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High-Ratio Quadratic Boost Converter with Voltage Lift and Voltage Doubler Techniques for Photovoltaic Powered EV Charging

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ABSTRACT

The rapid growth of electric vehicles (EVs) demands reliable charging infrastructure that aligns with sustainable energy sources. Photovoltaic (PV) systems are a promising candidate; however, their fluctuating and relatively low direct current (DC) voltage output requires effective conversion to meet EV charging standards. This study proposes a high ratio quadratic boost converter (QBC) integrated with voltage lift and voltage doubler techniques to enhance voltage gain, combined with a Proportional Integral Derivative (PID) controller for output stabilization. The converter was modeled and simulated in MATLAB/Simulink with PV modules as the power source under varying solar irradiance conditions. Simulation results show that the proposed topology achieved an output voltage of up to 450 V, suitable for EV charging, while the PID controller significantly reduced voltage ripple and improved transient performance, including time rise and settling time. These findings demonstrate that the proposed converter topology offers a stable, efficient, and scalable solution for photovoltaic-powered EV charging systems.

Keywords: Photovoltaic, Quadratic Boost Converter, Voltage Lift, Voltage Doubler, EV Charging

1. Introduction

The global transition toward renewable energy has accelerated efforts to reduce dependence on fossil fuels while meeting the increasing demand for sustainable energy solutions. Among various renewable sources, solar photovoltaic (PV) has gained significant attention due to its abundance, scalability, and declining cost of technology. In Indonesia, the solar energy potential is estimated at 207.8 GWp, positioning PV as a strategic resource to support national energy resilience [1]. Parallel to this development, the adoption of electric vehicles (EVs) has been encouraged by government policies, including Presidential Regulation No. 55/2019, which promotes the acceleration of battery-based EV programs. This creates a strong demand for charging infrastructure that is not only reliable but also aligned with sustainable energy initiatives.

Despite these opportunities, PV-based systems face inherent limitations when applied directly to EV charging applications. The output of PV modules is a low and fluctuating direct current (DC) voltage that depends heavily on solar irradiance and temperature conditions. In contrast, EV battery charging standards typically require voltages in the range of 200–450 V for standard charging and up to 600 V for fast charging [2]. Conventional boost converters can increase DC voltage levels but often suffer from efficiency loss, high duty cycles, and increased switching stress when required to achieve high step-up ratios [3].

Recent research has proposed advanced topologies to overcome these challenges. The Quadratic Boost Converter (QBC), integrated with voltage lift and voltage doubler techniques, enables a significantly higher voltage gain with reduced duty cycle requirements [4, 5]. Similarly, voltage multiplier and coupled inductor based designs have demonstrated improved efficiency and reduced current ripple, achieving gains above 90% [6-8]. However, most of these studies primarily emphasize theoretical modeling or general renewable applications, with limited focus on PV-powered EV charging systems under real irradiance variations.

Another critical aspect is the stability of the output voltage. Since solar irradiance fluctuates throughout the day, maintaining a constant output is essential for EV charging compatibility. Control strategies such as Proportional-Integral-Derivative (PID) controllers have been widely implemented to enhance stability and minimize voltage ripple in power electronic converters [9]. Yet, their integration with high-ratio QBC topologies for EV charging has not been comprehensively investigated.

This study aims to fill the research gap by designing and analyzing a high-ratio QBC using voltage-lift and voltage-doubler methods for PV-powered EV charging. The proposed topology is simulated in MATLAB/Simulink with varying irradiance conditions to evaluate its ability to deliver a stable DC output. Additionally, a PID controller is employed to regulate the output voltage and ensure compliance with EV charging requirements. The novelty of this work lies in its application-oriented approach, demonstrating that the proposed converter can not only achieve an output voltage of up to 450 V but also maintain stability under fluctuating solar conditions, thereby providing a sustainable solution for future EV charging infrastructure.

2. Research method

The methodology of this study was structured to evaluate the performance of a high ratio quadratic boost converter (QBC) for photovoltaic powered EV charging applications. The approach consists of four main stages: photovoltaic modeling, converter design, control and regulation, and simulation with test scenarios. The input source of the proposed system is a photovoltaic (PV) array. The PV module was modeled in MATLAB/Simulink based on the single-diode equivalent circuit, which considers irradiance (*G*) and temperature (*T*) as key parameters influencing the output [10]. The current output of the PV model is expressed as:

$$I = I_{ph} - I_0\left[exp\left(\frac{q(V + IR_S)}{nkT}\right) - 1\right] - \frac{V + IR_S}{R_{sh}} \qquad (1)$$

where *Iph* is the photocurrent, *I0* is the diode saturation current, *Rs* is the series resistance, *Rsh* is the shunt resistance, *n* is the ideality factor, *q* is the electron charge, and *k* is Boltzmann's constant.

To ensure realistic conditions, irradiance data were collected in Padang, Indonesia, using an HS1010 lux meter and converted into irradiance values (W/m^2) with the factor 1 lux = 0.0079 W/m^2**.** The PV model produced variable voltage outputs depending on irradiance, which serves as the input to the converter.

2.1. High ratio converter design

The proposed high ratio quadratic boost converter as shown in Figure 1, integrates two voltage lift cells and one voltage doubler cell to enhance the step up conversion capability. This hybrid structure minimizes the need for extreme duty cycles and reduces component stress compared to conventional boost converters [11, 12]. The theoretical voltage gain of the topology is defined as:

$$V_{out} = \frac{8 \times V_{in}}{(1-D)^2} \qquad (2)$$

where *Vin* is the PV input voltage and *D* is the duty cycle of the main switch. Key design considerations include:

- Voltage lift cells (C1, C2, L1a, L1b, D1, D2): Provide intermediate voltage amplification.
- Voltage-doubler cells (CM1, CM2, Lr, DM1, DM2): Double the intermediate voltage to reach the required output.
- Output capacitor (Co) and resistive load (R): Represent the EV battery charging interface, with a design target of 450 V output.

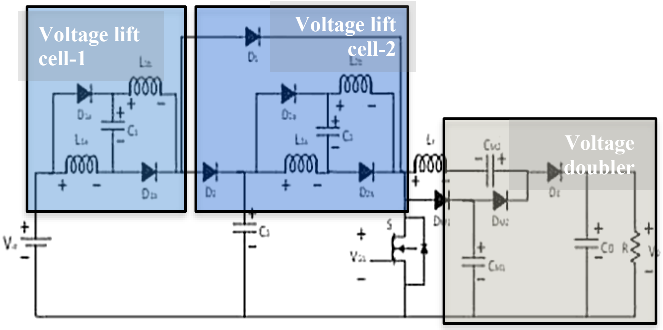

Figure 1. High ratio quadratic boost converter

Component parameters (inductors, capacitors, load) were determined based on ripple constraints and continuous conduction mode (CCM) operation, ensuring stable high gain performance [13].

2.2. Control and regulation

To maintain a constant and stable output voltage despite fluctuating irradiance, a Proportional Integral Derivative (PID) controller was implemented. The controller regulates the duty cycle of the MOSFET switch by processing the error between the reference output voltage (450 V) and the actual converter output:

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt} \quad (3)$$

where *e(t)* is the voltage error. The PID gains (Kp, Ki, Kd) were tuned using the Ziegler Nichols method to achieve optimal transient performance, characterized by short rise time, minimal overshoot, and reduced settling time. The regulated ≈450 V DC output aligns with the DC fast charging bus level described for SAE DC Level 2 systems, supporting the suitability of the proposed PV fed QBC as a front-end for EV charging.

The complete system comprising the PV source, converter, and PID controller was modeled in MATLAB/Simulink (Figure 1). Three irradiance scenarios were used to simulate real operating conditions: Before Peak Sun Hour (PSH): 600 W/m², During PSH: 1000 W/m², and After PSH: 800 W/m². For each scenario, two configurations were evaluated: Without PID control: to observe natural converter response, and With PID control: to analyze improvements in stability and transient response. Performance metrics include output voltage level, ripple, dynamic response (rise time and settling time), and ability to meet EV charging voltage requirements [14].

3. Result and discussion

A one day irradiance survey (08:00–16:00) under clear sky yielded an average of ≈620 W/m² with a peak of 670 W/m² at 11:00–12:00. These data informed the simulation scenarios at fixed irradiance levels of 600, 800, and 1000 W/m². Under the 1000 W/m² case, the PV model delivered an average 44.8 V and 11.6 A, which served as the converter input envelope.

With the PID controller engaged, the quadratic boost converter (QBC) with voltage lift and doubler stages consistently regulated the DC output around the 450 V reference across all irradiance levels: ~450 V (600 W/m²), ~450 V (800 W/m²), and 449 V (1000 W/m²), with average output current ≈1.17 A. This behavior matches the design target for EV fast-charging bus voltage. Dynamic tests with time varying irradiance (step like disturbances each 1 s) in Figure 2, show the controller rejects both downward and upward perturbations: the output dipped to 438 V at t = 1.034 s and overshot to 476 V at t = 2.041 s, then returned to 450 V within ≈0.56 s. Steady-state ripple/noise was bounded within ±0.4 V, and the steady-state regulation error remained <1% (≈448.4–452.9 V). Rise time and settling time were 0.23–0.32 s and 0.46–0.58 s, respectively adequate for PV driven EV DC bus regulation under typical irradiance fluctuations.

These results demonstrate robust line regulation and transient rejection from the closed loop duty cycle control. The small error band and short settling confirm the PID compensator is well tuned for the effective plant (QBC + voltage-multiplier network), despite PV induced input variation.

For context, the open loop converter exhibited pronounced output dependence on irradiance: 273.3 V @ 600 W/m², 363.6 V @ 800 W/m², and 463.3 V @ 1000 W/m², with average output currents 0.71 A, 0.95 A, and 1.17 A, respectively. Compared with the closed loop case, this baseline shows weaker line regulation and larger fluctuations, motivating the adoption of PID control in the proposed system. A side by side comparison is summarized in Figure 3.

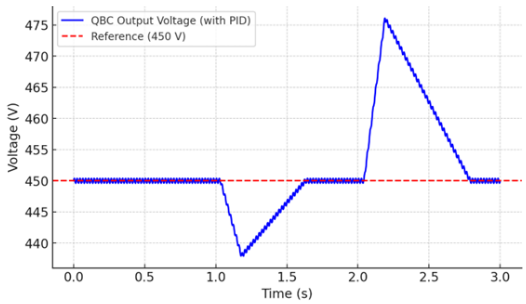

Figure 2. Dynamic tests with time varying irradiance

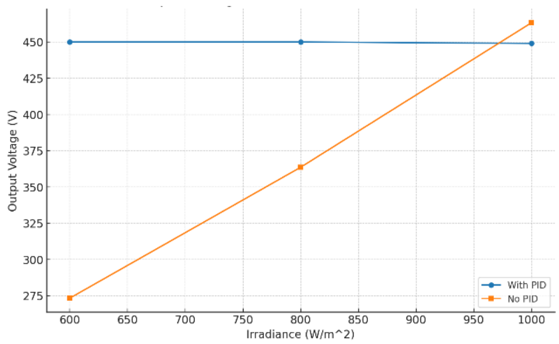

Figure 3. QBC output voltage vs. irradiance (with PID vs. no PID).

The findings confirm that the integration of voltage lift and voltage doubler cells within the quadratic boost converter (QBC) topology successfully achieves a high step up ratio without requiring extreme duty cycles. In comparison, a conventional boost converter would need duty cycles above 0.85 to reach 450 V from a 45 V PV input, resulting in severe efficiency losses and device stress [3]. The proposed topology effectively reduces this burden, supporting both efficiency and reliability. The implementation of the PID controller further addresses the dynamic challenges posed by solar irradiance fluctuations. Without control, the converter output varied significantly with irradiance, making it unsuitable for EV charging interfaces. With PID regulation, the system maintained <1% steady-state error, ±0.4 V ripple, and sub-second settling, all of which are acceptable for a DC bus in EV charging standards [2]. This highlights the role of control integration as an indispensable element in practical deployment.

In terms of novelty, while previous studies have explored high-gain converters [6-8], most focused on general renewable energy applications or efficiency optimization. This study is among the few that explicitly demonstrates the feasibility of a PV-powered high-gain QBC with closed-loop control for EV charging, bridging the gap between converter topology research and EV charging infrastructure requirements. From a practical perspective, the results suggest that the proposed converter can be scaled for DC fast-charging systems (≈450 V bus) and potentially adapted for ultra-fast charging (>600 V) with further optimization. The compact design, high conversion ratio, and stable regulation make it attractive for integrated solar-powered charging stations in regions with high solar potential, such as Indonesia.

4. Conclusion

This study has presented the design and simulation of a high-ratio quadratic boost converter (QBC) with voltage lift and voltage doubler techniques for photovoltaic powered EV charging. The results demonstrate that the proposed converter can deliver a stable DC output of around 450 V, meeting the voltage requirements of EV charging systems. The integration of a PID controller effectively minimized output fluctuations, reduced ripple, and ensured fast recovery under irradiance variations, achieving reliable voltage regulation suitable for charging applications. The findings highlight the feasibility of combining advanced converter topology with closed loop control to bridge the gap between photovoltaic generation and electric vehicle charging infrastructure. With further optimization and hardware validation, this approach can contribute to the development of sustainable solar powered EV charging stations, particularly in regions with abundant solar resources.

References

[1] Hipi, F., Sodri, A., & Chairani, E. Prospek Energi Surya sebagai Energi Baru Terbarukan di Indonesia. Jurnal Energi dan Lingkungan Indonesia, 19(2), 45–53, 2022.

[2] Yong, J. Y., Ramachandaramurthy, V. K., Tan, K. M., & Mithulananthan, N. A review on the state-of-the-art technologies of electric vehicle, its impacts and prospects. Renewable and Sustainable Energy Reviews, 49, 365–385, 2015. https://doi.org/10.1016/j.rser.2015.04.130

[3] Fariz, H., Setiawan, I., & Facta, M. Perancangan Boost Converter untuk Aplikasi PV Stand-Alone. Jurnal Nasional Teknik Elektro, 7(3), 123–132, 2018.

[4] Laha, P. Design and analysis of a quadratic boost converter with voltage multiplier cell. International Journal of Electronics and Electrical Engineering, 8(3), 49–56, 2020. https://doi.org/10.18178/ijeee.8.3.49-56

[5] Rezaie, S. M., Abbasi, V., & Kerekes, T. High step-up quadratic boost converter with voltage multiplier cell. Energies, 13(5), 1214, 2020. https://doi.org/10.3390/en13051214

[6] Baek, J. B., Kim, M., Nam, K., & Lee, J. High boost converter using voltage multiplier technique. Proceedings of the IEEE Power Electronics Specialists Conference (PESC), 256–261, 2005. https://doi.org/10.1109/PESC.2005.1581667

[7] Hu, X., Gong, C., Cao, D., & Zhang, L. A high voltage gain DC–DC converter integrating coupled-inductor and switched-capacitor techniques. IEEE Transactions on Power Electronics, 31(2), 1181–1194, 2016. https://doi.org/10.1109/TPEL.2015.2418736

[8] Guepfrih, D., Waltrich, G., & Lazzarin, T. B. High step-up DC–DC converters: A comprehensive review of voltage-boosting techniques, topologies, and applications. Renewable and Sustainable Energy Reviews, 135, 110220, 2021. https://doi.org/10.1016/j.rser.2020.110220

[9] Kunigar, A., Tahtawi, M., & Ilman, R. Design of PID Controller for DC–DC Converters in Renewable Energy Applications. International Journal of Power Electronics and Drive Systems, 14(1), 33–42, 2023.

[10] JA Solar. Datasheet: JAM60S10 325–345/PR. JA Solar Technology Co., Ltd. 2020. Retrieved from https://www.jasolar.com

[11] P. Saadat dan K. Abbaszadeh, "A single-switch high step-up DC–DC converter based on quadratic boost," IEEE Transactions on Industrial Electronics, 63(12), 7733–742, 2016.

[12] A. Andrade, T. Faistel, R. Guisso, dan A. Toebe. Hybrid High Voltage Gain Transformerless DC-DC Converter. IEEE Transactions on Industrial Electronics, 69(3), 2470–2479, Mar 2022.

[13] M. N. P. Andi, T. D. Rachmildha, Y. Haroen, dan A. P. Sadono, "The Effect of Safe Ball Size Changes on Boost," dalam The 3rd IEEE Conference on Power Engineering and Renewable Energy (ICPERE), 2016, 19–23.

[14] F. Ismail, Y. Warmi, dan A. M. N. Putra, "Perbaikan Performa DC-Link Inverter Satu Fasa Menggunakan Interleaved DC-DC Boost Konverter pada Aplikasi Photovoltaics," Jurnal Teknik Elektro ITP, vol. 7, no. 1, hlm. 74–78, 2018.