A Two-Input Nonisolated High Step-Up DC–DC Converter with Switched-Capacitors Technique

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***Abstract*— A high step-up two-input DC-DC converter is presented in this paper. The soft switching condition is provided for the switches in turn on instant, so the converter efficiency is high. Due to the fact that only the capacitor is used to increase the voltage gain and there are no coupled inductors in the converter, the input current of the converter is continuous. The technique used to increase gain can be used with more stages to achieve higher voltage gain. The converter can also be used as a single input interleaved instead of two inputs, which in this case the input current ripple is reduced. The voltage stress on the switches is lower than the output voltage, so lower voltage switches can be used, which reduces the converter cost. The proposed converter is completely analyzed and in order to prove the theoretical results, an experimental prototype is implemented at 500 watts. The results of the experimental test at full load show an efficiency of about 95.5%.**

Keywords*— DC-DC converter; soft switching; high step-up; zero current switching, two-input.

I. INTRODUCTION

Recently, high step-up converters have become very important in industry application [1]. In applications such as photovoltaic systems [2], [3] and fuel cell systems [4]-[6] which the voltage level is low, this voltage should be increased. The voltage of these systems is at a low level and it is necessary to increase this voltage a lot to reach an acceptable level for electricity production. Therefore, high step-up converters are needed [7],[8]. One way to increase the voltage gain is to use isolated converters, which can achieve high output voltages with high transformer conversion ratio [9]. But the isolated type has a low level of efficiency due to magnetic power transfer [10]. If there is no need for isolation between the input and output, it is better to use the non-isolated type [11]. In the non-isolated type, methods are needed to increase the voltage gain. For this purpose, coupled inductors [12], switch capacitors [13], voltage lift technique [14] or a combination of these methods [15] have been introduced. Also, in order to reduce switching losses and increase efficiency, soft switching techniques have been introduced. Techniques such as zero current switching (ZCS) [16], zero voltage switching (ZVS) [17], and zero voltage zero current switching (ZVZCS) [18]. In these techniques, sudden changes in voltage and current on the switch are eliminated and overlap of voltage and current is minimized. Therefore, the switching losses decreases and efficiency increases. Also, when the spurt in voltage and current is illuminated, the high frequency noises is decreased and electromagnetic interferences (EMI) improves [19].

One of the important applications of high step-up converters is in energy production systems due to their high voltage gain. In systems such as photovoltaic, fuel cell and etc. But in a system like photovoltaic, the important problem is not working when there is not sun energy. So that when the solar cells do not work, the energy production system does not work. Therefore, it is necessary to combine the systems so when one of them is not working, the other can supply energy. Therefore, at least the combination of two models of these systems is required. To use this combination in the form of a general system, converters are upgraded to two or more inputs [20]. For this reason, two-input, three-input and more converters have been considered in recent years. Figure 1 shows the general outline of a two-input energy production system, which shows the combination of two solar systems and fuel cells for energy production. As it is clear from this figure, to connect two energy production systems such as PV and fuel cell, a two-input step-up converter is needed. If the number of inputs increases, the converter is also upgraded.

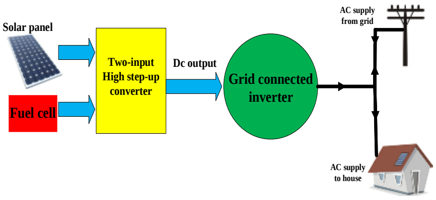


Fig. 1. The structure of energy production through renewable energy sources

Due to the importance of these converters, new converters have been presented for this purpose in recent years. In [21] A new high step-up converter that is used in an energy storage system is introduced. This converter is interleaved converter so the input current ripple is minimum, but this converter has four switches with complex control. In the work by [22] a multi-port high step-up converter is proposed. This converter does not have any coupled inductors and has a low volume and price. Also, the introduced converter has high voltage gain and due to the fact that the coupled inductor is not used, it has a continuous input current. Although the converter has the mentioned advantages, it has a large number of switches with different statuses and controls, which make the analysis and control of such a converter very complicated. Also, soft switching condition are not provided in this converter, so the efficiency level of this converter is low. A converter similar to this converter is given in [23], which is designed and presented by a large number of switches, diodes and capacitors. In this converter, there is no coupled inductors and the input current are continuous. The converter has a simple structure, but the use of many switches creates complexity in the converter, especially in terms of switching control. Also, this converter does not have the soft switching condition in any of the switch, so the level of efficiency is relatively low. The converter introduced in [24] is a converter with full soft switching, which also has a high voltage gain. In this converter, high voltage gain has been obtained from the combination of coupled inductors and capacitors, and due to the complete soft

15th Power Electronics & Drives: Systems and Technologies Conference, Tehran, Iran, 30 Jan.-1 Feb. 2024

switching in this converter, the efficiency is high. But the noteworthy point in this converter is the use of high number switches and coupled inductors, which is increased the volume of the converter. Also, the use of coupled inductors makes the input current as step, which is not suitable for applications such as photovoltaic due to the sudden current jump at the input. A high-gain two-input isolated converter is presented in [25], which is designed with only two switches to achieve high gain and soft switching condition. This converter also has isolation between inputs and outputs, but in order to separate and use the transformer, the efficiency level of such converters is low. Also, the common line on the input side of this converter is separate from each other, and the switches of this converter do not have a command in relation to a common line and are floating, so the control circuit design for floating switches is needed. The non-use of coupled inductors in the converter introduced in [26] has led to continuous input current, and such converters are very suitable for applications such as photovoltaics and fuel cells at the input. This converter has high gain and good efficiency, but the structure of the converter is such that the common line between the input and output is separated by diodes and such separation is not suitable in a non-isolated structure.

This paper presents a new high step-up converter that provides soft switching condition for the switches in turning on instant. In order to reach the high voltage gain, capacitors and diodes have been used and the coupled inductors is not used, therefore there is continuity of current at the input. The converter is fully introduced and analyzed in part II. In section III, the design of the elements is explained. The experimental results of the proposed converter in order to prove the theoretical analysis are given in Section IV. A comparison between the proposed converter and similar converters of recent years is given in section V, and finally, in section VI, the conclusion of this article is presented.

II. The Proposed Converter Structure and Operation

The proposed converter is shown in Figure 2. As it is known, by the capacitors and diodes, the condition for increasing the voltage gain have been provided. In order to create soft switching condition, two auxiliary inductors L_{a1} and L_{a2} are placed in the circuit, and for the voltage clamp of the switch, a clamp circuit is placed for both switches. The key waveforms of the converter are given in Figure 3. As it is clear, the converter has eight operating modes in one switching cycle, which will be explained.

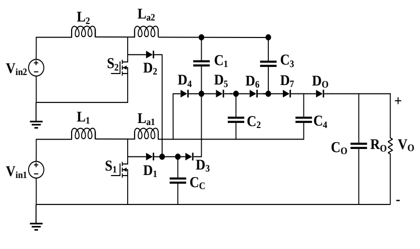


Fig. 2. the proposed converter

Mode 1 (t_0-t_1): This mode starts with S_2 turning on at t_0. Due to the presence of the auxiliary inductor L_{a2}, the switch current does not rise suddenly and increases with a slope. The slope of current increase in this case is shown in equation (1). When the current of the switch reaches the current of L_2, this mode is completed.

$$\alpha_1 = \frac{V_{C3} + V_O}{L_{a2}} \quad (1)$$

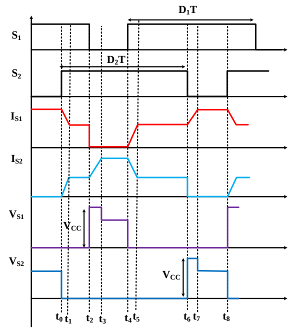


Fig. 3. The key waveform of the proposed converter

Mode 2 (t_1-t_2): When the current reaches the current of L_2, the current of the switch is fixed and this state continues until S_1 is turned off. In this mode, due to both switches are on, the current of both switches is equal to the current of the corresponding inductor and the input inductors are charged.

Mode 3 (t_2-t_3): S_1 is turned off in this mode, since the current of S_1 is cut off, this current falls on S_2, but because of the auxiliary inductor, the current does not increase suddenly on the switch and increases with the slope to the main current. Also, the voltage on the switch is clamped on the C_C voltage due to D_1 turning on, and the energy of the auxiliary inductor is discharged in this capacitor. The slope of the switch current in this mode is defined in equation (2).

$$\alpha_2 = \frac{V_{C1} + V_{cc}}{L_{a2} + L_{a1}} \quad (2)$$

Mode 4 (t_3-t_4): At the beginning of this mode the current reaches its final value, due to the fact that the diode D_1 turns off, the voltage on the switch drops and reaches the value of V_O-V_{C4}. This mode continues until S_1 is turned on again.

Mode 5 (t_4-t_5): When S_1 is turned on, the same condition as mode 1 occurs for this switch. The current of the switch increases due to the presence of an auxiliary inductor with a slope, which provides switching condition under zero current to turn on the switch. Also, in this case, the slope of current increase is shown in equation (3).

$$\alpha_3 = \frac{V_O - V_{c4}}{L_{a1}} \quad (3)$$

Mode 6 (t_5-t_6): This mode starts when the current of the switch reaches the current of the main inductor, the current is fixed and considering that both switches are on again, the input inductors are charged.

Mode 7 (t_6-t_7): With turning off S_2, due to the presence of the clamp circuit, D_2 turns on and the energy of the auxiliary inductor is discharged in C_C. In this mode, the voltage on the switch is equal to V_{CC}. During this mode, the current of S_1 is increased until the total current of each branch is placed on S_1.

mode 8 (t_7-t_8): In this mode, I_{S2} reaches the current of the main inductor and the auxiliary inductor energy is completely discharged, D_2 turns off and the switch voltage drops. Also, the current of the switch is fixed and is equal to the sum of the currents of both branches. This mode ends when S_2 is turned on again and returns to mode 1.

The equivalent circuits of the eight operating modes of the proposed converter are shown in Figure 4.

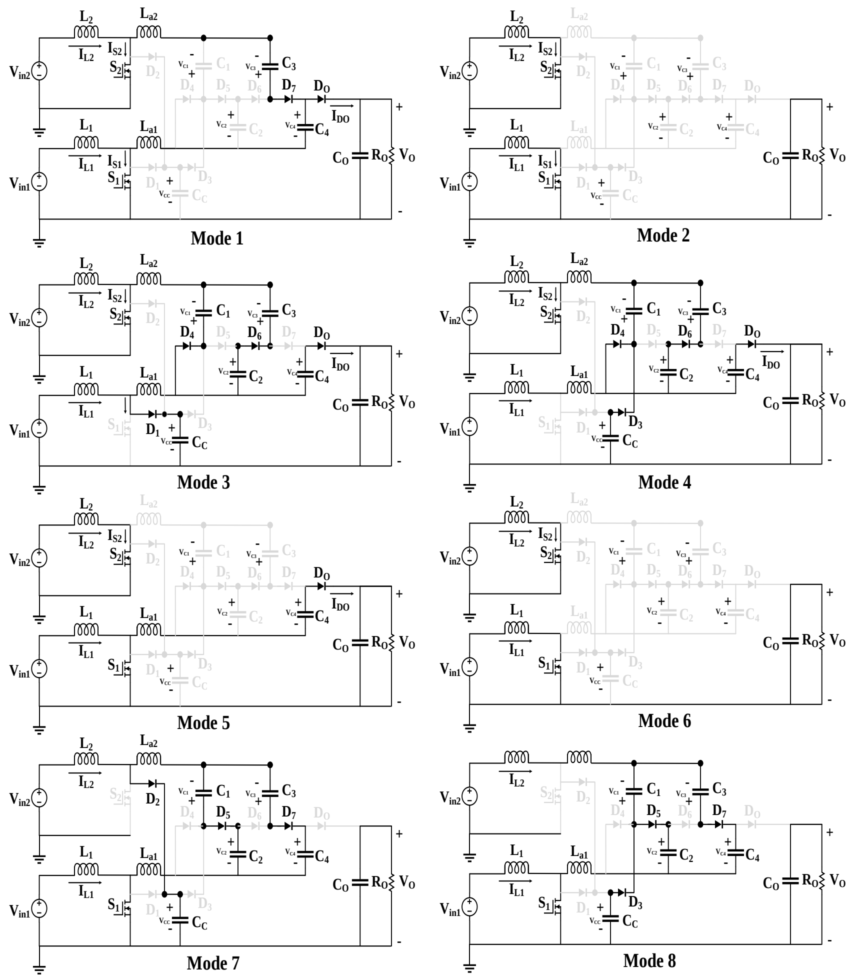


Fig. 4. The equivalent circuits of the proposed converter for eight modes

III. Design procedure of the proposed converter

A. Design of main elements

The main inductors and the output capacitor of the converter are calculated as follows in the same way as the calculation of the main elements of a conventional converter. Equation (6) is written based on the charging time of the output capacitor, which is written in time (1-D), which is the time when the switches are off.

$$L_1 = \frac{V_{in1} D_1}{\Delta I_{L1} f_{SW}} \tag{4}$$

$$L_2 = \frac{V_{in2} D_2}{\Delta I_{L2} f_{SW}} \tag{5}$$

$$C_O = \frac{I_O (1 - D)}{\Delta V_{CO} f_{SW}} \tag{6}$$

B. Design of Auxiliary inductors (L_{a1}, L_{a2})

The placed auxiliary inductors are known as snubber inductors, hence the snubber inductor design relationship is used to calculate these inductors.

$$L_{a1} < L_{min} = \frac{V_{S1} t_r}{I_{S1}} = \frac{(V_{CC}) t_{r1}}{I_{L1}} \tag{7}$$

$$L_{a2} < L_{min} = \frac{V_{S2} t_r}{I_{S2}} = \frac{(V_{CC}) t_{r2}}{I_{L2}} \tag{8}$$

So that V_{S1} and V_{S2} are the voltages on the switches and t_r is the rise time of the switch current, which is one of the structural characteristics of the switches and is available in their datasheet. Also, the current of the switch at the final moment of current increase is obtained by placing all the stated values of the design relationships of the auxiliary inductors. According to the relation (7) or (8) and in order to get the values of L_{a1} and L_{a2} more easily, the curves drawn in Figure 5 can be used as auxiliary curves. According to the given relationships, it is clear that these values are related to the current of the input inductors and therefore to the converter power, and the curves are drawn accordingly. Also, in the voltages of the clamp capacitor, which is the same as the voltage level of the switches, different curves are obtained as shown in the figure. Also, in this figure, according to the used switch model, t_r is considered to be 60 nanoseconds based on the characteristic of the switch. At the same time, the above relationships can be drawn based on the input voltage, so that the effect of changes in the input voltage on the amount of auxiliary inductors can be determined. Therefore, the curves of Figure 6 have been drawn based on the effect of changes in the input voltage on the value of these inductors in different working powers of the converter.

The placed clamp capacitor has a voltage according to equation (9).

$$V_{CC}=\frac{V_{in}}{1\text{-}D} \tag{9}$$

So that D is the switching duty factor, if it is the same in both switches, if the duty factor is different, the capacitor gets voltage in the larger duty factor, which leads to a higher voltage.

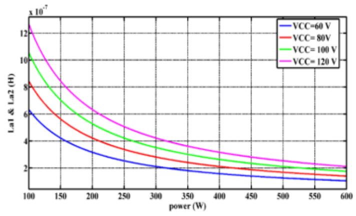


Fig. 5. L_{a1} and L_{a2} values according to power and different V_{CC} (t_r is equal to 60 nanoseconds)

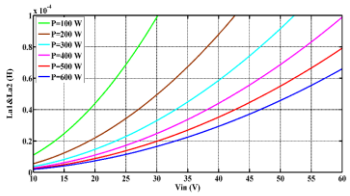


Fig. 6. The values of L_{a1} and L_{a2} according to the input voltage and different powers (t_r is equal to 60 nanoseconds)

C. *Voltage gain*

According to the structure of the converter, the diode capacitor stages have been placed to increase the voltage gain, in this design four stages have been placed, which can be increased or decreased and different gains can be obtained. The number of stages is represented by N and the voltage gain of each capacitor is calculated.

$$V_{C1}=\frac{V_{in1}}{1\text{-}D_1} \tag{10}$$

$$V_{C2}=\frac{V_{in1}}{1\text{-}D_1}+\frac{V_{in2}}{1\text{-}D_2} \tag{11}$$

$$V_{C3}=\frac{2V_{in1}}{1\text{-}D_1}+\frac{V_{in2}}{1\text{-}D_2} \tag{12}$$

$$V_{C4}=\frac{2V_{in1}}{1\text{-}D_1}+\frac{2V_{in2}}{1\text{-}D_2} \tag{13}$$

D_1 is the duty cycle of S_1 and D_2 is the duty cycle of S_2.

The output voltage can be calculated based on equation (14).

$$V_O=V_{C4}+\frac{V_{in1}}{1\text{-}D_1}=\frac{3V_{in1}}{1\text{-}D_1}+\frac{2V_{in2}}{1\text{-}D_2} \tag{14}$$

If the gain relation is generally written based on capacitor classes where N is entered, the relation is defined as relation (15) for N with an even number and relation (16) for N with an odd number.

$$V_O=V_{CN}+\frac{V_{in1}}{1\text{-}D_1}=\left(\frac{N+2}{2}\right)\frac{V_{in1}}{1\text{-}D_1}+\left(\frac{N}{2}\right)\frac{2V_{in2}}{1\text{-}D_2} \tag{15}$$

$$V_O=V_{CN}+\frac{V_{in2}}{1\text{-}D_2}=\left(\frac{N+1}{2}\right)\frac{V_{in1}}{1\text{-}D_1}+\left(\frac{N+1}{2}\right)\frac{2V_{in2}}{1\text{-}D_2} \tag{16}$$

If the duty cycle of both switches is considered the same and equal to D and the inputs are the same, the voltage gain relationship in this case can be calculated according to equation (17).

$$V_O=(N+1)\frac{V_{in}}{1\text{-}D} \tag{17}$$

Which N is number of capacitor branches, which in this study equal to 4. The curves of Figure 6 show the changes in the voltage gain values by changing the duty cycle and the number of capacitor branches of the converter. Considering that the converter with this structure always works at a duty cycle higher than 0.5, hence the curves have been drawn in the duty cycle within the stated range. As it is clear in the figure, by increasing the number of branches, high voltage gains can be achieved. But increasing the number of branches means increasing the number of elements, which is not economical, also increasing the number of diodes in the converter increases conduction losses and decreases efficiency.

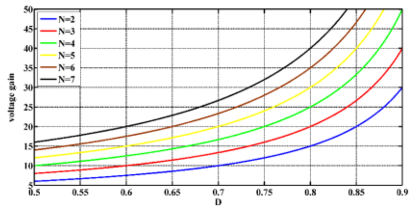


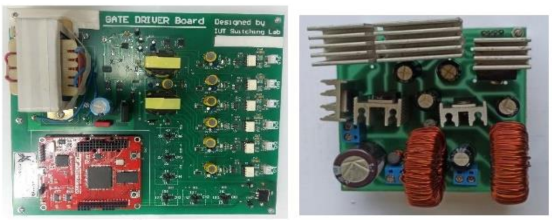
Fig. 7. Voltage gain according to the duty cycle and the number of different capacitor branches

D. *Voltage stress on the switches*

According to the structure of the converter and the placement of the voltage clamp circuit for the switch off time, the voltage of the switches is fixed on the voltage of the clamp capacitor (C_C). Therefore, the voltage stress of the switches is equal to the value of V_{CC}. According to equation (9), the value of this voltage is equal to Vin/1-D that is the low voltage level compared to the output voltage of the converter. In this sample design with 24V input at 0.7 duty cycle, the amount of this stress is equal to 80V.

IV. Experimental Results

According to specification in table 1, the proposed converter is implemented and tested, which photograph of the proposed converter is shown in Fig 8. The experimental results of the semiconductor elements are shown in Fig 9, which shows the voltage and current of the switches and current of clamp diodes. As can be seen from this figure, the theoretical analysis is confirmed and ZCS condition is provided for both switches when these switches are turned on. In turning on the switches, the current is increased with slope, which show ZCS condition is established. The diodes due to decreases with slope turns off under ZCS condition, which this condition is clear from the experimental figure. Therefore, the reverse recovery problem for these diodes is solved.



a b

Fig. 8. the prototype of the proposed converter (b) and controller circuit (a)

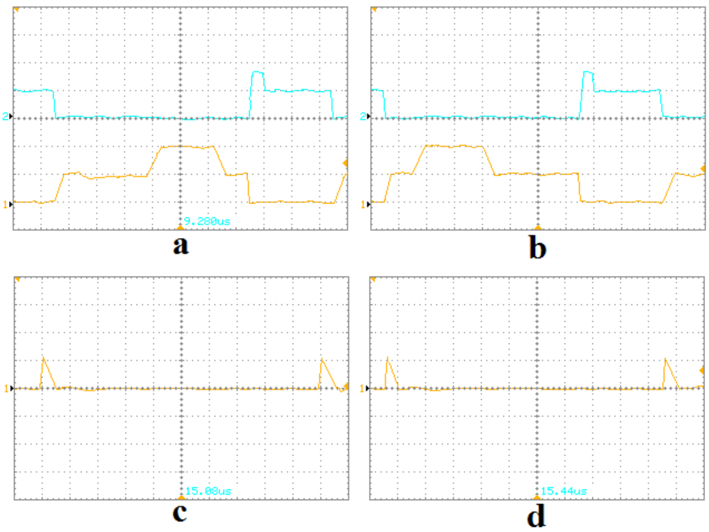


Fig. 9. The experimental of the proposed converter

a) Voltage (up-blue) and current (down-orange) of S_1 (voltage scale is 50 volts/div, current scale is 10 A/div and time scale is 1 µsec/div)

b) Voltage (up-blue) and current (down-orange) of S_2 (voltage scale is 50 volts/div, current scale is 10 A/div and time scale is 1 µsec/div)

c) Current D_1 (current scale is 5 A/div and time scale is 1 µsec/div)

d) Current of D_2 (current scale is 5 A/div and time scale is 1 µsec/div)

Table I. Specification of the proposed converter

component	symbol	Value/type
switches	S_1 and S_2	IRFP260NPbF
Diodes	D_1-D_7 & D_O	MUR860
Output Capacitor	C_O	100µF-450V
Clamp capacitor	C_C	10µF-100V
Leveling capacitors	C_1-C_4	10µF-200V
Auxiliary inductors	L_{a1}&L_{a2}	15µH
Main inductors	L_1&L_2	1mH
Output power	P_O	500w
Switching frequency	f_{SW}	100kHZ
Output voltage	V_O	400V
Input voltages	V_{in1}&V_{in2}	24V

V. Comparison of the Proposed Converter with Other Converters

A. *Comparison of the proposed converter with the basic converter*

In terms of efficiency, the proposed converter has been compared with the hard switching base converter, and the results of this comparison are shown graphically in Figure 10. As it is clear in this figure, according to the creation of soft switching conditions, the efficiency of the proposed converter has increased compared to the converter without soft switching. Also, in this form, the efficiency has been a little high at low powers, which is a little higher efficiency has been obtained due to the lower conductive losses of the elements. But since the proposed converter is designed and used in 500 W power, the efficiency is important in this power, but it is clear that the converter has high efficiency in lower powers as well.

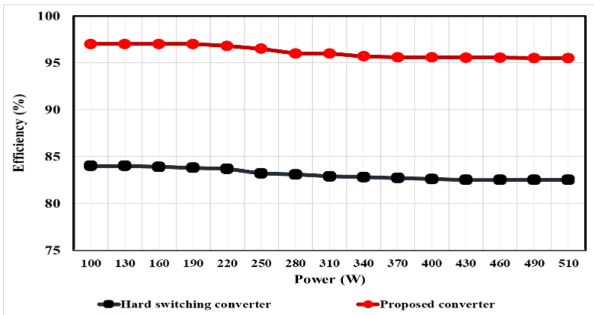


Fig. 10. The efficiency of the proposed converter with compare to conventional ones

B. *Comparison of the proposed converter with the converters provided in recent years*

The proposed converter has been compared with five new converters presented in recent years in terms of the important characteristics of the converters, and the results are shown in Table II. According to the results specified in Table II, although the converters of references [22] and [23] are very good high step-up converters, they do not have soft switching conditions, hence the efficiency of these two converters is low. Also, due to the lack of soft switching that leads to sudden jumps and rapid changes in the voltage and current of switches, the noise of such converters is high and they are limited in noise-sensitive applications. The converter introduced in [21] has a small number of switches and diodes, but the efficiency of this converter is lower than the proposed converter. Converters [25] and [26] are two-input converters that have good efficiency and voltage gain, but converter [25] has a high voltage stress on the switch. The converter [26] has more elements and the volume of the converter is high, and the voltage gain of this converter is lower than the proposed converter. The converter introduced in [24] has a very good efficiency, and the voltage stress on the converter switch is low. But this converter has a low gain compared to the proposed converter and coupled inductors are used in the converter, which increases the volume of the converter and the input current of the converter is pulsed.

The proposed converter has a small volume due to not using a coupled inductor, and at the moment the switch is turned on, soft switching condition is provided for the switch current and the current increases slowly. Also, in the proposed converter, the voltage gain is dependent on the number of capacitor branches, which by adding the branches very high voltage gain can also be achieved. In the proposed converter, by placing a voltage clamp circuit, the voltage is clamped at a lower level than the output voltage at the moment of shutdown, which lowers the voltage stress on the switch and enables the use of switches with lower voltage and lower price. Also, compared to most other converters, the proposed converter does not have an additional switch and works with the number of basic switches for two inputs, which leads to the simplicity of the control circuit design, because the more the number of switches increases, the more command pulses need to be generated. It complicates the control circuit.

Table II. Comparison between the proposed converter with six soft switching converters

Parameters / **Converters**	**Number of switches**	**Number of diodes**	**Soft switching condition**	**Voltage gain**	**Voltage stress on the switch**
[21]	4	4	ZVS	$\frac{2(2n+1)}{1-D}$	$\frac{V_{out}}{2(2n+1)}$
[22]	6	2	NO	$\frac{(3-d_1)}{(1-d_1)^2}$	$\frac{(2-d_1)}{(1-d_1)^2}V_1$
[23]	5	5	NO	$\frac{(5-2d)}{19(1-d)}$	$\frac{V_O}{3+d}$
[24]	5	5	ZVS	$\frac{1+nD}{1-D}$	$\frac{V_{in}}{1-D}$
[25]	2	6	ZCS	$\frac{n_1+n_2}{1-2D}$	$\frac{V_{in2}+V_{in2}}{1-D_1-D_2}$
[26]	2	12	ZVS	$n\left(\frac{V_{in1}}{1-D_1}+\frac{V_{in2}}{1-D_2}\right)$	$\frac{V_{in}}{1-D}$
Proposed converter	2	8	ZCS	$\frac{(N+1)}{1-D}$	$\frac{V_{in}}{1-D}$

VI. Conclusion

In this paper, a new high step-up converter with soft switching under zero current is presented. The proposed converter works on the basis of capacitor and diode and has no coupled inductors, which means that the volume of the converter is small. Also, the proposed converter has a continuous input current. The provided converter is designed as two inputs, which is suitable for use in new energy production systems such as solar and fuel systems that simultaneously receive inputs and create the required output for electricity generation. The proposed converter is fully analyzed and designed, and the experimental test along with its results proved the design and analysis of the converter. The experimental performed on the converter is performed at a power of 500 watts, which obtained a suitable efficiency of the converter at full load.

References

[1] M. Dezhbord, M. Babalou, S. Mohamadian and C. Cecati, " Low-Voltage Stress CI-based Quadratic Boost Converter for Distributed Energy Resources", *in 2023 14th Power Electronics, Drive Systems, and Technologies Conference (PEDSTC).* IEEE, 2023.

[2] A. Alizadeh Asl, R. Alizadeh Asl and S. H. Hosseini, " A New Non-Isolated High Step-Up DC-DC Converter Suitable for Renewable Energy Applications*", in 2023 14th Power Electronics, Drive Systems, and Technologies Conference (PEDSTC)*. IEEE, 2023.

[3] H. Arvani, A. Sajjadi, M. KalamiAlhashem and M. Hamzeh, " A Quadratic High Gain DC-DC Converter with Continuous Input Current for PV Applications", *in 2023 14th Power Electronics, Drive Systems, and Technologies Conference (PEDSTC).* IEEE, 2023.

[4] H. Soltani Gohari and K. Abbaszadeh, " Improving Performance and Efficiency of a Fuel-cell Hybrid EV Using New Three-Port DC-DC Converter and Optimized Energy Management Strategy", *in 2020 11th Power Electronics, Drive Systems, and Technologies Conference (PEDSTC)*. IEEE, 2023.

[5] K. R. Sree and A. K. Rathore, " Impulse Commutated High-Frequency Soft-Switching Modular Current-Fed Three-Phase DC/DC Converter for Fuel Cell Applications," *IEEE Transactions on Industrial Electronics*, vol. 64, no. 8, pp. 6618-6627, 2017

[6] V. F. Pires, A. Cordeiro, D. Foito and J. F. Silva, "High Step-Up DC–DC Converter for Fuel Cell Vehicles Based on Merged Quadratic Boost–Ćuk," *IEEE Transactions on Vehicular Technology*, vol. 68, no. 8, pp. 7521–7530, 2019

[7] N. Salehi, S. M. M. Mirtalaei and S. H. Mirenayat, "A high step-up DC–DC soft-switched converter using coupled inductor and switched capacitor," *International Journal of Electronics Letters*, vol. 6, no. 3, pp. 260-271., 2018.

[8] M. Hajilou ,Sh. Gholami nad Hosein Farzanehfard, " Ultra-high Step-up Soft Switched Quadratic DC-DC Converter with Continuous Input Current and Low Switch Voltage Stress", *in 2023 14th Power Electronics, Drive Systems, and Technologies Conference (PEDSTC).* IEEE, 2023.

[9] K. Zaoskoufis and E. C. Tatakis, "Isolated ZVS-ZCS DC–DC High Step-Up Converter With Low-Ripple Input Current," *IEEE Journal of Emerging and Selected Topics in Industrial Electronics*, vol. 2, no. 4, pp. 464–480, 2021.

[10] P. Jia, Z. Su, T. Shao and Y. Mei, "An Isolated High Step-Up Converter Based on the Active Secondary-Side Quasi-Resonant Loops," *IEEE Transactions on Power Electronics*, vol. 37, no. 1, pp. 659-673, 2022.

[11] T. Nouri, M. Shaneh, M. Benbouzid and N. Vosoughi Kurdkandi, "An Interleaved ZVS High Step-Up Converter for Renewable Energy Systems Applications," *IEEE Transactions on Industrial Electronics*, vol. 69, no. 5, pp. 4786-4800, 2022.

[12] S. B. Santra, D. Chatterjee, Y. P. Siwakoti and F. Blaabjerg, “Generalized Switch Current Stress Reduction Technique for Coupled-Inductor-Based Single-Switch High Step-Up Boost Converter,” *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 9, no. 2, pp. 1863-1875, 2021.

[13] H. Lei, R. Hao, X. You and F. Li, “Nonisolated High Step-Up Soft-Switching DC–DC Converter With Interleaving and Dickson Switched-Capacitor Techniques,” *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 8, no. 3, pp. 2007-2021, 2020.

[14] A. Rajabi, A. Rajaei, V. Moradzadeh Tehrani, P. Dehghanian, J. M. Guerrero and B. Khan, “A Non-Isolated High Step-Up DC-DC Converter Using Voltage Lift Technique: Analysis, Design, and Implementation,” *IEEE Access*, vol. 10, pp. 6338-6347, 2022.

[15] X. Liu, X. Zhang, X. Hu, H. Chen, L. Chen and Y. Zhang, “Interleaved high step-up converter with coupled inductor and voltage multiplier for renewable energy system,” *CPSS Transactions on Power Electronics and Applications*, vol. 4, no. 4, pp. 299–309, 2019.

[16] H. Bahrami, H. Allahyari and E. Adib, “A Self-Driven Synchronous Rectification ZCS PWM Two-Switch Forward Converter With Minimum Number of Components,” *IEEE Transactions on Industrial Electronics*, vol. 69, no. 12, pp. 12842-12850, 2022.

[17] J. Chen, C. Liu, H. Liu and G. Li, “Zero-Voltage Switching Full-Bridge Converter With Reduced Filter Requirement and Wide ZVS Range for Variable Output Application,” *IEEE Transactions on Industrial Electronics*, vol. 69, no. 7, pp. 6805–6816, 2022.

[18] Y. Shi, L. Feng, Q. Li and J. Kang, “High Power ZVZCS Phase Shift Full Bridge DC–DC Converter With High Current Reset Ability and No Extra Electrical Stress,” *IEEE Transactions on Industrial Electronics*, vol. 69, no. 12, pp. 12688-12697, 2022.

[19] H. Y. Huang, H. M. Villaruz and N. M. Mapula, “High-Efficiency Low-EMI Buck Converter Using Multistep PWL and PVT Insensitive Oscillator,” *IEEE Transactions on Power Electronics*, vol. 37, no. 8, pp. 9325-9332, 2022.

[20] P. Chavoshipour Heris, Z. Saadatizadeh and E. Babaei , “A New Two Input-Single Output High Voltage Gain Converter With Ripple-Free Input Currents and Reduced Voltage on Semiconductors,” *IEEE Transactions on Power Electronics*, vol. 34, no. 8, pp. 7693-7702, 2019.

[21] H. Moradisizkoohi, N. Elsayad and O. A. Mohammed, “An Integrated Interleaved Ultrahigh Step-Up DC–DC Converter Using Dual Cross-Coupled Inductors With Built-In Input Current Balancing for Electric Vehicles,” *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 8, no. 1, pp. 7693-7702, 2020.

[22] K. Varesi, S. H. Hosseini, M. Sabahi, E. Babaei, S. Saeidabadi and N. Vosoughi, “Design and Analysis of a Developed Multiport High Step-Up DC–DC Converter With Reduced Device Count and Normalized Peak Inverse Voltage on the Switches/Diodes,” *IEEE Transactions on Power Electronics*, vol. 34, no. 6, pp. 5464-5475, 2019.

[23] T. Jalilzadeh, N. Rostami, E. Babaei and S. H. Hosseini, “Multiport DC–DC Converter With Step-Up Capability and Reduced Voltage Stress on Switches/Diodes,” *IEEE Transactions on Power Electronics*, vol. 35, no. 11, pp. 11902-11915, 2020.

[24] R. Faraji and H. Farzanehfard, “Fully Soft-Switched Multiport DC–DC Converter With High Integration,” *IEEE Transactions on Power Electronics*, vol. 36, no. 2, pp. 1901-1908, 2021.

[25] C. L. Shen and L. Z. Chen, “Dual-Input Isolated Converter With Dual-Charge-Pump Cell for High Step-Up Voltage Ratio Achievement,” *IEEE Transactions on Industrial Electronics*, vol. 67, no. 11, pp. 9383-9392, 2020.

[26] B. Zhu, Q. Zeng, Y. Chen, Y. Zhao and S. Liu, “A Dual-Input High Step-Up DC/DC Converter With ZVT Auxiliary Circuit,” *IEEE Transactions on Energy Conversion*, vol. 34, no. 1, pp. 161-169, 2019