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Two Input Buck-Buck PWM DC-DC Converter fed Separately Excited DC motor: Design, Switch Realization and Simulation

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Abstract : The energy storage unit is one of the most important aspects in structure of hybrid electric vehicle and photo voltaic systems. Two input DC-DC converters used in such energy storage unit to improve efficiency, performance and also to reduce cost, component count. In this paper, proposed topologies of two input Buck-Buck dc-dc converter is designed through derivation by using H-Bridge cells as building block. Switch realization of the proposed converters were obtained with their voltage transfer ratios. This proposed converter is connected to Separately excited DC motor. The performances of the Buck-Buck converter fed separately excited DC motor is simulated using MATLAB/simulink .The output results were Compared and verified with theoretical Results.
Keywords : Buck-Buck dc-dc converter, Voltage transfer ratio & separately excited DC motor,MATLAB/simulink.

1. Introduction

In hybrid electric vehicles, photo voltaic systems, fuel cell systems the instantaneous power of input and output of power electronic converters are not same. However, the high specific power of ultra capacitors is the major reason of them being used as intermediate energy storage unit during acceleration, hill climbing, and regenerative braking. Energy storage system consists of battery or ultra capacitors. There are several different types of dc-dc converter belongs to buck, boost and buck-boost topologies have been developed to meet variety of application specific demands [1][3]. The conventional approach of connecting the energy storage unit is by using independent converter. The independent converter with energy sources can be connected either in series or parallel in multiple input converters. If the sources are connected in series it has to conduct the same current and if the converters are connected in parallel it should have same voltage levels. Both the conditions are practically undesirable. Instead of this multi input converter is used to connect multi sources in a single system to give required load demand and also to improve efficiency[6], reduce overall cost, reduce component count, more stability and simple control. In this paper, only two inputs are used named as two input dc-dc buck-buck converter. The fig.1 shows the block diagram of two input dc-dc converter fed separately excited DC Motor. Multi input converters can be constructed using either flux additivity or by combining the structure of the converters. There is not a systematic approach to design multi input converters through derivation[5].Design of new converters from existing converters is complicated task. Hence in this paper, a systematic approach to design a proposed two input converter through derivation by using H-bridge cells as building block.

The Fig.1 shows the block diagram of two input dc-dc converter fed separately excited dc motor. In this paper, design of converters using H-bridge cells along with various modes of operation is presented in part II. Realization of switches in proposed converter is presented in part III.

Voltage transfer ratios of proposed converter are obtained in part IV. Theory and calculation of parameters of separately excited dc motor is presented in part V.

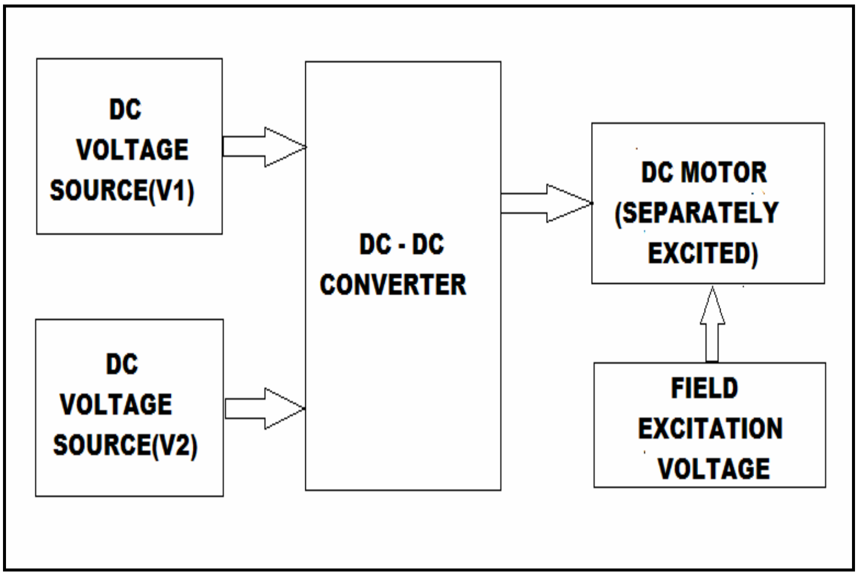

Fig.1.Block diagram of two input Buck-Buck dc-dc converter fed separately excited DC Motor.

Simulation model and results to compare the operating characteristics of the converter are presented in part VI.

2. Design of Two Input Dc-Dc Converter using H-Bridge Cells Fed Separately Excited Dc Motor

An H-bridge cell consists of four switches and one voltage source is shown in fig.2. Switches S_1,S_2,S_3,S_4 The voltage source can be battery, ultra capacitor, PV system, or fuel cell system. The output voltage is equal to +V when the switches S_1 and S_3 are turned on. The output voltage is equal to -V, when the switches S_2 and S_4 are turned on. The voltage sources used inthis circuit can be battery, Ultra capacitor, Photovoltaic system or fuel system. In this paper, the voltage sources are simply made as DC voltage sources(V1,V2).

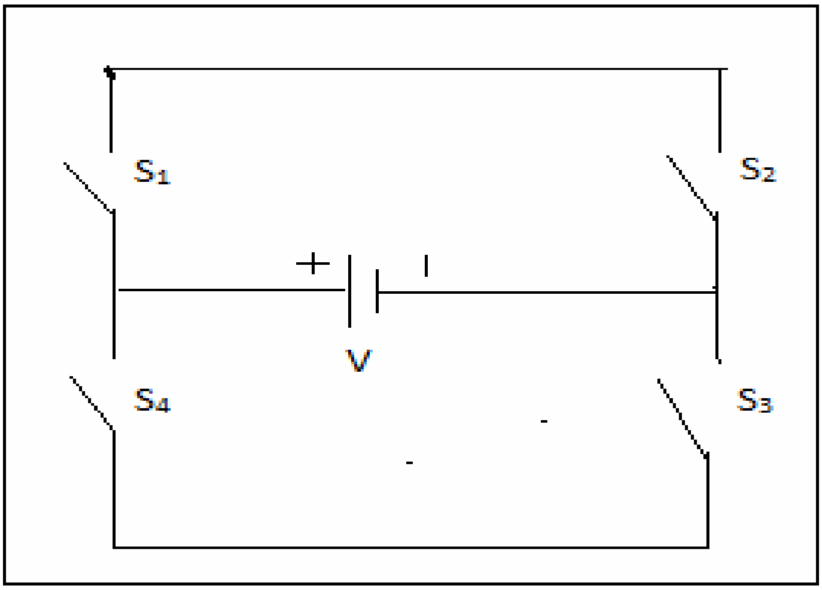

Fig.2 .Circuit diagram of an H-Bridge cell.

The first stage of two input buck-buck dc-dc converter is shown in fig.3. It is constructed by using the two cascaded H-bridge cells in series connection. In Two input converters it uses only one inductor.

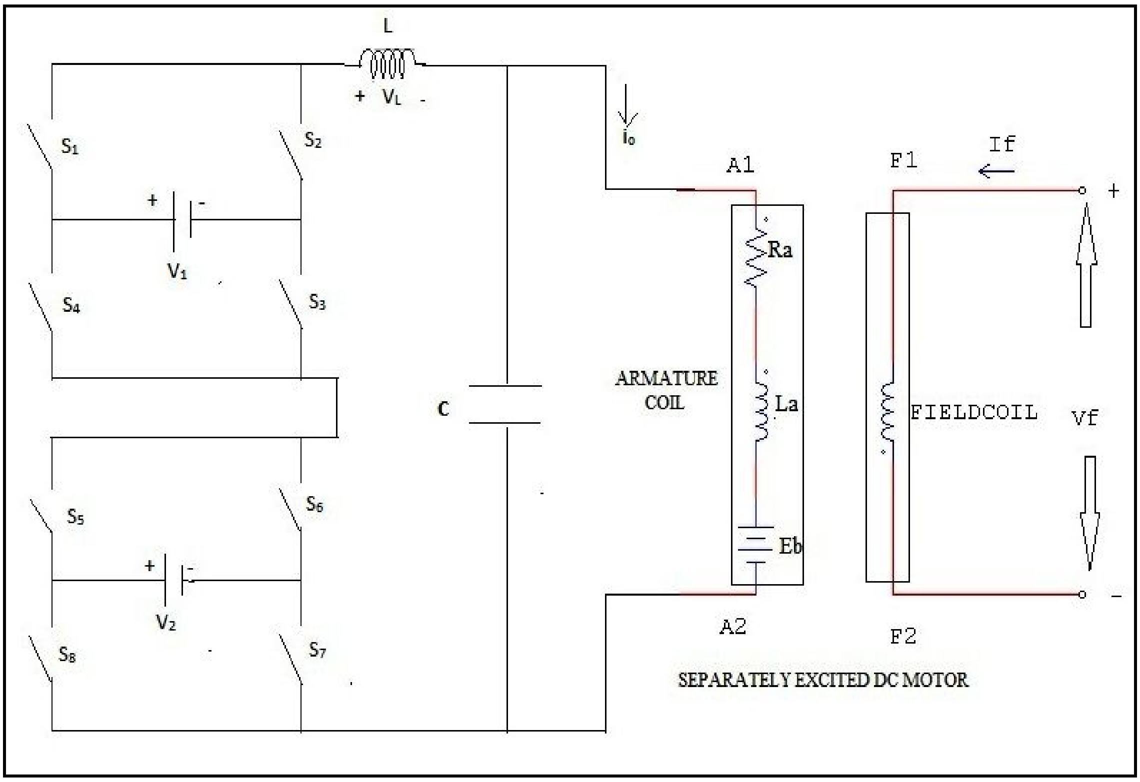

Fig.3 First stage of two input Buck-Buck dc-dc converter fed separately excited DC Motor using H-bridge Cells

According to the modes of operation given in table. I and Switches are replaced by switch or diode or either short circuited or open circuited [8]. The repeated switches in the four modes of operation are replaced by short circuited in the derived circuit the switches which are not used in four modes are replaced by open circuited. Voltage drop across the inductor depends on the switches which are in ON condition. The final stage of two input buck-buck dc-dc converter is shown in fig.4.

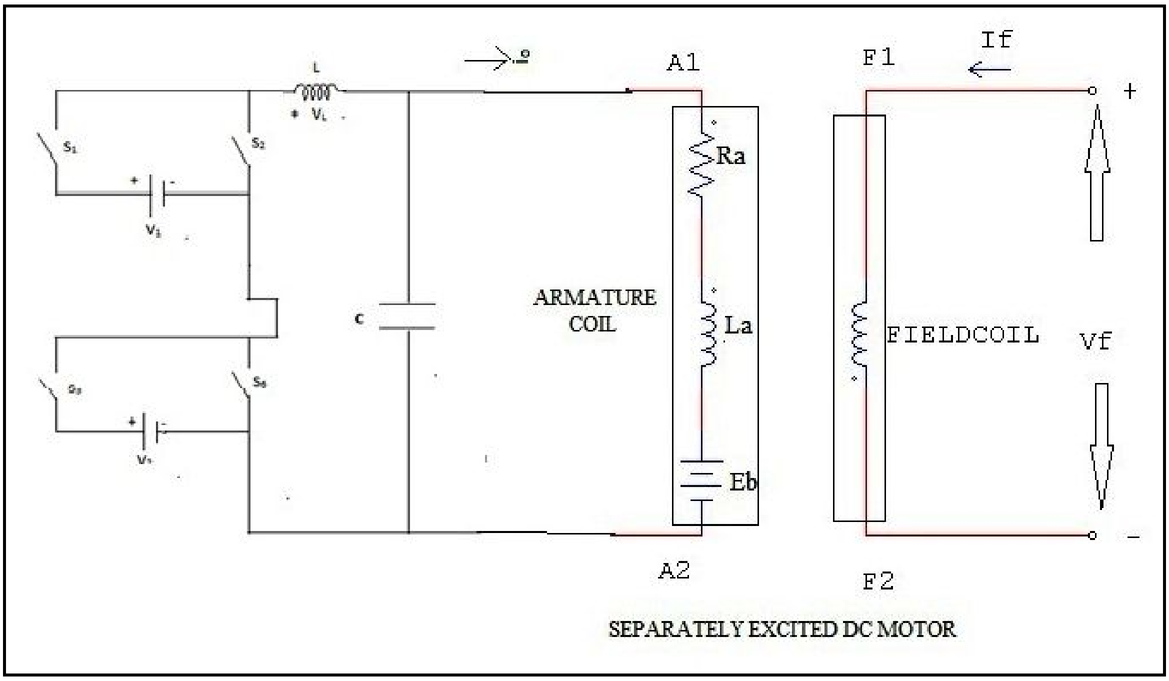

Fig.4: Final stage of two input Buck-Buck dc-dc converter fed separately excited DC Motor using H-bridge Cells

The basic idea in synthesis of two input dc-dc converters is to bring a new switching circuit which can able to connect or disconnect two input sources such as battery or photovoltaic system to charge an energy storage element individually or simultaneously[6]. Inductor is used as an energy storage element in this circuit.

Table.1.Voltage across the Inductor used in the Converter

Mode	ON condition switches	V_L	Description
I	$S_1, S_3 S_6$ &S_7	V_1-V_0	V_1 gives energy to the inductor
II	S_2, S_3,S_5 &S_7	V_2-V_0	V_2 gives energy to the inductor
III	S_2, S_3,S_6 &S_7	-V_0	Inductor dissipates Energy
IV	S_1, S_3,S_5 &S_7	V_1+V_2-V_0	V_1 &V_2 gives energy to the inductor

Considering the two input buck-buck dc-dc converter, In mode I the V_1 supplies the energy to the inductor. In mode II V_2 supplies the energy to the inductor, In mode III the inductor depletes the energy to the load[14], In mode IV the V_1 and V_2 supplies the energy to the inductor. The final designed circuit has only four switches. The remaining switches are eliminated[7].

In this paper until the power sources V_1 and V_2 are assumed to be power sources, which need not be charged. However if one of the sources is an energy storage unit, then it needs to be charged regularly.For this purpose, the converter needs to have bidirectional power capability this circuit can be used for bidirectional dc-dc converter by connecting diode in parallel connection [2]. The final designed circuit has only four switches from the above designed circuit one can conclude that the numbers of switches are reduced and the circuit has only one inductor [9]-[10].The remaining switches are eliminated.

3. Realization of Switches In Two Input Buck-Buck DC-DC Converter Fed Separately Excited Dc Motor

The switches are replaced by diodes, MOSFET device for the designed dc-dc converter. Considering the buck-buck dc-dc converter that in unidirectional power flow, switches S_4 and S_8 are eliminated from the circuit since it is not used in any mode. S_3 and S_7 are always on so they can be short circuited[14].

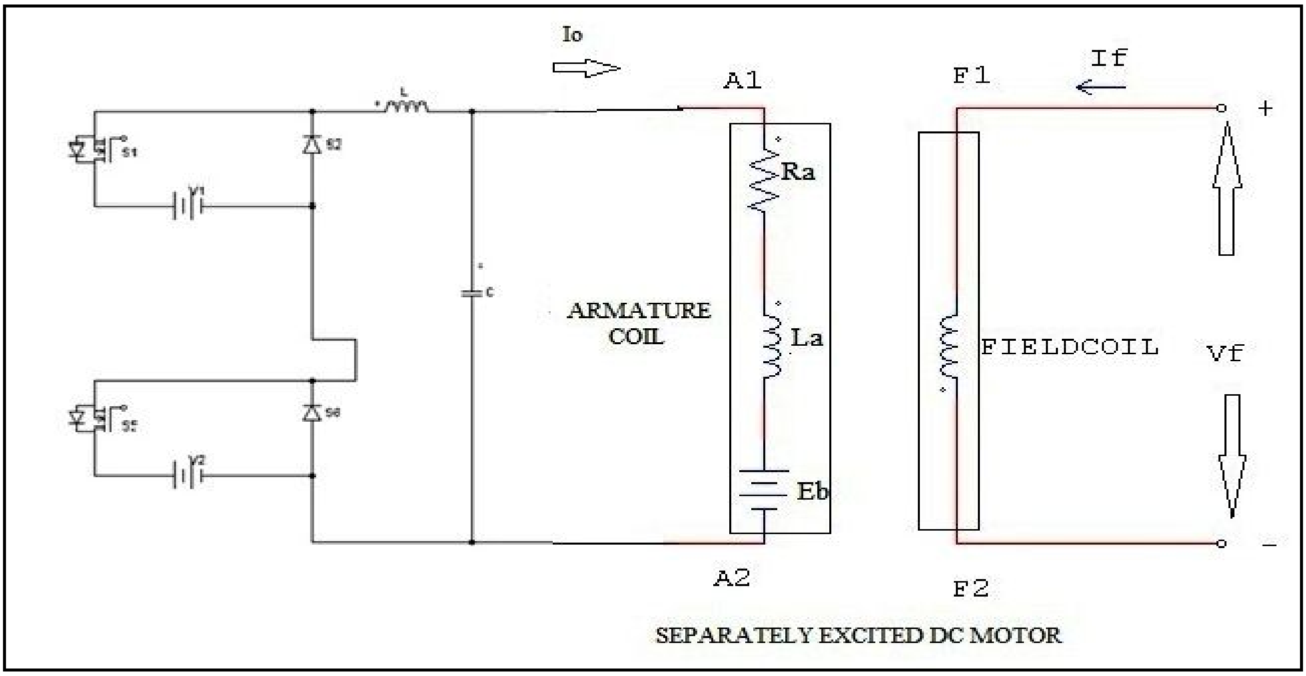

Fig.5: Designed circuit diagram of two input Buck-Buck dc-dc converter fed separately excited DC Motor using H-bridge Cells

If the power flow through the inductor is considered to be Unidirectional. i_L is always positive.

As switch S_2 conducts positive current and opposes negative current and positive voltage it can be replaced by a MOSFET. The MOSFET can be replaced by any other static switches depending upon their current, voltage and power rating. The final designed two input buck-buck dc-dc converter[4] is replaced by MOSFET and diodes is shown in fig.5.In this analysis, similar to the conventional single input dc-dc converter parasitic components will be neglected.

In the application of hybrid electric vehicle and photo voltaic system, V_1 or V_2 is a battery source. Similarly considering the two input buck-buck boost dc-dc converter S_3 always conducts so it can be replaced by short circuited S_4 and S_8 is eliminated[11]-[12] since it is not used in any mode.

4. Voltage Transfer Ratio of the Proposed Two Input Buck-Buck DC-DC Converter

The voltage transfer ratio gives the relation between the input voltages, output voltage, corresponding to their duty ratios.The switching pattern has four modes [9]. The Table.I shows the voltage across inductor for different modes of operation of the converter. Based on the table.1 The fig.6.shows the switching patterns of switches S_1 and S_5 .

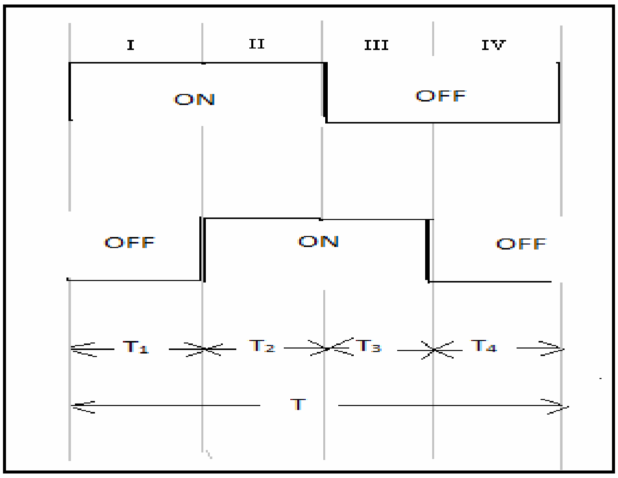

Fig.6 :Switching pattern of two input Buck-Buck dc-dc converter fed separately excited DC Motor using H-bridge Cells.

Based on the switching pattern,the following equations can be written as,Let

$T_1+T_2=d_1*T$ (1)

$T_1+T_3=d_2*T$ (2)

$T_1+T_2+T_3+T_4=T$ (3)

Where,

T is the total time period of the switching patterns of S_1 and S_5 and

d_1 and d_2 are the duty cycles of the switches S_1 and S_5 respectively.

Voltage second balance equation of the inductor is given by

$T_1*(V_1-V_0) +T_2*(V_1+V_2+V_0) +T_3*(V_2-V_0) +T_4*(-V_0) =0$ (4)

By combining the (1) (2) and (4),which gives the voltage transfer ratio of the two input buck-buck dc-dc converter fed separately excited DC Motor using H-bridge cells given in equation(5).

$V_0 = d_1 * V_1 + d_2 * V_2$ (5)

Where,

Vo is the Output voltage of the convereter

V_1, V_2 are the Input voltage sources.

5. Separately Excited DC Motor

A DC machine is an Electromechanical energy conversion device that works on the principle of electromagnetic induction. A DC machine mainly consists of an armature, Field winding, Commutator, and Brush gear. Armature is the rotating part of a DC machine which rotates in the magnetic field. It consists of core and windings, on the core, and is separated by a small distance from the field poles in order to avoid any rubbing inside the machine. The field windings are used for generating uniform magnetic field in which the armature rotates.The DC motors are very versatile in that they provide a smooth speed control over a wide range. They have been very widely used in the industry as variable speed drives. The main disadvantage of these motors is the presence of a mechanical commutator which limits the maximum power rating and the speed.

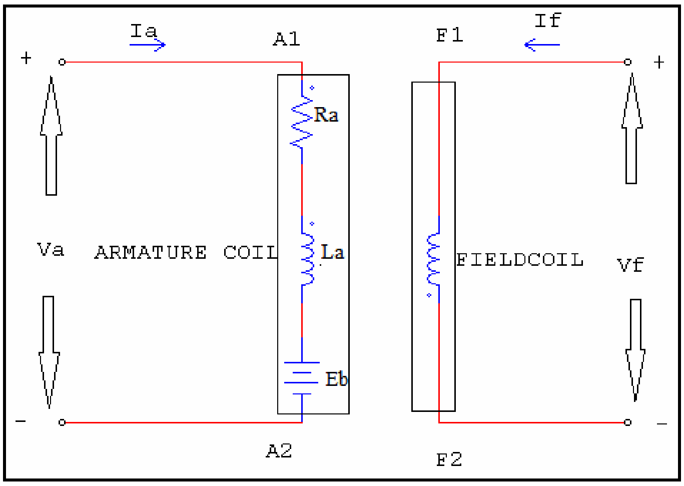

Fig.7: Equivalent Circuit of Separately excited DC Motor

When DC Voltage is applied to the armature of a DC motor with its field excited by DC source.a torque is developed and the armature rotates, It accelerates to a speed at which the emf induced in the armature conductors balances the applied voltage and the following equations is satisfied[16].

$Va = IaRa + E_b$ (6)

$E_b = \frac{\phi Z N}{60} \frac{2P}{2a} V$ (7)

where,

ϕ is flux per pole

Z is number of armature conductors

N is speed in rpm

2P is the number of poles

2a is number of parallel paths in the armature

For a given machine

$E_b = K_e\phi N = K_a\phi\omega$ (8)

where,

$\omega = 2\Pi n$

$Ke = \frac{z \times 2p}{z a}$

$Ka = \frac{Ke}{2\Pi}$

The torque developed by the armature is given by

$T_d = \frac{1}{2\Pi}\frac{2p\phi Ia}{2a} \times ZN = Ka\phi Ia$ (9)

K_a is called armature constant of the motor

Using equation (7) and (8) gives speed(N) of the motor,

$N = \frac{Va - Ia\ ra}{Ke\phi}$ (10)

In a separately excited motor ϕ can be assumed to be constant at a given field current when armature reaction is neglected. The speed of a dc motor can be varied by changing the value of (Va-Ia × ra).This is achieved by varying the value of applied voltage to the armature or by inserting an extra resistance in series with the armature.

6. Simulation Model and Results

The simulation model and the output results are verified using MATLAB/simulink. The simulation models of buck-buck converters separately excited DC Motor using MATLAB/simulink is shown in the fig 8. Two input voltage sources (V_1, V_2) are used. Output of the converter is connected to separately excited dc motor via starter.

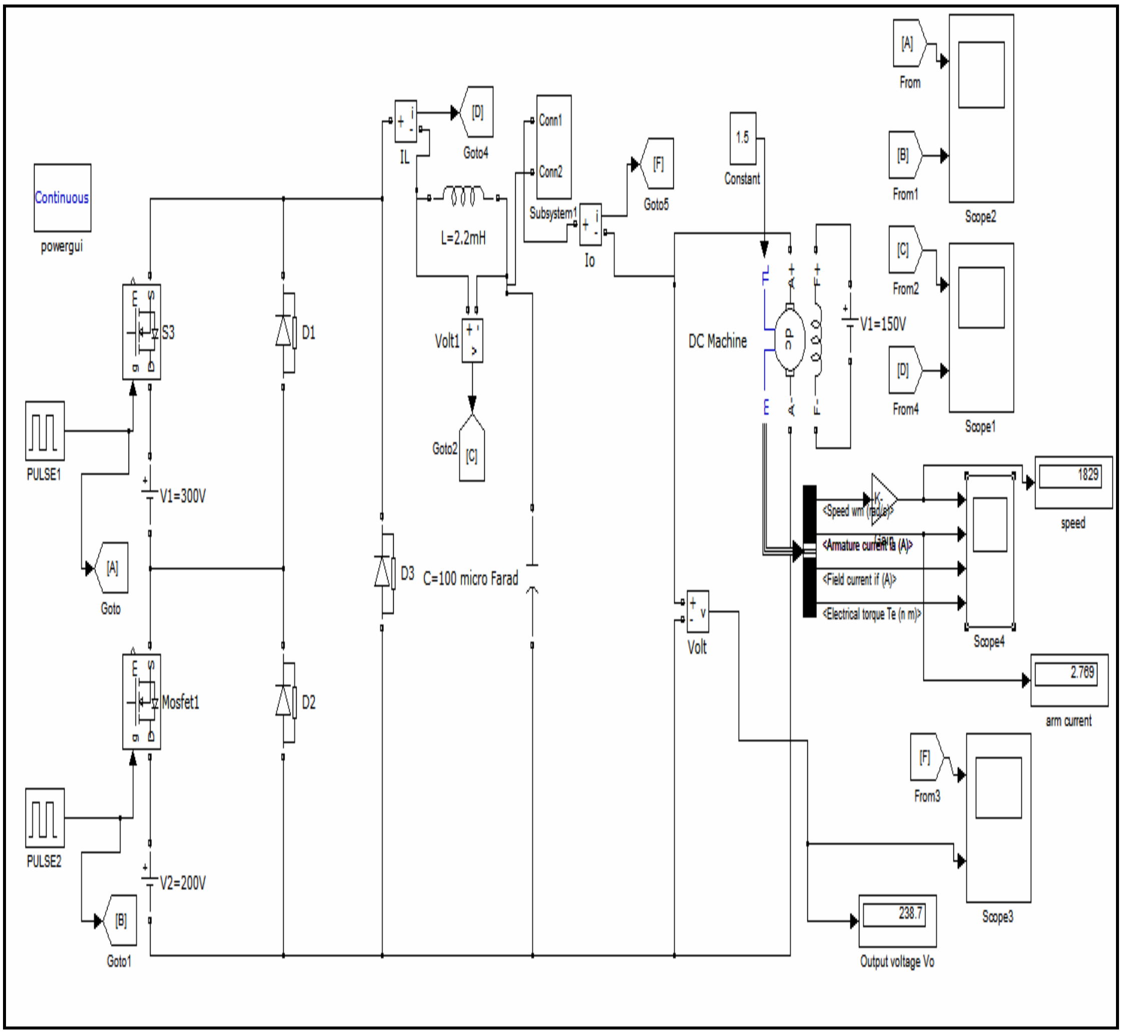

Fig.8:Simulation model of two input buck-buck dc-dc converter fed separately excited DC Motor using H-bridge cells obtained from MATLAB.

. The starter is modeled by adding a series of resistance from higher value of resistance to lower resistance. Starter is used to limit the staring current of armature windings.A circuit breaker is connected parallel to each resistance. The circuit breaker is controlled by step input with a time in seconds viz 1S, 2S, 3S, 4S, 5S, 6S.This starter block is created as sub system which is explored in fig.9.

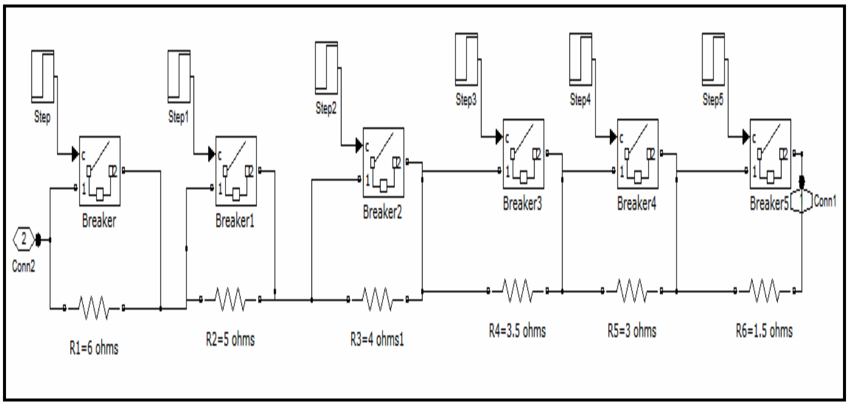

Fig.9: Simulation model of Starter for separately excited DC Motor obtained from MATLAB.

The values of inductance and capacitance of the proposed converter are L=2.2 mH and C=10KμF were used for the converter. Similar to the conventional single input converter this converter also operates in continuous conduction mode. The peak to peak ripple current of the converter is at its maximum level when the input voltages *V*1 and *V*2 are equal. The duty ratio for d_1=0.5,d_2=0.5 at a switching frequency of 10 kHz for switches *S*1 and *S*5 respectively [13]-[15].

The output simulated results shows the inductor voltage, inductor current, load current and output voltage. To operate the converter in this mode, the value of the inductance should be greater than critical inductance.

(a)Value of Critical Inductance

$$L_{critical} = \frac{R(1-d1-d2)}{2fs} \quad (7)$$

(b)Ratio of peak to peak ripple voltage

$$\frac{\Delta Vo}{Vo} = \frac{1-d1-d2}{8Lsfs^2} \quad (8)$$

Where,

ΔVo is the peak to peak ripple voltage
d_1 is the duty ratio of switch S_1
d_2 is the duty ratio of switch S_2
f_s is the switching frequency
L_s is the inductance
R is the Load Resistor
V_o is the output voltage

(c)DC Motor parameters are:

Armature Resistance (Ra) =0.78Ω,
Field Inductance (Lf)=112.5H,
Rated Speed=1750 Rpm
Rated Armature voltage=240volts
Rated Field excitation voltage=150volts
Rated power= 5HP.
Rated Armature Current=15.54 Amps.
Armature Inductance (La) =0.016H,
Field Resistance (Rf)=150 Ω,

(d)Simulated parameters are:

Actual Speed=1829 Rpm
Actual Armature voltage=238.7volts
Actual Field excitation voltage=150volts

The switching signals for Switches S_1,S_2 of buck-buck converter fed separately excited DC Motor using MATLAB/simulink is shown in the fig.10. Each switching signal has same duty ratio but phase shifted by an angle 180 degrees. Pulse width modulation technique is used in this converter. The fig.11 shows inductor voltage and inductor current of buck-buck converter fed separately excited DC Motor using MATLAB/simulink. From this we can observe that inductor voltage lies between 50 volts to -50 volts and inductor current value lies between 3.2 Amps to 4.2 Amps.

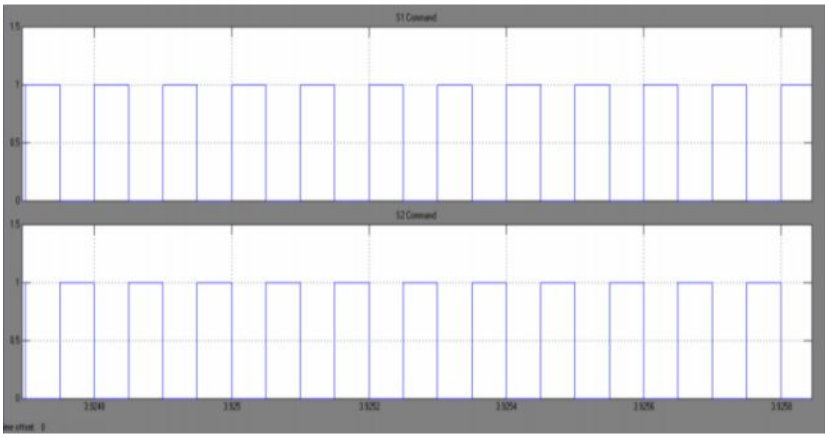

Fig.10:Switching signals two input Buck-Buck dc-dc converter fed separately excited DC Motor using H-bridge Cells obtained from MATLAB.

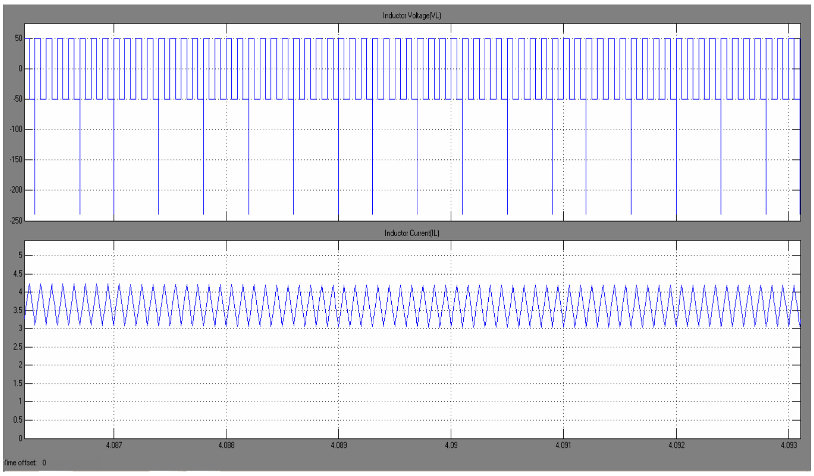

Fig.11:Inductor voltage and Inductor Current of two input buck-buck dc-dc converter fed separately excited DC Motor using H-bridge cells obtained from MATLAB.

The fig.12 shows Output voltage of the Converter and load current of buck-buck converter fed separately excited DC Motor using MATLAB/simulink. From this we can observe that initially load current has maximum value of 17 Amps at 0s.This starting current is reduced to 4 to 5 Amps at 1s.This current is further reduced to 3 Amps of no load current at 6s. Similarly the output voltage of the converter is 100 volts at 1s. 238.7 volts at 6s. This is the output voltage of the converter when it attains final value. After this final value it maintains constant voltage if there is no change in load current.

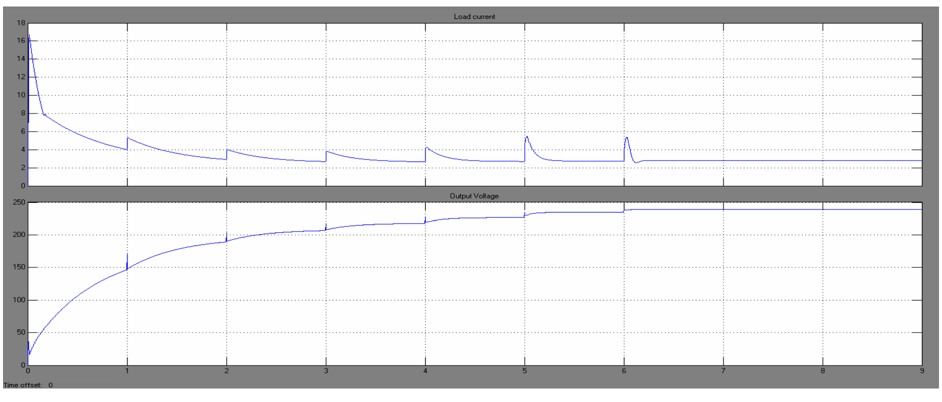

Fig.12:Output voltage and Load Current of two input buck-buck dc-dc converter fed separately excited DC Motor using H-bridge cells obtained from MATLAB.

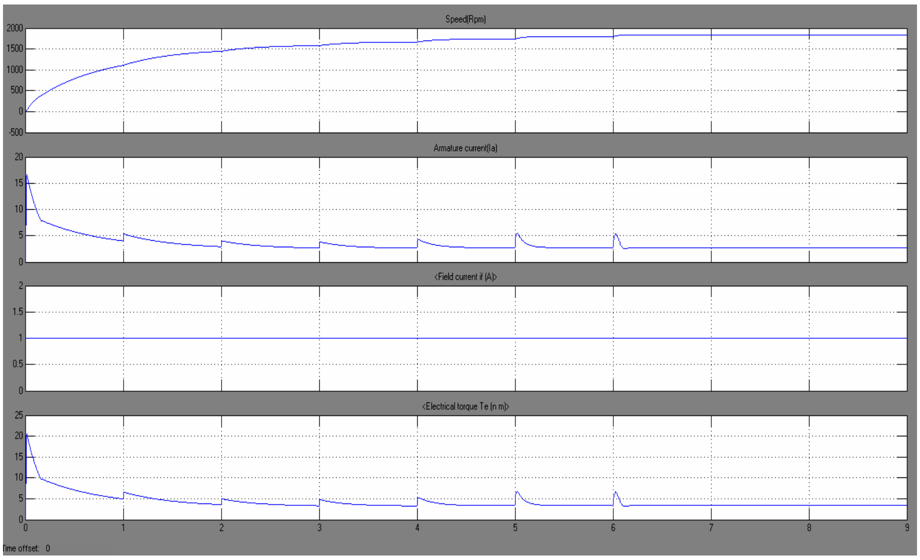

Fig.13:Simulation Results of two input buck-buck dc-dc converter fed separately excited DC Motor using H-bridge cells obtained from MATLAB.

The fig.13 shows the motor parameters like Speed, Armature current, Electrical torque and Field current of separately excited dc motor. From this figure we can observe that speed is 1829 rpm. Field current is maintained constant of 1 Amps. Armature control is used in this paper. But speed is not varied. Simply the output of converter is connected to the armature terminals of motor with required voltage.

Table.2: Comparison between Theoretical and Practical values of Voltage transfer ratio

Duty cycle(d1,d2)	**V1**	**V2**	**Voltage transfer ratio(V_0)**	**Theoretical value (V_0)**	**Simulated value (V_0)**
0.5	300v	200v	$V_0=d_1*V_1+d_2*V_2$	250v	238.7v

In this paper, the input voltage, duty cycles are shown in Table 2. The theoretical value and simulated value almost agree with each other.

7. Conclusion

The proposed buck-buck dc-dc converter topologies are designed through derivation by using H-bridge cells as a building block for separately excited dc motor. The converter use only one inductor which reduces the size, component count and cost of the converter. The operating performance is verified and compared using simulated results. Simulation and theoretical results almost agree with each other. The circuit is simulated in open loop control system. This converter provides the constant voltage only if load current is not varied. The proposed converter can be used with ultra Capacitor, battery, photovoltaic system, fuel cell system for automotive applications like hybrid electric vehicle.

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