ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
Vol 4, Issue 2, February 2018

Comparative study of DC-DC converter topologies for fuel cells

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***Abstract*: -- Converters and fuel cell technologies play an important role in the field of renewable energy. Fuel cells have become one of the main sources of power for portable applications and standalone applications like telecommunications. High-efficiency converter is an essential requirement in fuel cell systems. The selection of an appropriate converter topology is an important part of designing fuel cell systems as the converter plays a major role in determining the overall performance of the system. This paper presents a review of the comparative study of different topologies of DC-DC converters used in fuel cell systems, which include various topology combinations of DC converters and AC inverters and which are primarily used in fuel cell systems for portable or stand-alone applications. This paper also reviews the switching techniques used in power conditioning for fuel cell systems. This paper mainly discusses the current problem faced by DC converters and AC inverter.**

***Keywords:* — Switching elements- inductor, diode, and capacitor. Single-stage topologies, Multistage Topologies, DC/DC convertor, PWM, Resonant, ZVSs & ZCSs.**

I. INTRODUCTION

Among all types of green energy applications, fuel cells are the most popular because they can provide a continuous power supply throughout all seasons. However, the renewable energy supplied by fuel cells has a low-voltage output characteristic. High step-up DC-DC converter is required in Fuel cell systems. The characteristic electrical output of fuel cells has some shortcomings like low output voltage which decreases as the load current increases. However, the low emission and high efficiency of the fuel cell make them a favorable choice for energy sources in portable applications. Implementing power electronics applications in fuel cell systems is a solution that allows fuel cell technology to be used in any application.. Adopting different switching components and switching topologies of convertors in fuel cell systems yield different efficiencies. With the advances in technology made in the semiconductor industry, hard switching power electronics components were added to improve reliability and efficiency. However, there is still a large amount of electrical noise present. The idea behind using a soft-switching method is purposely to reduce noise and switching losses. In addition, switching losses can be reduced by implementing zero-voltage switches (ZVSs) or zero-current switches (ZCSs). This paper presents a review on various topologies of DC converters and AC inverters and combination of both, which are primarily used in fuel cell systems. This paper also reviews the switching techniques used in power conditioning for fuel cell systems.

II. CURRENT TECHNOLOGY BEHIND THE MAIN TOPOLOGY OF DC CONVERTERS.

Several DC converters are available that can increase or decrease the magnitude of the DC voltage and/or invert its polarity. The switch is realized using a power MOSFET and diode; however, other semiconductor switchers, such as IGBTs, BJTs, or thyristors, can be used based on delivering the highest efficiency and reliability.

2.1 DC-DC Boost converter:

Basically, a boost converter consists of switching element, a diode, an inductor, and a switching controller, as shown in Figure 1.

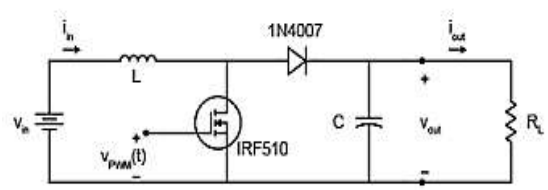

Fig 1.DC-DC buck-boost converter topology

The switching element is switched between the "on" and "off" state by the controller to boost the input voltage to the desired output voltage. During the "on" state of the switching element, electrical energy is stored in the inductor, and then the capacitor supplies current to the load and the diode with a reverse bias. When in the "off" state, stored energy is transferred to the load and capacitor through the diode .The boost converter operates in one of two modes, continuous-conduction mode or discontinuous-conduction mode, which is characterized by the current waveform of the inductor. The

ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
Vol 4, Issue 2, February 2018

inductor current is greater than zero all the time when in continuous-conduction mode, and the inductor current falls to zero after each switching cycle when in discontinuous-conduction mode.

The boost converter has characteristics such as a continuous input current, a low input ripple current, which are ideal for fuel cell applications, and many attempts have been made to improve the efficiency of the boost topology at low input voltages, making it the ideal choice for fuel cell applications. These improvements include optimizing the transformer design to achieve very low leakage inductances, taking advantage of modern power electronics switching, and eliminating the need for a voltage clamp circuit.

A soft-switching boost converter using a soft-switching method with a resonant inductor and capacitor, an auxiliary switch, and diodes and proved that the converter reduces switching losses more than a conventional hard-switching converter and that the efficiency increases approximately 96%.

2.2 DC-DC Buck Converter:

The buck converter is used to reduce the DC voltage and has a conversion ratio of M(D)=D . It is widely used because of its simple topology, which is characterized by a low number of components, low control complexity, and no isolation as in fig 2

In the conventional buck converter, only a single active switch is used, and the maximum voltage applied across the terminals of the semiconductors equals the input voltage obtained using the hard switching technique. However, this conventional method produces low efficiency because of the high conduction losses due to high-voltage-rated devices and high switching losses. Buck converters can be used in low-power-range regulators and very high range step-down converters.

In a Study of a DC-DC buck converter with three-level buck clamping, zero-voltage switching (ZVS), active clamping, and constant-frequency pulse width modulation (PWM) and proved that the voltages across the switch are 50% lower compared with a two-level ZVS buck-buck converter. It is proposed a new single-inductor quadratic converter using average-current-mode control without slope compensation, which minimises several power management problems, such as efficiency, EMI, size, transient response, design complexity, and cost . Jahanmahin [2] proposed an improved configuration for DC-DC buck and boost converters, which is a novel method for increasing output power by utilising two storage elements and reducing the output ripple voltage for buck and boost converters.

2.3 DC-DC Buck boost converter:

The basic circuit of a buck-boost converter consists of a switching element, inductor, diode, and capacitor. The difference between a buck-boost and a boost converter is the arrangement of the switching element placed before the inductor, as shown in Figure 2.

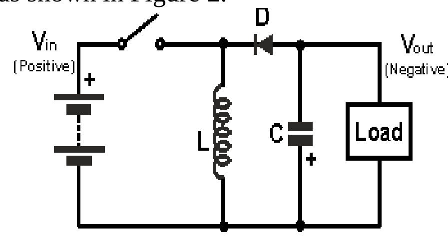

Fig 2. DC-DC Buck-Boost converter

The buck-boost topology can produce an output voltage that is equal to, less than, or greater than the input voltage. The buck-boost topology is suitable for portable applications, which require a wide range of output levels, and it is an attractive choice when a large current is supplied .The output voltage is equal to the input voltage when the duty cycle is 0.5. When the duty cycle is less than 0.5, the buck-boost converter operates in buck mode, causing the output voltage to be lower than the input voltage. To make the buck-boost converter operate in boost mode and cause the output voltage to be higher than the input voltage, the duty cycle must be greater than 0.5. This relationship is shown in Figure 3 [1].

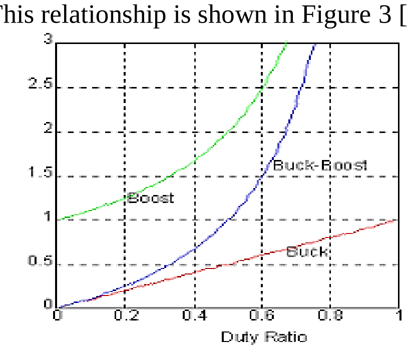

Figure 3: Comparison of duty ratio in buck,boost,and buck-boost converter.

Chen. [3] proposed a buck-boost PWM converter having two independently controlled switches that can work as a boost or as a buck converter depending on the input-output conditions; this approach puts lower stresses on the components.

Hwang et al. [4] proposed a low-voltage positive buck-boost converter using an average current controlled with a simple compensation design. This approach can reduce some power management problems, such as size, cost, design complexity, a maximum efficiency of 72% at a switching frequency of 1 MHz.

2.4 DC-DC Cuk converter:

The Cuk converter contains an inductor in series with the converter input and output port. The switch network alternately connects a capacitor to the input and output inductors. The Cuk converter is a modified boost-buck converter and can be used either to step up or step down the output voltage with respect to the input. It's advantage is the

IFERP
ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
Vol 4, Issue 2, February 2018

presence of both input and output inductors. These inductors lower the current ripple on the input source and the load. Furthermore, the Cuk converter also has a higher efficiency, reduced EMI generation,

2.5 DC-DC Sepic converter:

The single-ended primary inductance converter (SEPIC) can either increase or decrease the voltage magnitude. However, it does not invert the polarity. The conversion ratio is M(D) =D/D-1. . The SEPIC has the features of the buck-boost operating mode, no polarity inversion and wide input voltage range.

It also has the following advantages, which are applied to the electricity generation system of the fuel cell: (i) It is a converter that can operate under boost or buck situations, (ii) The input terminal of a SEPIC converter contains an inductor, which can reduce the input current pulses and overcome the disadvantage of the electric current pulses of the fuel cell to increase the accuracy of the control.

III. APPLICATION OF DC CONVERTERS IN FUEL CELL SYSTEMS:

Due to the limitations of fuel cells, which include low voltages, low current densities, and unstable power production, the DC converter has become the most important component in fuel cell systems for portable or stand-alone applications. Normally, a single DMFC (Direct Methanol Fuel Cell) can supply only approximately 0.3–0.5 V under loaded conditions. By using a DC converter, these limitations can be solved with a converted voltage source from the fuel cell .Various DC converters have been developed to support fuel cell systems, but the efficiency of a DC converter depends on the conduction and switching losses. If there are fewer conduction and switching losses, then the DC converter operation is more efficient. By reducing the number of components used and their operating ranges, the conduction losses can be effectively reduced. Therefore, it may require a nominal supply voltage, which can be above, below, or equal to the fuel cell generating voltage. Therefore, the system designed for the nominal supply voltage will require a converter capable of stepping up or stepping down the fuel cell voltage. There are two converters widely used in fuel cell systems for the single-stage level or for low-voltage portable applications to step up and step down the fuel cell voltage with a high efficiency: boost converters (step-up) and buck converters (step-down).

3.1 Single-stage topologies:

To fulfil the operational requirements of fuel cell systems, the researchers developed various topologies for single-stage conversion either using a DC-DC converter or a DC-AC inverter. The voltage generated from the fuel cell can be converted directly into a regulated DC voltage, or it can be converted directly into an AC voltage as a supply voltage, depending on the AC or DC load. A single-stage topology has reduced component counts and is simple to control. Many studies it is observed that conditioning of fuel cell systems in portable applications and it is claimed that the DC-DC boost converter gives the desired regulated output voltage level and maintaining an input current ripple below 2% of the nominal input current for low power fuel cells. Out of Buck and Boost topologies boost converter topology is more appropriate for low-voltage fuel cell applications. With zero-voltage-transition (ZVT) two-inductor boost converter using a single resonant inductor with a improves the efficiency due to the ZVS operation under the V condition.

3.2 Multi stage topology:

Power conditioning combinations involving two types of DC-DC converters or an AC inverter are recognized as multistage topology. In this topology voltage or current of the fuel cell will convert first to desired value by using DC-DC converter This DC-DC converter may involve any type of DC-DC converter such as boost, buck-boost, and so on to get desired value of voltage or current becoming input variable to the inverter and is also used to charge ultra-capacitor or battery. Second step in this topology is DC voltage from DC-DC converter inverted to AC voltage. The disadvantage of this topology using more components compared with a single stage will make the power loss in a multistage topology greater than that in a single-stage topology. Hybrid energy system topology between DMFC and a super capacitor in which the DMFC and the super capacitor bank are connected to a common DC voltage bus through a boost converter and a bidirectional converter.

The super capacitor can be charged and discharged rapidly under varying load conditions for an uninterrupted power flow to the load with suitable design of the bidirectional Converter.

Kwon et al. [7] proposed a high-efficiency active DMFC system for portable applications. This system used a smart battery to support the fuel cell system that consisted of two buck-boost converters to increase the power conversion efficiency. As shown in Figure 5, in which the synchronous boost converter is connected after the fuel cell to boost the voltage from the fuel cell up to the DC-bus voltage (typically 3.3 V for electronic devices). In a real application, the fuel cell withal on the battery side, the H-bridge buck-boost converter will be employed to manage charging and discharging the battery.

This H-bridge buck-boost converter is emerging with an analogue design, which means this converter can be operated as a buck converter when the battery is fully charged or as a boost converter when the battery is almost discharged.

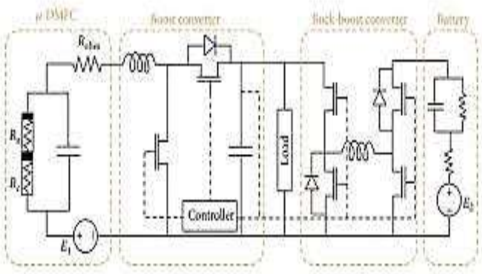

Figure 5: The hybrid power system (small-scale DMFC and Li-ion)

IV. LIMITATIONS OF CURRENT DC CONVERTERS:

Boost converters have a voltage collapse point when the output power is too high and the input current becomes excessive, leading to high losses, which in turn reduces the efficiency further, requiring even more input current, causing voltage collapse. There are also large voltage drops across the diode. For low-voltage applications, replacing the diode with a switching element can improve the efficiency of the converter. In this circuit, a time delay must be used to prevent a shoot-through current between turning off and turning on. In this way, the voltage drop across is the lowest, and the efficiency can be improved. Two power management schemes were used to achieve a high efficiency within the whole load range: PWM control for the heavy load condition and PFM control for the light load condition. The converter has different power losses (conduction loss and switching loss) under different load conditions.

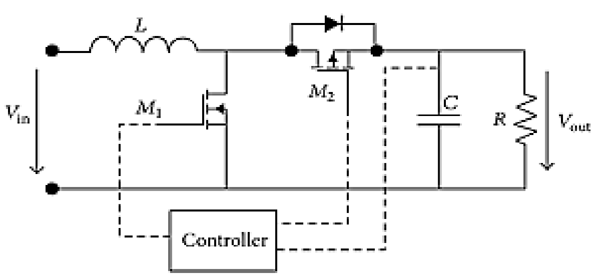

Figure 6: Synchronous DC-DC boost converter topology

The principal disadvantage of a "boost converter" is the high switching noise. This noise is generated when turning on and off the switching element, and it deteriorates the quality of the output voltage and degrades the performance of the fuel cell.

Several solutions to avoid this problem have been proposed: a snubber circuit can be placed at every switch and the soft switching technique can be used.

The buck-boost converter requires a greater duty cycle than the boost converter to boost the input voltage at the same output voltage level. This causes the buck-boost converter to be less efficient compared with the boost converter because higher duty cycles increase conduction losses in the switching element. To solve this problem, a noninverting buck-boost converter can be used. Noninverting buck-boost converter topology involves cascading between a buck converter and a boost converter, as shown in Figure 7.

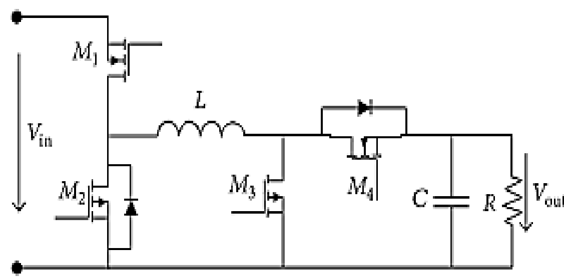

Figure 7.Non inverting buck-boost converter topology

Conventional hard-switched pulse-width modulation (PWM) suffers from high switching losses, high device stress, and objectionable EMI when operating at a high switching frequency compared with the soft-switching PWM technique, which is being used for high switching frequency operation with high efficiencies and large power-to-volume ratios [5].

V. RECENT DEVELOPMENT IN DC-DC CONVERTERS:

Saha [5] proposed that the efficient soft-switched boost converter can be increased by using an auxiliary network in addition to the boost inductor, boost switch, and boost diode as shown in Figure 8. The output voltage of this converter can be regulated by varying the pulse-width of the main switch. Lin and Dong [6] proposed a new zero-voltage switching DC-DC converter for renewable energy conversion systems based on a boost converter and a voltage-doubler configuration with a coupled inductor to achieve a high step-up voltage conversion ratio, as shown in Figure 9. A new soft-switched pulse-width-modulated (PWM) quadratic boost converter that is suitable for applications with a wide fluctuating DC input voltage range is designed for fuel cell systems.

The efficiency of this converter is equal to 92.3%. Finally, Delshad and Farzanehfard [8] proposed a new zero-voltage switching current-fed push-pull DC-DC converter. The auxiliary circuit in this method is introduced purposely to provide a zero-voltage switching condition and also to absorb the voltage surge across the switches at the turn-off instance.

ISSN (Online) 2395-2717

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Vol 4, Issue 2, February 2018

The reduction in size , weight and efficiency of the converter can be increased with high-frequency operation.

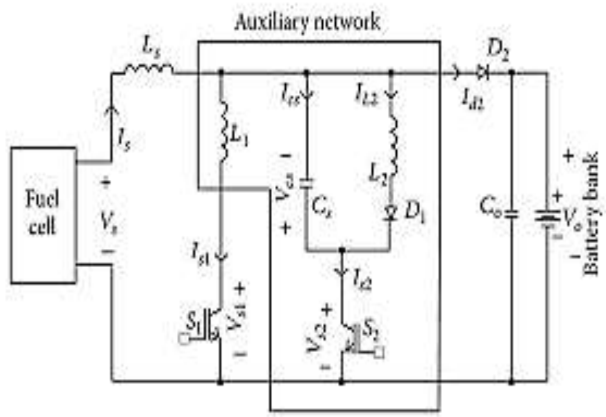

Figure 8: New soft-switched DC-DC boost converter,saha(5)

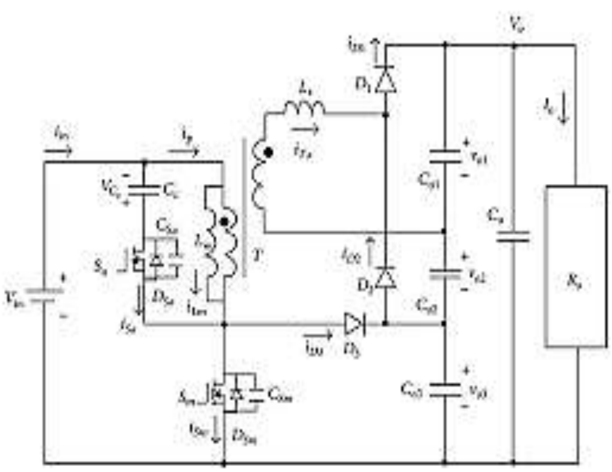

Figure 9.New zero-voltage switching DC-DC converter, Lin and Dong [6].

VI. CONCLUSIONS

The DC converters with various topologies contribute to the use of renewable energy in various applications, especially in portable or stand-alone applications. A review on DC converters shows that they can be used to produce a more efficient conversion of power from the fuel cell to the load. Using a DC converter or a combination of DC converters can address the limitations of fuel cell, which include unregulated voltage, low voltage, low current density, and unstable power. A hybrid DC converter with a battery or a super capacitor or other external supplies can stabilize the power conditioning to balance the excess and insufficient power condition in the fuel cell. This review also shows that the switching technique is the main element of a DC converter. Introduction of the soft-switching operation to DC converters introduces improvements in terms of increased converter power density and converter efficiency. The topology of the DC converter in the power conditioning unit can be divided into single-stage and multistage topologies. In single-stage topologies, the DC converter stands alone, but in multistage topologies, the DC converter is combined with DC converters or with AC inverters.In conclusion, the design of DC converter topologies is considered important in fuel cell systems. Therefore, more studies on the development of new topologies for DC converters, including new switching techniques, are needed to create a higher efficiency and improve the existing switching technique. For specific applications of portable fuel cell systems, the size and energy density are considered very important. Currently, portable fuel cell focuses on two types of fuel cells that can fulfil the size and energy density requirements: direct methanol fuel cells (DMFCs) and direct borohydride fuel cell (DBFCs). Fuel cells such as DMFCs and DBFCs with improved power converter technologies can be considered as promising alternative energy sources for portable applications.

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