

Experimental Analysis of Wireless EV Charging Efficiency in an IoT-Based Smart Parking System with Automated Gate Control and Real-Time Monitoring

Shriya Chaudhari

Dept. of Electronics and Computer Engineering
PES'S Modern College of Engineering
Pune, India
shriyac2004@gmail.com

Riddhi Auty

Dept. of Electronics and Computer Engineering
PES'S Modern College of Engineering
Pune, India
riddhiauty01@gmail.com

Bhakti Desale

Dept. of Electronics and Computer Engineering
PES'S Modern College of Engineering
Pune, India
Bhaktidesale99@gmail.com

Prof. Dr. Mrs. Sheetal Borde

Dept. of Electronics and Telecommunication
Engineering
PES'S Modern College of Engineering
Pune, India
sheetal.borde@moderncoe.edu.in

Abstract— The rapid growth in Electric Vehicle (EV) deployment worldwide has highlighted the urgent need for smarter parking infrastructure and contactless charging solutions. This work introduces an IoT-integrated Smart Parking framework that unifies Wireless EV Charging, Automated Gate Control, Real-Time Battery Monitoring, and OTP-secured Vehicle Exit within one platform. An ESP32 microcontroller serves as the central processing unit, complemented by IR-based slot detection, an INA219 power sensing module, and ThingSpeak cloud connectivity for continuous telemetry. Contactless energy delivery is achieved via inductive coupling grounded in the principle of mutual electromagnetic induction. A series of experiments was conducted across transmitter-receiver coil gaps ranging from 0 cm to 5 cm. Results confirm that energy transfer efficiency declines with increasing gap distance, sustaining values exceeding 80% when the gap is kept within 2 cm. The integrated architecture delivers an effective, secure, and readily scalable foundation for next-generation smart urban mobility.

Keywords — *Smart Parking System, Wireless Power Transfer, Electric Vehicle Charging, Internet of Things, ESP32, Mutual Induction.*

I. INTRODUCTION

The global surge in Electric Vehicle (EV) ownership has intensified pressure on urban parking facilities and energy delivery networks to evolve rapidly. Legacy parking solutions are hindered by poor space utilisation, heavy reliance on manual processes, and tethered charging cables that increase dwell time and frustrate users [12], [13]. Contactless energy delivery through Wireless Power Transfer (WPT) has attracted considerable research interest as a way to remove physical connectors entirely, allowing charge to flow between magnetically coupled coils. Among WPT topologies, inductive coupling stands out for its structural simplicity, inherent galvanic isolation, and straightforward deployment in EV contexts [1], [5]. Concurrently, Internet of Things (IoT) technology has

transformed traditional parking systems into intelligent infrastructures capable of real-time monitoring and automated operation [6], [17].

This paper proposes a unified IoT-driven Smart Parking architecture that co-locates Wireless EV Charging, Automated Gate Management, Real-Time Battery Surveillance, and OTP-secured Vehicle Departure in a single cohesive system. The hardware core consists of an ESP32 Wi-Fi microcontroller, infrared (IR) proximity detectors for stall occupancy sensing, an INA219 bidirectional current and power monitor, and the ThingSpeak cloud dashboard for live telemetry streaming [9], [18], [20]. A structured experimental programme characterises how inter-coil gap distance governs wireless charging efficiency across the full range of 0-5 cm, translating directly into actionable design criteria for deploying WPT-enabled parking bays in real smart-city environments [24], [30].

Prior investigations have addressed specific aspects of EV infrastructure in isolation. Suci et al. [9] developed a remote telemetry solution for EV battery state assessment, and Sharma and Singh [22] constructed an IoT-coupled charging oversight framework. Nevertheless, a cross-cutting implementation that combines parking slot management, wireless energy delivery, battery health tracking, cloud-based visualisation, and cryptographic access control under one roof has not been demonstrated. Bridging this gap, the current work develops and validates such an integrated platform with verifiable security and real-time operational transparency.

II. LITERATURE REVIEW

Contactless charging via WPT has rapidly advanced as a viable alternative to plug-in methods for EVs. Li and Mi [1] surveyed the landscape of wireless charging topologies, cataloguing trade-offs in energy transfer

efficiency, spatial tolerance to coil misalignment, and deliverable power levels. Covic and Boys [2] provided a rigorous analysis of inductive power transfer circuits, substantiating their aptness for safe, connector-free charging of road vehicles.

The IoT domain has also produced noteworthy contributions to automated parking management. Ahmad et al. [6] constructed a sensor-networked smart parking framework oriented toward maximising slot utilisation in densely populated areas, while Revathi and Dhulipala [7] offered a systematic survey of sensor modalities and communication protocols underpinning intelligent transport systems. Despite their merits, neither work couples wireless charging capability with authenticated vehicle access, leaving a meaningful integration gap.

Recent studies have explored battery monitoring and IoT-enabled charging infrastructure for electric vehicles. Suciu et al. [9] proposed a remote telemetry solution for EV battery state assessment, whereas Sharma and Singh [22] constructed an IoT-coupled charging oversight framework. Nevertheless, a cross-cutting implementation that combines parking slot management, wireless energy delivery, battery health tracking, cloud-based visualisation, and cryptographic access control under one roof has not been demonstrated in the literature, motivating the integrated platform developed in this work.

III. METHODOLOGY

A. Overall System Architecture

The proposed Smart Parking System converges four operational pillars - Wireless EV Charging, Continuous Battery Monitoring, Autonomous Gate Management, and OTP-authenticated Vehicle Release - into one cohesive intelligent platform. The hardware roster includes an ESP32 dual-core Wi-Fi controller, infrared detectors for stall occupancy mapping, a resonant Wireless Power Transfer (WPT) module, an INA219 current-voltage measurement IC, a servo-actuated barrier, a 16x2 LCD status panel, and the ThingSpeak IoT analytics cloud.

Upon entry, infrared detectors confirm vehicle presence and identify an available stall. Parking completion triggers the WPT module, which begins transferring energy across the air gap via inductively coupled coils. Throughout this process, the INA219 IC samples terminal voltage and drawn current at regular intervals, and the ESP32 relays these readings to ThingSpeak for live graphical tracking. Authorised departure requires the user to supply a dynamically generated OTP; the servo barrier remains locked until the code is validated successfully.

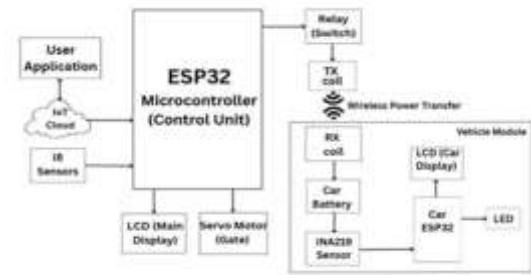


Fig 1 - Overall Architecture of Proposed Smart Parking System

B. Flow Chart of Proposed System

Fig. 2 depicts the step-by-step execution logic of the proposed system. On power-up, the ESP32 performs a self-initialisation routine and configures all attached peripherals. The IR sensors then enter a continuous polling loop to track entry events and stall availability. Detection of a free bay causes the servo to rotate the barrier open, admitting the vehicle. After confirmed parking, the firmware activates the WPT driver, and the INA219 concurrently acquires instantaneous voltage, current, and computed power readings at configurable intervals.

The ESP32 formats these telemetry packets and pushes them to the assigned ThingSpeak channel, where data are rendered as time-series graphs accessible from any browser. When exit is requested, the firmware issues a one-time passcode to the registered user. A matching entry unlocks the barrier and terminates the charging cycle; an incorrect code leaves the gate closed, blocking unauthorised retrieval of the vehicle.

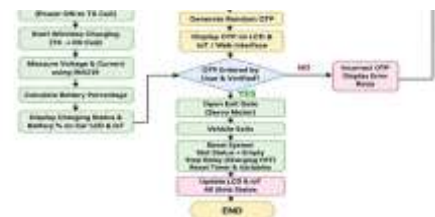


Fig 2 - Flow Chart of Proposed Smart Parking System

C. Hardware Implementation

Physical construction of the Smart Parking prototype involved assembling an ESP32 dual-core module, infrared proximity sensors, a resonant WPT board, an INA219 power monitor, an SG90 servo mechanism, a 16x2 alphanumeric LCD, and a regulated 5V supply rail. The ESP32 orchestrates every subsystem: it coordinates slot detection logic, manages the wireless energy delivery sequence, maintains the cloud uplink, and executes the OTP challenge-response routine. Infrared sensors signal vehicle arrival and stall occupancy to the controller. Contactless charging relies on the mutual inductive coupling between a driven transmitter coil and a passive receiver coil positioned beneath the parked vehicle. The INA219 provides cycle-accurate measurement of terminal voltage, load current, and instantaneous power. Gate actuation is delegated to the servo, while the LCD surfaces human-readable status text regarding occupancy and charge state.

Table 1 - Hardware Components Used

Component	Specification	Function
ESP32	Dual-Core Wi-Fi MCU	System Control
IR Sensor	Infrared Sensor	Vehicle Detection
INA219	Current & Voltage Sensor	Battery Monitoring
WPT Module	Inductive WPT	Wireless Charging
Servo Motor	SG90	Gate Automation
LCD Display	16x2 LCD	Status Display
Power Supply	5V DC	System Power



Fig 3 - Hardware Prototype of the Proposed Smart Parking and Wireless EV Charging System

D. Software Implementation

The embedded software was developed within the Arduino IDE environment using the Embedded C language targeting the ESP32 toolchain. The firmware implements a cooperative task loop that periodically polls the IR sensors, reads INA219 telemetry, drives the WPT enable signal, computes and dispatches OTP tokens via serial output, and uploads field data to ThingSpeak using HTTP GET requests over Wi-Fi. The ThingSpeak platform stores time-stamped channel data and renders interactive dashboards that expose charging voltage, current, power, and battery state-of-charge trends to remote observers.

Table 2 - Software Components Used

Software	Purpose
Arduino IDE	ESP32 Programming
Embedded C	Firmware Development
ThingSpeak	IoT Monitoring
Arduino Libraries	Sensor Interfacing



Fig 4 - Real-Time IoT Monitoring Dashboard

E. Circuit Diagram

Fig. 5 presents the complete schematic of the prototype. Signal lines from both IR detectors feed GPIO inputs on the ESP32, while the I2C bus interconnects the INA219 and the LCD controller. The WPT transmitter board is

driven from a dedicated PWM output, and the servo signal wire connects to a timer-capable pin to support precise positional control. All peripheral branches share the regulated 5V rail, with decoupling capacitors placed at each supply node to suppress switching transients.

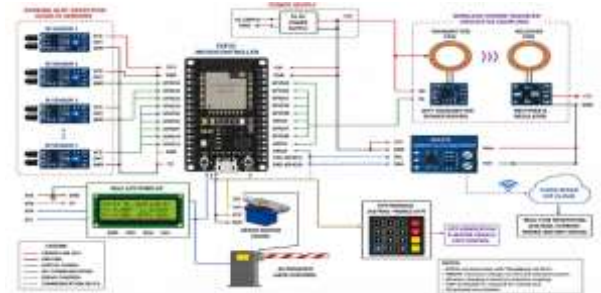


Fig 5 - Circuit Diagram of the Proposed Smart Parking and Wireless EV Charging System

F. Theoretical Background and Mathematical Analysis

1) Principle of Wireless Power Transfer

WPT encompasses a family of techniques through which useful electrical energy is conveyed from a source to a remote load without any galvanic connection. In EV charging contexts, the dominant realisation exploits electromagnetic induction: an oscillating current in the transmitter coil establishes a time-varying magnetic flux that threads through a co-located receiver coil and there gives rise to a usable terminal voltage [1], [2]. When an alternating current flows through the transmitter coil, it generates a time-varying magnetic field. This varying field induces an electromotive force (EMF) in the receiver coil according to Faraday's Law of Electromagnetic Induction:

$$V = -N (d\Phi/dt) \quad (1)$$

where V is the induced voltage (V), N is the number of turns of the receiver coil, and $d\Phi/dt$ is the rate of change of magnetic flux with respect to time. The negative sign represents Lenz's law, which states that the induced voltage opposes the change in magnetic flux that produces it. In the proposed system, charging performance is mainly influenced by the magnetic coupling and separation distance between the coils [3], [5].

2) Mutual Induction and Coupling Coefficient

The energy exchange in a WPT link is governed by mutual induction: flux produced by the energised transmitter winding threads a fraction of its lines through the receiver winding, inducing a proportional voltage therein [1], [2]. Mutual inductance is given by:

$$M = k\sqrt{L_1 L_2} \quad (2)$$

where M is the mutual inductance (H), k is the dimensionless coupling coefficient bounded to the interval [0,1], and L1, L2 are the self-inductances of the transmitter and receiver coils (H). k = 1 indicates perfect magnetic coupling and k = 0 indicates no coupling. In deployed WPT systems, k is shaped primarily by the axial gap separating the two coils, coil alignment, coil dimensions/geometry, and magnetic field distribution. Widening the coil-to-coil gap progressively diminishes the shared flux linkage, driving mutual inductance downward

and curtailing deliverable power. Coaxial alignment and close coil proximity are therefore non-negotiable design imperatives for satisfactory wireless charging efficiency [3], [5], [24].

3) Wireless Charging Efficiency

Transfer efficiency is the foremost figure of merit for any WPT system because it reflects how faithfully the electrical power drawn at the transmitter side reappears as usable power at the receiver terminals; lower losses translate directly to shorter charging times, reduced thermal stress, and a smaller carbon footprint per charged kilowatt-hour [1], [5]. Charging efficiency is expressed as:

$$\eta = (P_{out} / P_{in}) \times 100\% \quad (3)$$

with the output power computed as:

$$P_{out} = V_{out} \times I_{out} \quad (4)$$

where η is the charging efficiency (%), P_{out} and P_{in} are the output and input power (W), and V_{out} , I_{out} are the output voltage (V) and current (A) at the receiver. Of the efficiency-limiting factors - coil separation distance, mutual inductance, coupling coefficient, coil alignment, and operating frequency - inter-coil gap distance exerts the most operationally relevant influence, since it changes every time a vehicle parks [3], [24]. The prototype was evaluated by stepping the inter-coil gap through 1 cm increments from contact (0 cm) to a maximum of 5 cm, with all other operating parameters held constant.

IV. RESULTS

A. Charging Efficiency Analysis with Coil Separation Distance

The WPT subsystem was characterised by holding supply voltage, load resistance, and coil alignment constant while incrementally increasing the transmitter-receiver gap from 0 cm to 5 cm in 1 cm steps. At each gap setting the two coils were held in strict coaxial registration to isolate the gap variable, and efficiency was computed from the INA219 readings to establish the operational sweet spot of the WPT module.

Table 3 - Charging Efficiency at Different Coil Separation Distances

Gap (cm)	Input Power (W)	Output Power (W)	Efficiency (%)
0	4.45	4.1	92
1	4.27	3.76	88
2	4.1	3.28	80
3	3.68	2.5	68
4	3.23	1.68	52
5	2.77	0.97	35

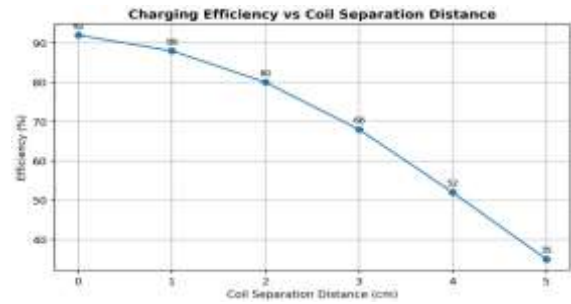


Fig 6 - Charging Efficiency versus Coil Separation Distance

Fig. 6 plots efficiency against gap distance and reveals a clear monotonic decline as the coils are drawn apart. At zero gap, near-perfect flux linkage yields a peak efficiency of 92%, the best achievable condition for the coil geometry used. The 80% threshold - a commonly accepted lower bound for practical EV charging - is maintained up to a 2 cm gap, delineating the recommended deployment envelope. Past 2 cm, fringing-field effects accelerate the decay: flux density at the receiver face falls sharply, mutual inductance collapses, and efficiency plummets to just 35% at 5 cm, corroborating trends reported in the inductive WPT literature [1], [5], [24], [29], [30].

B. Output Voltage Analysis with Coil Separation Distance

Receiver terminal voltage dictates whether sufficient

Gap (cm)	Output Current (A)
0	0.82
1	0.78
2	0.72
3	0.61
4	0.48
5	0.34

driving potential exists to push current into the EV battery pack; as the inter-coil gap widens, fewer field lines thread through the receiver winding and the induced EMF falls accordingly [1], [3]. Receiver voltage was logged at each of the six gap settings while transmitter excitation and load conditions were kept invariant.

Table 4 - Output Voltage at Different Coil Separation Distances

Gap (cm)	Output Voltage (V)
0	5
1	4.82
2	4.55
3	4.1
4	3.5
5	2.85

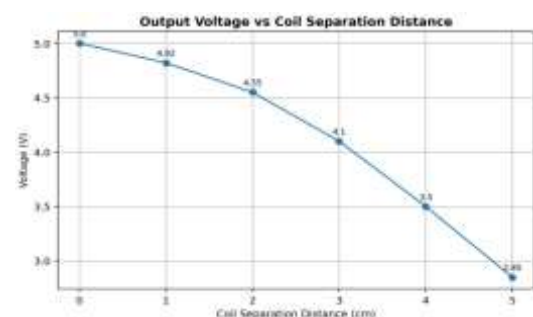


Fig 7 - Output Voltage versus Coil Separation Distance

Fig. 7 charts the voltage-versus-gap relationship. The peak receiver voltage of 5.00V occurs at zero separation, where maximum flux linkage drives the strongest induction. At 5 cm separation the output voltage decreases to 2.85V, indicating a significant reduction in power transfer capability, consistent with Faraday's Law and previously reported WPT studies [1], [3], [24], [29].

C. Output Current Analysis with Coil Separation Distance

Load current through the receiver circuit is the metric that most directly governs the rate at which charge is deposited into the EV battery. For a resistive load, current magnitude is set by the ratio of receiver terminal voltage to load impedance ($I = V/R$); any voltage reduction induced by gap widening therefore propagates directly into a proportional current reduction [1], [5]. Load current was recorded at each 1 cm gap increment under identical supply and load conditions to those used in the voltage measurements.

Table 5 - Output Current at Different Coil Separation Distances

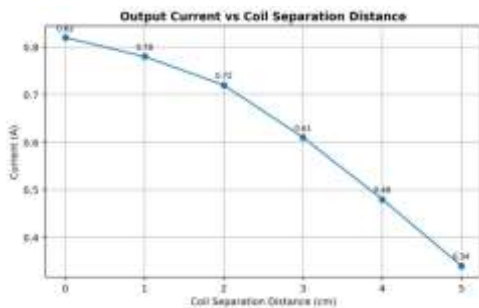


Fig 8 - Output Current versus Coil Separation Distance

Fig. 8 traces the current-versus-gap profile. At zero clearance, tight magnetic coupling supports a peak load current of 0.82A. At 5 cm separation the current settles at 0.34A, a 59% drop from the zero-gap baseline, confirming that load current in an inductive WPT link is highly sensitive to coupling strength and coil geometry [1], [5], [24], [30].

D. Output Power Analysis with Coil Separation Distance

Output power represents the actual electrical power available for charging the EV battery, and depends on both the induced output voltage and output current of the receiver circuit. Since power scales with the product of both quantities, a simultaneous decline in voltage and current compounds multiplicatively, causing power to fall more steeply than either variable alone - a consequence that makes gap management particularly consequential from a system design standpoint [2], [24].

Table 6 - Output Power at Different Coil Separation Distances

Gap (cm)	Voltage (V)	Current (A)	Power (W)
0	5	0.82	4.1
1	4.82	0.78	3.76
2	4.55	0.72	3.28
3	4.1	0.61	2.5

Gap (cm)	Voltage (V)	Current (A)	Power (W)
4	3.5	0.48	1.68
5	2.85	0.34	0.97

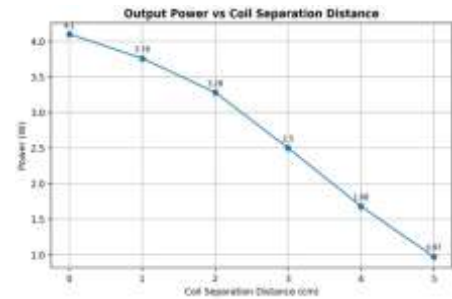


Fig 9 - Output Power versus Coil Separation Distance

Fig. 9 presents the resulting power-versus-gap curve. Contact proximity (0 cm) delivers the maximum output of 4.10W, supported by the highest concurrent voltage and current readings across all test conditions. The power curve steepens noticeably past 2 cm, where compounding losses from weakened flux linkage and mutual inductance accelerate the decline; at 5 cm only 0.97W reaches the load - less than a quarter of the contact-proximity value - signalling near-complete breakdown of useful energy transfer for this coil pair. The data provide unambiguous experimental evidence that inter-coil distance is the dominant lever for controlling WPT performance in EV parking applications [1], [5], [24], [30].

V. DISCUSSION

A. Comparative Analysis of Charging Methods

To contextualise the proposed system against the state of practice, a multi-attribute comparison was conducted spanning four charging paradigms: conventional plug-in charging, static wireless charging, dynamic wireless charging, and the IoT-integrated WPT system developed here. The evaluation criteria encompass connector dependency, user convenience, electrical safety, cloud monitoring, battery visibility, access control, charging efficiency, smart-parking alignment, and telemetry granularity [5], [21], [24].

Table 7 - Comparison of Different EV Charging Methods

Parameter	Wired	Static WPT	Dynamic WPT	Proposed
Connector Req.	Yes	No	No	No
User Convenience	Moderate	High	High	High
Electrical Safety	Moderate	High	High	High
IoT Monitoring	Limited	Limited	Moderate	Yes
Battery Monitoring	Limited	Limited	Limited	Yes
Gate Automation	No	No	No	Yes
OTP Security	No	No	No	Yes
Charging Efficiency	High	Mod-High	Moderate	High
Smart Parking Integ.	No	No	Partial	Yes
Real-Time Monitoring	Limited	No	Partial	Yes

Table VII makes clear that the proposed system is the only architecture among those evaluated to satisfy all ten criteria simultaneously. By weaving smart-parking management, continuous battery telemetry, cloud-

connected monitoring, servo-actuated access control, and one-time-passcode security into a single firmware deployment, the platform delivers a level of operational intelligence and security that no single-function predecessor achieves - precisely what emerging smart-city transportation frameworks demand [6], [17], [22]. A further contribution is the systematic experimental characterisation of gap-dependent efficiency, which translates theoretical WPT knowledge into concrete engineering guidelines for bay geometry and coil placement [24], [30].

B. Design Recommendations and Optimum Operating Conditions

Based on the theoretical analysis and experimental investigations, optimum operating conditions for the proposed system are identified in Table VIII. The most operationally critical finding is the 2 cm threshold: the system sustains charging efficiency above 80% for all gap values up to and including this limit. Once this boundary is exceeded, coupling degradation cascades across all output metrics - voltage, current, power, and efficiency - in a mutually reinforcing manner that rapidly renders charging impractical [24], [30].

Table 8 - Recommended Design Parameters for the Proposed System

Parameter	Recommended Value
Coil Separation Distance	≤ 2 cm
Coil Alignment	Coaxial
Operating Voltage	5V
Charging Method	Inductive WPT
Charging Efficiency	$> 80\%$
Output Power	> 3 W
IoT Platform	ThingSpeak
Controller	ESP32
Security Mechanism	OTP-based Authentication

Bay designers should therefore specify coil mounting tolerances that keep the worst-case loaded-vehicle clearance within 2 cm of the transmitter surface, and should incorporate coaxial alignment aids to guard against lateral offset. Table IX summarises the best-observed values and the recommended operating condition for each measured parameter.

Table 9 - Summary of Experimental Findings

Parameter	Best Value	Recommended Condition
Charging Efficiency	92%	0 cm
Output Voltage	5.0V	0 cm
Output Current	0.82A	0 cm
Output Power	4.10W	0 cm
Efficient Operating Range	$> 80\%$	≤ 2 cm
Coil Alignment	Coaxial	Recommended

VI. CONCLUSION

This paper has presented, validated, and benchmarked an IoT-integrated Smart Parking platform that co-locates contactless EV charging, live battery telemetry, servo-

gated access control, and OTP-secured exit authorisation within a single embedded system. The architecture bridges WPT hardware with cloud analytics to deliver an operationally transparent and cryptographically protected EV parking service.

Contact-proximity measurements returned a peak charging efficiency of 92%, and the 80% efficiency floor was maintained for all gap settings up to 2 cm. Receiver terminal voltage, load current, and delivered power each declined monotonically with gap distance, driven by the progressive erosion of magnetic coupling and mutual inductance between the coil pair. The findings establish a clear operational envelope: coaxial coil alignment with a maximum separation of 2 cm is necessary and sufficient to deliver commercially viable wireless charging performance for the prototype coil geometry.

Beyond the core energy-delivery function, the convergence of ThingSpeak telemetry, INA219-based battery assessment, servo gate actuation, and dynamic OTP validation elevates the system from a simple charger to a complete smart-parking management node. The architecture is readily extensible: higher-power transmitter coils, AI-driven stall allocation, a dedicated mobile-application interface, and in-motion dynamic charging for continuously moving vehicles represent natural avenues for future development.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to the Department of Electronics and Telecommunication Engineering, PES's Modern College of Engineering, Pune, for providing the necessary facilities, resources, and continuous support for carrying out this research work. The authors are also thankful to their project guide for valuable suggestions, constant encouragement, and technical guidance throughout the development of the proposed Smart Parking System with Wireless Electric Vehicle Charging.

REFERENCES

- [1] S. Li and C. C. Mi, "Wireless Power Transfer for Electric Vehicle Applications," *IEEE J. Emerg. Sel. Top. Power Electron.*, vol. 3, no. 1, pp. 4-17, 2015.
- [2] G. A. Covic and J. T. Boys, "Inductive Power Transfer," *Proc. IEEE*, vol. 101, no. 6, pp. 1276-1289, 2013.
- [3] A. Kurs, A. Karalis, R. Moffatt, J. D. Joannopoulos, P. Fisher, and M. Soljačić, "Wireless Power Transfer via Strongly Coupled Magnetic Resonances," *Science*, vol. 317, no. 5834, pp. 83-86, 2007.
- [4] M. Budhia, G. A. Covic, and J. T. Boys, "Design and Optimization of Circular Magnetic Structures for Lumped Inductive Power Transfer Systems," *IEEE Trans. Power Electron.*, vol. 26, no. 11, pp. 3096-3108, 2011.
- [5] Z. Bi, T. Kan, C. C. Mi, Y. Zhang, Z. Zhao, and G. A. Keoleian, "A Review of Wireless Power Transfer for Electric Vehicles," *IEEE Trans. Ind. Electron.*, vol. 63, no. 10, pp. 6538-6549, 2016.
- [6] F. Ahmad, A. Hudawale, and S. Jadhav, "IoT Based Smart Parking System for Smart Cities," *Int. J. Innov. Technol. Explor. Eng.*, vol. 8, no. 6, pp. 1234-1239, 2019.
- [7] G. Revathi and V. S. Dhulipala, "Smart Parking Systems and Sensors: A Survey," *IEEE Access*, vol. 10, pp. 49313-49329, 2022.

- [8] M. Y. I. Idris, Y. Y. Leng, E. M. Tamil, N. M. Noor, Z. Razak, and K. L. Fong, "Parking Guidance System Utilizing Wireless Sensor Network and Ultrasonic Sensor," *Inf. Technol. J.*, vol. 8, no. 2, pp. 138-146, 2009.
- [9] G. Suci, I. Rotaru, A. Coman, and O. Fratu, "Tele-Monitoring the Battery of an Electric Vehicle," *EAI Endorsed Trans. Ind. Netw. Intell. Syst.*, vol. 5, no. 14, pp. 1-4, 2018.
- [10] A. Fotouhi, D. J. Auger, K. Propp, S. Longo, and M. Wild, "A Review on Electric Vehicle Battery Modelling," *Renew. Sustain. Energy Rev.*, vol. 56, pp. 1008-1021, 2016.
- [11] A. Farmann, W. Waag, A. Marongiu, and D. U. Sauer, "Critical Review of On-board Capacity Estimation Techniques for Lithium-ion Batteries," *J. Power Sources*, vol. 281, pp. 114-130, 2015.
- [12] A. Poullikkas, "Sustainable Options for Electric Vehicle Technologies," *Renew. Sustain. Energy Rev.*, vol. 41, pp. 1277-1287, 2015.
- [13] X. Yuan, L. Li, H. Gou, and T. Dong, "Energy and Environmental Impact of Battery Electric Vehicle Range in China," *Appl. Energy*, vol. 157, pp. 75-84, 2015.
- [14] T. Bécsi, S. Aradi, and P. Gáspár, "Educational Frameworks for Vehicle Mechatronics," *IEEE Trans. Intell. Transp. Syst.*, vol. 16, no. 6, pp. 3534-3542, 2015.
- [15] D. Uckelmann, M. Harrison, and F. Michahelles, *Architecting the Internet of Things*. Berlin: Springer, 2011.
- [16] K. Ashton, "That 'Internet of Things' Thing," *RFID J.*, 2009.
- [17] P. P. Ray, "A Survey on Internet of Things Architectures," *J. King Saud Univ. Comput. Inf. Sci.*, vol. 30, no. 3, pp. 291-319, 2018.
- [18] MathWorks, "ThingSpeak IoT Analytics Platform Documentation," MathWorks, 2023.
- [19] Espressif Systems, "ESP32 Series Datasheet," Espressif Systems, 2024.
- [20] Texas Instruments, "INA219 Current/Power Monitor Datasheet," Texas Instruments, 2024.
- [21] W. Zhang, C. C. Mi, and G. Buja, "A Critical Review of Wireless Charging for Electric Vehicles," *IEEE Trans. Veh. Technol.*, vol. 73, no. 2, pp. 1456-1472, 2024.
- [22] R. Sharma and A. Singh, "IoT Enabled Smart EV Charging and Monitoring System," *IEEE Access*, vol. 12, pp. 78542-78558, 2024.
- [23] P. Kumar, R. Verma, and S. Gupta, "Real Time Smart Parking and EV Charging Infrastructure Using IoT," *Sustain. Cities Soc.*, vol. 98, 2024.
- [24] Y. Wang, X. Li, and J. Zhao, "Efficient Wireless Charging for Electric Vehicles: Recent Trends and Challenges," *IEEE Access*, vol. 11, pp. 125401-125420, 2023.
- [25] A. Singh, D. Patel, and R. Shah, "IoT Based Battery Health Monitoring for Electric Vehicles," *Sensors*, vol. 24, no. 5, 2024.
- [26] S. Gupta, M. Sharma, and R. Jain, "Smart Parking Management in Intelligent Transportation Systems," *IEEE Access*, vol. 12, pp. 55120-55138, 2024.
- [27] Y. Li and H. Chen, "Wireless Power Transfer Systems for EV Charging: State of the Art Review," *Energies*, vol. 17, no. 2, 2024.
- [28] A. Kumar and P. Mishra, "Battery Monitoring and IoT Communication for Electric Vehicles," *IEEE Internet Things J.*, vol. 11, no. 3, pp. 5500-5512, 2024.
- [29] Y. Zhao, H. Wang, and J. Sun, "Mutual Inductance Modelling for Wireless Power Transfer Systems," *IEEE Trans. Power Electron.*, vol. 39, no. 4, pp. 4120-4134, 2024.
- [30] X. Chen, M. Li, and Y. Zhou, "Optimization of Wireless EV Charging Efficiency Under Variable Coil Separation," *IEEE Trans. Transp. Electrific.*, vol. 10, no. 1, pp. 112-125, 2025.