ANALYSIS, DESIGN AND SIMULATION OF HIGH VOLTAGE GAIN TRANSFORMERLESS DC-DC CONVERTER

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES

OF

NEAR EAST UNIVERSITY

By
HABIBU MURTALA ABDULLAHI

In Partial Fulfilment of the Requirements for the Degree of Master of Science
in
Electrical and Electronic Engineering

NICOSIA, 2019

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Approval of Director of Graduate School of Applied Sciences

Prof. Dr. Nadire CAVUS

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

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Date: 29-05-2019

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the contributions of many individuals throughout the entire period of my studies who have directly or indirectly helped toward the writing of this thesis.

I would like to extend my deep gratitude to my beloved and high-ranking parliamentarian Hon. Comrade Aminu Suleiman GORO, for his numerous contributions and support, thanks a lot Sir. Moreover, I would like to thank the Management of the Federal University Gusau who provides me with a full Sponsorship to study Master's degree in abroad.

Also, I am grateful to my supervisor Prof. Dr. Ebrahim Babaei for his numerous fruitful discussions and kind guidance throughout the period of my research. His comments and corrections have always helped me to improve my work in many ways. Moreover, I would like to thank my other colleagues and friends for their cooperation encouragement and assistances.

Furthermore, I am mightily and forever indebted to my Father who demised amid the period of this research and my beloved mother Hajiya Saudat Muhd (NENE) for their love, tireless support and words of encouragement throughout my entire life. I am also very grateful to my brothers, sisters. and entire members of my family for their endless inspiration, support and guidance.

Last but not the least; I would like to thank my wife for her usual encouragement, supports and patient through the period of my study. Thank you so much and God bless you all.

ABSTRACT

The Generation and conversion of energy is critically important especially to the safety and sustainability of human life. The demand of energy conversion system is rapidly increasing per day especially in the areas of modern technology such as renewable energy, electric vehicles and telecommunication systems. The incapacities of the conventional non-isolated converters to generate high energy conversion ratio usually occurs as a result of power losses across the switches, high voltage stress, conversion operations near the unity duty cycle and switching mechanisms as well as power stress on the elements; have exposed the limitations of these converters and sparked the huge demand for higher step up non-isolated power electronics converters.

In this thesis, simple structure dc-dc transformer less converter with the higher voltage conversion ratio and an improved efficiency have been proposed. The converter consists of two sets of switches, inductors, capacitors, diodes as well as lift voltage circuit. The proposed converter has come up with solutions of the problems (mentioned above) suffered by conventional non-isolated converter.

Two inductors $L_1$and L_2 with equal inductance levels designed to charged parallelly when switches are in on-state and discharged serially when the switches are in off-state. the converter operates in continuous operating and discontinuous operating conditions and also the boundary between them. Under the same operational condition. The output capacitor designed to be very large in order to have constant voltage and also to avoid the overvoltage, the output of the proposed converter shows good conversion result. The most interesting behavior of this converter is that, only one power stage is acting at a time. The structures of the converter are designed to be very simple with suitable voltage rating of the components and low building cost.
PSCAD/EMT package were used for the simulations of theoretical analysis and designed result to verify the performance and general behavior of the converter

Keywords: Power stage; dc-dc boost converter; high step-up; voltage gain; PSCAD package

ÖZET

Enerjinin üretilmesi ve dönüştürülmesi, özellikle insan yaşamının güvenliği ve sürdürülebilirliği için kritik öneme sahiptir. Enerji dönüşüm sistemine olan talep, özellikle yenilenebilir enerji, elektrikli taşıtlar ve telekomünikasyon sistemleri gibi modern teknoloji alanlarında, gün geçtikçe hızla artmaktadır. Konvansiyonel izole edilmemiş konvertörlerin, anahtarlar boyunca güç kayıpları nedeniyle yüksek enerji dönüşüm oranı üretmedeki yetersizlikleri, elektromanyetik ters geri kazanımın etkileşimi, yüksek voltaj gerilimi, birlik görev döngüsü yakınındaki dönüşüm işlemleri ve anahtarlama mekanizmaları elemanlar, bu dönüştürücülerdeki sınırlamaları ortaya çıkarmış ve daha yüksek kademeli izole edilmemiş güç dönüştürücüleri için büyük talebi arttırmıştır. Bu tez çalışmasında, basit yapı trafosunda daha verimli ve daha yüksek gerilim dönüşüm oranına sahip daha az dc-dc dönüştürücü önerilmiştir. Dönüştürücü iki anahtar seti, indüktör, kapasitör, diyot ve asansör voltaj devresinden oluşmaktadır. Önerilen dönüştürücü, geleneksel izole edilmemiş dönüştürücünün yaşadığı sorunlara (yukarıda belirtilen) çözümler getirmiştir. Anahtarlar açık durumdayken paralelkenar yüklemek ve anahtarlar kapalı durumdayken seri olarak boşaltmak için tasarlanmış eşit endüktans seviyelerine sahip iki indüktör L1 ve L2. dönüştürücü sürekli çalışma ve süreksiz çalışma koşullarında ve ayrıca aralarındaki sınırda çalışır. Aynı işletme koşulunda, önerilen dönüştürücünün çıktısı aşırı düşük görev döngüsü ile yüksek voltaj dönüşüm oranı gösterir. Sabit bir gerilime sahip olmak ve ayrıca aşırı gerilimi önlemek için çıkış kapasitörü çok büyük olacak şekilde tasarlanmıştır. Bu dönüştürücüdeki en ilgi çekici davranışı, bir seferde yalnızca bir güç kademesinin hareket etmesidir. Dönüştürücünün yapıları, bileşenlerin düşük voltaj oranı ve bina maliyeti ile çok basit olacak şekilde tasarlanmıştır. Dönüştürücünün performansını ve genel davranışını doğrulamak için teorik, analiz ve tasarlanan sonucun simülasyonları için PSCAD paketi kullanılmıştır.

Anahtar kelimeler: Güç kademesi; dc-dc hizlandirici dönüştürücü; dc-dc dönüştürücü; PSCAD paketi

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LIST OF ABBREVIATIONS

AC:	Alternating Current
BJT:	Bipolar Junction Transistor
C:	Capacitor value
CCM:	Continuous Conduction Mode
D:	Duty cycle
DC:	Direct Current
DCM:	Discontinuous Conduction Mode
E:	Energy stored in the inductor
IGBT:	Insulated Gate Bipolar Transistor
L:	Inductor value
LCD:	Liquid Crystal Display
MOSFET:	Metal–Oxide–Semiconductor Field-Effect Transistor
P:	Power Switching loss
PV:	Photo-Voltaic
S:	Switch
SMPS:	Switching-Mode Power Supply
T:	Total time period
t:	Time period
$\mathbf{C_o}$**:**	Output Capacitor
$\mathbf{C_1}$**:**	The First Capacitor value
$\mathbf{C_2}$**:**	The Second Capacitor value
$\mathbf{D_o}$**:**	Output Diode
$\mathbf{D_1}$**:**	Diode number One
$\Delta\mathbf{I_L}$:	the variation Inductor current
$\Delta\mathbf{I_{Loff}}$**:**	the variation Inductor current during off-state
$\Delta\mathbf{I_{Lon}}$**:**	the variation Inductor current during on-state
$\mathbf{f_s}$**:**	Switching Frequency

IGBT:	insulated-gate bipolar transistor
$\mathbf{I_{Co}}$:	Output Capacitor Current
$\mathbf{I_{D}}$:	Diode Current
$\mathbf{I_{L}}$:	Inductor Current
$\mathbf{I_{L1p}}$:	Parallel Currant during Inductor number One
$\mathbf{I_{L2p}}$:	Parallel Currant during Inductor number Two
$\mathbf{I_{Lmax}}$:	Maximum inductor current
$\mathbf{I_{S}}$:	Switch Current
$\mathbf{L_{1}}$:	Inductor number One
$\mathbf{L_{2}}$:	Inductor number Two
R:	The value of Output Resistant
$\mathbf{S_{1}}$:	Switch number One
$\mathbf{S_{2}}$:	Switch number two
∂:	Constant
$\mathbf{t_{0}}$:	Time at the start point
$\mathbf{t_{1}}$:	Time at the point One
$\mathbf{t_{2}}$:	Time at the point One
$\mathbf{\tau_{LB}}$:	The Inductor Time constant for Boundary Condition
$\mathbf{T_{1}}$:	Switch constant time
$\mathbf{V_{i}}$:	Input Voltage
$\mathbf{V_{O}}$:	Output Voltage

CHAPTER 1

INTRODUCTION

The Generation and conversion of energy is critically important especially to the safety and sustainability of the creature. Converters play very important role in advancing modern technology through numerous means such as renewable energy system, industrial machineries and home appliances by laying the concrete foundation of energy conversion chain (Mao and Batarseh, 2005). Power Electronic converter takes low level unregulated input-voltage and covert it to desired level of regulated output-voltage and vice-versa depending on the arrangement of the components (Win and Okamoto, 2012). Power electronic converters are of different types such as dc- dc boost converters, bulk boost converters and many more. Despite the conversion capabilities of these converters, the issues related to environment and global warming; myriad economic challenges inherent to fossil fuels and introduction of renewable energy system exposed the limitation of these converters and sparked the huge demand for converter that has the capabilities of producing high voltage gain.

Several researchers contribute hugely by introducing different topologies of these type of converters. Recent research has examined combinations of basic converter configurations, for instance, recent non-isolated dc-dc converter brings good modification where it can convert unregulated low voltage into a high regulated voltage but still faces the challenges in switching mechanism, high voltage stress and duty cycle.

1.1 Transformerless Dc-Dc Converter

The typical example dc-dc transformerless converter is shown in Figure. 1.1 it is the simple converter with switched-inducted technique, it steps up low level unregulated direct current (dc) to higher direct current voltage at the converter output and vice-versa. It can reach a high level of conversion gain. This type of converter has numerous applications which include discharge lamp in an automobile and photovoltaic systems. It also used in battery backup systems for uninterruptible power supplies (UPS) and many more.

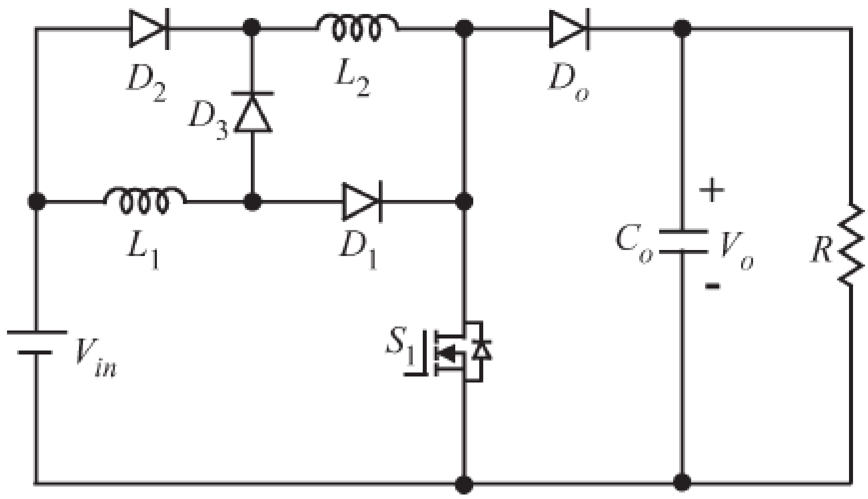

Figure 1.1: Transformerless dc-dc converter (Yang, 2009)

1.2 Thesis Problem

With all aforementioned advantages and applications, transformerless dc-dc converters are not capable to gives a very high voltage conversion ratio due to the effect of switching mechanism which results into complex duty ratio; high voltage stress, conversion operations near the unity duty cycle as well as power stress on the elements leads to limit the voltage gain. Moreover, it suppresses the overall conversion efficiency and the problem of power losses across the switches that becomes severe under this condition.

Several topologies have been presented by different researchers to provides the solutions for the above-mentioned problems. (Papanikolaou and Tatakis, 2004) established the converter with structural simplicity and high voltage gain but switch mechanisms of this converter suffered from voltage stress. In the recent years (Berkovich and Ioinovici 2008), introduced modified dc-dc converter by using capacitor-Switch and inductor-switch for design transformer less converter. Another researcher also works on three switches high voltage converter (Pietkiewicz and Cuk, 1999). The recent modified high voltage gains transformer less dc-dc converter using capacitor-switch inductor-switch was found to be prominent among them, it is simple and relatively inexpensive but still suffered from switching problems, low voltage gains and voltage stress.

1.3 Research Objective

The objective of this thesis research is to analysis and design the modified version of the transformerless dc-dc converter with high energy conversion ratio and low power losses. This work will also come up with latest converter that can solve the problems of switching mechanism, inductance leakage that produce high voltage stress to the components. Moreover, the overall conversion efficiency of this converter would be very reliable and the switches voltage stresses will be very low compare to previous non-isolated converters. The structures of the proposed converter are not complex only one power stage acting at a time. At steady-state, three different operating conditions have been taken, continuous conduction condition (CCC), discontinuous conduction condition (DCC) and boundaries between them. In the first condition, the transistor switches S_1 and S_2 are on to charge the inductors parallelly from the input voltage source. In the second mode two inductors discharged and act serially to transfer the storage energy while switches S_1 and S_2 remain inactive. Finally, both switches and inductors remain inactive allowing diode and output capacitor to transfer their storage energies to the output load. The process will keep repeating throughout the complete commutation cycle by controlling the duty cycle of the system. Under equal operating conditions both the output power, the input and output voltage; and also, the active current stresses across the switches throughout one commutation period are estimated to be the half of the total current on the active switches. Finally, the proposed converter produced high step-up boost ratio with the reasonable duty ratio.

1.4 Scope and Limitations

For simplicity of the investigation all the components are considered as ideal, the capacitors are extremely large enough to maintain the constant voltage and avoid overvoltage. The Simulation will be done using PSCAD software throughout the research.

1.5 Thesis Outline

This thesis has Four chapters as follows.

Chapter I of this thesis introduces general background, outlines the challenges and drawbacks inherited by conventional Transformerless dc-dc converter and proposed ways to minimize them.

Chapter II discusses the fundamental background, investigates the relevant theories, characteristics, comprehensive literatures review and recent achievements on DC-DC transformerless step-up (boost) converters.

Chapter III introduces different power circuit, circuits development and analysis; mathematical calculations, converter operation modes, design and multiple simulation of result using PSCAD software to prove the performances of the converter.

Chapter IV focuses on conclusions and summary of the thesis. General recommendations and areas to advance the work in the future will be presented.

1.6 Ethical Consideration

Considering the standard ethical feature and preparation of research procedures, the standard research procedures are implemented throughout the thesis. Moreover, the appropriate considerations and credit ware given during the use of other people`s words or ideas by proper citing.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

This chapter will review the circuit analysis and mode of operations; switching mechanisms and practical capabilities of the converter to produce output voltage with higher voltage gains and less voltage stress throughout the operation by focusing on dc-dc boost converters. Furthermore, the evaluation of the designed converters will discuss the basic topologies and several modifications made on the converters; and possible solution to the drawbacks suffered by the converters. This study will concentrate on dc-dc converter by putting maximum consideration on dc-dc boost converter.

Converter is an electronic circuit that can convert electrical quantities which can be phase, magnitude or frequency of current and voltage from low voltage level to higher level and vice-versa with the help of switching circuit arrangement. It can be step-up or step-down defends on the circuit arrangement. A dc-dc step-up is sometimes called a boost converter, on other hand dc-dc step-down converter is sometimes called buck converter. Basically, boost converters transform lower source voltage into higher level voltage while buck converter, down the high-level voltage into lower voltage. In the last decades before the allied technologies and development of semiconductor devices the only way for boosting dc supply voltage was conversion dc to ac using electromagnetic device called vibrator then step-up transformer followed by rectifier.

2.2 Conventional Dc-Dc Boost Converter

A conventional dc-dc boost converter is usually called step-up converter since it can boost the input voltage. It is one of the power electronic converters that step-down the current while step-up the direct current (dc) input voltage and produce greater direct current (dc) output voltage at desired level (Figure 2.1). The conversion method can be switches mode, electronic, linear and capacitive conversion. Dc-dc converters normally operates using switches elements arrangement with at least one semiconductor device (transistor and diode) and one energy storage device (inductor or capacitor) to boost the input voltage up to grater voltage at the output or to step-down it into desire level. The switch element can be insulated-gate bipolar transistor (IGBT), metal-oxide-semiconductor field-effect transistor (MOSFET) or bipolar junction transistor (BJT). In most cases IGBT switches is being used due to its capabilities to work in high power and high-speed applications. Unlike MOSFET which can be used only where the high power is needed and also BJT is been used only where the high speed is needed. Filters (first- or second-order filter) usually used to remove distortions. Figure 2.1 below shows the power circuit of conventional dc-dc boost converter.

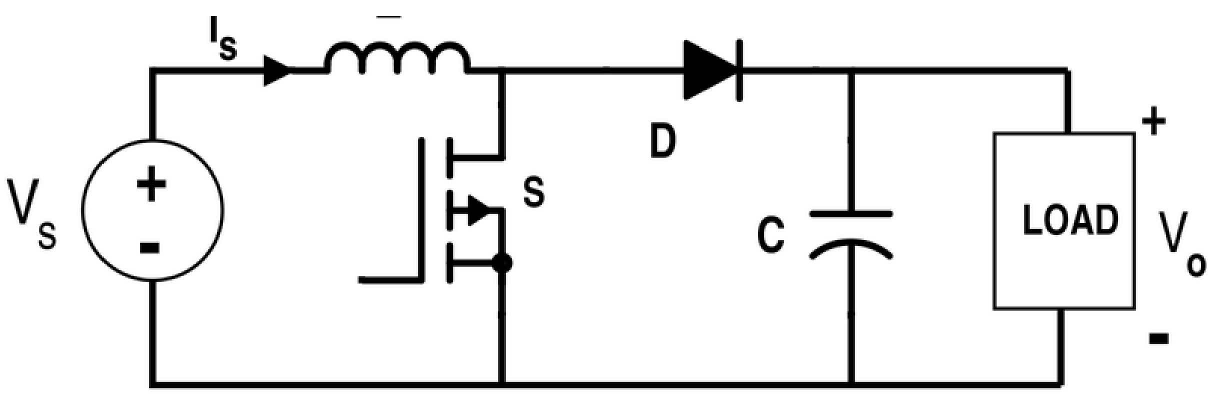

Figure 2.1: Dc-dc boost converter

The dc-dc boost converter shown in the figure above consists of semiconductor devices (transistor and diode) and one energy storage device (inductor). In addition, the output capacitor is prepared very large to maintain output voltage constant. The operation of dc-dc step-up converter start when switch S is closed it allows the storage device to charge from the input voltage source the energy storage device (inductor) transfers the energy stored to the output through the capacitor. Similarly, when switches are opened the charges stored in the diode will transfer to output. The process repeats throughout the complete commutation cycle. Simple structure, capability of higher voltage gain, higher degree of reliability, low building cost, and higher efficiency of the dc-dc boost converters accelerates the popularity and availability of the converter.

A dc-dc boost converter uses in variety of applications including renewable energy dc source (photovoltaic system fuel cell) industrial applications (dc motor drives), electric vehicles, office equipment (computers), spacecraft power systems as well as telecommunications equipment (Zhou and Pietkiewicz 1999). With all these sterling qualities of this converter, it experiences some limitation that needs appropriate improvements and drawbacks that generally decreases the overall conversion efficiency and virtually increases the building cost of the converter. The drawbacks suffered by the boost converters include higher switch conduction loss and interference of electromagnetic reverse recovery; high voltage stress, conversion operations near the unity duty cycle, power losses as well as over voltage spikes and switching mechanisms etc.

2.2.1 Advantages of dc-dc boost Converter

- Produce output voltage higher than source voltage.
- Switch can be easily driven with respect to ground
- It has continuous input current is which means it is be filtered easily

2.2.2 Disadvantages of dc-dc boost converter

- It requires Large capacitor at output side to minimize the ripple voltage
- Presence of continuous conduction mode (CCM) can lead to Slower feedback loop
- Compensation and transient response switch voltage stresses are high and the large peak current for the passive and power devices (Po-Wa and Yim-Shu, 2000).

2.2.3 Mode of operations of the step-up dc-dc converter

Basically, the fundamental operation principle of the converter comprises the current change resistance ability of an inductor by cancelling the magnetic field (Zhu and Ioinovici 1996). The inductor acts as energy absorber when its charging. Similarly, it acts as source of energy when its discharging. The mode of operation of dc-dc step-up (boost) converter involves the On-state that is period when the inductor is charging and the current increases and the Off-state that is period when the inductor is discharging and the current decreases by transferring accumulated energies to the output load through the diode and capacitor. Another key principle idea behind the boosting effect of the converter is that when inductor is discharging the voltage across the inductor is independent on input voltage from which it absorbed the energy rather, it depends on the rate at which its current change with respect to time. This characteristic gives the converter abilities to produce output voltage greater than source voltage. The operation modes of this converter are continuous and discontinuous current conduction modes. Sometimes the converter operates in both, as shown in the Figures 2.2 and 2.3 below:

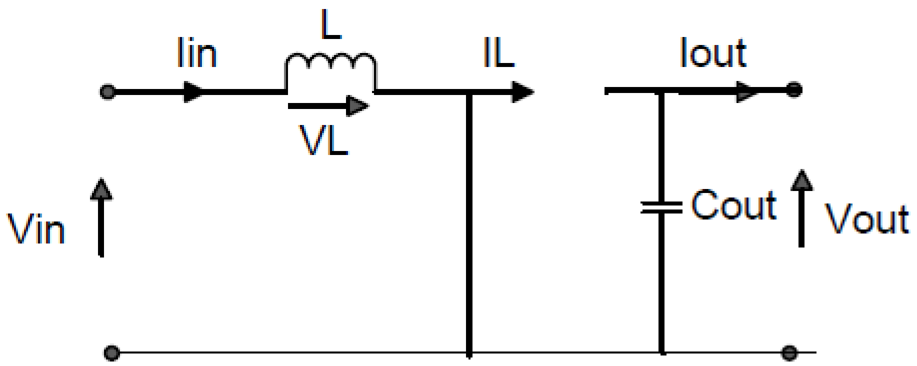

Figure 2.2: Converter with IGBT switching mode during charge period

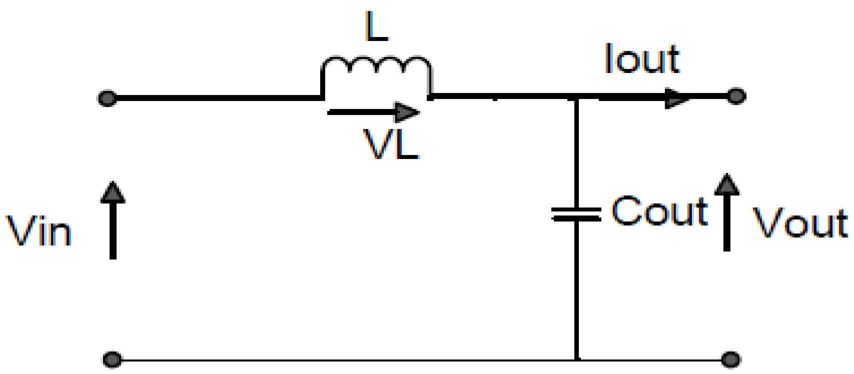

Figure 2.3: Converter with IGBT switching mode during discharge period

Ideally, the mode of operations of dc-dc step-up (boost) converter take place in two distinct modes viz:

i. Continuous conduction mode of operation

ii. Discontinuous conduction mode of operation

2.2.3.1 Continuous conduction mode (CCM) of operation

As the name implies, during the period of continuous conduction mode the current across the inductor I_L does no reach zero level, rather the converter operates in steady state condition. When switches are closed the inductor charged from input voltage source V_i and makes the current I_L following through the inductor to change with respect to time (t). Figure 2.4 shows the wave form of voltage and current during period of continuous conduction mode. Therefore,

$$\frac{\Delta I_L}{\Delta t} = \frac{V_i}{L} \tag{2.1}$$

During the maximum charging state, the continuous following of current through the inductor is given as:

$$\Delta\, I_{Lon} = \frac{1}{L}\int_0^{DT} v_i \mathrm{dt} = \frac{DT}{L} V_i \tag{2.2}$$

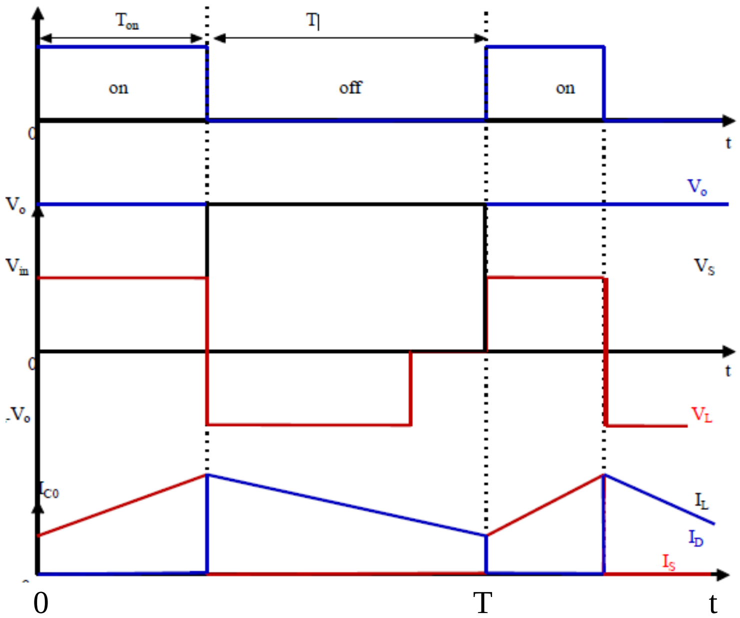

Figure 2.4: Voltage and current wave form of step-up converter during CCM

When the capacitor is discharging (switch is off) Therefore, the capacitor $C_{\circ}$ will transfer the energy stored in it directly to the load (assuming there is voltage drop) and capacitor is prepared to be large in order to be able to handle the maximum charges. The current I_L across the inductor evaluation is given as

$$V_i - V_o = L\frac{dI_L}{dt} \tag{2.3}$$

Therefore, during discharging period, the variation of inductor current I_L is expressed as:

$$\Delta I_{Lon} = \frac{1}{L} \int_{DT}^{T} \frac{(V_i - V_o)dt}{L} = \frac{(V_i - V_o)(1 - D)T}{L} \tag{2.4}$$

The current across the inductor should be equal throughout charged and discharged period. That the total change in current is equal to zero.

$$\Delta I_{Lon} + \Delta I_{Loff} = 0 \tag{2.5}$$

Therefore, the output conversion gain is expressed by: $\frac{V_o}{V_i} = \frac{1}{(1-D)}$ (2.6)

The above expression shows that, the input voltage was step-up to higher conversion ratio of the converter is always directly proportion to duty cycle within the range of zero to one (0 to 1). That is the reason why the converter is considered as step-up or boost converter.

2.2.3.2 Discontinuous conduction mode (DCM) of operation

Converter may reach stage during which current across inductor reached minimum (zero) that is, the time when the inductor is completely discharged before completing the commutation cycle. This usually occurred when transferred energy demands by the load is too small to complete commutation period (Liang and Chen 2009). Discontinuous conduction mode has an advantage of minor losses across the inductor when the switches are closed (Cheng and Xiu-Cheng). Figures 2.5 the wave forms respectively.

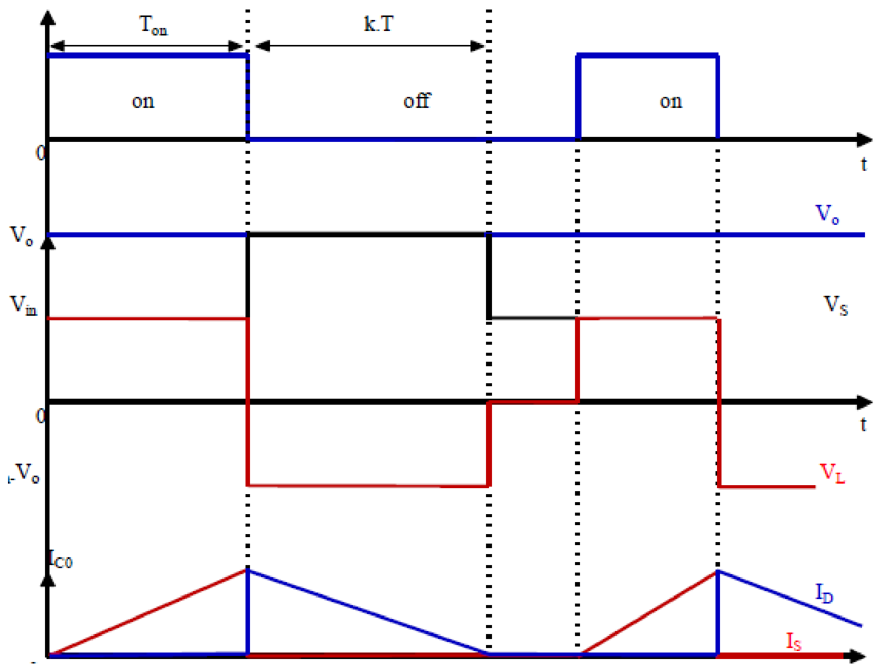

Figure 2.13: Voltage and current wave form during period of DCM

Although the variation is very small but it can affect the output load. At the beginning of the commutation cycle values of current across the inductor zero but at t = DT the maximum current across the inductor is expressed as

$$I_{Lmax} = \frac{V_i DT}{L} \qquad (2.7)$$

During discharging period (off-switch) inductor discharged its current I_L falls to zero after kT as in Figure.2.4

$$I_{Lmax} + \frac{(V_i - V_o)kT}{L} = 0 \qquad (2.8)$$

By comparing two equations $k = \frac{(V_i D)}{(V_i - V_o)}$ (2.9)

From Figure 2.5 above, During the discharged period current across the inductor and diode are the same. Similarly, current across the output load $I_o$is the same as average current across diode I_D, therefore the load current is expressed:

$$I_D = I_o = \frac{I_{Lmax}}{2}k \qquad (2.10)$$

Therefore, output voltage can be obtained as $\frac{V_o}{V_i} = 1 + \frac{V_i D^2 T}{2LI_o)}$ (2.11)

By comparing the expression for Discontinuous conduction mode (DCM) and continuous conduction mode (CCM), its shows that output voltage of Discontinuous conduction mode (DCM) does not depends on duty cycle only rather, it depends on output current, inductor level, input voltage source and period of commutation above shows that the output voltage.

2.2.4 Switching losses

The term switching losses represents the summation of individual power losses that take place during the period of on-state and off-state. The losses that take place during on-state and off-state include Conduction losses, blocking losses as well as power losses as shown in figure 2.6 below. Switching losses normally occurs during the states of on and off due to coexistence of voltage and current across the terminals. Ideally it is reparents non-negligible percentage of the whole losses but practically huge losses occurred. In the year 2008 new topology of multi-level converter with many steps but a smaller number of switches was presented (Babaei 2008). The converter produced maximum output voltage with minimum on-state voltage across the switches.

The switch uses in step-up converter takes the current instantly as the switch is on and falls to minimum as the switch-off. in practice where switch is not ideal the real switch takes certain time before the current path was established and some period of time before it releases the charges. Figure 2.7. Demonstrates the practical case of the switch where the shade portion represents the power loses which represents the product of current and voltage during on and off period (Zhao and Lee, 2003). Losses across the Switches plays very important role in reducing the efficiency and increasing building cost of the converters.

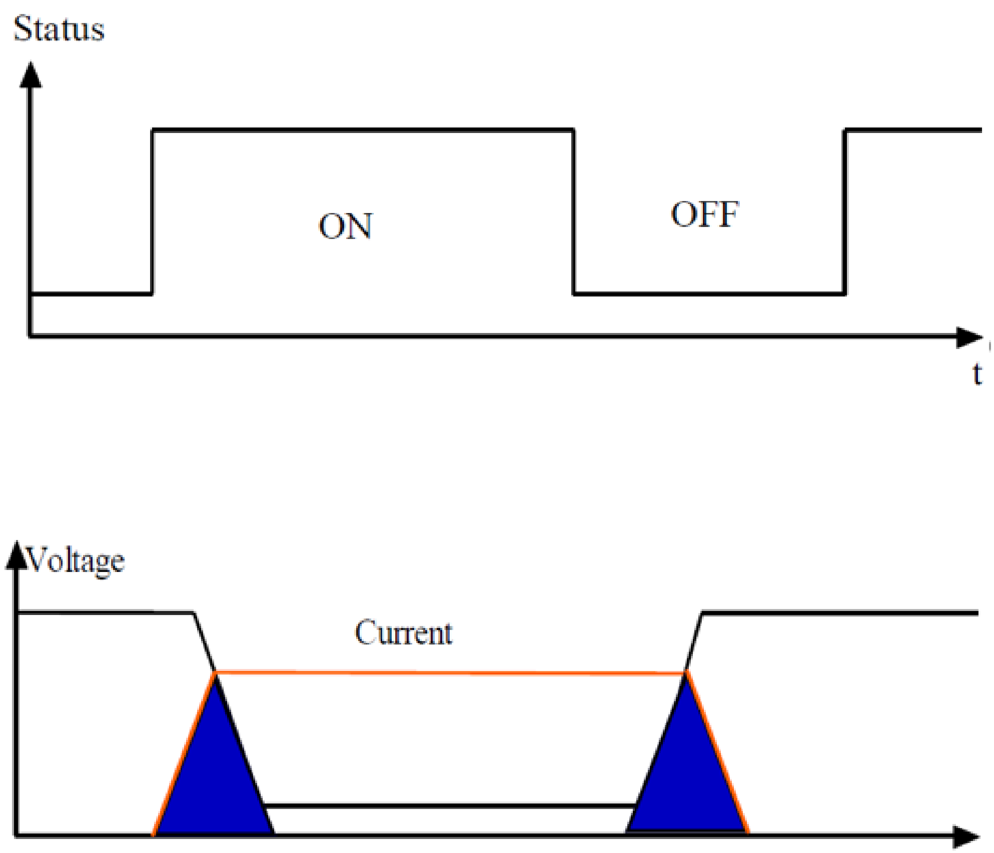

Figure 2.14: Switching Losses of Step-up Converter (Shaded area indicates power loss)

The fundamental idea behind switching converters is the conversion of energy where by in one phase Some energy stores in storage devices (transformer, capacitor, or inductor) is been transferred to the load in other phase in a desire level. Several improvements schemes have been made to eliminate the switching losses suffered by some power electronics converters such as

- Voltage with Zero source
- Zero current source
- Unipolar switches method
- Bipolar switching method.

ZVS was introduced to eliminate some part of the switching losses where by ZVS reduce switching losses during turn-on period and eliminate it during turn-off period therefore the stored energy in the capacitor will be dissipated. In unipolar switching method, the techniques of pulse width modulation are applied for one phase only. Although the method is responded slowly and relatively more complicated but it is perfervidly used by brushless direct current motor. Apart from switching losses the effect of dc voltage gain duty-ratio relationship also couses the losses as shown in the Figure 2.7

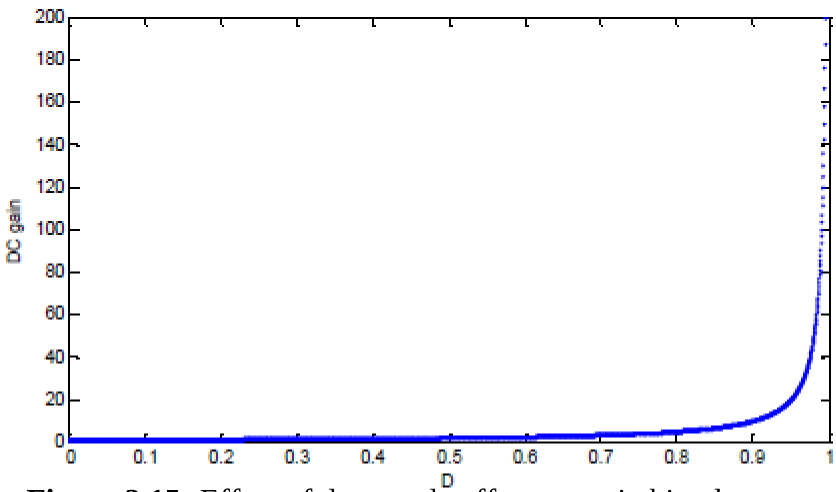

Figure 2.15: Effect of duty cycle effect on switching losses

From the above Figure the dc voltage conversion ratio is dependent on duty cycle as indicates by the gap between the actual and ideal. The gap increases as a result of poor switching utilization of the duty ratio which means their losses are higher. Moreover, several mechanisms can course the energy to be lost significantly. According to (Rashid, 2003)

During the process of reverse diode recovery higher extra losses of energy induced across transistor when the switch is in closed period. The energy stored in the transformer inductances and capacitor is dissipated when switch is in opened. The overall losses across switches is the same as product of switching frequency and total energy losses that arise through the components (Undeland and Robbins, 1995). During the period of transitions switching period, the current and voltage transistor are simultaneously large. In this case, significant power loss experiences by the transistor. As a result of that, instantaneous losses of power may occur, although the duration period of switches transitions are relatively minimum. The increase of Switching frequency leads to decrease the efficiency of converter. Also, as pointed out by the gain voltage expressions, by the time duty cycle approaches unity, the DC gain of voltage will also approach infinity.

$$\frac{V_o}{V_i} = \frac{1}{(1-D)} \tag{2.12}$$

Several literature reviews on dc-dc voltage conversion have been introduced and new characteristics have been defined to overcome the drawbacks of the converter such as switching losses, voltage stress and high duty ratio. Different topologies have been proposed to eliminate the switching problems. In the recent decade, researchers paid more attention on the problem of switching losses by modifying the conventional structures of step-up (boost) converter with new features and topologies to enhance the reliability, cost of building and reliability of the converters. In order to overcome the effect of switching losses which virtually affect the efficiency of the converters (Duan and Chang, 2008) introduced modified dc-dc step-up converter with soft switching method and the capability of producing zero voltage switching (ZVS). The converter also proposed to have multiport so that it can be inputted from several dc-sources. The converter is suitable for different types of dc source suitably the renewable energy source like wind turbine system solar system and (Axelrod and Ioinovici,2008). proposed a modification of higher dc-dc step-up converter by introducing two switching coupled inductors and capacitor circuit both step-down and step-up operations. The modified converter produced a reasonable high voltage gain compared with conventional boost converters.

2.3 Classification of Dc-Dc Step-up Converter

Dc-dc converters can be classified according to method of control viz: Pulse With Modulation (PWM) and Frequency Variation.

The converters that used Pulse Width Modulation (PWM) controlled method can be sub-divided into:

i. Dc-dc Non-isolated converters
ii. Dc-dc Isolated step-up converters (Kazimierczuk, 2016)

2.3.1 Dc-dc non-isolated converters

The term refers to circuit arrangement of converter that does not contain magnetizing devices such as high frequency transformers instead it uses energy storage component (like inductor) which made the converters to have lesser switching losses, lower power stress across the elements, smaller size as well as lower price with high conversion ratio. These sterling qualities made the non-isolated converters to have verities application such as photovoltaic and win turbine system (Li, and He, 2011).

In the recent decades, new topologies of non-isolated boost converter have been made and very reliable converters like, transformerless converter (Figure 2.8), capacitance of the single-ended primary-inductor converter (Sepic) converters, boost converters, inductor and capacitor switched converter; cascaded switched and transformer less boost converter et carta. have been introduced (Kumar and Rajesh, 2014). Similarly, (Yang, and Tsorng-Juu, 2009) works on new topology of simple transformer less converter and he succeeded a lot in term of producing soft switch converter which one part is working at time. The voltage gain equation of the converter is obtained as $\frac{V_\circ}{V_i} = \frac{1+D}{1-D}$ which is widely acceptable.

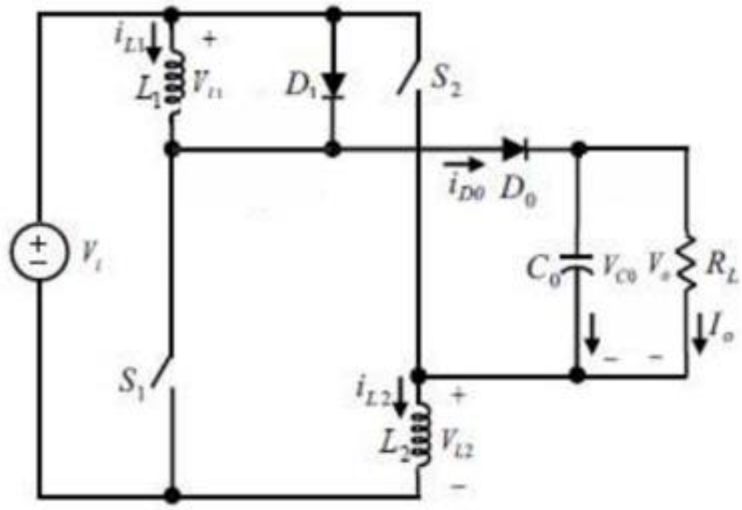

Figure 2.16: Modified dc-dc transformerless converter

Non-Isolated converter have established excellent solutions to the problem of low voltage generated by photovoltaic, wind turbine system and other renewable energies as well as industrial applications. Despite these good qualities of non-isolated step-up converter several modifications have been applied to overcome drawbacks that the converter suffered from and improve the quality of conversion ratio of the converters. For example, the new topology on very high voltage gain characteristic that makes the proposed boost converter more preferable to fuel cell dc source application (Kumar and Rajesh, 2014). The converter superseded the available boost converters like inductor and capacitor switched converters; cascaded switched boost converter, likewise down ranked the dc-dc Isolated converter like push-pull and forward converters; fly-back and bridge converters etc. To minimize the size and cost, the proposed converter uses smaller number of capacitors with high voltage step-up and one control signal designed to control all switches so that the switches complexity can be minimized. Moreover, the two buses produced voltage gains that depends upon one duty cycle and can be maintained within desired range. Also, (Jung and Won, 2010) proposed a new topology of cascaded DC-DC step-up converter using non-magnetic coupled inductor in the second step-up converter suitably for controlling the interface of different dc input and an inverter (DC-AC) to national grid. The proposed converter configured to be a quadratic step-up converter by successful combination of flyback converter and step-up (boost) converter. The power circuit of the proposed converter consists of one isolated converter circuit (dc-dc boost flyback converter) and conventional boost dc-dc converter. In first step-up converter there are two energy storage devices (Lin and C1) and two semiconductor devices. (D1 and D2), while in the second step-up stage converter there are two semiconductor devices (D_3 and D_4) and one energy storage device ($C_{\circ 1}$ and $C_{\circ 2}$). By levelling the two segments as first step-up stage and a second step-up stage, the initial and second boost stages acts as conventional boost and flyback converter respectively. All stages of proposed converter are control by single switch S_1 after satisfying all assumption (Kroposki and Pink, 2006). The performance (about 93.6% efficiency) of proposed converter verified by appropriate study of steady-state, the conduction mode of continuous and boundary between the two modes of operations. The proposed study achieved about twenty (20) times conversion ratio were achieved, the leakage energy across the couple- inductor recycled successfully and leads to minimize the voltage stress generated across the main switch. (Xiong and Siew-Chong, 2015) presented non-magnetic known as bidirectional switched capacitor converter that have low voltage stress across both capacitor and switches. The proposed converter produced output voltage with high conversion efficiency, minimum ripple voltage (less than 1%) and ability of dc-dc bidirectional Power delivery. The uses small number of components as compared to dc-dc bidirectional converter. (Krishna and Kumari, 2003) applied cascaded technique on boost converter to achieve higher voltage gains for the conversion of electrical energy. The conventional converter cannot provide higher voltage gains due diode problem of reverse-recovery, the effect of switching mechanisms and problem of parasitic resistive. This study proposed converter by integrating two buck-boost converters with a one switch and control it pulse width modulation techniques. (Lung-Sheng and Yang, 2009), studies three novel converters and investigated how dc-dc step-up converter can work without magnetizing device (transformer) and achieves high voltage gain. The proposed converter also set-up to overcomes the problems of switching mechanisms, limited voltage gains and the effect of capacitance and inductance equivalent series resistor. Proposed converter comes up with three advantages viz:

- i- Voltage stress across the active switches is far less the output voltage of the converter.
- ii- Two power devices are active during on-period and only one power device is active during off-period; and
- iii- When the switches are active the current stress across them during the charging period (on-state) is twice the current stress across the active switches of conventional ones

Both the three converters proposed to have two common energy storage devices (two inductors and one capacitor) and two semiconductor devices (two switches and diode). The second and third converter modified by addition of one and two lift-voltage circuits respectively (Gules and Pfitscher, 2003), both inductors have the equal level inductance and charged parallelly when switches are on and discharged serially during the time when switches are closed. Both voltage stresses and voltage gains of the three converters were compared and the voltage stresses across active switches of the designed converters is minimum compare to the one on with conventional boost converter. This leads to the selection of converter with lowest voltage stresses. The building structure of the modified converter is simple and has low building cost. (Ayoob, 2008), proposed new model of non-isolated dc-dc switched- inductor multilevel step-up converter that produces high voltage ratio (25 times) with less voltage. The new topology of the converter achieved by sourcing multilevel boost converter with new switched inductor. The proposed converter operates with single switch and singe inductor with 4N-1 diodes, and 2N-1 capacitors. The converter can provide 25 times output voltage when operate at 50HZ which essentially suitable to renewable energy (Rosas-Caro and Ramirez,2010). The Proposed multilevel boost converter operates very similar to conventional dc-dc step-up converter; however, the isolation properties and switch singularity of the converter stress leads to rates the converter as most advantageous and common types of multilevel boost converter.

2.3.2 Dc-dc isolated step-up converters

Dc-dc Isolated dc-dc step-up converters this are the type of dc-dc converter contains magnetizing device (high frequency transformer) as one of the design components. The types of this class converters include flyback dc-dc converter, forward and push-pull dc-dc converter; and bridge converters etc. these types of converters have the problems of resonant components and Soft switching

2.3.3 Dc-dc flyback converter

Flyback dc-dc converter is belong to family of an isolated common one-switch converter topology modified from buck-boost power converter by developing isolation device (split inductor) to acts as transformer so that the additional voltage gains will be obtained through the advantage of large turn ratio of isolation component (step-up transformer). Figure 2.8 shows ideal model equivalent circuits of flyback with transformer.

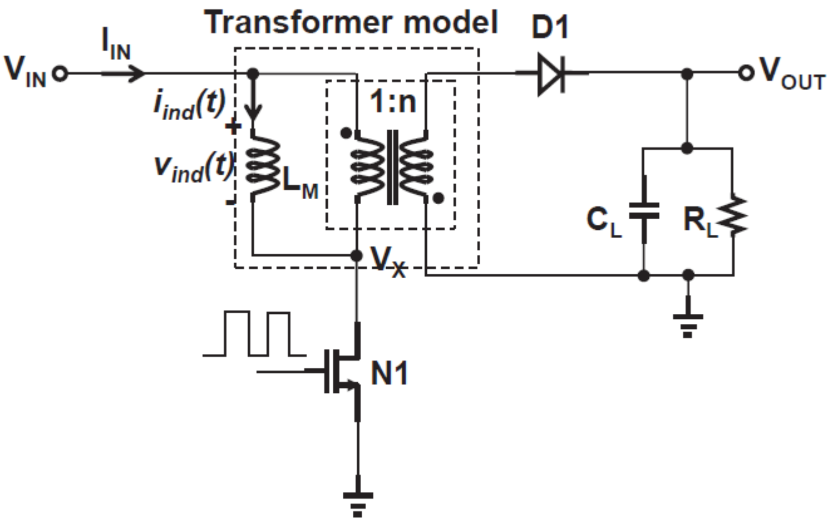

Figure 2.17: On-state ideal configurations of flyback converter (Shiuan and Ling , 2009)

Figure 2.9 shows circuit equivalent with transistor with on and off switches of the converter. The converter operates under principle of galvanic isolation (transformer) between two terminals. Converter voltage and current are control through the two schemes control modes by introducing signals related to output voltage using photocoupler isolation. Figures 2.10 and 2.11 show configurations of ideal flyback converter.

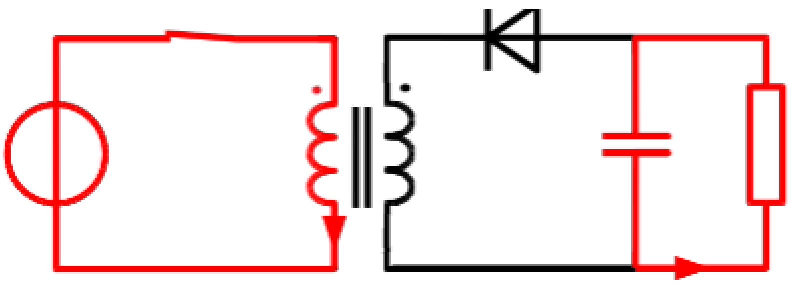

Figure 2.18: On-state configurations of ideal fly back converter

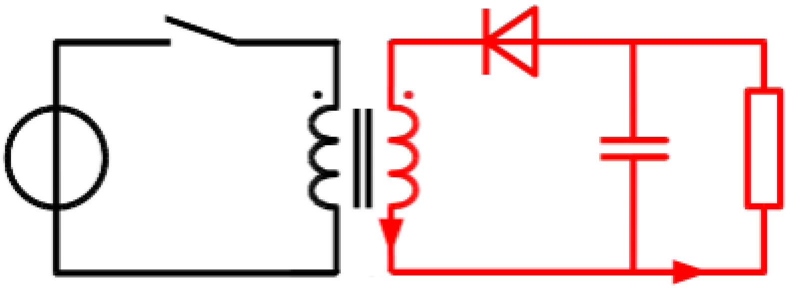

Figure 2.11: Off-state ideal configurations of flyback converter

As shown in the Figure 2.11 The ideal model configuration circuits of flyback converter consist of energy storage device (capacitor) which acts the transformer in the buck-boost converter (Shiuan and Ling , 2009). Initially when swathes are closed, energy in the input voltage source moves directly to energy storage device (transformer) then to the output. Similarly, during the period when the switches are opened, energy stored in the transformer moved to load thought output capacitor. Flyback converter is more popular and best among the isolation converters (Prieto and Cobos,1996) and many other applications various areas which includes:

i- Produce high voltage supply in cathode-ray tube in monitor and TVs

ii- Produce high generation of voltage in copier and camera

iii- generate Low-power across the switch-mode power supplies devices.

Apart from aforementioned advantages and application the dc-dc flyback converter has additional features which includes

i- Needs a smaller number of components which means low building cost

ii- Not need additional inductor at output that leads to fast transient response

iii- No occurrence of blocking voltage across the output diode

iv- Transformer with higher frequency (Chuanwen and Mark Smith, 1999)

With all aforementioned application of dc-dc flyback converter experiences some drawbacks that decreases the overall efficiency such as problem of high voltage stress across the transformer as a result inductor leakage (about 2%-10% of the total inductance)

(Papanikolaou and Tatakis, 2004), power losses as well as over voltage spikes and switching mechanisms. Several topologies have been proposed to overcome the above-mentioned problem and establish the modified highly efficient dc-dc flyback converter. According (Jain and Kang, 2002), the idea of active clamp with less dissipation of power is good enough to minimize the inductor-leakage and recycling voltage stresses across active switches. The modification is made by introducing an auxiliary converter with source of current which is load dependent that operates during the continuous operation mode instead 3of discontinuous conduction mode which is more convenient. The drastic solutions of new topology of proposed converter has been exhibited leading to high improvement of the converter. According to (Gwan-Bon and Koo, 2004), the solution for the problems of conventional flyback dc-dc converter is possible by modifying conventional dc-dc flyback converter by employing auxiliary circuit (capacitor and inductor) with the switches operates under the condition of zero voltage source (Bhaskar and SreeramulaReddy, 2014). Although the auxiliary inductor courses little losses but still the topology is simple and effective. Another interested topology has been made by (Wasng, 2008) with the idea of new minimum current-switching and pulse width modulation technique with both auxiliary and main switch operate under condition of ZCS throughout the on and off period. Similarly, remaining non-controlled devices operate under condition of ZVS throughout the turn-on and turn-off period. Moreover, designed current-switching and pulse width modulation flyback dc/dc converter possess the credits of the minimum current-switching and pulse width modulation methods in the absence of excess current stresses as for conventional method of hard-switching. Improvement resulted in good performance and generates high efficiency. The limitations of the converter when it is operates in CCM and DCCM includes:

i- Execution of higher flux in the inductor
ii- Needs compensation of slope when the duty cycle is high
iii- The current and RMS are high especially during design

2.3.4 The push-full converter

The term push-full generally associated with any bidirectional converter with an excitation of magnetizing devices (transformer). Push-full converter is a type of isolated converter topology that step-up lower input dc voltage into higher output dc voltage using magnetizing devices (transformer) as one of the design components and running out one phase. The power circuits of the converter consist of push and full switching circuits which is connected to either a positive or a negative terminal of a dc sources and step-up transformer with a split primary winding and large capacitor connected at the output to filter switching noise and send rectified voltage to the output. The switches circuit are prepared to be power metal-oxide-semiconductor field-effect transistor due to their minimum turn-on resistance and high capability of current switching (Luo and Ye, 2004). Alternatively, field-effect transistors (FETs), bipolar junction transistors (BJTs), or silicon-controlled rectifiers (SCRs) can be used as well but have to operate under "Dead Time" (wait time) to avoid shoot-through of transistor. The main advantage of full-push converter is that it needs only non-isolated power supply (transformer) to run both quadrants and resettle at every cycle (Tsorng-Juu, and Ren-Yi, 2007). However, as a result of due to the less cost, maximum efficiencies of the circuit as well as capability of holding high power, dc-dc push-pull converter becomes very common even though the push-pull device terminals are suffered from power lost and switching losses.

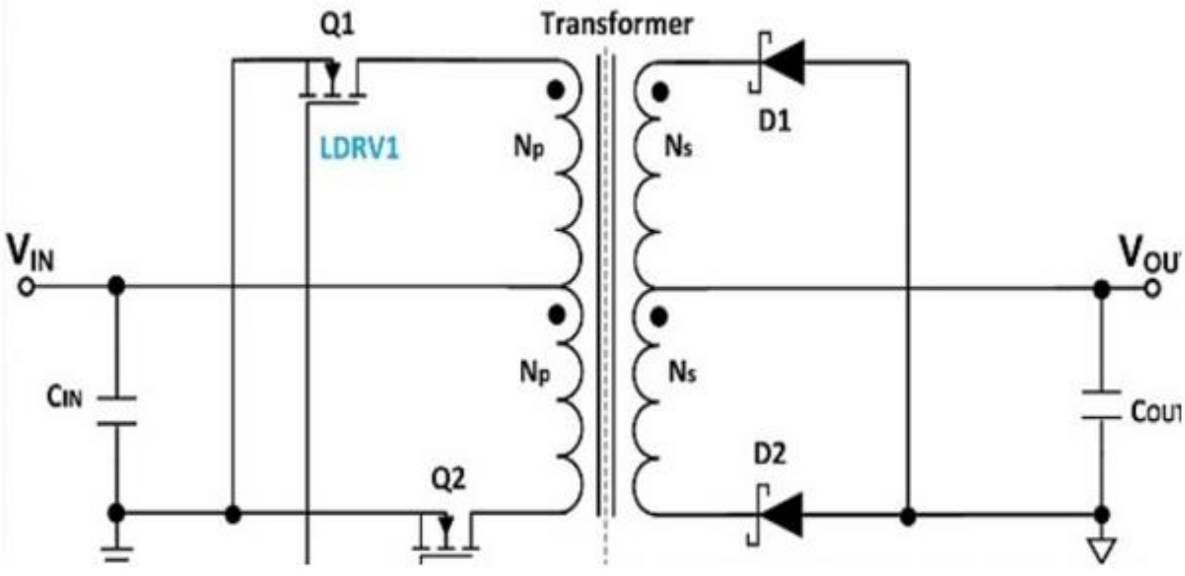

Figure 2.12: Full-push power circuit converter (Rudy Severns, 2003)

2.3.5 Forward converter

Forward converter belongs to the family of a non-isolated common one-switch converter topology look like flyback converter as the output voltage of both converters can be decreased or increased simultaneously but their operation is absolutely opposite since the forward converter does nor store energy during conduction (Rudy Severns, 2003). Forward converter consists of a magnetizing device (step-up or step-down transformer), switching device usually power metal-oxide-semiconductor field-effect transistor (MOSFETs), diode and energy storing devices (inductor and capacitor). The transformer operates as boost and step-down or step-up base on desired level voltage at output. The converter operates by passing the energy directly to load at output through the transformer during on-state conduction phase. The output is determined by input voltage, duty ratio and transformer ratio.

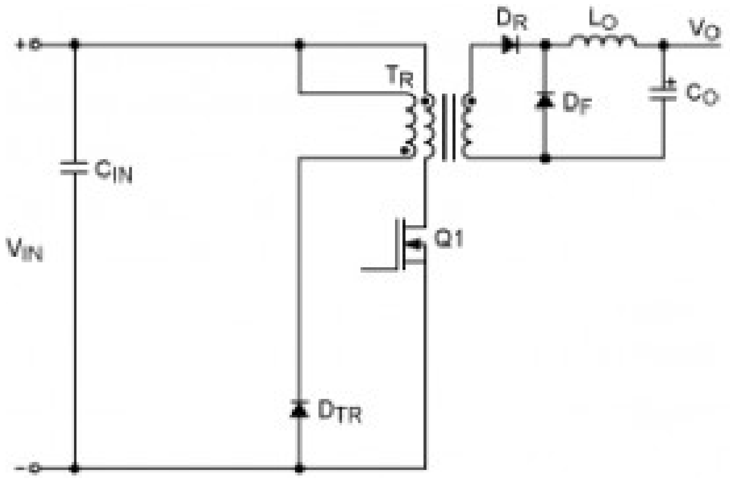

Figure 2.14: Operations of ideal forward converter

Forward converter is capable of using both one common switch and two common switch topologies. In one common switch topology normally, during the period of on-state, the current energy in the primary winding transfers to secondary winding then to the output load through diode and filter. On the other hand, when the switch is tur-off the action will reverse there by the voltage across the cathode of the diode will keep increase up the time when the switch turns on.

2.3.5.1 Advantages of one common switch topology operation

i- Input capacitor ripple current is low

ii- Operations, structure and construction are easy and simple

iii-The current across the secondary diode is low

2.3.5.2 Disadvantages of one common switch topology operation

i- Input capacitor ripple current is low needs bigger transformer

ii- Conduction loss is high

iii-The transistor rating should double the input voltage

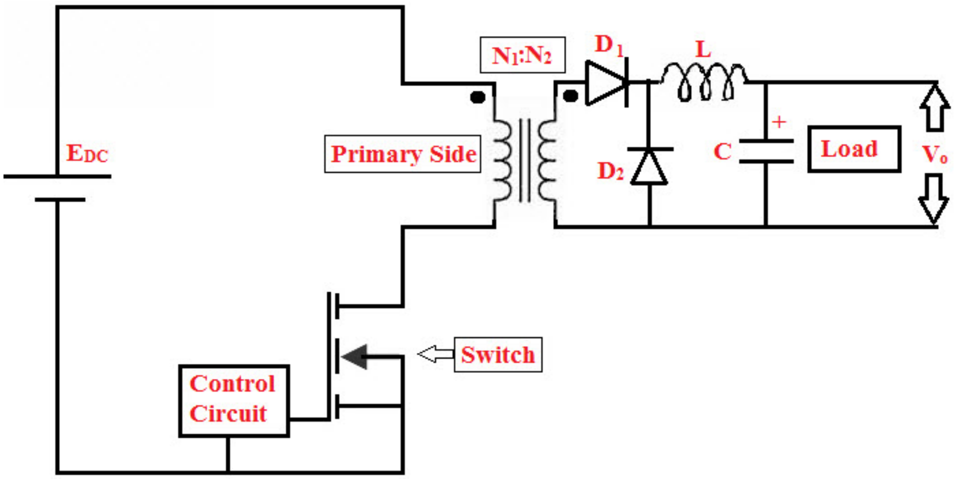

Figure 2.15: One common switch operations of ideal forward converter

In double-switch forward converter operations all the two switches turn-on simultaneously allowing the current energy in the primary side to transfer to the secondary side of the converter. On other hand, when the switches are off the transformer induced current transfers back to the input source, through the forward biased diodes. The diodes conduction persists until all the induced energy in the primary side along with the stored energy in the leakage inductances is taken back to the input source. Figures. 2.16 and 2.17 below shows typical circuit during on and off operations.

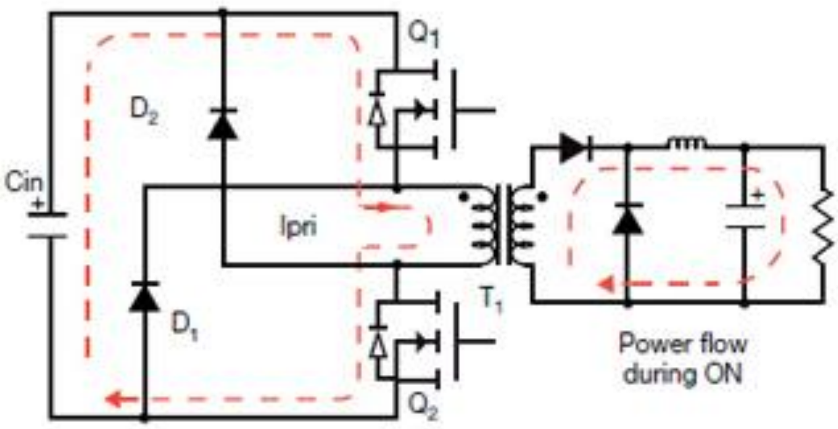

Figure 2.19: Power on double switch of ideal forward converter (et al (eds), 1989)

For the safety operation, the duty cycle of off-switch should be less than that of on-switch (less than 50%) to allow the transformer to reset.

2.3.5.3 Advantages of one common switch operation

i- The noise and losses are very low
ii- Enough multiple isolated outputs are provided
iii- Can operate over a wide range of output and input sources
iv- No need of snubber circuit

2.3.5.4 Disadvantages of one common switch topology operation

i- Frequency operation is limited
ii- Needs high rating components (larger transformer and inductor)
iii-High building cost since the component are larger

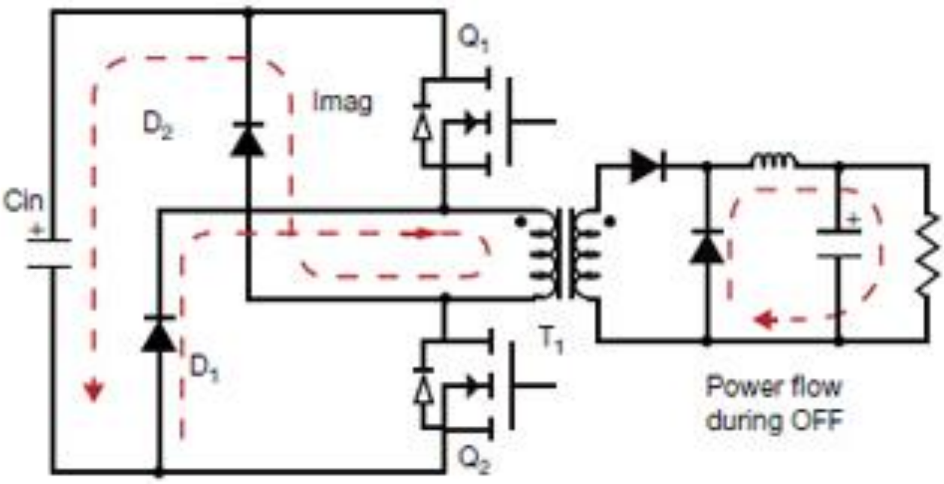

Figure 2.17: Power off double switch of ideal forward converter (et al (eds), 1989).

2.3.6 Bridge converter

A Bridge Converter belongs to isolated family. It consists of four active switches usually power metal-oxide-semiconductor field-effect transistor (MOSFETs) in a configuration bridged across magnetization device (transformer). The converter can be full or half bridge converter depending on the power circuit arrangement of the converter (et al (eds), 1989).

2.3.6.1 Full bridge converter

Full Bridge is a type of bridge converter consist of switches usually power metal-oxide-semiconductor field-effect transistor (MOSFETs) and transformer that provides isolation. However, the converter has capability of producing simultaneous multiple output voltage and reversing polarity. The full bridge converter can be buck or boost converter. Full bridge converter consists of three distinct stages namely:

- i- Rectifier network
- ii- Network of energy transfer and
- iii- Generator of square wave.

Basically, the full bridge converter uses pulse width modulation. Initially, first pair of MOSFETs turn-on simultaneously and conduct at first half cycle. Similarly, other pair conduct during the second half cycle of control wave form (square or sinusoidal) when the first pair are off. The MOSFETs, the winding of transformer and duty ratio determines the level of the output voltage. Furthermore, the switching loss can be decreased when operates at higher frequency in zero voltage switching modes (ZVS) (Tsorng-Juu, 2014). Moreover, minimum switching voltage enhance the size of component and less cost. In addition, at higher frequency operations, leads to small size and cost for magnetic components also reductions. Figure 2.18 below shows typical circuit of full bridge converter.

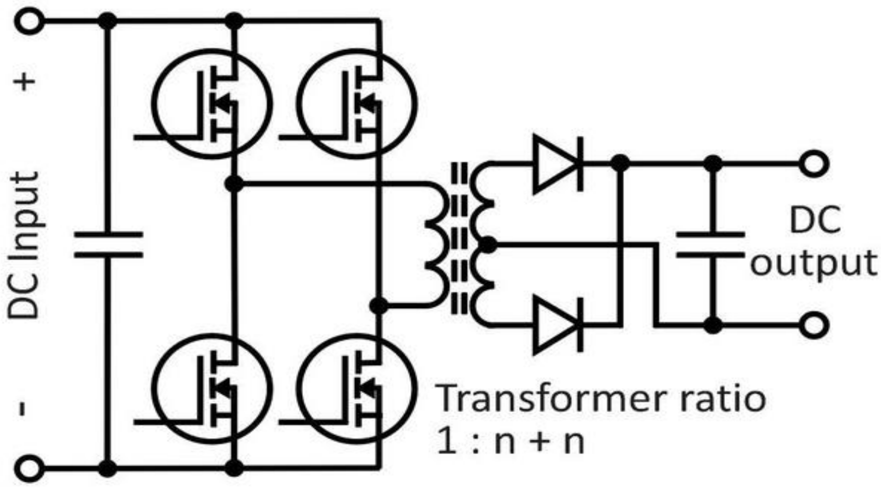

Figure 2.18: Typical full bridge converter

(Evran and Aydemir, 2007), proposed new Z-source converter with new isolated coupled inductor topologies to sort out the low dc voltage generated by photovoltaic system. The aim of this work is to boost input sources to a higher level without suffering from voltage stress and high duty ratio. In order to minimize the conduction loss, low MOSFET with low RDS (on) values were used. The conversion ratio of the converter is increased using above features. The study step-up converter compares both isolated and non-isolated and investigate the drawback suffered by non-isolated converter such as limited voltage gains and losses occurred across parasitic components such as inductor resistance, capacitor, ESR and diode reverse recovery may course by high duty cycle operation (Tseng and Liang, 2004). The improved proposed converter is obtained by simple modification of Z-source topology consist of coupled-inductor. The converter has an ability to boost the from photovoltaic output (usually low dc voltage) to a higher dc voltage. Component used in the proposed converter includes two couple inductors termed as primary L_1 and secondary L_2 ; and two core windings, turn ratio of these winding termed as N_1 and N_2 . the circuit also has five capacitors level as $C_1\,C_2\,C_3\,C_4\ and\ C_5$; and four diodes levels as $D_1\,D_2\,D_3\ and\ D_4$. Moreover, the new topology operates under the conditions of continuous and discontinuous conduction mode. The proposed converter has the following features:

i- Switch has low voltage rating
ii- Low Turn ration in the couple-inductor
iii- The inductance leakage does not generate stress across the diode or switch
iv- Gap exists between output and input.

The final result for prototype of the proposed converter shows that it can boost 25V dc to 400V at various voltage levels. The proposed converter has the advantage of using low rated component which means it has low building cost and higher conversion efficiency.

2.3.6.2 Half Bridge converter

Half Bridge converter is the single direction of Full Bridge converter that have two current device and double transformer turn ratio and split capacitor. Half Bridge converters have the capability of switches the polarity of applied output voltage. Most of the isolated converter like dc-dc push-pull converter and some DC-to-and ac-ac uses half bridge. Figure 2.19 shows Half bridge dc-dc converter

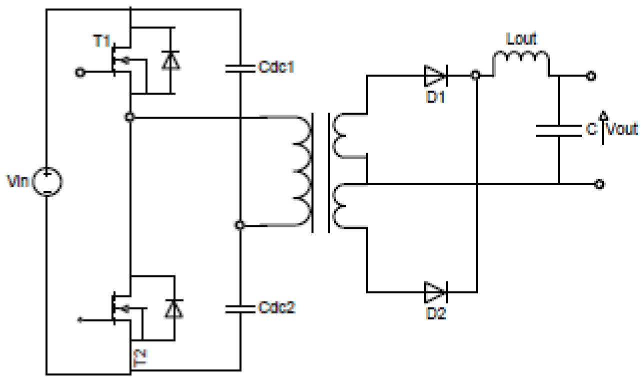

Figure 2.19: Power circuit of Half bridge dc-dc converter

Krein and Balog, 2013), proposed the new topology of boost converter that upgrades the overall conversion ratio of the converter to a high level of voltage simply by choosing the appropriate value of coupled inductor and proper duty cycle control. The modified converter contains the same structure with the conventional boost converter, the only different between the two is that, the coupled inductor is replaces the inductor in the conventional converter. The energy storage device is connected serially to the secondary side of the semiconductor device to eliminate the ripple voltage output. However, the ripple current in the input is also minimized by the appropriate control of the coefficient of the coupled inductor (Zhou and Huang, 2012). The diode blocks reverse current. The proposed converter is applied to solve the problem of low sources voltage generated by photovoltaic and fuel cell (Berkovich, and Tapuchi, 2014). according to (Musale and Deshmukh, 2016) a higher conversion ratio can be obtained by employing voltage multiplier to the conventional boost converter there by using diode and capacitor at the output (Huang and Shahin, 2008). The structure of the converter consists of consists of switch, inductors, diodes and capacitors. Which are amounted as 1,2,5 and 7 respectively. The higher conversion ratio of the proposed converter makes it applicable not only in inverter but also in electrical derives. In the year 2015, (Abbasi and Babaei 2016) proposed a new idea behind dc–dc boost converter with multi-input and independent multi-output (MIMO). The converter is feasible to be inputted with the energy containing different current-voltage behavior. The study produced solutions to various drawbacks of the step-up converters such as switches and diode voltage drop; effect of series equivalent resistor (ESR) for both capacitor and inductor voltage; and effect voltage stress. Moreover, the higher voltage gains and higher switching frequency were obtained.

2.4 Conclusion

Several dc-dc converters topologies and techniques have been discussed in this chapter. From this, it is clear that it is not easy to select the best; every converter topology possesses its own advantages and disadvantages and the selection is highly depends on the application. For example, every member of dc-dc non-isolated and isolated family can produce output voltage with high conversion ratio at the same times it has it is own drawbacks which is the most considerable factors in design of the converters. In particular, the performance of each class of the converter has been considered over a wide range of different topologies, in this case several researches proved that good options are non-isolated dc-dc family due to absent of magnetizing components that lead to low building cost and the ability of the converters to step-up the source voltage to higher level.

CHAPTER 3

CIRCUIT DESIGN, MATHEMATICAL ANALYSIS AND SIMULATION

3.1 Introduction

This chapter investigates working principles of dc-dc transformerless converter with an improved efficiencies and high voltage gain. It will also discuss the circuits development, the mathematical calculation, the circuits analysis and the performance of the proposed converter as well voltage gain equations for both continuous conduction mode and discontinuous conduction mode. Then, the calculations of critical inductance of inductors are presented. The simulation of the result using PSCAD software will also be discussed.

3.2 Circuit Development of Conventional Transformerless Converter.

The Circuit Development of the conventional dc-dc transformerless converter is shown in the Figure 3.1, it consists of two switches S_1 and S_2 made up from high power IGBT, two inductors $L_1 and\ L_2$ with equal inductance values, largely sufficient output capacitors $C_{\circ}$, output diode $D_{\circ}$ and load Resistance R_L. Divisions of duties of the converter is based on the source voltage and inductance levels. The voltage gains equation of the conventional transformerless converter is expressed as

$$\frac{V_{\circ}}{V_i} = \frac{1+D}{1-D} \tag{3.1}$$

Similarly, the voltage stress across the active switches is expressed as

$$\frac{v_{\circ} + 2v_i}{2} \tag{3.2}$$

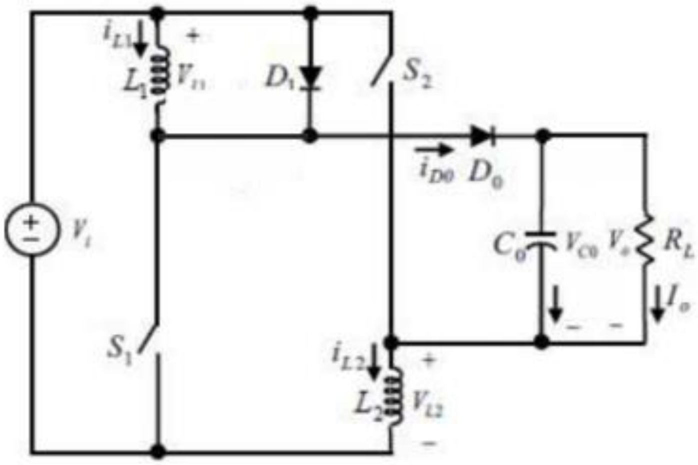

Figure 3.1: Conventional dc-dc transformerless converter

3.2.1 Circuit development of the transformerless dc-dc Converter

The power circuit of the modified dc-dc transformerless Converter shown in the figure 3.4 below. The converter consists of two sets of IGBT switches $S_1$and S_2, L_1 and L_1; two inductors L_1 and L_1 with the equal inductances values, one output capacitor $C_\circ$ with largely sufficient value, output diode $D_\circ$ and load Resistance. The converter was modified by adding voltage lift circuit consisting of capacitor C_1 and diode D_1 connected parallel to inductor L_1 and switch S_2. The operating conditions of the converter are studies under three different operating conditions viz: continuous operation, discontinuous operation conditions and operation across the boundary between them. The equivalent circuits of the converters are shown in the Figure 3.1

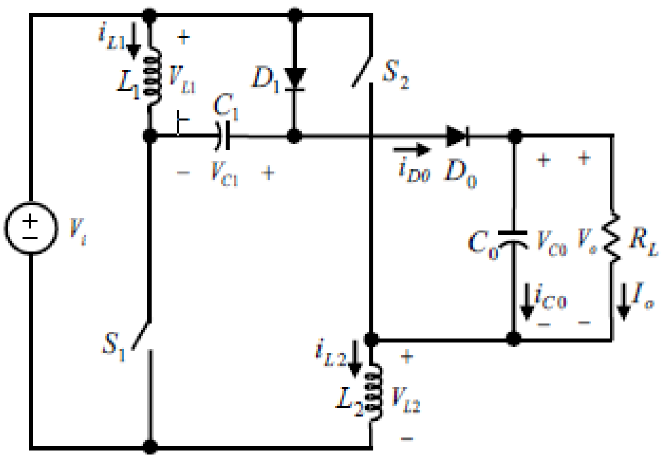

Figure 3.2: Circuit of modified dc-dc transformer less converter

3.3 Analysis of Modified Dc-Dc Transformerless Converter

Using the assumptions mentioned in section 1.5 and adopting of the notation analysis. The switches $S_1$and S_2 are closed, inductors $L_1 and\ L_2$ charge parallelly from the input voltage source. During second time interval, switches $S_1$and S_2 are opened, inductors $L_1 and\ L_2$ act serially to transfer the storage energy to output capacitor. Finally, both switches and inductors remain inactive allowing diode and output capacitor $C_\circ$ to transfer their storage energies to the output load. The typical wave form and equivalent circuits of the operating conditions are shown in the Figure. 3.3

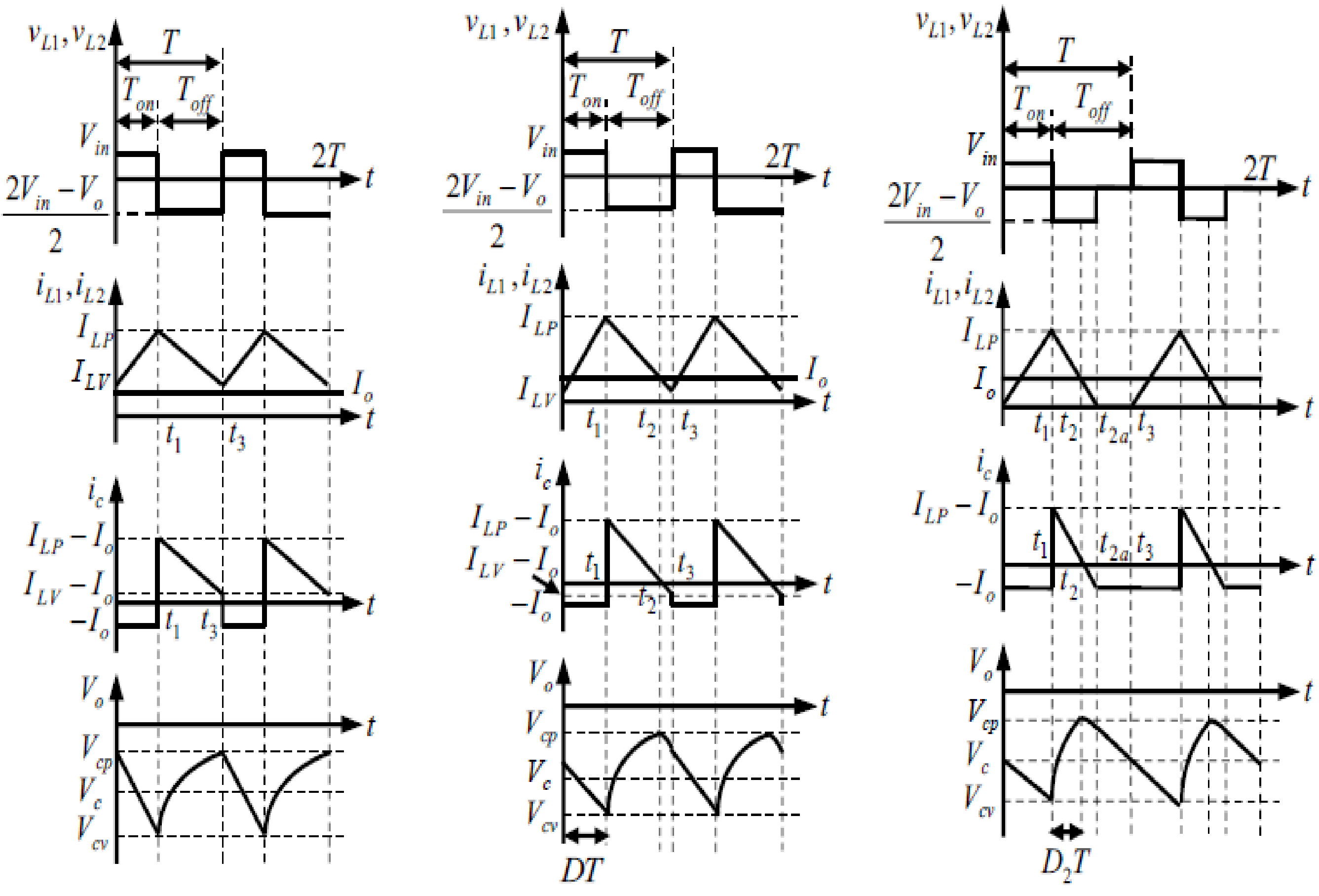

Figure 3.3: Typical wave forms for three operating periods

Meanwhile, During the period of conduction when switches are on the duty circle of can be expressed as

$$D = \frac{T_{on}}{T} \tag{3.1}$$

During the period when switches are off the duty circle of can be expressed as

$$1 - D = \frac{T_{off}}{T} \tag{3.2}$$

3.3.1 Analysis of modified converter During Continuous Conduction Period

The operation condition during continuous conduction period can be classify into conditions viz: operating condition (a) and operating condition (b).

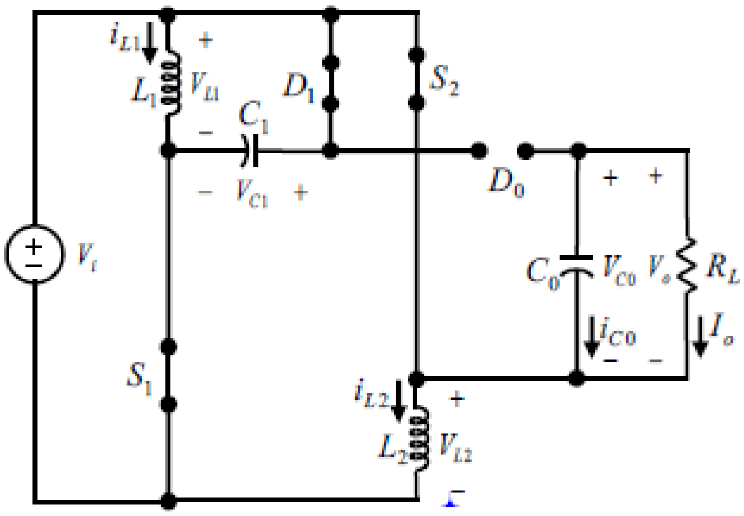

Figure 3.4: Circuit equivalent during continuous conduction operation at closed switches

Operating Condition a): The equivalent circuit of the converter is shown in Figure 3.3(a). Between time intervals t_0 and t_1 the switches S_1 and S_2 are closed parallelly, during this period the capacitor $C_1$and inductors L_1 *and* L_2 are charged directly from input voltage source V_i up to the stage when the charges across inductors are equal to input voltage V_i, the diodes D_1 and D_0 act as short circuit and open circuit respectively, the capacitor C. will transfer the energy stored in it directly to the output.

From the Equivalent circuit in Figure 3.4 the voltage across the capacitor C_1 and inductors L_1 L_2 can be expressed as

$$v_{L1} = v_{L2} = v_{C1} = v_{in} \quad (3.3)$$

Operating Condition b): as shown in figure 3.3(b). Between time interval t_1 and t_2 the switches S_1 and S_2 are opened, $L_1$and L_2 are serially connected, the diode D_1 is in reverse bias, the diodes D_0 and D_1 act as short circuit and open circuit respectively, therefore, the energy stored in the inductors L_1, L_2 and the capacitor C_1discharges simultaneously from maximum level to minimum level to charge and feed output capacitor through capacitor C.

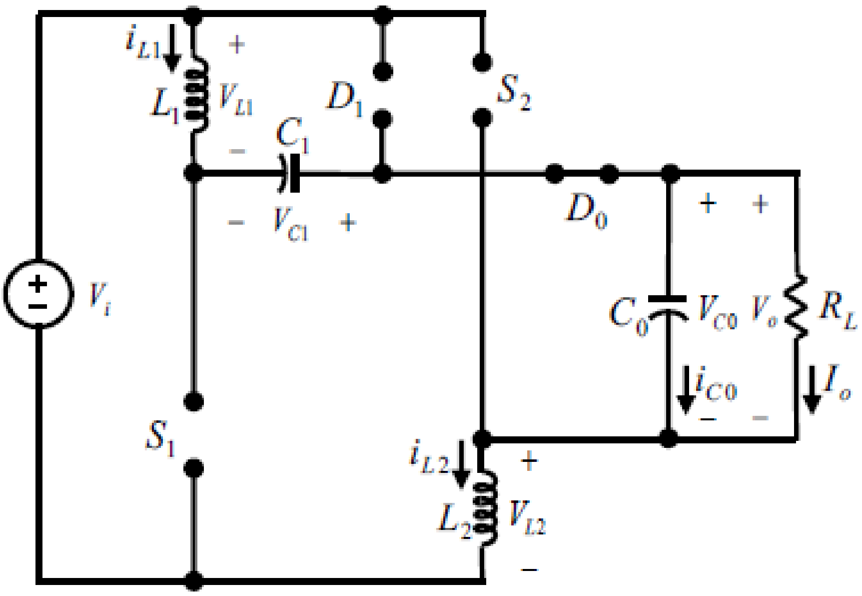

Figure 3.5: Circuit equivalent during Continuous Conduction at opened switches

As shown in Figure. 3.5 above inductor voltage is derived as

$$V_i + V_{C1} - V_0 = V_{L1} = V_{L2} \quad (3.4)$$

By applying the Kirchhoff voltage law in the circuit above the voltages is obtained as:

$$V_{L1} + V_{L2} = 2V_i - V_0 \tag{3.5}$$

Therefore, v_L is expressed as

$$v_L = \frac{2V_i - V_\circ}{2} \tag{3.6}$$

Using the volt–second balance in inductors During Continuous Conduction period t_0 t_1, At dc steady state, the average inductor voltage is equal to zero. that is:

$$\frac{1}{T} \int_0^T v_L(\text{t})\text{dt}=0 \tag{3.7}$$

With respect to Figure 3.3 (a) and 3.3 (b) the integral limit can be rewritten as

$$\frac{1}{T}\left[\int_0^{T_{on}} v_L\, (\text{t})\text{dt} + \frac{1}{T} \int_0^{T_{off}} v_L\, (\text{t})\text{dt}\right] = 0 \tag{3.8}$$

By substituting (3.5) and (3.6) the (3.27) can be expressed as

$$\frac{1}{T}\left[\int_0^{DT} v_L\, (t)dt + \int_0^{(1-D)T} v_L\, (\text{t})dt \right] = 0 \tag{3.9}$$

By integrating within specified limit, the voltage gain in the continuous conduction mode is obtained as follows:

$$\frac{V_\circ}{V_i} = \frac{2}{1-D} \tag{3.10}$$

Equation (3.10) can be rewrite as follows

$$D = \frac{V_\circ - 2V_i}{V_\circ} \tag{3.11}$$

From fig. 3.5 the voltage stresses across the diode D_1 switches S_1, S_2 are equal which is obtained as $\frac{V_\circ}{2}$ and for the diode D_0 is $V_{0.}$

3.3.2 Analysis of modified converter during Discontinuous conduction period

The operation condition during Discontinuous conduction period can further be classified as Operating Condition a, b and c.

Operating Condition a): as shown in the Figure 3.3 (a) Between time interval t_0 and t_1 the operation of discontinuous conduction mode is the same as continuous conduction mode discussed above. During this time interval, the peak inductances current I_{L1p} and I_{L2p} are also equal.

$$I_{L1p} = I_{L2p} = \frac{v_i}{L_{eq}} DT \tag{3.12}$$

Operating Condition b): as shown in Figure 3.3 (b). Between time interval t_1 and t_2 the switches S_1 and S_2 are opened L_1 *and* L_2 are serially connected, the diode D_1 is in reverse bias direction, the diodes D_0 and D_1 act as short circuit and open circuit respectively, therefore, the energy stored in the inductors L_1, L_2 and the capacitor C_1discharges simultaneously from maximum level to minimum level to feed output through capacitor $C_\circ$. The peak inductances current I_{L1p} and I_{L2p} are also equal.

$$I_{L1p} = I_{L2p} = \frac{v_{in}}{L_{eq}} D_2 T \tag{3.13}$$

By equating (3.12) and (3.13) D_2 is obtained as

$$D_2 = \frac{2DV_i}{V_0 - 2V_i} \tag{3.14}$$

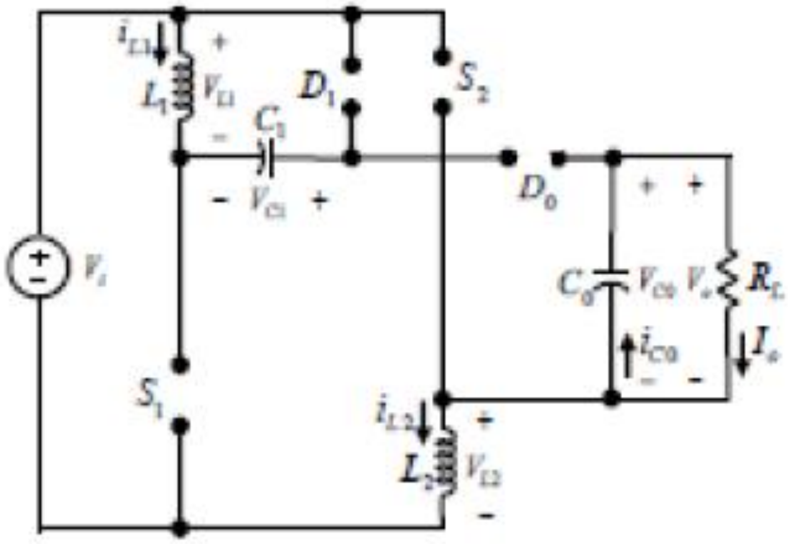

Figure 3.6: Circuit equivalent during DCM at opened switches

Condition c): During time interval t_2 and t_3 the switches S1 and S2 are still opened, and the energies stored in inductors L_1 and L_2 are at minimum therefore, the charges in the capacitor C_0 will be transferred to the load

During the discontinuous conduction period, the average current across the capacitor is equal to zero that is

$$\frac{1}{T}\int_0^T i_{c_\circ}(t)\, dt=0 \qquad (3.15)$$

According to Fig. 3.2 (b) between the time interval T_{on} (t_0 and t_1) the capacitor current $i_{c_\circ}$ is $(-I_o)$. Therefore:

$$i_{c_\circ} = i_L - I_o \qquad (3.16)$$

The inductor at this time is obtained from the following equation:

$$i_L(t) = \frac{2V_{i-}V_\circ}{2L}(t) + I_{LP} \qquad (3.17)$$

By substituting (3.10) in equation (3.17) the current across the capacitor $i_{c_\circ}$ is obtained as:

$$i_{c_\circ} = \frac{2v_{i-} v_\circ}{2L}(t) + I_{LP} - I_o \tag{3.18}$$

In order to calculate the integral, let us use the relationship that contains capacitor current $i_{c_\circ}$ at each time interval. according to Figure 3.3 (c) the $time$ interval T_{off} (t_1, t_3) is divided into two intervals (t_1, t_{2a}) and (t_{2a}, t_3) Therefore, the capacitor current $i_{c_\circ}$ is given as:

$$\frac{1}{T}\left[\int_0^{T_{on}} i_{c_\circ}(t)dt + \int_1^{t_{2a}} i_{c_\circ}(t)dt + \int_{t_{2a}}^{t_3} i_{c_\circ}(t)dt\right] = 0 \tag{3.19}$$

by Substituting $t_{2a} = D_2 T$ in (3.18) the following equation is generated:

$$\frac{1}{T}\left[\int_0^{T_{on}} i_{c_\circ}(t)dt + \int_{t_1}^{D_2 T} i_{c_\circ}(t)dt + \int_{t_{2a}}^{(1-D-D_2)T} i_{c_\circ}(t)dt\right] = 0 \tag{3.20}$$

By integrating within specified limit (3.20) will be equal to

$$\frac{2V_i - V_0}{4L} D_2{}^2 T + I_{LP} D_2 - I_o = 0 \tag{3.21}$$

by Substituting (3.33) in (3.40) the equation can be rewritten in term of voltage gain

$$\left(\frac{V_\circ}{V_i}\right)^2 - \frac{2V_\circ}{V_i} - \frac{R_L D^2}{Lf} = 0 \tag{3.22}$$

By solving the equation (3.22) the value of voltage gain during DCCM is obtained as:

$$\frac{V_\circ}{V_i} = 1 + \sqrt{1 + \frac{D^2 R_L}{Lf}} \tag{3.23}$$

According to (3.23) duty cycle is obtained as:

$$D = \sqrt{\frac{V_\circ(V_\circ - 2V_i)Lf}{R_L V^2{}_i}} \tag{3.24}$$

3.4 Calculation of the Peak Inductance Between Operation Conditions

By comparing Figure 3.3 (a) with Figure 3.3 (c), it can be seen that, the inductance current is zero in the boundary of operations between continuous and discontinuous conditions. Therefore, to obtain the value of minimum inductance current, there is need to find the peak inductance between two conditions.

$$\frac{1}{T}\int_0^T i_{c_\circ}(t)dt=0 \tag{3.25}$$

According to Figure 3.5(a) during time T_{on} $(t_0\ \ t_1)$ current across the capacitor $C_\circ$ is equal to

$$i_{c_\circ} = -I_o \tag{3.26}$$

similarly, during the time interval T_{off} $(t_1\ \ t_3)$ assuming $t_1 = 0$ the current across the capacitor $C_\circ$ can be expressed as:

$$i_{c_\circ} = i_L(t) - I_o \tag{3.27}$$

According to Fig. 3.5 (b), during the time interval T_{off} $(t_1\ \ t_3)$ the inductor voltage is given

$$v_L = \frac{2V_i - V_0}{2} \tag{3.28}$$

v_L can be express in term of inductor current

$$L\frac{di_L}{dt} = \frac{2V_i - V_0}{2} \tag{3.29}$$

During the time interval T_{off} $(t_1\ \ t_3)$ considering $t_1 = 0$ the inductance current can be expressed as:

$$i_L(t) = \frac{2V_i - V_0}{2L} + I_{LP} \tag{3.30}$$

Using equation (3.27) and (3.30), (3.25) can be rewritten as:

$$\left[\int_0^{T_{on}}(-I_o)\mathrm{dt} + \int_0^{T_{off}}\left(\frac{2V_i - V_0}{2L} + I_{LP}\quad\right)(\mathrm{t})\right] = 0 \qquad (3.31)$$

By integrating within specified limit, the following relation is obtained

$$I_{LP} = I_o\ \frac{1}{1-D} + \frac{V_0 - 2V_i}{4L_f}(1-D) \qquad (3.32)$$

From ohm`s law

$$I_o\ = \frac{V_0}{R_L} \qquad (3.33)$$

By substituting (3.32) and (3.10) in (3.12) the inductor peak current can be expressed as:

$$I_{LP} = I_o\left[\frac{1}{1-D} + \frac{R_L \mathrm{D}\ (1-D)}{4Lf}\right] \qquad (3.34)$$

From (3.34) the minimum inductor current I_{LV} can be expressed as:

$$I_{LV} = I_o\left[\frac{1}{1-D} - \frac{R_L \mathrm{D}\ (1-D)}{4Lf}\right] \qquad (3.35)$$

Using (3.29) in (3.35) L_C is obtained as

$$L_C = \frac{R_L \mathrm{D}\ (1-D)^2}{4Lf} \qquad (3.36)$$

Using (3.10) in (3.36) L_C ca be rewritten as

$$L_C = \frac{R_L v_i^2\ \mathrm{D}\ (V_0 - 2V_i\,)}{fV_0^3} \qquad (3.37)$$

Where is L_C critical inductor.

When $L > L_C$ during the time interval the converter will act as continuous conduction condition and when $L < L_C$ during the time interval the converter will act as discontinuous conduction condition.

3.5 Design Considerations

Using the assumptions mentioned in section 1.5 and adopting of the notation analysis. the following assumptions have also been considered to achieve the high conversion ratio of the converter:

i. The overall work is to be done in a steady state. thus, the output voltage is assumed to be constant
ii. All the elements are assumed to be ideal.

3.5.1 Selection of components

The component selected for design are as follows

- Voltage lift circuit
- Two set of IGBT switches S_1 and S_2
- Two inductors $L_1 and\ L_2$
- Output capacitor $C_\circ$ with largely sufficient value,
- output diode $D_\circ$ and
- Load Resistance.

The voltage lift circuit (Babaei and Farsadi, 2017) was selected to enhance the voltage gain and to reduce the current across the switches by current injection to the energy stored in inductors. Two inductors selected to have equal inductance values and to act as energy absorbers when charging and similarly as sources of energy when discharging. High speed and power IGTB switches ware selected to minimize power losses (conduction and blocking losses). However, the switches are controlled simultaneously using one control signal. The output capacitor is selected to be large enough to avoid fluctuation and over voltage

voltage lift circuit plays vital role in making the converter to have simple structure, minimum number of switches. small output voltage ripple; and leads to high power density, high efficiency and less cost.

3.6 Comparison Between the Modified Topology and Conventional Converters

Table 3.1 shows the summaries of comparison between the two conventional converters (Liang and Chen, 2009) and the modified transformerless dc-dc converter with high boost ratio. By considering Table 3.1 below, the voltage stress across the switches and conversion gain, it is clear that the modified topology has a lower voltage stress across the switch and high boost ratio. Similarly, by comparing the output voltage of the modified converter and conventional one, its clearly shows that the output was raised which means the power losses relatively reduced.

Table 3.1: Comparison between the modified topology and other boost converters

Boost Converters	Voltage Gain	Voltage Stress
Simple converter	$\frac{1}{1-D}$	V_o
Conventional	$\frac{1+D}{1-D}$	$\frac{V_{\circ} + V_i}{2}$
Modified converter	$\frac{2}{1-D}$	$\frac{V_{\circ}}{2}$

3.7 Simulation of Result

The modified dc-dc transformerless converter with high voltage ratio described in this chapter was simulated to verify the performance and high step-up boost ratio. the values of selected parameters of the converter are presented in Table 3.2

Table 3.2: Selected parameters for simulation

Parameters	Values
f (kHz)	100
Vi (V)	10
R_L (Ω)	150
C_1 (μF)	50
L1= L2(μH)	12
C_0 (μF)	3.33

The simulation was carried out using PSCAD software. The components used include two capacitors with sufficient large capacitance values, two IGBT switches, two equal inductors with the same inductance levels; voltage lift circuit which comprises of capacitor C_1, diode D_1 and load resistance R_L.

Figure 3.5 shows the selected input voltage source V_{in} of the converter with numerical values 10 volt, Figure 3.6 and Figure 3.7 represent triggering pulses for switch S_1 and switch S_1 respectively with the selected duty cycle D = 0.6; Figure 3.8 and Figure 3.9 represent current across the inductor L_1 and inductor L_2 respectively; The waveforms of the voltage across the voltage lift circuit are represented by Figure 3.10 and Figure3.11 respectively carrying the voltage across the capacitor C_1 and diode D_1. Figure 3.12 represents voltage across the output capacitor C_o which designed to be large enough to accommodates the large voltage and to maintain the constant voltage. Finally, Figure 3.13 shows the shows the entire output voltage with the 50.05 volt which is relatively corresponded to theorical result calculated in equation (3.10)

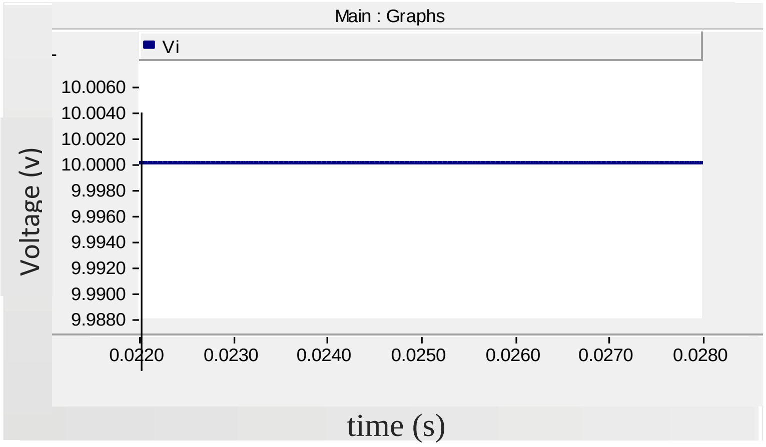

Figure 3.6: Input voltage

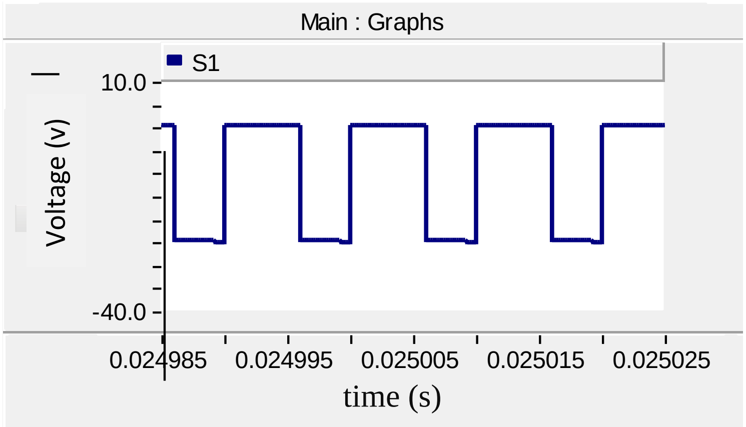

Figure 3.7: Voltage across switch 1

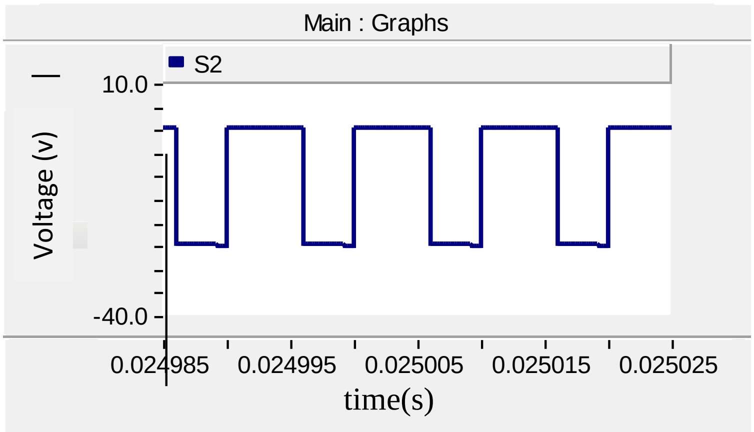

Figure 3.8: Voltage across switch 2

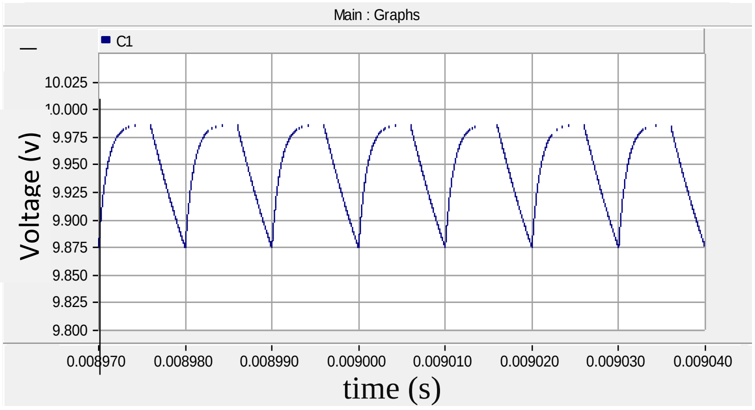

Figure 3.9: Voltage across Capacitor 1

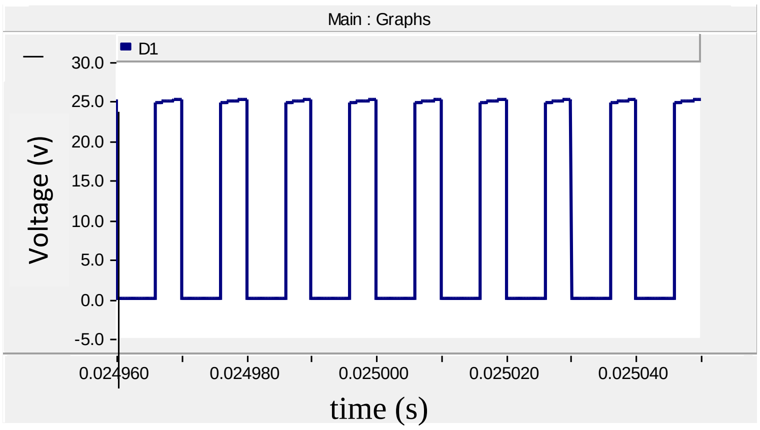

Figure 3.10: Voltage across the Diode 1

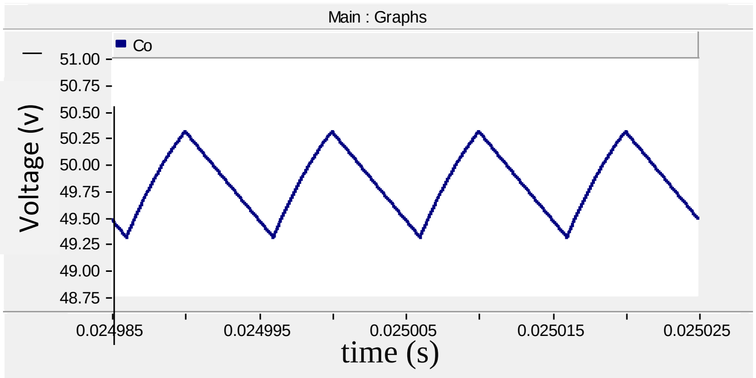

Figure 3.11: Voltage across output Capacitor

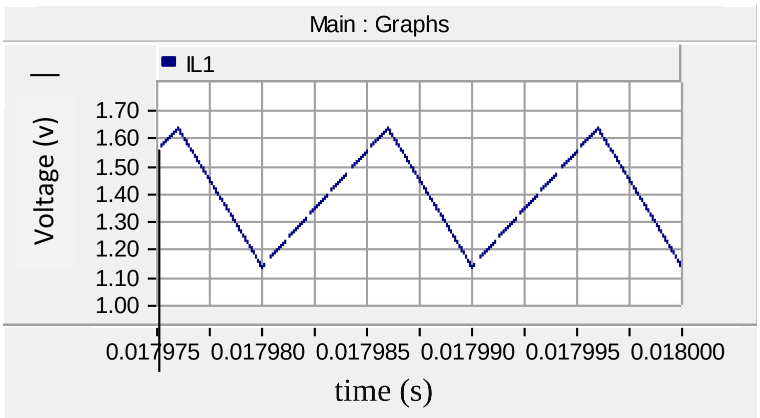

Figure 3.12: Voltages across switch 1

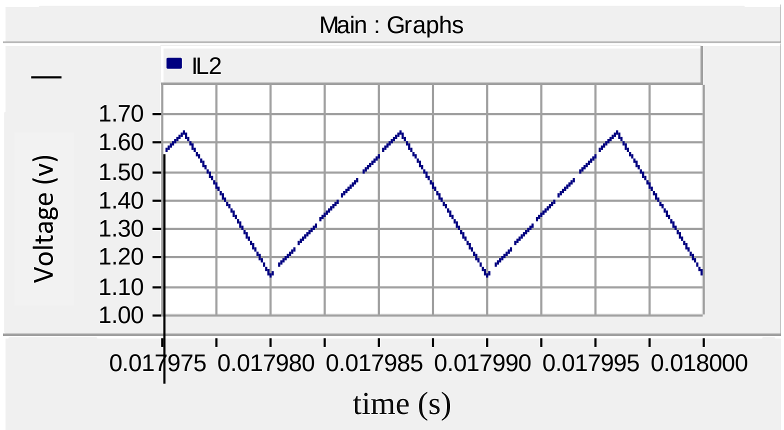

Figure 3.13: Voltages across switch 1

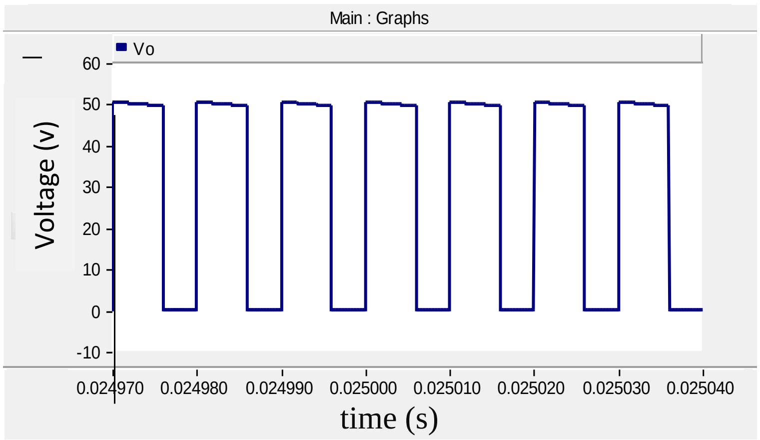

Figure 3.14: Output Voltages

3.8 Conclusion

This chapter has studied the circuit development of the transformer less converter where by the operations of the converter was analyzed when the switches are closed and inductors charged parallelly, secondly, when switches are inactive and inductors discharged serially and finally, when both switches and inductors are inactive only charges stored in output capacitor is been transferred to the output load. The wave forms of all stages have been presented and mathematical equations calculated by during the continuous and discontinuous operation conditions.

The design of modified converter with very reliable efficiency and high voltage gain was successful by considering the proper selection of suitable components with relative low voltage rating to reduce power losses as well as high building cost. Furthermore, in order to minimize the conduction and blocking losses as well as switching problems IGBT type of switches were selected for its capacities to operate in a high speed and retain high power without damage. The modified converter has simple structure with high voltage gain, low voltage stress and low power losses compare to the conventional converters.

Simulation part was carried out using PSCAD software by using selected parameters (Table 3.1). The results obtained proved the excellent performances and higher voltage gain of the converter. Moreover, the aforementioned problems of conventional converters such as low output voltage and switches voltage stress across as well as high duty cycle have been resolved

CHAPTER 4
CONCLUSION AND FUTURE WORK

4.1 Conclusions

This thesis has studied different non-isolated converters. The simple structure of transformerless dc-dc converter with the high voltage gain and an improved efficiency have been presented. The working principles, the performance and analysis of high step-up voltage ratio under different operation conditions have been discussed. The aims and objectives of this research were achieved by obtaining high conversion ratio of output voltage with minimum voltage stresses across the active transistors and extremely low duty cycle as well as low level of on-state resistance that leads to low rating voltage of the component and low building cost of the converter.

After a review of several non-isolated converter topologies, the research on transformerless DC-DC converters with different circuit arrangements have been conducted, the high conversion ratio of the output voltages have been achieved by proper addition of one lift voltage circuit to the one of conventional non-isolated boost converter. The presence of one lift voltage circuit have modified and improved the proposed converter to produces very reliable result. Importantly, the greatest output voltage delivered to the load, has more voltage gain, high efficiency and low duty cycle when compared with the conventional non-isolated converters.

The two inductors designed to charged parallelly during switches on-state period and discharged serially during the switches off-state period during the continuous operating and discontinuous operating conditions and the boundary between them. Under the same operational condition, the output of the proposed converter shows good performance than conventional non-isolated boost converter. The output capacitor designed to be very large to avoid over voltage and output voltage derived successfully using the volt–second balance of the source in an inductor. In each case, different equivalent circuits and wave forms have been presented and outputs under the various condition have been reported appropriately.

The output result obtained from the converters comprises of voltages gains and duty ratios were tabulated and compared. Finally, the modified converter selected.

The simple structures and low rating of the components have made the converter to be better for producing high energy conversion and relatively easy to design and control. The benefits of this studies include the capabilities of the proposed converter to produces solutions for the negative side drawbacks such as low voltage stresses across the active transistors, extreme high duty cycle which maximizes the overall losses and maximizes the overall efficiency of the converter. The most interesting behavior of the proposed converter was only one power stage acts at a time.

The high conversion ratio and sterling qualities of the converter have drawn the attention of an engineers to frequently use the converter especially in the areas of renewable energy (photovoltaic and fuel cell) where the high conversion ratio of energy is needed, the industrial application such as dc motors and so many modern technologies like electric vehicles as well as telecommunications equipment et carta.

With all these aforementioned applications, on other hand, the converter has some limitation that needs appropriate improvements and some drawbacks that generally decreases the overall conversion efficiency and virtually increases the building cost of the converter.

Finally, the duty cycle was improved by establishing low duty cycle. The problem of voltage stress was properly addressed and appropriately minimized. The converter performed excellently by generating output voltage with high conversion efficiency, extreme low duty cycle and less power losses. In this regard, the major objectives of this research have been achieved.

To prove the performance of the designed converter the result was simulated using PSCAD software and both the design and theoretical result are relatively corresponded to each other and proved the capabilities of producing high voltage gain by the converter.

4.2 Future Work

The operation modes in this thesis covered only modes in continuous and discontinuous conduction modes. A future research objective from this work is to design converter topology that can operate in the period between Complete non-complete supplying of inductors in modes. Moreover, I have being thinking of design the same converter with the same topology but with two voltage lift circuit. I am sure this will accelerate the capabilities of the converter to achieve maximum conversion efficiency at all times.

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