ABSTRACT

High Step Up - High voltage gain converter is becoming the most productively converter now a day's mostly in hybrid technology, mobile technology and for other portable devices that are in need of high voltages from low voltage input. Furthermore, these converters are widely used in battery charging that includes Fuel cells as well. This Thesis discusses Simulate and proposed advancement in Developed High Step up Voltage DC to DC converter. Detailed analysis on Integration of Double Boost – SEPIC and CUK has been proposed. Proposed Topology contains multiple inductors with one controlled switch that will make a control mechanism useful for every application. Secondly, voltage stresses across silicon conductor devices are very low. Conduction losses will also be reduced due to low voltage Stress. Reverse recovery current problem is also in under consideration of this thesis that will enables the use of Schotkey rectifiers. The keen purpose of the topology is to obtain the maximum output voltage with maximum voltage gain and less conduction losses reducing input ripple current. Without disturbing characteristics of Topology. A detailed analysis has been done on every converter separately and by integrating all converters to check the results. Mathematical equations are also derived for better understandings and simulation results are obtained as well.

Key words: Double boost converter; SEPIC converter; CUK Converter; Cascaded structure

ÖZET

Günümüzde yüksek gerilim kazançlı dönüştürücü, çoğunlukla hybrid teknolojisinde, mobil teknolojide ve düşük voltaj girişinden yüksek gerilimlere ihtiyaç duyan diğer taşınabilir cihazlarda kullanılan en verimli dönüştürücü haline gelmektedir. Ayrıca bu dönüştürücüler, yakıt hücrelerini de içeren batarya şarjında yaygın olarak kullanılmaktadır. Bu tezde, geliştirilmiş yüksek basamaklı gerilim yükselten DC- DC dönüştürücüsü geliştirilmiş ve bilgisayar ortamında simülasyonu yapılmıştır. Çift yükseltici entegrasyonu - SEPIC ve CUK gibi dönüştürücüler hakkında detaylı analiz önerilmiştir. Önerilen Topoloji, her uygulama için kullanışlı bir control mekanizması oluşturacak, tek bir control anahtarlı çoklu indüktörleri çerir. İkinci olarak, silicon iletken cihazlarındaki gerilim stresi çok düşüktür. İletim kayıpları da düşük gerilim stresinden dolayı azalacaktır. Bu tez kapsamında geri kazanım akım problemi de SCHOTKEY doğrultucularının kullanımına olanak sağlayacaktır.

Topolojinin asıl amacı, maksimum çıkış voltajını maksimum giriş voltajı ve giriş dalga akımı azaltarak daha az iletim kaybı ile elde etmektir. Entegre edilmiş tüm dönüştürücülerin sonuçlarını control etmek için, her dönüştürücü için ayrı ayrı detaylı analiz yapılmıştır. Matematiksel denklemler de daha iyi anlaşılmalar için türetilmiş ve simülasyon sonuçları da elde edilmiştir.

Anahtarkelimeler: Çifteleyen yükseltici dönüştürücü; SEPIC dönüştürücü; CUK dönüştürücü; Seri yapı

ISRAR HUSSAIN ANALYSIS, DESIGN AND SIMULATION OF HIGH STEP-UP DEVELOPED DC-DC CONVERTERNEU 2018

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Approval of Director of Graduate School of Applied Sciences

Prof. Dr. Nadire ÇAVUŞ

We certify this thesis is satisfactory for the award of the degree of Master of Science in Electrical and Electronic Engineering

Examining Committee in Charge:

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Prof. Dr. Ahmet Denker	Department of Electrical and Electronics Engineering, NEU
Assoc. Prof. Dr. Huseyin Haci	Department of Electrical and Electronics Engineering, NEU

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The department of Electrical generously supported the research and electronic engineering of Near East University. I am grateful to all my supporters.

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LIST OF ABBREVIATION

PV:	Photovoltaic
PI:	Proportional Integral
PID:	Proportional Integral and Differential
MPC:	Model Predictive Control
SEPIC:	Single Ended Primary Inductor Converter
CCM:	Continuous Conduction Mode
DCM:	Discontinuous Conduction Mode
PWM:	Pulse Width Modulation
IDBSAC:	Integrated Double boost SEPIC and CUK Converter

CHAPTER 1
INTRODUCTION

1.1 Introduction

Leading demand of energy enables scientist to focus on alternative energy resources, Natural Energy resources such as Petroleum, coal, Natural Gas and Non-renewable resources is reducing day by day and leaving a harmful impact on environment. Alternative energy resources that included Photovoltaic Systems, Wind Energy, Geo thermal Energy and Tidal Energy etc. are the sources of Renewable Energy. All these Renewable energy especially Photovoltaic (PV) Systems is the most auspicious and appealing alternative energy source because of their environment friendly operation. PV systems have wide Range of application including residential as well as for commercial purposes (Ahmad J et al, 2015). All these energy sources used Dc / Dc Converter. These converters are also extensively used in many application some of the special application such as aerospace, cranes, military purposes, and precision instrumentation (Yang L S et al, 2011). These Renewable energy resources have drawback of producing low and unregulated voltage especially Photovoltaic systems, because of the different and unexpected weather condition and Irradiance of temperature of PV systems and temperature of PV cells. V-I characteristics in solar system shows non-linear behavior and this behavior is unacceptable in PV application. Hence in order to alter voltage and current level Dc-Dc converter plays a vital role. (Buck, SEPIC, Boost, LUO, CUK, Buck boost) are widely used for traditional approaches (S.sivapriya et al, 2017).

Alternative sources of energy in Grid-connected systems largely need high step-up voltage conversion to process low voltage power input (Lenon Schmitz et al, 2016). However, used of parasitic elements like inductor and capacitor impose limitation on voltage gain (Manish kumaret el, 2017).Grid connected PV systems works independent of storage, as all the generated power from the PV plant is directly transfer to the distribution, Transmission and Consumption units. This generated PV power is not enough to fulfill the requirement of grid so it needs high voltage conversion (Sivapriya et al, 2017).Conventional method of increasing voltage is to arranged PV cells in a module of series connection or parallel connection to make a single module and further these module is connected parallel and in series with each other to generate DC current, (R. Teodorescu, M. Liserre 2011) greatly depends on terminal voltages, irradiance of temperature and partial shading. This conventional method is not much effective to increase voltage level as it reduce efficiency and increase the cost of a system as well.

Power Management methods with proper controlled techniques are essential for every application of renewable energy systems. Load Demand and Power balance should be fulfilled by control systems and power management strategy. Whenever the line voltages or load current changes the voltage regulator should have to maintain a constant output voltage by adjusting duty cycles provided to Mosfet switch, this type of systems are closed loop systems, they further need some linear controllers such as Proportional (P), Proportional-Integral (PI) and Proportional-Integral and Derivative Controllers and these controllers are widely used in closed loop system according to the response of systems. Control mechanism is important to secure circuitry, power quality, efficiency of the circuitry and load demand during operation mode. Power Electronics provided an efficient and quick solution to cater all these problem regarding low voltages, un regulated voltages and input output ripple current. Most of the PV applications and PV based appliances need high voltages so it become necessary to convert low input voltages into high voltages with maximum efficiency. Conventional Dc to Dc Boost converter enables us to increase output voltages but on some extent. In order to increase gain SEPIC converter and CUK converter will be integrated with boost converter to produce high voltage gain by using one switching element. Single switching enables the converter to increase the efficiency and reduces the switching losses. Voltage stress is also less than half of the output across all the semiconductors in result of low voltage stress further lowers the conduction loss because of low voltage on $R_{DS\text{-}ON}$ MOSFET Switch (Ahmad J. Sabzali, October 2015) SEPIC is the most adopted topology due to its dual operation of increasing and decreasing voltages by keeping the polarity same but we will only use its boost operation.

Whereas the CUK Converter is changes the polarity but able to do buck boost operation. As mentioned above it has more advantages of low voltage stress and low current and voltage ripples. (Sivapriya et al, 2017).

Contents of this thesis

In Chapter 2, complete literature review is done on Dc – Dc converters that include Boost Double Boost, SEPIC and CUK Converter. Literature review includes all important equations, Mode of operations, Control strategy and Advantages as well. Furthermore, Developed Cascaded converters topologies are reviewed in detail. Methods of deriving high gain from Dc-Dc converter and developed topologies for high gain will also be discussed in this chapter. Their performance is evaluated for better understanding of cascaded converter in order to propose a better and more efficient topology. In chapter 3, Integrated Double Boost – SEPIC and CUK converter topology is proposed. Chapter 3 covers each and every expect of proposed topology that include cascading of three converter into one topology, performance, gain ratio and efficiency graph on different duty cycle. All important equation of ON and OFF time of circuit is derived for better understanding. Complete circuit of proposed topology is discussed step by step from input to the output. Chapter 4 covers the results and simulation analysis of proposed topology that includes the waveform of current and voltages of every component in detail and complete behavior of every component used in the proposed topology is shown and in the end chapter 5 gives the conclusion of complete topology and discusses the future aspects and application of the proposed topology.

1.2 Integration methods of DC-DC Converter

High voltage output is needed in most of the application where the input voltage supply is low like fuel cells and especially PV panels. This problem can be solved by using high step up converter with high duty cycle that give high voltage stress on switching mosfet, Switching and conduction losses on the power devices and creates serious reverse recovery problem, (A.Moutabir et al, 2014)which is not much suitable method. In order to obtain high conversion ratio without extreme duty cycle, some converter based on coupled inductors or transformer or tapped inductor have been shown(Cacciato et al, 2010). However, Coupled and tapped inductor will produce high voltage spikes during switching and leakage inductance is produced in the transformer. Voltage Spikes can be eliminated by using snubber circuit such as capacitor-resistor-diode snubber, active clamp circuit and non-dissipative snubber but using these snubber will increase the complexity of a converter circuit (Jian Fu: et al Aug 2014) The other method to solve this problem is by using cascaded converter. Integration of Dc to Dc converter can called as back to back converter. To avoid extreme duty cycle and to achieve high ratio of conversion rate some non-isolated topologies have been proposed. This converter comprises of Voltage Doubler Circuit, Switched Inductor type, Switched capacitor type and capacitor-diode voltage multiplier (W.C. chow et al, 2000).These converters able to produce high voltage gain than the conventional boost converter and these converters used more switched inductor or switched capacitor stages for an extremely high ratio of conversion, which make converter costly and complex. Cascading two Dc-Dc converter is cascaded in such a way that last converter acts as a load for its previous converter and output voltage of previous converter will be input voltage of last converter. Presented topology will use one input and single switching semiconductor. To control back to back converter 4 schemes are presented before in (Zhenbing Zhang et al, 2015) different parameters. Figure 1 (a) and (b) shows the Model Predictive Control and cascaded control with modulator for better understanding Some of the schemes are

(i) Model Predictive Control (MPC)
(ii) Direct control with switching table
(iii) Cascaded current control with modulator
(iv) Direct control with modulator

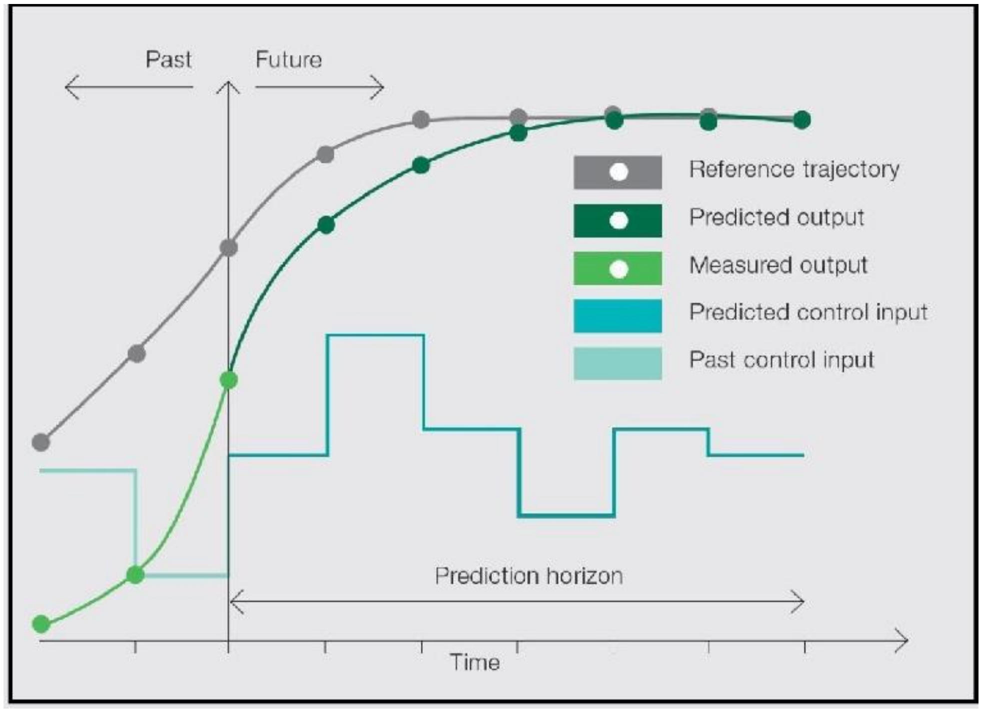


Figure 1.1: (a) Model Predictive control (Zhenbing Zhang et al, 2015)

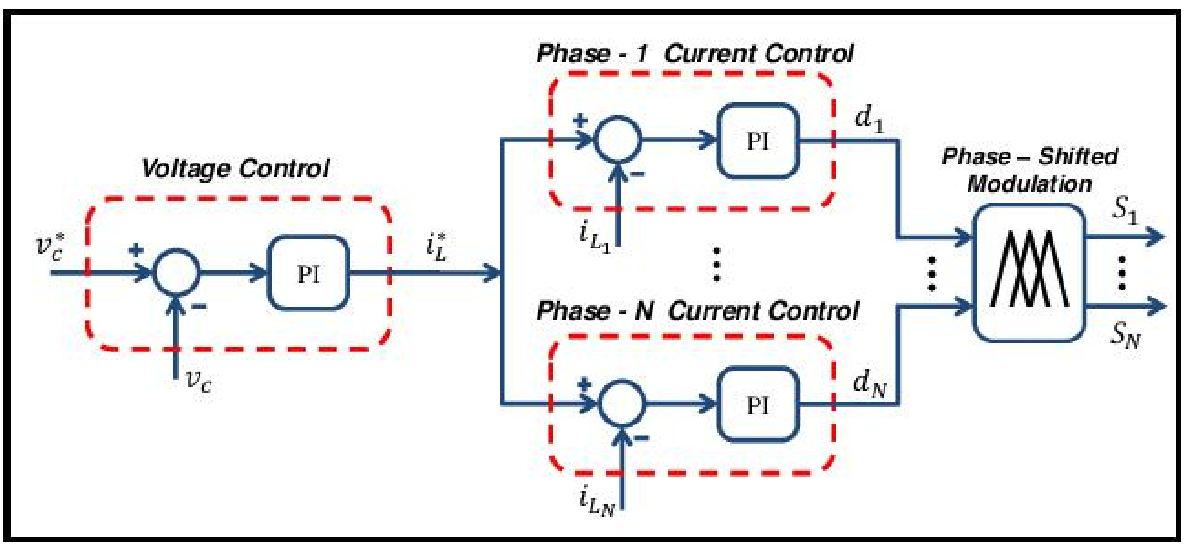


Figure 1.1: (b) Cascaded control method (Zhenbing Zhang et al, 2015)

Controlling of Dc-Dc converter is the most important and complicated part of power electronics that includes the controlling an ON and OFF time of switches called as switching pattern. There are many type of switching methods that can be used, different switching methods is discussed in detail in literature review.

CHAPTER 2
LITERATURE REVIEW

2.1 Review of DC-DC Converter

Family of non-isolated Dc-Dc converters called as choppers as well includes **Buck** (step down) , **Boost**(step up), **Buck Boost** (step up and step down), **CUK** , **SEPIC** and **LUO** converter. In this chapter their detailed review has been done to understand each and every aspect of these converters. Our main focus is on only Boost, SEPIC and CUK converter because our topology based on these three choppers.

2.2 Boost Converter

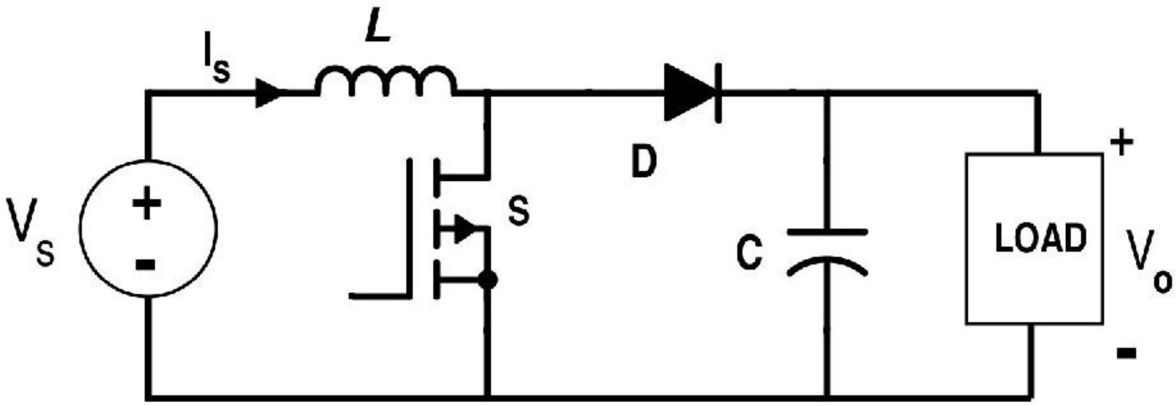


Figure 2.1: Step Up Boost Converter

Fig (2.1) represent standard step up or PWM based Boost converter. DC source Input voltage is labeled as *Vs*, Boost Inductor *L*, Controlled Switch *S*, diode *D*, Filter capacitor *C*, and Load Resistance *R*. When the switch *S* is turned on by applying controlled PWM the current increases in Inductor linearly. The diode become off because of reverse biased operation. Circuit diagram off ON time is shown in figure 2.2 (a). When the switch turned off, the stored energy of Inductor is released through the diode to the input of RC Circuit and it will charge

Capacitor. Figure 2.2 (b) shows OFF time of switch. During off time off switch inductor decreases its energy and capacitor is charged and load resistor utilizes capacitor voltage. Now mathematically the whole process is depicted in following equations

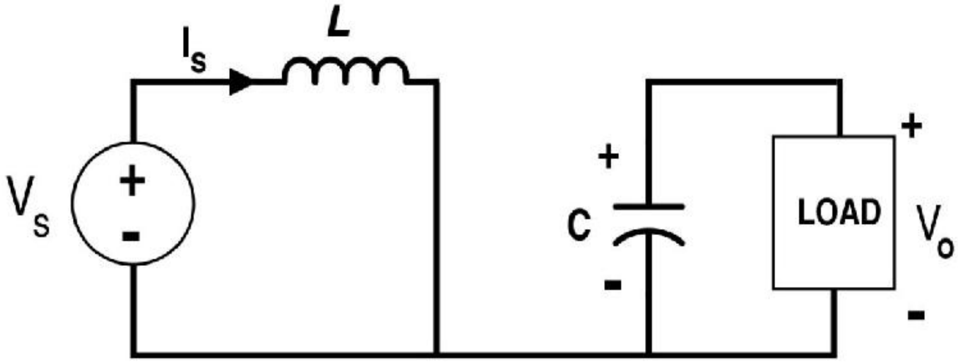


Figure 2.2:(a) On time of Boost Converter

When switch is ON

The equation are as follows.

$$\mathrm{Vs} = \mathrm{Vl} \Rightarrow \mathrm{L}\frac{\mathrm{d}}{\mathrm{d}} = \mathrm{Vs} \tag{2.1}$$

Current will increase with constant slope as shown in equation 2.1

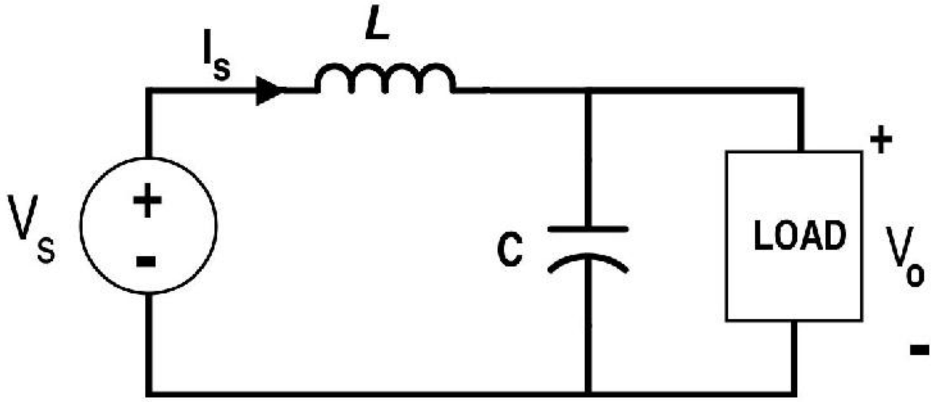


Figure 2.2:(b) OFF time of Boost Converter

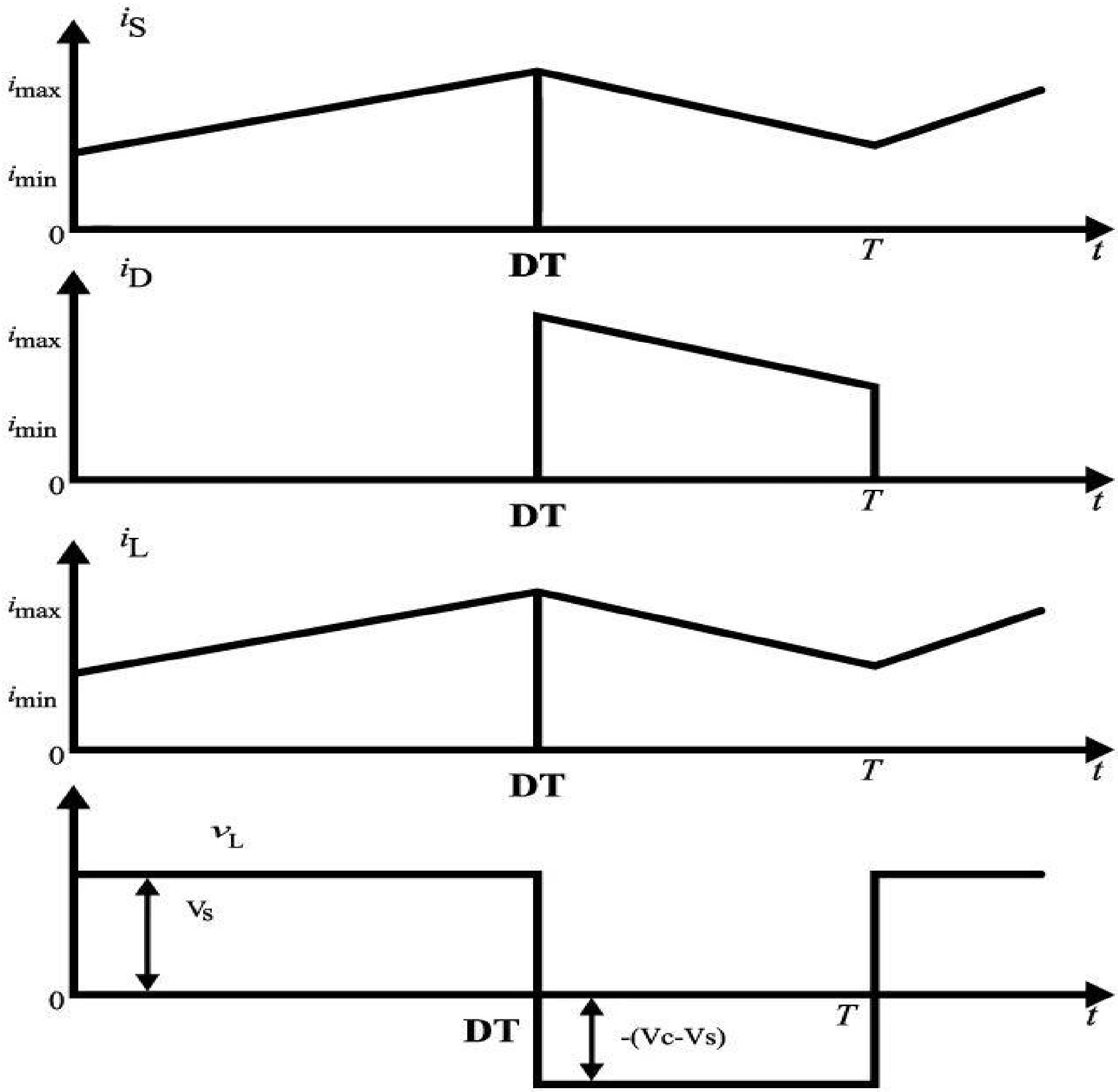


Figure 2.3: Current and Voltage Wave form

When Switch is OFF

$$V \quad = V \quad + V$$

$$V \quad = V \quad - V$$

$$L\frac{d}{d} = V \quad - V$$

$$\frac{d}{d} = \frac{(V - V)}{L} \tag{2.2}$$

Now, when switch is off current decreases linearly and must reach equal to the initial stage value as according to the steady state stability when switch is just on.

Current increases as per equation (2.3) when switch is ON

$$I - I = \frac{V}{L} D \tag{2.3}$$

Current Decreases as per equation (2.4) when switch is OFF

$$I - I = \frac{V - V}{L}(1 - D)T \tag{2.4}$$

By applying Inductor Volt-Sec balance using figure 2.4

$$V = (V - V)(1 - D)T \tag{2.5}$$

By evaluating above equation voltage gain of Boost Converter is shown in equation 2.6

$$\frac{V}{V} = \frac{1}{1-D} \qquad \text{as we know that } V = V \tag{2.6}$$

Input and Output Power is shown in equation 2.7 and 2.8 respectively

$$P = \frac{V^2}{R} = \frac{V^2}{(1-D)^2 R} \tag{2.7}$$

$$P = \frac{I + I}{2} * V \tag{2.8}$$

if the switch is consider to be ideal then switching losses will be zero then,

$$P = P$$

$$\frac{I + I}{2} = \frac{V}{R(1-D)^2} \tag{2.9}$$

By using equation 2.9 and 2.4 maximum and minimum current will be as follows

$$I_1 \quad = \frac{V}{R(1-D)^2} - \frac{V}{2L} DT \tag{2.10}$$

$$I_1 \quad = \frac{V}{R(1-D)^2} + \frac{V}{2L} D \tag{2.11}$$

2.2.1 Modes of Conduction:

DC-DC Converter consists of two mode of operation divided as Continues Conduction Mode (CCM) and Dis-Continues Conduction Mode (DCM). Mode of conduction totally depends on the Inductor current.

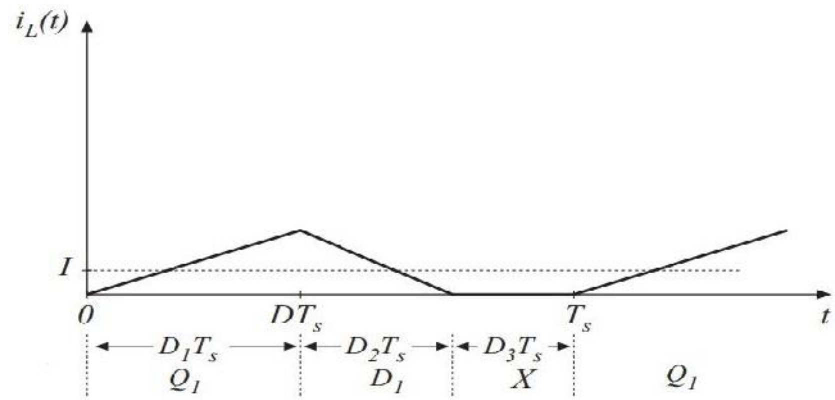


Figure 2.4: CCM and DCM wave form

CCM – Continues Conduction Mode:

CCM occurs when the Inductor current remains always greater than zero without interruption of current in a switching period. Boost converter topology will change according to the different state of the switch. During CCM switch is turns on and diode turns off from t=0. When input voltage is applied to the Inductor, then inductor current increases linearly when inductor current reaches its maximum value, then switch is turn OFF and diode turns ON from t to DT, as shown in the figure 2.5, D_2T_S is CCM till current *I is* greater than zero.Now power and energy of inductor is transferred to the load and capacitor, this energy charges capacitor, reduces inductor current linearly and inductor current goes to the output through diode. When t become equal to T then inductor current reaches its minimum limit then switch triggered and turn ON by gate plus and next cycle starts. Equation 2.12 shows the inductor selection equation. [20 - 21]

$$I_{min} = 0$$

$$L_m = \frac{D(1-D)^2}{2}T \qquad (2.12)$$

DCM – Discontinues Conduction Mode:

DCM occurs when the Inductor current goes to zero level as shown in Figure 2.5 during the switch is OFF.D_3T_S time shows the DCM mode. When the converter works in DCM, it works same as CCM from t = 0 to t = (D_2T_S) after this is a third switching stage D_3T_S where Switch is turn-off and diode turn off as well. During this time the energy to the load is supplied by the capacitor and inductor maintain zero current and the inductor current increases when the switch turns on in the next period of duty cycle.The ratio of duty cycle of boost converter not only dependent on the input and output voltages but also depend on the inductor L, switching frequency and Load resistor.The inductor ripple current at DICM and other equation is shown in[20 -21].

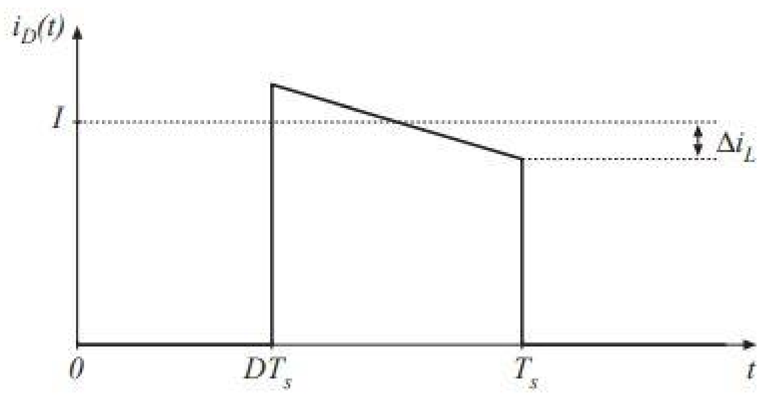


Figure 2.5: DICM

2.3 Conventional SEPIC Converter:

Figure 2.6 shows the SEPIC converter used in main topology as SEPIC converter is integrated with Double Boost at second stage. Input conductor is common as mention earlier and this inductor will act as a SEPIC converter input inductor as well. The output of double boost converter will become the input voltage for SEPIC converter. Some important equation for on and off time off only SEPIC converter are as follows.

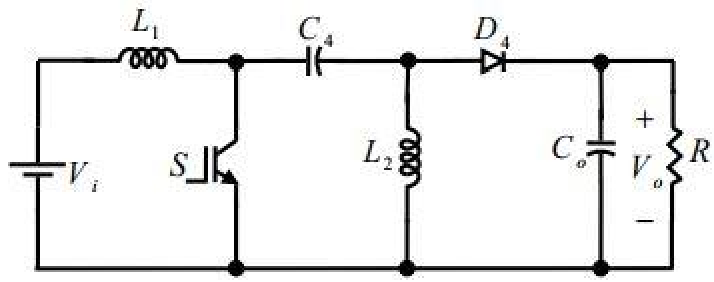


Figure 2.6:SEPIC Converter

Stage 1: [on time of switch] Considering Sepic Converter only

Fig 2.7(a) When Switch S is closed and diode D_4 is open. The equations are as follows

$$V_{L1} = V_i \tag{2.13}$$

$$V_{L2} = - V_{C4} \tag{2.14}$$

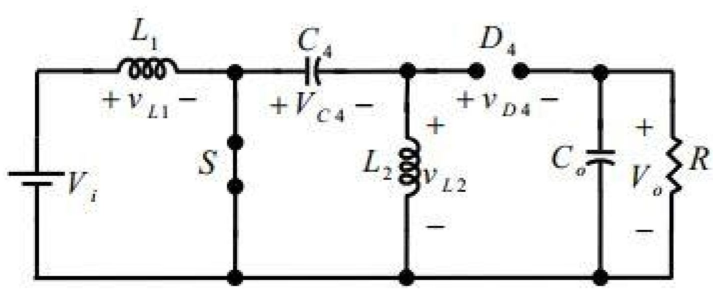


Figure 2.7 (a) ON time of SEPIC converter

Stage 2: [off time of switch] considering only SEPIC Converter

Fig –2.7 (b) When Switch S is open and Diode D_4 is close. The Equation is as follows

$V_{L1} = V_i - V_{C4} - V_O$ (2.15)

$V_{L2} = V_O$ (2.16)

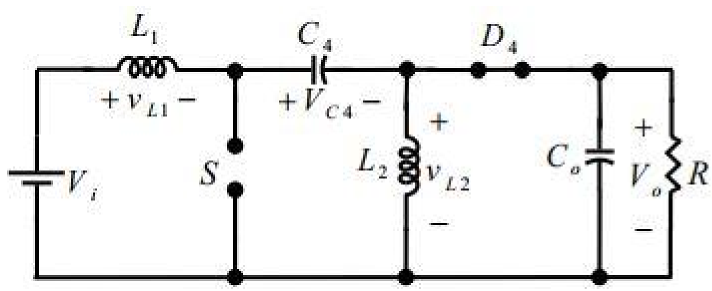


Figure 2.7 (b) OFF time of SEPIC converter

In order to calculate inductor average voltage at L_2 we use volt sec balance law in continuous current mode the average inductor voltage will be zero. And by using equation 1.10 and 1.12 the equation are as follows.

$$\frac{1}{T}\int_0^T v_{L2}d \;=\frac{1}{T}\int_0^D \left((-V_{C4})d \;+\; \int_D^T \;V_0\,d\;\right) = D(-V_{C4}) + (1-D)V_0 = 0 \quad (2.17)$$

$$V_{C4} = \;\frac{1-D}{D}V_0 \quad (2.18)$$

After solving equation 1.13 we obtained equation 1.14 as shown above

By using equation 1.9 and 1.11 the average voltage at inductor L_1 be calculated as follows using volt sec balance method.

$$\frac{1}{T}\int_0^T v_{L1}d \;=\; \frac{1}{T}\;[\int_0^D \;V_i\,d \;+\; \int_D^T (V_i - V_0 - V_{C4})d \;\;] = DV_i + (1-D)(V_i - V_0 - V_{C4}) = 0$$

(2.19)

Using equation 2.15 and by Putting equation 2.14 in equation 2.15 we computed the gain as shown.

$$D\,V_i + (1\text{-}D)\,(V_i - V_O - \frac{1-D}{D}V_O) = 0 \qquad (2.20)$$

After applying algebraic solution the Gain GS is as follows.

$$G_S = V_O / V_i = \frac{D}{1-D} \qquad (2.21)$$

Equation 2.21 shows the output voltage of SEPIC converter.

2.3.1 CCM and DCM Mode of SEPIC converter:

As every converter have two mode of operation CCM and DCM, SEPIC converter also works in both mode depends on the inductor current. If inductor Current of SEPIC converter never goes down to zero means it is operating in CCM mode. The complete equation and description CCM mode is shown in (SomyaRajhan et al, 2012).

DCM mode occurs when the inductor current goes to zero during the OFF time of the switch. Normally most the topology of SEPIC operates in CCM mode; it can be plunge into DCM mode by using the light load or to draw a maximum current from the inductor. It normally depends on the application where DCM mode is more usable because of its fast dynamic response then CCM mode. The design consideration Voltage conversion ratio, average current through switch, average inductor current, diode average voltage across the energy storage capacitor and all important equation of DCM and CCM mode is shown in (Ravikumarsheety et al,2012)

Figure 2.8 shows the CCM voltage and current wave form of Inductor L1 and L2 and it shows the wave form with respect to the duty cycle as well.

Figure 2.9 shows the current and voltage wave form of Inductors L1 and L2 in DCM and shows the wave form with respect to the duty cycle as well. D_3T_S interval shows the DICM mode when the current become less than zero as shown in figure the converter will operate in a DCM and current would not be continuous.

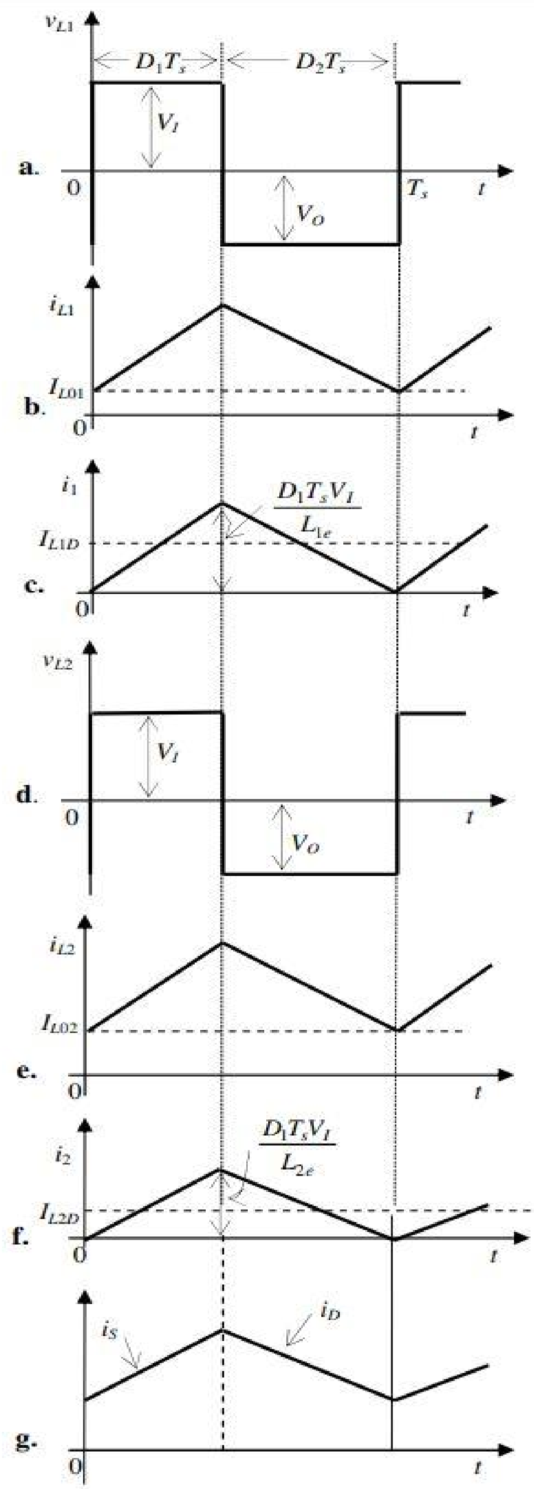


Figure 2.8: CCM wave form of Current and Voltage in PWM

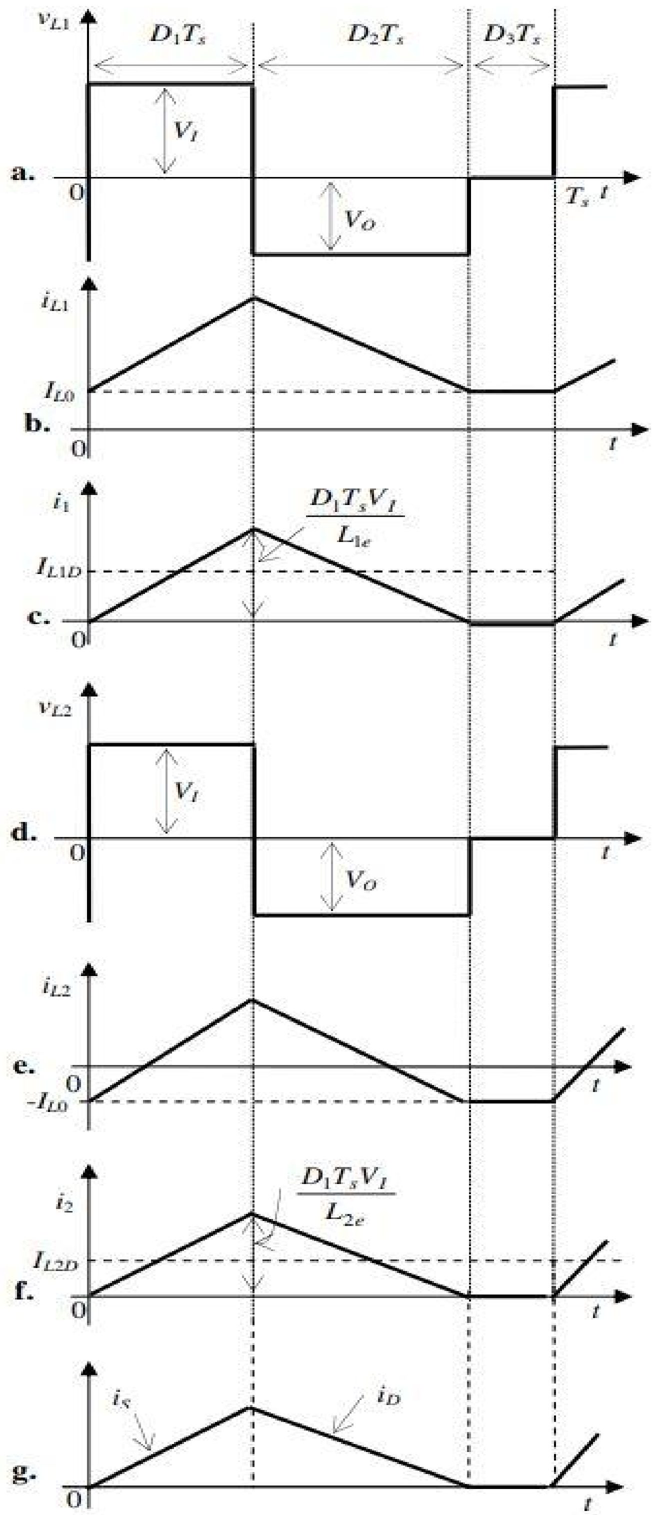


Figure 2.9: DICM waveform of Current and voltages in PWM

2.4 Conventional CUK Converter

CUK converter is another important Dc-Dc converter in the chopper family. CUK converter is also a STEP UP and STEP DOWN converter able to increase and reduce the input voltages. CUK converter is easy to implement, its ability to protect circuitry from inrush current during over load condition and Low input ripple current also increase its importance other DC-DC converter.CUK converter has continuous output and input currents with very low ripples. It is useful in the application where low ripple current is needed. Figure 2.10 shows the CUK converter circuit.Mathematical equation for ON and OFF time of CUK converter is done in order to obtain Voltage gain and better understanding. CUK converter has two inductor current and two capacitor voltage equations

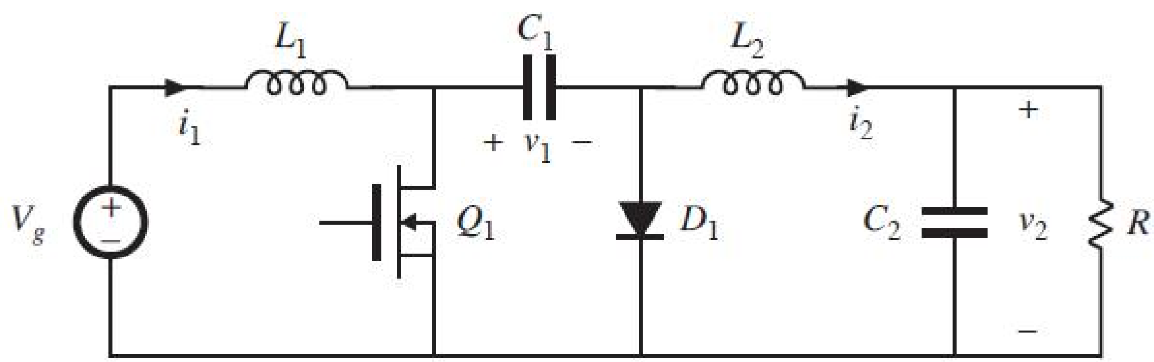


Figure 2.10: CUK Converter

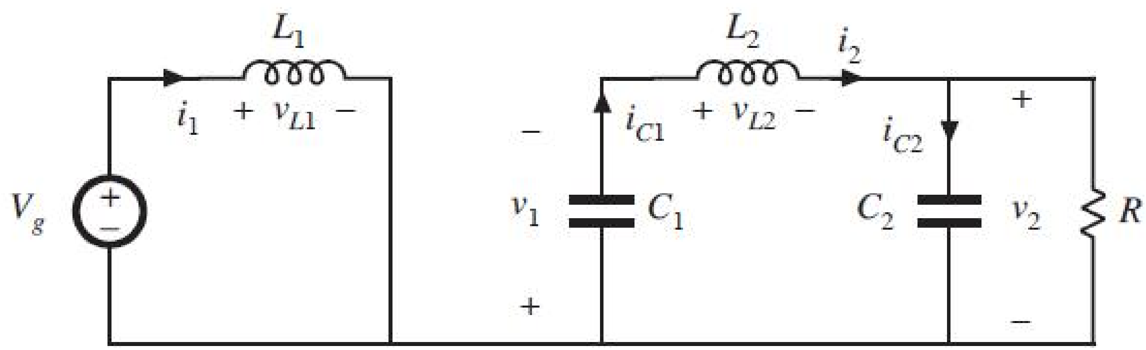
Stage 1: when switch is ON

When the switch is on the input voltages charges the inductor L1 and capacitor C1 releases its energy to output. Diode D1 act as open circuit. The equivalent circuit at this stage is shown in figure 2.11 (a).

$$V_{L1} = V_g \tag{2.22}$$

$$V_{L2} = -V_{C1} - V_{C2} \tag{2.23}$$

Current of capacitor C1 goes from the inductor L2 into the output capacitor



(a)ON Time of CUK converter

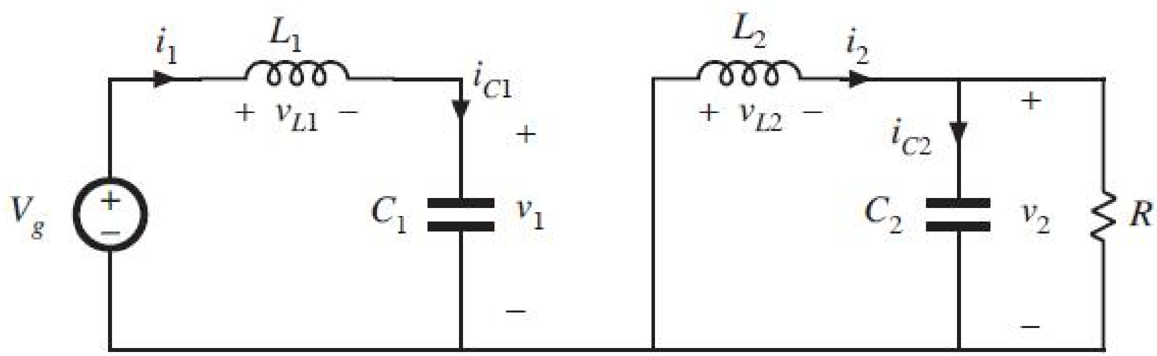


Figure 2.11: (b) OFF time of CUK Converter.

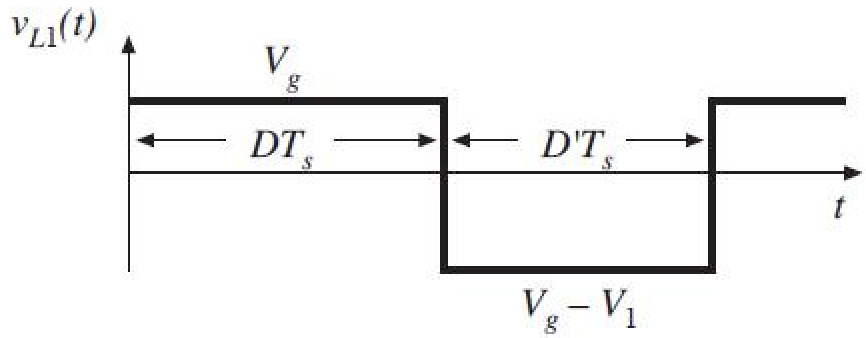
Stage 2: when switch is OFF

When switch is OFF diode conducts and capacitor C1 charges from input voltage. The equivalent circuit is shown in figure 2.11(b)

$$V_{L1} = V_g - V_{C1} \tag{2.24}$$

$$V_{L2} = -V_2 \tag{2.25}$$

Now by applying inductor volt sec balance on Inductor L1 and Inductor L2 we are able to find out the voltage gain of CUK converter. The most interesting factor of the result would be inverting and non-inverting output of CUK converter. Now before applying volt sec law we need to have a look in the wave form of switch and conduction time as shown in figure 2.12 (a) and (b) for inductor L1 and L2.



(a)

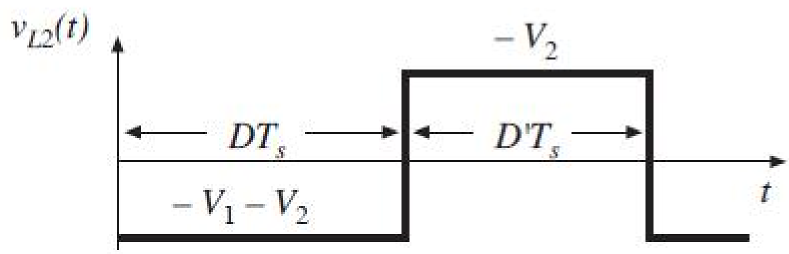


Figure 2.12: (b)

After applying volt sec balance on Inductor L1 we have the following equation

$$V_g D \quad = \left(V_g - V_{C1}\right)(1 - D)T = 0 \tag{2.26}$$

After solving above equation

$$V_{C1} = \frac{V_i}{(1-D)} \tag{2.27}$$

By applying volt sec balance on inductor L2 we have following equations shown below

As we know that $V_2 = V_O = V_{C2}$

$$(-V_{C1}-V_{O})D \quad -V_{O}(1-D)T=0 \text{ or } (V_{C1}+V_{O})D \quad +V_{O}(1-D)T=0 \qquad (2.28)$$

By equating above equation we have

$$V_{O}=-DV_{C1}=-D\frac{V_{i}}{(1-D)} \qquad (2.29)$$

Equation 2.29 shows the gain output of CUK converter and it shows that CUK converter is inverting DC-DC converter.

2.5 Integrated or Cascaded DC-DC Converter

Cascading and integrating of two or more than two DC-DC converter is more in practice after the vast and comprehensive rule of high voltage application. Conventional DC-DC converter is unable to provide a high gain not more than 6 or 7 time of input voltage. In order to tackle this need integration of DC-DC converter starts taking important place in power electronics. It increases the component selection and complexity of circuit but the main and important purpose is being driven. Lots of research and papers has been written on the Cascading method and topology as mentioned earlier as well.

Some of the cascaded topologies and circuit are well explained and describe in (Le Huy et al, 2018).

CHAPTER 3
PROPOSED TOPOLOGY DESCRIPTIONAND DEVELOPMENMT

3.1 Introduction:

On the basis of literature view done in previous chapter, that shows the several flaws in conventional DC – DC converter for high voltage applications especially in application where input voltages are low and need high voltage at output, conventional converter won't fulfill this requirement. The proposed DC-DC converter topology has very high gain with minimum losses and has better efficiency. The proposed converter is high step-up voltage converter consist of three Converters boost, SEPIC and CUK converter. These three converters are integrated with each other such that the output of the first converter (Double boost) will be input for second converter (SEPIC) and CUK converter is integrated as shown in figure 3.1. The first inductor is common for all converters and Single controlled power switch is used and three inductors of each converter that provides high voltage gain without high duty cycle. It allows the converter to decrease switching losses. Input ripple current can be reduced by coupling inductor in one core, that will not effect any DC charactersitics of the converter. Further more topology take care of voltage stress on semiconductors that enables the low voltage switching and $R_{DS\text{-}on}$ mosfet switch. Due to the low voltage stress a SCHOTKEY rectifiers is used for reverse recovery current problem. Output of the proposed topology is ripple free, continuous and non-inverting. **A design example of 250 W / 380V_{dc} with 24$V_{dc\ input}$ voltage is provided.**

3.2 Advantages of Using Proposed Topology:

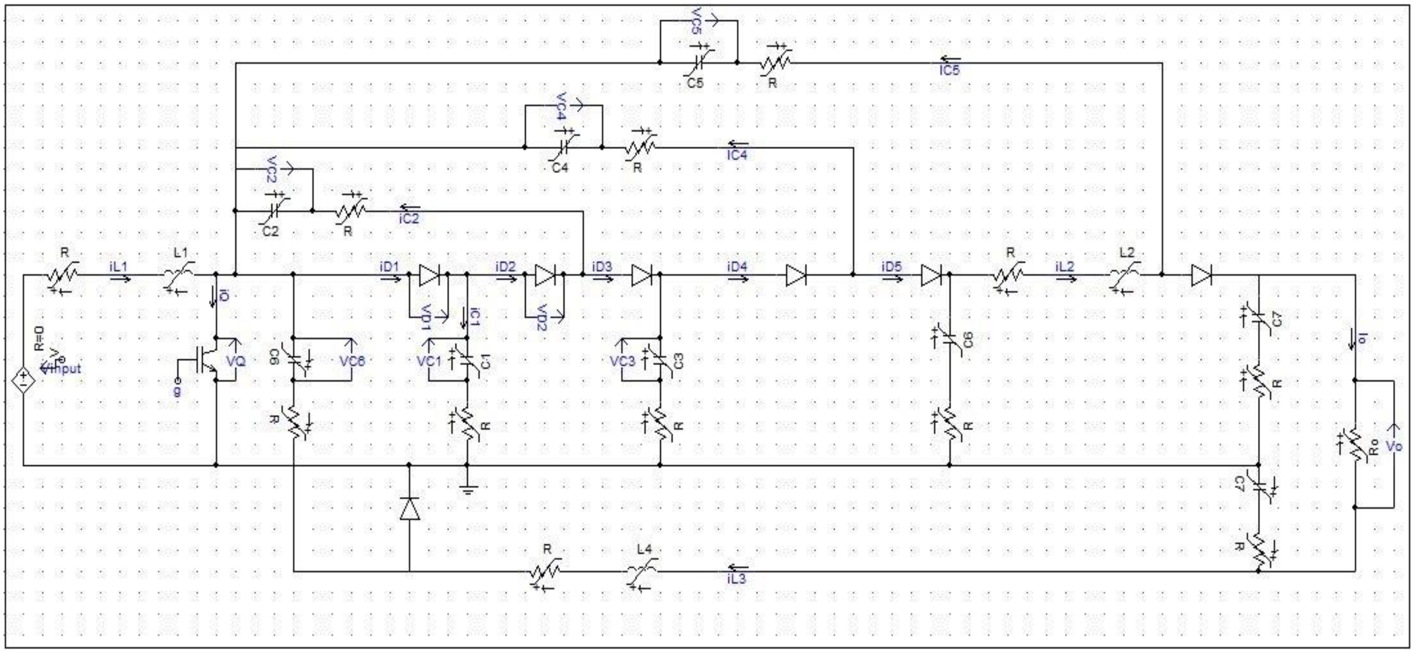
- Conventional Converter unable to provide a high gain and needed a high voltage and current rated diode and MOSFET which in result gives high conduction and switching losses. But proposed topology is able to solve this entire problem.
- Proposed topology uses a single switch and provided a large voltage step without using high duty ratio.
- Used of Separate Secondary inductor for each Converter provides a high gain.
- This topology reduces the effect of leakage inductance
- Zero voltage switching turn on operation is implemented.

The Double boost converter integrated with SEPIC and CUK converter is used for high step up, low input ripple current and without extreme duty cycle.

Double boost is chosen because of high step up capability, isolated output circuit and able to produce unidirectional step up voltage moreover input side inductor is able to resist sudden variation in input current as it stores energy in ON time and discharge during OFF time and SEPIC converter is used because of low input ripple current property, non-inverting output, continuous inductor current and able to perform buck and boost operation. CUK converter is used because of its better efficiency and ripple free output and it enables to reduce reluctance in the circuit and able to give high gain as well.

In result after integrated all three converters (IDBSAC) Integrated Double Boost SEPIC and CUK converter allows the duty cycle to be extended further and makes a proposed converter more suitable for very high step up application. The proposed topology maintains the main property of continuous input current, inherent inrush current limitation during start up and overload conditions, inductive component can be integrated on the same core, and reduced EMI (electromagnetic Interference) noise. This chapter illustrates all the important derivations and explains the principle of operation of proposed converter along with important circuit equation.

3.3 Operation Principle of IDBSAC:



The complete proposed topology is shown in figure 3.1it consists of Double Boost, SEPIC and CUK converter as mentioned earlier. This chapter will discuss in detail, all the aspects of the circuit and design specification of topology by mathematical calculation. Notice that Input part of all three converters is same Inductor L1 and Switch Q. Circuit comprise of single MOSFET switch and three Inductors. Input Inductor L1 is boost converter Inductor but used as common for SEPIC and CUK converter operation as well. Topology consists of SCHOTKEY diode used to resolve reverse recovery problem and filtering capacitor for ripple free output. SCHOTKEY diode enables fast switching as well and increase the protection.

Figure 3.1: Integrated Double Boost SEPIC and CUK Converter

3.4 Integrated Double Boost – SEPIC and CUK converter

3.4.1 High Step-up Double Boost Converter:

Input Stage of proposed topology is Double Boost Converter as shown in figure 3.2. ON and OFF time analysis has been done mathematically in order to achieve the desire result and for better understanding. Figure 3.3(a) shows the ON time of double boost converter and figure 3.3(b) shows the OFF time. Double boost converter consist of inductor L1 and this inductor is common for all other stages and the SCHOTKEY diodes is used to for reverse recovery problem and fast switching. Double boost converter is the only controlled stage with the switch. First the inductor L1 is being charged by the input voltage and when the inductor will be charged it will discharge itself through D1 as diode D1 acts forward biased. While analyzing the converter it is important to mention that all the components of converter is working in ideal case and 100 % efficient, the input voltage is pure dcand all the capacitor are chosen such that their voltage ripple are relatively small at switching frequency. These assumption should be keep in mind.

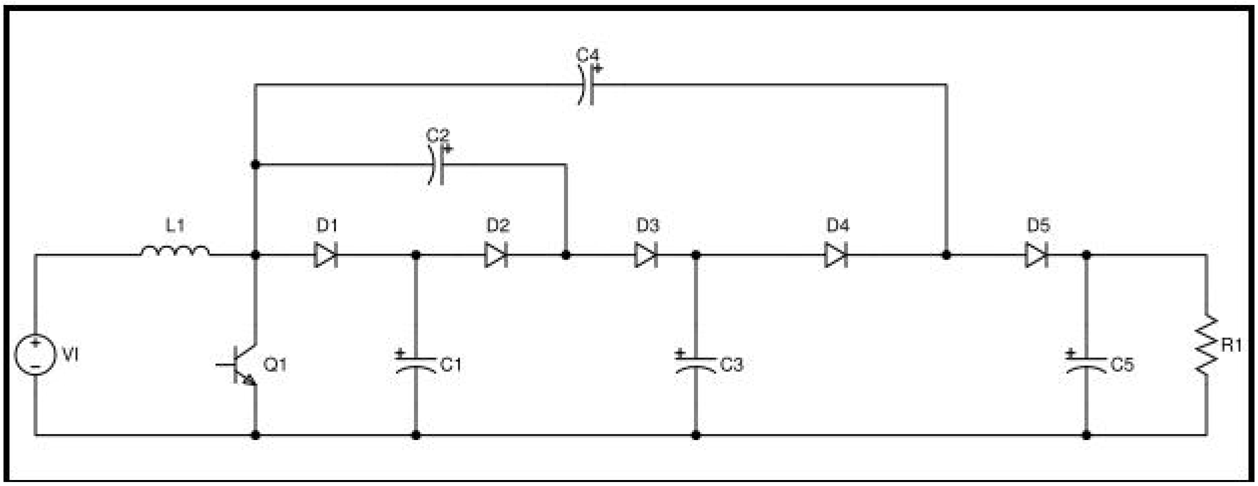


Figure 3.2: Double Boost Converters

Stage 1: [on time of switch] only considering double boost converter

Figure 3.3(a) when switch S, D_2 and D_4 is closed and D_1, D_3 and D_5 is open the equation are as follows.

$$V_{C1} = V_{C2} \quad (3.1)$$

$$V_{C3} = V_{C4} \quad (3.2)$$

$$V_{L1} = V_I \quad (3.3)$$

Equation 3.1 derived by considering loop 1 that include inductor and input voltage. Equation 3.2 and equation 3.3 is derived from loop 2 and 3 as shown in figure 3.3 (a)these equations will be used to derive the voltage gain.

Stage 1: [of time of switch] only considering double boost converter

Fig 3.3(b) when Switch S, D_2 and D_4 is open and D_1, D_3 and D_5 is closed the equation are as follows.

$V_{L1} = V_i - V_{C1}$ (3.4)

$V_{C4} - V_{C2} + V_{C3} = V_O$ (3.5)

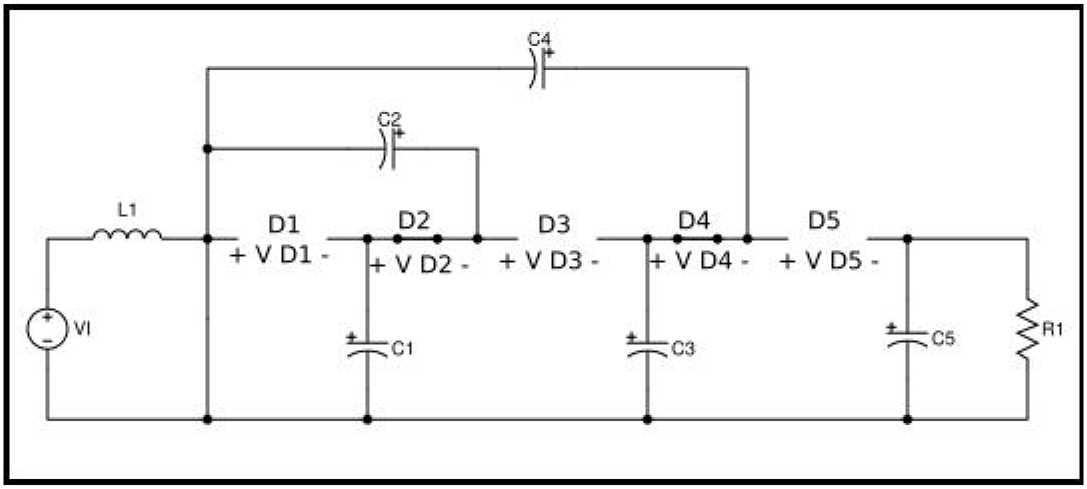


Figure 3.3:(a) ON Time of double boost converter

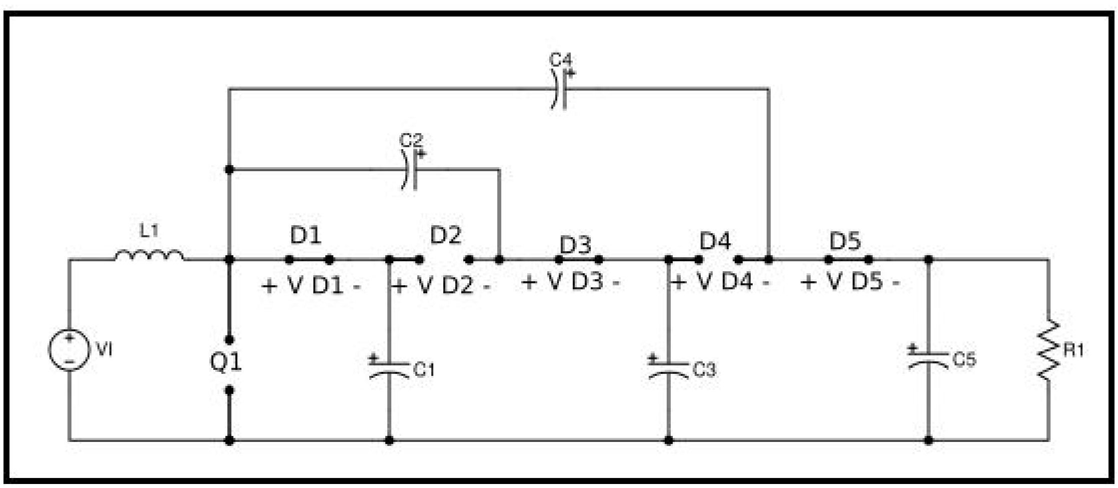


Figure 3.3: (b) OFF Time of double boost converter

By using equation 3.2 and 3.1 in equation 3.5 above equation will be

$$V_O = 2V_{C3} - V_{C1} \tag{3.6}$$

$$V_{C3} = V_{C1} + V_{C2} \tag{3.7}$$

Using equation 3.1 in equation 3.7

$$V_{C3} = 2V_{C1} \tag{3.8}$$

By putting equation 3.8 in equation 3.6

$$V_O = 3V_{C1} \tag{3.9}$$

In order to calculate inductor average voltage according to the volt sec balance law in continuous current mode the average inductor voltage will be zero.

These equations are really very important and useful to obtaining voltage gain of Double boost converter. As double boost converter is the most important part of topology because we are only controlling the voltage of double boost converter and other converters voltages is depending upon Double boost Output. So by applying volt sec balance on inductor equation.

$$\frac{1}{T}\int_0^T \mathrm{v}_{L1} d \;= \frac{1}{T}\left[\int_0^D (V_i) d \;+ \int_D^T (V_i - V_{C1}) d\;\right] = DV_i + (1-D)(V_i - V_{C1}) = 0$$

$$V_i = (1\text{-D})\, V_{C1} \tag{3.10}$$

As output equation is stated as in equation 3.9

$$V_O = 3\, V_{C1} \tag{3.9}$$

By using equation 3.9 and 3.10 we compute the gain as shown in equation 3.11

$$\text{Gain} = G_{DB} = \frac{V_O}{V_i} = \frac{3}{1-D} \tag{3.11}$$

Equation 3.11 shows the voltage conversion ratio of double boost converter (G_{DB}) of figure 3.2 by analyzing this conversion ratio it is easily understandable that the gain is quite high and even on small duty cycle ratio the output gain is more. Capacitor C4 worked as output filter it reduces all the ripples and reduced the overshoot before settling time when analyzed separately without adding other converter.

From figure 3 we can notice that all three converters have same input part boost inductor L_1 and semiconductor Switch S. Therefore, all three converters can be connected with single input and we can take triple output as shown in figure 3.5, some changes need in order to get triple output the inductor L2 should be connected with the ground, after connecting inductor with the ground the first output will be of double boost and second will be from sepic and third from CUK and for taking output from CUK converter capacitor C8 and C9 we need to separate both capacitor.

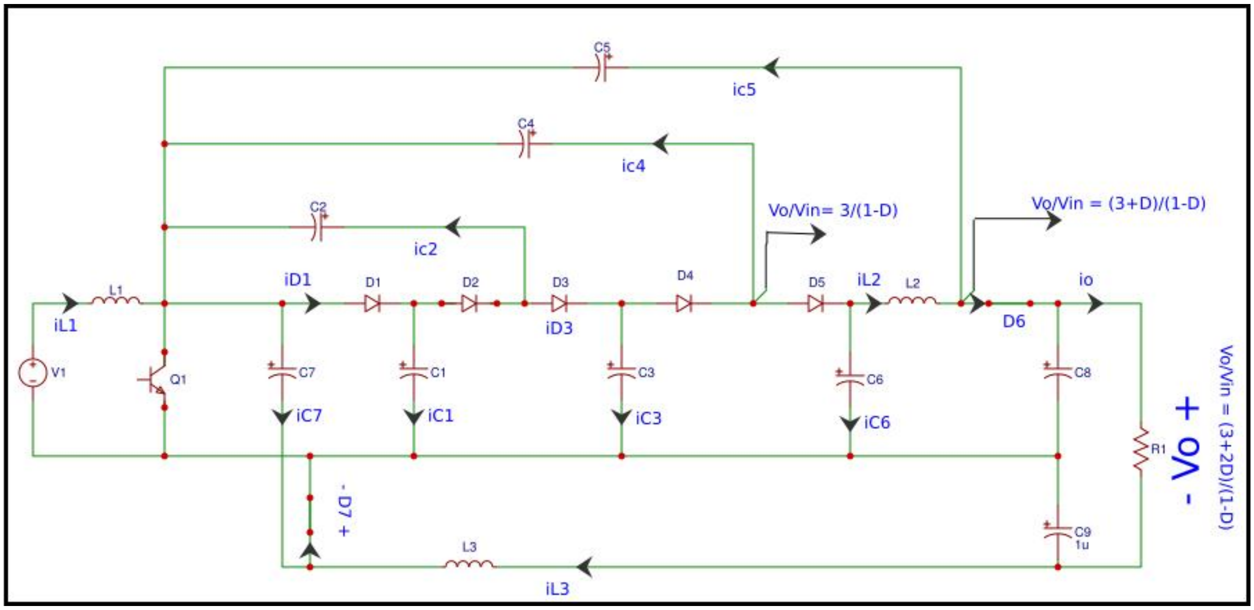


Figure 3.5: Three Output on different stages

The SEPIC Inductor L2 must be connected between D5 and D6 rather than ground to achieve high gain so that voltage conversion ratio for the proposed converter would be the sum of individual converter. After Integrating SEPIC with Double boost converter next stage is to integrate CUK converter. Integrating CUK converter with Double Boost and SEPIC in last stage provides extended static voltage gain compared to other high gain converter with very low output ripple voltage. As CUK converter is inverting converter but proposed topology used CUK converter in non-inverting manner.

Complete description of SEPIC and CUK converter is done in chapter 2 Literature review.

3.4.2 Voltage Gain of IDBSAC converter.

The voltage gain of SEPIC converter and CUK converter is $V \quad = \frac{D}{1-D} * V$ and $V \quad = -\frac{D}{1-D} * V$ Respectively as derived completely in literature review but CUK converter is used in non-inverting form so there will be no negative in gain formula of CUK converter.

As mentioned earlier the over-all gain is the sum of the gain of each converter.

$G_{DB} = \frac{3}{1-D}$ gain of Double boost

Gain of SEPIC and CUK converter = $\frac{D}{1-D}$

$$G_{IDBSAC} = \frac{3}{1-D} + \frac{D}{1-D} + \frac{D}{1-D} = \frac{3+2D}{1-D} \qquad (3.12)$$

Over-all voltage gain of proposed topology is shown in above equation.

3.4.3 Proposed Converter Analysis and Operation:

Figure 3.1 shows the complete topology, some important points to be notice before analysis of the proposed converter. All the components are working in an ideal Condition. Diode forward bias drop voltages are considered as default. Converter operates in CCM mode so the current is continuous in proposed converter and switching losses assume to be very less as the voltage stress is low because of not using high duty cycle. Analysis is done in two stages ON time of a switch from time 0 to D and in second stage OFF time of a switch from (D-T) to T.

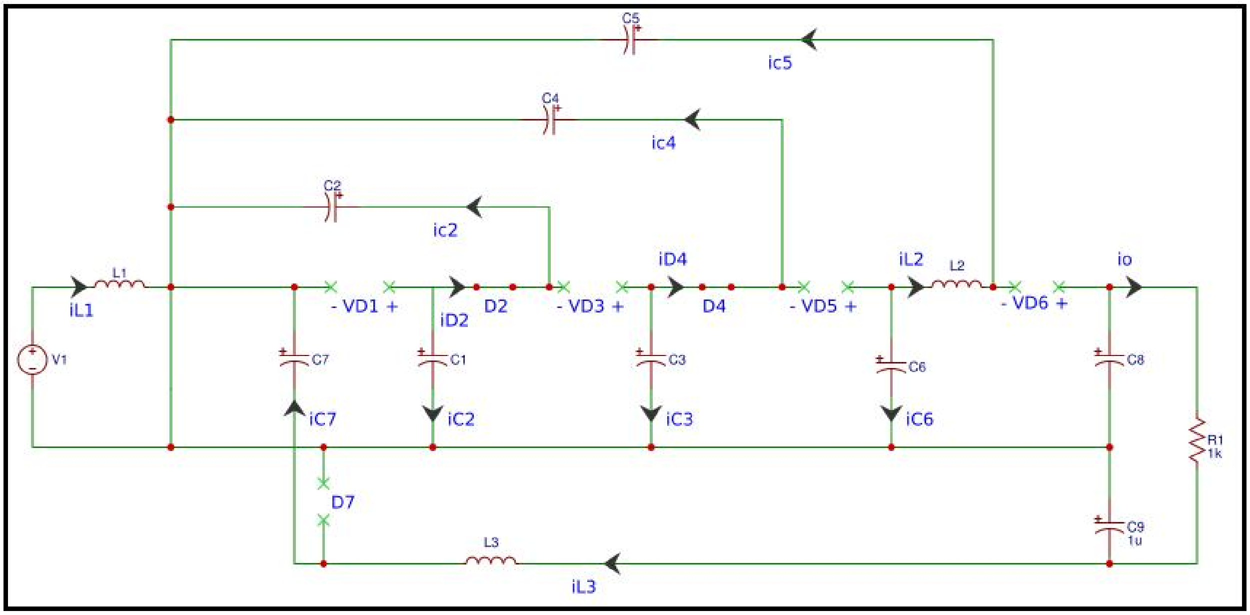


Figure 3.6:(a) ON Time of switch

STAGE 1: when Switch is ON

The ON time of proposed topology Equivalent circuit is shown above. When Switch S is ON Inductor L1, L2 and L3 is charged and current through inductors increases linearly and stores energy. Diode D1, D3, D5 and D6 are blocked by negative voltages of capacitor C1, C3, C6 and C8. Capacitor C2 is being Charged by Capacitor C1, C4 is being charged by C4 and C5 is being charged by C6 through inductor L2 and capacitor C7 is discharging or consist of negative voltage due to Capacitor C8 has greater voltages. While switch is on some of the important equation are as follows.

$$V_{i1} = V_L$$

Equation shown above depicted that when the switch S is on all the voltage is going from the input inductor L1.

$$V_{C1} = V_{C2}$$

Second loop gives above equation as voltage at capacitor C1 and C2 is equal. Similarly equation shown below is taken from the third loop

$V_{C3} = V_{C4}$

Voltage at inductor L2 will be the difference of voltages at capacitor C5 and C6

$V_{L2} = V_{C5} - V_{C6}$

Output voltage is equal to the sum of voltages of Capacitor C8 and C9 driven from the graphical result and the circuitry.

$V_O = V_{C8} + V_{C9}$

$V_{L3} = V_{C8} - V_{C7}$

Voltage at inductor L3 is equal to the difference of voltage at capacitor C8 and C7. All above equation shows the ON time equation of proposed topology.

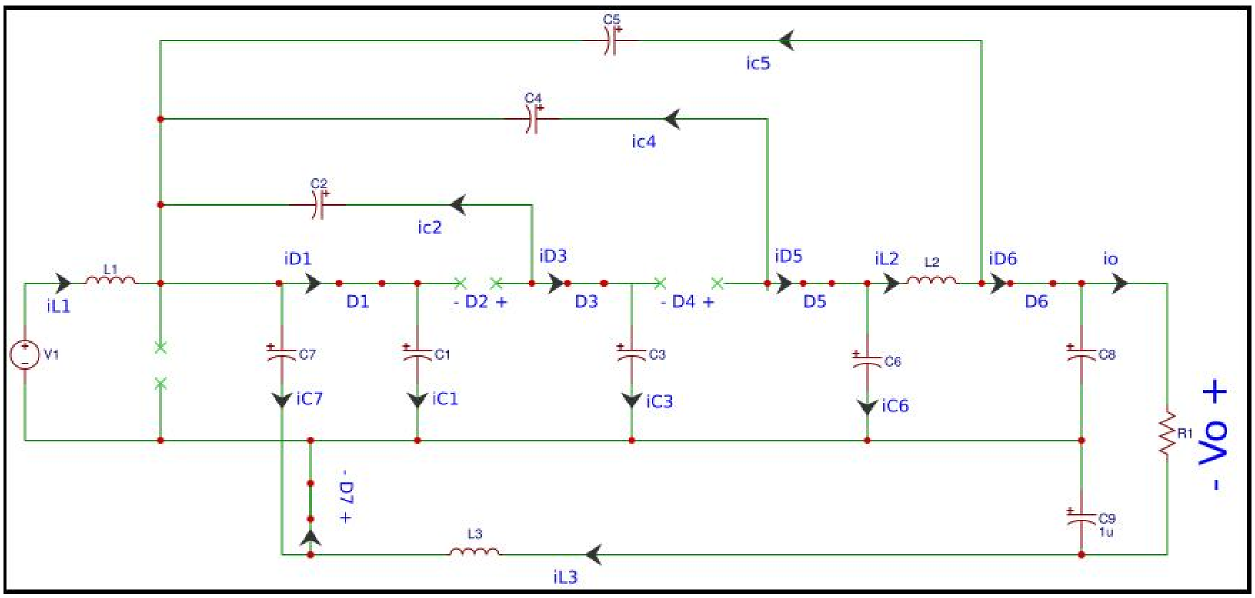


Figure 3.6 (b) OFF time of a switch

STAGE 2: when Switch is OFF

Equivalent circuit of the proposed topology when the switch is OFF is shown in figure above. Inductors L1, L2 and L3 discharges its energy and the current through them decreases linearly and diodes D1, D3, D5, D6 and D7 closed instantly providing inductor current to flow from them. Diode D2 and D4 is reverse biased due to the voltage of capacitor C3 and C6. Capacitor C1 and C7 is being charged by current (iL1, iD1 and iC2) and (iL1, iC2) respectively. Some of the important equation of OFF time switch is as follows

$$V_{L1} = V_{i} - V_{C1}$$

$$V_{C3} = V_{C1} + V_{C2}$$

$$V_{C4} - V_{C6} = V_{C2} - V_{C3}$$

$$V_{L2} = V_{C4} - V_{C5}$$

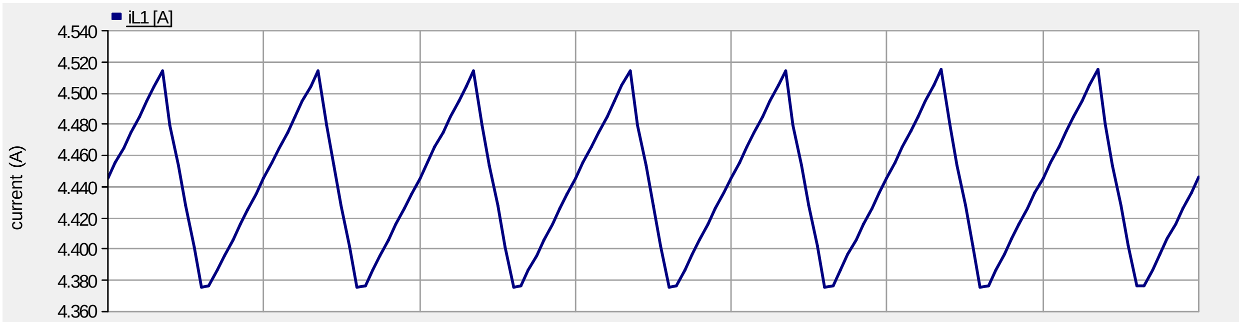
$$V_{L3} = V_{C9}$$

$$V_{O} = V_{C8} - V_{C9}$$

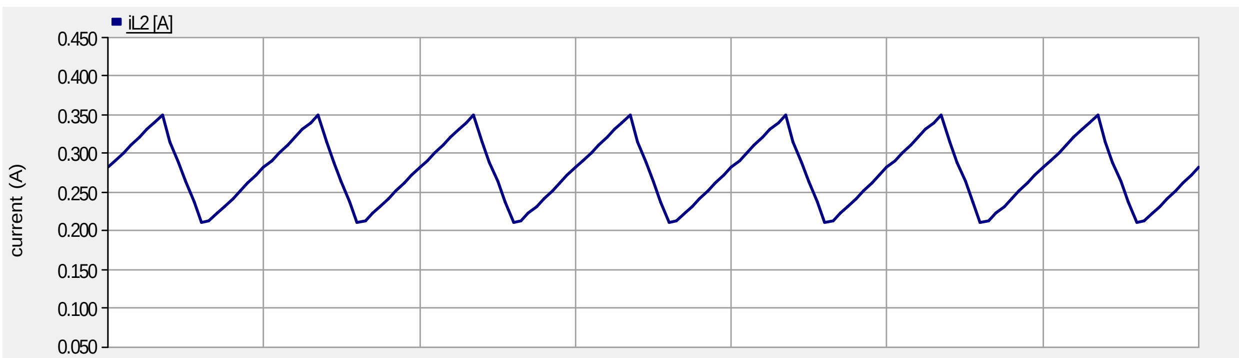
All above equation depicts the OFF time of circuitry. Correctness of these equations is shown in chapter 4 of experimental result.

3.4.4 CCM and DICM Mode:

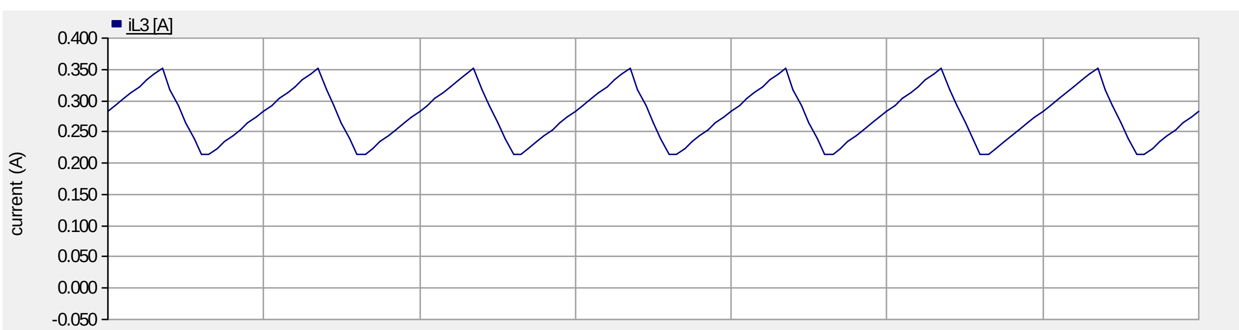
CCM mode occurs when the inductor current goes to zero or inductor become completely discharge due before the next ON time of a switch or during the OFF time off a switch. When the converter operates in CCM mode the current ripples through inductor L1, L2 and L3 can be assumed negligible. According to the operation as the circuit is divided into stages above within the $T_s$time as shown above in figure 3.6 and 3.7. The proposed topology is completely working in continuous conduction mode. As all the inductor current is not becoming zero before the switch triggered. It can be clearly seen from the inductor and gate pulse wave form as shown in the figure 3.8 (a), (b), (c), (d)



(a)Inductor L1 waveform



(b)Current wave form of Inductor L2



(c) Current waveform of Inductor L3

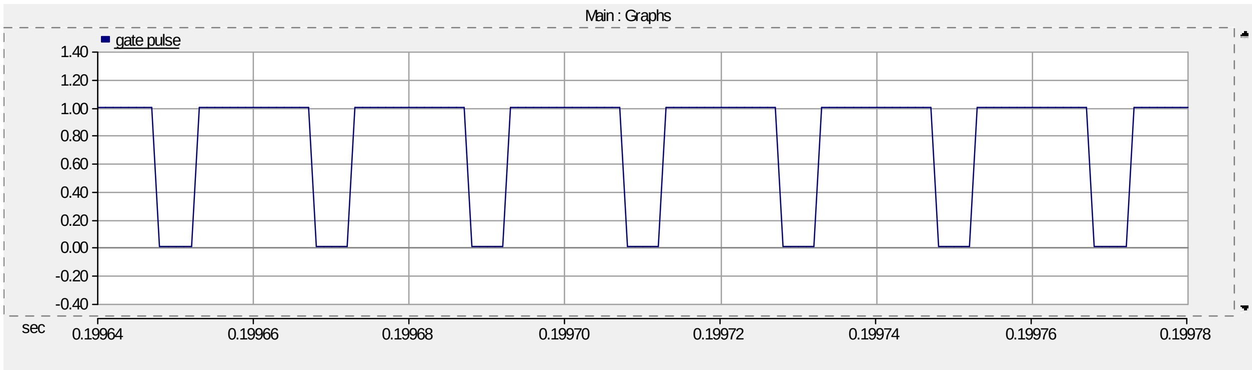


Figure 3.8: (d)Gate Pulse of Switch S1

3.5 Comparison of Proposed converter Gain with Conventional Current:

Figure 3.12 shows the comparison graph between proposed topology and other step up converters that include Boost, SEPIC and Double boost DC-DC converter. The graph shows the output voltage of each converter at different duty cycle. It can be clearly observe that the gain of proposed topology is much greater than the conventional converters.From the beginning of the graph the voltage gain of proposed circuitry is more. Main aim is to reduce the voltage stress from the switching circuitry it can clearly noticed that at normal duty cycle of 75% there is a clear difference of output voltage gain.

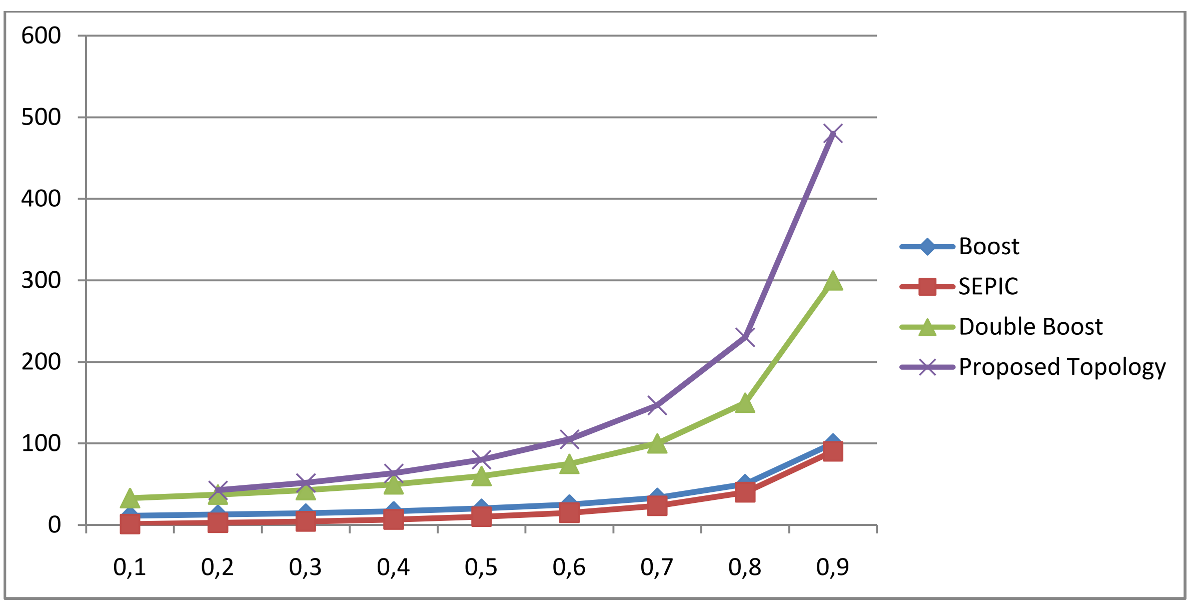


Figure 3.12: Comparison between proposed and other DC-DC Converter

3.6 Components of Proposed Circuit

Table 3.1 Components Table

Components	Value
Inductor L1, L2, L3	1mH
Capacitors C1, C2, C3, C4,C5,C6, C7, C8, C9	47 uF
Diode D1, D2, D3, D4, D5, D6, D7	Default voltage drop 0.7 v
Switch	IGBT
Load	20 ohms
Input Voltage	24 volts
Duty cycle	73%
Ripple voltage	Less than 2%
Output voltage	386 volts
Power Output	250 watts

Summary

The IDBSAC (Integrated double boost SEPIC and CUK)has been present in this chapter by explaining all the important aspects. At first the voltage gain of each stage has been derived and there a sub stage has been explained as well. Integration method and the way to integrate the more than one converter and combine voltage gain has been discussed in details. All important equation of each stages has also been shown for analytical prove with the simulation. Hence the mathematical equations are proving all the simulation results.

CHAPTER 4
SIMULATION AND RESULTS

Proposed circuitry has been simulated in PSCAD software. PSCAD software is able to simulate Power Electronics Circuit with improved accuracy and efficiency. All the results is of real time simulation taken from PSCAD. Keep in mind all the components are working in the ideal condition and with maximum efficiency.

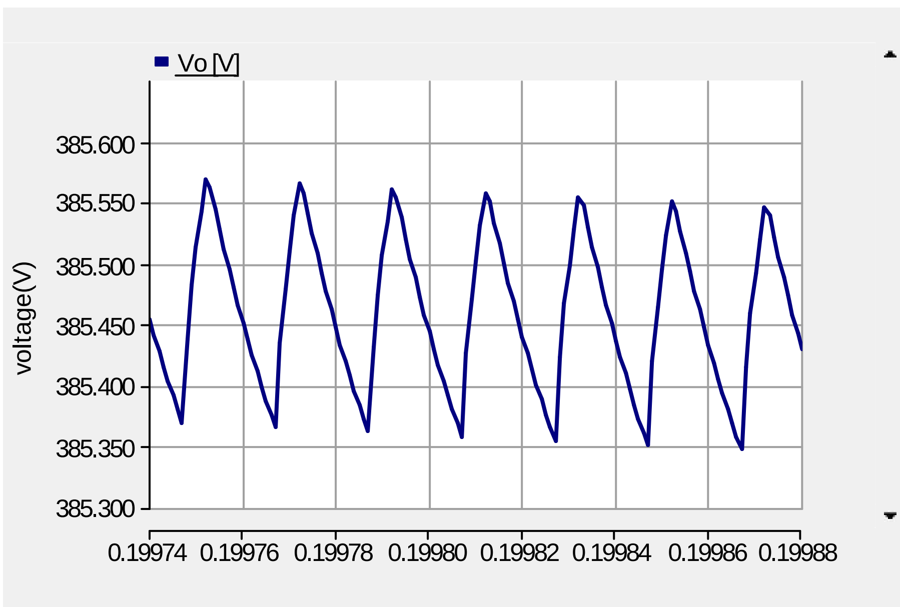


Figure 4.1: Output voltage

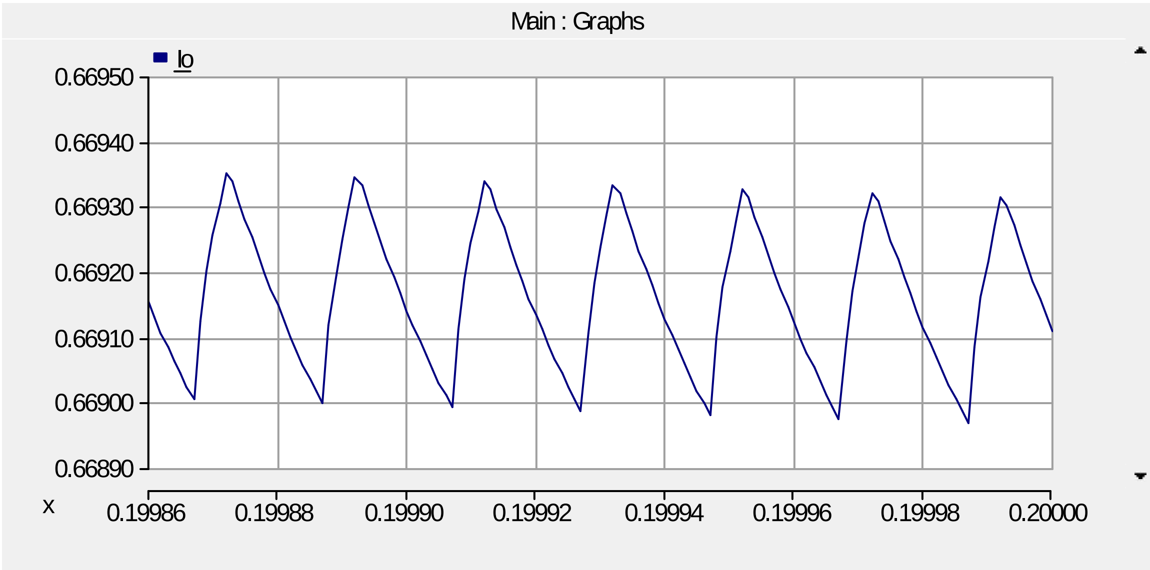


Figure 4.2: Output Current

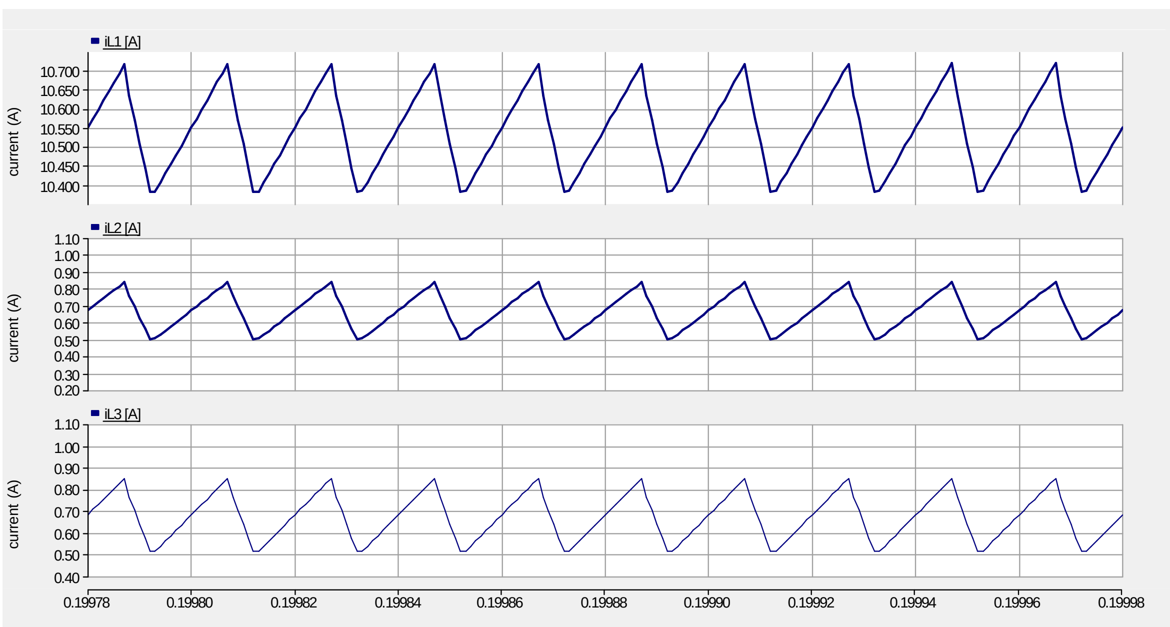
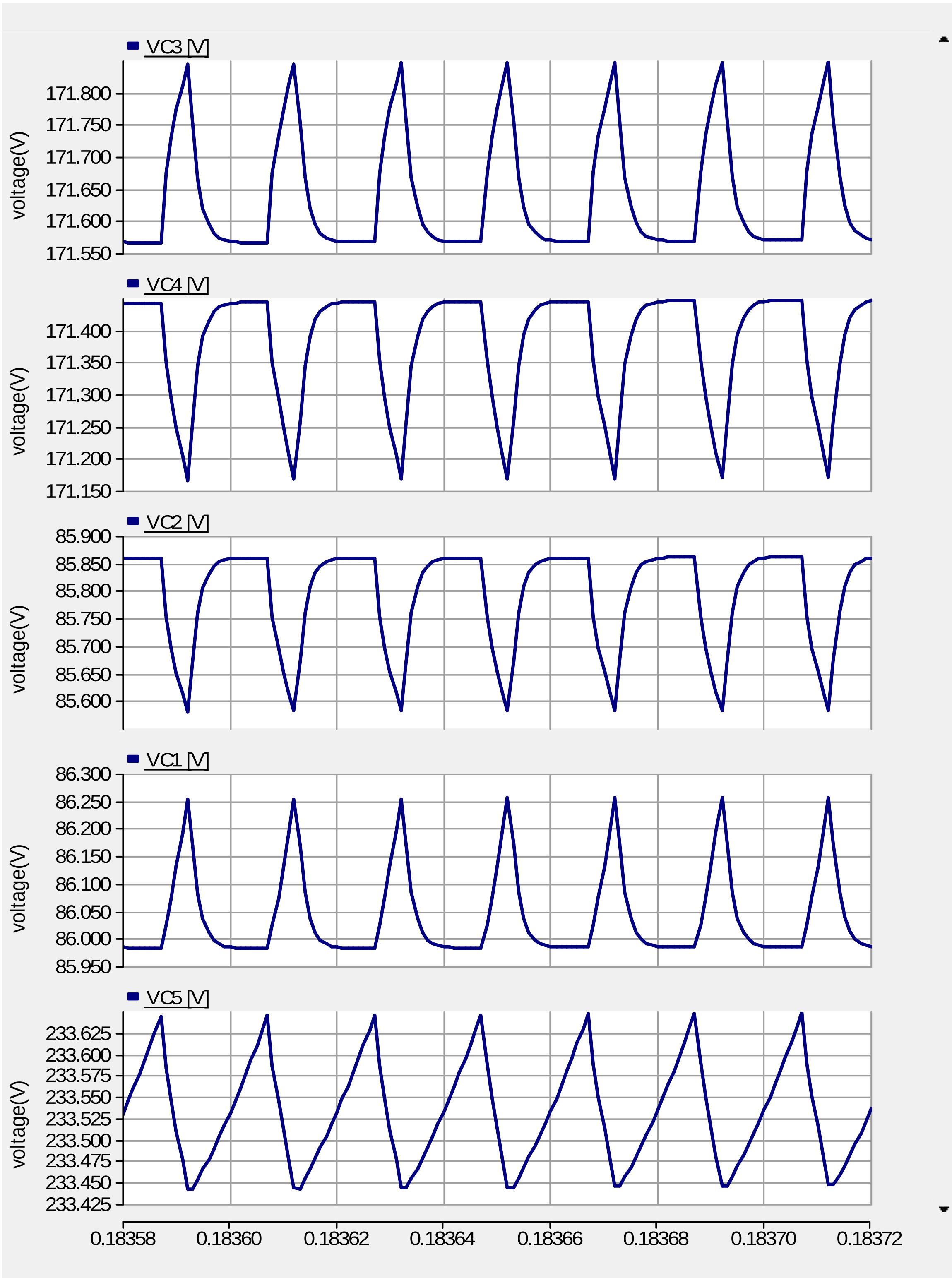
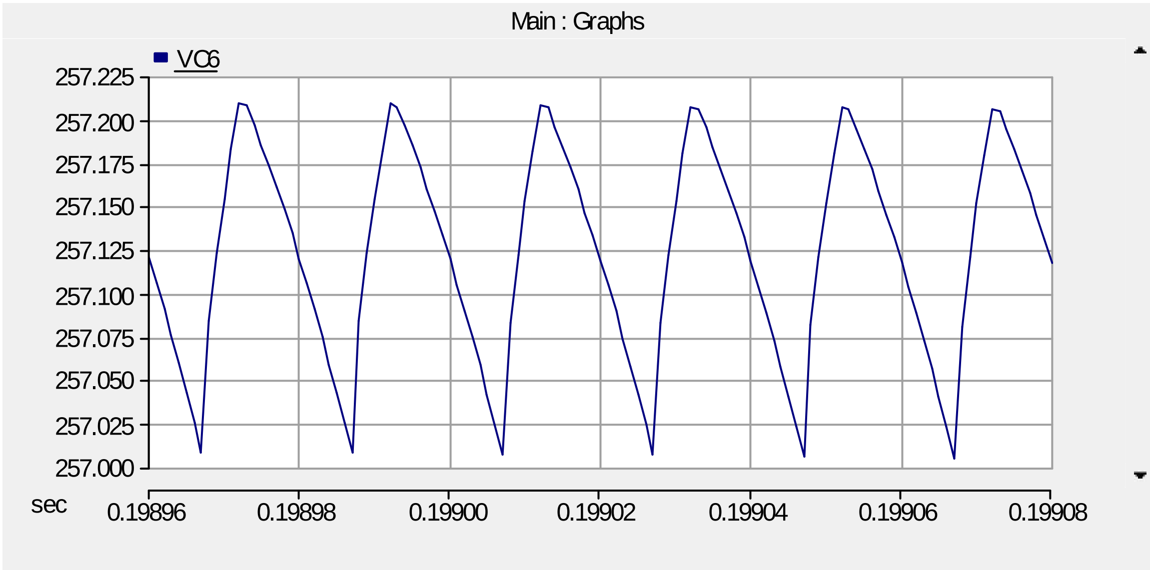


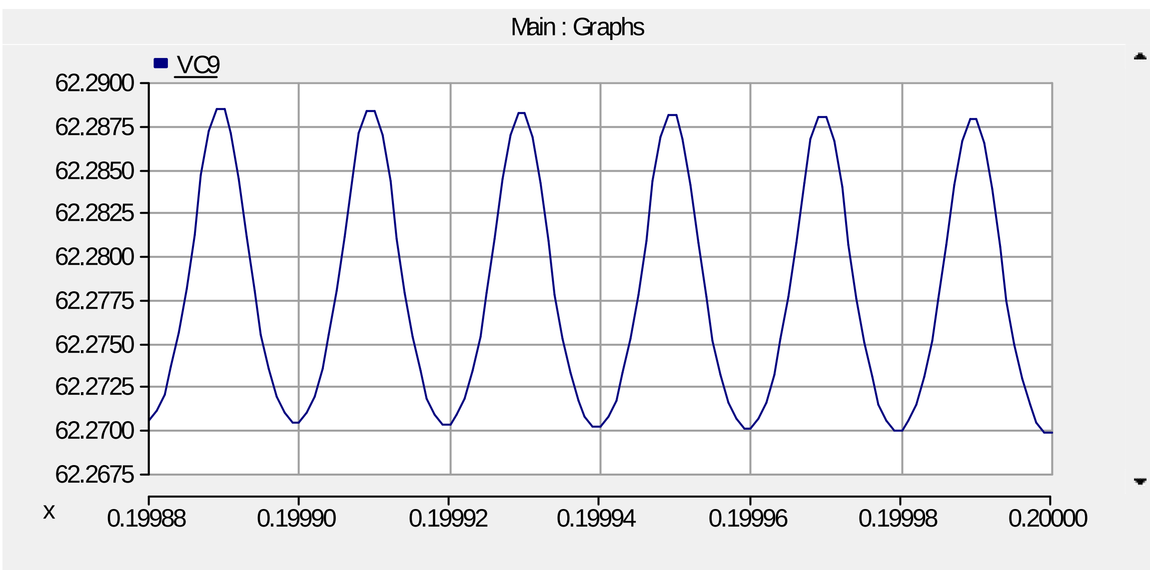
Figure 4.3: Inductor current of L1, L2 and L3


VC3 [V]
171.800
171.750
171.700
171.650
171.600
171.550
voltage(V)
VC4 [V]
171.400
171.350
171.300
171.250
171.200
171.150
voltage(V)
VC2 [V]
85.900
85.850
85.800
85.750
85.700
85.650
85.600
voltage(V)
VC1 [V]
86.300
86.250
86.200
86.150
86.100
86.050
86.000
85.950
voltage(V)
VC5 [V]
233.625
233.600
233.575
233.550
233.525
233.500
233.475
233.450
233.425
voltage(V)
0.18358
0.18360
0.18362
0.18364
0.18366
0.18368
0.18370
0.18372

(a)


Main : Graphs
VC6
257.225
257.200
257.175
257.150
257.125
257.100
257.075
257.050
257.025
257.000
sec
0.19896
0.19898
0.19900
0.19902
0.19904
0.19906
0.19908

(b)


Main : Graphs
VC9
62.2900
62.2875
62.2850
62.2825
62.2800
62.2775
62.2750
62.2725
62.2700
62.2675
x
0.19988
0.19990
0.19992
0.19994
0.19996
0.19998
0.20000

(c)

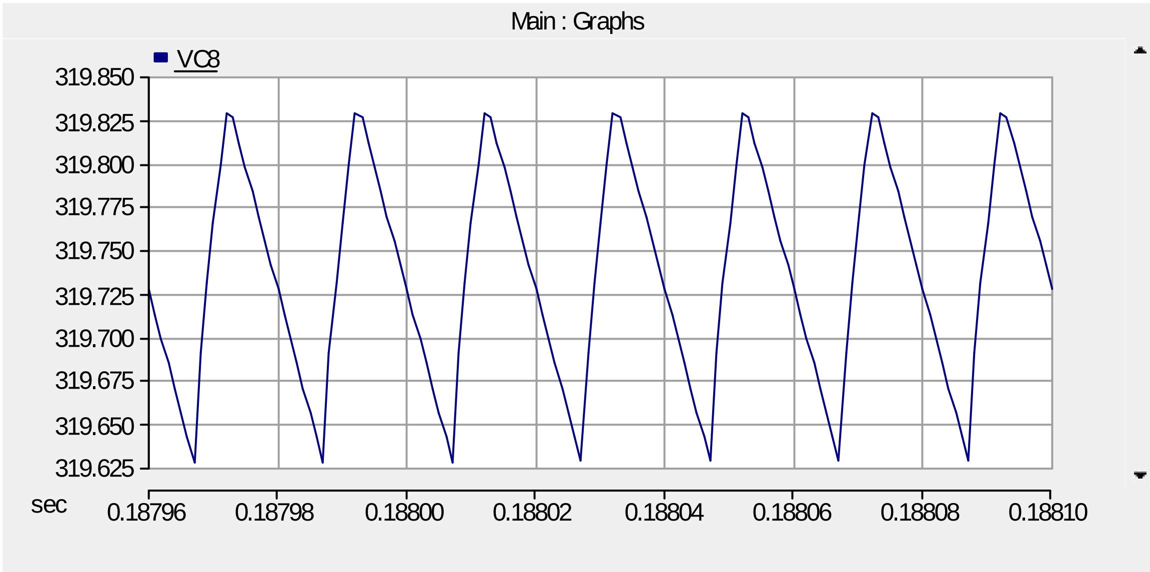


Figure 4.4: Capacitors Voltages (d)

C1 to C5 (a), C6 (b) C7, C8 (c)

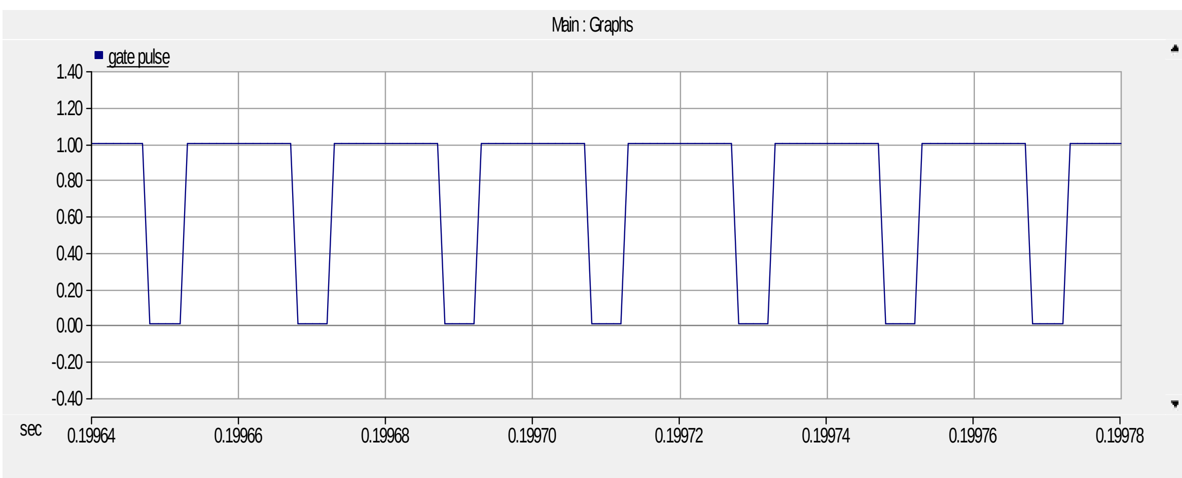


Figure 4.5: Gate Pulse

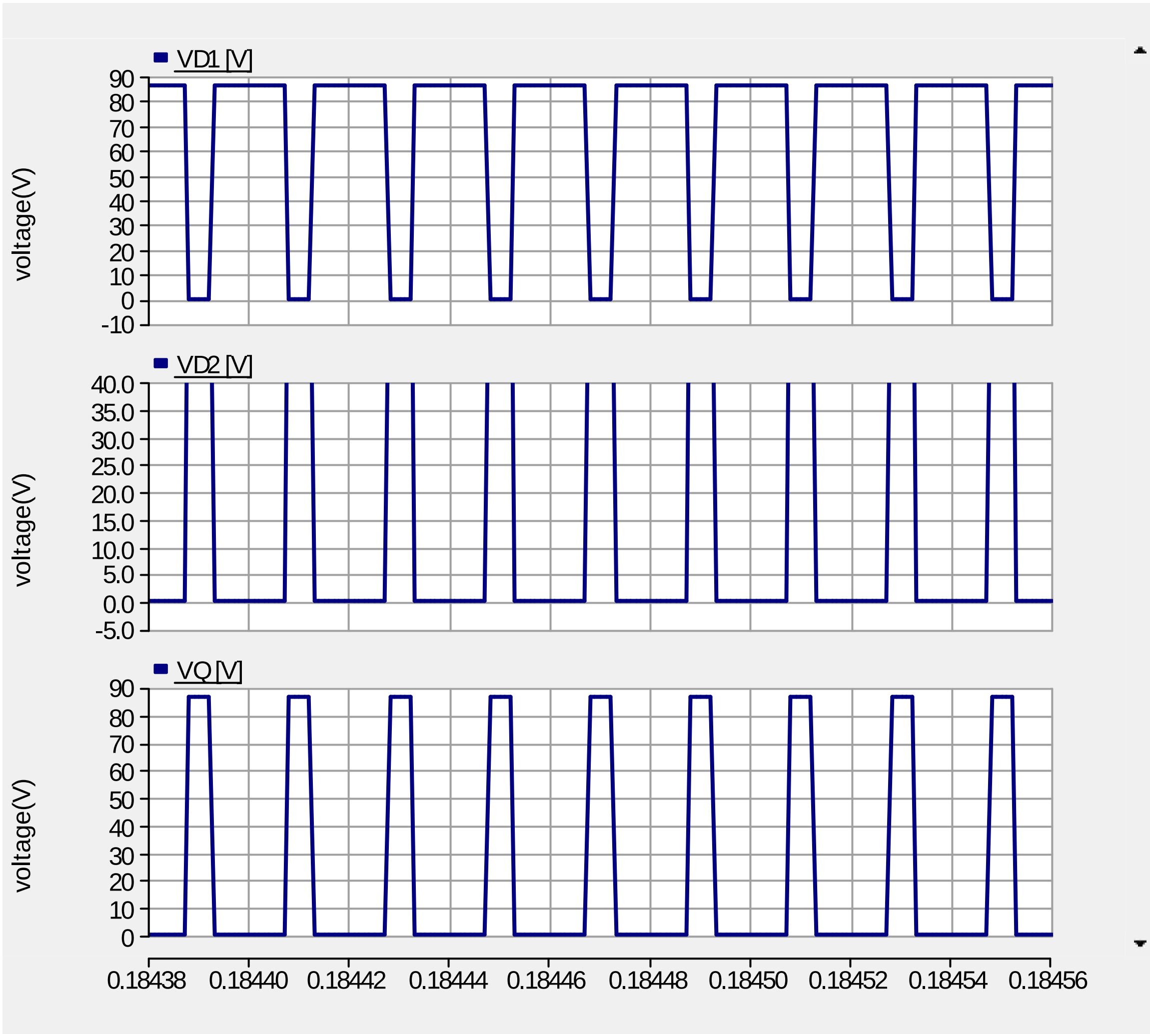


Figure 4.6: Diode D1, D2 and MOSFET Switch Voltage

CHAPTER 5
CONCLUSION

Presented topology depicts Integrated Double Boost SEPIC and CUK converter for high voltage applications. Prime Purpose of the thesis is achieved by cascading three converters as three stages. In first stage double boost converter is used as input stage and it is the only controlled converter with the switching signal. SEPIC and CUK converter is integrated in second and third stage as a un-controlled converter because the topology used only one switch to reduce the switching losses and normal duty cycle is applied in order to have a less voltage stress on switch. SCHOTKEY diodes are used to reduce reverse recovery problem and for protection of circuit. The output voltage and current has less than 2% ripples and the circuit is handful for all sensitive high voltage devices. Mathematical Equation has been driven to prove simulation results. Comparison of proposed topology is being done with other conventional converters in order to demonstrate that proposed topology is the finest.Furthermore topology has wide range of enhancement to use in a closed loop systems as well in PV systems and in Fuel cells application.

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