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Dual Input Boost Converter for Renewable Energy Applications

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ABSTRACT

DC-DC converters are drawing its wide importance in renewable energy applications due to the draining conventional fossil fuels. The multiple sources are commonly used with renewable power solutions to provide uninterrupted supply. A boost converter topology with dual input is realized here to provide single output. The circuit is capable of converting DC from multiple renewable energy sources into a single constant output voltage. The converter circuit presented here can do step-down, step-up or both operations with multiple input at different voltage levels. Generally output from renewable energy sources vary with environmental conditions. A constant and steady output voltage is generated by coupling different renewable inputs to power electronic converters. A type III compensator is designed and operated with the transfer function model of the dual input boost converter to regulate output, which is mandatory at consumer end. As an alternative of using individual converter for each renewable source, a single converter is used with multiple inputs, which will reduce complexity, cost and improve quality of power. The closed loop dual input single output boost topology is validated through simulation in non-ideal conditions to ensure tight regulation and improved transient performance.

Keywords: *Multiple input, Input voltage addition, Regulated voltage, Single output*

1. INTRODUCTION

Now a days solar energy is widely used as one of the major renewable energy source in power systems. The power can also be produced from other renewable sources like viz. wind, geothermal heat, tide. The power generations [1,2]along with DC-DC conversions are facing major issues of multiple input, multiple output, power quality, regulation and transients. One of major research focus is the synchronization of multiple renewable sources and to yield single output by utilizing DC-DC converter.

In domestic applications AC power is converted to DC and used. The applications of mobile phones, televisions and computers require DC voltage. The multiple input renewable sources can be utilized to avoid power interruption for essential loads. Solar and wind power [3, 4] are utilized to provide regulated output voltage. Due to usage of multiple renewable energy source inputs the intermittency can be compensated. Favorable input sources can be selected using a number of switches. Also due to a variety of power electronic components used, the complexity of this device can be decreased and there by lessening the cost.

The converter consists of a number of inputs with different V-I characteristics that gives a common output through a DC converter. The design in [5] replaces the individual input DC converters into multiple input single converters, which reduces the complexity and improves the compactness and efficiency. During the DC to DC conversion, the voltage level maybe increased or decreased and the feature is useful in electric vehicles, portable chargers and other appliances[6].

Large number of investigations is carried out to develop single output from multiple renewable source input to energize power to local communities. The detailed analysis, synthesis and the extension of application to micro grid with DC power is discussed in [7]. The generated power is converted to provide reliable operation with critical and dynamic loads. Multiple output voltage with fly back transformer [8], boost operation [9] develop the output voltage with tight regulation. The converter output voltages are controlled independently without affecting the other magnitudes. The switched capacitor in boost converter [10] improves the voltage gain with multiple ports to provide voltages to more than single loads. The converter with multiple outputs yields step-down and step-up operation with integrated circuit topologies [11]. Also the diode clamped circuits with DC-DC converter [12] generates different voltages at the output. The additional circuitry in the converters to develop multiple outputs reduces the reliability and increases the losses. The analysis of multilevel converter [13] to develop output with reduced steady state error provides modular feature. The number of levels can be increased by inserting modular circuits are major advantage in the paper. The step-down converter to use more number sources is elaborated [14] and performance is analyzed. The converter improves the regulation, transient and dynamic performances.

The converter topology proposed here has the ability of energy diversification from different sources, which are connected series and have the flexibility for control of individual magnitudes of voltage on input. The proposed dual input single output converter can drive the load from each source individually or from adding the magnitudes of all sources. A type III compensator is developed and used in the feedback circuit. The proposed converter is validated through simulation.

The working of the proposed converter is discussed in section II and also the design of components is mentioned. The modeling and design of type III compensator are illustrated in section III. The simulation results and conclusion are respectively discussed in sections IV and V.

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2. PROPOSED DUAL INPUT SINGLE OUTPUT BOOST CONVERTER TOPOLOGY

The block diagram of the proposed converter is shown in Fig.1.

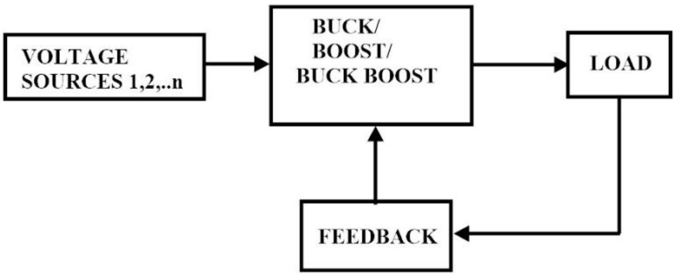

Fig. 1. *Topological structure of the proposed converter with multiple input sources*

The number of different type of renewable energy sources connected in series and which is connected to DC/DC converter. The intermediate converter modifies the source voltage as required for the load. The multiple input sources connected in series is controlled by switches and diodes. The energy storage element inductor in the converter must be properly designed to transfer requisite amount of power. In this circuit topology the various renewable energy sources can be solar, wind, fuel cell etc..

The circuit of proposed topology of dual input single output converter is shown in Fig. 2.

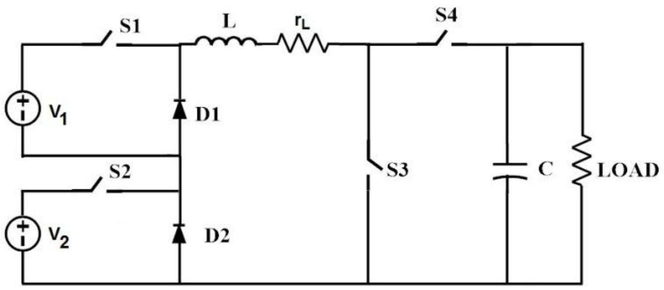

Fig. 2.*Basic circuit schematic of the proposed dual input converter topology*

In this paper two input sources represented as V_1 and V_2.Switches S_1 and S_2 are used to connect the sources to converter. The diodes operate when switches are in OFF position and act as bypass paths. The output voltage is controlled by the switches S_3 and S_4 to get buck, boost or buck boost mode of operation. The output voltage equations for the three modes are derived by volt-sec balance of inductor at different states of four switches. The states of switches, output voltage equation with the three modes of operation of the converter are tabulated in the Table I. In the table the input, output voltage, duty ratio and devices operating are given in t_{on} and t_{off} intervals. The table indicates the expression for buck, boost and buck boost modes by using the same converter topology.

3. PHASE SHIFTED PWM SWITCHING SCHEME

TABLE I

DERIVED OUTPUT VOLTAGE EQUATION OF THE DUAL INPUT CONVERTER AT DIFFERENT MODES WITH INPUTVOLTAGES V_1 AND V_2

Mode	Output voltage	Devices active during t_{on}	Devices active during t_{off}
buck	$v_o=v_1d_1+v_2d_2$	S_1,S_2, S_4	D_1,D_2, S_4
buck-boost	$v0 = \frac{v1d1 + v2d2}{1 - d1 - d2 + d12}$	S_1,S_2, S_3	D_1,D_2, S_4
boost	$v0 = \frac{v1d1 + v2d2}{1 - d3}$	S_1,S_2, S_3	S_1/S_2, S_4

The phase shifted PWM logic is generated for boost mode with d_1 ,d_2 and d_3 as duty ratios for switches S_1, S_2 and S_3 respectively. The switch S_4 is operated in complementary with S_4. The developed PWM technique for activating the switches is shown in the Fig. 3.

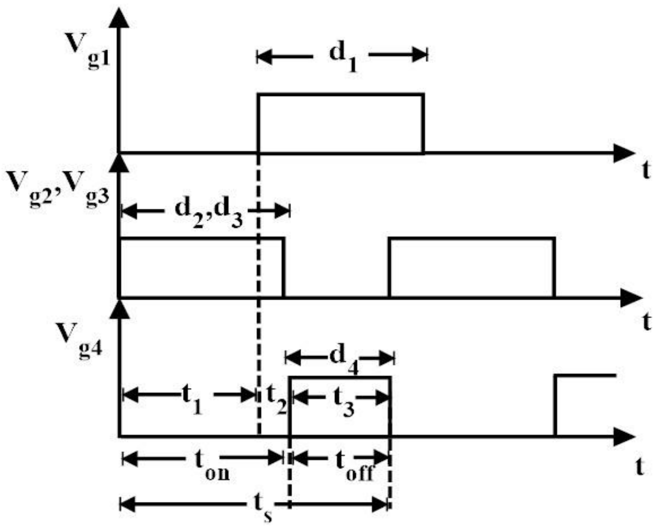

Fig. 3. *PWM scheme for activating switches in boost mode*

The time duration of working states can be defined as

$$t_1 = (d_2 - d_{12})T_S \quad (1)$$

$$t_2 = (d_{12})T_S \quad (2)$$

$$t_3 = (d_1 - d_{12})T_S \quad (3)$$

Where T_s is the switching period.

There are mainly three states of operation for boost converter as indicated in Table II. The charging and discharging of inductor is shown in the table along with connected sources through different states of switches. During the periods of t_1 and t_2 (state-1 and state-2 respectively) the inductor stores energy by charging with sources V_1 and V_2 .During the period t_3 (state-3), the inductor transfers its energy to the load along with the magnitude of active voltage source V_1 Hence this mode provides boost operation with three states.

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TABLE II
DIFFERENT WORKING STATES OF PROPOSED DUAL INPUT BOOST CONVERTER($V_2 > V_1$)

working state	supplying source	ON state switch	inductor voltage	inductor status
state-1	V_2	$S_2$and S_3	V_2	charging
state-2	$V_1$and V_2	S_1, $S_2$and S_3	V_1+ V_2	charging
state-3	V_1	$S_1$and S_4	V_1	discharging

4. ANALYSIS AND DESIGN OF DUAL INPUT CONVERTER BOOST MODE

The circuit is analyzed in boost mode with different states in continuous conduction mode (CCM).The output voltage is derived by applying volt-sec balance of inductor with states of operation as indicated in the Table II and Fig. 3 . In this design the parasitic resistances are neglected to avoid complex analysis. According to the volt-second balance theory,

$$\int_0^{T_S} V_L\, dt = 0$$

$$V_2 t_1 + (V_1 + V_2)t_2 + (V_1 - V_0)t_3 = 0 \qquad (4)$$

Substituting the equations (1), (2) and (3) in equation (4), and also from the switching diagram Fig. 3, d_1 - d_{12}=1- d_3, the output voltage equation is derived as,

$$V_0 = \frac{V_1 d_1 + V_2 d_2}{1 - d_3} \qquad (5)$$

The design of inductor and capacitor in the converter is worked out with respective expression for ripple values. Current ripple is given by the equation (6)

$$\Delta i = \frac{V_0(1 - d_3)}{L f_s} \qquad (6)$$

Similarly, voltage ripple is given by

$$\Delta v = \frac{V_0 d_3}{RC f_s} \qquad (7)$$

From the above equations (6) and (7) the component values for inductor and capacitor are designed. The designed components are shown in Table III.

TABLE III
DESIGNED VALUES FOR DUAL INPUT SINGLE OUTPUT CONVERTER

V_1	V_2	d_1	d_2	L	C	f_S	R
24V	12V	0.6	0.6	2.4mH	40 uF	25kHz	30Ω

5. CLOSED LOOP OPERATION IN BOOST MODE

Since renewable energy sources like solar and wind are used as input, their output voltage varies with environmental conditions. So the output is to be controlled to a constant value. Hence a closed loop feedback circuit shown in Fig. 4 is essential to make the output constant against line and load variations.

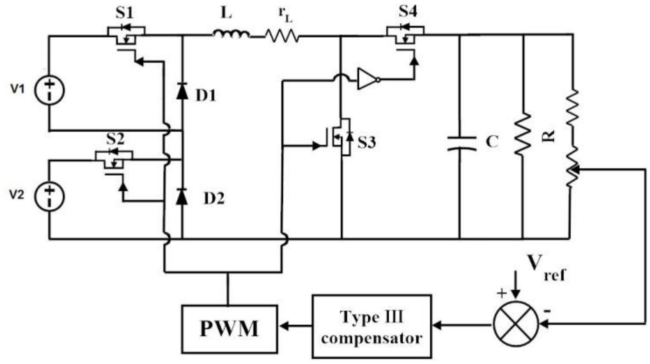

Fig. 4. *closed loop model of multiple input converter*

6. MODELLING AND DESIGN

The dual input single output boost converter is modeled in ideal case using state space analysis method [15].The state matrices and output matrix for different states in boost mode is discussed below in three states with reference to Fig. 2 and 3.

State - 1 ($0<t<t_1$)
In this state the switching position is
S_2andS_3 - ON,
S_1 and S_4 – OFF
The state and output equation are derived as follows

$$\frac{di_l}{dt} = \frac{V_2}{L} \qquad (8)$$

$$\frac{dV_C}{dt} = \frac{-V_C}{RC} \qquad (9)$$

From above equations, the state space equation is

$$\begin{bmatrix} \frac{di_l}{dt} \\ \frac{dV_C}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & \frac{-1}{RC} \end{bmatrix} \begin{bmatrix} i_l \\ V_C \end{bmatrix} + \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

$$V_C = [0\ 1] \begin{bmatrix} i_l \\ V_C \end{bmatrix}$$

The matrices in this state are termed as A_1, B_1 and C_1.

State - 2 ($t_1<t< t_2$)
In this state the switching position is
S_1 ,S_2 and S_3 - ON, S_4 - OFF.
Similar to state -1 the state space equations are

$$\begin{bmatrix} \frac{di_l}{dt} \\ \frac{dV_C}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & \frac{-1}{RC} \end{bmatrix} \begin{bmatrix} i_l \\ V_C \end{bmatrix} + \begin{bmatrix} \frac{1}{L} & \frac{1}{L} \\ 0 & 0 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

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$$V_C = [0\ 1]\begin{bmatrix} i_l \\ V_C \end{bmatrix}$$

The notations A_2 , B_2 and C_2represents the state matrices for this state.

State 3 (t_2<t<t_3)
In this state the switching position is
S_1 and S_4 - ON,
S_3 and S_2- OFF.
The state space and output equations are derived as,

$$\begin{bmatrix} \frac{di_l}{dt} \\ \frac{dV_C}{dt} \end{bmatrix} = \begin{bmatrix} 0 & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{RC} \end{bmatrix}\begin{bmatrix} i_1 \\ V_C \end{bmatrix} + \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & 0 \end{bmatrix}\begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

$$V_C = [0\ 1]\begin{bmatrix} i_l \\ V_C \end{bmatrix}$$

Here A_3, B_3 and C_3 indicate state matrices. Substituting the designed parameters from Table III to the model [15] to obtain the plant transfer function of output voltage to control duty ratio as shown in the equation (10)

$$V_{osds} = \frac{-8.241e^{04}s+6.816e^{06}}{s^2+463s+5.144e^{04}} \quad (10)$$

7. COMPENSATOR DESIGN

From the bode plot 5 (blue color) of the uncompensated system, the phase margin is -89.6°. so the phase margin has to be increased by a compensator. A lead compensator can be used here to improve the phase lag by 45°. A compensator is required here to improve phase phase margin from -89.6° to +50°. The design leads to a type III compensator .The compensator is designed with the values of gain cross over frequency and phase cross over frequency obtained from the bode plot 5. The poles and zeroes are designed [16] to obtain the transfer function of the type III compensator. The designed transfer function is shown in equation (11).

$$tf_{compensator} = \frac{s^2 + 3.741e^{04}s + 3.499e^{08}}{s^3 + 1.055e^{06}s^2 + 2.78e^{11}s} \quad (11)$$

The bode plot of the uncompensated and compensated systems are shown in Fig. 5.Fromthe bode plot (blue color) it can be seen that system is not stable as the phase and gain margin are negative. So a compensator transfer function is designed and multiplied with uncompensated plant transfer function. A type III compensator [16] is used and the bode plot of the compensated system is shown in Fig. 5 with red color.

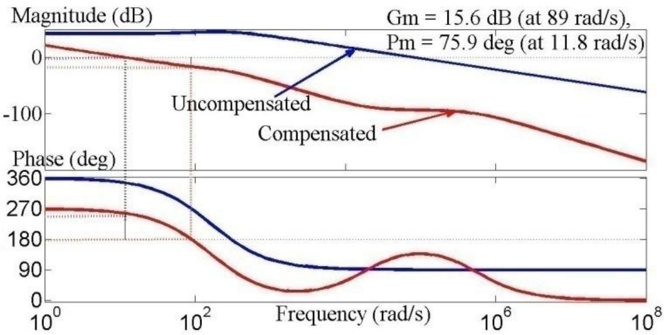

Fig. 5.*bode plot of uncompensated (blue colour) and compensated (red colour)*

8. RESULTS AND DISCUSSIONS

The Dual input single output converter in buck, boost and buck boost are validated by simulation. The results of three modes are discussed in steady state and performances are analyzed. The output voltage is fed back to the error detector as shown in Fig. 4. The reference value is compared and error is processed in type III compensator. The DC signal received from the compensator is compared with the triangular signal and PWM pulses are generated. The component and parameter values for validation of the converter is shown in the Table III.

The simulation result of buck converter is shown in Fig. 6. The waveforms of the two input voltage sources, voltage across inductor, current through inductor and output voltage are shown. The output voltage of buck converter is 13.7V, which mathematically corroborates with the equation mentioned in first row of Table I.As the duty ratios changes output voltage also changes .The output voltage is lesser than the sum of the two input voltage in buck mode at a duty ratio of $d_1 = d_2 = d = 0.4$ as shown in Fig. 6.

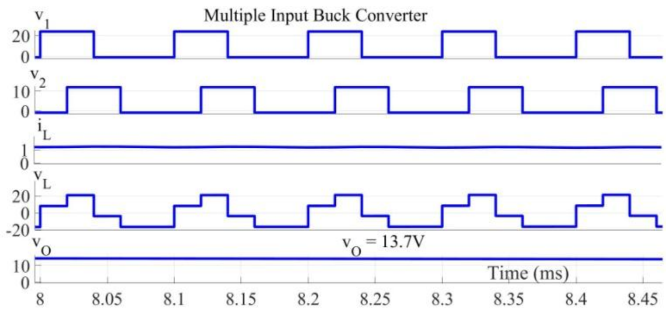

Fig. 6. *Results of Multiple Input Buck Converter: V_1, V_2 - source voltages; I_L - inductor current; V_L - inductor voltage and v_O - output voltage*

The simulation result of buck-boost converter is shown in Fig. 7.With the duty ratio of 0.4, the source voltages V_1 and V_2 are applied in buck boost mode. The inductor current is I_L = 8.4A with a ripple of 0.1A (1.2%). The inductor voltage and output voltage are shown for t_{on} and t_{off} states. The output voltage is 35.3 V, which validates the equation in second row of Table I. The output voltage in buck boost mode is regulated by applying modified switching and controlling duty ratio.

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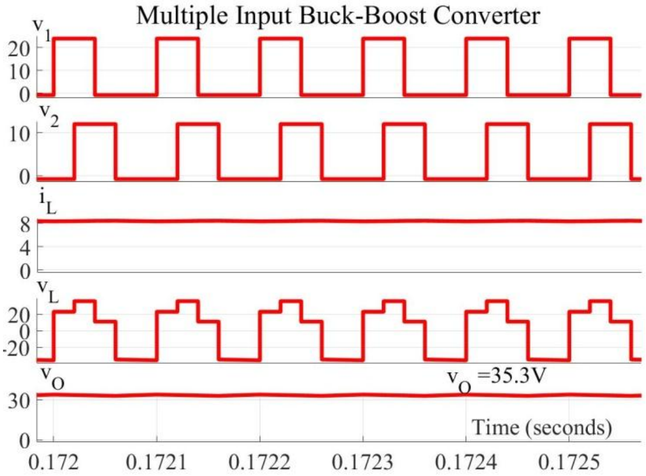

Fig. 7. *Results of Multiple Input Buck-Boost Converter (V_1, V_2 - source voltages; I_L - inductor current; V_L - inductor voltage and v_O - output voltage)*

The dual input single output boost converter with feedback circuit is designed. A compensator is designed to make output voltage constant against line voltage and load current changes. The type III compensator generates DC signal, which is compared with triangular signal to create PWM pulses. The switching scheme is created by using logic gates suitable to operate as shown in Fig. 3 for boost mode. The validation result of dual input single output boost converter is shown in Fig. 8.

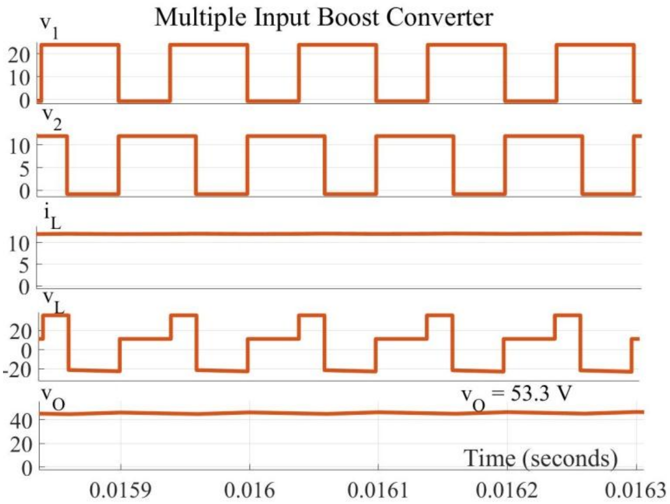

Fig. 8. *Results of Multiple Input Boost Converter : (V_1, V_2 - source voltages; I_L - inductor current; V_L - inductor voltage and v_O - output voltage)*

The waveform of the two input sources V_1 and V_2 across diodes, inductor voltage, inductor current and output voltage are shown. The simulation parameters are according to the Table III (duty ratio are $d_1 = d_2 = d_3 = 0.6$). The output voltage is observed from simulation is 53.3 V and boost action can be controlled by controlling the duty ratio of switch S_3 (d_3) with specified PWM switching scheme.

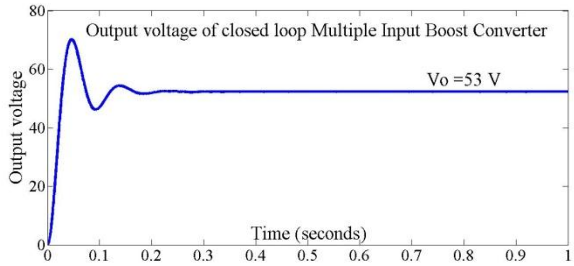

Fig. 9. *simulation result of closed loop control of proposed dual input single output boost converter*

The closed loop control of the converter in boost mode is carried out with a reference voltage of 53 V. The output voltage of the dual input converter in boost mode with the type III compensator is given in Fig. 9.The output voltage is obtained as 53V as the set value with less overshoot. The output voltage obtained from validation corroborates mathematically with the boost mode equation shown in third row of the Table I.

9. CONCLUSION

Multiple input converters are essential when the source voltages are changing due to environmental reasons and other issues. A single output converter with two input sources is proposed in this paper. The converter provides three types of operations as buck, boost and buck boost modes by applying different PWM logic patterns. In each mode the according to switching logic the converter operates in three or four states. In the boost mode the converter has three states and the validated result establishes the output voltage is step-up of input voltage. The converter is modeled using state space analysis and the designed type III compensator is utilized in closed loop control. The proposed simulation shows the output voltage settles fast with low overshoot. The multiple renewable energy sources are necessary to provide uninterruptable power to domestic loads. The proposed multiple input converter has less number of components in comparison with similar type of converters. The steady state and dynamic stability ensures the proposed converter suitable for the applications like electric vehicles, embedded systems and medical equipments.

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