Quad quadrant Bidirectional DC/DC Converter for Electric Vehicles With high gain voltage

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Abstract— **To improve the energy quality, most of the renewable energy systems and DC motor drive systems include an energy storage element charged by the bidirectional Converter. This paper propose quad quadrants dc-dc converter with high gain voltage and has a smooth output current The low current ripple and high gain features result are helpful for devices. This paper propose bidirectional DC-DC converter employs two MOSFET switch, two capacitor, two couple inductor and one small inductor, in this converter it`s not necessary increase turn ratio Transformer for obtain high gain. The simulation and Theoretical analysis results match with good agreement. Simulation using MATLAB/SIMULINK.**

Keywords-component; Bidirectional DC-DC converter, quad quadrants, Voltage gain, Small signal Model, energy storage system, EHV, PHEV, FCV,EV

Introduction

Today, conventional cars use combustion engines which burn fossil fuels (e.g. gasoline, diesel) to generate the required propulsion power. The products of the combustion process mainly the nontoxic compounds H2O and CO2 are exhaled into the air. CO2, however, is known as a greenhouse gas and partly accounts for global warming. Besides that, excessive burning of fossil fuels causes environmental pollution and the resources to exhaust [1-3]. Hybrid electric vehicles EVs and PHEVs save energy due to the employment of reverse regenerating braking, during the deceleration cycle. This recuperated energy can be proficiently stored in batteries and/or ultra-capacitors. The power train of a HEV typically consists of an internal combustion engine (ICE) and one or more electrically powered machines improve the overall efficiency [4-5]. The typical power system architecture of a EVs(PHEV, EV, FCV, HEV) is illustrated in Fig.1.

In EVs needed a bidirectional DC-DC converter in order to provide an effective path to charge or discharge the battery. Recently many bidirectional DC-DC converters have been proposed. The conventional bidirectional DC-DC converters operate in two quadrants; one quarter for charge and another for discharge but in some applications like DC motors four quarters is needed. EVs a quad quadrant DC/DC converter is required that provides four modes operation (forward and backward motoring mode ,also forward and backward breaking mode.). In aforementioned application charge mode is supplied by battery and discharge mode uses motors inertia to charge the battery and Ultra capacitor [5-8].

Traditionally Full bridge bidirectional converters operate in four quadrants by using four switches which increases the complexity and the cost of the converter [9]. in order to solve the above mentioned flaws a bidirectional DC-DC converter has been proposed [10] with two switches. Three capacitors and three inductors, Although this converter has been developed better features but the large number of elements increases the cost and complicate the implementation of the converter. A Quasi source converter and z-source inverter with two switches has been proposed in [11]. In this paper propose a quad quadrants DC-DC converter based on Trans Z source and ʃ-Z Source based inverter has been proposed in which has the lowest components and there is no need to increase turns ratio to achieve high voltage gain [12]. The Conventional converter is shown in Fig.2. Due to complementary switches, duty cycles for switch S1 and switch S2 are D and 1-D respectively.

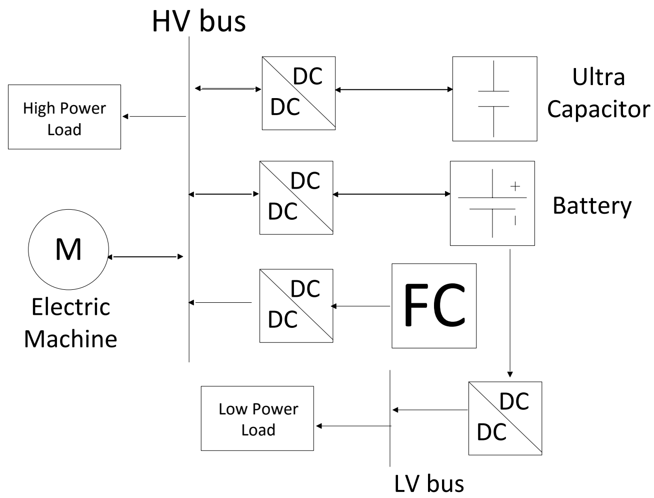
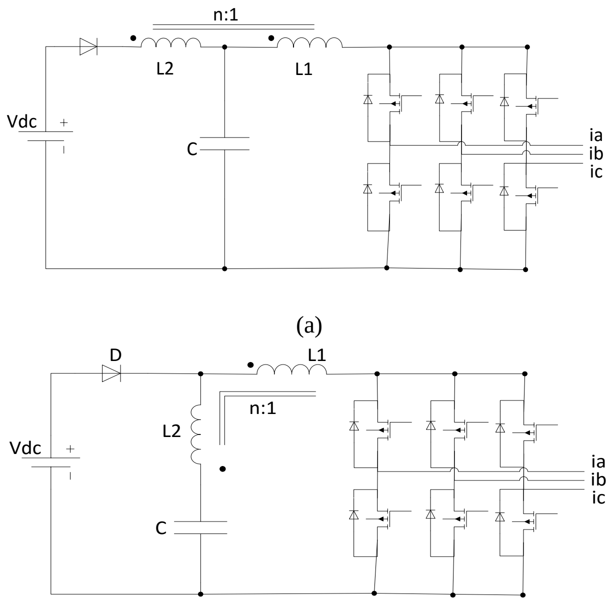


Fig.1. Power system architecture for EVs (FCV, HEV, PHEV).

I. DESCRIPTION OF THE PROPOSED CONVERTER

A. analysis of the proposed converter

The proposed converter has two switches, two capacitors, one inductor and two coupled inductors. The two switches are complementary (when S_1 is still ON state, S_2 is still OFF state and vice-versa). The proposed converters are shown in Fig. 3.



(a)

(b)

Fig.2. Trans Z source inverter (a) and ɼ-Z source inverter (b)

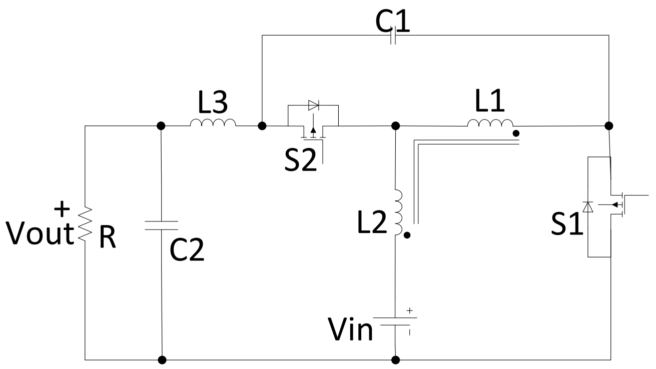
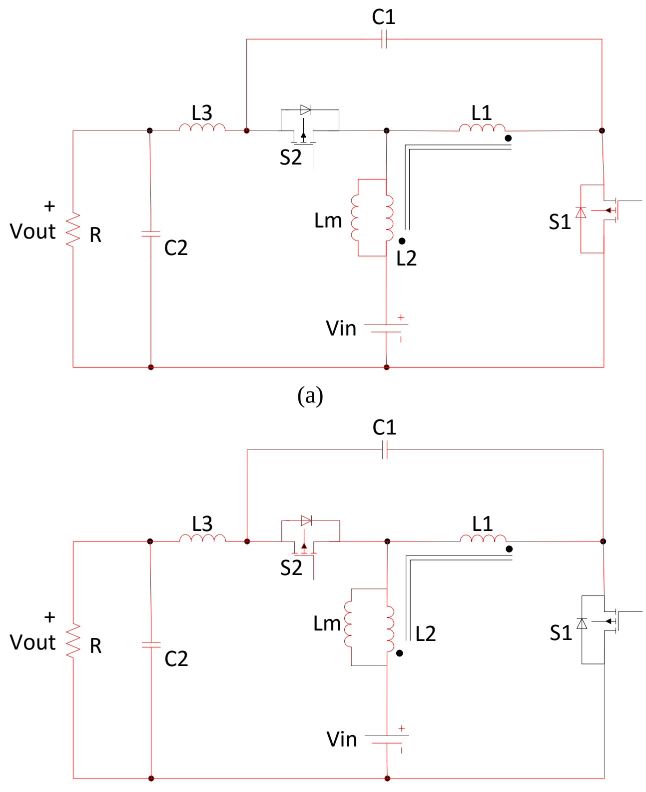


Fig.3. proposed quad DC-DC converter

B. steady state analysis of the first topology

In this topology the coupled inductors are modeled as an ideal transformer and a magnetic inductance (Lm) which is parallel with second winding. Fig. 4.a and 4.b is shown the equivalent circuits of this topology. From Fig. 3.a it can be seen when switch S1 is turned ON voltage across the magnetic inductance Lm equation Following

$$V_{Lm}(\text{stage1}) - n.V_{Lm}(\text{stage1}) - V_{in} = 0$$
$$V_{Lm}(\text{stage1}) = \frac{V_{in}}{1-n} \quad (1)$$



(a)

(b)

Fig.4. Equivalent circuits of propose converter. First stage (a) second stage (b).

From Fig. 3.b when switch S2 is turned ON voltage across magnetic inductance can be expressed as:

$$nV_{Lm}(\text{stage 2}) - V_{C1} = 0$$
$$V_{Lm}(\text{stage 2}) = \frac{V_{C1}}{n} \quad (2)$$

In one switching cycle the relation of magnetic inductance can be written as

$$DV_{Lm}(\text{stage1}) + (1-D)\,V_{Lm}(\text{stage 2}) = 0 \quad (3)$$

$$V_{C1} = \frac{-n.D.V_{in}}{(1-n)(1-D)} \quad (4)$$

Voltage across the inductor L_3 equation Following;

$$V_{L3}(\text{stag1}) = -V_{C1} - V_{in} \quad (5)$$

$$V_{L3}(\text{stag 2}) = -V_{Lm}(\text{stage 2}) + V_{in} - V_O$$
$$V_{L3}(\text{stag 2}) = \frac{-V_{C1}}{n} + V_{in} - V_O \quad (6)$$

$$D.V_{L3}(\text{stage1}) + (1-D)\,V_{L3}(\text{stage 2}) = 0 \quad (7)$$

Using (7) we have

$$\frac{V_o}{V_{in}} = \frac{-nD^2 + D(1-D) + (1-n)(1-D)^2}{(1-n)(1-D)} \quad (8)$$

Above equation confirms that if D(1+n)>1 the output voltage of the proposed converter is negative and when D(1+n)<1 the Output voltage is positive. The voltage gain of the proposed converter versus duty cycle For Different transformer turn ratio is depicted in Fig. 5. From Fig. 4 it can be derived when output voltage is positive the proposed converter operates in buck mode and if the output voltage is negative the proposed converter operates in buck-boost mode and its voltage gain can varies in a wide range. In order to minimize the leakage inductance the coupled inductors turn ratio is n=2 and from (4) it can be written

$$\frac{V_o}{V_{in}} = \frac{-4D^2 + D(1-D) - (1-D)^2}{-(1-D)} \quad (9)$$

The proposed converter voltage gain can be controlled with two parameters which are duty cycle and the coupled inductors turns ratio. When n=2 and D< 0.5 the output voltage is positive and when n=2 and D>0.5 output voltage is negative. Furthermore the proposed converter has lower components compared to the aforementioned converters.[10-11]

Fig. 6 depicts the proposed converter equivalent circuit in quarter one and two. Fig. 5(a,b) and 5(c,d) demonstrates voltage and current path in which D< 0.5 and D>0.5 respectively.

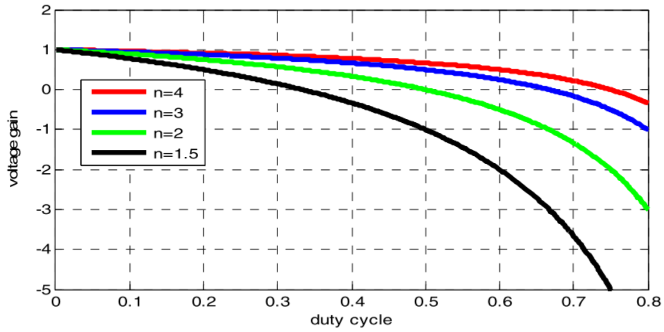
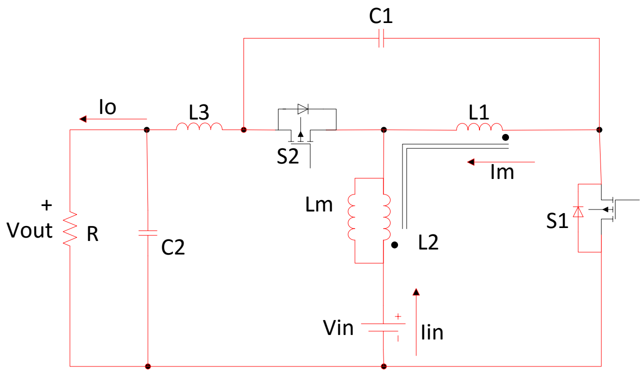
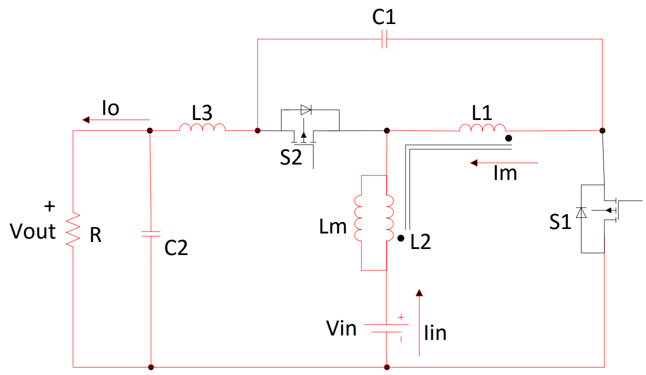


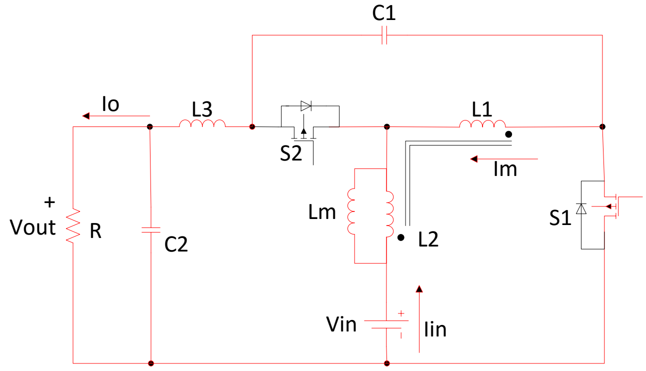
Fig.5. Voltage gain of the propose topology versus the transformer turn ratio



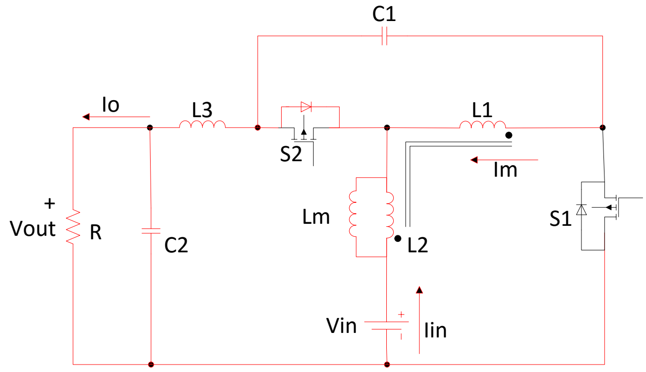
(a) First stage D<0.5



(b) Second stage, D<0.5



(c) First stage, D>0.5

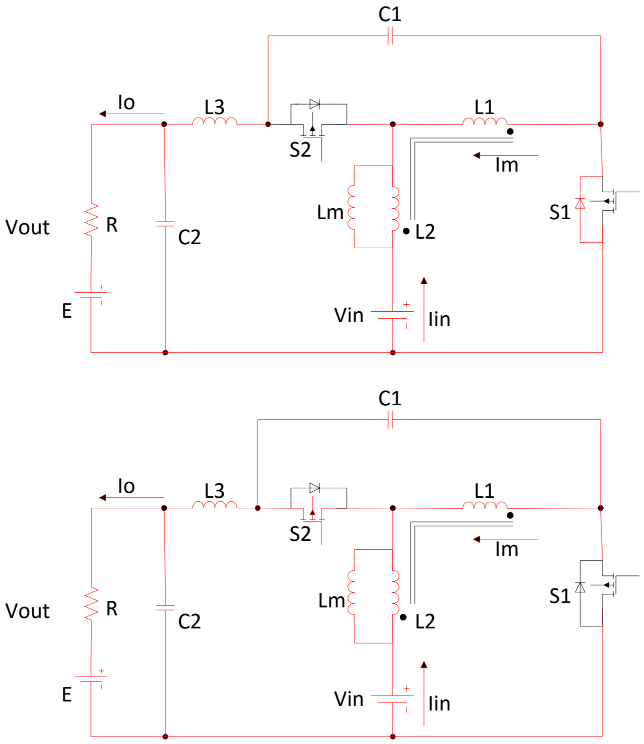


(d) Second stage, D>0.5

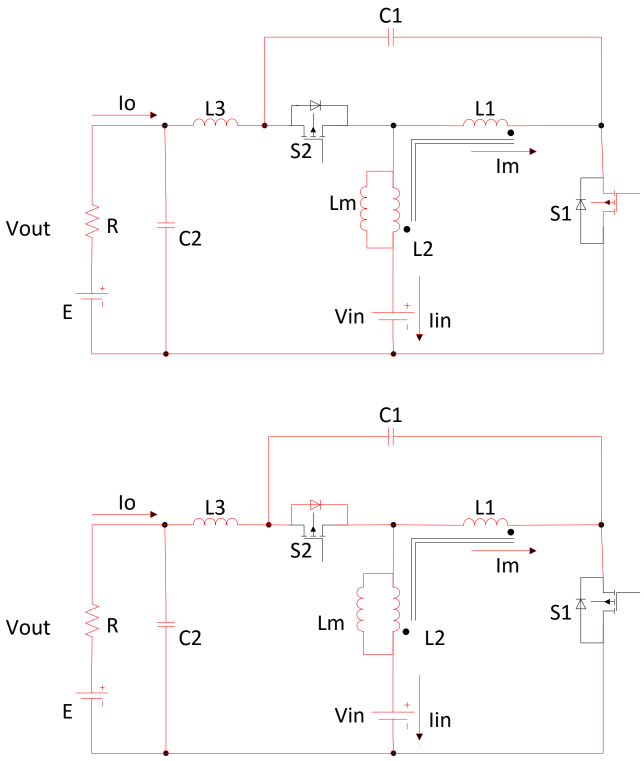
Fig.6. Equivalent circuits of propose converter under n=2

C. *Quad quarters operation of the proposed converter*

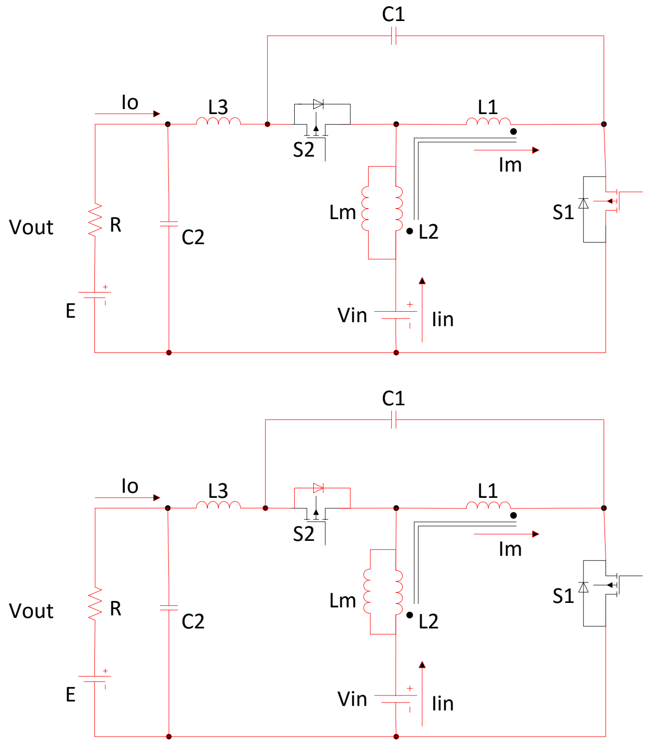
The proposed has bipolar and bidirectional features. The quad quadrants operation of the first topology with n=2 has been shown in Fig.7. In the first and the third quadrants the power flows from source to the load so that the battery is in discharge mode and in the second and the fourth quadrants power flows from load to battery and charge it. The output voltage in the first and the second quadrants is positive with D<0.5 and in the third and the fourth quadrants the output voltage is negative with D>0.5.



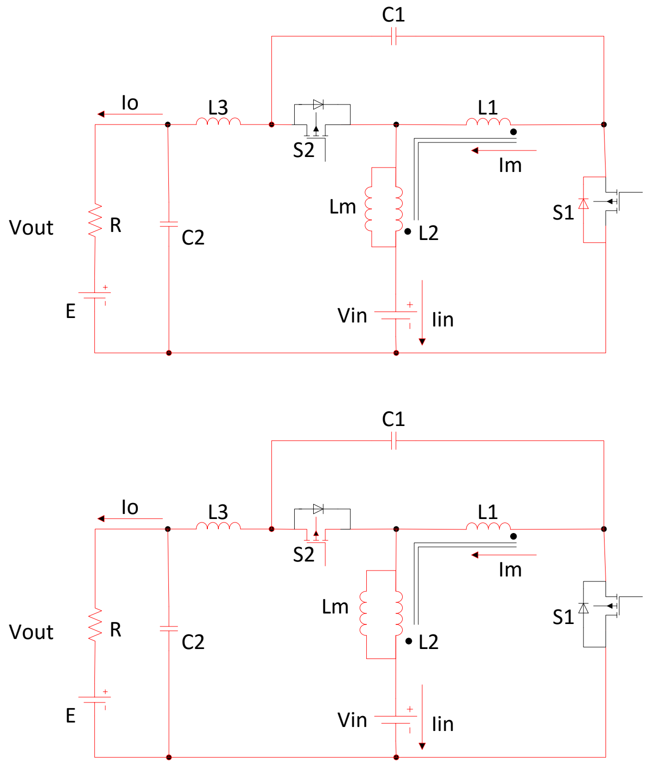
(a) Operation mode in first quadrant D<0.5 and Vo>E



(b) Operation modes in second quadrant: D<0.5 and Vo<E



(c) Operation mode in third quadrant D<0.5 and |Vo|>|E|



(d) Operation modes in third quadrant: D<0.5 and|Vo|<|E|

Fig.7. quad quadrant operation of the propose converter

II. SIMULATION RESULTS

In order to verify the theoretical results, the propose topology under n=2 is simulated using MATLAB/SIMULATION, The load is modeled with a voltage source (E) and an internal resistance (R). the circuit parameters that were used in simulation are: Vin=50 V, Lm = 1 mH , L3 = 1mH, C1=C2= 100 μF, R = 50Ω , f_{switch}=100 KHz in these following cases:

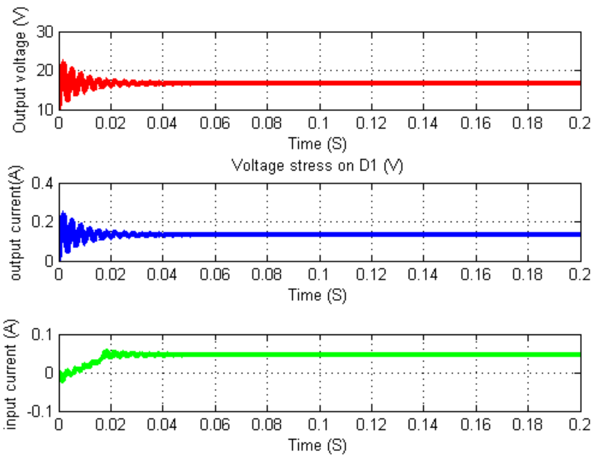
Operation in first quadrant: D=0.25 and E= 10V

Operation in Second quadrant: D=0.25 and E= 40V

Operation in third quadrant: D=0.75 and E= -40V

Operation in Second quadrant: D=0.75 and E=-260V

The simulation results in these cases are shown in Fig.8. to Fig.11. Respectively



Fiq.8. Operation in first quadrant (Vo>0, Io>0 and Iin>0)

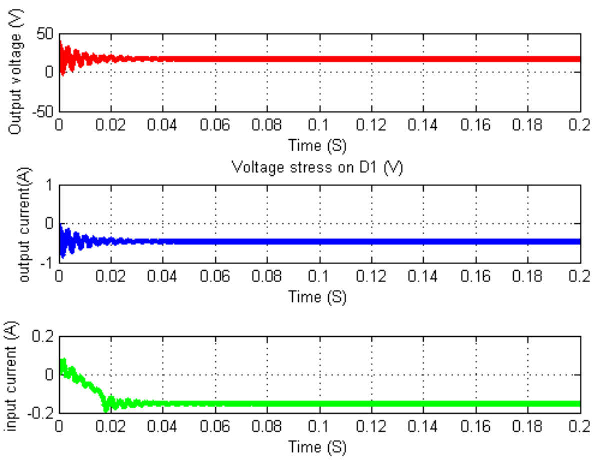


Fig.9. Operation in second quadrant (Vo>0, Io<0 and Iin<0)

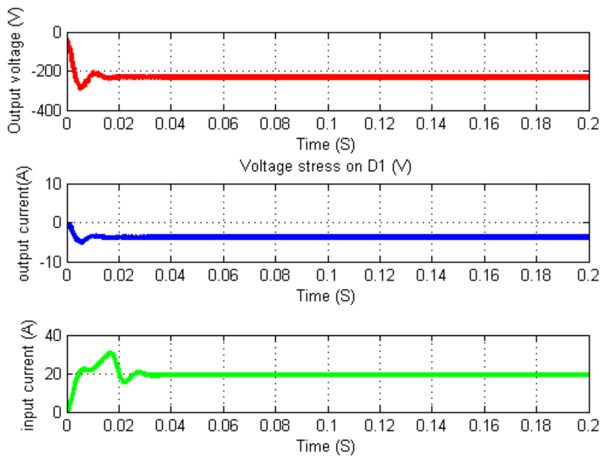


Fig.10. Operation in third quadrant (Vo<0, Io<0 and Iin>0)

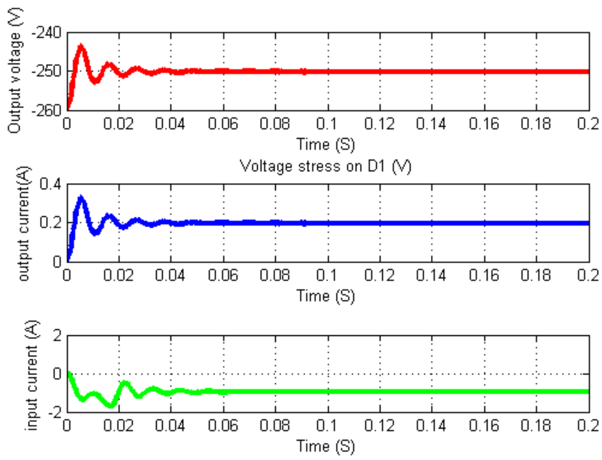


Fig.11. Operation in third quadrant (Vo<0, Io>0 and Iin<0)

The output voltage value is 16.68V when D=0.25 and is -238V when D=0.75. Both of these values are identical with theoretical results . the simulation results clearly shows that proposed converters can work in four quadrant modes. Also it can be used in motor drive systems like HEVs and in renewable energy systems.

III. CONCLUSION

In this paper a novel quad quarter DC-DC converter has been proposed. Inductor positions in the proposed converter are unique. By putting the inductors in the load side the voltage fluctuations is reduced and reliability of the proposed converter is increased. The low output current ripple and high gain features are very helpful for system. Even more the high voltage gain can be reached without large duty_cycle the coupled inductors turns ratio. Voltage gain in the proposed converter by varying duty cycle and the coupled inductor turns ratio can be both positive and negative. Whenever positive or negative output voltage is needed the two phase topology converter can operate in buck-boost mode. The proposed converter can be used in many applications such as electrical vehicles, renewable energies, distributed generation and etc.

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