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Design and Simulation of Dual Input DC/DC Converter

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Abstract: In this paper a Dual Input DC/DC Converter (DIC) is proposed for Hybridization of renewable and storage energy sources. The converter provides a regulated voltage at the load. The two input sources to the converter may include Photo Voltaic (PV) cell, Fuel cell, Wind source etc. Converter may beoperated in Buck, Boost or Buck-Boost modes. Based on the operating conditions power is delivered to load from thetwo sources either simultaneously or individually.The complete DIC hassmaller size hence overall cost is reduced due to the less number of components. Using MATLAB/Simulink software proposed converter is simulated and performance of the converter is analysed.

Keywords: Dual input DC/DC converter, PV cell, Battery, MATLAB/Simulink.

I. INTRODUCTION

Hybrid energy system (HES) is a growing technology that is capable of meeting future energy needs. HES are sustainable and reliable sources of energy compared to conventional sources. In this system, non-conventional sources and renewable energy sources are interfaced to power the load. HES provides reliable operation, high durability, it is a clean form of energy and gives efficient operation.It also has better power handling capability during steady-state operation and better dynamic response during transients.In HES, an interfacing circuit is used to interface different energy sources of different V-I characteristics and power ratings to meet the load demand [9].

Multiple-input DC/DC converters (MICs) are widely used in interfacing different energy sources. Energy sources like solar panel, wind energy source, fuel cell, ultra capacitor etc. with different V-I characteristic are interfaced using single-input DC/DC converter then their outputs are combined to supply load by connecting single converters in series or parallel [3]. However, such configurations are costlier, bulky and complex in design and also reduce the overall efficiency as well as reliability of the system. Hence, multiple single-input DC/DC converters are used in place of single multiple-input DC/DC converter. MICs are simple and compact in design and less costly. In addition, they provide efficient DCpower distribution at regulated output voltage which increases the reliability of the converter.

Several isolated and non-isolated topologies of MIC have been proposed. The isolated topologies are based on magnetically connected circuit (MCC) and non-isolated topologies are based on electrically connected circuit (ECC). In MCC, for energy transformation from sources to load flux addition along with time domain multiplexing technique is commonly used. The presence of transformer along with additional peripheral circuitry makes MCC complex, bulky, costly and increases dependency on circuit parameters. ECC has modular structure, which reduces cost and absence of transformer makes it attractive and minimizes the issue associated with MCC [1].

The electrically connected MIC topologies combine various input energy sources either in parallel or in series. The major drawback of parallel connected source topologies is that, input source voltages should be asymmetric and only one input source can supply power to the load at a time to avoid power coupling effect. In order to supply power simultaneously, input sources are connected in series.

However, such configurations are costly, bulky and relatively complex in design and reduce overall efficiency as well as reliability of system. Therefore, multiple single-source DC/DC converters have been successfully replaced with a dual input converter (DIC) or multiple input converters (MIC). It offers simple and more compact design and reduces the cost and complexity of the system. In addition efficient DC power distribution and higher degree of flexibility can be achieved [5].

The dual input DC/DC converter has the ability to transfer power from different sources individually or simultaneously either in series or parallel combination of sources. It has capability of producing regulated dc bus voltage, which is subsequently interfaced with electric load through front end converter with improved dynamic response. The designed converter is proficient in energy diversification from different sources but it also offers power flow control among both the source and load. In

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addition, proposed topology can be operated in buck, buck-boost or boost modes. It offers bidirectional flow of power, compact design and flexibility in control as well as selection of input source voltage magnitude (i.e. symmetric or asymmetric).

II. CONVERTER TOPOLOGY AND WORKING

A. Converter Topology

Basic structure of Dual input DC/DC buck-boost converter is as shown in Fig. 1. In this topology, switches T_1 and T_2 are bidirectional conduction and bidirectional blocking (BCBB) in nature. The diodes D1 and D2 offers freewheeling of load current. This structure consists of switches that are connected with two input sources which are in turn connected to load through basic converter circuit, which consists of two switches T_3 and T_4 along with inductor and capacitor for buck-boost operation.

Combination of switches T_1, T_2 chooses the mode of operation of this buck-boost converter. Buck-boost capability is given by switch T_3, while bidirectional operation to the DC/DC converter is provided by switch T_4. It has two input dc voltage sources namely E_1 and E_2, where Eo is the output voltage and Io is the load current. This converter has four modes of operation.

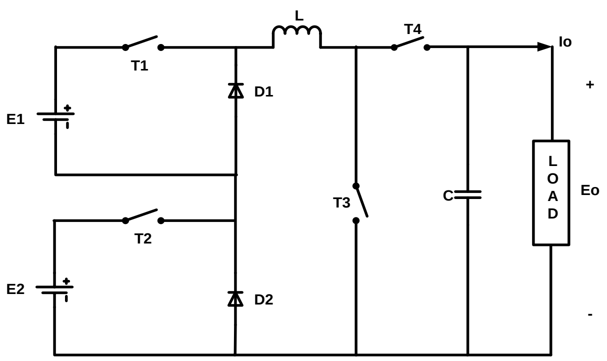

Fig. 1: Basic structure of Dual input DC/DC converter

B. Working

There are four operating states; working of each state is as stated in TABLE I below;

TABLE I: WORKING STATES

Working State	Source supplying	Active switch	Inductor voltage	Inductor status
State 1	E_1	T_1 and T_3	E_1	Charging
State 2	E_2	T_2 and T_3	E_2	Charging
State 3	E_1 and E_2	T_1, T_2 and T_3	E_1+E_2	Charging
State 4	None	T_4	E_o	Discharging

III. STEADY STATE ANALYSIS

Depending on the switching strategy of switches various operation states are obtained. Based on the power utilization of sources, switching scheme is selected. There are three ways for generating gate pulsenamely; a) Rising edge synchronization, b) Falling edge synchronization and c) Intermediate synchronization of gate pulses.

The different operating time over single switching cycle in terms of duty cycle can be defined as;

$$t_1 = (d_1 - d_{12})\ Ts \quad (1)$$

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

$$t_3 = (d_2 - d_{12})\ Ts \quad (3)$$

$$t_4 = (1 - d_1 - d_2 + d_{12})\ Ts \ (4)$$

Where, d_1 and d_2 are the duty ratio of switches T_1 and T_2 respectively.

Intermediate synchronization switching sequence of fixed frequency is used for generating gate pulse.For the analysis it is assumed that switching loss is zero and inductor and capacitor drops are negligible. Voltage across the load is maintained constant due to the large capacitor present. From the Fig.2, for the time t1, E1 supplies power to load, for t2 seconds sources are connected in series,for time t3, E2 supplies, for the period t4 both the sources are inactive.

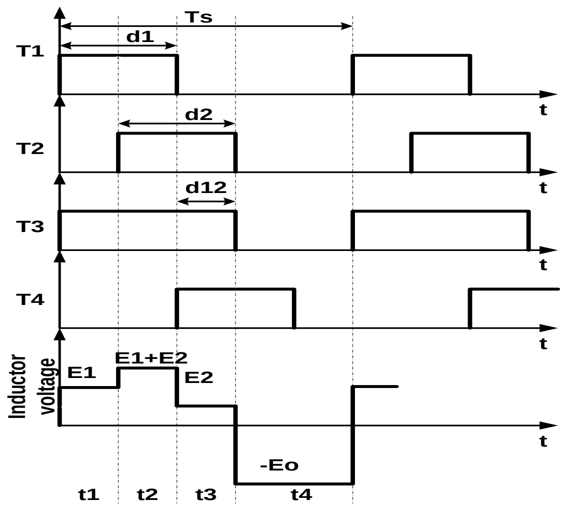

Fig. 2: Analytic analysis of inductor voltage waveform

Therefore inductor voltage, when switch T1 is conducting for time duration t_1

$$e_L = E_1 * t_1 \quad (5)$$

Inductor voltage when switch Ts is conducting for time duration t2

$$e_L = (E_1+E_2) * t_2 \quad (6)$$

When switch T2 is conducting for time duration t_3

$$e_L = E_2 * t_3 \quad (7)$$

And, When all the switch are OFF for time $T=t_4$

$$e_L = (-E_0)\ T_{off} \quad (8)$$

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In steady state operation, by volt-second balance equation, the average inductor voltage should be zero.Therefore,

$$\text{Average inductor voltage} = \int_0^{Ts} e_L = 0 \quad (9)$$

Here, e_L = Voltage across inductor and Ts is the switching period of one cycle;

$$T_s=(T_{on}+T_{off}) \quad (10)$$

Therefore,

$$\int_0^{T_s} e_L = (E_1 * t_1) + ((E_1+E_2)*t_2) + (E_2 * t_3) + (-E_0)T_{off} = 0 \quad (11)$$

Simplifying the equation (11) we get input-output voltage relationship as,

$$E_0 = \frac{E_1 d_1 + E_2 d_2}{(1 - d_1 - d_2 + d_{12})} \quad (12)$$

Where $d_1 = \frac{t_1+t_2}{T_s}$, $d_2 = \frac{t_2+t_3}{T_s}$, $d_{12} = \frac{t_2}{T_s}$.

Inductor current ripple (Δi) and capacitor ripple voltage (Δv) can be used to determine the value of inductance and capacitance used in the system, respectively.

$$\Delta i = \frac{E_o\{1 - d_1 - d_2 + d_{12}\}}{L * f_s} (13)$$

$$\Delta v = \frac{E_o(d_1 + d_2 - d_{12})}{R * C * f_s} (14)$$

IV. INPUT SOURCES

Dual Input Converter is powered using solar energy source and battery.

C. PV Cell

A solar cell is basically a p-n semiconductor junction. When light falls on its surface a dc current is generated. With the change in solar irradiance the produced current varies.

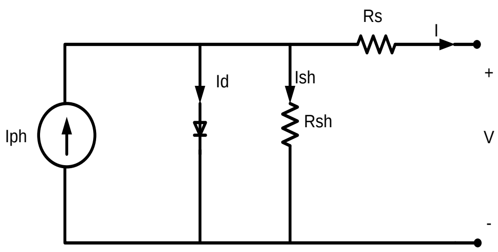

Fig. 3: Equivalent circuit of solar cell

The current-voltage characteristic equation of a solar cell is given as

$$I = I_{ph} - I_0 \left[e^{\frac{q(V+I*Rs)}{n*k*T}} - 1\right] - \frac{V+I*Rs}{Rsh} (15)$$

Where,

I_{ph} is the Light-generated current or photocurrent, I_0 is diode reverse saturation current (A), q is the electron charge (1.602×10^{-19} C), K is the Boltzmann's constant (1.381×10^{-23} J/K), T is the junction temperature in Kelvin (K), R_s is the series resistance,R_p is the parallel resistance.

The photocurrent mainly depends on the solar insolation and cell's working temperature, which is described as

$$Iph = [\, Iph,ref + KI\,(T - Tn)\,]\, \boldsymbol{\alpha} (16)$$

Where,

KI is the cell's short circuit temperature coefficient, Tn is Cell's reference temperature, **α**is the solar insolation in kw/m^2.

The parameters of solar array (SLP010 at 25°C and 1000W/m^2) were chosen for modelling and simulation using MATLAB/Simulink are given in TABLE II.

TABLE II: PARAMETERS OF SOLAR PANEL

At temperature	25°C
Open circuit voltage, V_{OC}	20.6 V
Short circuit current, I_{SC}	0.69 A
Voltage at maximum power, V_{mp}	17.3 V
Current at maximum power, I_{mp}	0.58A
Maximum power, P_m	10 W
No. of cells in parallel, N_p	1
No. of cells in series, N_s	36

D. Battery

Battery consists of one or more electro-chemical cells. It is provided with external connections for powering external devices. Cathode is positive terminal and anode is negative terminal. The negative terminal will provide power to external devices.

V. SIMULATION RESULTS

Dual Input DC/DC Converter is simulated using MATLAB/Simulink to verify the theoretical results. It has 4 modes of operation.

TABLE III: SIMULATION PARAMETERS

Parameter	**Value**
E_1	12 V
E_2	6 V
R	10 **Ω**
C	240 **μ**F
L	634.36**μ**H
Current ripple	5%
f_s(switching frequency)	50 kHz
Duty ratio (series) d_1, d_2, d_{12}	0.4, 0.4, 0.2,

E. Series mode of operation

In this mode of operation switches T_1 and T_2 are operated in an intermediate synchronizing manner. Inductor voltage changes from E_1, E_1+E_2 and E_2 consequently due to the series combination of sources. Fig. 6 shows linear rise in inductor current in three steps of different slope and inductor voltage during the series operation. Therefore, it can be concluded from inductor voltage and current

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waveform that by controlling the duty cycle of each switch of corresponding source controlled charging and discharging of inductor can be achieved. Hence regulated output voltage can be obtained by controlled power diversification from each source. The loadcurrent and load voltage waveforms for series combination of sources are as shown in Fig. 7.

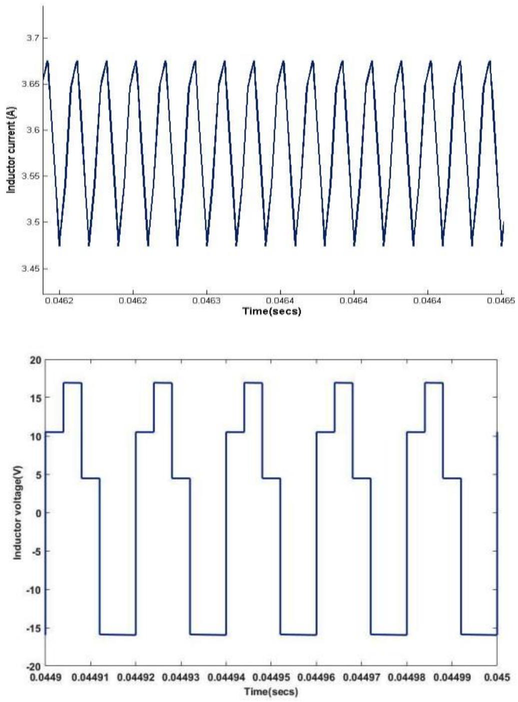

Fig. 6: Inductor current and voltage waveform

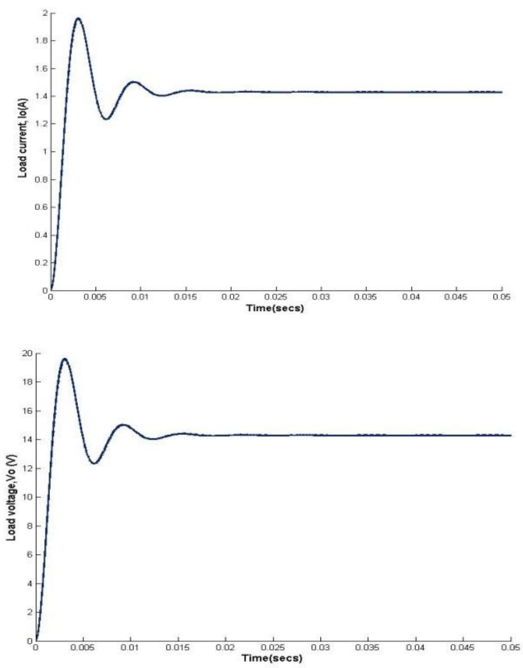

Fig. 7:Load current and loadvoltage waveform

VI. CONCLUSION

A Dual Input DC/DC converter is presented in this paper. The converter provides regulated load voltage. The proposed converter is simulated for Buck-Boost mode of operation using MATLAB/ Simulink.It can be seen that power can be delivered to load from two sources either simultaneously or individually.

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