A NOVEL STEP-UP MULTI INPUT DC-DC CONVERTER FOR HYBRID VEHICLES APPLICATION

S.Rajalakshmi[1], R.Thenmalar[1], G.Padmakala[1], S.Merlin Joys Mary[2] and Dr.K.Punitha[3]

1, 2, 3 Department of Electrical and Electronics Engineering

Abstract- In this paper, a multi-input DC-DC converter is proposed and studied for hybrid vehicle (HEVs). Compared to conventional works, the output gain is enhanced. Fuel cell (FC), photovoltaic (PV) panel and energy storage system (ESS) are the input sources for the proposed converter. The FC is considered as the main power supply and roof-top PV is employed to charge the battery, increase the efficiency and reduce fuel economy. The converter has the capability of providing the demanded power by load in absence of one or two resources. Moreover, power management strategy is described and applied in control method. A prototype of the converter is also implemented and tested to verify the analysis.

***Index terms*- multi input converter, hybrid electric vehicle (HEV), power management.**

I.INTRODUCTION

Global warming and lack of fossil fuels are the main drawbacks of vehicles powered by oil or diesel. In order to overcome the aforementioned

Problems and recording the potential clean energies in producing electricity, car designers have shown interest in hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs). The overall structure of hybrid electric vehicle powered by renewable resources is depicted in Fig.1. Electric vehicles (EVs) have also been studied. EVs rely on energy stored in energy storage system (ESS) [1]. Limited driving range and long battery charging time are either main drawbacks. However, by using a bidirectional on/off board charger, they could have the V2G capability. Solar-assisted EVs have also been studied. Employing fuel cell as the main power source of HEVs is the result of many years of research and development on HEVs. Pure water and heat are the only emissions of fuel cells. Furthermore, FCs have other advantages like high density output current ability, clean electricity generation, and high efficiency operation. However, high cost and poor transient performance are the main problems of FCs, are hybridized by ESSs. The main advantages of hybridizing are enhancing fuel economy, providing a more flexible strategy, overcoming fuel cell cold-start and transient problems and reducing the cost per unit power.

In the literature, few numbers of researches have been reported on EVs' and HEVs' electronic interfaces and employing a Z-source inverter (ZCI) for EV vehicles. Boosting input voltage in one stage is its advantage, while high voltage and current stress and complex control method are the main drawbacks of the presented converter. The system was

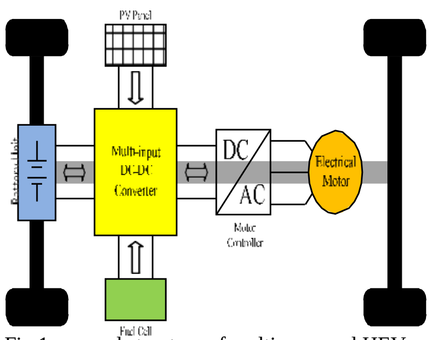


Fig.1. general structure of multi-powered HEV

Powered by FC and a battery unit. V2G is one of the advantages of proposed converter. However, the great number of power switches could reduce the reliability and increase the cost. In [3], a multi-input DC-DC boost converter for hybrid PV/FC/Battery is proposed. But the proposed converter cannot work properly because the battery can be only discharged by PV and only charged by FC. So a two-input DC-DC converter is proposed to interface two power source with a dc bus or load. The converter has high efficiency due to achieving turn-on zero voltage switching (ZVS) of all switches. However, it lacks a bidirectional port. Hence, in application in need of ESS, it can't be used. A two input converter is proposed for standalone PV systems. Moreover, high voltage gain of the converter makes the converter suitable for low input voltage applications. However, the high number of semiconductors and passive elements reduced the efficiency.

Control method preset in the vehicles controller should control the power flow between the renewable resources, battery unit and electric motor. Optimal utilization of power resources demand power permanently, operating fuel cell and PV panel in their optimum region are the main duties of control scheme. Some converters have been proposed recently for PVs systems. But the required converter for HEV applications should extract power from PV and FC. Besides, in order to supply Back-up power from the battery according to discrepancy between generated power and demanded energy. A multi-input converter (MIC) can provide power to the load from different energy sources simultaneously or individually.

In literature, several attempts have been done get the task done. An attempt has been done in which an intelligent optimal power management was introduced. The scheme has three main advances including control of temperature fan, fuzzy hydrogen control and adaptive current-voltage fast-charging control.

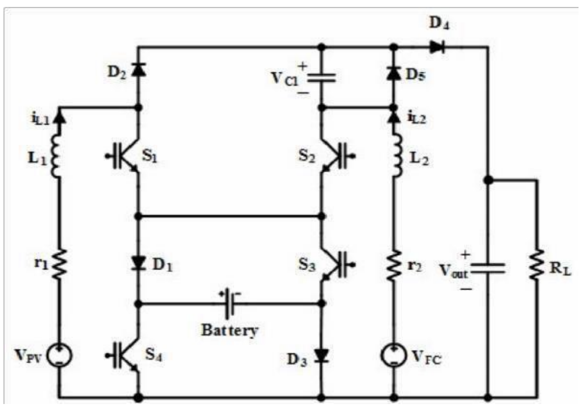


Fig. 2. Three input DC-DC boost converter

Minimizing hydrogen consumption is the objective of the study.

Due to the fact that initial cost of PVs is high and in order to increase the extracted power from the PV panels, MMPT algorithm has to be utilized. A general comparision is made between different MMPT techniques with respect to tracking factor, dynamic response, PV voltage ripple and use of sensors. The other way to improve the efficiency is to enhance the efficiency of the electrical components. In this study, a novel three- input DC-DC converter is proposed to merge a PV, a fuel cell and a battery and connect them to the grid. Furthermore, DC gain is enhanced in respect of conventional converter. Meanwhile, MPPT can be obtained for PV. The battery can be charged and discharged in order to achieve power management. In the following two sections, the proposed structure is studied and different operation modes are discussed. In section (3), the converter is modeled and linearized control the converter. Principles of power management. Additional advantages and useful features of the presented converter and adapting it HEVs are discussed .Finally section (6) concludes the whole paper.

III. PROPOSED CONVERTER TOPOLOGY

The structure of the proposed three-input DC-DC boost converter is depicted in Fig. 2. The converter is formed of two conventional boost converters, substituting extra capacitor in one of the converters, and a battery to store the energy. Characteristics of the converter is suitable for hybrid systems. In this paper, the behavior of the converter in terms of managing the sources is analyzed in power management and control part. Then

V_{PV} and V_{FC} are two independent power sources, that output is based on characteristics of them. L_1 and L_2 are the inductances of input filters of PV panel and fuel cell. Using L_1 and L_2 as in series with input sources change PV and FC modules to current sources. r_1 and r_2 are V_{PV}'s and V_{FC}'s equivalent resistance, respectively. R_{Load} is the equivalent resistance of the loads connected to the DC bus. S_1, S_2, S_3, and S_4 are power switches. Diode D_1, D_2, D_3, D_4 are used to establish modes, which will be described. Capacitor C_1 is used increase output gain and output capacitor C_0 is performed as output voltage filter. System is operating in continuous conduct mode (CCM) to produce smooth current with least possible amount of current ripple.

II.OPERATION MODES

In this section, principles of the proposed converter are discussed. Operation of the converter is divided into three states: 1- The load is supplied by PV and FC and battery is not used. 2- The load is supplied by PV and FC and battery, in this state battery is in discharging mode. 3- The load is supplied by PV and FC and battery is in charging mode.

3.1 First operation state (The load is supplied by PV and FC while battery is not used):

In this state, as it is illustrated in Fig. 3, there are three operation modes. During this state, the system is operating without battery charging and discharging. Therefore, there are two paths for current to flow (through S_3 and D_3 or D_1 and S_4). In this paper S_3 and D_3 is considered as common path. However D_1 and S_4 is could be chosen as an alternative path. During this state, switch S_3 is permanently ON switch S_4 is OFF.

Mode 1 ($0< t <d1T$): In this interval, switches S_1, S_2, S_3 and diode D_3 are turned ON.mm inductors L_1 and L_2 are charged via power sources V_{PV} *and* V_{FC}, respectively [see Fig. 3(a)].

Mode 2 *($d_1T < t <d_2T$):* in this interval, switch S_1 is turned OFF and D_2 is turned ON and S_2, S_3, and D_3 are still ON. Inductor L_2 is still charged and inductor L_1 is being discharged via V_{PV}-V_{C1} [see Fig. 3(b)].

Mode 3 *($d2T <t <T$):* In this interval, S_1 is turned ON and S_2 is turned OFF and S_3 and D_3 are still ON. Inductor L_1 is charged with V_{PV} and inductor L2 is discharged via $V_{PV}+V_{C1}-V_0$ [see Fig. 3(c)].

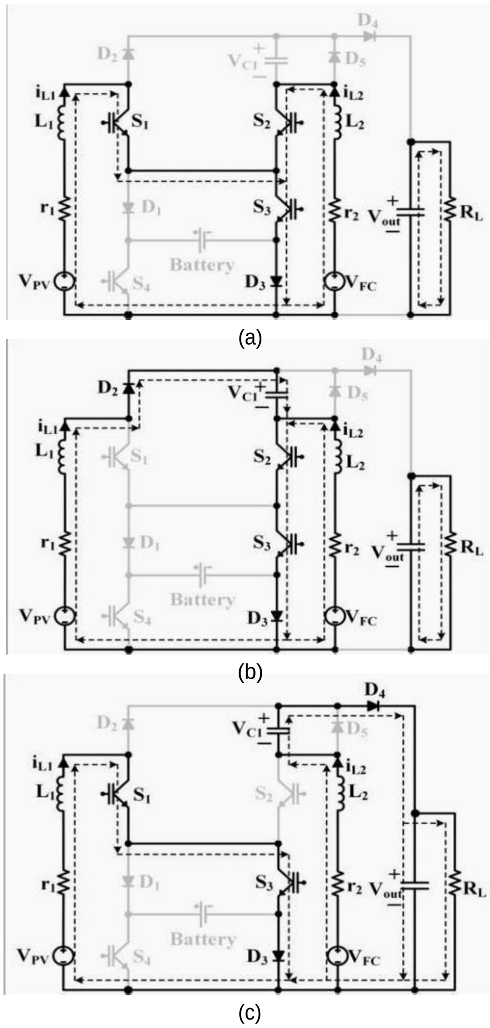


Fig. 3Current-flow path of operating state. (a) Mode 1. (b) Mode 2. (C) Mode 3.

3.2 Section operation state (The load is supplied by PV, FC and battery)

In this state, as it is illustrated in Fig. 4, there are four operation modes. During this state, the load is supplied by all input sources (PV, FC, and battery). In first mode there is only one current path. However, in other modes, there are two current paths through (S_3 and D_3 or D_1 and S_4). In this state, current flows through D_1 and S_4. Switch S_4 is permanently ON during this state.

Mode 1 *($0 < t < d_1T$):* In interval, S_1, S_2, S_3 and S_4 are turned ON. Inductor L1 and L2 are charged by $V_{PV}+ V_{Battery}$ and $V_{FC} + V_{Battery}$ respectively [see Fig. 4(a)].

Mode 2 *($d_1T < t < d_2T$):* In this interval, S_1, S_2, S_4 and D_1 are turned ON. Inductors L_1 and L_2 are charged by V_{PV} and V_{FC} respectively [see Fig. 4(b)]

Mode 3 *($d_2T < t < d_3T$):* In this interval, S_2, S_4, D_1 and D_2 are turned ON. Inductor L_1 is discharged to capacitor C_1 and L_2 is charged by V_{FC} [see Fig. 4(c)].

Mode 4 *($d_3T < t < d_4T$):* In this interval, S_1, S_4, D_1 and D_4 are turned ON. Inductor L_1 is charged by V_{PV} and inductor L_2 is discharges C_1 to the output capacitor. [see Fig. 4(d)].

3.3Third operation state (The load is supplied by PV and FC while is in charging mode)

In this state, as it is illustrated in Fig. 5, there four modes. During this state, PV and FC charges the battery and supply the energy of load. In the first and second operation modes, there are two possible current paths, through (S_3 and D_3 or D_1 and S_4). The path D_1

and S_4 is chosen to flow the current in this state. During this state, switch S_3 is permanently OFF and diode D_1 conducts.

Mode 1 *(0 < t < d1T):* In this interval, S_1, S_2, S_4 and D_1 are turned ON. Inductors L_1 and L_2 are charged by V_{PV} and V_{FC} respectively [see Fig. 5(a)].

Mode 2 *($d_1T < t < d_2T$):* In this interval, S_2, S_4 and D_1 are turned ON. Inductor L_1 is charged to capacitor C_1 and inductor L_2 is discharged by V_{FC} [see Fig. 5(b)].

Mode 3 *($d_2T < t < d_3T$):* In this interval, S_1, S_2, D_1 and D_3 are turned ON. Inductors L_1 and L_2 are charged by V_{PV} - $V_{Battery}$ and V_{FC} - $V_{Battery}$ respectively [see Fig. 5(c)].

Mode 4 *($d_3T < t < d_4T$):* In this interval, S_1, S_4, D_1 and D_4 are turned ON. Inductor L_1 is charged by $V_{PV} – V_{Battery}$ and inductor is discharged by $V_{FC} – V_{C1}- V_0$ [see Fig. 5(d)].

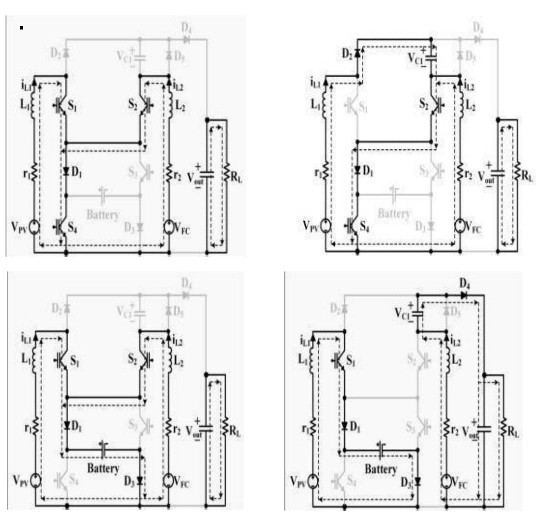


Fig. 5. Current-flow path of operating modes in third operating state

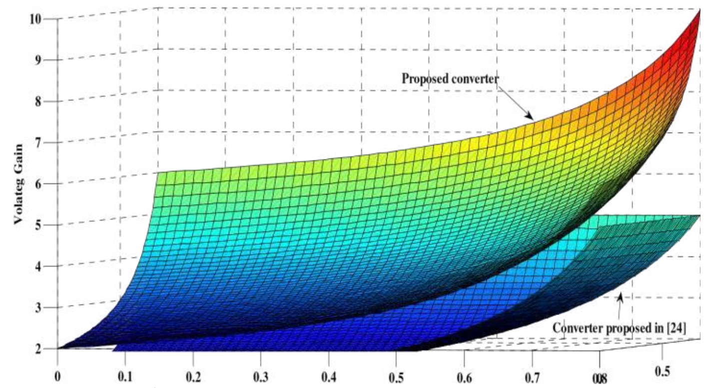
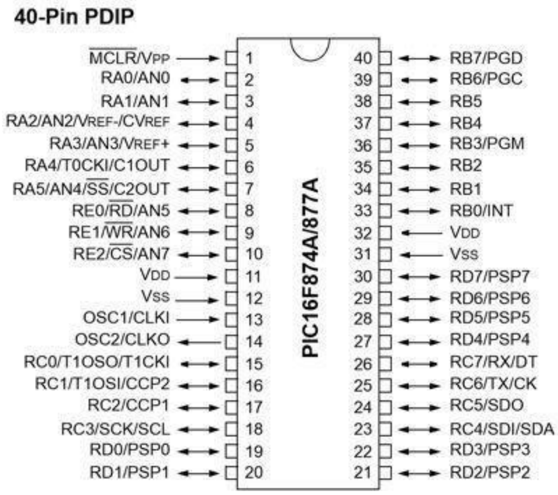


Fig. 7. Output of the proposed converter and converter proposed in [24]

IV. PIC MICROCONTROLLER

The PIC microcontroller family is manufactured by Microchip Technology Inc. Currently they are one of the most popular microcontrollers, used in many commercial and industrial application. Over 120 million devices are sold each year. The PIC microcontroller architecture is based on a modified Harvard RISC (Reduced Instruction Set Computer) instruction set with dual-bus architecture, providing fast and flexible design with an easy migration path from only 6 pins to 80 pins, and from 384 bytes to 128k bytes of program memory, PIC microcontroller are available with many different specification depending on: Memory type, Input-output pin count, memory size Special features. In this paper PIC16F877A is used.



Key Features	PIC16F877A
Operating Frequency	DC – 20 MHz
Resets (and Delays)	POR, BOR (PWRT, OST)
Flash Program Memory (14- bit words)	8 K
Data Memory (bytes)	368
EEPROM Data Memory (bytes)	256
Interrupts	15
I/O Ports	Ports A, B, C, D, E
Timers	3
Capture/Compare/PWM modules	2
Serial Communications	MSSP, USART
Parallel Communications	PSP
10-bit Analog-to-Digital Module	8 input channels
Analog Comparators	2
Instruction Set	35 Instructions
Packages	40- pin PDIP

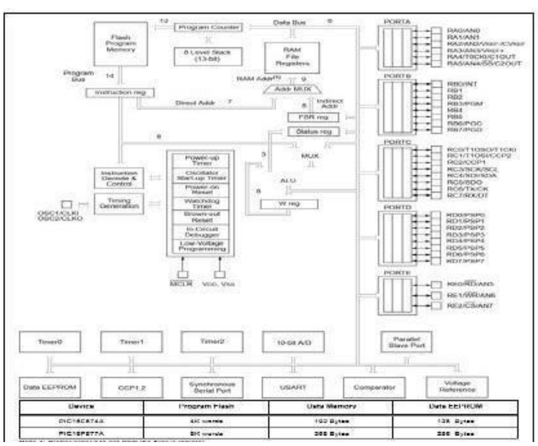


Fig. Block diagram of PIC16F6877A

V. EXPREMENTAL RESULT

In order to verify the performance of the proposed converter, an 80W prototype version of the circuit is built and tested in presented three states. Switching frequency is considered about 30KHZ. A digital signal processor (DSPIC30F4011) is employed to control switches. Ignoring the transient time of the power sources, they could be replaced by DC power supplies to obtain experimental results. A Li-iron, 12V, 7Ah battery is used as energy storage element.

VI. CONCLUSION

In this study, a novel three-input DC-DC converter is proposed and analyzed thoroughly. The converter has the capability of providing the demanded power by load in absence of one or two sources. The converter is modeled for three different operational states and utilized to design a controller. Finally a laboratory prototype of the proposed converter is implemented and result are taken and depicted.

VII. REFERENCES

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PROTOTYPE IMPLEMENTATION