Advanced International Journal for Research (AIJFR)

E-ISSN: 3048-7641 ● Website: www.aijfr.com ● Email: editor@aijfr.com

Smart Optimization of Fast Charging Systems in EVsusing Partial Power Processing

Mr. Yogesh Vasudev

Abstract

The increasing adoption of Electric Vehicles (EVs) demands efficient and scalable fast charging infrastructure. Conventional fast charging systems rely on Full Power Processing (FPP), where the entire power is processed through converters, resulting in high losses, increased cost, and poor efficiency at partial loads.

This paper proposes a Partial Power Processing (PPP)-based multiport DC-DC converter architecture for EV fast charging applications. The proposed system utilizes a bidirectional buck converter for bulk power transfer and multiple Dual Active Bridge (DAB) converters for differential power processing.

The system is modelled and simulated in MATLAB/Simulink to evaluate performance in terms of efficiency, power distribution, and voltage regulation. Results demonstrate that the proposed PPP architecture significantly reduces converter power rating and improves overall efficiency compared to conventional FPP systems.

Keywords

Partial Power Processing, EV Fast Charging, Multiport Converter, Dual Active Bridge, DC-DC Converter, Power Electronics

1. Introduction

The transition towards Electric Vehicles (EVs) is driven by the need to reduce carbon emissions and dependence on fossil fuels. However, the development of efficient fast charging infrastructure remains a critical challenge.

DC fast charging systems enable rapid energy transfer by bypassing onboard chargers. Despite this advantage, conventional systems employ Full Power Processing (FPP), where the entire load power is handled by power electronic converters. This leads to increased system size, higher cost, and reduced efficiency, particularly under partial load conditions.

To address these limitations, Partial Power Processing (PPP) has emerged as an alternative approach. In PPP, only a fraction of the total power is processed by converters, while the bulk power is transferred through a direct high-efficiency path. This approach reduces converter stress and improves system performance.

The current EV charging infrastructure shows a significant gap between existing capacity and future requirements. At present, the number of public charging stations is approximately in the range of 25,000 to 29,000. However, projections indicate that this number must increase drastically to meet future EV demand, with targets estimated between 1.3 million to 3.9 million charging stations by 2030. This highlights the scale of infrastructure expansion required and the urgency for cost-effective and scalable charging solutions.

In addition to infrastructure availability, the cost of charging equipment plays a critical role in deployment. Basic DC fast chargers in the range of 30–60 kW cost approximately ₹5 lakh to ₹12 lakh, making them suitable for small-scale or entry-level installations. Mid-range chargers around 60 kW are priced between ₹9.9 lakh to ₹15 lakh and are commonly used in urban and commercial environments.

As power levels increase, the cost rises significantly. High-power DC fast chargers rated at 120 kW and above can cost between ₹20 lakh to ₹48 lakh or more, while ultra-fast chargers (around 360 kW) exceed ₹48 lakh. These high costs are driven by the requirement for high-power-rated converters, advanced cooling systems, and robust infrastructure.

These statistics clearly indicate that scaling EV charging infrastructure using conventional full power processing approaches would result in substantial capital investment. Therefore, improving efficiency and reducing converter rating through approaches such as Partial Power Processing becomes essential for enabling economically viable large-scale deployment.

This paper presents a PPP-based multiport EV charging architecture and evaluates its performance through simulation.

2. Literature Review

Recent studies have explored various architectures for EV fast charging systems.

Multiport DC-DC converter topologies using differential power processing have been proposed to reduce converter rating and improve efficiency. Dual Active Bridge (DAB)-based converters are widely used due to their bidirectional capability and isolation.

Conventional charging systems, such as those implemented in commercial charging stations, rely on full power conversion, leading to inefficiencies and thermal challenges.

Previous research demonstrates that PPP can significantly reduce processed power and improve efficiency. However, challenges remain in control strategy implementation and system optimization for multiport charging applications.

3. Problem Statement

Conventional EV fast charging systems face several limitations:

- Over-dimensioning of converters for peak power conditions
- Reduced efficiency under partial load operation
- High thermal losses (typically 6–8%)
- Increased capital cost due to oversized components
- Inefficient utilization of power electronic resources

These limitations motivate the need for an alternative architecture that improves efficiency while reducing system cost.

4. Proposed System

Proposed System Overview

A. Architecture Description

The proposed system employs a PPP-based series-connected multiport charging architecture. It consists of:

- A central bidirectional buck converter
- Multiple auxiliary Dual Active Bridge (DAB) converters
- A common DC bus.

The proposed system is designed to charge multiple EV batteries efficiently using Partial Power Processing (PPP). Instead of sending all the power through converters, the system splits the power flow into two parts.

The first part is the **main power path (outer loop)**. Here, a **bidirectional buck converter** sends most of the power directly from the DC source to the batteries. This path handles the bulk of the energy and is very efficient because it avoids unnecessary conversion.

The second part is the **auxiliary path (inner loop)**. In this path, **DAB converters** are connected to each battery. These converters do not handle full power. Instead, they only handle the small difference or mismatch in power between batteries. This helps in balancing the batteries and controlling their charging.

All the DAB converters are connected to a **common virtual bus capacitor**, which acts like a temporary energy storage point. One of the DAB converters controls the voltage of this bus to keep the system stable.

The batteries are connected in series, so the same current flows through all of them. The main converter ensures this current is maintained, while the DAB converters make small adjustments for each battery individually.

The DAB converters use **phase shift control**, which means they control power flow by adjusting the timing between signals. This allows smooth and flexible control of charging.

Brief Overview:

- Main converter → handles most of the power
- DAB converters → handle only small corrections
- Result → higher efficiency, lower cost, and better control

This separation of power flow is what makes the system more efficient than conventional charging systems.

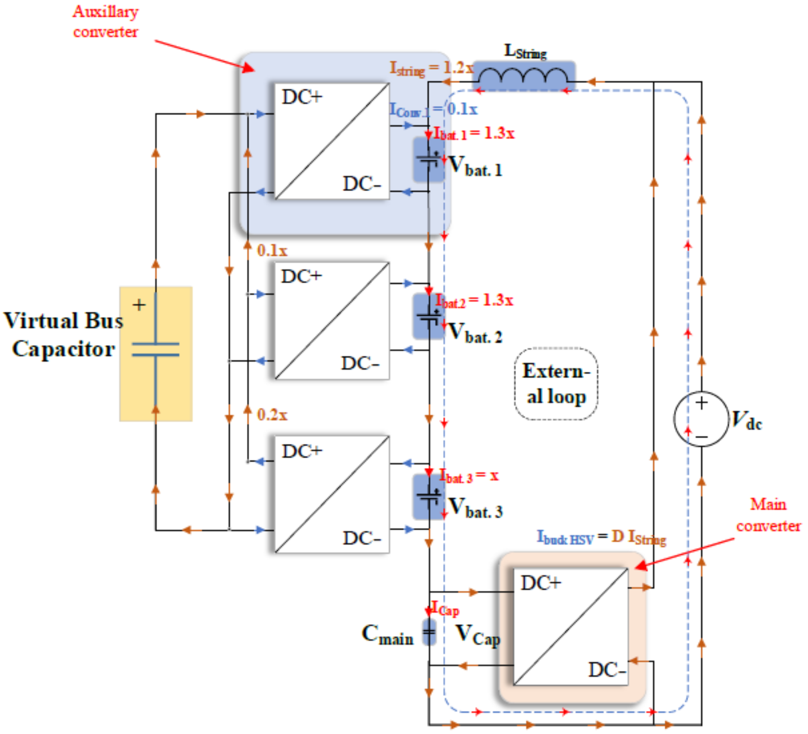


Figure1: Proposed DC - Partial Power Processing Charging System

B. Power Flow Structure

The system operates through two power paths:

1. **Main Power Path (Outer Loop)**
    - Transfers bulk power directly from DC bus to EV batteries
    - Ensures high efficiency

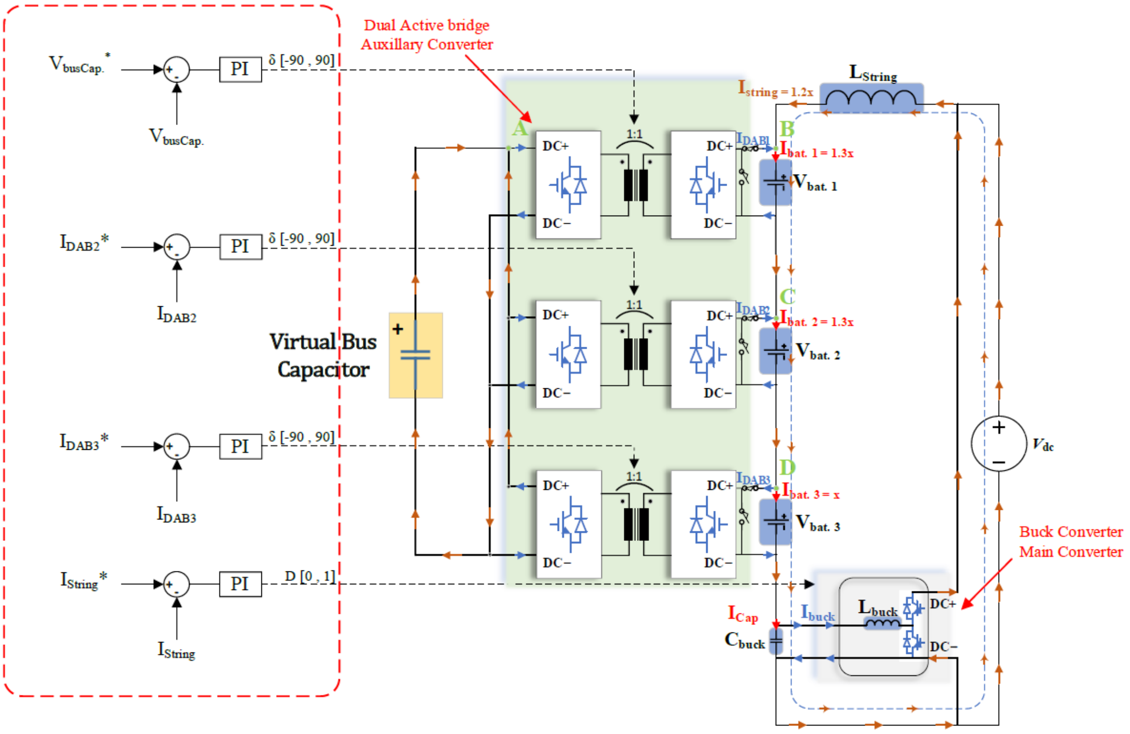
2. **PPP Path (Inner Loop)**
    - Processes only differential power
    - Enables voltage regulation and load balancing

5. Control Strategy

A hierarchical control strategy is implemented:

- **Buck Converter:**
    - Regulates string current using PI control
- **DAB Converters:**
    - Controlled using Single Phase Shift (SPS)
    - One DAB regulates virtual bus voltage
    - Others regulate individual battery currents

This structure ensures stable operation and accurate power distribution.



The proposed topology with Control diagram

6. Mathematical Modeling

The system is modelled based on:

- String current averaging equations
- Phase-shift-based power transfer in DAB converters

The DAB power transfer is controlled by phase shift (δ), which determines the direction and magnitude of power flow.

A. Auxiliary DC-DC converter (Dual Active Bridge)
The transmitted power is given by

$$P = \frac{n\, V_1 V_2}{2\, \pi^2\, f_s\, L} .\delta\, (\pi - \delta)$$

The converter rated power is designed based on the rated voltages of the ports and a 30% of the rated power of the port, where n is the transformer turns ratio, V1 and V2 are the voltages at the two ports of the DAB, fs is the switching frequency, L is the AC link inductance and d is the phase shift between the AC voltages generated by the two H—bridges of the DAB. The phase shift angle can take a positive or negative value according to power flow. From the above equation, it can be concluded that the controlled parameter is the
phase shift angle d, where all the remaining parameters are kept constant.

B. Bi-directional Buck Converter(Outer Loop)
The buck converter, responsible for string current regulation, is designed with ripple current of ±5% of rated current and voltage ripple is kept at ±10%. The buck converter is the main converter in the proposed architecture. Additionally it must be designed at the rated voltage of the system as it is directly connected to the main DC

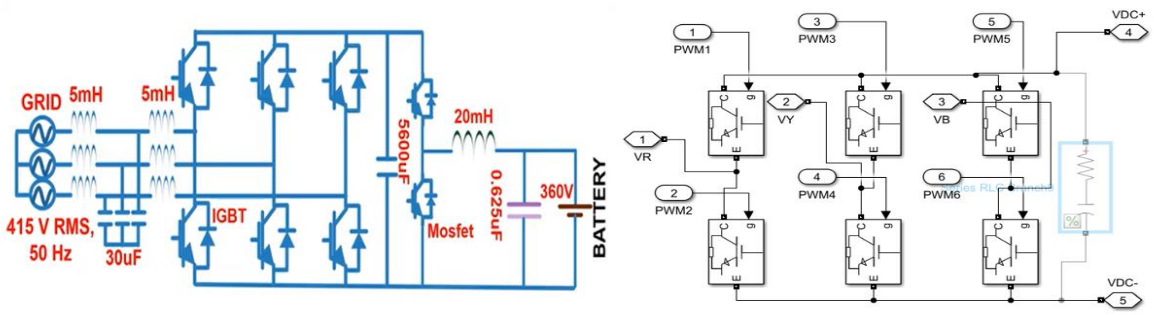
7. Simulation Setup

The proposed system is implemented in MATLAB/Simulink.

Simulation includes:

- DC bus modelling
- Converter topology implementation
- Control algorithm integration

Performance is evaluated under Grid-to-Vehicle (G2V) mode.



Figures Showing Full Power Processing Architecture

8. Results and Discussion

Simulation results show:

- Stable DC bus voltage under varying load conditions
- Controlled current distribution across multiple ports
- Reduced power processed by auxiliary converters

Key Findings:

- System efficiency improved to **93–95%**
- Only **30–40% of total power processed** by converters
- Reduced thermal stress and converter rating

Comparison with FPP systems confirms improved performance.

9. Conclusion

This paper presents a PPP-based multiport EV fast charging architecture that improves efficiency and reduces system cost by minimizing converter power processing.

The use of a bidirectional buck converter for bulk power and DAB converters for partial power enables efficient power distribution and control.

Simulation results validate the effectiveness of the proposed system, making it a promising solution for next-generation EV charging infrastructure.

10. Future Work

- Hardware implementation and experimental validation.
- Advanced control strategies for dynamic load conditions.
- Integration with renewable energy sources.
- Real-time energy management systems.