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The overview of Non-isolated dc to dc converters

***Abstract**. DC-to-DC converters are Today widely used in power conversion systems that demand a continuous source and a continuous output, and the most prominent of these systems is the photovoltaic panels system, where dc-dc converters have become an integral part of this application, thanks to the advantages offered by dc-dc converters in this application as stability The system and performance improvement, as well as raising or lowering the output voltage compared to the input voltage, and increase the efficiency of the system and achieve the maximum power point that can be produced from photovoltaic panels by application of MPPT in addition to the ability to provide a fixed output voltage in the case of a variable input voltage due to natural factors such as a change in radiation and temperature. In this study, we describe Buck, Boost, Buck-Boost, CUK, and Zeta Converters, which are the most significant non-isolated DC-DC Converters that are frequently utilized in solar energy systems. This paper also provides an overview of recent studies for each converter; we also present a comparison between these converters, highlighting the most notable benefits and drawbacks of each converter.*

***Streszczenie.** Przetwornice DC-DC są obecnie szeroko stosowane w systemach konwersji energii, które wymagają ciągłego źródła i ciągłej mocy wyjściowej, a najbardziej znanym z tych systemów jest system paneli fotowoltaicznych, w którym przetwornice DC-DC stały się integralną częścią tej aplikacji , dzięki zaletom oferowanym przez przetwornice dc-dc w tej aplikacji, jak stabilność systemu i poprawa wydajności, a także podniesienie lub obniżenie napięcia wyjściowego w stosunku do napięcia wejściowego oraz zwiększenie wydajności systemu i osiągnięcie maksymalnego punktu mocy które można wytworzyć z paneli fotowoltaicznych poprzez zastosowanie MPPT oprócz możliwości zapewnienia stałego napięcia wyjściowego w przypadku zmiennego napięcia wejściowego spowodowanego czynnikami naturalnymi, takimi jak zmiana promieniowania i temperatury. W tym badaniu opisujemy przetwornice Buck, Boost, Buck-Boost, CUK i Zeta, które są najważniejszymi nieizolowanymi przetwornicami DC-DC, które są często wykorzystywane w systemach energii słonecznej. Ten artykuł zawiera również przegląd ostatnich badań dla każdego konwertera; przedstawiamy również porównanie tych konwerterów, podkreślając najważniejsze zalety i wady każdego konwertera. (**Przegląd nieizolowanych konwerterów prądu stałego na prąd stały**)*

Keywords: Non-isolated converters, DC-DC Converters, Buck-boost converter, SEPIC Converter.
Słowa kluczowe: Przetwornice nieizolowane,Przetwornice DC-DC, Przetwornica Buck-boost, Przetwornica SEPIC

Introduction

Fossil energy is nearing of extinction, as well as hazardous to human health due to the emissions from burning fossil fuels, and has caused environmental damage and contributed significantly to global warming due to the gases generated.Due to this, the world today is attracted towards renewable energies, or as it is also called clean and environmentally friendly energies to achieve sustainable development, as its main source is nature, and dependence on it limits gas emissions such as carbon dioxide and environmental pollution , as it is inexhaustible energy that is renewed daily, for example, energy Wind and solar energy. Photovoltaic energy is the cleanest renewable energy, the most environmentally friendly, and the most in demand due to its simplicity, reliability, ease of control, and does not require much maintenance. However, the latter suffers from low and unstable output voltage due to natural factors as well as an energy storage issue. To overcome these challenges, researchers directed to use of converters DC to DC.

Various renewable energies applications use DC-DC converters, especially PV applications, as these converters are the beating heart of this system due to the advantages they provide such as reducing or raising the voltage/current produced by photovoltaic panels according to the requirements of the system, and facilitate the possibility of using MPPT techniques, achieves a regulated and stable output voltage regardless of the input voltage fluctuations due to the natural factors affecting the solar panels, Moreover, the employ of DC to DC converters Contributes to overcoming challenges of energy storage and battery charging in renewable energy applications. Converters operating in a direct current system can be classified into two main types. Firstly, the isolated converters operate efficiently in a wide range of voltages and at high frequencies. Secondly, non-isolated converters, operate at lower voltages and at lower frequencies. More clearly, in low or medium-power applications it is preferable to use the second type, whereas in the case where power requirements are medium or high-power the first type will be more appropriate for its ability to meet the requirements of these applications.

This study focuses on a range of non-isolated converters widely used in the PV world that include the buck, boost, buck boost, the Cuk, and the SEPIC "Single-Ended Primary Inductor Converter", and finally zeta converters, which are the most commonly used in solar energy applications. A detailed and comprehensive definition is presented with operating principle of each converter in addition to an overview of some recent studies conducted on each of these converters, in addition to highlighting the most essential benefits and drawbacks of each converter. This paper is structured on the following necro, sections: II. What are the DC to DC converters?, Section III is non-isolated dc-dc converters, a Commentary about non-insulated DC converters , and finally a Conclusion of this paper.

What is the dc-dc converters

The DC to DC Converters are essentially electronic devices that are supplied a continuous electrical voltage and create a continuous electrical voltage [1] adjusted to be higher, lower, or equal to the voltage's input, this is according to demand. DC to DC Converters have the ability to operate in very low to very high power applications. In solar applications, The DC to DC Converters play a vital and major role by functions as matching the impedance, which ensures efficient transfer of energy between the photoelectric panels and the load.

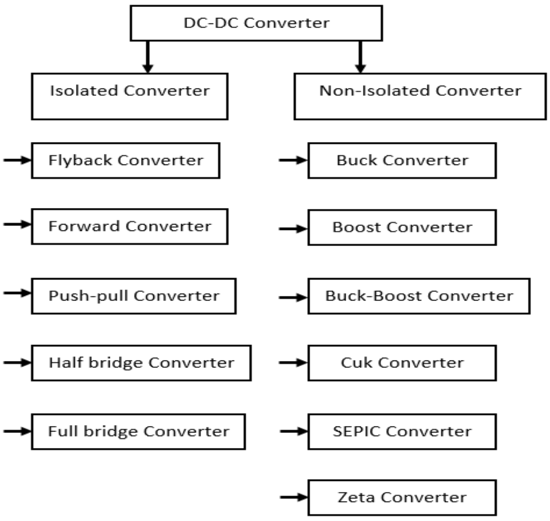


Fig.1. Types of DC-DC converters.

Non-isolated DC-DC converter

Non-isolated DC-DC converters refer to in which the inputs and outputs are coupled in a single chain and are not separated by isolation, allowing current to flow from the source directly to the load. It is characterized by uncomplicated installation, small size, low cost [3] in addition to the ability to control it simply, In addition to good efficiency. However, it prone to issues such as both current and voltage ripples and high switching pressure on the switch. Also, this type cannot be used in high-power applications, i.e. working under high switching frequencies means an increase in power losses for these converters [4] and thus a decrease in converter efficiency. In this case, it can be said that non-isolated converters do not provide safety and become very susceptible to damage, and cannot operate in a high switching frequency range. In the following points, we present the concepts of these converters and the principle of their operation with an overview of recent studies in this field.

Buck DC-DC converter

The dc buck converter is used in direct current applications and its objective is to provide a regulated output voltage and a lower value compared to the input voltage [5][6]. Step-down converters are another name for this type of converter [7].

The following parts make up a dc buck converter circuit: a power switch (S), a diode (D), an inductor (L), a capacitor (C), and a load (R), as shown in Fig. 2. A high voltage PV array can be connected to a low load or battery voltage using a buck converter [8].

The buck converter is operated in two modes. The first occurs when a power switch is turned on. The input current passes through the inductor, capacitor, and load resistor R. When the power switch is switched off in the second situation, the free diode is connected, and current flows in a closed circuit through the inductor, diode, capacitor, and load.

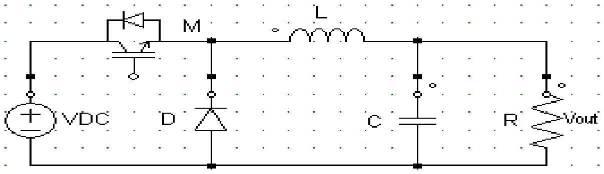


Fig.2. Buck DC-DC converter

In a study conducted by Andoni Urtasun [9], the Two-Input Buck converter was proposed as an ideal DC/DC stage for PV cascaded converters. The converter demonstrates the ability to achieve dual MPPT using only one power switch, resulting in a cost-effective and reliable system. With an impressive efficiency of up to 99.7%, the Two-Input Buck converter offers significant advantages. Furthermore, to address the complex control requirements arising from the nonlinear PV arrays and converter coexistence, a novel control scheme was introduced to regulate the two input voltages, facilitating simultaneous MPPT for both arrays. The effectiveness of this approach was validated through simulations and experimental analysis, as documented in the same reference.

In a publication [10] presented a buck converter specifically designed for PV panel applications, incorporating soft switching cells. The suggested converter allows for the realization of zero-voltage-switching (ZVS) characteristics for the main and auxiliary switches because it incorporates an active soft-switching cell. This design adds a significant reduction in freewheeling diode reverse-recovery losses during turn-off transitions. Consequently, This enhancement reduces switching losses, pressures on active switches, minimized EMI, and improves overall switching efficiency.

In the paper [11] a two-switch synchronous buck converter (SBC) is proposed for each sub-module of a PV module, Furthermore, the authors of this paper apply distributed maximum power point tracking (DMPPT) control, which assures optimal output power extraction even when mismatch conditions exist. The study used a perturb and observe-based, two-step sub-module DMPPT algorithm, which significantly lowers costs and boosts system performance and efficiency.

The paper[12] by Z. A. Ghani et al, suggests the creation of a dc buck converter for PV applications utilizing the PIC16F877A microcontroller, This converter's control algorithm is designed that aims to specify a certain input voltage range, such as 18V to 12V, assuring consistent regulation of the output voltage within the desired range. The controller uses the input voltage as the feedback parameter. They simulated the system in the PROTEUS ISIS Professional software environment also tested a prototype buck converter in a laboratory setting. The outcomes confirmed the effectiveness of the control algorithm and its applicability for real-world applications by demonstrating the system's capacity to consistently stabilize the output voltage at the intended level.

For the control of photovoltaic dc converter, researchers presented in work [13] a dual RPWM technique (RSFM-RPPM), with the aim of minimizing conducted electromagnetic interference (EMI) coming from the PV source side and reducing power harmonics. the suggested strategy uses a model to efficiently analyze the effectiveness of the method by analyzing the input current's power spectrum and lowering its amplitude. In comparison to basic RPWM and conventional DPWM approaches, the results from the study's generic mathematical model demonstrate that the suggested dual RPWM strategy produces superior power spectral density (PSD) spreading with smaller amplitude peaks, As a result, this technique offers a significant advantage in terms of electromagnetic compatibility (EMC), which is demonstrated by analyzes of the input buck current and the PV solar current.

Teguh Tri Lusijarto et al in the paper [14], Presented modeling and simulation of a buck converter for a freestanding solar power system meant to support low-power DC loads without the usage of batteries. closed-loop control with a VCM-based PI controller was constructed for To keep the output voltage at 12V despite fluctuations in solar radiation from 600 to 1500 W/m2. The buck converter's capacity to sustain the desired output voltage under fluctuating radiation levels was validated by simulation results.

In the study [15], N H Baharudin et al analyzed the DC-DC buck converter used in renewable energy applications. Decrease in DC voltage from a high level to a low level is accomplished using this converter. By adjusting the duty cycle of the buck converter the required output voltage is provided.

Kanhu Pul and Monalisa Pattnaik presented the design and execution of a synchronous buck converter for a freestanding photovoltaic (PV) system in their work [16]. where this converter was controlled by a microcontroller-based circuit utilizing the Arduino UNO platform that contains the maximum power point tracking (MPPT) algorithm. The converter's performance was evaluated through testing in both open-loop mode, where a range of switching frequencies and duty cycles were tested, and MPPT mode, which used an enhanced step size Perturb and Observe algorithm to minimize oscillation around the maximum power point. the experimental findings showed an amazing converter efficiency of up to 97%, While drastically reducing current ripple.

Ferran Reverter and Manel Gasulla concentrated in the paper [17] on the efficiency of a DC buck converter working in burst mode (BM), while adjusting the operational point of two low-power PV modules under varying irradiance levels. This converter uses an optimum inductor current value to efficiently transmit PV panels' energy is successfully to a storage unit. The researchers' findings showed that, in contrast to conventional converters, where efficiency normally rises with radiation, this converter's efficiency does not necessarily follow a linear pattern as radiation levels rise.

DC converters are critical they operate as power processing units that allow input voltages from PV sources to be adjusted to satisfy the needs of batteries, loads, and inverters. Walid Merrouche and colleagues in [18] provided an in-depth pulse-width-modulated (PWM) buck converter's description utilized in a PV controller to successfully control energy flow inside a self-contained PV system. The study includes detailed the converter's schematic, component specifications, and extensive testing, both static (conducted without PV sources) and dynamic (conducted with PV sources), to assess its performance. Where the results showed higher error rates in dynamic tests than those obtained in static tests, and this refers to the PV panel's dynamic properties.

PWM buck converter incorporating a low-stress zero-voltage transistor (ZVT) with a soft switching is proposed by L.Ashok Kumar et al in the paper [19]. This new design is intended to reduce component stress and conduction losses by minimizing the voltage and current stresses associated with resonant converter capacitors. The researchers presented a detailed model and simulation of the novel converter (ZVT PWM) using PSIM Software, A comparison of the results revealed that the zero-voltage revealed switching (ZVS) resonant buck converter had higher switching losses, while the proposed ZVT PWM converter had lower losses.

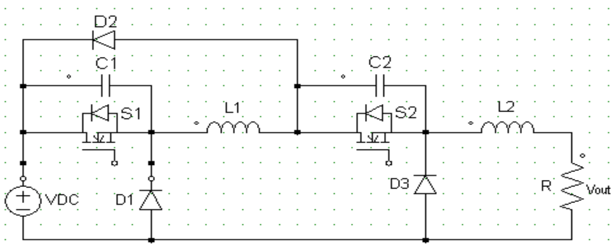


Fig.3. Proposed converter in [19]

While in the paper [20] the authors propose a DC-DC Buck converter that is controlled using adaptive predictive (AP) techniques, this method's main objective is to effectively regulate the converter's output voltage, ensuring accuracy and stability even in the presence of frequent disturbances in the operation of the converter like input voltage variation, swift changes in the reference command voltage or potential flaws in the buck process parameters; through the use of adaptive and predictive algorithms. One significant advantage of the proposed control approach over existing controllers is that the AP control system can infer the plant's parametric condition online owing through its adaptive stage. In order to improve the efficacy of the control strategy's closed-loop control and the adaptive mechanism's (AM) dynamic behavior, a hysteresis modulator's (HM) dynamic is also strategically added. To validate what was discussed, the researchers implemented your proposed adaptive and predictive control approach in a benchmark experimental platform. The results demonstrate the excellent performance of the proposed method, and its ability to rapidly control with variable load, input, and reference voltage circumstances.

In another study, researchers presented in [21] evaluated the photovoltaic (PV) modules' power output when combined with a DC-DC buck converter for effective solar energy consumption. The primary focus of their study was to investigate the efficacy of utilizing a PID control strategy to optimize the output power and ensure the stability of the DC voltage at a predetermined level. The proportional, integral, and derivative terms are integrated by the PID controller, which dynamically modifies the control inputs based on the error signal. The PID controller eliminates output power variations and maintains a constant DC voltage level through continuous monitoring and control parameter adjustments. The outcomes show that incorporating PID control in the buck converter arrangement led to notable gains, resulting in a voltage rise of 6.2V, a current increase of 0.76A, and a noteworthy power improvement of 13.85W.

The authors of paper [22] proposed to use NNPC (neural network predictive controller) as a novel technique for buck converter voltage regulation, where the NN is the core component of the controller. This groundbreaking research addresses the shortcomings of conventional controllers and makes use of NNs' strength to achieve the best possible control performance. Model predictive control (MPC) advantages and precise system modelling with neural networks are combined in the NNPC. In contrast to linearized models, The NNPC successfully manages uncertainties and nonlinearities to guarantee reliable voltage control. The NNPC gets over the performance restrictions brought on by inaccurate or flawed models by training the neural network to predict the system model appropriately. This guarantees stable voltage regulation even when there are difficult operating circumstances and disturbances. The researchers proved the NNPC's superiority to conventional controllers like PI or PID through simulations. The NNPC outperformed its rivals in terms of control accuracy and stability. This notable gain is credited to the NNPC's proficiency in managing nonlinearities, which provides improved control precision and performance in voltage regulation jobs for the DC-DC converter system.

Boost DC-DC converter

The DC-DC boost converter enables to convert of the low source voltage i.e. a low input voltage to a larger output voltage and regulator. This converter also referred to as a step-up converter, has been utilized in a variety of power applications, including regulated DC power supplies [23] and PV systems. There are two current operation modes of the converter: discontinuous current mode (DCM) and the continuous current mode (CCM)[24][8], where In CCM, the inductor current is nonzero throughout the cycle as opposed to DCM, where it becomes zero after each cycle.

The key parts of a DC-DC boost converter are a power switch (S), a diode (D), an inductor (L), a capacitor (C), and a load resistor (R). Together, these components increase the output voltage by boosting the input voltage. A boost converter's configuration is shown in Figure 4.

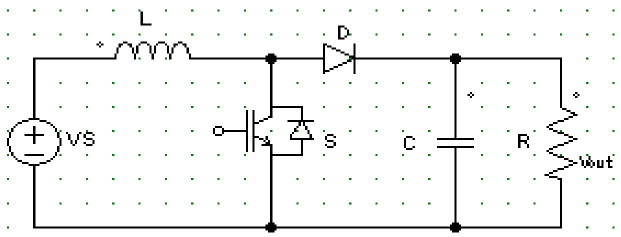


Fig.4. Boost converter

Two alternative modes of operation exist for the boost converter. When the switch is turned on, the diode is reverse-biased in the first mode [23]. Therefore, the inductor stores energy and VL=Vi is achieved. The induction increases current linearly. While in the second situation, when the switch is off, the diode becomes forward-biased, and the capacitor and load receive the inductor's stored electrical energy [8]. And the inductor voltage during this case is given by Vl=Vi-Vo.

In the paper [25] the authors propose a control for a boost converter aimed at optimizing power tracking from PV modules by using Fuzzy Logic. PV cells have non-linear properties, and their optimal power point is affected by solar irradiance and temperature. They used Fuzzy logic because it could solve problems with non-linearities and uncertain information. Even under variable irradiation and temperature settings, experimental implementation of the suggested converter shows its great performance and efficacy. The outcomes demonstrate that the controller is capable of maximizing power extraction from solar panels.

In the paper [26] the authors present the approach combining the Particle Swarm Optimization (PSO) technique with a PI controller for improving the efficiency of photovoltaic (PV) panels; where different addresses disturbances that may affect the regular operation of the PV panel using PSO techniques. The PI controller reduces steady-state errors and speeds up response time. This control strategy offers a variety of advantages, including higher tracking speed and accurate tracking of the Maximum Power Point (MPP), enhanced stability under varying environmental conditions.

To assure a DC microgrid's stable operation, the authors in the paper [27] proposed a control architecture for a boost converter operating in Continuous Conduction Mode (CCM) was developed, Their method combined Sliding Mode (SM) voltage management with Pulse Width Modulation (PWM) to assure stable functioning. The strategy has been applied to consider a microgrid setup. To assess the effectiveness of their suggested PWM-based SM voltage control for the Dual-Boost Dual-Buck Converter (DDBC), performed MATLAB simulation. The simulation results showed that the suggested control approach successfully controlled the DC bus voltage of the DDBC, confirming the dependability and effectiveness of PWM-based sliding mode control for upholding steady voltage in a microgrid.

The authors in the paper [28] presented a basic boost converter constructed in MATLAB/Simulink. Circuit switching was accomplished by the use of PWM pulses. A comparison was made between the converter connection with MPPT technology and the converter integrated with the PV system directly. According to the results, the output voltage was improved using the MPPT control algorithm, where MPPT ensures the optimal power extraction independent of the load or the weather.

In the paper [29] Miguel Ángel Abundis Fong et al presented, a boost converter that runs in both Island mode and Network mode while supplying power to a load that is controlled by an average current mode. The Boost converter's purpose to solar panels' increased and controlled output to power a single-bridge full-bridge inverter. The PI-type voltage and current loop controllers were used in their paper. They performed simulations to ensure the correctness of these controllers so that the results revealed compliance with the required settling time and maximum overshoot criteria during the transient response to input disturbances.

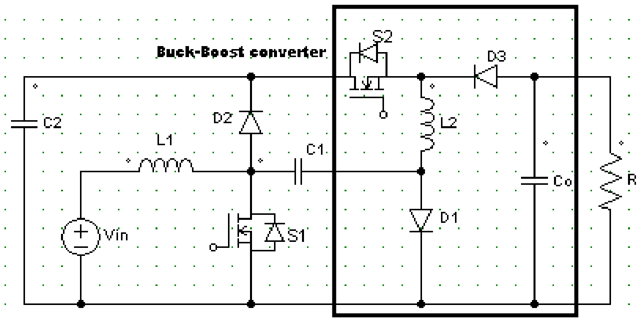


Fig.5. Buck –boost converter.

S. Belhimer et al give simulations and practical testing of new hybrid boost architecture for a DC converter in their paper [30]. This topology mixes conventional and quadratic boosts (CB)/ (QB). Two operating modes—QB mode and CB mode—were used in the study to assess the P and O MPPT algorithm's performance. The simulated system was evaluated under rapid changes in solar irradiation. Both modalities have successfully undergone simulation and experimental verification. The results appear to be quite promising, demonstrating that hybrid boost can be useful in photovoltaic applications.

A method for calculating the parts of an MPPT boost converter was introduced by the authors of [31], By considering the converter's perceived resistance as being the same as PV module's perceived resistance; while the PV module serves as a non-linear input source. The allows's derivation to generate easy equations for calculating both the input and output capacitance and inductance, It also enables modifying the ripple factor and duty cycle in order to meet specific requirements while overdesigning the system is avoided f the MPPT boost converter and thus minimizing the costs of and size. The suggested derivation enables more accurate estimates for the MPPT boost converter based on the condition's ideal and continuous current mode.

Buck-boost DC-DC converter

A DC-DC buck-boost converter topology combines the functionalities of both buck and boost converters [32]. This converter type is capable of either increases or decreases the input voltage. Step-up/down converters are another name for it. this type is used in many power applications, such as photovoltaic PV systems. This converter is more capable than both buck and boost converter[33].

the converter includes a number of crucial parts namely a power switch, an inductor, a diode, a capacitor, and a resistance, These parts work as a unit to operate the converter.

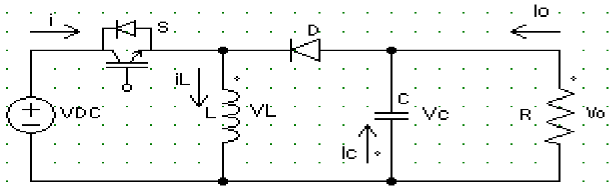


Fig.6 The proposed Buck-boost converter.

There are two states for operating the Buck-boost converter. In the first state, S is activated, while the diode reverse-biased. At this point, the current passes via inductor L and switch S causing the rise of inductor current. In the second situation, when the switch S is turned off, the diode still permits the inductor current to flow. Thus transferring energy stored in the pre-stage to the load, while decreasing the inductor current until switch S is reactivated.

In the paper [34] the authors present a novel non-isolated buck-boost DC-DC converter with a wide range of conversion ratios and Continuous Input Current for PV Applications. This proposal is shown in Figure 6. The aim of this transformer is to overcome the low shunt ratio and intermittent input current as the constant input current of the transformer makes it more demanding for industrial and renewable energy applications. Moreover, it also aims to achieve high efficiency and low cost. The operating principle of this DC-DC converter, its steady-state analysis as well as small signal modelling are presented in detail in this paper. To verify the validity of this topology, the authors made a prototype where In step-down or step-up mode, the input voltage is Vin = 22 V, and the output voltage is Vo = (18 or 110 V) respectively, with fs = 100 kHz. The results proved its good ability to work in step-down and step-up modes and good dynamic response. According to the authors, the suggested converter's efficiency is respectively 91.2 and 89 percent in step-up and step-down mode, with a maximum efficiency of 93.9 percent in step-up mode and 0.6A output current. This topology is characterized by uninterruptible input current and high step-up voltage gain. A set of buck-boost DC-DC converters from previous studies were compared to the proposed topology, based on the following parameters: the number of components, voltage gain, and voltage stress of switches and also the type of input current if it is continuous or intermittent.

In the study [35], the authors presented the design, analysis, and simulation of the PI controller of the Buck-Boost dc-dc converter in order to address the output voltage ripple problem so that the load voltage amplitude is maintained through the PI controller, whether in the case of constant or variable input voltage. The authors simulate this work in two cases (when the input voltage is constant and also when the input voltage is variable) and through the results, in both cases, the output voltage is identical to the reference voltage with a small output voltage ripple, less voltage overshoot and a quick transition time.

In the study [36], the authors introduce a Soft-Switching buck-boost converter ZVS by adding a single inductor Lr and a capacitor Cr compared to a conventional buck-boost converter. See Figure 7.

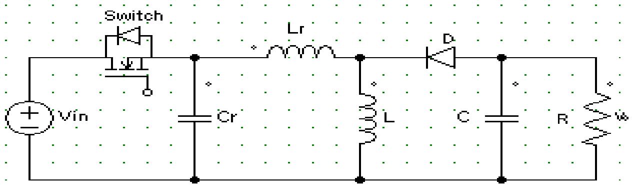


Fig.7 The Buck-Boost circuit proposed in [36]

The proposed structure was designed and discussed. This new topology aims to overcome the disadvantages of hard-switching of conventional converters and achieve soft switching without using auxiliary switches, which means reducing and controlling switching losses and thus improving the efficiency of the proposed converter .this topology can be utilized in PV systems that have a resistive load. The authors presented a simulation and a prototype of the Soft-Switching buck-boost converter ZVS with a capacity of 200W, and through the results, the ZVS was achieved and the required output voltage was also provided, and this proves the validity and efficiency of this topology.

A New High Gain Single-Switch DC-DC Buck-Boost Converter with Continuous Input and Output Power is discussed and analyzed by the authors in ref [37]. The suggested Converter for grid-connected renewable energy applications is shown in Figure 8.

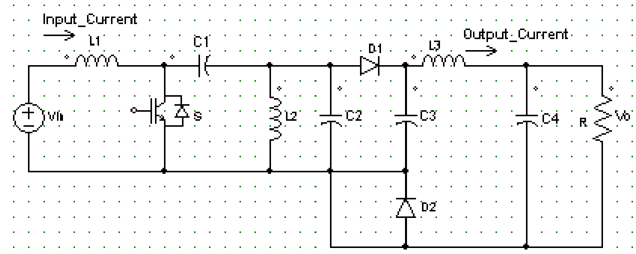


Fig.8 Proposed buck-boost converter architecture [37]

The converter's principle functioning is explained in detail. This suggested topology has better voltage gain than standard buck-boost, Cuk, SEPIC, and ZETA converters, no galvanic isolations or linked inductors are needed, and it delivers continuous input and output power by using two inductive filters; L1 at the inputs and L3 at the outputs. The suggested converter also has minimal voltage strain over the switch and diodes. The authors simulated the proposed Converter in the buck mode and in the boost mode to ensure the validity of the theoretical analysis, so that the input voltage is 20 volts and the output voltage for both the buck mode and the boost mode 15volts and 50volts, respectively, while the switching frequency is 33 kHz, and the results proved that the input power and the output of this converter in both modes work continuously and this is thanks to the input and output inductors have a constant current in both modes, which helps to smooth the power, Thus this structure is a suitable option for renewable energy applications connected to the distribution network.

The authors of the paper [38] discuss MPPT for PV DC-DC buck-boost converters using the Perturb & Observe (P&O) algorithm and the Fuzzy Logic Controller technique

FLC. Both algorithms' performances were compared and evaluated. Both techniques were evaluated using a 100W PV module (Solar Alpex Panel 1552P-3613G-166109) connected to a buck-boost DC-DC converter in MATLAB-Simulink. Through the simulation results and their comparison, it is shown that the FLC algorithm achieves higher MPP tracking, good performance with a buck-boost DC-DC converter, fast response, and more stability compared to the Conventional P&O algorithm.

In this paper [39], the authors discuss the analysis, design, and simulation of a proportional integral differential PID of a buck-boost converter. The goal is to provide a well-regulated output voltage regardless of load changes and parameters. The authors discuss the buck-boost converter's mathematical model as well as the construction of the quantum module in detail. The authors tested the studied work by simulating it on Matlab/Simulink and making sure of its validity and its conformity with the theoretical analysis with input voltage Vi=24V and reference voltage Vref=48V. The results have proven that the system studied in this paper achieves a regulated voltage and follows the reference voltage Vout=48V. Moreover, the dynamic response of the proposed system and its durability against changes in the input voltage or load and parameters are improved, and the output voltage is also kept regulated, which improves the converter's efficiency.

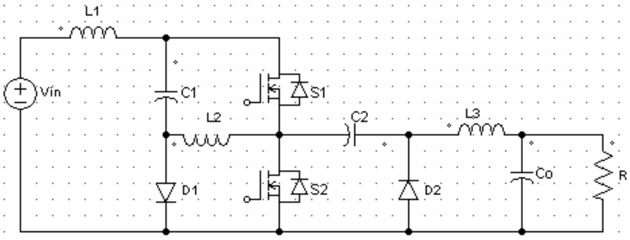


Fig. 9 Proposed Quadratic buck-boost converter

The authors of the paper [40] proposed a quadratic buck-boost converter for solar applications with continuous input/output current and positive output voltage. Figure 9 shows this converter.

This topology aims to provide a continuous input and output current and also achieves a square voltage gain, ie equal to the square of the conventional converter voltage gain, in addition to a positive output voltage. All of this contributes to reduce the current pressure on the input and output filters, which means reducing their size in addition to reducing the output voltage ripple. Therefore, it can function over a wide variety of output voltages. The suggested converter is more suited for renewable energy applications. The proposed converter's operating principle and small-signal modelling are thoroughly discussed and validated using PLECS simulation. In this work the authors present the suggested converter compared to current quadratic buck-boost converters by concentrating on the number of components, voltage stress on switches and diodes, input and output current types, output voltage polarity, testing results, and conclusions. The comparison revealed that the proposed converter has a continuous input and output current, as well as a positive output voltage polarity, in contrast to the other converters listed. To verify and confirm the validity, performance, and efficiency of the proposed converter, The authors built and tested a prototype in boost and buck modes with the input voltage Vin = 24 V and output voltage VO = 12–48 V, as well as fs = 60 kHz and load value R = 12–48Ω Through the results, the validity and effectiveness of this new topology has been proven, as it is characterized by a continuous input current as well as for the output current, and also a positive and regulated output voltage The required value is achieved whether in the step-up mode VO = 48 V or step-down VO = 12V using the PI controller. According to the authors, the efficiency of the experimentally proposed converter reaches 90.9% in the step-up mode, while in the step-down mode it reaches 86.6%.

The authors of the paper [41] investigate and develop a double-switch Buck-Boost converter, which they simulate with a photovoltaic system. The photovoltaic system studied here uses two types of converters, the first for the purpose of tracking the maximum power point MPPT, which is a Single Ended Primary-Inductance Converter (SEPIC), and the second is the proposed double switch Buck-Boost converter, which uses two power switches Q1, and Q2 that are controlled by pulse width modulation (PWM) signals so that this proposed structure regulates the output voltage to a fixed value, whether with fixed or variable input values, by employing an algorithm that assures consistent output voltage under different weather circumstances. Figure 10 depicts a suggested dual-switch Buck-Boost converter.

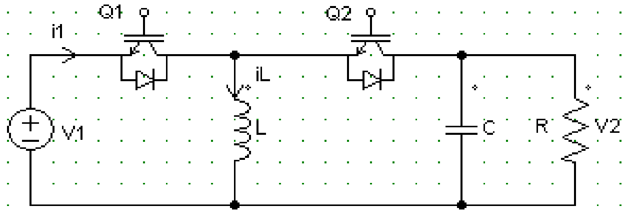


Fig.10 The proposed double switch Buck-Boost converter

This topology has the benefit of achieving effective energy transfer while eliminating the hazards of over-voltages that can have a negative influence on the load. Furthermore, the converter's and the system's overall efficiency are increased. The authors presented simulations of the proposed converter with an open-loop mode without regulation and then with a regulated output mode and the results revealed that the regulated output voltage mode gets better and faster reaction outcomes when the input voltage is changed by a significant amount. The simulations of the entire system that includes six PV modules and a Single Ended Primary-Inductance Converter controlled by an incremental conductance algorithm to achieve maximum power, as well as the proposed double switch-regulated output voltage Buck-Boost. These simulations are intended to validate the suggested structure's efficacy and dependability with the system as a whole. The system was simulated in seven stages for different atmospheric conditions and each 0.2 seconds, starting with ideal conditions (1000 W/m2, 25 C), then changing only the radiation from 1000 W/m2 to 900 W/m2, then changing both the radiation And the temperature from 900 W/m2 to 800 W/m2 and from 25 C to 20 C respectively, and then keeping the radiation constant and reducing the temperature from 20 C to 10 C, then increasing the radiation from 800 W/m2 to 900 W/m2 whether the temperature is stabilized. In this case, the radiation and temperature are increased from 900 W/m2 to 1000 W/m2 and from 10 C to 20 C respectively, while in the latter case the radiation is fixed and the temperature is changed from 20 C to 35 C. The results showed that the suggested converter's output voltage (double switch controlled output voltage Buck-Boost) is stable at roughly 108V regardless of the SEPIC's output voltage discrepancy in addition to the rapid response time that does not exceed 0.04 seconds and that the system efficiency is 92 percent, according to the authors.

Cuk DC-DC converter

A DC–DC Cuk converter can provide an output voltage that can be higher or lower than the input voltage, where it functions like to buck-boost converter. The output polarity produced by this topology is inverted. In this converter design, two inductors are employed, one of which acts as a filter [42], reducing the high harmonic current. The Cuk converter has minimal switching losses and high effectiveness compared to the boost, Buck, and also buck-boost converters.

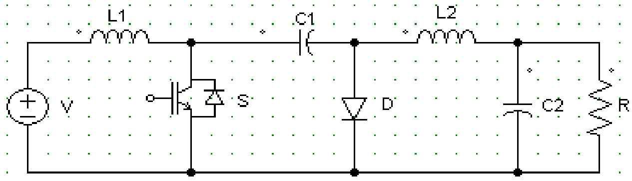


Fig.11 Cuk DC-DC converter

The converter includes a number of crucial parts namely a MOSFET switch S, L1 and L2 inductors, C1 and C2 capacitors, diode D, and load R. The converter is seen in Figure 11.

There are two modes in which the converter can operate:

In the first mode, MOSFET switch S turned on, while the diode D reverse biased, and capacitor C1 transfers its power to L2, C2, and load.

In the second mode, MOSFET switch S turned off, As for the diode, it becomes forward-biased. thus the power stored in the inductor is transferred to the load, While the iL1 and iL2 currents decrease. and the capacitor C1 also begins to charge.

Among the previous studies that dealt with this subject, we mention the following:

In the paper [43] the authors discuss the design of a Cuk converter that includes MPPT. The authors simulate a Cuk converter in three modes: the first mode has a duty cycle of 25%, the second mode has a duty cycle of 50%, and in the third mode, the duty cycle is 75%. Through the results, according to the authors, The best performance of the converter is at a second mode, where it represents a maximum output power.

In the study [44], the authors present a new CUK converter that incorporates soft switching for all semiconductor devices, In addition, the converter operates in the discontinuous-capacitor-voltage mode. See Figure 12.

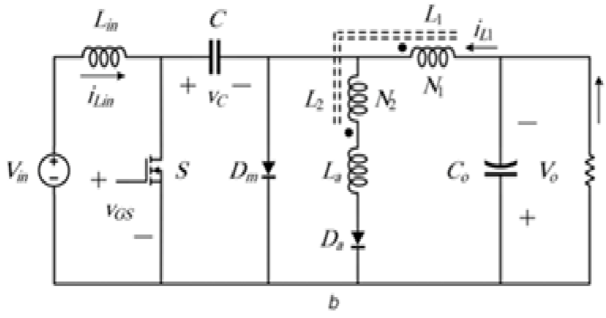


Fig.12 Diagram of a new Cuk converter

This topology aims to reduce switching losses and improve converter efficiency with as few components as possible and without a protection circuit. The proposed converter includes an additional L2 coil, auxiliary La inductor and auxiliary Da diode compared to a conventional Cuk DC-DC converter. These passive components aid in soft converter switching, allowing the power switch to function in the zero-current switched (ZCS) mode, while it is turned off in the zero-voltage switched (ZVS) mode, and also works on Reducing the interference between current and voltage during instant operation and reducing the switching current, which results in a lower current pressure compared to the traditional dc-dc Cuk converter. The proposed converter utilizes only a single switch so that keeps this circuit simple to control during the turn-off mod. The classic Cuk converter's capacitor is used as a snubber capacitor in this novel topology to produce ZVS conditions for its switch. To confirm all this, the authors prepared a prototype for both the novel and conventional Cuk converters and compared the results obtained (output power 100 W, input voltage equal to 150 volts, and output voltage -24 volts). according to the authors, the suggested converter achieves amazing efficiency and reaches 92 percent at full load.

to generate a high voltage gain and low pressure, Almalaq Yasser, and Mohammad Matin [45], proposed a new Cuk converter. Non-Isolated Cuk Converter with Two-Switch High Gain is seen in Figure 13.

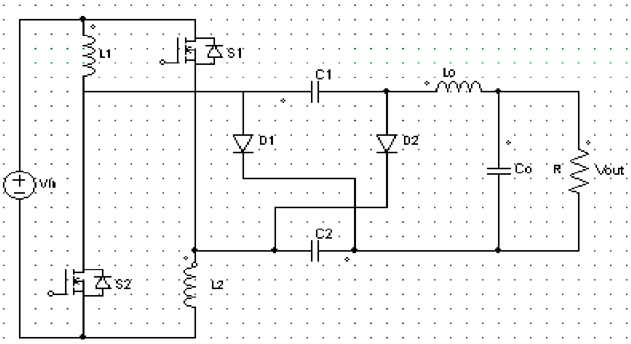


Fig.13 Two-Switch High Gain Non-Isolated Cuk Converter [45]

In this new topology, a MOSFET and an inductor are added in addition to a diode and a capacitor compared to the traditional topology of a Cuk converter. The MOSFET and the inductor form a switched-inductor while the diode and the capacitor form a switched-capacitor. This makes the new converter realize high voltage gain and low voltage stress. Thus, conduction losses become reduced and the converter's overall efficiency improves. According to the study, at a duty cycle of 0.75, the converter produces a voltage gain 13 times the input voltage. To confirm and demonstrate the converter's validity and advantages, the authors prepared a prototype of the novel converter. With an input voltage of 12V the output voltage is -152V, also a switching frequency 50kHz and rated power of 100W. At 180W output power, the converter efficiency is up to 92%.

In [46], K. Balachander et al presented a Cuk converter designed specifically for electric hybrid vehicles with the use of a PI controller to increase and adjust the output voltage and thus effectively improve vehicle performance. The study objective of using a cuk converter is centred on optimizing the output voltage, which will help extend the range of the vehicle and its efficiency. The authors simulate the present Prius system with a boost converter and a PI controller, as well as the existing Prius system with a Cuk converter and a PI controller. The findings reveal that the Cuk converter achieves a higher output voltage; up to 120 volts from a 12-volt input, while a boost converter produces only 50 volts output voltage.

Jean P. de Souza et al in the study [47] present a Cuk converter that includes a voltage multiplier cell to boost a static gain and features improved performance characteristics. See Figure 14.

This topology achieves a stable high gain and furthermore low both voltage pressure and current ripple and thus improves performance. The authors have demonstrated the correctness of the performance and efficiency of this converter by constructing a prototype and testing it, The prototype operates with Input Voltage Vi= 30 V, and both the output voltage and power Vo= 230 V and Po= 220 W, respectively, with Input current and Output current ripples ∆iLi=54% of iLi and ∆iLo=43% of iLo, respectively. According to the authors, the converter efficiency was 94.5% under nominal operating conditions which confirms the effectiveness of the proposed converter.

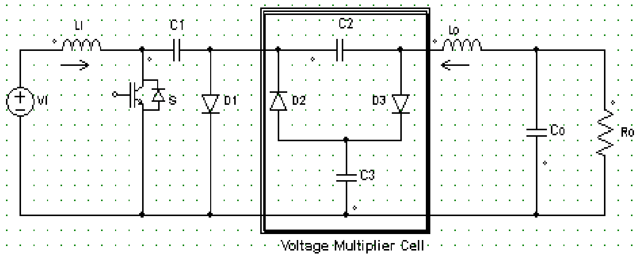
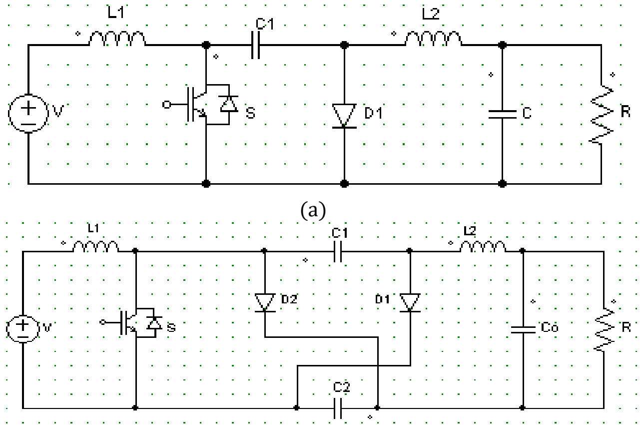


Fig.14 Diagram of the new Cuk Converter proposed in [47]

A.Lavana et al. compared the performance of a normal Cuk converter to that of a modified Cuk converter in their study [48]. Figure 15 depicts the compositional differences between normal and modified Cuk converters.



(a)

(b)

Fig.15 (a) Normal Cuk Converter. (b) Modified Cuk Converter.

The modified converter demonstrated significant advantages and improvements such as a higher ratio of conversion, lower conduction losses as well as reduced current stress on the switches; this unavoidably entails increasing the converter's efficiency. Moreover, according to the simulation results presented by the authors for both converters, the new one achieved higher output voltage and efficiency compared to the conventional one. so that during the 0.75 duty cycle, the new converter achieved an output voltage that exceeded the conventional converter's output voltage by about 35 V.

In the paper [49] ,Nibedita & al. studied and analyzed the Cuk converter and presented a comparison of both controller PI and fuzzy logic in a closed loop for Cuk converter. This comparison focuses on the difference in settling time between both controllers, and The authors' simulations revealed that the fuzzy logic controller greatly reduces the settling time and peak overshoot when compared to the PI controller. The output voltage of the fuzzy logic controller remains nearly constant for different input voltages, while it varies with the PI one; and according to the authors, using a fuzzy logic controller enhances the efficiency and effectiveness of the Cuk converter.

The DC–DC SEPIC converter

The DC–DC SEPIC converter stands for the Single-Ended Primary Inductor Converter. It can produce output voltages that are greater or lower than the input voltage [50], which is highly efficient. It is also called fourth order converters, because It has four elements that store energy (two capacitors and two inductors) [42]. This converter can operate in either boost or buck mode and has a non-inverting output characteristic [51]. Among its advantages are reducing input current ripple, lowering the switching stress and electromagnetic interference in addition to achieving continuous output current.

It is made up with: an active and passive switch pair S, inductors L1 and L2, and capacitors C1 and C2, also a diode D and load R. Figure 16 shows a SEPIC converter

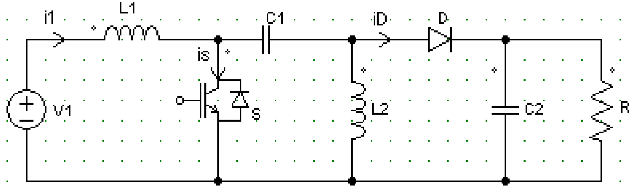


Fig.16 SEPIC DC-DC converter

When the SEPIC converter is operated in the CCM [42], two modes can be observed:

In the first Mode the switch S is turned on, and diode D becomes reverse biased, permitting input voltage source Vin and capacitor C1 to supply energy to inductors L1 and L2, respectively. while The output capacitor Co provides energy to the load resistance R, ensuring a continuous and stable power supply.

In a second mode switch S is turned off, and the diode becomes forward-biased. The power that was previously stored in the first case is transferred to the load while the iL1 and iL2 currents decrease linearly as time goes on.

Ibrahim Alhamrouni, & al. [52] proposed a new SEPIC converter designed for solar applications, which consists five capacitors, three inductors, and a power switch (MOSFET), four diodes, and a connected inductor. See Figure 17 represents the proposed structure.

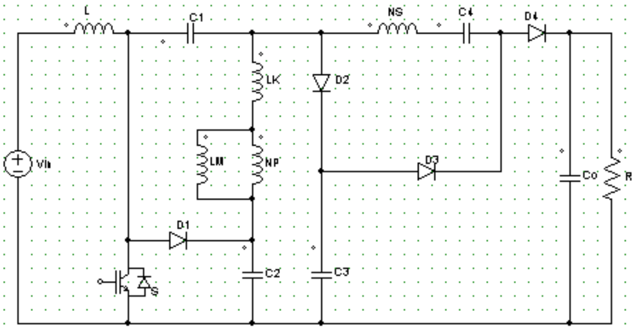


Fig.17 Scheme of the proposed new SEPIC converter in [52]

The purpose of this innovative topology is to overcome the shortcomings of a classic SEPIC converter by achieving high voltage gain, continuous input current, reduced voltage stress and voltage ripples, resulting in improved overall efficiency compared to the traditional SEPIC converter. The authors conducted a simulation of the new converter using Matlab. It was operated at fixed frequency fs=30 kHz and a variable duty cycle, and then vice versa. This is intended to validate its functionality. The results demonstrated a direct relationship between the duty cycle and the output voltage which increases with the duty cycle and vice versa, while inversely related with the switching frequency. In comparison to an IGBT, the authors demonstrated that a MOSFET is best suited for this suggested circuit. They also demonstrated the achievement of low input ripple current and stable both output voltage and current outputs at moment t=0.2 s with a value of Vo(RMS)= 300V and Io(RMS)= 0.7327A respectively. Through this study, the authors emphasize that the new structure is suitable for renewable energy applications, especially photovoltaic. to provide the required results for the proposed converter the authors used duty cycle equal to 0.45 with a switching frequency of 30 kHz, and an input voltage equal to 26V and thus produces a stable output voltage of 300V while improving the efficiency of the new converter to 94%.

In the study [53], Muranda et al. introduced a modified SEPIC DC-to-DC converter comprising an additional capacitor and inductor compared to the conventional SEPIC converter. The goal was to solve its limitations such as efficiency, low output voltage and parasitic effects as these drawbacks limit the efficiency and effectiveness of the converter, especially with high voltage applications for renewable energy. The new topology achieves a higher output voltage shunt ratio and lowers current/voltage ripple as well as eliminating the parasitic effects of new SEPIC converter elements thanks to an additional single inductor and capacitor. The Figure 18 represents the proposed structure of the SEPIC converter.

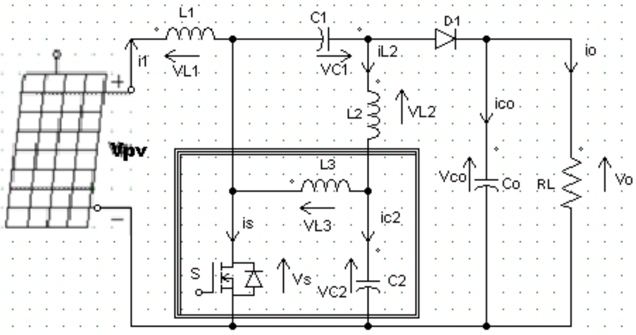


Fig.18 Scheme of modified SEPIC DC-to-DC converter

To validate the new converter, the authors simulated it with three different operating ratio cases δ equal 0.1, 0.5, and 0.9 respectively and the same 15V input voltage, resulting in an output voltage of 15.9V, 31V, and 149.1 respectively. The results of the simulations have proven the correctness of the performance of this converter and the agreement of the results with the theoretical analysis. Furthermore, the current and voltage frequencies are the same as the switching frequency. This innovative topology enables the SEPIC DC-to-DC converter to perform appropriately and efficiently in high voltage applications including industrial and renewable energies sectors.

In the study [54] , D. M Sangalad et al. introduce a new SEPIC architecture in order to save power from different power sources, and provide a wide range of output voltages as well as low cost and losses compared to using two single input converters. See Figure 19 represents the proposed structure of the SEPIC converter.

The novel structure is a dual input SEPIC converter with two different input values and the number of inputs can be expanded depending on the requirements of the studied system, where it employed time sharing switching strategy to generate gating pulses for efficient power electronic switches control. The study describes the suggested converter's architecture and operation in detail. To check the effectiveness of this new structure, simulations were conducted in both open-loop and closed-loop. In the case of open-loop and with input voltages of 24 volts and 12 volts, the converter achieved an output voltage equal to 48 volts. The resulting output voltage ripples were 1V and the inductor current was 0.3A. In the case of closed-loop, a PI controller was employed to regulate the output voltage at 48 volts. The results demonstrate a stable output voltage ranging from 47.5 to 48.5 volts with a reduced output voltage ripple of 1V and an inductor current of 0.25A. The results validated the correctness of the new topology and its agreement with the theoretical predictions.

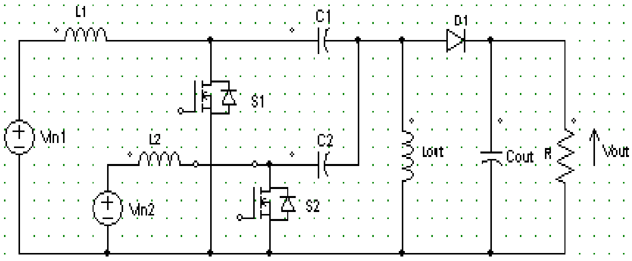


Fig.19 Scheme of Dual input SEPIC Converter

The authors of the study [55] offer a new dual output converter, a SEPIC converter merged with the Cuk converter. Among the advantages of the new topology is that it increases voltage gain, reduces switch stress voltage, and it also decreases the size and cost of the converter compared to the one based on two separate converters. Figure 20 shows the proposed converter in this study.

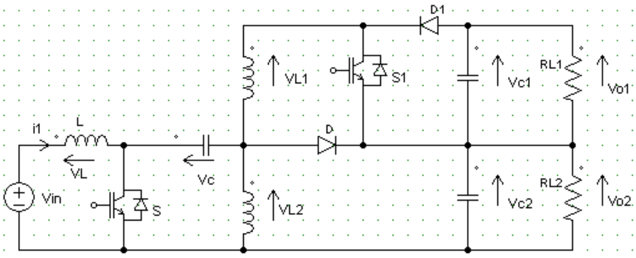


Fig.20 Scheme of the proposed topology

From a single input source, the compact structure of the SEPIC converter and Cuk achieves two different output voltages, Marjani and others have conducted simulations of the proposed converter with a single input voltage of 30 v and yielding to a first and second output voltages of respectively −230V and +70V and both achieved within D=70%. This new topology has proven to be very suitable for applications of renewable energy, electrical machinery, and others that require multi-level voltage.

In the paper [56], the authors presented a novel EV charger based on an Improved SEPIC PFC converter to achieve better performance. The SEPIC converter has been improved by adding an inductor, capacitor, switch, also a diode are added. The new design of the converter aims to improve the electric vehicle charging system by achieving lower voltage stress, increasing voltage gain, and reducing conduction losses through a lower duty cycle. The study provides a comprehensive explanation of the operational principles and design of the novel design. The proposed converter operated in a DCM system where ensuring soft switching of switches and diodes is provided thus improving overall converter efficiency.

In the study [57], the authors presented a PID-controlled SEPIC converter. The objective is to optimize parameters of a PID controller by the Bat algorithm (BA), thus allowing control of the output voltage and stabilize it at the required value under different operating conditions. The authors simulated their proposal to evaluate its performance by entering a variable voltage's reference so that in the first case it was changed from 29.3 to 27 and in the second case it was changed from 29.3 to 33. The voltage output was not affected and remains stable at the desired value.

The same effect was observed during step changes in the load current. Thus according to the authors, the proposed system provided excellent performance and indicates its ability to achieve stability.

In the [58] study, Majstorović et al. used the SEPIC Converter to implement the MPPT technique. In the study, the authors focused on the P&O and IC algorithms to achieve MPPT. Both methods are based on voltage and current measurements of photovoltaic panels in order to control the PWM signal of the SEPIC switch. Through the simulation results presented by the authors for the proposed transformer with the application of the two algorithms for MPPT, it is found that both the P&O and IC algorithms perform well in tracking the maximum power point. However, the authors suggested adding a PI controller to the system in order to achieve more positive results, especially when it comes to atmospheric changes where adding a PI controller gives the ability to track the MPP more accurately which means enhancing system efficiency.

In the study [59], The P&O algorithm and control FLC were employed to simulate a SEPIC converter to achieve MPP. The aim of the study is to verify the system's ability to track the MPP under various irradiance and temperature conditions. the authors simulated the system by entering different both irradiance levels and temperature values, which are respectively 1000W/m2, 900W/m2, 700W/m2, 500 W/m2, and 30, 25, 20 and 18 degrees. From the simulation results, the maximum voltage produced by the SEPIC converter while using the Perturb And Observe algorithm with a radiation W/m21000 and a temperature of 18 degrees is 58.76 V, while it is 58.70 V while employing the Fuzzy Logic Control, and also it was observed that the maximum output voltage decreases with the lower radiation value and the same is true for the current and power, The maximum current value during P and O is 5.51 A while during FLC it is 5.49 A. Moreover, the use of the FLC MPPT method limits the fluctuations of the output voltage, making it more suitable for MPPT in PV modules instead of the P&O. In general, the study showed the effectiveness of both methods in MPP tracking, with FLC showing superiority in achieving output voltage stabilization.

The authors provide a SEPIC converter with sliding mode control (SMC) in their study [60] to achieve MPPT of PV system. The study aimed to overcome the obstacles faced by other control methods (the P&O algorithm and INC) such as oscillation of the output voltage and the slow tracking speed. Although, the SMC control is complex and it provides better results. The authors present analysis and simulations to evaluate the performance of their proposal under variable radiation and temperature conditions, then the results of the performance and response speed of the SEPIC converter that uses the sliding mode controller with P&O and INC algorithms are compared. The simulation was carried out in four stages. In the first stage the radiation and temperature are constant, in the second stage the radiation is constant but the temperature is changing, in the third stage the temperature is constant and the radiation is variable and in the latter stage the simulations were carried out in under partially shaded conditions. T*he results of all these cases demonstrated the distinction of the SMC method with the SEPIC converter compared to the two previous algorithms in terms of response speed and accurate tracking, as well as reducing the oscillation of The output voltage compared dramatically.

The SEPIC converter is known for its good performance and efficiency, among its advantages are continuous input current, thus reducing ripple, and also achieving a stable, non-inverting output voltage. To confirm this, the authors discussed in the study [61] the hardware design of the converter as well as its simulation. the results proved that the considered converter provides non-reversing output in addition to low input current ripples, making it a suitable option for charging batteries.

The DC-DC zeta converter

The DC–DC zeta converter can adjust the output voltage to be either stepped up/down relative to the input voltage. A Zeta converter serves almost the same function as a buck-boost converter [62]. It's a fourth-order nonlinear system, in reference to the four energy storage components (L1, L2, C1, C2). Zeta converters are notably used in applications for voltage regulation and power factor adjustment [63]. Among its advantages are continuous input current, thus reducing ripple, and also achieving a stable, non-inverting output voltage [64] and reducing pressure on the switch. Figure 21 shows a zeta converter.

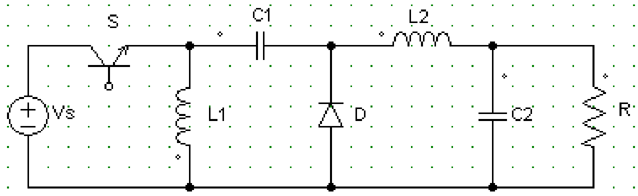


Fig.21. Zeta DC-DC converter

During operation in the CCM, the Zeta converter has two separate modes. In the First mode, the switch S is on, while the diode D is reverse biased. At the same time, L1, L2 and C2 are all charging while capacitor C1 is discharged. The iL1 and iL2 currents increase linearly. In the second mode, the switch S is off, while the diode becomes biased forward. The stored power in L2 is transferred to the load, while L1 transfers its stored energy to C1 [65]. The iL1 and iL2 current decreases linearly.

The authors of the [66] study implemented MPPT with Zeta converter, where P&O and ICT (Incremental Conductance Technology) algorithms were used in achieving MPPT and their comparison of their results. According to the results of the study, the ICT provides better performance with Zeta converter and is suitable for varying operating conditions while the P&O algorithm is suitable for constant conditions. These results offer helpful recommendations for choosing the best MPPT algorithm to maximize power extraction efficiency in the Zeta converter under particular operating conditions.

A.G. Karthikeyan & al. presented in [67] a Zeta Converter with Multi inputs and outputs to enhance the performance of the integration of renewable energy sources with the power storage systems. This new topology offers high voltage gain, maintains continuous output current thanks to the modification of the multi input/output DC-DC converter and the installation of a Zeta converter in place of the boost one. Three inputs are proposed for this Converter namely Solar PV, Super capacitor, and battery and two outputs. Figure 22 shows the new Converter.

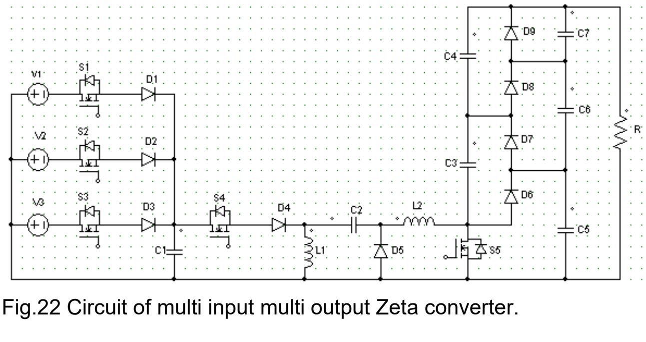


Fig.22 Circuit of multi input multi output Zeta converter.

The authors presented the operating principle of the Converter. To validate the effectiveness of the new topology, they simulated it and presented the results to prove it. The innovative converter transforms the direct current voltages from the PV panels and fuel to a controlled output DC voltage with no losses, resulting in minimal energy losses throughout the process.

Vosoughi & al. presented in [68] a Zeta-based switched-capacitor DC-DC converter that contains multiple coupling capacitors (SCs) in contrast to conventional ones that contain a single coupling capacitor such as a conventional zeta converter. The proposed converter relies on SCs to achieve low voltage stress on switches and coupling capacitors in addition to provide a higher voltage conversion ratio during lower duty cycles compared to conventional converters such as Cuk, Zeta, and SEPIC. Figure 23 shows the proposed Zeta-based switched-capacitor (SC) converter. This converter has been compared with previous topologies conventional Cuk and Zeta converters, and their hybrid structures with the blocks Up2 and Up3, Converter of Banaei and Bonab. This comparison is considered in several respects, First in terms of Voltage gain (voltage conversion ratio) based on three different values of the parameter n (4, 8, and 12), The authors demonstrated that the proposed converter has a higher conversion ratio, and the higher the coefficient n, the greater the difference between the proposed converter's conversion ratio and other topologies. The new topology is best for applications that require a high voltage switching ratio.

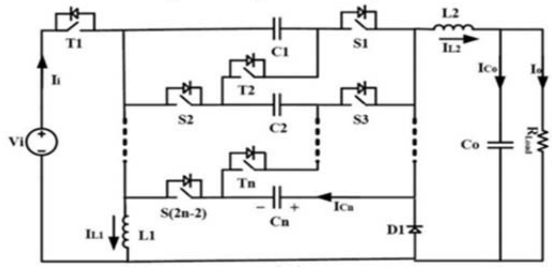


Fig.23. circuit of Zeta-based switched-capacitor (SC) converter

Secondly, in terms of voltage stress on coupling capacitors (SCs), In comparison to previous converters, the suggested converter places less stress on its capacitors. Third, the authors have shown that the voltage stress on switches in the suggested structure is lower in comparison to other topologies. The proposed converter's voltage stress on diodes is the same as the rest of the topologies stated. The new Zeta-based switched-capacitor (SC) dc-dc converter achieves better efficiency than other topologies in applications with high conversion voltage and high power rates, and its efficiency reaches 98%. To the validity of the suggested converter's correctness as well as the theoretical analysis, Naser Vosoughi and others presented the experimental results of the new topology based on duty cycles of 0.65 and 0.75, respectively.

Alia M. Khatab et al. introduced a new zeta Converter-based charger for electric car batteries in their study [69], because of its advantages as a continuous output current without a ripple, non-reversing output voltage and low voltage stress compared to other conventional converters. This charger consists of a zeta converter which is fed through a PV array, and uses the (P&O) algorithm to provide the appropriate gate signal to the zeta converter switch as well as to achieve the maximum power point MPPT for the PV panels; See Figure 24 represents the circuit of proposed battery charger.

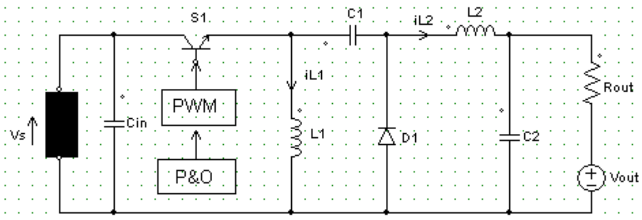


Fig.24. Structure of the proposed battery charger

To test the proposed Battery charging system for electric vehicles and confirm its operation and performance, the authors simulated the proposed system in three different solar radiation modes of 1000 W/m2, 750 W/m2, and 500 w/m2, respectively. The results proved their agreement with the theoretical analysis.

Gaurav P. Modak and Dhote V. P. performed a study, analysis, and simulations of a Zeta Converter fed by a Solar Photovoltaic System employing a PID Controller in open-loop and closed-loop systems, as well as a comparison between them, in their paper [70]. The authors simulate a zeta Converter in the system in two-stage Constant Input to Solar Panel, and Variation in Input to Solar Panel, with step-up and step-down modes so that the input voltage is 18 V and the output voltage for the Step-down and step-up modes are 12V and 24V, respectively. The results proved that operating the zeta converter using PID Controller in the step-down and step-up model has better performance during closed-loop systems, especially through Variation in Input to Solar.

In order to improve DC-DC converter efficiency, and achieve a wider operating ratio range and reduce output voltage ripple. In the paper [71] suggested an Interleaved Zeta converter controlled by the Fuzzy controller. The proposed circuit includes the parallel connection of two zeta converters. See Figure 25 represent the proposed circuit.

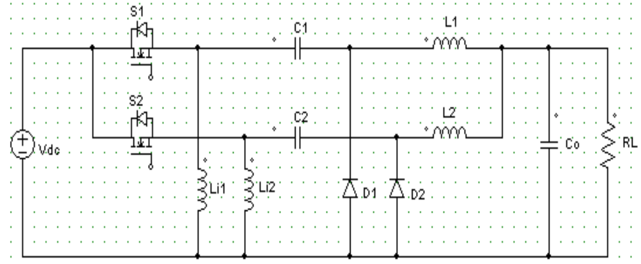


Fig.25. Structure of DC-DC Interleaved Zeta converter

The study provided a comprehensive explanation of the working principle and design of the new topology. Compared to the traditional zeta converter, the proposed structure is characterized by low output voltage operating range and ripple, as well as input current distortion is minimal. To validate the performance and effectiveness of the proposed converter, the results showed that employing the fuzzy controller led to the proposed converter's performance being better, efficiency increased, and the voltage stabilization time becomes faster so that it is 0.02s with FLC, while it is 0.32s during the use of the PI controller. The study reported an efficiency of 91.32% for the proposed Fuzzy based converter.

Commentary about non-insulated conventional DC-DC converters

In this section, we mention some of the advantages and disadvantages of conventional non-isolated converters that were touched upon:

Stepping down the input voltage to a lower output voltage level is a common use for the buck converter. Despite its cost-effective, the possibility of significant output current ripples. Moreover, it cannot be utilized in applications that demand an input voltage greater than the supply voltage.

Contrarily, the boost converter is used to raise the input voltage to a higher output voltage level. It is affordable and has an easy structure.

The buck-boost converter was developed to overcome the drawbacks of both buck and boost converters. With the ability to function at output voltages either greater or lower than the source voltage, it offers improved performance and efficiency. However, it generates erratic input and output currents as well as an inverted output voltage and is more expensive.

The Cuk converter was subsequently created by researchers as a replacement for the buck-boost converter. It provides comparable functionality while being more effective, providing continuous input and output currents, and having fewer ripples. The output voltage is still inverted, though.

Although the SEPIC converter has similarities with the Cuk converter, it offers a non-inverting output voltage and smaller output ripple which enhances its performance and efficiency.

Lastly, the zeta converter provide a non-inverting output, almost zero ripples, lower circuit losses and therefore higher efficiency than other converters, but more expensive.

Each of these converters has benefits and drawbacks that make them ideal for some applications depending on the needs and limitations of those applications.

Table 1 summarizes the comparison between various conventional non-isolated converters including buck, boost, buck-boost, Cuk, SEPIC, and zeta. The comparison is focused on key points such as output voltage's polarity, relationship between Vi and Vo, complexity, output ripples, Relationship between Vi and the duty cycle (D), and the components of each converter.

Table 1. Comparison between the conventional non-isolated converters

Converters	Buck	Boost	Buck-boost	Cuk	SEPIC	Zeta
Number of switches	1	1	1	1	1	1
Number of Diodes	1	1	1	1	1	1
Number of Inductors	1	1	1	2	2	2
Number of Capacitors	1	1	1	2	2	2
polarity of the output voltage	inverted	non-inverted	inverted	inverted	non-inverted	non-inverted
Relationship between Vi and Vo	$\boldsymbol{V_o = V_i . D}$	$\boldsymbol{V_o = V_i(\frac{1}{1-D})}$	$\boldsymbol{V_o = V_i(\frac{-D}{1-D})}$	$\boldsymbol{V_o = V_i(\frac{D}{1-D})}$	$\boldsymbol{V_o = V_i(\frac{D}{1-D})}$	$\boldsymbol{V_o = V_i(\frac{D}{1-D})}$
Relationship between Vi and dutyCycle (D)	Non-linear	Non-linear	Non-linear	Non-linear	Non-linear	Non-linear
complexity	Low	Low	Low	Medium	Medium	Medium
control	Easy	Easy	Easy	Easy	Easy	Easy
Inpout courant	intermittent	intermittent	intermittent	continuous	continuous	continuous
The output ripple	high	high	high	Low	Low	Low

Conclusion

Considering the critical importance that DC-DC converters play in renewable energy systems, especially solar energy, this paper focused on the most commonly used traditional converters which include buck, boost, buck-boost, cuk, SEPIC, and zeta converters. Each type was defined and its principle of operation explained. Furthermore, an overview of current studies conducted by researchers on these converters was also presented. In addition, a comparison between these traditional transformers was presented, through which the most prominent pros and cons of each transformer were highlighted.

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