Design and Simulation of DC Fast Charging System

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***Abstract*—The rapid growth of electric vehicles (EVs) has increased the demand for efficient and high-speed charging infrastructure. This paper presents the design and simulation of a DC fast charging system for EV applications using MATLAB/Simulink. The proposed system converts three-phase AC grid power into a regulated DC output suitable for fast battery charging. The architecture includes an AC grid source, filtering unit, unity power factor (UPF) front-end converter, DC bus, isolated DC-DC converter, and EV battery pack. The front-end converter ensures stable DC voltage output of approximately 800 V while maintaining power quality and reducing harmonic distortion. The DC-DC converter, equipped with a high-frequency transformer and rectifier, provides electrical isolation and controlled charging current to the battery. The system also incorporates measurement and control units for monitoring voltage, current, and state of charge (SOC). Simulation results demonstrate stable DC bus voltage, efficient energy conversion, and smooth battery charging characteristics. The proposed model achieves improved efficiency, reduced losses, and enhanced system reliability. This work contributes to the development of advanced EV charging infrastructure and supports the transition toward sustainable transportation systems.**

Keywords— Electric Vehicles (EV), DC Fast Charging, MATLAB/Simulink, DC-DC Converter, Unity Power Factor (UPF), State of Charge (SOC)

I. INTRODUCTION

The rapid advancement of electric vehicles (EVs) has become a key solution to reduce greenhouse gas emissions and dependence on fossil fuels [1]. With the increasing adoption of EVs, the demand for efficient and fast charging infrastructure has grown significantly [2]. Conventional charging methods, such as AC Level 1 and Level 2 charging, require long charging durations, which limits their practicality for widespread usage [3]. As a result, DC fast charging technology has emerged as a promising solution to reduce charging time and improve user convenience [4].

DC fast charging systems directly supply regulated DC power to the EV battery, eliminating the need for onboard conversion and significantly increasing charging speed [5]. However, the design of such systems presents several challenges, including power quality issues, harmonic distortion, and efficient energy conversion [6]. To address these challenges, advanced power electronic converters such as front-end converters and isolated DC-DC converters are widely used [7].

The front-end converter plays a crucial role in converting AC grid power into stable DC voltage while maintaining unity power factor (UPF) and minimizing harmonics [8]. Additionally, the DC-DC converter stage ensures voltage adaptation and electrical isolation using high-frequency transformers and rectifiers [9]. These components enable controlled charging current and enhance battery safety and lifespan [10].

Recent research has focused on improving converter efficiency, reducing switching losses, and enhancing control strategies using PWM techniques [11]. Furthermore, simulation tools such as MATLAB/Simulink have been extensively used to model and analyze EV charging systems due to their flexibility and accuracy [12]. These tools allow detailed evaluation of system performance, including voltage regulation, current control, and state of charge (SOC) estimation [13].

In this paper, a DC fast charging system is designed and simulated using MATLAB/Simulink. The system includes an AC grid supply, filtering stage, unity power factor front-end converter, DC bus, isolated

DC-DC converter, and EV battery pack. The proposed model aims to achieve efficient power conversion, stable voltage output, and controlled battery charging. The simulation results demonstrate improved performance in terms of voltage stability, reduced harmonic distortion, and efficient energy transfer [14], [15].

II. LITERATURE SURVEY

Electric vehicle (EV) charging systems have been widely studied due to the increasing demand for sustainable transportation and efficient energy utilization [1]. Several researchers have focused on the development of advanced charging infrastructures to reduce charging time and improve system efficiency [2]. DC fast charging has emerged as a promising solution, offering high power delivery and reduced charging duration compared to conventional AC charging methods [3].

Power electronic converters play a crucial role in EV charging systems. Various AC-DC and DC-DC converter topologies have been investigated to improve efficiency and reliability [4]. Front-end converters are widely used to achieve unity power factor (UPF) and minimize harmonic distortion in grid-connected systems [5]. Advanced control strategies have also been developed to enhance converter performance and ensure stable output voltage [6].

DC-DC converters are essential for voltage regulation and battery charging. Different topologies such as buck, boost, resonant, and bidirectional converters have been explored in literature [7]. Recent studies highlight the use of high-gain and multiport converters to improve efficiency and reduce losses [8]. Additionally, wide bandgap devices such as GaN and SiC have been introduced to enhance switching performance and reduce converter size [9] .

Several studies have focused on isolated and non-isolated converter configurations for EV charging applications [10]. Isolated converters using high-frequency transformers provide safety and voltage flexibility, making them suitable for fast charging systems [11]. Moreover, bidirectional converters enable vehicle-to-grid (V2G) functionality, enhancing energy management capabilities [12].

Recent research also emphasizes the importance of charging station architecture and energy management systems. DC fast charging stations are typically connected to AC grids or DC microgrids to improve efficiency and reduce conversion losses [13] . Furthermore, control strategies such as PWM and digital control techniques are used to ensure stable operation and efficient power transfer [14].

Simulation tools such as MATLAB/Simulink have been extensively used for modeling and analysis of EV charging systems [15]. These tools enable detailed evaluation of system performance, including voltage stability, current control, and state of charge (SOC) estimation [16]. Studies also highlight challenges such as harmonic distortion, thermal management, and electromagnetic interference in high-power charging systems [17].

Ultra-fast charging technologies have been investigated to support high-power applications, incorporating advanced converter topologies and solid-state transformers [18] . Researchers have also explored integrated energy storage systems and battery energy storage systems (BESS) to improve charging station reliability [19]. Additionally, cyber-physical aspects of EV charging infrastructure, including communication and security, have gained attention in recent years [20].

The literature further discusses the classification of charging systems into on-board and off-board chargers, with off-board DC fast chargers providing higher power levels [21]. Various studies analyze the impact of EV charging on grid stability and propose solutions to mitigate voltage fluctuations and load variations [22]. Advanced control algorithms and decentralized charging strategies have been developed to optimize grid integration [23].

Moreover, improvements in DC-DC converter design, including interleaved, resonant, and coupled-inductor topologies, have been proposed to enhance efficiency and power density [24] . Finally, ongoing research focuses on improving system reliability, reducing cost, and developing next-generation fast charging technologies to support the growing EV market [25]

III. PROPOSED SYSTEM ARCHITECTURE

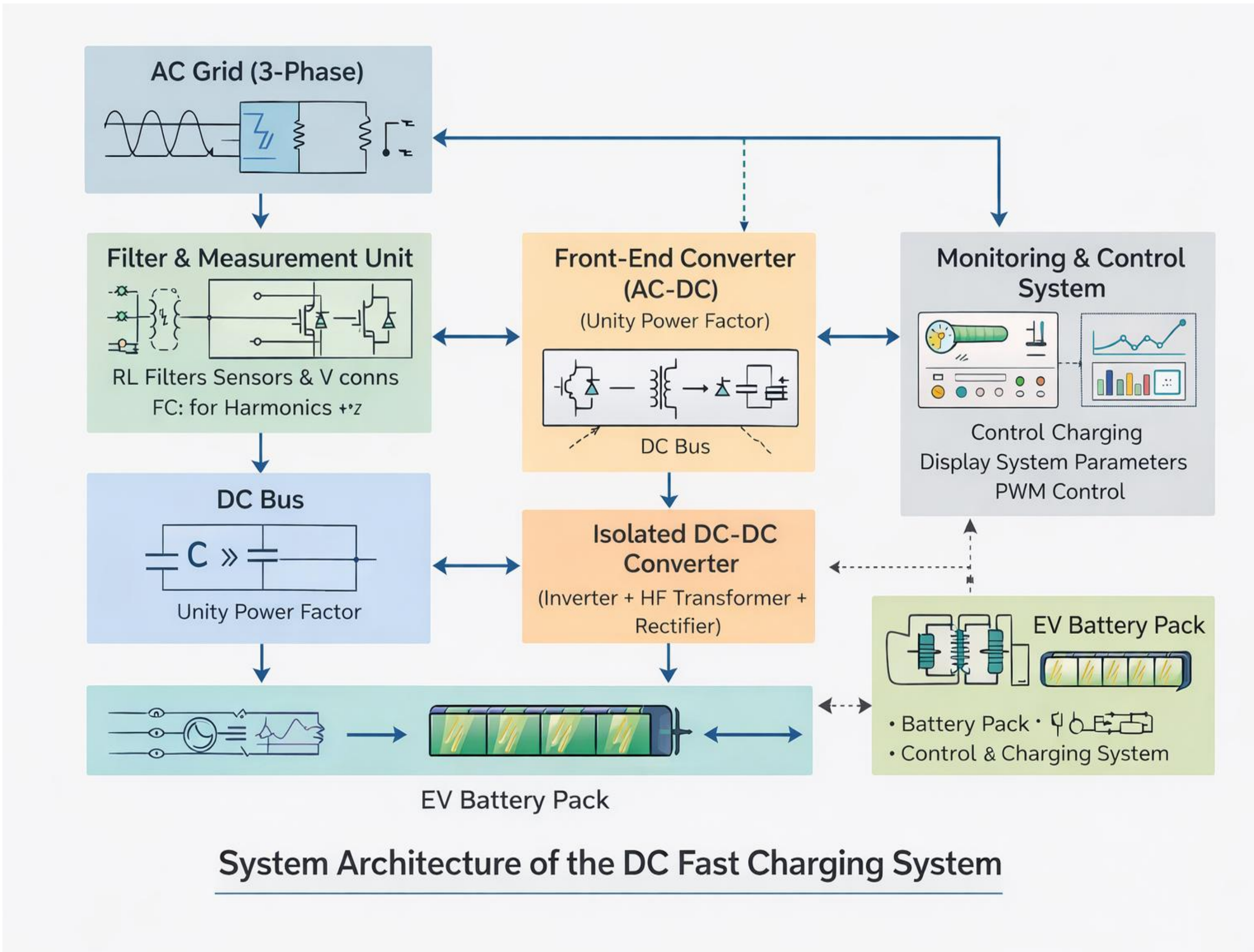

Fig. 1. System Architecture

A. AC Grid Supply

The system starts with a three-phase AC grid, which serves as the main power source. It provides electrical energy required for charging the EV battery. The grid ensures continuous power availability for high-power fast charging applications.

B. Filter and Measurement Unit

The AC input passes through an RL filter to remove harmonics and improve power quality. Sensors are used to measure voltage and current, ensuring proper monitoring and stable system operation. This stage protects the system from disturbances and noise.

C. Front-End Converter (AC-DC Conversion)

The filtered AC supply is converted into DC using a front-end converter. This converter maintains a stable DC output of approximately 800V and operates at unity power factor (UPF), reducing reactive power and improving efficiency.

D. DC Bus

The DC bus acts as an intermediate energy storage unit. It stabilizes the DC voltage and provides a constant power supply to the next stage. It helps in reducing voltage fluctuations and ensures smooth system operation.

E. Isolated DC-DC Converter

This stage converts DC power into controlled DC suitable for the EV battery. It includes an inverter, high-frequency transformer, and rectifier. It provides electrical isolation, voltage regulation, and maintains constant charging current.

F. EV Battery and Control System
The final stage consists of the EV battery pack and control system. The battery stores energy, while the control system regulates charging using PWM techniques. It monitors voltage, current, and state of charge (SOC) to ensure safe and efficient charging.

IV. METHODOLOGY

The proposed DC fast charging system is designed and simulated using MATLAB/Simulink to efficiently convert AC grid power into controlled DC power suitable for electric vehicle (EV) battery charging. The methodology involves modeling each stage of the system and analyzing its performance.

A. System Modeling
The overall system is modeled as a combination of interconnected subsystems, including the AC grid, filter unit, front-end converter, DC bus, DC-DC converter, and EV battery. Each component is developed using Simulink blocks to replicate real-world behavior.

B. AC Grid and Filtering
A three-phase AC voltage source is used to represent the grid. RL filters are implemented to eliminate harmonics and improve power quality. Voltage and current sensors are incorporated to measure system parameters for monitoring and control.

C. Front-End Converter Design
The front-end converter is designed to convert AC input into DC output while maintaining unity power factor (UPF). Pulse Width Modulation (PWM) control is used to regulate switching operations. The converter maintains a constant DC output voltage of approximately 800 V.

D. DC Bus Implementation
The DC bus is modeled using capacitors to stabilize voltage and store energy temporarily. It ensures a smooth and continuous DC supply to the DC-DC converter stage, minimizing fluctuations.

E. DC-DC Converter Modeling
An isolated DC-DC converter is implemented using an inverter, high-frequency transformer, and diode rectifier. The inverter converts DC to high-frequency AC, which is then transformed and rectified back to DC. This stage provides voltage regulation and electrical isolation.

F. Battery Modeling
The EV battery is modeled as a series connection of battery cells. The model includes parameters such as voltage, current, and state of charge (SOC). The charging process is controlled to ensure constant current and safe operation.

G. Control Strategy
A PWM-based control strategy is used to regulate both the front-end converter and DC-DC converter. Feedback signals from voltage and current sensors are used to maintain stable output and ensure efficient charging.

H. Simulation and Analysis
The complete system is simulated in MATLAB/Simulink. Key parameters such as DC bus voltage, charging current, battery voltage, and SOC are analyzed. The results are evaluated to verify system performance, stability, and efficiency.

V. RESULT

The simulation of the DC fast charging system was carried out using MATLAB/Simulink to evaluate its performance under standard operating conditions. The results show that the front-end converter successfully converts the three-phase AC input into a stable DC output of approximately 800 V. The DC bus maintains a constant voltage with minimal fluctuations, ensuring a steady power supply to the DC-DC converter stage. The isolated DC-DC converter effectively regulates the output voltage and provides a constant charging current to the EV battery. The filtering unit significantly reduces harmonic distortion, resulting in improved power quality and efficient system operation.

Furthermore, the battery charging characteristics indicate a smooth and controlled increase in battery voltage and state of charge (SOC) over time. The charging current remains stable, which is essential for maintaining battery health and safety. The system demonstrates high efficiency, reduced losses, and reliable performance throughout the simulation. The overall results confirm that the proposed DC fast charging system is capable of delivering fast, stable, and efficient charging for electric vehicles, making it suitable for real-world implementation.

VI. CONCLUSION

This paper presented the design and simulation of a DC fast charging system for electric vehicles using MATLAB/Simulink. The proposed system effectively converts three-phase AC grid power into regulated DC power suitable for fast battery charging. The implementation of a front-end converter operating at unity power factor ensures improved power quality and reduced harmonic distortion. The DC bus provides stable voltage, while the isolated DC-DC converter enables controlled voltage and current delivery with electrical isolation. The simulation results demonstrate that the system maintains a constant DC output of approximately 800 V and delivers a stable charging current to the EV battery. The battery charging process shows a smooth increase in voltage and state of charge (SOC), ensuring safe and efficient operation. Overall, the proposed system achieves high efficiency, reliable performance, and fast charging capability. This work contributes to the development of advanced EV charging infrastructure and supports the growing demand for sustainable transportation solutions.

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