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A Review on High Gain DC-DC Boost converter for Renewable Energy Applications

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***Abstract*—This paper presents a the growing integration of renewable energy sources such as photovoltaic (PV) systems, fuel cells, and wind energy into modern power systems demands efficient power conversion interfaces capable of delivering high voltage gain with minimal losses. Conventional DC–DC boost converters are limited by extreme duty cycles, high voltage stress, and poor efficiency at large conversion ratios. To overcome these challenges, numerous advanced high-gain converter topologies have been developed, incorporating techniques such as switched inductors/capacitors, coupled inductors, voltage multipliers, and impedance networks. This review paper presents a comprehensive analysis of recent high-gain DC–DC boost converter topologies designed for renewable energy applications. The paper compares different architectures in terms of voltage gain, efficiency, component count, voltage and current stress, and control complexity. Furthermore, emerging trends such as non-isolated versus isolated structures, soft-switching techniques, and integration with maximum power point tracking (MPPT) algorithms are discussed. Finally, potential research directions are highlighted to enhance converter performance, reliability, and suitability for next-generation sustainable energy systems.**

***Keywords*—high gain, DC–DC boost, renewable energy, photovoltaic, coupled inductor, switched-capacitor, quasi-Z-source, wide-bandgapResonant Frequency, Return Loss (S11), Bandwidth, Gain, Radiation Pattern.**

I. Introduction

The growing demand for clean and sustainable energy has accelerated the development of efficient power conversion systems for renewable energy applications. Among these, high-gain DC–DC boost converters play a crucial role in interfacing low-voltage renewable energy sources—such as photovoltaic (PV) panels, fuel cells, and thermoelectric generators—with high-voltage DC buses or grid-connected inverters. Conventional boost converters often face limitations in achieving high voltage gain due to factors such as extreme duty ratios, high switching losses, and reduced efficiency. To overcome these challenges, advanced high-gain converter topologies have been developed, incorporating techniques such as coupled inductors, switched capacitors, and voltage multiplier networks to enhance the voltage conversion ratio while maintaining compact size and high efficiency. These converters not only improve energy harvesting from renewable sources but also ensure stable operation and power quality across a wide range of load and environmental conditions. Consequently, high-gain DC–DC boost converters have become an essential component in the design of modern renewable energy systems, enabling reliable and efficient integration of distributed generation units into the power grid.

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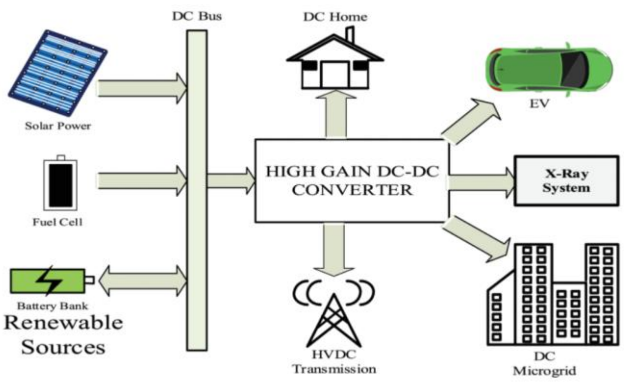

Fig. 1 DC energy system

The high-gain DC-DC boost converters are essential in converting small input direct current (DC) voltage ranging from a few volts to substantially higher DC voltage levels [1]. These DC-DC converters must have a constant input current and step-up capabilities. Such converters are used in various applications like solar photovoltaic (PV) systems, robotics, high-voltage DC systems, and electric vehicles [2], [3]. The

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energy produced by sources like fuel cells or solar photovoltaic is quite low and the required output voltage is relatively high for various household and industrial applications. These pressing concerns enable the researchers to focus more on the development of high-step-up DC-DC converters. DC-DC converters consist of various arrangements of inductors, capacitors, diodes, and switches. These components are interconnected to enable energy exchange between inductors and capacitors. The process begins with the exchange of stored energy in the inductors. Subsequently, this stored energy is transferred to the capacitors, resulting in the achievement of a higher voltage level [4]. Figure 1 illustrates the schematic of a DC energy system. In a DC microgrid, a high-gain DC-DC converter regulates the DC voltage to a specified level. Modern DC microgrids employ a combination of supercapacitors and a high-gain DC-DC converter. In the islanded mode operation of a DC microgrid, it is common practice to pair an inverter with a high-gain DC-DC converter to supply alternating current (AC) loads. High-gain DC-DC converters have increasingly become a popular alternative to traditional boost converters and their derivatives [5]. The conventional DC-DC boost converter has some drawbacks. These include high voltage stress, upswing electromagnetic interference (EMI), intolerable input current ripples, and low efficiency at light load conditions and therefore it is unsuitable in practical applications where the duty ratio exceeds a predetermined threshold value.

The growing global demand for clean and sustainable energy has accelerated the transition from conventional fossil fuels to renewable energy sources such as solar, wind, and fuel cells. However, these sources often produce low and fluctuating DC voltages, which are inadequate for practical applications and grid integration. To overcome this challenge, high-gain DC-DC boost converters have emerged as a vital solution, enabling efficient voltage step-up while maintaining compact size, high efficiency, and reduced component stress. By improving power conversion performance and reliability, these converters play a pivotal role in maximizing the utilization of renewable energy systems. Their development not only enhances the efficiency of green technologies but also contributes to a sustainable and energy-secure future, empowering societies to move closer toward carbon neutrality and environmental preservation.

The High Gain DC-DC Boost Converter plays a crucial role in renewable energy applications by efficiently stepping up low-level voltages obtained from sources such as solar panels, fuel cells, and wind turbines to higher, usable levels suitable for grid integration or battery charging. Traditional converters often suffer from efficiency loss, high voltage stress on switches, and bulky components when achieving high voltage gains. However, advanced high gain topologies—such as switched capacitor, coupled inductor, or cascaded boost converters—overcome these limitations by providing large voltage boosts with improved power density, reduced component stress, and enhanced overall system performance. These converters ensure maximum power extraction from renewable energy sources through techniques like Maximum Power Point Tracking (MPPT), while maintaining stability and reliability under varying environmental conditions. Consequently, the high gain DC-DC boost converter contributes significantly to the development of sustainable, efficient, and cost-effective renewable energy systems, making it an essential component in modern power electronics for clean energy technologies.

II. LITRATURE REVIEW

Hamed MoradmandJazi et al. (2025) -A high step-up converter that combines coupled inductor and voltage multiplier techniques to achieve high voltage gains. Also, since the ZVT method is utilized, the ZVS performance is achieved for the main switch in a whole range of output power. On the other hand, the proposed converter offers continuous input current and a shared ground between the input source and output voltage. These attributes, combined with the previously mentioned features, position this circuit topology as an ideal candidate for high step-up applications. Furthermore, compared to other high step-up converters with similar features and total components, the proposed converter not only provides almost high-power density, but also costs remain constant. The implementation of a 200W, 40V to 400V laboratory prototype illustrated acceptable performance, achieving full load measured efficiency of 96.5%

Sergio Coelho et al. (2025) -The increasing penetration of renewable energy sources (RESs) into medium-voltage (MV) and low-voltage (LV) power systems presents significant challenges in ensuring power grid stability and energy sustainability. Advanced power conversion technologies are essential to mitigate voltage and frequency fluctuations while meeting stringent power quality standards. RES-based generation systems typically employ multistage power electronics to achieve: (i) maximum power point tracking; (ii) galvanic isolation and voltage transformation; (iii) high-quality power injection into the power grid. In this context, this paper provides a comprehensive review of up-to-date isolated DC–DC converter topologies tailored for the integration of RES. As a contribution to support this topic, recent advancements in solid-state transformers (SSTs) are explored, with particular emphasis on the adoption of wide bandgap (WBG) semiconductors technologies, such as silicon carbide (SiC) and gallium nitride (GaN).

Chang-Hua Lin et al. (2024) -High-gain DC-DC converters are becoming increasingly popular in renewable energy applications and solar PV systems. The converter comprises only two switches, and a single PWM signal governs its operation. These characteristics result in a topology that is more compact, less costly, lighter weight, and easier to control. The proposed converter is compared with some previously developed topologies of high-gain boost converters across various performance parameters. This comparison illustrates that the proposed model surpasses them in every aspect. A 300 W hardware prototype of a proposed model is developed and tested in a laboratory environment to confirm the theoretical assertions of a proposed model. The proposed topology

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offers a promising solution and enables a high gain of approximately 12 times the input voltage at a smaller duty ratio, specifically 11.25 at a duty of 0.6 and 17.77 at a duty of 0.7. The efficiency of a proposed converter ranges between 92.5% to 94.5% making it appropriate for numerous medium-high power applications. The uniqueness of the suggested system is its simple design and greater efficiency, which provides a more considerable gain and higher output voltages for sustainable energy systems

Khaja Shahini Begum et al. (2024) - The various topologies of DC-DC boost converters which are designed for optimal integration with RES like photovoltaic (PV) systems. Photovoltaic applications demand efficient energy harvesting and management to maximize the conversion of solar energy into electrical power. The DC-DC topologies include switched coupled inductor, basic coupled inductor, coupled capacitor with coupled inductor with a snubber circuit, active clamp, high step-up and three-winding dual switches are considered for study. Each topology is analyzed in terms of its suitability for PV applications, considering factors such as efficiency, voltage gain, and reliability. The basic coupled inductor topology is explored as a reference point, providing a foundation for understanding the subsequent advanced configurations. This work explores and compares several prominent boost converter configurations, incorporating advanced techniques to enhance overall performance and efficiency for RES applications.

H. Shayeghi et al. (2024) - A non-isolated coupled inductor and VMC based topology. The performance and superiority of the proposed topology is verified by operation modes survey, steady-state analysis, efficiency measurement, and comparison study with other similar converters. Considering the presented analysis, the benefits of this converter can be categorized as: A) only one power switch is used in its structure, which reduces the converter's cost, B) low number of components, B) high efficiency due to the ZCS and ZVS of diodes, 4) low blocking voltage of power switch and diodes, 5) using a low rated power switch; because the VMC acts as a passive clamp circuit and reduces the voltage stress across the power switch, 6) negligible reverse recovery problem of diodes due to the ZCS. The main contribution of the proposed converter and the critical factors of the proposed converters and other converters were discussed in detail in the literature. In order to verify the mathematical analysis, a 160 W experimental prototype with 50 kHz switching frequency and 17 V input voltage are built. It was shown that the suggested structure's efficiency is higher than 95 %. Therefore, related to technical survey, steady-state calculation and the experimental result, the recommended high step-up converter could be a proper topology for renewable energy systems.

Arafa S. Mansour et al. (2023) -High-gain DC/DC converters are considered one of the most important components of green energy systems. Large numbers of these converters are used for increasing the voltage gain by using an extreme duty cycle. However, it increases losses and the cost, degrades the system performance, and hence obtains a low efficiency. In this article, a new design of a high-gain DC/DC boost converter is proposed. This converter has the potential to be used in low input voltage applications that need a high voltage gain such as systems powered by solar photovoltaic panels and fuel cells. The new topology is characterized by its simplicity of operation, high voltage gain, better efficiency, continuity of the input current, reduced number of inductors and capacitors, and can be extended to get higher gains. The converter structure, principle of operation, and design consideration of inductors and capacitors are presented in detail. Derivation of power losses and efficiency is presented. A laboratory prototype is implemented, and various experimental tests are given.

J. Gnanavadivel et al. (2023) - An efficient DC-DC converter for renewable energy applications. The proposed high-gain converter is designed with switched inductor cell and voltage multiplier cell. In the proposed converter, the continuous source current is obtained by switched inductor cells, and high-voltage gain is achieved using voltage multiplier cells. The proposed converter provides a voltage gain of 10 when operated with a duty ratio of 27.3%, whereas a voltage gain of 39 is obtained for an 80% duty ratio. The efficiency of 96.54% is achieved in simulation for the rated condition of 24 V/240 V, 120W. The converter operation under steady-state, state-space modelling, and voltage and current stress of the power semiconductor components are analyzed. In addition to that, loss distribution and efficiency analysis are made. The performance of the converter is analyzed using the Matlab Simulink tool. Also, the experimental hardware prototype model is developed to validate the simulated and theoretical analysis.

Arafa S. Mansour et al. (2022) - A new non-isolated high voltage gain DC/DC converter by integrating a dual boost converter with a switched inductor structure is proposed. The proposed converter operates with a modest duty cycle (less than 0.5) with a continuous input current. The converter operates with a soft switching (ZCS) for all diodes and switches which plays an important role in reducing the losses. A wide operating range of the duty cycle is available. An equal current sharing among boost inductors makes it easy to control. Also, the proposed converter offers high efficiency due to the low switching losses, lower voltage stress for all passive and active components, and the lack of reverse recovery loss on diodes. It requires a small inductor, and a small nominal rating for all semiconductor devices which reduces the size, weight, and price of the proposed converter. These features make the converter a good choice for many applications such as PV, x-ray, fuel cells, etc. Moreover, the description, operating modes in DCM, design guidelines, and open and closed-loop performance are presented. Besides, a comparative analysis with recent converters is presented. The converter is examined at various power ratings for efficiency analysis and maximum efficiency of 93% is achieved.

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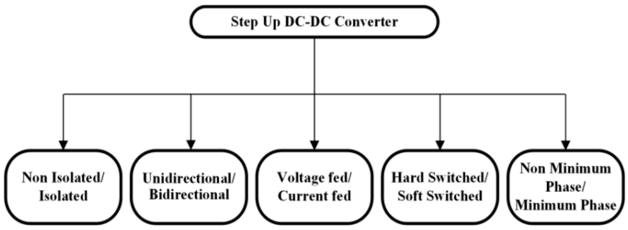
III. CLASSIFICATION OF STEP-UP DC-DC CONVERTERS

A broad classification of boost DC-DC converters is shown in Fig. 1. The following general form describes each type of converter's details together with its corresponding principal circuits in the subsections that follow.



Isolated / Non-Isolated Converters - By using a transformer to transfer power electromagnetically and minimize efficiency loss through careful design, isolated converters retain distinct grounds for input and output. In regulated devices, where isolation of feedback signals is necessary, signal routing over the isolation barrier is crucial. Electrical insulation is used to achieve isolation for AC and DC signals, respectively, with a small signal transformer or optocouplers. Isolation may be compromised if the isolation voltage is exceeded. Because they don't have transformers or physical separation, non-isolated converters are more efficient and may be made smaller and lighter. When isolation is not required, non-isolated converters have the advantages of simpler design and lower cost because they have fewer components.

Uni-Directional / Bi-Directional Converters - Energy conversion systems come in two varieties: unidirectional and bidirectional. Usually converting input energy into output energy without allowing the flow to be reversed, unidirectional converters allow energy to flow in only one way. Power system inverters and rectifiers are two examples. Conversely, bidirectional converters permit bidirectional energy flow, making it possible to transform energy sources reversibly between different forms. Due to their versatility, these converters are frequently used in regenerative braking systems in electric vehicles, battery chargers, and grid-tied energy storage systems, among other applications needing bidirectional power transfer. In order to improve efficiency and adaptability in dynamic energy conditions, bidirectional converters provide flexibility by allowing energy input from several sources and returning power to the source or grid.

Current /Voltage Converters - Power electronic converters be able to operate as either current or voltage fed, and they have different features related to energy transmission. By providing a fixed voltage to the system, the input power source controls the output current in a voltage-fed converter. In situations when keeping the voltage constant is essential, this design is often used. An output voltage is regulated by a controlled input current in a currentfed converter, on the other hand. In applications where exact current control is necessary, such induction heating, currentfed converters are useful. Based on particular application needs, one can choose between these converter types, with an emphasis on either voltage or current control for best results in a variety of electronic systems.

Hard Switched / Soft Switched Converters - In power electronics, the switching properties of transistors in converters are referred to as hard-switched and soft-switched. Transistors undergo quick transitions between the on and off states when they turn on, which causes substantial switching losses and component stress. This is typical of conventional converters. However, by adjusting the transistor's turn-off and turn-on transitions, soft-switching uses strategies to reduce switching losses. Soft-switched converters reduce stress on semiconductors and increase overall efficiency by utilizing auxiliary components or resonant circuits to achieve smoother transitions. The decision between hard and soft switching is based on the size, cost, and efficiency requirements of the particular application.

Non-Minimum Phase\Minimum Phase Converters - Signal processing and control theory distinguish between minimum phase and non-minimum phase converters. Zeros beyond the region of convergence are indicative of a nonminimum phase converter and cause delayed or oscillatory responses. Reaching stability and peak performance is difficult with non-minimum phase converters because of their intrinsic characteristics, which include delayed responses to control inputs. On the other hand, all of the zeros in minimum phase converters are located within the convergence region, which leads to more advantageous and predictable reactions. In control system design, minimum phase converters are typically chosen because of their quicker and more reliable characteristics. In order to satisfy certain application requirements, engineers strategically choose between nonminimum and minimum phase converters, taking into account variables like response speed, stability, and overall system performance.

IV. CONCLUSION

This research article presented the the High Gain DC–DC Boost Converter plays a vital role in enhancing the performance and efficiency of renewable energy systems such as solar photovoltaic panels, fuel cells, and wind energy sources. By providing a significantly higher voltage gain with reduced component stress, improved efficiency, and minimized losses, it ensures the optimal utilization of low-voltage renewable energy sources. The converter's ability to maintain a stable output voltage under varying input and load conditions makes it suitable for integration into modern power systems, including microgrids and electric vehicle applications. Furthermore, advancements in converter topology and control strategies have contributed to achieving compact size, lower cost, and higher reliability. Overall, the High Gain DC–DC Boost

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Converter serves as a key enabling technology for sustainable and efficient renewable energy conversion, supporting the global transition toward cleaner and more reliable power systems.

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