SINGLE STAGE MULTI - INPUT DC–DC/AC BOOST CONVERTER

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ABSTRACT:- Multi input DC-DC or DC-AC boost converter is presented in this paper. A new extendable single stage technology is used here. Several unidirectional boost converters are used to get power from different input sources. Output load is interfaced on the central part of the proposed structure. Two sets of boost converters are connected in parallel in the proposed topology. Independent output voltage control is implemented in both side. The converter has two modes of operations dc – ac mode and dc – dc mode. By providing pure dc reference in both side of the converter we can obtain dc – dc mode and by providing dc biased sinusoidal reference we can obtain dc – ac mode. The number of power switches used to obtain high level voltage from low level voltages are minimum. Another advantage of the proposed topology is that we can add any number of low level dc power sources as the converter inputs. For obtaining desired output voltage two voltage control loops are included in the converter control system which automatically regulates the output voltage. Simulation and experimental results are used to verify the performance and effectiveness of the proposed converter.

INDEX TERMS: - Multi input converter, boost converter, hybrid systems, voltage control

I. INTRODUCTION

Power generation from different renewable energy sources have greater importance in the current global energy scenario. The need of electric power is increasing day by day. Major power generation is from fossil fuels and from nuclear energy. The availability of such fuels are limited and various environmental hazards are associated with these traditional power generation methods. Various grid connected renewable systems are becoming popular. The main problem of renewable energy sources are that their power is not constant throughout its operation.

Solar and wind energy are the most common and clean renewable energy sources. Their power is intermittent and unpredictable. Thus they are not highly reliable. Different renewable sources are combinly used as a hybrid system in order to obtain almost constant power. In order to accommodate different renewable sources the concept of Multi Input Converters has been proposed[1]-[4]. Simple deign, easy centralized control, high reliability, less cost and small size make these converters more popular. Most of the multi input converts has low level dc as input. These converters can be broadly classified into two according to the output of the converter, dc-dc converter or dc-ac multi input converter.

Most of the dc-dc multi input converters are based on boost converter structure[5]-[7]. The converter in [7] uses minimum number of switches and its design is simple. There are a family of multi port converters which uses different structures of magnetic coupling , half bridge boost converter, hybrid dc-dc control etc.[8]-[10]. A new approach of three input converter topology with battery power backup is proposed in[11]-[12].

The dc-ac multi input converters has different topologies like isolated multi input bidirectional converter[13], three input full bridge structure[14], line interactive fuel cell topology[15], and grid connected models[16].

Multi input converters has several advantages, but some of the disadvantages are the use of several stages in power conversion which increases the number of power switches and devices used. Also for supporting ac loads filters are required. These disadvantages increase the cost, size, weight and power loss of the hybrid system, also the control become difficult.

In this paper a new multi input boost converter which uses a single stage power conversion is proposed. Single stage power conversion decreases the power loss in the conversion stages and complexity of the converter is reduced. Also the efficiency and reliability of the converter is increased in a lower cost and less size. The proposed topology uses several unidirectional boost converters for different low level dc inputs sources. The converter has the ability to step up from low level input to required high level output voltage.

The load is interfaced in the central part of the converter. The output load voltage is differentially obtained from the both side of the load. In dc-dc mode of operation two pure dc reference is given to both side of the converter to get two regulated dc voltages. For dc-ac mode two controlled dc biased sinusoidal voltages which are 180^0 out of phase are produced. Two voltage control loops are used in the proposed converter in order to obtain constant output voltage. Simulation and experimental results are used to verify the performance and effectiveness of the proposed converter.

Comparing with other multi input topologies, the proposed converter topology uses a single stage power conversion which is able to obtain both dc-dc conversion and dc-ac conversion. The proposed topology uses lesser number of switches and no special output filters are required.

II. PROPOSED CONVERTER TOPOLOGY

The structure of proposed multi input converter topology is illustrated in Fig.1. As in the figure the load is interfaced on the central part of the structure. Several unidirectional boost converters are incorporated on both sides of the converter in order to include different low level dc inputs. The two output dc link voltages are V_{01} and V_{02}. They are obtained across the two output capacitors. The output from different boost converters are obtained cross these two capacitors. the boost converters are feed from different dc sources (V_{i1}, V_{i2}, V_{i3}… V_{in}).

In the proposed topology each boost converter is controlled independently in order to obtain required constant output voltage. So n different duty ratios are given to different switches S_1, S_2, S_3…. S_n. the duty ratio of each switch is controlled independently in order to obtain constant voltage across the load.

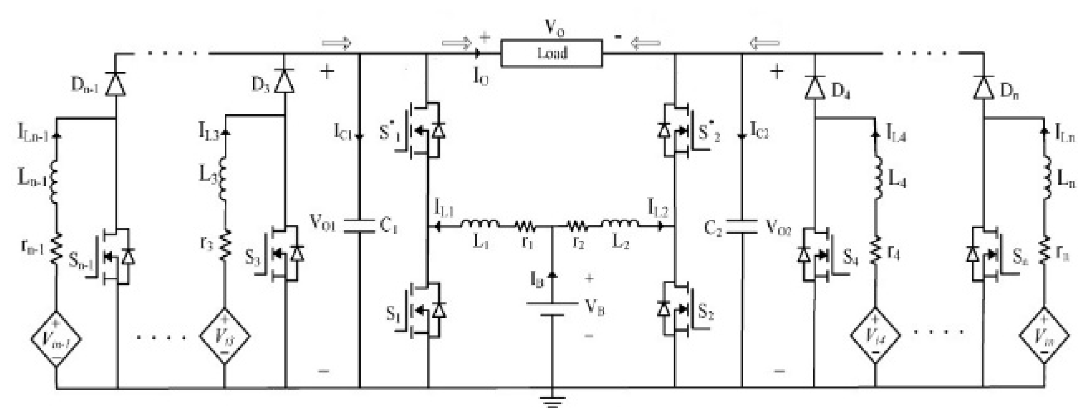

Fig. 1. Proposed converter structure

III. OPERATION MODES

Two modes of operation can be obtained from the proposed converter. The operation of proposed converter in different modes are demonstrate in the following section.

A. DC–DC Mode

If two different dc values are chosen as the converter output reference voltages, then a pure dc voltage appears across the output load as follows:

$$V_{o_1} = V_1,\ V_{o_2} = V_2,\ V_o = V_1 - V_2 \qquad (1)$$

For an output resistive load the consumed power can be expressed by the following equations:

$$I_o = (V_1 - V_2)/R_L$$

$$P_o = V_o I_o = (V_1^2 - 2V_1V_2 + V_2^2)/R_L \qquad (2)$$

Now, we obtain the converter first- and second-side powers $Po1$ and $Po2$ delivered to the load as follows:

$$P_{o_1} = V_{o_1} I_o = (V_1^2 - V_1V_2)/R_L$$

$$P_{o_2} = -V_{o_2} I_o = -(V_1V_2 - V_2^2)/R_L \qquad (3)$$

Instantaneous current and power of an output resistive load can be expressed by the following equations:

$$I_o(t) = I_m \sin\omega t\,, \qquad I_m = V_m/R_L$$

$$P_o(t) = V_o(t)I_o(t) = \tilde{P}_o + \bar{P}_o$$

$$= -\frac{V_m I_m}{2}\cos 2\omega t + \left[\frac{V_m I_m}{2}\right] \qquad (6)$$

In (6), the average quantity $V_m I_m/2$ corresponds to the load average power P_o , while the alternative term at the angular frequency of *2ω* denotes the pulsation component of the load power. Now, the converter first- and second-sides instantaneous powers delivered to the load are obtained as follows:

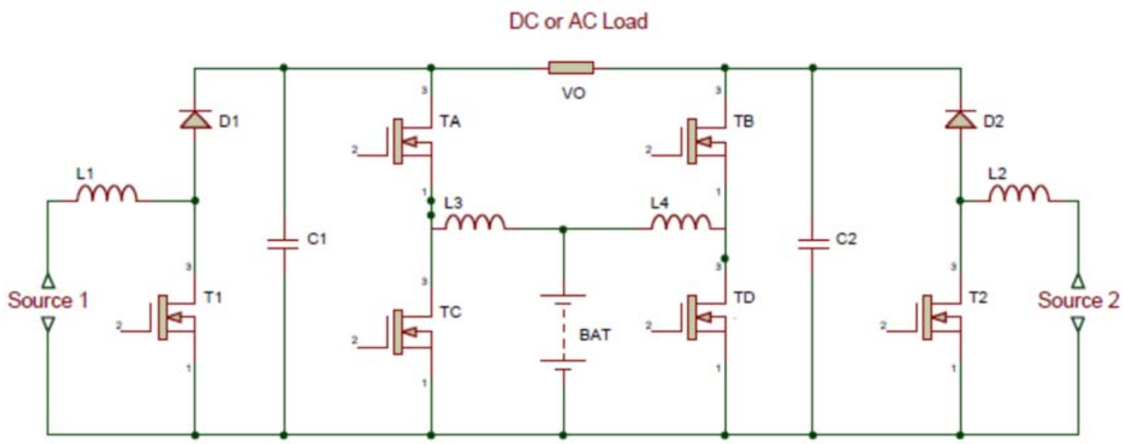

Fig. 2. Two-input structure of the proposed converter.

B. DC–AC Mode

If the converter reference voltages are chosen as (4), then the proposed converter will operate in the dc–ac mode as

$$V_{O_1}(t) = V_{dc} + \frac{V_m}{2}\sin\omega t$$

$$V_{O_2}(t) = V_{dc} - \frac{V_m}{2}\sin\omega t \qquad (4)$$

where their dc parts are the same as V_{dc} and the modulation of each sinusoidal part is 180◦ out of phase with the other one. This concept results in generating a pure sinusoidal voltage across the load as follows:

$$V_o(t) = V_{o_1}(t) - V_{o_2}(t) = V_m \sin\omega t \qquad (5)$$

$$P_{o_1} = V_{o_1}(t)I_o(t)$$

$$P_{o_1} = V_{dc}I_m \sin\omega t + \frac{V_m I_m}{2}\sin\omega t^2$$

$$= V_{dc}I_m \sin\omega t - \frac{\bar{P}_o}{2}\cos 2\omega t + \left[\frac{\bar{P}_o}{2}\right]$$

$$P_{o_2} = -V_{o_2}(t)I_o(t)$$

$$P_{o_2} = -V_{dc}I_m \sin\omega t - \frac{\bar{P}_o}{2}\cos 2\omega t + \left[\frac{\bar{P}_o}{2}\right] \qquad (7)$$

IV. CONVERTER DESIGN

Figure 2 shows a five input structure of the converter topology. Six passive elements are present in the structure. Two capacitors and four inductors. The values of passive elements can be determined according to the desired voltage and current ripples of the converter. Let ΔV_{max} and ΔI_{max} are the maximum voltage and current ripple. Thus the capacitors and inductors can be selected with values greater than the minimum values which are obtained as:

$$Li_{min} = \frac{D_{max}\ V_i}{\Delta I_{\max}\ \ f_s}$$

$$C_{min} = \frac{D_{max}\ V_m}{R_L\ \ \Delta V_{\max}\ \ f_s} \quad (8)$$

The converters predefined maximum duty ratio is denoted by D_{max} , f_s is the switching frequency of the converter. R_L is the load resistance. Input dc voltage and peak sinusoidal output voltages are V_i and V_m respectively. For D_{max}=0.8, f_s=30kHz, ΔV_{max}=10V and ΔI_{max}=7A the minimum values of capacitors and inductors are:

$$Li_{min} = 2.5mH$$

$$C_{min} = 30\mu F \quad (9)$$

Voltage stress experienced across the switches of the proposed converter is given by $V_{str}=V_{dc}+V_m/2$. If V_{dc} is minimized then this stress voltage can be decreased. Assuming the converter duty ratios and input voltage ranges as

$$V_{dc}|min = V_H + V_m/2$$

$$V_{str}|min = V_H + V_m$$

$$V_L|min = (1 - D_{max})\ (V_H + V_m) \quad (10)$$

If the converter duty ratio range and input voltage range are selected as DL=0, Dmax=0.8, VH=100V and Vm=280V, then using (10) the converter design considerations are:

$$V_{dc}|min = 180V$$

$$V_{str}|min = 350V$$

$$V_L|min = 70V$$

V. SIMULATION RESULTS

The performance of the proposed converter topology in both dc-dc mode and dc-ac mode is validated using MATLAB/Simulink simulations. Simulink model is given in fig.3.

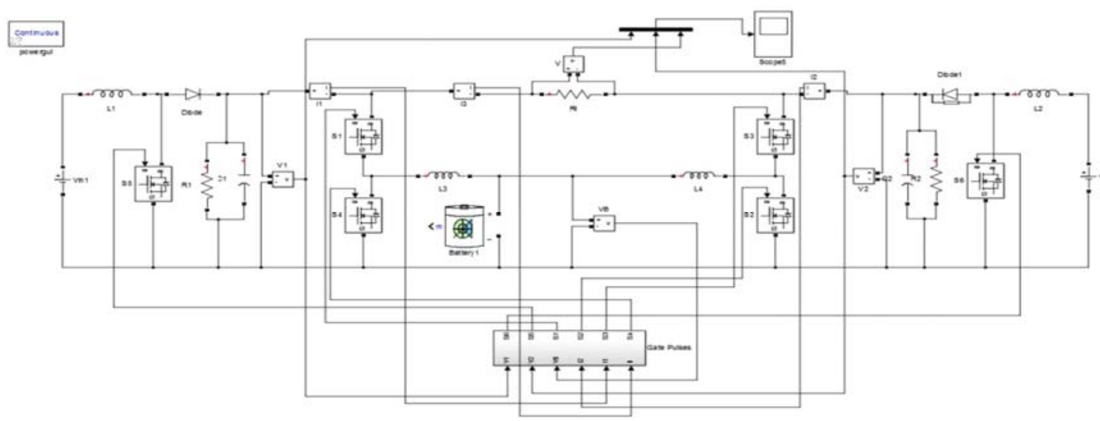

Fig. 3. Simulink model of DC-DC/AC boost converter

A. DC – DC Mode

In dc - dc mode of operation the two boost converters operates at constant duty ratios to obtain constant dc voltage. The load is connected in between these two boost converters. The load voltage will be the difference of the voltages between the two boost converters. The side with more voltage act as the positive terminal. Output voltage Vo = 220V is the desired load voltage. For obtaining this voltage the reference voltages for both sides of the converter is set as Vo1= 320V and Vo2= 100V.

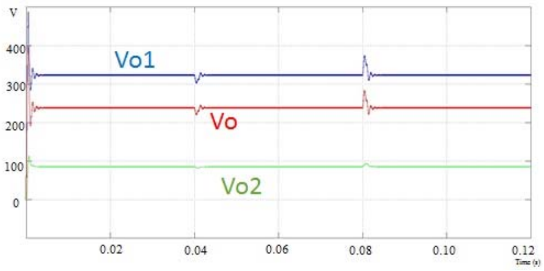

Fig. 4. Converter output voltage in dc-dc mode

Figure 4 shows the output voltage waveforms obtained in dc-dc mode operation of the proposed converter topology. V_{o1} waves Shows the voltage waveform of the left boost converter and the V_{02} waveform is the voltage of the right converter. V_o waves shows the voltage waveform across the load.

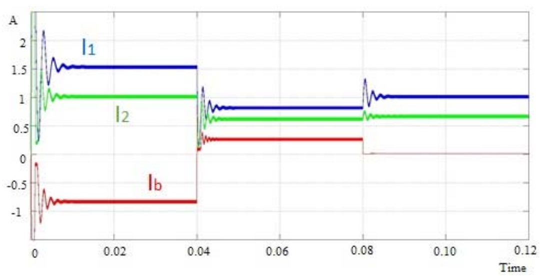

Fig. 5. Converter output current in dc-dc mode

The drawn currents from the input dc sources are illustrated in Fig. 5. I_1 and I_2 shows the currents drawn from the sources and the I_b waves shows the battery current. From the figure it is clear that the battery current takes positive and negative values denoting delivering and absorbing powers. Po1 and Po2 are the powers at both sides of the converter and Po is the output power, the theoretical battery current is

$$I_B = (Po - Po1 - Po2)/V_B$$

In the first period (0 < t < 0:04s) the load resister absorbs a power of 40W. The currents in input sources are set as I_{i1} = 1.5A and I_{i2} = 1A. In this state the converter total input power is Pi = 60W is more than the load power. And the extra power of 20W is absorbed by the battery showing a negative battery current. In the second simulation period (0.04 < t < 0.08s), the input source currents I_{i1} and I_{i2} are reduced to 0.8A and 0.6A respectively. The converter input power in this condition is P_i = 33.6W. Thus the battery is discharged to meet the deficiency of 6.4W producing a positive battery voltage.

The input currents I_{i1} and I_{i2} are increased to 1A and 0.67A in the last simulation period (0.08 < t < 0.12s). The total input power extracted in this time period is 40.1W which is sufficient t meet the load. That means there is no extra power nor deficiency in power, thus the battery current seen to be zero.

B. DC–AC Mode

The second mode of operation of the designed converter is dc - ac mode of operation. In this mode we are giving varying duty ratios to both sides of the converter. The duty ratios vary in a sinusoidal manner. Fig 6 shows the variation of duty ratios. These duty ratio instantaneously compares with a 5kHz carrier signal to produce Sinusoidal voltage of 50Hz is desired in the output.

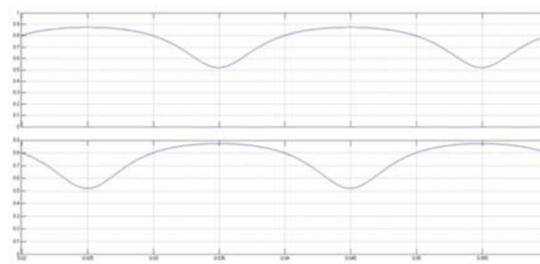

Fig. 6. Duty ratios in DC-AC mode

Let the output ac voltage be Vm= 230V. Inorder to obtain desired ac voltage, two DC biased sinusoidal voltages are selected as the reference of the two sides of the converter. Vo1 and Vo2 are selected as the reference voltages. Both references are equal and they re phase shifted by 180^o . Vm=2 = 160V and Vdc= 180V. For achieving similar simulation results, load power, input voltages and their reference currents are chosen to be same as in dc -dc mode. Also three similar simulation period are selected. Step changes are done at 0.04s, 0.08s and 0.12s. Figure 7 shows the output voltage waveforms obtained in dc-ac mode operation of the proposed converter topology after applying the step changes.

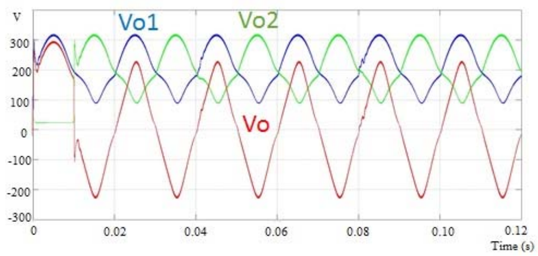

Fig. 7. Converter output voltage in dc-ac mode

In the fig 7 the V_{01} waves shows a dc shifted sine wave obtained in the left side of the converter and the V_{02} waves shows the dc shifted voltage obtained in the right side of the load. The difference of these two voltages will be appear as the output load voltage. The V_o waves shows the voltage across the load. The output voltage is a perfect sinusoidal wave. Currents drawn from input sources and the battery current are illustrated in the fig 8. I_1 and I_2 waves shows the currents drawn from the sources and the I_b waves shows the battery current. From the waveform it is clear that the battery current is a dc-biased sinusoidal waveform with an angular frequency of 2ω. The battery current takes negative, positive and zero current representing discharging, charging and stand by modes of operation of the battery.

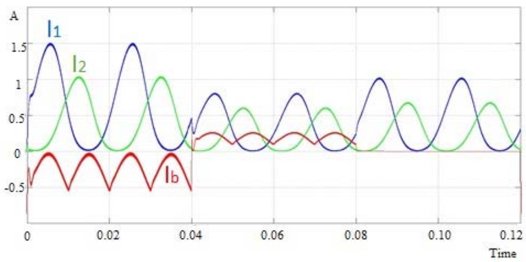

Fig. 8. Converter output current in dc-ac mode

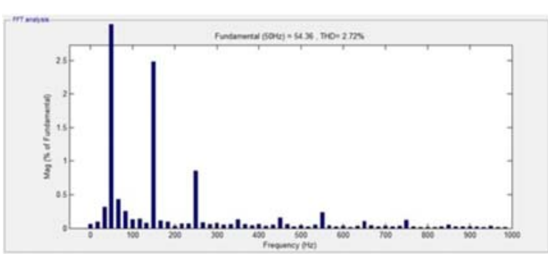

Figure 9. FFT analysis of output ac voltage

FFT analysis of the output voltage waveforms gives a THD of only 2.7 % . Which shows that the output voltage is a pure sinusoidal voltage. Thus we obtained a sinusoidal output voltage with very low THD without using any filters.

VI. HARDWARE MODEL

Complete hardware setup of the proposed converter circuit is shown below. In the figure, the two input boost converter is shown in which the gate pulses are supplied through driver circuits interfaced with Matlab/Simulink using Arduino Mega microcontroller board.

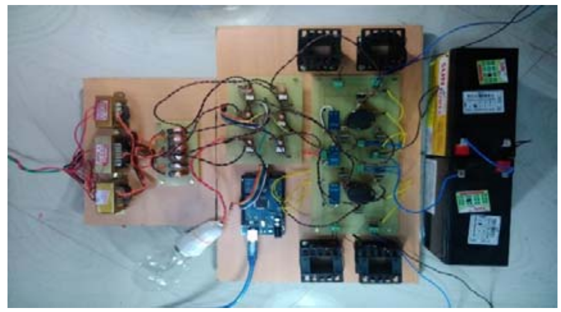

Fig. 10. Converter hardware model

Two variable DC sources are used to fed the system. Also a battery storage unit is connected to the system in order to balance the power flow within the system.

For dc dc mode, the output dc voltage of the converter is desired to be Vo = 220 V. Thus, two dc reference voltages of V_{O1}ref = 320 V and V_{O2}ref = 110 V are chosen for the converter. The converter output voltages are illustrated in fig 11

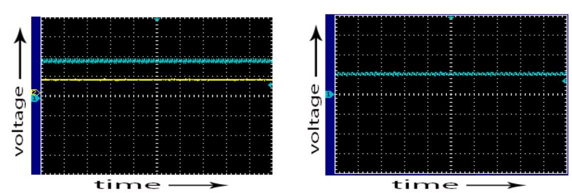

Fig. 11. Converter output voltage in dc-dc mode

In dc ac mode, the output voltage of the converter is desired to be a 50 Hz sinusoidal waveform with an rms-value equals to the load voltage in the dc-dc mode V_{rms} = 230 V (V_m = 325 V). Thus, the parameters of the two output dc-biased sinusoidal voltages V_{O1} and V_{O2} are chosen to be V_m=2 = 160 V and V_{dc} = 180 V.

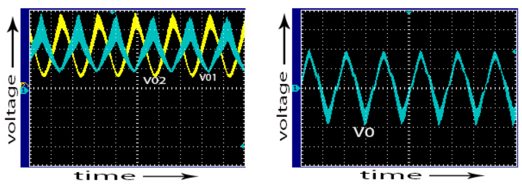

Fig. 12. Converter output voltage in dc-ac mode

VII. CONCLUSION

A multi input boost converter with a single stage power conversion is introduced in this paper. The proposed converter works in both dc-dc mode and in dc-ac mode. Lesser number of power switches and active components are used in this topology. Output filter is not needed in this proposed topology. Closed loop voltage control is implemented in the converter control strategy in order to obtain constant output voltage. Simulation results shows that the converter output voltage has low ripples.

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