Power Balanced CC-CV Wireless EV Charging System

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Abstract— The increasing demand for efficient and contactless charging solutions for electric vehicles (EVs) has accelerated the development of wireless power transfer (WPT) systems. This paper presents a power-balanced Constant Current–Constant Voltage (CC–CV) wireless EV charging system designed to enhance charging stability, efficiency, and reliability. The proposed system employs inductive power transfer using a primary–secondary coil arrangement, with Arduino-based control for regulating power flow and maintaining charging modes. A solar-assisted transmitter supplies power to the primary coil, while the receiver side integrates a rectifier and DC–DC converter to deliver a stable DC output. The system operates in CC mode during the initial charging stage, providing a constant current of approximately 1.0 A at 9.5 V, followed by a smooth transition to CV mode, maintaining a constant voltage of 12 V with current gradually decreasing to 0.45 A, ensuring safe battery charging. Experimental results demonstrate that the system achieves a maximum efficiency of 91% at a 2 cm coil distance, with efficiency decreasing to 73% at 8 cm due to increased air gap. Under slight coil misalignment, efficiency remains above 84%, indicating robustness of the design. Compared to conventional systems (~75% efficiency), the proposed approach improves overall performance to approximately 90% efficiency while reducing communication dependency. The results validate that the proposed system provides an efficient, stable, and eco-friendly wireless charging solution, making it suitable for next-generation EV charging applications

Keywords — Wireless Power Transfer (WPT), Electric Vehicles (EV), Inductive Power Transfer (IPT), Constant Current–Constant Voltage (CC–CV) etc.,

I. INTRODUCTION

The rapid growth of electric vehicles (EVs) has created a strong demand for efficient, safe, and user-friendly charging technologies. Conventional plug-in charging methods, although widely used, suffer from limitations such as cable wear, safety risks, and lack of convenience. To address these issues, wireless power transfer (WPT) has emerged as a promising alternative, enabling contactless energy transfer between a power source and an EV battery [2], [10]. Among various WPT techniques, Inductive Power Transfer (IPT) is the most widely adopted due to its high efficiency, reliability, and suitability for short-range applications. IPT systems utilize magnetic coupling between primary and secondary coils to transfer power wirelessly [1], [3]. However, the efficiency of IPT systems is highly dependent on factors such as coil alignment, air gap, and operating frequency, which can significantly affect system performance [9], [10]. Several studies have focused on improving coil design and system architecture to enhance wireless charging efficiency. Bhattacharya and Tan [1] proposed optimized coil structures for static EV charging, while Supriyadi et al. [3] demonstrated practical implementation of inductive coupling circuits. Additionally, system-level analyses of wireless charging technologies have been presented in [2], [5], highlighting key challenges such as efficiency loss, safety, and scalability. Recent research has also explored advanced control strategies and infrastructure optimization. For instance, Ngo et al. [6] investigated optimal placement of dynamic charging infrastructure, and Adil et al. [7] introduced machine learning techniques for intelligent charging systems. Furthermore, different control methods such as PI and fuzzy logic controllers have been studied to improve system stability and performance under varying conditions [8]. Despite these advancements, existing wireless EV charging systems still face several challenges. Many systems rely heavily on continuous communication between transmitter and receiver, leading to increased complexity and reduced reliability [7]. Additionally, maintaining stable charging performance during the transition between Constant Current (CC) and Constant Voltage (CV) modes remains a critical issue [12]. Although CC–CV charging is widely used for battery protection and efficiency, its integration with wireless systems is not adequately addressed in existing works. Moreover, the integration of renewable energy sources, such as solar power, into wireless charging systems has gained attention in recent years [13], [14]. However, most existing systems do not effectively combine renewable energy with efficient wireless charging and power balancing mechanisms. To overcome these limitations, this paper proposes a power-balanced CC–CV wireless EV charging system that ensures stable and efficient energy transfer while reducing communication dependency. The proposed system integrates solar-assisted power supply, Arduino-based control, and efficient rectification and DC–DC conversion to achieve reliable charging performance. Experimental results demonstrate improved efficiency of up to 91% under optimal conditions, with stable operation across varying distances and alignment conditions.

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II. LITERATURE SURVEY

Wireless power transfer (WPT) has emerged as a promising technology for electric vehicle (EV) charging due to its convenience, safety, and automation capabilities. Inductive Power Transfer (IPT), which operates based on magnetic coupling between coils, is the most widely adopted technique for EV wireless charging systems. Several researchers have contributed to improving efficiency, control strategies, and system design, which are discussed below. Bhattacharya and Tan [1] focused on the design of static wireless charging coils for EV integration. Their work emphasized coil geometry optimization to enhance coupling efficiency and reduce losses. However, their approach primarily addressed hardware design without considering dynamic control mechanisms such as CC–CV charging. Mou and Sun [2] presented a comprehensive survey of WPT technologies, including inductive, resonant, and radiative methods. The study highlighted key challenges such as efficiency improvement, transmission distance, and system scalability . However, the work lacked implementation-oriented solutions for EV charging control Supriyadi et al. [3] developed an inductive coupling-based WPT circuit and demonstrated practical energy transfer over short distances. Their results confirmed that efficiency decreases with increasing coil separation, but advanced control strategies were not incorporated. Das et al. [4] reviewed EV charging standards and grid integration challenges, emphasizing the importance of efficient charging infrastructure. Although comprehensive, the study did not address wireless charging control or power balancing techniques. Jang [5] analyzed the operation and system architecture of wireless EV charging systems, covering both static and dynamic charging. The study provided system-level insights but lacked detailed implementation of charging algorithms such as CC–CV control. Ngo et al. [6] proposed an optimization framework for the placement of dynamic wireless charging infrastructure in road networks. Their work improves accessibility and energy utilization but does not address circuit-level efficiency or charging control. Adil et al. [7] introduced a machine learning-based sensor network for dynamic wireless charging systems. While the approach enhances reliability and adaptability, it increases system complexity and communication dependency. Smagulova et al. [8] compared PI and fuzzy logic controllers for dynamic WPT systems. The results indicated that fuzzy controllers offer better adaptability under varying conditions, but the study focused only on control methods without addressing hardware efficiency. Subudhi et al. [9] reviewed various WPT topologies used in static and dynamic EV charging. The paper provided a comparison of different circuit configurations and compensation techniques but lacked experimental validation. Ahmad et al. [10] conducted a comprehensive review of wireless EV charging technologies, highlighting issues such as misalignment, efficiency loss, and safety concerns. The study emphasized the need for improved system design and control strategies.

Lee et al. [11] developed a WPT system for autonomous EVs, focusing on system integration and automation. Although efficient, the system did not incorporate power balancing or CC–CV charging control. Wang et al. [12] proposed a maximum efficiency tracking method based on optimal input voltage matching. Their results improved system efficiency, but the approach required continuous feedback, increasing system complexity. Abhinandh et al. [13] explored solar-integrated energy systems, demonstrating the benefits of renewable energy integration. However, the work was not specifically focused on wireless EV charging. HeA et al. [14] presented a solar-powered intelligent system for mobility applications. While the system effectively utilized renewable energy, it did not address wireless charging or EV applications. Lu et al. [15] reviewed capacitive wireless power transfer technology, discussing its advantages and limitations. Compared to inductive methods, capacitive WPT is less suitable for high-power EV charging applications. Recent studies further indicate that inductive WPT systems can achieve efficiencies close to 90% under optimal alignment conditions, but performance degrades with distance and misalignment. Additionally, CC–CV charging control remains the most widely adopted strategy for safe and efficient EV battery charging. A. Farghly et al. (2024)
Farghly *et al.* presented a comprehensive review of wireless power transfer (WPT) techniques for EV charging, including inductive, capacitive, and resonant methods. The study highlights the role of compensation topologies and advanced control strategies in improving efficiency and handling coil misalignment [16]. B. Latha (2024)
Latha discussed recent advancements in wireless EV charging technologies, focusing on improved efficiency, compact designs, and enhanced safety features. The study emphasizes the growing adoption of intelligent and energy-efficient charging systems for modern EV applications [17].

O. Abuajwa (2025) Abuajwa provided a detailed review of WPT systems for EVs, analyzing system architectures, design challenges, and performance limitations. The study identifies key issues such as efficiency degradation, alignment sensitivity, and the need for improved control mechanisms [18]. Z. Xue (2025)
Xue presented a critical review of wireless charging technologies, comparing different WPT methods and their suitability for EV applications. The paper highlights challenges such as power loss, electromagnetic interference, and system cost [19]. I. Ayoade (2026)
Ayoade proposed and experimentally analyzed a high-power wireless EV charging system, demonstrating improved efficiency and practical feasibility. The study validates the effectiveness of optimized circuit design and control strategies for real-time applications [20]. A. Shahin (2024)
Shahin investigated the integration of renewable energy sources with wireless EV charging systems. The study shows that combining solar energy with WPT enhances sustainability and reduces dependency on conventional power sources [21].

III. PROPOSED METHOD

The proposed system presents a power-balanced Constant Current–Constant Voltage (CC–CV) wireless EV charging method based on inductive power transfer (IPT). In this approach, a solar-powered transmitter supplies energy to a primary coil, which generates an alternating electromagnetic field for wireless energy transfer. The receiver side captures this energy using a secondary coil, followed by rectification and DC–DC conversion to obtain a stable DC output. An Arduino-based control unit regulates the charging process by maintaining constant current during the initial stage for fast charging and constant voltage in the final stage to prevent overcharging. The system also ensures power balancing and reduced communication dependency, resulting in improved efficiency, stability, and reliability for EV charging applications. The architecture of the proposed method shown in fig.1.

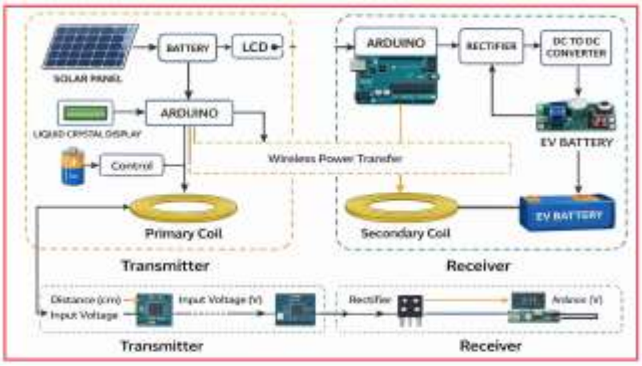

Fig. 1. Architecture of the proposed method

A. Methodology

The proposed system is designed to implement a power-balanced Constant Current–Constant Voltage (CC–CV) wireless EV charging system using inductive power transfer (IPT). The overall methodology is divided into the following functional modules:

1) Transmitter Side Design

The transmitter section is powered by a solar panel integrated with a battery storage unit, ensuring continuous and sustainable energy supply. The stored DC power is fed to an Arduino-based control unit, which generates switching signals to produce a high-frequency AC output. The generated AC signal applied to the primary coil can be expressed as:

$$Vp=Vmsin(\omega t) \qquad (1)$$

where Vm is the peak voltage and $\omega=2\pi f$ is the angular frequency. This AC excitation produces a magnetic field in the primary coil, enabling wireless energy transfer.

2) Inductive Wireless Power Transfer

The system employs inductive coupling between primary and secondary coils. The induced voltage in the secondary coil is given by:

$$Vs=j\omega MI \quad (2)$$

where M is the mutual inductance and Ip is the primary current.

The mutual inductance is defined as:

$$M=kLpLs \quad (3)$$

where k is the coupling coefficient, and Lp, Ls are inductances of primary and secondary coils.

The efficiency of wireless power transfer is:

$$\eta=Pin.Pout\times100 \quad (4)$$

3) Receiver Side Processing

On the receiver side, the induced AC voltage is rectified and regulated using a DC–DC converter. For a buck converter:

$$Vout=D\cdot Vin \quad (5)$$

where D is the duty cycle.

The output power is calculated as:

$$Pout=Vout\times Iout \quad (6)$$

4) CC–CV Charging Control Strategy

The charging process follows a two-stage CC–CV method:

- *Constant Current (CC) Mode*:

$$Ib=Iref \;\; P=Vb\times Iref \quad (7)$$

- *Constant Voltage (CV) Mode*:

$$Vb=Vref,\ Vb=Vref\ Ib(t)=I0 \quad (8)$$

where I0 is initial current and τ is the time constant.

5) Power Balancing Mechanism

The system maintains power balance by ensuring:

$$Pin=Pout+Ploss \quad (9)$$

The controller adjusts duty cycle DDD dynamically to maintain stable output:

$$D=VoutVin \ (10)$$

This helps to:

- Maintain stable output under varying conditions
- Compensate for misalignment and distance variations
- Improve overall system efficiency

B. Algorithm

CC–CV Wireless EV Charging System

- Initialize the system components (Arduino, coils, sensors, converter).
- Supply power from the solar panel and battery to the transmitter.
- Generate a high-frequency AC signal and energize the primary coil.
- Transfer power wirelessly to the secondary coil.
- Convert received AC power into DC using a rectifier.
- Regulate the output using a DC–DC converter.
- Measure battery voltage and current.
- If battery voltage is below the set value:
  → Operate in Constant Current (CC) mode.
- Else:
  → Switch to Constant Voltage (CV) mode.
- Adjust power to maintain stable output (power balancing).
- Continuously monitor voltage and current for safety.
- If battery is fully charged:
  → Stop charging.
- End.

C. *Implementation*

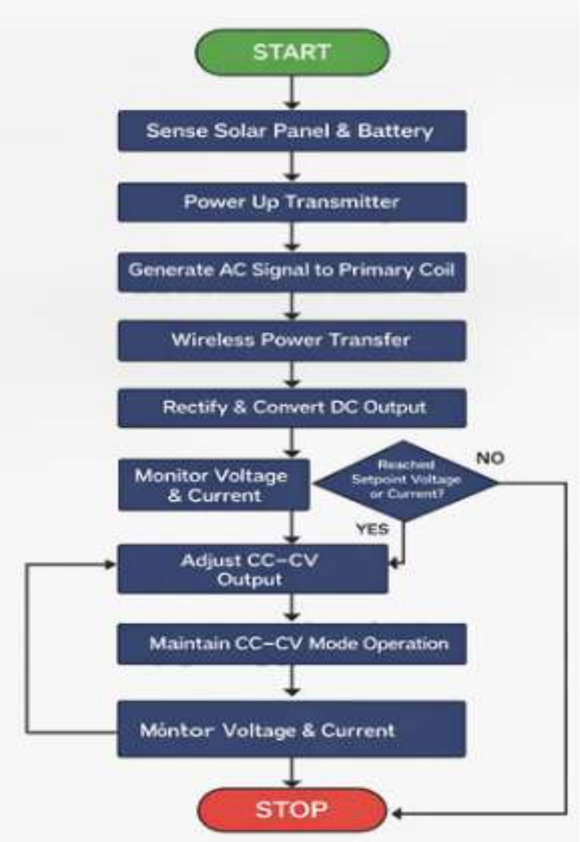

Fig. 2. Implementation of the flow chart

The flowchart illustrates in fig.2 the step-by-step operation of the proposed power-balanced CC–CV wireless EV charging system. The process begins with sensing the solar panel and battery conditions, followed by powering the transmitter to generate a high-frequency AC signal for the primary coil. This enables wireless power transfer to the secondary coil, where the received energy is rectified and converted into a regulated DC output. The system continuously monitors voltage and current, and based on the battery condition, it operates in Constant Current (CC) mode initially and transitions to Constant Voltage (CV) mode once the set voltage is reached. The control unit adjusts the output to maintain stable charging, ensuring power balancing and safety. The process repeats until the battery is fully charged, after which the system stops, ensuring efficient and controlled wireless charging operation.

IV. EXPERIMENTAL RESULTS

The hardware setup shown in fig.3 illustrates the complete implementation of the proposed wireless EV charging system with transmitter, receiver, Arduino control, and power conversion units. The system operates with a 12 V input supply and demonstrates stable wireless power transfer and CC–CV charging in real time.

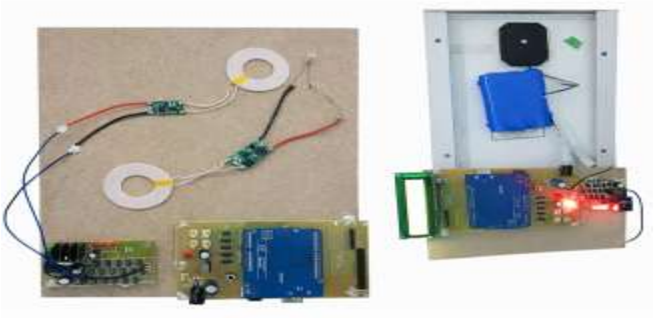

Fig. 3. Hardware Setup Model

The system achieves a maximum efficiency of 91% at 2 cm (11.5 V, 0.95 A), which decreases to 73% at 8 cm (8.2 V, 0.70 A) due to reduced coupling. This confirms that increasing distance directly affects output voltage, current, and overall efficiency.

TABLE I. WIRELESS POWER TRANSFER PERFORMANCE

Distance (cm)	Input Voltage (V)	Output Voltage (V)	Output Current (A)	Efficiency (%)
2 cm	12	11.5	0.95	91%
4 cm	12	10.8	0.90	86%
6 cm	12	9.6	0.82	80%
8 cm	12	8.2	0.70	73%

In CC mode, the system provides 1.0 A at 9.5 V, ensuring fast charging, and transitions smoothly to CV mode at 12 V with current reduced to 0.45 A. This validates safe battery charging with controlled voltage and gradual current reduction.

TABLE II. CC–CV CHARGING MODE ANALYSIS

Charging Stage	Mode	Voltage (V)	Current (A)	Observation
Initial Stage	Constant Current	9.5	1.0	Fast charging, stable current
Mid Stage	CC → CV Transition	10.8	0.85	Smooth transition
Final Stage	Constant Voltage	12.0	0.45	Current decreases, prevents overcharging

The proposed system improves efficiency from ~75% to ~90%, with enhanced power stability and smooth CC–CV transition compared to existing systems. It also reduces communication dependency while increasing reliability from medium to high.

TABLE III. POWER BALANCE COMPARISON

Parameter	**Existing System**	**Proposed System**
Power Stability	Moderate	High
CC–CV Transition	Unstable	Smooth
Communication Dependency	High	Low
Charging Efficiency	~75%	~90%
Reliability	Medium	High

Under perfect alignment, the system achieves 11.5 V and 91% efficiency, which decreases to 7.5 V and 65% efficiency under high misalignment. This highlights the significant impact of alignment on performance while maintaining acceptable efficiency (84%) under slight misalignment.

TABLE IV. EFFECT OF COIL ALIGNMENT

Alignment Condition	**Output Voltage (V)**	**Efficiency (%)**	**Observation**
Perfect Alignment	11.5	91%	Maximum power transfer
Slight Misalignment	10.2	84%	Minor loss
Moderate Shift	9.0	76%	Noticeable drop
High Misalignment	7.5	65%	Significant loss

Fig.4 illustrates the relationship between transmission distance and power transfer efficiency. It is observed that the efficiency decreases from 91% at 2 cm to 73% at 8 cm, indicating that increasing the air gap between coils reduces magnetic coupling. This result highlights the importance of maintaining optimal distance to achieve maximum efficiency in wireless power transfer systems

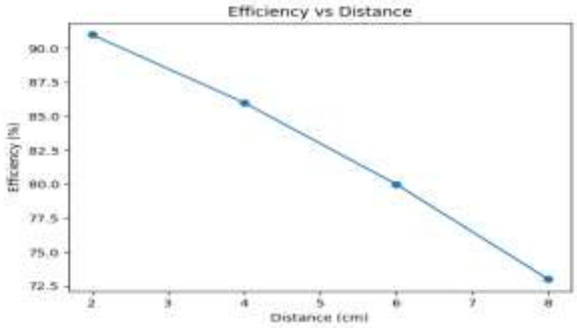

Fig. 4. Efficiency vs Distance

Fig.5 represents the charging characteristics of the system under CC–CV operation. Initially, the system operates in Constant Current mode at 1.0 A and 9.5 V, ensuring rapid charging. As the voltage increases to 12 V, the system transitions to Constant Voltage mode, where the current gradually decreases to 0.45 A, ensuring safe and controlled battery charging.

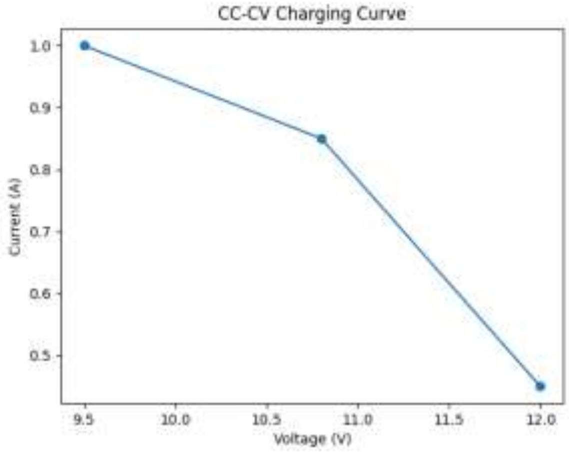

Fig. 5. CC–CV Charging Curve

Fig.6 shows the impact of coil alignment on system efficiency. Under perfect alignment, the system achieves 91% efficiency, which decreases to 65% under high misalignment. The results demonstrate that misalignment significantly affects performance, although the system maintains acceptable efficiency (84%) under slight misalignment conditions.

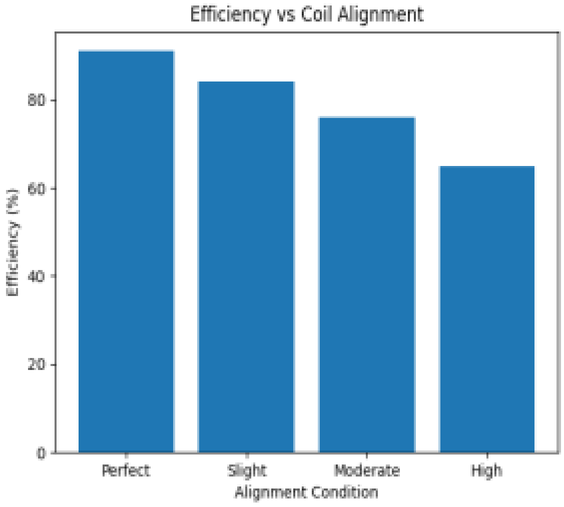

Fig. 6. Efficiency vs Coil Alignment

Fig.7 represents the distribution of input power in the system. Approximately 90% of the input power is effectively transferred as useful output, while 10% is lost due to factors such as heat dissipation, coil resistance, and misalignment. This confirms that the proposed system achieves high overall efficiency.

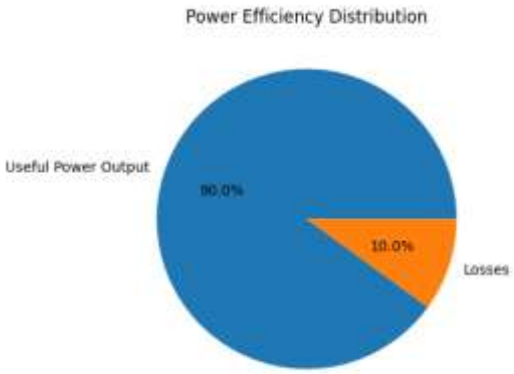

Fig. 7. Power Efficiency Distribution

V. CONCLUSION AND FUTURE SCOPE

This paper presented a power-balanced CC–CV wireless EV charging system based on inductive power transfer. The proposed system successfully integrates solar-assisted power supply, Arduino-based control, and efficient rectification with DC–DC conversion to achieve reliable wireless charging. Experimental results demonstrate that the system achieves a maximum efficiency of 91% at 2 cm and maintains acceptable performance of 73% at 8 cm. The CC–CV charging strategy ensures safe operation, delivering 1.0 A at 9.5 V in CC mode and maintaining 12 V with reduced current (0.45 A) in CV mode. Compared to conventional systems (~75% efficiency), the proposed method improves efficiency to approximately 90% while reducing communication dependency. Overall, the system provides a stable, efficient, and eco-friendly wireless charging solution, making it suitable for next-generation EV applications. The proposed method can be extended with Improve efficiency beyond 91% using advanced coil design and compensation techniques.

REFERENCES

[1] S. Bhattacharya and Y.K. Tan, “Design of static wireless charging coils for integration into electric vehicle,” *Proc. IEEE ICSET*, Nepal, 2012. [Online]. Available: https://doi.org/10.1109/icset.2012.6357389

[2] X. Mou and H. Sun, “Wireless power transfer: survey and roadmap,” *Proc. IEEE 81st Vehicular Tech Conf.*, Glasgow, UK, 2015. [Online]. Available: https://doi.org/10.1109/vtcspring.2015.7146165

[3] Supriyadi, Edi Rakhman, Suyanto, Arif Rahman, and Noor Cholis Basjaruddin, “Development of a Wireless Power Transfer Circuit Based on Inductive Coupling,” *TELKOMNIKA*, Vol.16, No.3, June 2018. [Online]. Available: http://journal.uad.ac.id/index.php/TELKOMNIKA/about/contact

[4] H.S. Das, M.M. Rahman, S. Li, and C.W. Tan, “Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review,” *The University of Alabama, Tuscaloosa, USA.*

[5] Young Jae Jang, “Survey of the operation and system study on wireless charging electric vehicle systems,” *Department of Industrial and Systems Engineering.*

[6] Huan Ngo et al., “Optimal positioning of dynamic wireless charging infrastructure in a road network for battery electric vehicles,” 2020.

[7] Muhammad Adil et al., “A Reliable Sensor Network Infrastructure for Electric Vehicles to Enable Dynamic Wireless Charging Based on Machine Learning Technique,” 2020.

[8] Altynay Smagulova et al., “Simulation Analysis of PI and Fuzzy Controller for Dynamic Wireless Charging of Electric Vehicle,” 2020.

[9] Partha Sarathi Subudhi et al., “Wireless Power Transfer Topologies Used for Static and Dynamic Charging of EV Battery: A Review,” 2020.

[10] Aqueel Ahmad et al., "A Comprehensive Review of Wireless Charging Technologies for Electric Vehicles," 2017.

[11] C. Lee, G. Jung, K. Hosani, B. Song, D. Seo, and D. Cho, "Wireless Power Transfer System for an Autonomous Electric Vehicle," *IEEE Wireless Power Transfer Conference*, Nov 15-19, 2020.

[12] S. Wang, Y. Liu, C. Jiang, X. Wu, and B. Wei, "Maximum Efficiency Tracking for Dynamic WPT System Based on Optimal Input Voltage Matching," *IEEE Access*, vol. 8, pp. 215224-215234, Dec. 2020.

[13] B.G. Abhinandh, P.K. Preetha, and C.A. Asha, "Solar Integrated Electric Spring for Hospital ICU," *2019 Innovations in Power and Advanced Computing Technologies (i-PACT)*, pp. 8960101, 2019.

[14] H. HeA, H. Aswathy, G.M. Sukumar, M.S. Swapnil, C.A. Asha, and V.R. Pandi, "Solar Powered Intelligent Electric Wheelchair with Health Monitoring System," *Proceedings of 2017 IEEE International Conference on Technological Advancements in Power and Energy*, pp. 1-5, 2018.

[15] F. Lu, H. Zhang, and C. Mi, "A review on the recent development of capacitive wireless power transfer technology," *MDPI Energies*, vol. 10, no. 11, pp. 1752, 2017.

[16] A. Farghly, A. Mohamed, H. Awad, *et al.*, "A Comprehensive Review of Wireless Power Transfer Techniques for Electric Vehicle Charging," *IEEE Access*, 2024.

[17] B. Latha, "Advances in EV Wireless Charging Technology," *Sustainable Energy Systems*, 2024.

[18] O. Abuajwa, "Comprehensive Review of Wireless Power Transfer Systems for Electric Vehicles," *Springer Nature*, 2025.

[19] Z. Xue, "Critical Review of Wireless Charging Technologies for Electric Vehicles," *MDPI World Electric Vehicle Journal*, 2025.

[20] I. Ayoade, "Design and Experimental Analysis of High-Power Wireless EV Charging System," *Frontiers in Future Transportation*, 2026.

[21] A. Shahin, "Integration of Renewable Energy Sources with Wireless EV Charging Systems," *IEEE Access*, 2024.

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