Standardization-Oriented Design of SiC-Enabled Wireless EV Charging Infrastructure for Electrification and Smart Energy Systems

Haoxiang Lian[1]
[1]College of Engineering Science and Technology, Shanghai Ocean University, Shanghai 200120, China
Corresponding author: Haoxiang Lian (e-mail: 15561486699@163.com).

ABSTRACT Transportation electrification is a central component of future sustainable energy systems, and the large-scale deployment of electric vehicles (EVs) requires charging infrastructure that is efficient, interoperable, grid-compatible, and suitable for standardized deployment. Wireless power transfer (WPT) is increasingly recognized as a convenient and automated EV charging approach, but its transition from laboratory prototypes to energy infrastructure introduces strict constraints on operating frequency, power level, alignment tolerance, electromagnetic compatibility, efficiency consistency, and cross-vendor interoperability. These constraints become especially important when wireless charging is considered as part of smart energy infrastructure rather than as an isolated charging device. This paper presents a standardization-oriented design framework for SiC-enabled wireless EV charging infrastructure in the context of electrification and smart energy systems. Rather than treating silicon carbide (SiC) power devices as isolated component upgrades, the proposed framework connects SiC device characteristics with resonant network design, modular power conversion architecture, standard-aware control, and future grid-facing functions such as efficiency management and demand-response readiness. The framework aims to support fixed-frequency operation within standardized bands, scalable infrastructure deployment across power classes, and consistent efficiency performance under load and coupling variations. A quantitative case study evaluates silicon- and SiC-based implementations under representative standardized operating scenarios. The SiC-enabled system achieves higher efficiency, expanded thermal margin, reduced sensitivity to coupling variation, and improved performance stability across the standardized operating envelope. Loss composition analysis further shows that SiC devices shift dominant losses away from high-frequency switching loss, supporting robust fixed-frequency operation. The results demonstrate that SiC-based wireless EV charging architectures can contribute to energy-efficient, interoperable, and scalable charging infrastructure for future electrification and smart-grid applications.

INDEX TERMS Electric vehicle charging infrastructure, energy efficiency, silicon carbide, smart energy systems, smart grid, standardization, transportation electrification, wireless power transfer.

I. INTRODUCTION

TRANSPORTATION electrification is reshaping the design requirements of future energy systems. As EV adoption increases, charging infrastructure must not only deliver power to vehicles but also support efficient energy conversion, standardized operation, reliable user experience, and eventual coordination with smart-grid functions such as load management and demand response. Within this broader energy-system context, wireless power transfer (WPT) has emerged as a transformative EV charging technology that can enhance charging convenience, reduce connector wear, and enable automated or infrastructure-integrated charging scenarios [1], [2]. The principle of resonant inductive coupling, where power is transferred through coupled coils tuned to a common resonant frequency, remains central to EV WPT due to its ability to achieve high efficiency over practical air gaps without significant radiative losses [3], [4].

The foundational design and operation of wireless charging systems, including compensation network topologies, coil configurations, and control strategies, have been extensively surveyed in the literature, with key challenges including alignment sensitivity, efficiency optimization, safety, and integration into EV powertrains and smart-grid environments [5], [6]. Recent overviews further emphasize the importance of resonant network design and magnetic coupling characteristics for maximizing power transfer efficiency and system robustness [7], [8]. However, when wireless EV charging is treated as part of distributed energy infrastructure, system design must also address interoperability, reproducible performance, infrastructure scalability, and compatibility with evolving standards. Transitioning WPT from laboratory research toward industrial and energy-infrastructure deployment requires alignment with evolving standards and interoperability frameworks. The SAE J2954 Recommended Practice defines charging classes, resonant frequency bands around 85 kHz, alignment tolerances, and communication protocols to enable medium-power wireless charging of light-duty EVs [9], [10]. Extensions of this standard, including SAE J2954/2, aim to support higher power levels and dynamic charging applications for heavy vehicles and roadway systems, broadening the role of wireless charging as a component of future electrified transportation infrastructure [11]. Despite advancements in system architecture and electromagnetic design, the underlying power electronics continue to impose significant limitations on standardized wireless charging infrastructure. Conventional silicon (Si)-based converters and inverters exhibit high switching losses and thermal stress at elevated resonant frequencies, which can degrade efficiency, reduce thermal margin, and limit power-class scalability [12], [13]. This limitation is especially pronounced in systems operating at standardized frequencies, where frequency cannot be arbitrarily tuned for performance optimization without compromising compliance and interoperability [5].

Wide bandgap (WBG) devices, particularly silicon carbide (SiC), have attracted considerable attention due to their low switching and conduction losses, high voltage capability, and superior thermal performance compared with Si, making them attractive for high-frequency and high-power converter applications [14], [15]. Comprehensive reviews show that SiC power converters can improve efficiency and power density in high-frequency power electronics, underscoring their potential not only for EV charging devices but also for compact, efficient, and scalable charging infrastructure [16], [17]. In addition to device-level advantages, recent research has explored system-level strategies to reduce sensitivity to misalignment and load variation, such as hybrid compensation networks and adaptive control mechanisms that aim to maintain high efficiency across real-world parking conditions [18], [19]. However, many studies focus on isolated subsystems, either resonant network design or enhanced control methods, without integrating power electronics, resonant design, standard-aware control, and infrastructure-level deployment requirements into a unified framework suitable for standardized EV WPT implementations. Another emerging area of interest is dynamic wireless charging, where vehicles receive power while in motion, potentially reducing battery size, extending range, and reshaping the energy demand profile of electrified transportation corridors [20], [21]. Dynamic charging frameworks introduce additional complexity in system design and control but also reinforce the need for high-performance power electronics and robust system design under variable coupling conditions. Higher-power WPT research has also examined electromagnetic safety, field distribution, and coil design optimization to meet regulatory requirements and minimize exposure risks during vehicle charging [22]. These perspectives show that WPT system design must balance energy efficiency, safety, electromagnetic compatibility, manufacturability, and standard compliance. Despite progress across these domains, there remains a research gap in developing a holistic, standard-aware system design that connects SiC device capabilities with resonant network architecture, control strategy, standardized operating envelopes, and the broader requirements of energy-efficient charging infrastructure. Such a framework is essential to ensure that the advantages of SiC power electronics translate into wireless charging systems that are not only high-performance but also deployable, interoperable, scalable, and compatible with future smart energy systems.

To address this gap, this paper proposes an integrated design framework for SiC-enabled standardized EV wireless charging infrastructure. By aligning device-level characteristics with resonant network design, modular converter architecture, standardized control interfaces, and energy-system deployment needs, the framework aims to enable high-frequency operation, consistent efficiency across alignment and load variations, and compatibility with standardized power and communication protocols. This approach bridges the divide between component-level research and infrastructure-oriented implementation readiness. Unlike prior studies that primarily evaluate device- or topology-level benefits, this work focuses on how SiC technology reshapes system-level architectural and control choices under standardized operating constraints and how such systems can support the electrification and smart-energy objectives emphasized by future energy infrastructure development.

II. OVERVIEW OF EV WIRELESS CHARGING AS ELECTRIFIED ENERGY INFRASTRUCTURE

Wireless charging for electric vehicles (EVs) is based on near-field magnetic coupling between a ground-side transmitter and a vehicle-mounted receiver. By eliminating physical connectors, wireless power transfer (WPT) improves user convenience, environmental robustness, and operational safety, making it attractive for residential, commercial, fleet, and public charging infrastructure. From an energy-system perspective, standardized wireless charging can be viewed as a terminal-side electrification interface that connects vehicles, power electronics, grid supply, and future energy-management functions. Therefore, a clear understanding of both its physical operating principles and infrastructure-level constraints is essential.

A. OPERATING PRINCIPLES OF WIRELESS POWER TRANSFER

The fundamental operating principle of EV wireless charging is illustrated in Fig. 1. A high-frequency alternating current excites the transmitter (primary) coil, generating an alternating magnetic field in the near field region. This magnetic field couples across an air gap to the receiver (secondary) coil mounted on the vehicle, inducing an alternating voltage that is subsequently rectified and conditioned to charge the vehicle battery.

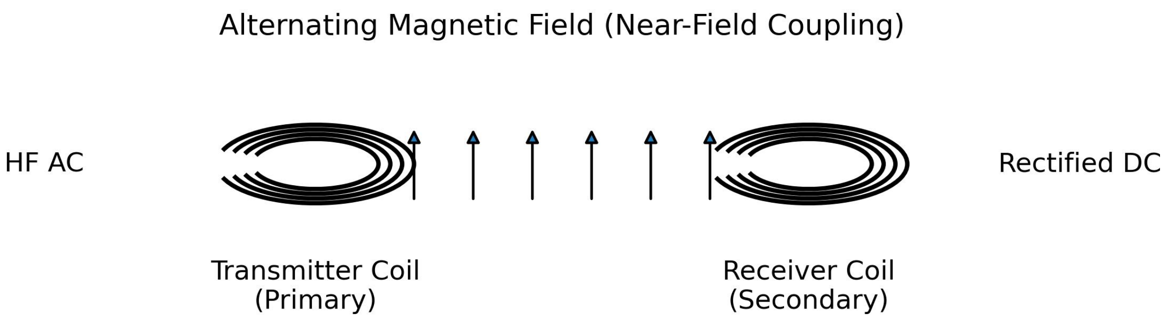

FIGURE 1. Operating principle of electric vehicle wireless power transfer based on near-field magnetic coupling.

Power transfer capability in inductive wireless charging systems is primarily governed by the operating frequency and the magnetic coupling between the transmitter and receiver coils. At a fundamental level, the transferred power can be expressed as

$$P \propto \omega M I_{\mathrm{tx}} I_{\mathrm{rx}} \tag{1}$$

where ω is the angular frequency of operation, M is the mutual inductance between the coils, and I_{tx} and I_{rx} are the transmitter and receiver currents, respectively. This relationship highlights the importance of both frequency selection and magnetic coupling in determining achievable power transfer.

Because coupling between the coils is inherently weak and sensitive to air-gap distance and lateral misalignment, resonant operation is employed to enhance efficiency and mitigate reactive power circulation. Resonant compensation networks are added to the transmitter and receiver coils so that the system operates near a resonant frequency defined by

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

where L and C represent the effective inductance and compensation capacitance of the resonant network. Resonant tuning improves power transfer efficiency but also introduces sensitivity to component tolerances, load variation, and alignment conditions, which must be carefully managed in practical systems.

B. POWER LEVELS, FREQUENCY RANGES, AND INFRASTRUCTURE APPLICATION SCENARIOS

EV wireless charging systems span a wide range of power levels, from low-power stationary charging to higher-power residential, fleet, depot, and public charging applications. Correspondingly, operating frequencies are typically selected in the tens of kilohertz range, where a tradeoff exists among magnetic component size, efficiency, electromagnetic emission, thermal management, and infrastructure cost.

Higher operating frequencies enable smaller coils and passive components, improving power density and system integration. However, increased frequency also exacerbates switching losses in power electronic devices and raises challenges related to electromagnetic compatibility and thermal management. As a result, frequency selection represents a critical design compromise, particularly as charging power levels increase and as charging infrastructure must remain efficient during repeated or continuous operation.

C. SYSTEM REQUIREMENTS DRIVEN BY STANDARDIZED AND GRID-COMPATIBLE DEPLOYMENT

As wireless charging systems move toward standardized and grid-compatible deployment, additional constraints are imposed beyond basic power transfer efficiency. Standardized EV wireless charging requires interoperability across vehicles and charging infrastructure from different manufacturers, reproducible performance under prescribed alignment conditions, compliance with electromagnetic and safety regulations, and the ability to operate predictably as part of a broader energy infrastructure.

These requirements lead to fixed or narrowly bounded operating frequency bands, defined alignment tolerances, and standardized power classes. Unlike laboratory-optimized systems, standardized implementations cannot rely on frequency detuning or relaxed operating envelopes to recover efficiency under nonideal conditions. Consequently, the performance of the power electronics and resonant network must remain robust within strict operating constraints.

The physical principles described in this section underscore why operating frequency, coupling robustness, efficiency consistency, and thermal stability are central challenges in standardized EV wireless charging. These challenges motivate the examination of advanced power semiconductor technologies, such as silicon carbide (SiC), which are capable of supporting high-frequency operation and continuous-duty performance within standardized limits. The characteristics of SiC power devices and their system-level implications are discussed in the following section.

D. ROLE IN ELECTRIFICATION AND SMART ENERGY INFRASTRUCTURE

Beyond the immediate charging function, standardized wireless EV charging can support broader electrification objectives by creating a repeatable interface between vehicles and energy infrastructure. A standardized interface can reduce market fragmentation, simplify infrastructure planning, and enable charging assets to be deployed consistently across homes, workplaces, public parking facilities, fleets, and transportation corridors.

The energy-system value of wireless charging depends on efficiency, controllability, and interoperability. High-efficiency power conversion reduces system-level energy waste, while predictable control behavior enables future coordination with load management, renewable-energy utilization, and demand-response programs. These infrastructure-level considerations provide the rationale for connecting SiC device capability with standard-aware system architecture in the following sections.

III. CHARACTERISTICS OF SiC POWER DEVICES AND IMPLICATIONS FOR ENERGY-EFFICIENT CHARGING INFRASTRUCTURE

Silicon carbide (SiC) power devices have attracted increasing attention for high-frequency and high-power applications due to their wide bandgap material properties and superior electrical and thermal performance. In the context of wireless power transfer (WPT) systems, these characteristics have important system-level implications, particularly when operation is constrained by fixed frequency bands, continuous-duty requirements, and infrastructure-level efficiency targets. This section reviews the key characteristics of SiC power devices and conceptually examines how they influence WPT system design, providing motivation for the standardization-oriented and energy-infrastructure framework developed in the subsequent sections.

A. ELECTRICAL AND THERMAL CHARACTERISTICS OF SiC POWER DEVICES

Compared with conventional silicon-based power devices, SiC MOSFETs exhibit higher breakdown electric fields, lower specific on-resistance, and significantly faster switching transitions. These properties enable efficient operation at higher voltages and switching frequencies while reducing switching and conduction losses. In addition, SiC devices support higher maximum junction temperatures, offering increased thermal margin under continuous operation.

From a system design perspective, these characteristics translate into reduced sensitivity to switching frequency-related loss and improved thermal robustness. Rather than treating high-frequency operation as a limiting factor, SiC devices expand the feasible operating range available to the designer. This expanded design space is particularly relevant for WPT systems, where switching frequency is closely tied to resonant operation and magnetic component design.

B. FREQUENCY-CONSTRAINED SWITCHING BEHAVIOR OF SiC DEVICES

In standardized EV wireless charging systems, the inverter is typically required to operate within a fixed or narrowly bounded frequency range rather than at an arbitrary frequency selected for device-level convenience. Under these conditions, switching loss becomes a primary constraint because it increases with switching frequency and contributes directly to device heating, converter efficiency loss, and thermal-management burden. Conventional silicon-based devices are therefore often forced to operate with conservative margins, larger cooling capacity, or reduced power density when the operating frequency approaches the range required by standardized wireless power transfer.

SiC MOSFETs mitigate this limitation through faster switching transitions, lower switching energy, and higher thermal tolerance. These characteristics do not merely improve component-level efficiency; they expand the feasible design space for fixed-frequency WPT operation. In particular, SiC devices provide additional margin for maintaining soft-switching behavior, limiting junction-temperature rise, and preserving efficiency when load or coupling conditions vary within the standardized operating envelope. This makes the device technology directly relevant to infrastructure-scale wireless charging, where stable operation and repeatable performance are more important than isolated peak efficiency.

C. SYSTEM-LEVEL DESIGN IMPLICATIONS FOR STANDARDIZED WIRELESS CHARGING

The system-level benefits of SiC adoption arise from the interaction among device behavior, resonant-network design, thermal management, and standard-aware control. Higher feasible switching frequency can reduce the size of resonant passive components and support more compact power-conversion modules, but this benefit can only be realized if switching loss and thermal stress remain manageable. Similarly, modular scaling across standardized power classes requires the inverter, resonant network, and protection logic to maintain predictable behavior across load and alignment variations.

Table I summarizes these device-to-system relationships. The table replaces purely conceptual trend plots with a more structured design-oriented comparison, highlighting how SiC characteristics influence practical infrastructure requirements such as fixed-frequency compliance, thermal margin, component size, modularity, and readiness for future energy-management functions.

TABLE I. SYSTEM-LEVEL IMPLICATIONS OF SiC DEVICE ADOPTION IN STANDARDIZED EV WIRELESS CHARGING INFRASTRUCTURE

Design consideration	Conventional Si-based implementation	SiC-enabled implication for standardized infrastructure
Fixed-frequency operation	Limited margin at elevated WPT frequencies because switching loss rises rapidly	Supports efficient operation within standardized frequency bands such as the 85 kHz range
Switching-loss sensitivity	Higher switching energy increases thermal stress and may require conservative derating	Lower switching energy improves efficiency stability under load and coupling variation
Thermal management	Reduced junction-temperature margin and greater cooling demand during continuous operation	Expanded thermal headroom supports sustained infrastructure-duty operation
Resonant component design	Lower practical frequency tends to require larger passive components	Higher feasible frequency enables more compact resonant networks and improved installation density
Modular scalability	Scaling across power classes may require redesign of inverter and cooling hardware	Reusable SiC power modules support scalable and standardized charging platforms
Control and grid readiness	Narrower operating margins limit flexibility for power regulation and derating	Improved efficiency and thermal margin support standard-aware control and future demand-response functions

D. IMPLICATIONS FOR EFFICIENCY, POWER DENSITY, AND INFRASTRUCTURE DEPLOYMENT

The combined electrical and thermal characteristics of SiC devices, together with the system-level implications summarized in Table I, indicate that SiC technology offers a pathway to achieving higher efficiency and power density in wireless charging systems. Reduced switching loss improves efficiency across a broad operating range, while increased thermal margin supports sustained high-power operation without excessive cooling complexity. These characteristics are directly relevant to charging infrastructure, where repeated daily use, compact installation, and predictable operating cost are important deployment considerations.

Importantly, these advantages do not, by themselves, guarantee improved system performance under standardized deployment constraints. Instead, they provide the underlying capability required to design power conversion architectures and control strategies that remain efficient and robust when operating frequency, power level, alignment conditions, and infrastructure interfaces are externally constrained. This distinction motivates the system-level design considerations discussed in Section IV and the standardization-oriented architecture and quantitative evaluation presented in Section V.

IV. SYSTEM DESIGN CONSIDERATIONS FOR SiC-ENABLED WIRELESS POWER TRANSFER INFRASTRUCTURE

The adoption of silicon carbide (SiC) power devices introduces new design degrees of freedom for wireless power transfer (WPT) systems, particularly in applications requiring high efficiency, continuous operation, compact system integration, and scalable infrastructure deployment. Prior to considering standardized deployment constraints, it is essential to examine the fundamental system-level design considerations associated with SiC-enabled wireless charging. These considerations define the feasible design space and motivate the architectural and control choices presented in subsequent sections.

A. SWITCHING FREQUENCY AND POWER CONVERSION CONSIDERATIONS

Switching frequency is a critical design parameter in wireless power transfer systems, as it directly influences resonant network design, magnetic component size, and overall system power density. Higher operating frequencies enable reduced passive component volume and improved dynamic response; however, they also exacerbate switching losses and electromagnetic stress in power devices.

Conventional silicon-based power devices experience rapidly increasing switching losses and reduced efficiency as switching frequency increases beyond several tens of kilohertz. This limitation constrains practical operating frequency and often necessitates conservative design margins. In contrast, SiC power devices exhibit fast switching transitions and significantly lower switching energy, enabling efficient operation at substantially higher frequencies. As a result, SiC devices expand the feasible operating frequency range for WPT systems and allow designers to explore resonant topologies and compensation strategies that are impractical with silicon technology.

At the system level, the ability to operate efficiently at higher switching frequencies directly impacts resonant tuning flexibility and current waveform shaping. These characteristics are particularly important in WPT systems, where reactive power circulation and resonant detuning can significantly influence device stress and efficiency.

B. THERMAL MANAGEMENT, CONTINUOUS-DUTY OPERATION, AND INFRASTRUCTURE AVAILABILITY

Wireless charging systems for electric vehicles are typically required to support extended continuous operation under varying environmental conditions. Thermal performance therefore represents a fundamental design constraint for charging infrastructure, independent of standardization considerations. Excessive junction temperature rise not only reduces efficiency but also limits long-term reliability, increases cooling system complexity, and may reduce infrastructure availability during high-utilization periods.

SiC power devices offer higher allowable junction temperatures and improved thermal robustness compared with silicon devices. This increased thermal margin provides designers with greater flexibility in balancing power density, cooling complexity, and reliability. Importantly, the improved thermal performance of SiC devices enables sustained high-power operation without aggressive derating, which is particularly advantageous for infrastructure-oriented charging systems.

From a system perspective, enhanced thermal margin also facilitates the implementation of thermal-aware control strategies, such as dynamic power regulation and soft derating, without compromising overall system availability. These capabilities are difficult to achieve consistently with silicon-based devices operating near their thermal limits.

C. SCALABILITY AND MODULAR ARCHITECTURE FOR STANDARDIZED INFRASTRUCTURE

Scalability across different power levels is a persistent challenge in wireless power transfer system design and infrastructure deployment. In silicon-based implementations, scaling output power often requires substantial redesign of the inverter stage, resonant components, and thermal management system. Such redesign efforts reduce component reuse, increase system complexity, and slow the deployment of standardized charging platforms across residential, public, fleet, and corridor applications.

The high-frequency and high-temperature capabilities of SiC devices support modular power conversion architectures in which inverter modules can be reused and scaled with minimal modification. By maintaining efficiency and thermal performance across a wide operating range, SiC-enabled modules can serve as building blocks for scalable WPT systems. This modularity reduces design complexity and facilitates faster system development across multiple power levels.

Although scalability is ultimately influenced by application-specific constraints, the intrinsic characteristics of SiC devices provide a strong foundation for modular system design that is difficult to achieve with conventional silicon technology. This modularity is also important for standardization, because reusable power modules can help maintain consistent behavior across different power classes and installation environments.

D. RESONANT OPERATION AND CONTROL ROBUSTNESS

Resonant operation is central to wireless power transfer efficiency, but it introduces sensitivity to load variation, coupling changes, and component tolerances. Maintaining stable resonant conditions while minimizing device stress is therefore a key design challenge.

The fast switching behavior of SiC devices enables effective implementation of soft-switching and resonant control techniques, such as zero-voltage or zero-current switching, over a wider operating range. These techniques reduce switching losses and mitigate voltage and current overshoot, improving both efficiency and reliability. In addition, the ability of SiC devices to tolerate higher dv/dt and di/dt facilitates robust control under transient conditions, including coupling variation and dynamic load changes.

At the system level, these control advantages translate into improved robustness and reduced sensitivity to operating condition variation, which are essential characteristics for practical WPT deployment. They also support future energy-management functions, because a stable and controllable power stage is a prerequisite for predictable grid-facing behavior. These considerations form the basis for the standard-aware architecture and control framework developed in Section V.

V. STANDARDIZATION-ORIENTED SYSTEM DESIGN FOR SMART EV CHARGING INFRASTRUCTURE

A. DESIGN OBJECTIVES FOR STANDARDIZED AND ENERGY-EFFICIENT EV WIRELESS CHARGING SYSTEMS

Standardized electric vehicle (EV) wireless charging systems are required to satisfy a broader set of constraints than laboratory-optimized or proprietary implementations. In addition to achieving high power transfer efficiency and sufficient output capability, standardized systems must ensure interoperability across manufacturers, scalability across power classes, reproducible performance under diverse operating and environmental conditions, and compatibility with future smart-energy infrastructure. These requirements introduce system-level constraints that extend beyond conventional power electronics optimization and directly influence architecture selection, control strategy, and component technology.

Unlike experimental wireless charging platforms, standardized deployments impose strict limitations on operating frequency, electromagnetic emission, thermal behavior, and control dynamics. For example, emerging international standards define fixed or narrowly bounded operating frequency bands, allowable power levels, misalignment tolerances between transmitter and receiver coils, and mandatory communication and safety protocols. Compliance with these constraints is essential to guarantee cross-vendor interoperability and regulatory acceptance, but it also reduces design freedom and amplifies the impact of component-level inefficiencies and nonidealities. From an energy-system perspective, these constraints further affect infrastructure efficiency, cooling demand, installation density, and long-term operating cost.

Recent standardization efforts for EV wireless power transfer, exemplified by specifications such as SAE J2954, explicitly prescribe operating frequency ranges, alignment envelopes, power classes, and vehicle-to-infrastructure communication requirements. While these specifications enable large-scale deployment and ecosystem compatibility, they also challenge the applicability of conventional silicon-based power devices, particularly at higher power levels and elevated switching frequencies. Silicon devices typically experience increased switching losses, thermal stress, and reduced efficiency when operating near the upper limits of standardized frequency bands, thereby constraining achievable power density and robustness.

To address these challenges, this work adopts a standardization-oriented system design framework that leverages the intrinsic advantages of silicon carbide (SiC) power devices. By exploiting the superior switching speed, lower switching losses, and higher thermal tolerance of SiC technology, the proposed architecture enables stable high-frequency operation within standardized bands while maintaining high efficiency and thermal margin. Furthermore, the use of SiC devices facilitates modular and scalable power conversion architectures that can be adapted to different standardized power classes without fundamental redesign, supporting infrastructure rollout across multiple EV charging scenarios.

Importantly, the proposed framework emphasizes performance consistency under practical operating conditions, including coil misalignment and load variation, which are explicitly accounted for in standardized test procedures. By aligning the power conversion stage, control strategy, and interface design with standardized communication, protection, and monitoring requirements, the system architecture supports seamless integration into standardized EV wireless charging ecosystems. This standard-aware approach establishes a foundation for scalable, interoperable, energy-efficient, and reproducible wireless charging systems suitable for real-world infrastructure deployment.

B. STANDARD-AWARE SYSTEM ARCHITECTURE AND CONTROL FRAMEWORK

1) System-Level Architecture for Standardized Wireless Power Transfer Infrastructure

The overall system architecture of the proposed standardized EV wireless charging system is shown in Fig. 2. The architecture follows a grid-to-vehicle power conversion chain that is explicitly designed to comply with standardized operating constraints while maintaining high efficiency, robustness, and infrastructure compatibility. Grid-side AC power is first processed by an AC/DC conversion stage, which provides a regulated DC-link serving as the energy buffer for high-frequency power conversion. The DC-link feeds a silicon carbide (SiC)-based high-frequency inverter operating at the standardized wireless power transfer frequency of 85 kHz. The inverter output is coupled to a resonant compensation network that interfaces with the transmitter coil, enabling efficient magnetic coupling across the air gap to the receiver coil on the vehicle side.

Within this architecture, the SiC high-frequency inverter represents the key enabling element. Its placement between the DC-link and the resonant network reflects its central role in shaping the voltage and current waveforms required for efficient resonant operation under standardized frequency constraints. Compared with conventional silicon-based power devices, SiC devices exhibit substantially lower switching losses and superior thermal performance at elevated switching frequencies. These characteristics allow the inverter to operate stably within standardized frequency bands while supporting higher power density and improved efficiency, even under partial misalignment and varying load conditions. By explicitly structuring the power conversion path around standardized frequency operation and modular power stages, the architecture shown in Fig. 2 supports scalability across standardized power classes and facilitates reproducible performance across different vehicle and infrastructure implementations.

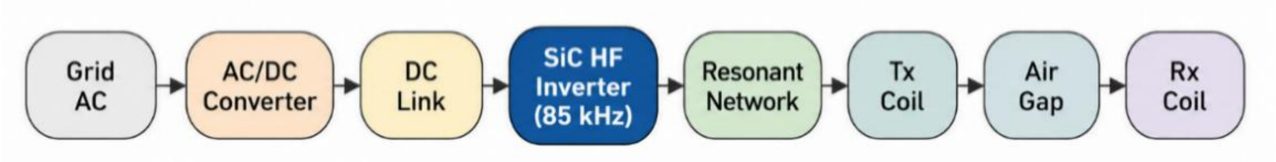

FIGURE 2. System architecture of a SiC-based electric vehicle wireless charging system for standardized infrastructure deployment.

2) Standard-Aware Control and Operational Flow

While Fig. 2 describes the physical power flow, the system-level control logic governing standardized operation is illustrated in Fig. 3. The control framework is explicitly designed to enforce compliance with standardized constraints throughout all operating phases. Following system initialization, a standard compliance evaluation stage verifies that key parameters—including operating frequency, requested power level, and transmitter–receiver alignment—fall within allowable standardized limits. This compliance check acts as a gating mechanism that prevents nonconforming operation and ensures interoperability across vehicles and charging infrastructure from different manufacturers.

Upon successful compliance verification, the control system enables the SiC high-frequency inverter and establishes resonant matching and soft-switching conditions. These actions are critical for minimizing switching losses and voltage stress while maintaining stable resonant operation under varying coupling conditions. The system then transitions into steady-state wireless power transfer, during which real-time monitoring of power, efficiency, and temperature is continuously performed. Feedback from this monitoring stage enables dynamic power regulation and thermal-aware derating, ensuring that both standard-defined limits and device-level operating constraints are respected. In cases where standardized conditions are violated or abnormal operating states are detected, the control flow transitions to fault handling or standby operation. This structured control sequence ensures that standard compliance is maintained not only at system startup but throughout continuous operation.

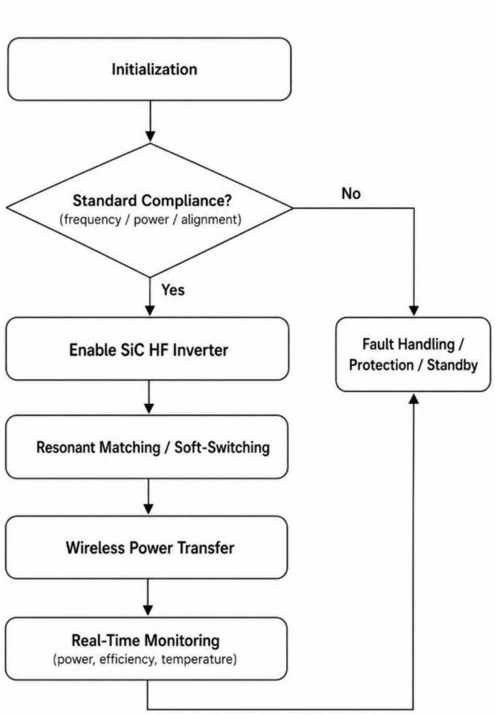

FIGURE 3. Standard-aware control and power flow for the proposed EV wireless charging system.

3) Layered Interface Framework for Standardization, Scalability, and Smart-Energy Integration

To further clarify the interaction between standardized requirements, control logic, and physical hardware, Fig. 4 presents a layered interface framework that abstracts the system into three functional domains. The uppermost layer corresponds to the standard and communication interface, which encapsulates standardized power classes, frequency constraints, interoperability requirements, vehicle-to-infrastructure signaling, and potential energy-management communication. This layer defines the external behavioral envelope within which the wireless charging system must operate. The intermediate control and protection layer translates standardized requirements into real-time control objectives. This layer governs power regulation within standard limits, thermal-aware derating based on system and device temperatures, robustness mechanisms that mitigate performance degradation due to coil misalignment, and monitoring functions that could support future load-management or demand-response interfaces. By isolating standard-specific and energy-management logic within this layer, the system can accommodate evolving standards with minimal impact on the underlying hardware. The lowest layer represents the physical and power domain enabled by SiC technology. This layer includes the SiC high-frequency inverter, gate drive circuitry, resonant compensation network, and magnetically coupled transmitter and receiver coils. The superior switching speed and thermal capability of SiC devices directly enhance the system's ability to satisfy the constraints imposed by the upper layers, particularly under high-frequency, high-power operation. Together, the layered framework shown in Fig. 4 enables a clean separation of concerns between standard compliance, control functionality, energy-management interfaces, and hardware implementation. This separation is essential for achieving scalable, interoperable, reproducible, and smart-grid-ready EV wireless charging systems suitable for standardized deployment.

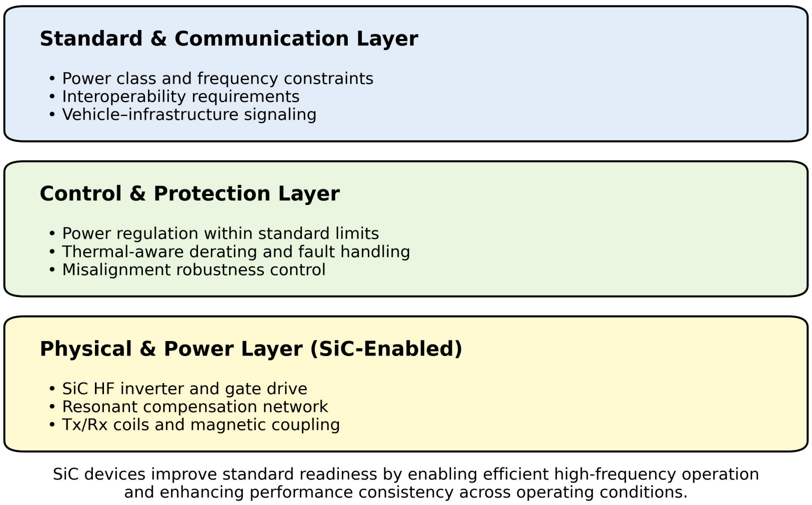

FIGURE 4. Standardization-oriented interface framework illustrating the interaction among standardized communication requirements, control and protection logic, and the SiC-enabled physical power layer.

C. SiC POWER DEVICE DESIGN CONSIDERATIONS FOR STANDARDIZED WIRELESS CHARGING

The selection and application of silicon carbide (SiC) power devices are central to enabling standardized electric vehicle (EV) wireless charging systems to meet stringent constraints on operating frequency, efficiency, thermal robustness, and scalability. Unlike conventional silicon-based power devices, SiC MOSFETs offer superior switching performance, higher allowable junction temperatures, and improved voltage blocking capability, making them particularly well suited for standardized wireless power transfer systems operating at fixed high-frequency bands and under repeated infrastructure-duty operation.

In standardized EV wireless charging applications, inverter operation is typically constrained to a narrow frequency range, such as the 85 kHz band specified in current standards. Under these conditions, conventional silicon devices exhibit rapidly increasing switching losses and thermal stress, which limit achievable power density and reduce efficiency margins. SiC devices, by contrast, maintain low switching losses and fast transition characteristics at elevated frequencies, enabling efficient high-frequency operation without excessive thermal derating. This fundamental distinction is summarized in Table III, which compares the efficiency- and thermal-related attributes of silicon and SiC devices from a system-relevant perspective.

Beyond device-level switching behavior, the adoption of SiC power devices directly influences system architecture and scalability under standardized constraints. As shown in Table II, the ability of SiC devices to operate efficiently at higher switching frequencies enables compact resonant components and supports modular inverter architectures. These modular designs facilitate scalability across standardized power classes while maintaining consistent system behavior. In contrast, silicon-based designs are often constrained by limited switching frequency capability, leading to larger passive components, reduced modularity, and narrower compliance margins when operating near standardized limits.

TABLE II. MODULAR SYSTEM DESIGN FOR STANDARDIZED POWER CLASSES

Design aspect	Conventional Si-based design	Proposed SiC-based design
Switching frequency	20–40 kHz	80–150 kHz
Power module scalability	Limited	High (modular)
Passive component size	Large	Compact
Efficiency consistency	Moderate	High
Standard compliance margin	Narrow	Wide

Efficiency consistency across operating conditions is another critical requirement for standardized deployment, as performance must remain reproducible under varying load levels and transmitter–receiver alignment conditions. The reduced switching and conduction losses of SiC devices contribute to more stable efficiency profiles across these conditions, reducing sensitivity to coupling variations and simplifying compliance with standardized test procedures. This advantage is reflected in both the efficiency consistency and standard compliance margin entries in Table II.

Thermal robustness further distinguishes SiC-based designs in standardized wireless charging systems. Standardized deployments often require extended continuous-duty operation across diverse environmental conditions, placing significant demands on thermal management. As summarized in Table III, SiC devices offer a wider operating temperature margin and reduced cooling complexity compared with silicon devices. This thermal headroom enables the implementation of thermal-aware control and derating strategies that preserve standard compliance without compromising system availability or reliability.

The fast switching characteristics of SiC devices also enable effective implementation of soft-switching and resonant control techniques at standardized frequencies. These techniques reduce switching losses and electromagnetic emissions, supporting compliance with electromagnetic compatibility requirements while improving long-term device reliability. In silicon-based implementations, achieving similar control performance at standardized frequencies often requires additional circuit complexity or conservative operating margins, which negatively impact system efficiency and scalability.

Overall, the comparative analyses presented in Tables II and III illustrate that the benefits of SiC power devices extend beyond incremental efficiency improvements. By enabling high-frequency operation, modular system architectures, consistent efficiency, and enhanced thermal robustness, SiC technology provides a system-level foundation for standardized EV wireless charging deployment. This alignment between device-level capability and standardized system requirements is essential for achieving scalable, interoperable, energy-efficient, and reliable wireless charging solutions suitable for widespread adoption as part of electrified transportation infrastructure.

TABLE III. EFFICIENCY AND THERMAL PERFORMANCE COMPARISON

Parameter	Silicon devices	SiC devices
Switching loss	High	Low
Operating temperature margin	Limited	Wide
Cooling complexity	High	Moderate
Long-term reliability	Moderate	High

D. QUANTITATIVE CASE STUDY AND PERFORMANCE EVALUATION UNDER STANDARDIZED INFRASTRUCTURE CONDITIONS

To validate the effectiveness of the proposed standardization-oriented system design and the role of silicon carbide (SiC) power devices, a quantitative case study was conducted under representative standardized operating conditions. The objective of this case study is to evaluate system-level efficiency, robustness to coupling variation, thermal performance, and performance stability, which are critical metrics for standardized EV wireless charging infrastructure deployment.

The case study considers a mid-power EV wireless charging configuration aligned with standardized frequency operation at 85 kHz and representative power class levels. Two system implementations are evaluated: a conventional silicon-based inverter design and a SiC-based inverter design integrated within the system architecture described in Section V-B. All other system parameters, including resonant topology, compensation network, and control strategy, are held constant to isolate the impact of the power device technology.

1) Efficiency Performance at Rated Power

Fig. 5 presents a comparative evaluation of system efficiency for silicon-based and SiC-based wireless charging implementations at rated power under nominal alignment conditions. The SiC-based system exhibits a higher average efficiency than its silicon counterpart, consistent with the reduced switching losses and improved high-frequency operating characteristics of SiC power devices. In addition, the SiC-based implementation shows a narrower efficiency spread, indicating enhanced stability and reduced sensitivity to steady-state operating variations. This behavior is particularly relevant in standardized wireless charging systems, where operation is constrained to a fixed resonant frequency and efficiency recovery through frequency detuning or non-standard control strategies is not permitted. The results in Fig. 5 therefore demonstrate that the proposed SiC-enabled design sustains superior efficiency while adhering strictly to standardized operating conditions.

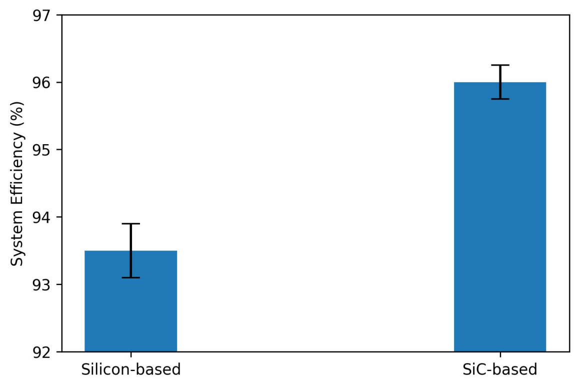

FIGURE 5. System efficiency comparison between silicon-based and SiC-based EV wireless charging systems at rated power under standardized operating conditions.

2) Robustness to Coupling Variation

In practical EV wireless charging scenarios, transmitter–receiver misalignment is unavoidable and is explicitly considered in standardized test and qualification procedures. Fig. 6 examines the impact of coupling variation on system efficiency for silicon-based and SiC-based wireless charging implementations. As the coupling coefficient decreases, both systems experience a reduction in efficiency due to increased reactive power circulation and current stress. However, the SiC-based system consistently maintains a higher absolute efficiency across the entire coupling range.

As shown in the upper panel of Fig. 6, the efficiency degradation of the SiC-based implementation with decreasing coupling is noticeably less pronounced than that of the silicon-based system. The shaded uncertainty bands further indicate reduced sensitivity to operating variation, reflecting improved stability under steady-state standardized operation. The lower panel quantifies the efficiency advantage, demonstrating that the SiC-based system sustains an efficiency gain of approximately 2–4% across the evaluated coupling range, with the largest benefit observed under weaker coupling conditions.

This behavior can be attributed to the superior high-frequency switching performance of SiC devices, which mitigates additional switching losses arising from increased reactive current and detuned operating conditions. From a standardization perspective, this robustness is particularly significant, as it enables consistent efficiency performance across the allowable alignment envelope without resorting to frequency detuning or nonstandard control strategies. The results in Fig. 6 therefore demonstrate that the proposed SiC-enabled design supports interoperability and reproducibility objectives central to standardized EV wireless charging deployments.

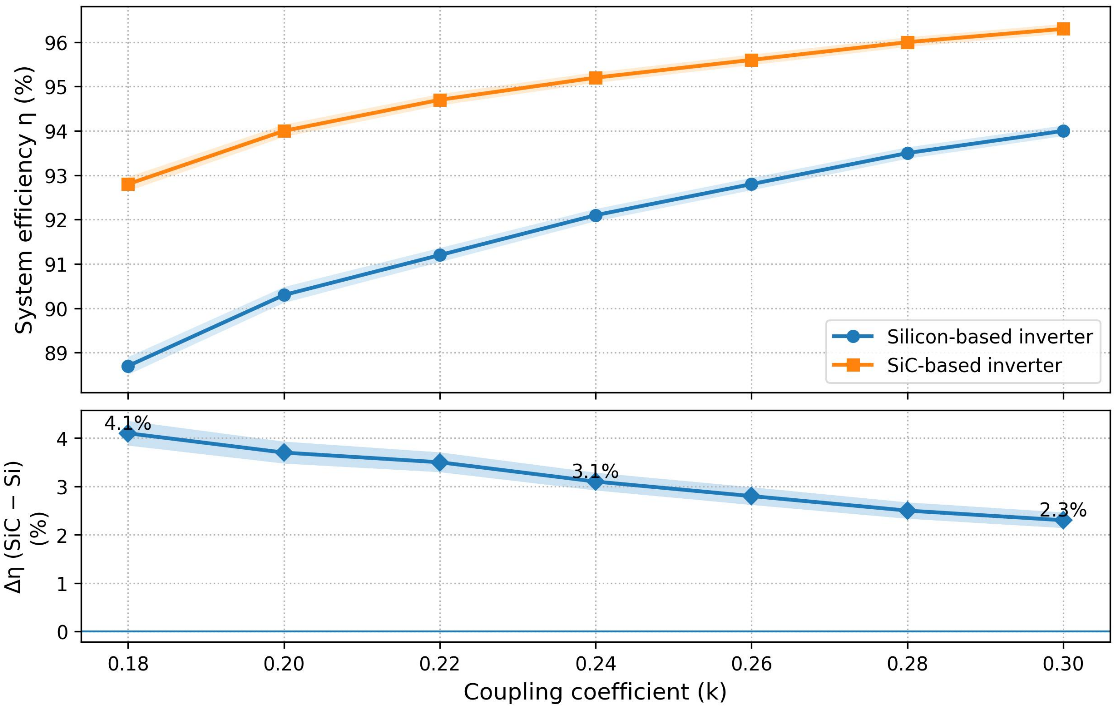

FIGURE 6. Efficiency variation as a function of coupling coefficient for silicon-based and SiC-based wireless charging systems operating within standardized alignment tolerances.

3) Thermal Performance Under Load Variation

Thermal robustness is a critical requirement for standardized EV wireless charging systems, which are expected to operate continuously across a wide range of load conditions and ambient environments. Fig. 7 evaluates the thermal behavior of silicon-based and SiC-based inverter implementations by examining the peak junction temperature of the power devices as a function of output power. As output power increases, the silicon-based inverter exhibits a steep rise in junction temperature, approaching thermal limits near rated operation and thereby constraining available thermal margin.

In contrast, the SiC-based implementation maintains substantially lower junction temperatures across the evaluated power range, resulting in a significantly expanded thermal operating window. As illustrated in the lower panel of Fig. 7, this translates into a consistent junction temperature reduction on the order of tens of degrees Celsius relative to the silicon-based design, with the thermal margin increasing at higher power levels. This additional headroom enables more effective thermal-aware control and power derating strategies while maintaining compliance with standardized power class requirements and fixed-frequency operation.

The thermal performance trends observed in Fig. 7 are consistent with the comparative loss characteristics summarized in Table III and confirm the suitability of SiC devices for sustained, high-power wireless charging under standardized operating constraints. Collectively, these results demonstrate that SiC-enabled architectures can achieve improved thermal reliability without relying on oversized cooling solutions or conservative derating, which is essential for practical standardized deployment.

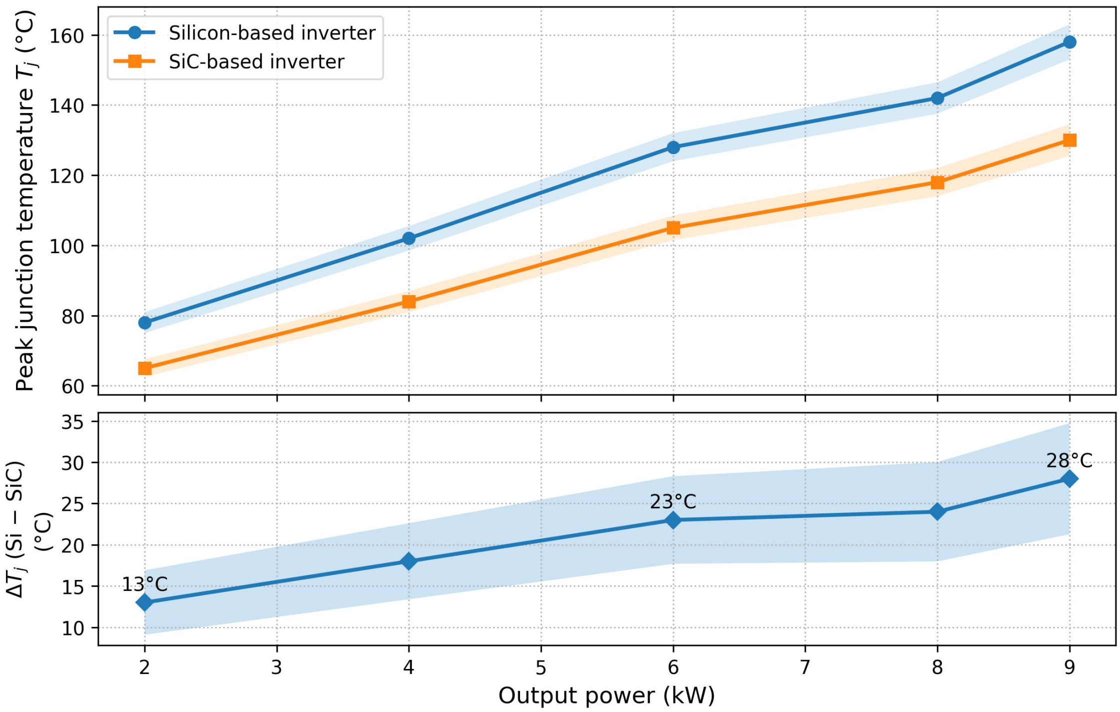

FIGURE 7. Peak junction temperature of inverter power devices as a function of output power for silicon-based and SiC-based wireless charging systems.

4) Loss Composition Analysis

While the efficiency trends presented in Fig. 5 demonstrate overall system-level improvements, further insight can be obtained by examining the underlying loss mechanisms. Fig. 8 presents a comparative loss breakdown for the silicon-based and SiC-based wireless charging systems operating at rated power and standardized frequency.

As shown in Fig. 8, switching loss constitutes a dominant portion of total loss in the silicon-based implementation under high-frequency operation. This behavior is consistent with the rapid increase in switching energy associated with silicon devices at elevated frequencies. In contrast, the SiC-based system exhibits a substantially reduced switching loss component, reflecting the fast switching transitions and lower switching energy of SiC devices. As a result, the relative contribution of conduction and passive component losses becomes more prominent.

This shift in loss composition has important system-level implications. Reduced switching loss not only improves overall efficiency but also mitigates thermal stress in the inverter stage, enabling more stable operation under standardized continuous-duty conditions. The loss breakdown in Fig. 8 therefore provides mechanistic validation of the efficiency and thermal improvements observed in Figs. 5 and 7, linking device-level characteristics directly to system-level performance.

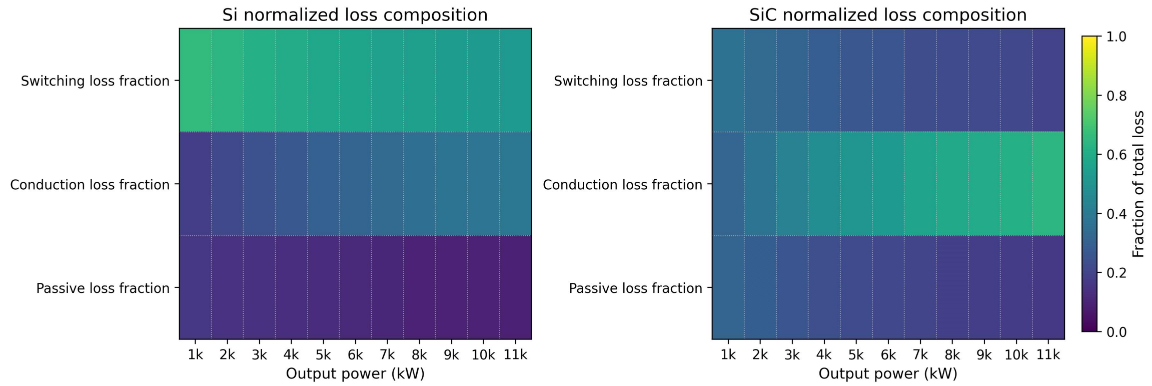

FIGURE 8. Comparison of loss composition for silicon-based and SiC-based EV wireless charging systems at rated power and standardized operating frequency. Total loss is decomposed into switching, conduction, and passive component losses. The SiC-based system exhibits significantly reduced switching loss, resulting in improved efficiency and enhanced thermal margin.

5) Performance Stability Across Standardized Operating Conditions

In addition to peak performance metrics, standardized EV wireless charging systems must maintain consistent behavior across the full range of operating conditions defined by the standard. Fig. 9 evaluates the performance stability of the proposed system across a representative standardized operating envelope, including variations in output power and alignment conditions.

Fig. 9 illustrates that the SiC-based implementation maintains a narrower efficiency variation across the standardized operating space compared with the silicon-based system. As operating conditions approach standardized limits, the silicon-based design exhibits increased sensitivity to frequency-constrained switching loss and thermal stress, resulting in greater performance degradation. By contrast, the SiC-based system preserves higher efficiency and more uniform behavior across the same operating envelope.

This performance stability is particularly relevant for standardized deployment, where certification and interoperability depend on reproducible behavior rather than isolated peak performance. The results shown in Fig. 9 demonstrate that the proposed SiC-enabled, standard-aware design not only improves average performance but also enhances robustness within standardized operating bounds.

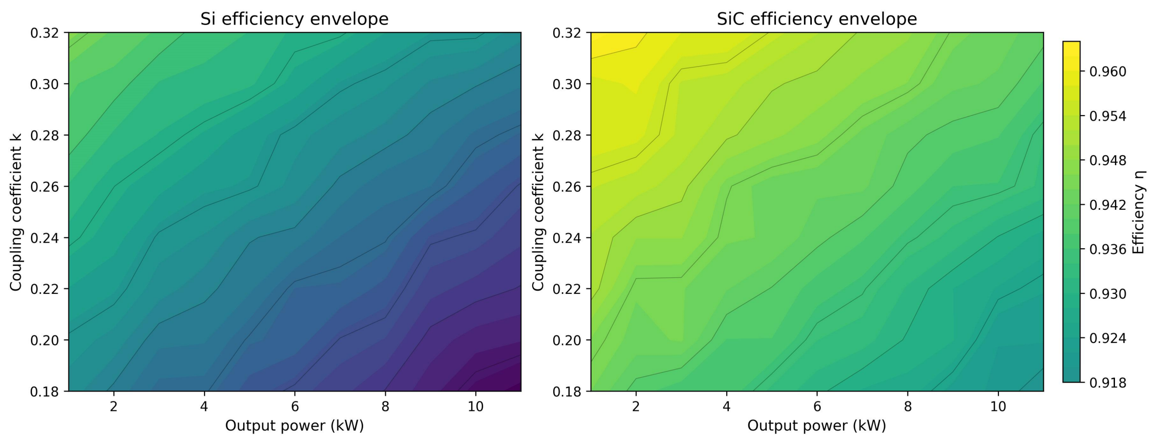

FIGURE 9. Performance stability comparison across standardized operating conditions for silicon-based and SiC-based wireless charging systems. The SiC-based system exhibits reduced efficiency variation and improved robustness across standardized power and alignment conditions, supporting reproducible and interoperable deployment.

6) Discussion and Implications for Standardized Infrastructure Deployment

Collectively, the efficiency, misalignment robustness, and thermal performance results demonstrate that the proposed SiC-based, standard-aware system design delivers consistent and quantifiable advantages under standardized operating conditions. Importantly, these improvements are observed not only in nominal operating points but also across variations in coupling and output power that are explicitly considered in standardized test and certification procedures. This consistency is important for infrastructure deployment because charging providers require predictable efficiency, thermal behavior, and service availability across different vehicles and parking conditions.

The enhanced performance consistency of the SiC-based implementation, evidenced by reduced efficiency degradation under misalignment and increased thermal margin at higher power levels, directly addresses key challenges associated with interoperability, repeatability, long-term reliability, and energy-efficient operation in standardized EV wireless charging systems. Unlike approaches that rely on nonstandard operating modes or aggressive derating to maintain compliance, the proposed design sustains high performance while operating strictly within fixed-frequency and power-class constraints.

The quantitative case study therefore provides system-level validation of the design framework introduced in Sections V-A to V-C. By explicitly mapping SiC device characteristics to architectural choices, resonant network design, control strategies, and infrastructure-level requirements constrained by standards, the proposed approach enables scalable, reliable, and reproducible wireless charging implementations suitable for large-scale standardized deployment.

E. POTENTIAL GRID-LEVEL FUNCTIONS AND DEMAND-RESPONSE READINESS

Although the present quantitative case study focuses on power-conversion performance, the proposed layered architecture is compatible with future grid-facing functions. Because the standard and communication layer is separated from the physical power layer, charging schedules, power-limit commands, and infrastructure monitoring signals can be incorporated without redesigning the resonant power stage. This structure is important for future smart charging applications in which charging assets may participate in load shaping, peak reduction, or renewable-energy utilization.

In such applications, SiC-enabled efficiency and thermal margin provide practical value beyond nominal charging performance. Lower conversion loss reduces wasted electricity during high-utilization operation, while expanded thermal headroom allows the system to respond to controlled power adjustments without excessive derating. Therefore, the same device-level advantages that improve standardized WPT operation also support the broader SPEE-related goals of energy efficiency, infrastructure flexibility, and resilient electrification.

VI. DISCUSSION

A. POSITIONING WITHIN ELECTRIFIED TRANSPORTATION INFRASTRUCTURE

Most existing standardized EV wireless charging implementations are derived from laboratory-optimized resonant power transfer concepts that are subsequently constrained to comply with standard requirements. In such designs, standard compliance is often enforced through conservative derating, oversized passive components, or restricted operating envelopes, particularly when silicon-based power devices are employed. As a result, standardized systems may exhibit reduced efficiency margins, limited thermal headroom, and sensitivity to misalignment when compared with their nonstandard or experimental counterparts. For electrified transportation infrastructure, these limitations can translate into higher operating losses, larger cooling requirements, and reduced deployment flexibility. In contrast, the approach presented in this paper adopts standardization constraints as primary design inputs rather than post-hoc limitations. By explicitly aligning inverter operating frequency, control behavior, thermal management strategy, and infrastructure scalability with standardized requirements, the proposed framework redefines how power electronics are integrated into standardized WPT systems. The use of SiC power devices is not treated as a drop-in efficiency enhancement, but as a system-level enabler that reshapes architectural choices and control strategies under fixed-frequency, power-class, and infrastructure-availability constraints. The quantitative results in Figs. 5–9 highlight this distinction. Unlike conventional designs that trade efficiency or robustness to maintain standard compliance, the proposed SiC-based system achieves improved efficiency consistency, enhanced tolerance to coupling variation, and increased thermal margin simultaneously. This combination of characteristics represents a meaningful advancement toward deployable, large-scale wireless charging infrastructure that can support transportation electrification without imposing unnecessary energy losses or thermal burdens.

B. IMPLICATIONS FOR INTEROPERABILITY, REPRODUCIBILITY, AND MARKET DEPLOYMENT

Interoperability and reproducibility are foundational objectives of EV wireless charging standards. However, in practice, device-level limitations can introduce variability in performance across implementations that nominally comply with the same standard. The results presented in this work suggest that SiC-enabled architectures can reduce such variability by providing wider efficiency and thermal margins under standardized conditions. This improvement is relevant not only to technical certification but also to market deployment, because infrastructure providers, automakers, and users benefit from predictable performance across installations. The improved robustness to misalignment demonstrated in Fig. 6 is particularly relevant from an interoperability perspective. Standardized alignment tolerances are designed to accommodate diverse vehicle geometries and parking conditions, but many existing systems experience pronounced performance degradation near the boundaries of these tolerances. By maintaining higher efficiency across the allowable coupling range, the proposed approach supports more uniform user experience and simplifies compliance verification across manufacturers. From a reproducibility standpoint, the layered interface framework illustrated in Fig. 4 further reinforces standard-driven system behavior. By decoupling standard logic, control functions, energy-management interfaces, and physical hardware, the framework enables consistent system response to standardized inputs while allowing hardware innovation at the device and module level. This separation of concerns is critical for maintaining reproducibility as standards evolve, as new power device technologies are introduced, and as grid-facing communication functions become more common.

C. IMPLICATIONS FOR ENERGY EFFICIENCY AND DEMAND RESPONSE

Energy efficiency is a direct link between the proposed power-electronics framework and the broader SPEE direction. In large-scale EV charging deployment, even modest improvements in conversion efficiency can reduce cumulative energy waste, heat generation, and cooling demand. The results in Figs. 5–9 therefore have infrastructure-level significance: they indicate not only improved converter performance but also more efficient use of electricity within standardized charging networks. Demand response and smart charging require charging systems to operate predictably under externally requested power adjustments. The improved efficiency stability and thermal margin of the SiC-based architecture can help maintain reliable operation when charging power is scheduled, curtailed, or adjusted to match grid conditions. While detailed grid-control algorithms are outside the scope of this paper, the proposed architecture provides a technically suitable foundation for future integration with demand-response and energy-management frameworks.

D. IMPLICATIONS FOR SCALABILITY AND RESILIENT INFRASTRUCTURE DEPLOYMENT

Scalability across standardized power classes remains a challenge for current EV wireless charging systems, particularly when higher power levels are targeted. Silicon-based implementations often require substantial redesign of the inverter stage, passive components, and thermal management system when scaling power, limiting modular reuse. In infrastructure planning, this limitation can increase deployment cost and make it more difficult to adapt charging systems to different use cases, such as home charging, public charging, fleet depots, and dynamic charging corridors. The modular SiC-based architecture discussed in Section V-C and summarized in Table II offers a pathway to improved scalability and infrastructure resilience. By enabling higher switching frequency operation with reduced loss and thermal stress, SiC devices support compact and reusable inverter modules that can be adapted across multiple standardized power classes. This modularity has direct implications for cost reduction, manufacturing consistency, maintenance simplification, and accelerated deployment of standardized wireless charging infrastructure.

E. IMPLICATIONS FOR FUTURE STANDARD EVOLUTION

While current standards specify fixed operating frequencies, alignment tolerances, and power classes, future revisions are likely to incorporate tighter efficiency requirements, extended power ranges, enhanced safety and diagnostic features, and stronger coordination with energy-management systems. The results of this study indicate that SiC-enabled system architectures are well positioned to accommodate such evolution without fundamental architectural changes. In particular, the thermal and efficiency margins demonstrated in Figs. 5 and 7 suggest that SiC-based designs can absorb additional standard-driven constraints, such as extended continuous-duty operation, higher ambient temperature ratings, or more stringent infrastructure efficiency targets, more readily than silicon-based designs. Furthermore, the standard-aware control framework shown in Fig. 3 provides a foundation for integrating future communication, monitoring, demand-response, and certification requirements with minimal impact on the physical power layer.

VII. CONCLUSION

This paper presented a standardization-oriented system design framework for SiC-enabled wireless EV charging infrastructure in the context of transportation electrification and smart energy systems. By explicitly treating standardized constraints as primary design inputs at the architectural, control, infrastructure, and power-device levels, the proposed approach addresses fundamental limitations encountered in existing standardized wireless power transfer implementations.

First, the study demonstrates that standardized EV wireless charging systems impose fixed-frequency, interoperability, efficiency, and thermal constraints that directly shape system-level design choices. Incorporating these constraints at the outset of system design, rather than accommodating them through post-hoc tuning or conservative derating, is essential for achieving scalable and reproducible performance suitable for standardized infrastructure deployment.

Second, the results confirm that SiC power devices provide a decisive advantage for standardized wireless charging by enabling stable and efficient high-frequency operation within mandated frequency bands. This capability supports compact resonant network design, improved efficiency consistency, and enhanced robustness under standardized operating conditions, including load variation and transmitter-receiver misalignment.

Third, the proposed standard-aware system architecture and control framework facilitates interoperability and reproducibility across manufacturers and deployment environments. The explicit separation of standard logic, control functionality, energy-management interfaces, and physical hardware enables flexible adaptation to evolving standards without requiring fundamental changes to the underlying system architecture.

Fourth, the quantitative case study validates the proposed framework by demonstrating improved efficiency, reduced sensitivity to coupling variation, increased thermal margin, and stronger performance stability for the SiC-based implementation under standardized conditions. These system-level improvements directly address practical challenges associated with continuous operation, certification testing, infrastructure scalability, and long-term energy efficiency.

Finally, the integration of SiC power devices within a modular, standard-oriented system framework provides a viable pathway for scaling wireless charging systems across standardized power classes and accommodating future standard evolution. The results indicate that SiC-enabled architectures are well suited to support the next generation of standardized EV wireless charging infrastructure, bridging the gap between laboratory-level performance and real-world deployment needs in electrified and smart energy systems.

REFERENCES

[1] Z. Liu, T. Li, S. Li, and C. C. Mi, "Advancements and challenges in wireless power transfer: A comprehensive review," *Nexus*, vol. 1, no. 2, 2024, Art. no. 100014.

[2] H. S. E. Mansour, M. Samir, B. Elhady, and S. Abdelmaksoud, "Wireless charging systems for electric vehicles: Review," *Green Energy Intell. Transp.*, 2025, Art. no. 100371.

[3] A. Ali and U. Mehta, "A comprehensive review of wireless power transfer systems: Focused study with fractional-order elements," *Int. J. Circuit Theory Appl.*, vol. 52, no. 7, pp. 3664–3678, 2024.

[4] Z. Xue, W. Liu, C. Liu, and K. T. Chau, "Critical review of wireless charging technologies for electric vehicles," *World Electr. Veh. J.*, vol. 16, no. 2, 2025, Art. no. 65.

[5] I. Bentalhik et al., "Analysis, design and realization of a wireless power transfer charger for electric vehicles: Theoretical approach and experimental results," *World Electr. Veh. J.*, vol. 13, no. 7, 2022, Art. no. 121.

[6] P. Chowdhury, M. M. A. Shovon, R. Yeassin, and O. Farrok, "Wireless charging for electric vehicles: A review on environmental, health, technical, and policy landscape," *Energy Convers. Manage.: X*, vol. 28, 2025, Art. no. 101363.

[7] X. Wang et al., "Lateral and angular misalignments of coil in wireless power transfer system," *Sens. Actuators A, Phys.*, vol. 341, 2022, Art. no. 113577.

[8] T. Bouanou, H. El Fadil, H. Abbade, and Z. El Idrissi, "Wireless charging for electric vehicles: A comprehensive review of technologies, challenges, and solutions," *J. Power Sources*, vol. 660, 2025, Art. no. 238501.

[9] *Wireless Power Transfer for Light-Duty Plug-In/Electric Vehicles and Alignment Methodology*, SAE Standard J2954_202408, 2024.

[10] *Communication for Wireless Power Transfer Between Light-Duty Plug-In Electric Vehicles and Wireless EV Charging Stations*, SAE Standard J2847/6_202009, 2020.

[11] *Wireless Power Transfer for Heavy-Duty Electric Vehicles*, SAE Standard J2954/2_202212, 2022.

[12] O. Abuajwa, S. P. Thiagarajah, Z. Ambak, M. T. Sarker, G. Ramasamy, and A. P. David, "Comprehensive review of wireless power transfer systems for electric vehicle charging applications," *Discover Appl. Sci.*, vol. 7, 2025, Art. no. 1176.

[13] W. X. Zhong and S. Y. R. Hui, "Maximum energy efficiency tracking for wireless power transfer systems," *IEEE Trans. Power Electron.*, vol. 30, no. 7, pp. 4025–4034, 2014.

[14] A. Rasul, R. Teixeira, and J. Baptista, "Silicon carbide converter design: A review," *Energies*, vol. 18, no. 8, 2025, Art. no. 2140.

[15] B. Shi et al., "A review of silicon carbide MOSFETs in electrified vehicles: Application, challenges, and future development," *IET Power Electron.*, vol. 16, no. 12, pp. 2103–2120, 2023.

[16] L. Yang, K. Dong, Y. Wang, C. Cai, and X. Zhou, "Analysis, design, and validation of a dual-channel high-power WPT system based on bilateral coil decoupling," *IEEE J. Emerg. Sel. Topics Power Electron.*, vol. 12, no. 4, pp. 4288–4295, 2024.

[17] E. Robles, A. Matallana, I. Aretxabaleta, J. Andreu, M. Fernandez, and J. L. Martin, "The role of power device technology in the electric vehicle powertrain," *Int. J. Energy Res.*, vol. 46, no. 15, pp. 22222–22265, 2022.

[18] C. Tao, L. Wang, Y. Zhang, S. Li, and C. Da, "Research on three-phase hybrid compensation WPT system with high misalignment tolerance and its ZVS control strategy," *IEEE Trans. Power Electron.*, vol. 38, no. 12, pp. 14847–14860, 2023.

[19] W. Pan et al., "An adaptive and scalable wireless charging system for electric vehicles with enhanced interoperability and misalignment tolerance," *IEEE Trans. Power Electron.*, 2025, early access.

[20] M. Pei, H. Zhu, J. Ling, Y. Hu, H. Yao, and L. Zhong, "Empowering highway network: Optimal deployment and strategy for dynamic wireless charging lanes," *Commun. Transp. Res.*, vol. 3, 2023, Art. no. 100106.

[21] A. Goyal, D. Kumar, and S. Sharma, "Review of dynamic wireless charging of electric vehicles," *J. Electron. Power Eng.*, vol. 2, no. 1, pp. 49–53, 2025.

[22] Q. Wang, W. Li, J. Kang, and Y. Wang, "Electromagnetic safety evaluation and protection methods for a wireless charging system in an electric vehicle," *IEEE Trans. Electromagn. Compat.*, vol. 61, no. 6, pp. 1913–1925, 2018.