

A Novel Step-Up Multi-input DC-DC Converter for Grid Connected and HEV Application

Dr. N. Samba Siva Rao¹, M. Rakesh²

¹Professor, Department of Electrical & Electronics Engineering, NRI Institute of Technology, Agiripalli, Andhra Pradesh, India

²PG Scholar, Department of Electrical & Electronics Engineering, NRI Institute of Technology, Agiripalli, Andhra Pradesh, India

ABSTRACT

A multi-input dc-dc converter is proposed and studied for hybrid electric vehicles. Compared to conventional works, the output gain is increased. Fuel cell (FC), photovoltaic panel, and energy storage system 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, the power management strategy is described and applied in a control method. Also the proposed concept not only for HEV and also we can use these type of systems for grid connected systems using separate converter. The overall system is designed and simulated using MATLAB/SIMULINK software.

Keywords : Hybrid Electric Vehicle (HEV), Multi-Input Converter, 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 regarding the potential of clean energies in producing electricity, car designers have shown interest in hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles. The overall structure of HEV powered by renewable resources is depicted in Figure 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 their main drawbacks. However, by using a bidirectional on/off board charger, they could have the V2G capability. Solar-assisted EVs have also been studied. Required location and size of PV panels have made them impractical at present [2]. 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 [3].

However, high cost and poor transient performance are the main problems of FCs. It is important to note that vehicles mainly powered by FCs are hybridized by ESS. The main advantages of hybridizing are enhancing fuel economy, providing a more flexible operating strategy, overcoming fuel cell cold start and transient problems, and reducing the cost per unit power [4]. In the literature, few numbers of researches have been reported on EVs' and HEVs' electronic interfaces. In [5], Miaosen has studied employing a Z-source inverter 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. Another approach was done in [6]. The system was powered by FC and a battery unit. V2G is one of the advantages of the proposed converter.

However, the great number of power switches could reduce the reliability and increase the cost. In [7], 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. In [8], a two-input dc–dc converter is proposed to interface two power sources with a dc bus or load. The converter has high efficiency due to achieving turn-on zero voltage switching of all switches. However, it lacks a bidirectional port. Hence, in applications in need of ESS, it cannot be used. A compact two-input converter is proposed for standalone PV systems in [9]. 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 reduce the efficiency. Control method preset in the vehicle's controller should control the power flow between renewable resources, battery unit, and electrical motor. Optimal utilization of power resources, providing 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 [10]–[12], 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, a bidirectional port is needed to charge and discharge the battery according to discrepancy between generated power and demanded energy [13], [14]. A multi input converter can provide power to the load from different energy sources simultaneously or individually. In the literature, several attempts have been done to get the task done [15]–[19]. An attempt has been done in [20], 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. In [21], a two-layer energy management has been studied. Minimizing hydrogen consumption is the objective of this study.

Due to the fact that initial cost of PVs is high and in order to increase the extracted power from the PV panels, MPPT made between different MPPT 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 electric components [23]. 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 converters. 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 IV, the converter is modeled and linearized to control the converter.

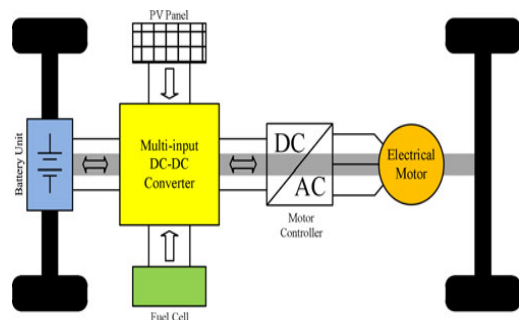


Figure 1. General Structure of the multi powered HEV.

II. PROPOSED CONVERTER TOPOLOGY

The structure of the proposed three-input dc–dc boost converter is depicted in Figure 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. Characteristic of the converter is suitable for hybrid systems. In this paper, 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 characteristic 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 loads connected to the dc bus. S_1, S_2, S_3 , and S_4 are power switches. Diodes D_1, D_2, D_3 , and D_4 are used to establish modes, which will be described. Capacitor C_1 is used to increase output gain and output capacitor C_o is performed as an output voltage filter. System is operating in continuous-conduct mode to produce smooth current with least possible amount of current ripple.

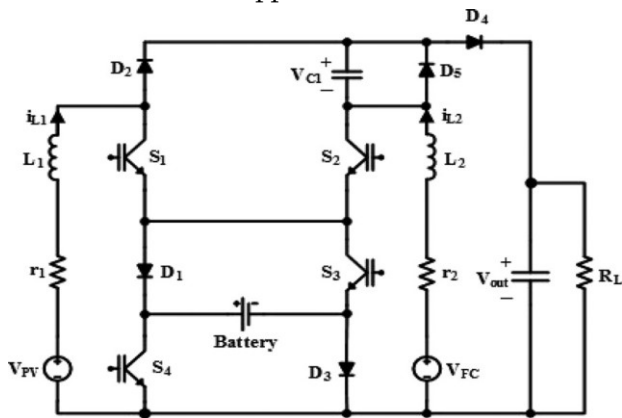


Figure 2. Three-input dc-dc boost converter.

III. 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, 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.

A. First Operation State (the Load is supplied by PV and FC While Battery is not used)

In this state, as it is illustrated in Figure 3, there are three operation modes. During this state, the system is operating without battery charging or 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 could be chosen as an alternative path. During

this state, switch S_3 is permanently ON and switch S_4 is OFF.

Mode 1: ($0 < t < d_1T$): In this interval, switches S_1, S_2, S_3 , and diode D_3 are turned ON. Inductors L_1 and L_2 are charged via power sources v_{PV} and v_{FC} , respectively [see Figure 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 $V_{PC} - V_{FC}$ [see Figure 3(b)].

Mode 3: ($d_2T < t < T$): 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 L_2 is discharged via $V_{PV} + V_{C1} - V_o$ [see Figure 3(c)].

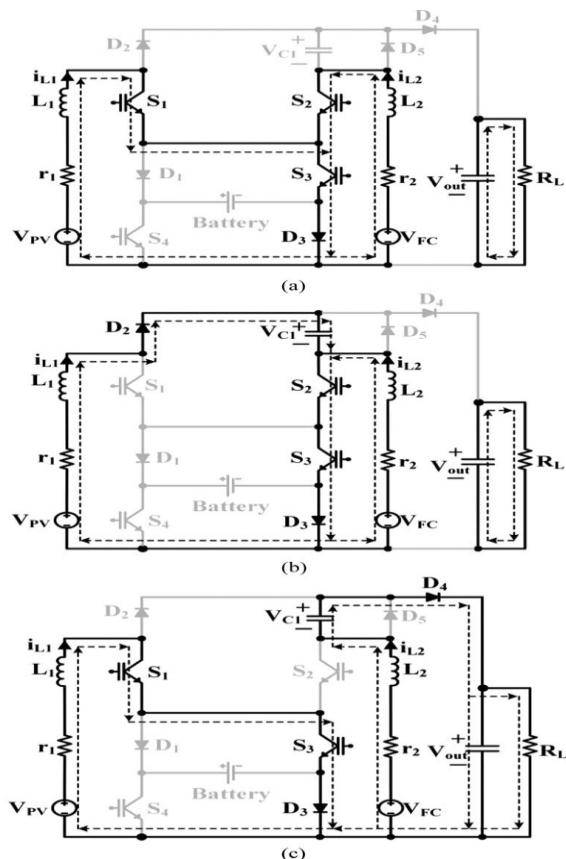


Figure 3. Current-flow path of operating modes in first operating state.

(a) Mode 1. (b) Mode 2. (c) Mode 3.

B. Second Operation State (the Load is Supplied by PV, FC, and Battery)

In this state, as it is illustrated in Figure 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 three modes, there are two current paths (through S3 and D3 or D1 and S4). In this state, current flows through D1 and S4. Switch S4 is permanently ON during this state.

Mode 1: ($0 < t < d1T$): In this interval, S1, S2, S3, and S4 are turned ON. Inductors L1 and L2 are charged by $V_{PV} + v_{Battery}$ and $V_{FC} + v_{Battery}$, respectively [see Figure 4(a)].

Mode 2: ($d1T < t < d2T$): In this interval, S1, S2, S4, and D1 are turned ON. Inductors L1 and L2 are charged by V_{PV} and V_{FC} , respectively [see Figure 4(b)].

Mode 3: ($d2T < t < d3T$): In this interval, S2, S4, D1, and D2 are turned ON. Inductor L1 is discharged to capacitor C1 and L2 is charged by v_{FC} [see Figure 4(c)].

Mode 4: ($d3T < t < d4T$): In this interval, S1, S4, D1, and D4 are turned ON. Inductor L1 is charged by V_{PV}

and inductor L2 discharges C1 to the output capacitor [see Figure 4(d)].

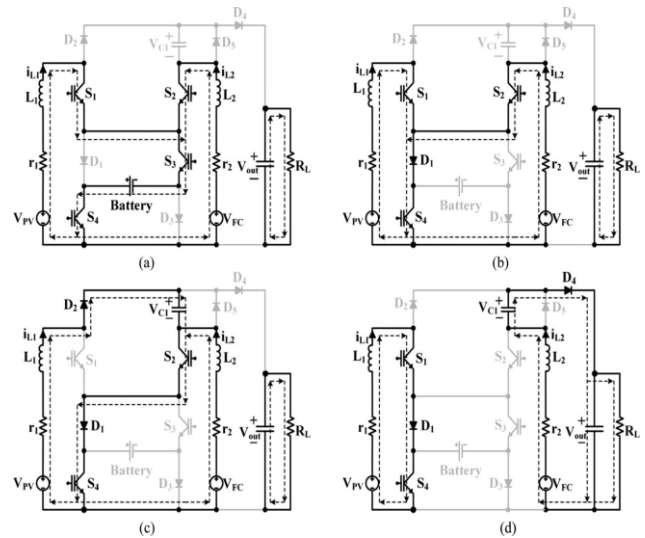


Figure 4. Current-flow paths in different operation modes of second state. (a) Mode 1. (b) Mode 2. (c) Mode 3. (d) Mode 4.

C. Third Operation State (the Load is Supplied by PV and FC While Battery is in Charging Mode)

In this state, as it is illustrated in Figure 5, there are 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 S3 and D3 or D1 and S4). The path D1 and S4 is chosen to flow the current in this state. During this state, switch S3 is permanently OFF and diode D1 conducts.

Mode 1: ($0 < t < d1T$): In this interval, S1, S2, S4, and D1 are turned ON. Inductors L1 and L2 are charged by v_{PV} and v_{FC} , respectively [see Figure 5(a)].

Mode 2: ($d1T < t < d2T$): In this interval, S2, S4, and D1 are turned ON. Inductor L1 is discharged to capacitor C1 and inductor L2 is charged by v_{FC} [see Figure 5(b)].

Mode 3: ($d2T < t < d3T$): In this interval, S1, S2, D1, and D3 are turned ON. Inductors L1 and L2 are charged by $v_{PV} - v_{Battery}$ and $v_{FC} - v_{Battery}$, respectively [see Figure 5(c)].

Mode 4: ($d_3 T < t < d_4 T$): 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 L_2 is discharged by $v_{FC} - v_{C1} - v_o$ [see Figure 5(d)].

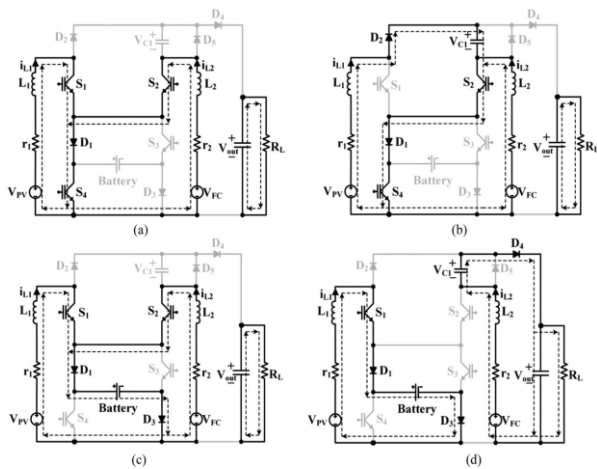


Figure 5. Current-flow path of operating modes in third operating state. (a) Mode 1. (b) Mode 2. (c) Mode 3. (d) Mode 4.

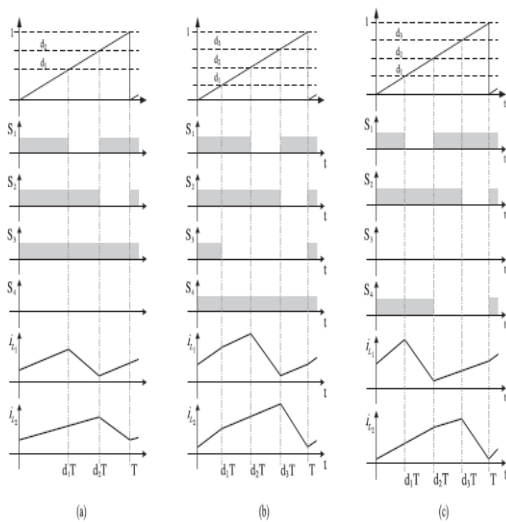


Figure 6. Switching pattern for three states. (a) First state. (b) Second state. (c) Third state.

IV. GRID CONNECTED INVERTER

A grid-connected photovoltaic power system, or grid-connected PV system is an electricity generating system that is connected to the utility grid. A grid-connected PV system consists of solar panels, one or several inverters, a power conditioning unit and grid connection equipment.

They range from small residential and commercial rooftop systems to large utility-scale solar power stations. Unlike stand-alone power systems, a grid-connected system rarely includes an integrated battery solution, as they are still very expensive. When conditions are right, the grid-connected PV system supplies the excess power, beyond consumption by the connected load.

While synchronizing a DG with a utility grid it shall not cause a voltage fluctuation of more than $\pm 5\%$ of the existing voltage level at the Point of Common Coupling (PCC). The allowable voltage harmonic distortion is specified at the PCC. It is normally required that the maximum voltage total harmonic distortion is 5% and maximum individual frequency voltage harmonic is 3% of the fundamental component.

A phase-locked loop is a control system that generates an output signal whose phase is related to the phase of an input "reference" signal [5]. This circuit compares the phase of the input signal with the phase of the signal derived from its output oscillator and adjusts the frequency of its oscillator to keep the phases matched. The output signal from the phase detector is used to control the oscillator in a feedback loop. Frequency is the time derivative of phase. Keeping both the input and output phase in lock step implies keeping the input and output frequencies in lock step. Consequently it can track an input frequency or it can generate a frequency that is a multiple of the input frequency.

V. SIMULATION RESULTS

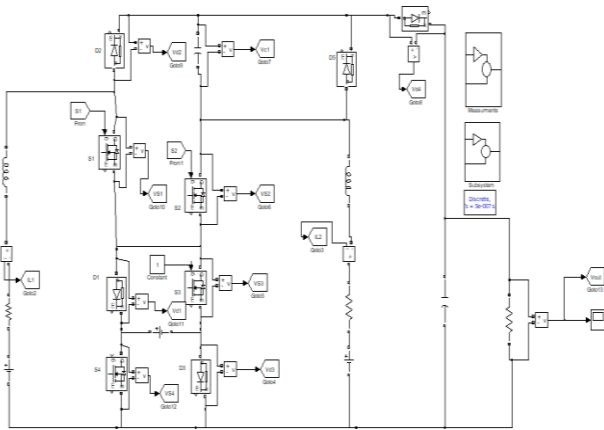


Figure 7. shows the Matlab/Simulink model of proposed three input DC-DC converter

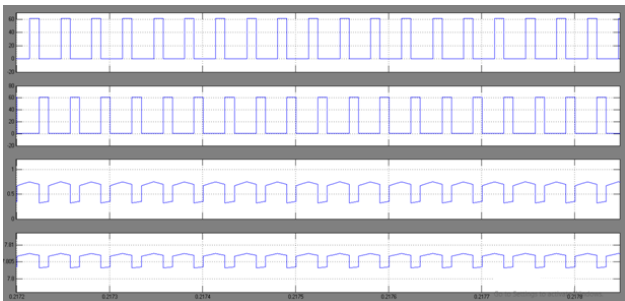


Figure 8. shows the switch voltages S1,S2,S3 and S4

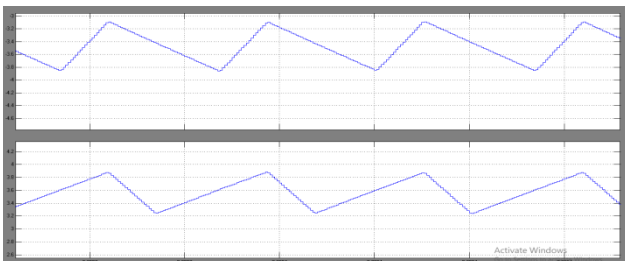


Figure 9. shows the Inductor Currents of L1 and L2

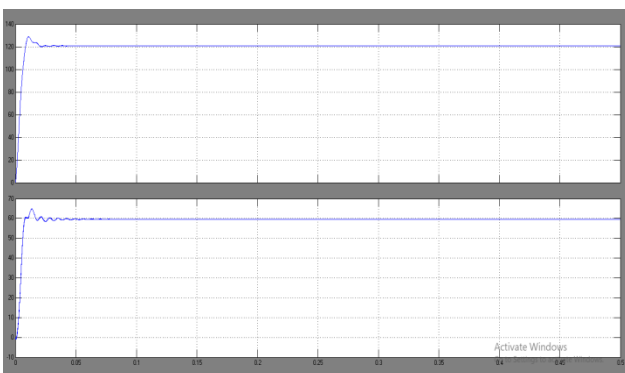


Figure 10. shows the output voltage of the proposed converter and voltage across capacitor

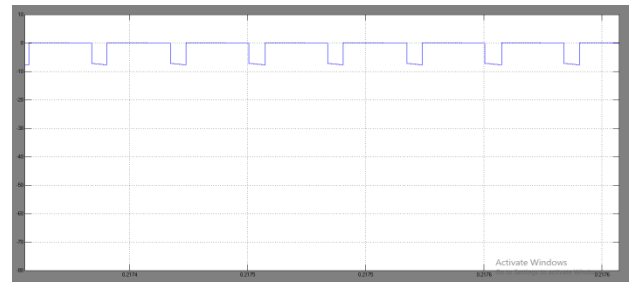


Figure 11. shows the battery discharging mode

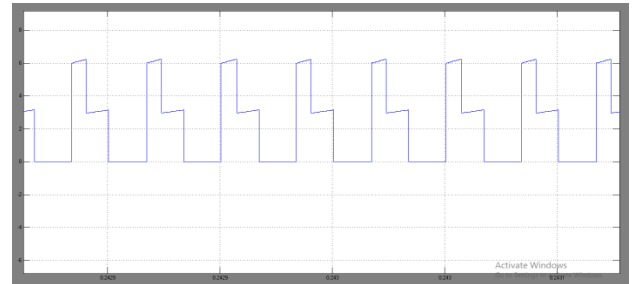


Figure 12. shows the battery charging mode

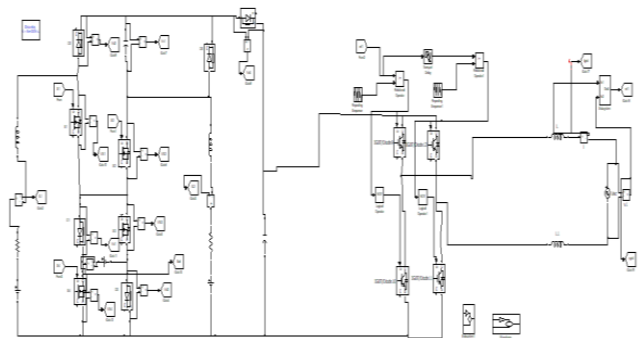


Figure 13. shows the Matlab/Simulink model of proposed three input DC-DC converter applied to grid-tied inverter system

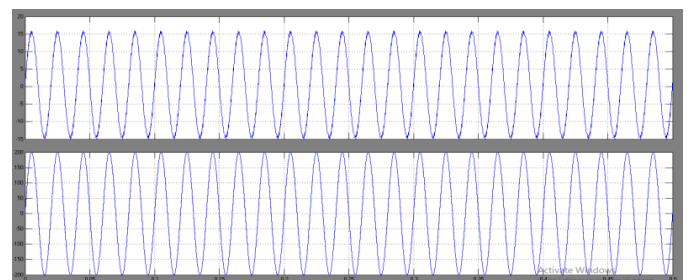


Figure 14. shows the grid current and grid voltage of the grid-tied system

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 resources. The promising performance of the converter and employed control method offer a high reliability for utilizing the converter in industrial and domestic applications. The converter is modeled for three different operational states and simulated. The topic further implemented with grid-tied inverter to synchronize PV with grid using PLL logic. The results are shown that grid current is having less tolerance of THD. The total study is simulated using Matlab/Simulink and results are observed.

VII. REFERENCES

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