ISSN: 2583-5637
International journal of Inventive Research in Science and Technology
Volume 5 Issue 6 June 2026

Solar Cogeneration-Integrated DC Fast Charging Infrastructure for Electric Vehicles: A Comprehensive Review

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Abstract—The widespread adoption of electric vehicles (EVs) is critically dependent on the availability of rapid, reliable, and sustainable charging infrastructure. DC fast charging (DCFC) technology, capable of delivering 50-350 kW, addresses range anxiety by enabling 80% state of charge in under 30 minutes. However, the substantial power demands of DCFC stations pose significant challenges to grid stability. This review paper presents a comprehensive examination of solar cogeneration-integrated DCFC stations, focusing on system architectures, power electronic converters, and control strategies. Photovoltaic (PV) integration offers a synergistic solution by reducing grid dependency and leveraging the coincidence of solar irradiance with peak daytime charging demand. The paper analyzes grid-connected and standalone PV-DCFC topologies, evaluates multiport converter configurations with maximum power point tracking (MPPT) capabilities, and discusses energy management systems incorporating battery storage for enhanced reliability. Key findings indicate that advanced control algorithms, including droop-based constant current-constant voltage (CCCV) charging and meta-heuristic optimization techniques, significantly improve system efficiency and grid stability. The review also addresses critical challenges including intermittent renewable generation, bidirectional power flow management, and standardization requirements. Future research directions emphasize intelligent load management, machine learning-based demand forecasting, and enhanced interoperability protocols for next-generation charging ecosystems.

Keywords—DC Fast Charging, Electric Vehicles, Solar Cogeneration, Multiport Converters, Maximum Power Point Tracking, Energy Management Systems, Vehicle-to-Grid

1. Introduction

The global transportation sector is undergoing a paradigm shift towards electrification, driven by urgent environmental imperatives and technological advancements in energy storage. Conventional internal combustion engine vehicles contribute significantly to greenhouse gas accumulation through emissions of carbon dioxide, nitrous oxide, sulfur dioxide, and particulate matter, posing severe health risks and accelerating climate change . Electric vehicles (EVs) present a compelling alternative, offering zero tailpipe emissions, higher energy conversion efficiency exceeding 85%, regenerative braking capabilities, and reduced operational costs . Despite these advantages, EV adoption faces persistent obstacles: high initial purchase costs, limited driving range, battery degradation concerns, and critically, inadequate charging infrastructure .

Among these challenges, the lack of fast-charging stations that can replicate the refueling experience of conventional vehicles represents a primary barrier to widespread EV acceptance. DC fast charging (DCFC) technology addresses this by bypassing the limitations of onboard chargers, delivering high-power direct current directly to the EV battery at power levels ranging from 50 kW to 350 kW . However, the deployment of DCFC stations introduces substantial and unpredictable loads to the electricity grid, potentially causing localized voltage fluctuations, power quality issues, and grid congestion .

The integration of renewable energy sources (RES), particularly solar photovoltaic (PV) systems, with DCFC infrastructure offers a transformative solution to these challenges. Solar cogeneration—the simultaneous production of electrical power and useful thermal energy from solar irradiation—presents unique opportunities for EV charging applications. PV systems are particularly attractive due to their declining costs, near-zero maintenance requirements, and the natural temporal correlation between solar availability and peak daytime charging demand . When integrated with grid-connected DCFC stations, PV systems can reduce grid burden during peak hours, provide cost savings through self-consumption, and enhance the environmental sustainability of EV transportation .

This review paper provides a comprehensive synthesis of the current state of solar cogeneration-integrated DC fast charging stations. The paper systematically examines system architectures, power electronic converter topologies, control strategies, energy management approaches, and standardization requirements. The remainder of this paper is organized as follows: Section 2 presents the fundamentals of DC fast charging technology and charging standards. Section 3 analyzes PV-integrated DCFC system architectures. Section 4 examines power electronic converters and control strategies. Section 5 discusses energy management and optimization approaches. Section 6 addresses challenges and future research directions. Section 7 concludes the review.

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2. DC Fast Charging Technology Fundamentals

2.1 Charging Levels and Standards

EV charging infrastructure is categorized into three primary levels based on power delivery capability and charging duration. Level 1 charging operates at 120 V AC with power ratings of 1.3-2.4 kW, requiring 6-10 hours for a full charge. Level 2 charging utilizes 204-240 V AC at 3-19 kW, achieving full charge in 1-3 hours. Level 3, or DC fast charging, delivers 50-350 kW at 480 V DC directly to the battery, enabling 80% state of charge (SOC) in approximately 30 minutes .

DCFC technology bypasses the onboard charger limitations by performing AC-DC conversion at the charging station, significantly increasing charging speed. The charging time depends on multiple factors including battery capacity, charger nominal power, and the number of vehicles connected simultaneously . International standards for DCFC connectors include CHAdeMO (primarily Japanese vehicles), Combined Charging System (CCS, preferred in Europe and North America), and Tesla Supercharger systems, each with distinct communication protocols and connector designs .

2.2 DC Fast Charging Architecture

The architecture of a typical DCFC station comprises several essential components. The front-end AC-DC converter transforms grid AC power to a regulated DC bus voltage, incorporating power factor correction (PFC) and harmonic filtering to maintain power quality . The DC-DC converter stage then conditions the DC voltage to match the EV battery requirements, employing isolated or non-isolated topologies depending on safety and efficiency considerations .

Advanced DCFC stations increasingly incorporate bidirectional power flow capability, enabling vehicle-to-grid (V2G) operations. This functionality allows EV batteries to discharge back to the grid during peak demand periods, supporting grid stability and offering economic benefits to EV owners . However, bidirectional operation requires sophisticated control algorithms to manage power flow safely and efficiently .

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3. Solar Cogeneration-Integrated DCFC Architectures

3.1 Grid-Connected PV-DCFC Systems

Grid-connected solar PV-DCFC systems represent the predominant architecture for urban charging infrastructure. These systems utilize solar PV arrays as primary energy sources during daylight hours, with the grid serving as backup to ensure continuous operation. The major components include PV arrays, DC-DC converters with MPPT capability, battery energy storage systems (BESS), and grid interface converters .

In grid-connected operation, PV energy is prioritized for EV charging through self-consumption, reducing electricity costs during peak tariff periods. Excess PV power can be stored in BESS or exported to the grid, providing additional revenue streams through feed-in tariffs . The grid-connected system configuration offers lower installation costs compared to standalone systems while providing enhanced reliability through grid backup .

3.2 Standalone PV-DCFC Systems

Standalone or off-grid PV-DCFC systems operate independently of the utility grid, making them suitable for remote locations or areas with unreliable grid infrastructure. In this configuration, PV arrays charge battery storage systems, which then supply the DCFC station's power requirements. The standalone system necessitates larger BESS capacity and more sophisticated energy management to handle intermittent solar availability and variable charging demand .

While standalone systems offer complete grid independence, they require substantial battery capacity to ensure 24/7 operation, increasing capital costs. Research has demonstrated that hybrid configurations combining PV with multiple energy storage units can enhance system reliability and cost-effectiveness .

3.3 Multiport Converter Architectures

Multiport converters have emerged as a promising topology for PV-integrated DCFC stations, enabling the integration of multiple energy sources and loads through a single power conversion stage. These converters can interface PV arrays, BESS, grid connection, and EV charging ports simultaneously, reducing component count and increasing system efficiency .

Single-stage multiport converters offer advantages including simplified design, reduced conversion losses, and lower system cost compared to traditional multi-stage topologies. They provide power factor correction, harmonics filtering, and mitigation of power quality issues while maintaining stable operation . Converters incorporating MPPT capability ensure maximum solar energy utilization, while bidirectional capability enables V2G operation for grid support .

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4. Power Electronics and Control Strategies

4.1 DC-DC Converter Topologies for DCFC

The selection of appropriate DC-DC converter topology is critical for DCFC station efficiency and reliability. Buck converters are employed for step-down voltage conversion in EV battery charging applications. Boost converters facilitate step-up conversion when interfacing PV arrays with higher-voltage DC buses. Buck-boost and SEPIC topologies offer flexibility for variable voltage requirements .

Comparative analysis indicates that the full-bridge converter with high-frequency transformer (HFT) outperforms other topologies due to galvanic isolation and reduced harmonic content. Isolated topologies are particularly advantageous in DCFC applications where safety and ground fault protection are paramount . Emerging trends include the use of modular and multilevel converter designs for high-power applications exceeding 1 MW .

4.2 MPPT Algorithms for PV Integration

Maximum power point tracking (MPPT) algorithms are essential for maximizing energy harvest from PV arrays under varying irradiance and temperature conditions. Common MPPT techniques include perturb and observe (P&O), hill climbing, and incremental conductance methods. Evolutionary approaches including particle swarm optimization (PSO), fuzzy logic controllers, and artificial neural networks (ANN) have demonstrated superior performance under partial shading conditions .

Advanced MPPT algorithms such as Parabolic Curve-fitting based Hill Climbing (PCHC) have achieved accuracy of 99.6% in voltage estimation, significantly enhancing PV energy utilization . Learning-based hill climbing (L-HC) and Harmonic Perturb and Observe (HPO) algorithms further improve tracking performance under dynamic conditions .

4.3 Control Strategies for Grid Integration

Grid integration of PV-DCFC systems requires sophisticated control algorithms to maintain power quality and system stability. Voltage source converters (VSCs) employing adaptive control strategies such as Adaptive Modified Kalman Filter (AM-MKF) and Delayed Signal Cancellation-based Frequency Locked Loop (DFOGL) provide precise control under varying grid conditions . These controllers mitigate harmonics, ensure clean power supply, and provide reactive power support for weak grids.

The voltage sensorless predictive control (VSPC) scheme eliminates voltage sensors, reducing controller cost while maintaining performance. Model predictive control (MPC) techniques offer optimal power flow management but require precise tuning and detailed system knowledge . Droop-based CCCV control implemented in battery management systems (BMS) improves battery life and maintains thermal limits during fast charging .

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5. Energy Management and Optimization

5.1 Energy Management Systems

Energy management systems (EMS) coordinate power flow between PV generation, BESS, grid connection, and EV charging loads. The EMS optimizes energy utilization based on multiple objectives: minimizing grid power consumption, maximizing renewable energy utilization, reducing operational costs, and ensuring charging station reliability .

EMS strategies typically prioritize PV power for EV charging, followed by BESS discharge, and finally grid import. During high solar availability, excess energy is stored in BESS or exported to the grid. During low solar periods or peak demand, BESS discharge supplements PV generation before grid import is initiated . Intelligent EMS incorporating demand forecasting and price signals can further optimize charging schedules and grid interaction .

5.2 Battery Energy Storage Integration

Battery energy storage systems (BESS) are critical for mitigating solar intermittency and providing fast response capability for DCFC applications. BESS sizing optimization is essential to balance capital costs against operational benefits. Studies have demonstrated that hybrid energy systems combining PV, BESS, and grid support provide robust charging infrastructure, compensating for the intermittent nature of solar energy .

Recent research applying meta-heuristic optimization techniques, including the Ant-Lion Algorithm (ALA), has demonstrated superior performance in maximizing net present value (NPV) for grid-RES-BS-EV systems. The ALA has shown faster convergence and better exploration-exploitation balance compared to genetic algorithms, grey wolf optimization, and particle swarm optimization . Optimal BESS sizing considering EV demand characteristics, arrival-departure times, and SOC variations can significantly enhance system profitability .

5.3 V2G and Grid Support Services

Bidirectional power flow capability enables V2G operation, allowing EV batteries to discharge back to the grid. This functionality provides valuable grid support services including frequency regulation, peak shaving, and load leveling. V2G operation can generate additional revenue streams for EV owners and charging station operators .

However, V2G implementation requires robust control algorithms to manage battery degradation concerns and ensure availability for transportation needs. The economic viability of V2G depends on electricity pricing structures, battery replacement costs, and grid service compensation mechanisms .

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6. Challenges and Future Research Directions

6.1 Technical Challenges

Several technical challenges impede widespread deployment of PV-DCFC stations. Solar intermittency requires substantial BESS capacity and sophisticated forecasting to ensure reliable operation. Power quality issues including harmonics, voltage fluctuations, and grid congestion require advanced mitigation strategies . The development of more robust control algorithms capable of handling dynamic conditions such as partial shading remains an active research area .

Cybersecurity concerns are increasingly important as EV charging infrastructure becomes more connected. Charging stations integrated with smart grids and communication networks are vulnerable to cyberattacks, necessitating comprehensive security frameworks .

6.2 Standardization and Interoperability

The lack of universal charging standards and communication protocols creates interoperability challenges. Although protocols such as Open Charge Point Protocol (OCPP) have evolved to version 2.1, improving remote access and load control, fragmented standards across regions remain problematic . Future research must focus on developing universal interoperability standards to enable seamless roaming across diverse charging networks .

6.3 Future Research Directions

Emerging research directions include developing intelligent charging algorithms incorporating machine learning for demand forecasting and grid management. Wireless charging technologies offer potential for convenience, but require evaluation of efficiency, cost-effectiveness, and user acceptance . Advanced battery technologies with higher energy density and faster charging capability will reduce infrastructure requirements .

Studies investigating the impact of different EV models on charging station placement, considering varying charging requirements and mobility patterns, are needed. Development of precise EV demand forecasting models is crucial for optimal infrastructure planning . Further research is required on optimizing renewable resource utilization, implementing fast-response storage schemes, and incorporating multiple renewable sources or backup generation to enhance system stability and reliability .

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7. Conclusion

This review has comprehensively examined solar cogeneration-integrated DC fast charging stations for electric vehicles, analyzing system architectures, power electronic converters, control strategies, and energy management approaches. The integration of PV systems with DCFC infrastructure offers a synergistic solution to grid stability challenges while enhancing environmental sustainability. Grid-connected PV-DCFC configurations provide cost-effective operation with grid backup, while standalone systems offer grid independence for remote applications.

Advanced multiport converter topologies with MPPT capability maximize solar energy utilization while maintaining power quality. Sophisticated control strategies, including droop-based CCCV charging and meta-heuristic optimization techniques, improve system efficiency, battery life, and grid stability. Energy management systems coordinating PV generation, BESS, and grid power are essential for optimal operation.

Key challenges remain including solar intermittency, power quality issues, standardization gaps, and cybersecurity concerns. Future research should focus on intelligent load management, machine learning-based forecasting, enhanced interoperability standards, and improved battery technologies. The development of robust, scalable, and sustainable PV-DCFC infrastructure is essential for accelerating EV adoption and achieving global climate goals.

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