Analysis of Synchronous and Interleaved Converter

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Declaration

We do hereby declare that thesis titled “**Analysis of Synchronous and Interleaved Converter**” is submitted to Department of Electrical and Electronics Engineering of BRAC University in partial fulfillment of Bachelor of Science in Electrical and Electronics Engineering. This is our original work and was not submitted anywhere else for award of any other degree or any other publication.

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It was a very beneficial experience for our group. This thesis helped us to learn different aspects of DC-DC converters and the benefits of modifying those converters and the concern of most efficient and fast responding systems by analyzing different sources, papers, as well as practical work.

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Abstract

Converter circuits are different kinds of power electronics circuit which analysis the current and voltages from one level to another level with the importance of high efficiency. In the new era of power electronics, the voltages and current can be calculated and thus the power analysis is maintained for effective and stable electronics circuits. For the need of power electronics engineers, the output voltage must be low for the high source voltages for different devices where a buck converter is used. In telecommunication power supply system, buck converter is also used to take care the power quality issues. It is worked on modern electronic devices and telecommunication power supply system by using several mathematical methods of converters. Different power theories are considered to validate the work. Finally, switching frequency is fixed according to operating range. However it cannot make that converter effective and efficient, for that purpose the synchronous and interleaved buck converter is analyzed here. The one of the benefits of interleaving synchronous buck converter is reducing the ripple current which makes that convert more convenient. Moreover for developed electronics devices it may need higher voltages than the source voltages and in that case a boost converter is being used here. Furthermore, for more efficient circuit the interleaved boost converters are analyzed here. One of the major purposes of analyzing interleaved boost converters is the reduction of output voltage ripple over the conventional boost converters which makes the converter more effective.

Therefore, it is essential to improve the converter circuits by using the method of interleaving for an efficient system. Later, by varying the duty cycles and the input voltages, the ripple voltages and currents are reduced which provide highest efficiency of that converter hence the efficiency is calculated and is taken the most effective factors of that converter.

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Chapter 01

Introduction

1.1 Introduction:

At present time there is an increasing demand for efficient system whenever we talked about power consumptions so to keep up effectively these demands engineers have been coming forward developing efficient conversion techniques and also been able to design circuits with high efficiency. However new Challenges are facing every day in this field.

Applications of power electronics range in size increasingly day by day. Smartphones, tablets, digital cameras, navigation systems, medical equipment and other low power portable devices often contain multiple integrated circuits manufactured on different semiconductor processes. These devices typically require several independent supply voltages, each usually different than the Voltage supplied by the battery or external AC to DC power supply. For several purposes of power consumption electronics devices, it may need a low voltages from a high source voltage or in the similar way may need high voltage from a low source voltage. As engineers need a low voltage where as the source voltage is high it should be used the step down or buck converter in this case. Moreover it is also needed a high voltage from a low source voltage there a step up or boost converter should be used.

Our thesis project is about the analysis of increasing efficiency of buck and boost converters with synchronous and interleaved module to control the stability and effectiveness of that converter by changing the duty cycle in a certain range of load.

1.2 DC-DC Converter:

DC-DC converters are power electronics circuits which converts a DC voltage to a different DC voltage level, often providing a regulated output [1]. The aims of developing the converters are high frequency and high gain with fast response. Today's world is looking for the low power application devices which is the mainstream research area for the power electronics researchers. There are lots of parameters are used to develop the converters. A lot of computer soft wares are being used to develop these converters without any hardware which can prevent the damages. The dc-dc converter means the input is DC and the output are also DC. The basic two DC-DC converters are buck and boost converters. Based on these two converters the other converters are derived. The different arrangements of inductors and capacitors are used to operate the converter as a filter circuit. The resistance act as a load in the circuit which can be varied to study the behavior for heavy or light load. Switch-mode DC-DC converter is used to convert the unregulated DC input into a controlled DC output at a desired level. A switch-mood DC-DC converter is much more efficient than a linear converter due to reduce losses in the electronic switch. Looking ahead to this application of these converters, we find that these converters are very often used with an electrical isolation transformer in the switch-mode dc power supplies and almost without an isolation transformer in case of DC motor drives. If we consider output stage of the converter, a small filter is considered as an integral part of DC-DC converters. Therefore, to analyze these circuits, only the non-isolated converters are being considered here specially the step-down buck converters.

1.3 Controls of DC-DC Converters:

In the control of DC-DC converters, two control objectives are needed: Performance and Efficiency. In DC-DC converters, switching mood requires one or more switches to transform DC from one level to another. For instance, the switching frequency can be reduced at low loads, or the control circuit could be switched between a constant on time and a constant off-time control circuit depending on the load conditions [2]. The average DC output voltage must be controlled to equal a desired level, though the output load and the input voltages may vary. Switch–mode DC-DC converters utilize one or more switches to transform DC from one level to another. In a dc-dc converter with a given input voltages the average output voltages is controlled by controlling the switches on or off duration. Here we can control the converters by varying the duty cycle simply where duty cycle is the percentage of output and input.

We can also vary the components which we have used in electrical circuits to control the efficiency and stability of that converter.

1.4 Buck Converter:

This converter also called the step down converter and as the name implies, a step-down converter produces a lower average output voltage than the DC input voltage [5]. Conceptually the basic circuits consist of a purely resistive load, assuming an ideal switch, a constant instantaneous input voltage, a diode, a capacitor and an inductor. The circuit for the buck regulator operates by varying the amount of time in which inductor receives the energy from the source. The average output voltage is being calculated in terms of duty ratio.by varying the duty cycle the output voltage can be controlled. Another important decision will be observed that the output voltages linearly changes with the input voltage by varying the duty cycle. While there are various theories, conventional standard step-down converters were diode-rectified (asynchronous) devices, and it became customary to refer to diode-rectified step-down converters as buck converters. Regardless of the names used, there are a number of step-down methods used in step-down converters, and the step-down converter of this example is the previously mentioned diode-rectified device.

1.5 Synchronous Buck converter:

Modern electronic systems usually have a number of different regulated dc supply voltages providing power to various functional blocks. Buck converter can deliver the voltage on our desirable level which might be very simple regarding operation but using a synchronous buck converter the increases losses in diode can be addressed. Moreover, by using synchronous buck converter, the diode conduction losses in converter can be minimized and to improve the efficiency of the converter. The general trend for these supply voltages is to become moving into 0.6v to 3.3v [3]. In such applications one and multiphase pin of load synchronous buck converter have become preferably solution which generating low voltages from relatively high voltage DC input bus generated by battery or intermediate bus converter. Usually the voltage drop across the diode is high in practical position but here the MOSFET is replaced with this diode and the practical voltage loss has been decreased.

1.6 Interleaved Buck Converter:

Interleaving also known as multiphase is a method which is very useful for reducing the size of filter components. In general, the task of interleaved buck converter is to control high current by reducing the switch stress of converter. Interleaved buck converter has grabbed a lot of attention because of its simple structure and low current complexity. The standard voltage regulator (VR) topology used to deliver high current and low voltage power is the multiphase buck converter [4]. Here the multiphase implementation distributes the power among several phases and some ripple current cancellation is achieved in input and output capacitor banks by interleaving the phase. Here the number of phase is varied accordingly the switch is being open or closed in a pattern in order to get the highest efficiency in a certain level of load.

1.7 Interleaved Synchronous Buck Converter:

Here the buck converter with a MOSFET as a switch is used in order to get synchronous buck converter and multiphase this buck with more than one to get more effective and stable converter in this discussion. As in conventional buck converter where a power diode is used as a switch and the power dissipation through the diode is very high thus makes the converter more ineffective. On the contrary the uses of MOSFET as a switch in buck converter make that converter synchronous converter hence that converter merge with another one or more synchronous converters called the interleaved buck converter. Moreover the power loss is very low as it is known that power dissipation through MOSFET is low that makes the convert more effective and stable. Here also the efficiency and the power consumption is being varied by controlling the changes of duty cycle as well.

1.8 Boost Converter:

This is also called the step-up converter as the output voltage is highly raised than the input voltages. The widespread use of boost is significant in power electronics like the use of battery in portable devices such as cell phones and laptops has established the need of DC- DC power supplies in this concern. Moreover, the distributed energy sources such as solar photovoltaic system, trolley cars, forklifts trucks, electric automobiles have created a huge demand for DC-DC converters. It provides high efficiency as well as high controls and fast responses. Here a power diode is used to achieve the voltages to maintain the high gain. Boost Converter is a very common converter in power electronics circuits hence some modified converter is established from this basic converter. The Output voltages is analyzed by changing the input voltages as well as varying the duty cycle of this converter.

1.9 Interleaved Boost Converter:

In the concern of power electronics, it has required the improvements of the efficiency of power as well as the reduction of size in power electronics devices. For the fulfillment of that required criteria of boost converter it is a huge concern of making that converter interleaved. Interleaved means the two or more boost converters are in parallel combination in phase differences of switches that makes the converter more efficient and more stable. The main benefits of making the converter in interleaved situation is the reduction of ripple voltages thus make the converter efficient more than the normal conventional boost converters. The ripple output voltage is one of the main concerning factors for the high controlling and fast responses.

1.10 Conclusion:

In this chapter we discussed about the modern technologies used in power electronics. The uses of and the need of converters in different prospective. Moreover, we have learned about the step-down buck converter and the step-up boost converters basic topology and how these interact with the synchronous and interleaved positions in order to get more effective and stable. The basic operations of synchronous and interleaved buck is discussed in this chapter to make understand the further chapters of this project. Moreover, the basic concepts of boost are discussed and how the boost converter worked mentioned here. Finally, the interleaved boost was discussed for the more efficient system.

Chapter 2

Designing of Buck converter

2.1 Introduction:

In this chapter, the topology of designing conventional DC-DC buck converter is analyzed. Buck converter is mostly used for its efficiency than the linear regulator as small packets of power is transferred using two switch, an inductor and a capacitor initially. For switching purpose Buck converter can be operated in two mode:

1. Continuous conduction mode,

   &

2. Discontinuous conduction mode

Before starting the design, it is required to choose the mode of operation according to the application. Generally, buck converter is operated in continuous conduction mode (CCM). Apart from that, Discontinuous operating mode have some certain application also. Following that, the components are designed, according to the mode of operation. Later on the chapter, the component design and selection are discussed further.

2.2 Designing of Buck Converter:

Fig. 2.1 shows the circuit of a Buck DC-DC Converter. To start its designing, different parameters such as operating frequency, input-output requirement, load changing criteria, current deviation across load etc. has to be considered. In designing buck converter, switching frequency is opted at 25 kilo hertz which suitable for the converter to take twelve-volt DC as input and step it down to 5v DC. Output ripple voltage **ΔV** is considered not more than 0.5% of required output. The buck converter is designed to operate in continuous current conduction mode.

Duty Cycle, D = $\frac{V_0}{Vi}$

$= \frac{5\ volts}{12\ volts}$

= 0.25

Where,

V_0 = output voltage

V_i = input voltage

As shown in figure 2.1, a diagram simple buck converter is demonstrated which consists a switching MOSFET, an inductor, a capacitor and a diode. Here, R_1 is denoted as resistive load and V_s is the DC voltage source which is in need to convert.

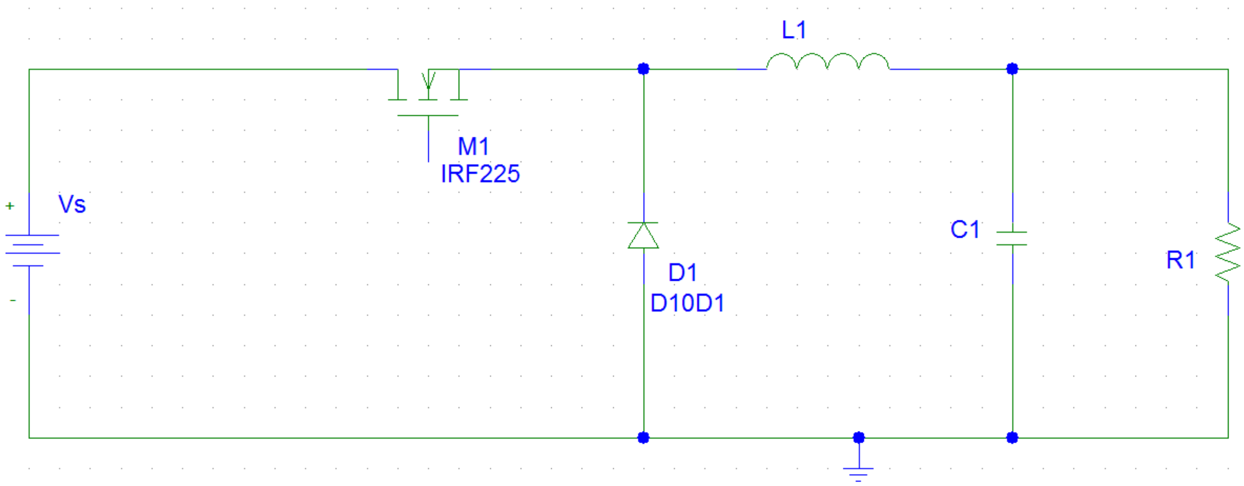

Figure 2.1 Buck Converter Design

2.3 Inductor designing of Buck Converter:

Determining Inductor value is the most crucial thing in designing a buck converter. From figure 2.1, while the MOSFET M_1 is on, current is flowing through the resistive load via the inductor L_1. The main principle of an inductor is to oppose changes in direction of current flow and also stores energy in it and prevent the output of MOSFET current increasing it to peak. Operating buck converter in continuous conduction mode, minimum boundary value must be calculated first. Below this value, it will operate in discontinuous conduction mode. The higher of taking the inductor value, the higher will be the highest output current and it is because of the ripple current reduction. In general, by taking of lower inductor values, the solution size will be smaller. It can be also mentioned that the chosen inductor always should have a higher current rating because the current will be increased with decreeing inductance. Also, saturation level should be taken into account when we want to use that device. For high frequency application we can use Toroid component inductor [10].

The current flowing through inductor will be,

$I = V_0R$

For ease of theoretical calculation, one kilo ohms resistor is used as resistive load. From Ohms law, the required output current is measured as, $I_0 = \frac{Output\ voltage, V_0}{load\ resistance,\ \ R} = 5$ mA (mili Ampere)

Minimum inductance needed, $L_{min} = \frac{(1-D)*R}{2f}$

$=11.68$ mH (mili Henry)

The close value we can use is 12 mili Henry inductor, practically.

The deviation in current, $\Delta i_L = \frac{(V_{in}-V_0)}{L}DT$

$= 9.99$ mA (mili Ampere)

Figure 2.2 shows the waveform of inductor current. This current splits between the output capacitor and the resistive load. When the MOSFET M_1 is open, current flow to the output which ensures the consistency at output.

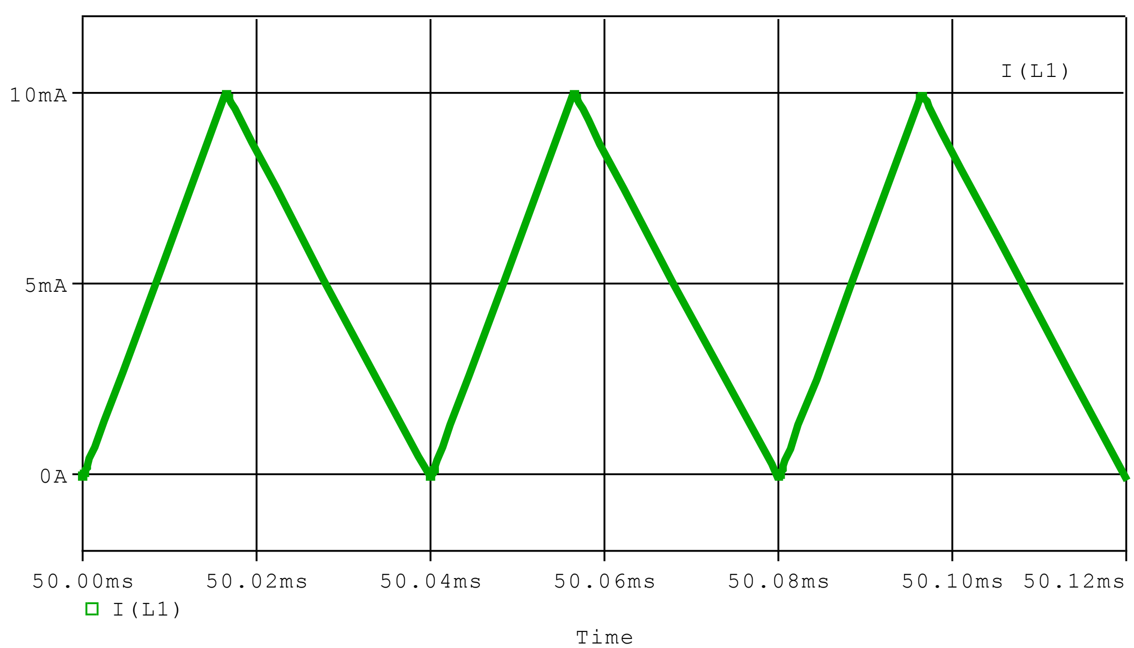

Figure 2.2: Inductor current in buck converter

2.4 Capacitor Designing Of Buck Converter:

Capacitor in buck converter is used to smooth and stabilize inductor current by minimizing voltage overshoot and ripple. Maximum allowed output voltage ripple is specified before starting the designing. Ceramic Capacitor can be a good choice for smoothing inductor current in this case. If the converter has an outer compensation, it can be used any capacitor values above the recommended minimum used in this circuit.

Equation for capacitance in terms of specified voltage ripple, C = $\frac{(1-D)}{8L*\left(\frac{\Delta_{V_0}}{V_0}\right)*f^2}$

$$= 2\ \mu F$$

Where, D = Duty ratio

L = Inductor

$\frac{\Delta_{V_0}}{V_0}$ = Output ripple voltage

f = Operating Frequency

Capacitor selection also depends on output transient response which determines how fast it catches up with deviation of current. Figure 2.3 shows the ripple current across capacitor. Notice that, the average of capacitor current is near zero because of its charging and discharging phenomenon.

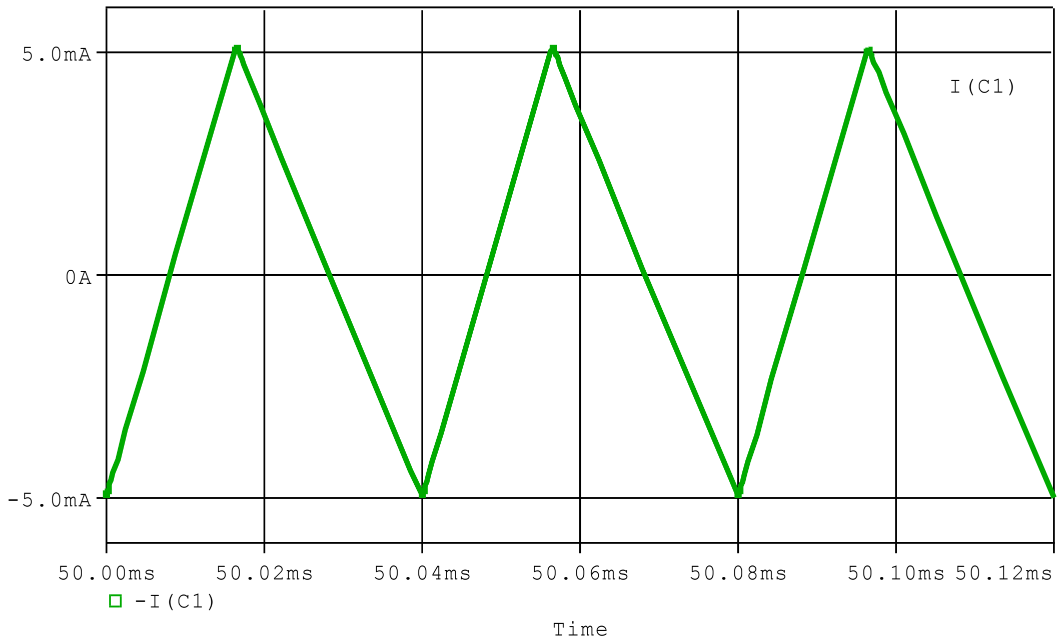

Figure 2.3: Capacitor current in buck converter

2.5 Switch Selection:

Current drifting from source side to load side, is controlled by two switches i. e. the diode and transistor or MOSFET. For designing conventional dc-dc buck converter, one IRF225 single N-channel MOSFET Switch selection is one of the important endeavor in designing buck converter.In buck converter, and one D10D1 fast recovery diode are selected. Power dissipation criteria of the diode must be acknowledged to reduce power loss. Usually Schottky diode is used for its low voltage drop characteristics. Instead of diode, another low side power MOSFET can be integrated as a switch. Low voltage drop results less power dissipation and higher efficiency leads MOSFET easier to use over diode. Here, for designing conventional dc-dc buck converter one IRF225 N-channel MOSFET is used as active controlling switch and a diode D10D1 is selected. Apart from that, while working with synchronous interleaved buck converter, MOSFET gets priority over diode.

2.6 Load Resistance of Buck Converter:

One kilo Ohm 0.025 Watt resistor as a resistive load is added to simplify the simulated parameter. The total current flow across load resistance (i_R) is the difference between inductor current and capacitor current (i_L-i_C). The ultimate goal of designing buck converter is to reduce ripple across the load and continuously regulate current on it with a closed feedback loop. In the open loop analysis, only the ripple reduction parameter are analyzed. Effect upon Arbitrary loading is discussed on later section. Figure 2.4 indicates the current waveform across load resistance. Due to fixed load consideration, a fixed current is flowing to the load keeping the output voltage constant on average.

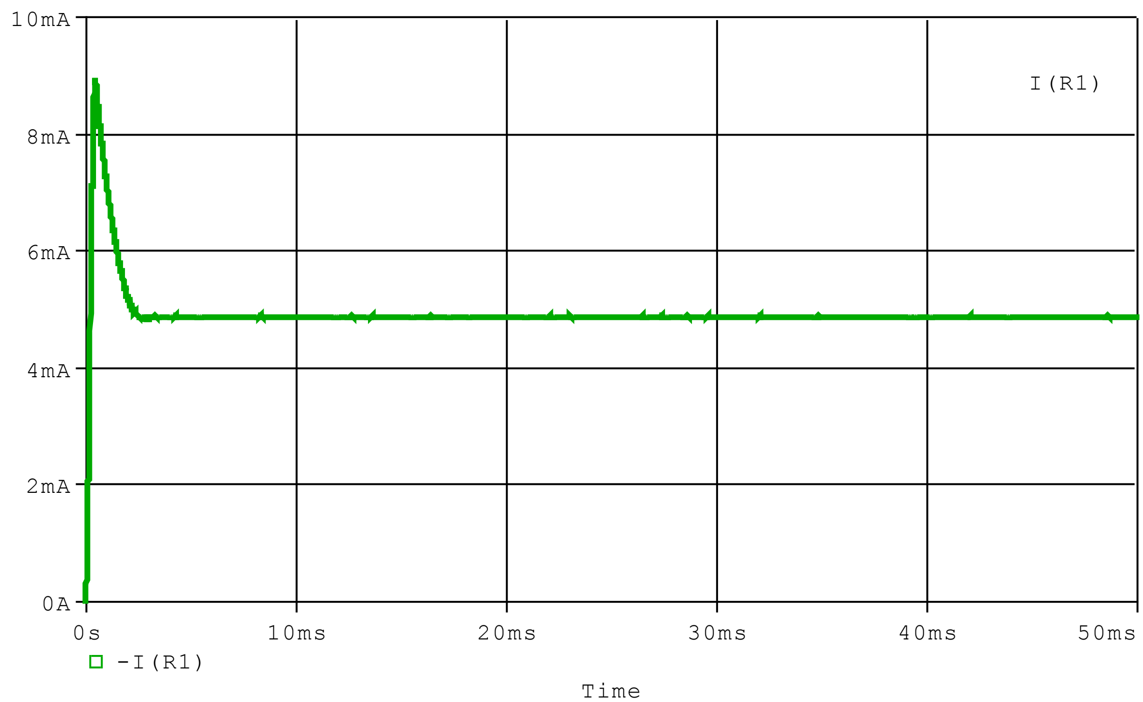

Figure 2.4:waveform of current across resistance

Here, on figure 2.5 shows the waveform of output voltage across load resistance. The transient time needed to achieve steady state depends on capacitor size.

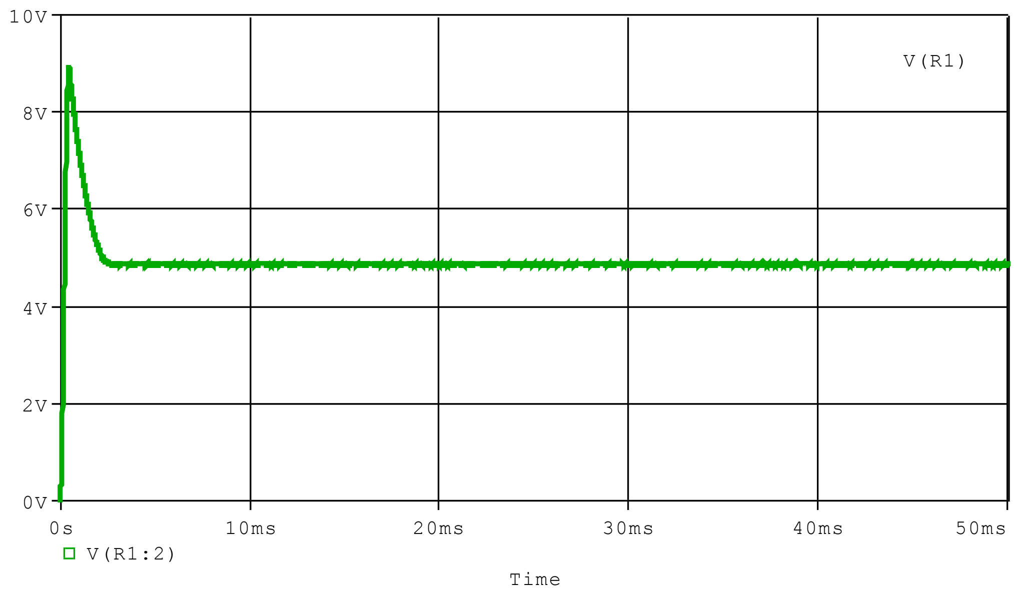

Figure 2.5 Waveform of output voltage across resistance

Table 2.1 shows the calculated parameters regarding conventional DC-DC buck converter.

Table 2.1 Designing parameters of buck converter

DC input voltage (V_s)	12 V
Desired output voltage (V_0)	5 V
Duty ratio (D)	0.41
Frequency (f)	25 kHz
Time period (T)	40 µs
Load resistance (R_1)	1 k-Ohm
Load current (I_L)	5 mA
Threshold inductance (L_{min})	11.68 mH
Capacitance (C_{min})	2 µF
Output voltage ripple (ΔV_0)	0.5%

2.7 Effects on Buck Converter in Continuous-Discontinuous Mode:

The effects on buck converter operating in continuous and discontinuous mode can only be obtained by taking the nearest data of boundary values. For that purpose, inductor and capacitor need to be redesigned to make the converter operate in continuous and discontinuous mode. To operate buck converter in more stable in continuous conduction mode, 30% increase of its threshold values of LC components are assumed for the analysis.

2.7.1 Effects of Continuous Conduction Mode:

In earlier chapter, the LC components of buck converter is designed using threshold values to operate it in continuous conduction mode. To examine the effects more precisely, LC components are redesigned by increase the values by 30 percentage

After increasing the inductor value by 30 percentage,

Inductance on CCM,

L_{con} = 30% of L_{min} + L_{min}

= 15.18 mH

Figure shows the effect due to the change in LC components. The inductor current influenced inductor current to raise up. Moreover, the current ripple shrinks which helps to achieve smooth output current.

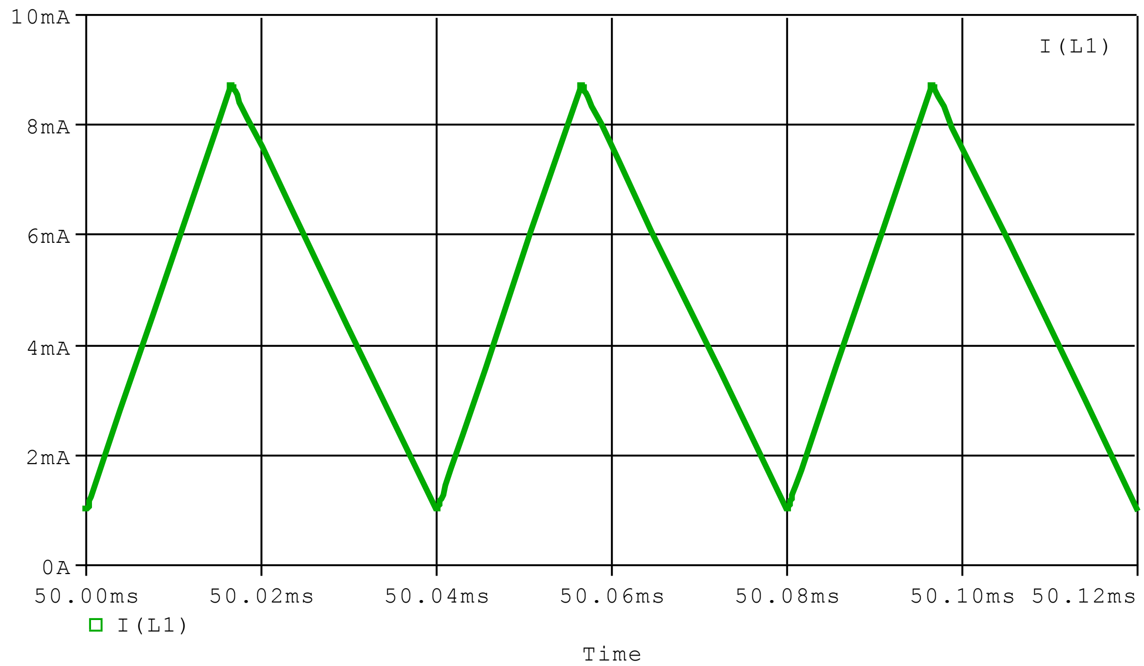

Figure2.6: Ripple current waveform across inductor in CCM mode

Change in current through inductor, $\Delta i_L = \frac{(V_s - V_0)}{L} DT$

= 7.67 mA (mili Ampere)

Value of capacitance after 30% inductance increase, $C = \frac{(1-D)}{8L*\left(\frac{\Delta V_0}{V_0}\right)*f^2}$

= 1.53 μF (micro Farade)

Size of capacitor has also been reduced. Figure indicates the current variation across the capacitor. The average value of the capacitor current is also zero like mentioned in 2.4 section.

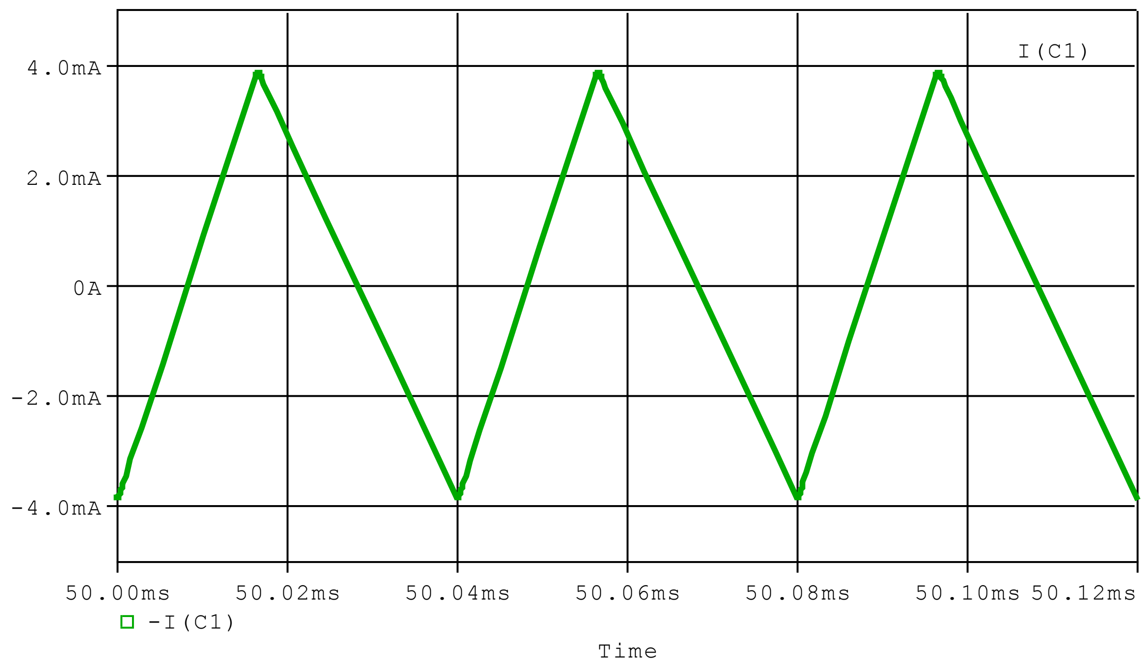

Figure2.7: Current waveform across capacitor in CCM mode

As a result of increasing low pass filter component values, it is observed in figure that smaller time is required to achieve the steady state faster than the threshold values.

2.7.2 Effects on Buck Converter in Discontinuous Mode:

During continuous conduction period, inductor current never reaches zero value before the end of the period. Apart from that, in discontinuous conduction mode, the inductor currents falls to zero ever before the period ends. The converter becomes load dependent then.

To operate the buck converter in discontinuous conduction mode, it is opted 30% less than the threshold values of LC components obtained in section 2.3.

Inductance in discontinuous conduction mode, $L_{dis} = L_{min}$ - 30% of L_{min}

$$= 8.18 \text{ mH}$$

The change in current, $\Delta i_L = \frac{(V_S - V_0)}{L} DT$

$$= 14.24\ \mu\text{A}$$

The value of capacitance, C = $\frac{(1-D)}{8L*\left(\frac{V_0}{V_i}\right)*f^2}$

= 2.86 μF

It is observed that the change in inductor current is much smaller than the values calculated in continuous conduction period. [Section 2.3 and 2.6.1]. Yet, discontinuous conduction mode can also be used for certain applications such as for the low-current and loop-compensation applications.

2.8 Load Changing Effect on Buck Converter:

Up to the section 2.7, buck converter operated in open loop considered with fixed 1 kilo Ohm resistance as load which determines output current ripple, output voltage on that particular load. Apart from this, if buck converter encounter frequent load change, those change in load effects upon output voltage and the current draw from input.

To observe load changing effect, few resistors as a load are connected in parallel with time variant switches. These switches determine the amount of loads connected with the converter. The switch timing is designed in such a way that the deviation of current due to load change has enough time to establish its steady state before another time variant switches connects another load. We observes the analyzed output voltage when load is changed on a given time switch. Here, input value is set to 13 volts and the duty ratio is kept constant at 0.4. Switch state is determined at 250, 350 and 650 mili seconds. Load resistors of 600 Ohms, 300 Ohms and 500 Ohms resistor are opted to observe the effect due to load change. Following graphs shows the output voltage corresponding to load changes at different times.

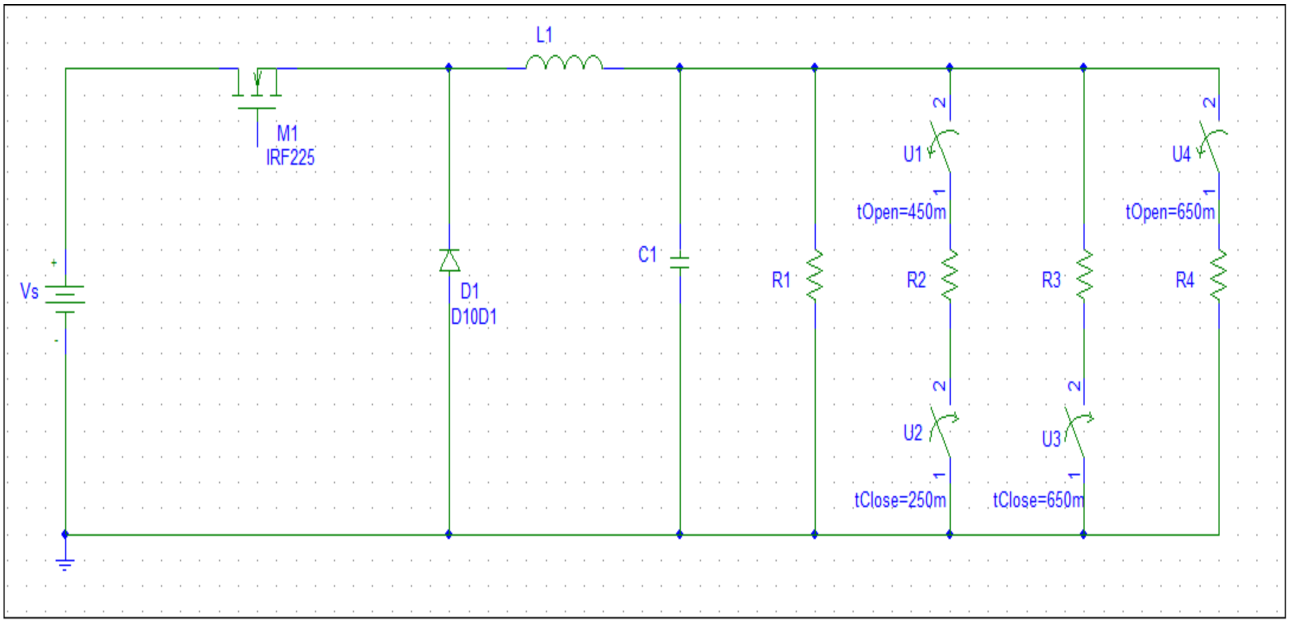

Figure 2.8: Load changing effect on buck converter

Figure has illustrates the effect due to load change. Time variant switches controls the load connected to the converter at specific times. As an example, in between 250 mili seconds and 450 mili seconds interval, load R2 are connected in parallel with R1 load resistor. R4 resistor is also added to the combination as the switch associates with it opens in 650 mili seconds. At transitional time at 250 mili seconds, the output connected load draw more current. As for the open loop buck converter, in cannot regulate the extended output current. So, the waveform of current has shifted up till next transitional time.

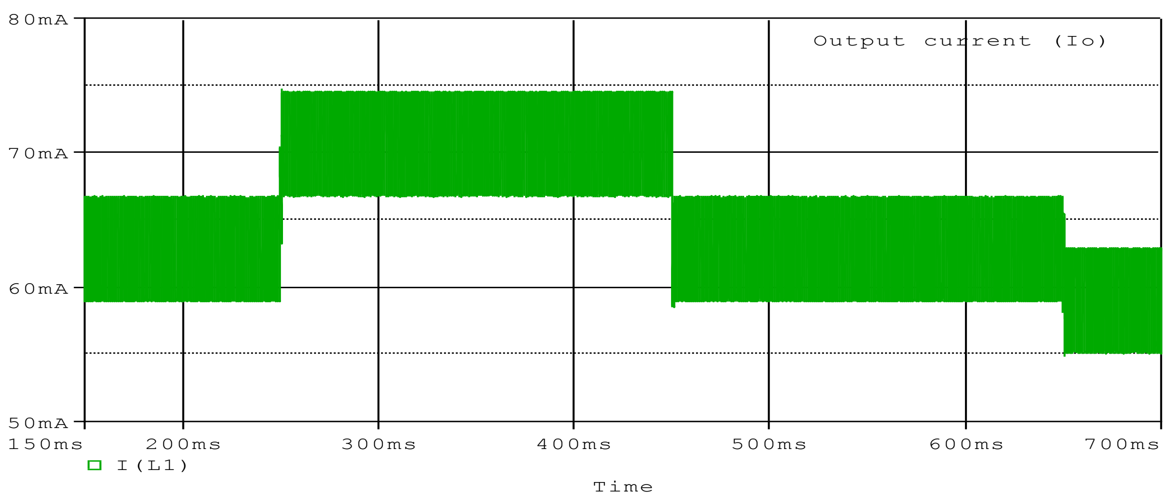

Figure2.9: Current waveform effect due to load change

2.9 Isolation System of Buck Converter:

When one part of circuit concerns with high currents or frequencies are needed to be protected from another part of the circuit, isolation is a kind of option [11]. There are several methods to make circuits isolated. Optocoupler system is considered as isolation for the buck converter.

When using voltage controlled voltage source, gate voltage cannot be controlled with ease. Also, it has no protection against high current due to the induction coil. To protect other components due to this high current, isolation is necessary. There are several methods to make a system isolated. Here, isolation is done by using optocoupler. An optocoupler connects input and output sides with a beam of light modulated by input current. It transforms useful input signal into light, sends it across the dielectric channel, captures light on the output side and transforms it back into electric signal. We use double emitter follower as buffer to source and sink the required gate current to maintain V_{gs} greater than the input.

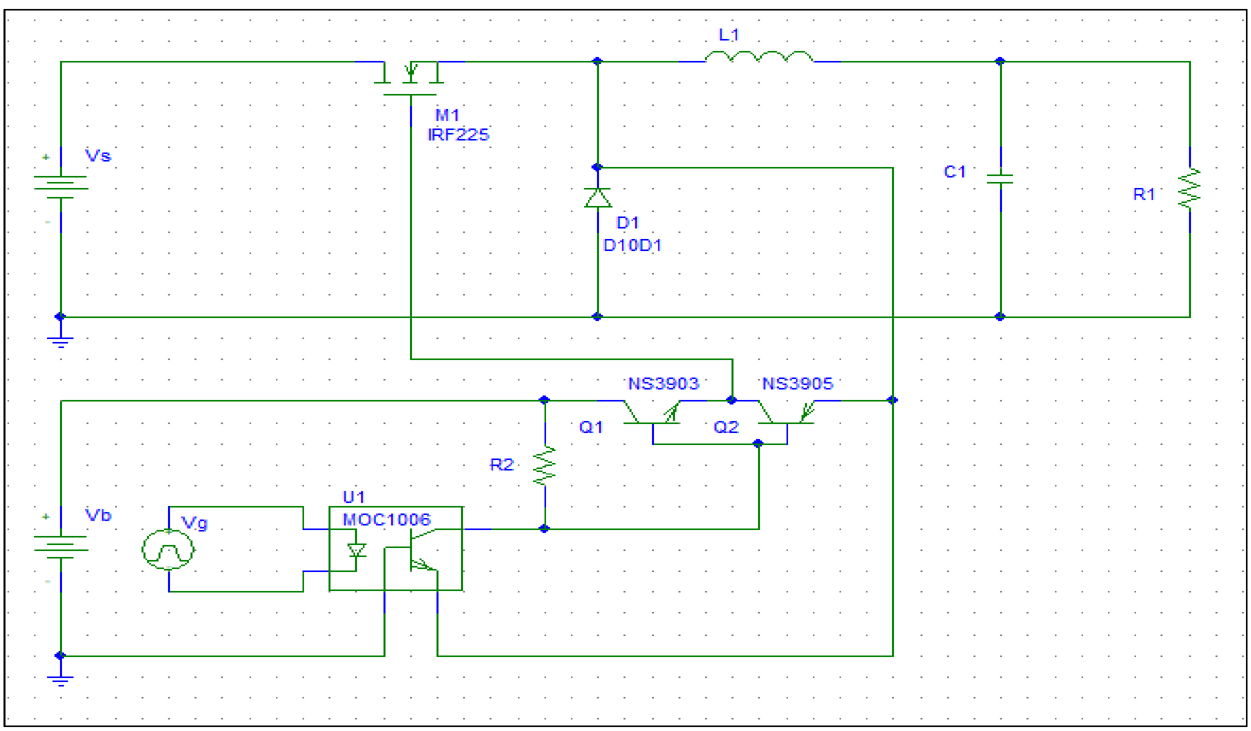

Figure 2.10: Optoisolated buck converter

2.10 Conclusion:

In this chapter LC components are designed considering output ripple voltage in both continuous and discontinuous conduction mode. A method is being used to protect converter circuit from high current flow. The effect on output current due to frequent load change is discussed.

Chapter: 03

Synchronous & Interleaved Buck Converter

3.1 Introduction:

In modern era, the demand of electrical power is increasing in a following rate according to its demand. Typically power supplies issues are size, efficiency, cost, temperature, accuracy and transient response [7]. Architects endeavor to enhance the proficiency without expanding cost, particularly in a high volume customer hardware applications where diminishing force utilization by one watt can spare megawatt from the lattice [7].The main focus is about more efficiency and low power consumption in a system. In order to meet up that higher demand, more efficient devices and effective portable systems are required. So, here we are proposing about interleaved DC-DC buck converter which gives low voltage and high current at its output. Basically, Synchronous buck converter makes that converter more efficient than a non-synchronous buck converter. Later here in this chapter interleaved synchronous buck converter is discussed which tells about the integration of two or more synchronous buck topology. The input current ripple will reduce more and the efficiency is achieved with a certain duty cycle.

3.2 Synchronous Buck Converter:

A typical diagram for a step down regulator is analyzed here where the main components are Q_1, which is the high side MOSFET; the power inductor is used here L_1, and the output capacitor is C_1. Moreover for the synchronous buck topology a low side MOSFET (Q_2) is used where in a non-synchronous buck a power diode (D_1) is used.In non-synchronous buck the diode utilized is a standout amongst the most essential determinations as a power diode are the turnaround voltage, the forward voltage drop, and the forward current. Here forward voltage drop should be small for higher frequency. When the duty cycle is low the diode operates which conducts more current than the high side MOSFET. So lots of consideration are taken place here, However to avoid this problems the diode is now replaced with a MOSFET and which makes the converter a synchronous buck converter. The main advantages of a synchronous rectifier the voltage drop across the MOSFET is very low comparatively the voltage drop of the diode. If there is no changes in current label, the lower voltage drop translates into less power dissipation which makes a higher efficiency than the non- synchronous buck converter.

Later in Fig 3.1 shows that the synchronous buck converter which have two MOSFETS as a switch in high side and the low side. Here the inductor current is worked as an output current and the current ripple is less than the non-synchronous buck converter. Different duty cycle is used for calculating the higher efficiency in this concern. The input voltage is fixed in this case where as the input current, output voltage, output current is varying according the change of different duty cycle.

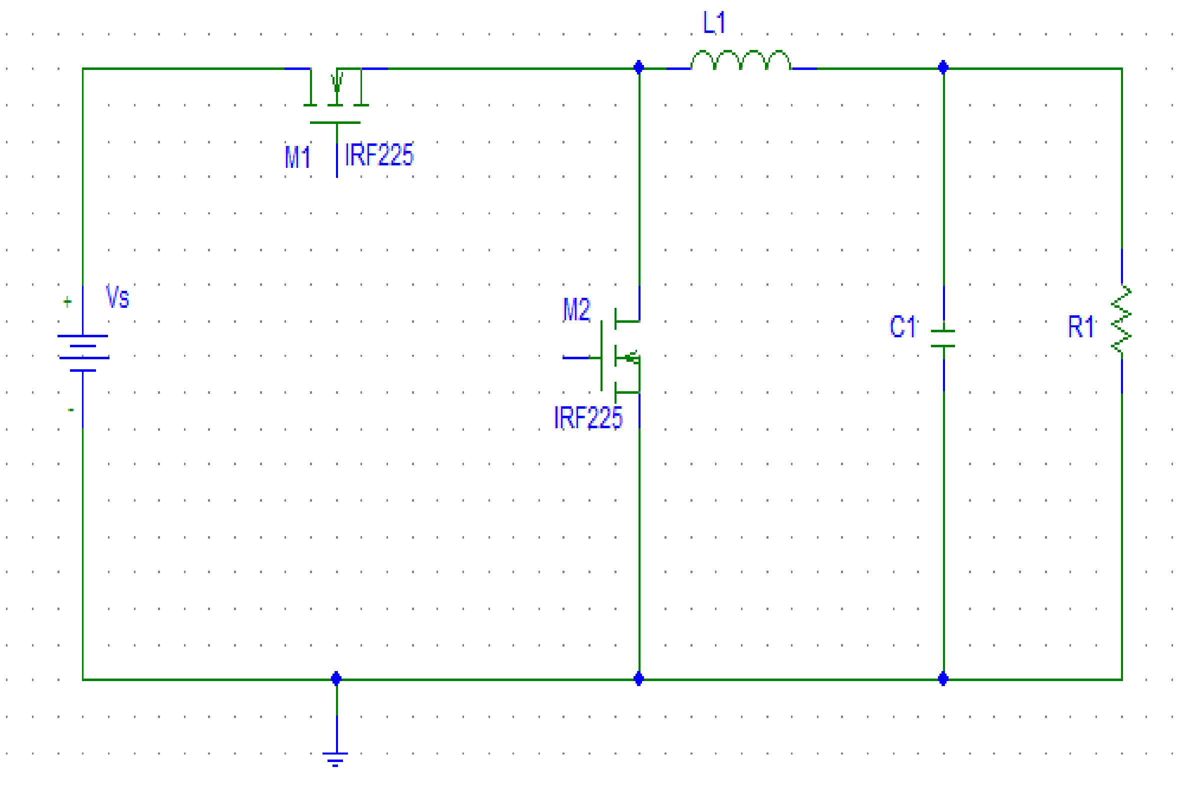

Fig 3.1: Synchronous Buck Converter

Table 3.1 Parameters for Synchronous Buck Converter:

$V_1(V_{dc})$	12V
$V_2(V_{pulse})$	20V
Time delay (TD)	0 s
Rise time (TR)	0.4μs
Fall time (TF)	0.4μs
Pulse width (PW)	10 μs
Period (PER)	40μs
L(Inductor)	11.8mH
C(Capacitor)	2μs
R (Resistor)	1K

3.3 Data Analysis of Synchronous Buck Converter:

In Table 3.2 for Synchronousbuck converter we have seen that the input current is increasing towards the increasing the ratio of output voltage and input voltages which is called the duty cycle. The more the duty cycle is increased the more the output voltage and the output current is increased. The output voltage is changing in a regular way according to the input current and the duty cycle. At the end we can see that the output voltage is highest at the highest duty cycle at 0.9 and the output current is highest on that specific duty cycle.

Furthermore, in Table 3.3 the efficiency is not fixed while we are increasing the ratio of duty cycle. For the synchronous buck converter, the efficiency is higher when the duty cycle is used 0.72 and it is 99.97%. After increasing the duty cycle simultaneously, the input power is increasing continuously and the output power is following similar. At duty cycle 0.1 to 0.2 the input power is increased by double. Moreover, from one duty cycle to another duty cycle the differences of input power is decreased when we are increasing the ratio of output and input. However, the output power differences are increased when we increased the duty cycle. The efficiency is gradually increasing after the duty cycle 0.1 however the efficiency increased little bit after the duty cycle 0.2 which is at 0.3. Then it is increased continuously till 0.74 then it decreased again at 0.76. Again it is being increased in a while then again decreased. We can see that the changes of efficiency is nor regular in this case. In below, we have shown graphs comparing about duty cycle, input current, output current, efficiency measurement on each other.

Table 3.2 Data for Synchronous Buck Converter:

V_{in} (V)	Duty Cycle	V_{out}	I_{in}(mA)	I_{out}(mA)
12	0.1	1.6	0.35	2
	0.12	1.75	0.43	2.11
	0.14	1.92	0.512	2.28
	0.16	2.18	0.623	2.57
	0.18	2.39	0.746	2.89
	0.2	2.6	0.86	3.12
	0.3	3.7	1.59	4.54
	0.4	4.9	2.71	5.98
	0.5	6.0	4.06	7.44
	0.6	7.1	5.67	8.88
	0.7	8.5	7.36	10.2
	0.72	8.80	7.68	10.47
	0.74	9.06	8.08	10.67
	0.76	9.30	8.60	11.02
	0.78	9.56	8.93	11.20
	0.8	9.8	9.58	11.5
	0.9	10.5	12.06	12.93

Table 3.3 Efficiency Data for Synchronous Buck Converter:

Duty ratio	P_{in} (mW)	P_{out} (mW)	Efficiency (%)
0.1	4.2	2.992	71.238
0.12	5.16	3.692	71.55
0.14	6.144	4.377	71.24
0.16	7.476	5.602	74.93
0.18	8.952	6.90	77.07
0.2	10.32	8.112	78.60
0.3	9.088	16.798	88.03
0.4	32.52	29.302	90.10
0.5	48.72	44.64	91.62
0.6	68.04	63.09	92.72
0.7	88.32	86.78	98.25
0.72	**92.16**	**92.136**	**99.97**
0.74	96.96	98.02	99.70
0.76	103.2	94.77	91.83
0.78	107.16	107.07	99.91
0.8	113.76	112.79	99.14
0.9	144.72	135.765	93.81

3.4 Waveform Analysis of Synchronous Buck Converter:

From the Figure 3.2 to 3.5 the graphs show that the input current, output current, output voltages relation with the Duty Cycle. How the input current varies with the duty cycle can be seen here. The input current vs. the duty cycle graph shows the almost non- linear changes of current with the duty cycle. Similarly the output current is also changes with the duty cycle accordingly and it is also applicable for the graph of output current which has been taken from the inductor and it also similarly varies with the changing of duty cycle.

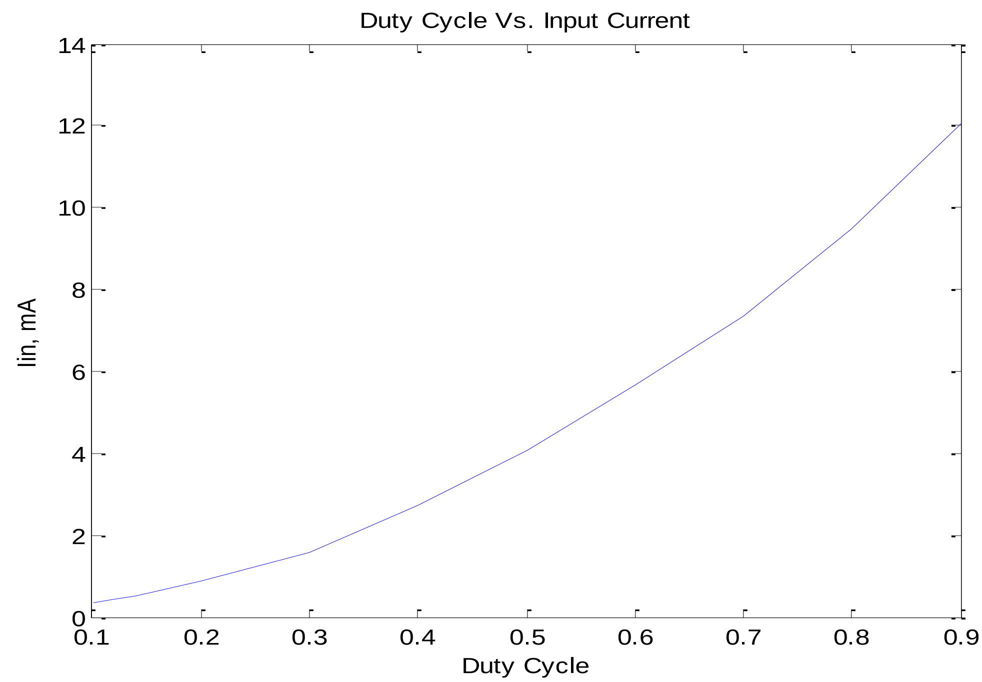

Fig 3.2: Duty Cycle vs. Input Current

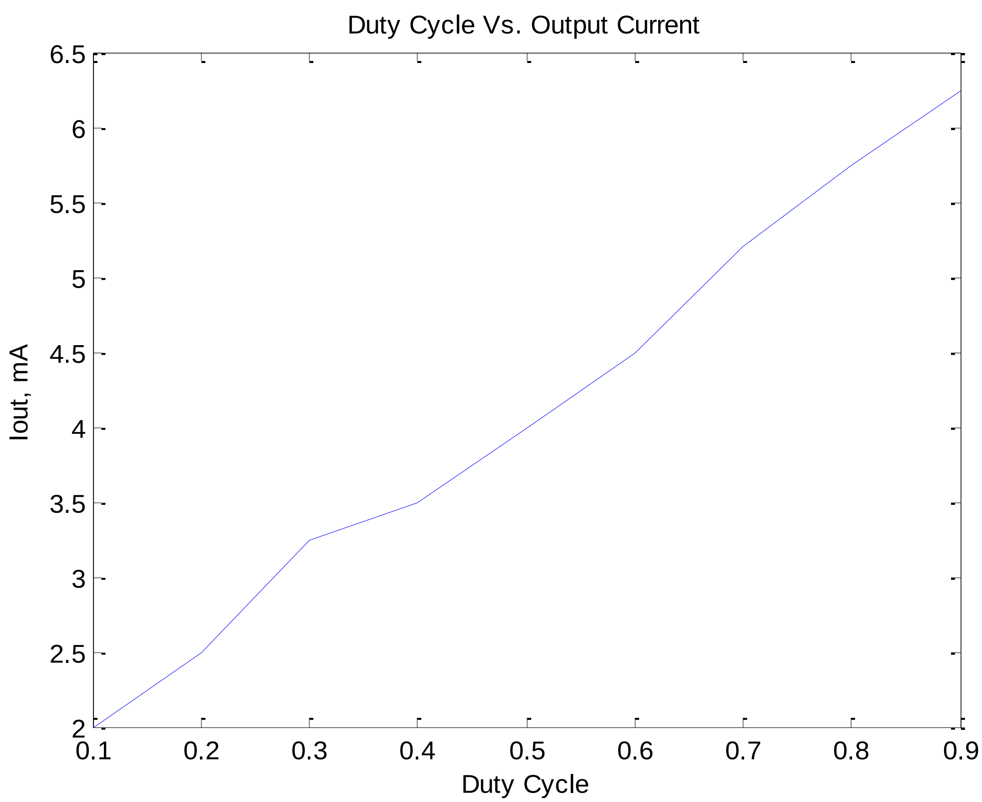

Fig 3.3: Duty Cycle vs. Output Current

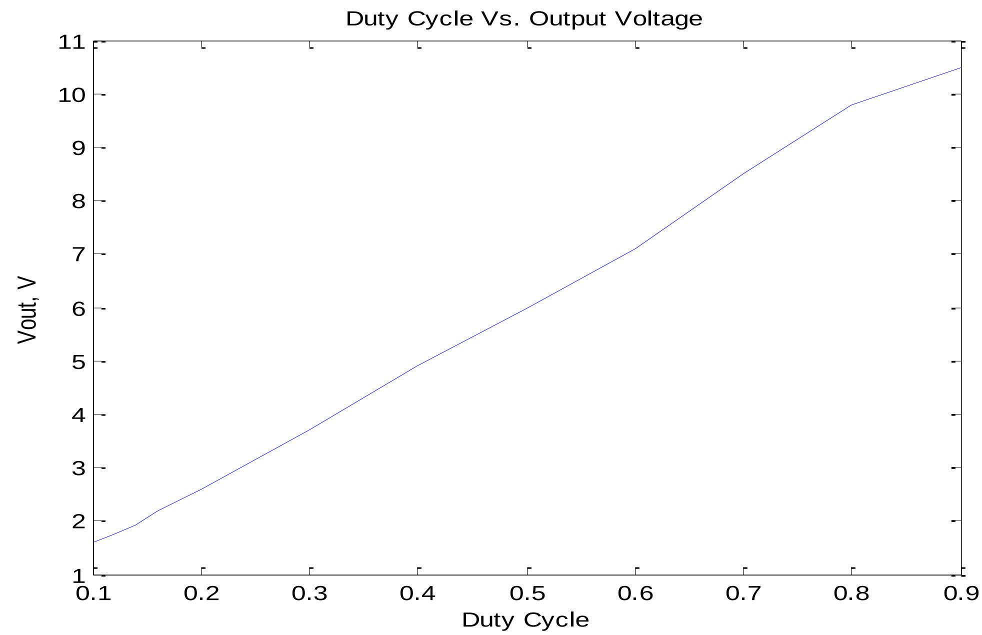

Fig 3.4: Duty Cycle vs. Output Voltage

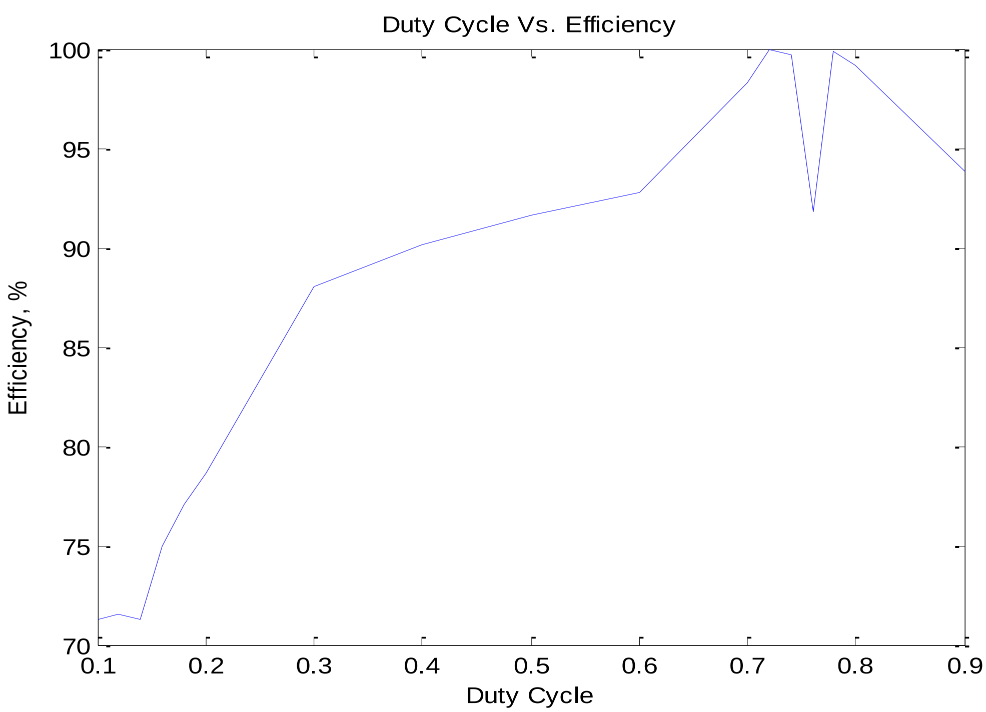

Fig 3.5: Duty Cycle vs. Efficiency

3.5 Interleaved Synchronous Buck Converter:

In figure 3.6 the interleaved buck converter is designed where we can see that the two synchronous buck converter is integrated and which makes the interleaved buck converter. Single phase buck converters woks good at low voltage converter application at a high current that makes a bigger power loss and less efficiency at that circuit [8].Interleaving, also said Multi-Phasing is a technique that is helpful for reducing the size of components of filters. This is an equivalent to a parallel combination of two sets of MOSFETS and the inductor is connected to a common filter capacitor and a load. The switches are operated at 180 degree phase differences which produce inductor current which is accordingly 180 degree phase differences. The current which is measured across the capacitor or the register is the sum of all the inductor currents which were integrated in the circuit. As a result the smaller peak to peak current is achieved that the synchronous buck converter. The variation in current which is coming from the source is also reduced here. Interleaving reduces the ripple current of input and the output side accordingly. Not only this, by interleaving the buck circuit the transitional losses be reduced as well. At Table 3.4 the time delay has been changed for 180 degree phase difference which results a two phase synchronous buck converter. The circuit is analyzed in different criteria for achieving the benefits of interleaved buck converter. From the figure 3.7 to 3.10 for a particular Duty cycle which here is taken 0.3 the output voltages, output current and the input current and the average input current graphs are taken which tell the general aspects of interleaved synchronous buck converter.

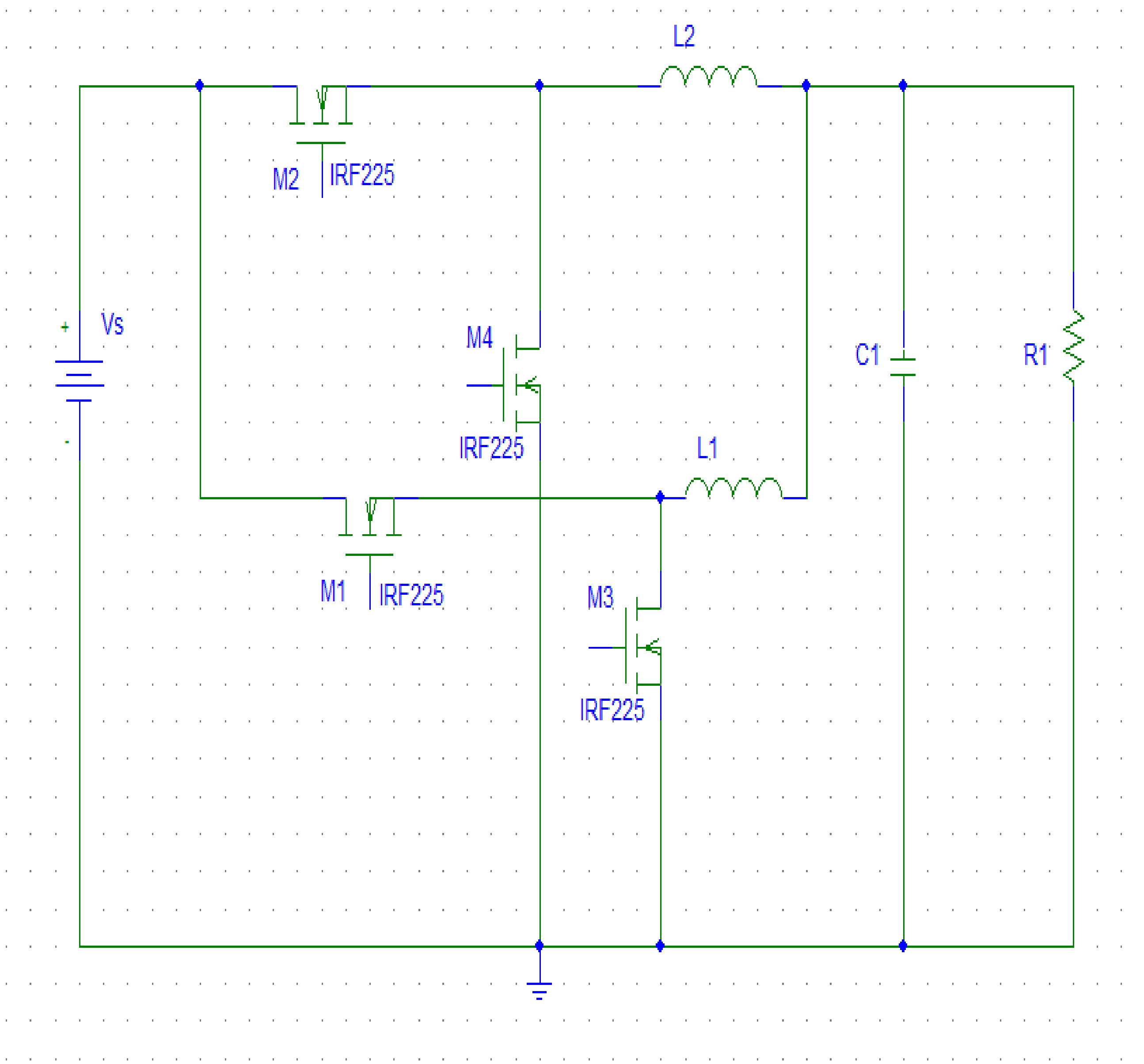

Fig 3.6: Interleaved Synchronous Buck converter

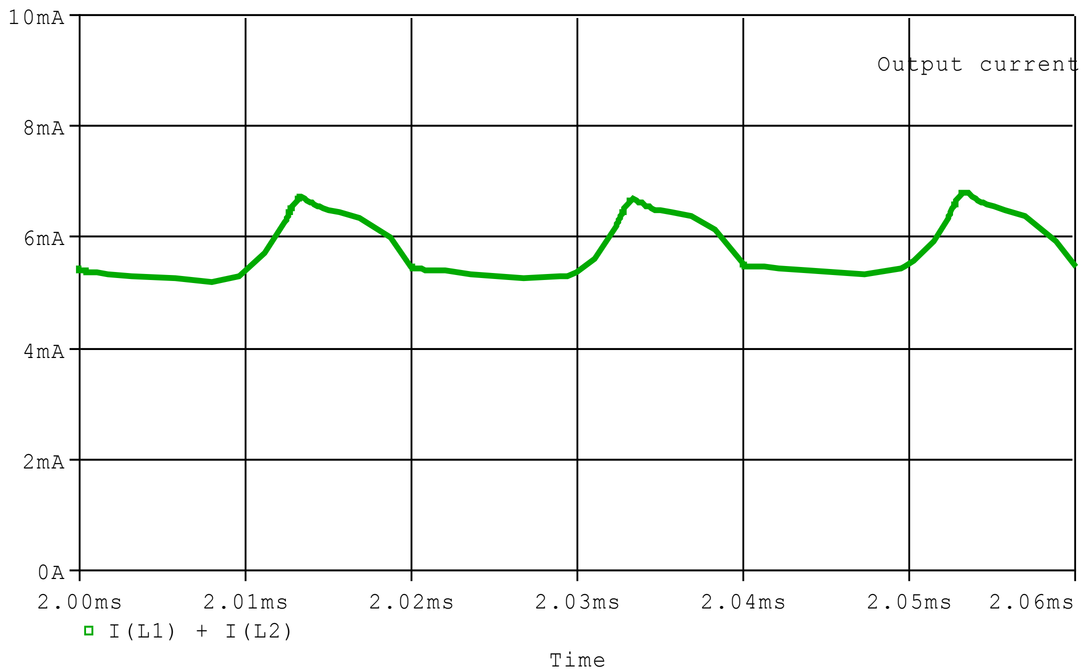

Fig 3.7: Output current wave shape of two interleaved

Synchronous buck converter

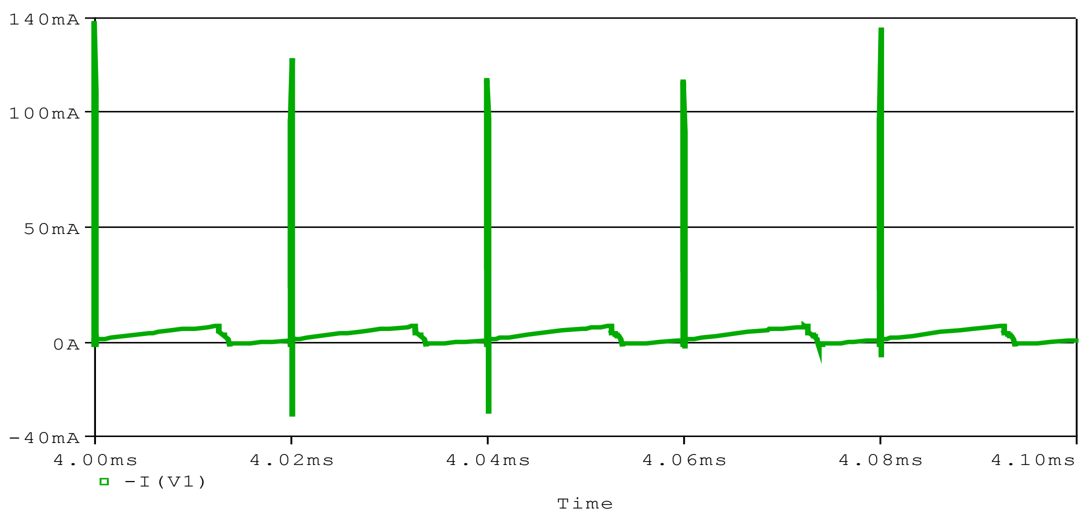

Fig 3.8: Input current wave shape of two interleaved synchronous buck converter (a)

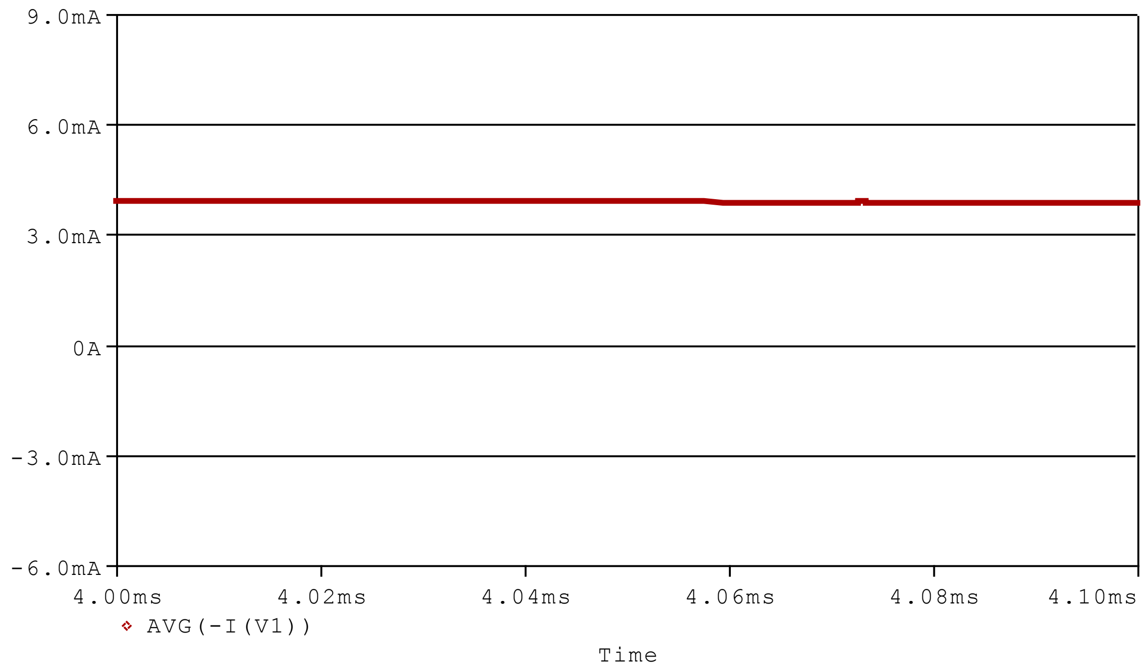

Fig 3.9: Average Input current wave shape of two interleaved synchronous buck converter (b)

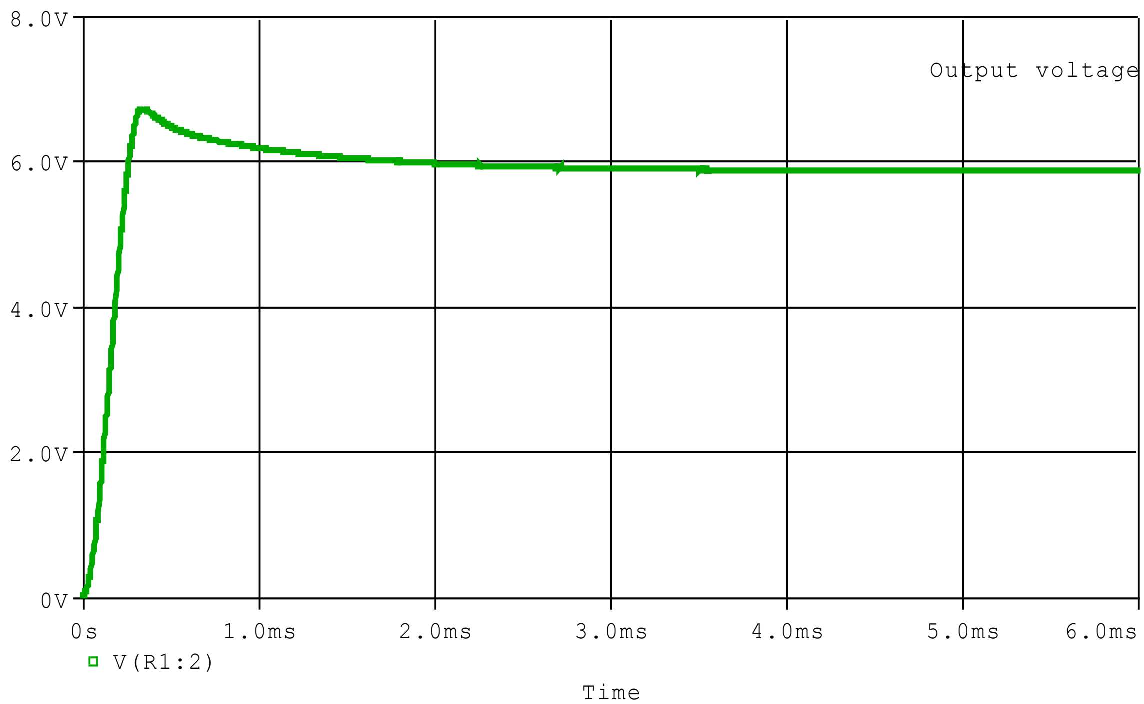

Fig 3.10: Output voltage of two interleaved synchronous buck converter

Table 3.4: Parameters for Interleaved Synchronous Buck:

$V_s(V_{dc})$	12V
V_2 (V_{pulse})	20V
Time delay (TD)	20μ
Rise time (TR)	0.4μ
Fall time (TF)	0.4μ
Pulse width (PW)	10μ
Period (PER)	40μ
L(Inductor)	11.8m
C(Capacitor)	2μ

3.6 Data Analysis of Interleaved Buck Converter:

In the table 3.5 it is seen that the input current is increased according to the increases of duty cycle. Here the output current and the output voltage is also increases by increasing the duty cycle. In the single phase synchronous buck converter, on the duty cycle 0.1 the input current was 0.35 mA where in double phase or multiphase synchronous buck the input current increases to 0.9 mA. The ripple current is been reduced. The output voltages was 1.6V in single phase where for double phase it increased by 1.1V for a particular duty cycle. Output voltage is achieved here highly for a particular duty cycle. Finally at 0.5 duty cycle the input current is 4.84mA where as in single phase 4.06 mA. Similarly the output voltage is 6.50V where in single phase it was 6V. The output current is also increases by 1.05 mA. The output current ripple is decreased by increasing the number of phase in multiphase synchronous buck converter.

In the Table 3.6 the power dissipation is calculated here in different duty cycle. According to the data the input and output power continuously increases by the increasing of duty cycle. From the duty cycle 0.1 to 0.2 the input power is almost 2.5 times increases similarly the output power is increased by three times here. Then the output power is not very much increased here. The highest efficiency is being achieved at 0.24 duty cycle which is almost 99.26 %. The most stable high frequency is calculated in between 0.2 to 0.3 duty cycle. From 0.3 to 0.4 the efficiency reduced highly.

Table 3.5 Data for Interleaved Synchronous Buck:

Duty Cycle	**I_{in}(mA)**	**I_{out} (mA)**	**V_{out} (V)**
0.1	0.9	3.23	2.7
0.12	1.06	3.57	2.98
0.14	1.28	4.01	3.33
0.16	1.57	4.49	3.69
0.18	1.75	4.85	4.04
0.2	2.1	5.36	4.4
0.22	2.29	5.69	4.74
0.24	2.60	6.11	5.07
0.26	2.86	6.4	5.27
0.28	3.16	6.67	5.54
0.3	3.6	7.10	5.9
0.4	4.25	7.89	6.25
0.5	4.84	8.49	6.50

Table 3.6 Efficiency Data for Interleaved Synchronous Buck:

Duty Cycle	P_{in} (mW)	P_{out} (mW)	Efficiency (%)
0.1	10.8	8.72	80.74
.12	12.72	10.63	83.56
.14	15.36	13.35	86.91
.16	18.12	16.56	91.39
.18	21.0	19.59	93.28
0.2	25.2	23.58	93.58
0.22	27.48	26.97	98.14
0.24	**31.2**	**30.97**	**99.26**
0.26	34.32	33.72	98.27
0.28	37.92	36.95	97.44
0.3	43.2	41.89	96.96
0.4	75	49.31	65.74
0.5	78	55.18	70.75

3.7 Waveform Analysis of Interleaved Synchronous Buck Converter:

From the Figure 3.11 to 3.14 it can be seen that the input current, output current, output voltages all are changes in a very similar way. It shows the nonlinear changes of data by increasing the value of duty cycle. The highest efficiency is achieved at 0.24 duty cycle and it decreased again in an irregular way.

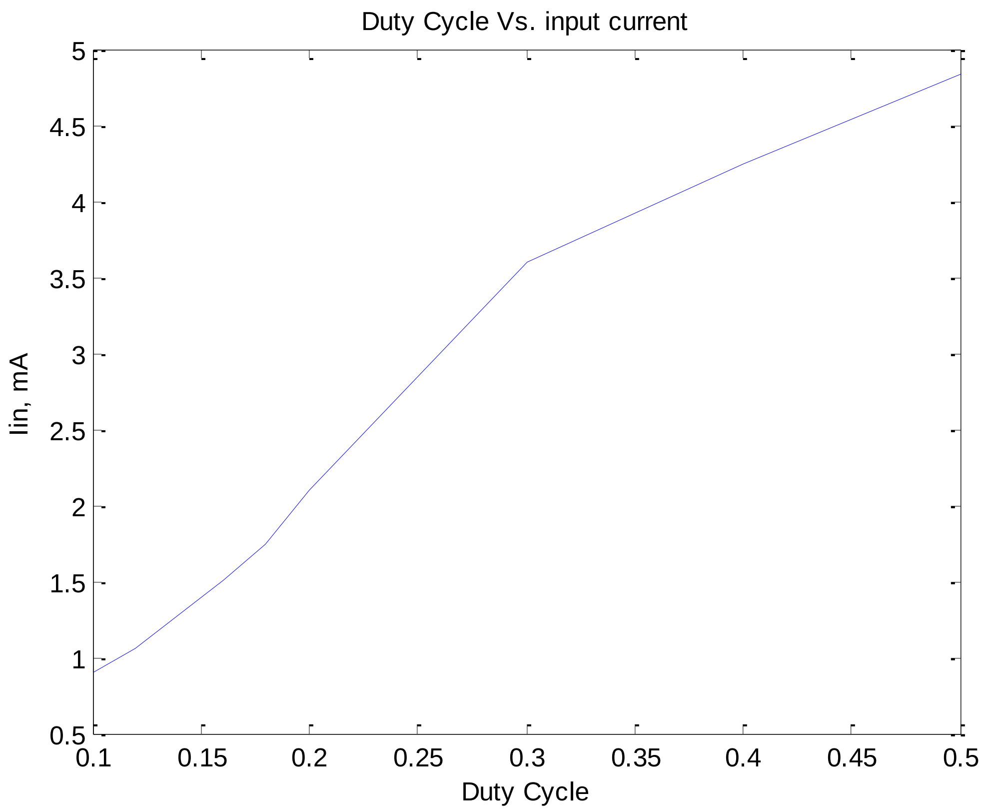

Fig 3.11: Duty Cycle vs. Input Current

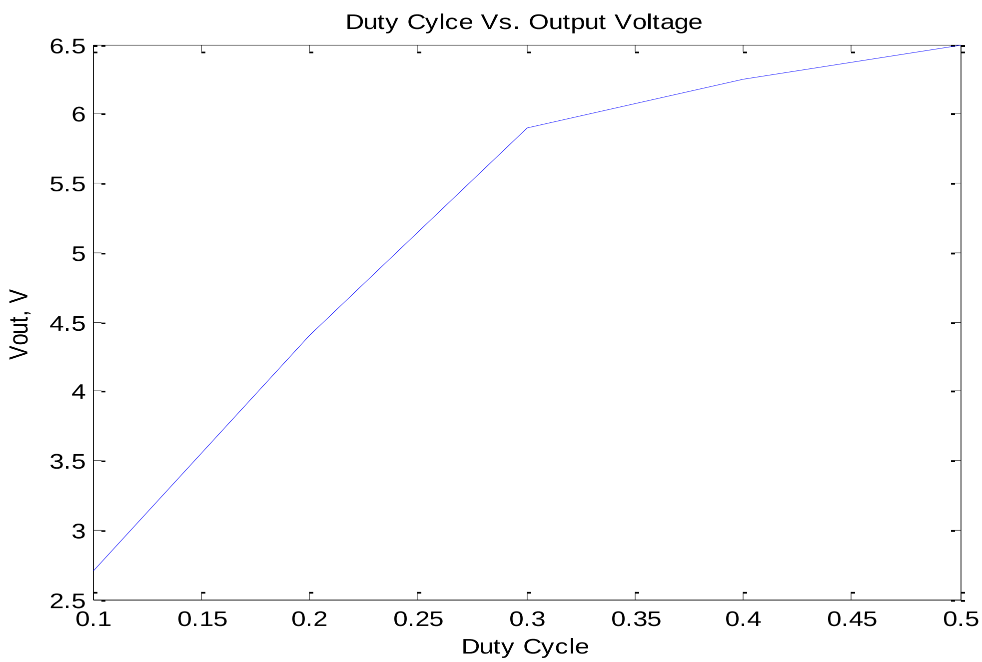

Fig 3.12: Duty Cycle vs. Output Voltage

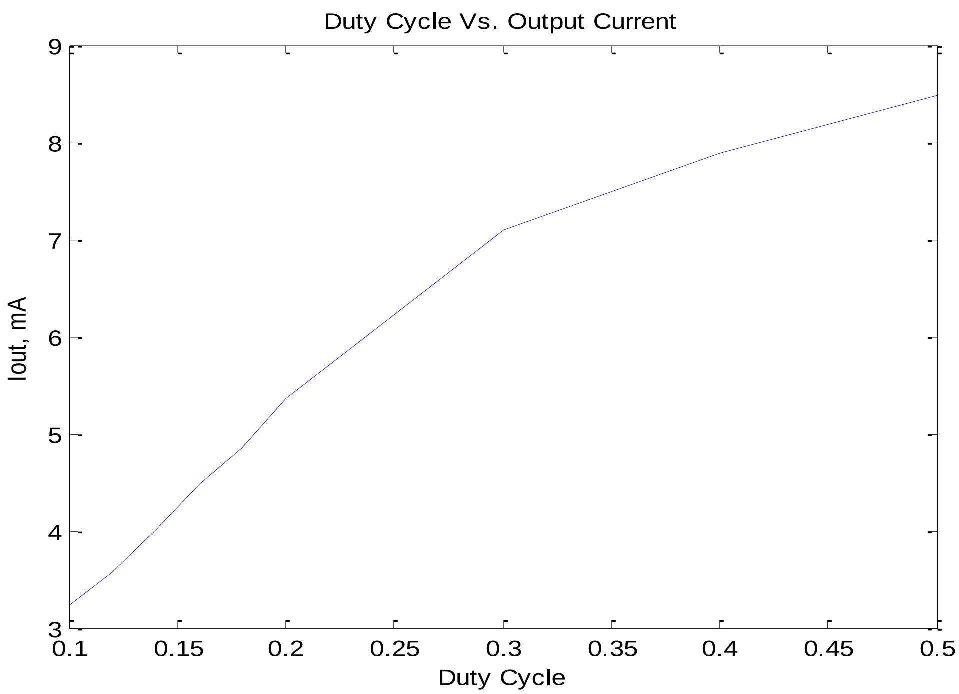

Fig 3.13: Duty Cycle vs. Output Current

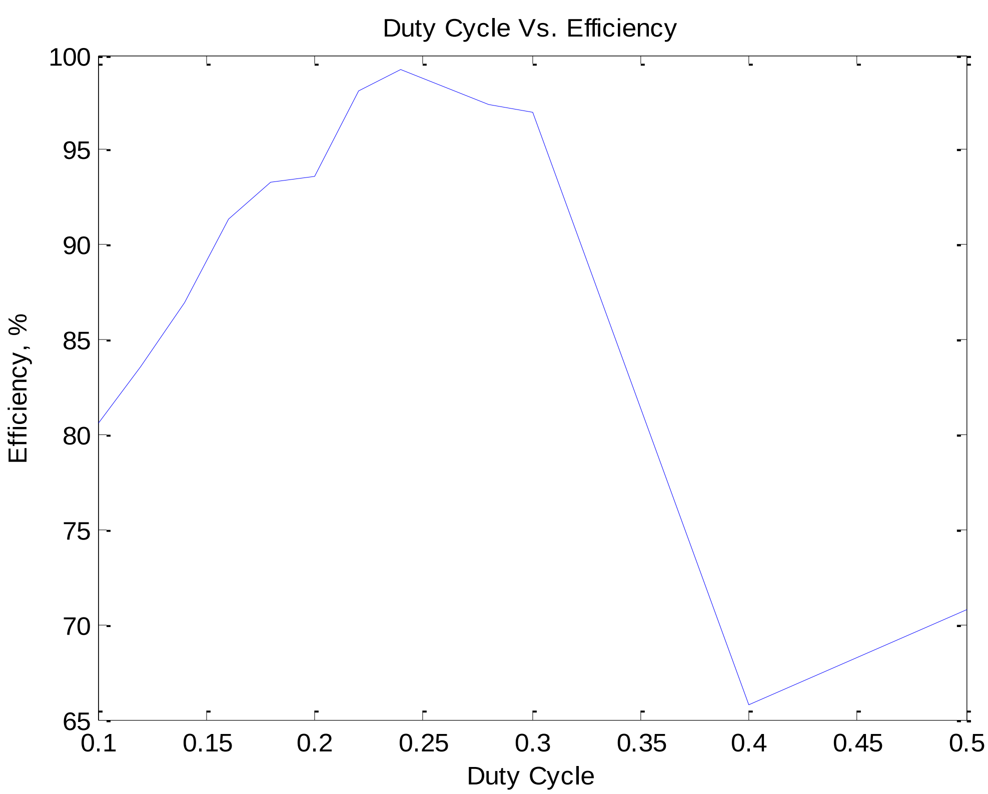

Fig 3.14: Duty Cycle vs. Efficiency

3.8 Ripple Current Analysis of synchronous and Interleaved Buck Converter:

One of the main purpose of giving priority to interleaved buck converter is the ripple current reduction. The ripple current loss maintain the converter more effective and efficient than the normal synchronous buck converter. As in modern power electronics the efficiency is more when the power dissipation should be less and the ripple current should be less in that particular circuit. By Interleaving the buck converter makes that converter more efficient and the power dissipation is less through the switches. In the table 3.7 and 3.8 it can be seen that the ripple current is less in multiphasing buck where the ripple current is more at normal synchronous buck converter. By increasing the duty cycle of synchronous buck converter the ripple current is increasing for the first half which is from 3.89mA to 7.95mA of the all duty cycle and later it is decreasing in the last half which is from 6.9mA to 4.43 mA of the overall duty cycle. Furthermore, in figure 3.15 the waveform shows that ripple current is reduced in the case of interleaved buck over synchronous buck when the duty cycle is varying.It also shows that for interleaved buck converter in the very similar way the ripple current is decreasing for the first half of the duty cycles which is from 2.84 to 1.54 mA and later the ripple current again increased from 2.62 to 3.47mA. From these data it can be easily analyzed that the ripple current is less in interleaved buck converter than the synchronous buck converter.

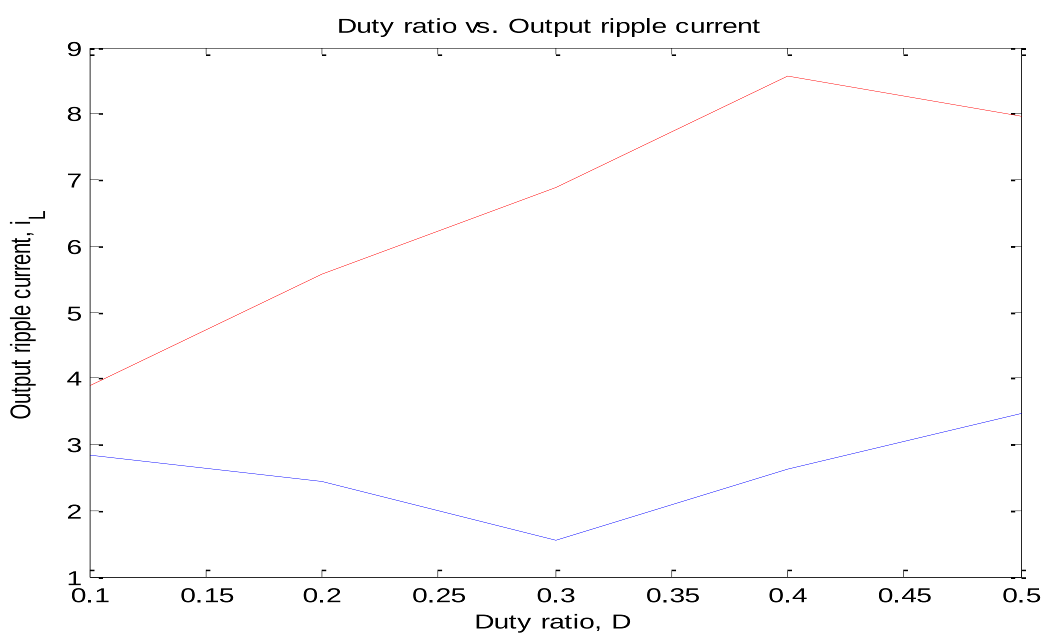

Fig 3.15: Duty Ratio vs. Output Ripple Current for Synchronous and Interleaved Buck

Table 3.7 Data for Synchronous Buck Converter Ripple Current:

Duty Cycle	$I_{L\,min}$(mA)	I_{Lmax}(mA)	Δi_L(mA)
0.1	-0.35	3.54	3.89
0.2	-0.48	5.10	5.58
0.3	-0.58	6.31	6.89
0.4	0.56	9.13	8.57
0.5	3.80	11.75	7.95
0.6	3.41	10.31	6.9
0.7	3.00	9.70	6.70
0.8	8.10	14.05	5.95
0.9	27.92	32.35	4.43

Table 3.8 Data for Interleaved Synchronous Buck Converter Ripple Current:

Duty Cycle	$I_{L\,min}$(mA)	$I_{L\,max}$ (mA)	Δi_L(mA)
0.1	0.96	3.80	2.84
0.2	3.05	5.50	2.45
0.3	5.21	6.75	1.54
0.4	4.76	7.38	2.62
0.5	3.94	7.47	3.47

3.9 Merits of Interleaved Buck:

Traditionally, multiphase buck DC/DC converters have been utilized in high-control processor applications, for example, servers or PC work areas and workstations.Application processors are common in small form factor designs such as smartphones and tablets that have had their peak-power demands steadily increase. It has a lot of attention as it has a simple structure and low control complexity. In addition, it is required that the converter operates at high higher switching frequencies. However the higher switching frequencies increases the higher switching losses with turn-on, turn-off and reverse recovery [9]. As a result,the determination of a yield inductor begins to end up an issue in the single-stage buck converter on account of the lower immersion current of the single bundled inductor. In these types of applications, multiphase buck converters can become an attractive option. The methods of controlling for multiphase converters are almost similar to single-phase converters such as voltage-mode or in current-mode PWM control. Multiphase converters additionally have similar highlights found in their single-stage, for example, finished and under-voltage security, impede, in-surge current constraining, auto PFM activity, yield voltage slew-rate control, and enhancement of effectiveness over the heap current range. Again a multiphase converter offers an extraordinary arrangement of favorable circumstances like adaptable stage setups and stage shedding to guarantee the converter is working in an ideal state. A multiphase outline permits noteworthy adaptability while picking the yield inductors, which is critical in little frame factor applications. Another favorable position of a multiphase outline is that the information RMS current is smaller than in its single-phase partner, again due to the interleaved idea of the stages. Multiphase buck converters remain the best decision for high-current outlines, and they normally bolster smaller frame factors. The ripple current is reduced in multiphasing where on the other hand in synchronous buck the ripple current is comparatively high [8]. These converters also have the benefits of higher operating current with smaller inductor sizes; thereby, providing optimal use of board space. The reduction of inductor ripple current and output ripple voltage, along with lower RMS input currents, are benefits of the interleaved phase control. The lower RMS input currents allows smaller input decoupling capacitors, which means even more space savings.

3.10 Interleaved Challenges:

While multiphase bucks offer numerous advantages over single-stage converters, they do exhibit a few difficulties that must be overcome with a specific end goal to effectively implement a design. Adding extra phases to a converter expands bill of materials (BOM) cost and PCB region. The cost of more inductors and FETs must be weighed against the expanded cost of sourcing more vigorous parts and requiring higher capacitor tallies to execute a solitary stage controller. To limit the more prominent board territory required for multiphase arrangements, a harmony between current abilities and warm execution versus general stage number must be found. Maybe the greatest test of multiphase converters is stage administration. With a specific end goal to accomplish the most noteworthy conceivable execution, current must be equitably adjusted between dynamic stages to stay away from thermally focusing on any one stage and give ideal swell cancelation. Furthermore, stages must be immediately added or evacuated amid homeless people to limit outings on the yield voltage. Keeping the stages adjusted requires a more refined controller versus a solitary stage buck. The complexity originates from more sense lines, flag directing, and current sense segments that must be nourished back to the controller keeping in mind the end goal to precisely adjust stage streams. Deciding the stage current is generally done through a present sense resistor in arrangement with every inductor or by using the parasitic DC protection (DCR) of the inductor. These techniques are touchy to segment situation and flag steering making execution troublesome. The sense hardware for each stage requires extra uninvolved parts to give separating and on account of resistor detecting, includes an extra purpose of energy misfortune

3.11 Conclusion:

To conclude, in this chapter the synchronous and interleaved buck converter has been discussed where the efficiency and the response has been analyzed. From these analysis it is seen that the efficiency is increased when it is used the synchronous buck converter over conventional buck converter and later on the efficiency was highest when it is used the interleaved buck converter. Moreover the highest efficiency result got previously at the varying of duty cycles in interleaved buck where the highest efficiency got later on the synchronous buck converter. Finally it is also seen that for the fast response and for the reduction of ripple current the gain is in peak thus make that converter more efficient.

Chapter 4

Performance Analysis of Boost Converter

4.1 Introduction:

The boost converter is a switching converter which is used to shift up an input DC voltage to some higher DC level by using opening and closing electronics switches, required by a load. Storing energy in an inductor and releasing it to the load at a high voltage is one of the key characteristics. In interleaved boost converter, system can have step up to high voltage and less ripple at output ripple voltage [12]. The system has not only faster transient response but also have low switching losses. As a result we can have such as doubled voltage conversion ratio, low input current ripple, less size of passive current stresses of switches because of interleaved design. In this chapter, there are some analysis for steady state operation and interleaved boost dc-dc converter is presented with its various modes of operation. Initially, using the duty ratio, there are some data which is taken to measure output ripple and graphs are shown to define input and output current, power and the efficiency of boost converter.

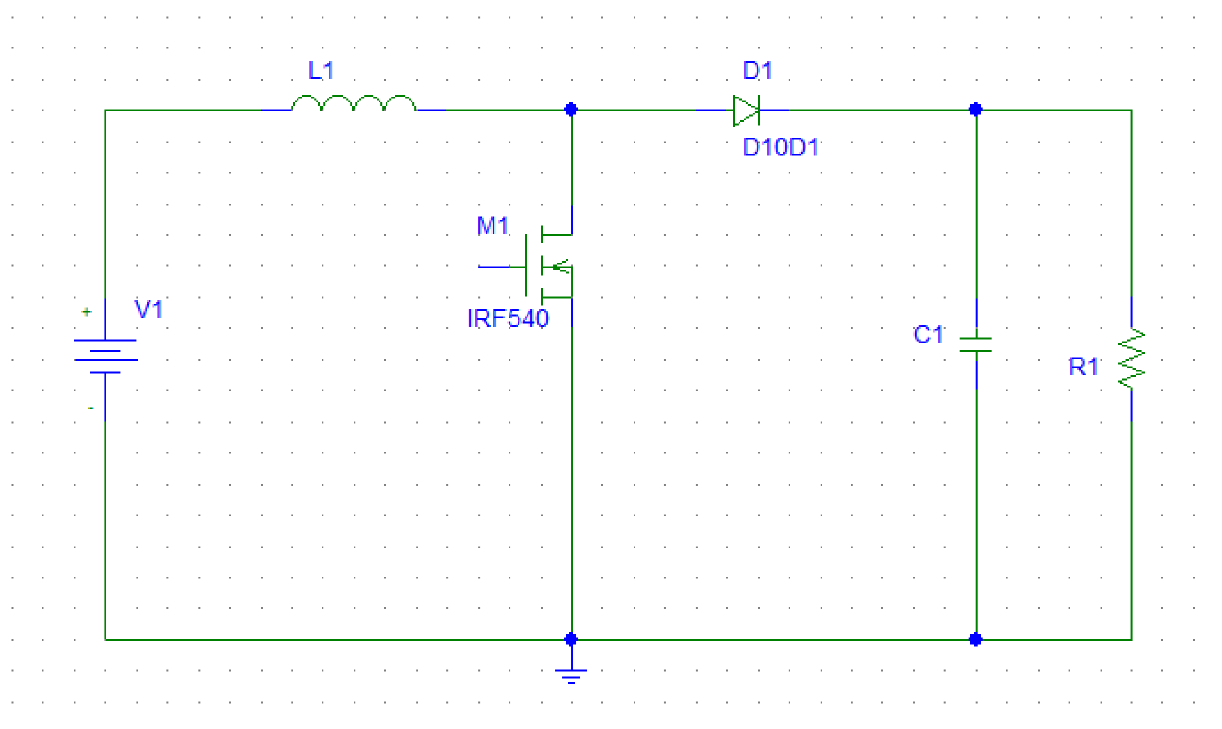

Figure 4.1: Conventional Boost Converter

4.2 Circuit Analysis of Conventional Boost Converter:

In this part, the circuit components of conventional DC-DC boost converter is analyzed. Figure 4.1 represents a conventional boost converter including its basic components. In circuit designing, the input is considered as five volts and the expected outcome is twelve volts. The switching frequency is opted at 10 kilo hertz and ripple voltage is considered is not more than 10%. Inductance value, capacitance value, pulse width of active switch is calculated to designed in this chapter.

Duty ratio, D = $(1 - \frac{Vi}{V0})$

$= 1 - \frac{5}{12}$

$= 0.6$

Where,

V_i = Input voltage

V_0 = Output voltage

Inductor value, Lm = $\frac{D(1-D)^2 R}{2f}$

$= \frac{0.6*(1-0.6)^2*100}{2*10000}$

= 480uH

Capacitor value, C = $\frac{D}{R(\frac{\Delta V}{V})f}$

$= \frac{0.6}{100*0.1*10000}$

= 6uF

Where, $\frac{\Delta V}{V}$= Output ripple voltage

f = Operating frequency

D = Duty ratio

In order to get the best combination of fast switching, low on-resistance and cost-effectiveness a switch IRF540 is used. By varying the duty ratio there is a data sheet given which includes input current, output current, output voltages. All of that data is taken through simulation. Notice that each of values are gradually increasing while we increasing the duty cycle respectively.

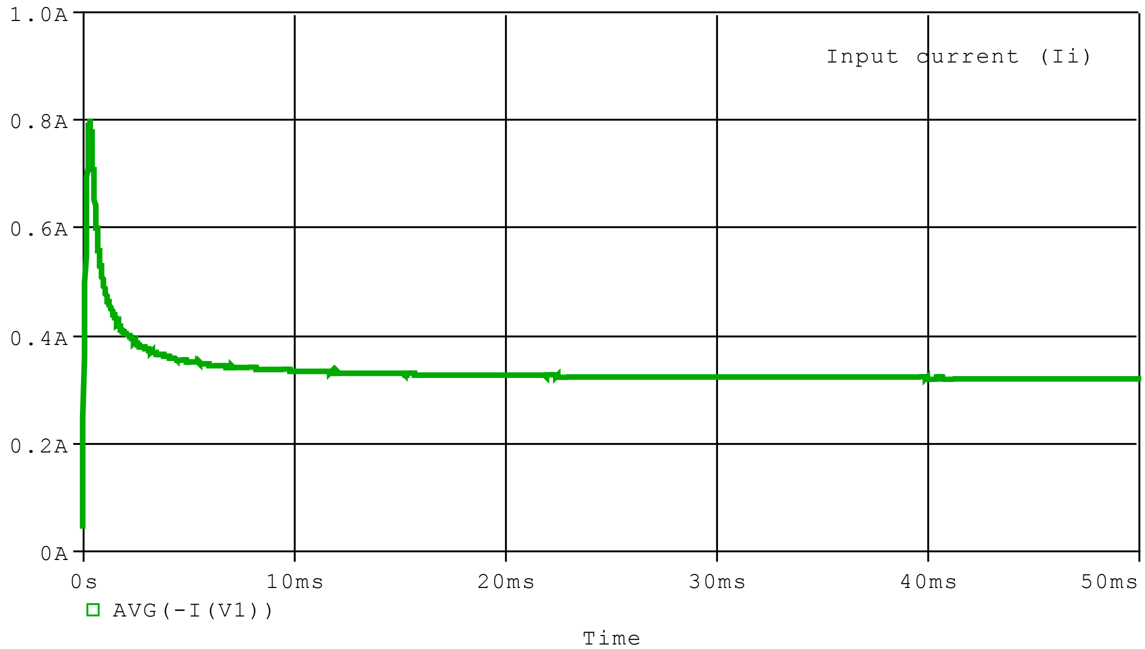

Figure4.2: Input current waveform of Boost converter

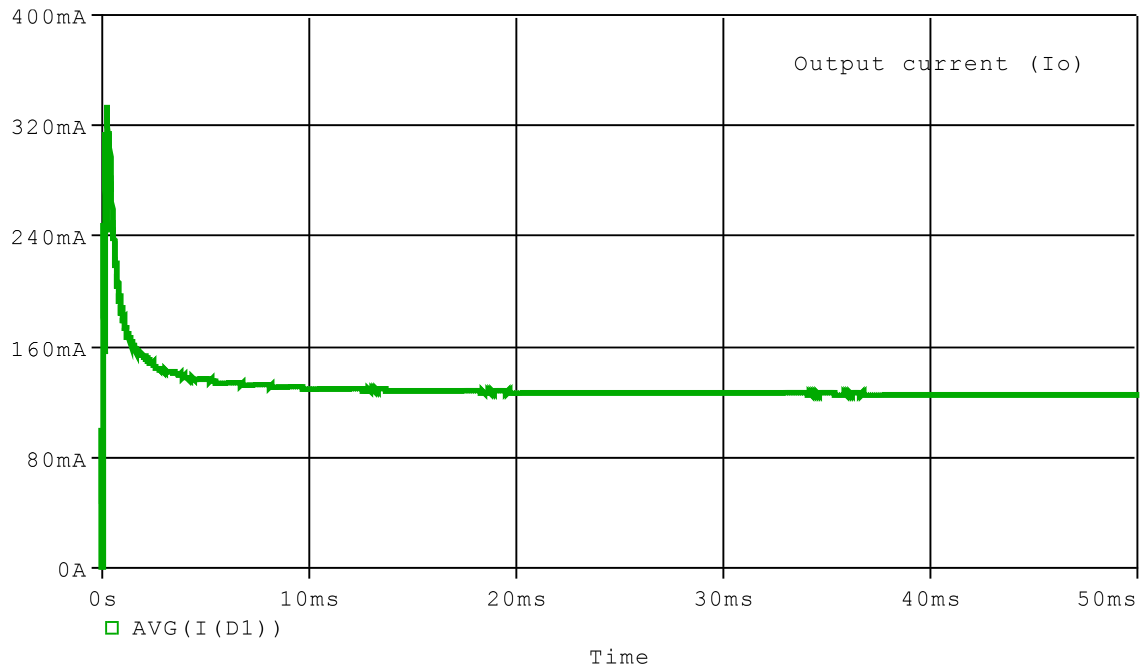

Figure4.3: Output current waveform of Boost converter

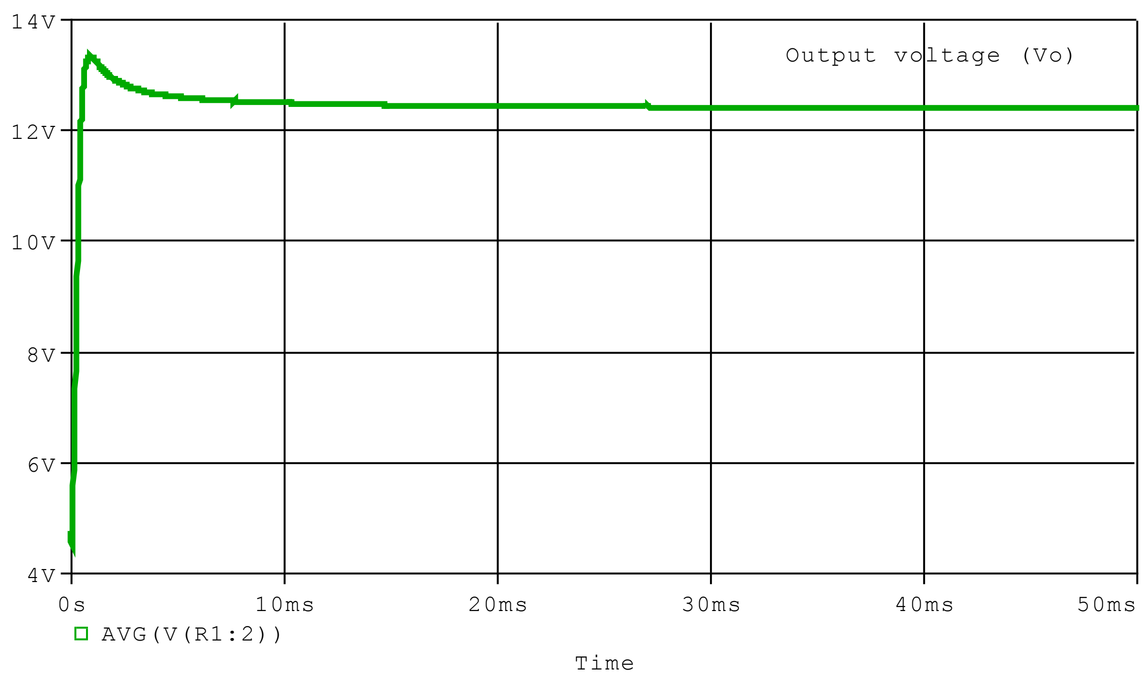

Figure4.4: Output voltage of Boost converter

By using calculated parameters, a conventional boost converter is constructed. The waveform of input current, output current and input voltage is graphically shown in figure 4.1, figure 4.2 and figure 4.3 respectively. In a fixed duty ratio it is observed that the output current is decreasing compared to input current. Apart from this, input voltage is shifted to twelve as shown in figure 4.3.

The table of 4.1(a) and 4.1(b) illustrates input current, output current and associated output voltage along with its output ripple. At high duty ratio, simulated input current value is found higher. Comparing to that value, output current value is much lower.

Table4.1(a) Data for conventional Boost Converter:

Duty cycle	Input current mA (simulated)	Output current mA (simulated)	Output voltage V (simulated)
0.1	59.8	53.12	5.32
0.2	87.02	64.36	6.43
0.3	127.74	78.27	7.82
0.4	179.64	93.27	9.3
0.5	242.98	108.58	10.85
0.6	316.08	123.75	12.37
0.7	561.04	164.96	16.45
0.8	1.3 A	252.12	25.12

Table4.1(b) Data For Output Voltage and output Voltage ripple:

Duty cycle	Output voltage V(max)	Output voltage V(min)	Output Ripple
0.1	5.42	5.14	0.28
0.2	6.66	6.11	0.55
0.3	8.15	7.37	0.78
0.4	9.71	8.75	0.96
0.5	11.34	10.15	1.19
0.6	12.94	11.62	1.32
0.7	17.36	15.40	1.96
0.8	26.82	23.43	3.39
0.9	55.08	47.32	7.76

4.3 Data Analysis For Conventional Boost:

In the simulation, output ripple is calculated by varing of duty cycle of boost converter. In boost converter simulation intially the duty cycle is measured as 0.6. Varying the duty cycle signifies the avarage output voltage. Also, for different duty cycle there is different output voltage range as maximum and minimum output value. Usisng that data output ripple voltage is calculated. The percentage is gradually increasing at the time of varying on duty cycle. In order to compare the ripple voltage with interleved boost converter ripple voltage ratio is the main objective here. For each scale increasing of duty cycle output ripple voltage is gradually increasing. Moreover, there is a calculation about the input current output current ratio in order to measure power, efficiency.

Table4.2 Efficiency Data for Conventional Boost Converter**:**

Input voltage V_{in}	P_{in}(w)	P_{out}(w)	Efficiency(%)
1	0.062	0.054	87.09
2	0.25	0.232	92.8
3	0.57	0.535	93.86
4	1.008	0.97	96.23
5	1.58	1.534	97.09

4.4 Analysis of Efficiency for conventional Boost Converter:

In this section, The results obtainfrom table 4.1 is analyzed graphically. The efficiency of conventional boost converter, input voltage is taken as a variable. Input power is calculated from input voltage and input current and output power is calculated from output voltage and output current. The curve which is shown here signifies that for five volts input efficiency is 97 percent which is maximum than the efficiency is found at one volt as input voltage. The efficiency is getting more stepper including the increase of input voltage.

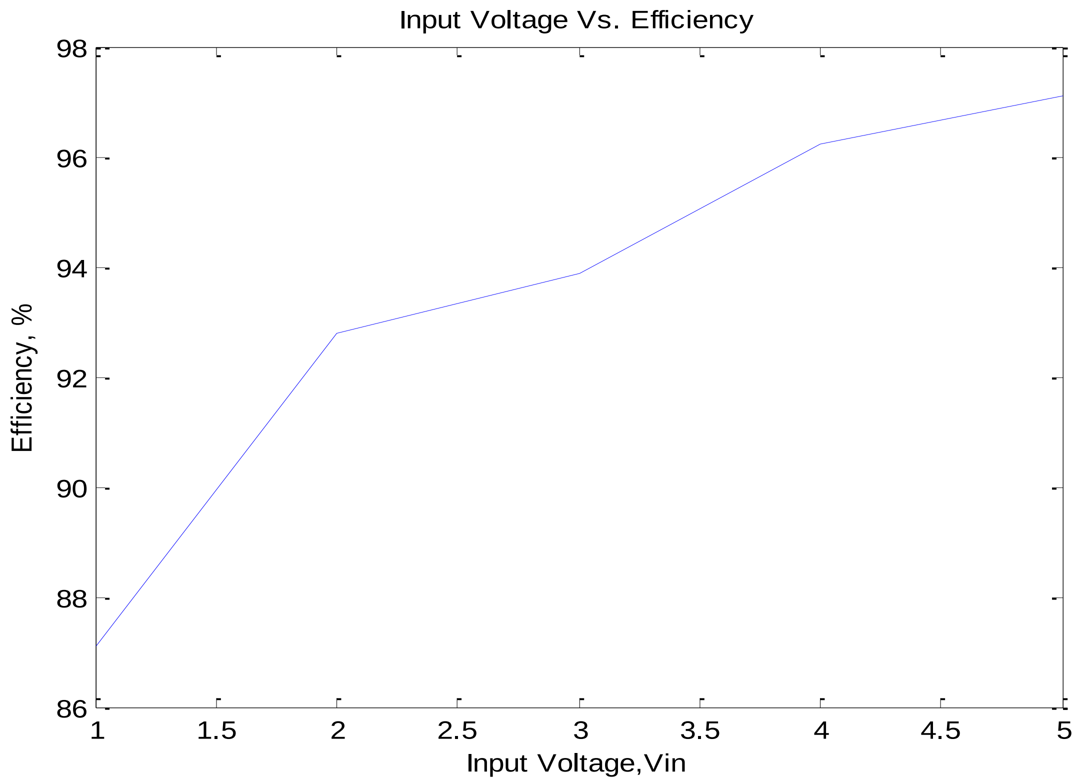

Figure4.5: Input voltage vs. efficiency graph for conventional Boost Converter

4.5 Interleaved Boost Converter:

An interleaving technique is not only saves energy but also improves power conversion without affecting any conversion efficiency. In figure the design is defines a interleaved boost converter which consists of two stages parallel connected switches. In this design, two switches are controlled by phase shifted switching function. Also, for both inductance the value are calculated equal and so does for duty cycle, phase shifted are kept by 180 degree. The duty cycle for interleaved boost converter is 0.6. In order to calculate the output ripple voltage, average of output voltage is measured through varying the value of duty cycle and input voltage.

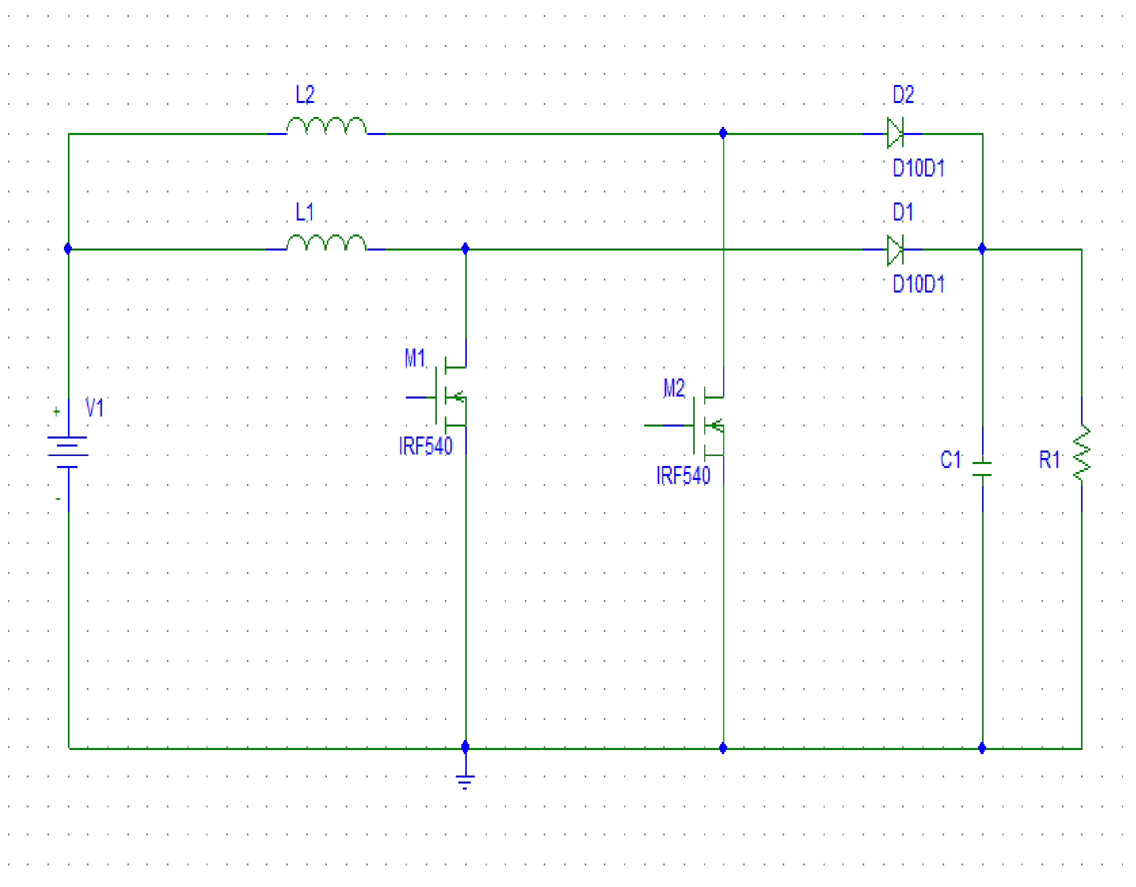

Figure4.6: Interleaved Boost Converter

Table 4.3(a) Data for Interleaved Boost Converter**:**

Duty cycle	Output voltage V(max)	Output voltage V(min)	Output ripple
0.1	5.78	5.66	0.12
0.2	7.70	7.43	0.27
0.3	9.85	9.45	0.4
0.4	12.10	11.54	0.56
0.5	14.47	13.78	0.69

Table4.3(b) Data for varying voltage for Interleaved Boost Converter:

Input voltage	Output voltage (Theoretical)	Output voltage (Simulated)	Output ripple
1	2.5	2.71	0.2
2	5	5.59	0.41
3	7.5	8.47	0.66
4	10	11.37	0.83
5	12.5	14.28	1.03

Table4.4 Efficiency data analysis for Conventional Boost Converter:

Input voltage V_{in}	P_{in}(w)	P_{out}(w)	Efficiency(%)
1	0.109	0.085	78
2	0.44	0.359	81.59
3	0.98	0.824	84.08
4	1.75	1.48	84.57
5	2.75	2.34	85.09

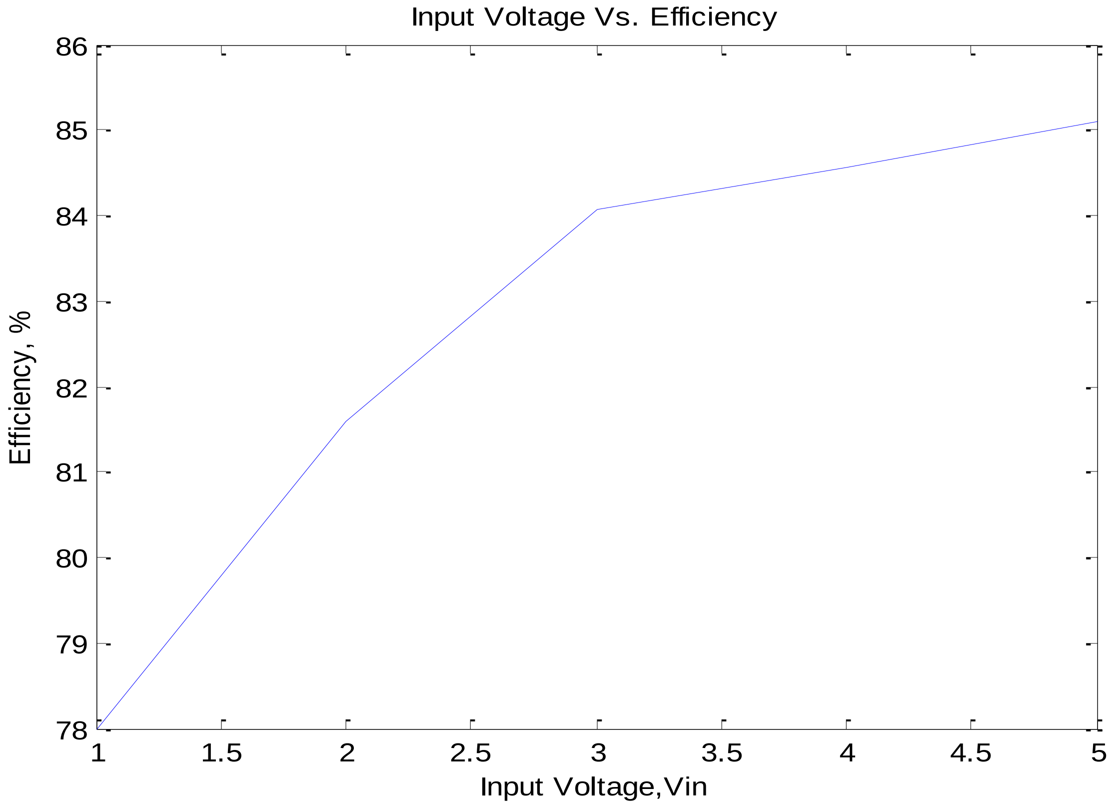

Figure4.7: Input voltage vs. efficiency graph analysis

4.6 Comparison of Output Ripple Voltage:

Output ripple voltages have been obtained from both conventional boost and interleaved DC-DC boost converter. In figure, the comparison of table 4.1(a) and 4.3(a) are graphically analyzed by varying duty ratio from 0.1 to 0.5. Here the figure 4.7 indicates that the output ripple voltage of interleaved boost converter is lower than the conventional boost converter for a particular duty ratio.

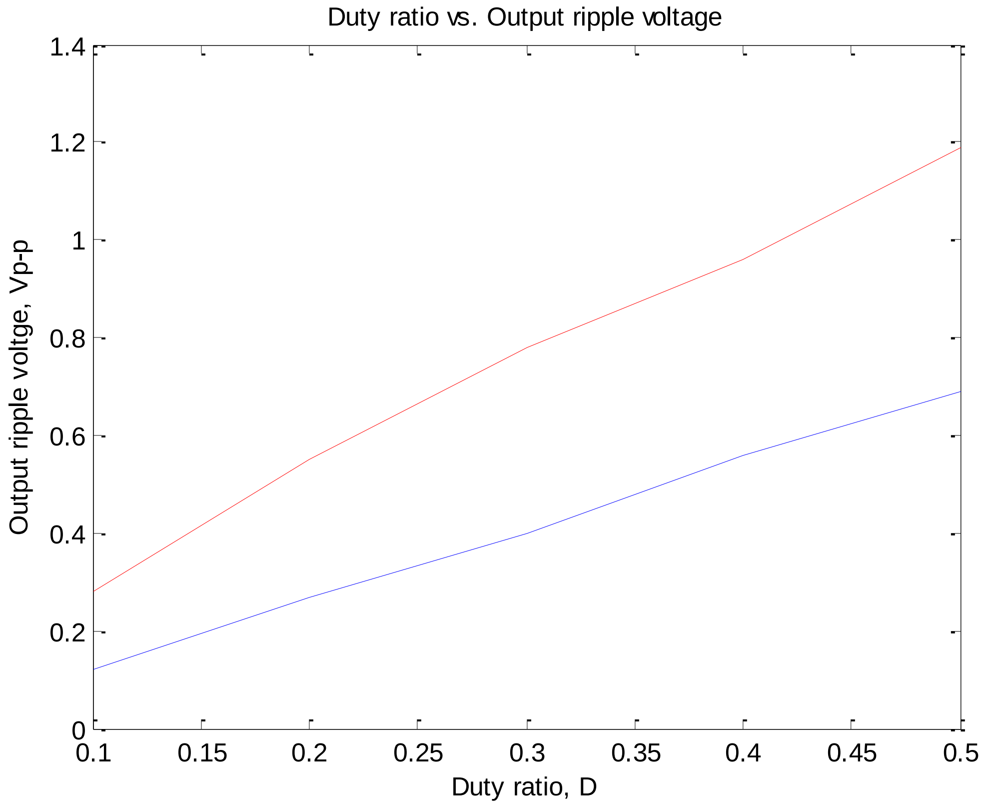

Figure4.7: Comparison of output ripple voltage

4.7 Conclusion:

In this chapter, the basic design of boost converter is discussed elaborately. Besides, the performance analysis has been done in terms of efficiency. From experimental data it is studied that the output ripple voltage is reduced in interleaved boost converter in comparison to conventional boost converter.

Chapter 5

Summary

5.1 Developments:

The interleaved converter that has been analyzed, supporting the main aspects of increasing efficiency in various ways. Now a day, with the use of these converters the devices are establishing with the proper requirements and here by these analyses the requirement will be fulfilled. In addition to that it is required more efficient and fast response system for the electronic devices which can be achieved by interleaving the converters method.

For the improvement of electronics devices, the power dissipation is a major factor for more efficient system. By reducing the voltage ripple and the current ripple in the method of interleaved converter the efficiency is increased.

Moreover, the analyzed data tells the increasing of efficiency with the varying of duty cycles and input voltages. Hence the system used for the device will have a fast response and effective characteristics.

5.2 Conclusion:

During this thesis project, it is studied and analyzed different types of converters in many ways which helped a lot to understand the topic to us.

It is analyzed the conventional DC-DC converters and the interleaved converters to understand the basic topology of gaining the system and more fast responding systems. Later, the data which were taken was analyzed and the decision has been taken for more efficient system.

It is used the P-SPICE and MATLAB software for these thesis project which has been gained a great knowledge about these software to us. The simulation process of these software was highly effective for this project.

The topic which has been selected for this project which is the mainstream analysis of efficiency of interleaved DC-DC converters has fulfilled the target by this thesis project for the future developments of electronic devices and in telecommunication system.

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