

# Global Efficiency Analysis of an Isolated Three-Port Bidirectional Dc-Dc Converters

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**ABSTRACT:** An isolated three port DC-DC converter proposed for handling hybrid energy source consisting of fuel cell, storage device and a load. Individual converter topology requires individual control units and it should be integrated. It makes the system costly and complex. To avoid the above mentioned drawbacks, three port bidirectional DC-DC converters proposed which offers galvanic isolation for safety reasons and high voltage ratio in addition. This paper presents a control strategy for the hybrid source and includes a global efficiency analysis of power sharing between modules. The proposed system is validated through different simulation results. The proposed circuit is designed with the help of MATLAB/Simulink.

**KEYWORDS:** Fuel Cell (FC), Hybrid Source, Multiport Converter.

## I. INTRODUCTION

Nowadays, renewable energy is increasingly valued and employed because of energy shortage and environmental contamination. Hybrid renewable energy source is becoming popular because it is composed of two or more energy sources. This combination of two energy source is an efficient way of generating energy. Hybrid renewable energy sources draw much attention from researchers due to the fact that fossil energy source is scarce and global temperature is increasing[1],[2]. Each renewable energy sources has its limitations due to its nature, and using different sources together may reduce those obstacles[1]. To do that, one needs a hybrid converter system, which is based on either non isolated converters[3],[4] or isolated converters[5],[6]. The latter can give galvanic isolation for safety reasons and a high voltage ratio.

These advantages come from using transformers generally operating at high frequencies. Renewable energy systems generate low voltage outputs ; thus high step up dc-dc converters are widely employed in many renewable energy applications including fuel cell, wind power, photovoltaic system etc. Energy sources like PV, and wind turbine systems are intermittent and unpredictable; therefore they are not highly reliable. In order to address this issue, renewable resources are either combined with each other or fuel cell and ESS (battery). Fuel cells are widely recognized as one of the most promising technologies to meet the future power generation requirements and as an aid for decreasing oil consumption and dangerous CO<sub>2</sub> gas emission. The combination of fuel cell and battery will reduce fluctuations in electric vehicle based applications and also reduce the hydrogen consumption in the fuel cell. The fuel cell and battery have different voltage levels, so to provide a specific voltage level for load and control power flow between input sources, using of dc-dc converter is needed.

Fuel cells generate electricity by an electrochemical reaction in which oxygen and a hydrogen-rich fuel combine to form water. 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 space heating, hot water or to drive refrigeration cycles. For high power applications, and when isolation between sources and load is required, isolated topologies of dc-dc converters connected in parallel have to be used.

DC-DC Converters are electronic devices used whenever we want to change DC electrical power efficiently from one voltage level to another. They are needed because unlike AC, DC cannot simply be stepped up or down using a transformer. In many ways, a DC-DC converter is the DC equivalent of a transformer. Typical applications of DC-DC converters are where 24V DC from a truck battery must be stepped down to 12V DC to operate a car radio, CB

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transceiver or mobile phone; where 12V DC from a car battery must be stepped down to 3V DC, to run a personal CD player; where 5V DC on a personal computer motherboard must be stepped down to 3V, 2V or less for one of the latest CPU chips; where the 340V DC obtained by rectifying 240V AC power must be stepped down to 5V, 12V and other DC voltages as part of a PC power supply; where 1.5V from a single cell must be stepped up to 5V or more, to operate electronic circuitry; where 12V DC must be stepped up to +/-40V or so, to run a car amplifier's circuitry; or where 12V DC must be stepped up to 650V DC or so, as part of a DC-AC sine-wave inverter.

A multiport converter is used to minimize the number of switches in the hybrid power source. There is a huge variety of dc-dc converter concepts. They can be divided into the categories "galvanically non isolated & "galvanically isolated. Whereas, the converters that are not galvanically isolated usually have a poor efficiency when high voltage conversion ratios are needed. Galvanically isolated converters can achieve high efficiency even at high conversion ratios as they can step up or step down voltage through the integrated transformer. The voltage sources are phase shifted from each other by controlled angles and these displacements impose the power flow between the sources. In this paper, the two modules of a three-port isolated dc-dc converters, connected in parallel, with each converter owning its own storage element. After detailing the model of the system and defining the proposed control method, the choice of architecture associated with an adapted power sharing algorithm allows optimizing the global efficiency of the system.

## II. PROPOSED CONVERTER STRUCTURE

In this proposed structure, each source is connected to other sources or loads through a three-winding transformer and dc-dc converter. Three-port isolated bidirectional dc-dc converters are used. The proposed converter structure presented in Fig.1. Each three-port converter represents a module of the segmented power system, and each module is the same. The power flow is controlled by controlling two powers,  $P_1$ , which is the power delivered by the FC, and  $P_3$ , which is the power at the output terminal. These two powers are supposed to be the output variables of the control where the phase shifts  $\phi_{13}$  and  $\phi_{23}$  are the input variables. Suppose that the dynamics of voltages  $V_1$ ,  $V_2$ ,  $V_3$  variations are much lower than those of the power loop, one can get the small-signal linearized transfer function in the matrix form.

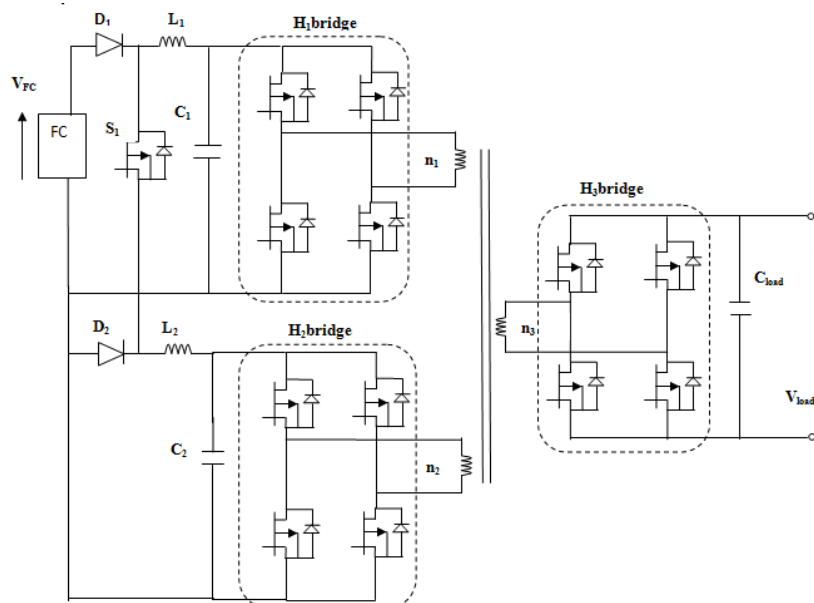


Fig.1. Proposed converter structure

The diode  $D_1$  is used to protect the negative current flowing to the FC. The  $L_1$  and  $C_1$  represents a low-pass filter to attenuate the FC current ripples. In this paper, five modes of operation are discussed below.

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## III. MODES OF OPERATION

### 1) Steady state mode:

In this steady state, the power deliver by the fuel cell is equal to the load power. The power requirement for the load is satisfied by the fuel cell power. In this mode,

$$P_{fc} = P_{load}$$

Whereas  $P_{fc}$ ,  $P_{load}$  are the power flows through the fuel cell and load respectively. In this mode,  $H_1$  Bridge is on,  $H_2$  Bridge is off,  $H_3$  Bridge is on and  $S_1$  switch is off. The steady state mode operation is presented in fig. (a).

### 2) Dual-Output (DO) mode:

In this dual output mode, both the load and battery take the power from fuel cell. This mode is possible when the fuel cell power is greater than or equal to the load power.

$$P_{fc} \geq P_{load}$$

In this mode,  $H_1$  Bridge is on,  $H_2$  Bridge is off,  $H_3$  Bridge is on and  $S_1$  switch is on and also super capacitor gets charged. The dual-output mode operation is represented in fig. (b).

### 3) Dual-Input (DI) mode:

In this dual-input mode, the battery discharges to feed the load along with the fuel cell. When the load requirement is higher than the fuel cell power, the load requirement is satisfied by discharging super capacitor along with fuel cell.

In this mode,  $P_{fc} \leq P_{load}$ . The  $H_1$  Bridge is on,  $H_2$  Bridge is on,  $H_3$  Bridge is on and  $S_1$  switch is off. In this mode, super capacitor gets discharged. This mode operation is represented in fig. (c).

### 4) Single-Input Single-Output (SISO) mode:

In this mode, the battery alone supplies power to the load. In this operation, fuel cell power is equal to zero.

$$P_{fc}=0$$

Here  $H_1$  Bridge is off,  $H_2$  Bridge is on,  $H_3$  Bridge is on and  $S_1$  switch is off and also super capacitor gets discharges. This mode operation is represented in fig. (d).

### 5) Feedback mode:

In this mode, power flows from load to battery. When  $P_{fc}=0$  and  $P_{sc}=0$ , this mode is possible. In this mode,  $H_1$  Bridge is off,  $H_2$  Bridge is on,  $H_3$  Bridge is on and  $S_1$  switch is off and also super capacitor gets charged. This mode operation is represented in fig.(e). When  $P_{fc}=P_{load}$  exactly, the solar supplies the load power alone and the converter operates in a boundary state of DI and DO modes.

This state can be either treated as DI or DO modes. The mismatch in power between the fuel cell and load has to be charged into or discharged from the super capacitor port. Fig 2 represents the five modes of operation.

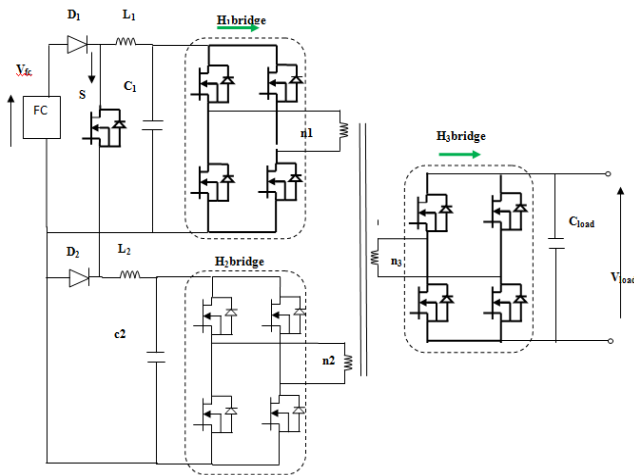


Fig.2 (a)

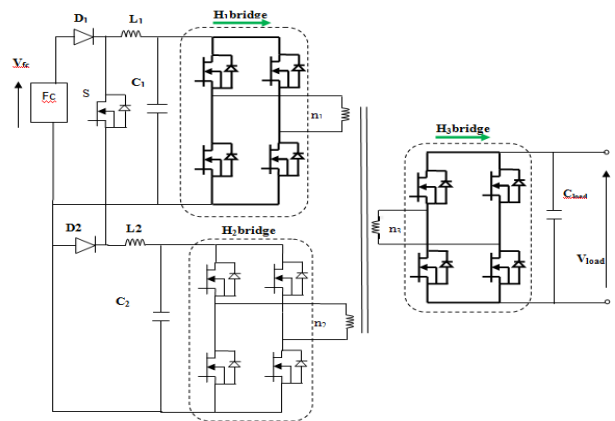


Fig.(b)

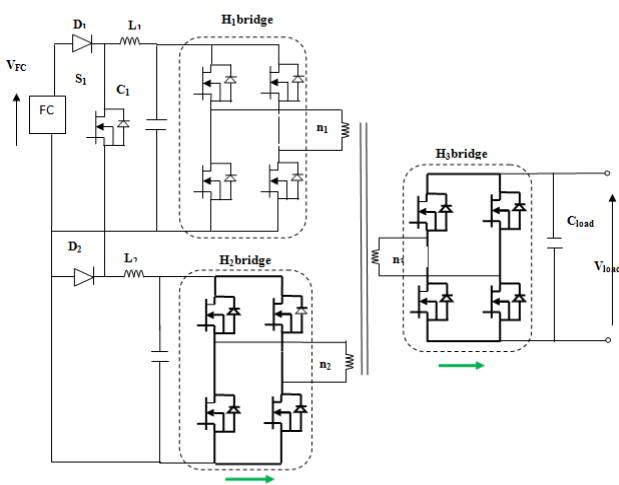


Fig.(c)

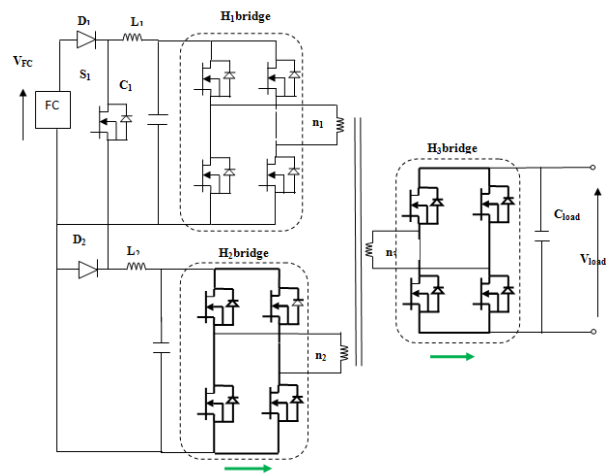


Fig.(d)

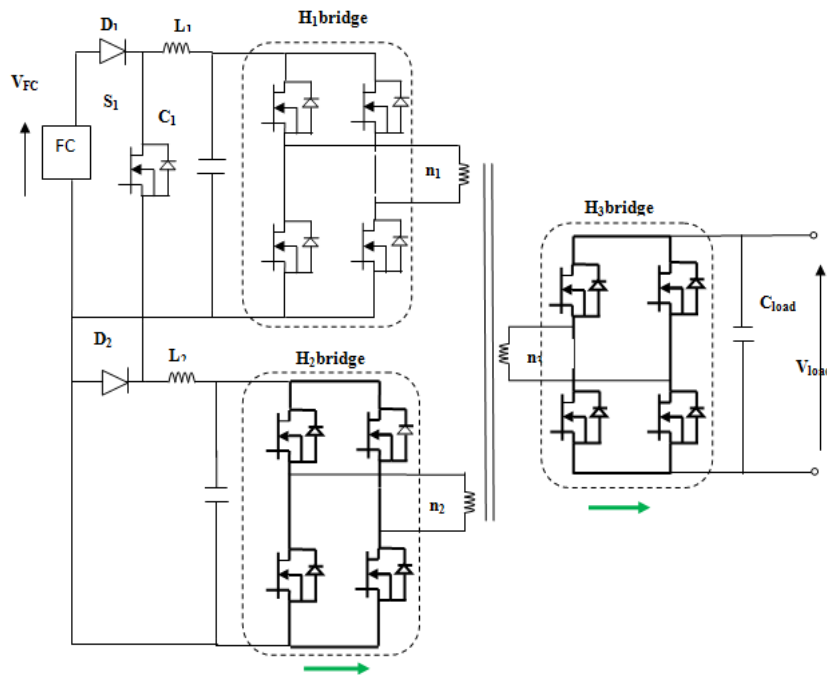


Fig.(e)

Fig.2 (a) Mode 1,(b)Mode 2,(c)Mode 3,(d)Mode 4,(e)Mode 5

#### IV. GLOBAL EFFICIENCY ANALYSIS

Global efficiency depends on the efficiency of each module. Therefore, it depends on the power sharing method. The efficiency in steady state and in normal operating mode ( $0 < P_{load} < P_{FCmax}$ ), the hypothesis that there is no power exchange with the SC bank is made. The efficiency of the three port converter is shown in fig.3

Supposing that each module has identical efficiency, the global efficiency with three different power sharing methods is shown in fig 4.

In order to maximize the global efficiency, at low power load, only one module must deliver power to the load, whereas the other one does not operate.

When the load power is higher than  $P_0$  (the power that makes both curves intersect), both modules must share the same power. To demonstrate that the proposed sharing method is optimized, an analysis of the global efficiency is carried out.

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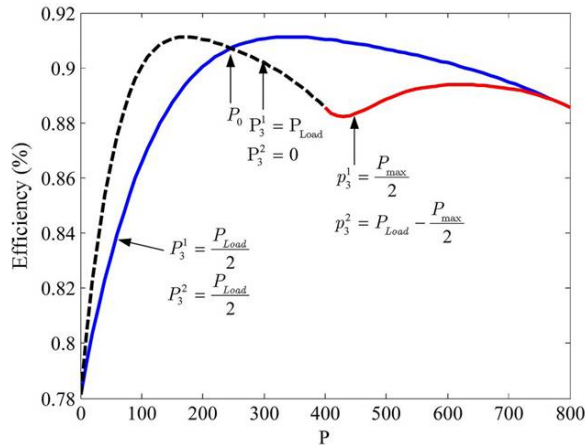


Fig.3 Global efficiency with different power sharing methods

For low power load, the maximum efficiency is obtained at the beginning and at the end of each graph. It means that only one module operates. In contrast, for higher load, the maximum efficiency is found when both modules share load power equally. Therefore, to increase the global efficiency, power sharing between each module is proposed. If load power is lower than  $P_0$  (e.g.,  $P_{Load} = 100$  and  $200W$ ), the first module functions; if load power is higher than  $P_0$  (e.g.,  $P_{Load} = 400$  and  $600 W$ ), both modules function and share the same power.

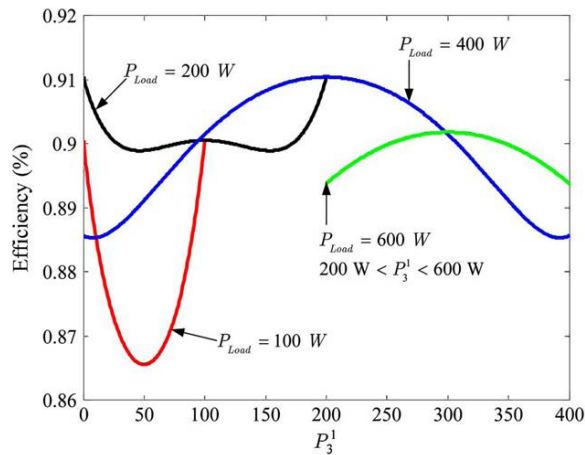


Fig.4 Global efficiency as a function of load power sharing

## V. SIMULATION RESULTS

Simulations are done for dual-input mode using MATLAB/ simulink software in order to verify the performance of the proposed converter. The simulation parameters of the proposed converter are listed below.

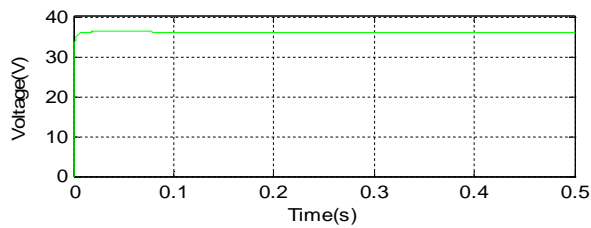
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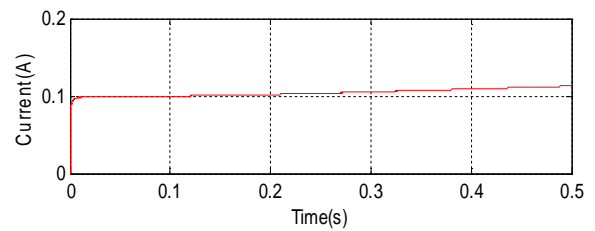
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S.NO	VALUES	PARAMETERS
1	20kHz	Switching frequency
2	60V	$V_1$
3	13V	$V_{SC}$
4	13V,10F	Super capacitor(SC)
5	5:1:5	$n_1:n_2:n_3$

In this mode, the battery discharges to feed the load along with the fuel cell. Fig 5 represents the simulation results. Fig(a)represents fuel cell voltage,(b) represents fuel cell current,(c)represents capacitor voltage,(d)represents capacitor current,(e)represents load voltage,(f)represents load current.



Fig(a)



Fig(b)

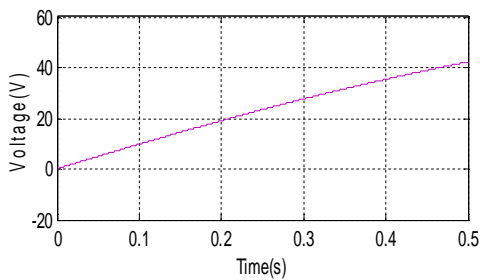


Fig.(c)

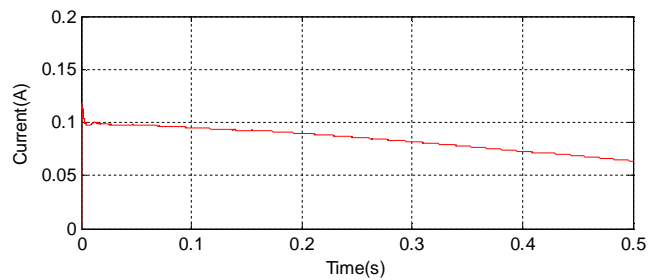
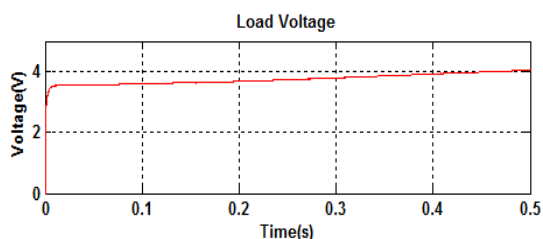
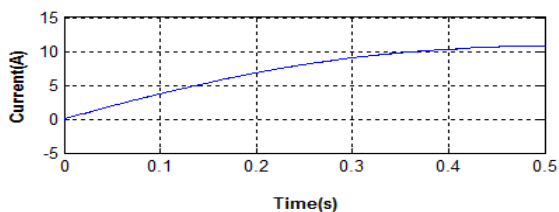


Fig.(d)



Fig(e)



Fig(f)

## VI. CONCLUSION

A hybrid source with three energy sources consists of a fuel cell as a main source and two banks of SCs. This source is built with two three-port isolated DC-DC converters. To increase the global efficiency, power sharing between each module was proposed. The control strategy to manage energy in the system while taking into account the FC constraints has been proposed. Moreover, using parallel converter structure allows optimizing the global efficiency. Its effectiveness has been demonstrated through simulation results.

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