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Boost converter topologies, hybrid boost and new topologies of voltage multiplier in photovoltaic systems

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A B S T R A C T

Renewable energy generation has experienced lot growth in the last not many years, with close to several billion dollars financing in 2017. Selection of an appropriate converter is one of the challenges since it has an impact on the behavior of the PV (photovoltaic) system. In recent years, many converters have been reported in the literature.
This paper presents a review of non-isolated C-DC converters of voltage enhancers. Relevant review details are presented about the topologies of converters, including boost, hybrid boost, three-level boost, multi-level boost, and three-level hybrid converters that are most commonly used in photovoltaic systems. In the end, there are also several voltage level enhancers that can replace the converters provided in photovoltaic systems. Finally, a comparison is made between the converters in terms of the number of elements used in the circuit and the complexity of controlling the switches in the converters with their advantages and disadvantages being presented in a table. Since the use of multi-level boost converters reduces the switch voltage stress, weight, and cost compared to the conventional mode and as they are also better at higher powers, they have been used significantly in different systems.

1. ntroduction

Photovoltaic (PV) power generation has obtained importance as a renewable energy source as of its several deserves such as clarity of allocation, absence of noise, extensive life, absence of pollution, less time for installation, high movability and portability of parts, and the output power capability to match peak load requirements [1]. However, PV generation systems have faults including lowering in the conversion efficiency and dependence on climate conditions [2]. PV arrays have been take care of for a variety of applications, such as battery charging systems, solar-powered water-pumping systems, solar hybrid conveyances, and satellite power systems [1,3]. Several countries, such as China, Finland, New Zealand, Canada, South Korea, and Spain are allocating funds to support renewable energy-based projects [4–9]. There have been numerous publications related to the scope of renewable energy in various countries. For example, Yushchenko et al. [10] analyzed land suitability factors for large-scale grid-connected concentrated solar power plants and PV systems as well as off-grid PV systems in countryside areas of West Africa. Studies on the status of current renewable energy sources

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in Mexico have been done by Alemán-Nava et al. [11]. In the Middle East, the problems and disputes in the field of renewable energy were analyzed for Yemen by Rawea and Urooj [12]. The main challenges are related to financial, market, technical, social, and institutional barriers. The author suggested recommendations such as research and development, creation of a schedule for the production of renewable energy, improvement of market policies and development of distributed generation. Honrubia et al. [13] evaluated the economic details of PV power plants in Europe. Photovoltaic power differs with insolation, temperature, and load features [14,15] and it is straightly proportional to irradiance and inversely equivalent to temperature. The circuit-based model of a solar cell as shown in Fig. 1 consists of a current source connected in parallel with a diode. The current's source illustrates photon-generated currents (I_{ph}). The resistance Rs represents the losses due to the contacts and connections. The leakage currents in the diode are represented by parallel resistance R_p [16]. Parameters like the short-circuit current (Isc) and open-circuit voltage (Voc) are used to examine the characteristics of a Photovoltaic cell. The I_{sc} is the maximum value of the current produced by a cell, and is sensitive to irradiance. The V_{oc} is the maximum value of voltage obtained from a solar cell at zero current. The I–V characteristics of a solar cell are shown in Fig. 2. There is no intersection between the voltage characteristics of the PV generator and DC bus since the DC bus voltage is far higher than V_{oc} [2,29].

In PV systems, high voltage is favorable, like in uninterruptible power supplies (UPS) and micro PV inverters [17-19]. For such approaches, little input voltage from PV the source should be stepped-up. For example, in micro PV inverters, interfacing PV panel with a 230 V_{RMS} grid requires the low PV voltage (typical around 30 V_{DC}) to be stepped up to around 375-400 V_{DC} [13, 20-22]. For such applications, the voltage boosting required is too big to be accessible appling conventional fundamental boost DC-DC converter topology; therefore there remains a urgency for modified topologies offering a high voltage gain. DC-DC converters are commonly been categorized into isolated and non-isolated topologies [23-28].

contrary to many various topologies, the conventional boost converter yet enjoys remarkable degree of amicability due to the following advantages: little number of components which explicate into system cost decrease; non-pulsating input current (if the converter acts in CCM), and ordinary drive circuit. For this reason, the main emphasis of the paper is on non- isolated DC-DC converters from boost and hybrid boost converters as well as some converters for photovoltaic systems.

The main objective of the paper is introducing:

1.Conventional boost converters and hybrid boost converters

2.Three-level boost converter and three-level hybrid boost converter.

3.A Multi-level boost converter

4.Voltage multiplier converters for future work on its application in photovoltaic systems

The remainder of the paper is organized as follows. The second section deals with introducing isolated and non-isolated DC-DC converters. Section 3 introduces conventional boost converter and hybrid boost converter, three-level boost converter and three-level hybrid boost converter, multi-level boost converter and some proposed voltage multipliers and, finally, discusses the comparison between existing converters.

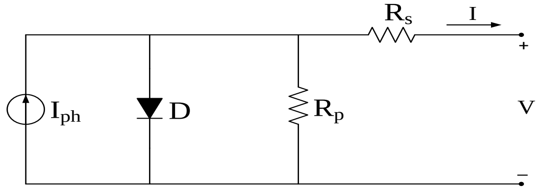


Figure 1: Equivalent model of the PV cell[29].

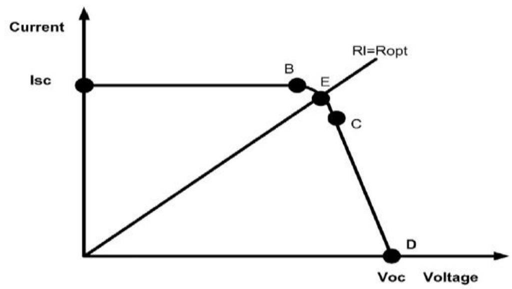


Fig. 2. I-V Characteristics of solar cell with load line.

2. Isolated and non-isolated DC–DC converts

Figure 3 presents only the chief isolated and non-isolated converters [23-28].

The DC-DC converters are generally categorized into isolated and non-isolated converters. The input and output voltage are separated from each other in isolated convertors and there is greater protection between them, while the input and output voltages are not separated in non-isolated convertors and they are related to each other, which is called non-isolated.

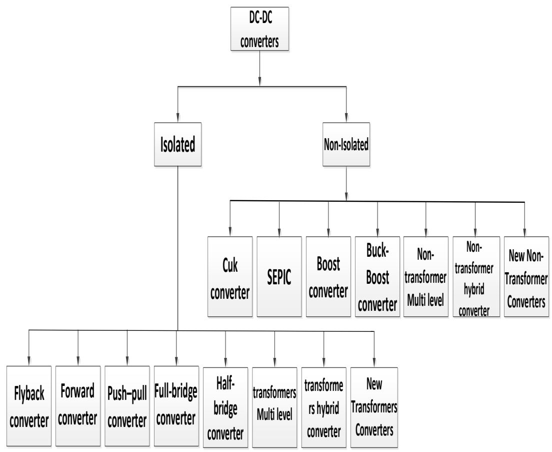


Fig. 3. Isolated and non-isolated DC–DC converts

3. Types of boost converter topologies

3.1. Boost converters

A boost converter is a DC-DC converter that is capable to produce an output voltage greater than the input voltage. Since the output voltage of a boost converter is greater than the input voltage, it is also known as step-up converter [30-34]. According to the law of conservation of energy, the input power must be equal to the output power. Since the output voltage of a boost converter is greater than its input voltage, the output current will be lower than the input current. The circuit topology of a conventional boost converter is shown in Fig. 4.

When the switch is made ON, one direction of the inductor suits linked to the source of energy. The current via the inductor ascents from the least level to its most level during this course. The output voltage appears in the cathode while zero voltage appears in the anode of the diode hence it is reverse biased and OFF. So, the load is isolated from the source pending the ON period, and in turn the load current is retained continuous by the output hand capacitor. When the switch is turned OFF, the plural of the voltage of the inductor and source voltage becomes visible on the switch and in the anode of the diode that is greater than the output voltage. So, the diode obtains forward biased and onsets the conduction current. Pending this period, the inductor current falls from the topmost level to least level where all energy stored in it along with the source voltage is rendered to the load and output capacitor. The output current is always continuous in the boost converter, while the input current can be continuous or discontinuous. This converter has been widely used in photovoltaic systems [35-38].

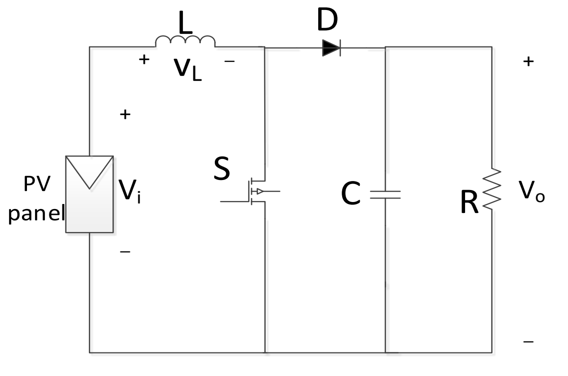


Fig. 4. DC-DC Boost converter[24].

3.2. Hybrid boosting converters

A hybrid boosting converter or (HBC) using bipolar voltage multiplier or (BVM) is shown in Fig. 5. The characteristics of interleaving are inherited to this converter which reduces the voltage on the output filter capacitor while enhancing the utilization rate of the components as the voltage gain is higher during a shorter duty cycle. Topologies in [39,40] have employed an interleaving method for ripple decrease and power increment; although, these topologies require rather components. This converter represents minor ripples while maintaining high voltage gain with only one single inductor and single switch. A higher gain was archived in topologies in [41-46], but they implemented two inductors and two switches. The HBC topology has advantages including low-cost design and the potential to be employed in high power applications. As a disadvantage to applications where common ground is required, this topology has different grounds for the source and load. Moreover, due to this problem, audible noise may be experienced, which may necessitate a fast control loop and an input filter.

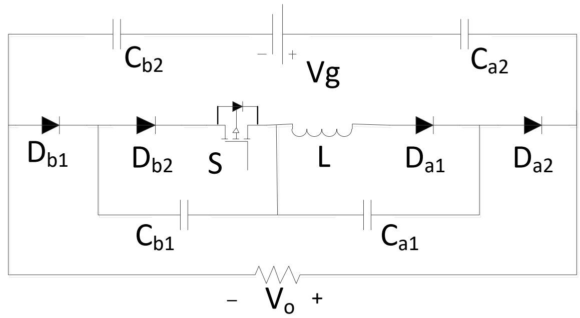


Fig. 5. Hybrid Boosting Converter [47].

3.3 Three-level boost type converter (TLBC)

As shown in Fig. 6, the switching signal G_1 is obtained from the comparison of the control signal v_{cont1} with the triangular signal v_{tri1}. Due to the low output voltage ripple, V_O is assumed constant. Therefore, the sum of two capacitor voltages will be fixed $v_{C1} + v_{C2} = V_O$.

In addition, the other switching signal G_2 is obtained by comparing the control signal v_{cont2} with the triangular signal v_{tri2}, where there is a 180° phase difference between two triangular signals.

Due to the input inductor L and two diodes D_1 and D_2 in the TLBC, both switches can be turned on at the same time. Therefore, there are four possible switching states as plotted in Fig. 7.

In Table 1, the states are described as follows:

State (a) : T_1=ON and T_2=ON then $V_{PV}=V_L$.

State (b) : T_1=ON and T_2=OFF then $V_L=V_{pv}-V_{C2}$ then C_2 capacitor is charged.

State (c) : T_1=OFF and T_2=ON then $V_L=V_{pv}-V_{C1}$ then C_1 capacitor is charged.

State (d) : T_1=OFF and T_2=OFF then $V_L=V_{pv}-V_{C1}-V_{C2}$.

All of the capacitor currents in various switching states are tabulated in Table 1.

In case $1 < v_{cont1} + v_{cont2} < 2$, $v_{cont1}=0$ and $v_{cont2}=0$ do not occur at the same time. Therefore, State 4 in Figure 4 does not develop.

In case $0 < v_{cont1} + v_{cont2} < 1$, $v_{cont1}=1$ and $v_{cont2}=1$ do not occur at the same time. Therefore, State 1 in Figure 4 does not develop.

Table 1: Capacitor currents in each state

Switching States of TLBC	Capacitor Output current	State 1	State 2	State 3	State 4
$1<v_{cont1}+v_{cont2}<2$	i_{C1}	$-i_O < (0)$	$-i_O < (0)$	$i_L - i_O > (0)$	
	i_{C2}	$-i_O < (0)$	$i_L - i_O > (0)$	$-i_O < (0)$	
$0<v_{cont1}+v_{cont2}<1$	i_{C1}		$-i_O < (0)$	$i_L - i_O > (0)$	$i_L - i_O > (0)$
	i_{C2}		$i_L - i_O > (0)$	$-i_O < (0)$	$i_L - i_O > (0)$

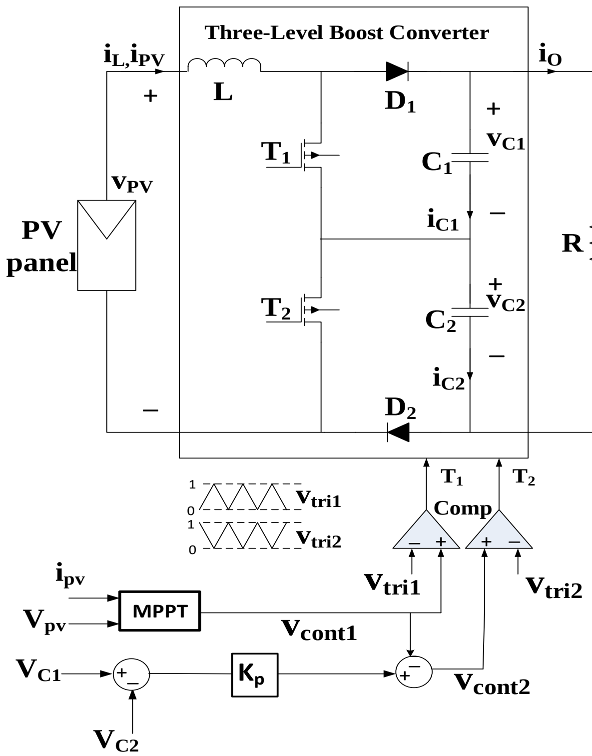


Fig 6. Three level boost converter[49].

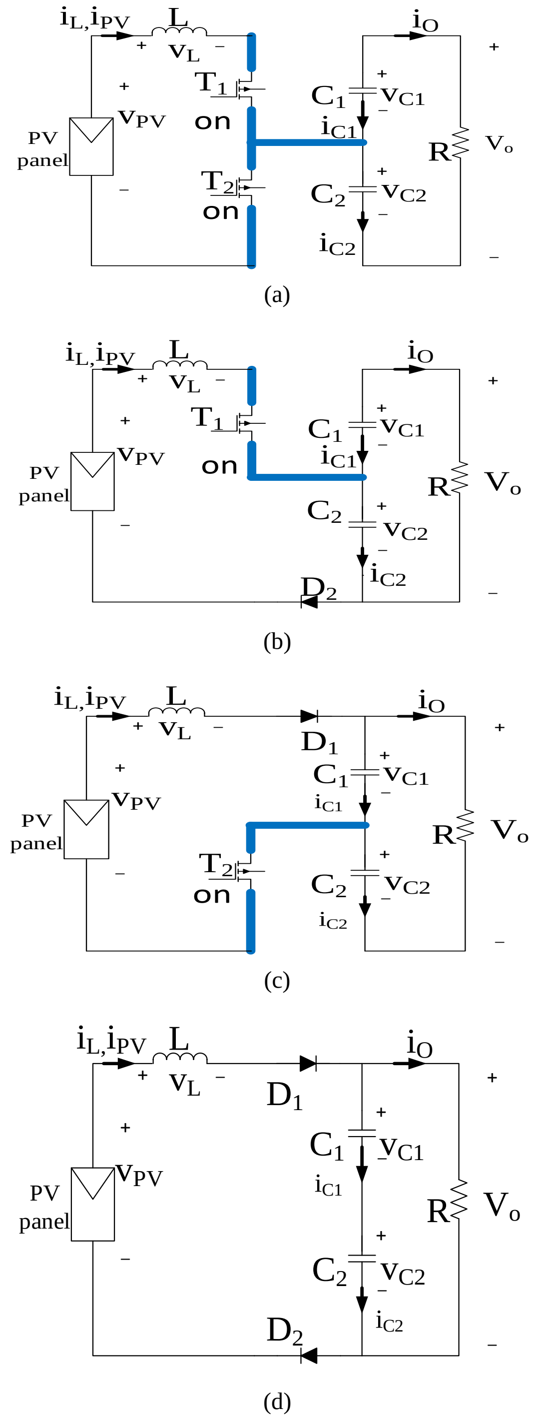


Fig. 7. Possible switching states in three-level boost-type converter: (a) state 1; (b) state 2; (c) state 3; (d) state 4[49].

As shown in Fig. 6, the current and PV voltage are sensed and introduced into the MPPT control block. This block generates the output signal v_{cont1}. The existing signal is compared with the triangular signal v_{tri1} with zero-phase angle and can create signal G_1 for switch SW_1. Then, voltage capacitors C_1 and C_2 are sensed and compared with one another to obtain an unbalanced voltage. This signal is then introduced into the proportional control to make the errors zero. The resulting signal from the controller output is added to signal v_{cont1}. The obtained signal is then compared with signal v_{tri2} (there is 180^o phase difference between v_{tri2} and v_{tri1}). Next, the obtained signal G_2 enters the second switch. In this way, two rates of D_1 and D_2 will be created with half of the period of the phase difference, where, three-level voltage is obtained in the output converter. This not only increases the input voltage, but also reduces the switch voltage stress. It can also lower the filter size due to increased frequency [48-51].

3.4. Hybrid boost three-level DC-DC converters

The single-phase diode-clamped three-level inverter is shown in Fig. 8(a), where there are four switches Qa1 − Qa4 with corresponding antiparallel diodes Da1 − Da4 . Leaning on this topology, two three-level DC-DC converters (buck and boost converters) are deduced, as shown in Fig. 8(b) and (c). Note that there are still two other boost three level converters shown in Fig. 9 [18], which can also be deduced from the inverter in Fig. 8(a). However, these two boost three level converters cannot operate individually, due to the unbalanced capacitor voltages across (C_{11}, C_{12}) or (C_{21}, C_{22}). For both improving the dc-bus voltage and power level of PV generation systems and for obtaining narrower pulse voltages from the difference between wider ones through the idea based on the topology of a single-phase diode-clamped inverter with two three-level legs , a new hybrid boost three- level converter can be combined naturally by the two boost three-level Converters I and II in Fig. 9. V_{in1}, V_{in2}, and $L_{f\ 1}$, $L_{f\ 2}$ represent the input dc voltages and filtering inductors of Converters I and II, respectively. Then, the input power level of the hybrid converter can be improved by two inputs of two series converters called V_{in1} + V_{in2} . Also, the output power level of the hybrid converter can also be enhanced by the parallel connected outputs of Converters I and II called (i_1 + i_2) as displayed in Fig. 9. Accordingly, the process of synthesizing the hybrid converter by the mode of inputs in series and outputs in parallel is depicted in Fig. 10. The input node c is cut off from node $g1$ in Converter I, which is abbreviated as "Cut I." In addition, the other input node d is also cut off from node p_2 in Converter II, abbreviated as "Cut II." Then, the two input nodes c and d can be connected in series, i.e. both of the input dc voltage supplies V_{in1} and V_{in2} are in series. On the other hand, the output structures of Converters I and II are identical, nodes p_1 and p_2, as well as g_1 and g_2 can be connected in parallel leading to the "paralleled output +" and "paralleled output –" for the hybrid converter as shown in Fig. 10. The synthesized hybrid boost three-level converter is shown in Fig. 11, where the equivalent input dc voltage V_{in} and inductor L_f can be obtained linearly due to the input sides of Converters I and II in series.

In addition, the parallel-connected capacitors (C_{11}, C_{12}) and (C_{21}, C_{22}) as shown in Fig. 10, can be equivalent to $C_{f\ 1}$ and $C_{f\ 2}$ in Fig. 11, as well as the parallel-connected load resistors R_1 and R_2 which are equivalent to R_L . However, the neutral points n_1 and n_2 in Fig. 10 have to be connected to each other, leading to the neutral point n which may keep the blocking voltages across power switches as the corresponding capacitors' voltages in Fig. 11. So, the proposed hybrid converter, combined by Converters I and II in Fig. 9, contain Half-Bridges I and II, as shown in Fig. 11.

The significant point on this hybrid converter is that one inductor, two capacitors in series, and those power switches and diodes, which are simple to be united, are pursue to instate the topology with a transformer-less great voltage gain.

So, the proposed converter can both act with a high voltage gain and fetch the duty cycles of power switches near to 0.5.

Also, the voltages through the capacitors in series are well balanced in both stable and dynamic states, As the blocking voltages of the power switches are half of the output dc voltage. Finally, a 1-kW archetype is set up in our laboratory, where the measured maximum revenue of the proposed converter is about 93.1%.

The three-level hybrid boost converter conversion function is also described further:

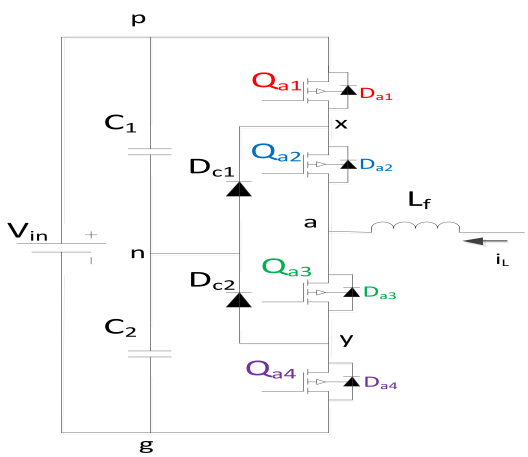
d_1 and d_2 are the duty cycles of Q_1 and Q_2 , respectively. Then, all the duty cycles of power switches can be described as follows with the modulation indices m_a and m_b:

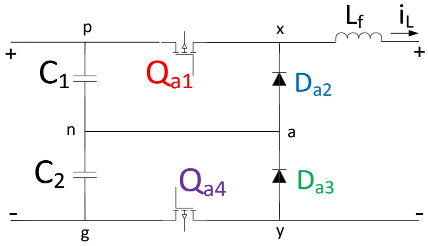
$$\begin{aligned} d_1 &= d_4 = 1 - m_b \\ d_2 &= d_3 = m_a \end{aligned} \tag{1}$$

Also, d_3 and d_4 are the duty cycles of $Q3$ and $Q4$, respectively. Then, the voltage gain M of the hybrid converter is written as follows by:

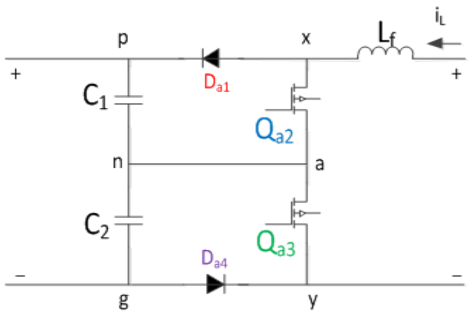
$$M = \frac{V_o}{V_{in}} = \frac{1}{1-(d_1+d_2)} = \frac{1}{m_b - m_a} \tag{2}$$

(a)



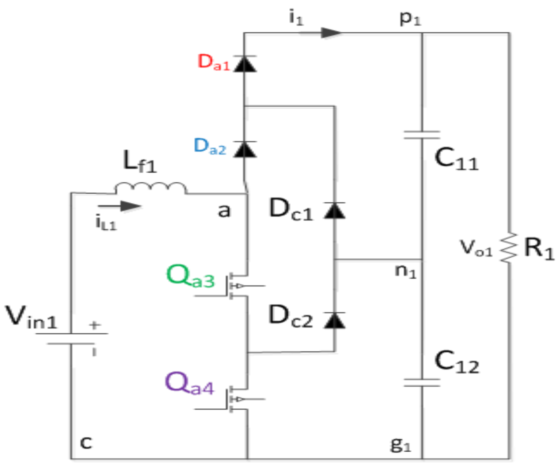


(b)

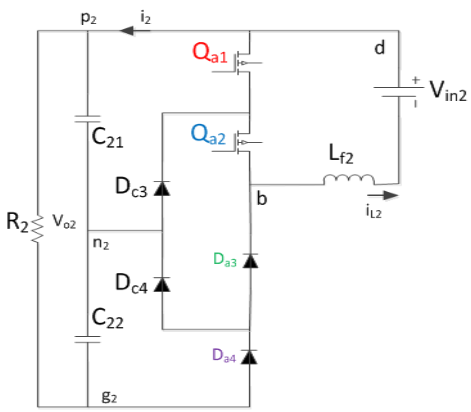


(c)

Fig. 8. Single-phase diode-clamped three-level inverter and two classical three-level dc–dc converters[52].



(a)



(b)

Fig. 9. Two deduced boost three-level dc–dc converters[52].

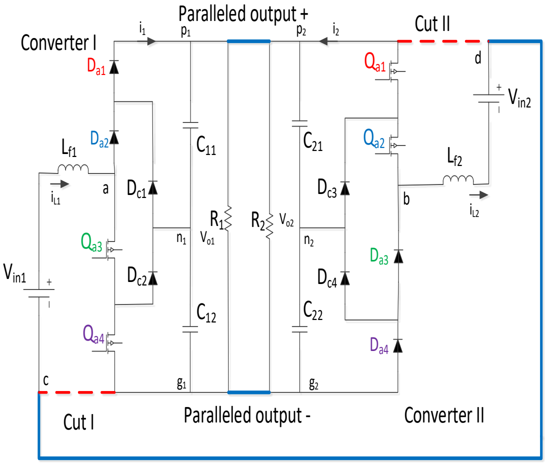


Fig. 10. Synthesized process of the hybrid boost three-level dc–dc converter by the mode of inputs in series and outputs in parallel[52].

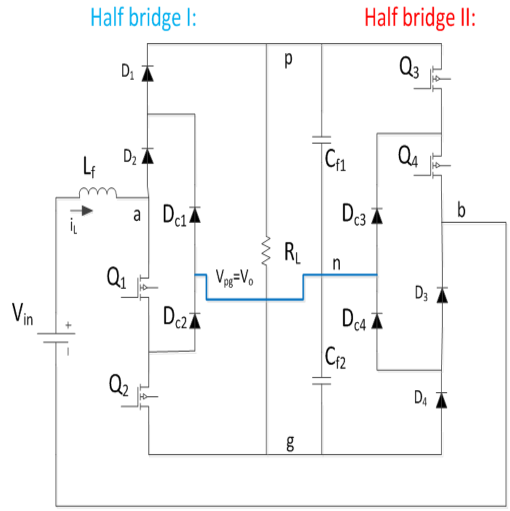


Fig. 11. Proposed hybrid boost three-level dc–dc converter[52].

3.5. Analysis of the new Converter

The new converter with two switches is shown in Fig. 12, where V_{in} is the input voltage and the resistor R_o represents the load. Each of the two phases of the converter is composed of one switched inductor circuit and its corresponding switch and diode. The new converter combines switched inductor circuit and interleaved technique to integrate the advantage of these converters in one structure. The proposed structure is called switched inductor interleaved double boost converter (SIIDBC). The output voltage V_o is given by:

$$V_o = V_{C1} + V_{C2} - V_{in} \tag{3}$$

The current delivered by the source V_{in} (input current) is given by:

$$i_{in} = i_1 + i_2 - i_o \tag{4}$$

In the analysis, all the components are ideal while all the parasitic parameters are ignored. Also, the ripples of the capacitor voltages are neglected. In addition, since the converter is required to operate in a continuous conduction mode (CCM) for the renewable power system applications, the steady-state behavior of the converter has been analyzed in CCM. The operation of the second phase is the same as the first phase, so the equation of the first phase is provided. The equation of the second phase is the same as that of the first phase. Also, the values of inductors are equal. On the other hand, the voltage stress of the capacitors, diodes, and power devices are reduced. The new converter has a switching network for the inductor which allows the use of smaller inductors [53].

$$L_{11} = L_{12} = L_{21} = L_{22} = L_1 = L_2 \tag{5}$$

The conversion function of this new converter is as follows:

$$\frac{V_o}{V_{in}} = \frac{(1+3D)}{(1-D)} \tag{6}$$

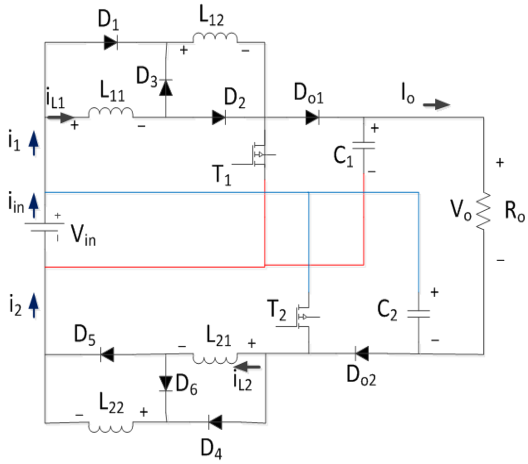


Fig. 12 The circuit of the new converter[53].

3.6. Fault-tolerance basic converter (FIBC) topologies

Considering fault-tolerance, basic modifications brought to the classic boost converter topology are given in Ref. [54]. These novel topologies let building error tolerant interleaved converter topologies with a vast voltage ratio and decreased input current ripple. For this proof, these topologies are solely proper for FC and PV applications. A 2-leg FIBC is displayed in Fig. 13. The second is built from the non-floating version of the boost converter (i.e. upper section) and the floating version of the boost converter (i.e. lower section). The interleaving notion is guaranteed by the parallel connection among the non-floating and floating versions of the boost converter and the respective shift among the two power switches (S1 and S2).

This interleaving allows reducing the input current ripple. Further, this topology allows minimizing the electrical stresses (voltage and current) on the power devices. The voltage ratio is given by the following expression [54] and [55]:

$$M(D) = \frac{v_{dc}}{v_{fc}} = \frac{1+D}{1-D} \tag{7}$$

Where, v_{dc} is the DC bus voltage in [V], v_{fc} denotes the FC stack voltage in [V], and D is the duty cycle value.

Starting from this converter, others converters can be built [54] and [55]. Two novel topologies are shown in Fig. 14 and Fig. 15. The first is a 4-leg FIBC, while the latter is a floating interleaved cascade boost converter or (FICBC). It is important to emphasize that the number of legs of FIBC topologies must be necessarily even in order to keep a balance between the non-floating and floating parts. If 2-leg and 4-leg FIBCs are compared from the power switch fault-tolerance point of view, the 4-leg FIBC is more reliable. Indeed, once one leg of the 2-leg FIBC is lost, this leads to an unsteadiness between the non-floating and floating bus. In summary, this converter will tine all these affairs formerly given. On the other side, the loss of one leg of one of the sections (i.e. non-floating or floating) for a 4-leg FIBC could be maked up by the other leg on the defective part since the non-floating and floating part are absolute of each further.

However, keeping the balance between the two parts leads to the leg overload, causing additional electrical stress, particularly on inductive components. An analysis carried out by Kabalo et al. [56] on a 2-leg, 4-leg and 6-leg FIBC based on several criteria (i.e. volume of inductors, FC current ripple, efficiency) suggested that the 4-leg FIBC is the best choice among the proposed converters. As to the FICBC, the cascade junction allows getting a high voltage respect and a decreased output voltage ripple. The FICBC voltage ratio is given by the following phrase:

$$M(D) = \frac{v_{dc}}{v_{fc}} = \frac{2}{(1-D_1)(1-D_2)} - 1 \tag{8}$$

Where, D_1 and D_2 represent the duty cycles of the first and second stages respectively.

In order to minimize the input current ripple of the FICBC, a large inductor value and thus increasing the overall volume of the converter is required. Note that the reliability of the converter decreases when using the cascade connection. On the other side, the credibility of the FICBC can be added by using the interleaving implication, but this increments the intricacy of the converter.

Starting from this lysis, the 4-leg FIBC has been selected in order to carry out a all investigation in terms of fault-tolerance. This research will allow to work out remedial tactics for minimizing the unfavorable agents in case of degraded operating modes.

In order to sate the fault tolerance requirements, fuses (Fuse 1, Fuse 2, Fuse 3, and Fuse 4) have been added in sequel with every power switch, as shown in Fig. 14. The fuses let isolating faulty legs in instance of SCFs. Also, the PEMFC has to be electrically secure (e.g. addition of a fuse series jointed with the FIBC) against feasible SCFs [57]. The diode D is applied to maintain the PEMFC from negative currents. This diode conducts the current for the all duration of the system revenue. As a result, in order to decrease its conduction losses, the parallel connection of two diodes is applied. In this converter, the ripple diminishes [58].

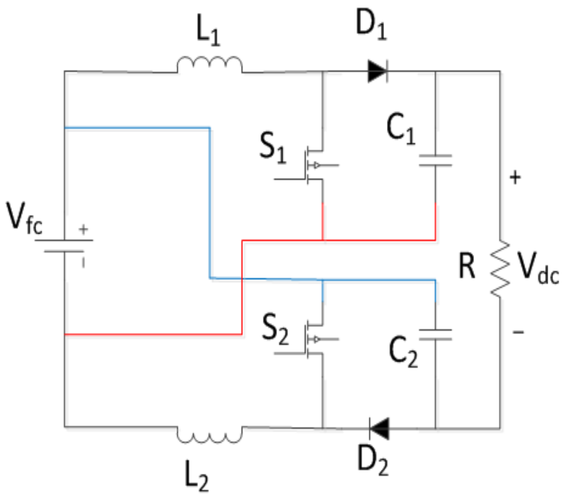


Fig. 13. 2-leg FIBC[58].

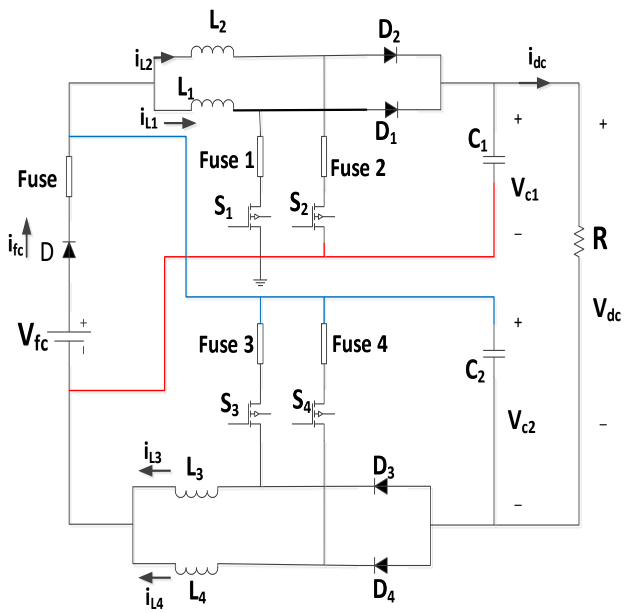


Fig. 14. 4-leg FIBC[58].

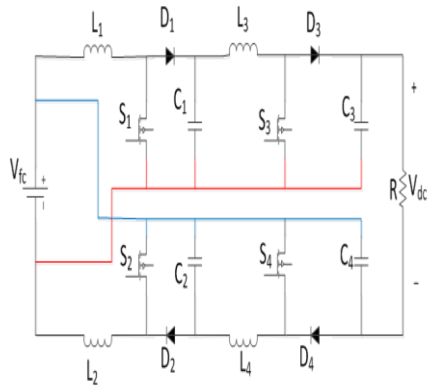


Fig. 15. Floating Interleaved Cascade Boost Converter (FICBC)[58].

3.7. Multi-level boost converters

A multi-level boost converter (MLBC) employs extra diodes and capacitor network at the output stage to achieve a higher gain for the same duty cycle when compared with conventional boost converters [59]. The voltage increase for N level multilevel boost converter is appointed by:

$$\frac{V_o}{V_{in}} = \frac{N}{1-D} \tag{9}$$

Today, many researchers use multi-level converters (three-level, five-level, ...) in photovoltaic systems. According to Formula 11, it increases both the voltage level and the power. In addition, switches with a lower voltage stress can be used to enhance the converter level. References [60-63] have been used in this regard.

As an example, the circuit schematic view of ZVS in MLBC is shown in Fig 16. M type full wave quasi-resonant configuration is incorporated to the multi-level boost converter to achieve ZVS during the 'on' phase. A diode is placed in series with the switch. L_r and C_r are designed such that both gain and resonance are achieved. The gain in ZVS with MLBC will be slightly less than the one without ZVS, accounting for the losses in new elements.

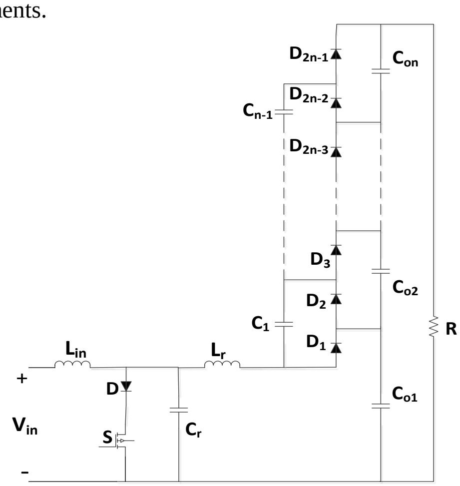


Fig. 16. ZVS in Multi level boost converter topology[64].

In this work, a high gain DC-DC converter along with zero voltage switching (ZVS) is proposed to minimize the switching losses [64-68].

3.8. A generic $(\frac{k}{m}X)$ converter

Figure 17 illustrates the structure and of a generic $(\frac{k}{m}X)$ converter. It can be seen that the proposed converter has 'n' different arms and 'n' different legs leading to a total of '2n' limbs. Each arm is comprised of a series connection of two capacitors and two arm switches labeled with suffixes 'a' and 'b'. For example, arm no. 1 consists of capacitors C_{1a} and C_{1b} connected in series with switches S_{1a} and S_{1b}. Each leg of the converter consists of a half-bridge cell composed of two switches switched in a complementary function. Leg 1 consists of S_{1p} and S_{1n}. In comparison to the double wing structure proposed in [69], it can be observed that an extra degree of freedom with respect to the location of input voltage and output voltage is introduced in the $(\frac{k}{m}X)$ converter. Both the input voltage V_{in} and output voltage can be connected across any of the 'n' arms of the converter. For a generic location of the input voltage, V_{in} on the m^{th} arm of the converter, the "effective input" voltage, V_x across C_x can be expressed as:

$$V_x = \frac{1}{m}.\frac{V_{in}}{2} \tag{10}$$

For a generic location of the load across arm 'K', the output voltage V_{out} can then be expressed as:

$$V_{out} = 2n.V_x = \frac{k}{m}V_{in} \tag{11}$$

Where, m denotes the arm across which the input voltage is connected and k is the arm across which the load is connected where $k,m \leq n$.

If k > m, the converter functions as a boost converter. Figure 18 also shows that one other degree of freedom can be obtained by placing the source or load across C_x. If the input voltage, V_{in} is placed across C_x and the load is connected across the generic arm, 'k' as described above, the output voltage,

$$V_{out} = 2k.V_{in} \tag{12}$$

This converter includes the following advantages:
An inductor-less, high gain DC-DC converter with a high efficiency and high power density is a much desired circuit in electric vehicle (EV) powertrain and solar photovoltaic (SPV) power converters. Modular multi-level capacitor clamped DC-DC converter circuits (MLCCCs) provide a viable solution for this case. However, their application is limited owing to their limitations in terms of fixed output voltage gains and lack of fractional output gains [70].

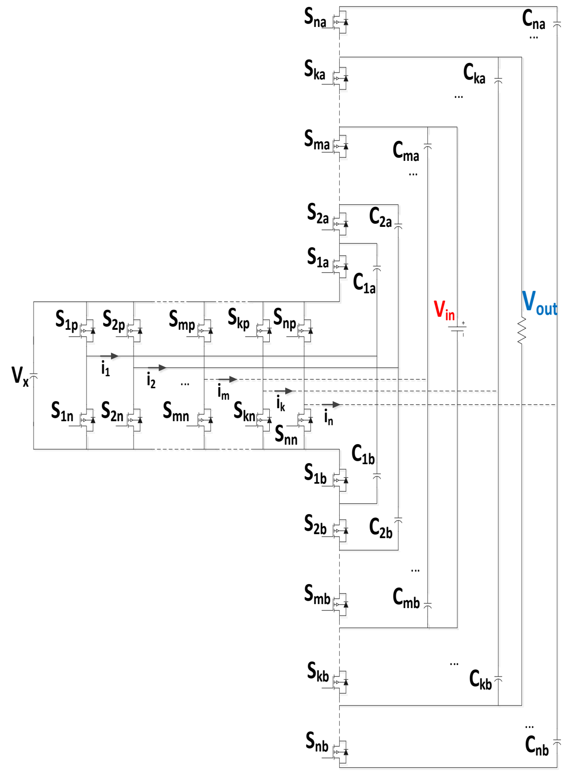


Fig. 17. A generic $(\frac{k}{m}X)$ converter[70].

There has also been many multiplier converters made by researchers around the world which, according to the statements of this paper one of them can be used in photovoltaic systems whose advantages and disadvantages can also be discussed.

Table 2 Advantages and Disadvantages of Boost converters

DC-DC Converters	**Advantages and Disadvantages**	**Number of elements used in the circuit**	**Utilized in photovoltaic systems**
Fig. 4. DC-DC boost converters	1.Semiconductor power electronic switches with high voltage rate 2.High cost of power electronic switches 3. Large size and larger weight than TBLC. 4. Application in power systems with a low voltage-power rate.	Number of inductances: 1 Number of capacitors: 1 Number of diodes: 1 Number of keys: 1	yes
Fig. 5. Hybrid boost converters	1.Increase in power rate 2.Reduction of power ripple 3.Requires more elements than conventional boost converter in circuits 4.Increasing the voltage level only with an inductance 5. The cost of the converter is less than that of conventional boost converters. 6.The disadvantage of the earth separated by the load and the source	Number of inductances: 1 Number of capacitors: 4 Number of diodes: 4 Number of keys: 1	yes
Fig. 6. Three level boost converter	1. Use of power electronic switches, with a lower voltage rate than conventional boost converters (about half voltage rate of conventional boost converter). 2. Application in power systems with a medium and high voltage-power rate. 3. Reducing the size in inductance filter of TBLC compared with inductance filter of conventional boost converters (about a quarter size of the conventional boost converter). 4. Reducing the capacity of TBLC compared with that of conventional boost converters (about half of the capacity of conventional boost converters). 5. Reducing the current ripple by a quarter. 6. Increasing the frequency of the voltage across the LC filter to double the switching frequency. 7. Decreasing the cost of power switch; Reducing the total weight and size of the converter.	Number of inductances: 1 Number of capacitors:2 Number of diodes: 2 Number of keys: 2	yes
Fig. 11. Hybrid boost three level converter	1. The converter's efficiency is about 93 %. 2.The magnitude of duty of the cycle for increasing the voltage is about 0.5 3. Voltage stress on the switch is half the output voltage. 4. Application in power systems with a medium and high voltage-power rate. 5. Decreasing the cost of power switch. 6. Reducing the total weight and size of the converter.	Number of inductances: 1 Number of capacitors: 2 Number of diodes: 8 Number of keys: 4	yes
Fig. 12. Proposed dc-dc converter	1. The voltage stress of the capacitors, diodes, and power devices is reduced. 2. The converter has a switching network for the inductor which allows the use of smaller inductors.	Number of inductances: 4 Number of capacitors: 2 Number of diodes: 7 Number of keys: 2	no
Fig. 13-15. FIBC	1. Including reduced input current ripple. 2. Benefits of this topology, operating degraded modes lead to undesirable effects such as electrical overstress on components and input increasing current ripple.	**2-Leg:** Number of inductances: 2 Number of capacitors: 2 Number of diodes: 2 Number of keys: 2 **4-leg:** Number of inductances: 4 Number of capacitors: 2 Number of diodes: 5 Number of keys: 4	yes
Fig. 16. Multi-level boost converter	1. Total advantages of three-level boost converters with more reduction in switching losses, cost, and weight. 2. The complexity of the converter control is due to increased number of switches.	Number of inductances: 2 Number of capacitors: 2n Number of diodes: 2n Number of keys: 1	yes
Fig. 17. A generic (k/M)X converter	1.Inductor-less, high gain DC-DC converter witha high efficiency and high power density 2. Their application is limited owing to their limitations in terms of fixed output voltage gains and lack of fractional output gains. 3. The complexity of control in the photovoltaic system is greater upon increase in the number of switches and applications in the stepper motors, due to the stepped output of the voltage.	Number of capacitors: 2 n Number of keys: 4 n	no

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