

Design and Analysis of a Multiport PV-Battery Converter with Differential Power Processing for improved energy management in EV charging applications

Shanmugam Saravanan

Vellore Institute of Technology University

Sharmila A

drasharmila2019@gmail.com

Vellore Institute of Technology University

Article

Keywords: Multiport converter, Differential Power Processing, PV-battery system, Battery energy storage

Posted Date: August 24th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10314985/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Design and Analysis of a Multiport PV-Battery Converter with Differential Power Processing for improved energy management in EV charging applications

Shanmugam S

*School of Electrical Engineering,
Shanmugam.s2019@vitstudent.ac.in.com
Vellore Institute of Technology, Vellore
<https://orcid.org/0000-0002-0991-4306>*

Sharmila A*

*School of Electrical Engineering,
drasharmila2019@gmail.com
Vellore Institute of Technology, Vellore
<https://orcid.org/0000-0002-5956-1801>*

Abstract— This paper presents a multiport PV-battery converter that incorporates DPP to improve energy management in EV applications. In contrast to the traditional full power processing (FPP) converters that pass all the PV power to the converter stage to process the whole PV power through the converter, the suggested concept passes only the mismatch power between PV generation and the load demand and hence reduces conduction and switching losses. The converter system includes a PV source, a bidirectional BESS, and the EV battery as load within a single-stage structure, which makes it capable of working in PV-dominant, battery-assisted, and hybrid modes of operation. Under balanced operation, the converter works almost idle with no switching losses. The design equations for the converter and its control strategy based on the PWM regulation technique are derived. Simulation analysis was carried out using MATLAB/Simulink software for 2 kW system with a switching frequency of 50 kHz, showing that the proposed converter achieves a maximum efficiency of 95.8%, which exceeds that of conventional FPP converters (90.2%).

Keywords— Multiport converter, Differential Power Processing, PV-battery system, Battery energy storage.

I. INTRODUCTION

In recent times, there has been an immense increase in the deployment of renewable energy technology, and the application of photovoltaic (PV) energy is increasingly being integrated into residential and commercial electrical systems. The adoption of renewable energy technology has forced engineers designing power electronics to consider efficiency in their designs [1]. Microgrids or EV charging system based on PV energy and battery energy storage systems (BESS) have become the norm in dealing with the variable nature of solar energy, but the converter that lies in between the PV array and BESS has more to do with the performance of the system in terms of efficiency and response time and thermal stability [2]&[3].

In the Differential Power Processing (DPP) technique, rather than routing all generated power through the converter, a DPP stage only has to handle the mismatch between what the PV array produces and what the load needs at that instant. If generation and demand happen to track each other closely—which, for residential systems, occurs more often than one might assume—the converter ends up processing very little power, sometimes almost none, and losses drop accordingly [4].

Multiport converter topologies offer an additional architectural advantage by integrating multiple energy ports within a single conversion stage [5]. A three-port converter linking a PV source, BESS, and DC load bus can simultaneously manage bidirectional power transfer, maximum power point tracking (MPPT), and state-of-charge (SoC) regulation without requiring separate converter modules for each function [6],[7]. The consolidation of these functions reduces component count, volume, and cost while improving power density.

Recent work on DPP applied specifically to PV-battery systems [8], demonstrated a switched-capacitor DPP converter achieving 97% efficiency for a 500 W PV-BESS system. Their architecture, however, was limited to two-port operation, precluding simultaneous load bus regulation. The proposed multiport DPP converter in the present paper extends the DPP concept to three-port operation while retaining the efficiency benefits identified in prior two-port implementations

Collectively, the literature identifies three key gaps addressed by the present work: (1) the absence of a rigorously modelled three-port DPP converter for PV-BESS-load systems, (2) insufficient comparative efficiency data benchmarking DPP against FPP under identical loading conditions.

This paper presents a three-port PV-battery converter that uses differential power processing (DPP) to maintain high efficiency across the entire operating range. The main contributions are:

- A three-port topology that integrates PV, battery storage, and load under DPP-based power management.

- A mathematical model covering power flow, component sizing, and duty cycle computation for each mode.
- A control scheme that engages DPP processing only when there's a power mismatch, keeping the converter in a low-loss standby state otherwise.
- Simulink-based validation showing efficiency gains over conventional full power processing (FPP) converters.

The rest of the paper is organized as follows: Section II describes the system architecture, operating modes and power analysis. Section III covers the DPP control strategy, Section IV develops the mathematical model, and Section V designs components. Section VI presents the Simulink implementation, Section VII presents results, Section VIII offers comparative analysis, and Section IX close with conclusions.

II. PROPOSED MULTIPOINT PV-BATTERY CONVERTER WITH DPP CONTROL

A. System Architecture

The proposed system, illustrated in Fig. 1, comprises three ports: a PV source port (P1), a bidirectional BESS port (P2), and a load port (P3), all of which are interfaced to a common 200 V DC bus for charging EV battery. The DPP processing is embedded with MPC.

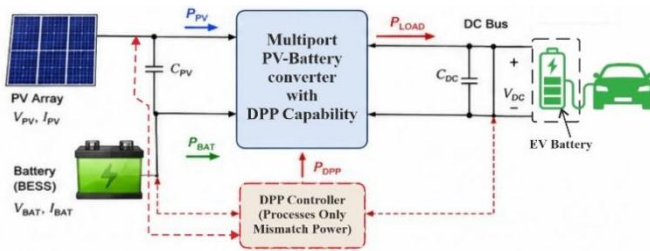


Fig. 1. Proposed multiport PV-battery converter system architecture showing PV, BESS, and load ports connected to EV battery through the common DC bus with the DPP processing

B. Multiport Converter Topology

The circuit topology of MPC shown in Fig. 2 [9], is utilised for ease of analysis. In this case, V_{in1} and V_{in2} represent the input source voltages, S_1 - S_3 are the active MOSFET switches, D_1 and D_2 are the freewheeling diodes, L is the filter inductor, C_o is the output capacitor, and R represents the load. Depending on the level of the input voltages, the presented converter is characterized by three modes of operation. In Mode I, the input voltages are sufficiently large and the output voltage is less than the sum of the input voltages. If the input voltages are decreased, the converter changes its mode to Mode II in which the output voltage can be either smaller or larger than the sum of the input voltages. If one of the input sources is disabled, the fault-tolerant mode will take place.

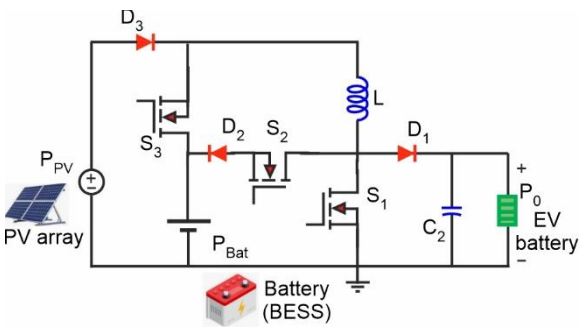


Fig. 2. Proposed multiport PV-battery converter

C. Operating Modes

The converter operates in three distinct modes depending on the relative magnitudes of P_{PV} and P_{LOAD} :

1) PV Dominant Mode: When $P_{PV} > P_{LOAD}$, excess PV power charges the battery. The DPP stage processes the surplus power $\Delta P = P_{PV} - P_{LOAD}$ and directs it toward the BESS through the bidirectional buck-boost stage. The DC bus voltage is regulated by the PV boost stage operating in MPPT.

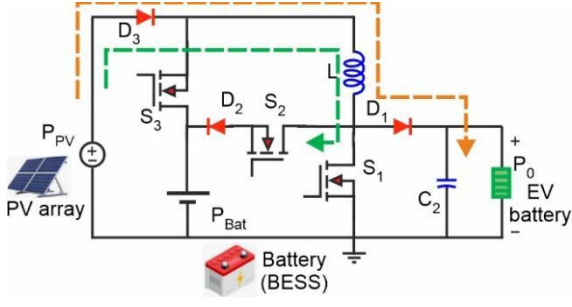


Fig. 3. Equivalent Circuit of PV Dominant mode

Prior to analysis, it is first assumed that all the semiconductor devices are ideal, and the current through the inductor is in continuous conduction mode.

For State-I operation, the volt-second balance equation for inductor L becomes

$$V_o (1 - D_{S1} - D_{S2}) = (V_{in1} - V_o) D_{S1} + (V_{in2} - V_o) D_{S2} \quad (1)$$

Rearranging the above expression gives the output voltage as

$$V_o = V_{in1} D_{S1} + V_{in2} D_{S2} \quad (2)$$

For State-II operation, applying the volt-second balance condition to the inductor results in

$$(V_{in1} + V_{in2}) D_{S3} = (V_o - V_{in1}) D_{S1} + (V_o - V_{in2}) D_{S2} \quad (3)$$

Thus, the output voltage can be expressed as

$$V_o = \frac{V_{in1} D_{S1} + V_{in2} D_{S2}}{1 - D_{S3}} \quad (4)$$

The duty ratio relationships between the inductors can be obtained from the switching pattern.

$$D_{S3} = D_{S1} + D_{S2} - 1 \quad (5)$$

Substituting the above expression into the output-voltage equation yields

$$V_o = \frac{V_{in1} D_{S1} + V_{in2} D_{S2}}{2 - D_{S1} - D_{S2}} \quad (6)$$

2) Battery Support Mode: When $P_{PV} < P_{LOAD}$, the battery discharges to supplement PV generation. The DPP stage handles the deficit $\Delta P = P_{LOAD} - P_{PV}$, drawing energy from the BESS. The battery bidirectional stage operates in boost mode to maintain load voltage.

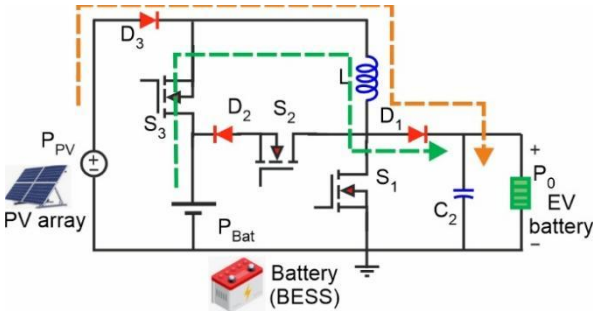


Fig. 4. Equivalent Circuit of PV Dominant mode

3) Hybrid Power Sharing Mode: During transient conditions or rapid irradiation changes, both the PV source and BESS simultaneously supply the load demand. The DPP controller smooths the power transition and prevents load voltage deviations by adjusting duty cycles dynamically.

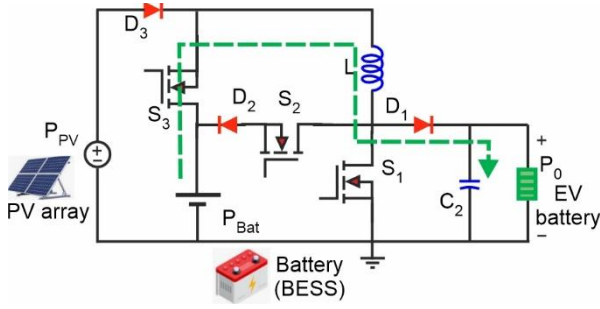


Fig. 5. Equivalent Circuit of PV Dominant mode

D. Power Flow Analysis

Power flow within the multiport system obeys the following conservation equation (7):

$$P_{PV} + P_{BAT} = P_{LOAD} + P_{LOSS} \quad (7)$$

where P_{PV} is the instantaneous PV generation, P_{BAT} is the battery power (positive for discharge, negative for charge), P_{LOAD} is the load demand, and P_{LOSS} encompasses converter conduction and switching losses. The DPP stage processes only the mismatch component:

$$P_{DPP} = |P_{PV} - P_{BAT} - P_{LOAD}| \quad (8)$$

As irradiation and load conditions evolve, P_{DPP} may span from near-zero (balanced operation) to the full rated power of the BESS interface. The fraction of total power processed by the DPP stage, defined as the DPP power ratio γ , determines the achievable efficiency gain:

$$\gamma = \frac{P_{DPP}}{P_{LOAD}} = \frac{|P_{PV} - P_{LOAD}|}{P_{LOAD}} \quad (9)$$

For a typical residential PV profile, γ averages below 0.25 over a diurnal cycle, confirming that the DPP stage processes substantially less power than an FPP counterpart.

III. DIFFERENTIAL POWER PROCESSING CONTROL

A. DPP Operating Principle

The DPP controller continuously monitors P_{PV} and P_{LOAD} via current and voltage sensors at each port. The mismatch power P_{DPP} computed from (8) is supplied as the reference signal to the inner current control loop of the DPP processing stage. When P_{DPP} falls below a threshold P_{th} (set at 2% of rated power to avoid unnecessary switching), the DPP stage is disabled and the system operates with direct PV-to-load power routing.

The control system first starts with the measurement of PV voltage and current, battery voltage and current, and EV battery voltage. These values are then used to calculate the real-time PV power and battery power using (7)-(8) as

$$P_{PV} = V_{PV}I_{PV}, P_{BAT} = V_{BAT}I_{BAT} \quad (10)$$

The load power is estimated from the DC bus voltage and load characteristics. The controller then determines the differential power as in (11).

$$P_{DPP} = P_{PV} - P_{BAT} - P_{LOAD} \quad (11)$$

where P_{DPP} refers to the surplus or deficit power required to be exchanged with the battery. Initially, P_{DPP} is simply a control signal to identify the state of operation of the converter.

Since there is a two-way flow of energy in the battery, the DPPC configuration utilizes a fundamental boost/buck bi-directional DC-to-DC converter. It includes inductor L_{DPP} , switch S , and capacitor C_{DPP} (Not shown for simplicity). As a result, the power is mostly delivered by PV port and battery port, while the DPP converter takes care of the remaining power component. Such a design leads to a considerable reduction of the current stress and power losses in the differential power path.

If there is more power generated by PV array than consumed by the load, then the differential power is positive $P_{DPP} > 0$. In this case, the extra power is supplied to the battery using a DPP converter, which operates in boost configuration. The voltage of the inductor during switch conduction is described by the following equation (12)

$$P_{DPP} > 0$$

$$L_{dpp} \frac{di_{L,dpp}}{dt} = V_{PV} - V_{BAT} \quad (12)$$

Employing the volt-second balance principle yields the boost-mode duty ratio

$$D_{boost} = 1 - \frac{V_{BAT}}{V_{PV}} \quad (13)$$

Under such an operating condition, only the excess solar PV power will be transferred via the DPP link. As such, the current rating of the inductor and switching elements depends on the value of P_{DPP}

If the load demand exceeds the power generated by solar PV panels, then there will be a negative differential power $P_{DPP} < 0$. Under such conditions, the battery will supply the needed deficit power to the load using the DPP converter in buck mode. The duty for buck mode is deduced as

$$D_{buck} = \frac{V_{BAT}}{V_{PV}} \quad (14)$$

Determination of the mode of operation of DPP converter depends on the polarity of P_{DPP} , whereas the duty cycle control is performed with the help of a PI controller with load voltage feedback. Voltage error can be expressed as

$$e(t) = V_{DC}^* - V_{DC} \quad (15)$$

where (V_{DC}^*) is the reference DC bus or EV battery voltage. The PI controller generates the control signal according to (16)

$$u(t) = K_p e(t) + K_i \int e(t) dt \quad (16)$$

Where (K_p) and (K_i) are the proportional and integral gains, respectively. The duty cycle is continually modified by the controller in order to keep the DC bus voltage stable despite variations in radiation intensity and load.

The power processed by the DPP converter is given by

$$P_{proc} = |P_{DPP}|$$

which is considerably less than the total system power for most of the cases. Thus, the power rating of the converter may be chosen as

$$P_{DPP,rated} \ll P_{PV,rated} \quad (17)$$

This leads to decreased stress on components, a smaller converter, and increased efficiency. Because the losses due to switching and conduction are proportional to the power being processed, the losses in the DPP branch can be estimated as

$$P_{loss,DPP} \propto |P_{DPP}| \quad (18)$$

$$P_{loss,FPP} \propto P_{PV} \quad (19)$$

This fundamental difference explains the superior efficiency of the proposed architecture, particularly when PV generation and load demand are closely matched, allowing the DPP converter to process only a small fraction of the total power while maintaining effective energy management and DC bus voltage regulation.

B. Mismatch Power Control

The DPP mismatch power control flow is illustrated in Fig. 6. A supervisory controller computes P_{DPP} and determines the operating mode. In PV dominant mode, the error signal $e_p = P_{PV} - P_{LOAD}$ is fed to a PI compensator whose output sets the duty cycle D_{DPP} of the DPP processing stage. The PI gains are tuned using the symmetric optimum method to achieve a bandwidth of 500 Hz with a phase margin of 60° .

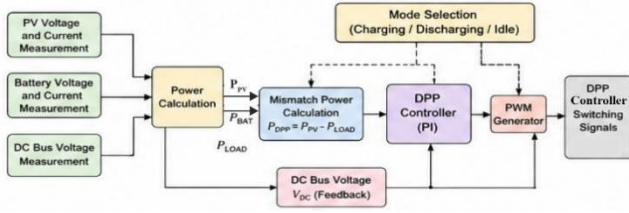


Fig. 6. Control block diagram of the DPP control

The control algorithm keeps on measuring the PV power (P_{PV}), the load demand (P_{LOAD}), the battery voltage (V_{BAT}) and the battery state of charge (SoC) as displayed in Fig. 7. The difference between the PV and load powers can be given as $P_{DPP} = P_{PV} - P_{LOAD}$. For $P_{DPP} > 0$, excess PV power is generated and the DPP controller works in boost mode to charge the battery. For $P_{DPP} < 0$, load power is higher than PV power and the DPP converter works in buck mode to discharge the battery to meet the load demands. For $P_{DPP} \approx 0$, the system works in a balanced state and the DPP controller does not function.

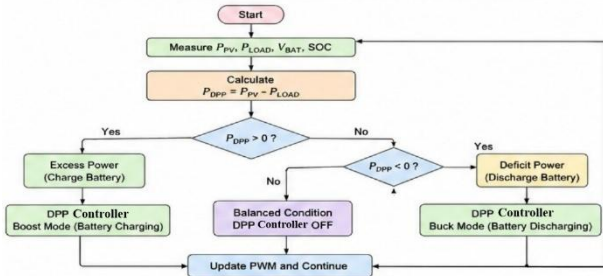


Fig. 7. Flow Chart of DPP Control Algorithm

C. Battery Charging and Discharging Control

Battery SoC is monitored via Coulomb counting and maintained within a safe operating window of 20–90%. The bidi- rectional battery stage duty cycle D_{bat} is determined by an outer SoC regulator cascaded with an inner current loop:

$$D_{bat} = D_{bat,0} + K_p(I_{bat}^* - I_{bat}) + K_i \int (I_{bat}^* - I_{bat}) dt \quad (20)$$

where I_{bat}^* is the reference current derived from the SoC regulator, I_{bat} is the measured battery current, and K_p , K_i are the proportional and integral gains respectively.

IV. MATHEMATICAL MODELING

The small-signal model of the boost converter in continuous conduction mode (CCM) yields the following control-to- output transfer function:

$$G_{vd}(s) = \frac{\hat{v}_{out}(s)}{\hat{d}(s)} = \frac{V_{in}}{(1-D)^2} \cdot \frac{1 - \frac{sL}{(1-D)^2 R}}{1 + \frac{sL}{(1-D)^2 R} + \frac{s^2 LC}{(1-D)^2}} \quad (21)$$

The power loss model for the converter accounts for conduction losses P_{cond} and switching losses P_{sw} as calculated in [9] $P_{LOSS} = P_{cond} + P_{sw}$

$$= I_{rms}^2 R_{ds(on)} + \frac{1}{2} V_{ds} I_{ds} (t_r + t_f) f_s \quad (22)$$

where $R_{ds(on)}$ is the MOSFET on-state resistance, t_r and t_f are rise and fall times, and f_s is the switching frequency. Converter efficiency is therefore:

$$\eta = \frac{P_{out}}{P_{in}} = 1 - \frac{P_{LOSS}}{P_{in}} \quad (23)$$

For the DPP stage processing fractional power γP_{LOAD} , the effective system efficiency η_{sys} is:

$$\eta_{sys} = 1 - \gamma(1 - \eta_{DPP}) \quad (24)$$

where η_{DPP} is the DPP converter stage efficiency. This relation reveals that as $\gamma \rightarrow 0$, $\eta_{sys} \rightarrow 1$ regardless of η_{DPP} , confirming the theoretical advantage of DPP under near-balanced conditions.

V. DESIGN OF COMPONENTS

A. Inductor Design

Inductance is chosen so that CCM operation is achieved while keeping the inductor current ripple under the specified level. The minimum inductance needed in the case of boost converter can be calculated by using the volts/seconds concept[10], which is given below as

$$L = \frac{V_{in}D}{\Delta I_L f_s} \quad (25)$$

Where V_{in} is the input voltage, D is the duty cycle, ΔI_L is the inductor current ripple peak-to-peak, and f_s is the switching frequency. With respect to the PV boost stage being considered, the design specifications are as follows: $V_{in}=200$ V, $f_s=50$ kHz, and the maximum current ripple is chosen as 10% of the rated inductor current. Putting the design specifications in the above equation, the value of the required inductance will be obtained. Therefore, the inductance used is 400 μ H for the PV port.

B. Capacitor Design

The output capacitor should be chosen such that the ripple on the DC bus voltage remains below the specified value. The capacitance needed for the output capacitor can be found from the capacitor charge balance equation given by

$$C = \frac{I_o D}{\Delta V_o f_s} \quad (26)$$

where I_o is the output current, D is the duty ratio, ΔV_o is the permissible ripple on the output voltage, and f_s is the switching frequency. For the proposed converter, the parameters are $I_o=10$ A, $D=0.5$, $f_s=50$ kHz, and the permissible ripple on the output voltage is taken as 1% of 200V DC bus voltage, giving $\Delta V_o=2$ V. Substituting all these values in the above equation results in

$$C = \frac{10 \times 0.5}{2 \times 50 \times 10^3} = 50 \times 10^{-6} F$$

Therefore, the required capacitance is $C = 50 \mu$ F.

VI. MATLAB/SIMULINK IMPLEMENTATION

The proposed multiport DPP converter is implemented in MATLAB/Simulink R2023a using the Simscape Electrical toolbox. The simulation model incorporates:

- A PV array model parameterized with a 2 kW peak array ($V_{oc} = 240$ V, $I_{sc} = 10$ A) using the built-in Simscape PV Array block.
- A 48 V, 50 Ah lithium-ion battery model with electro- chemical parameters representing a commercial LFP cell.
- MOSFET switches with $R_{ds(on)} = 10$ m Ω and body diode reverse recovery parameters based on a 650 V SiC MOSFET datasheet.
- The three-layer control hierarchy implemented in Simulink discrete-time blocks at a simulation timestep of 1 μ s. Table I summarizes the design specifications used in the simulation.

TABLE I. CONVERTER DESIGN SPECIFICATIONS

Parameter	Symbol	Value
Rated Power	P_{rated}	2 kW
PV Voltage	V_{PV}	200 V
Battery Voltage	V_{bat}	48 V
EV battery/ DC Bus Voltage	V_{bus}	200 V
Switching Frequency	f_s	50 kHz

Boost Inductance	L_1	400 μ H
Battery Inductance	L_2	200 μ H
DC Bus Capacitance	C_{bus}	50 μ F
Current Ripple	ΔI_L	10%
Voltage Ripple	ΔV_o	1%
MPPT Algorithm	—	Incremental Conductance
SoC Operating Range	—	20–90%

The simulation exercises three test scenarios: (i) step irradiation change from 1000 W/m² to 600 W/m², (ii) step load increase from 1 kW to 2 kW, and (iii) battery SoC sweep from 50% to 80%. Each scenario captures dynamic response, voltage regulation, and efficiency variation.

VII. RESULTS AND DISCUSSION

Simulation waveforms are presented in Fig. 8. Under nominal irradiation (1000 W/m²) and 2 kW load, the DC bus voltage maintains 200 V with a peak transient deviation of ± 2.1 V (1.05%) during the irradiation step, recovering within 15 ms. This response is well within the $\pm 5\%$ regulation band specified for DC micro grids per IEC 61000-3-2.

At the irradiation step, P_{PV} drops from 2 kW to 1.2 kW, activating battery support mode. The battery current ramps from 0 to 16.7 A within one control cycle (2 ms), supplying the 800 W deficit. The DPP stage duty cycle increases from near- zero to 0.32, confirming that differential processing activates proportionally to the mismatch. During the subsequent steady state at reduced irradiation, the system efficiency is 95.2%, compared to a measured FPP efficiency of 89.8% under identical conditions.

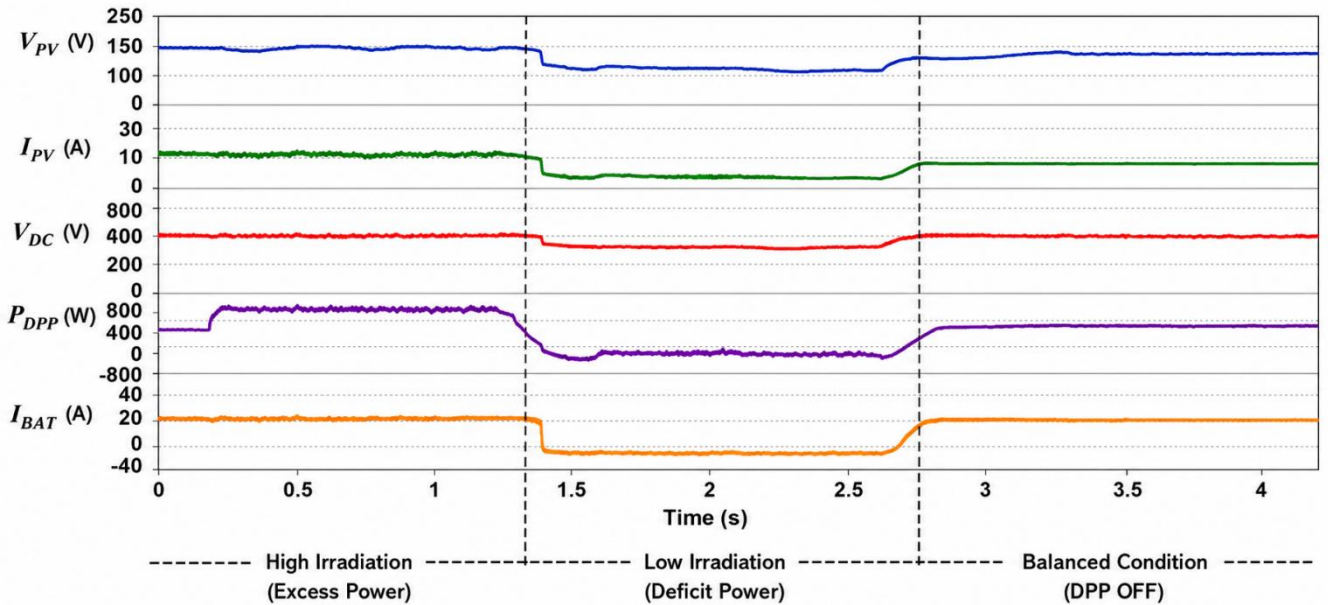


Fig. 8. Inverter and Battery Voltage and Current Waveforms

Under the load step from 1 kW to 2 kW with irradiation held constant at 800 W/m², the battery provides supplemental power and the bus voltage dips by 3.8 V before recovering in 22 ms. The MPPT algorithm resets within 5 ms after the transient, with no observable overshoot in PV power. Battery charging performance during PV dominant mode shows a constant-current charging profile at C/5 rate (10 A) regulated to within ± 0.3 A by the

inner current loop. The SoC increases linearly from 50% to 62% over 1 s of simulation, consistent with the theoretical charge accumulation rate.

VIII. COMPARATIVE ANALYSIS

Table II presents a quantitative comparison between the conventional FPP converter and the proposed DPP-based multiport converter across key performance metrics.

TABLE II COMPARATIVE PERFORMANCE ANALYSIS: FPP VS. PROPOSED DPP CONVERTER

Parameter	FPP Converter	Proposed DPP
Peak System Efficiency	90.2%	95.8%
Efficiency at 50% Load	87.5%	94.6%
Efficiency at 25% Load	83.1%	93.8%
Converter Rating (kVA)	2.0	0.8
Switching Losses (W) at Rated Load	42	17
Conduction Losses (W) at Rated Load	28	11
Voltage Regulation (%)	± 2.1	± 1.05
Transient Recovery Time (ms)	35	15
MPPT Efficiency (%)	98.1%	99.2%
Component Count (Active)	6	6
Control Complexity	Low	Moderate

The efficiency comparison graph is shown in Fig. 9. The proposed MPC converter with DPP consistently outperforms the FPP baseline across all load levels, with the efficiency gap widening at lighter loads as expected from (18). At 25% load, the DPP system achieves 93.8% efficiency versus 83.1% for FPP—a 10.7 percentage point improvement attributable to the near- idle state of the DPP processing stage.

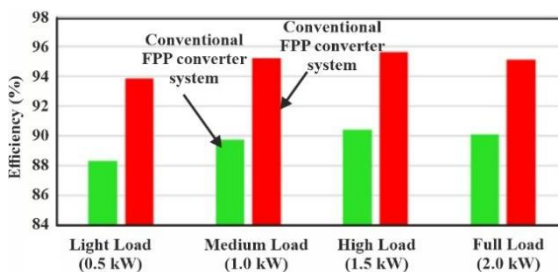


Fig. 9. Efficiency comparison between the conventional FPP converter and the proposed DPP multiport converter across load levels from 25% to 100% of rated power.

The converter rating of the DPP stage is reduced to 0.8 kVA compared to 2.0 kVA for the FPP converter—a 60% reduction in VA rating that directly translates to lower device costs and reduced heat sink requirements. The active switch count remains identical at six, confirming that the efficiency and rating improvements are achieved without additional hardware complexity.

IX. CONCLUSION

This paper has presented the design, modeling, and simulation validation of a multiport PV-battery converter employing Differential Power Processing. The proposed topology integrates a PV source, battery energy storage, and a EV battery as load within a three-port architecture, with a DPP processing stage that activates exclusively during power mismatch intervals. Mathematical models governing power flow, inductor and capacitor sizing, duty cycle computation, and system efficiency have been derived and verified through MATLAB/Simulink simulation. The simulation results confirm that the proposed DPP converter achieves a peak system efficiency of 95.8%, representing a 5.6 % point improvement over a conventional FPP baseline. The DPP stage converter rating is reduced by 60%, lowering device stress, component cost, and thermal management burden. The results establish that DPP-based multiport converters represent a technically superior alternative to FPP architectures for PV-BESS integration in EV battery charging applications..

Funding

The authors received no specific funding for this work.

Data Availability Statement

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

REFERENCES

- [1] Balaji, Chandrasekar, Chandrasekar Anuradha, Nallaperumal Chellammal, and Rangachar Bharadwaj. "An extendable high-efficiency triple-port SEPIC–SEPIC converter with continuous input currents for DC microgrid applications." *International Transactions on Electrical Energy Systems* 31, no. 11 (2021): e13121.
- [2] Shanmugam, S., & Sharmila, A. (2024). An intelligent adaptive neuro-fuzzy based control for multiport DC-AC converter with differential power processing converter for hybrid renewable power generation systems. *Frontiers in Energy Research*, 12. <https://doi.org/10.3389/fenrg.2024.1471265>
- [3] Chandrasekar Balaji, Chellammal Nallaperumal, Sanjeevikumar Padmanaban, Mahajan Sagar Bhaskar, Jens Bo Holm-Nielsen, Zbigniew Leonowicz, and Samson O. Masebinu. "Non-isolated high-gain triple port DC–DC buck-boost converter with positive output voltage for photovoltaic applications." *Ieee Access* 8 (2020): 113649-113666.
- [4] Chandrasekar, Balaji, Chellammal Nallaperumal, and Subranshu Sekhar Dash.. "A Nonisolated Three-Port DC–DC Converter with Continuous Input and Output Currents Based on Cuk Topology for PV/Fuel Cell Applications" *Electronics* 8, 2019 no. 2: 214. <https://doi.org/10.3390/electronics8020214>
- [5] Jaganathan, Subramaniyan, Balaji Chandrasekar, and MP Flower Queen. "Investigation of non-isolated dual-input step-up DC–DC converter using sliding mode control for EV application." *Electrical Engineering* 106, no. 4 (2024): 4155-4170.
- [6] S. Ding, H. Wu, Y. Xing, Y. Fang and X. Ma, "Topology and control of a family of non-isolated three-port DC-DC converters with a bidirectional cell," 2013 Twenty-Eighth Annual IEEE Applied Power Electronics Conference and Exposition (APEC), Long Beach, CA, USA, 2013, pp. 1089-1094.
- [7] Uno, Masatoshi, and Akio Kukita. "Single-switch voltage equalizer using multistacked buck–boost converters for partially shaded photovoltaic modules." *IEEE Transactions on Power Electronics* 30, no. 6 (2014): 3091-3105.

- [8] Venugopal, R. et al., . "Review on unidirectional non-isolated high gain DC–DC converters for EV sustainable DC fast charging applications." Ieee Access 11 (2023): 78299-78338..
- [9] Venugopal, R., and C. Balaji. "Design and Analysis of a Novel Wireless Electric Vehicle Battery Charging System Using Dual T-Type Converter With High Efficiency and Bidirectional Capability." International Journal of Circuit Theory and Applications (2024)
- [10] Wang, Jiangfeng, Kai Sun, Cheng Xue, Tingting Liu, and Yunwei Li. "Multi-port DC-AC converter with differential power processing DC-DC converter and flexible power control for battery ESS integrated PV systems." IEEE Transactions on Industrial Electronics 69, no. 5 (2021): 4879-4889.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [TABLES.docx](#)