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COMPARATIVE ANALYSIS OF DC-DC CONVERTER TOPOLOGIES

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Abstract

Power electronics applications frequently make use of DC-DC converters, and this paper presents a comprehensive comparison of all of the available topologies. An exhaustive evaluation of various converter designs' performance, efficiency, size, and cost is the goal of this study. The following configurations are available for converters: buck, boost, buck-boost, Cuk, SEPIC, and flyback. The goal of this study is to compare and contrast the merits of each topology in different operational contexts, with varying loads and control approaches available in literature. The comparison analysis aids designers in optimizing system performance and reducing development time and costs by enabling a more thorough understanding of the trade-offs involved in choosing the best converter architecture for specific application needs.

Keywords-: DC-DC, Converters,Topologies.

INTRODUCTION

In modern power electronics systems, DC-DC converters play a crucial role. Many different types of applications benefit from their efficient power conversion and management capabilities. These include, but are not limited to, electric vehicles, portable devices, renewable energy systems, and telecommunications. With the ever-increasing demands for smaller form factors, higher performance, and more efficiency in these applications, choosing the right converter topology is crucial. This paper will provide a comparative examination of various DC-DC converter topologies in an effort to shed light on the features, benefits, and limitations of each. The goal of this research is to provide designers with the information they need to optimize converter topologies for their particular applications.[1] To achieve this goal, we have methodically evaluate several converter configurations based on their efficiency, size, cost, and performance parameters. Various commonly used topologies of DC-DC converters has been explored in the comparative examination. Flyback converters, buck-boost, Cuk, SEPIC, and boost converters are all examples of topologies that fall into this category. For different input/output voltage ratios and load situations, each topology has its own advantages and disadvantages in terms of efficiency, voltage control, transient responsiveness, and flexibility.[2] Finding out how each converter topology works, what control methods are available, and what performance characteristics they have is what this study is all about. Results have been taken from experimental validation, where necessary, and theoretical analysis has been used to achieve this goal. Software tools like LTspice and MATLAB/Simulink has beennormally employed for such simulation investigations.[3] Practical considerations including component selection, switching frequency, and magnetic component design will also be considered in order to offer a comprehensive understanding of the design trade-offs. Engineers and researchers can use this comparison to help them choose the best DC-DC converter topology for their specific needs. This study aims to evaluate the pros and cons of each topology under different operating conditions in order to help enhance power electronics design and optimization. With this, we can create power conversion systems that are smaller, more efficient, and more reliableas shown in Fig.1.

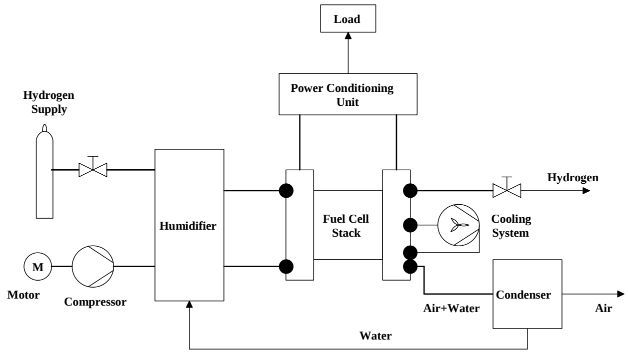

Fig. 1: Schematic diagram of fuel cell system

One has the ability to select from a diverse selection of DC-DC converters that are now accessible. On the other hand, for the purpose of this explanation, only the first four converters on the list will be discussed in this paper. These converters are essentially made up of input output terminals that are not isolated from one another.[4]

The Buck Converter:

One common kind of converter used in circuits is the buck converter. According to requirements, it lowers the voltage level from the input voltage. The fact that it is inexpensive and simple to use are two of its many great qualities. Figure 2 shows a buck converter. At the very beginning of the Buck converters' operation, there is no current flowing through any part of the circuit because the switch is open. As time passes with the switch closed, current starts to flow through the inductor at a modest but steady rate.[5] A lower voltage is observed at the inductor's "output" when the switch is closed because current is drawn through the diode by the inductor. In fact, this is the most basic idea behind how a buck circuit works.

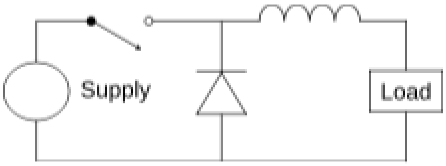

Figure 2: BUCK Converter

Making these assumptions is the first step in doing an analysis of the buck converter:

1. At this moment, the circuit is functioning in the static condition.
2. The current flowing through the inductor is continuous and constantly positive.
3. The capacitor is of a very high size, and the voltage at the output is maintained at the same level as the voltage Vo.
4. After some time has passed, this constraint will be loosened in order to demonstrate the implications of limited capacitance.
5. The switching period is denoted by the letter T, and the switch is closed during the time DT and open during the time (1-D)T.
6. All of the components are perfect.

Finding the voltage Vo requires a research that primarily focuses on the inductor current and voltage, first with the switch closed and then with the switch open.[6] For an inductor to operate in steady state, the total current flowing through it must remain constant for the duration of a single period. On average, the inductor does not have any voltage. This circuit may function in either Continuous Conduction Mode or Discontinuous Conduction Mode. Here we will go over what they are.

Continuous Conduction Mode

When the current flowing through the inductor (IL) of a buck converter is never allowed to drop below zero throughout the commutation cycle, the converter is said to be operating in continuous mode.[7] The chronogram shown in Figure 1 provides an explanation of the operating concept that is utilized in this mode.

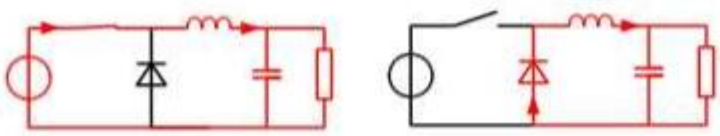

Figure 3: On and off state of Buck converter

Figure. 3: In a buck converter, there are two different circuit configurations: (a) the On-state, which occurs when the switch is closed, and (b) the Off-state, which occurs when the switch is open.

- When the switch pictured above is closed (On-state, top of Figure 2), the voltage across the inductor is VL = Vi − Vo. The current through the inductor rises linearly. As the diode is reverse-biased by the voltage source V, no current flows through it;
- When the switch is opened (off state, bottom of figure 2), the diode is forward biased. The voltage across the inductor is VL = − Vo (neglecting diode drop). Current IL decreases.

The energy stored in inductor L is

$$E = \frac{1}{2} L \times I_L^2$$

Consequently, it is possible to observe that the amount of energy that is stored in L grows during the On-time (corresponding to the increase in IL), and subsequently drops during the Off-state. It is the function of L to facilitate the movement of energy from the converter's input to its output. IL's rate of change may be determined by using the following formula:

$$V_L = L \frac{dI_L}{dt}$$

For the On-state, the value of VL is equal to Vi minus Vo, whereas for the Off-state, it is equal to -Vo. The increase in current that occurs during the On-state may thus be calculated as follows:

$$\Delta I_{L_{on}} = \int_0^{t_{on}} \frac{V_L}{L}\, dt = \frac{(V_i - V_o)}{L} t_{on}, \qquad t\{on\} = DT$$

Identically, the decrease in current during the Off-state is given by:

$$\Delta I_{L_{off}} = \int_{t_{on}}^{t_{off}} \frac{V_L}{L}\, dt = -\frac{V_o}{L} t_{off}, \qquad t\{off\} = T$$

The amount of energy that is stored in each component at the conclusion of a commutation cycle T is equivalent to the amount that was stored at the beginning of the cycle, provided that we assume that the converter runs in a steady state.[8] Therefore, the present IL is the same at t=0 as it is at t=T (see to Figure 3 for more explanation).In light of the equations shown above, we may write:

$$\frac{(V_i - V_o)}{L} t_{on} - \frac{V_o}{L} t_{off} = 0$$

HIGH GAIN CONVERTER TOPOLOGY

The DC-DC converter may be divided into two groups, namely the non-isolated (transformer less) converter and the isolated converter, depending on the type of isolation that is required.[9] In order to get a greater conversion ratio, an isolated converter has to have a high frequency transformer so that it can function properly. Depending on the switching loss situation, a DC-DC converter may be divided into two categories: a hard switching converter and a soft switching converter.[10] To ensure the dependability of the distributed generation system, the front end DC-DC converter should be able to function throughout a broad spectrum of input and output voltages. This implies that the converter should function at a duty cycle that ranges from the least desirable duty cycle to the maximum desirable duty cycle. Limitations imposed by practical considerations place restrictions on both the minimum and maximum conversion ratios of classical converters. Whenever a classical converter is subjected to the maximum duty cycle, there is a noticeable decrease in conversion efficiency.[11] The work that can be found is considered to be one of the earliest examples of constructing a wide conversion ratio switched mode power converter. It is mentioned in that a systematic categorization of non-isolated DC-DC converters is carried out with regard to their capacity to manage a broad conversion rate.

A. Non isolated step up converter without wide conversion ratio

The magnitude of the unregulated DC voltage that is input is increased by the utilization of a boost converter. In theory, the conversion ratio of the converter in question is unlimited; however, in practice, the conversion ratio is restricted to four to five times due to the presence of various parasitic components in the passive component and the limitations imposed by the controller. It is because of the existence of right half plane zero (RHPZ) that the transfer function of a boost converter displays non-minimum phase behavior and has a delayed dynamic response. Several structural modifications are made to the boost converter in order to mitigate the adverse impacts of RHPZ. Additionally, a novel converter topology, which is referred to as the tri-state boost converter, is presented.[12] A rectifier for the input bridge and a capacitor for the input filter are both components of standalone power supply. In addition to causing harmonic distortion on the line, this design also causes an excessive peak input current, which ultimately leads to a decrease in power factor. Buck-Boost converters, Single-Ended Primary Inductor converters (SEPIC), and Cuk converters are examples of power converter topologies that are appropriate for power factor correction (PFC) or power factor pre-regulator (PFP) techniques.

Enhancing the gain of the front-end DC-DC converter may be accomplished by the utilization of either interleaved types of boost converters, which is one of the alternatives. Some of the most well-known examples of non-isolated high gain converters are the interleaved boost converter and the floating interleaved boost converter.[13] The most significant drawback of the interleaved variation of the boost converter, however, is that it suffers from a loss of efficiency as a result of the sophisticated controller architecture. The three-level boost converter has the capability of providing a conversion ratio that is twice as high as that of the boost converter. It is possible to lower the size of the inductor in a three-level boost converter, which results in the converter being more compact in terms of both size and weight The curve displayed in Figure 4 illustrates the relationship between voltage gain and duty ratio for a variety of typical converters. This table presents a comparative examination of several non-isolated converter topologies, which are illustrated in Table I based on literature review conducted . Specifically, the voltage gain and the number of components has been the two criteria that serve as the foundation for the comparison study.

TABLE I: Analysis of the various topologies of non-isolated converters

Topology	Voltage Gain	MOSFET	Diode	Inductor
Boost converter	$\frac{1}{1-D}$	1	1	1
Buck-Boost	$\frac{-D}{1-D}$	1	1	1

converter				
Cuk converter	$\frac{D}{1-D}$	1	1	2
SEPIC	$\frac{D}{1-D}$	1	1	2
2-ph IBC	$\frac{1}{1-D}$	2	2	2
2-ph FIBC	$\frac{1+D}{1-D}$	4	4	4
3-level Boost	$\frac{2}{1-D}$	2	2	1

Non isolated step up converter with wide conversion ratio

The utilization of cascaded boost converters is one of the alternatives that may be selected in order to enhance the voltage conversion ratio of a classical boost converter [14]. In a cascaded boost converter, boost converters are connected in series mode, which results in an increase in the converter's voltage conversion ratio. Despite the fact that the voltage conversion ratio is enhanced, cascaded boost converters have a greater number of components, which results in an increase in cost and makes the controller design more challenging. An instability in the converter is the consequence of a problem with the reverse recovery of the diode that is located in the second stage of the converter. A modified cascaded boost converter is referred to as a single switch quadratic boost converter. This type of boost converter has one switch rather than two switches. the quadratic boost converter is superior to the cascaded boost converter in terms of both its efficiency and its stability performances.

When it comes to raising the voltage gain of a converter, there are essentially two methods that may be utilized, namely the utilization of an inductor and the utilization of a capacitor. It is possible to utilize a coupled inductor as a transformer by altering the turns ratio of the primary and secondary windings in the appropriate manner in order to increase the value of the gain. Losses that are caused by leakage inductance, on the other hand, have the potential to reduce the efficiency of such converters . A flyback converter with connected inductor offers a voltage gain that is substantially higher than average; nevertheless, the efficiency of the converter is low because of the existence of leakage inductance.[15] Increasing the voltage gain of the converter is accomplished with the assistance of the capacitor in a converter that is based on switched capacitors. The duty cycle of the converter is quite low, and it has a greater number of active switches than similar devices. It is proposed that a boost converter combined with switched capacitor technology has been developed. presents an approach that is a modified version of the boost type switching inductor technique. There are certain adjustments that are recommended in for the switched inductor-based converter that is currently in use. Both the voltage lift technique and the voltage multiplier approach, which makes use of the capacitor-diode technique, have the potential to significantly raise the voltage. It has been observed that the primary switch of the converter experiences transient current, which leads to conduction loss. Because of the extensive structural complexity of these converters, the cost of the converters is also rather expensive.

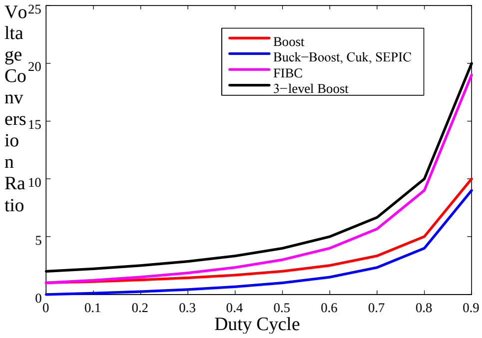

Fig. 4: In traditional converters, the voltage gain and duty ratio

ISOLATED FULL BRIDGE TOPOLOGIES

Voltage fed converter

When it comes to a basic isolated full-bridge converter, there are a variety of output designs that may be utilized. Some examples include the diode bridge configuration, the center-tapped transformer configuration with two diodes, and the voltage doubler configuration. Figure 5 depicts a conventional complete bridge converter for your reference. The secondary side rectifier of a voltage-fed converter is plagued by a leakage inductance problem, which causes a rise in the diode breakdown voltage.[16] This is the major constraint of the converter. It is necessary to have a diode snubber circuit because of this reason. The voltage fed converter does not offer a notion of voltage boosting, and it is necessary to have a high turns ratio.

A phase-shifted full bridge ZVS converter is utilized in order to circumvent the constraints that are associated with a voltage-fed full bridge converter. In phase-shifted full bridge ZVS, the primary switches have the capacity of being switched on in zero, which is the key advantage of this configuration.

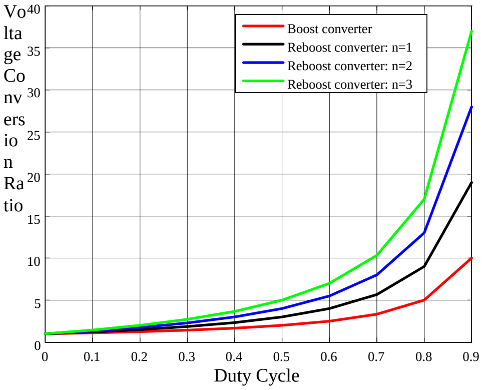

Fig. 5: The reboost converter's amount of voltage gain

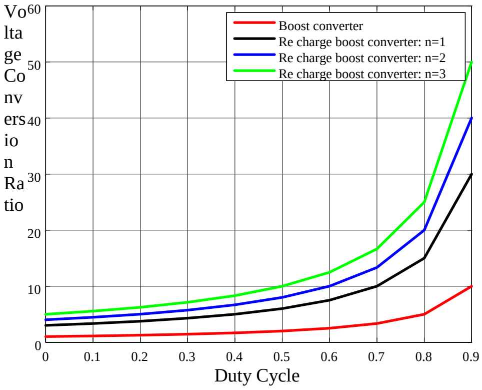

Fig. 6: Gains in voltage that replenish boost converters experience

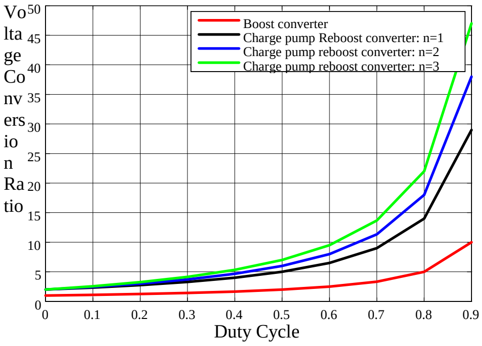

Fig. 7: The voltage gain of the reboost converter for the charge pump

SOFT SWITCHED CONVERTER

In order to function properly, the switches of PWM converters need to be able to endure high voltage and high current. This causes the devices to experience significant switching loss and voltage stress. Extremely high levels of stress and loss have a significant impact on the converter's efficiency. Making use of a snubber circuit is one of the alternatives that may be utilized in order to eliminate the significant switching loss. This is done in order to lessen the dtdi and dvdt rating of the power devices. There are a variety of methods that may be utilized to accomplish soft switching, and one of the techniques that is utilized frequently is the utilization of auxiliary circuits .[17] A soft switched converter is often distinct from an active switch in terms of both the high current and voltage stress that it experiences. As a result, the authors of have developed a ZC-ZVS commutation cell that is capable of providing soft switching to both active switches and passive switches.

The schematic representation of a boost converter that includes an auxiliary circuit is shown in Figure 8 The primary purpose of the auxiliary circuit is to generate zero-voltage-switching (ZVS) in the converter.

RESONANT CONVERTER

There is a category of converters known as resonant type converters. These converters have a topology that includes at least one resonant tank circuit. An inductor and a capacitor are the two components that make up the resonant tank circuit.

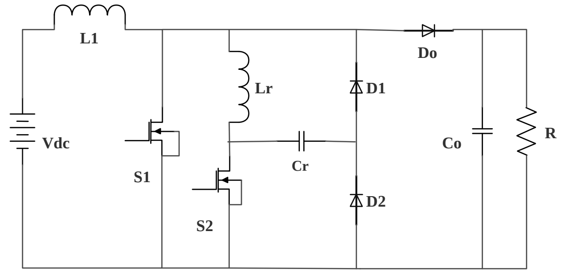

Fig. 8: Boost converter using ZVS in conjunction with an auxiliary circuit

the capacitor. The series resonant converter (SRC), the parallel resonant converter (PRC), the series-parallel resonant converter (SPRC), and the LLC resonant converter are some of the most used topologies for resonant converters. There are two modes of operation that may be utilized by a resonant converter: fixed frequency mode and variable frequency mode. The operation in the fixed frequency mode is favored since the design of control circuit and filter components presents a substantial difficulty when operating in the variable frequency mode.

The greater amount of stress that is placed on the semiconductor switches and the bigger inductance value that is required for ZVS operation are two of the most significant limitations that are associated with resonant converter topologies. The usage of a quasi-resonant converter is employed in order to counteract the impact of a high circulating current in the resonant converter; nevertheless, the most significant restriction of the quasi-resonant converter is that it has a restricted switching frequency.[18] A multi-resonant converter is therefore utilized. The multi-resonant converter is capable of operating in conditions ranging from full load to no load, with a wide range of input variation. One of the most significant drawbacks of the multi-resonant converter is that it has a greater circulating current because of the continual resonance of the equilibrium circuit. has a full study of the advantages and disadvantages of resonant, quasi-resonant, and multi-resonant converters. You can find this analysis here. There are three primary sorts of resonant converter designs that are utilized extensively for fuel cell software applications. The voltage fed resonant converter, the current fed resonant converter, and the fixed frequency resonant transition ZVS PWM converter are all examples of resonant converters. In comparison to the other topologies, the semiconductor rating of the current fed resonant converter is significantly greater, which results in the converter being more cumbersome and expensive.[19] An investigation on the similarities and differences between eight distinct fixed frequency resonant converters for use in fuel cell-based applications is published in.

CONCLUSION

In this study, a comprehensive categorization of the various DC-DC converter topologies that are utilized in power conversion units (PCUs) for a renewable energy source (fuel cell) is presented. During the process of developing a power control unit (PCU), the power electronics designer has a number of significant obstacles, including the reduction of the cost of the PCU, the increase in the fuel cell life cycle, reliability, and efficiency. The purpose of this study is to present a categorization of DC-DC converters based on the conversion ratio as well as the number of components. A comprehensive examination of converters, including non-isolated, isolated, and soft switched converters, is presented, along with a critical analysis of each of these types of converters.

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