RESEARCH ARTICLE OPEN ACCESS

# High Efficiency Interleaved Active Clamped Dc-Dc Converter with Fuel Cell for High Voltage Applications

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***Abstract***
A high efficiency interleaved ZVS active clamped current fed dc-dc converter is proposed in this paper specially used for fuel cell applications. As the fuel cell output is very low we are in need of a step up dc-dc converter. Here a current fed dc-dc converter is used. Two current fed dc-dc converters are interleaved by connecting their inputs in parallel and outputs in series. With this proposed methodology input current ripples in the fuel cell stacks can be reduced and a regulated output voltage ripples can be obtained. The active clamping circuit used in this model absorbs the turn off voltage spikes hence low voltage devices with low on state resistance can be used.Voltage doubler circuits will give double the output voltage than normal with smaller transformer turns ratio and flexibility**.** The proposed method is simulated in MATLAB for verifying the accuracy of the proposed design.
***Keywords:*** Current fed dc-dc converter, Fuel cell, Interleaving, Active clamp circuit, Zero voltage switching (ZVS)

## I. INTRODUCTION

Energy needs are increasing day by day. But our fossil fuel deposits are also depleting. Unfortunately more than 70% of our energy requirement is met by thermal power plants. So we should think about an alternative method for the production of electricity.

Even though renewable energy resources like solar, wind energy etc are available at free of cost, but they are not reliable because of their intermittent nature. Here the significance of fuel cell comes.

The fuel cell is drawing the attention by researchers as one of the most promising power supply in the future. Due to high efficiency, high stability, low energy consumed and friendly to environment, this technology is in the progress to commercialize. Fuel cell has higher energy storage capability thus enhancing the range of operation for automobile and is a clean energy source. Fuel cells also have the additional advantage of using hydrogen as fuel that will reduce the world dependence on non-renewable hydrocarbon resources [3]. A Fuel Cell Electric Vehicles (FCEV) has higher efficiency and lower emissions compared with the internal combustion engine vehicles. So, FCEV is providing a much better promising performance [4].

Fuel cells can be an important component of future energy systems. The fuel cell output is secure and continuous in all seasons as long as fuel is supplied. It can also be used for cogeneration as it gives heat as byproduct. The fuel for the fuel cell hydrogen or similar substances with high efficiency and low or nearly zero emission. Fuel cells provide a variable dc current at variable fuel cell voltage. To feed into the mains they have to be connected to the ac mains by means of inverters. Because of the comparatively low voltage of a fuel cell stack for low and medium power compared to the mains voltage, the inverter has to increase the voltage when feeding into the mains.

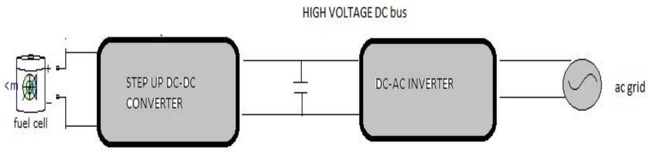



Fig 1. Block diagram of fuel cell converter system.

Here fuel cell is taken as the source of the power. A current fed dc-dc converter is used to step up dc to feed the dc-ac inverter. The dc-dc converter must satisfy 1) high step up ratio – for boosting low terminal voltage of batteries to variable high voltage dc bus. 2) high power handling capacity 3) Isolation- A transformer coupled converter not only realizes the electrical isolation between the fuel cell and the high voltage output side , but allows series connection of dc-dc converters. 4) Low input current ripple- the ripple current inside the fuel cell must be small since it acts as a catalyst lifetime of fuel cell.

## II. PROPOSED INTERLEAVED CURRENT FED DC-DC CONVERTER WITH VOLTAGE DOUBLER

In this paper, an interleaved current fed dc-dc converter with voltage doubler is proposed. Two current fed dc-dc converters are interleaved by parallel connected their input and their outputs are connected in series in order to reduce current ripples inside the fuel cells. This interleaved design increases the power handling capacity and reliability. In the case of failure of one of the cells, the system can still deliver 50% of rated power. It composed of input chokes $L_{in1}$ & $L_{in2}$ which acts as boost inductor to store and release the energy from the fuel cell, power switches $Q_1$ –$Q_8$, step up transformers, an active clamp circuit a secondary voltage doubler

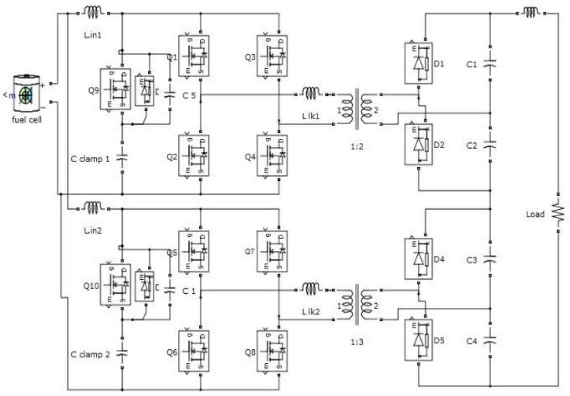



Fig 2: circuit diagram of the proposed system

Active clamp snubs the voltage turn off spikes across the power switches and thus aids in ZVS. Voltage doubler circuits will give smaller transformer turns ratio and reduce the voltage stresses of the secondary rectifier diodes. The L filter connected in series with the load reduces ripples in the output wave.

## III. OPERATING STATES OF THE PROPOSED CIRCUIT

For the simplicity of the study of the operation and analysis, the following assumptions are made for the operation and analysis of the converter: 1) boost inductors $L_{in1}$& $L_{in2}$ are large enough to maintain constant current through them. Output capacitors are large enough to maintain constant voltage across them. 2)all components are assumed ideal 3)series inductors $L_{lk1}$& $L_{lk2}$ include the leakage inductances of the transformers and 4)magnetising inductances of the transformers are infinitely large.

The duty cycle D for power switches $Q_1$ – $Q_8$ should be greater than 50% inorder to retain the continuity of the input inductor current [1]. Here D is chosen as 80%. The gate pulses for $Q_1$& $Q_4$, $Q_2$& $Q_3$, $Q_5$& $Q_8$ and $Q_6$-$Q_7$ are same. The gate pulses for $Q_2$& $Q_3$ are delayed by 50%, $Q_5$& $Q_8$ are delayed by 25% w.r.t $Q_1$& $Q_4$and $Q_6$-$Q_7$ are delayed by 50% w.r.t gate pulses of $Q_5$& $Q_8$ .

There are 8 switching modes in this interleaved active clamped current fed dc-dc converter.

In mode 1, mode 3, mode 5 & mode 7all the switches $Q_1$& $Q_8$ are in on state. Auxiliary switches $Q_{aux1}$and$Q_{aux2}$ are off. Input inductors $L_{in1}$&$L_{in2}$are storing energy. The voltage across transformer windings are zero, resulting in soft switching turn-off condition for the power switches $Q_2$,$Q_3$, $Q_6$ & $Q_7$ . Power is transferred to the load by the energy stored in the output filters, C1, C2, C3 & C4.

Mode 2 stays same as in mode 1 in cell 1. But in cell 2 the switches$Q_5$& $Q_8$ are in off state. $Q_5$,$Q_6$& $Q_{aux2}$ are turned on in ZVS condition since both parasitic capacitances are fully charged. Input inductors $L_{in1}$ & $L_{in2}$ is storing energy. The voltage across transformer 2 windings are zero. Power is transferred to the load by the energy stored in the output filters C3 & C4.

In mode 4 cell 2 stays remain same as in mode 3. But in cell 1the switches $Q_1$&$Q_4$are in on state. $Q_2$, &$Q_4$are turned off in ZVS condition since both parasitic capacitances C-2, C-3 of the main switches $Q_2$ and $Q_3$ and discharges the parasitic capacitances $C_{aux1}$ of the auxiliary switch $Q_{aux1}$.Current in the input boost inductor is diverted in the auxiliary circuit path causing zero current through all main switches. The magnetising current flows through leakage current $L_{lk1}$, antiparallel diodes D1,D4 of main switches $Q_1$ & $Q_4$ .Voltage across transformer 1 winding increases.

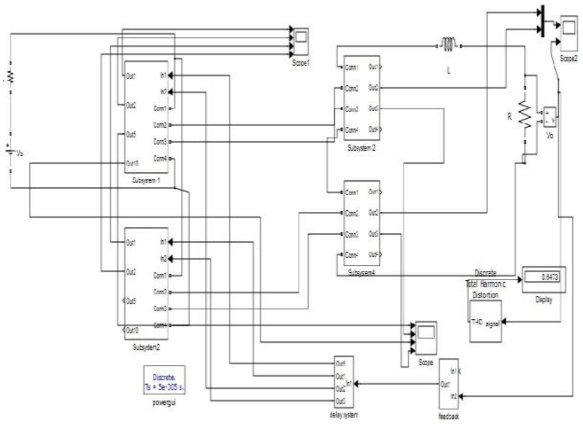
In mode 6 cell 1 remains same as that of mode 5. In cell 2 switches $Q_5$&$Q_8$are on and $Q_6$& $Q_7$ are off. The input inductance current $I_{Lin}$ charges C-6 and C-7 of the main switches $Q_6$& $Q_7$and discharges the parasitic capacitance of the auxiliary switch $Q_{aux2}$ .Voltage across transformer 2 winding decreases.

In mode 8 cell 2 remains same as that of mode 7. In cell 1 $Q_1$& $Q_4$are turned off in ZVS condition since voltage across transformer 1 are zero during mode 7. $Q_3$, $Q_2$& $D_1$' are conducting and C1 and C2 are charged.

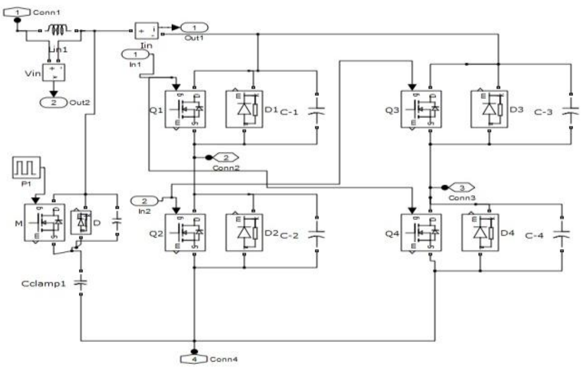
## IV. SIMULINK MODEL

The proposed circuit- interleaved current fed dc-dc converter with voltage doubler is modelled and simulated in MATLAB2010a and made closed loop by adding a feedback network. The specification of the converter for simulation are:

input voltage, $V_S$=37V,switching frequency= 25KHz, C1,C2,C3,C4=1000μF/120V ,the parasitic capacitances-C-1,C-2,C-3,C-4,C-5,C-6,C-7,C-8 =20μF/20V , $L_{in1}$ & $L_{in2}$ are taken as 62 mH and $L_{lk1}$ and $L_{lk2}$ are chosen as 5μH and the value of the filter L is chosen as 0.03 mH.
The Simulink model of the proposed system and the circuit in the subsystem 1, 2, 3 and 4 are shown in fig 3-a , 3-b , 3-c , 3-d ,3-e



(a)



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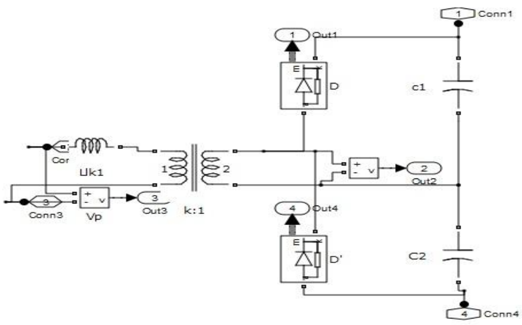

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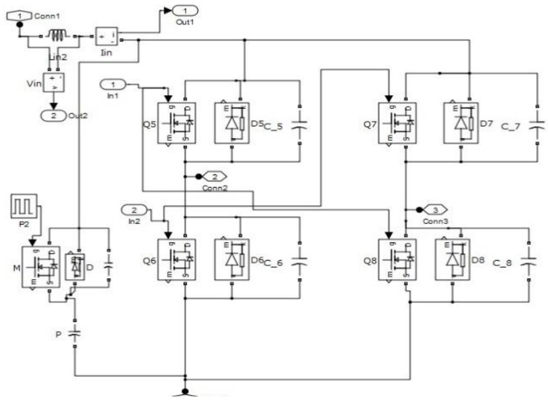

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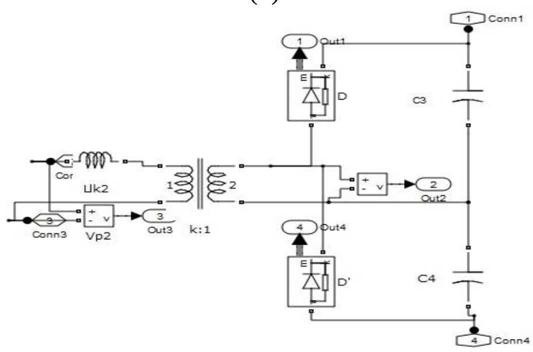
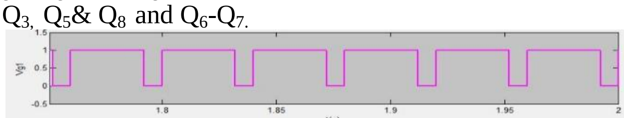


(e)

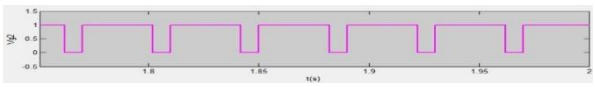
Fig 3 : (a)Simulink model of the proposed system ,(b) model of subsystem 1, (c) model of subsystem 2,(d) model of subsystem 3 , (d) model of subsystem4

## V. SIMULATION RESULTS

The simulation results of gate pulses created by feedback loop given to the proposed circuit.$V_{g1}$ , $V_{g3}$ , $V_{g2}$ and $V_{g4}$ are the gate pulses to $Q_1$& $Q_4$, $Q_2$& $Q_3$, $Q_5$& $Q_8$ and $Q_6$-$Q_7$.



(a)



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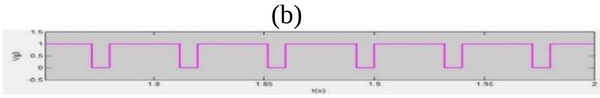

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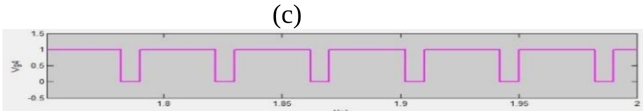
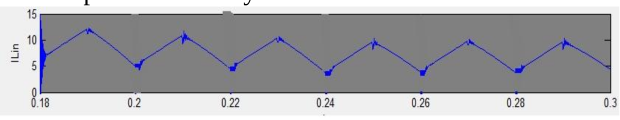


*(d)*

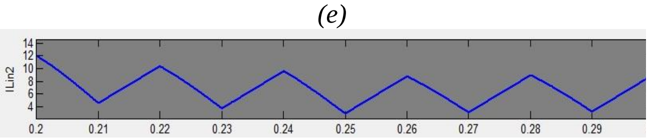
Fig 4:gate pulses generated through feedback network connected to proposed system. (a), (b),(c) and (d) are the waveforms of $V_{g1}$ , $V_{g3}$ , $V_{g2}$ and $V_{g4}$ which are gate pulses to $Q_1$& $Q_4$, $Q_2$& $Q_3$, $Q_5$& $Q_8$ and $Q_6$-$Q_7$.

Simulation waveforms of input boost inductor currents $I_{Lin1}$ , $I_{Lin2}$ , voltage across input boost inductor $V_{Lin1}$ , $V_{Lin2}$ , primary and secondary voltages of transformer windings ,$V_{p1}$ ,$V_{p2}$,$V_{s1}$ ,$V_{s2}$ and high voltage output

$V_o$ are shown in fig 4-e, f , g, h , i, j, k, l , m. The input current is of reduced current ripple because of the ripple cancellation of $I_{Lin1}$ &$I_{Lin2}$ . $I_{Lin1}$ &$I_{Lin2}$ are phase shifted by $180^0$ .



*(e)*



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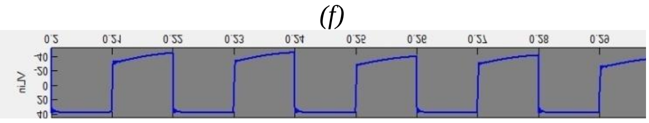
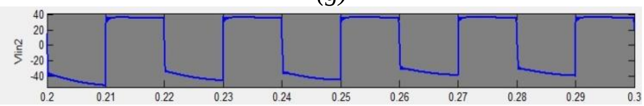


*(g)*



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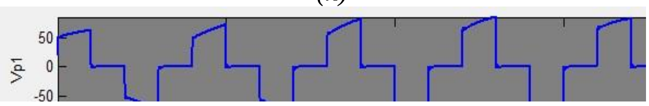
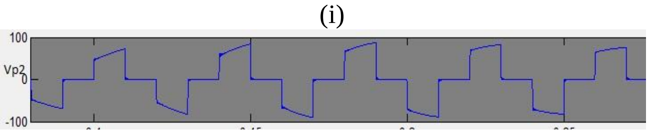
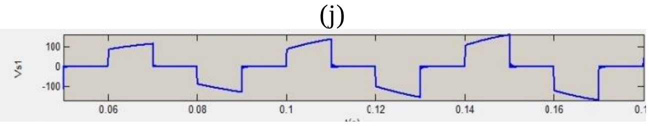


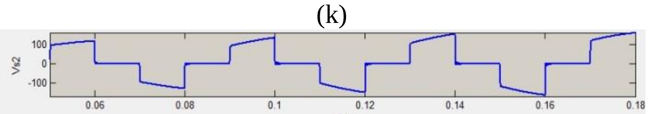
(i)



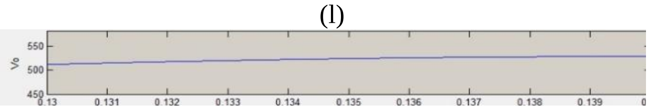
(j)



(k)



(l)



(m)

Fig 4: (e) ,(f) , (g) , (h), (i), (j) , (k), (l) and (m) are the simulated waveforms of input boost inductor currents $I_{Lin1}$ , $I_{Lin2}$ , voltage across input boost inductor $V_{Lin1}$ , $V_{Lin2}$ , primary and secondary voltages of transformer windings ,$V_{p1}$ ,$V_{p2}$,$V_{s1}$ ,$V_{s2}$ and high voltage output $V_o$ respectively

| | Total Harmonic distortion | Output voltage |
|---|---|---|
| Current fed dc-dc converter with active clamp | 0.8897 | 265 |
| Interleaved current fed dc-dc converter with voltage doubler and L filter | 0.7504 | 510 |
| Interleaved dc-dc current fed converter with voltage doubler, L filter and feedback | 0.6473 | 510 |

Table 1: THD and output voltage of ICF active clamped dc-dc converter with L filter and feedback at each stage of the system

The THD of the proposed system and the output voltages are measured at each stages of the interleaved dc-dc converter with voltage doubler and tabulated above in table 1. We get minimum THD at the last stage of the system. The harmonic in the output dc voltage is reduced to 65.72% and output dc voltage is boost to 510V.

## VI. CONCLUSION

An interleaved active clamped current fed dc to dc converter with voltage doubler is proposed for fuel cell application. The proposed converter maintains ZVS of primary switches. An interleaved design is adopted to increase the power handling capacity, reduces current ripples inside the fuel cells, the size of the converter, voltage and current rating, better thermal distribution are obtained. It also results low conduction losses in primary switches. An L filter added improved the output voltage waveform. The feedback circuit is added for improving the performance of the system. Hence the harmonic in the output dc voltage is reduced to 65.72% and output dc voltage is boost to 510V. This ICF dc-dc converter with voltage doubler, L filter and feedback network seems to be more suitable for a high power fuel cell system. This converter has the limitation that duty cycle of the main switches should be greater than 50%. Instead of using two we can do interleaving with four current fed dc-dc converter to get better performance and output voltage.

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