Partial Power Converter Topologies for Renewable Integrated Ultra-Fast Ev Charging Stations

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***Abstract*—Ultra-fast electric vehicle (EV) charging stations draw hundreds of kilowatts per port, so even small converter losses become large heat and cost burdens. Partial power processing (PPP) reduces this burden by passing only the voltage difference between source and load through the power converter, while the rest of the power flows directly. This paper reviews partial power converter (PPC) topologies for the DC-DC stage of renewable-integrated ultra-fast charging stations. It first describes station architectures that combine photovoltaic (PV) generation and battery energy storage on a common DC bus, then derives the power-processing ratio and efficiency relation that explain why PPCs help. Isolated (input-parallel output-series, input-series output-parallel) and non-isolated (series-connected, transformerless) topologies are compared on efficiency, converter rating, isolation, control complexity and suitability for ultra-fast charging. The analysis shows that PPCs are most attractive where the battery voltage varies over a narrow range around the bus voltage, and that isolation and safety requirements remain the main design constraint. Open challenges and research directions are summarised.**

***Index Terms*—Partial Power Converter, Partial Power Processing, Ultra-Fast Charging, Electric Vehicle, DC-DC Converter, Renewable Energy, Battery Energy Storage**

I. INTRODUCTION

EV adoption is rising quickly worldwide, and long charging times remain one of the main barriers to it. DC fast and ultra-fast chargers address this barrier, but they place heavy demands on the power electronics inside the station.

In a conventional DC charger, every watt delivered to the battery passes through a full-rated DC-DC converter. Its losses, cooling needs, size and cost all scale with the full charging power. At ultra-fast power levels this becomes a major limit on station efficiency and on the number of ports a site can support.

Partial power processing offers a different approach. The converter handles only the fraction of power needed to regulate the battery voltage and current, and the remainder reaches the load directly. Studies of PPC-based fast chargers report gains in efficiency, converter size and cost compared with full-power designs.

Renewable sources add a second motivation. PV arrays and battery energy storage (BESS) can be connected to the station DC bus to reduce peak grid demand, and PPP has already been proposed for exactly these PV and storage interfaces.

This paper makes three contributions: (i) it explains the PPP principle with a clear efficiency derivation; (ii) it classifies and compares PPC topologies for the charging-station DC-DC stage; and (iii) it discusses control, integration with renewables and open research problems.

The rest of the paper is organised as follows. Section 2 describes station architecture. Section 3 presents the PPP principle. Section 4 reviews topologies. Section 5 compares them. Section 6 covers control and integration. Section 7 lists challenges, and Section 8 concludes.

II. RENEWABLE-INTEGRATED ULTRA-FAST CHARGING STATION ARCHITECTURE

A renewable-integrated station is built around a common DC bus fed by three sources: the AC grid through an AC-DC rectifier, PV arrays through DC-DC converters, and a BESS through a bidirectional DC-DC converter. Each charging port then connects to the bus through its own DC-DC stage that regulates the EV battery voltage and current.

Two coupling styles are used. In an AC-coupled station, every source joins at an AC bus, which needs more conversion stages. In a DC-coupled station, sources share the DC bus, which cuts conversion steps and suits PV and storage naturally. Because the per-port DC-DC stage carries the full charging power in a conventional design, it is the best place to apply PPP.
An extreme fast charging architecture with partial-power-rated DC-DC converters per vehicle has been demonstrated on a scaled laboratory prototype. It gives independent charging control for each EV while processing only a fraction of the battery power, and PV and storage can be added to ease the grid impact of multi-megawatt charging.

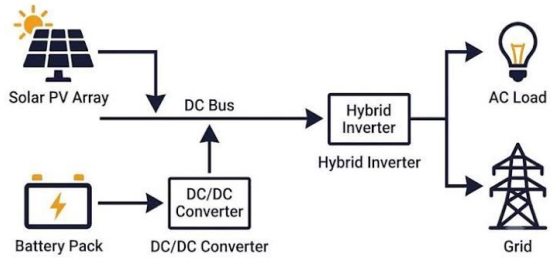

Fig. 1: Block Diagram of the DC-Coupled Station with Grid, PV, BESS, DC Bus And PPC-Based Charging Ports.

III. PRINCIPLE OF PARTIAL POWER PROCESSING

In a series-connected PPC, the DC-DC converter sits in series with the load path and supplies only the voltage difference between output and input. The rest of the power flows directly from source to load.
For a step-up case with bus voltage V_{in} and battery voltage V_{out}, the converter voltage is $V_{out} - V_{in}$ and the converter current equals the load current. The power-processing ratio k, defined as converter power over load power, is therefore:

$$P_{conv} / P_{load} = [(V_{out} - V_{in}) \times I_{out}] / [V_{out} \times I_{out}]$$

$$= 1 - (V_{in} / V_{out})$$

If the embedded converter has efficiency η_c, only its own share of power produces losses, so the system efficiency is:

$$\eta_{sys} = 1 / [1 + k \times (1/\eta_c - 1)]$$

When $k = 1$ this reduces to η_c, the full-power case. As k falls, system efficiency rises toward 100 %, and the converter can be rated for kP_{load} instead of P_{load}.

3.1 Illustrative example (own calculation, not measured data). Take $\eta_c = 97$ % and $k = 0.2$, meaning the battery voltage is 20 % above the bus voltage at that operating point. Then $\eta_{sys} \approx 99.4$ %, against 97 % for a full-power converter. Losses fall by about a factor of five.
This also shows the main limit. During charging the battery voltage swings widely, so k changes, and the benefit shrinks when V_{out} and V_{in} are far apart. PPCs therefore suit applications with a narrow voltage ratio, or designs that adjust the bus voltage or reconfigure the battery pack.

IV. PARTIAL POWER CONVERTER TOPOLOGIES

PPC topologies divide first by whether they provide galvanic isolation, and then by how the converter ports connect to source and load.
4.1 Isolated PPCs. These use a high-frequency transformer, so safety isolation can be provided. The main connection types are input-parallel output-series (IPOS), input-series output-parallel (ISOP) and input-series output-series (ISOS). For fast charging, an isolated DC-DC converter can inject a controlled voltage source between the DC link and the battery, giving the control freedom needed to regulate charging [8]. A dual-active-bridge or full-bridge converter with synchronous rectification is a common core, and an isolated full-bridge PPC has been validated in simulation for a BESS.

4.2 non-isolated PPCs. These omit the transformer and so reach higher power density and lower cost. Series-connected types are typical. A transformerless step-up PPC has been proposed for the regulation stage of fast-charging stations, and a non-isolated bidirectional Cuk converter in a partial-power arrangement has been studied for battery storage with vehicle-to-grid current injection. Their weakness is the lack of isolation, which must then be provided elsewhere in the station.

4.3 Multiport and differential-power designs. A multiport DC-DC converter with differential power processing stages has been proposed for fast-charging stations, aiming to cut converter cost while keeping efficiency high. A station can also share one main converter among several ports, with a small partial-power stage per port.

4.4 Novel directions. A recent review compares partial and full power converters and proposes guidelines for choosing PPC architectures for future fast-charging stations. New topologies are generally motivated by three goals: keeping the processing ratio low over the whole battery voltage range, supporting bidirectional V2G operation, and using wide-bandgap devices.

V. COMPARATIVE ANALYSIS

Non-isolated PPCs give the best efficiency and power density, while isolated PPCs are needed were safety rules demand isolation. The table is a qualitative synthesis of the cited reviews and papers, not measured data.

Topology	Isolation	Converter rating	Main strength	Main limitation	Fit for ultra-fast charging
Full-power converter (baseline)	Yes or no	Full load power	Simple, mature	Highest losses, size, cost	Poor at very high power
IPOS / ISOP / ISOS isolated PPC [2]	Yes	Fraction of load power	Isolation with reduced rating	Transformer adds size and design effort	Good
Series-connected non-isolated PPC [10]	No	Fraction of load power	High efficiency, high power density	No isolation	Good, with isolation upstream
Bidirectional Cuk-based PPC [7]	No	Fraction of load power	Bidirectional, V2G current	Control complexity, ripple	Medium
Multiport differential-power design [6]	Depends on design	Reduced overall	Lower station converter cost	Coordinated control of ports	Good

In all cases the benefit depends on the power-processing ratio k from Section 3. The closer the battery voltage stays to the bus voltage, the larger the saving.

VI. CONTROL AND INTEGRATION WITH RENEWABLES AND STORAGE

The PPC must regulate the battery charging profile, typically constant current followed by constant voltage, while the bus voltage is held by the grid converter and BESS. Because the PPC controls only the series voltage, its control loop acts on a small voltage and is coupled to the bus, so bus regulation and port control must be coordinated.

PV integration uses MPPT on the PV-side converters. PPP has also been applied to PV stages themselves, where a partial converter processes only the power needed to track the maximum power point. For the BESS, a partial-power interface regulates charge and discharge current and can support current injection to the DC bus for V2G.

Control methods for PPC-based fast chargers, including their comparison with full-power control, are covered in the recent review. In a multi-port station, power sharing between ports, PV and BESS is the central control problem.

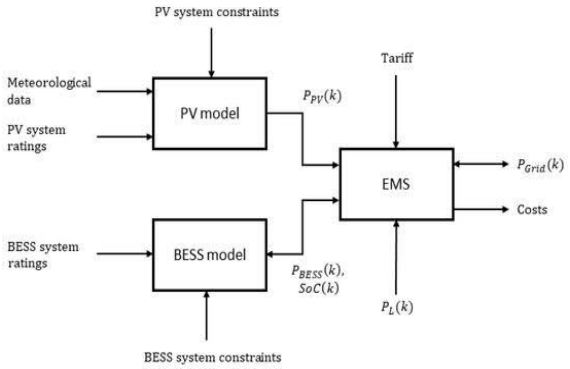

Fig.2 Station-Level Control Block Diagram.

VII. CHALLENGES AND FUTURE SCOPE

- Wide battery voltage range: the processing ratio k grows when battery and bus voltages differ, which erodes the benefit. Reconfigurable packs or adjustable bus voltage are possible answers.
- Isolation and safety: non-isolated PPCs need isolation provided elsewhere in the station, and standards must be met at the system level.

- Bidirectional operation: V2G and BESS support need PPC designs that handle both power directions.
- Wide-bandgap devices: SiC and GaN switches can raise efficiency and switching frequency, reducing passive-component size.
- Control and protection: coordinated multi-port control, fault handling and grid-code compliance remain open topics.
- Validation: most reported PPC results come from simulation or scaled prototypes, so full-scale ultra-fast demonstrations are still needed.

VIII. CONCLUSION

Partial power converters reduce the power each charger converter must handle, which lowers losses, size and cost in ultra-fast charging stations. The efficiency relation in Section 3 shows the gain depends on the power-processing ratio, so PPCs work best when battery and bus voltages stay close. Isolated, non-isolated and multiport topologies each trade isolation, density and control complexity differently. Integrated with PV and BESS on a DC bus, PPC-based ports are a promising route to efficient, grid-friendly ultra-fast charging. Future work should address wide voltage ranges, bidirectional operation and full-scale validation.

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