

Article

Design and Experimental Validation of an Inductive Wireless Power Transfer Platform for Static EV Charging

Nikolay Madzharov¹ and Nikolay Hinov^{2,3,*} 

¹ Department of Electronics, Faculty of Electrical Engineering and Electronics, Technical University of Gabrovo, 4 H. Dimitar, 5300 Gabrovo, Bulgaria; madjarov@tugab.bg

² CoE “National Center of Mechatronics and Clean Technologies”, 1000 Sofia, Bulgaria

³ Department of Computer Systems, Faculty Computer Systems and Technology, Technical University of Sofia, 8, Kliment Ohridski Blvd, 1000 Sofia, Bulgaria

* Correspondence: hinov@tu-sofia.bg; Tel.: +359-2965-2569

Abstract

This paper presents the design, prototype realization, and experimental validation of an inductive wireless power transfer (WPT) platform for static charging of electric vehicles. The study integrates magnetic-coupler design, resonant power-stage realization, and occupied-area magnetic-field assessment within a prototype-oriented engineering framework. The realized Tx/Rx magnetic assembly has dimensions of approximately $700 \times 800 \times 60$ mm per coil, an inductance of about 60 μ H, a coupling factor of about 0.45, and estimated coil losses of around 2%. The proposed system belongs to the 35 kW class, while the realized prototype was experimentally validated at a nominal 30 kW operating level, with peak capability up to 45 kW for 1 min. Experimental evaluation was carried out for air gaps up to about 100 mm, with measured transfer efficiency in the range 80–92% and favorable operation around 30 kW and a vertical air gap of approximately 70 mm. Representative occupied-area magnetic-flux-density measurements remained below the adopted 27 μ T reference level under the reported operating conditions. The results confirm the practical feasibility of the proposed static EV charging platform and support its engineering relevance for high-power inductive charging applications. Possible extension toward on-route charging is discussed only as future work.

Keywords: wireless power transfer; electric vehicle charging; inductive power transfer; static charging; magnetic coupler; resonant compensation; electromagnetic safety

1. Introduction

The rapid development of electric mobility has intensified the need for charging solutions that are not only energy-efficient, but also convenient, reliable, and suitable for seamless integration into future transport infrastructure. In this context, wireless power transfer (WPT) has emerged as a promising alternative to conventional plug-in charging because it eliminates exposed conductive interfaces, improves user comfort, and enables a higher degree of charging automation. In electric-vehicle applications, wireless charging can also reduce vulnerability to environmental conditions, mechanical wear, vandalism, and user-dependent charging behavior, while supporting more flexible infrastructure deployment in private, public, and transit environments [1–3].

Among the different wireless energy-transfer approaches, near-field inductive and resonant-inductive techniques are the most suitable for electric vehicles because they can deliver useful power levels over practical air gaps with comparatively high efficiency.



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In their simplest form, such systems operate through magnetic coupling between a transmitting coil and a receiving coil, similarly to a loosely coupled transformer [4,5]. However, unlike conventional transformers, EV charging systems usually operate with significant air gaps, limited magnetic coupling, and possible lateral misalignment between the primary and secondary pads. For that reason, the design of the magnetic coupler, the choice of resonant compensation, and the tuning of the operating frequency become critical factors that directly influence power-transfer capability, efficiency, and system stability. General WPT reviews also show that although many transmission methods exist, electromagnetic induction and resonance-enhanced inductive transfer remain the most practical options for short- and medium-range high-power applications [6–8].

Existing research and industrial developments confirm the strong potential of inductive WPT for both stationary and dynamic electric-vehicle charging. Stationary systems are intended for applications such as home charging, parking areas, depots, and opportunity charging at stops, where the vehicle is positioned over a ground pad and energy is transferred through the vehicle-mounted pickup [9,10]. Dynamic or on-route charging extends this concept by energizing road-embedded transmitting structures so that vehicles can receive power while moving or while passing over energized segments. Such an approach has the potential to reduce charging downtime, alleviate range anxiety, and decrease the need for oversized battery packs [11–13]. Previous developments reported in the literature include stationary commercial pads, public-transport charging installations, and concepts for online electric vehicles and segmented road-powered systems, demonstrating that both charging modes are technically feasible and highly relevant for future transport systems.

Despite this progress, several engineering challenges still limit the broader deployment of inductive EV charging systems. A recurring issue is the strong dependence of efficiency on the coupling factor between the transmitting and receiving coils. As the air gap increases or the relative alignment worsens, the coupling factor decreases and the transfer efficiency drops accordingly [14,15]. The geometry of the coils, the number of turns, the magnetic-core arrangement, and the shielding concept therefore play a decisive role in overall system performance. At the same time, the power-electronic interface must provide high-frequency excitation with acceptable switching losses and controllable operating conditions, while the resonant network must maintain efficient power transfer under realistic loading and geometric constraints. Prior studies have shown that impedance matching and resonant tuning can significantly improve transfer performance, but practical optimization remains strongly dependent on the intended application and package constraints [16,17].

Another important challenge is electromagnetic safety in the occupied area around the charging system. Because EV wireless chargers rely on alternating magnetic fields, their design must account not only for transferred power and efficiency, but also for magnetic-field leakage and exposure in the vicinity of the vehicle and infrastructure [18–20]. This requirement becomes even more important when a system is intended for real deployment scenarios, including public-access charging areas and on-route applications. Consequently, a practically relevant EV WPT study should not stop at conceptual circuit design, but should also include prototype-level validation and assessment of field levels around the charging platform. The literature contains examples of systems designed for improved field distribution and low electromagnetic exposure, which highlights the need to integrate performance optimization with safety-oriented verification [21,22].

In this context, the main gap addressed by the present work is the limited number of studies that combine magnetic-coupler realization, resonant power-stage integration, prototype-level validation, and occupied-area magnetic-field assessment within one application-oriented study of static EV wireless charging.

The contribution of this paper is not a general review of EV wireless charging technologies, but the design and prototype-level validation of a static WPT platform. The main contributions are as follows: (1) development of a practical coupled magnetic/electrical design procedure for a 35 kW-class inductive charging platform; (2) realization of a Tx/Rx magnetic coupler with reported dimensions, inductance, and coupling characteristics; (3) prototype-level validation of the implemented platform at a nominal 30 kW operating level under reported static charging conditions; and (4) representative occupied-area magnetic-field assessment. Dynamic or on-route charging is not experimentally validated in the present work and is discussed only as a possible direction for future extension.

2. Related Works

Wireless power transfer for electric vehicles has evolved from a primarily exploratory topic into a mature research field with clearly differentiated directions, including system-level reviews, resonant converter studies, magnetic-coupler optimization, prototype demonstrations, and safety- or standards-oriented investigations. Across this body of work, near-field inductive and resonant-inductive approaches remain the most practically relevant for EV charging because they provide a favorable compromise among transferred power, transfer distance, implementation maturity, and packaging feasibility [3–7,11,23–25].

A substantial part of the literature focuses on electrical architecture and resonant compensation. These studies address converter topologies, resonant-network selection, operating-frequency control, impedance matching, and the interaction between compensation strategy and transferred power [11–14]. Their contribution is essential for understanding the behavior of high-frequency EV charging systems, but such works often place less emphasis on the simultaneous optimization of the magnetic structure, the physical implementation constraints, and the occupied-area field distribution [26–28].

Another major research direction concerns the magnetic coupler itself. Published studies investigate coil geometry, ferrite arrangement, shielding, misalignment tolerance, leakage-field reduction, and coupling-factor improvement under constrained air gaps and realistic packaging conditions [29–31]. These contributions are especially important because the coupler directly determines the achievable power density, efficiency, field distribution, and tolerance to installation inaccuracies [30–32]. However, many of these studies optimize magnetic performance indicators in relative isolation, without carrying the design through to a fully integrated power-stage implementation and prototype-level validation [32–35].

Experimental and application-oriented publications have further demonstrated the feasibility of both stationary and dynamic EV charging. The literature includes laboratory demonstrators, public-transport charging systems, segmented transmitting structures, and roadway-oriented dynamic charging concepts [36–40]. These studies confirm the technological relevance of both static and on-route charging modes, but they often emphasize infrastructure concepts, moving-vehicle operation, or proof-of-concept functionality rather than a unified design route that consistently links coupler design, converter integration, and safety-oriented field verification.

In parallel with purely technical developments, the field has increasingly incorporated safety, interoperability, and standardization requirements. Safety-focused studies and broader system-level analyses highlight that EV wireless charging must be evaluated not only in terms of power transfer and efficiency, but also in terms of electromagnetic exposure, installation conditions, alignment reproducibility, and infrastructure compatibility [18–22]. This evolution is also reflected in normative documents such as IEC 61980 Parts 1–3 [41–43], IEC PAS 61980-5 [44], ISO 19363 [45], SAE J2954 [46], and the ICNIRP exposure guidelines [47,48], which collectively frame wireless charging as a deployment-oriented engineering system rather than as an isolated converter or magnetic-coupler problem.

Overall, the reviewed literature shows substantial progress in resonant converter design, magnetic-coupler optimization, prototype realization, dynamic charging concepts, and standards-oriented safety assessment. At the same time, these research directions are often treated separately. In this context, the present study is positioned as an application-oriented contribution that integrates magnetic-coupler design, resonant power-stage realization, prototype-level static validation, and occupied-area magnetic-field assessment within one experimentally supported workflow for static EV wireless charging. Possible extension toward on-route charging is discussed only as future work.

3. System Concept and Operating Principle

3.1. Overall Architecture of the Wireless Charging System

The proposed charger is organized as a ground-side transmitting unit, a vehicle-side receiving unit, and the associated power-electronic interface. On the primary side, a DC source feeds a full-bridge inverter and the resonant compensation network, which excite the transmitting pad at high frequency. On the secondary side, the receiving pad, compensation stage, rectifier, and DC interface deliver power to the vehicle load. In functional terms, the whole system behaves as a loosely coupled high-frequency transformer with a significant air gap and non-ideal magnetic coupling.

The developed platform is intended for static wireless charging and was experimentally validated under static operating conditions. From an engineering perspective, the proposed architecture belongs to the 35 kW-class, while the realized laboratory prototype was validated at a nominal 30 kW operating level, with peak capability up to 45 kW for 1 min. The primary power stage is based on a full-bridge inverter topology designed for operation in the reported low-tens-of-kHz range. The overall system concept links high-frequency power conversion, resonant compensation, and optimized contactless magnetic coupling for practical EV charging applications across air gaps up to about 100 mm.

The overall architecture of the proposed wireless power transfer charging system is illustrated in Figure 1. The platform is organized into two main subsystems: the ground-side power unit and the vehicle-side receiving unit. Energy is transferred wirelessly between the transmitting and receiving coils through inductive coupling across an air gap.

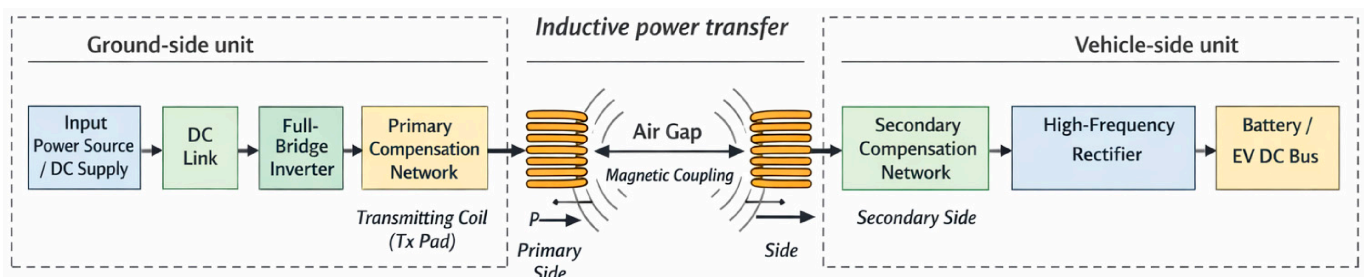


Figure 1. Overall architecture of the proposed inductive wireless power transfer platform for static electric-vehicle charging.

On the ground side, the electrical energy provided by the input power source is first conditioned through a DC link stage and then converted into high-frequency alternating voltage by a full-bridge inverter. The generated high-frequency current excites the primary resonant compensation network and the transmitting coil (Tx pad), producing a time-varying magnetic field in the vicinity of the charging platform. This alternating magnetic field forms the basis of the inductive wireless power transfer mechanism.

The transmitting and receiving coils form a loosely coupled inductive structure separated by an air gap. The alternating magnetic field generated by the transmitting coil induces voltage in the receiving coil (Rx pad) mounted on the vehicle. The efficiency

of the power transfer process depends on several parameters, including the coil geometry, coupling coefficient, operating frequency, and the resonant compensation networks implemented on both sides of the system.

On the vehicle side, the induced high-frequency voltage is processed by the secondary compensation network and subsequently converted into DC power through a high-frequency rectifier stage. The resulting electrical energy is then delivered to the vehicle battery or to the EV DC bus. This architecture allows the charging system to operate without a direct conductive connection between the vehicle and the charging infrastructure.

The presented architecture is experimentally validated for static charging only. In static operation, the vehicle is positioned above the transmitting pad and remains stationary during energy transfer. Possible extension toward segmented or on-route charging scenarios remains outside the current validation scope and is considered only as future work.

3.2. Operating Principle of Inductive Power Transfer

Wireless transfer is achieved by generating an alternating magnetic field in the transmitting coil and inducing a voltage in the receiving coil through mutual inductance. Because EV charging operates with a relatively large gap and possible lateral misalignment, the system cannot rely on tight transformer coupling. Instead, efficient transfer is obtained by resonant operation, where the Tx/Rx inductances and compensation capacitors are tuned to the same operating frequency to reduce reactive power and increase useful transferred power.

3.3. Static Charging Mode

In static charging, the vehicle is parked above the ground-side transmitting pad and the relative position of the coils remains almost constant during energy transfer. This operating mode provides the most stable coupling conditions and is therefore used as the reference case for validating the magnetic coupler, the resonant compensation network, and the prototype-level power-transfer capability of the proposed system.

3.4. Perspective for Future On-Route Extension

The same inductive transfer principle may in principle be extended to segmented transmitting structures for future on-route charging applications. However, such operation introduces additional challenges related to time-varying coupling, changing alignment, power-transfer continuity, segment activation, and control adaptation. Since these aspects are not experimentally addressed in the present study, on-route operation is discussed here only as a future extension of the underlying static charging concept.

The same IPT principle underlies both static and future on-route charging concepts. In the present study, Figure 2 illustrates the equivalent Tx/Rx representation used for the static charging platform, while on-route operation is discussed only conceptually. In static charging, energy transfer takes place between one fixed transmitting pad and one fixed receiving pad. In on-route charging, the same electromagnetic principle is preserved, but the ground-side transmitting structure is distributed into segmented pads that are energized according to vehicle position.

This transformer-based interpretation provides the basis for the electromagnetic modeling and optimization of the coupled coil system presented in the following sections.

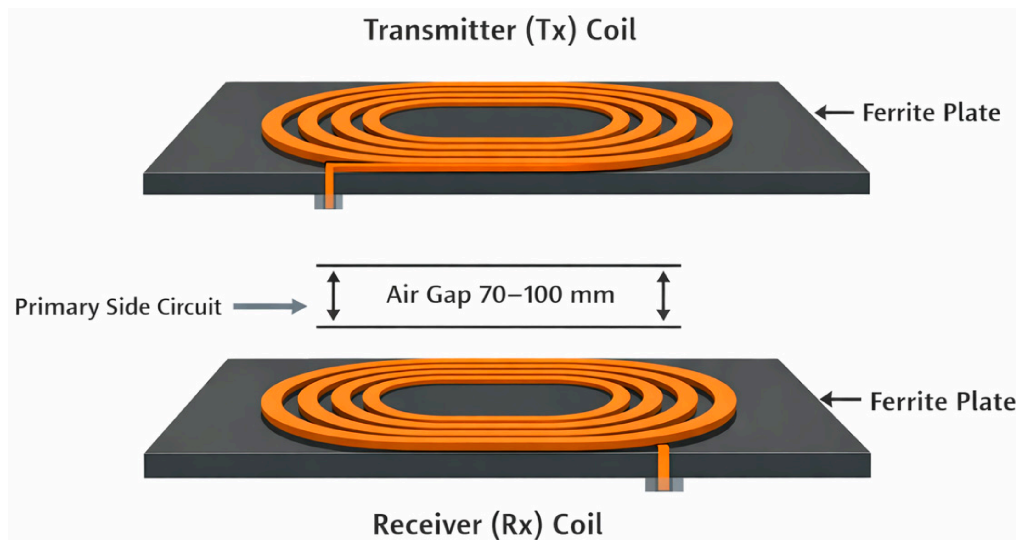


Figure 2. Equivalent inductive power transfer (IPT) transformer representation of the proposed static charging platform, illustrating the transmitter (Tx) and receiver (Rx) coils for air gaps up to about 100 mm. Each coil has approximate dimensions of $700 \times 800 \times 60$ mm.

3.5. Engineering Rationale of the Proposed Concept

The proposed coupler concept was developed and validated for static charging. The design is driven by a common set of engineering requirements, including adequate coupling across the air gap, compact pad dimensions, low coil losses, practical material use, and controlled stray-field exposure. These requirements define the basis of the design procedure presented in the next section. Possible extension of the concept toward segmented or on-route charging remains a topic for future investigation rather than a validated contribution of the present work.

4. Design Procedure and Formalized Parameter Selection

4.1. Engineering Requirements and Design Criteria

The development of the proposed WPT platform was treated as an engineering trade-off problem rather than as a purely single-objective optimization task. The main design criteria were (i) sufficient self-inductance of the transmitting and receiving pads; (ii) adequate magnetic coupling across the target air gap; (iii) low coil losses; (iv) acceptable pad dimensions, mass, and ferrite usage; and (v) controlled magnetic-field exposure in the occupied area. These criteria were considered jointly in order to obtain a practically realizable static EV charging platform.

4.2. Design Variables and Constraint Set

To formalize the parameter-selection process, the design vector can be written as

$$x = [N, s, l_{cond}, n_f, m_f, C_1, C_2, f]^T, \quad (1)$$

where N is the number of turns, s is the turn spacing, l_{cond} is the effective conductor length, n_f is the number of ferrite plates, m_f is the ferrite mass, C_1 and C_2 are the primary and secondary compensation capacitances, and f is the operating frequency. The final design is required to satisfy constraints related to inductance, coupling, transferred power, operating frequency range, overall package dimensions, and occupied-area magnetic-flux density.

In compact form, the constrained design problem may be expressed as

$$\max_x J(x) = w_\eta \eta(x) - w_{loss} P_{loss}(x) - w_m m_{tot}(x) - w_B B_{occ}^{max}(x), \quad (2)$$

subject to

$$\begin{aligned} L_{min} &\leq L_1(x), L_2(x) \leq L_{max}, \\ k(x; g = 100 \text{ mm}) &\geq k_{min}, \\ B_{occ}^{max}(x) &\leq B_{ref}, \\ P_L(x) &\geq P_{target}, \\ f_{min} &\leq f \leq f_{max} \end{aligned} \quad (3)$$

Here, η is the transfer efficiency, P_{loss} denotes the estimated coil and conduction losses, m_{tot} is the total magnetic-pad mass, B_{occ}^{max} is the maximum magnetic flux density in the occupied area under the considered operating condition, and w_η , w_{loss} , w_m , and w_B are weighting factors reflecting the relative importance of the design objectives.

4.3. Iterative Parameter Selection Procedure

The final parameter set was selected by iterative constrained parameter sweep and simulation-supported refinement. The procedure started from the available geometric envelope of the equivalent IPT structure and then refined the number of turns, turn spacing, conductor arrangement, ferrite layout, and resonant compensation values. Candidate configurations were screened analytically with respect to inductance, coupling-dependent power-transfer capability, estimated losses, and geometric feasibility. The feasible candidates were then further refined using simulation-supported evaluation of magnetic behavior and field distribution.

This procedure does not seek a universal mathematical optimum in an abstract sense; instead, it identifies a practically balanced design that satisfies the imposed electrical, geometric, and safety-related constraints of the intended static charging application.

4.4. Design and Parameter-Selection Workflow

The workflow used for the design and validation of the proposed wireless charging platform is illustrated in Figure 3. Rather than representing a black-box optimization routine, the workflow summarizes the sequence of engineering steps used to define, evaluate, refine, and finally validate the selected WPT platform.

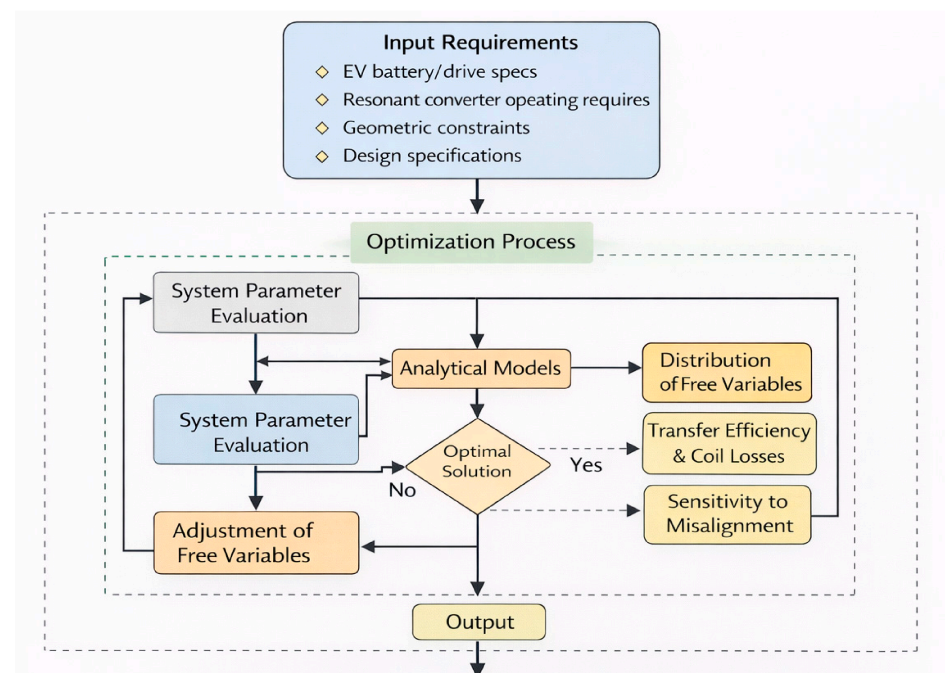


Figure 3. Schematic representation of the design workflow and parameter-refinement sequence used for the magnetic/electrical development of the proposed static EV WPT platform.

As shown in Figure 3, the process starts from the specification of the main application requirements, including EV-related operating conditions, target power level, geometric constraints, operating-frequency range, and occupied-area magnetic-field considerations. These inputs define the feasible design space of the system.

The workflow then proceeds through analytical IPT modeling and parameter screening, followed by simulation-supported refinement of the magnetic and electrical subsystems. At this stage, candidate configurations are evaluated with respect to inductance, coupling behavior, estimated losses, resonant compatibility, geometric feasibility, and occupied-area field control. If the obtained parameter set does not satisfy the imposed design criteria, the selected variables are adjusted and the evaluation sequence is repeated.

Once a feasible and practically balanced parameter set is identified, the resulting design is used as the basis for prototype-oriented implementation and experimental validation. Therefore, Figure 3 should be interpreted as a formalized engineering design-and-selection workflow linking requirements, analytical modeling, refinement, and prototype verification for the proposed static EV WPT platform.

The formal mathematical relations used within this workflow are introduced in the Analytical Relations for the Compensated IPT System section, where the coupling-dependent power-transfer capability, reflected impedance, resonance conditions, and efficiency trends are derived explicitly.

5. Magnetic Coupler and Coil Design

5.1. Equivalent IPT Transformer Model

The magnetic subsystem is represented by the equivalent IPT transformer model shown in Figure 4. The model consists of the primary self-inductance L_1 and winding resistance R_1 , the secondary self-inductance L_2 and winding resistance R_2 , and the mutual inductance M between the two coupled pads. The resonant compensation capacitors on the primary and secondary sides are included in the equivalent representation in order to link the magnetic-coupler design with the high-frequency power-transfer behavior of the complete charging system.

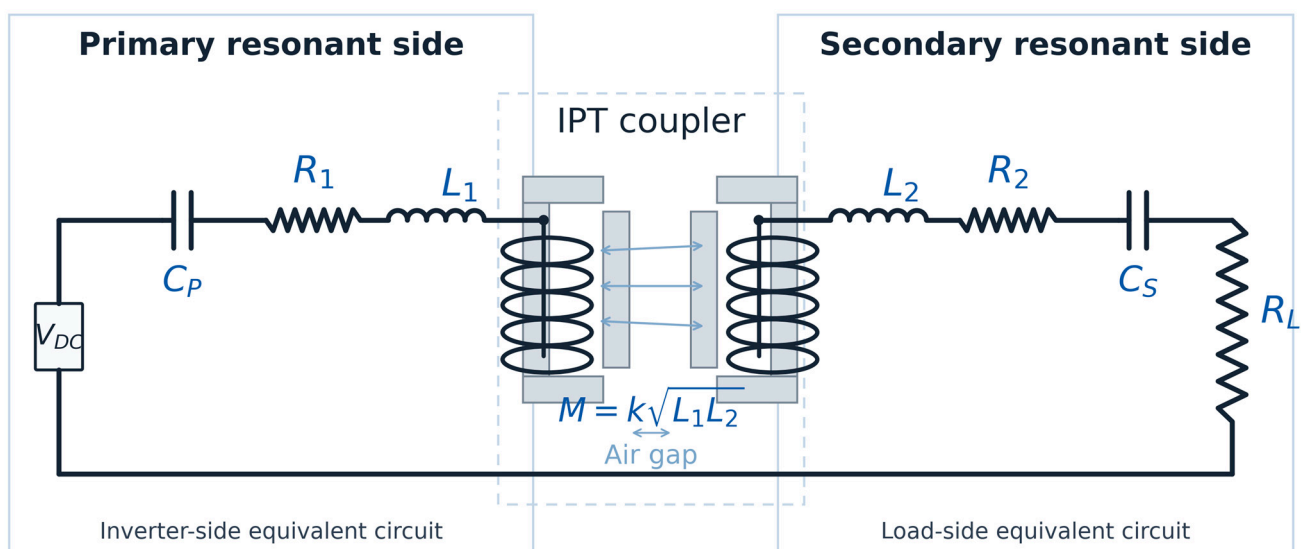


Figure 4. Equivalent IPT transformer model of the proposed wireless charging system, including the primary and secondary self-inductances and winding resistances, mutual inductance, and primary/secondary compensation capacitors.

Because the transmitting and receiving coils are separated by a significant air gap and operate under weak coupling, the structure must be interpreted as a compensated loosely coupled transformer rather than as a conventional tightly coupled magnetic component. This equivalent model is therefore used as the analytical bridge between coil optimization, resonant tuning, and converter-level design.

Analytical Relations for the Compensated IPT System

In order to quantify the interaction between the magnetic coupler and the resonant power stage, the Tx/Rx structure is modeled as a compensated loosely coupled transformer with self-inductances L_1 and L_2 , winding resistances R_1 and R_2 , mutual inductance M , and primary/secondary compensation capacitors C_1 and C_2 . The coupling factor k is related to the mutual inductance by

$$M = k \sqrt{L_1 L_2}. \quad (4)$$

Using phasor notation, the primary- and secondary-side circuit equations can be written as

$$V_1 = Z_1 I_1 + j\omega M I_2, 0 = j\omega M I_1 + Z_2 I_2, \quad (5)$$

where

$$Z_1 = R_1 + j(\omega L_1 - 1/(\omega C_1)), Z_2 = R_2 + R_{L,ac} + j(\omega L_2 - 1/(\omega C_2)). \quad (6)$$

Here, $R_{L,ac}$ denotes the equivalent AC load referred to the resonant secondary side, and $\omega = 2\pi f$ is the angular operating frequency.

From (5), the secondary current is obtained as:

$$I_2 = -(j\omega M/Z_2)I_1 \quad (7)$$

Therefore, the reflected impedance seen from the primary side is

$$Z_{ref} = (\omega M)^2/Z_2, \quad (8)$$

and the total input impedance becomes

$$Z_{in} = Z_1 + Z_{ref} \quad (9)$$

At resonant operation, the dominant reactive terms are minimized by satisfying

$$\omega_0 L_1 = 1/(\omega_0 C_1) \quad \omega_0 L_2 = 1/(\omega_0 C_2) \quad (10)$$

Accordingly, the compensation capacitances are selected as:

$$C_1 = 1/(\omega_0^2 L_1), C_2 = 1/(\omega_0^2 L_2) \quad (11)$$

Under near-resonant conditions, the secondary impedance becomes predominantly resistive, i.e.,

$$Z_2 \approx R_2 + R_{L,ac}, \quad (12)$$

and the magnitude of the secondary current may be approximated by

$$|I_2| \approx (\omega M/(R_2 + R_{L,ac}))|I_1|. \quad (13)$$

The active power delivered to the equivalent load is then

$$P_L = |I_2|^2 R_{L,ac}, \quad (14)$$

which yields

$$P_L \approx \left((\omega M)^2 R_{L,ac} / (R_2 + R_{L,ac})^2 \right) |I_1|^2. \quad (15)$$

By substituting (3) into (15), the transferred power can be expressed explicitly as a function of the coupling factor:

$$P_L \approx \left(\omega^2 k^2 L_1 L_2 R_{L,ac} / (R_2 + R_{L,ac})^2 \right) |I_1|^2. \quad (16)$$

Equation (16) directly shows that the transferable power increases with the square of the coupling-dependent term ωM , and therefore decreases when the air gap increases or lateral misalignment reduces the coupling factor.

A compact near-resonant estimate of the transfer efficiency can be written as

$$\eta \approx \left(|I_2|^2 R_{L,ac} \right) / \left(|I_1|^2 R_1 + |I_2|^2 (R_2 + R_{L,ac}) \right). \quad (17)$$

Using (13), this becomes

$$\eta \approx \frac{(\omega M)^2 R_{L,ac}}{R_1 (R_2 + R_{L,ac})^2 + (\omega M)^2 (R_2 + R_{L,ac})}. \quad (18)$$

Thus, the transfer efficiency improves with stronger magnetic coupling, lower winding losses, and appropriate resonant tuning, while degraded coupling due to increased air gap or lateral misalignment leads to reduced power-transfer capability and lower efficiency.

For practical static EV charging, the coupling factor can be viewed as a function of the vertical air gap g and lateral displacements Δx and Δy , i.e.,

$$k = k(g, \Delta x, \Delta y). \quad (19)$$

Around the nominal aligned operating point, this dependence may be approximated in compact form as:

$$k(g, \Delta x, \Delta y) \approx k_0 - a_g(g - g_0) - a_x \Delta x^2 - a_y \Delta y^2 \quad (20)$$

where a_g , a_x , and a_y are sensitivity coefficients. This approximation captures the experimentally observed trend that larger gap and coil misalignment reduce the coupling factor and therefore reduce the transferred power and the transfer efficiency.

The analytical relations above provide the formal link between the magnetic-coupler parameters and the electrical performance of the WPT platform. In particular, they show that the realized values of self-inductance, coupling factor, and winding loss are not isolated geometric outputs, but parameters that directly govern the reflected impedance, resonant current levels, transferable power, and efficiency behavior of the complete system.

5.2. Transmitting and Receiving Coil Geometry

The geometry of the optimized transmitting and receiving coils is presented in Figure 5. As shown in Figure 5a, the top view of the optimized coil is based on a rectangular planar winding with outer dimensions of 700 mm × 800 mm. The final configuration includes 7 turns with a spacing of 8 mm between adjacent turns, while ferrite plates are arranged around the winding in order to improve magnetic-flux guidance and support effective coupling between the transmitting and receiving pads. This geometry is consistent with

the practical realization of the equivalent IPT transformer and reflects the compromise achieved between size, coupling capability, and structural feasibility.

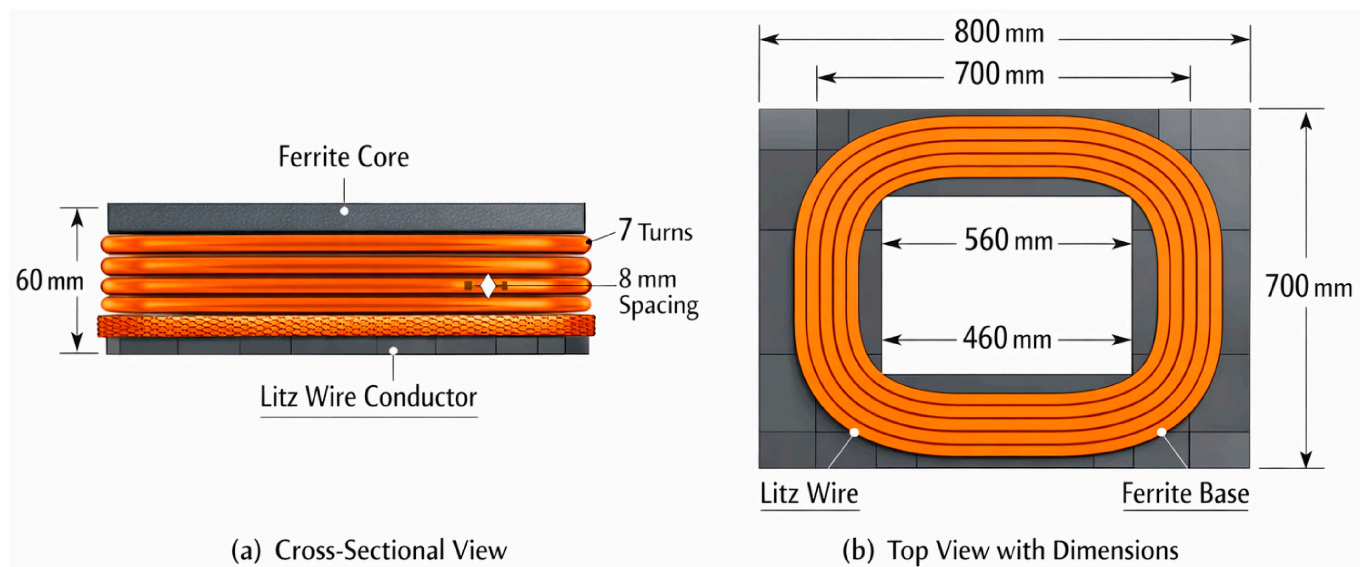


Figure 5. Geometry of the IPT coil design: (a) cross-sectional view of the coil stack and ferrite-assisted structure; (b) top view of the realized rectangular spiral geometry with principal dimensions.

Figure 5b illustrates the cross-sectional concept of the coupled Tx/Rx pad structure. The transmitting and receiving coils are arranged as magnetically coupled planar elements separated by a design air gap of 100 mm, while ferrite material is positioned beneath the winding structure to improve field shaping and magnetic utilization. The pad thickness is approximately 60 mm, which corresponds to the developed equivalent IPT transformer configuration. This cross-sectional representation is useful for understanding the layered structure of the coupler and its relevance to practical EV charging implementation.

According to the finalized prototype-oriented design, the optimized high-frequency coil uses 7 turns with a spacing of 8 mm between adjacent turns, a total conductor length of 14 m, and conductor mass of approximately 4 kg. The ferrite-assisted structure includes 58 ferrite plates with a total ferrite mass of 7.7 kg, resulting in an overall coil-system mass of about 24 kg. For the realized magnetic assembly, the inductance is approximately 60 μH , the coupling factor is about 0.45, and the estimated coil losses are approximately 2%. These values confirm that the selected geometry is not only magnetically effective, but also practical from the viewpoint of manufacturability, structural compactness, and EV-oriented integration.

The geometric configuration shown in Figure 5 is the result of the constrained design procedure described in Section 4. It is not merely a mechanical layout, but a design solution that directly determines the self-inductance, coupling factor, and loss characteristics of the magnetic subsystem. In this respect, the selected coil geometry forms the electromagnetic basis for the final optimized parameters reported in this work.

5.3. Ferrite Arrangement and Optimized Parameters

Ferrite plates are used to guide the magnetic flux, improve useful coupling, and help control the stray field around the charger. The realized coupler uses 58 ferrite plates with a total ferrite mass of 7.7 kg. Together with the selected conductor arrangement, this ferrite-assisted structure yields a coil inductance of approximately 60 μH , a coupling factor of about 0.45, and estimated coil losses of around 2%. These values indicate that the final geometry provides a practical compromise between electromagnetic performance, structural compactness, manufacturability, and EV-oriented integration. The main geometric,

material, and electromagnetic parameters of the finalized magnetic coupler are summarized in Table 1.

Table 1. Final optimized magnetic coupler parameters.

Parameter	Value
Equivalent IPT transformer geometry	$700 \times 800 \times 60$ mm per coil
Number of turns	7
Wire length	14 m
Wire mass	4 kg
Turn spacing	8 mm
Ferrite plates	58
Ferrite mass	7.7 kg
Overall coil-system mass	24 kg
Inductance	60 μ H
Coupling factor	0.45
Coil losses	$\approx 2\%$

6. Power Electronics and Compensation Network

6.1. Full-Bridge Topology and Resonant Operation

The power-electronic stage of the proposed wireless charging platform is based on a primary-side full-bridge inverter followed by a resonant compensation network and a coupled Tx/Rx magnetic structure. This arrangement provides the required high-frequency excitation of the transmitting coil and forms the electrical basis for inductive wireless power transfer.

On the primary side, the DC input source is conditioned by a DC-link stage, where the capacitor C_{dc} stabilizes the supply voltage. The full-bridge inverter converts the DC input into a high-frequency AC voltage in the range required for resonant inductive operation. This excitation is applied to the primary compensation network and the transmitting coil.

Because the transmitting and receiving coils are weakly coupled due to the relatively large air gap, efficient power transfer requires resonant operation. The compensation network is therefore designed to cancel the dominant inductive reactance of the coupled coils and to improve the transfer of active power across the air gap. In this way, the system operates close to resonance, reducing reactive power circulation and improving overall efficiency.

The transmitting and receiving coils form a loosely coupled inductive structure characterized by their self-inductances and mutual inductance. The alternating magnetic field generated by the transmitting coil induces a voltage in the receiving coil, thereby enabling contactless energy transfer between the ground-side and vehicle-side subsystems.

Equivalent resistive elements on the load side represent the aggregated losses and load behavior of the resonant circuit. These elements are included in the adopted circuit model in order to capture the practical operating conditions of the system.

The selected full-bridge topology ensures reliable high-frequency operation, efficient utilization of the DC source, and compatibility with the resonant compensation strategy. This configuration supports the experimentally validated static charging platform described in this paper. Possible extension toward segmented or on-route charging would require further investigation under time-varying coupling conditions and is therefore outside the present validation scope.

6.2. Secondary Interface and System-Level Topology Rationale

The compensation capacitors on the primary and secondary sides are selected to match the optimized inductance values of the realized coupler. In this way, the electrical design

remains consistent with the magnetic design and maintains acceptable input impedance, resonant behavior, and power-transfer capability under practical EV charging conditions.

On the secondary side, the received high-frequency power is processed through the secondary resonant branch and converted into DC power by a high-frequency rectifier. The rectified output is then supplied to the battery or the vehicle DC bus. This arrangement allows the vehicle-side subsystem to receive useful electrical energy without a direct galvanic connection to the ground-side charging infrastructure.

The secondary-side interface must preserve resonant operation while providing a usable DC output for charging. In this respect, the adopted topology is justified by system-level rather than purely converter-level considerations. Its role is to excite the optimized coupler reliably, maintain resonant transfer, and support a practical EV charging platform that integrates magnetic performance, converter operation, and safety-oriented validation.

Static charging benefits from steady alignment and stable operating conditions, whereas future on-route charging extensions would require the same resonant principle to remain effective under changing coupling conditions and segmented infrastructure.

7. Prototype Development and Experimental Setup

7.1. Prototype-Oriented Development Approach

The proposed charging platform was validated through prototype realization rather than through simulation alone. The development sequence included optimized coil design, implementation of the primary full-bridge excitation stage, construction of a first prototype, extension to a second demonstrator installation, and magnetic-field measurements around the realized system. In this way, the study progressed from analytical and numerical optimization toward application-oriented hardware verification.

7.2. Prototype Realization and Test Conditions

The optimized coupler was physically built using the final dimensions and material set reported in Section 5. The realized hardware therefore represents the direct embodiment of the analytical and simulation-supported design procedure. The manufactured Tx/Rx magnetic structure preserved the optimized rectangular geometry and ferrite-assisted arrangement required for practical inductive power transfer across a non-negligible air gap. To further document the realized hardware platform, the main technical specifications of the developed IPT module and the corresponding prototype operating conditions are summarized in Table 2.

From the viewpoint of practical implementation, the transmitting pad was not treated merely as a laboratory magnetic assembly, but as a ground-side module intended for protected installation. Since the receiving coil is integrated into the electric vehicle, the transmitting coil requires mechanically robust and environmentally suitable housing. In the realized demonstrator, the ground-side module was implemented using a layered construction that included reinforced structural support, epoxy-resin encapsulation of the winding region, and ferrite-bar elements combined with shielding features. This packaging-oriented realization strengthens the practical relevance of the developed IPT platform beyond purely electromagnetic design considerations.

The first prototype was used to verify the compatibility of the optimized Tx/Rx coils, the equivalent IPT transformer, and the primary full-bridge inverter under controlled operating conditions. The available prototype data confirm operation at a nominal 30 kW charging level, with a peak capability of 45 kW for 1 min. At the rated 30 kW/5 Ω load condition, the realized system delivered 400 V DC and 75 A DC. Depending on load and coil alignment, the converter operated in the 12–20 kHz range using combined frequency-shift and phase-shift PWM control. Experimental validation was carried out for air gaps up to

100 mm, confirming the electrical compatibility between the optimized magnetic coupler and the implemented high-frequency full-bridge power stage.

Table 2. Main technical specifications of the realized IPT module and reported prototype operating conditions.

Parameter	Value	Note
System class	35 kW-class	Application-oriented platform classification
Nominal experimentally validated operating level	30 kW	Static charging prototype validation
Peak capability	Up to 45 kW for 1 min	Short-time overload capability
Measured transfer efficiency	80–92%	Up to 92% under reported alignment and power conditions
Transformation ratio	7:7	Primary-to-secondary winding ratio
Transmitting pad dimensions	700 mm × 800 mm	Packaged ground-side module based on the realized IPT geometry
Receiving pad dimensions	700 mm × 800 mm	Vehicle-side receiving pad
Reported module build height	About 60–90 mm	Depending on coil side and packaging interpretation
Reported operating frequency range	Low tens of kHz	Design target and prototype test range reported in the manuscript
Air gap	Up to about 100 mm	Representative reported operating range
Favorable operating air-gap region	About 70–100 mm	Region of appropriate transfer performance reported in the prototype tests
Horizontal coil displacement	Reported X- and Y-direction misalignment conditions	Included in the reported experimental efficiency evaluation
Coupling factor	About 0.45	Realized magnetic assembly
Inductance	About 60 µH	Realized magnetic assembly
Estimated coil losses	About 2%	For the realized magnetic structure
Primary/secondary implementation	Ground-side transmitter/vehicle-side receiver	Realized IPT architecture
Mechanical realization of the transmitter	Protected packaged transmitting module	Implemented with structural support, encapsulation, ferrite, and shielding features

A second prototype was developed as an installation and demonstration platform in order to move the work closer to practical deployment conditions and to support application-oriented validation of the concept. This demonstrator strengthens the engineering relevance of the study because it shows that the optimized coupler and converter concept can be transferred from prototype-level verification toward installation-oriented implementation.

In addition to the prototype-level validation, the realized platform was further documented from the viewpoint of practical implementation and representative converter-side operation. The corresponding mechanical realization of the transmitting module and the demonstrator installation are illustrated in Figure 6.

In addition to the documented mechanical realization, representative converter-side waveforms were recorded in order to verify the electrical behavior of the realized IPT module under practical operating conditions. These measurements illustrate the voltage and current behavior at the transmitting side of the resonant stage for a representative charging condition and defined coil displacement. The recorded waveforms provide direct experimental support for the electrical compatibility of the resonant power stage and the magnetic coupler beyond averaged efficiency measurements.

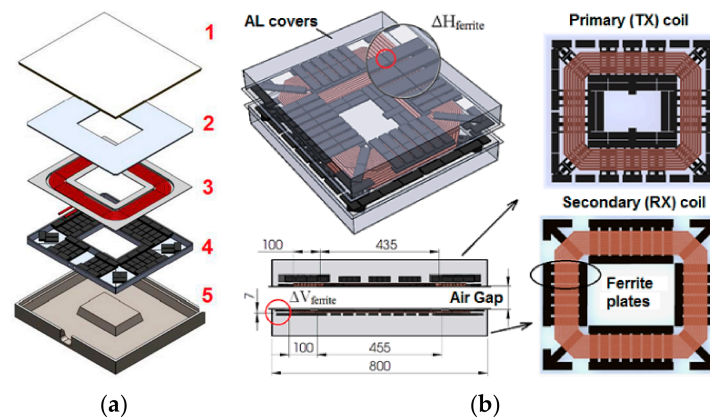


Figure 6. Mechanical realization of the transmitting IPT module and demonstrator installation: (a) layered construction of the ground-side transmitting pad; (b) overall view of the realized IPT module and test arrangement.

Representative measured waveforms obtained at the transmitting side of the IPT system are shown in Figure 7.

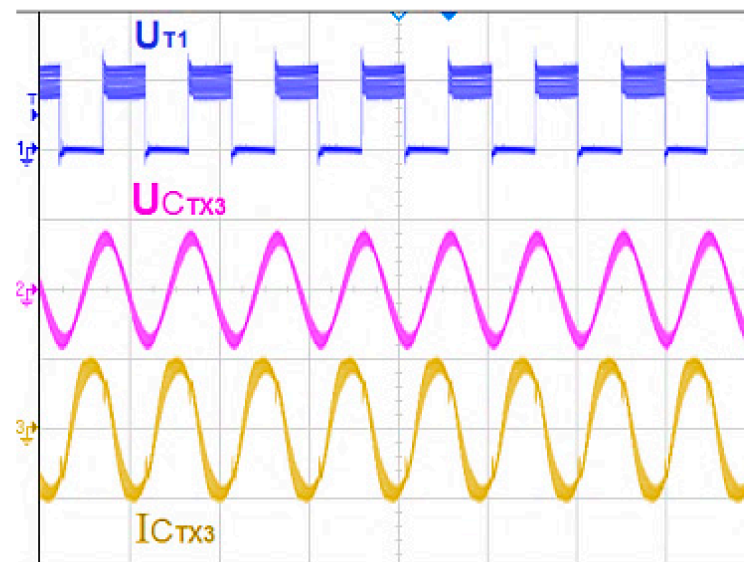


Figure 7. Representative measured waveforms at the transmitting side of the IPT system, illustrating the transmitting-coil voltage u_T , the primary compensation-capacitor voltage u_{CTX3} , and the transmitting-side current i_{CTX3} for $I_{DC} = 60$ A, $d_z = 100$ mm, $d_x = 0$, and $d_y = 100$ mm.

Thermographic images of the transmitting coil obtained using an infrared (FLIR) camera are presented in Figure 8. The images illustrate the temperature distribution along the winding during operation and provide indirect experimental evidence of current distribution and loss localization in the coil structure. The thermographic patterns qualitatively indicate a non-critical temperature distribution under the reported operating conditions and provide additional experimental support for the practical operation of the realized transmitting pad.

The experimentally reported operating data indicate an efficiency range of 80–92%, with the most favorable values obtained around 30 kW and a vertical air gap of approximately 70 mm. Appropriate transfer efficiency was maintained for air gaps in the range of about 70–100 mm. The corresponding efficiency map also illustrates the sensitivity of the realized IPT module to horizontal coil displacement under the investigated X- and Y-direction misalignment conditions, confirming that useful transfer performance was maintained for

the reported experimental cases. Figure 9 presents the experimentally measured efficiency as a function of output power for different X- and Y-direction coil misalignments and supports the practical operating range reported for the realized prototype.

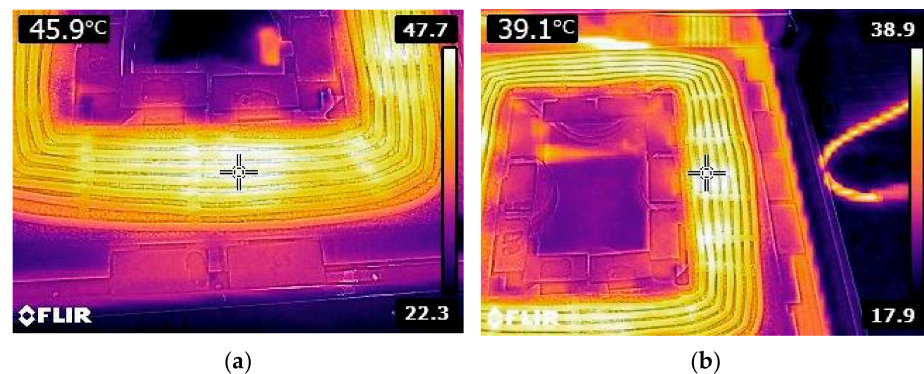


Figure 8. Thermographic (FLIR) images of the transmitting coil during representative operation, illustrating the temperature distribution along the winding and indicating the main current-path and loss-localization regions: (a) side region of the coil; (b) corner region of the coil.

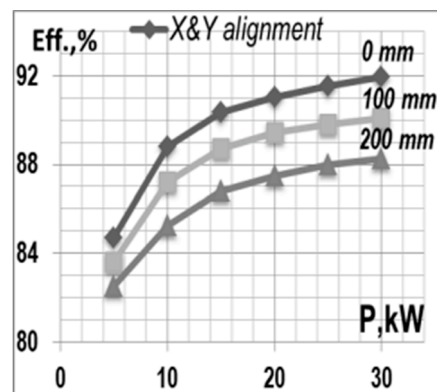


Figure 9. Experimentally measured transfer efficiency as a function of output power for the investigated X- and Y-direction coil-misalignment conditions.

In addition to transfer-efficiency validation, representative occupied-area magnetic-field measurements were performed around the demonstrator installation in order to assess the practical field-exposure behavior of the realized platform.

7.3. Demonstrator Installation and Measurement Basis

In addition to transfer-oriented validation, the experimental campaign included representative measurements of magnetic flux density in the accessible area around the charging coils. Representative magnetic-flux-density measurements performed around the demonstrator installation are shown in Figure 10.

The purpose of these tests was to assess representative magnetic-field levels in the occupied area around the demonstrator and to support safety-oriented validation of the proposed design. The reported values correspond to representative spot measurements obtained under the stated operating conditions and should be interpreted as indicative measurements rather than as a complete spatial field map. For frequencies up to 150 kHz, the adopted reference safety level was $B = 27 \mu\text{T}$.

The developed hardware platform supports the experimental validation of the proposed static charging concept. In the present work, the prototypes verify the operation of the coupler and converter under fixed-position charging conditions. Any extension toward

segmented or on-route charging should be regarded as future work rather than as part of the current validation scope.



Figure 10. Representative magnetic-flux-density measurements in the occupied area around the realized WPT platform: (a) measurement at 125 mm from the transmitting module, $B = 13.8 \mu\text{T}$; (b) measurement at 225 mm from the transmitting module, $B = 5.4 \mu\text{T}$.

The validation campaign progressed through three stages: first, verification of the electrical compatibility and basic WPT functionality of the initial prototype; second, demonstrator-level installation of the developed platform; and third, representative occupied-area magnetic-field measurements for safety-oriented assessment.

8. Results and Discussion

8.1. Magnetic and Electrical Performance

The optimized coupler achieved an inductance of $60 \mu\text{H}$, a coupling factor of 0.45, and coil losses of approximately 2%, confirming that the proposed design route yields a physically realizable high-power EV charging coupler. The prototype platform was experimentally validated at a nominal 30 kW operating level, with a peak capability of 45 kW for 1 min. The measured efficiency was in the range 80–92%, with the most favorable operation observed around 30 kW and a vertical air gap of approximately 70 mm. Appropriate transfer efficiency was maintained for vertical air gaps in the range 70–100 mm, while the reported tests also confirmed the expected sensitivity of transfer efficiency to horizontal coil misalignment under the investigated displacement conditions. In addition, representative occupied-area magnetic-flux-density measurements remained below the adopted reference threshold of $27 \mu\text{T}$ for frequencies up to 150 kHz.

The analytical relations developed in Section Analytical Relations for the Compensated IPT System support the interpretation of the reported experimental trends. In particular, the transferred power and the near-resonant efficiency depend strongly on the coupling-dependent term $\omega M = \omega k \sqrt{L_1 L_2}$. Consequently, the experimentally favorable operating region observed around 30 kW and a vertical air gap of approximately 70 mm can be interpreted as a practical compromise between sufficiently strong coupling, acceptable current levels, and effective resonant tuning. Conversely, when the vertical gap increases or lateral misalignment becomes more pronounced, the coupling factor decreases, the reflected impedance changes, and the useful transferred power and efficiency are correspondingly reduced. This analytical interpretation is consistent with the measured efficiency range of 80–92% and with the experimentally observed sensitivity to coil displacement.

The achieved coupling factor is favorable for a practical EV charger with a non-negligible air gap. At the same time, the low reported coil losses indicate that the improvement in coupling was not obtained at the expense of excessive internal dissipation. The design therefore performs as a balanced engineering compromise.

The realization of a first prototype and a second demonstrator confirms that the proposed concept progresses beyond analysis and optimization to application-oriented hardware validation. This substantially strengthens the contribution of the work.

The measured magnetic induction in the occupied area remained below the adopted threshold of 27 μT for frequencies up to 150 kHz. This is a key practical result because it demonstrates that the optimized charger combines transfer-oriented design with controlled field exposure.

The final realized platform should be interpreted as a constrained engineering trade-off solution rather than as a universally optimal design in a purely mathematical sense. Its practical value lies in the simultaneous achievement of adequate coupling, acceptable winding losses, feasible dimensions, manageable mass, and controlled occupied-area magnetic-field levels under the reported static charging conditions.

8.2. Limitations and Strength of the Experimental Results

The reported results should be interpreted as prototype-level validation of the proposed design methodology rather than as a complete deployment-ready characterization. The strongest experimentally supported findings concern the realized magnetic coupler, the nominal 30 kW static prototype validation, and the representative occupied-area magnetic-field assessment. In this sense, the manuscript presents a coherent combination of design, realization, and measurement-based verification that supports the practical relevance of the proposed WPT platform. Future work should extend the efficiency mapping under vertical and horizontal misalignment, provide broader spatial field characterization, and investigate segmented dynamic charging operations.

9. Electromagnetic Safety Assessment

9.1. Assessment Basis and Measurement Context

Electromagnetic safety assessment is essential for any inductive EV charger because the transfer process relies on alternating magnetic fields in an area that may be accessible to users or bystanders. For this reason, field exposure is treated here as part of the design validation rather than as a secondary issue.

Representative magnetic-flux-density measurements around the demonstrator installation yielded 13.8 μT at 125 mm from the coil and 5.4 μT at 225 mm, both below the adopted reference threshold of 27 μT for frequencies up to 150 kHz. These results support the practical suitability of the realized coupler for occupied-area operation under the reported experimental conditions, while remaining limited to representative measurement points rather than a full spatial exposure map.

The measured magnetic field in the occupied area is shaped by the geometry of the Tx/Rx pads, the coupling condition, the ferrite layout, and the operating frequency. In the present system, these factors are governed by the optimized $700 \times 800 \times 60$ mm coupler and the ferrite-assisted magnetic design. Representative magnetic-flux-density measurements around the demonstrator installation are shown in Figure 10.

9.2. Experimental Safety Result and Implications

The favorable safety result is consistent with the ferrite-assisted coupler design and the selected electrical operating conditions of the realized static charging platform. For static charging, the result supports the suitability of the charger for user-accessible installations.

9.3. Scope and Limitations of the Safety Evaluation

The present manuscript supports the safety conclusion at the level of the adopted threshold, the frequency range, and the occupied-area compliance result. It does not

claim a full spatial field map or a complete point-by-point exposure matrix, because those numerical details are not available in the current source material.

Overall, the safety assessment confirms that the optimized WPT platform satisfies an essential practical requirement for EV charging applications and strengthens the application-oriented value of the proposed methodology. To support the safety-oriented interpretation of the experimental results, the representative occupied-area magnetic-flux-density measurements are summarized in Table 3 together with the corresponding distances from the transmitting module and the adopted reference threshold.

Table 3. Representative magnetic-flux-density measurements around the demonstrator.

Measurement Point	Distance from Coil	Measured Magnetic Flux Density
Point 1	125 mm	13.8 μ T
Point 2	225 mm	5.4 μ T
Reference threshold	—	27 μ T

10. Conclusions

This work presented the design and prototype-level validation of an inductive wireless power transfer platform for static EV charging. The realized coupler achieved an inductance of about 60 μ H, a coupling factor of about 0.45, and estimated coil losses of approximately 2%, while the developed prototype was validated at a nominal 30 kW operating level for air gaps up to about 100 mm. The measured transfer efficiency was in the range 80–92%, with favorable operation observed around 30 kW and a vertical air gap of approximately 70 mm. Representative occupied-area magnetic-flux-density measurements remained below the adopted 27 μ T reference level under the reported operating conditions, supporting the practical suitability of the realized system for static charging applications.

The present study experimentally validates the platform under static charging conditions only. Possible extension toward segmented or on-route charging remains outside the current validation scope and is reserved for future work. Future research should include broader efficiency mapping under vertical and horizontal misalignment, extended spatial magnetic-field characterization, and experimental investigation of dynamic or quasi-dynamic charging operation.

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References

- Okasili, I.; Elkhateb, A.; Littler, T. A Review of Wireless Power Transfer Systems for Electric Vehicle Battery Charging with a Focus on Inductive Coupling. *Electronics* **2022**, *11*, 1355. [[CrossRef](#)]

2. Musavi, F.; Eberle, W. Overview of wireless power transfer technologies for electric vehicle battery charging. *IET Power Electron.* **2014**, *7*, 60–66. [[CrossRef](#)]
3. Patil, D.; McDonough, M.K.; Miller, J.M.; Fahimi, B.; Balsara, P.T. Wireless Power Transfer for Vehicular Applications: Overview and Challenges. *IEEE Trans. Transp. Electrification*. **2018**, *4*, 3–37. [[CrossRef](#)]
4. Latha, B.; Irfan, M.M.; Flah, A.; Blazek, V.; Prokop, L.; Rangarajan, S.S. Advances in EV wireless charging technology—A systematic review and future trends. *E-Prime-Adv. Electr. Eng. Electron. Energy* **2024**, *10*, 100765. [[CrossRef](#)]
5. Sagar, A.; Kashyap, A.; Nasab, M.A.; Padmanaban, S.; Bertoluzzo, M.; Kumar, A.; Blaabjerg, F. A Comprehensive Review of the Recent Development of Wireless Power Transfer Technologies for Electric Vehicle Charging Systems. *IEEE Access* **2023**, *11*, 83703–83751. [[CrossRef](#)]
6. El-Shahat, A.; Ayisire, E.; Wu, Y.; Rahman, M.; Nelms, D. Electric vehicles wireless power transfer state-of-the-art. *Energy Procedia* **2019**, *162*, 24–37. [[CrossRef](#)]
7. Palani, G.; Sengamalai, U. A critical review on inductive wireless power transfer charging system in electric vehicle. *Energy Storage* **2023**, *5*, e407. [[CrossRef](#)]
8. Rajamanickam, N.; Shanmugam, Y.; Jayaraman, R.; Petrov, J.; Vavra, L.; Gono, R. Review of Compensation Topologies Power Converters Coil Structure and Architectures for Dynamic Wireless Charging System for Electric Vehicle. *Energies* **2024**, *17*, 3858. [[CrossRef](#)]
9. Ta, A.R.; Marshiana, D. Adaptive coil and compensation integration design (ACCID) for enhancing wireless charging for electric vehicles with efficient power transfer. *Comput. Electr. Eng.* **2025**, *123*, 110184. [[CrossRef](#)]
10. Chen, Y.; Seyedi, S.M.; Toliyat, H.A. Coil Design of Integrated LCC-S Compensation Topology for Wireless Charging. In *Proceedings of the 2024 IEEE Transportation Electrification Conference and Expo (ITEC), Chicago, IL, USA, 19–21 June 2024*; IEEE: Piscataway, NJ, USA; pp. 1–6. [[CrossRef](#)]
11. Farghly, A.; Mohamed, A.; Awad, H.; Abdelfatah, S.; Alharbi, M.A.; Alqarni, M.; Abdelrazik, S.A. A Comprehensive Review of Wireless Power Transfer Techniques for Electric Vehicle Charging. *IEEE Access* **2025**, *13*, 199683–199718. [[CrossRef](#)]
12. Rayan, B.A.; Subramaniam, U.; Balamurugan, S. Wireless Power Transfer in Electric Vehicles: A Review on Compensation Topologies, Coil Structures, and Safety Aspects. *Energies* **2023**, *16*, 3084. [[CrossRef](#)]
13. Roslan, M.A.A.; Nanda, N.N.; Yusoff, S.H. Series-Series And Series-Parallel Compensation Topologies For Dynamic Wireless Charging. *IIUM Eng. J.* **2021**, *22*, 199–209. [[CrossRef](#)]
14. Erel, M.Z.; Imtiaz, T.; Elsanabary, A.; Mekhilef, S.; Mubin, M.; Soon, T.K. Enabling Quadruple-D Compensation Coil Integration for Efficient Power Transfer to Receiver in Wireless Power Transfer Systems for EV Charging. *IEEE J. Emerg. Sel. Top. Power Electron.* **2025**, *13*, 4278–4289. [[CrossRef](#)]
15. Xue, Z.; Liu, W.; Liu, C.; Chau, K.T. Critical Review of Wireless Charging Technologies for Electric Vehicles. *World Electr. Veh. J.* **2025**, *16*, 65. [[CrossRef](#)]
16. Mahesh, A.; Chokkalingam, B.; Mihet-Popa, L. Inductive Wireless Power Transfer Charging for Electric Vehicles—A Review. *IEEE Access* **2021**, *9*, 137667–137713. [[CrossRef](#)]
17. Bouanou, T.; El Fadil, H.; Abbade, H. Wireless charging for electric vehicles: A comprehensive review of technologies, challenges, and solutions. *J. Power Sources* **2025**, *660*, 238501. [[CrossRef](#)]
18. Niu, S.; Jia, Q.; Hu, Y.; Yang, C.; Jian, L. Safety Management Technologies for Wireless Electric Vehicle Charging Systems: A Review. *Electronics* **2025**, *14*, 2380. [[CrossRef](#)]
19. Chowdhury, P.; Shovon, M.M.A.; Yeassin, R.; Farrok, O. Wireless charging for electric vehicles: A review on environmental, health, technical, and policy landscape. *Energy Convers. Manag.* **2025**, *28*, 101363. [[CrossRef](#)]
20. Ronanki, D.; Karneddi, H. Electric Vehicle Charging Infrastructure: Review, Cyber Security Considerations, Potential Impacts, Countermeasures, and Future Trends. *IEEE J. Emerg. Sel. Top. Power Electron.* **2024**, *12*, 242–256. [[CrossRef](#)]
21. Martins, J.A.; Rodrigues, J.M.F. Intelligent Monitoring Systems for Electric Vehicle Charging. *Appl. Sci.* **2025**, *15*, 2741. [[CrossRef](#)]
22. Arooj, A.; Ahmed, Q.Z.; Farooq, M.S.; Umer, T.; Aslam, N.; Alade, T. Unraveling the Smart Charging Technologies, Energy Sources, and Regulatory Standards for EVs. *IEEE Access* **2025**, *13*, 108148–108167. [[CrossRef](#)]
23. Bosshard, R.; Iruretagoyena, U.; Kolar, J.W. Comprehensive Evaluation of Rectangular and Double-D Coil Geometry for 50 kW/85 kHz IPT System. *IEEE J. Emerg. Sel. Top. Power Electron.* **2016**, *4*, 1406–1415. [[CrossRef](#)]
24. Bosshard, R.; Kolar, J.W. Multi-Objective Optimization of 50 kW/85 kHz IPT System for Public Transport. *IEEE J. Emerg. Sel. Top. Power Electron.* **2016**, *4*, 1370–1382. [[CrossRef](#)]
25. Kalwar, K.A.; Mekhilef, S.; Seyedmehmoudian, M.; Horan, B. Coil Design for High Misalignment Tolerant Inductive Power Transfer System for EV Charging. *Energies* **2016**, *9*, 937. [[CrossRef](#)]
26. Bosshard, R.; Kolar, J.W.; Mühlethaler, J.; Stevanović, I.; Wunsch, B.; Canales, F. Modeling and η - α -Pareto Optimization of Inductive Power Transfer Coils for Electric Vehicles. *IEEE J. Emerg. Sel. Top. Power Electron.* **2015**, *3*, 50–64. [[CrossRef](#)]
27. Bandyopadhyay, S.; Venugopal, P.; Dong, J.; Bauer, P. Comparison of Magnetic Couplers for IPT-Based EV Charging Using Multi-Objective Optimization. *IEEE Trans. Veh. Technol.* **2019**, *68*, 5416–5429. [[CrossRef](#)]

28. Zhao, H.; Liu, K.; Li, S.; Yang, F.; Cheng, S.; Eldeeb, H.H.; Kang, J.; Xu, G. Shielding Optimization of IPT System Based on Genetic Algorithm for Efficiency Promotion in EV Wireless Charging Applications. *IEEE Trans. Ind. Appl.* **2022**, *58*, 1190–1200. [\[CrossRef\]](#)
29. Shi, W.; Dong, J.; Soeiro, T.B.; Riekerk, C.; Grazian, F.; Yu, G.; Bauer, P. Design of a Highly Efficient 20-kW Inductive Power Transfer System With Improved Misalignment Performance. *IEEE Trans. Transp. Electr.* **2022**, *8*, 2384–2399. [\[CrossRef\]](#)
30. Ramakrishnan, V.; A, D.S.; C, B.; R, N.; Vishnuram, P.; Yang, T.; Bajaj, M.; Rathore, R.S.; Zaitsev, I. Des. Implement. A High Misalignment-Toler. *Wirel. Charg. Electr. Veh. Control Constant Curr. /Volt. charging. Sci. Rep.* **2024**, *14*, 13165. [\[CrossRef\]](#)
31. Sabzevari, S.I.H.; Sabzevari, S.A.H.; Sima, N. A low-cost coil alignment system for electric vehicle inductive wireless chargers. *J. Energy Storage* **2025**, *114*, 115722. [\[CrossRef\]](#)
32. Ramezani, A.; Narimani, M. Optimized Electric Vehicle Wireless Chargers with Reduced Output Voltage Sensitivity to Misalignment. *IEEE J. Emerg. Sel. Top. Power Electron.* **2020**, *8*, 3569–3581. [\[CrossRef\]](#)
33. Triviño, A.; Sánchez, J.; Delgado, A. Efficient methodology of the coil design for a dynamic wireless charger. *IEEE Access* **2022**, *10*, 83368–83378. [\[CrossRef\]](#)
34. Song, K.; Lan, Y.; Zhang, X.; Jiang, J.; Sun, C.; Yang, G.; Yang, F.; Lan, H. A Review on Interoperability of Wireless Charging Systems for Electric Vehicles. *Energies* **2023**, *16*, 1653. [\[CrossRef\]](#)
35. Song, K.; Wei, R.; Zhang, H.; Huang, X.; Zhang, H.; Yang, G.; Liu, R.; Wei, B.; Zhu, C. Interoperability Evaluation of Wireless EV Charging Systems Using Coil Ampere-Turns. In *Proceedings of the 2019 22nd International Conference on Electrical Machines and Systems (ICEMS), Harbin, China, 11–14 August 2019*; IEEE: Piscataway, NJ, USA; pp. 1–4. [\[CrossRef\]](#)
36. Bentalhik, I.; Lassioui, A.; EL Fadil, H.; Bouanou, T.; Rachid, A.; EL Idrissi, Z.; Hamed, A.M. Analysis, Design and Realization of a Wireless Power Transfer Charger for Electric Vehicles: Theoretical Approach and Experimental Results. *World Electr. Veh. J.* **2022**, *13*, 121. [\[CrossRef\]](#)
37. Tavakoli, R.; Pantic, Z. Analysis, Design, and Demonstration of a 25-kW Dynamic Wireless Charging System for Roadway Electric Vehicles. *IEEE J. Emerg. Sel. Top. Power Electron.* **2018**, *6*, 1378–1393. [\[CrossRef\]](#)
38. Wang, H.; Pratik, U.; Jovicic, A.; Hasan, N.; Pantic, Z. Dynamic Wireless Charging of Medium Power and Speed Electric Vehicles. *IEEE Trans. Veh. Technol.* **2021**, *70*, 12552–12566. [\[CrossRef\]](#)
39. Xue, L.; Galigekere, V.; Su, G.J.; Zeng, R.; Mohammad, M.; Gurpinar, E.; Chowdhury, S.; Onar, O. Design and Analysis of a 200 kW Dynamic Wireless Charging System for Electric Vehicles. In *Proceedings of the 2022 IEEE Applied Power Electronics Conference and Exposition (APEC), Houston, TX, USA, 20–24 March 2022*; IEEE: Piscataway, NJ, USA; pp. 1096–1103. [\[CrossRef\]](#)
40. Mohamed, N.; Aymen, F.; Alqarni, M.; Turkey, R.A.; Alamri, B.; Ali, Z.M.; Aleem, S.H.A. A new wireless charging system for electric vehicles using two receiver coils. *Ain Shams Eng. J.* **2022**, *13*, 101569. [\[CrossRef\]](#)
41. IEC 61980-1:2020; Electric Vehicle Wireless Power Transfer (WPT) Systems—Part 1: General Requirements. International Electrotechnical Commission: Geneva, Switzerland, 2020.
42. IEC 61980-2:2023; Electric Vehicle Wireless Power Transfer (WPT) Systems—Part 2: Communication and Activities. International Electrotechnical Commission: Geneva, Switzerland, 2023.
43. EC 61980-3:2022; Electric Vehicle Wireless Power Transfer (WPT) Systems—Part 3: Specific Requirements for the Magnetic Field Wireless Power Transfer Systems. International Electrotechnical Commission: Geneva, Switzerland, 2022.
44. IEC PAS 61980-5:2024; Electric Vehicle Wireless Power Transfer (WPT) Systems—Part 5: Interoperability and Safety of Dynamic Wireless Power Transfer (D-WPT) for Electric Vehicles. International Electrotechnical Commission: Geneva, Switzerland, 2024.
45. ISO 19363:2020; Electrically Propelled Road Vehicles—Magnetic Field Wireless Power Transfer—Safety and Interoperability Requirements. International Organization for Standardization: Geneva, Switzerland, 2020.
46. SAE J2954_202408; Wireless Power Transfer for Light-Duty Plug-In/Electric Vehicles and Alignment Methodology. SAE International: Warrendale, PA, USA, 2024.
47. International Commission on Non-Ionizing Radiation Protection. Guidelines For Limiting Exposure to Time-Varying Electric And Magnetic Fields (1 Hz to 100 kHz). *Health Phys.* **2010**, *99*, 818–836. [\[CrossRef\]](#) [\[PubMed\]](#)
48. International Commission on Non-Ionizing Radiation Protection (ICNIRP). Guidelines for Limiting Exposure to Electromagnetic Fields (100 kHz to 300 GHz). *Health Phys.* **2020**, *118*, 483–524. [\[CrossRef\]](#) [\[PubMed\]](#)

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