VOL. 10, NO. 8, MAY 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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REVIEW AND ANALYSIS OF NON-ISOLATED DC-DC POWER ELECTRONIC INTERFACE WITH FUEL CELL SYSTEM

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ABSTRACT

Fuel cells are becoming the most interesting and promising alternative resources for both automotive industry and stationary power plants. However the technological hurdle lies in the design of an efficient power electronic interface for the development of commercial products in the aforementioned fields. As the fuel cell output voltage is low, achievement of high step-up, low cost and high efficiency DC-DC conversion is the major consideration. This paper reviews and analyses the various DC-DC converters suitable for fuel cell system applications which mainly focuses on the non-isolated topology along with its advantages, disadvantages and its suitability for various power applications. In addition a clear overview about the parameters to be considered for the selection of converters is also described.

Keywords: boost converters, fuel cell, non-isolated, power conditioning unit, renewable energy.

1. INTRODUCTION

Depletion of fossil fuels, increasing energy consumption and rising public awareness for environmental pollution effects have turned the focus of research work towards alternative renewable energy sources. Fuel cells are one of the most promising sources of energy because of their high efficiency and low environmental impact. As it is focused only in recent years and considered as a relatively new technology, the perception of risk and lack of user experience are obstacles. The capital expense of fuel cell systems may have been the most significant barrier in the past, but as technology improves, this may no longer be the case. Some tedious obstacles are: i) No acceptance of reverse current, ii) Low output voltage and its degradation with age and current, iii) Low efficiency with output ripple current, iv) Limited overload capability and v) Respond sluggishly to step variation in load. To overcome these technical challenges, power converters are often necessary to boost and regulate the output voltage to provide an applicable DC power source. This paper gives a brief introduction about the typical electrical characteristics of fuel cells, different types of fuel cell and their applications. This paper also focuses on the examination of various topologies of DC-DC converters used for power conditioning of fuel cells for various applications.

2. INTRODUCTION TO FUEL CELL TECHNOLOGY

The basic operation of fuel cell is very simple. In 1839, lawyer and scientist, William Groove discovered the reverse electrolysis of water (Larminie *et al*., 2003). By combining hydrogen and oxygen in a particular configuration, electricity could be produced. A fuel cell is an electrochemical cell that derives electrical energy from spontaneous redox reaction taking place within the cell. The process is implemented by using two electrodes. At one electrode, hydrogen fuel is oxidised and at the other electrode oxygen is reduced. Electrolyte which is in between two electrodes transmits ions from anode to cathode but does not allow movement of electrons (Hoogers, 2002). Thus the reactions exchange electrons through an external circuit which gives the electrical power to the load. The reactants flow into the cell and the reaction products flow out of it whereas the electrolyte remains within the cell (EG and G Technical Services, 2004). The basic reactions involved in energy conversion of Hydrogen-Oxygen fuel cell are:

$$\text{At Anode: } 2H_2 \rightarrow 4H^+ + 4e^- \quad (1)$$

$$\text{At Cathode: } O_2 + 4H^+ + 4e^- \rightarrow H_2O \quad (2)$$

$$\text{Net reaction: } 2H_2 + O_2 \rightarrow 2H_2O \quad (3)$$

When pure hydrogen is used as fuel the products are thus water and energy which makes it advantageous. The fuel cell provides DC voltage which can be used for various applications directly or by converting to AC with the help of inverter (Behling and Hikosaka, 2012).

2.1 Importance of fuel cell

At present the entire world is in energy and environment crisis which forces people to go for a clean and more efficient renewable energy sources. Generating renewable electricity is an important way to reduce carbon dioxide (CO_2) emissions and many countries are installing wind and solar power plants to meet the targets for reducing CO_2 emission. One drawback of these energy sources is their variability: the wind tends to blow intermittently and solar power is only available during the daytime. Storing excess renewable energy generated during times of plenty is a difficult task. One of the alternative sources of power is fuel cell. Excess electricity can be fed into an electrolyser to split water into its constituent parts: oxygen and hydrogen. The hydrogen is then used in fuel cells to produce electricity when needed, releasing the stored energy.

Fuel cells also promise greater operating efficiency with lower emissions over conventional power sources used today. Unlike internal combustion engines, the fuel is not combusted, the energy instead being released electro catalytically. This allows fuel cells to be highly energy efficient, especially if the heat produced by the reaction is also harnessed for cogeneration. The advantages of fuel cell are its high efficiency, low environmental impact, reliable and very quiet operation. But it has some technical challenges which include expensiveness in manufacturing, production and storage of hydrogen-a difficult task and extreme heat generation in some models.

The major applications are: (i) Stationary (A.C. Applications)-Power plants, Residential use and Commercial use; (ii) Enclosed Environments (D.C. Applications)-Auxiliary power unit, Space Station, Space vehicles (space shuttle) and underwater vehicles (submarine); (iii) Transportation and portable electronics (D.C. Applications)-Personal Vehicles (Zero Emission Vehicles), Public Transportation, Commercial and Military Vehicles.

2.2 Types of fuel cells

There are many different types of fuel cells which are mainly distinguished by the electrolyte/fuel that is used; though there are other important differences in performance parameter as well (Larminie *et al*., 2003). The general classifications of fuel cells are: (i) Alkaline Fuel Cell (AFC); (ii) Proton Exchange Membrane Fuel Cell (PEMFC); (iii) Phosphoric Acid Fuel Cell (PAFC); (iv) Molten Carbonate Fuel Cell (MCFC); (v) Solid Oxide Fuel Cell (SOFC)

The operating temperature of the fuel cell can be determined by the choice of electrolyte and the type of material used for it (Hoogers, 2002). Liquid electrolytes limits the operating temperature to about 250° C or below because of the rapid degradation and vaporization of fluids at higher temperatures. Low temperature fuel cells include AFC, PAFC and PEMFC types. The rate of chemical reaction is too slow in low temperature fuel cells and hence it requires precious nobel metals such as platinum at any one electrode or both to catalyse the reaction. As low temperature fuel cells cannot tolerate CO concentration in the fuel which causes degradation of the operation, it requires external reformer to purify the hydrogen. Their applications are mainly focused on vehicle applications which requires quick start up and higher power density.

Higher temperatures fuel cells include MCFC and SOFC which has an operating temperature of 500° C and above typically promote faster reactions (Behling and Hikosaka, 2012). As high temperature fuel cells react more readily and efficiently, it does not require the precious nobel metal catalyst. It is also fuel flexible and do not necessitate the use of external reformer as hydrocarbon fuels can be internally converted to hydrogen or even directly oxidized electrochemically during cell reaction.

Fuel cell is also classified based on the type of fuel used. Direct Methanol Fuel cell (DMFC) uses liquid form of Methanol or alcohol as fuel directly instead of pure hydrogen (Kirubakaran *et al*., 2009). So it operates without reforming. DMFC is a subtype of PEMFC which uses polymer as electrolyte and other operations are similar to that of it. It suits for some applications where the power density can be low but the energy density must be high such as portable electronic systems of low power and running for long times. It operates at a low temperature range of 20-60° C.

2.3 Electrical behaviour of fuel cell

The cell potential vs current density behaviour of the fuel cell predominantly determines the performance of fuel cell systems (Larminie *et al*., 2003). The theoretical open circuit voltage (E) of a hydrogen fuel cell is given by the equation (4).

$$E = (-\Delta G)/2F \tag{4}$$

where ΔG indicates the change in Gibbs free energy and F indicates the Faraday's constant.

The open circuit voltage value of a single fuel cell is about 1.2 V. When the amount of current is increased, the voltage drop is also increased. This drop in voltage is due to the losses such as activation losses, fuel crossover, ohmic losses and concentration losses at the electrode and in the electrolyte (Kirubakaran *et al*., 2009).

Activation losses are dominant when the current density is low. It is due to the slowness of the electrochemical reaction of hydrogen and oxygen at the surface of the electrode. Some of the voltage is lost in transferring electrons between the electrodes which makes this loss as highly non linear with the increase in current. Fuel crossover and internal currents contribute less to the voltage losses when the cell is operated at high temperature. It takes place due to the passing of fuels and electron conduction through the electrolyte.

Ohmic losses take place due to the resistance offered by the electrode and various interconnections to the flow of electron and also by the resistance to the flow of ions through the electrolyte. Ohmic losses are highly linear as it is purely dependent on the resistance.

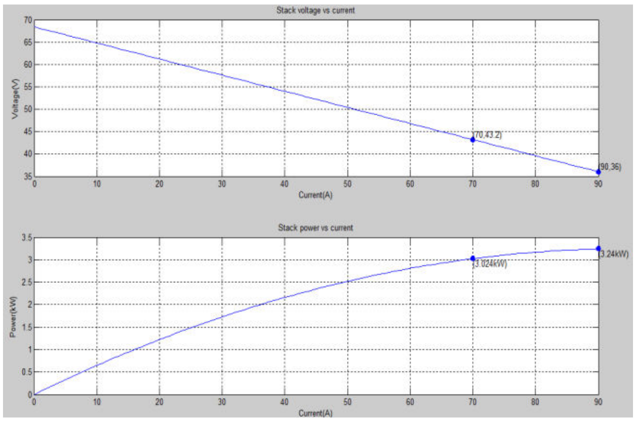

Figure-1. Polarization curve of PEMFC.

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Concentration losses are due to the difference in the concentration of the reactants as the fuel is consumed. Only at high current densities, this loss will be dominant (Doyle *et al*., 2010).

Figure-1 shows the polarization curve of the PEM fuel cell stack using MATLAB/SIMULINK. The fuel cell stack produces an open circuit voltage of 68V and 3KW power at nominal operating point. The voltage curve decreases with increase in current density due to increase in losses.

3. NEED FOR POWER ELECTRONIC CONVERTERS

All electrical power sources generate voltage which varies with time, temperature and other factors such as current. But fuel cells are badly regulated when compared to the other sources which is evident from its electrical characteristics (Figures 1 and 2). Since the voltage of an elementary cell is only about 0.6-0.7 V at the rated current, the fuel cells are connected in series known as stack to produce a useful voltage. But higher stacking has a disadvantage of higher production cost, reducing the reliability and lifetime. Even when there is a small variation in one of its cell in stack the output will get heavily affected. Therefore the fuel cell stack output voltage is mostly limited to a maximum of 100 V to improve the lifetime and reliability. But various applications such as electric vehicles require high DC-bus voltage of few hundred volts to drive the powertrain. Therefore an effective DC-DC converter is needed to interface fuel cell stack with utility DC- bus. As fuel cell strongly varies with the load, the DC-DC converter should also serve as a voltage conditioning unit. The dynamic response of the fuel cell during load variations is very slow i.e. the output voltage cannot match the required demand and fluctuates. Typically, the cell voltage varies from 1 V to 400 mV, so a 60% voltage variation must be managed. Then high stresses can be imposed on the switching devices (Pera *et al*., 2007). Also a diode is connected in series with the fuel cell module as fuel cells obstruct reverse current flow and do not absorb power back. Thus an additional energy storage system such as battery or supercapacitor is required to store braking energy in vehicles and to manage high power transients (Zhang *et al*., 2012).

One major problem with the DC-DC converter is the injection of ripple onto the fuel cell which affects the performance of the fuel cell (Kovacevic *et al*., 2008; Erickson *et al*., 2001). This ripple current is the result of switching characteristics of the electronic devices used in the power conditioning system which generates two components: a low frequency component and a high frequency component. The low frequency component has a frequency twice that of the output AC frequency, generally in the range of 100 Hz or 120 Hz. The high frequency component is in the range of kHz and is caused by the internal switching characteristics of the electronic devices. If the capacitor bank is added at the output of the fuel cell to absorb ripple current, the capacitor should be selected properly to avoid over stress on it. Moreover it increases the cost, size and reliability of the converter. The ripple factor must be lower than 5% and switching frequencies must be greater than 1.25 kHz for the fuel cell output current to have mirror impact to the fuel cell operating conditions (Gemmen, 2003).

The power electronic devices need to be thermally isolated from the fuel cell modules especially from high temperature fuel cells because power electronic units have high losses and it may even get failure under high temperature.

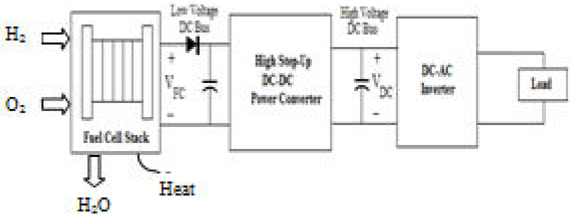

Figure-2. General fuel cell power conditioning system.

Sometimes to provide electrical isolation between the low output voltage of the fuel cell and the high voltage DC link, transformer will be added in DC-DC converters which protects the fuel cell. Thus the power conditioning unit plays an important role in all types of fuel cell applications. The basic power conditioning unit generally consists of a DC-DC converter to raise DC output voltage to DC bus voltage followed by a DC/AC inverter to convert DC bus voltage to AC voltage as shown in Figure-2 (Changchien *et al*., 2010).

The power conditioning unit should be capable of controlling the fuel cell voltage and convert the fuel cell output to the appropriate type. It should be able to operate efficiently under all conditions which mainly depend upon the conduction losses and switching losses. To reduce the conduction losses, the number of components used in the converter and their operating ranges has to be reduced.

The switching losses can be efficiently reduced by adapting soft switching techniques. Thus the configuration particularly number of stages and efficiency of individual components determine the overall efficiency of the power conditioning unit. It also depends on the mode of operation and it varies with the operating point of the system. Efficiencies close to 90% can be achieved for a well-designed power conditioning system, and probably higher for single stage conversion without transformers (Doyle *et al*., 2010). A limitation in power electronic interface is that it cannot perform efficiently beyond certain limit of voltage gain. Hence the fuel cell modules have to be designed in such a way to produce its minimum output voltage more than the least value required by the power electronics unit for the providing voltage gain during interfacing.

4. DC-DC CONVERTERS

DC-DC converters play an important role in fuel cell system to control and regulate the power output. Input to these converters is an unregulated DC voltage from fuel cell stack. It converts the unregulated DC voltage to a regulated voltage based on application.

A study was done by Thounthong *et al*., (2009) about different DC link voltage level based on its applications as 270 V or 350 V for electric aircrafts, 270-540V for electric vehicles, 350 V - 750V for locomotives, 48V, 120V or 400-480V for stand-alone or parallel grid connections. Therefore, a high step-up DC-DC converter is required to boost the low voltage output of the fuel cell stack into the high voltage at the DC bus. Due to non ideal characteristics of fuel cell the development and designing of power conditioning units play an important role to interface the fuel cell system with the end user. The main characteristics required for dc-dc converter are (Song, 2004): (i) High efficiency in power conversion; (ii) High power density; (iii) Small size and light weight; (iv) Low electromagnetic interference (EMI); (v) Reduced ripple current to avoid the FC damage and increase its lifetime; (vi) Low cost.

5. TYPES OF DC-DC CONVERTERS

There are various topologies of unidirectional and bidirectional DC-DC converters suitable for fuel cell interface. Based on the existence of electrical barrier between the input and output, DC-DC converters are classified as Isolated and Non-Isolated Converters. The operation of a semiconductor device, during a given turn-on or turn-off switching transition, can be classified as hard switched, zero-current switched, or zero-voltage switched. Zero current switching (ZCS) and Zero voltage switching (ZVS) are the soft switching techniques in which zero-voltage switching comes at the expense of increased conduction loss. Based on switching topology used, DC-DC converters classified as soft and hard-switched converters. Soft switched converters are mainly adopted to reduce the switching losses over the device, to overcome the problems of switching stress and the EMI and to improve the efficiency at higher switching frequency (Mohan *et al*., 2007).

5.1 Conventional boost converter

Among the DC-DC converters the efficiency of the conventional boost converter (Figure-3) is always greater than the other converter topologies because it has reduced number of components and simplicity in control. It consists of an inductor for energy storage, a switch to control the output, a diode to isolate the output stage when the switch is on and a capacitor to reduce ripple. When the switch is closed (t_{on}) the input current flows through the inductor L and switch S. Hence inductor stores some energy during this operating mode. When the switch is open (t_{off}) the current changes its path as inductor, diode, capacitor and load. The energy stored in the inductor is transferred to the load (Rashid, 2003). Some design parameters such as duty cycle, inductor values and design of output filter are to be considered for boosting the voltage to the required level (Robert and Dragan, 2001).

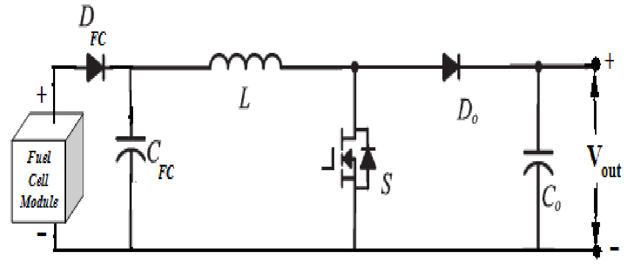

Figure-3. DC-DC boost converter.

During switching-on period DT_s,

$$\frac{di_L}{dt} = \frac{V_{in}}{L} \tag{5}$$

During switching-off period (1-D) T_s,

$$\frac{di_L}{dt} = \frac{V_{in} - V_o}{L} \tag{6}$$

where i_L is the inductor current, V_{in} is the input voltage and V_o is the voltage across the load.

The output voltage for the selected duty cycle (D) is given by

$$V_o = \frac{V_{in}}{1-D} \tag{7}$$

Inductor selection is based on the changes in inductor current,

$$\Delta I_L = \frac{V_{in} D T_s}{2L} \tag{8}$$

Capacitor selection is based on the output ripple voltage,

$$\Delta V_o = \frac{V_o D T_s}{2RC} \tag{9}$$

where T_s is the switching time period.

The voltage gain of this boost converter is extremely high when the duty ratio is close to one. However, the switch turn-off period becomes short when the duty cycle increases and also large duty ratio leads to losses in power switches and diodes. It also cause reverse-recovery problem of diode. As the output voltage is very sensitive to changes in duty cycle it is difficult to stabilize the regulator. For high step-up conversion the current ripples on the devices are large which increases the power device conduction losses and turn-off current (Liu and Lai, 2007). The voltage stresses of the switch and the diode are equal to the output voltage, which is large in high output voltage applications. Hence it requires high rating passive components. The cost of the switches with high voltage stress is rather higher than that of the switches with low voltage stress (Li and He, 2011).

Figure-4 shows the MATLAB/SIMULINK model of the DC-DC boost converter.

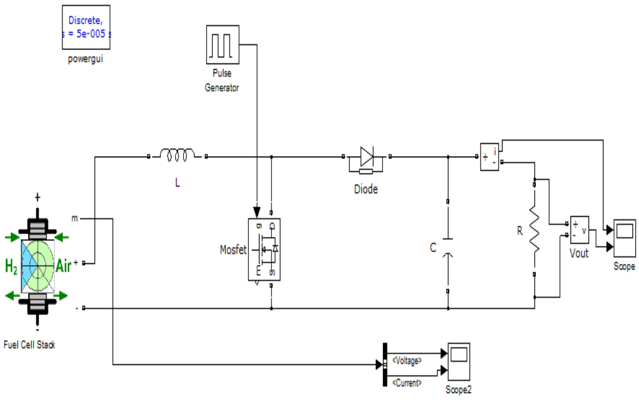

Figure-4. MATLAB/SIMULINK model of the DC-DC boost converter.

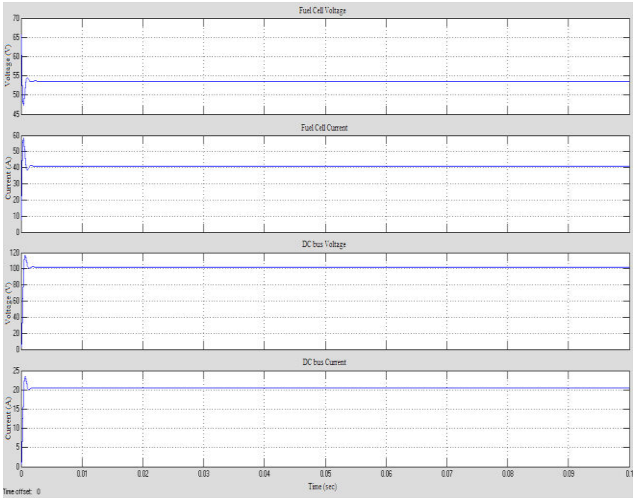

Figure-5. Simulation results of DC-DC boost converter.

Figure-5 shows the simulation results of the conventional DC-DC boost converter for 3kW fuel cell stack input. For high conversion ratio greater than 5, the boost efficiency decreases drastically as a function of duty cycle. Thus conventional boost converter can be operated at reasonable duty cycle to achieve high efficiency and high voltage gain. Furthermore, the power level of the classical boost converter is limited and also it does not meet the criteria of electrical isolation.

5.2 Cascaded boost converter

The DC-DC converter should have a high voltage ratio to satisfy the requirements of various applications. The boost conversion ratio can be increased by connecting several boost components in series known as cascade connection. Important feature expected from the DC-DC converter is a low input current ripple. By cascading the current ripple can be significantly reduced to satisfy high step up requirements (Figure-6). The first stage conversion is achieved with high switching frequency as the voltage stress on the devices is low. The second stage can be achieved with a low switching frequency to reduce the switching losses. The major limitation of the cascade converters is the requirement of two sets of boost components, which is complex and expensive. However, the inductance requirement may be reduced if the switching frequency will increase, but this may be limited as semiconductor switching losses are increasing with frequency. Another issue in the cascade converters is the system stability which requires careful designing (Feng *et al.*, 2002). Moreover, the output-diode reverse-recovery problem of the second stage is severe because a high voltage level should be sustained in the high output-voltage applications.

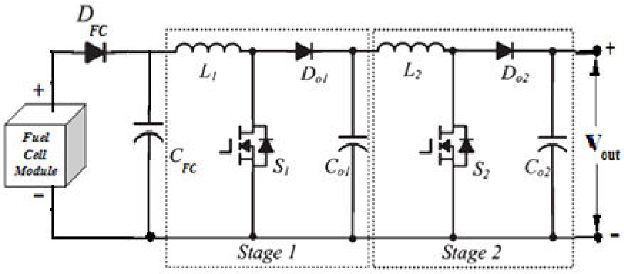

Figure-6. Cascaded boost converter.

If the voltage across the capacitor C_1 is charged to V_1 and the voltage across the capacitor C_2 is charged to V_o, the current flowing through inductor L_2 increases with V_1 during the switching-on period DT_s and decreases with voltage $-(V_o-V_1)$ during the switching-off period (1-D) T_s (Luo and Ye, 2004). Thus the inductor selection is based on the ripple current ΔI_{L2} and ΔI_{L1} given by,

$$\Delta I_{L2} = \frac{I_{L2}D((1-D)^2R}{fL_2} \tag{10}$$

$$\Delta I_{L1} = \frac{I_{L1}D((1-D)^4R}{fL_1} \tag{11}$$

The capacitor selection is based on the ripple voltage,

$$\Delta V_o = \frac{V_o(1-D)}{RfC_2} \tag{12}$$

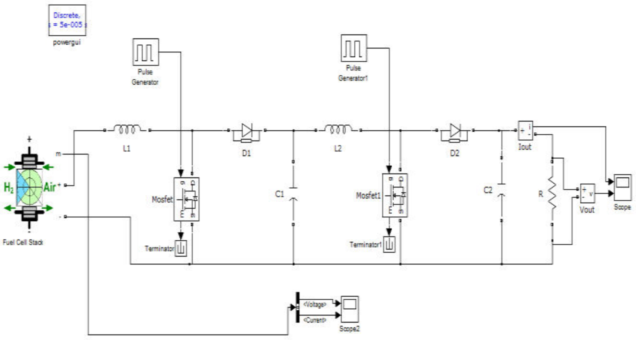

Figure-7. MATLAB/ SIMULINK model of cascaded boost converter.

Figure-7 shows the MATLAB/SIMULINK model of the cascaded boost converter. The model is designed for 3kW fuel cell stack input. Figure-8 shows the simulation results of cascaded boost converter obtained for the fuel cell input.

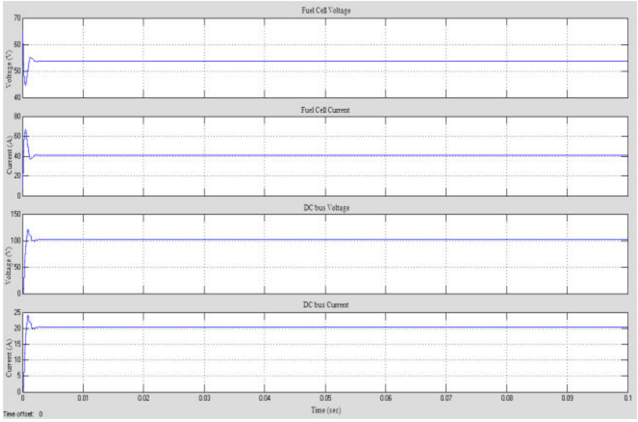

Figure-8. Simulation results of cascaded boost converter.

In order to reduce the circuit complexity the two switches can be integrated into one switch (Wu and Yu, 2004; Lin and Chen, 2008). The integrated cascade boost converter is shown in Figure-9 (Wu and Yu, 2004). When switch S turns on the inductors *L*1 and *L*2 stores energy. When switch S turns off *L*1 transfers stored energy through diode *D*1 to capacitor *C*1 and *L*2 transfers stored energy through diode *D*0 to the load. The circuit is simplified, and the instability caused by the cascade structure is avoided, compared with the cascade boost converter.

Figure-10 shows the MATLAB/SIMULINK model of the integrated cascaded boost converter. Figure-11 shows the simulation results of integrated cascaded boost converter obtained for 3 kW fuel cell stack input.

An integrated cascade boost converter with active clamping circuit is shown in Figure-12 (Lin and Chen, 2008). The auxiliary circuit is composed of a small

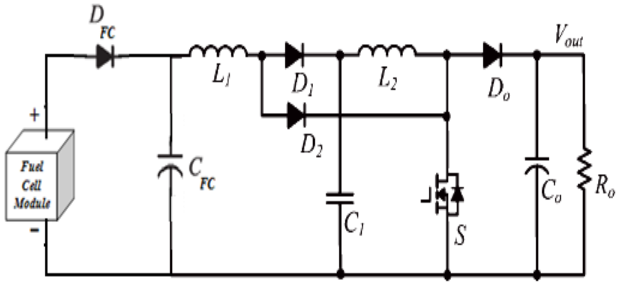

Figure-9. Integrated cascaded boost converter.

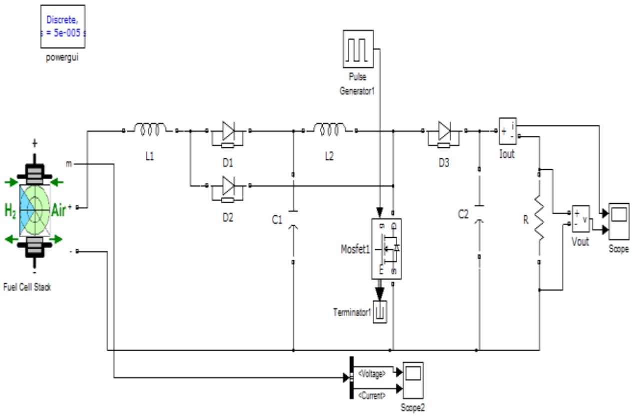

Figure-10. MATLAB/SIMULINK model of the integrated cascaded boost converter.

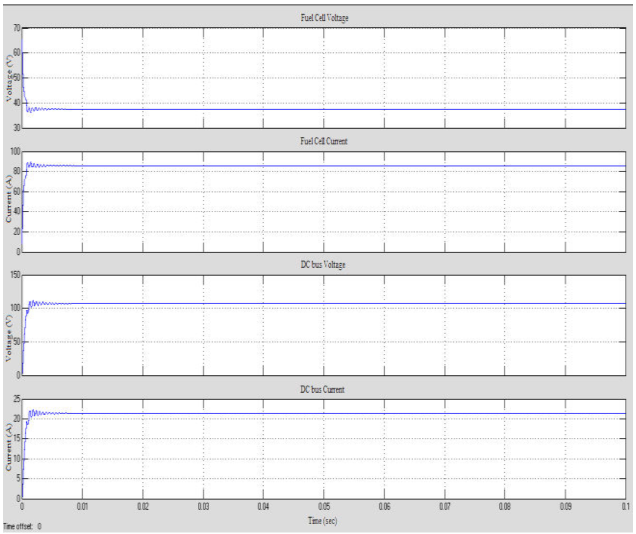

Figure-11. Simulation results of integrated cascaded boost converter.

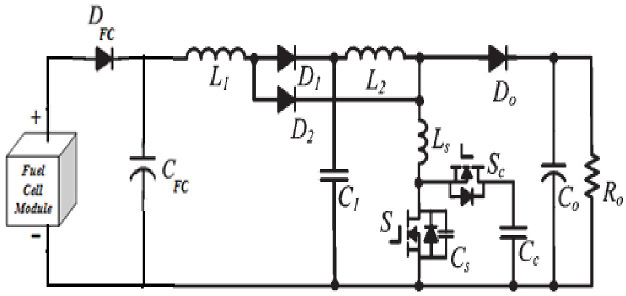

Figure-12. Integrated cascaded boost converter with active clamping circuit.

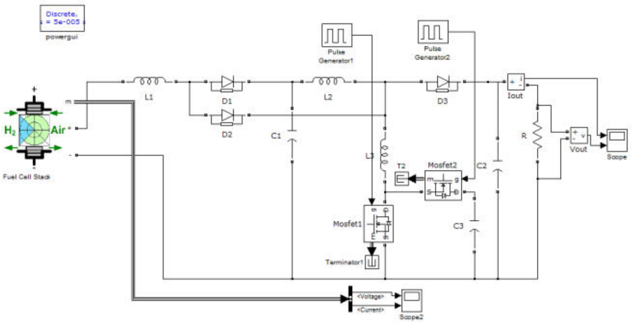

Figure-13. MATLAB/SIMULINK model of the integrated cascaded boost converter with active clamping circuit.

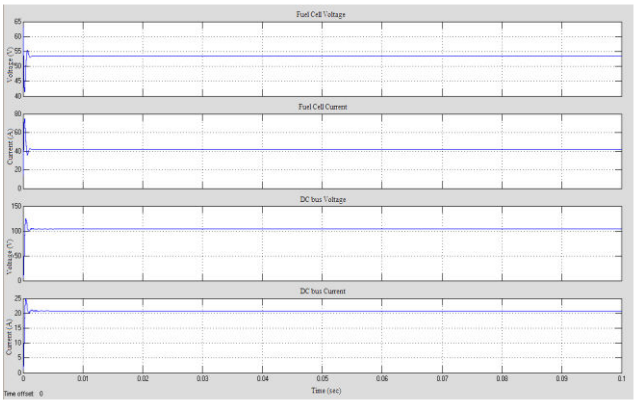

Figure-14. Simulation results of integrated cascaded boost converter with active clamping circuit.

inductor *Ls*, a resonant capacitor *Cc*, and a power MOSFET S*c*, which is used to realize the soft switching (ZVS) for both main and clamp switches. The voltage stress of main switch can be effectively limited by the active clamp circuit. Therefore low-voltage stress of power switches with low Rds,on can be used to further reduce the conduction losses. However, the switch voltage stress of the integrated cascade boost converters is equal to the high output voltage, and the current stress is large because the current of the inductors *L*1 and *L*2 flows through the switch when it turns on. These two factors increase the conduction losses and reduce the circuit efficiency. An auxiliary circuit is often necessary to improve the efficiency.

Figure-13 shows the MATLAB/SIMULINK model of the integrated cascaded boost converter along with the active clamping circuit. The model is designed to reduce the voltage stress. Figure-14 shows the simulation results of integrated cascaded boost converter along with the active clamping circuit obtained for 3 kW fuel cell input.

5.3 Interleaved boost converter

The interleaved structure is another effective solution for dc-dc power conversion. This structure can be used to increase the power level, minimize the current ripple, can reduce the passive component size, minimize the current stress on the power electronic devices, can improve the transient response, and can realize the thermal distribution (Xu *et al*., 2005).

The converters can be designed with multiple legs interleaving each other by means of input coupling inductors. It reduces the size and weight of the passive components and high efficiency can be obtained. For high-power applications, interleaved boost converters are preferable to increase the output current and to reduce the input current ripple. Since the currents through the switches are just fractions of the input current, current stress also can be minimized.

The Design parameters to be considered are decision of duty ratio and number of phases, selection of inductor values and the design of output filter (Rahavi *et al*., 2012). Ripple content is inversely proportional to the number of phases (N). Ripple content decreases with increase in N. But if the number of phase is increased more the circuit complexity and cost increases so high without much decrease in ripple content. So the number of phase is limited to 2. Inductor values can be calculated based on the ripple current requirement which is given by

$$\Delta I_L = \frac{V_{in} D T_S}{L} \tag{13}$$

Capacitor serves the purpose of output voltage filtration. Thus its design calculation plays a major role in the elimination of ripples at the output which is based on the ripple voltage tolerable (ΔV_o).

$$\Delta V_o = \frac{V_O D T_S}{RC} \tag{14}$$

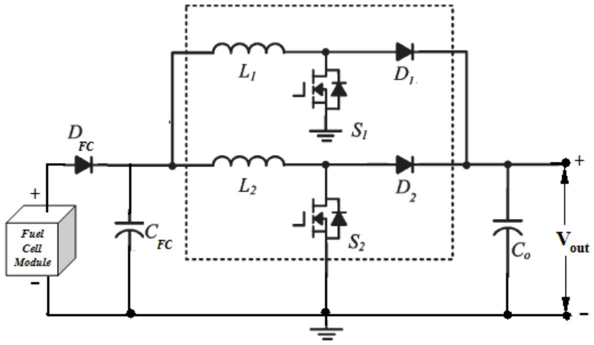

Figure-15. Interleaved boost converter.

Figure-15 shows the conventional interleaved boost converter. However, the power devices still operate at hard switching which causes switching losses. The efficiency is limited because the output diode reverse-recovery problem is still serious in high-output voltage applications.

Figure-16 shows the MATLAB/SIMULINK model of the conventional interleaved boost converter. Simulation results for the interleaved boost converter are shown in Figure-17. The output is obtained for a fuel cell stack of 3 kW power.

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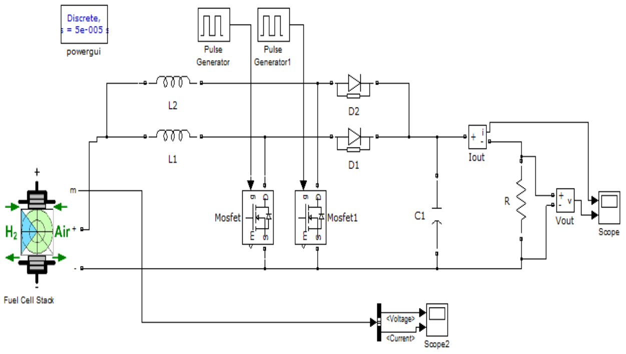

Figure-16. MATLAB/SIMULINK model of the interleaved boost converter.

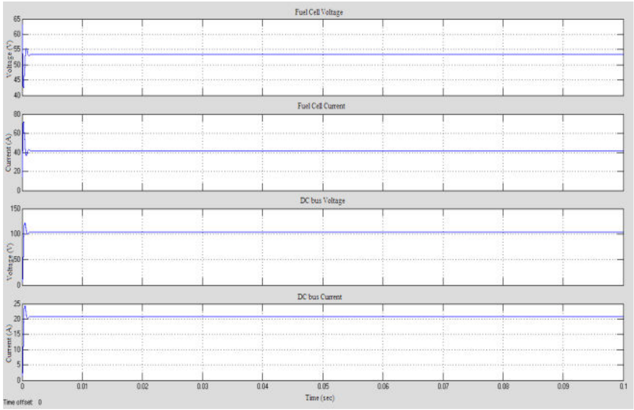

Figure-17. Simulation results of interleaved boost converter.

By adding a set of auxiliary commutation circuit to each phase switch turn off which happens at maximum current conduction can be reduced. The auxiliary circuit consists of an active switch, a capacitor, and an inductor (Xu *et al*., 2005). The interleaved boost converter with auxiliary commutation circuits is introduced in Figure-18. Turning on of the main switches occurs naturally at zero current, and the output-diode reverse-recovery problem is alleviated due to the critical discontinued current mode (DCM) operation. The auxiliary commutation circuits provide Zero Current Transition (ZCT) when the main switch turns off.

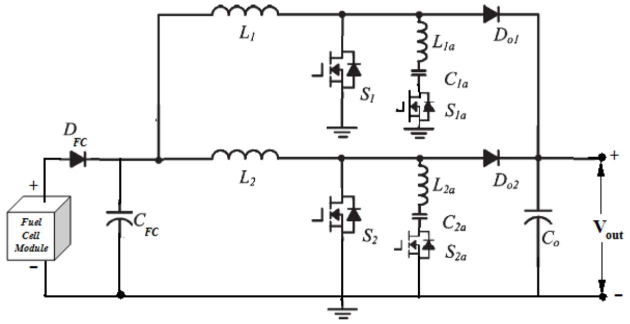

Figure-18. Interleaved boost converter with an auxiliary commutation circuit.

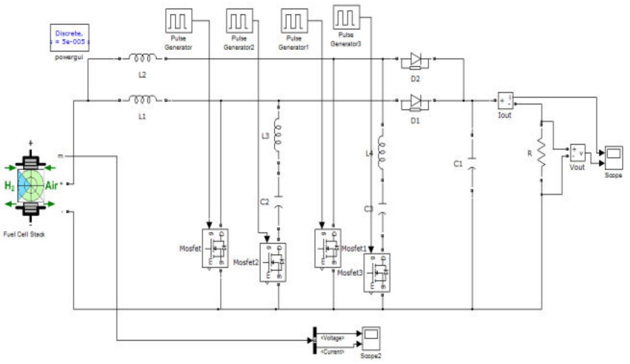

Figure-19. MATLAB/SIMULINK model of the interleaved boost converter with auxiliary commutation circuit.

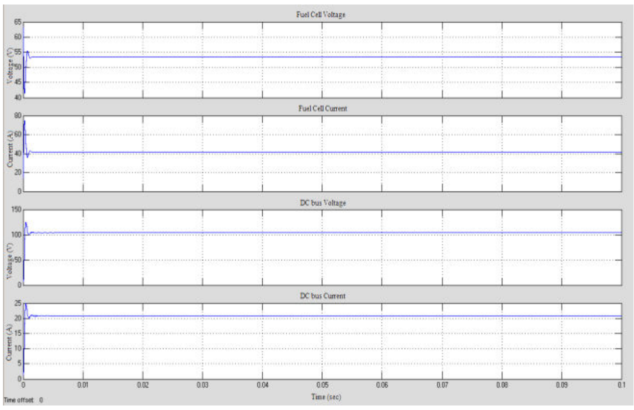

Figure-20. Simulation results of interleaved boost converter with auxiliary commutation circuit.

However, a variable frequency control is mandatory for this converter, which is difficult for the electromagnetic interference (EMI) filter design.

The MATLAB/SIMULINK model of the interleaved boost converter with auxiliary commutation circuit is shown in Figure-19. Auxiliary commutation circuit reduces the maximum current conduction. Figure-20 shows the obtained simulation results for the interleaved boost converter with auxiliary commutation circuit.

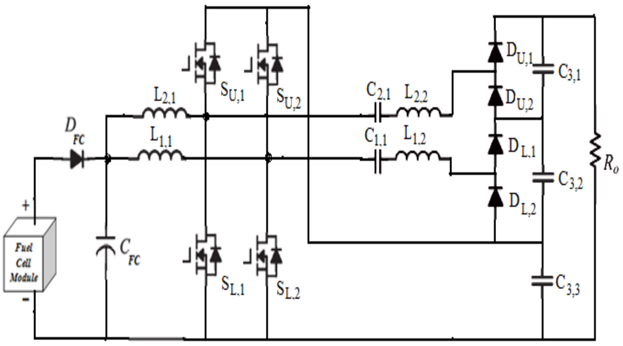

Figure-21. Interleaved boost converter for high step up applications.

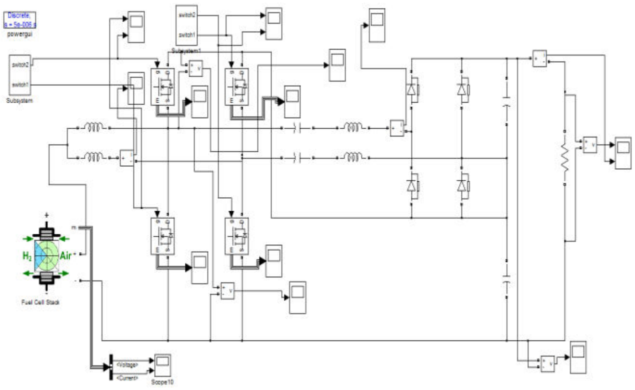

Figure-22. MATLAB/SIMULINK model of the interleaved boost converter for high step up applications.

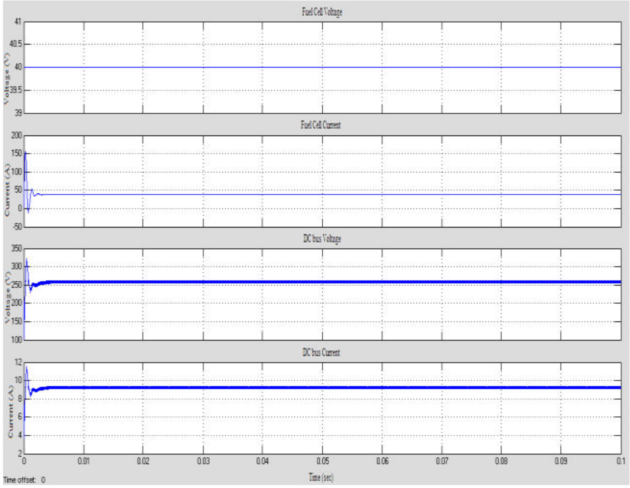

Figure-23. Simulation results of interleaved boost converter for high step up applications.

To achieve the requirements of high efficiency and high power applications, an auxiliary circuit with an inductor and capacitor can be added along with the input filter inductor, a switch leg and diode leg (Park *et al.*, 2011). It reduces the voltage stresses of switches and diodes and enables soft switching which can eliminate losses and reverse recovery problem of Diode. Number of legs can be extended to desired voltage gain and power level. However the converter circuit becomes complex and the overall cost increases. Integrated circuit methodology can be adapted to improve the performance of the interleaved converter (Pan and Lai, 2010). However, current sharing among the parallel paths is a major design problem. Auxiliary circuits can be used but it increases the system cost and the overall converter circuit becomes bulky.

Two leg interleaving boost converter is shown in Figure-21 and its MATLAB/SIMULINK model is shown in Figure-22. Figure-23 shows the simulation results of the interleaved boost converter which can be used for high-step up applications with high efficiency. The input is given from the fuel cell stack of 3 kW power.

6. CONCLUSION

As one of the most prominent sources of energy in the future, fuel cells are under consideration for almost every application including automotives and stationary power generation. Yet, a power electronics interface must be incorporated between the fuel cell and output to provide flexibility due to the inherent restrictions fuel cells produce, such as low voltage, large voltage variation, low efficiency when ripple current is high, slow load step responsibility and no acceptance of reverse current. The topology selection is not an easy process as it requires many constraints to be considered. The non isolated converters allows for the minimum size design. It is preferred for automotive applications. The converter must provide a high efficiency over the wide load range and maintain a high efficiency. The isolated DC- DC converters are usually not considered for a vehicle powertrain as they require additional voltage conditioning systems. In general, high power converters tend to be multiphase for current sharing. Also, multiphase structure allows for increased part-load efficiency. The non-isolated converter is the most optimal solution for a low size converter in a low to medium voltage gain range. The lowest input current ripple is available from multiphase converters due to current ripple cancelation. This paper has addressed the various parameters to be considered for the selection of DC-DC topology based on the application requirement.

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