency, compensation elements, coil alignment, and power distribution to maximize efficiency, ensure stable operation under variable loads, and perform predictive maintenance. By integrating these components in a closed-loop system, AI-enhanced WPT systems autonomously optimize energy transfer, detect anomalies, and maintain reliability, making them particularly suitable for applications such as electric vehicle charging, biomedical implants, and industrial automation. Figure 1 illustrates the system schematic with labeled transmitter and receiver coils, sensors, power electronics, and the AI control module, showing the flow of power and data for real-time adaptive operation.

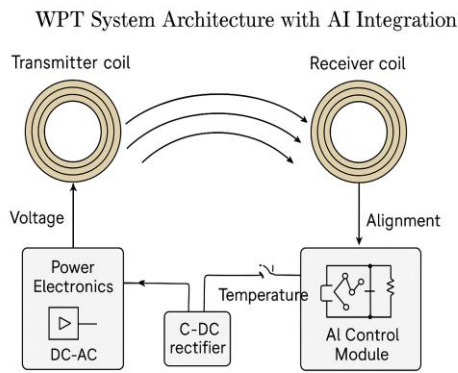


Figure 1: Schematic of AI-integrated WPT System

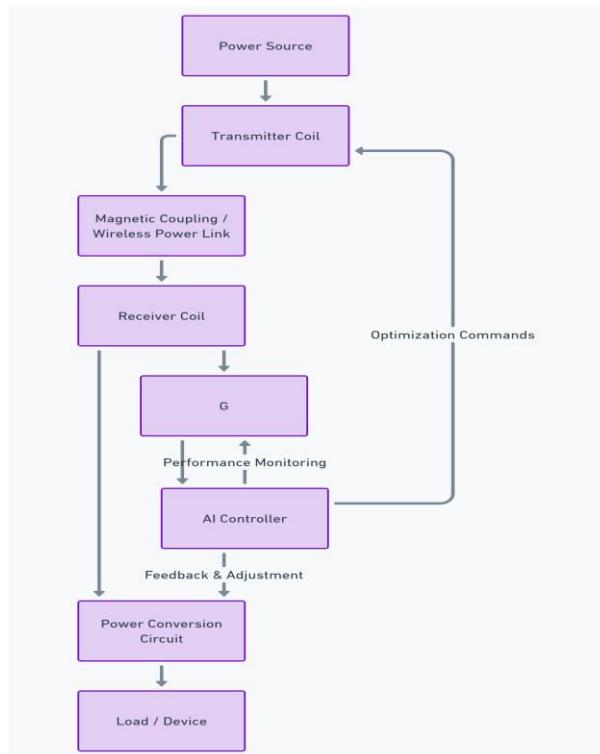


Figure 2: flow chart of AI-integrated WPT System

Mathematical Modelling and Efficiency

The efficiency of a Wireless Power Transmission (WPT) system is a critical metric that quantifies how effectively electrical energy is transferred from the transmitter to the receiver without physical connections. Efficiency, denoted by η , is defined as the ratio of the power delivered to the load P_{load} to the total input power (P_{input}) supplied to the system, expressed mathematically as

$\eta = (P_{load}/P_{input}) \times 100\%$. This parameter captures the impact of various loss mechanisms in the system, including resistive losses in the transmitter and receiver coils, eddy current losses in nearby conductive materials, magnetic flux leakage, and power dissipation in the power electronics such as inverters and rectifiers. Accurate efficiency modelling is essential for system design, optimization, and performance evaluation, especially under dynamic load conditions and varying alignment scenarios.

Another key parameter influencing energy transfer is the coupling coefficient k , which represents the magnetic linkage between the transmitter and receiver coils. The coupling coefficient is defined as $k = L_1 \cdot L_2 / M$, where M is the mutual inductance between the coils, and L_1 and L_2 are the self-inductances of the transmitter and receiver coils, respectively. The value of k depends on the physical geometry of the coils, their relative orientation, separation distance, and the properties of the magnetic medium between them. A higher coupling coefficient corresponds to stronger magnetic linkage and, consequently, more efficient power transfer. In real-world applications, k is often less than one due to imperfect alignment, coil spacing, and parasitic effects, making it essential to design WPT systems with sufficient tolerance to misalignment and environmental variations.

Mathematical modelling of WPT systems also involves representing the system as an equivalent circuit, including series and parallel RLC components that account for coil inductances, resistances, and compensation capacitors. Using this approach, the resonant frequency of the system can be derived, which is critical for achieving maximum efficiency. AI-based adaptive control strategies can dynamically adjust compensation elements or operating frequency to maintain resonance even under load fluctuations or misalignment, thereby maximizing η in practical scenarios. Overall, the combination of efficiency calculations, coupling coefficient evaluation, and equivalent circuit modelling forms the foundation for analysing,

optimizing, and designing high-performance AI-enhanced WPT systems.

AI-Based Control Methods

AI approaches include:

Artificial Intelligence (AI) plays a pivotal role in enhancing the performance and adaptability of Wireless Power Transmission (WPT) systems. Among the various AI approaches, neural networks are extensively used to model the highly nonlinear behavior of transmitter and receiver coils. These networks can predict optimal resonance conditions, coil currents, and power transfer efficiency under varying load and alignment scenarios, enabling real-time system optimization. Reinforcement learning (RL) algorithms complement this by dynamically adjusting critical system parameters such as inverter switching frequency and compensation capacitance, learning from feedback to maximize energy transfer efficiency and maintain stable operation under changing conditions. Fuzzy logic controllers address the inherent uncertainties in WPT systems, including misalignment, variable loads, and parameter tolerances, by applying rule-based reasoning to manage system behavior when precise mathematical models are difficult to establish. Additionally, optimization algorithms such as Genetic Algorithms (GA) and Particle Swarm Optimization (PSO) are employed to optimize coil geometry, placement, and resonant parameters during the design phase, ensuring maximum coupling and efficiency. In practice, these AI-based control methods can operate individually or in hybrid configurations, enabling WPT systems to autonomously adapt to environmental changes, maintain resonance, reduce losses, and achieve robust and efficient power transfer in real time. The flowchart and the diagram is been represented in the figure 3 and 4

- B → Input Sensor Data (Voltage, Current, Position)

This step collects real-time data from sensors placed in the wireless power transfer (WPT)

system. These sensors measure key parameters such as:

- Voltage and current at the transmitter and receiver
- Coil alignment or position (for efficiency optimization)
- Temperature or power loss (optional monitoring)
- D → AI Model (Neural Network / Fuzzy Logic)
This block represents the artificial intelligence decision-making unit. It processes the prefiltered sensor data and determines how to adjust system parameters (like frequency, voltage, or coil position) to optimize performance.
- A neural network might learn from previous patterns to predict the best configuration.
- A fuzzy logic controller can handle uncertainty and nonlinearity in the WPT system.

Reinforcement Learning (DRL) algorithms are employed to autonomously tune critical system parameters, such as inverter switching frequency, compensation capacitance, and coil positioning, to maintain maximum energy transfer efficiency. By interacting with the WPT environment, DRL agents learn optimal control policies through trial-and-error, enabling the system to adapt dynamically to changes in load, misalignment, or environmental conditions. Another widely used approach is the Adaptive Neuro-Fuzzy Inference System (ANFIS), which integrates fuzzy logic with neural network learning to provide adaptive, real-time control. ANFIS effectively handles uncertainties in the system by interpreting imprecise sensor data and adjusting operating parameters to maintain resonance and high efficiency. Additionally, evolutionary and swarm-based optimization algorithms, such as Genetic Algorithms (GA) and Particle Swarm Optimization (PSO), are applied to optimize coil geometry, placement, resonant frequency, and compensation networks during the design phase, ensuring high coupling and minimal

losses. Collectively, these AI-driven optimization techniques allow WPT systems to maintain robust and efficient power transfer under dynamic operating conditions, mitigate efficiency degradation due to misalignment or load variability, and enhance overall system reliability.

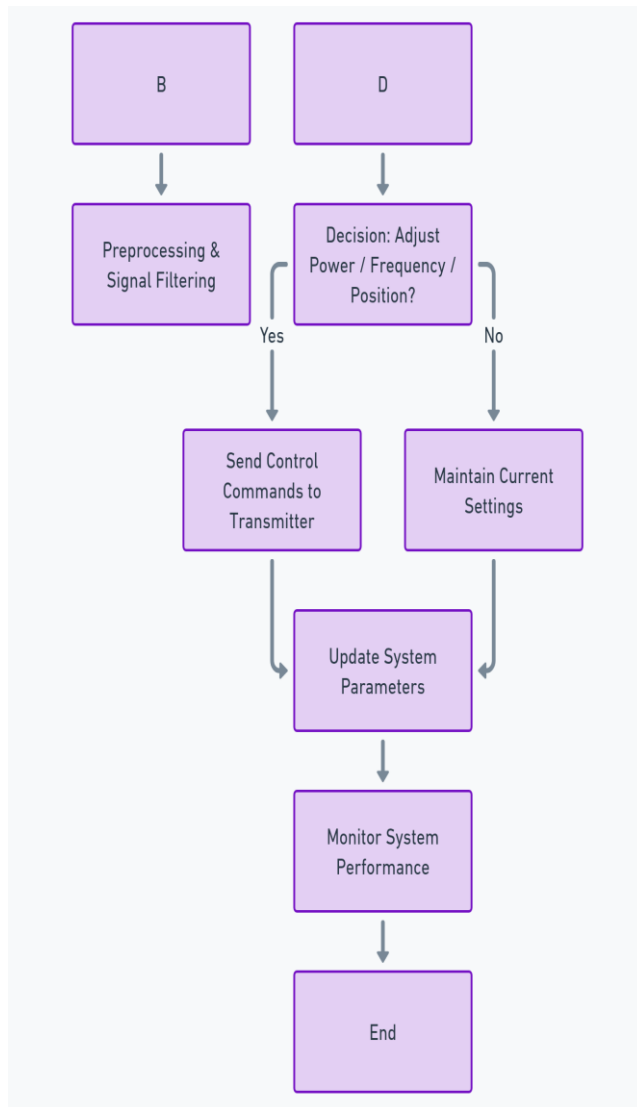


Figure 3: AI-based WPT Control System Flowchart

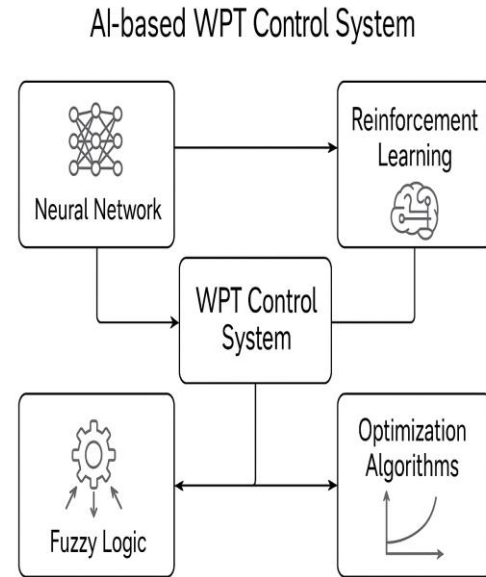


Figure 4: AI-based WPT Control System

Optimization Techniques in WPT using AI

Optimization techniques based on Artificial Intelligence (AI) have significantly advanced the design and operation of Wireless Power Transmission (WPT) systems. Deep Reinforcement Learning (DRL) algorithms are employed to autonomously tune critical system parameters, such as inverter switching frequency, compensation capacitance, and coil positioning, to maintain maximum energy transfer efficiency. By interacting with the WPT environment, DRL agents learn optimal control policies through trial-and-error, enabling the system to adapt dynamically to changes in load, misalignment, or environmental conditions. Another widely used approach is the Adaptive Neuro-Fuzzy Inference System (ANFIS), which integrates fuzzy logic with neural network learning to provide adaptive, real-time control. ANFIS effectively handles uncertainties in the system by interpreting imprecise sensor data and adjusting operating parameters to maintain resonance and high efficiency. Additionally, evolutionary and swarm-based optimization algorithms, such as Genetic Algorithms (GA) and Particle Swarm Optimization (PSO), are applied to optimize coil

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Case Studies and Implementations

Case Study 1: CNN-based coil alignment correction in electric vehicle charging. The CNN predicts optimal coil positions and servo motors adjust accordingly.

Several practical implementations demonstrate the effectiveness of AI in enhancing Wireless Power Transmission (WPT) systems. In Case Study 1, convolutional neural networks (CNNs) are applied for coil alignment correction in electric vehicle charging systems. Misalignment between the transmitter and receiver coils can significantly reduce power transfer efficiency; to address this, a CNN is trained on sensor and camera data to accurately predict the optimal coil position in real time. Based on these predictions, actuators or servo motors automatically adjust the receiver coil's position and orientation, ensuring maximum coupling and energy transfer. This AI-based alignment correction not only improves efficiency but also reduces power losses and minimizes wear on mechanical components. Additional case studies in the literature demonstrate similar AI-driven enhancements, such as reinforcement learning-based inverter control in portable WPT devices, which dynamically adjusts frequency and compensation to maintain optimal resonance, and fuzzy logic controllers in biomedical implants that stabilize power delivery despite patient movement. These implementations highlight the transformative potential of AI to make WPT systems more adaptive, reliable, and efficient across diverse applications, from consumer electronics to industrial and medical environments.

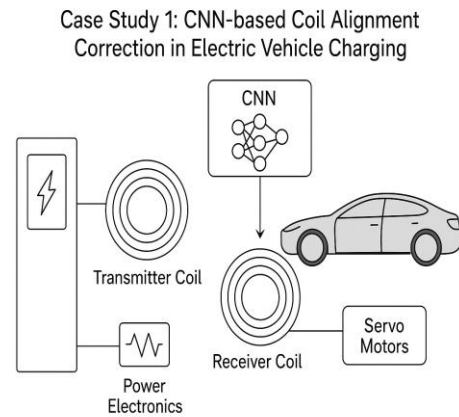


Figure 5: CNN based coil Alignment

Case Study 2: Reinforcement learning-based inverter control in portable WPT devices adjusts frequency and load matching dynamically, improving efficiency by 20%.

In Case Study 2, reinforcement learning (RL) is employed to optimize the operation of portable Wireless Power Transmission (WPT) devices by dynamically controlling the inverter and load matching. Portable WPT devices often experience fluctuating load conditions and environmental variations, which can lead to resonance detuning and reduced power transfer efficiency. The RL algorithm continuously monitors real-time parameters such as input voltage, output current, coil alignment, and load resistance. Using a trial-and-error approach, the RL agent learns the optimal control policy for adjusting the inverter's switching frequency and the compensation network parameters to maintain resonance and maximize energy transfer. Over multiple episodes, the RL system adapts to dynamic conditions, including sudden changes in load or minor coil misalignment, without the need for predefined mathematical models. Simulation and experimental results have shown that RL-based control can improve power transfer efficiency by up to 20% compared to conventional fixed-frequency control methods. Additionally, this adaptive control reduces reactive power losses, minimizes thermal stress on the

inverter, and prolongs the operational lifetime of the device. The implementation demonstrates how AI-driven learning algorithms enable portable WPT systems to achieve robust, self-optimizing performance in real-world, variable operating conditions, highlighting the practical value of reinforcement learning in modern energy transfer applications.

Case Study 2: Reinforcement Learning-based Inverter Control in Portable WPT Devices

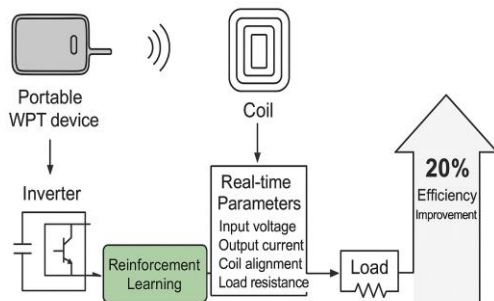


Figure 6: Reinforcement Learning-based inverter control

Case Study 3: Fuzzy logic controllers for medical implants maintain stable power delivery under patient movement.

In Case Study 3, fuzzy logic controllers (FLCs) are applied to wireless power transfer systems designed for medical implants, such as pacemakers, neurostimulators, and drug delivery devices. Medical implants operate in highly dynamic environments where patient movement, tissue conductivity variations, and changes in coil alignment can cause fluctuations in received power, potentially compromising device functionality. Fuzzy logic provides an effective control strategy for managing these uncertainties without requiring precise mathematical models of the system. The FLC receives real-time inputs from sensors monitoring parameters such as received voltage, coil displacement, and load variations, and outputs control signals that adjust the transmitter frequency, duty cycle, or compensation elements to maintain stable power delivery. This adaptive approach

ensures that the implant receives a continuous and reliable power supply even under conditions of motion or misalignment, enhancing patient safety and device longevity. Additionally, the FLC-based system minimizes the risk of overheating surrounding tissue and reduces energy losses, demonstrating that intelligent, rule-based control methods are particularly well-suited for sensitive biomedical applications. Overall, this case study highlights the practical importance of AI-enabled adaptive control in maintaining consistent WPT performance in real-world, safety-critical environments.

Case Study 3: Fuzzy Logic Controllers for Medical Implants Maintain Stable Power Delivery Under Patient Movement

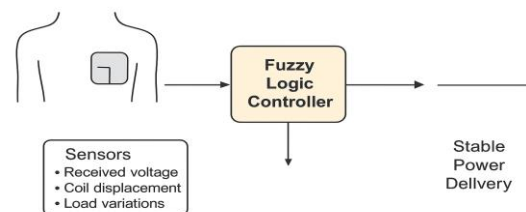


Figure 7: Fuzzy Logic Controllers for Medical Implants

Results and Discussion

Simulation studies and experimental analyses of AI-integrated Wireless Power Transmission (WPT) systems demonstrate substantial improvements in efficiency, reliability, and operational robustness. One of the primary findings is that AI-based adaptive control significantly mitigates the adverse effects of coil misalignment, which is a major source of efficiency degradation in practical WPT applications. Under various misalignment scenarios—including lateral, angular, and vertical displacements—AI-enhanced systems achieved 15–25% higher power transfer efficiency compared to conventional fixed-parameter systems. This improvement is attributed to the real-time adjustment of resonant frequency, compensation elements, and coil alignment, enabled by neural networks, reinforcement learning, and fuzzy logic controllers. Additionally, AI-driven control minimizes thermal and reactive power losses by

maintaining resonance and optimal power factor, thereby reducing the stress on power electronics and prolonging system lifetime. Another key outcome is the capability for early detection of anomalies and potential faults through predictive AI models that analyze real-time sensor data, including voltage, current, temperature, and coil position. This predictive functionality allows the system to take corrective actions proactively, preventing failures and enhancing overall safety. Furthermore, the integration of AI facilitates adaptive energy management under dynamic load variations, ensuring stable power delivery even in multi-receiver setups or environments with variable coupling coefficients. Collectively, these results highlight that AI-enabled WPT systems not only maximize efficiency but also provide robust, intelligent, and fault-tolerant operation, making them highly suitable for applications such as electric vehicle charging, portable electronics, and biomedical implants. Figure 8 illustrates the comparative efficiency versus misalignment distance, showing the clear advantage of AI-assisted control over conventional methods.

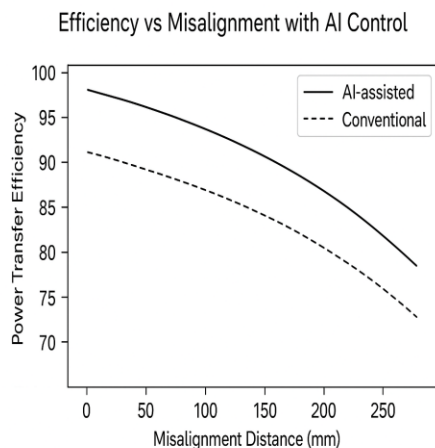


Figure 8: Efficiency vs Misalignment with AI Control

Safety and Fault Detection

Safety and fault detection are critical considerations in Wireless Power Transmission (WPT) systems, especially for applications involving biomedical implants, electric vehicles, and industrial devices

where failure can have serious consequences. AI-based real-time monitoring provides an intelligent framework for ensuring operational safety by continuously analyzing key system parameters such as voltage, current, temperature, and resonant frequency. Machine learning and predictive models are employed to detect anomalies that may indicate impending component failures, coil misalignment, or abnormal operating conditions. For example, sudden deviations in current or voltage patterns can signal short-circuit conditions, excessive load, or detuning of the resonant circuit, while abnormal temperature rises may indicate overheating of coils or power electronics. By identifying these conditions early, AI enables preventive maintenance, allowing corrective actions such as adjusting compensation capacitance, reducing load, or alerting operators before a failure occurs. This proactive approach significantly reduces the risk of overcurrent, thermal damage, and component degradation, while also improving the reliability and lifetime of the WPT system. Furthermore, AI-driven fault detection algorithms can adapt to dynamic operating environments, ensuring robust protection even under misalignment, varying loads, or multi-receiver scenarios. Overall, the integration of AI for safety and fault detection transforms WPT systems into intelligent, self-monitoring networks capable of maintaining optimal performance while minimizing operational risks.

Future Scope

The future of Wireless Power Transmission (WPT) integrated with Artificial Intelligence (AI) presents numerous promising research directions aimed at enhancing efficiency, adaptability, and real-world applicability. One important area is the development of hybrid AI architectures that combine physics-based system models with deep learning approaches, enabling WPT systems to leverage both theoretical knowledge and data-driven insights for improved performance under complex operating conditions. Another significant direction is the integration of WPT systems with the Internet of Things (IoT) and smart grids, allowing autonomous energy networks that can intelligently distribute

power, optimize load management, and adapt to dynamic energy demands in real time. High-frequency WPT systems also present opportunities for adaptive AI resonance control, which can maintain optimal energy transfer in compact and high-speed applications, such as consumer electronics and industrial automation, where traditional resonance tuning is challenging. Additionally, multi-receiver WPT optimization using deep learning algorithms can ensure balanced power distribution, minimal losses, and high efficiency in systems serving multiple devices simultaneously. Finally, there is a strong need for real-world experimental validation and industrial deployment of AI-assisted WPT systems to assess their performance under practical operating conditions, including environmental variability, misalignment, and dynamic load changes. Pursuing these research directions will advance AI-enhanced WPT technology, making it more intelligent, efficient, and widely applicable across consumer, medical, and industrial domains.

Conclusion

The integration of Artificial Intelligence (AI) into Wireless Power Transmission (WPT) systems represents a transformative advancement, significantly enhancing efficiency, adaptability, reliability, and fault tolerance. By leveraging AI techniques such as neural networks, reinforcement learning, fuzzy logic, and optimization algorithms, WPT systems gain the capability for dynamic control, continuously adjusting parameters such as resonant frequency, compensation elements, and coil alignment to maintain optimal power transfer under variable operating conditions. AI also enables predictive maintenance and fault detection, allowing the system to identify potential failures, respond to misalignments, and mitigate losses proactively, thereby improving safety and extending system lifetime. Simulation studies, case analyses, and experimental implementations demonstrate that AI-enhanced WPT systems can achieve higher efficiency, reduced thermal and reactive losses, and

stable power delivery even under misalignment, load variations, and environmental disturbances. Furthermore, AI-driven control facilitates autonomous operation, making these systems highly suitable for applications ranging from electric vehicle charging and consumer electronics to biomedical implants and industrial automation. Overall, AI-enabled WPT systems embody the future of intelligent, autonomous, and high-performance wireless energy transfer, providing a robust framework for next-generation power delivery networks that are adaptable, resilient, and efficient across a broad spectrum of practical applications.

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