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A Study of High Gain DC-DC Boost Converters for Renewable Energy Sources

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ABSTRACT- This paper presents a comprehensive investigation into 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.

Keywords: DC-DC converter, renewable energy, high gain, voltage stress, efficiency.

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1. INTRODUCTION

Now days the world is moving towards the energy generation by using renewable energy resources. The Renewable energy resource used is mostly of Photovoltaic type. In general, the output produced from this type of resource is relatively low when compared to others. But the output produced is not enough for the all the applications. So, the voltage level is to be boosted Up. Hence a DC-DC Boost converter is used for improving the low voltage level DC to high voltage level DC. The Boosting Capability of the voltage level depends upon the topology of the converter used. The improvement in technology and semiconductors operating range made to result in design of various topologies DC-DC Boost converters for various applications. Boost converter is also called as Step-up/High gain DC-DC Converter [1].

Boost DC-DC converters trace their origins back to the improvement of PWM boost converters. With the help of temporary energy storage and subsequent release at a higher voltage level, these converters are designed to boost lower DC voltage levels to higher ones. Power switches and diodes are just a handful of the active or passive switching components that can be used in this storage process. It can also take place in magnetic field storage components (like single or coupled inductors) or electric field storage components (like capacitors). As semiconductor switches were available in the 1950s, step-up DC-DC converter development gained momentum, leading to continuous enhancements in performance. In the 1960s, the commercial availability of semiconductor switches, coupled with related manufacturing technologies, further accelerated the widespread adoption of these converters. The aerospace and telecommunication industries played a crucial role in expanding the research limitations of high gain converters, particularly in the areas where as power density, efficiency and weight were critical considerations [2][3].

The Increase in use of PWM boost DC-DC converters is propelled by their streamlined configuration, offering a significant improvement in terms of different stages of processes. Technological advancements and the expanded operating range of semiconductors have led to the development of various topologies of DC-DC boost converters for diverse applications. These converters are used in line with DC-AC converters for the use of RES to the grid [4]-[6]. Many modulation techniques are existing in the literature to controls MLIs [7]-[12]. High-gain DC-DC converters are widely used in RES, where voltage management and effective power conversion are essential. For example, in solar PV system, DC electricity produced by solar panels needs to be transformed into a voltage that can be used for grid-tying or battery charging. To effectively step up or step down the voltage to meet the needs of the load or the energy storage system, high-gain DC-DC converters can be used. And also, in off-grid or hybrid renewable energy systems, batteries are crucial for storing excess energy for later use. High-gain DC-DC converters facilitate efficient charging of batteries from various renewable sources such as solar panels or wind turbines. This paper presents a comprehensive investigation into the various topologies of DC-DC boost converters designed for optimal integration with photovoltaic (PV) systems.

2. 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.

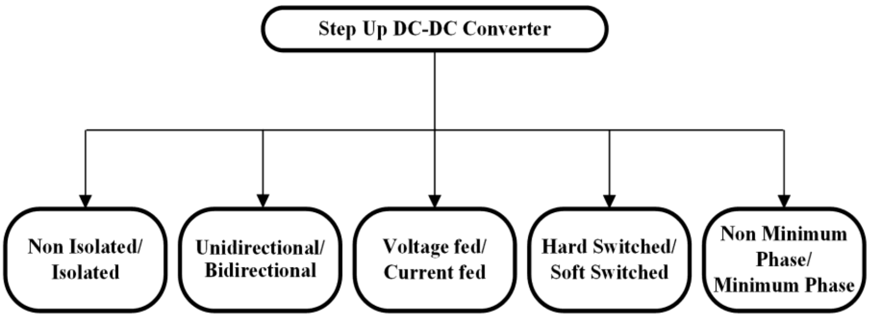

Figure 1. Classification of step-up DC–DC converters [1]

2.1 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.

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2.2 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.

2.3 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 current-fed converter, on the other hand. In applications where exact current control is necessary, such induction heating, current-fed 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.

2.4 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.

2.5 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 non-minimum 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 non-minimum and minimum phase converters, taking into account variables like response speed, stability, and overall system performance.

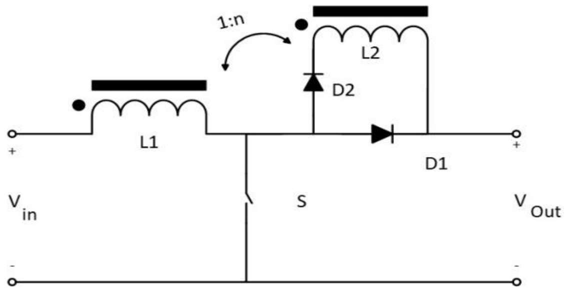

Figure 2. Transformer based converter [11]

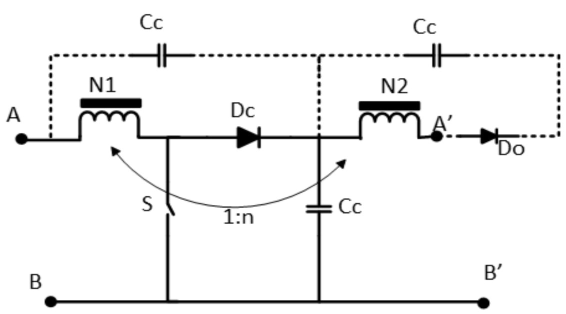

Figure 3. Basic Coupled Inductor [13]

3. MAGNETICALLY COUPLED DC-DC CONVERTER

Additionally, there are two kinds of transformer converters: magnetically coupled converters and tapped inductor/autotransformer converters. The transformer winding turns ratio gives an additional extent of design choice that may be used through the duty cycle to provide ultra boost capabilities, which is why transformer-based DC-DC converters, such as the ones shown in *fig. 2*, are usually becoming more and more widespread.

A tapped inductor, also known as an autotransformer, is an electrical component used for voltage change. It is made up of a winding with a connection point, or tap, along its length. Unlike a standard transformer, which has distinct primary and secondary windings, an autotransformer shares a portion of its winding between the input and output. When a voltage is supplied over the entire winding, the tap point determines the transformed output voltage. Magnetically coupled converters are a type of power electronic converter that uses magnetic components, such as transformers or inductors, to transfer energy between the output and input. Magnetically coupled converters are critical in such applications as power supplies, electric cars and renewable energy systems. These Magnetically coupled converters are classified into various topologies according to the design of the circuit as follows.

3.1. Basic coupled inductor converters

Figure 3 displays a basic coupled inductor-based boost converter. In this setup, the secondary winding serves as the source of voltage in the power branch, with a clamp diode (DC) and capacitor (CC) utilized to recover the leakage energy. The position of the clamp capacitor within the circuit is changed, but its clamping function remains unchanged. This versatility allows for the efficient recycling of leakage energy, either to the load directly or via the secondary winding.

High-step-up applications are best suited for coupled-inductor converters, like the isolation Sepic converters and flyback converters. While a linked inductor facilitates more voltage gain, low efficiency and voltage stress is increased due to its leaky inductance. Although it increases losses, a clamp circuit of resistor-capacitor-diode (RCD) reduces the switch stress. The coupled-inductor circuit featuring lossless leakage energy recovery, on the other hand, outperforms the RCD clamp technique in terms of efficiency. The research demonstrates the manner in which a clamp capacitor recovers previously stored leakage energy while restricting the voltage within the switch.

3.2. Switched coupled-inductor converters

There have been a number of ideas put up to address the possibility that passive clamping may not be an efficient means of completely eliminating voltage spikes in switches.

Figure 4 shows the circuit that uses active-clamp help to solve the problem. An internal combustion engine is less efficient than a fuel cell overall. Clamping circuit, coupled inductors L1

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and L2, boost diode Do, output filter capacitor Co, and main switch set M1. The clamping circuit consists of the clamping capacitor Cclamp, auxiliary switch set M2, and resonant inductor Lk + Lk1. In order to increase the converter's load range under the ZVS situation, inductor Lk is added because the amount of leakage inductor Lk1 is not very large. To achieve ZVS, switches are pushed simultaneously during a dead time. With the recommended converter, component stresses may be minimized since it can provide a high boost voltage ratio while keeping the duty cycle accurate. For the recovery of the energy, an active-clamp circuit might be utilized from the leaky inductor, effectively eliminate voltage spikes, and actualize ZVS characteristics.

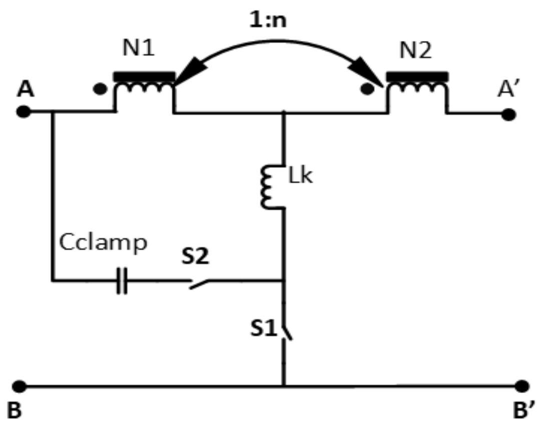

Figure 4. Switched Coupled Inductor Converter [12]

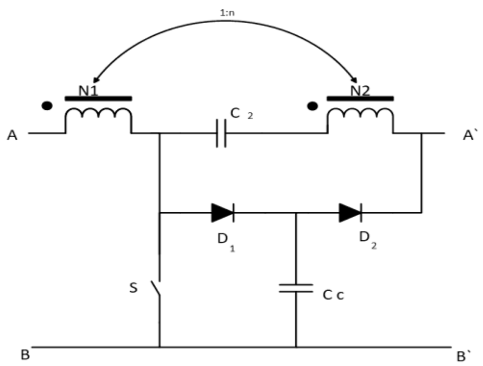

Figure 5. Coupled Inductor with Active Clamp [16]

3.3. Coupled inductor with active clamp converters

The linked inductor with an active clamp converter shown in Fig. 5 seeks to address voltage-clamping issues in high-voltage applications. Despite these attempts, significant switch voltage strains continue, which are principally impacted by constraints imposed by the auxiliary switch's turn-on time. To address these challenges, a soft-switched boost converter featuring an active single switch that allows for soft switching via pulse-width modulation (PWM) has been created. The goal of this design is to reduce the voltage and current strains that come with high-voltage applications.

Fig. 5 illustrates a combined inductor and active clamp converter that addresses problems in high-voltage applications in a comprehensive way. The design incorporates creative elements like linked inductors and an active clamp with the goal of increasing efficiency and step-up ratios. However, in order for implementation to be successful, issues with switch voltage stressors, leakage energy, and possible efficiency degradation in real-world power conversion scenarios must be carefully taken into account. The converter presents a viable option for increasing the efficiency of power conversion systems in difficult high-voltage environments as it works to overcome these obstacles.

3.4. Coupled inductor with snubber circuit converters

Moreover, by absorbing the energy of leaky inductance, a snubber circuit may be used to boost efficiency. The circuit under this assumption is shown in *fig. 6.* The configuration, which includes a power MOSFET, two diodes, two capacitors, and a linked inductor, is unique in a few ways. A charge pump capacitor (Cpump) is interestingly linked to both the secondary and primary sides of a tightly coupled inductor.

Furthermore, a charge pump diode (Dpump) and clamp diode (Dc) are used to connect the main and secondary sides of the coupled inductor to the clamp capacitor's junction point (Cc). The polarity of the connected inductor windings is shown by the standard dot symbols. This circuit creates a special blend by combining elements from the boost, flyback, and charge pump converter topologies. By utilizing the flyback feature, the transformer turns ratio can be optimized, leading to noticeably greater voltage gains than with a typical boost converter. This converter is designed primarily for applications involving photovoltaic (PV) modules and flexible input. This design's salient advantages include the efficient recovery of energy from leakage inductance, the reduction of ripple current that eliminates the requirement for electrolytic capacitors, and the minimizing of transformer and device current and voltage stresses through constant input current operation. Combined, these features, which include efficiency, dependability, and fewer component requirements, make the converter a viable option for PV module applications.

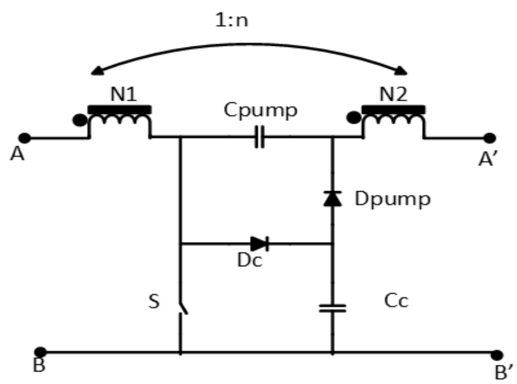

Figure 6. Coupled Inductor with Snubber Circuit [15]

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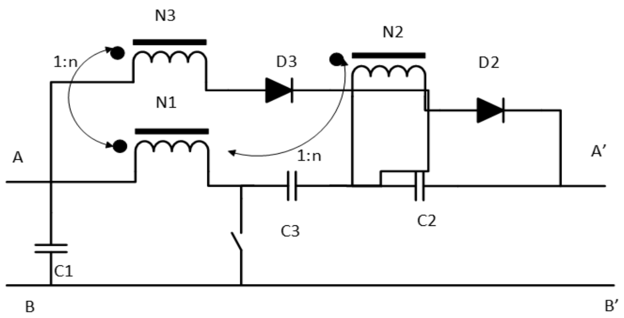

Figure 8. Three Winding Converter [14][17]

3.5. Three winding converters

When a larger voltage conversion is needed, a three-winding linked inductor may be helpful. A common use of the three-winding boosting approach is depicted in *fig. 8*. Lowering the conducting loss is achieved by reducing the switch conduction time through the use of the method outlined in with extra high boost capabilities. Additionally, the output recycles the energy that leaks in. By crossing an inductor's primary and secondary currents, one can manipulate the delay duration and solve the reverse-recovery problem.

If more voltage conversion is desired, using a connected inductor with three windings is advantageous. Fig. 8 illustrates a common application of this technique, demonstrating how it can be applied to satisfy higher voltage requirements. The method described lowers conducting losses by reducing switch conduction time when combined with increased boost capacity. The additional benefit of recycling leakage energy at the output increases total system efficiency. Another innovative way to solve the reverse-recovery problem is to use a three-winding connected inductor. The comparison of the above-mentioned topologies is shown in *Table-1*, where n is turns ratio.

Table 1. Comparison of various high gain DC-DC converters

DC-DC Topology	Voltage Gain	Voltage Stress	No. of Semiconductor Components		No. of Passive Components	
			Switch	Diode	Capacitor	Inductor
[13]	$\frac{\delta(n+1)}{1-\delta}$	$\frac{V_{out}}{\delta(n+1)}$	1	1	1	2 coupled
[18]	$\frac{n\delta+1}{1-\delta}$	$\frac{V_{out}}{n\delta+1}$	2	0	1	2 coupled 1 normal
[14]	$\frac{2+n}{1-\delta}$	$\frac{V_{out}}{2+n}$	1	2	2	2 coupled
[15]	$\frac{2+n\delta}{1-\delta}$	$\frac{V_{out}}{2+n\delta}$	1	2	2	2 coupled
[16]	$\frac{1+n+n\delta}{1-\delta}$	$\frac{V_{out}}{1+n+n\delta}$	1	3	3	2 coupled
[17]	$\frac{1+n+\delta}{1-\delta}$	$\frac{V_{out}}{1+n+\delta}$	1	2	3	3 coupled
[19]	$\frac{1+n+\delta}{1-\delta}$	$\frac{V_{out}}{1+n+\delta}$	2	3	3	3 coupled

4. CONCLUSION

High-voltage boost DC-DC converters are constantly evolving due to several important criteria, including cost, complexity, power density, energy efficiency, and dependability. This study provides information on different voltage boosting methods, facilitating speedy decision-making based on factors such as power density, weight, integration, power density, cost, dependability, and complexity. Emerging new topologies that combine several strategies keep improving the performance of applications. The future of power conversion systems is shaped by developments in wide-band-gap technologies, magnetic materials, digital control platforms, power semiconductor devices, and creative design and packaging. The maximum voltage gain that the existing DC-DC converters can reach is nearly half of the output voltage; nevertheless, it hasn't been thoroughly investigated whether modular implementation might further boost the gain and lower switch voltage stress. Moreover, fast Schottky diodes cannot be used to reduce switching losses since the total output voltage declines across the converter diode when it is in the off-state. This research gap motivates the researcher to provide the solution for the abovementioned research gap. This paper is a great resource for academia and industry since it makes it easier to understand and identify the benefits and downsides of high gain DC-DC converter topologies.

AUTHOR CONTRIBUTIONS

All authors contributed to the study, conception and design. Material preparation, data collection and analysis were performed by KSB and D. The first draft of the manuscript was written by MRRR, BTRR and BRK. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

REFERENCE

[1] Amir, Asim.; Aamir Amir.; Hang Seng Che.; Ahmad Elkhateb.; and Nasrudin Abd Rahim. Comparative analysis of high voltage gain DC-DC converter topologies for photovoltaic systems. *Renewable energy*. 2019, 136: 1147-1163.

[2] Suresh, P. V.; Arvind Mittal.; and Amit Ojha. Review on High Gain DC/DC converters for Renewable Energy Applications and their comparison with proposed converter. *International Journal of Emerging Trends in Engineering Research (IJETER)*. 2015, 3, no. 6: 471-476.

[3] Qin, Yaxiao.; Yun Yang, Sinan Li.; Ying Huang.; Siew-Chong Tan.; and Shu Yuen Hui. A high-efficiency DC/DC converter for high-voltage-gain, high-current applications. *IEEE Journal of Emerging and Selected Topics in Power Electronics*. 2019, 8, no. 3: 2812-2823.

[4] Hemanth Kumar, B., and Makarand M. Lokhande. "Investigation of switching sequences on a generalized SVPWM algorithm for multilevel inverters." Journal of Circuits, Systems and Computers. 2019, 28, no. 02: 1950036.

[5] B. H. Kumar.; and M. M. Lokhande, An enhanced space vector PWM for nine-level inverter employing single voltage source. IEEE Transportation Electrification Conference (ITEC-India). 2017, 1-6 doi: 10.1109/ITEC-India.2017.8333711.

[6] Kumar, Busireddy Hemanth.; and Vivekanandan Subburaj. Integration of RES with MPPT by SVPWM Scheme. *Intelligent Renewable Energy Systems.* 2022; 157-178. https://doi.org/10.1002/9781119786306.ch6

[7] Hemanth Kumar, B., S. Prabhu, K. Janardhan, V. Arun, and S. Vivekanandan. "A switched capacitor-based multilevel boost inverter for photovoltaic applications." Journal of Circuits, Systems and Computers. 2023, 32, no. 04 : 2350057.

[8] Kasinath Jena, Dhananjay Kumar, B. Hemanth Kumar, K. Janardhan, Arvind R. Singh, Raj Naidoo, Ramesh C. Bansal, "A Single DC Source Generalized Switched Capacitors Multilevel Inverter with Minimal Component Count", International Transactions on Electrical Energy Systems, vol. 2023, Article ID 3945160, 12 pages, 2023. https://doi.org/10.1155/2023/3945160

[9] B. Hemanth Kumar, Makarand M. Lokhande, Raghavendra Reddy Karasani and Vijay B. Borghate. "A Modified Space Vector PWM Approach for Nine-Level Cascaded H-Bridge Inverter," Arabian Journal for Science and Engineering (AJSE), vol.44, no.3, pp 2131–2149, March 2019.

[10] Saahithi, S., Hemanth Kumar, Jyotheeswara Reddy, Ritesh Dash, and Vivekanandan Subburaj. "Dual-Topology Cross-Coupled Configuration of Switched Capacitor Converter for Wide Range of Application." In 2022 IEEE 21st Mediterranean Electrotechnical Conference (MELECON). 2022, pp. 796-800.

[11] Kumar, Busireddy Hemanth, Makarand Mohankumar Lokhande, Karasani Raghavendra Reddy, and Vijay Bhanuji Borghate. "An improved space vector pulse width modulation for nine-level asymmetric cascaded H-bridge three-phase inverter." Arabian Journal for Science and Engineering. 2019, 44: 2453-2465.

[12] Kumar, B. Hemanth, and Makarand M. Lokhande. "Analysis of PWM techniques on multilevel cascaded H-Bridge three phase inverter." In 2017 Recent Developments in Control, Automation & Power Engineering (RDCAPE). 2017, pp. 465-470.

[13] Zhao, Qun, and Fred C. Lee. "High-efficiency, high step-up DC-DC converters." IEEE Transactions on Power Electronics. 2003, 18, no. 1: 65-73.

[14] Wai, Rong-Jong, and Rou-Yong Duan. "High step-up converter with coupled-inductor." IEEE transactions on power electronics. 2005, 20, no. 5: 1025-1035.

[15] Yu, Wensong, Chris Hutchens, Jih-Sheng Lai, Jianhui Zhang, Gianpaolo Lisi, Ali Djabbari, Greg Smith, and Tim Hegarty. "High efficiency converter with charge pump and coupled inductor for wide input photovoltaic AC module applications." In 2009 IEEE Energy Conversion Congress and Exposition. 2009, pp. 3895-3900.

[16] Hsieh, Yi-Ping, Jiann-Fuh Chen, Tsorng-Juu Liang, and Lung-Sheng Yang. "Novel high step-up DC–DC converter for distributed generation system." IEEE Transactions on Industrial Electronics. 2011, 60, no. 4: 1473-1482.

[17] Wai, Rong-Jong, Chung-You Lin, Rou-Yong Duan, and Yung-Ruei Chang. "High-efficiency DC-DC converter with high voltage gain and reduced switch stress." IEEE Transactions on Industrial Electronics. 2007, 54, no. 1: 354-364.

[18] Wu, Tsai-Fu, Yu-Sheng Lai, Jin-Chyuan Hung, and Yaow-Ming Chen. "Boost converter with coupled inductors and buck–boost type of active clamp." IEEE Transactions on Industrial Electronics. 2008, 55, no. 1: 154-162.

[19] Tang, Yu, Dongjin Fu, Jiarong Kan, and Ting Wang. "Dual switches DC/DC converter with three-winding-coupled inductor and charge pump." IEEE Transactions on Power Electronics. 2015, 31, no. 1: 461-469.