Modified Multi Input Multilevel DC-DC Boost Converter for Hybrid Energy Systems

Ram Prakash Ponraj, Devadharshini Ganeshprabhu, Haripriya Balaji, Hemadharshini Ganesan, Keerthana Dhanabalan

Abstract: DC-DC converters are playing an important role in designing of Electric Vehicles, integration of solar cells and other DC applications. Contemporary high power applications use multilevel converters that have multi stage outputs for integrating low voltage sources. Conventional DC-DC converters use single source and have complex structure while using for Hybrid Energy Systems. This paper proposes a multi-input, multi-output DC-DC converter to produce constant output voltage at different input voltage conditions. This topology is best suitable for hybrid power systems where the output voltage is variable due to environmental conditions. It reduces the requirement of magnetic components in the circuit and also reduces the switching losses. The proposed topology has two parts namely multi-input boost converter and level-balancing circuit. Boost converter increases the input voltage and Level Balancing Circuit produce Multi output. Equal values of capacitors are used in Level Balancing Circuit to ensure the constant output voltage at all output stages. The operating modes of each part are given and the design parameters of each part are calculated. Performance of the proposed topology is verified using MATLAB/Simulink simulation which shows the correctness of the analytical approach. Hardware is also presented to evaluate the simulation results.

Keywords: DC-DC converter, Multi input Multi output (MIMO), PWM technique, wide-input range, level-balancing, hybrid energy systems.

I. INTRODUCTION

Availability of fossil fuels depleted and the price increases over the years. Increasing demand thrive the studies on alternate energy sources. Renewable energy sources are found to be the right alternate for the fossil fuels and available abundant in nature. New methodologies have been introduced over the past years to increase the stake of the renewable energy sources and also to meet the increasing power demand. Inverters and Converters were widely used however choppers had less attention in power conversion in spite of used virtually in all power conversion processes [1]. At the present time, due to Electric Vehicles and of various advantages like low harmonics and low EMI DC-dc converters are gathering attention and the use of DC-DC converters are burgeoning [2].

Choppers also use less magnetic components that decrease the complexity of the circuit and overall manufacturing cost [3]. But the DC-DC converters have more voltage balancing problems compared to converters and inverters [4]. Most of the renewable energy sources are not being used throughout the year and their utilization is limited. By using multiple sources; normally renewable energy sources, hybrid power systems increase the reliability and utilization of renewable energy sources [5].

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Contemporary applications like Electric Vehicle also require multiple DC voltages and uses Multiple Input and Multiple Output (MIMO) choppers [6]. Basic multiple input DC converter structure is given in Fig.1 and Fig.2. In these structures, output voltage is the sum of all input voltages [7]. These type of converters used in Distributed generations and high voltage applications due to their simple structure, less volume, less switches and magnetic components [8]. These converters are categorized in to three major categories such as magnetic, Electrical and Electromagnetic type [9]. Earlier days the inputs are connected in parallel to develop a multi-input DC-DC converter. Modern topologies use many configurations to create multiple inputs [10,11]. These topologies use high energy rating capacitors to reduce stress on components and inductor, ripple in the input current and to achieve high effective switching frequency [12,13].

To reduce the effect of capacitors and inductors in increasing the input and output voltages, many inputs are connected in series through semiconductor switches. Output voltage of these converters is the sum of input voltages and these converter reduce the effect of magnetic components in the circuit also [14,15]. The important contemporary applications of these converters are Electric Vehicle for torque ripple reduction [16,17] and Multi-level Inverter circuits [18]. From the manuscripts cited above, this article proposes a novel DC-DC converter topology with multiple inputs and multiple outputs. A General structure of the proposed topology also presented. Performance of the converter is verified using simulation and Hardware implementation.

II. BASIC MODULES

The Basic module of Multi-input DC converter is presented in Fig.2. It uses ‘n’ number of sources in which each source connected in series with a switch. If the switch is ‘ON’ then the sources is connected with the circuit. If the switch is ‘OFF’ then the source is not connected in the circuit and bypassed using a diode connected in parallel.

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Fig.3. General structure of Multi input DC-DC Converter System

The double input structure derived from Fig.3, is given in Fig.4. It uses two sources connected in series with the switches. Each module is connected with a bypass diode to bypass the current when the source is not connected. The inputs are connected with a normal boost converter comprising of an Inductor L_M, Switch S_M and capacitor C_M. Entire setup is connected with a load R_L.

Fig.4 Double input boost converter topology

Fig.5 operation of boost converter when a) S_1 ON b) S_2 ON c) both S_1 and S_2 ON d) Both inputs are OFF

Fig.5.a shows the operation of the topology when V_1 alone is supplying power to the Load. The load voltage is described by the switching angle of S_M and input V_1 alone. V_2 is in OFF condition and it is bypassed through the diode D_2.

Fig.5.b shows the operation of the topology when V_2 alone is supplying power to the Load. The load voltage is described by the switching angle of S_M and input V_2 alone. V_1 is in OFF condition and it is supplied by S_M through D_1.
bypassed through the diode D).

Fig.5.c shows the operation of the topology when both \( V_1 \) and \( V_2 \) are supplying power to the load. Now the load voltage is described by the switching angle of \( S_M \) and sum of inputs \( V_1 \) and \( V_2 \). No bypass diodes are conducting at this mode.

Fig.5.d shows the operation of the topology when both inputs are OFF. Now, Inductor \( L_M \) starts discharging through the load \( R_L \) or through the Switch \( S_M \) and the loop closed through the bypass diodes \( D_1 \) and \( D_2 \).

**A. Design of Basic Module**

The duty cycle of the boost converter used in the system is calculated for the output voltage \( V_o \) and the maximum input voltage of \( n \times V_S \) as,

\[
D = 1 - \frac{n V_S}{V_o} \tag{1}
\]

Output Voltage \( V_o \) is given by,

\[
V_o = \frac{n V_S}{(1-D)} \tag{2}
\]

Where \( n \) is the number of input sources. The minimum value of inductance \( L_{\text{Low}} \) and Capacitance \( C_{\text{Low}} \) are,

\[
L_{\text{Low}} = \frac{D(1-D)^2 R_L}{2 f} \tag{3}
\]

\[
C_{\text{Low}} = \frac{D}{RL + A + f} \tag{4}
\]

The ripple voltage with respect to the output voltage is taken as,

\[
A_{\text{ripple}} = \left( \frac{\Delta V_o}{V_o} \right) \tag{5}
\]

The determined value of load current and the change in load current value is given by,

\[
I_{L,\text{high}} = \frac{n V_S}{(1-D) R_L} \tag{6}
\]

\[
\frac{\Delta I_L}{2} = \frac{V_o \Delta t}{2 L_M} \tag{7}
\]

Where, \( V_S \) – source voltage, \( f \) – switching frequency and \( R_L \) – Load impedance. Ripple Voltage \( A_{\text{ripple}} \) is considered as 0.5% of the output voltage

**III. PROPOSED CONVERTER MODULE**

The proposed DC converter is shown in Fig.6. It consists of a multi input boost converter and a level balancing circuit. Multi input boost converter was already discussed in previous chapter. The level balancing circuit consists of two diodes \( D_1, D_2 \), a voltage balancing capacitor \( C_A \) and a voltage level shifting capacitor \( C_L \).

The overall load of the proposed network includes the resistance of Load \( R_L \), Internal Resistance of each switch \( R_{SW} \) and the internal Resistance of each diode \( R_{diode} \) at forward bias condition.

\[
R_{\text{L, max}} = R_L + 2 \times R_{SW} + 3 \times R_{diode} \tag{8}
\]

Since the internal resistance of the switches and diode is negligible, then (8) would be restated as

\[
R_{\text{L, max}} = R_L \tag{9}
\]

The Voltage across each capacitor is equal to the input voltage \( V_{DC} \). So the overall output voltage across the capacitor \( C_A \) is,

\[
V_{O1} = \frac{2V_S}{(1-D)} \tag{10}
\]

Since the input voltage of the self-balancing circuit is the output of the boost converter, then the output voltage of the level-balancing circuit is,

\[
V_{O2} = V_{C1} = 2 \times V_{O1} = \frac{4V_S}{(1-D)} \tag{11}
\]

The load current \( I_L \) is calculated for the proposed inverter from (2) – (6) and is given by,

\[
I_{L,\text{high}} = \frac{4V_S}{(1-D) R_L} \tag{12}
\]

Various operating modes of proposed DC-DC converter is given in Fig.7. It shows the output and input voltages at various conditions. It also shows the output current and inductor current at various time periods.

![Fig.6. Proposed DC/DC Boost Multi-level Converter circuit](image)

![Fig.7. Circuit parameters at various operating modes](image)

At operating mode 1 (t1 - t2): Both inputs are OFF which is shown in Fig.8(a). The magnetic components are discharging through the diodes \( D_{S1} \) and \( D_{S2} \). The input voltage is \( V_S = 0 \) and the output of boost converter is also zero. Take the inductor is charged at a value of \( V_{M1} \).

At operating mode 2 (t2 - t3): Shown if Fig.8(b) at which any of the two inputs \( V_1 \) and \( V_2 \) is ON and the input voltage is \( V_S = V_1 \) or \( V_2 \). Output voltage of the boost converter is described from (10) and is given by,

\[
V_{O1} = \frac{V_S}{(1-D)} \tag{13}
\]
Capacitors C1 and C2 start charging and the output voltage start increasing. Inductor also starts charging, take initial value of inductor current as IM1 and the new value of inductor current IM2 at time t3 is,

By comparing multiple input multiple output (MIMO) topologies presented in [19-21] and [15], it states that proposed topology requires less number of magnetic components and switches. Table 1 summarizes the comparison of proposed topology and conventional topologies in view of inductor and switch requirement.

Table.1. comparison of topologies with component requirement

| Proposed topology | NDC SOURCES | NINDUCTORS | NSWITCHES |
|-------------------|-------------|------------|-----------|
| Topology in [19]  | n           | 1          | m         |
| Topology in [20]  | m           | 1          | n+m       |
| Topology in [21]  | m           | m          | m²        |
| Topology in [15]  | n           | 1          | n+1       |

Topology [21] requires ‘m’ number of inductors for multi-stage output which increases complexity of the circuit. Proposed topology requires less number of switches compared to [19] and [20]. This decreases cost, volume and deliver requirement. Topology [15] requires same number of components but it requires asymmetric input voltages to get multi-stage output.

IV. SIMULATION AND HARDWARE RESULTS

Performance of the proposed topology is evaluated with the Simulation and Hardware. Simulation has been carried out using Matlab/Simulink R2014a and the results are presented in Fig.9. Simulation was carried out for an input voltage of 50V. The load values of 50Ω and 25Ω are considered for full load and half load conditions respectively. The inductor value has been chosen as 8mH and the capacitor values at both the stages are made equal at a value of 89µF. Switching frequency of 10kHz is chosen for the switch SM.
Fig. 9. a)- d) Output Voltage and Current waveforms at different load conditions

Fig.9.a describes the output voltage $V_{02}$ which is around 192 V for an input of 50V. Voltage across $C_M$ ($V_{01}$) is 96 V which is exactly half of the load voltage. Fig.8.b. shows the load current $I_L$ and current due to voltage $V_{01}$ at half load conditions. It shows the load current of 0.6A and current of 0.45A due to voltage $V_{01}$ at half load is used across it. Fig.8.c shows the output voltage $V_{02}$ of 165V and capacitor Voltage $V_{01}$ of 82V at half load condition (25Ω). Fig.8.d shows the current values at half load condition.

Fig.10 Performance parameters of proposed topology at various inputs

Simulation diagrams clearly describe that the output voltage $V_{02}$ is twice as the capacitor voltage $V_{01}$ as stated in (10) and (11). Fig.10 shows the performance parameters of proposed topology at different input conditions. Output voltage $V_o$ is decrease slightly when input increases from $V_S$ of 50V to 2V $S$ of 100V. There is a sudden change in the output voltage due to charging and discharging of capacitors.

Inductor starts charging with change in input voltage and starts discharging. Load current decrease slightly when the input changes to zero. From the load current values, it is clearly known that the topology working in continuous conduction mode.

Fig.11. Output voltage of Proposed DC-DC converter

To evaluate the simulation results, hardware prototype has been developed and the output voltage is shown in Fig.11. An output voltage of 30V is achieved for an input of 6V. Hardware use IRF840 Mosfet as switch. IC8951 is used to generate the gate pulses of Switches for switches $S_1$ and $S_2$. A PWM pulse of 10 KHz is given to switch $S_M$. The parameters used in prototype are given in table 2.

Table 2. Parameters used in Hardware Prototype

| Load | 25Ω |
| Switch | IRF840 |
| Controller | IC8951 |
| Switching Frequency | 10 kHz |
| Input Voltage | 6 V (both inputs) |
| Output Voltage | 30 V |

Fig.12 shows the input waveforms and output voltage waveform. Inputs are given alternatively and it shows no decrement or change in the output voltage. The output voltage is maintained as constant at 30V for the alternating inputs of 6V. From the simulation and experimental results, it is clearly shown that the the topology can produce constant output voltages for variable input voltages.
V. CONCLUSION

A novel multi-input and multi-output (MIMO) DC-DC converter was presented in this paper. The generalized structure and a dual input dual output topology also presented. This topology is suitable for hybrid power system uses renewable energy sources with variable output. Performance of the topology was discussed with analytical approach. This topology requires less number of inductor and switches to reduce the cost, volume and driver requirements. A detailed comparison with other topologies was also given. Performance of the topology was verified using simulation and hardware prototype. The output was maintained constant with variable input voltages. By using closed loop control and MPPT techniques, the proposed topology can also be used for the hybrid systems with unequal input voltages.

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