ISSN (Online): 2583-7052

International Journal of Advanced Trends in Engineering and Management (IJATEM)
Vol. 03 (07), July 2024, pp. 44-52

Article Title: Comprehensive Review of DC-DC Converters for PV Connected Grid System

Comprehensive Review of DC-DC Converters for PV Connected Grid System

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ABSTRACT

Renewable Energy Systems (RES) harness natural sources like sunlight, wind, and water to generate sustainable power. They decrease dependency on fossil fuels and minimize greenhouse gas emissions, promoting environmental sustainability and energy security. Photovoltaic (PV) systems are a prominent application of renewable energy, converting sunlight directly into electricity. However, the efficiency of PV systems adversely affected by varying environmental conditions and climatic changes, leading to fluctuations in voltage output. To address these challenges and optimize energy extraction, the integration of DC-DC converters into PV system is essential. In this paper an exhaustive review of various DC-DC converters technologies used in PV-connected grid systems, including SEPIC converter, Buck-boost converter, Boost converter, and CUK converter. Every converter plays a crucial role in managing and stabilizing voltage levels by adjusting the output voltage to meet the needs of the grid or load. A comparative analysis of recent research highlights various methodologies for enhancing converter performance. The review includes studies on ultra-gain converters, Fourth-order boost DC-DC converter (FBDC), high step-up interleaved converters, and Quasi Z-source converters. Each approach presents unique benefits and challenges, reflecting ongoing efforts to optimize DC-DC conversion in PV systems. The paper concludes with insights into the future direction of converter technologies and their role in enhance the stability and efficiency of PV connected systems.

Keywords: DC-DC converters, Photovoltaic, Quasi Z-source converter.

1 Introduction

In today's context, both the ecosystem and humanity are adversely affected by climate change for fossil fuel. The energy generation sector in power systems adds to CO2 emissions globally, which contributes to Green House Gas (GHG) emissions and weather change. The most prevalent conventional energy sources include fossil fuels such as oil, coal, and natural gas. Fossil fuels is one of the largest consumers in the world by responsible for global warming. In recent times, the harm expenses suffer by fossil fuels are uncertain. Greenhouse gas emissions, rising global temperatures, and climate change impacts are significant components of energy generation from fossil fuels. While they provide significant power for various industries, their environmental impact is detrimental, and their availability is finite. [1-2]

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To address this issue, using green energy sources like solar and wind power is essential. Those energy sources have minimal environmental impact and crucial for decrease carbon emissions, addressing weather change, and offering sustainable energy solutions. Today, renewable energy sources are preferred in many countries globally to environmental characteristics and sustainability. To address the swiftly growing energy needs, solar and wind power have emerged as primary solutions. Solar PV systems transform sunlight directly into electrical power. Concentrated PV cells achieve exceptionally high efficiency levels. [3]

However, the variable source of solar PV power generation greatly impact on the stability of grid voltage power supply. PV energy sources are enhancing to their plentiful availability, minimal maintenance needs, and quiet operation. Solar radiation and temperature influenced by factors such as cloud cover, mist, rainfall, and sandstorms. Additionally, solar energy is not available during the night. Consequently, as PV energy sources become more widespread, a substantial portion of the power supplied to the grid inherently variable. Even minor weather changes, such as cloud cover, dramatically decrease the performance of a PV system, leading to abrupt fluctuations in power generation. Voltage stability is a significant issue with the huge integration in fluctuating solar PV sources. In a PV system, the voltage gain play a critical roles in optimizing the efficiency and performance of energy conversion. [4-5]

In this scenario, PV system is underperforming and experiences a low power output. To tackle this problem and enhance energy generation, the DC-DC converters are employed to boost the system's effectiveness and overall production. These converters adjust the voltage potential from the PV panels to meet the load's demands. They are engineered to maintain a consistent of voltage despite variations in the conditions of the PV cells.

DC-DC converters, include Boost converter, Buck boost Converter, CUK converter, and SEPIC converters, are employed to grid-connected PV systems to efficiently manage voltage levels and increase the production system . Those converters offer significant advantages, including improved energy conversion efficiency and greater flexibility in optimizing power delivery. A boost converter with minimized voltage strain on switches and increase voltage enhancement at lesser duty cycles. A SEPIC converter offers flexible voltage conversion, maintaining a stable output regardless of whether the PV panel voltage is the desired level. The CUK converter provides voltage inversion and stable regulation, useful for specific applications. Among various buck-boost inverter designs, flyback converters have attracted considerable research interest their simpleness and less expense. Overall, DC-DC converters offer the advantage of efficient voltage regulation and power conversion, allowing for flexibility in managing different input and output voltage levels while improving system performance and energy efficiency. [6-7].

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2 Review of Comprehensive Analysis of Dc-Dc Converters for PV Connected Grid System

2.1 Boost Converter

The boost converter is engineered to increase a varying solar voltage to stable high-rise DC voltage. This converter is crucial to transforming from less input DC voltage to high-rise DC voltage levels. The power generated by sources such as PV panel is fairly low, while the desired voltage is considerably huge for various residential and industrial applications. DC-DC boost converters include various configurations of switches, capacitors, inductors, and diodes. These elements are connected to facilitate the transfer of energy between capacitors and inductors. These operations commence with the transfer of stored energy within the inductors. If the voltage input expressed in V_{in} and the voltage output expressed in,

$$V_{out} = \frac{V_{in}}{1-D} \tag{1}$$

In this converter have certain limitations including, significant voltage strain, increased electromagnetic interference, reduced efficiency under light load conditions, and unacceptable input current fluctuations. However, they are impractical for real-world applications where the duty cycle surpasses a specified threshold. [8]

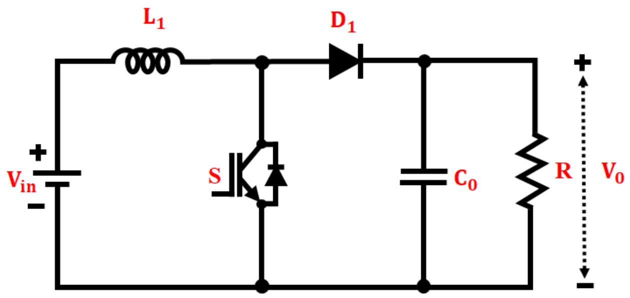

Figure 2.1: *Boost converter*

2.2 Buck Boost Converter

The Buck-boost converter circuit used to generate in output voltage level that exceeds to input voltage level. It provides a higher step-up and step-down voltage transformation ratio compared to standard buck-boost converters, and keeps the output voltage positive. It is a bi-directional port for boosting circuit for capturing and storing PV power. It also intends to retain the power and utilize to during periods of power shortfall. This converter function is describe two operational modes. In Mode 1, the converter maintains a stable operating condition by applying Kirchhoff's Voltage Law (KVL).

$$\frac{di_L}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{DT} = \frac{V_{in}}{L} \tag{2}$$

Since the switch is closed,

$$(\Delta i_L)_{closed} = \left(\frac{V_{in}}{L}\right) DT \tag{3}$$

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For Mode 2, stable operating condition using KVL,

$$\frac{di_L}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{(1-D)\,T} = \frac{V_o}{L} \tag{4}$$

The switch is open state,

$$(\Delta i_L)_{open} = \left(\frac{V_o}{L}\right)(1-D)T \tag{5}$$

PV energy is transformed into a high-voltage DC system and is well-suited for diverse sustainable power sources because it ability to manage several inputs. However, need a substantial amount of semiconductor devices along a linked inductor, leading to a high voltage rating and increased cost of the system. [9]

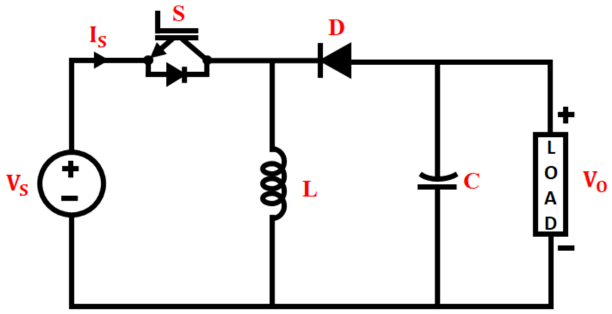

Figure 2.2: *Buck boost converter*

2.3 CUK Converter

This study presented a CUK converter is DC-DC converter that moves energy connecting load and source during both active and inactive phases. It is a type of switching power supply where the output greater or lesser than input potential, but the direction of the output potential is reversed to relative input potential. This converter achieving an increase steady gain and decrease voltage across switch. These attributes fascinating with high input current regarding less input voltage for application source. The calculation for a DC-DC converter functioning determined by:

$$\frac{V_o}{V_i} = \frac{2\,.\,D}{1-D} \tag{6}$$

The switches and diode are as follows:

$$V_{S1} = V_{S2} = \frac{V_i + V_{Cs}}{2} = \frac{2.\ V_i + V_o}{2} = \frac{V_i}{I-D} \tag{7}$$

$$V_{Do} = V_i + V_{Cs} = 2\,.V_i + V_o \tag{8}$$

However, the static gain for stepping up voltage in the CUK converter insufficient for a less voltage solar cell and voltage across switch equals to total voltage from both input and output. Operating at an extreme duty ratio neglected due to the consequent increased electrical stress and voltage load as well as reduced efficiency. [10]

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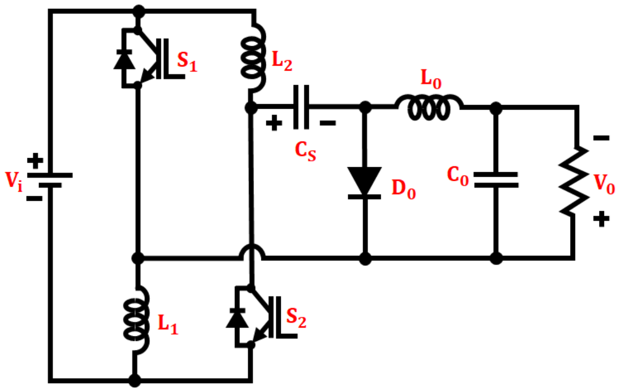

Figure 2.3: *Switched inductor CUK DC-DC converter*

2.4 SEPIC Converter

The SEPIC DC-DC converter is developed and modeled as part of a standalone PV system. It is a step-up and step-down circuit that delivers a stable positive output voltage from an input voltage either greater or lesser than the intended output. This converter offers excellent efficiency in transferring power from the generator to the circuit. It keeps the output potential steady without relying on a feedback control system. The SEPIC converter clearly outperforms traditional models. The final output voltage expressed as:

$$V_{out} = V_{in} \times \frac{D}{1-D} \quad (9)$$

Input power equals the output power so that,

$$I_{out} = I_{in} \times \frac{1-D}{D} \quad (10)$$

The output capacitor is given by,

$$C_{out}(min) = \frac{I_{out} \times D}{\Delta V_{ripple} \times f} \quad (11)$$

Nevertheless, this converter's function maintains a consistent output potential, which enhances the efficiency and ensures effective energy transmission in the PV system. [11]

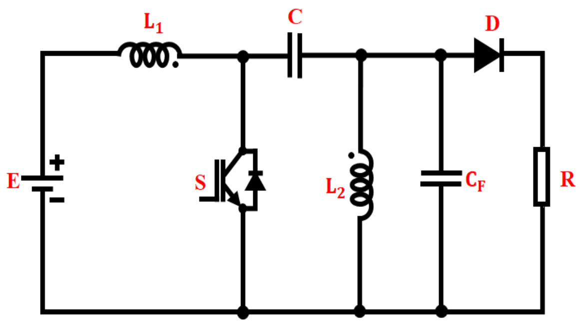

Figure 2.4: *SEPIC converter*

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3 Comparative Analysis

An evaluative comparison of DC-DC converters for PV connected grid systems.

Table 1: *Comprehensive evaluation of DC-DC converters for PV connected grid systems.*

SI. NO	Author / Year of publication	Methodology	Advantages	Limitations
1	Gangavarapu Guru Kumar el at (2020) [12]	This study proposed ultra-gain DC-DC converter based on Switched Capacitor Inductor Network (SCLN).	The proposed model offer a high voltage amplification and an improve efficiency.	However, it needs extra inductors, diodes, and components result in reduced efficiency.
2	Ashima Kulshreshtha el at (2021) [13]	This study presented a Fourth-order Boost DC-DC converter (FBDC) in PV power management.	The proposed model enhance the constancy and operational efficiency.	However, this model causes an up-down fluctuation.
3	Mojtaba Forouzesh el at (2018) [14]	This study proposed a High Step-up interleaved DC-DC converter for Grid Connected PV grid systems.	This technique achieve the highest efficiency and voltage gain.	Nevertheless, this technique causes to power losses due to conduction in the coupled inductor wires and the capacitors.
4	Ataollah Samadian el at (2020) [15]	This study proposed a Quasi Z-source DC-DC Converter is developed for renewable PV application.	This proposed model converter attain a high voltage amplification through the use of an interlinked inductor and a voltage multiplier.	However, this converter affect voltage gain and potential efficiency losses of under varying solar conditions.

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Table 2: *Comparative evaluation of efficiency in DC-DC converters for PV connected grid system.*

Methods	Efficiency
Boost converter [6]	94.5%
SCLN DC –DC converter [12]	91.2%
Quasi Z-source converter [15]	96.37%

Table 2 represent an efficiency contrast of DC-DC converters in PV connected grid systems. From the table that the, Quasi Z-Source converter [15] model exceeds Boost converter [6] model and SCLN converter [12] model in relation to efficiency with a rate of 96.37%.

Table 3: *Comparative analysis of voltage gain in DC-DC converters for PV connected grid system.*

Methods	Voltage Gain
SCLN DC-DC converter [12]	1:8
High setup DC-DC converter [14]	1:9
Quasi Z-source converter [15]	1:9

Table 3 represent a voltage gain contrast of DC-DC converters in PV connected grid system. From the table that the, Quasi Z-source converter [15] model exceeds SCLN DC –DC converter [12] model and High setup DC-DC converter [14] model in relation to voltage gain with a ratio of 1:9.

4 Conclusion

DC-DC converters are integral components in the efficient integration of PV systems into grid-connected environments. Each converter type offers unique benefits that address specific challenges such as voltage regulation, energy efficiency, and adaptation to varying PV output conditions. In this research DC-DC converters provided a comprehensive examination of various converters, including Boost, SEPIC, CUK, and Buck-boost, Quasi Z-source and SCLN converters. The review methods aims to focus advantages in efficiency and voltage gain from PV sources. It is verified that the, Quasi Z-source converter model results is higher efficiency and voltage gain when compared several DC-DC converters. Future prospects in this approach suggest that it enhance the performance of PV connected grid systems, particularly in the efficiency and effectiveness of DC-DC converters. This improvement is expected to lead to more reliable and optimized energy conversion, ultimately benefiting the incorporation of green power sources into the power grid.

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