Chapter

Application of DC-DC Converters at Renewable Energy

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Abstract

Photovoltaics usually produce low voltage at their outputs. So, in order to inject their power into utility grids, the output voltage of solar panels should be increased to grid voltage level. Usually, the boost DC-DC converters will be connected between solar panels and grid-connected inverters to boost the panels' output voltage to more than 320 V (for 380/220 utilities). Various DC-DC converter topologies have been proposed in the past three decades to boost the photovoltaic panels' output voltage which will be discussed in this proposal. In order to increase the life span of photovoltaic panels, the DC-DC converts should absorb continuous low ripple current from solar panels. Maximum power point tracking (MPPT) is an algorithm implemented in photovoltaic (PV) inverters by DC-DC technology to continuously adjust the impedance seen by the solar array to keep the PV system operating at, or close to, the peak power point of the PV panel under varying conditions, like changing solar irradiance, temperature, and humidity. In this research work, various topologies of DC-DC converters that are suitable for renewable energy applications along with the advantages and disadvantages of control methods and the stability of converters with related control methods are discussed.

Keywords: DC-DC converters, photovoltaic cells, boost converters, nonisolated, MPPT, control methods

1. Introduction

Step-up DC-DC converter stores feed-in energy in magnetic field storage components like inductors, coupled inductors or electrical field storage components like capacitors and then flows it to the load with the higher voltage value compared to the feed-in voltage by using active and passive switching elements such as IGBTs, MOSFETs, and diodes. These converters have increasingly been used in many applications such as renewable energy sources and uninterruptable power supplies (UPS) [1–3].

A fundamental DC-DC converter is a simple PWM boost converter that is suitable for low-powerup to high-power and portable up to stationary devices. The major benefit of this converter that simplifies the modeling and implementation is lower element numbers. Higher efficiency, small size, lightweight, and reliable converters are strong demand for various applications. By increasing the duty cycle for reaching higher voltage gain, the voltage stress of active and passive elements increases, so the conversion efficiency is degraded. In practice, the voltage gain of conventional boost converters is limited due to the parasitic effects of MOSFETs or IGBTs and passive components [4–7].

Various voltage boost techniques such as charge pump, voltage multiplier, switched inductor, magnetic coupling, and multistage topologies were proposed for DC-DC converters.

Between charge pump topologies because of the modular structure, the popular topology is the switched capacitor topology. The critical issue of switched capacitor topology is the high-current transient that leads to lower efficiency and power density. To improve the current transient problem, an inductor has been added at the output of the converter to form a buck converter with the switches.

The advantages of switched capacitor technique are efficient regulation and elimination of current transients [8]. Hence, because of reduced power losses, the voltage and current spikes of converter are reduced, and the efficiency increases. Switched capacitor base converter can achieve high voltage gain with low voltage ratings of the output capacitance and low capacitance [9, 10].

Voltage multiplier topologies including a set of diodes and capacitors are of low-cost, efficient, and simple. Voltage multiplier converters divided into two types: (a) the voltage multiplier located in the middle of the circuit to reduce voltage stress, and (b) the voltage multiplier rectifier has been located at the output of the circuit to convert AC or pulse output voltage of the converter to DC voltage. The voltage stress of all parts of the circuit is lower than the output voltage which can be an advantage for this topology [11].

Also, high step-up DC-DC converters can be applied voltage lift and switched inductor technique. In this technique, capacitors will be charged to the input voltage and then the output voltage will be stepped up to the sum of voltage level of the capacitors. In these converters, the inductors are charged in parallel and discharged in series with the load [12].

Some new techniques proposed for high voltage gain DC-DC converters such as cascaded, multilevel, and interleaved in [13]. In quadratic boost, the first stage voltage stress is low and the switching frequency could be increased but the switching frequency limitation is for reducing the switching losses of the second stage [14]. So, the disadvantage of this converter is that the two stages of control are related to each other. Therefore, it can be concluded that this converter is suitable for low-power applications [15, 16]. Multilevel DC-DC converters because of high power and high voltage applications are suitable for industrial applications. The simplicity, flexibility, and modularity of a single-source multilevel DC-DC converter are the main advantages.

2. Nonisolated DC-DC converter

As expressed in the first section, DC-DC converters are widely utilized for renewable energy applications. Nonisolated DC-DC converter topologies in comparison with isolated converter topologies have a lot of advantages.

2.1 Buck topology

The basic DC-DC converter, the Buck converter, is shown in **Figure 1**. In this converter the power switch is connected between the input power supply and the load.

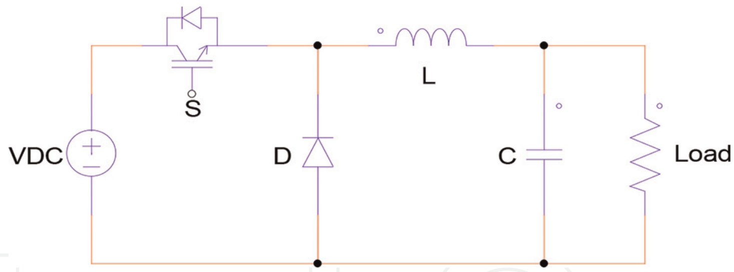

Figure 1.
Buck converter.

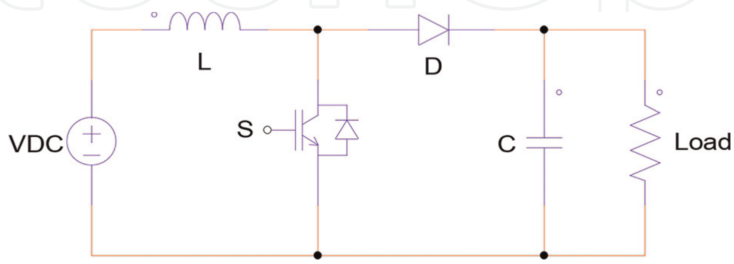

Figure 2.
Boost converter.

The power switch connects and disconnects periodically. The output voltage of the switch has a rectangular waveform that pass from a low pass filter and makes ripples DC output voltage. By assuming that the circuit elements are ideal, the conversion ratio of buck converter can be written as:

$$G_v = D \tag{1}$$

where D is the duty cycle of power switch. It is clear that the output voltage of converter can vary from zero to the input DC voltage.

2.2 Boost topology

The next topology is boost converter that is made from an interchanging inductor, switch, and diode, as shown in **Figure 2**. When the power switch is connected, the input current increases on the inductor. When the power switch is disconnected, the inductor current flow to the load through the diode. By assuming the ideal elements in circuit, the conversion ratio of boost converter can be expressed as:

$$G_v = {}^1\!/_{1-D} \tag{2}$$

where D is the duty cycle of power switch. It shows that the output voltage of converter can vary from input voltage up to higher voltages that limited by the parasitic elements of the circuit's active and passive components.

2.3 Buck-boost topology

Buck-boost converter is a mix of two different topologies as shown in **Figure 3**. The buck converter and the boost converter. The buck converter steps down and the

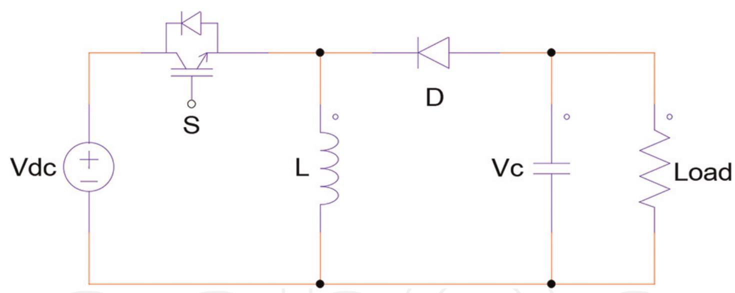

Figure 3.
Buck-Boost converter [17].

boost converter steps up the output voltage. This combined converter topology is used in many applications such as drive applications, stand-alone, and grid-connected photovoltaic (PV) systems. However, buck-boost converter is still under research to enhance the impression of the photovoltaic (PV) system. Researchers are working to increase the voltage gain of nonisolated DC-DC converters, as a result, many DC-DC converters are developed that include SEPIC, Cuk, Lou, and Z-source that all are based on buck-boost topology.

A novel topology of a double-switch buck-boost converter is proposed in [18]. It was shown experimentally that the converter is able to effectively track maximum power point for the photovoltaic application and also maintained maximum efficiency during load-varying conditions. Hybrid fuel cell-based system is using a coupled-inductor buck-boost converter. The proposed converter has higher efficiency, noninverting output, and low input and output ripples. Also, buck-boost converter is widely used in industrial applications. In [19], a bridgeless converter, i.e., the buck-boost converter for the motor drive application is proposed. In this topology, the converter and motor drive are integrated which leads to lower switching losses and conduction losses. Author in [20], proposed a boost-interleaved buck-boost converter, which consists of two switches, that is used for power factor correction application. This topology also decreases switching voltage stress, inductor losses and size of the magnetic interference. A cascade connection of two buck-boost converters that has one control switch has been utilized in the LED drive application. This topology leads to lower filter capacitance size [17]. In [21], a novel buck-boost converter for electrical vehicles proposed. The proposed converter controls the power transition between batteries and capacitors by using interleaved converter controlled by FPGA. In [22] a buck-boost converter is used to generate the telecommunication power system energy. In this converter, multiple input buck-boost converter is used that is between sources and DC-bus. This converter could reduce switching losses. In [23], a new technique was utilized for a smooth transition between switching modes of noninverter buck-boost converter.

2.4 SEPIC topology

Like buck-boost converter, single-ended primary inductor converter (SEPIC) is shown in **Figure 4**. SEPIC converter could step up and step down the output voltage. SEPIC topology could be utilized in various applications such as photovoltaic applications to improve the power factor and regulate the flickering DC voltage. Noninverting output of the SEPIC converter makes it more interesting than the buck-boost converter and it is suitable for high-power applications. To achieve high voltage output at SEPIC converter, duty cycle of the switch must be high.

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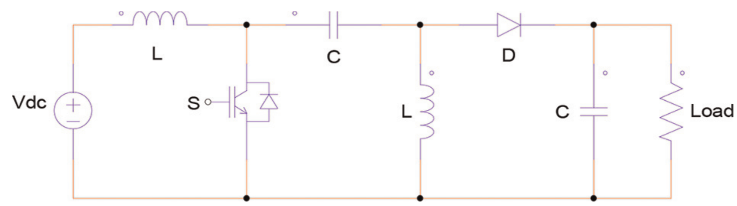

Figure 4.
SEPIC converter.

SEPIC topology is utilized in various applications. An inductor base SEPIC converter is used for renewable energy systems in [24]. The advantage of this topology include continuous input current and lower switching stress that leads to higher efficiency. In [25] a novel SEPIC converter is proposed that is suitable for high power factor correction. Proposed converter is an isolated bridgeless SEPIC and operates like a single-phase rectifier controlled with slide mode to achieve a high power factor. The advantage of this converter is low total harmonic distortion (THD) with suitable power factor correction. A modified converter of SEPIC proposed in [26] is a combination of two DC-DC converters and is suitable for renewable energy applications.

The advantage of this converter is low switching stress besides low input voltage and high output voltage. For photovoltaic application, an Integrated double-boost SEPIC converter is proposed in [27], which have a single switch and two inductors. This converter is able to provide high voltage gain with a low duty cycle. For increasing voltage gain and reducing voltage stress on the main switch a new topology of SEPIC was proposed in [28]. In this topology, SEPIC converter is combined with an inductor and two voltage multipliers. Because of continuous input current, it is suitable for renewable energy systems.

2.5 Cuk topology

As shown in **Figure 5**, Cuk converter topology is consist of a boost converter in the first stage and a buck converter in the second stage. The main application of Cuk converter is for voltage regulation and power factor correction (PFC) applications. Cuk converter is inverting converter that has an inverted output in compare to input voltage polarity. Also, this converter has lower switching losses that lead to higher efficiency. Voltage gain of the converter depends on duty cycle of switch. When the switch is ON, capacitors are discharged while inductors store energy. When the switch is OFF, the diode is conducted. In this topology, capacitors act as energy storage while in other converters inductors act as energy storage.

In [30], for the photovoltaic application, to achieve high voltage gain, the Cuk converter is coupled with switched inductor that leads to lower switching voltage. In

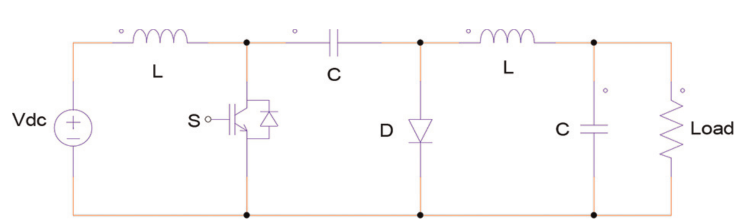

Figure 5.
Cuk converter [29].

[31], a novel high step-up DC-DC Cuk converter that is used for fuel cell application is proposed that gives a wide range of duty cycle and high voltage gain. For improving the power factor correction and power quality of a motor drive of air-condition, a Cuk converter was proposed in [32]. Over a wide range of the operation, the converter was able to keep the power factor near one. In [33], a Cuk converter is proposed for power factor correction. The proposed bridgeless Cuk converter reduces the conduction losses and switching losses and could reduce the inductance size for power factor correction purposes.

In [34], a bridgeless Cuk converter for lighting application is proposed that has high efficiency with a low number of conductive components and low losses. In [35], a single-stage switched inductor Cuk converter for improving the efficiency of electrical bikes battery charging applications is proposed. This topology improves the efficiency, power factor, and total harmonic distortion of the converter.

2.6 Z-Source topology

One of the efficient topologies is the Z-Source topologies. Z-Source topology could step-up and step-down the voltage. As shown in **Figure 6**, its topology is based on inductor and capacitor network that connects the converter to the power source. Z-Source topology is mostly used in medium-power to high-power applications. Z-Source converter output ripple is low and the duty cycle is less than 0.5. At the same duty cycle, Z-Source converter have higher voltage boosting capability compared to conventional boost converter. Also, in compare to others, Z-Source converter has higher efficiency, and lower cost and size.

In [36], a new topology from combination of Z-source network, voltage multiplier, and flyback that achieve an efficiency of 89% has been proposed. This converter has higher component number compare to conventional Z-source topology. In [31], a modified Z-source converter proposed for photovoltaic application has been proposed. This converter has a common ground and the advantage include low switching stress and reduced size. In [37], a hybrid Z-source converter suitable for motor drive application was proposed. In [38], a Z-source converter controlled by sliding mode controller (SMC) was proposed for controlling a permanent magnet synchronous machine in electric traction application. Also, voltage adaption strategy was validated and the system efficiency improved. In [39], by using a z-source converter, the power factor correction of wireless power transfer applications for electrical vehicles and transportation improved. Power factor correction and regulation of the output voltage is done without using additional components only by applying the control circuit.

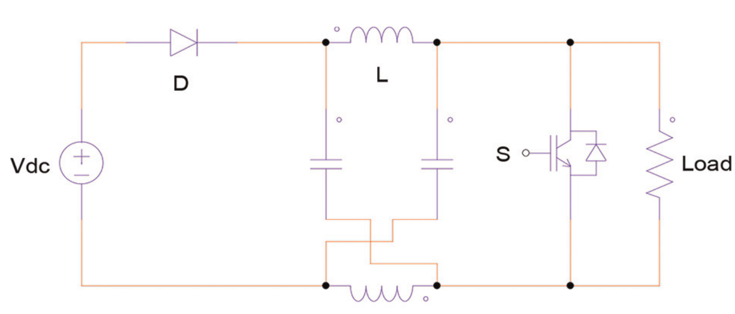

Figure 6.
Z-source converter [31].

2.7 Zeta topology

Zeta topology is well-known to be as a power optimizer. Zeta converters like SEPIC converter could be used in many applications like photovoltaic. Zeta converter in compare to other topologies, has a higher component count and higher complexity, asshown in **Figure 7**. It has the advantage of noninverting, regulated, and low ripple output voltage and continues current at output of converter. Some applications of Zeta converter are found, such as integration of Zeta converter with photovoltaic system to drive the BLDC water pump [40]. Also, this converter has fewer power losses and implements maximum power point tracking from PV cells. A constant output voltage under load-varying condition of wind turbine application is achieved by Zeta converter in [41]. A novel modified Zeta topology is used for high voltage conversion that improve efficiency in high voltage applications proposed in [42, 43]. In [44], a smart combination of Zeta converter and SEPIC converter is proposed for plugin electric vehicles that could operate in three modes, i.e., regenerative, propulsion, and plugin charging modes. This converter prepares the capability of voltage gain in all modes which leads to increasing the efficiency of electrical vehicles.

2.8 Recently developed nonisolated topologies

Nowadays, nonisolated topologies are used abundantly in many modern applications. Traditional nonisolated converters have lower efficiency and reduce the life span of electrical parts and systems in comparison to recently proposed topologies. So, the combination of topologies is an active manner to propose new topologies. Combination of topologies is just based on the advantages and disadvantages of topologies. Important parameters of nonisolated topologies are input and output ripples, continuous and discontinuous input and output current, switching voltage and current stress and duty cycle of switches. Also, **Table 1** shows the advantages and disadvantages of these converters. **Figure 6**, shows recently proposed common ground nonisolated DC-DC topologies. **Figure 8(a)** presents a DC-DC topology that could step up and step down the output voltage [58]. It is suitable for photovoltaic applications. For increasing the voltage gain, it uses dual coupled inductors in series. Also, it works on low-duty cycle for preparing high voltage gain.

Figure 8(b) proposed a high-gain DC-DC topology with parallel input and series output DC-DC topology. It has dual coupled inductors with a voltage multiplier [59]. The output of the converter is composed of interleaved series-connected capacitors while the input side is composed of two inductors that connect in parallel to share the input current and voltage ripple. This topology is used in both industrial and domestic applications. Proposed converter has normal switching stress, lower output voltage ripple and high voltage gain. **Figure 8(c)** shows a transformer-less high-gain DC-DC topology, as proposed in [60]. The advantage of this converter is low component

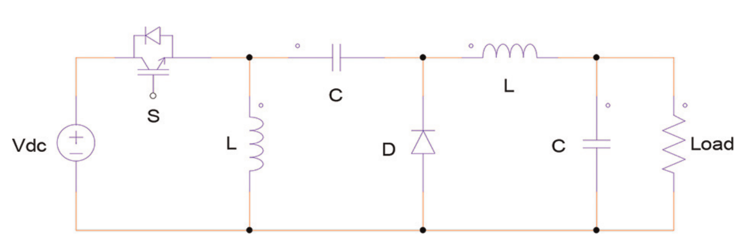

Figure 7.
Zeta converter.

Topology	Features	Benefits	Limitations
Buck Boost [18, 29, 45–47]	• Low complexity • Small size • Simple Control • Low Cost	• Suitable for low-power application • High switching frequency	• High output ripple • Discontinues output current
SEPIC [24, 25, 48–50]	• Low complexity • Small size • Simple Control • Low Cost	• Noninverting Output voltage • utilized as PFC	• Low voltage gain • Complex control in multiinput and multioutput
CUK [30, 31, 36, 51–53]	• Low complexity • Small size • Simple Control • Low Cost	• Suitable for low-power application	• Inverted Output voltage • Discontinues output current
Z-Source [31, 36, 37, 54, 55]	• Medium complexity • Small size • Simple Control • Low Cost	• Noninverting Output voltage	• Unidirectional power flow • Discontinues input current
Zeta [40, 45, 56, 57]	• Medium complexity • Small size • Simple Control • Low Cost	• Suitable for medium and high-power application • Noninverting Output voltage	• Unidirectional power flow
[58]	• Medium complexity • Small size • Complex Control • High Cost	• Noninverting Output voltage • Common ground • Renewable energy application	• Input conduction losses (Coupled Inductor)
[59]	• Medium complexity • Medium size • Complex Control • High Cost	• Noninverting Output voltage • Renewable energy application	• Unidirectional power flow
[60]	• Medium complexity • Medium size • Complex Control • High Cost	• Noninverting Output voltage • Renewable energy application	• Unidirectional power flow

Table 1.
DC-DC converter topologies compare.

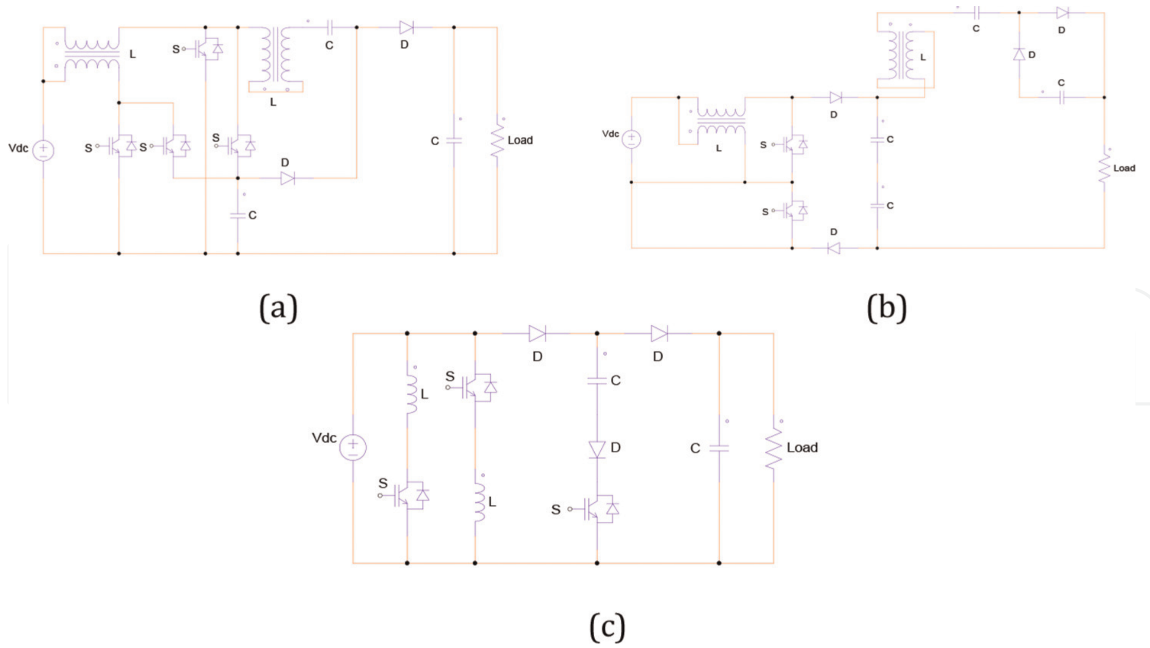

Figure 8.
Novel nonisolated topologies (a) [58], (b) [59], (c) [60].

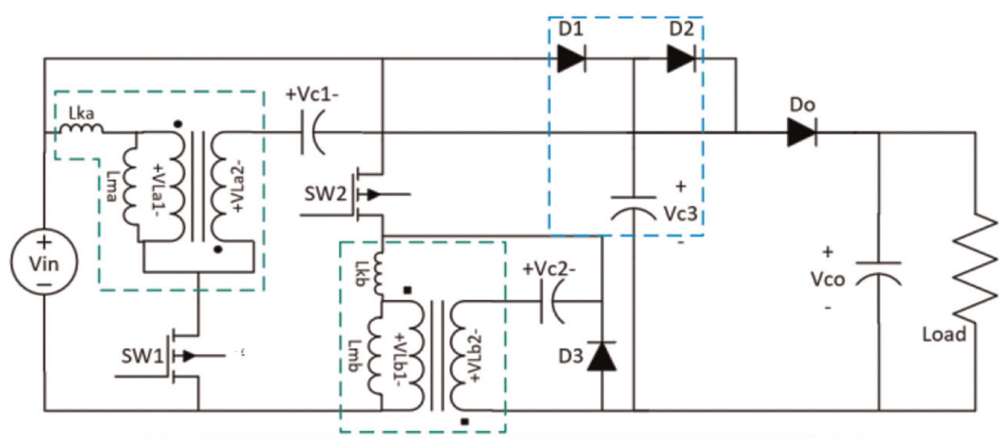

Figure 9.
Proposed topology of [1].

counts and high efficiency. This converter uses the component best which leads to higher voltage gain with lower component counts. So, it is not necessary to use circuits such as: voltage lift, voltage multiplier, and coupled transformers. This topology is used for DC-microgrid, and renewable energy systems like photovoltaic cells.

In [1], a novel step-up coupled inductor-based DC-DC converter has been proposed. The topology consists of two coupled inductors, and two power switches that work simultaneously. **Figure 9** shows the topology of the proposed converter. The conversion ratio of the converter can be expressed as:

$$G_V = \frac{V_o}{V_{in}} = \frac{3 + 2N_b + N_a}{1 - D} \tag{3}$$

where $N_a = {}^{V_{La2}}\!/_{V_{La1}}, N_b = {}^{V_{Lb2}}\!/_{V_{Lb1}}$ and D is the duty cycle.

Switching frequency	$f_s = 50\text{kHz}$
Coupled inductors	
$L_a = 196\mu H$	$L_b = 196\mu H$
$N_a = 1$	$N_b = 1$
Capacitors	
$C_1 = C_3 = 220\mu F/100V$ $C_2 = 220\mu F/50V$	$C_o = 1500\mu F/400V$
Switches & Fast diodes	
$S_1 = S_2 = IRFP150$ $(100V, 29A, R_{DS(on)} = 0.055\ \Omega($	$D_1 = D_3 =$ FR303 (200V, 3A) $D_2 = D_o =$ MUR840 (400V, 8A)

Table 2.
Parameters of the experimental setup of [1].

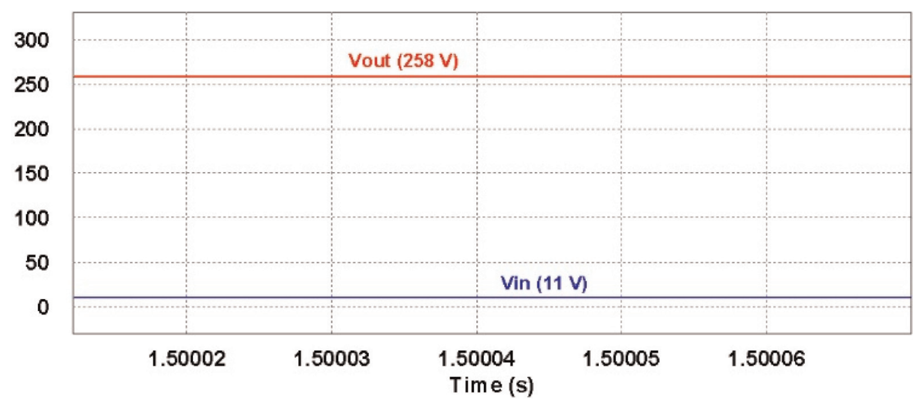

Figure 10.
Simulated input and output voltage of proposed topology in [1].

The proposed topology is simulated in PSIM software and the related results are shown in **Figure 10**. Real-time (experimental) results of the related topology with the parameters that are written in **Table 2** are shown in **Figure 11**. for the input voltage of 11 V. So, the voltage gain is 268/11 = 24.36.

3. Control techniques

Control techniques are essential for achieving maximum efficiency in DC-DC topologies because these techniques could optimize the operation of the converters. The parameters that we could control include: input and output voltage, duty cycle, and reference signal. For achieving the high voltage gain, the controller increases the duty cycle to step up the voltage and for achieving the lower voltage gain, the controller decreases the duty cycle to step down the voltage by considering the reference signal. All scenarios of the controller are applied to achieve optimum control on DC-DC converters to get the required output [61]. Features like response time, efficiency could be controlled by some control techniques [62, 63] but all features cannot be achieved simultaneously. Designer must trade off due to the special application.

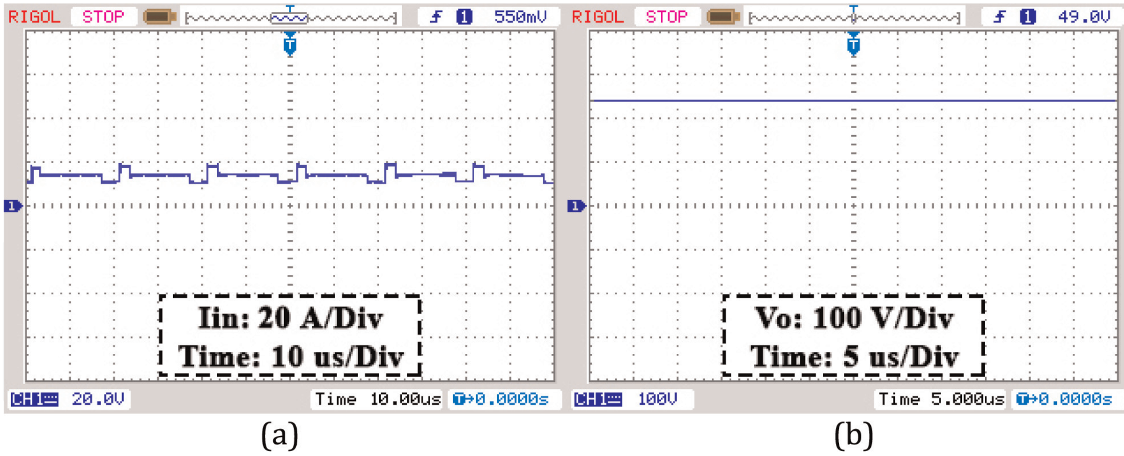

Figure 11.
Real-time results (a) input current, and (b) output voltage of proposed topology in [1] for input voltage of 11 V.

3.1 PID control

The first and the most common control technique that has been applied in industry is proportional integral derivate (PID) control which is accepted for various applications like motor drive and renewable energy systems. PID controller is preferred due to simple implementation and the robust response over a wide range of operating, as shown in **Table 3**. For controlling the DC-DC converter,

PID controller is conventional and effective technique that take the feedback signal from the output and control the duty cycle of the switch to achieve the required voltage gain. Its efficiency is constant in various applications. The main advantages of PID controllers are easy implementation and low complexity. Novel hybrid control techniques are proposed in [77] that improve the control and efficiency of system in renewable energy applications.

Controller	Features	Benefits	Limitations
PID [47, 52, 64, 65]	• Easy to Implement & Low complexity	• Fast transient response • Easy to combine with other control strategies	• High steady-state error and overshoot
SMC [52, 66–68]	• Robust & Nonlinear Control	• Fast Dynamic • Fast settling time • Robust	• Chattering Problem • Large Overshoot
MPC [47, 69–71]	• Robust & Nonlinear Control • Predict future state	• Fast Response • Efficient tracking	• Depends on parameters • High calculation
SSM [72, 73]	• Robust & Nonlinear Control • Suitable for MIMO systems	• Better transient response • Lower Overshoot by load varying	• Large initial time • Needs model details
FLC [73–76]	• Robust & Nonlinear Control • High Stability	• Low Overshoot • Efficient tracking response • Without mathematical model	• High calculation • Needs rules to operate • Large settling time

Table 3.
Control techniques compare.

3.2 Sliding mode control

Sliding mode controller (SMC) is a nonlinear discontinuous controller. SMC controller is suitable for applications that have external disturbances. To reduce the error between desired and output voltages, the system converges to the sliding surface. For continued stability, the system tends to slide on a sliding surface. The error found in this operation calls the chattering effect [66, 78]. Before the system tends to a constant sliding mode, the oscillation calls chattering effect. Mixing other control techniques with SMC leads to overcoming this problem. The principle of this control method is to reach the output signal equal or close to the reference value on the sliding surface. **Figure 12** shows the SMC control system on a DC-DC converter. The feedback signal is read by the SMD controller to produce the required signal and generate the switching signals.

3.3 Model predictive control

Novel control method that is not conventional is model predictive control (MPC). The principle of this controller is getting feedback to control algorithm. This controller method uses model of the system to predict the next state value to create suitable signals for controlling the converter [69]. MPC controller is capable to control multiinput, multioutput systems (MIMO). As an advantage, the MPC controller is a multivariable controller. MPC could manage the outputs and inside system parameters. Also, the MPC controller could combine with the minimization of cost function, operating cost, economic load dispatch and optimized power flow management.

Due to the intermittent changes occurring and uncertain behavior of the DC-DC converter, controlling the converter is a critical task. Implementation of model predictive control on DC-DC converter shown in **Figure 13**. Feedback from output signal of DC-DC converter with utilization of predictive control algorithm, predict the next state of the converter and send the related signal to operate the converter smoothly. Turbulences could occur in the input or output side of the converter.

3.4 State space modeling

The mathematical modeling of a real system by means of inputs, outputs, state variables, and equations is state space modeling (SSM). SSM of a real system is represented by state equations which are two types of equations that call state equations. The number of equations and the order of state space model depends on the number of inputs/outputs that include the physical system [80, 81]. The state space model is able to represent higher-order real systems in the time domain simply. Since

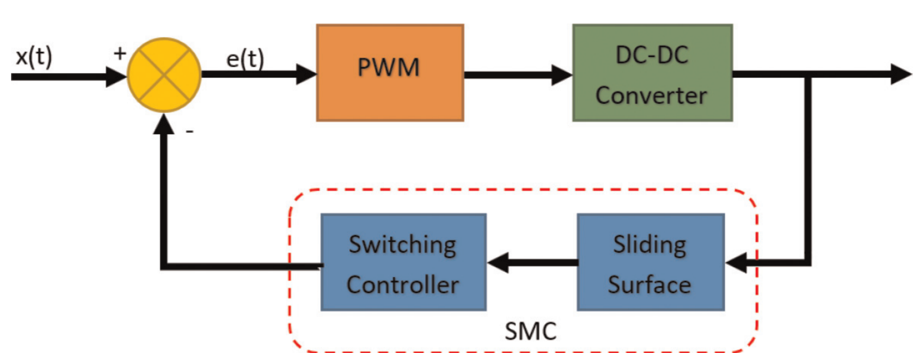

Figure 12.
SMC integration with DC-DC converter [25].

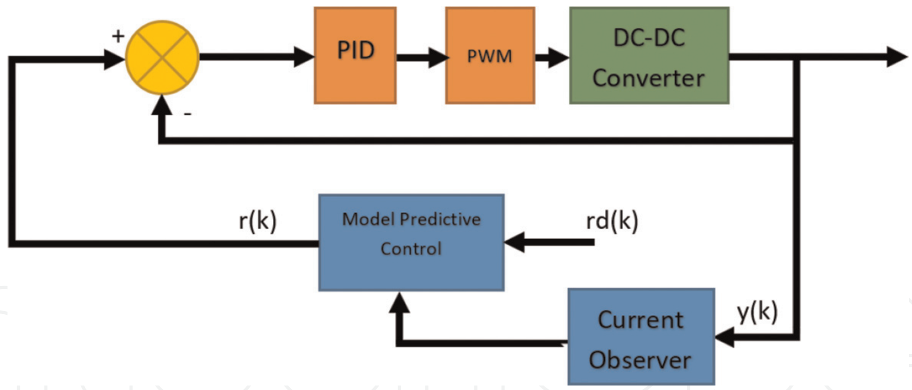

Figure 13.
Controlling of the DC-DC converter using the MPC control technique [79].

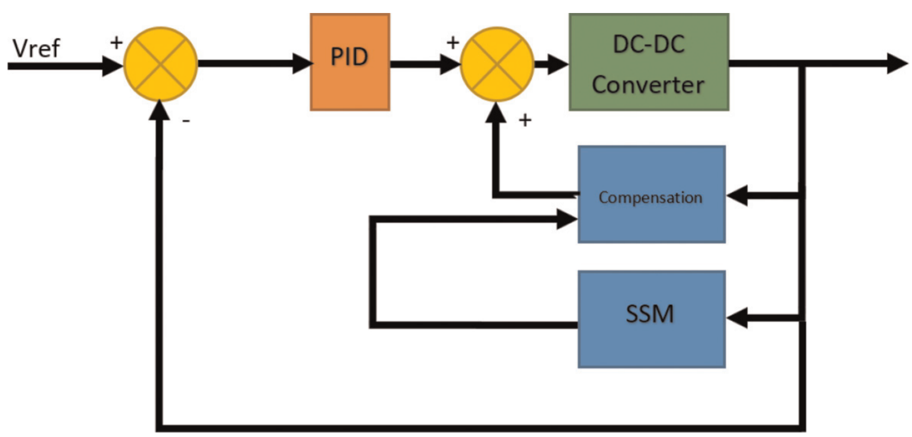

Figure 14.
SSM control for DC-DC converter.

just fundamental representations of real system are necessary for state space modeling, it can be used for nonlinear and multiinput, multioutput systems [51].

The operation of the state space modeling technique controller on DC-DC converter is shown in **Figure 14**. SSM is a mathematical controller that uses a mathematical model to control the system in different states that have higher efficiency compared to other methods. The advantage of this method is in reducing the order of complex system which leads to minimizing the computational time of the controller. Feedback control loop of state space modeling implemented on DC-DC converter is shown in **Figure 14**. In high-precision needed systems, SSM control is suitable.

3.5 Fuzzy logic control

The newest controller in category of nonconventional and nonlinear controllers is the fuzzy logic controller (FLC). FLC works like human thought process. Predefined rules are required to implement the human thought process. Membership function is lingual rules that define the input and output of the system. FLC does not need any mathematical model, so, it is much simpler than SSM and MPC. Also, the FLC controller could implement on nonlinear systems. FLC controller takes the feedback of system's crisp value, change it to lingual form and compares it with the membership functions which calls fuzzification. After the process, convert the lingual phrases back to the crisp value that is named defuzzification. For nonlinear control systems that

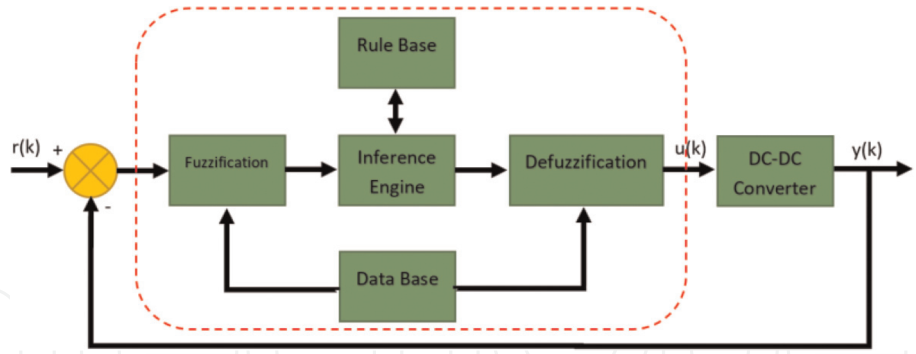

Figure 15.
Fuzzy logic control for DC-DC Converter [76].

have vague boundary conditions, FLC has an efficient response. The disadvantage of this control method is higher computational time. To resolve this problem, FLC is combined with other control techniques and works in offline mode [74].

Because of the higher effectivity of the FLC controller, it could be used in domestic and industrial applications. In [82, 83], an FLC controller applied to automatic car brake system charge controller in electrical vehicles. Also, in [84] it is used for controlling of marine surface vessels and underwater vehicles. On the other hand, FLC is used for industrial applications and the power generation systems [75, 85, 86]. In a grid-connected inverter, the FLC controller is used for multiinput DC-DC converter to operate it in boost mode [87]. In [88], FLC implemented on integration of photovoltaic panels (PV) with SEPIC topology to increase efficiency. The control algorithm of a DC-DC converter by FLC is shown in **Figure 15**. The feedback of controller can be obtained from the output of DC-DC converter.

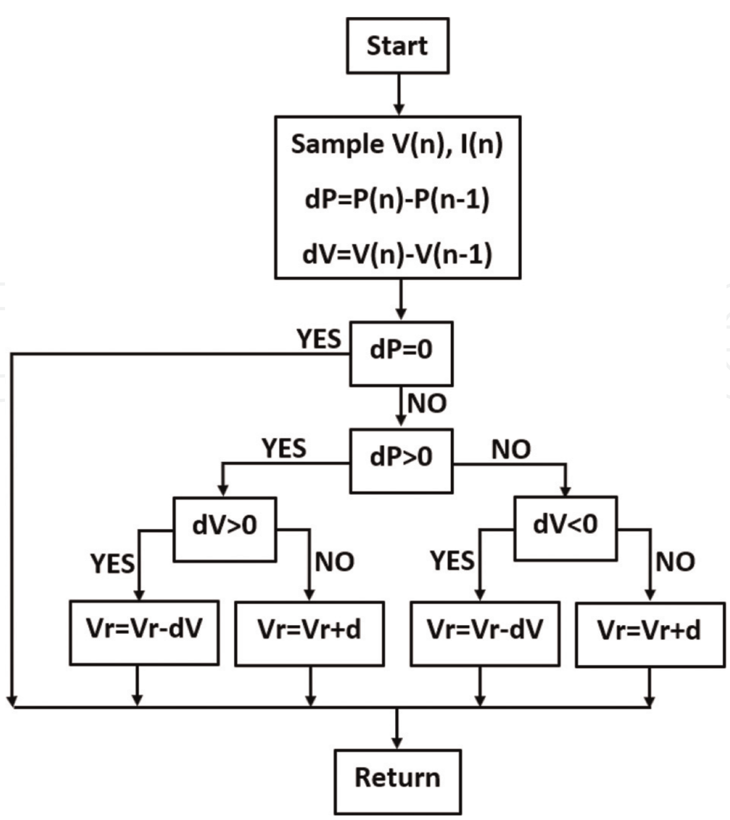

Figure 16.
Algorithm of P&O.

3.6 MPPT Algorithm

To improve the efficiency of photovoltaic energy systems, PV modules must operate at maximum power points to deliver the maximum power to the load. Some MPPT techniques are used to deliver the maximum energy of solar to the load and batteries. Different techniques of maximum power point tracking methods have been proposed like open circuit voltage method [89, 90], short circuit current method [91, 92], fuzzy logic method [93, 94], perturb and observe method [95–97], and incremental conductance method [98–100]. The most popular method is perturbed and observes (P&O) method that its algorithm is shown in **Figure 16**. In this method, a small perturb on duty cycle is applied to cause power variation and the output power of PV is measured. If the new measured power is higher than the last measured power the perturbation is continued in this direction otherwise the perturbation is continuing in the reverse direction. In this algorithm, when voltage increase leads to an increase in the power, it means that the operating point of modules is on the left side of the peak of MPPT diagram and when voltage increase leads to decrease in the power, it means that the operating point of modules is on the right side of the peak of MPPT diagram.

4. Conclusions

The purpose of this research work is based on the performance study of DC-DC converter topologies that are applicable in renewable energy systems. Advantages and disadvantages of converters are discussed with their applications. Also, the advantage and disadvantages of control methods and stability of converters with related control methods in renewable energy application are explained. Both conventional and novel DC-DC converters are discussed in this chapter with their advantages and disadvantages. The buck-boost, Cuk, SEPIC, Z-Source, and Zeta topologies in conventional category and some new proposed topologies in novel category are explained. The converters are compared in terms of voltage gain, voltage stress over switches and diodes and the number of components.

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