A Review of the Impact of Electric Vehicle Charging on Vehicle Electrical Components: Challenges and Future Directions

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Abstract— The rapid global adoption of electric vehicles (EVs) is driving advances in charging technology, particularly fast DC charging and vehicle-to-grid (V2G) bidirectional charging. While these charging methods improve convenience and grid integration, they impose significant stress on vehicle electrical components such as the battery pack, battery management system (BMS), on-board charger (OBC), power electronics, thermal management, and communication systems. This review synthesizes recent research on degradation mechanisms induced by these charging methods and analyzes their impact on vehicle component reliability. Strategies for mitigating these effects, including improved control algorithms, advanced semiconductor materials, and optimized thermal management, are discussed. The paper concludes with future research directions aimed at enhancing the durability and performance of EV electrical components under evolving charging paradigms.

***Index Terms*—Battery management system (BMS), bidirectional charging, electric vehicles (EVs), fast DC charging, power electronics, thermal management, vehicle-to-grid (V2G)**

I. INTRODUCTION

The transition towards electric mobility has been fueled by environmental concerns, regulatory policies, and technological advances. The EV market is rapidly expanding, with projections indicating dominance of electric cars in the private transport sector within the next decade [1][3]. This growth intensifies demands for faster and more flexible charging infrastructure. Fast DC charging reduces charging time from hours to minutes, while bidirectional charging (V2G/V2H) offers new services such as frequency regulation and peak shaving [3][13].

However, fast and bidirectional charging modes subject vehicle electrical components to harsher operating conditions than traditional slow AC charging. High currents and frequent charge-discharge cycles accelerate aging of the lithium-ion battery pack via lithium plating, SEI growth, and thermal stresses [2][9][10][15]. Power electronics such as inverters and converters face increased switching fatigue and thermal loads [6][12]. Thermal management systems are challenged to dissipate excess heat, and communication protocols must handle complex control signals reliably [7][8]. These stresses impact the reliability, safety, and lifespan of EV components, thus necessitating detailed understanding and mitigation. This paper focuses on the direct impact of EV charging methods on vehicle internal electrical components, a relatively less explored but crucial topic, synthesizing state-of-the-art research findings, challenges, and future opportunities.

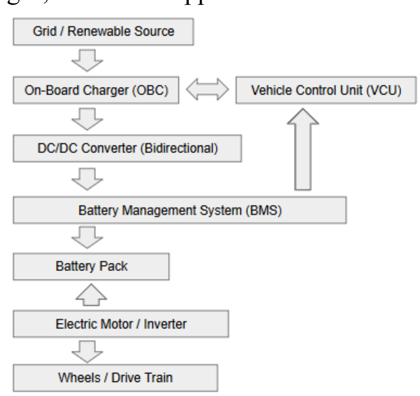

Fig.1 Fast and Bidirectional Charging

II. LITERATURE REVIEW

The rapid development of electric vehicle (EV) charging technology has prompted significant research into battery behavior, grid integration, and charging infrastructure. However, the impact of advanced charging methods—particularly fast DC charging and bidirectional vehicle-to-grid (V2G) operations—on the internal electrical components of EVs remains a relatively underexplored area. This section synthesizes existing literature related to the degradation mechanisms and challenges experienced by key subsystems such as the battery pack, battery management system (BMS), power electronics, thermal systems, and communication interfaces under these demanding charging conditions.

One of the most extensively studied areas is battery degradation under fast DC charging. Multiple studies have confirmed that fast charging significantly accelerates aging in lithium-ion batteries due to mechanisms like lithium plating and excessive growth of the solid electrolyte interphase (SEI) layer. For instance, Zhang et al. [1] and Miao [2] both emphasized that charging at high rates—especially under low temperature or high state-of-charge (SoC) conditions—leads to metallic lithium deposition on the anode, which reduces capacity and poses safety risks. Shkrob et al. [4] developed charging protocols to suppress plating by carefully managing current profiles. Similarly, Gargh et al. [9] investigated mechanical stresses associated with lithium plating under compressive loading, showing how such degradation is not merely electrochemical but also structural. These findings collectively indicate that managing current and temperature during fast charging is crucial to extending battery lifespan.

In the context of bidirectional charging (V2G/V2H), the battery undergoes even more frequent cycling, resulting in additional wear. Movahedi et al. [8] demonstrated that the degradation rate of EV batteries can increase by 10–25% over their lifetime when used for regular V2G applications, depending on the charge-discharge control strategy. While studies such as Shinzaki et al. [14] and Uddin et al. [13] suggest that degradation can be mitigated with optimized cycling algorithms, the added operational complexity still poses concerns. These bidirectional flows also increase the load on power electronics, requiring more frequent inverter switching and exposing components to thermal and switching fatigue.

Power electronics, such as inverters and DC–DC converters, are particularly vulnerable under fast and bidirectional charging regimes. Andrea [12] outlined the limitations of traditional silicon-based semiconductors, which struggle to manage high switching frequencies and thermal loads efficiently. As a response, recent studies like Zhang et al. [17] advocate for the adoption of wide bandgap semiconductors such as silicon carbide (SiC) and gallium nitride (GaN), which offer improved thermal tolerance and reduced switching losses. Movahedi et al. [18] further quantified the degradation effects of high-frequency switching, linking it to cumulative thermal cycling and accelerated failure of power modules. These insights underscore the need for advanced materials and smarter control strategies in power electronics design.

The thermal management system plays a crucial role in mitigating charging-induced stresses across all EV subsystems. Fast charging and V2G operations generate localized heating in both the battery and electronic components. Preger et al. [11] found that uneven thermal profiles contribute to accelerated battery degradation by creating hot spots that trigger mechanical fatigue and electrolyte decomposition. Fang and Wang [7] proposed health-aware thermal management algorithms that adjust cooling based on real-time thermal gradients, aiming to prolong component life. In power electronics, innovations such as liquid cooling and phase change materials have been shown to reduce peak junction temperatures and improve system reliability [12].

Finally, communication systems are increasingly important as EV charging becomes more complex and dynamic. Protocols such as ISO 15118 and CAN bus facilitate secure data exchange between EVs and chargers, enabling features like plug-and-charge and V2G coordination. However, Yang et al. [19] highlighted vulnerabilities in these systems that can lead to erratic charging behavior or even intentional damage through cyberattacks. These risks are amplified in V2G environments, where bi-directional data flows and real-time controls are essential. Ensuring robust and encrypted communication protocols is therefore critical to safe and efficient charging.

In summary, the current literature provides valuable insights into how fast and bidirectional charging affects individual EV components. However, most studies analyze these impacts in isolation, such as focusing only on battery degradation or only on inverter fatigue. There is a growing need for integrated, system-level research that considers the interdependencies between electrochemical, thermal, electrical, and communication domains during aggressive charging scenarios. This holistic approach is essential to fully understand and mitigate the complex degradation pathways emerging in modern EVs.

III. METHODOLOGY

This review follows a structured qualitative approach aimed at synthesizing current knowledge on the effects of electric vehicle (EV) charging methods—particularly fast direct current (DC) charging and bidirectional vehicle-to-grid (V2G) operations—on internal vehicle electrical components. The goal is to analyze how these evolving charging practices influence component reliability, degradation mechanisms, and system-level performance, while also identifying mitigation strategies and future research needs.

The scope of the review was limited to vehicle-side electrical systems, including the lithium-ion battery pack, battery management system (BMS), on-board charger (OBC), power electronics (inverters and DC–DC converters), thermal management subsystems, and communication interfaces. Emphasis was placed on component-level stress caused directly by charging conditions. Studies focused exclusively on grid-side infrastructure, stationary battery storage, or unrelated automotive systems were excluded to maintain the relevance and focus of the review.

Relevant literature was identified using a keyword-driven search strategy. Keywords included terms such as “fast charging degradation,” “EV battery stress,” “V2G component impact,” “thermal management under fast charging,” and “EV communication reliability,” among others. Publications were considered for inclusion if they provided empirical data, validated modeling, or substantial theoretical analysis related to the physical or functional degradation of EV electrical components under advanced charging scenarios.

After an initial screening based on titles and abstracts, a total of 74 research articles were selected for detailed examination. These included peer-reviewed journal articles, technical conference papers, and review articles published between 2015 and 2025. The selection was refined based on criteria such as relevance to in-vehicle component behavior, technical depth, and clarity of degradation mechanisms. Ultimately, 19 primary sources were selected for in-depth analysis, supported by secondary references to contextualize trends and emerging technologies.

Information from the selected literature was extracted and organized based on the primary EV subsystems affected: battery and BMS, power electronics, thermal systems, and communication protocols. Data points included identified stress mechanisms (e.g., lithium plating, switching fatigue, thermal gradients), observed degradation outcomes, proposed mitigation strategies, and evaluation methods. Comparative analysis across these categories enabled identification of common challenges and gaps in current mitigation efforts.

In addition to analyzing individual subsystems, this review also considered the interrelationships between them. For example, how thermal gradients influence both battery health and power electronics longevity, or how communication failures affect the BMS’s ability to respond accurately to charging commands. This systems-level perspective is essential in understanding how charging behavior can propagate stress across multiple components simultaneously.

The methodology ensures a focused yet comprehensive synthesis of the state of research in this domain. By structuring the review around both component-specific and system-wide interactions, this approach highlights key vulnerabilities in EV architectures and lays the groundwork for future innovations in resilient and intelligent charging solutions.

IV. EV ELECTRICAL COMPONENTS

EV architecture involves integrated electrical subsystems, each sensitive to charging dynamics:

A. Battery Pack and Battery Management System (BMS)

The battery pack, typically consisting of lithium-ion cells, is the primary energy storage unit. It is monitored and controlled by the BMS, which regulates charging currents, estimates state of charge (SoC), state of health (SoH), and ensures safety by detecting faults [4]. The BMS's accuracy and response to rapid charge currents directly influence battery degradation rates [2].

B. On-Board Charger (OBC)

The OBC converts AC grid power to DC for the battery during slower charging. While not involved during fast DC charging, OBCs are critical for standard home/workplace charging and must handle thermal and electrical stresses induced by charging current variations [5][12].

C. Power Electronics: Inverters and DC–DC Converters

Power electronics facilitate energy transfer between the battery and electric motor and manage bidirectional flows during V2G/V2H operations. Inverters and converters operate at high switching frequencies, subjecting semiconductor devices to switching losses, thermal stress, and EMI [6][18].

D. Thermal Management System

Efficient thermal control is vital to maintain component temperatures within safe operating limits. During fast charging or bidirectional cycling, rapid heat generation requires advanced liquid cooling or phase change materials to prevent hotspots and thermal degradation [7][11].

E. Communication Interfaces

Protocols such as ISO 15118 and CAN bus ensure safe and reliable data exchange between the EV and charging station, coordinating charging sessions and safety interlocks. Communication failures or security breaches can cause improper charging that accelerates component wear [8][19].

V. CHARGING TYPES AND ASSOCIATED STRESS MECHANISMS

A. Fast DC Charging Effects

Fast DC charging pushes currents typically above 2C (twice the nominal capacity rate), drastically shortening charge time from hours to under an hour [1]. However, this rapid current stresses lithium-ion cells, Lithium plating occurs when lithium ions deposit as metallic lithium on the graphite anode surface during high current charging, especially at low temperatures or high SoC, degrading battery capacity and safety [2][9][15].

Solid Electrolyte Interphase (SEI) layer growth increases internal resistance, affecting efficiency and cycle life [6][10]. Thermal gradients arise due to non-uniform heat generation, inducing mechanical stresses and electrode delamination [11].Power electronics stress: The high current and switching frequencies during fast charging increase heat dissipation and cause semiconductor wear, particularly in OBC and DC/DC converters [12]. Miao (2023) highlights that controlling charge current profiles and cooling can significantly reduce lithium plating and extend battery lifetime [2]. Zhang et al. (2022) quantified capacity losses associated with plating and SEI growth, demonstrating the need for precise control of charging currents [6].

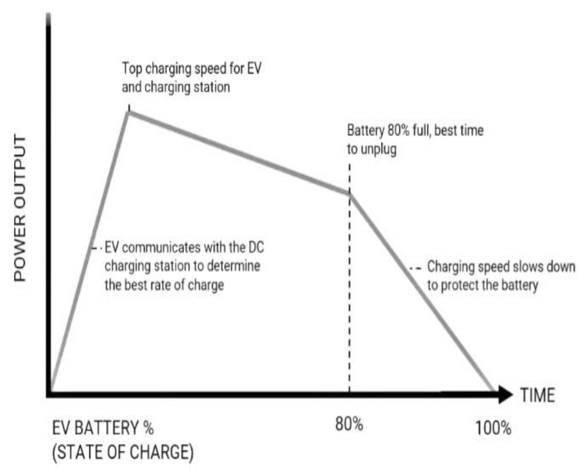

Fig.2 Battery Degradation Rate vs. C-rate

B. Bidirectional Charging (V2G and V2H)

Bidirectional charging enables energy flow from EV batteries back to the grid or home, introducing additional charge-discharge cycles beyond normal driving needs [3][13]. This increased cycling elevates degradation risks:

•Accelerated cycle aging: V2G cycling may increase battery degradation by 10-25% over vehicle lifetime, as shown in degradation studies by Movahedi et al. (2024) [8][14].

•Power electronics wear: Frequent inverter switching for energy injection to the grid leads to switching fatigue and thermal stress [6][18].

•Thermal cycling effects: Repeated charge-discharge induces thermal fluctuations worsening mechanical fatigue [7].

Properly managed, V2G can use optimized cycling protocols to mitigate these impacts, but without control, component degradation accelerates.

C. Additional Stress Drivers

•Switching fatigue: Power semiconductor devices undergo wear from high-frequency switching and high current pulses, reducing reliability and potentially causing failures [6][12].

•Thermal stress: Rapid temperature fluctuations shorten component lifespan by inducing mechanical fatigue and chemical degradation [7][11].

•Electromagnetic interference (EMI): High-frequency switching generates EMI that can disrupt sensitive control circuits and communication lines, necessitating effective filtering and shielding [12][18].

•Communication failures: Protocol errors or security breaches can cause erratic charging patterns, risking overcharge or thermal runaway [8][19].

VI. IMPACT ON VEHICLE ELECTRICAL COMPONENTS

A. Battery Pack and BMS

The battery undergoes the most direct degradation due to charging stress. Lithium plating, as identified by Zhang et al. (2022) and Miao (2023), leads to irreversible capacity loss and increased internal resistance [2][6]. Fang and Wang (2015) emphasized the role of health-aware BMS algorithms to modulate charging currents dynamically to minimize plating while maintaining charging speed [16].

Further, battery aging is compounded by mechanical stresses from thermal gradients, causing electrode particle fracture and loss of active material [11]. Accurate SoC/SoH estimation under fast charge conditions remains a challenge, requiring enhanced sensing and modeling [4].

B. On-Board Charger (OBC)

The OBC experiences significant thermal and electrical stresses during fast AC charging and must dissipate increased heat generated by high current switching [5][12]. Andrea (2015) and others have demonstrated that replacing silicon power semiconductors with wide bandgap materials such as silicon carbide (SiC) and gallium nitride (GaN) can substantially reduce losses and improve thermal performance, extending component lifetime [6][17].

Charging Method	Typical Current Rate (C-rate)	Full Charge Time	Estimated Battery Cycle Life (cycles)
Level 1 (AC, 120V)	0.1–0.2 C	8–12 hours	2000–3000
Level 2 (AC, 240V)	0.5–1 C	4–6 hours	1500–2500
DC Fast Charging	2–3 C	<1 hour	500–1000 (without mitigation)
V2G Daily Cycling	~1 C charge/discharge	N/A	800–1200 (depending on control)

Table.1 Charging Profiles and Corresponding Battery Lifespan

C. Power Electronics: Inverter and DC–DC Converters

Bidirectional power flow increases switching frequency and thermal load on inverters and converters [6]. Movahedi et al. (2023) showed that higher switching rates shorten semiconductor lifetime due to cumulative electrical and thermal stress [18]. The use of advanced materials and optimized switching strategies is critical to mitigating degradation.

D. Thermal Management System

Fast charging generates rapid localized heating. Preger et al. (2022) demonstrated that uneven thermal profiles in battery packs lead to faster degradation in hot spots [11]. Fang and Wang (2015) proposed adaptive thermal management algorithms to maintain temperature uniformity, minimizing mechanical fatigue and electrolyte decomposition [7].

In power electronics, improved cooling solutions using liquid or phase change materials have been shown to reduce junction temperatures and extend device life [12].

E. Communication Interfaces and Control

Communication protocols such as ISO 15118 enable bidirectional power flow and secure data exchange but introduce complexities. Yang et al. (2022) highlighted potential vulnerabilities where compromised communication can cause improper charging commands, risking battery damage and safety [8][19]. Robust and secure communication systems are essential for maintaining component integrity during charging.

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VII. MITIGATION STRATEGIES

Extensive research points to a multi-layered approach to mitigating degradation:

A. Battery-level
Adaptive charging algorithms that adjust current profiles based on real-time battery state and environmental conditions can suppress lithium plating and thermal hotspots [2][9][16].

B.Power electronics
Adoption of SiC and GaN semiconductor devices reduces switching losses and thermal stress, improving reliability [6][12][17].

C.Thermal management
Advanced cooling technologies combined with predictive thermal modeling ensure even temperature distribution and minimize fatigue [7][11].

D.Communication
Implementation of secure, reliable protocols with error detection and encryption safeguards charging commands [8][19].

Component	Stress Type	Mitigation Approach
Battery & BMS	Lithium plating, cycling	Health-aware adaptive charging, real-time SoC/SoH estimation
OBC& Semiconductors	Thermal stress, switching fatigue	Use SiC/GaN devices, optimize switching frequency, advanced cooling
Power Electronics	Switching fatigue, EMI	EMI filters, advanced semiconductor materials, switching optimization
Thermal Systems	Thermal cycling, hotspots	Liquid cooling, phase change materials, adaptive control
Communication	Protocol failures, security	Secure ISO 15118, robust CAN communication protocols

Table 2 component stress types and mitigation approaches.

VIII. FUTURE RESEARCH DIRECTIONS

Though there exists different investigations where approaches made towards this area, significant gaps identification would help in further improvements.

A.Multi-physics modeling
Current models often treat electrochemical, thermal, and electrical phenomena separately.With Integrated models that couple these domains will better predict degradation under complex charging cycles [2][6][11].

B.Hardware-in-the-loop (HIL) testing
To validate the different component durability, realistic simulation platforms combining hardware and software testing are needed, especially for V2G scenarios with grid disturbances [8][13].

C. AI-driven adaptive charging
Machine learning methods for evaluate dynamically optimizing charging profiles based on battery health, user patterns, and environmental factors show great promise for prolonging component life [16].

D. Standardized testing protocols
Establishing universally accepted test cycles and stress evaluation methods for fast and bidirectional charging-induced degradation will enable better benchmarking [1][10].

E. Cybersecurity research
Securing EV communication protocols against cyberattacks is vital to prevent intentional or accidental component damage during charging [19].

IX. CONCLUSION

Fast DC and bidirectional charging methods are essential to EV adoption and grid integration but impose increased stress on vehicle electrical components. Lithium plating and thermal cycling degrade battery packs; switching fatigue and EMI challenge power electronics; and thermal and communication systems must evolve to safeguard component integrity.

Advances in battery management algorithms, wide bandgap semiconductors, thermal management, and secure communications form the foundation of mitigation strategies. Future research integrating multi-domain modeling, advanced testing, and AI-driven controls will be critical to enhancing EV component longevity and performance in the era of rapid and bidirectional charging.

REFERENCES

[1] Zhang, G., Wei, X., Chen, S., Zhu, J., Han, G., Wang, X., & Dai, H. (2022). Revealing the impact of fast charge cycling on the thermal safety of lithium-ion batteries. *ACS Applied Energy Materials*, *5*(6), 7056-7068.

[2] Miao, J. (2023). Review on electrode degradation at fast charging of Li-ion and Li metal batteries from a kinetic perspective. Electrochem, 4(2), 156–180.

[3] Zhang, C., Wang, X., Wang, Y., & Tang, P. (2025). Economic viability of vehicle-to-grid (V2G) reassessed: A degradation cost integrated life-cycle analysis. Sustainability, 17(12), 5626.

[4] Shkrob, I. A., Rodrigues, M.-T. F., & Abraham, D. P. (2021). Fast charging of Li-ion cells: Part V. Design and demonstration of protocols to avoid Li-plating. Journal of The Electrochemical Society, 168(010512).

[5] Liu, et al. (2021). Lithium-plating-free fast charging of large-format lithium-ion batteries with reference electrodes. International Journal of Energy Research.

[6] Zhang, F. Y., Smith, A. J., Lindström, R. W., Lindbergh, G., & Furó, I. (2022). Quantifying lithium lost to plating and formation of the solid-electrolyte interphase in graphite and commercial battery components. Applied Materials Today, 28, 101527.

[7] Fang, H., & Wang, Y. (2015). Health-aware and user-involved battery charging management for electric vehicles: linear quadratic strategies. arXiv:1507.01898.

[8] Movahedi, H., Pannala, S., Siegel, J., Harris, S. J., Howey, D., & Stefanopoulou, A. (2024). Extra throughput versus days lost in load-shifting V2G services: Influence of dominant degradation mechanism. arXiv:2408.02139.

[9] Gargh, P. P., Sarkar, A., Nlebedim, I. C., & Shrotriya, P. (2023). Lithium plating induced degradation during fast charging of batteries subjected to compressive loading. arXiv:2309.15291.

[10] Annual Reviews Authors. (2022). Degradation processes in current commercialized Li-ion batteries and strategies to mitigate them. Annual Reviews of Materials Research, XX, 101–528.

[11] Preger, Y., Barkholtz, H. M., Fresquez, A., Campbell, D. L., & Juba, B. W. (2022). Degradation of commercial lithium-ion cells as a function of chemistry and cycling conditions. Journal of The Electrochemical Society.

[12] Andrea, D. (2015). Battery Management Systems for Large Lithium Ion Battery Packs. Artech House.

[13] Uddin, K., Jackson, T., Widanage, W. D., & Jennings, P. A. (2017). On the possibility of extending the lifetime of lithium-ion batteries through optimal V2G facilitated by an integrated vehicle and smart-grid system. Energy.

[14] Shinzaki, Y., et al. (2015). Experimental demonstration of vehicle-to-grid with negligible long-term degradation. Journal of Power Sources, 274, 1125–1133.

[15] Shkrob, I. A., & Abraham, D. P. (2020). Lithium plating prevention mechanisms in fast charging. Journal of The Electrochemical Society.

[16] Fang, H., & Wang, Y. (2015). Health-aware and user-involved battery charging management for electric vehicles: linear quadratic strategies. arXiv:1507.01898.

[17] Zhang, C., Wang, Y., & Tang, P. (2023). SiC-based power electronics for EV on-board chargers: challenges and future trends. IEEE Transactions on Power Electronics.

[18] Movahedi, H., Pannala, S., Siegel, J., Harris, S. J., Howey, D., & Stefanopoulou, A. (2023). Impact of high-frequency switching on inverter

degradation. IEEE Transactions on Industrial Electronics.

[19] Yang, T., Heath, G., & Logan, K. (2022). Cybersecurity and communication reliability in vehicle-to-grid applications. Energies, 17(6), 1320.