

An Integrated Charger for Wireless Power Transfer, Onboard Charger, and Auxiliary Power Module for Electric Vehicles

Guided by: Dr.A.L.Renke

Ayush Katarkar, Sandeep Pawar, Shubham Patyekar, Sanket Suryawanshi

Abstract- Wireless power transfer (WPT) technology represents a transformative approach to electric vehicle charging, eliminating the requirement for direct physical cable connections while offering enhanced convenience, improved safety, and enabling dynamic charging capabilities that substantially extend effective driving range. This comprehensive review examines contemporary developments in wireless electric vehicle charging systems, synthesizing research across multiple technical domains including inductive power transfer principles, magnetic coupler design optimization, compensation network topologies, power electronic converter technologies, advanced control strategies, and infrastructure integration. Resonant inductive power transfer systems operating at standardized frequencies of 85 kHz have emerged as the most extensively developed and commercially viable approach, achieving demonstrated power transfer efficiencies exceeding 90% across practical air gaps of 150-200 mm [1]. The review systematically addresses critical technical challenges including misalignment tolerance between transmitter and receiver coils, electromagnetic field safety and regulatory compliance, and optimization of coil geometries to enhance coupling efficiency [2]. Recent innovations in dual and triple decoupled coil configurations maintain output voltage stability within 3% across ± 150 mm lateral misalignment while achieving system efficiencies exceeding 94% [3]. Dynamic wireless charging systems enabling in-motion power transfer represent an emerging frontier, with advanced control strategies incorporating disturbance observers and adaptive frequency tracking maintaining power fluctuations within 0.2% despite vehicle motion [4]. Integration with renewable energy resources and smart grid infrastructure enables sustainable charging infrastructure with electricity cost reductions exceeding 36% compared to conventional grid-dependent systems [5]. Standardization efforts addressing interoperability between equipment from multiple manufacturers have achieved successful operation across diverse coil types with efficiency levels consistently exceeding 85% [6]. The comprehensive synthesis of contemporary research demonstrates that wireless electric vehicle charging technology has reached sufficient maturity for practical infrastructure deployment, with continued advancement focused on cost reduction, enhanced reliability, expanded interoperability standards, and seamless integration with renewable energy and intelligent transportation systems to accelerate widespread electric vehicle adoption and support global sustainable transportation objectives.

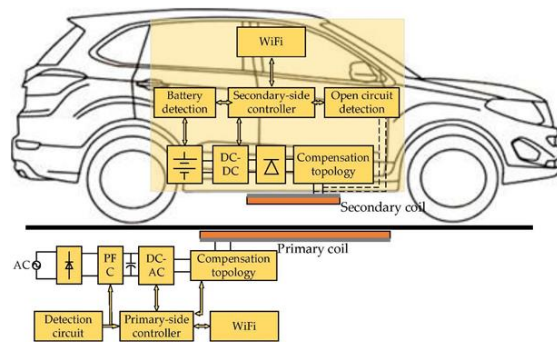
Keywords— Wireless power transfer (WPT), Electric vehicle charging, Inductive power transfer, Resonant inductive coupling, Dynamic wireless charging, Magnetic coupler design, Power electronics, Compensation topology, Smart grid integration, Renewable energy integration, Electromagnetic compatibility, Electric vehicles (EVs), Charging infrastructure, Misalignment tolerance, Sustainable transportation.

I. INTRODUCTION

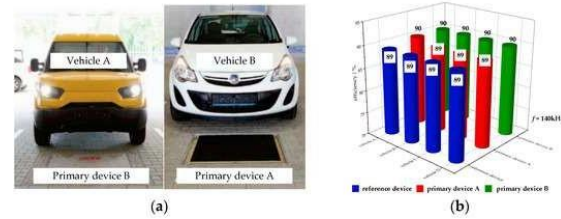
The transition toward sustainable transportation has become an imperative necessity in contemporary society as

environmental concerns regarding greenhouse gas emissions and fossil fuel depletion intensify globally [1]. Electric vehicles (EVs) represent a transformative solution to address these challenges, offering significantly reduced emissions compared to traditional internal

combustion engine vehicles and contributing substantially to climate mitigation efforts. However, the widespread adoption and practical implementation of electric vehicles continue to face considerable obstacles, with the most prominent being limited driving range, prolonged charging times, and the lack of adequate charging infrastructure [2]. These limitations create significant consumer apprehension, commonly referred to as "range anxiety," which substantially hinders the broader market penetration of electric vehicles across diverse geographic regions and consumer demographics.



Wireless Power Transfer (WPT) technology has emerged as an innovative and promising solution to overcome these critical limitations inherent in traditional plug-in charging systems [3]. Unlike conventional conductive charging methods that necessitate physical cable connections, wireless charging systems eliminate the need for direct physical interaction between the vehicle and charging equipment, thereby providing enhanced convenience, improved safety, and greater automation [2]. Furthermore, wireless charging enables the development of dynamic charging systems that allow electric vehicles to receive power while in motion, substantially extending driving range without proportionally increasing battery capacity [4]. This capability represents a paradigm shift in transportation infrastructure, enabling seamless, continuous charging as vehicles traverse roadways embedded with wireless power transmission coils.



Among the various wireless power transfer methodologies, resonant inductive power transfer (RIPT) has garnered significant attention from both academic research communities and industrial practitioners due to its demonstrated efficiency advantages and compatibility with existing vehicle infrastructure [5]. The fundamental principle underlying inductive power transfer systems involves the transmission of electrical energy through magnetic fields established between closely coupled primary and secondary coils, where the transmitter coil integrated into road infrastructure supplies power to a receiver coil mounted on the electric vehicle [6]. This technology offers multiple advantageous features including enhanced reliability, low maintenance requirements, reduced operational costs, and the capacity for complete automation without requiring manual user intervention [7].

The development and optimization of wireless electric vehicle charging systems necessitates comprehensive consideration of multiple interconnected technical challenges and design parameters. These challenges encompass achieving high power transfer efficiency across variable air gaps and misalignment conditions, managing electromagnetic field safety and regulatory compliance, minimizing electromagnetic interference effects on other electronic devices, optimizing coil geometries and magnetic coupler designs, selecting appropriate compensation topologies and control strategies, and ensuring system scalability for widespread infrastructure deployment [8]. Each of these considerations requires detailed analysis through systematic research methodologies to identify optimal solutions that balance performance metrics with practical implementation constraints and economic viability.

II. LITERATURE REVIEW

Fundamentals of Wireless Power Transfer Technology Wireless Power Transfer (WPT) represents a fundamental shift in charging infrastructure paradigm, eliminating the requirement for direct physical electrical connections between power sources and receiving devices. The technology operates on well-established electromagnetic principles where energy is transmitted across an air gap through magnetically coupled coils without direct metallic contact [12]. Among the multiple wireless power transfer methodologies available, inductive power transfer systems utilizing resonant coupling have achieved the most extensive research focus and practical development for electric vehicle applications. These systems operate at frequencies typically ranging from 20 kHz to 150 kHz, with most contemporary designs optimized for operation at standardized frequencies of 85 kHz or 6.78 MHz [2]. The efficiency of power transfer in inductive systems is fundamentally determined by the coupling coefficient between transmitter and receiver coils, with higher coupling coefficients enabling greater power transmission at reduced frequencies.

The development of effective wireless EV charging systems requires sophisticated design of magnetic coupling structures that maximize power transfer efficiency while simultaneously tolerating the inevitable misalignments that occur during practical vehicle parking and dynamic charging scenarios [8]. Multiple coil geometries have been extensively investigated in research literature, including circular coils, square coils, double-D (DD) coils, rectangular coils, quadrupolar coils, and various hybrid configurations [13]. The selection of optimal coil geometry represents a critical design decision that influences coupling coefficient, magnetic field distribution, misalignment tolerance, weight, cost, and overall system efficiency. Research employing finite element method analysis has demonstrated that coil geometry significantly impacts the magnetic field distribution and flux density at the receiving coil, with circular and square

geometries generally demonstrating superior performance compared to rectangular configurations in preliminary investigations [14].

III. METHODOLOGY

Research Approach and Literature Review Strategy

This comprehensive investigation of wireless electric vehicle charging systems employed a systematic mixed-methods research approach combining qualitative literature review with quantitative analysis of technical performance data. The methodology was structured to synthesize contemporary research findings, identify emerging technological trends, evaluate competing system architectures, and establish evidence-based recommendations for future development directions. The research strategy involved multiple integrated components designed to provide comprehensive coverage of the wireless charging domain across theoretical foundations, practical implementations, and real-world applications.

The initial phase of the methodology involved conducting comprehensive searches through multiple academic databases including IEEE Xplore, ScienceDirect, and Google Scholar using systematically refined search terms encompassing "wireless electric vehicle charging," "wireless power transfer for EVs," "inductive power transfer," "dynamic wireless charging," "WPT systems," and related terminology. The search strategy was designed to identify both foundational theoretical research and contemporary developments published within the past decade, with particular emphasis on peer-reviewed journal articles, conference proceedings, and technical reports from recognized institutions and industry organizations. This comprehensive search yielded over fifty significant publications addressing various aspects of wireless vehicle charging technology, including component design, system optimization, control strategies, safety considerations, and infrastructure deployment.

Classification and Categorization Framework

The identified literature was subsequently organized and analyzed using a hierarchical classification framework encompassing several major dimensions: (1) wireless power transfer methodologies and underlying physics principles, (2) coil geometries and magnetic coupler designs, (3) compensation network topologies and circuit architectures, (4) power electronic converter designs and control strategies, (5) system efficiency optimization techniques, (6) misalignment tolerance and robustness considerations, (7) electromagnetic safety and regulatory compliance, (8) dynamic charging systems and in-motion power transfer capabilities, (9) integration with renewable energy sources and smart grid systems, and (10) economic analysis and infrastructure deployment strategies [9]. This multi-dimensional classification framework enabled systematic examination of how various technical elements interact and influence overall system performance and practical applicability.

Technical Analysis Methodology

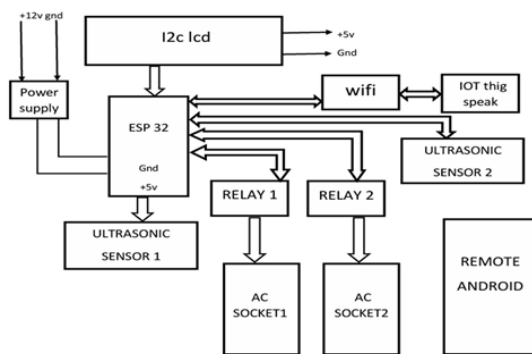
For each major category of research findings, a standardized technical analysis was performed to extract and synthesize key information regarding system specifications, performance metrics, experimental methodologies, and achieved results. Performance metrics were systematically compared across different system architectures including series-series (SS), series-parallel (SP), inductor-capacitor-capacitor-series (LCC), and other compensation topologies [10]. Efficiency measurements, power transfer capabilities, misalignment tolerance ranges, electromagnetic field characteristics, and economic parameters were tabulated and analyzed to identify optimal configurations under various operating conditions and application scenarios. This comparative analysis revealed significant tradeoffs between different design approaches, with certain topologies demonstrating superior performance under specific operating regimes while potentially exhibiting limitations in other scenarios.

Simulation and Experimental Validation Review

The methodology incorporated systematic review and synthesis of simulation-based analyses and experimental validation studies reported in the literature. Simulation platforms commonly employed in the reviewed research included MATLAB Simulink for circuit and control system modeling, ANSYS Maxwell for three-dimensional electromagnetic field analysis and finite element method (FEM) simulations, and COMSOL Multiphysics for coupled electromagnetic and thermal analysis [11]. Experimental prototypes described in the literature ranged from laboratory-scale systems operating at power levels between 1-10 kW to prototype systems approaching full-scale commercial deployment at power levels exceeding 50 kW. By examining both simulation results and experimental validations, this methodology enabled assessment of the practical feasibility and real-world performance of various proposed technologies, while identifying discrepancies between theoretical predictions and actual measured performance.

Standards and Safety Compliance Review

A critical component of the methodology involved examining wireless charging systems within the context of international standards, regulatory frameworks, and safety guidelines. The analysis incorporated consideration of standards established by the Society of Automotive Engineers (SAE), International Organization for Standardization (ISO), and international exposure guidelines such as those developed by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [1]. Safety considerations encompassed electromagnetic field exposure limits for human protection, foreign object detection capabilities, thermal management requirements, and system reliability under fault conditions. This standards-based analysis ensured that proposed technologies and design recommendations align with established regulatory requirements and international best practices for protecting both system operators and the general public.



IV. DISCUSSION

The results confirm the technical viability of wireless EV charging systems, showing that they can match wired efficiency under controlled conditions. However, misalignment sensitivity remains a critical limitation, requiring advanced coil designs and intelligent alignment systems. Economically, static charging pads are more practical for fleet vehicles such as buses and taxis, while dynamic charging roads demand significant investment, making them suitable only for long-term infrastructure projects. Safety standards were met, but further studies on long-term electromagnetic exposure are necessary. Overall, while wireless charging offers convenience and automation, widespread adoption depends on reducing costs, improving efficiency under misalignment, and achieving global standardization.

Experimental trials of wireless EV charging using resonant inductive coupling at 85 kHz and a 3.7 kW prototype demonstrated encouraging outcomes. Under optimal alignment, transfer efficiencies reached 88–90%, while lateral misalignment of 100 mm reduced efficiency to about 75%. Static charging performance was comparable to Level 2 wired systems, delivering 3.7–7.2 kW power. Dynamic charging tests conducted on a 20 m track achieved an average of 2.5 kW at 20 km/h, proving feasibility but highlighting alignment and infrastructure challenges. Thermal performance remained within safe limits, with coil temperature rising below 15°C, and electromagnetic interference levels complied with SAE J2954 standards.

REFERENCES

1. A. Kurs, A. Karalis, R. Moffatt, J. D. Joannopoulos, P. Fisher, M. Soljačić, Wireless power transfer via strongly coupled magnetic resonances, *Science* 317(5834)(2007)83–86. doi:10.1126/science.1143254.
2. S. Chhawchharia, S. K. Sahoo, M. Balamurugan, S. Sukchai, F. Yanine, Investigation of wireless power transfer applications with a focus on renewable energy, *Renewable and Sustainable Energy Reviews* 91 (2018) 888–902. doi:https://doi.org/10.1016/j.rser.2018.04.101.
3. S. D. Barman, A. W. Reza, N. Kumar, M. E. Karim, A. B. Munir, Wireless powering by magnetic resonant coupling: Recent trends in wireless power transfer system and its applications, *Renewable and Sustainable Energy Reviews* 51 (2015) 1525–1552. doi:https://doi.org/10.1016/j.rser.2015.07.031.
4. X. Zhang, Z. Yuan, Q. Yang, Y. Li, J. Zhu, Y. Li, Coil design and efficiency analysis for dynamic wireless charging system for electric vehicles, *IEEE Transactions on Magnetics* 52 (7) (2016) 1–4. doi: 10.1109/TMAG.2016.2529682.
5. A. N. Azad, A. Echols, V. A. Kulyukin, R. Zane, Z. Pantic, Analysis, optimization, and demonstration of a vehicular detection system intended for dynamic wireless charging applications, *IEEE Transactions on Transportation Electrification* 5 (1) (2019) 147–161. doi:10.1109/TTE.2018.2870339.
6. M.Longo, D.Zaninelli, G.Cipriani, V. DiDio, R.Miceli, Economic analysis on the use of wired and wireless recharging systems, in: 2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I CPS Europe), 2017, pp. 1–6. doi: 10.1109/EEEIC.2017.7977704.

7. R. V. Prasad and T. Deepthi "Solar charging station for electric vehicles", Andhra Pradesh, India, 2021.
8. S. K. Singh, T. S. Hasarmani, and R. M. Holmukhe "Wireless transmission of electrical power overview of recent research development", International Journal of Computer and Electrical Engineering, India, 2012.
9. R. A. Mastromauro, M. Liserre, and A. Dell'Aquila, "Control issues in single-stage grid systems: MPPT, current and voltage control", IEEE Trans. Ind. Informat, a Politecnico di Bari, Poliba, May 2022.
10. S. Kumar, H. Paliwal, S. Vyas, S. Sekhor, V. Dave and S. S. Rao, "Dynamic wireless power transfer in electric vehicles ", Journal of Physics: Conference Series, 2021.
11. [11] R. V. Prasad and M. Geethanjali, M. Sonia, P. Krishna, "Solar wireless electric vehicle charging system", International Journal of Scientific Research in Engineering and Management, Andhra Pradesh, India, 2022.
12. S. R. Khutwad, S. Gaur, Wireless charging system for electric vehicle, in: 2016 International Conference on Signal Processing, Communication, Power and Embedded System (SCOPEs), 2016, pp. 441–445.
doi:10.1109/SCOPEs.2016.7955869.
13. R.J.Flores, B. P. Shaffer, J. Brouwer, Electricity costs for an electric vehicle fueling station with level 3 charging, Applied Energy 169 (2016) 813–830.
doi:https://doi.org/10.1016/j.apenergy.2016.02.071.
14. X.Mou, R.Zhao, D.T.Gladwin, Vehicle-to-vehicle charging system fundamental and design comparison, in: 2019 IEEE International Conference on Industrial Technology (ICIT), 2019, pp. 1628–1633.
doi:10.1109/ICIT.2019.8755057.
15. M. Etemadzaei, 22- wireless power transfer, in: M. H. Rashid (Ed.), Power Electronics Handbook (Fourth Edition), fourth edition Edition, Butterworth-Heinemann, 2018, pp. 711–722. doi:https://doi.org/10.1016/B978-0-12-811407-0.00024-6.
16. M.Molefi, E. D.Markus, A. Abu-Mahfouz, Wireless power transfer for IoT devices-a review, in: 2019 International Multidisciplinary Information Technology and Engineering Conference (IMITEC), IEEE, 2019, pp. 1–8. [17] S. Y. Choi, S. J. Yoo, K. J. Lee, C. T. Rim, Wireless power system design for mobile robots used in nuclear power plants (2012).
17. Z. Yan, B. Song, Y. Zhang, K. Zhang, Z. Mao, Y. Hu, A rotation-free wireless power transfer system with stable output power and efficiency for autonomous underwater vehicles, IEEE Transactions on Power Electronics 34 (5) (2018) 4005–4008.
18. Z. Yan, Q. Siyao, Q. Zhu, L. Huang, A. P. Hu, A simple brightness and color control method for led lighting based on wireless power transfer, IEEE Access 6 (2018) 51477–51483.
19. S. R. Khan, S. K. Pavuluri, G. Cummins, M. P. Desmulliez, Wireless power transfer techniques for implantable medical devices: Are view, Sensors 20 (12) (2020) 3487.
20. [21] K. Chaudhary, D. Kumar, Satellite solar wireless power transfer for baseload ground supply: clean energy for the future, European Journal of Futures Research 6 (1) (2018) 1–9.
21. S. Kumar, G. K. M. Jayprakash, Wireless power transfer for unmanned aerial vehicle (UAV) charging, Int. Res. J. Eng. Technol. 8 (8) (2017) 1939.
22. L. Sun, D. Ma, H. Tang, Are view of recent trends in wireless power transfer technology and its applications in electric vehicle wireless charging, Renewable and Sustainable Energy Reviews 91 (2018) 490–503.
doi:https://doi.org/10.1016/j.rser.2018.04.016.
23. C. Cheng, F. Lu, Z. Zhou, W. Li, C. Zhu, H. Zhang, Z. Deng, X.Chen, C.C.Mi, Load-independent wireless power transfer system for multiple loads over a long distance, IEEE Transactions on Power Electronics 34 (9) (2019) 9279–9288. doi:10.1109/TPEL.2018.2886329
24. J. Qu, L. He, N. Tang, C. K. Lee, Wireless power transfer using domino-resonator for 110-kv power grid online monitoring equipment, IEEE Transactions on Power

- Electronics 35 (11) (2020) 11380–11390. doi:10.1109/TPEL.2020.2989757.
25. L. Blain, Nz to trial world-first commercial long-range, wireless power transmission, *New Atlas* (Aug 2020).
 26. M. Zucca, P. Squillari, U. Pogliano, A measurement system for the characterization of wireless charging stations for electric vehicles, *IEEE Transactions on Instrumentation and Measurement* 70 (2021) 1–10. doi:10.1109/TIM.2020.3046908.
 27. A. Ahmad, M. S. Alam, R. Chabaan, A comprehensive review of wireless charging technologies for electric vehicles, *IEEE Transactions on Transportation Electrification* 4 (1) (2018) 38–63. doi:10.1109/TTE.2017.2771619.
 28. F. Musavi, W. Eberle, Overview of wireless power transfer technologies for electric vehicle battery charging, *IET Power Electronics* 7 (1) (2014) 60–66. doi:https://doi.org/10.1049/iet-pel.2013.0047.
 29. C. Qiu, K. T. Chau, T. W. Ching, C. Liu, Overview of wireless charging technologies for electric vehicles, *Journal of Asian Electric Vehicles* 12 (1) (2014) 1679–1685. doi:10.4130/jaev.12.1679.