Development of a New High Frequency Two Quadrant DC-DC Sepic Converter

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Abstract

The DC-DC converter find a wide scope in industries, telecommunication sectors, power electronics area, etc. Nowadays bi-directional converters have a higher end over them since the energy from the load during regenerative braking is fed back to the source, thus obtaining energy efficient system. A single topology that can provide Buck-Boost operation with positive output having four quadrant operations is not available in the literature. A common limitation of power coupling effect in some known multiple-input dc-dcconverters has been addressed in many kinds of literatures. In this paper, a new single topology of two quadrants DC-DC Sepic converter has been developed to provide four quadrant operation of a high- frequency dc-dc converter having one supply source and proper control of the converter. The combined topology has been analyzed and studied by spice simulation.

Key words

DC-DC converter, topology, two quadrant, high frequency

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Introduction

Development in the field of power electronics has constituted one of the great success stories of the 20th century. As manufacturing technology has improved, the cost of the semiconductor devices has decreased. Solid-state electronics brought in the first electronics revolution, whereas solid-state power electronics is the second electronics revolution. It is interesting to note that power electronics blends the mechanical, electrical and electronic era (Bose, 2000). A high-level productivity of the industries and product quality enhancement is not possible by using non-power electronic systems. Today, power electronics is an indispensable tool in any country's industrial economy (Bose, 1992a).

Silicon control rectifier (Thyristor, SCR) based DC Choppers were introduced in the early 1960's. SCRs were constrained to operate at low chopping frequencies. The advent of power MOSFET's and IGBT's allow power switches to operate at high frequency (Bose, 1992b). Conventional switch mode dc-dc converters (SMPS) operate either in single quadrant or in two quadrants (Rashid, 2004; Mohan etal, 1995). A switch mode DC-DC power supply is switched at very high frequency. Luo (Luo, 2000; Luo, 2000a; Luo etal, 2000b; Canesin and Barbi, 1997) has proposed the incorporation of voltage lift techniques in conventional switch mode circuits to obtain better voltage gain and efficiency in a wide range of duty cycle variation. Luo also suggested four quadrant operation of switching dc-dc converter using two separate circuits. None of the Luo converters operate in the single source circuit configuration in all four quadrants.

Two-quadrant DC-DC Luo-converter

Two-quadrant dc-dc Luo-converter in forward operation

Two-quadrant dc/dc Luo-converter in forward operation is derived from the positive output Lou-converter. It performs in the first quadrant QI (electrical energy transfers from source side V1 to load side V2) and the second quadrant QII (electrical energy is transferred from load side V2 to source side V1) corresponding to the dc motor forward operation in motoring and regenerative braking states. Where in Fig. 3 and 4 shown switches S1 and S2 are power MOSFET devices and driven by Pulse with Modulation (PWM) signal with repeating frequency f and duty cycle k. And switch on the voltage drop across the switch and diode is Vs and Vd.

And equivalent here is two modes of operation as-

Mode-A: First Quadrant Q I: The equivalent circuits of this converter during switch on and off the output voltage and current are shown in Fig. 1

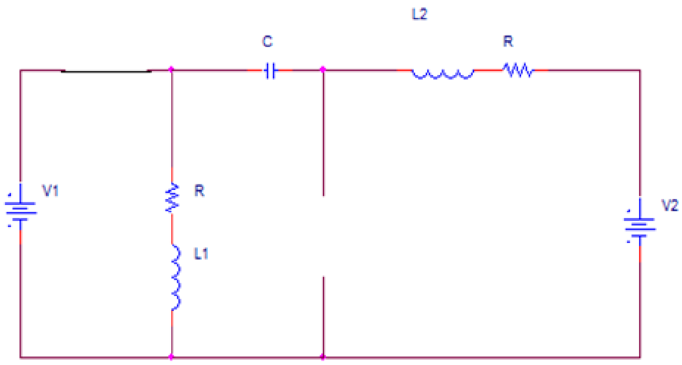

Figure 1: Switch (S_1) on-Forward two quadrants operating Luo -converter

$$I_2 = \frac{V_1 - V_S - V_D - V_2 \frac{1-k}{k}}{R\left(\frac{k}{1-k} + \frac{1-k}{k}\right)} \quad (1)$$

When minimum conduction duty k corresponding $I_2=0$ then

$$K_{\min} = \frac{V_2}{V_1 + V_2 - V_S - V_D} \quad (2)$$

Mode-B: Second Quadrant Q II: The equivalent circuits of this converter during switch on and off the output voltage and current are shown in Fig. 2

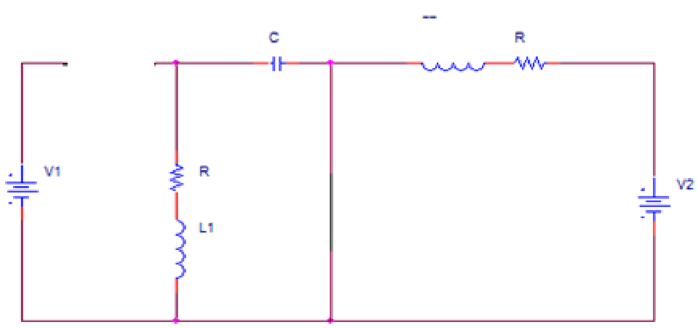

Figure 2: Switch (S_2) on-Forward two quadrants operating Luo -converter

$$I_1 = \frac{1-k}{k} I_2 \quad (3)$$

And

$$I_1 = \frac{V_2 - (V_1 + V_S + V_D)\frac{1-k}{k}}{R\left(\frac{k}{1-k} + \frac{1-k}{k}\right)} \quad (4)$$

When minimum conduction duty k corresponding $I_1=0$ then

$$K_{\min} = \frac{V_1 + V_S + V_D}{V_1 + V_2 + V_S + V_D}$$

Two-quadrant dc-dc Luo-converter in Reverse operation

Luo proposed two separate working in two quadrants forward mode and the other working in two quadrant reverse mode switched by complex gate pulses to obtain the four quadrant dc-dc switch mode dc-dc converters with voltage lift circuits, one operation. Two sources are necessary for such circuit. Two-quadrant dc/dc Luo-converter in forward operation has derived from the Lou-converter. It performs in the first quadrant QI (electrical energy is transferred from source side V1 to load side ±V2) and the second quadrant QII (electrical energy flow from load side ±V2 to source side V1) corresponding to the dc motor forward operation in motoring and regenerative braking states.

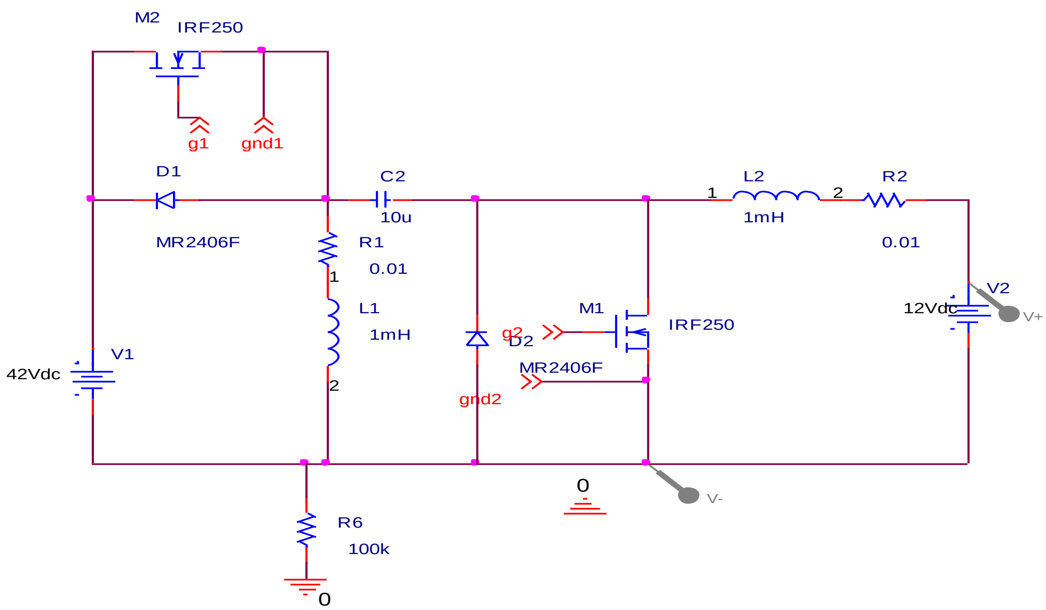

Figure 3: Forward operation of Luo Converter

Two-quadrant dc-dc Luo-converter in reverse operation has been derived from the negative output Lou-converter as shown Fig.4. It performs in the third quadrant Q III (electrical energy flows from source side V_1 to load side $\pm V_2$) and the fourth quadrant Q IV (electrical energy is transferred from load side $\pm V_2$ to source side V_1) corresponding to the dc motor reverse operation in motoring and regenerative braking states.

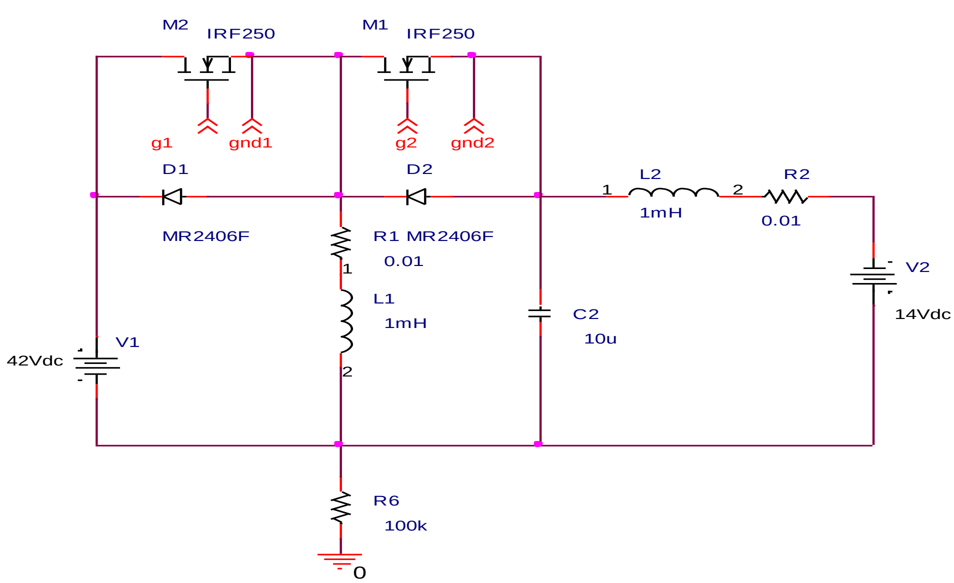

Figure 4: Reverse operation of Luo converter

However, it is found in the simulation that these two source converters do not operate as claimed, and they cannot be combined in any way with the differentially connected load to operate in four quadrants as a single power conversion circuit. Because of combined circuit arrangement should identical as Fig. 5.

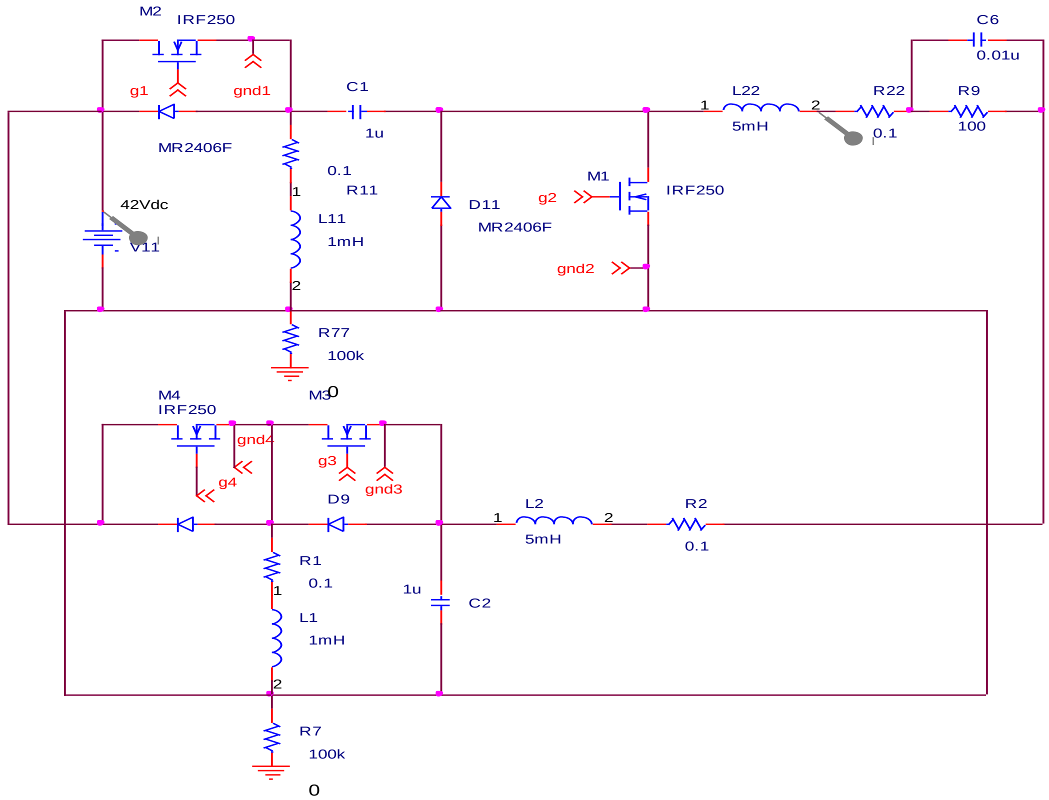

Figure 5: Four quadrant DC-DC converter with the differential load

In this paper attempt was made to make the four -quadrants chopper out of forward and reverse Luo converters with differential load connection as shown in Fig.4 but the converter did not perform as four-quadrants chopper because the reverse Luo converter does not work as it has been claimed; secondly these circuits are working individually for Quadrants I & II and Quadrants III & IV. So it is needed to design such kind of two-Quadrants which can be incorporated in a single source four quadrant dc-dc converter.

PROPOSED TWO-QUADRANT DC-DC CONVERTER

1-Q SEPIC dc-dc converter

Initially, a 1-Q SEPIC DC-DC converter as shown Fig. five which is controlled by a pulse waveform studied for input voltage 24V and load resistance 20 ohms.

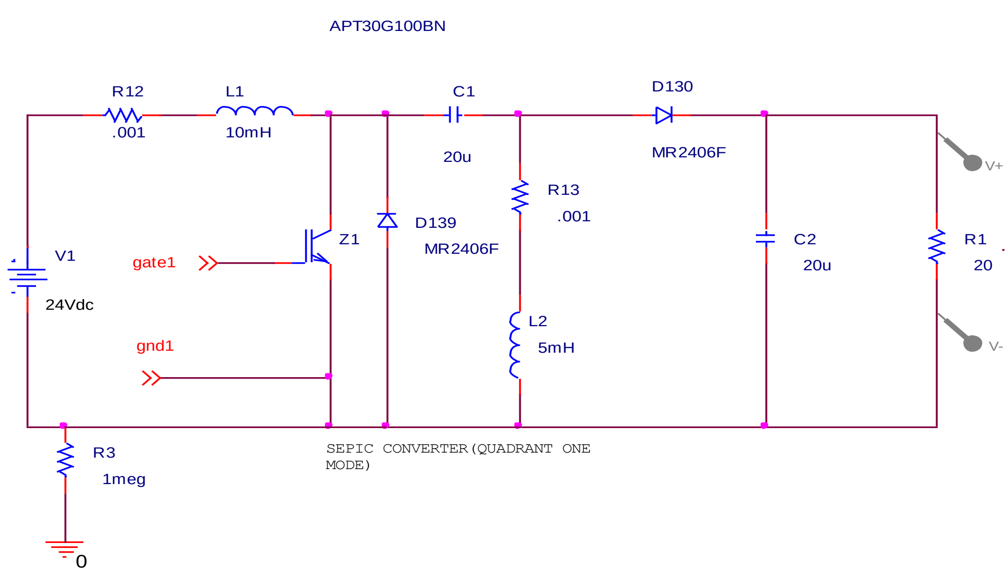

Figure 6: One Quadrant SEPIC Chopper

2-Q SEPIC dc-dc converter

The Circuit used for 2-Q SEPIC dc-dc converter that derived from 1-Q SEPIC dc-dc converter. The 1-Q SEPIC converter is extended to a 2-Q SEPIC dc-dc converter in the quest for development of a 4Q SEPIC dc-dc converter. The Circuit used for 2-Q SEPIC dc-dc converter which has been derived from 1-Q SEPIC dc-dc converter shown in Fig. five the Circuit has an extra switch across output diode and an anti parallel diode across the switch.

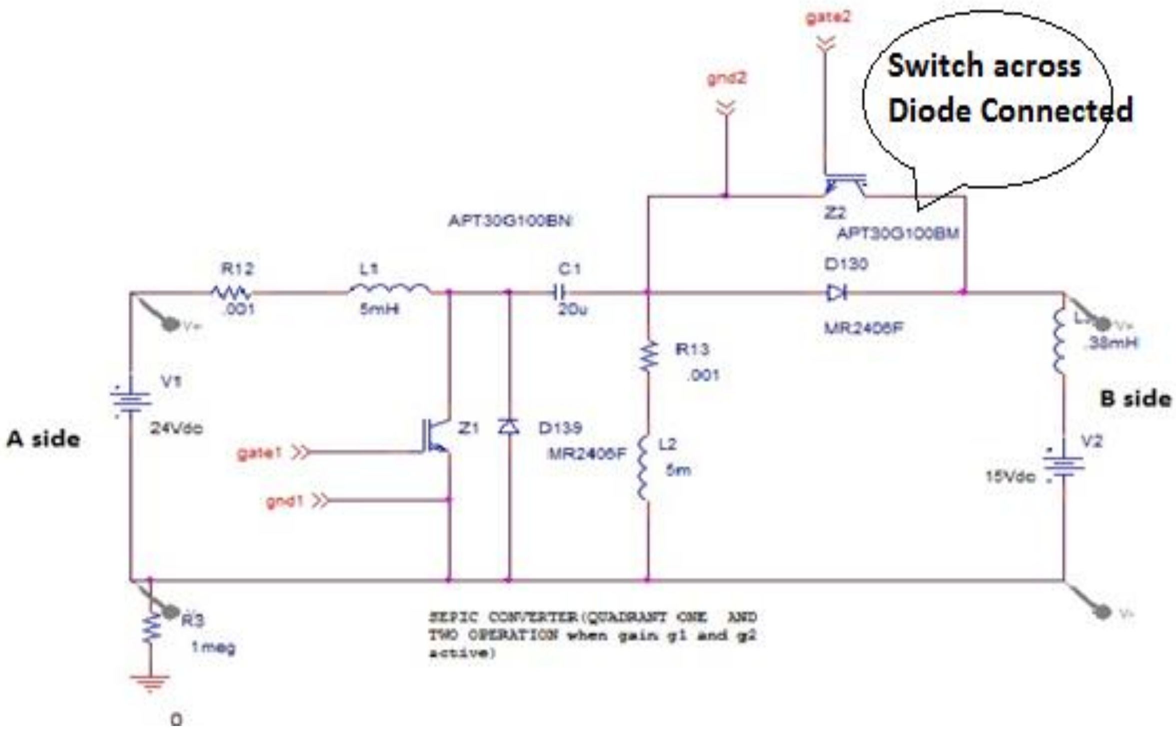

Figure 7: Two Quadrant SEPIC Chopper

Operation Mode

The operation of the 2-QSEPIC converter in the forward direction is the same as the circuit of Fig.7 which is shown in Fig. 8

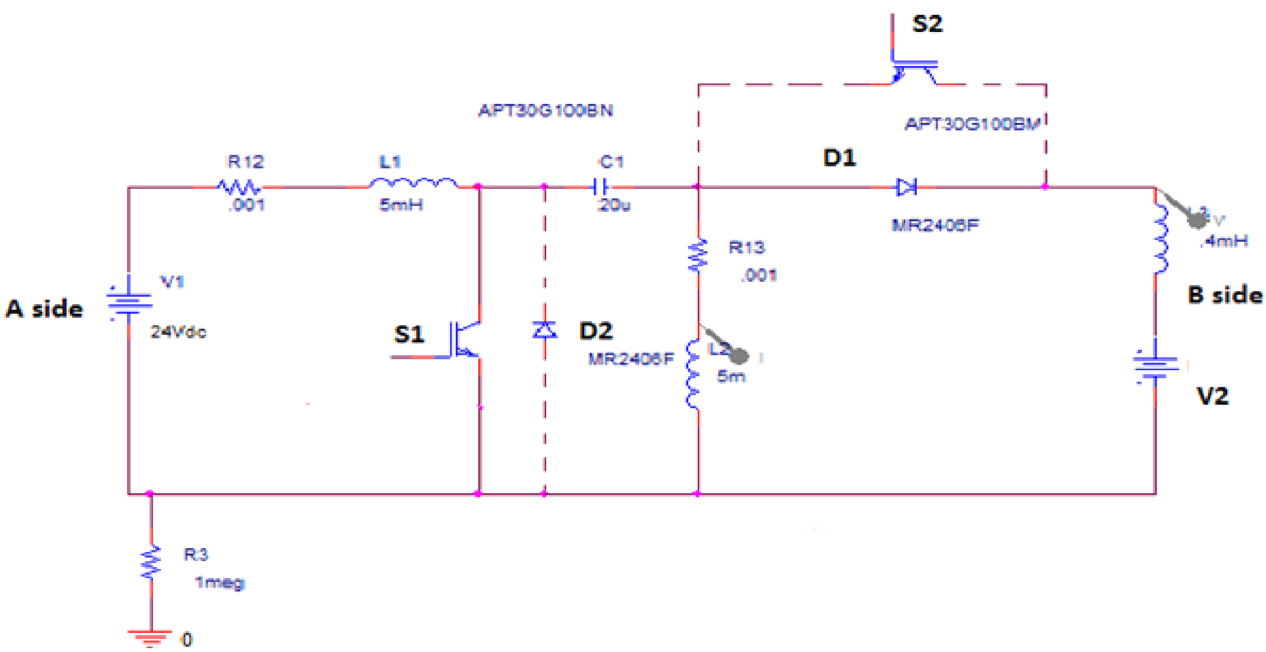

Figure 8: Two Quadrant SEPIC converter in forward direction (left to right)

The operation of the 2-Q SEPIC converter of Fig.7 in the reverse direction can be understood from Fig 11-12.

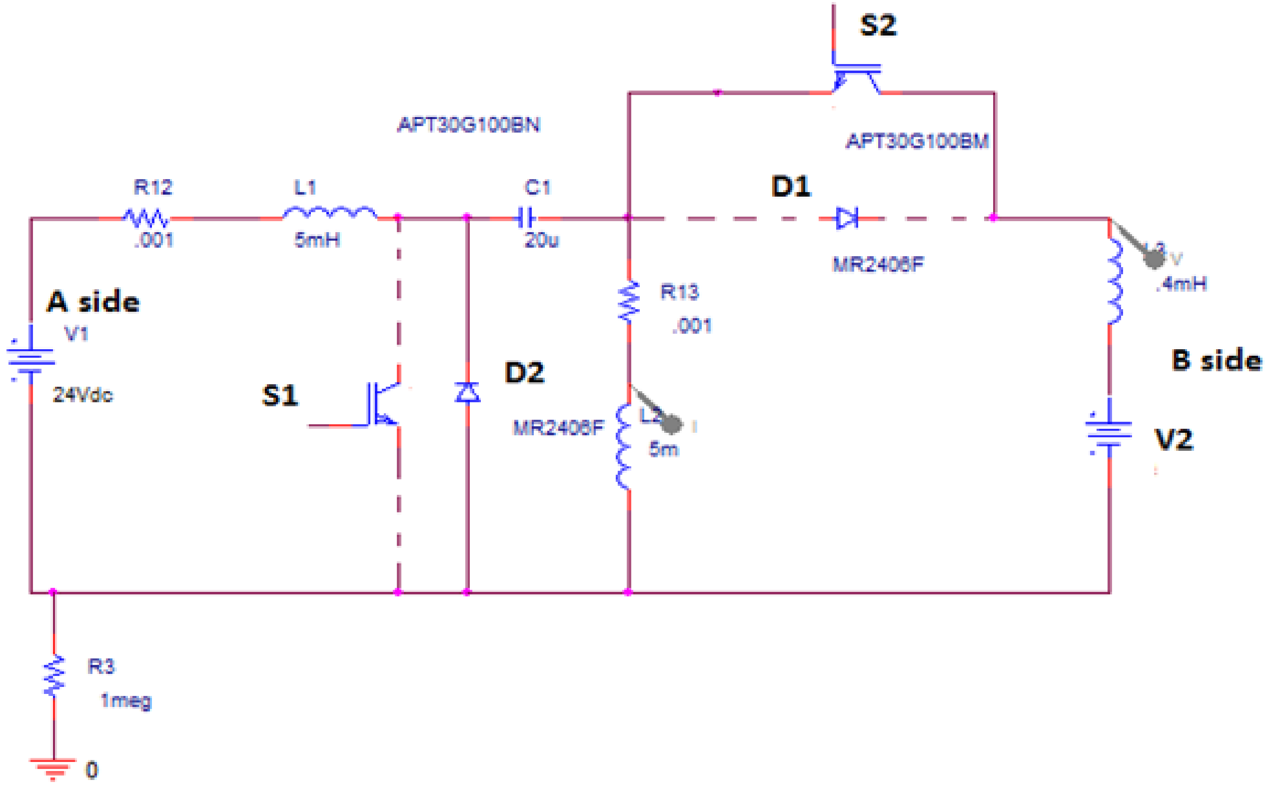

Figure 9: Two Quadrant SEPIC converter in Reverse direction (right to left)

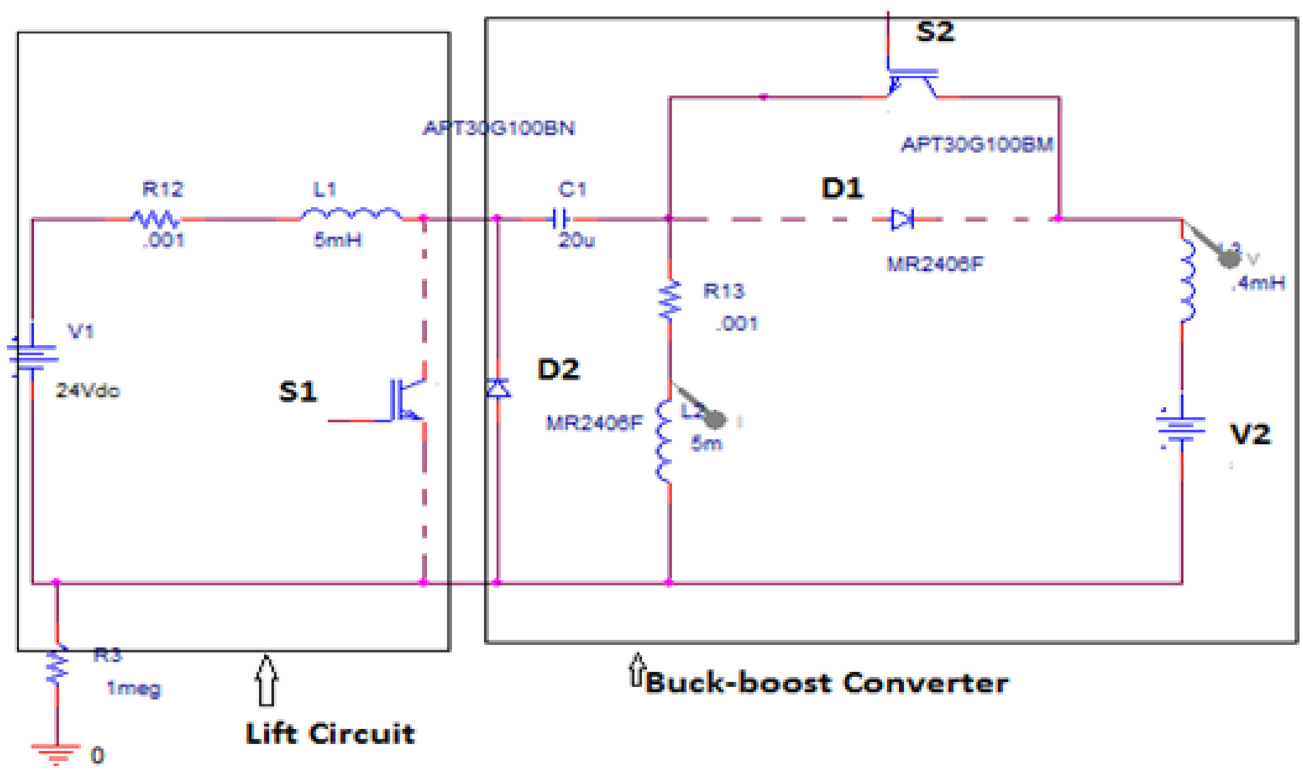

Figure 10: Two quadrant SEPIC converter in Reverse direction (right to left) as combination of a Buck-Boost (right box part) and lift circuit (left box part)

The operation in the reverse direction does not use the switch 1 and diode 1(as shown dotted) as shown in Fig. 8 The Circuit of Fig.11 can be identified as a Buck-Boost converter of the right box of Fig. 9 with the output at the capacitor as shown. The left box part of circuit acts as a lift circuit that transfers the capacitor charge to appear as a +ve voltage at the output at the left side as in SEPIC converter.

SIMULATION RESULT

Simulation Result t of Two Quadrant SEPIC Converter

In the simulation the converter is switched by two pulses as shown in Fig. 11.

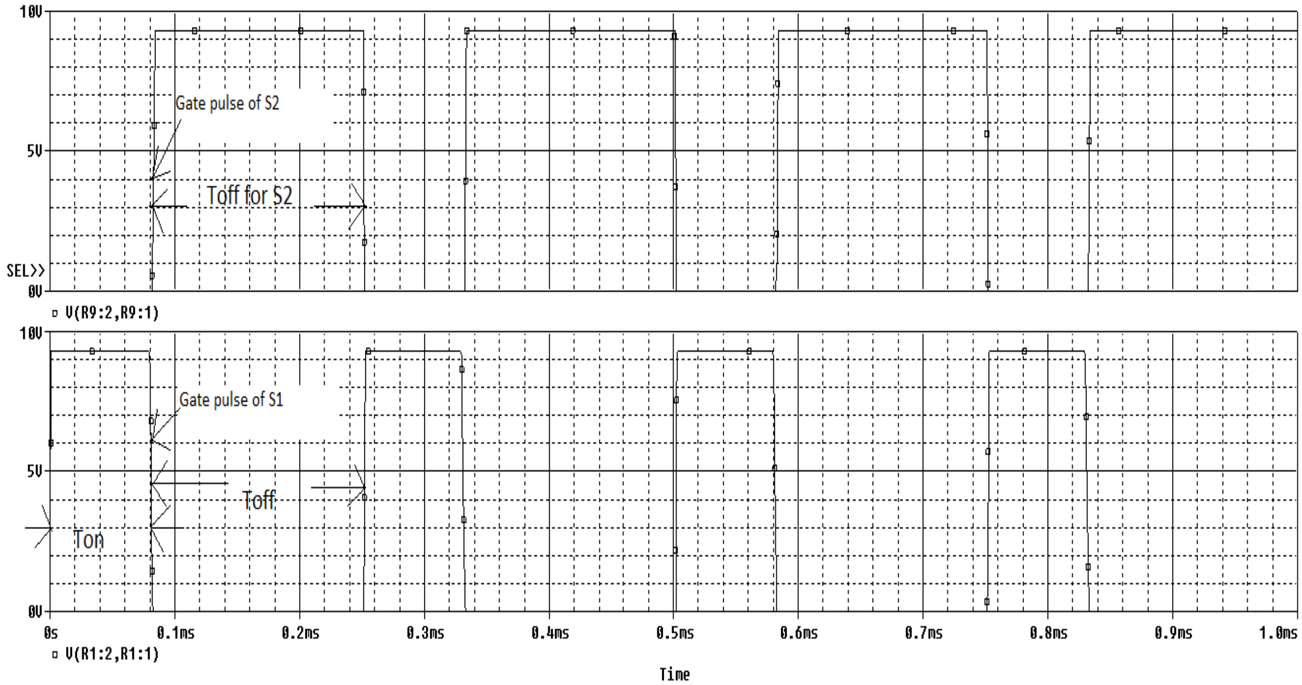

Figure 11: Gate pulse of switches of Circuit of Fig.7

If we choose for gate signal at DC level 5V than duty cycle of S1 will be greater than duty cycle of S2, Energy transfer in Forward direction (from A side to B side) that is shown in Fig. 12

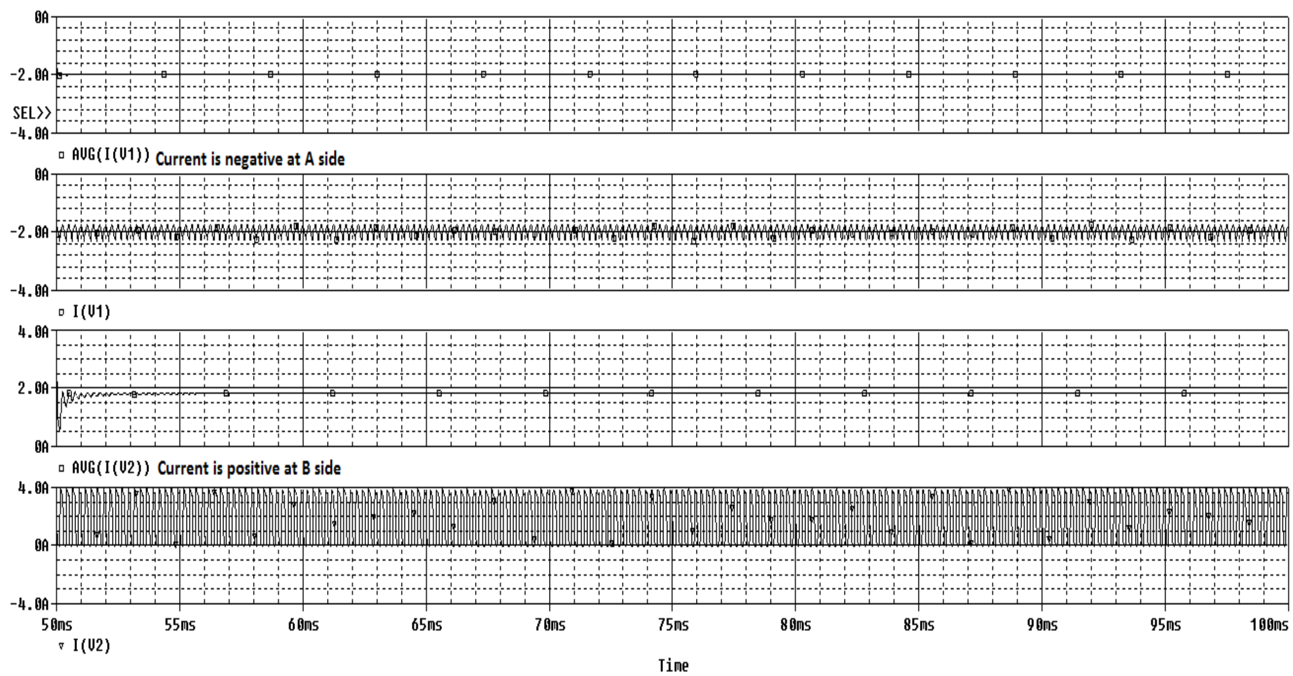

Figure12: Current is Positive at B-side for Positive output of circuit of Fig.8 for gate signal at DC level 5V (Quadrant-I)

If we choose for gate signal at DC level 2V than the duty cycle of S2 will be greater than the duty cycle of S1, Energy transfer in Reverse direction (from B side to A side) that is shown in Fig. 13

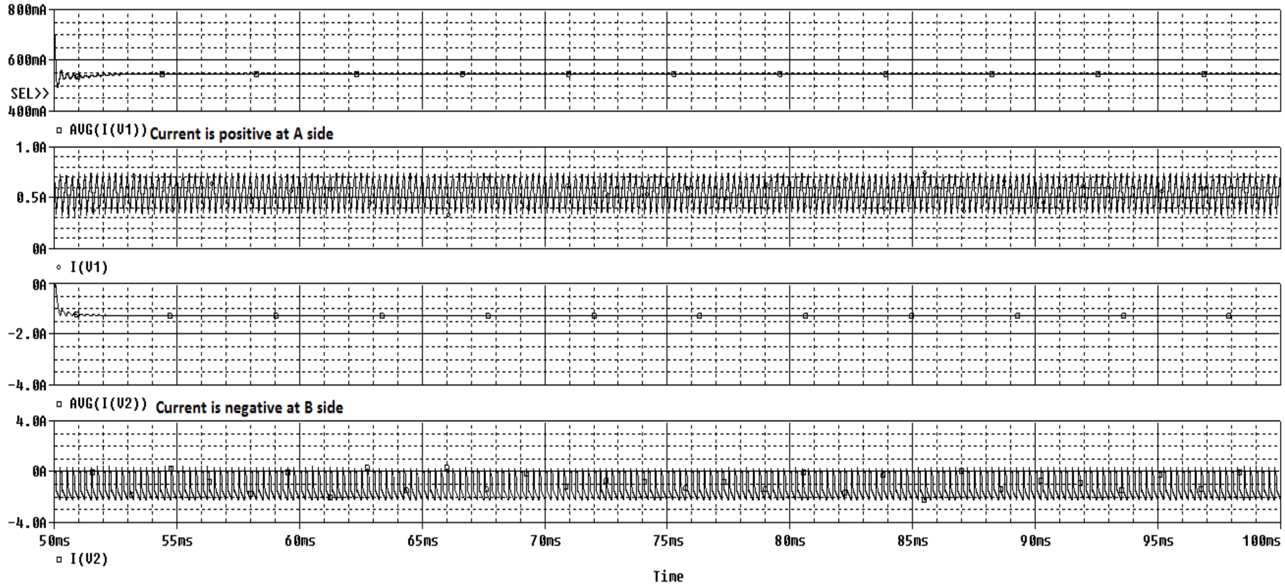

Figure 13: Current is Negative at B side for Positive Voltage of circuit of Fig.7 for gate signal at DC level 2V (Quadrant-II)

Simulation Result of Four Quadrant SEPIC Converter switched by sine PWM wave

The 2-Q SEPIC converter showed Fig.6 is extended to a 4-Q SEPIC dc-dc. The Circuit used for 4-Q SEPIC dc-dc converter which has been derived from 2-Q SEPIC dc-dc converter is shown in Fig.15. Two 2-Q SEPIC converter dc-dc converter have been connected with the differentially connection to obtain 4-Q SEPIC dc-dc converter shown Fig.13. Here A indicates input side and B indicates output side.

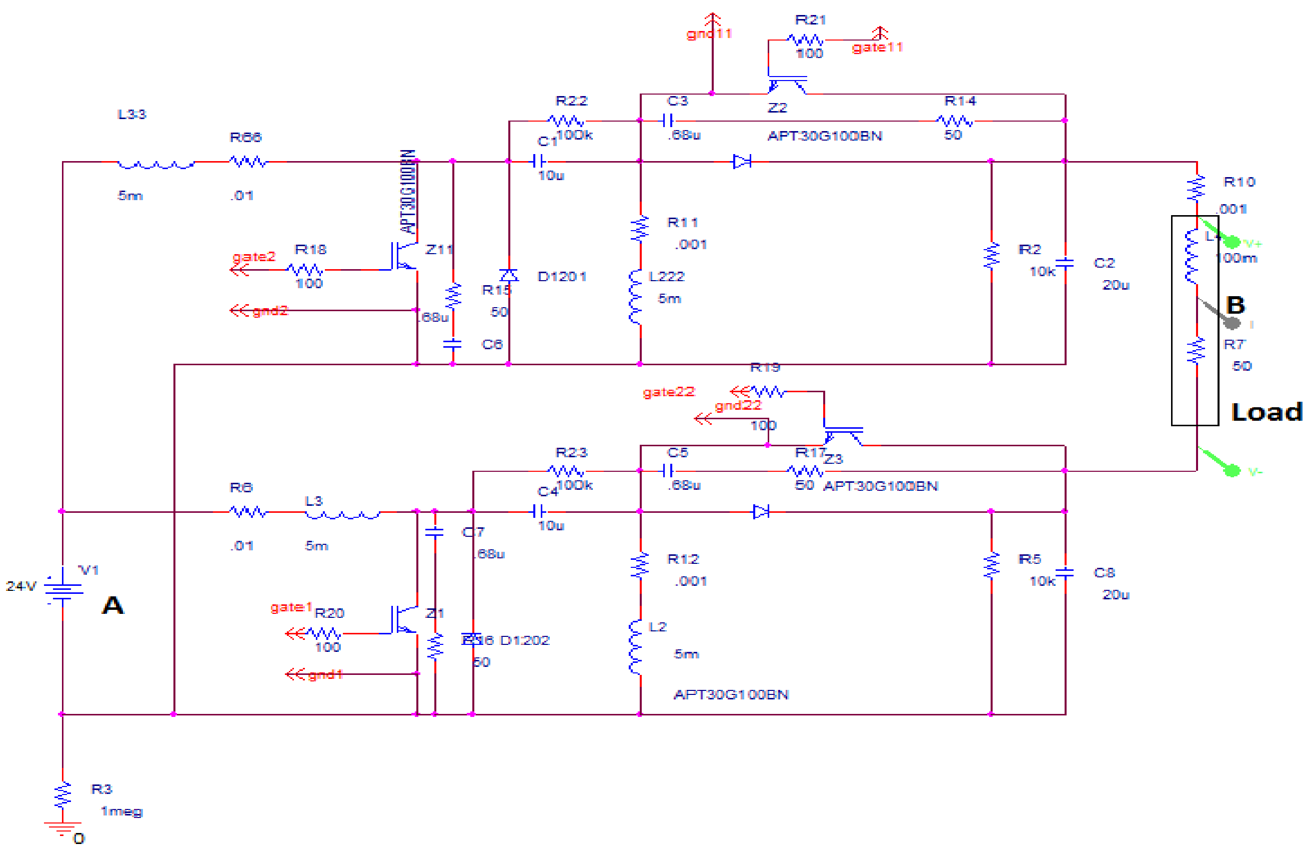

Figure 14: Four Quadrant SEPIC Chopper with the differentially connected R-L load

In simulation among four gate pulses, using gate1, gate11 same signal and gate2, gate22 same signal for the converter of circuit Fig.13 is switched shown in Fig.14

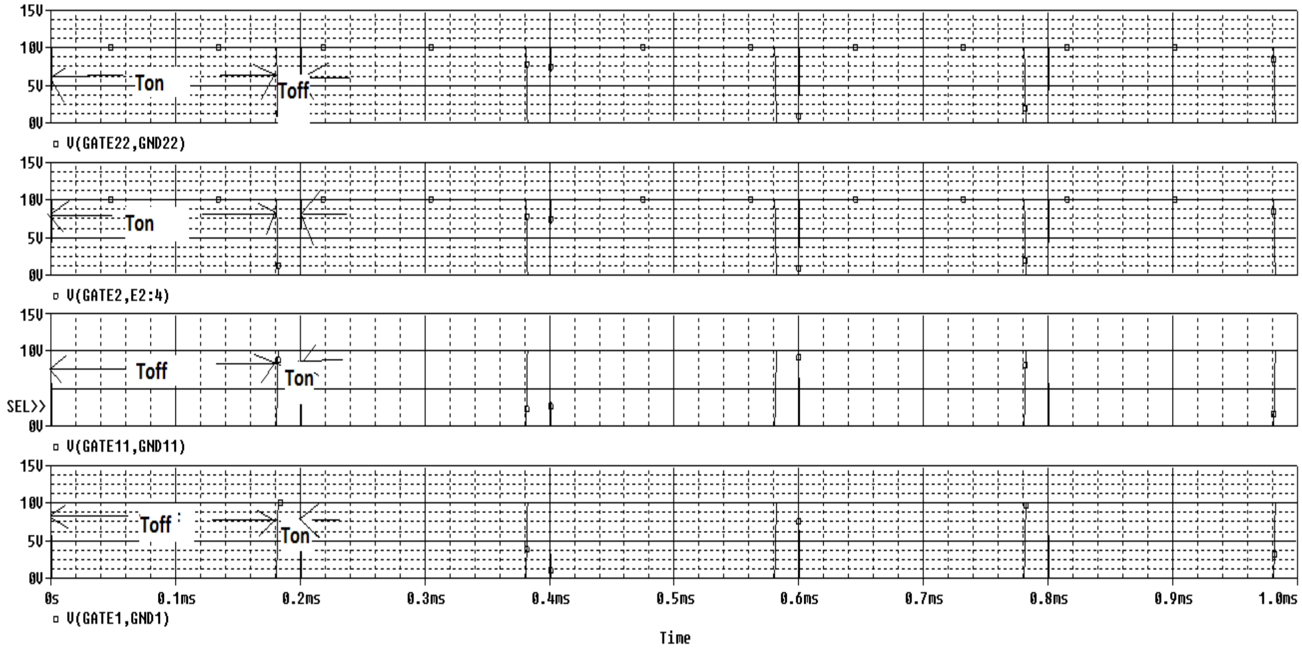

Figure 15: Typical Gate pulses of four quadrant SEPIC dc-dc Converter

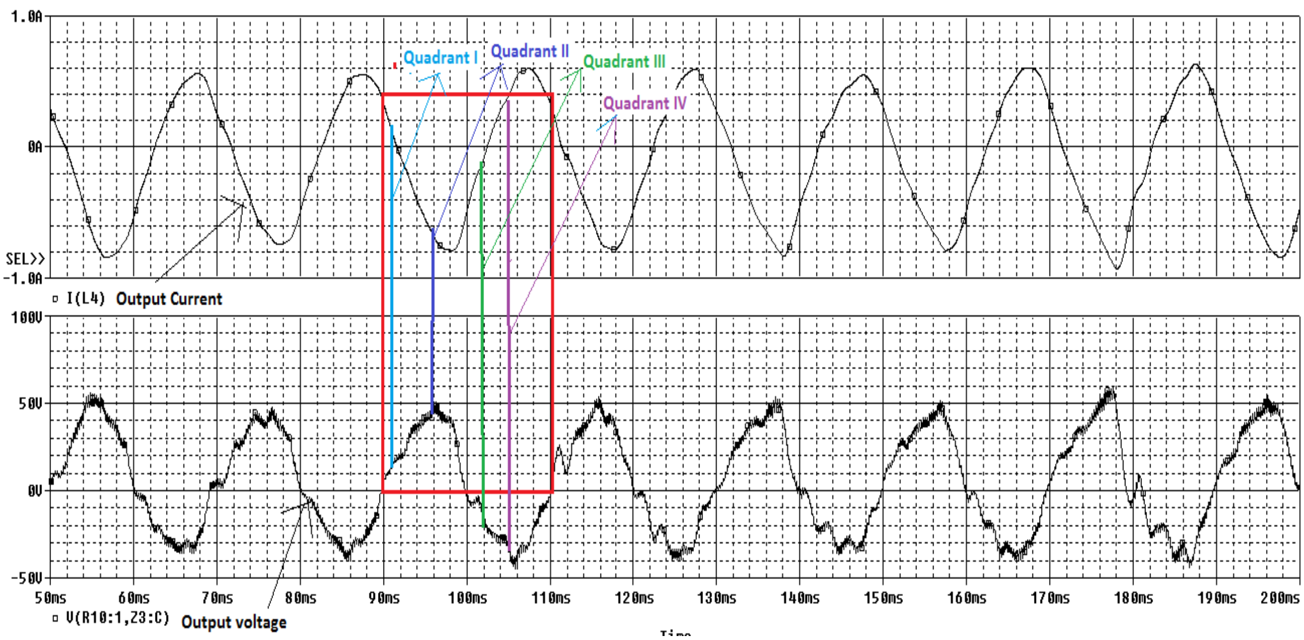

Figure 16: Typical Gate pulses of four quadrant SEPIC dc-dc Converter

Typical waveforms of Four Quadrant SEPIC Chopper connected R-L load of circuit of Fig. 14showed in Fig.15. Fig. 16 shows that the value of Output Voltage amplitude and current are alternating**.** From the above investigation, it is evident that the 4Q SEPIC dc-dc converter works as a dc-dc converter and with R-L or R-L-emf load it clearly demonstrates 4-Quadrant operation.

Conclusion

High frequency switching DC-DC converters are part of the electronic equipment to provide regulated dc of desired voltage. These converters have advantages over their counterpart the linear power supplies. They have high efficiency, light weight, wide voltage control range and cost less. In this paper, a two quadrant dc-dc converter has been developed. The circuit has investigated with input/output dc sources connected for two quadrant operation as the duty cycle is varied from 0 to near one**.** The result has been as expected of two quadrants SEPIC dc-dc converter and was suitable for adopted the topology for the development of single source 4-Quadrant SEPIC dc-dc Converter.

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