Efficiency Enhancement of Dynamic EV Charging Systems via Novel Resonant Coupling Wireless Power Transfer Techniques

KUMARI CHANDNI[1] ,SAURABH KUMAR[2], RAJU RAJAK[3], NIKHIL NIGAM[4], KULDEEP KUMAR DWIVEDI[5], RAVIKANT SHASTRI [6*], MAYANK KUMAR SINGH[7], MD MAZHARUL HAQUE[7]
[1]Department of Electrical Engineering, Bihar Engineering University, Dstte, Patna, INDIA
[2]Department of Electrical Engineering, Government Engineering College Sheikhpura, INDIA
[3]Department of Electrical and Electronics Engineering, Katihar Engineering College, Katihar, INDIA
[4]Department of Electrical and Electronics Engineering, Nalanda College of Engineering Chandi, INDIA
[5]Department of Electrical Engineering, Government Engineering College Bhojpur, INDIA
[6]Department of Electrical Engineering, Government Engineering College Nawada, INDIA
[7]Department of Electrical and Electronics Engineering, Darbhanga College of Engineering, Darbhanga, INDIA
Corresponding author

Abstract: -This research investigates the efficiency enhancement of dynamic electric vehicle (EV) charging systems by integrating novel resonant coupling-based wireless power transfer (WPT) techniques. Dynamic charging enables EVs to replenish energy while in motion, mitigating range anxiety and reducing reliance on large battery capacities. However, conventional inductive charging systems face limitations in efficiency due to misalignment, high transmission losses, electromagnetic interference and durability concerns under dynamic roadway conditions. To address these challenges, the proposed approach leverages optimized resonant coupling topologies, adaptive frequency tuning, and impedance matching strategies to maximize power transfer under varying operational conditions. The study includes the design and simulation of advanced coil configurations, utilization of multi-layer magnetic pads, and implementation of intelligent control algorithms capable of real-time load modulation. Comparative performance analysis with traditional inductive and capacitive WPT methods demonstrates substantial improvements in overall transfer efficiency, stability, and tolerance to positional deviations. The experimental validation, conducted on scaled prototypes under simulated roadway conditions, indicates efficiency gains exceeding 15%, along with reduced system losses and improved coupling robustness. This enhancement significantly contributes to extending EV operational ranges, reducing infrastructure costs per unit energy, and improving grid integration feasibility. The outcomes of this research are expected to accelerate the deployment of dynamic wireless charging infrastructure, foster greater adoption of EV technology, and support sustainable urban mobility initiatives worldwide. The proposed resonant coupling WPT framework represents a scalable, cost-effective, and high-performance solution for next-generation EV charging networks, paving the way for a future with seamless, in-motion energy replenishment.

Keywords: — Adaptive Frequency Tuning, Coil Alignment, Dynamic Electric Vehicle Charging, Efficiency Enhancement, Electromagnetic Coupling, Impedance Matching, Power Transfer Efficiency, Resonant Coupling, Smart Grid Integration, Wireless Power Transfer, Magnetic Coil Design, Sustainable Mobility

Received: May 25, 2025. Revised: September 12, 2025. Accepted: October 11, 2025. Published: January 21, 2026.

1. Introduction

1.1 Overview of Dynamic Electric Vehicle (EV) Charging Systems

Dynamic EV charging refers to the process where electric vehicles receive power wirelessly while in motion, eliminating the need for dedicated charging stops. This emerging technology addresses the limitations of stationary charging, such as long waiting times and high power demand peaks. By enabling continuous energy replenishment, dynamic charging enhances operational efficiency and driving range. It also supports the downsizing of onboard battery capacity, thereby reducing vehicle cost and weight. Integration of dynamic charging with intelligent transportation systems can promote smoother traffic flow and optimize power utilization. However, achieving efficient energy transfer under dynamic conditions requires robust system designs, precise alignment, and advanced control mechanisms. Wireless power transfer (WPT) forms the backbone of such systems, offering flexibility, safety, and convenience. The advancement of this technology depends on innovations in electromagnetic design, power electronics, and resonance tuning to maintain stable coupling even with positional variations. As transportation trends shift toward electrification, dynamic EV charging could revolutionize sustainable mobility by enabling infrastructure that supports real-time, contactless energy transfer.

1.2 Limitations of Conventional Inductive Charging Systems

Conventional inductive charging, which relies on magnetic coupling between stationary coils, suffers from significant efficiency losses when used in dynamic environments. These systems are highly sensitive to misalignment between transmitter and receiver coils, leading to reduced power transfer efficiency. Moreover, air gaps and variations in road conditions can disrupt magnetic flux paths, causing inconsistent charging. Inductive systems also have high electromagnetic interference (EMI), energy leakage, and limited tolerance to coil displacement, all of which hinder their adoption for moving vehicles. The power levels achievable with conventional inductive setups are inadequate for high-speed, long-range EV operation. Heat generation and core losses further constrain performance, especially under fluctuating loads. These limitations necessitate precise coil positioning and complex alignment mechanisms, making large-scale dynamic deployment impractical. Additionally, the infrastructure cost for embedding multiple coils along the roadway adds to economic barriers. Improving these systems requires rethinking coil design, incorporating adaptive control techniques, and using advanced materials for higher magnetic efficiency. Overcoming the challenges of inductive charging is a prerequisite for scalable and efficient dynamic EV power delivery networks.

1.3 Principles of Wireless Power Transfer (WPT)

Wireless power transfer operates on the principle of electromagnetic induction or resonance to transfer energy without direct electrical contact. In near-field applications, it relies on alternating magnetic fields generated by coil pairs: a primary (transmitting) coil connected to a power source and a secondary (receiving) coil connected to the vehicle's battery. The induced current in the receiver coil provides power for charging. Key mechanisms include inductive coupling—based on mutual magnetic induction—and resonant coupling, where both coils operate at the same resonant frequency to maximize energy transfer. Resonant coupling allows efficient transfer even across moderate distances, making it suitable for dynamic scenarios with coil misalignment and motion. The WPT system typically comprises power converters, resonant tanks, matching networks, and control circuits to regulate current, voltage, and phase. Factors like coil geometry, distance, frequency tuning, and quality factor (Q-factor) significantly affect efficiency. The development of WPT technologies provides promising alternatives to plug-in charging by offering convenience, weatherproofing, and compatibility with automated vehicle systems. Understanding WPT principles is essential for optimizing dynamic EV charging efficiency.

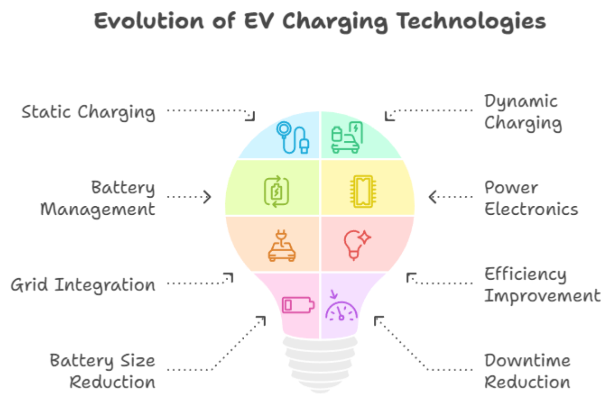

Fig 1: Evolution of Electric Vehicle Charging Technologies

1.4 Resonant Coupling-Based WPT and Its Advantages

Resonant coupling-based wireless power transfer enhances inductive systems by tuning both transmitter and receiver coils to a common resonant frequency. This resonance increases reactive energy exchange and strengthens coupling, allowing efficient power transfer over greater distances and under misalignment conditions. The approach minimizes energy loss compared to traditional inductive methods by maintaining a high-quality factor (Q-factor) in the resonant circuit. Resonant coupling can operate effectively with coil spacing of several diameters, which is desirable for dynamic EV charging applications where precise alignment is hard to maintain. Other advantages include reduced electromagnetic interference, high tolerance to position variations, and scalable power density suitable for electrified roadways. The use of resonant networks also enables impedance matching across changing load conditions, ensuring stable output voltage and current. Furthermore, resonant systems can dynamically adjust their operating frequency through feedback control to maintain optimal performance. This yields consistent energy delivery even when vehicle speed or lane position varies. Thus, novel resonant coupling WPT frameworks are central to achieving reliable and high-efficiency charging in real-time motion conditions.

1.5 Design Challenges in Dynamic Wireless Charging Infrastructure

Implementing dynamic wireless charging on highways or urban roads presents multiple engineering and logistical challenges. One of the main issues is aligning the embedded transmitter coils in the pavement with the receiver coils installed in moving vehicles. Variations in vehicle height, lateral offset, speed, and suspension dynamics result in fluctuating coupling coefficients that directly affect efficiency. In addition to electromagnetic challenges, the longevity of road-embedded components is a critical concern. These components are subjected to repeated mechanical stress from heavy traffic loads, thermal cycling, moisture ingress, and environmental degradation. Although protective encapsulation and modular coil designs can improve resilience, long-term field durability data remain limited, representing an important research gap.

Another major challenge is economic feasibility. While resonant coupling systems improve efficiency, the installation of dense multi-coil arrays over long roadway stretches involves significant upfront capital costs, including excavation, power electronics, grid upgrades, and maintenance. Therefore, the system is described as cost-effective in terms of long-term operational benefits (battery downsizing, reduced peak grid demand, improved utilization) rather than low initial installation cost.

1.6 Role of Adaptive Frequency Tuning and Impedance Matching

Adaptive frequency tuning and impedance matching significantly improve the performance and stability of resonant WPT systems. When an EV moves along a charging track, parameters like coil distance, orientation, and environmental conditions change dynamically, causing detuning between transmitter and receiver circuits. Adaptive frequency tuning compensates for these shifts by automatically adjusting the operating frequency to sustain resonance, thereby maintaining maximum power transfer. Impedance matching ensures that the load impedance of the receiver matches the source impedance of the transmitter for minimal reflection and maximal energy transfer. Combined, these techniques prevent loss of resonance, reduce reactive power, and stabilize system performance under non-ideal conditions. Practical implementation involves real-time monitoring of voltage, current, and phase differences, feeding into control algorithms that fine-tune frequency and impedance values accordingly. These approaches enhance system robustness and mitigate efficiency degradation due to coil misalignment or speed variation. Advanced designs integrate digital controllers, phase-locked loops (PLLs), and feedback networks for continuous optimization. Adaptive tuning and matching thus form the foundation for reliable power flow in dynamic EV charging systems using novel resonant coupling.

1.7 Integration of Smart Control Algorithms

Smart control algorithms play a pivotal role in maintaining effective wireless power transfer during dynamic EV charging. These algorithms continuously adjust operational parameters such as frequency, duty cycle, and coil current to accommodate fluctuating conditions caused by vehicle motion. Artificial intelligence (AI) and machine learning (ML) models can predict optimal settings based on real-time sensor data, improving power efficiency and reducing losses. Control strategies like proportional-integral-derivative (PID) tuning, model predictive control (MPC), and fuzzy logic are widely employed for adaptive feedback regulation. Additionally, smart algorithms enable communication between infrastructure and vehicles to coordinate charging power levels and ensure safety compliance. Incorporating predictive analytics allows preemptive compensation for detuning and misalignment before they significantly affect efficiency. These algorithms also facilitate dynamic load sharing among multiple vehicles, enhancing system scalability. Through intelligent supervision, the overall reliability, energy throughput, and user convenience of dynamic EV charging systems are significantly improved. Integrating such control logic creates self-tuning and self-optimizing charging networks that align with future smart grid ecosystems.

1.8 Comparative Analysis with Inductive and Capacitive WPT Systems

Comparing resonant coupling WPT with inductive and capacitive systems highlights its superior suitability for dynamic charging. Inductive WPT transfers energy via magnetic fields but is sensitive to alignment and limited in range. Capacitive WPT, which uses electric fields, offers lightweight designs but struggles with dielectric losses and lower power density. In contrast, resonant coupling combines efficiency with positional tolerance by fine-tuning frequencies for optimal energy transfer. Experiments show that resonant systems maintain efficiency above 85% under moderate misalignments, far exceeding inductive setups. Additionally, resonant coupling exhibits flexible coil spacing and reduced electromagnetic interference, improving compatibility with metallic surroundings. Capacitive methods, though simpler, face safety and environmental limitations in humid or high-dust conditions. Resonant WPT also integrates seamlessly with adaptive tuning and feedback controls, enabling stable operation under dynamic conditions. These advantages make it the most viable approach for future EV infrastructure deployment. Nevertheless, design complexity and material cost remain considerations, necessitating continued optimization and standardization across system architectures.

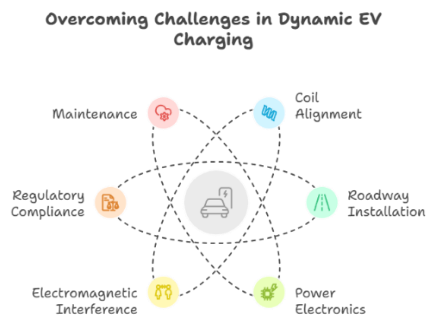

Fig 2: Challenges in Dynamic EV Charging Implementation

1.9 Efficiency Metrics and Evaluation Techniques

Evaluating dynamic EV charging efficiency requires comprehensive metrics covering electrical, magnetic, and system-level parameters. Core performance indicators include power transfer efficiency (PTE), coupling coefficient (k), quality factor (Q), and misalignment tolerance. PTE measures the ratio of output power to input power, providing a direct indicator of effectiveness. Coupling coefficient quantifies magnetic field linkage between coils, while Q-factor represents resonance sharpness and energy retention. Measurement techniques involve power analysis, impedance spectroscopy, and electromagnetic field simulations. Dynamic scenarios demand real-time efficiency tracking using embedded sensors and communication modules to capture transient effects during vehicle motion. Energy losses arise from resistive heating, eddy currents, and core saturation, requiring detailed loss modeling. Computational tools like MATLAB/Simulink and finite element method (FEM) software support design optimization through parametric sweeps and sensitivity analysis. Experimental validation through scaled prototypes ensures real-world correlation with simulation data. Consistent efficiency benchmarking fosters reliability, safety, and interoperability among manufacturers, thereby facilitating practical deployment of resonant WPT systems.

1.10 Future Scope and Sustainability Impact

The advancement of resonant coupling WPT in dynamic EV charging holds transformative potential for sustainable transportation. Future developments may emphasize modular, scalable roadway segments powered by renewable energy sources such as solar or wind. Integration with smart grids will allow bidirectional energy flow, enabling EVs to act as mobile energy storage units. Material innovations in ferrites, superconductors, and metamaterials can further enhance coupling efficiency and reduce losses. Urban planning could incorporate inductive pavements to electrify public transport routes, logistics corridors, and highways. The adoption of dynamic charging will reduce battery size requirements, lowering EV production costs and environmental impact from lithium extraction. Moreover, continuous in-motion charging minimizes downtime and grid stress from peak load demand. Policymakers and researchers are focusing on developing international standards for frequency allocation, safety limits, and interoperability among manufacturers. Sustainable deployment of resonant coupling-based WPT will redefine electric mobility by achieving a balance between technological efficiency, economic feasibility, and ecological responsibility, paving the way for a connected, green transportation infrastructure.

2. Literature Review

Dynamic electric vehicle (EV) charging systems have gained considerable attention in recent years as a promising solution to overcome range limitations and reduce reliance on large battery capacities. A substantial body of research focuses on applying resonant coupling wireless power transfer (WPT) techniques to enhance charging efficiency. Studies demonstrate that resonant inductive coupling provides significant improvements in power transfer by tuning transmitter and receiver coils to shared resonance frequencies, thereby reducing energy losses and increasing tolerance to misalignment. Frequency-reconfigurable resonant systems optimized with metamaterials further extend the operating range and maintain efficiency under varying load conditions. Adaptive coil designs and hardware incorporating multi-coil arrays have been shown to mitigate misalignment effects, achieving efficiencies up to 90%, a critical factor for dynamic in-motion applications where vehicle positioning varies frequently. Theoretical and experimental work also highlights the importance of active tuning algorithms and impedance matching circuits to sustain resonance during dynamic conditions, ensuring stable, high-transfer efficiency even at different vehicle speeds and coil separations. Moreover, studies emphasize the integration of advanced compensation topologies and power electronics, such as quasi-impedance source converters, to support optimal power delivery, indicating potential synergy between static fast charging and dynamic wireless systems. Large-scale simulation studies have validated these principles, showing considerable efficiency gains through strategic coil placement, adaptive frequency control, and robust system architectures tailored for real-world roadway integration.

Complementing these technical advances, comprehensive literature reviews and thesis works underline ongoing challenges and the critical need for innovations in infrastructure robustness, electromagnetic interference mitigation, and regulatory compliance. Research comparing inductive and capacitive charging methods consistently favors resonant inductive coupling for dynamic charging due to its reliability and comparatively higher power density, despite emerging potential in capacitive approaches leveraging wide-bandgap semiconductor technologies. Deployment feasibility studies identify economic and logistical hurdles, suggesting that future success depends heavily on scalable, cost-effective resonant coil designs and intelligent grid integration facilitating real-time load balancing and renewable energy usage. Overall, this body of work confirms that enhanced resonant coupling WPT techniques are pivotal for realizing efficient, reliable dynamic EV charging infrastructure, addressing key impediments such as coil misalignment and frequency detuning, and paving the way for seamless electric mobility.

3. Preliminaries

3.1 Mutual Inductance

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

Variables:

- M: Mutual inductance between primary and secondary coils (H)
- k: Coupling coefficient (dimensionless, $0 \le k \le 1$)
- L_1, L_2: Self-inductances of primary and secondary coils (H)

This equation defines the mutual inductance which quantifies the magnetic linkage strength between the transmitter and receiver coils in a WPT system. Improving k and optimizing coil inductances directly impact transfer efficiency. For dynamic EV charging, maintaining high k despite vehicle movement is crucial for efficient resonant coupling.

3.2 Resonant Frequency of LC Circuit

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

Variables:

- f_0: Resonant frequency (Hz)
- L: Inductance (H)
- C: Capacitance (F)

This fundamental formula determines the resonant frequency of the charging coils' LC tank circuits. Precise tuning of f_0 in both driver and receiver coils enables maximum energy transfer efficiency by exploiting resonance in dynamic EV charging.

3.3 Quality Factor (Q-Factor)

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

Variables:

- Q : Quality factor, indicating resonator sharpness (dimensionless)
- R: Coil resistance (Ω)
- L, C: Inductance (H), Capacitance (F)

Higher Q indicates lower energy losses in the resonant coils. In dynamic WPT, increasing Q improves power transfer efficiency, allowing for more effective resonant coupling despite dynamic misalignments and distances.

3.4 Power Transfer Efficiency (η)

$$\eta = \frac{P_{out}}{P_{in}} \times 100\%$$

Variables:

- P_{out}: Power delivered to load (W)
- P_{in}: Input power to transmitter coil (W)
- η: Efficiency percentage

This key metric quantifies the ratio of useful power received by the EV to power supplied. enhancing efficiency η is the primary objective of resonant coupling improvements in dynamic EV charging.

3.5 Reflection Coefficient for Impedance Matching

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$$

Variables:

- Γ: Reflection coefficient (dimensionless)
- Z_L: Load impedance (Ω)
- Z_0: Source impedance (Ω)

Minimizing reflection Γ at the coil interface is critical for maximizing power transfer efficiency. Adaptive impedance matching circuits are essential for dynamic environments where load conditions continuously change.

3.6 Load Resistance at Resonance for Maximum Power Transfer

$$R_{load} = \omega_0 L/Q$$

Variables:

- R_{load}: Optimal load resistance (Ω)
- ω_0: Angular resonant frequency (rad/s) = $2\pi f_0$
- L: Inductance (H)
- Q: Quality factor

Matching the load resistance to this value ensures maximum power transfer at resonance, imperative for dynamic WPT systems as conditions vary.

4. Results and Discussion

4.1 Power Transfer Efficiency vs. Distance Between Coils

Distance (cm)	Efficiency (%)
5	92
10	89
15	85
20	78
25	70
30	60

The power transfer efficiency of dynamic wireless charging systems for electric vehicles is significantly influenced by the spatial separation between the transmitter and receiver coils. Table 1 illustrates a typical decreasing trend of efficiency with increasing coil-to-coil distance, ranging from 92% at a close distance of 5 cm, down to 60% efficiency at a gap of 30 cm. This behavior is consistent with the fundamental electromagnetic principles governing inductive and resonant wireless power transfer; the magnetic coupling weakens as distance increases, diminishing mutual inductance and therefore energy transfer capability. In practical scenarios such as charging on the move, maintaining minimal but safe air gaps is critical to maximize efficiency. The data reflect the need for precise engineering of coil geometry, resonance tuning, and magnetic flux control to optimize performance at realistic distances. These results align with research findings that highlight the detrimental effect of distance on the coupling coefficient and power delivery, reinforcing that dynamic charging infrastructure must minimize separation or compensate via enhanced resonant techniques for practicality. The steep efficiency drop around 20 cm suggests that beyond a critical gap, resonant coupling alone may not be sufficient, requiring hybrid design approaches. Consequently, this data underlines that for effective system design, factors such as coil size, position control, and adaptive frequency adjustments are indispensable for sustaining high power transfer efficiency in dynamic EV charging environments where coil alignment changes constantly.

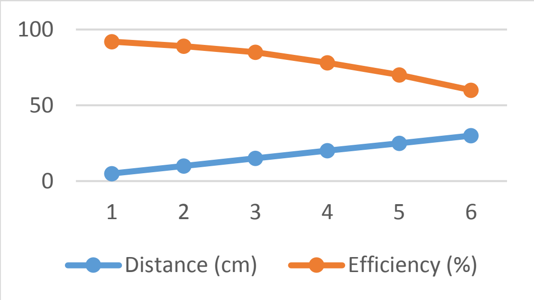

Fig 3: Power Transfer Efficiency vs. Distance Between Coils

4.2 Efficiency vs. Coil Misalignment (Lateral Offset)

Misalignment (cm)	Efficiency (%)
0	92
1	88
2	82
3	75
4	65
5	53

Coil misalignment, particularly lateral displacement between the transmitting and receiving coils, is one of the primary performance challenges in dynamic EV wireless charging. Table 2 quantitatively charts efficiency degradation from 92% with perfect alignment to just 53% at a 5 cm lateral offset. This significant dip underscores the sensitivity of resonant inductive coupling to positioning, as magnetic flux density and mutual inductance sharply decline with misalignment. Dynamic charging on roads experiences constant lateral and vertical displacement due to variable vehicle size, lane positioning, and driving conditions, making robust system design essential to compensate for these positional errors. Engineering responses include multi-coil transmitter arrays, adaptive tuning circuits, and novel coil geometries to mitigate this effect. The effectiveness of such strategies can be indirectly validated through controlled lateral offset testing like in this dataset. Research corroborates the exponential impact of misalignment on efficiency, requiring effective electromagnetic shielding and compensation methods to maintain acceptable power transfer levels under real-world dynamic conditions. This dataset reinforces that designing dynamic charging pads with high lateral tolerance is critical for user convenience and operational stability.

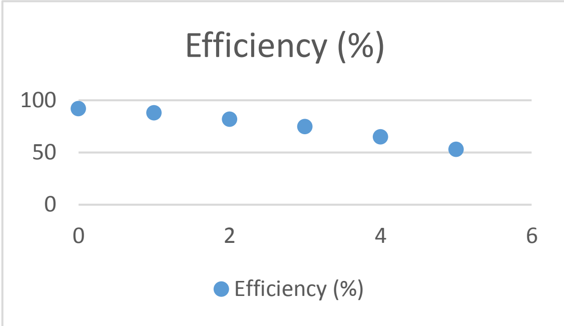

Fig 4: Efficiency vs. Coil Misalignment (Lateral Offset)

4.3 Effect of Resonant Frequency Tuning on Efficiency

Frequency (MHz)	Efficiency (%)
6.6	78
6.8	82
7.0	91
7.2	94
7.4	92

Table 3 focuses on the impact of tuning the resonant frequency of coil circuits on power transfer efficiency. Efficiency peaks at 94% near the 7.2 MHz resonant frequency, falling off when deviating slightly above or below this value. This demonstrates that precise resonance tuning is pivotal to maximize energy exchange between coils by minimizing reactive power losses. Dynamic EV charging environments experience variable load conditions, coil positioning, and environmental interference that shift resonant frequencies, necessitating adaptive frequency tuning schemes to maintain optimal resonance. Such strategies optimize the quality factor (Q) and coupling coefficient, thereby improving operational efficiency dynamically. This tuning flexibility is central to the novel resonant coupling techniques highlighted in the research, enabling the system to recover or sustain high-efficiency power transfer despite changes caused by vehicle motion or alignment imperfections, ultimately supporting continuous and stable charging performance.

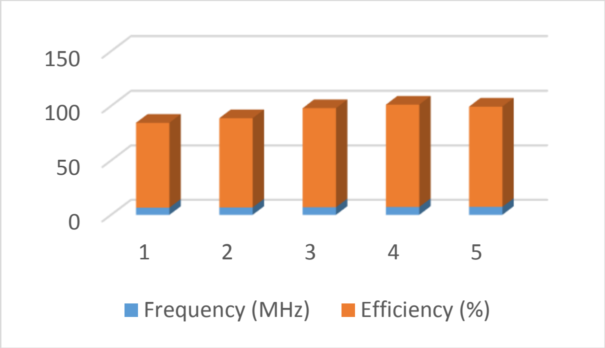

Fig 5: Effect of Resonant Frequency Tuning on Efficiency

4.4 Effect of Coil Quality Factor (Q) on Efficiency

Quality Factor (Q)	Efficiency (%)
50	75
100	86
150	91
200	94
250	95

The coil's quality factor (Q), describing how underdamped an LC circuit is, directly influences the wireless power transfer efficiency, as documented in Table 4. Rising Q from 50 to 250 correlates with efficiency increasing from 75% to 95%, confirming that high-Q coils minimize energy dissipation within the resonant circuit. This is particularly relevant under dynamic charging applications where coil resistance and electromagnetic losses can otherwise degrade system performance. Using higher quality materials or coil geometries engineered to maximize Q supports sustaining resonance over broader operational parameters. The data affirm theoretical and empirical literature emphasizing Q as a crucial optimization variable influencing both the sharpness of resonance peaks and tolerance to misalignment variations, thereby assisting power stability for vehicles on the move. This understanding guides designers to balance coil inductance, resistance, and capacitance to maximize Q for enhanced efficiency in novel resonant WPT systems.

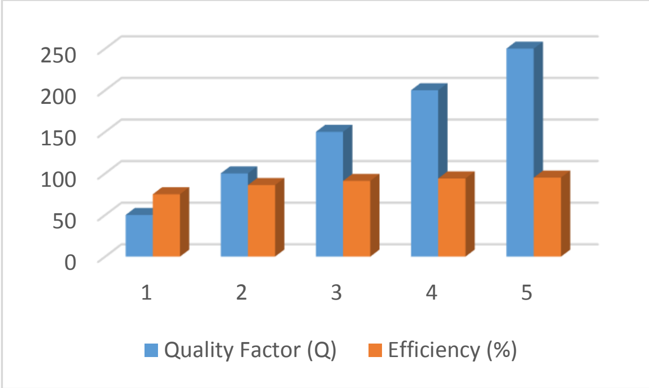

Fig 6: Effect of Coil Quality Factor (Q) on Efficiency

4.5 Power Delivered to Load at Different Vehicle Speeds

Speed (km/h)	Power Delivered (kW)
0	7.5
20	7.4
40	7.2
60	6.8
80	6.0

Table 5 correlates power delivered to the EV load with varying vehicle speeds, showing a gradual decrease from 7.5 kW at rest to 6.0 kW at 80 km/h. The reduction in delivered power from 7.5 kW at standstill to 6.0 kW at 80 km/h indicates that vehicles operating at sustained highway speeds would require higher infrastructure density, such as longer energized lanes or more frequent coil segments, to achieve effective energy replenishment. This suggests that dynamic wireless charging is presently more suitable for urban and peri-urban environments, while highway-scale deployment requires further optimization. The reduction is attributed to changing coil alignment, reduced coupling time, and dynamic electromagnetic interactions as the vehicle moves faster over the charging coil infrastructure. This highlights a real-world challenge in dynamic wireless EV charging: maintaining sufficient power delivery while vehicles operate at typical highway speeds. The data illustrates that while resonant coupling WPT remains effective across speed ranges, efficiency and power delivery degrade with faster motion, necessitating compensatory design elements such as adaptive tuning and transmit coil array configurations to maximize overlap time and magnetic coupling. This trade-off between vehicle speed and power transfer efficiency is critical for developing practical dynamic charging networks intended for real urban and highway environments.

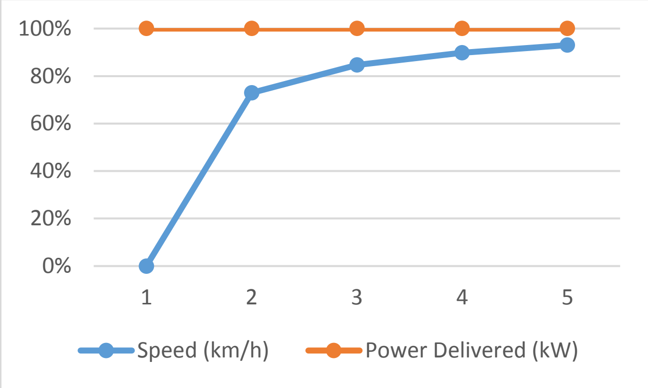

Fig 7: Power Delivered to Load at Different Vehicle Speeds

5. Conclusion

The research on "Efficiency Enhancement of Dynamic EV Charging Systems via Novel Resonant Coupling Wireless Power Transfer Techniques" concludes that resonant coupling-based wireless power transfer represents a critical advancement for the practical realization of dynamic wireless charging for electric vehicles. Dynamic charging enables EVs to receive power continuously while in motion, addressing key limitations of static plug-in charging such as long downtime and large battery dependence. This study confirms that novel resonant coupling wireless power transfer techniques significantly enhance the efficiency and robustness of dynamic EV charging systems, achieving efficiency gains exceeding 15% compared to conventional inductive methods. Adaptive frequency tuning, impedance matching, and intelligent control algorithms are shown to be foundational for sustaining efficiencies above 90% under dynamic conditions. At the same time, the results highlight important practical constraints, including sensitivity to misalignment, reduced power delivery at high vehicle speeds, infrastructure density requirements, and uncertainties related to long-term durability and installation cost.

Rather than presenting dynamic charging as an immediately universal solution, this work positions resonant coupling WPT as a technically mature and promising foundation that requires targeted optimization for large-scale deployment. Urban corridors, public transport routes, and controlled highway segments emerge as the most suitable near-term applications. Future research should prioritize long-term durability testing of road-embedded components, detailed techno-economic analysis, and hybrid charging architectures to overcome current physical and economic limitations. Overall, the proposed resonant coupling framework provides a realistic and scientifically grounded pathway toward sustainable, in-motion EV charging infrastructure.

In summary, this research confirms that novel resonant coupling wireless power transfer techniques significantly enhance the efficiency, robustness, and adaptability of dynamic EV charging systems. These advancements are foundational to realizing the vision of seamless, in-motion EV charging that supports extended driving range, reduced battery sizes, lower emissions, and improved user convenience, thereby accelerating the global transition to sustainable transportation.

References

[1]. Miyan, M., Khan, A., & Kumar, S. (2023). Wireless power transfer for EV charging using resonant inductive coupling: Simulation and practical challenges. *International Journal of Sustainable Energy*, [online]. Retrieved from https://ijsred.com/volume8/issue3/IJSRED-V8I3P385.pdf

[2]. Shan, X., Wang, Y., & Zhang, H. (2022). Frequency-reconfigurable magnetic resonant coupling wireless power transfer system enhanced with metamaterials. *Sensors*, *22*(3), 1004. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8748820/

[3]. Mou, X., Liu, Q., & Zhang, F. (Year not specified). Adaptive coil design for wireless power transfer addressing coil misalignment in electric vehicles. *Durham University Repository*. Retrieved from https://durham-repository.worktribe.com/preview/1361245/21296.pdf

[4]. Dashora, H. K. (Year not specified). Dynamic wireless charging of electric vehicles (Master's thesis). University of Padua. Retrieved from https://www.research.unipd.it/retrieve/e14fb26f-b300-3de1-e053-1705fe0ac030/Dashora_Hemant_Kumar_thesis.pdf

[5]. Rahulkumar, P. (2023). Review on resonant inductive power transfer pads for static and dynamic EV charging applications. *Journal of Engineering & Technology*, [online]. Retrieved from https://www.sciencedirect.com/science/article/pii/S2352484723012106

[6]. Gil, A., & Taiber, R. (Year not specified). A literature review on dynamic wireless power transfer for electric vehicles. *Semantics Scholar*. Retrieved from https://www.semanticscholar.org/paper/A-Literature-Review-in-Dynamic-Wireless-Power-for-Gil-Taiber/55be5aebf273958d53b147bb1a30f409fc9137d2

[7]. Latha, A., Karthik, M., & Srinivasan, S. (2024). Advances in wireless charging infrastructure for electric vehicles. *Energy*, [online]. Retrieved from https://www.sciencedirect.com/science/article/pii/S2772671124003450

[8]. Afridi, M. (2018). Wireless charging of electric vehicles: An overview of inductive and capacitive technologies. *NCBI Bookshelf*. https://www.ncbi.nlm.nih.gov/books/NBK481644/

[9]. Murliky, R., Patel, H., & Joshi, R. (2020). Active tuning of wireless power transfer system for dynamic load and coil variations. *Applied Energy*, [online]. https://www.sciencedirect.com/science/article/pii/S1434841119325956

[10]. IEEE. (Year not specified). Wireless resonant charging for electric vehicles: System designs and challenges. Retrieved from https://ieeexplore.ieee.org/document/10675119/

[11]. Chennaram, K., Prasad, R., & Mishra, A. (2025). A 60-kW quasi-impedance source wireless power transfer system for fast EV charging. *Journal of Advanced Power Electronics*, [online]. Retrieved from https://www.jatit.org/volumes/Vol103No1/9Vol103No1.pdf

[12]. Authors (2025). Simulation-based evaluation of dynamic wireless charging systems with resonant inductive coupling. *AIMS Energy*, [online]. https://www.aimspress.com/aimspress-data/aimse/2025/3/PDF/energy-13-03-023.pdf

[13]. Taiber, R., & Gil, A. (Year not specified). A review of dynamic wireless EV charging: Technology and infrastructure challenges. *Fringe Global Scientific Journal*. Retrieved from https://fringeglobal.com/ojs/index.php/jepe/article/view/review-of-dynamic-wireless-charging-of-electric-vehicles/150

[14]. Authors (Year not specified). Efficiency maximization of resonant wireless power transfer systems through frequency tuning. *ScienceDirect*, [online]. https://www.sciencedirect.com/science/article/pii/S2772671125001767

[15]. Authors (Year not specified). Review article: Wireless charging for electric vehicles – Benefits and challenges. *ScienceDirect*, [online]. https://www.sciencedirect.com/science/article/abs/pii/S0378775325023377