Time-domain performance of QBC with self-lift circuit

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ABSTRACT

This study examines the performance of a high-gain quadratic boost converter (QBC) coupled with a self-lift circuit under two control methodologies: sliding mode control (SMC) and fractional-order proportional integral derivative (FOPID) control. The QBC topology is used because it can boost voltage significantly, which is especially useful for renewable energy applications. Simulation studies show that both controllers can control the output voltage of the converter, but the FOPID controller works better in dynamic situations. In particular, it makes settling happen faster, cuts down on overshoot, and lowers steady-state error compared to the SMC method. The overall results show that the FOPID controller is a good choice for improving stability and transient response. This makes it a good choice for advanced high-performance power electronic systems.

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1. INTRODUCTION

The increasing global dedication to sustainable development has greatly sped up the use of renewable energy technologies. In this context, high step-up DC–DC converters are very important for photovoltaic (PV) generation, fuel cells, and hybrid electric vehicles (HEVs), where low-level input voltages need to be raised to higher levels to work with grid-connected systems and real-world loads. The quadratic boost converter (QBC) with a self-lift mechanism stands out among these because it has a high voltage gain and better overall efficiency. A control strategy for DC microgrids with variable renewable generation and energy storage integration has been delineated in [1], highlighting the necessity for dependable and high-performance converters. In the same way, [2] looked at autonomous control methods for hybrid microgrids with DC links, which showed how important it is for converters to work reliably.

Several new advanced converter setups have been made available in the last few years to improve the conversion of low to high voltage. The designs that use coupled inductors and switched capacitors, as described in [3] and [4], get a lot more gain and efficiency, while the changes made in [5] make sure that the system works safely, especially when connected to a PV grid. For electric mobility, [6] showed an interleaved multi-device converter made for fuel cell HEVs. This made the power density better and the energy losses lower. At the same time, [7] suggested predictive control strategies for modular multilevel converters that would improve transient response and stability in high step-up applications.

To reduce switching loss, especially in fuel cell systems, naturally clamped current-fed converters that work under ZCS/ZVS conditions were created in [8] and [9]. Switched-inductor and switched-capacitor architectures, as explained in [10], made switch use even better. The switched-coupled inductors topology studied in [11] is flexible and can be used in a variety of situations. Also, the voltage-multiplier-based coupled-inductor converters studied in [12] and [13] were more efficient and had a higher voltage gain for PV systems.

The three-winding coupled inductor structure shown in [14] is an example of an innovative design that greatly improves step-up capability. Preview study [15], a hybrid converter that combines quadratic and conventional boost stages was made for PV systems that need high voltage conversion ratios. Interleaved converters with diode-capacitor multipliers [16] lower both conduction and switching losses. Single-switch Zeta-type [17] and voltage-multiplier-cell-based designs [18] have also added to the list of high-efficiency solutions. According to [19], combining active-clamp circuits with voltage multiplier stages led to new types of interleaved high step-up converters with better features. Preview study [20] and [21], more work was done on coupled inductors and voltage-lift methods, which showed better gain and less stress on the components.

Hybridized approaches that combine switched-capacitor units, multi-winding coupled inductors, and interleaved boost techniques have led to more progress, as shown in [22]-[25]. These advancements collectively demonstrate the capabilities of high step-up converters within renewable energy systems. This study presents a time-domain analysis of a quadratic boost converter equipped with a self-lift circuit, utilizing sliding mode control (SMC) and fractional-order proportional–integral–derivative (FOPID) control for output voltage regulation. The suggested topology not only allows for high step-up conversion, but it also reduces stress on both active and passive parts. Simulation results show that both the SMC and FOPID controllers can effectively regulate, but the FOPID controller has better dynamic performance, with a faster transient response and a lower steady-state error than the SMC controller.

2. PROPOSED HIGH STEP-UP QBC WITH SELF-LIFT CIRCUIT

The design incorporates three inductors (denoted as L_1, L_2, and L_3) and five capacitors (C_1, C_2, C_3, C_4, and the output capacitor C_0). Additionally, it includes seven diodes (D_0 to D_6) and a single MOSFET switch as the primary switching element. Figure 1 illustrates the power circuit layout of the proposed converter topology. The self-lift module within the circuit is composed of inductors L_2 and L_3, capacitor C_2, and diodes D_2 and D_3. This section is energized through the intermediate capacitor C_1. A separate switched-capacitor network is formed using capacitors C_3 and C_4 along with diodes D_4 and D_5. Here, capacitor C_3, connected in series with the self-lift network, receives its charge from the combined potential of C_4 and C_1. Meanwhile, the input inductor L_1 draws energy from the source through diode D_1 during the active switching period. In this mode, diode D_7 remains reverse-biased, and the load current is provided solely by the C_0. The voltage gain at the output is achieved through the cumulative effect of voltages transferred via diodes D_6 and D_7, which become forward-biased during the discharge phase. In parallel, capacitor C_4 is charged by the energy stored in i L_2 via diode D_5. All other diodes are non-conducting during this specific operating interval. The mathematical expressions characterizing Mode 2 behaviour are derived in the subsequent section.

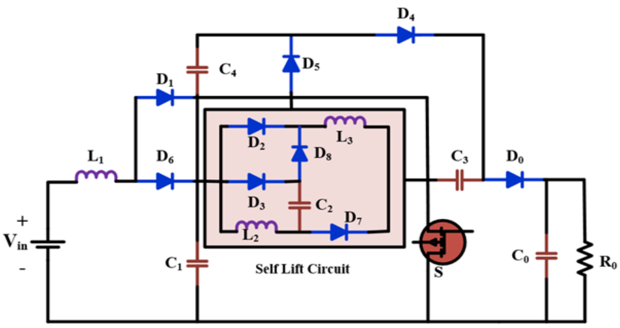

Figure 1. High step-up QBC with self-lift circuit

3. SIMULATION OF PROPOSED CONVERTER

The performance of a quadratic boost converter (QBC) combined with a self-lift configuration was analyzed through simulation under two different control methods: closed-loop sliding mode control (SMC) and a fractional-order proportional–integral–derivative (FOPID) controller. Simulation outcomes revealed that the FOPID controller achieved a higher output voltage than the SMC. The complete closed-loop schematic, where the QBC with the self-lift stage is regulated by the FOPID controller, is shown in Figure 2. The input supply voltage of 35 V is provided in Figure 3. The output voltage response across the resistive load, illustrated in Figure 4, reaches nearly 473 V. Figure 5 depicts the corresponding load current of about 9.5 A, while Figure 6 highlights the power delivered to the load, which is approximately 4470 W.

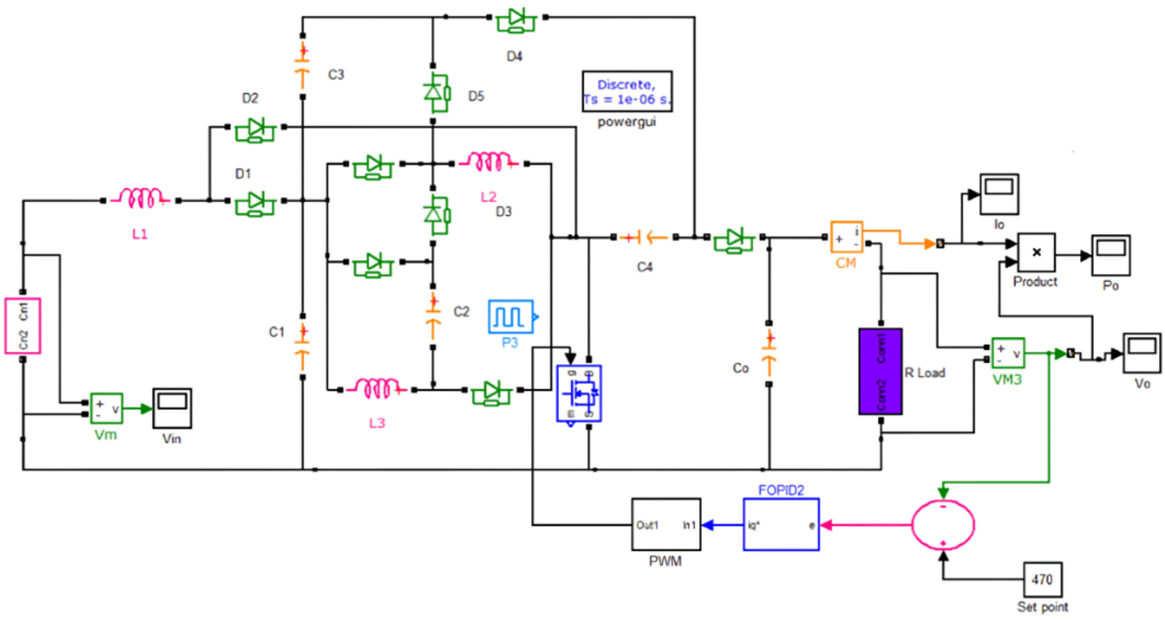

Figure 2. FOPID system

Figure 3. Input voltage

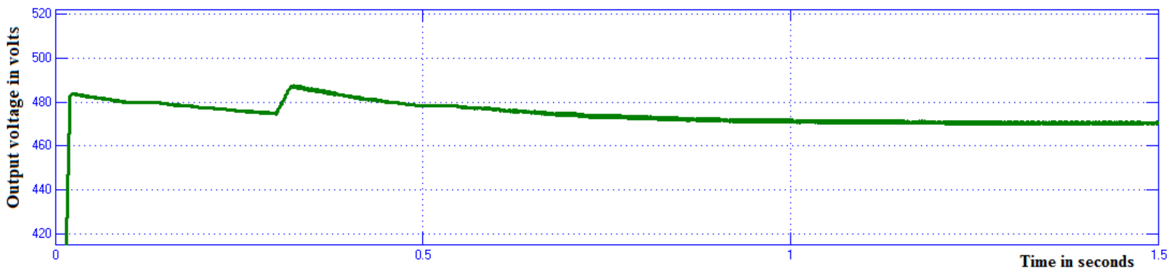

Figure 4. Output voltage across R-load

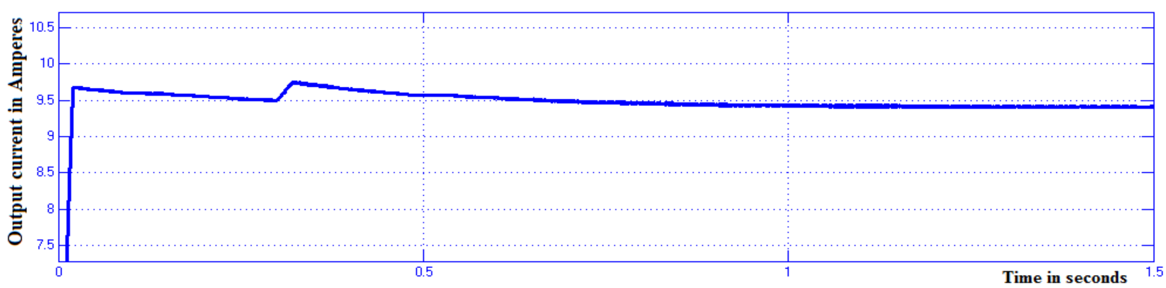

Figure 5. Output current through R-load

Figure 7 shows the schematic of the proposed system, where a quadratic boost converter (QBC) is combined with a self-lift circuit and regulated through a closed-loop sliding mode control (SMC) strategy. The applied input voltage of 35 V is illustrated in Figure 8. The output voltage across the resistive load, as presented in Figure 9, stabilizes at nearly 473 V. The corresponding load current, depicted in Figure 10, is approximately 9.5 A.

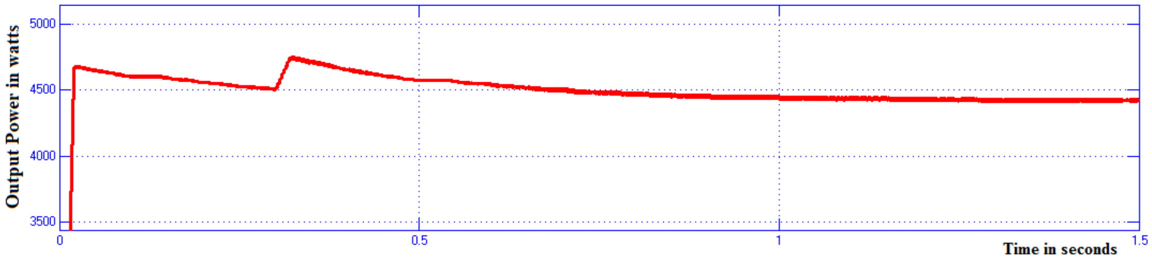

Figure 6. Output power

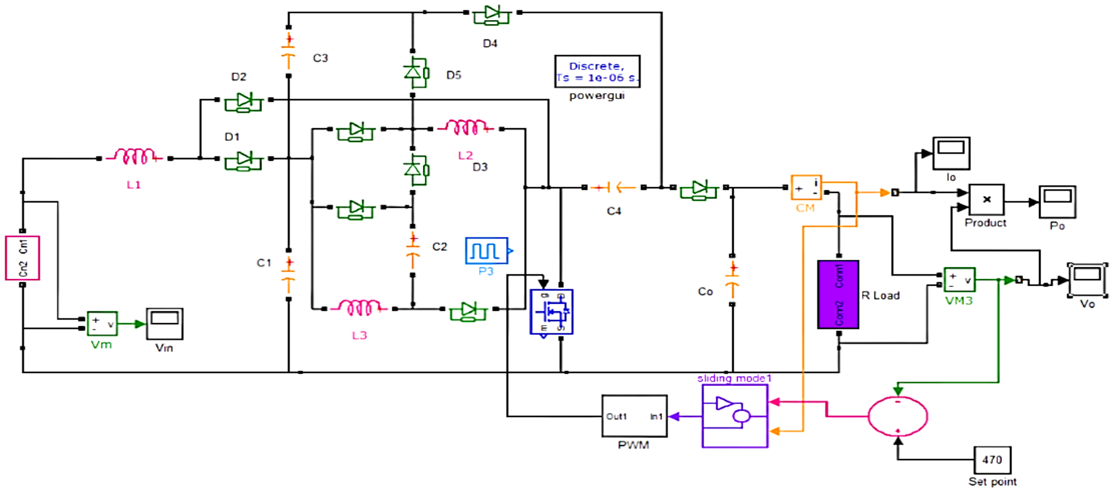

Figure 7. SMC system

Figure 8. Input voltage

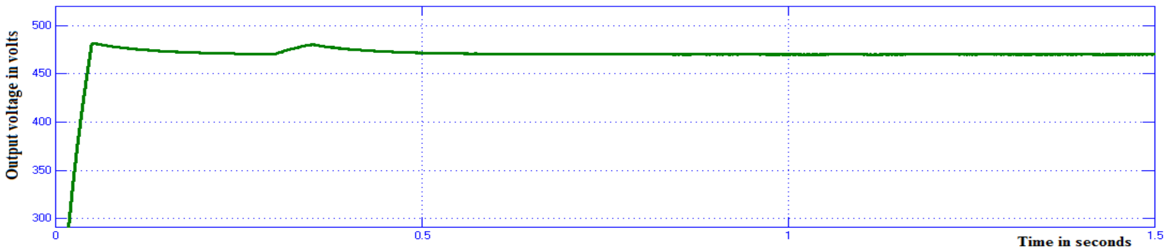

Figure 9. Output voltage across R-load

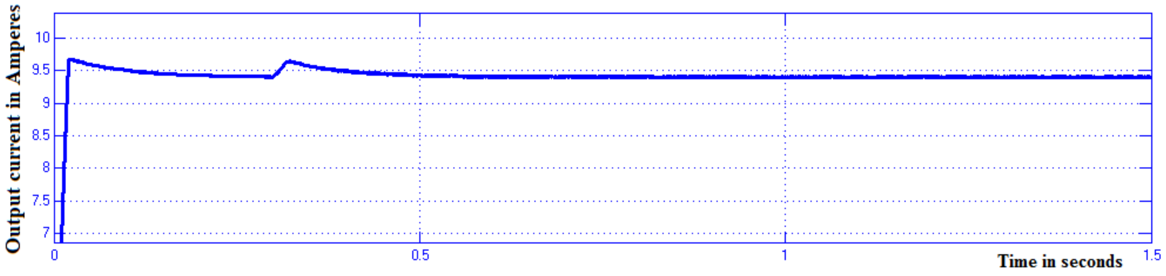

Figure 10. Output current through R-load

4. HARDWARE IMPLEMENTATION

The proposed high-step-up quadratic boost converter employing a self-lift technique was designed, developed, and tested to validate the simulation results. The hardware prototype delivers around 1 kW power and operates at a switching frequency of 10 kHz. A PIC18F25K20 microcontroller generates the PWM signals, which are isolated using a TLP250 opto-coupler and fed to the MOSFET driver. An IR840 MOSFET (600 V, 8 A) serves as the main switch, and 1000 V, 3 A diodes are used for rectification. The inductors L_1, L_2, and L_3 (10 µH ferrite cores) and capacitors C_1 = 1µF, C_2 = 47 µF, C_3 = 33 pF, C_0 = 2.2 µF ensure smooth energy transfer and reduced ripple. The experimental results closely matched the simulation outcomes, proving the effectiveness of the proposed converter.

Figure 11 shows the prototype of the QBC, which includes the power circuit, control circuit, and gate driver section. The input voltage waveform is depicted in Figure 12, confirming a stable 30 V DC supply. The gate pulse waveform generated by the controller is shown in Figure 13, indicating proper switching operation of the MOSFET. The corresponding output voltage waveform, shown in Figure 14, illustrates that the converter effectively boosts the input voltage to 473 V with minimal ripple. The experimental results validate the theoretical and simulated performance of the proposed converter, confirming its suitability for high-gain DC conversion applications.

Table 1. Hardware parameters

Name	Rating	Name	Rating
Capacitor (C1)	1 µF	Diode	1000 V, 3 A
Capacitor (C2)	47 µF	Inductance (L_1, L_2&L_3)	10 uH
Capacitor (C3)	33 pF	MOSFET(IR840)	600 V, 8 A
Capacitor (C0)	2.2 µF		

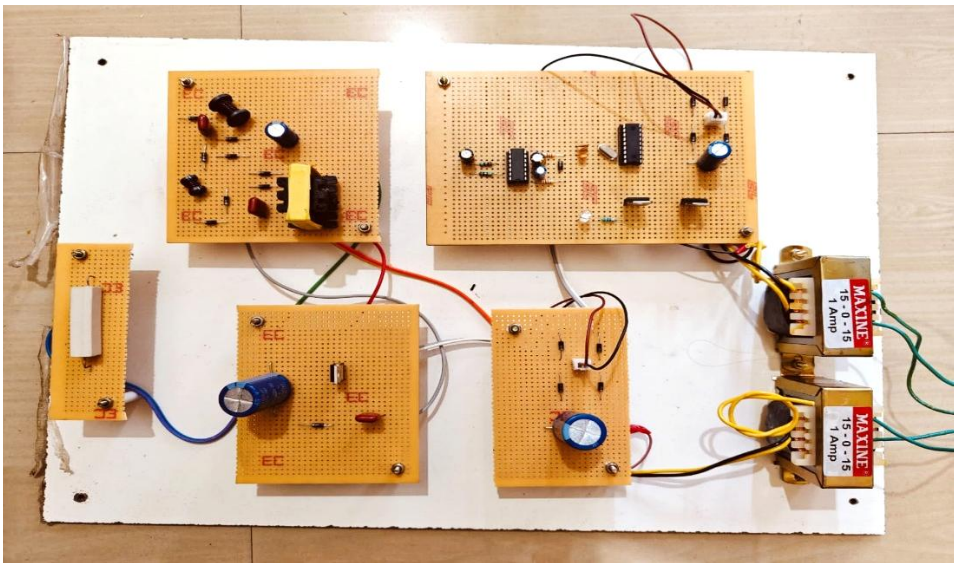

Figure 11. Prototype of QBC

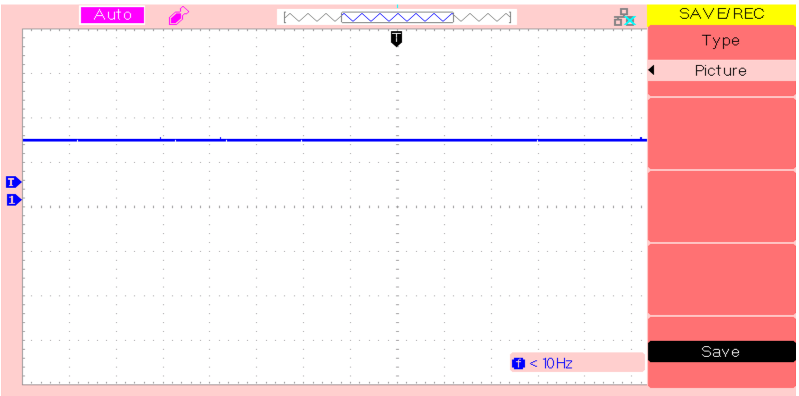

Figure 12. Input voltage

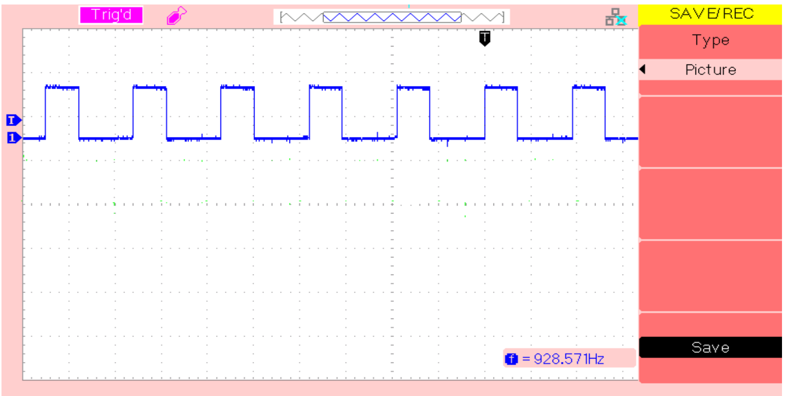

Figure 13. Gate pulse

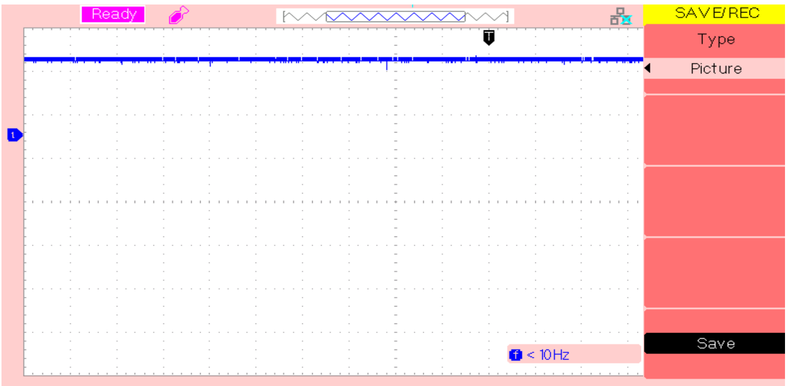

Figure 14. Output voltage

5. COMPARISON OF FOPID AND SMC CONTROLLERS

Table 2 provides a comparative evaluation of the time-domain characteristics of the proposed high step-up quadratic boost converter with a self-lift configuration, operated under FOPID and SMC controllers. To complement this, Figure 15 presents a bar chart that visually contrasts the performance indices of both control strategies. The results indicate that the SMC controller offers superior transient response across all measured parameters. The rise time improves from 0.31 s with FOPID to 0.29 s under SMC, while the peak time is slightly shortened from 0.34 s to 0.33 s. A more notable improvement is observed in the settling time, which decreases from 0.65 s (FOPID) to 0.47 s (SMC). Additionally, the steady-state error is significantly minimized, dropping from 1.78 V with FOPID to 0.93 V under SMC control.

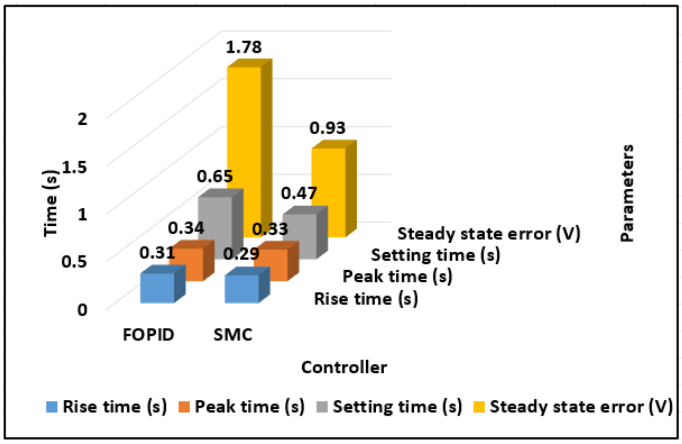

Figure 15. Comparison of controllers

Table 2. Comparison of output voltage, output current, and output power

Controllers	Rise time (s)	Peak time (s)	Setting time (s)	Steady state error (V)
FOPID	0.31	0.34	0.65	1.78
SMC	0.29	0.33	0.47	0.93

6. CONCLUSION

This study compared two cutting-edge control methods: fractional order proportional-integral-derivative (FOPID) control and sliding mode control (SMC) for a high step-up quadratic boost converter (QBC) combined with a self-lift circuit. In terms of transient behaviour, the FOPID controller continuously beats SMC, giving faster settling times, less overshoot, and noticeably lower steady-state error, according to thorough time-domain simulations. These performance gains are a result of the FOPID controller's increased flexibility and accuracy in controlling converter output in dynamic operating environments. Additionally, the QBC topology's incorporation of the self-lift mechanism leads to a significant improvement in output voltage gain, current delivery, and overall power efficiency. For applications requiring high voltage levels, such as low-voltage DC distribution networks, sustainable energy systems, and electric mobility, the designed converter architecture works incredibly well.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
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Palani Velmurugan	✓	✓	✓			✓	✓		✓	✓	✓	✓		✓
Shobana Devendiren	✓	✓		✓	✓			✓	✓	✓	✓	✓	✓	✓
Soundarapandiyan Manivannan	✓	✓	✓	✓		✓		✓	✓		✓			✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, upon reasonable request. All simulation results and analysis outputs used in this research are documented within the manuscript. No publicly archived datasets were used or generated specifically for this study. Additional information may be provided to qualified researchers upon request.

REFERENCES

[1] X. Lie and D. Chen, "Control and operation of a DC microgrid with variable generation and energy storage," *IEEE Transactions on Power Delivery*, vol. 26, no. 4, pp. 2513–2522, 2011, doi: 10.1109/TPWRD.2011.2158456.

[2] P. C. Loh, D. Li, Y. K. Chai, and F. Blaabjerg, "Autonomous operation of hybrid microgrid with DC subgrids," *IEEE Transactions on Power Electronics*, vol. 28, no. 5, pp. 2214–2223, May 2013, doi: 10.1109/TPEL.2012.2214792.

[3] Y.-P. Hsieh, J.-F. Chen, T.-J. Liang, and L.-S. Yang, "Novel high step-up DC-DC converter with coupled-inductor and switched-capacitor techniques," *IEEE Transactions on Industrial Electronics*, vol. 59, no. 2, 2012, doi: 10.1109/TIE.2011.2151828.

[4] S. Ramamurthi and P. Ramasamy, "High step-up DC-DC converter with switched capacitor-coupled inductor and voltage multiplier module," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 13, no. 3, pp. 1599–1604, 2022, doi: 10.11591/ijpeds.v13.i3.pp1599-1604.

[5] S.-M. Chen, T.-J. Liang, L.-S. Yang, and J.-F. Chen, "A safety-enhanced, high step-up DC-DC converter for AC photovoltaic module application," *IEEE Transactions on Power Electronics*, vol. 27, no. 4, 2012, doi: 10.1109/TPEL.2011.2170097.

[6] O. Hegazy, J. Van Mierlo, and P. Lataire, "Analysis, modelling, and implementation of a multi-device interleaved DC/DC converter for fuel cell hybrid electric vehicles," *IEEE Transactions on Power Electronics*, vol. 27, no. 11, pp. 4445–4458, 2012, doi: 10.1109/TPEL.2012.2183148.

[7] L. Pu, W. Yue, C. Wulong, and L. Wanjun, "Study on predictive control strategy of modular multilevel converter optimization model," *Proceedings of the CSEE*, vol. 34, no. 36, pp. 6380–6388, 2014, doi: 10.13334/j.0258-8013.pcsee.2014.36.002.

[8] K. Rathore and U. R. Prasanna, "Analysis, design, and experimental results of novel snubber less bidirectional naturally clamped ZCS/ZVS current-fed half-bridge DC/DC converter for fuel cell vehicles," *IEEE Transactions on Industrial Electronics*, vol. 60, no. 10, pp. 4482–4491, 2013, doi: 10.1109/TIE.2012.2213563.

[9] P. Xuewei and A. K. Rathore, "Novel interleaved bidirectional snubber less soft-switching current-fed full-bridge voltage doubler for fuel cell vehicles," *IEEE Transactions on Power Electronics*, vol. 28, no. 12, 2013, doi: 10.1109/TPEL.2013.2252199.

[10] Y.-H. Chang and Y.-J. Chen, "A switch utilization improved switched-inductor switched-capacitor converter with adapting stage number," *International Journal of Circuit Theory and Applications*, vol. 44, no. 3, pp. 709–728, 2016, doi: 10.1002/cta.2102.

[11] S.-M. Chen, M.-L. Lao, Y.-H. Hsieh, T.-J. Liang, and K.-H. Chen, "A novel switched-coupled-inductor DC-DC step-up converter and its derivatives," *IEEE Transactions on Industry Applications*, vol. 51, no. 1, 2015, doi: 10.1109/TIA.2014.2332642.

[12] Y.-H. Chang and K.-W. Wu, "A gain/efficiency-enhanced bidirectional switched-capacitor DC-DC converter," *International Journal of Circuit Theory and Applications*, vol. 42, no. 5, pp. 468–493, 2015, doi: 10.1002/cta.1863

[13] M. S. El-Nozahy, M. A. Elgendy, and B. Zahawi, "A single switch high step-up DC-DC converter derived from coupled inductor and switched capacitor for grid-connected photovoltaic systems," *Scientific Reports*, vol. 14, no. 1, 2024, doi: 10.1038/s41598-024-78739-y.

[14] R. Reisi, M. R. Zolghadri, and H. Farzanehfard, "New structure of step-up DC-DC converter based on three winding coupled inductor for renewable energy applications," *Scientific Reports*, vol. 14, no. 1, pp. 1–10, 2024.

[15] S. M. Mousavi, M. H. Nazari, and A. H. Ranjbar, "Hybrid high step-up DC-DC converter based on quadratic and boost converters for photovoltaic applications," *International Journal of Electronics*, vol. 111, no. 5, pp. 1–15, May 2024, doi: 10.1080/00207217.2024.2378490.

[16] M. L. Alghaythi, R. M. Oconnell, N. E. Islam, and J. M. Guerrero, "A non-isolated high step-up interleaved DC-DC converter with diode-capacitor multiplier cells and dual coupled inductors," *arXiv preprint arXiv:2009.04602*, 2020, doi: 10.1109/NAPS50074.2021.9449790.

[17] Abadifard, P. Ghavidel, S. H. Hosseini, and M. Farhadi, "Non-isolated single-switch zeta based high-step up DC-DC converter with coupled inductor," *arXiv preprint arXiv:2110.08390*, 2021.

[18] M. L. Alghaythi, R. M. Oconnell, and N. E. Islam, "Design of a high step-up DC-DC power converter with voltage multiplier cells and reduced losses on semiconductors for photovoltaic systems," *arXiv preprint arXiv:1909.05411*, 2019, doi: 10.1109/ESTS.2019.8847808.

[19] R. Beiranvand and S. H. Sangani, "A family of interleaved high step-up DC-DC converters by integrating a voltage multiplier and an active clamp circuit," *arXiv preprint arXiv:2305.18241*, May 2023, doi: 10.1109/TPEL.2022.3141941.

[20] I. P. Rosas, E. Agostini, and C. B. Nascimento, "Single-switch high-step-up DC-DC converter employing coupled inductor and voltage multiplier cell," *IEEE Access*, vol. 10, pp. 82626–82635, 2022, doi: 10.1109/ACCESS.2022.3196563.

[21] S. Khan *et al.*, "A High Step-up DC-DC Converter Based on the Voltage Lift Technique for Renewable Energy Applications," *Sustainability*, vol. 13, no. 19, p. 11059, Oct. 2021, doi: 10.3390/su131911059.

[22] K.-C. Tseng and C.-C. Huang, "High step-up high-efficiency interleaved converter with voltage multiplier module for renewable energy system," *IEEE Transactions on Industrial Electronics*, vol. 61, no. 3, pp. 1311–1319, Mar. 2014, doi: 10.1109/TIE.2013.2261036.

[23] A. Ma and R. Harikumar, "A high step-up DC/DC converter for PV power system applications," in *2018 International Conference on Current Trends towards Converging Technologies (ICCTCT)*, IEEE, Mar. 2018, pp. 1–6. doi: 10.1109/ICCTCT.2018.8550909.

[24] L. He and Y. Liao, "An advanced current-auto-balance high-step-up converter with a multi-coupled inductor and voltage multiplier for a renewable power generation system," *IEEE Transactions on Power Electronics*, pp. 1–1, 2015, doi: 10.1109/TPEL.2015.2509159.

[25] W. Margaret Amutha and P. Srinivasan, "Hybrid falcon optimization algorithm-PID controller based wind powered improved bridgeless CUK converter for telecom applications," *Arabian Journal for Science and Engineering*, Apr. 2025, doi: 10.1007/s13369-025-10155-4.

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