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Modelling and Simulation of Current Fed Interleaved Isolated DC-DC Boost Converter for Fuel Cell Applications

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ABSTRACT:

In this paper, a current fed, interleaved, high gain, DC-DC converter is proposed for fuel cell applications. The converter also provides electrical isolation between the load and the source by using a transformer. The input features two current fed, full bridge inverters in parallel while the output features two full bridge diode rectifiers in series. By using this topology, the high input current is shared between the two inverters. This enables the use of lower current rating semiconductor devices, reduces switching stresses and reduces the size of magnetic components. It also results in reducing the input current ripple and the output voltage ripple.

KEYWORDS:

Current fed full bridge; DC-DC; Fuel cell; ICFFBI; Interleaved; Boost converter

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1. Introduction

In recent years, due to the growing energy need and environmental issues, there has been a huge push towards renewable sources of energy. One of the many options that we have among renewable sources is fuel cells. Fuel cells generate power from the reversed reaction of electrolyzed water and give out only water as emission so they are completely non-polluting. There are many kinds of fuel cells. Amongst them proton exchange membrane fuel cells are the most commonly used because they have many merits like lower temperature during operation accordingly leading to rapid turning on and off and rapid reaction to the load change. They also operate at lower pressures, which increase safety. Moreover, they also have a lower emission ratio and higher conversion ratio [1]. A fuel cell normally produces a voltage of around 1V [2]. By stacking many fuel cells together in series, we can get around 40V. But even this voltage is too low for most practical applications and hence it is required to boost this voltage by using appropriate power electronic converters.

The input current ripple through the fuel cell stack also needs to be as low as possible [3] because it plays an important role in determining the catalyst lifetime of the fuel cell plates [4]. Hence, having a power electronic converter between the load and the fuel cell is vital in order to satisfy these requirements. In addition to this, it also needs to be ensured that the fuel cell is always operating in the linear region so that the change in input voltage with load is around ±2%. There are many converter topologies that can be used to boost the voltage from a fuel cell. We have chosen a high gain, interleaved, full bridge, isolated converter (ICFFBI Converter) by taking into account the requirements of the system. The input features two current fed full bridge inverters connected in parallel and each operating with a phase difference of 180 degrees. This enables the use of less expensive and lower current rating MOSFETs and source inductances as the high input current from the fuel cell is shared equally by the two inverters. It also reduces the stress on the switches during switching. Most importantly, it helps in reducing the ripple factor in the input current which is vital for the longevity of the fuel cell.

A high operating frequency of 100 kHz is chosen so that the size of the magnetic components can be kept small and the circuit can be made compact. Two high frequency transformers having turns ratio of 1:2 are used to double the inverter output. In addition to this, the transformers also provide electrical isolation between the high voltage output side and the low voltage input side. This is fed to two full bridge diode rectifiers connected in series so that the voltage from both the stages is added up and fed to the load. Since we are using current fed inverters, it is possible to increase the voltage gain further by charging the source inductance between half cycles by using a duty cycle above 0.5 [6-7]. The concept of interleaving comes with many other benefits like reduction of peak current in the transformer windings, reduced heat sink requirements due to separation of heat generating components, improved form factor and reduced EMI as a result of the reduced peak currents [5]. A schematic diagram of the proposed converter is shown in Fig. 1.

2. Modes of operation

In Mode I, MOSFETs M1 and M2 are conducting in the first input stage. As 2 stages are interleaved, there will be a phase shift of 180 degrees between the 2 stages. Hence, in the second input stage, at the same time MOSFETs M7 and M8 will be conducting. In the output side, the voltage from the transformer secondary's will forward bias diodes D1, D2, D7, D8 and reverse bias diodes D3, D4, D5, D6. The conduction path will be: Transformer1 – D1 – Load – D8 – Transformer 2 – D7 – D2 – Transformer1. The equivalent circuit diagram for this mode is shown in Fig. 2. The non-conducting path is shown as dotted.

In Mode II, all the 8 MOSFETs of both the stages are in conduction together. This results in the source getting shorted across the source inductances. Therefore the source inductance gets charged without output voltage in this stage. The equivalent circuit is illustrated in Fig. 3.

Mode III is complementary to mode I. MOSFETs M3 and M4 are conducting in the first input stage while MOSFETs M5 and M6 are conducting in the second input stage. Similarly in the output side, diodes D3, D4, D5, D6 will be in conduction while the rest will be reverse biased. The conduction path will be: Transformer 1 – D3 – Load – D6 – Transformer 2 – D5 – D4 – Transformer 1. The equivalent circuit for this mode is shown in Fig. 4.

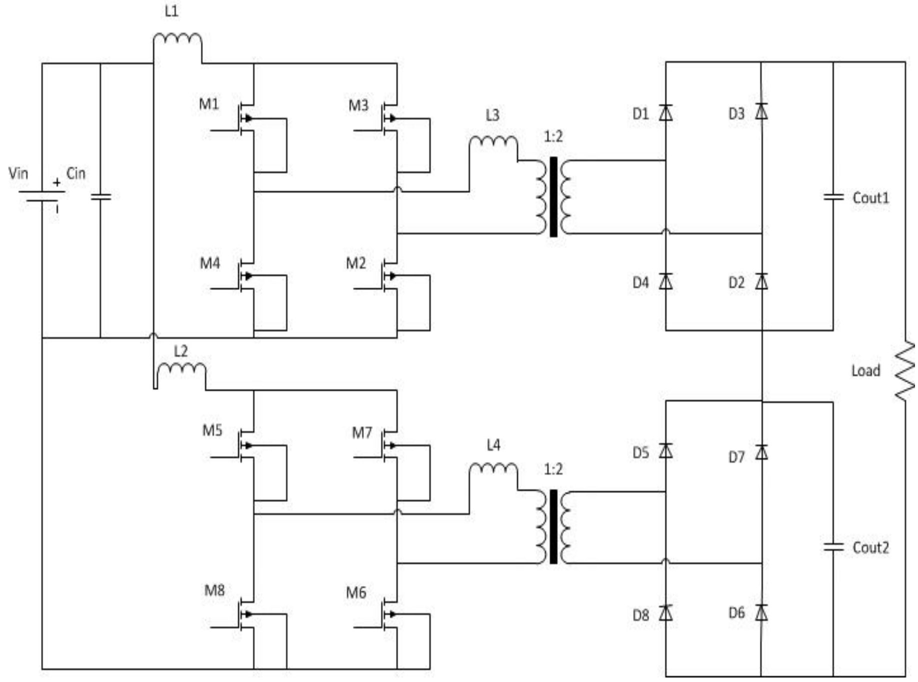

Fig. 1: Schematic diagram of the ICFFBI converter

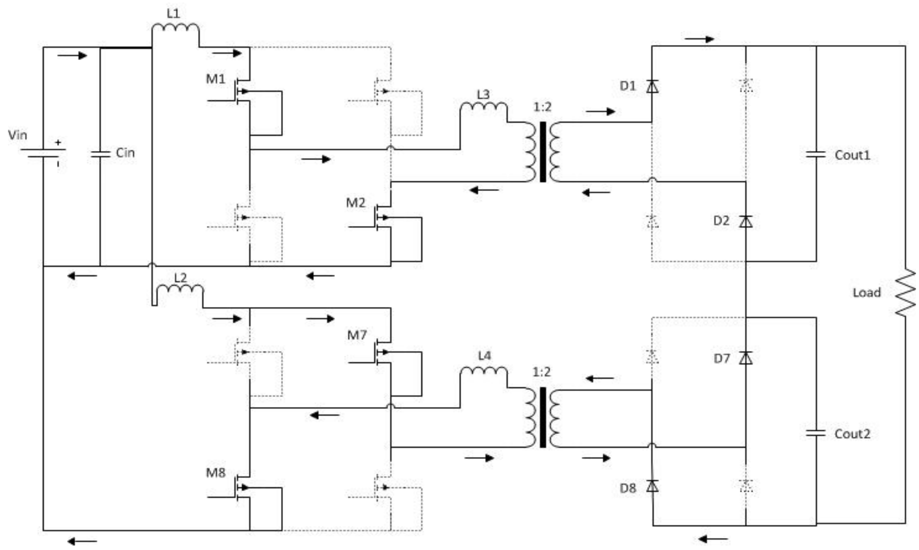

Fig. 2: Illustration of mode I conduction path

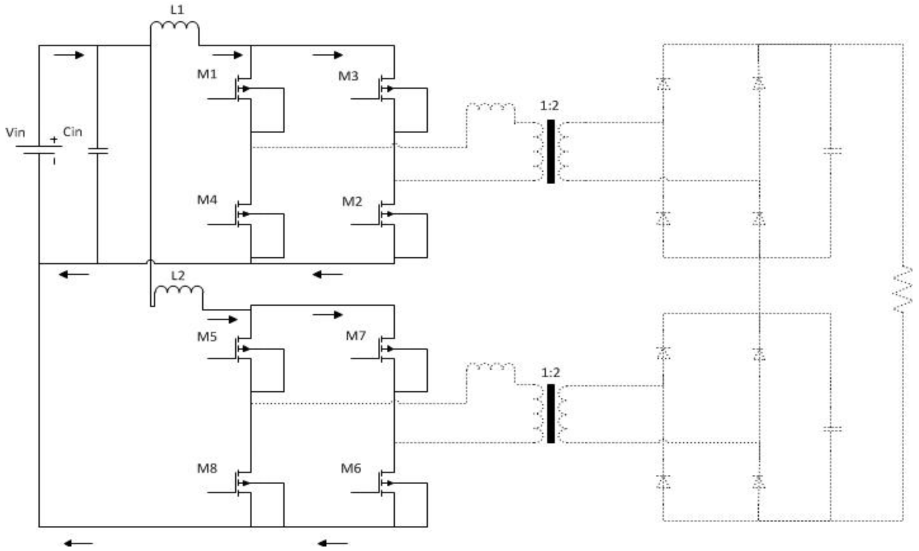

Fig. 3: Illustration of mode II conduction path

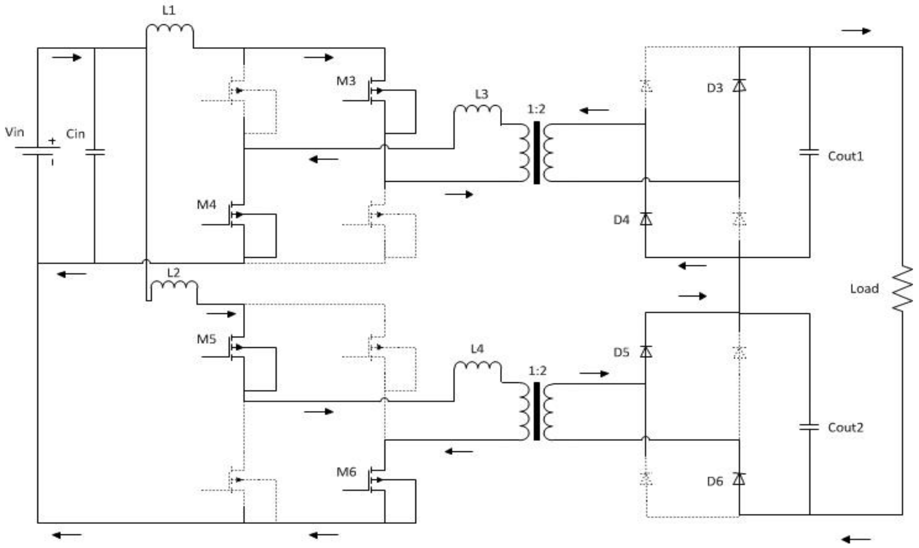

Fig. 4: Illustration of mode III conduction path

3. Simulation results

The circuit simulated in P-Sim software is showed in Fig. 5. Table1 details the components used in the circuit. The performance parameters of the proposed converter are given in Table 2. Fig. 6 shows the output voltage profile for 1kW application. It can be seen that after the initial transients die down in about 0.02 seconds, the voltage is a constant 350 V DC. Fig. 7 and Fig. 8 show the output current and input current respectively. It can be seen that they both settle down to a constant value barring very small ripple content. Input current sharing between the 2 stages is shown in Fig. 9. It can be seen that the current is equally shared between the 2 parallel inverters. Fig. 10 and Fig. 11 show the output voltage profile for half load and light load (25%) conditions respectively. It can be seen that the output voltage remains constant at 350 V DC irrespective of the load conditions.

Table 1: Details of circuit components

Component	Number/Value
Input capacitor	0.1 uF
Input inductors	L1 - 150 uH L2 - 150 uH
Maximum output power	1 kW
Output capacitors	C1 - 20 uF C2 - 20 uF
Transformer leakage inductance	0.1 uH
Load (R-load)	122.5 Ω
Transformer turns ratio	1:2

Table 2: Details of circuit parameters

Parameter	Value
Output voltage	350 V
Output power	1000 W
Input voltage	40 V
Switching frequency	100 kHz
Duty ratio	77%

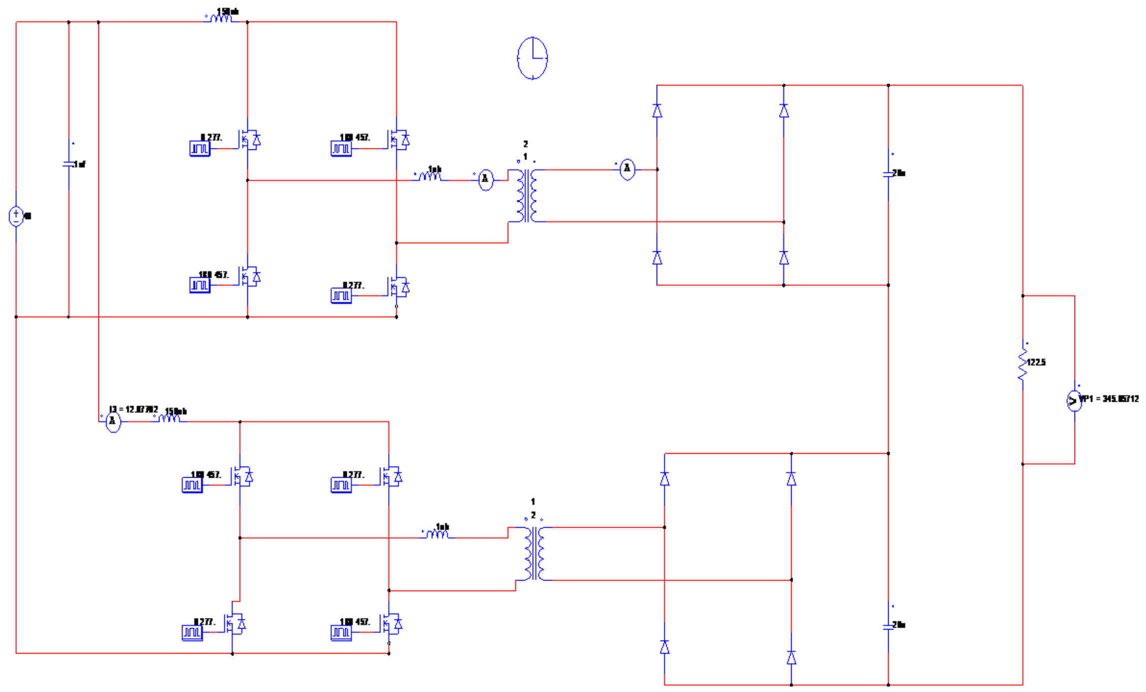

Fig. 5: Simulation circuit in P-Sim software

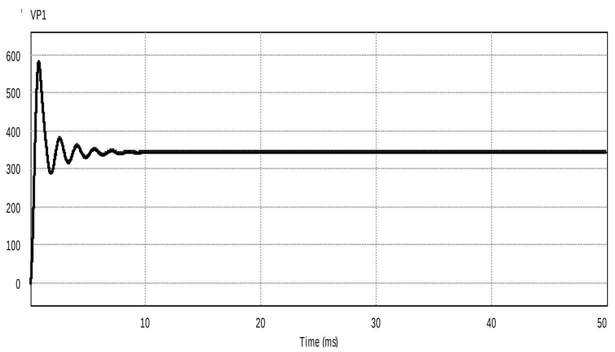

Fig. 6: Output voltage

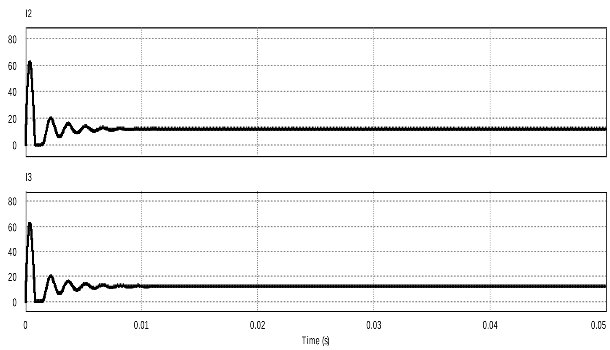

Fig. 9: Input current sharing between stages

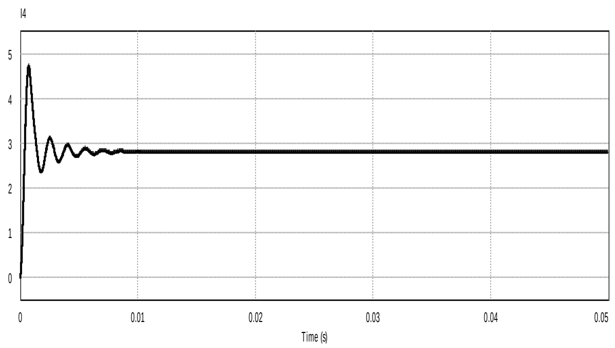

Fig. 7: Output current

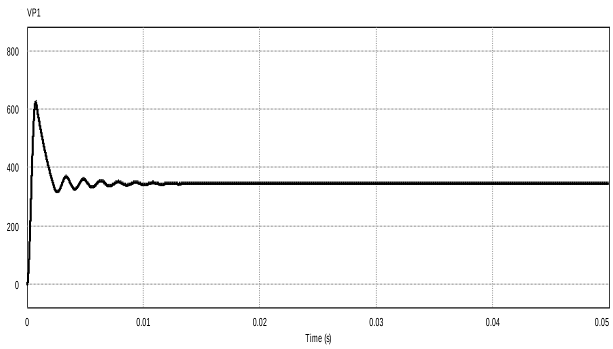

Fig. 10: Output voltage with half load

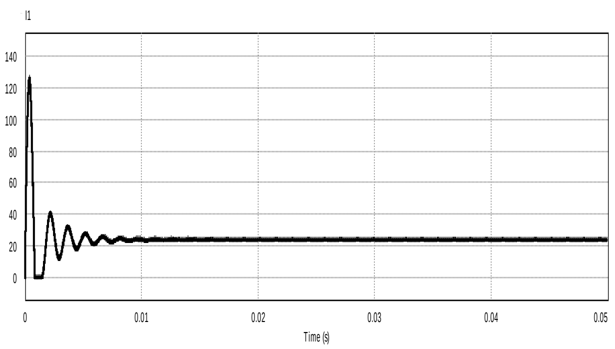

Fig. 8: Input current

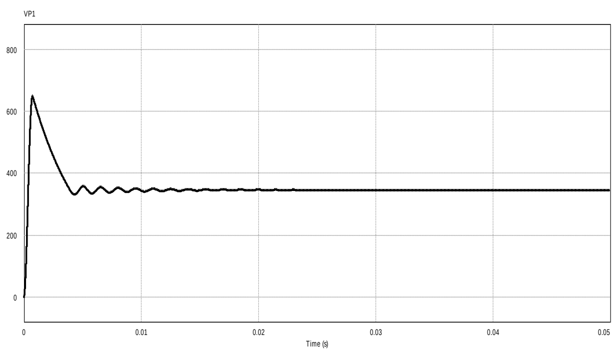

Fig. 11: Output voltage with light load

4. Conclusion

Simulation results for a 350V, 1kW, interleaved, current fed, isolated DC-DC boost converter have been provided in this paper. The simulations have been done using P-Sim software. We have obtained satisfactory results in the simulations for full load, half load and light load conditions as the output voltage remains more or less constant irrespective of the loading. Due to the interleaving of two converters, the input ripple current and output ripple voltage have been suppressed sufficiently. A combination of current sharing in the input side, and voltage sharing on the output side between the two stages have ensured that the switching stresses on the semiconductor devices have been reduced considerably and it has also enabled us to use cheaper, compact, lower rating semiconductor devices. This, along with the employment of high operating frequency for the converter has enabled us to reduce the size of the magnetic components as well. Due to these advantages, this interleaved current fed converter is ideal for high power fuel cell applications.

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