A

DISSERTATION REPORT

ON

IMPLEMENTATION OF SOFT SWITCHING WITH ZVT-ZCT TECHNIQUE IN OPEN LOOP BUCK CONVERTER USING A SNUBBER CIRCUIT

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Submitted to:	**Guided by:**	**Submitted by:**
Mr. M.Sashilal	Miss. Vishu Gupta	Manisha Kanyal
Head Of Department.	Asst. Professor	SGVU081491053

Department of Electrical Engineering

SURESH GYAN VIHAR UNIVERSITY JAIPUR

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I would like to express a lovely thanks to my **parents** from my heart for always supporting me and guiding me to choose right way in my life.

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CERTIFICATE

I **MANISHA KANYAL (** En.no SGVU081491053**)**, hereby certify that the work which is being presented in the Dissertation report entitled **"IMPLEMENTATION OF SOFT SWITCHING WITH ZVT-ZCT TECHNIQUE IN OPEN LOOP BUCK CONVERTER USING A SNUBBER CIRCUIT"** in partial fulfilment of the requirement for the award of M-TECH DUAL DEGREE in Power System and submitted in the department of Electrical Engineering of the **SURESH GYAN VIHAR UNIVERSITY, JAIPUR** is an authentic record of my work under the supervision of **Mr.M SASHILAL** Head of Department of Electrical Engineering and in the guidance of Asst. Professor. **Miss. VISHU GUPTA.**

The matter presented in the report embodies the result of own work and studies carried out by me is have not been submitted for the award of any other degree of this or any other university.

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Date:

MANISHA KANYAL
SGVU081491053

Miss. VISHU GUPTA

Assistant professor
Department of Electrical Engineering
Suresh Gyan Vihar University, Jaipur

ABSTRACT

In this thesis a new type of soft-switching DC-DC buck converter with zero-voltage transition (ZVT) zero-current transition (ZCT) is proposed instead of hard–switching. In conventional (hard switching) converter there is some loss across switch at the time of switching and then the efficiency of the device is limber down.

This proposed converter uses a soft-switching method which ensures zero crossings at any time required for soft switching and provides ZVT turn-ON and ZCT turn-OFF together for the main switch by active snubber cell in buck converter which is presented. This is a very efficient technique (resonant technique) with a buck or step down voltage and higher efficiency than the conventional hard-switching converter. In this proposed converter we apply the soft switching technique on both the switches (main and auxiliary). This will also increase the converter efficiency.

As we know efficiency of the any soft switching converter is improved only by reducing the switching losses as putting some stress or tension on the converter component but in this proposed converter we also reduce or minimize these stresses by ZVT turn ON and ZCT turn OFF of the main switch.

The soft switching buck converter has been simulated in MATLAB software and the performance of the buck converter which is verified through the theoretical analysis and simulation result by the prototype of a 63 watt and 100 KHz circuit. Also shows the application of the proposed converter.

CONTENTS

Main page……………………………………………………………………………i
Certificate……………………………………………………………………........ii
Acknowledgement……………………………………………………………….......iii
Abstract…………………………………………………………………………….....iv
Contents……………………………………………………………………………...v
List of Figures ……………………………………………………………………… viii
List of Tables ……………………………………………………………………..….. ix

CHAPTER 1

Introduction:

1.1 Aim..1
1.2 Thesis Objective..4
1.3 Switching Mode Regulator..4
1.4 Types of DC-DC power Regulator..5
1.5 DC-DC Buck Converters..6
1.5.1 Overview...6
1.5.2 What is a DC/DC Buck Converter..6
1.5.3 Operating Principle of buck converter..7
1.6 On the basis switching, DC-DC Buck Converters are classified in following ways..8
1.7 Technique of hard switching for DC-DC Buck Converters...8
1.7.1 Disadvantage of Hard-Switching..9
1.7.2 Possible ways to reduce effect of hard switching..9
1.8 Technique of soft switching for DC-DC Buck Converters...9
1.9 Types of soft switching or resonant techniques are...10
1.9.1 Process of Zero voltage switching..10
1.9.2 Process of Zero current switching..11

CHAPTER 2

Configuration of the proposed buck converter

2.1 Introduction...13
2.2 Operation of the proposed soft switching buck converter..14

2.3 Modes of operation for the proposed converter..15

2.3.1 Mode 1..16

2.3.2 Mode 2..17

2.3.3 Mode 3..18

2.3.4 Mode 4..19

2.3.5 Mode 5..20

2.3.6 Mode 6..21

2.3.7 Mode 7..22

2.3.8 Mode 8..23

2.3.9 Mode 9..24

2.3.10 Mode 10..25

2.4 Key waveforms of the operation modes…………………………………………..26

CHAPTER 3

Design and consideration:

3.1 Introduction…………………………………………………………………...27

3.2 Design procedure……………………………………………………….......27

3.3 Power switches..29

3.3.1 Switch (MOSFET) parameter when Switch is in off state………………..…..29

3.3.2 Switch (MOSFET) parameter when Switch is in ON state………………..….30

3.4 Buck Converter Diode Selections..30

3.5 Calculate Inductance of the Buck Converter …………………………………...31

3.6 Inductor Ripple Current Estimation…………………………………………….31

3.7 Select Output Capacitor of the Buck Converter.......................................………..32

3.8 Output voltage ………………………………………………………………......32

3.9 Converter features ……………………………………………………….…...33

CHAPTER 4

Simulation analysis of the proposed buck converter:

4.1 Simulation studies………………………………………………………………….34

4.2 Waveform of Voltage and current of main switch………………………………...37

4.3 Waveform of voltage and current of auxiliary switch………………………......38

4.4 Waveform of main diode current and voltage……………………………......39

4.5 Waveform of gate pulse of main and auxiliary switch……………………………40

4.6 Waveform of input, Output voltage and output current ………………………......41

4.7 Output power of the simulated converter..42

CHAPTER 5

Application of the proposed converter...43

CHAPTER 6

Conclusion and future works:

6.1Future work...45

6.2 Conclusion...46

Reference..47

List of figures:

Name of the figure **Page no.**

1.1 Open Loop Buck Converter...7

1.2 Current and voltage waveforms of hard and soft switching 9

1.3 Soft switching with Zero-voltage (ZV),**[5]**...11

1.4 Soft switching with Zero-current(ZC),**[5]**..12

2.1 Proposed soft switching buck converter with snubber cell......................................14

2.2 Modes 1 of the proposed soft switching buck converter...16

2.3 Modes 2 of the proposed soft switching buck converter...17

2.4 Modes 3 of the proposed soft switching buck converter...18

2.5 Modes 4 of the proposed soft switching buck converter...19

2.6 Modes 5 of the proposed soft switching buck converter...20

2.7 Modes 6 of the proposed soft switching buck converter...21

2.8 Modes 7 of the proposed soft switching buck converter...22

2.9 Modes 8 of the proposed soft switching buck converter...23

2.10 Modes 9 of the proposed soft switching buck converter.......................................24

2.11 Modes 10 of the proposed soft switching buck converter ……………..……...25

2.12 Key waveforms of the operation modes in the proposed converter……………....26

4.1 Simulated scheme of the proposed soft switching converter…… ………………...36

4.2 Switching, voltage and current waveform of the main switch…………………......37

4.3 Switching, voltage and current waveform of the auxiliary switch………………...38

4.4 Voltage and current waveform of the Main diode…………………………………39

4.5 Gate signal for the main switch and for auxiliary switch…………………………40

4.6 Output voltage and current waveform of the proposed buck converter……………41

5.1 Block diagram representation of converter application……………………….......43

List of Table:

Table Name **Page no.**

3.1 Switch parameter when OFF..29

3.2 Switch parameter when ON..30

3.3 Diode parameter...31

Chapter 1

Introduction

1.1Aim

In this study, the discussion is about how the power loss can be reduced with higher power density and faster transient response of pulse width (PWM) converter. Actually for generating higher power density and faster transient response the switching frequency is being increased simultaneously. By doing so, the power loss during the switching is also get increased also, there is increased in noise and electro-magnetic interference. All these factors reduce the efficiency of the circuit.

In conventional converters, the use of hard switching leads to power losses, which result the efficiency of the converter is low. The use of hard switching is no more useful in the converters as there is a high power loss during the turn OFF and turn ON states. So, there is a demand of new technique which can reduce the power loss during ON and OFF state. In this technique, either the voltage or current must be zero at one time. For EX- when we turn ON the switch from OFF mode, to reduce the loss the zero current or zero voltage, (one at a time) will be provided to the circuit this in turn reduce the power loss of the circuiting.

The proposed buck converter uses the soft switching technique with magnetic coupled inductor and capacitor, auxiliary switch and diodes on an auxiliary or resonant circuit. In this thesis an advance Zero-voltage switching – Zero current switching quasi resonant buck converter is used. As discussed earlier for any time we provide (ZVS) and turn ON and (ZCS) turn OFF together. This switching is done only an a single auxiliary switch with reduced component only conventional converter the devices felt a high stress in sense of current and voltage; but now they have less upper case drawback.

The semiconductor device operates a zero voltage and zero current switching during turn ON and turn OFF by the use of resonant technique.

As discussed earlier the switching losses can be reduced by the commutation with either zero voltage switching or zero current switching. However, the problem occurred at controlling the PWM converter because there is excessive voltage and current stresses. Also, there is increased in total power loss in the converter by using a snubber circuit with reduce switching loss.

In this technique zero voltage and zero current switching during turn ON and turn OFF is achieved. Also the switching loss are significantly reduced by means of ZVS and ZCS switching but the excessive voltage and current stresses leads to the low power density is hard to control than by using conventional PWM converters.

In ZCS converters the switching frequency and efficiency is increased by capacitive turn ON loss holds prior to turn OFF this also eliminate turn OFF losses. In ZVS by shaping the switch's voltage waveform so it reduces the voltage to zero prior to turn ON, we achieved the elimination of power loss during switching. This technique also gives the advantage of using ZVS at high frequency. For high power density and faster transient response of (PWM), ZVS is very useful. But the active switch felt high voltage stress in single ended topologies.

The ZVT, ZCT, PWM technique works soft switching in PWM converter [2]. This technique works same as previous soft switching but has some extra advantage over conventional soft switching. This reduces the switching loss with minimum voltage, current stress and the energy which is circulating in the system.

The ZVT technique works over the incoming switch. The voltage across the incoming switch is being forced to zero to achieve the minimum efficiency state. It is very effective only on low frequency operation but it gets limber down and a state of cognition is occurred at high frequency operation. This occurred due to a capacitor snubber size for high frequency operation has only small work down over the turn OFF loss. Similarly ZCT technique is just an opposite turn OFF technique. It reduces the outgoing switch current to zero for reducing the power loss. Both techniques are used simultaneously with one another. We can't use only a single technique because for proper function we require same voltage and current with alternate effect. For continuation of the operation of the operation, both the techniques are used. The priority statement is no longer effective in this case. [2]

ZVT and ZCT still have additional current stress on the main switch on the circuit, parallel to that switches turns ON hard in the converters and the partial hard turn off the switch and has additional voltage stress in the converters.

In this study a converter we used a universal auxiliary circuit, zero voltage and zero current transition (ZCZVT) commutation cell is also used. This is implied to the buck converter with ZCZVT PWM commutation cell. The main switch is kept parallel to that ZCZVT PWM commutation cell. The commutation cell is activated only during the soft switching for full load ranges. For differentiate current and voltage the diodes reverse recovery losses are minimized during the commutation which allows the slower devices in these commutation cell. At the commutating state of cell, when the main switch is turn ON and turn OFF, there is a flow of majority and minority charges which is highly, when we use MOSFETs and IGBTs. This implies that this technique is very useful for large variety of devices whether high or low power frequency distribution.

The different types semiconductor devices taking a variable power sources as inputs are easily be taken into account by this technique, this new snubber cell can be easily implemented to other converter topologies for taking variable output. Circuit here is designed with most features of the presented previous circuit and for reducing the drawbacks of these circuits. The main device is kept with no more voltage and current stress.

1.2 Thesis objective

The following objectives are achieved by the end of the project desirably.

1) Study the different converter topologies and how soft switching minimize switching losses and how is better than hard switching.

2) To study the types of soft switching or method to achieve the method of soft switching and how this method work to reduce or overcome the losses.

3) To study the proposed converter with proposed snubber cell and also study the design parameters of the proposed soft switching buck converter.

4) Simulate the Soft Switching Buck Converter in MATLAB and getting the waveform of current and voltage, also the switching waveform of current and voltage of the main and auxiliary switch compare with the theoretical analysis.

5) To compare conventional DC-DC buck converter with the proposed soft switching buck converter with auxiliary resonant circuit in terms of improving power quality and decreased switching losses.

1.3 Switching mode regulators

An electronic power system has had one or more of the power converters. An electronic power converter is constituted by semiconductor devices of power controlled by integrated circuits. The switching characteristics of semiconductor devices allow a power electronic converter to shape the input power of a one form of power to another. The static power converters are doing this in a very efficient manner. The power electronic converters are classified into five types as below.[4][11]

i) Rectifier - The AC input voltage is converted into DC voltage .The flexibility is that input AC voltage can be of either single or three phase type.

ii) AC-DC converter (Phase controlled Rectifiers)- It converts AC voltage to DC output voltage in controlled manner. The output of phase controlled converter will be DC however the input may be fed by single phase or three phase AC source.

iii) DC-DC converters (DC Circuit) -. A DC voltage chopper converters convert a fixed DC voltage to a variable DC voltage and vice versa.

iv) DC-AC converters (Inverter)- conversion of DC voltage to Ac voltage is done by this converter. Inverter is example of this converter which converts fixed DC voltage to a variable AC voltage. The output may be a variable voltage or a variable frequency or both.

v) AC-AC converters- This converts the AC voltage of fixed magnitude to variable magnitude AC output voltage. It is divided into two types

1) These voltage AC driver-AC voltage converter becomes secured directly to a variable AC voltage at the same frequency.

2) This cycloconverter-power converter circuit in a frequency input to the output power at a different frequency through a conversion step.[4]

1.4 Types of DC-DC power regulators

There are three basic topologies of switching regulators.

1.) Buck Regulators
2.) Boost Regulators
3.) Buck-Boost Regulators
4.) Cuk Regulators

Furthermore, depending upon the direction of current and voltage, dc converters can be classified into five types: [11]

1.) First Quadrant Converters
2.) Second Quadrant Converters

3.) First and Second Quadrant Converters

4.) First and Fourth Quadrant Converters

5.) Four-Quadrant Converters

1.5 DC-DC buck converters

1.5.1 Overview

The process of changing high DC voltage to another low DC voltage or in other words we can say that a change of fixed DC voltage to variable low DC voltage. A buck converter is a DC- DC converter in which the output voltage always is less as compared to the input voltage.

A buck converter is also treated a step-down chopper since it “steps downs” the input voltage and output received at the output terminal of converter is very low in magnitude as compared to input voltage fed to the converter.

The output current is higher than the source current. Power of the buck converter can come from any of the suitable DC sources, such as batteries, solar panels, also come AC source through rectifiers and from DC generators etc.

1.5.2 DC/DC buck converter

Buck converters are basically a step-down chopper or power converter that converts a high input voltage to a lesser output voltage,[4]. A figure shows a prototype of DC/DC buck Converter.

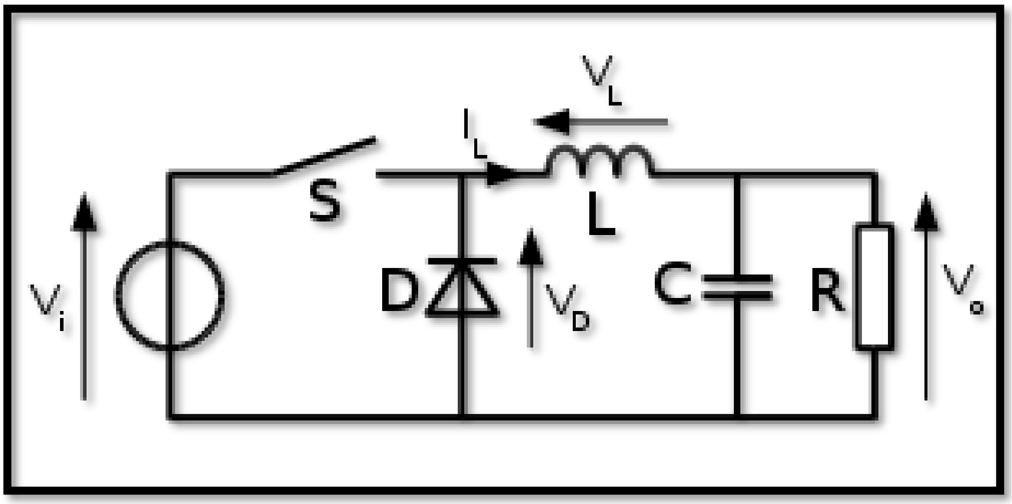


Fig.1.1 Open loop buck converter **[7]**

1.5.3 Operating principle of buck converter

The principle to achieve lower output voltage is associated with Buck converter. As we know it is basically a step down chopper so in buck converter, the average output voltage Vo achieved is always less than the source voltage Vs of the converter topology.

First the switch is closed, current will ready to increase, but as we know the inductor doesn't want it to change from 0, (oppose the change in current) so it will oppose or fight the increase by limber down a voltage. This voltage drop counteracts the voltage of the source and therefore reduces the net voltage across the load. Over time, the inductor will allow the current to increase slowly by decreasing the voltage it drops and therefore increasing the net voltage seen by the load. During this time, the inductor is storing energy in the form of a magnetic field.[8[11]]

If the switch is opened before the inductor has fully charged, then there will always be a voltage drop across it, so the net voltage at the load end always is less than the input source voltage**.**

The input voltage and output voltage relation is managed by the duty cycle D of the switch.

According to the below equation.[1],[6]

$$\mathrm{Vout} = \frac{\mathrm{D}}{1}\mathrm{Vin} \tag{1}$$

V_{out} = Output voltage

V_{in} = Input voltage

D = Duty cycle

D = Ton/T

Input/Output Characteristic of a buck converter

1.6 On the basis switching, DC-DC buck converters are classified in following ways

i) DC-DC Buck converters with hard-switching.

ii) DC-DC Buck converters with soft-switching.

1.7Technique of hard switching for DC-DC buck converters

The Converters in which conventional switching is implemented are called as hard switched converter. It poses a drawback of switching loss during the switching of switches in the whole operation. At the time of turn ON the voltage across the switch connected in the converter is seen to increase and the current start to decrease that give result in some switching losses. Similarly during turn OFF time the voltage across the switch starts to decrease and the current starts to increase. Hence some switching losses are seen in the switches of the converter.

The power electronics device connected in the converter generally suffers from high voltage and high current during switching processes, which resulting in more switching losses and stresses are across the switches. As it is very well known that switching losses are proportional to the switching frequency and hence in hard switching the limit of maximum switching frequency are kept to be low to reduce switching losses across the switches The inductive and the capacitive components connecter in the converter topology and the power electronics devices cusses considerable transient effects, which in give increases the problem of electromagnetic interference (EMI). Various research has been done and the result shows that hard switching gives stressful switching for power electronic component used in converters.[5]

This is also realize from the fig there are overlap between the voltage and the current of the switch, due to this power loss is occur during the overlapping reason of the voltage and the current(or during switching).

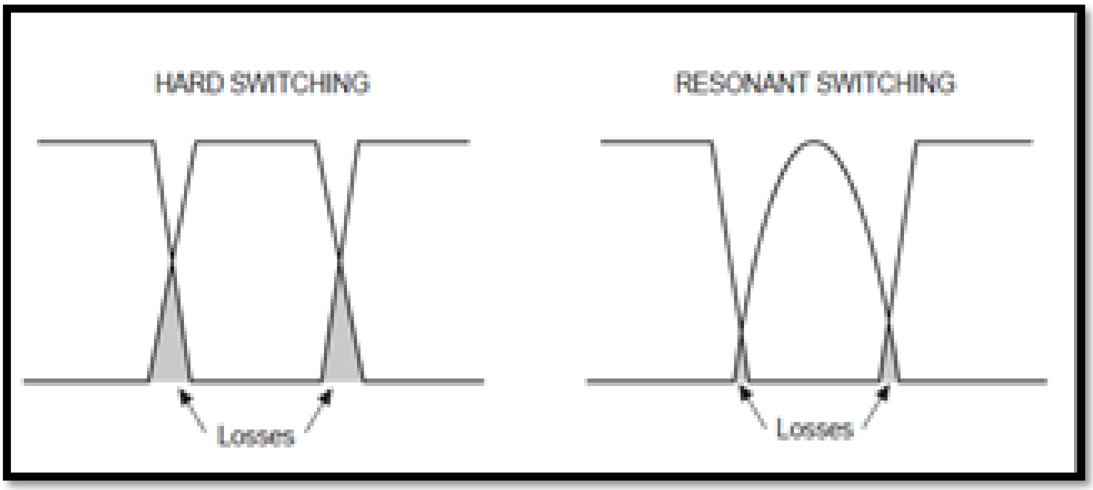


Fig 1.2 Current and voltage waveforms of hard and resonant (soft) switching systems,**[4]**

1.7.1 Disadvantage of hard-switching

1) Switching losses

2) Device stress, thermal management

3) EMI due to high di/dt and dv/dt

4) Loss of energy in the stray L and C

1.7.2 Possible ways to reduce effect of hard switching

1) Snubbers to reduce di/dt and dv/dt

2) Circuit layout to reduce stray inductances

3) Gate drive

  3.1) Circuit layout

  3.2) Turn on / off speeds

4). Soft switching to achieve ZVS and/or ZCS

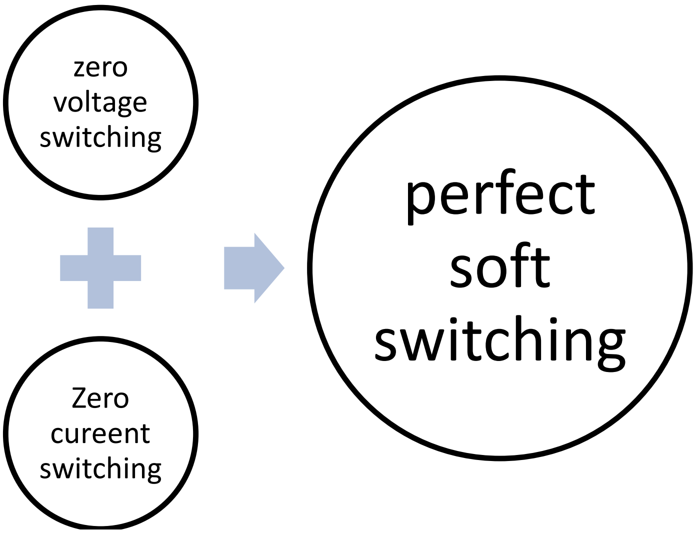
1.8 Technique of Soft Switching for DC-DC buck converters

The technique that is used to reduce switching losses so that the power loss in the switches becomes zero is called as Soft switching techniques. It can reduce switching losses and the stress across the switches. On the other hand reduction in electromagnetic interference by the use of this technique has been seen.

When the value of current or voltage is zero during the time of switching on or off, then as we know the product of the voltage and the current becomes zero due any component being in zero state, leading to zero power loss.

Hence loss due to switching is eliminated and the switch can easily operate at high switching frequency. Due to high operation in switching frequency dimensions and weight of the device is reduced since it does not require the heat sink.[1],[4],[5].

1.9 Types of Soft Switching or Resonant techniques Are



This art shows the perfect soft switching method, zero voltage and zero current soft switching is the perfect soft switching technique.

1.9.1 Process of Zero Voltage Switching (ZVS)

In ZV resonant converter switch, the resonant capacitor Cr is connected in parallel with the switch S to achieve zero voltage switching (ZVS). When the switch S behaves one-way switch, the voltage across the capacitor Cr is free to move backwards and forwards in the positive and negative half-cycle. This operation of resonant capacitor shows that the resonance switch may operate in full-wave mode. If the body diode in the switch is connected in anti-parallel with the unidirectional switch, the resonant capacitor voltage across the diode clamped to zero for negative half cycle.

The main purpose of switch connected in ZV resonant circuit is to provide better shape to the voltage waveform during the operation of switch in free time in order to create the condition for the zero voltage switching for the switch connected in the converter topology.[5]

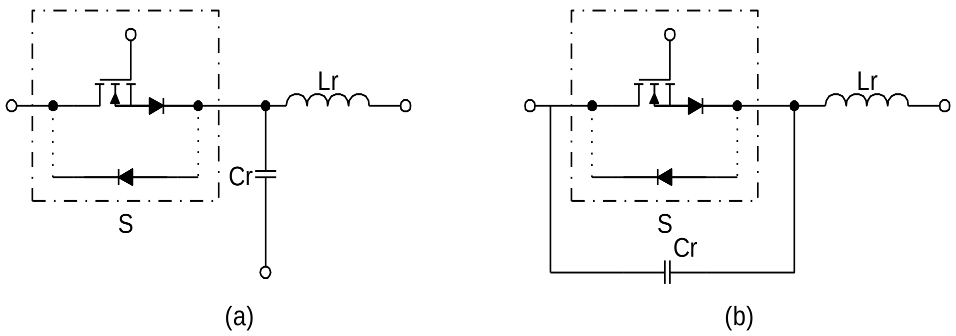
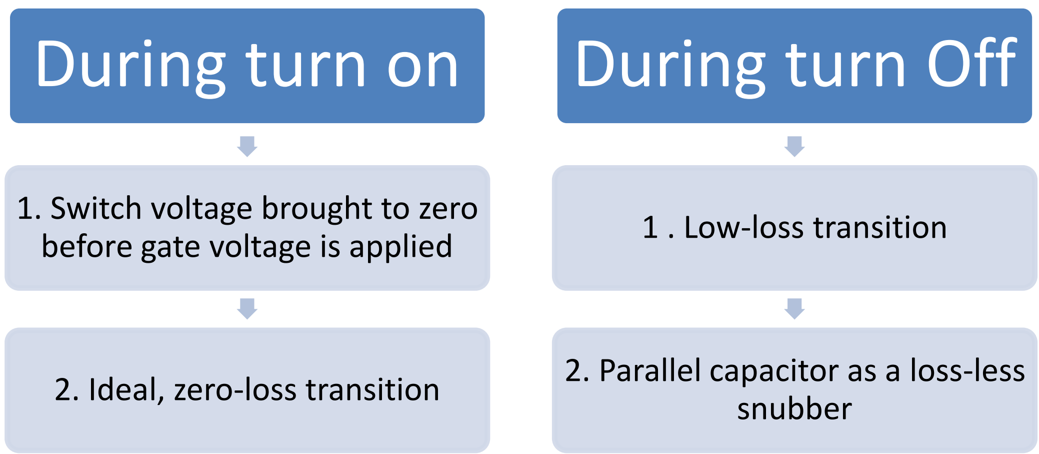


Fig 1.3 Soft switching with zero-voltage (ZV), **[5]**



<u>1.9.2 Process of Zero Current Switching (ZCS)</u>

To achieve proper ZCS, a resonant inductor Lr is connected in series with a power switch S connected in converter. If the switch S operates in one direction, the flow of current is only allowed to resonate in the half-cycle. The switch resonant is said to operate in half-wave.[9]

If the diode is connected in anti parallel with the switch, the switch current can flow in both directions. In this operational phase, the switch resonant can operate in full-wave. During the period of turn-on, the current in the power switch will rise linearly from zero to maximum. Then current will seen to be oscillating due to the resonance between the inductor Lr and capacitor Cr, This will result in the soft switching in the switch and the switch can be switched to the next term of zero current. The main aim of this type of switching is to provide smooth shaping to the waveform of the current of the switch during the conduction time of switch so that the condition of zero current to the switch to turn off time can be achieved [5].

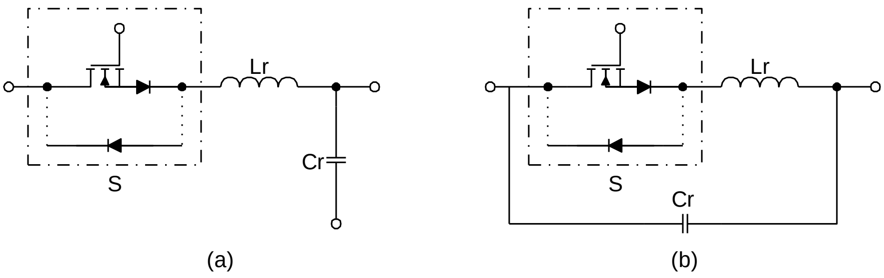
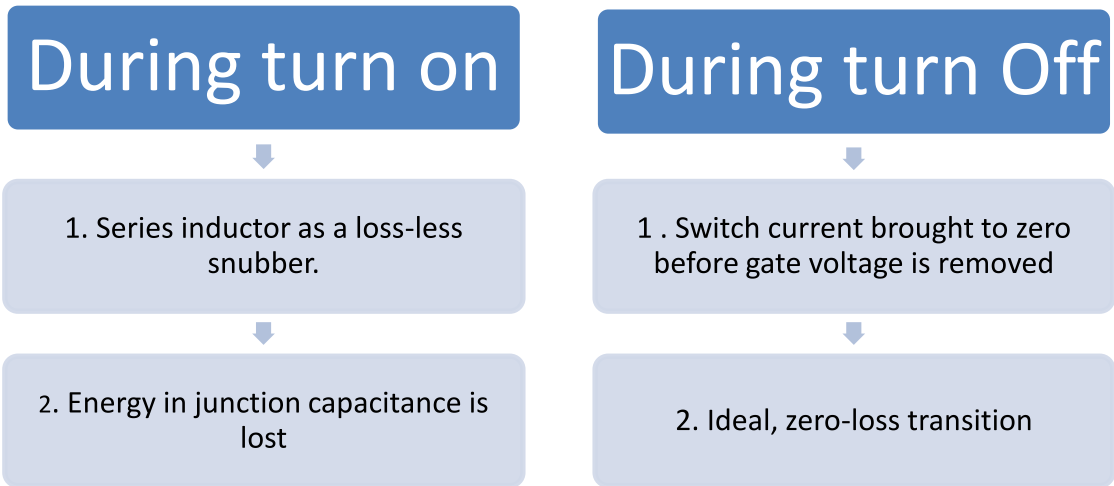


Fig 1.4 Soft switching with zero-current (ZC),**[5]**



Chapter 2

Configuration of the proposed converter

2.1 Introduction

In this research study a new soft switching quasi resonant DC-DC converter with an auxiliary switch is introduced. Resonant circuit use in this proposed converter for provides the resonance to for the main switch of active snubber cell in buck converter is presented. In this thesis proposed a active snubber cell which consists a centre tapped and magnetic-coupled snubber inductor (LS1 and LS2), a snubber capacitor (Cs), a main switch (Sm), an auxiliary switch (Sa), the output filter capacitor (CF), main inductor (Lm) and two auxiliary diodes (D1 and D2). The diode D1 is also considered the body diode of the main switch. So we not need to connect separate diode when we using MOSFET as a switch. The parasitic capacitors of the semiconductor devices Sm, D2 and Sa are incorporated the capacitor Cr, and this is generally sufficient for the operation of the converter. Thus, Cr can be assumed the sum of these parasitic capacitors (Sum of the parasitic capacitors of the main switch, auxiliary switch and the diode D2).

The whole circuit consist a voltage or a power source, and a buck inductor L (for step down purpose), magnetic-coupled snubber inductor, snubber capacitor, auxiliary diode D2, a main switch S_m and auxiliary circuit S_a and a output capacitor for decreased the output voltage ripple and make the output voltage constant.

This proposed converter is better than other conventional converter which are introduced earlier this converter had better efficiency than other.

In this proposed converter soft switching technique is used for both auxiliary and main switch this technique will another make this converter more desirable and more efficient.

In this thesis study do some experiment in MATLAB, with calculate all the parameter and show the theoretically result by MATLAB Simulation to verified the steady state operational principle of the proposed circuit.

In this study introduced proposed converter work at 100KHZ switching frequency.

<u>2.2 Operation of the proposed Soft Switching Buck Converter</u>

Conventional Buck converter circuits have more losses across the switch when the switch turns ON and OFF. Result in reduction system efficiency. So by introducing proposed topology the generation of switching losses are avoided by forcing voltage and current to Zero during switching. The efficiency is improved due to reduction in switching losses, [1], [2], [4], [5].

Way of the component connecting in the circuit of the proposed converter for achieving the low loss or zero switching loss is shown in fig.

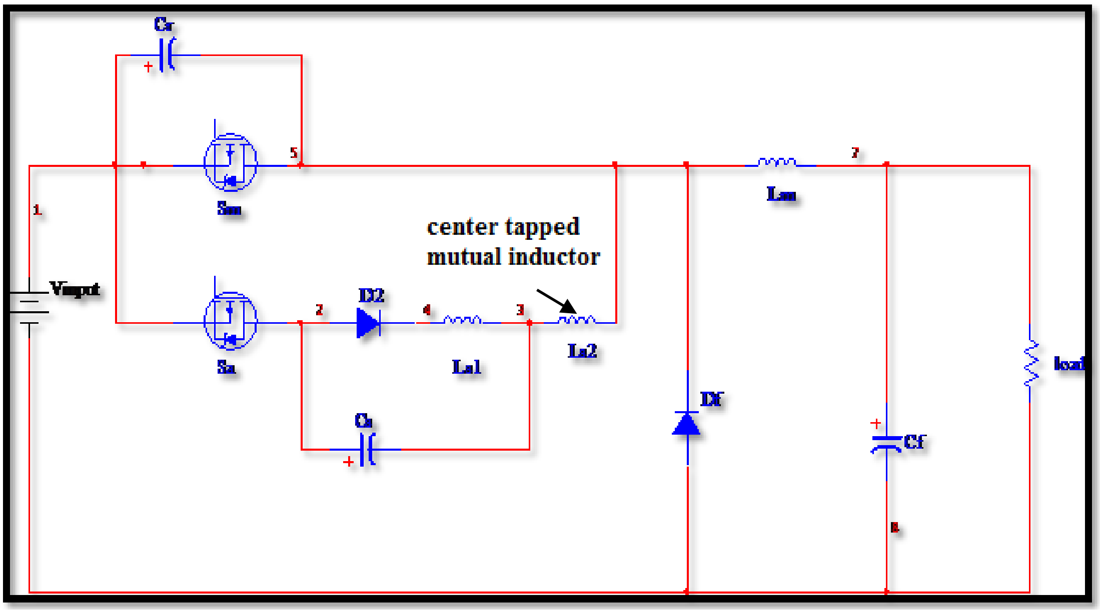


Fig 2.1 proposed soft switching buck converter with snubber cell.

Take all switching devices and passive elements are ideal.

In this circuit one voltage source, two MOSFET as switch (main switch and auxiliary switch), one step down (buck) inductor, resonant capacitors, parasitic capacitor, a centre tapped mutual inductor, two diodes and an output capacitor to make the output voltage constant are used.

2.3 Modes of operation for the proposed buck converter

In this part of thesis take some assumption to easily or simply understand the circuit steady state analysis during one switching cycle.

1). All switching device and passive element are taken ideal.

2). Input or source (V_{in}) voltage is taking constant.

3). The output or load voltage (V_{out}) also taking constant.

4). All diode reverse recovery time are ignored.

Here For simple calculation take ten (1 to 10) Operation Modes in a single switching cycle.

The equivalent circuit schemes of the proposed converter operation modes are shown in the Figures. 2.3.1 to 2.3.10 respectively and key waveforms concerning these stages are shown in figure 2.4.

The detailed analysis of this proposed converter is presented as follows.

2.3.1 Mode 1

From the beginning of this mode, the initial conditions are $I_{SM} = 0$, $I_{SA} = 0$, $I_{DF} = IL$, $iCs = I_{LS1} = I_{LS2} = 0$ and $V_{CS} = V_{CS}$ max 2. The main switch Sm and the auxiliary switch S_A both are in OFF state, and the main diode D_F is in the ON state and conducts the load current I_L.

This mode starts at that moment where we apply the turn-on signal to the gate of auxiliary switch (Sa). The current of Sa start rises and the current of D_F limber down simultaneously during this mode. The voltage of VCs decreases to VCs (t2).

Vcs(t) = (Vin + Vcsmax2) Cos(wo(t-to)) - Vin

This stage ends at t=t1, Isa reaches to IL and I_{DF} decreases to 0. Later I_{DF} reaches to –Irr at t2, thus DF is turned OFF .

Therefore Sa is turned on with ZCS because of the LS2, and DF is turned off with nearly ZCS and ZVS. In this state, the followings are the equations for Wo and Zo.[2]

$$Wo = \frac{1}{\sqrt{Ls2 \times Cs}}, \ Zo = \frac{Ls2}{Cs} \qquad (2)$$

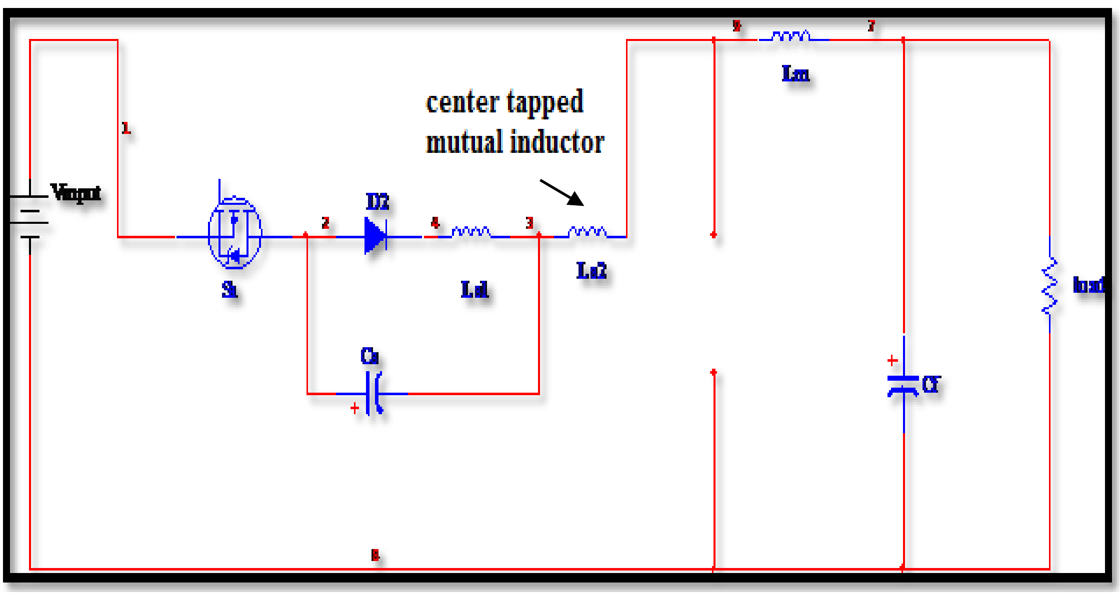


Fig 2.2 Mode 1 of the proposed soft switching buck converter

This figure shows the conduction path in mode1. Here we not show the initial conditions. From the figure the main switch is in OFF state and at the end of this mode the auxiliary switch is start conducting.

2.3.2 Mode 2

The initial conditions for this mode at t = t2 are main switch and free wheel diode are in OFF state and auxiliary switch is conducting. $I_{SA} = I_{Cs} = IL_{S2} = I_L + Irr$, $VCs = VCs(t2)$ and $V_{Cr} = Vin$.

Now the resonance start via the path S_A-C_{S2}- L_{S2}-Cr under the load current is I_L. For this resonance

$$I_{LS2} = I_{SA} = I_{CS} = (I_{LS} + Irr)\ \mathrm{Cos}\ (wo(t\text{-}t2)) + \frac{Vcs2(t2)}{Zo}\ \sin(wo(t-t2)) \qquad (3)$$

This mode is complete at that moment when VCr and VCs are zero at t = t3. So the energy transfer from resonant capacitor Cr to the inductor L_{S2} is ends. At the same point current and energy values of L_{S2} reach their maximum levels.[2]

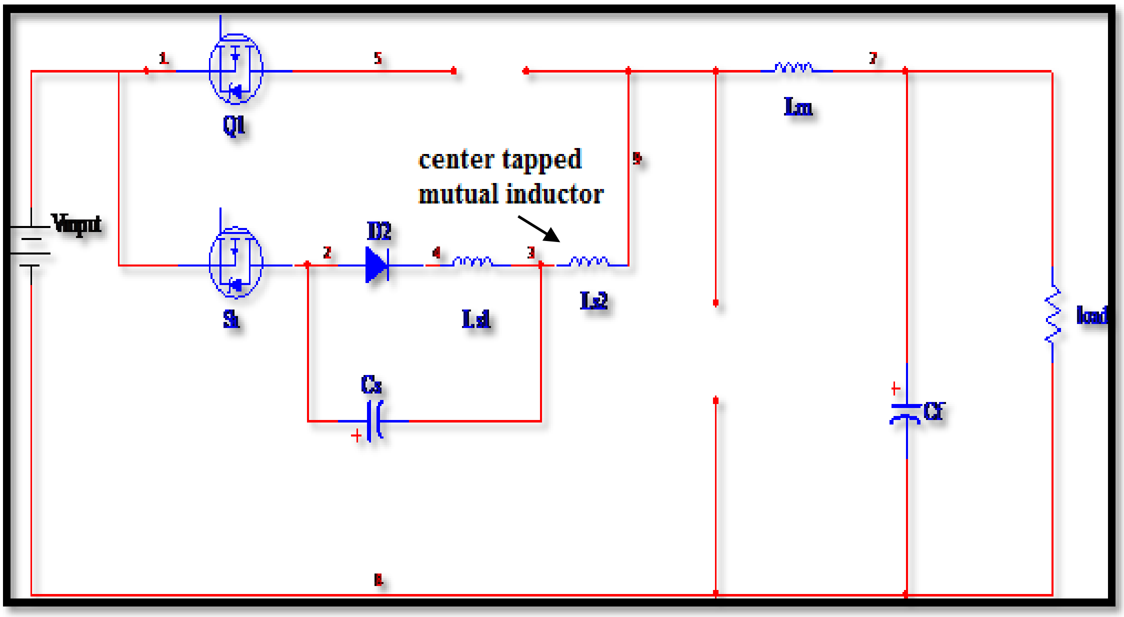


Fig 2.3 Mode 2 of the proposed soft switching buck converter

This figure helps us to getting the information about the operation of mode 2. Simply seen from the figure the auxiliary switch is conduct and main switch is off. And snubber circuit is in working state. Free wheel diode is also in OFF state.

2.3.3 Mode 3

This modes initial conditions are I_{SM} = I_{DF} =0, I_{SA} = I_{D2} = I_{LS1} = I_{LS2} = $I_{LS\ max}$ 1 /2, VCs = VCr = 0. This mode start just after VCr becomes 0 at t3 and the body diode of main switch (D_1) is turned ON. During this mode, body diode of main switch conducts the excess of $I_{LSmax/2}$ from I_L. The period of this mode is the zero voltage transition time of the main switch. For this state, the following equations can be written

$$I_{LS1} = I_{LS2} = I_{SA} = I_{D2} = \frac{ILSmax1}{2} \tag{4}$$

$$I_{D1} = \frac{ILSmax1}{2} - I_L \tag{5}$$

This stage completes at that moment where the gate signal of auxiliary switch is discconect at t4 and turn ON signal is applied to the main switch gate during ZVT.[2]

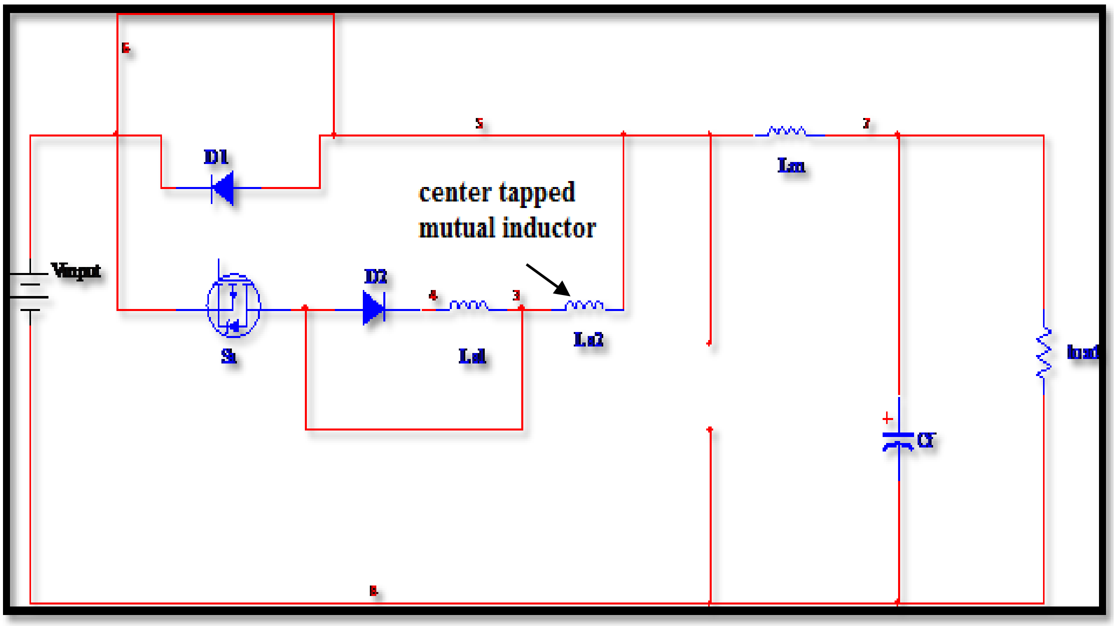


Fig 2.4 Mode 3 of the proposed soft switching buck converter

From the figure we easily seen the main switch is getting the condition of zero voltage switching due to the own body diode. And at the end of this mode the auxiliary switch is turned OFF.

2.3.4 Mode 4

This modes initial conditions are $I_{SM} = I_{DF} = 0$, $I_{SA} = I_{D2} = I_{LS1} = I_{LS2} = I_{LS\ max\ 1}/2$, $V_{Cr} = 0$ and $V_{Cs} = 0$. Where the gate signal of auxiliary switch is turned OFF at t4, switch becomes OFF, main switch becomes ON and start conducting I_L, and a resonance starts between the L_{S1} and C_S via the path D_2–L_{S1}–C_S. For this resonance, the following equations can be written.

$$I_{LS1} = I_{D2} = I_{CS} = I_{LSmax1} \cos(w_1(t-t4)) \qquad (6)$$

$$V_{CS} = Z_1 I_{LS\ max\ 1} \sin(V_1(t-t4)) \qquad (7)$$

This resonance, end at t5, where I_{LS1} becomes zero. So now the energy stored in the snubber inductor is completely transferred to the snubber capacitor. The voltage value of C_S reaches its maximum level at that moment. [2]

Here W_1 and Z_1 are defining as. $W1 = \sqrt{\frac{1}{LS1 \times CS}}$, $Z1 = \sqrt{\frac{LS1}{CS}}$ (8)

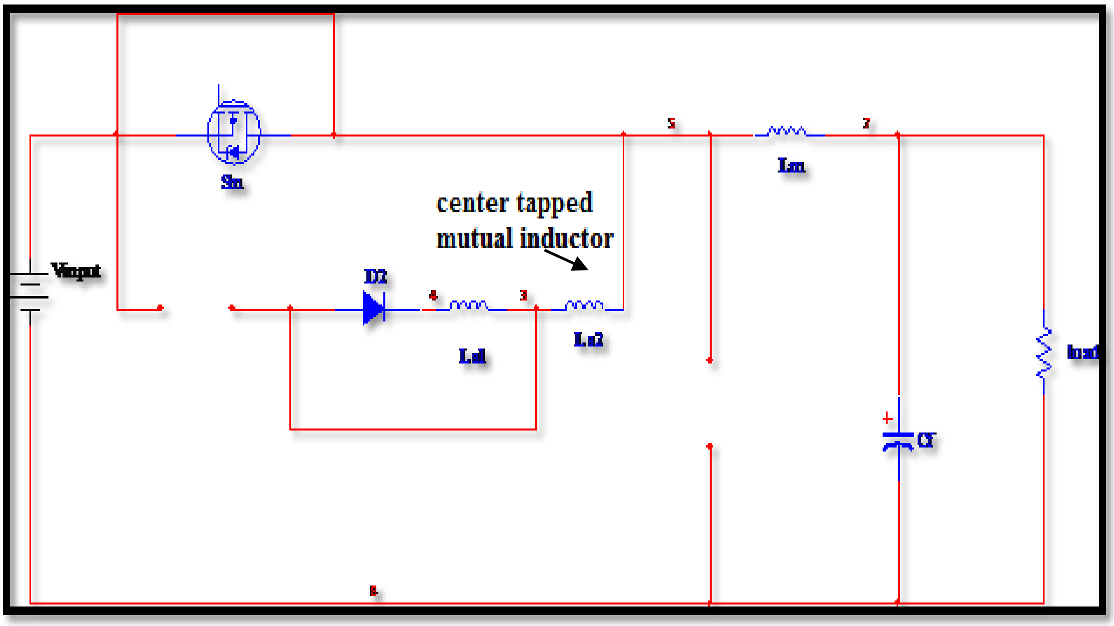


Fig 2.5 Mode 4 of the proposed soft switching buck converter

Therefore the main switch S_M is perfectly turned ON under ZVS provided by ZVT, and the auxiliary switch is turned OFF under ZVS through the snubber capacitor in this mode.

2.3.5 Mode 5

This mode of operation refer as ON state of the converter so the inductor is fed by the source I_L via the main switch S_M.

For this stage I_{SM} can be written as follows[2]

$$I_{SM} = I_L = I_{in} \tag{9}$$

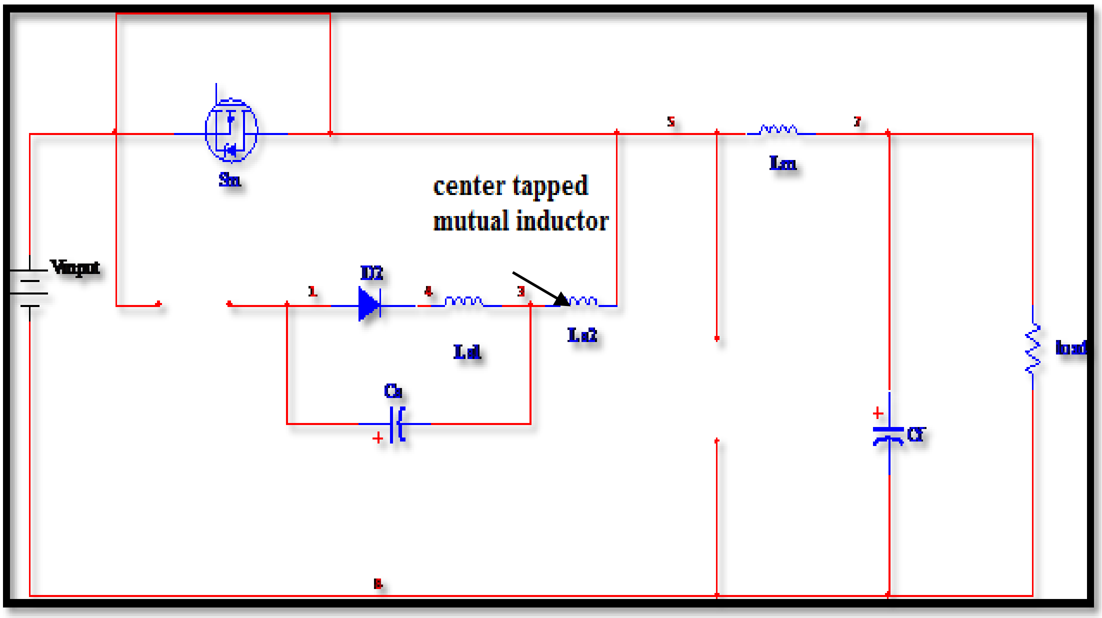


Fig 2.6 Mode 5 of the proposed soft switching buck converter

From the figure, easily seen the auxiliary switch is completely in OFF state and at the same time the main switch is completely enters in ON state. And in this mode the free wheel diode is also in OFF state. And energy is transferred from input to load via main switch.

2.3.6 Mode 6

At the starting of this mode, at $t = t_6$ current in the circuit are I_{SM} = Iin = I_L and I_{SA} = I_{LS2} = I_{LS1} = I_{DF} = 0 and V_{CS} = V_{Csmax1}.

Now at $t = t_6$ we apply the turn-ON signal to the gate of auxiliary switch, a resonance is starting between C_S and L_{S2} via the path S_A–C_S–L_{S2}–S_M. During this mode, auxiliary current (S_A) rises while main switch(S_M) current falls.

This mode end at that moment where the current of S_A reaches I_L and the current of S_M drops to zero. The voltage of V_{CS} decrease to V_{CS} (t7). For this mode the following equations are formed.[2]

$$I_{SM} = IL - I_{SA} \tag{10}$$

$$ILS2 = ISA = ICs = \frac{Vcsmax1}{Zo} \sin (wo\,(t-t6)) \tag{11}$$

$$V_{CS} = V_{CS}\max 1 \cos (wo\,(t - t6)) \tag{12}$$

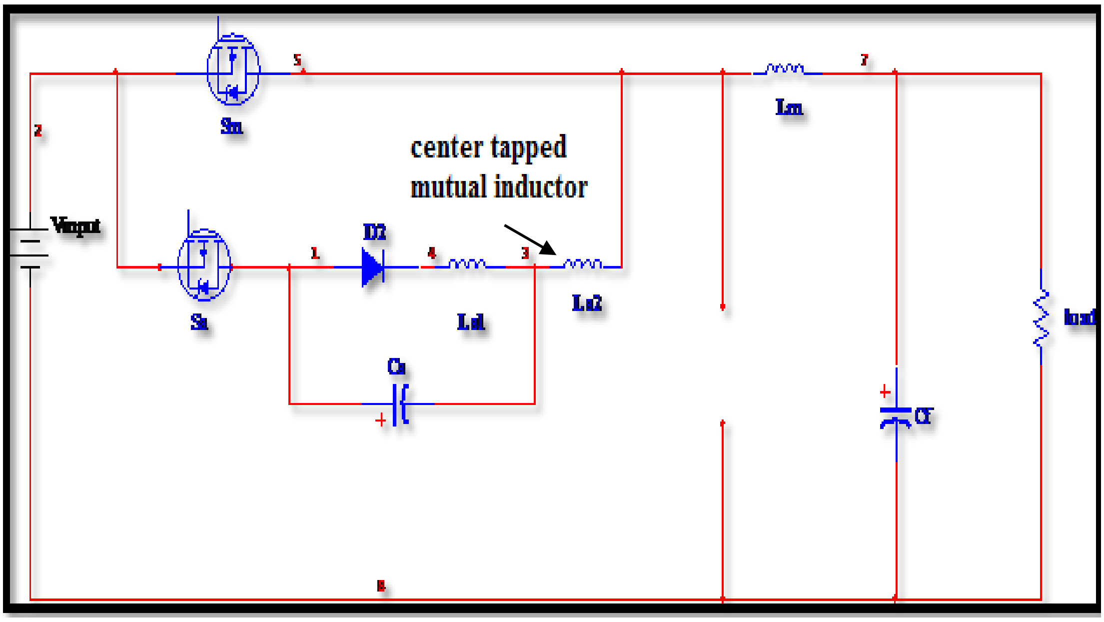


Fig 2.7 Mode 6 of the proposed soft switching buck converter

In this mode we turned ON the auxiliary switch under the zero current condition and main switch is turned OFF under the same condition, so with the help of this mode we easily says our proposed converter getting the condition of soft switching.

2.3.7 Mode 7

The initial conditions for this mode are $I_{SM} = 0$ and $I_{SA} = I_{LS2} = I_{CS} = I_L$ and $V_{CS} = V_{CS}$ (t7). At time $t = t_{7,}$ this mode start working when body diode of main switch (D_1) is ignite just after the main switch current drops to zero. During this mode, the resonance which is already started before continues via the path S_A–C_S–L_{S2}– D_1. This mode ends at t_8 as V_{CS} falls to zero, values of the current and energy of L_{S2} reaches their maximum level. For this mode the following equations can be obtained

$$I_{LS2} = I_{SA} = I_{CS} = \frac{VCSmax1}{Zo}\sin\,(wo\,(t_{67} + (t - t7)) \qquad (13)$$

$$V_{CS} = V_{CS}\max 1\,\mathrm{Cos}\,(wo\,(t_{67} + (t - t7)) \qquad (14)$$

During this mode, D1 conducts the excess of I_{LS2} from I_L.[2]

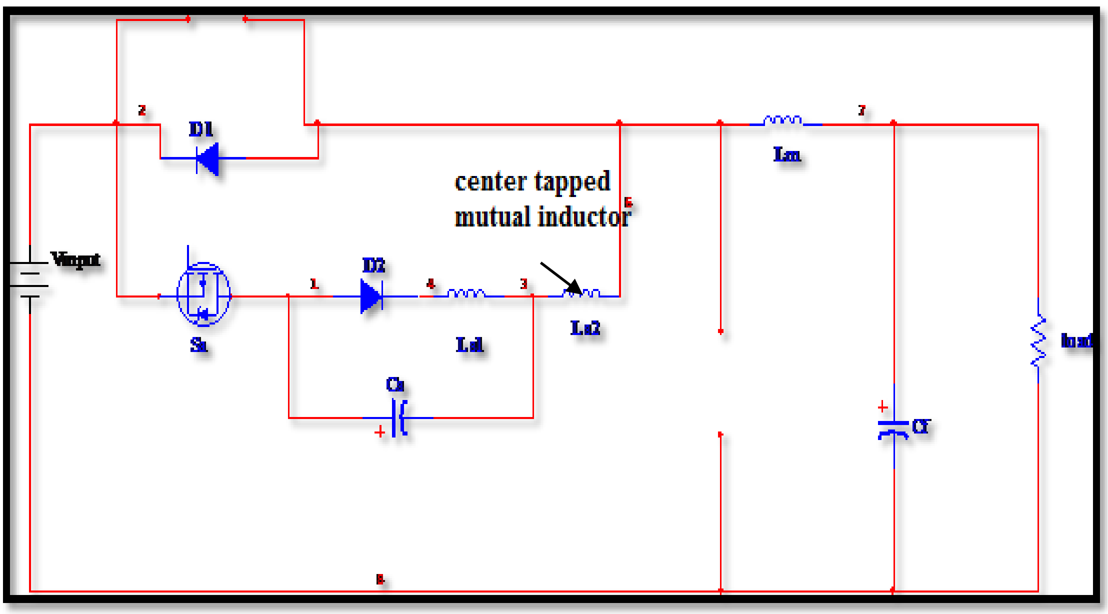


Fig 2.8 Mode 7 of the proposed soft switching buck converter

From the figure, the main switch is turned OFF completely but the body diode of this is in working state to provide the zero voltage switching. And the auxiliary switch is also working. This is a resonance mode in this mode resonance occur via auxiliary switch, snubber capacitor, snubber inductor L_{S2} and the body diode of the main switch D_1.

2.3.8 Mode 8

For this mode, initial conditions are as, at time t_8, $I_{SM} = 0$, $I_{SA} = I_{LS2} = I_{LS\ max\ 2}/2$, $V_{Cr} = V_{CS} = 0$. This mode starts at $t = t_8$ just after V_{CS} becomes zero and when the diode D2 is turned. During this mode, D1 conducts the excess of ILSmax 2 from IL. The sum of the time periods of mode 7 and mode 8, in which body diode of the main switch D1 is in the ON state, is the zero current transient time of the main switch. For this mode, equations are.[2]

$$I_{LS2} = I_{LS1} = I_{SA} = I_{D2} = \frac{\text{ILS max 2}}{2} \tag{15}$$

$$I_{D1} = \frac{\text{ILS max 2}}{2} - I_L \tag{16}$$

This mode ends at that moment where the gate signal of auxiliary switch is turned OFF at time t_9. The signal of main switch is also turned OFF during zero current transient (ZCT).

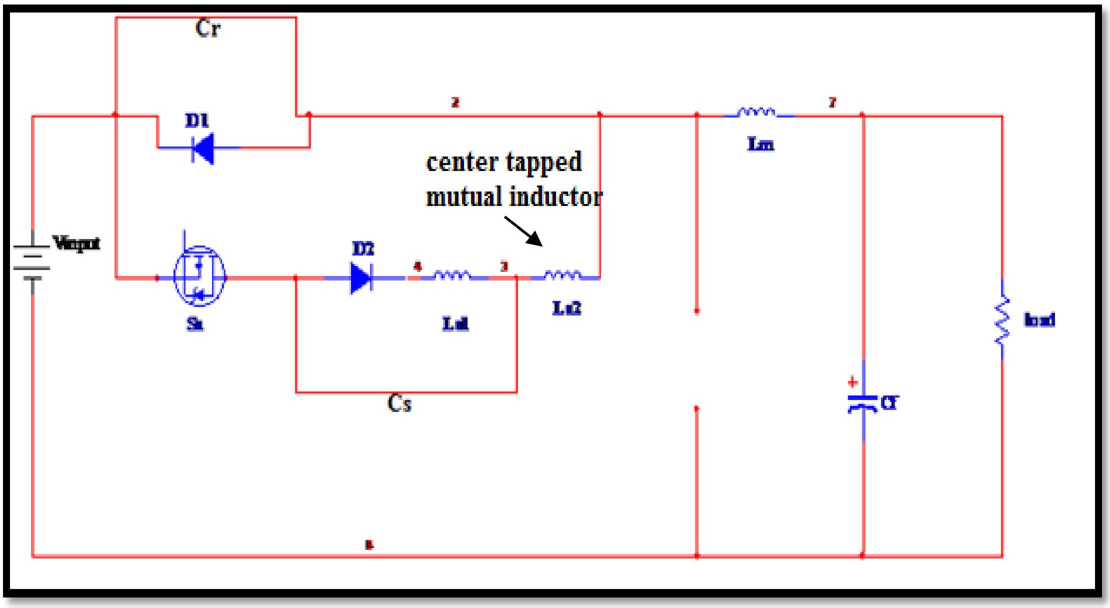


Fig 2.9 Mode 8 of the proposed soft switching buck converter

From the figure, the main switch is turned OFF completely but the body diode of this is in working state. And the auxiliary switch is also working at the starting of this mode but at the end of the mode the auxiliary switch and main switch turned OFF with the zero current switching condition

2.3.9 Mode 9

The initial conditions for this mode, at t = t_9 are $I_{SM} = I_{SA} = I_{LS2} = I_{LS\ max} = I_{DF} = V_{Cr} = 0$ and $V_{CS} = 0$. This mode begins when the gate signal of auxiliary switch is turned off. Two different-different closed circuits take place during this mode. Cr is charged by I_L linearly in the first circuit. A resonance starts between the L_{S1} and C_S via the path D_2–L_{S1}–C_S with the initial current $I_{LS\ max1}$ of L_{S1} in the second circuit. The voltage value of C_S reaches its maximum level at that time. When I_{LS1} current drops to zero this mode ends. For this mode the following equations are[2]

$$I_{LS1} = I_{D2} = I_{LS\ max\ 2}\ \mathrm{Cos}\ (w_1\ (t - t_9)) \tag{17}$$

$$V_{CS} = Z_1 I_{LS\ max\ 2}\ \mathrm{Sin}(w_1(t - t9)) \tag{18}$$

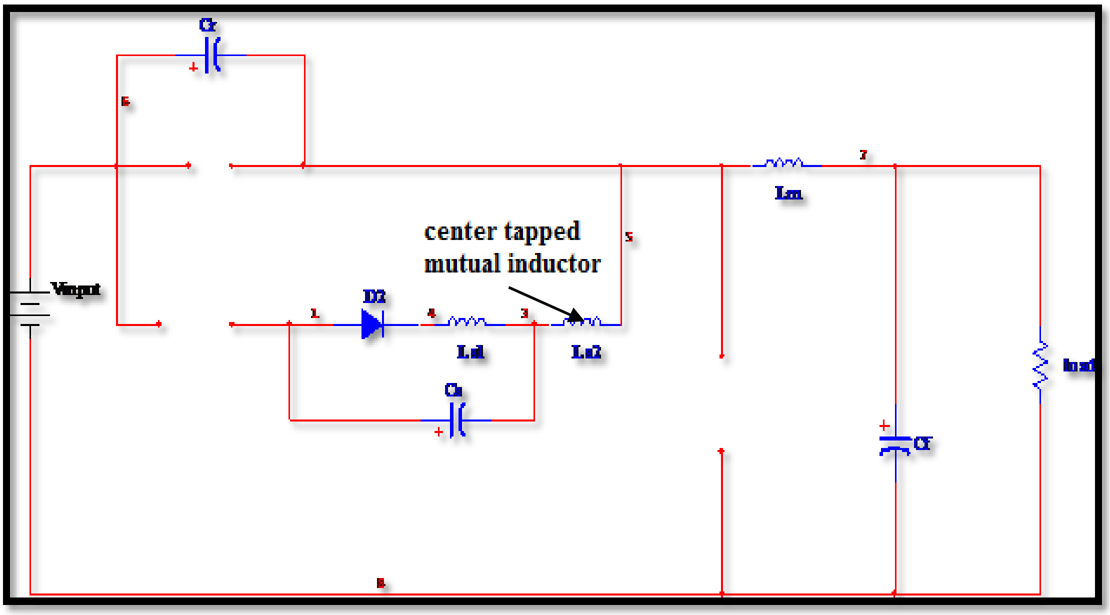


Fig 2.10 Mode 9 of the proposed soft switching buck converter

From the figure, the main switch S_M is perfectly turned OFF under zero current switching (ZCS) provided by zero current transient (ZCT), and the auxiliary switch S_A is also turned OFF under zero voltage switching (ZVS) through the capacitors C_S and C_r. and free wheel diode also in OFF state. At the end of this mode all switching device are going in OFF state.

2.3.10 Mode 10

This mode is the OFF-state period of the proposed converter circuit. For this mode the current values are as follows.

$$I_{SM} = 0 \tag{19}$$

$$I_{SA} = 0 \tag{20}$$

$$I_{LS2} = 0 \tag{21}$$

$$I_{DF} = I_L \tag{22}$$

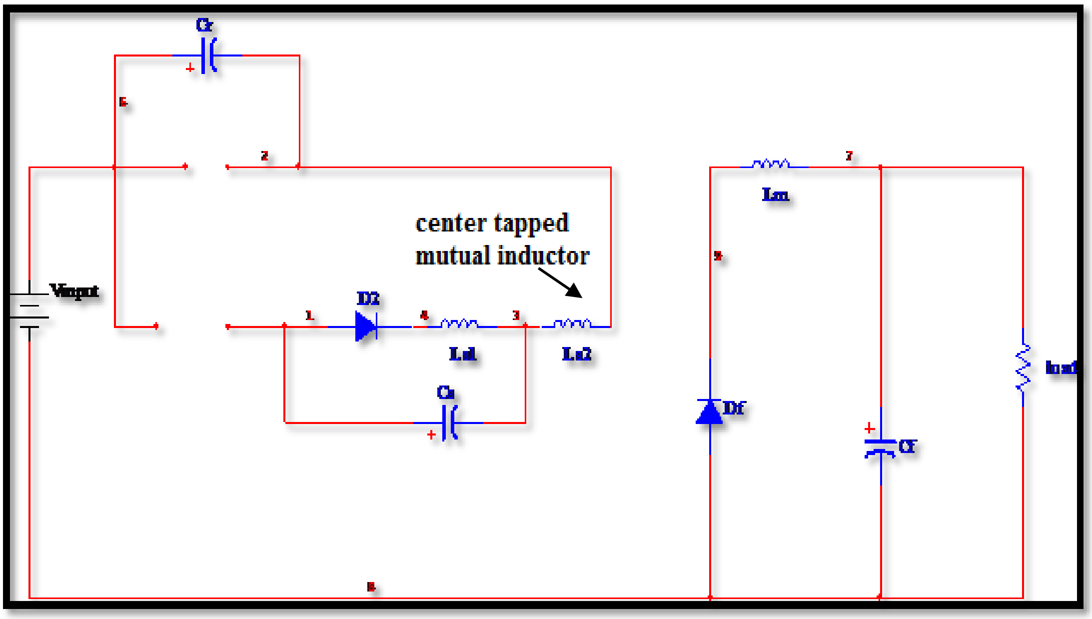


Fig 2.11 Mode 10 of the proposed soft switching buck converter

From the figure we easily seen both the mosfet switch are turned OFF and the free wheel diode are turned ON. In this mode load current is draw by the diode D_F. And this mode is the last mode of the one switching cycle after that mode the another switching cycle is start.

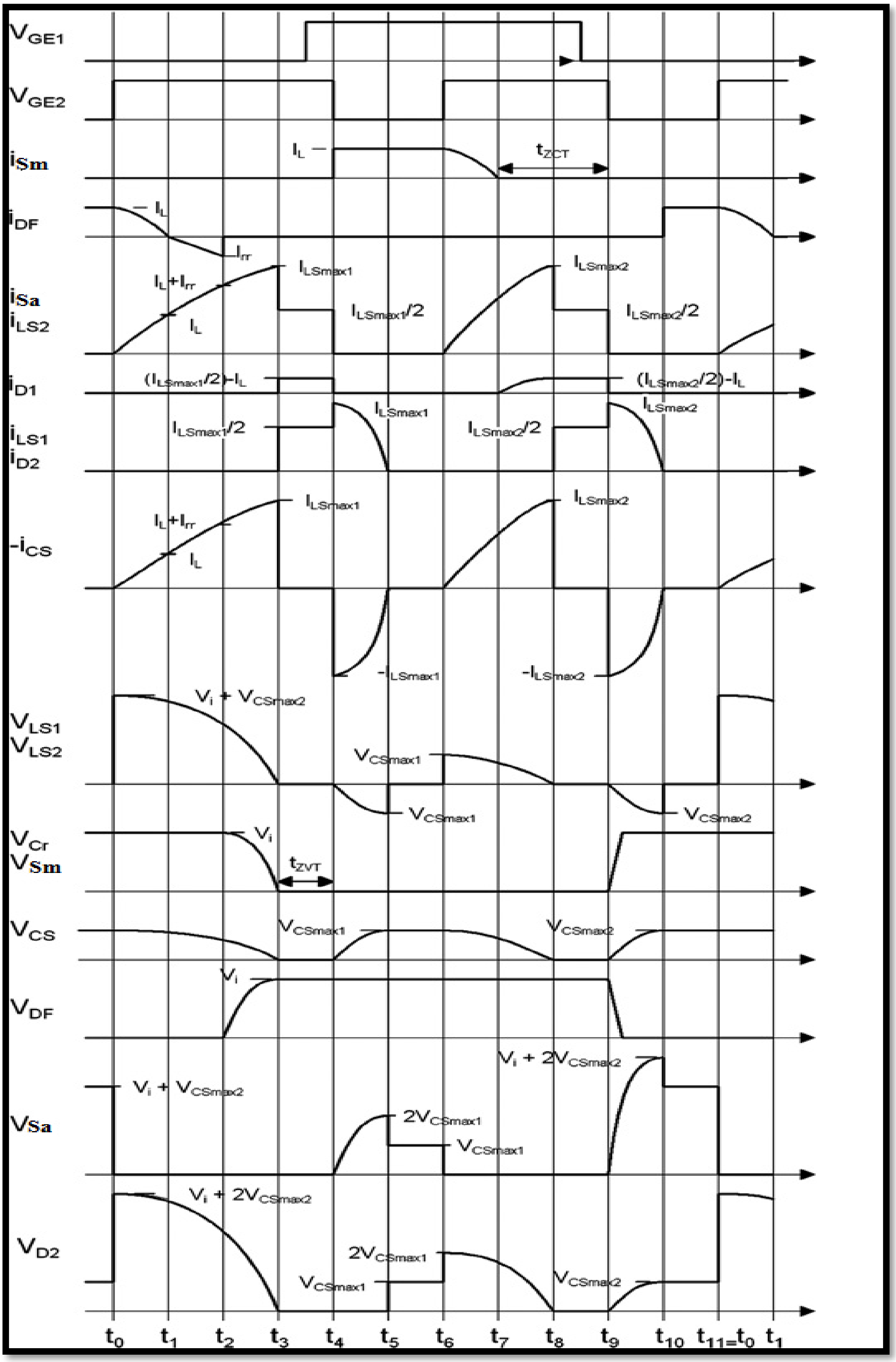


Fig 2.12 Key waveforms of the operation modes in the proposed converter [2]

Chapter 3

Design and consideration

3.1 Introduction

In this section we focus on design the parameters of the purposed soft switching buck converter for better, result and efficiency. The detailed design procedure of the proposed new active snubber cell is mainly based on the ZVT turn-on and ZCT turn-off processes of the main switch and the proposed cell also provides soft switching for the other semiconductor devices in the converter circuit.

Also In this section the function of the main components of the power stage buck converter are discussed and the values of the individual components are determined to meet the project specifications. The analysis for the buck converter in previous section shows that the conduction mode of the power stage.

3.2 Design Procedure

Detailed design procedure of the buck converter is simple as a step down converter but here we discuss the design procedure of snubber circuit that provide the soft switching to our proposed converter and make different or more efficient from another conventional converter. Snubber cell is based on the ZVT turn-on and ZCT turn-off phenomena of the main switch S_m. The proposed cell also provides soft switching to other semiconductor devices which are exist in proposed converter. About the operation of the new proposed converter the following general comments are must to understand the design procedure.

1.) Intervals of the operation modes must be in limit to minimum as much as possible at the time of selection of component. The period's t_3 to t_4 and t_8 to t_9 are zero voltage transient (ZVT) and zero current transient (ZCT) time of the main switch S_M, respectively.

Here capacitor Cr is taking as a sum of parasitic capacitors of the main switch S_M, auxiliary switch and the diode D_2.

2.) Center tapped mutually coupled snubber inductor selected as to provide the following conditions. [3][2]

$$\frac{Vin}{Ls1} trSa \leq Iin \text{ And } \frac{Vin}{Ls1} 3trr \leq Iin \tag{23}$$

We must select the Ls as large as possible to decrease the turn-ON losses of the auxiliary switch and the reverse recovery losses of the free wheel diode D_f. also larger Ls selection having longer transient intervals and thus more limitations in duty cycle of the switches. Here t_{rSa} is the rise time of the auxiliary switch and trr is the reverse recovery time of the free wheel diode.

3. At steady state operation, $V_{CS\ max1} = V_{CSmax2}$.

4. This equation (24) must be achieved to turn ON the auxiliary switch S_A under the condition of soft switching.

$$\frac{\text{Vin+Vcs max}}{\text{Ls2}} \text{trSa} \leq \text{Ilsmax} \tag{24}$$

5. To turn-OFF D_F diode under the condition of soft switching, this equation (25) must be achieved.[2]

$$\frac{\text{Vin+Vcs max}}{\text{Ls2}} \text{trr} \leq \text{Ilsmax} \tag{25}$$

6. To be limit the voltage stress on the auxiliary switch (S_A) and diode (D_2) with 2Vin.[2]

$$V_{CSmax} \leq \frac{\text{Vin}}{2} \tag{26}$$

7. When we decrease the value of snubber capacitor C_S results in transient intervals are shorter, but at the same instant voltage which the auxiliary switch S_A is subjected are higher. S_A is subjected to a voltage by $2V_{CS}$ at time $t = t_5$. If C_S is selected as to charged up to the half of input voltage (Vin).

3.3 Power switches

The power switch is used to control the flow of energy from the entrance to the output source. When the switch is ON it must provide the path to conduct current. And when it is OFF, it must stop or cut the path of output voltage to flow. Additionally, the switch must change from the ON and OFF states as quick as possible in order to save a large amount of power dissipation.

The most common switch used is a metal oxide semiconductor field effect transmitter that's why we use this in our thesis, MOSFET. There are two types p-channel and n-channel MOSFET but N Channel MOSFETs are most commonly used for buck converters and we use N Channel MOSFETs in this thesis research.

Switch (MOSFET) parameter and range of the parameter are discussed in this table, [6].

3.3.1 Switch (MOSFET) parameter when the switch is in off state

Table no 3.1 Switch parameter when switch OFF

Symbol	Parameters	Testing Condition.	Minimum	Maximum	Unit
V(BR)DSS	Drain-source Breakdown Voltage	ID = 250 μA, VGS = 0	500		V
IDSS	Zero Gate Voltage Drain Current (VGS = 0)	VDS = Max Rating 1 μA VDS= Max Rating, TC = 125 °C		1 50	μA μA
IGSS	Gate-body Leakage Current (VDS = 0)	VGS = ±30V		±100	nA

In this table we try to specify the MOSFET parameter range minimum as well maximum value when the MOSFET is off state or in other word is in open circuit. In this table specify parameters are Drain-source Breakdown Voltage of the mosfet, Zero Gate Voltage (VGS = 0) Drain Current and Gate-body Leakage Current (VDS = 0).

3.3.2 Switch (MOSFET) parameter when the switch is in ON state

Table no 3.2 Switch parameter when switch ON

Symbol	Parameters	Testing Condition.	Minimum	Maximum	Unit
VGS(th)	Gate Threshold Voltage	VDS = VGS, ID = 250µA	2	4	V
RDS(on)	Static Drain-source On Resistance	VGS = 10V, ID = 9 A		0.27	Ω
ID(on)	On State Drain Current	VDS > ID(on) * RDS(on)max, VGS = 10V	18.4		A

In this table we specify the MOSFET parameter range minimum as well maximum value when the MOSFET is in ON state or in other word is short circuited. In this table specify parameters are Gate Threshold Voltage of the mosfet, Static Drain-source On Resistance and On State Drain Current. These parameters help us for getting the information about the type of the MOSFET we used in our converter.

3.4 Buck converter diode selections

Estimate Diode Current. [2]

$$I_D = (1\text{-}D) * I_{LOAD} \tag{27}$$

Where D = Duty cycle

The diode's average current is equal to the load current times the portion of time the diode is conducting.

The time in which diode is ON is: (1 – duty cycle)

The maximum reverse voltage on the diode is Vin. The current and voltage ratings are low enough that a small schottky diode can be used for this application.

By using a schottky diode, switching losses are negligible.

We used diode in proposed converter for taking best performance from the converter circuit which we introduced.

Table no 3.3 Diode Parameters

Symbol	Parameters	Testing Condition.	Minimum	Maximum	Unit
VGS(th)	Gate Threshold Voltage	VDS = VGS, ID = 250μA	2	4	V
RDS(on)	Static Drain-source On Resistance	VGS = 10V, ID = 9 A		0.27	Ω
ID(on)	On State Drain Current	VDS > ID(on) * RDS(on)max, VGS = 10V	18.4		A

In this table we try to specify the diode parameter range minimum as well maximum value. In this table specify parameters are gate threshold voltage or cut-in voltage of the diode, drain source on resistance and on state drain current. These parameters help us for getting the information about the type of the diode we used in our converter.

3.5 Calculate inductance of the buck converter

For an Inductor $V = L*\Delta I / \Delta T$ (28)

Rearrange and substitute: $L = (Vin – Vout) *(D / F_{sw}) / I_{ripple}$

Starting with the basic equation for current flow through an inductor:

$$V = L\ di/dt$$

We rearrange the terms to calculate "L" so.

$$L = V\ dt/di \quad (29)$$

3.6 Inductor ripple current estimation [6]

$$\Delta I_l = (0.2 \text{ to } 0.4) \times Iout(max) \times \frac{Vout}{Vin} \quad (30)$$

Inductor ripple current means difference between the maximum and minimum value of the main inductor current.

3.7 Select output capacitor of the buck converter

The functionality of output capacitor is to store the energy and maintain a constant voltage at the output terminal. In a buck converter the output capacitance is selected to limit the ripple of the output voltage to meet the design specifications. The ripple of the output voltage is determined by the series impedance of the capacitor and the output current.[1],[6].

Simplify

$\Delta V = \Delta I * (ESR + \Delta T / C)$

Rearrange:

$$C = (\Delta I * \Delta T) / (\Delta V - (\Delta I * ESR)) \quad (31)$$

The term in the denominator of the equation (ΔV - (ΔI ESR)) shows that the capacitor’s ESR rating is more important than the value of the capacitance. If the selected ESR is big large, the voltage due to the ripple current will be equal or exceed the target output voltage ripple. We will have a divide by zero issue, indicating that an infinite output capacitance is required. If a normal ESR is select, then the actual value of capacitance is reasonable.

3.8 Output voltage

Output voltage ratio is depending on the duty cycle of the switch shown in the equation.

Equation (32), ratio shows the input-output ratio in the hard switching or conventional converter.

$$Vout = D * V_{input} \quad (32)$$

D = duty cycle of the switch.

3.9 Converter features

In this thesis proposed a new zero voltage transition (ZVT) and zero current transition (ZCT) quasi-resonant DC–DC buck converter with the proposed active snubber cell combines most of the very effective features of both the ZVT and ZCT techniques (advance soft switching technique) here the features of this new converter are briefly summarized.

1. All the semiconductor device which is use in this converter circuit is operate under the condition of soft switching. The main switch of this converter is perfectly turned ON with ZVT and turned OFF with ZCT. Also the auxiliary switch is turned ON and turn-OFF with ZCS and ZVS respectively. In addition, the other devices like diode operate under soft switching

2. In this proposed converter the main switch S_M and the main diode (free wheel) D_F are free to any additional voltage and current stresses. The stress on the auxiliary devices is occurring but they are very low.

3. The new proposed converter operation under soft switching is maintained for the whole line and ranges of load.

4. The proposed converter can operate at high frequencies (100 kilo or more) because during most of the intervals load is supplied the resonant modes.

5. The control or gate signals of both the switches main and auxiliary of the proposed new active snubber cell can be easily achieved by PWM signals.

6. This new converter simpler and cheaper also other than the most of the ZVT and ZCT converters which are presented previously. This proposed new active snubber cell can be applied to the other basic converter topologies.

Chapter 4

Simulation Analysis Of The Proposed Buck Converter

4.1 Simulation Studies

Simulation studies of the proposed DC-DC buck converter are under taken.
The proposed buck converter with additional snubber cell circuit (shown in figure no 2) is simulated in MATLAB-Simulink. The values of the parameters for the circuit are given below.

Input voltage (Vinput) = 60V

Switching Frequency (fs) = 100 KHz

Main Inductor (Lmain) = 300 μH

Snubber inductor (L_{S1}) = 4 μH

Snubber inductor (L_{S2}) = 12 μH

Snubber Capacitor (Cs) = 44 nF

Parasitic Capacitor (Cr) = 12 nF

Output capacitor (Cout) = 1000 μF

Output voltage (Vout) = 18 V

Switching frequency **(Fs) = 100 kHz**, than total time period for the single cycle is **T = 1/100000** sec and this is **10** micro second.
The proposed buck converter has two switches i.e. main switch and auxiliary switch. The main switch has the duty ratio of **0.54**(or on period is **5.4** micro sec), while that the auxiliary switch has the duty ratio **.30** (or on period is **1.3** micro sec).

The delay time for the auxiliary switch is **0** second and the delay time for the main switch is **3.8 micro second** this will be seen from the figure.

The main switch duty ratio is help to determine the average output voltage. Function of auxiliary switch is to provide soft switching for main switch.

The PWM signal of the main switch is given after some delay compared with auxiliary contact. The phase difference is obtained by delaying the waveform carrier. The main switch is turned on while the auxiliary switch is turned OFF state.

We use or designed resonance auxiliary switch for main switch to make able to operate at zero voltage switching (ZVS). By switching on the main switch the ZVS is ensured with ZVT. If the snubber capacitor voltage is completely discharged and the body diode of the main switch is turn ON while the auxiliary contact is turned off.

so we conclude from that point our proposed buck converter's, main switch and auxiliary switch and also main diode is enables zero voltage transition and zero current transition with zero voltage and zero current switching and this soft switching perform with the help of snubber circuit.

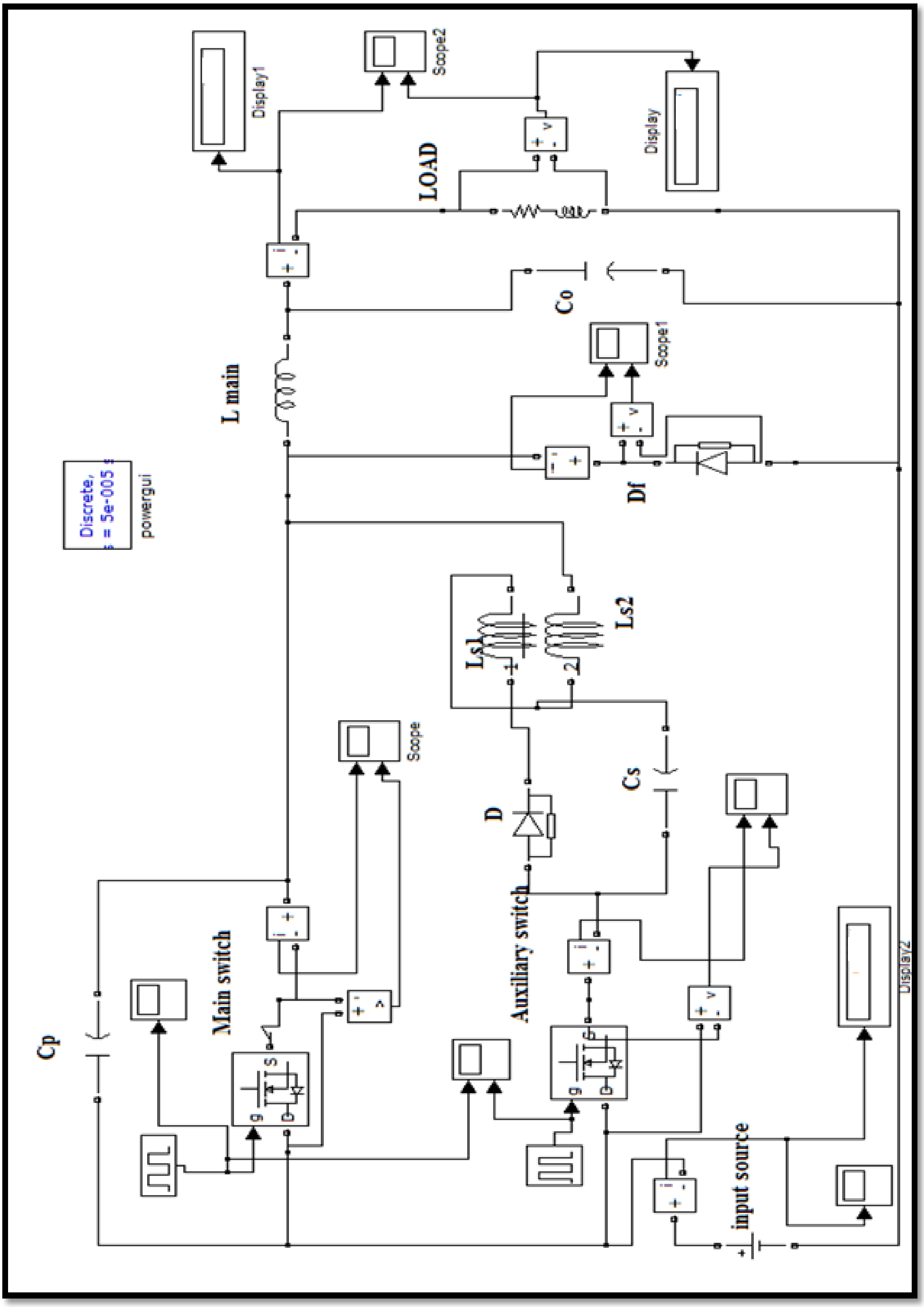


Fig 4.1 Simulated scheme of the soft switching converter.

4.2 Waveform of voltage and current of the main switch

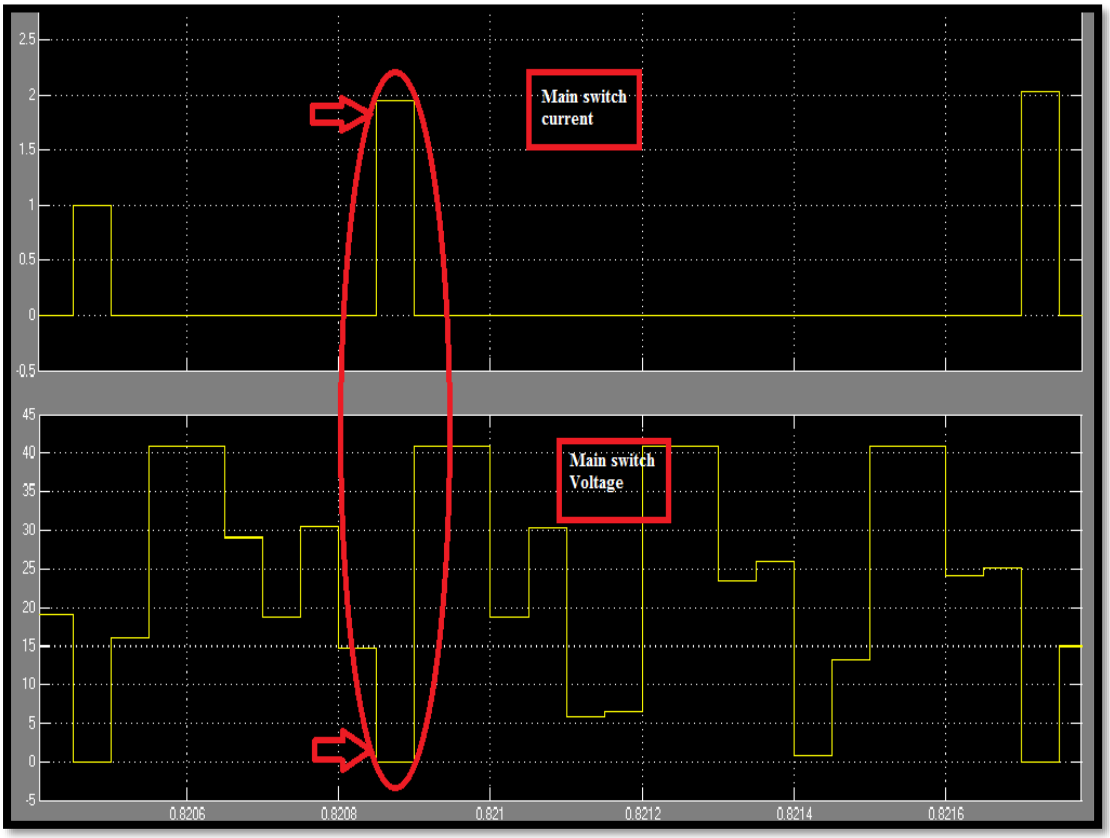


Fig 4.2 Switching voltage and current waveform of the main switch.

From this wave form, we try to shows the characteristics of main switch voltage and current, the current wave form is upper one and the voltage waveform is in bottom. From the waveform we easily conclude that our proposed converter is achieved soft switching across the main switch.

Seen from the figure 4.2, during switching time, when the current is higher than zero the voltage is zero and when the voltage is higher than zero the current through main switch is zero so energy loss across the main switch is null because power loss across the any switch is the product of voltage and current, so now here, voltage is not equals to zero the current is zero and when the current is not equals to zero the voltage is zero so power loss is negligible or null and here we can say this is the condition of soft switching. So in proposed buck converter the power loss across the main switch is reduced to zero and also stress on the switch is less with the ZVT and ZCT technique.

4.3 Waveform of voltage and current of the auxiliary switch

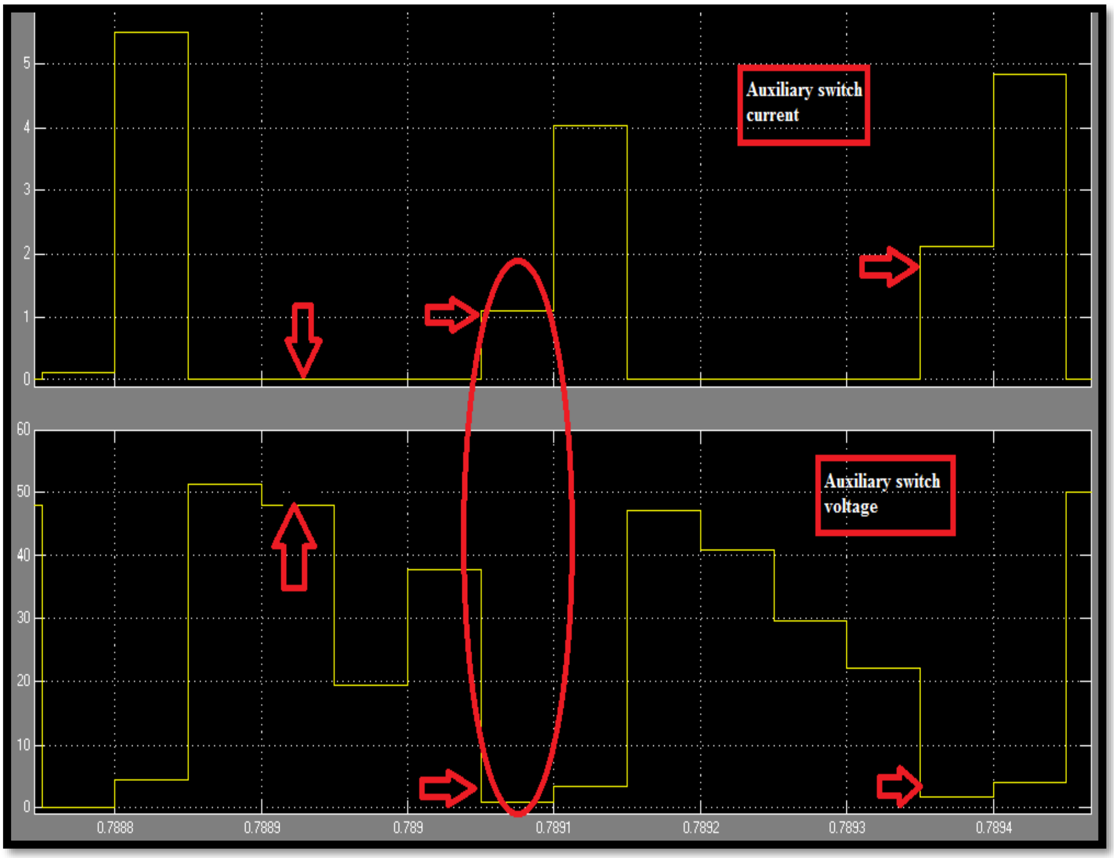


Fig 4.3 Switching, voltage and current waveform of the auxiliary switch.

From this wave form, we try to shows the characteristics of auxiliary switch voltage and current, the current wave form is upper one and the voltage waveform is in bottom. From the waveform we easily conclude that our proposed converter is achieved soft switching across the auxiliary switch. Arrow sign in the figure shows the maximum value of the one (current or voltage) and minimum value of another one at the same time.

Seen from the figure 4.3, At the switching time, when the voltage is higher than zero the current is zero and when the current is higher than zero the voltage across auxiliary switch, is zero so power loss across the auxiliary switch is zero or nil . Here we can say this is the condition of soft switching. So in proposed converter the power loss across the auxiliary switch is reduced to zero and the efficiency of the proposed converter is increase.

4.4 Waveform of main diode current and voltage

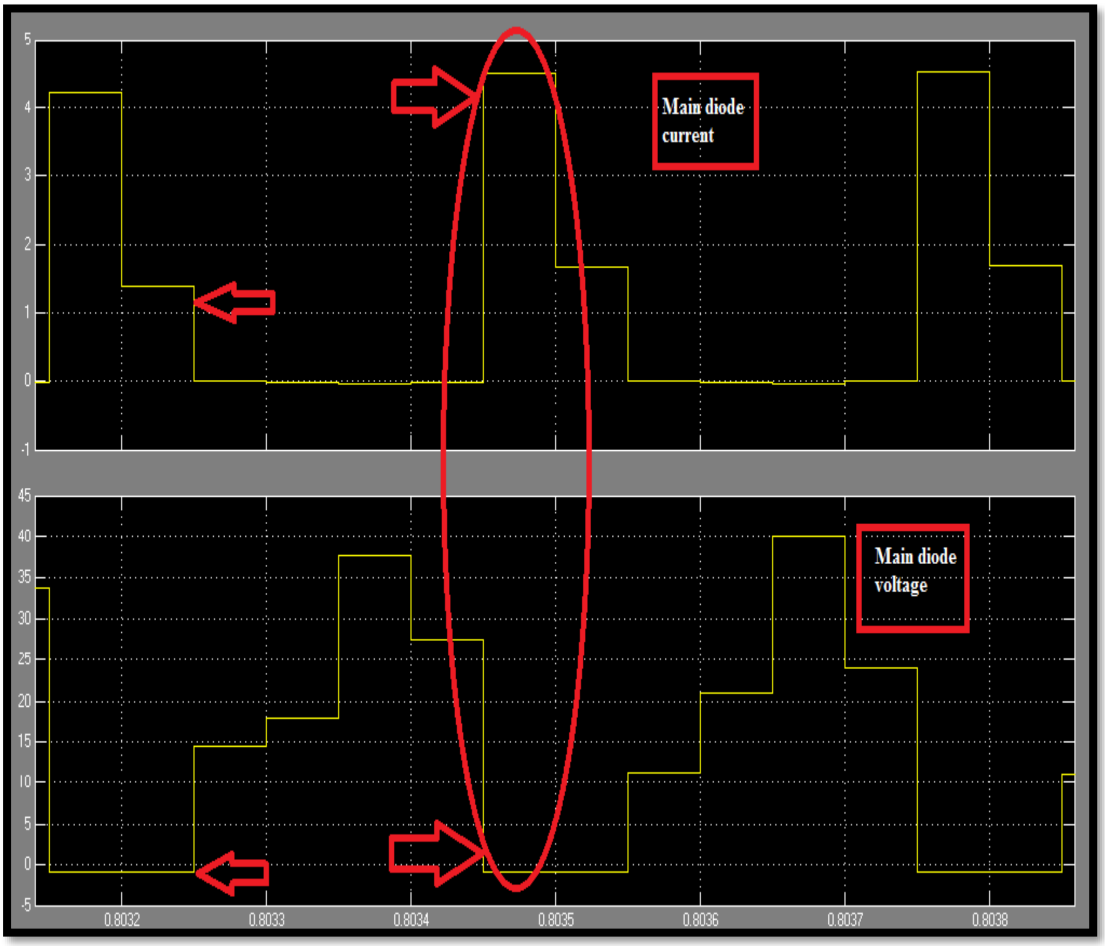


Fig 4.4 Voltage and current waveforms of the main diode.

From this wave form, we try to shows the characteristics of main diode (switch) voltage and current, the current wave form is upper one and the voltage waveform is in bottom across the diode. From the waveform we easily conclude that our proposed converter is achieved soft switching across the main diode. Arrow sign in the figure shows the maximum value of the one (current or voltage) and minimum value of another one at the same time.

So due to this effect power loss across the main diode is minimize and then efficiency of our proposed buck converter is improve.

4.5 Waveform of gate pulse of main and auxiliary switch

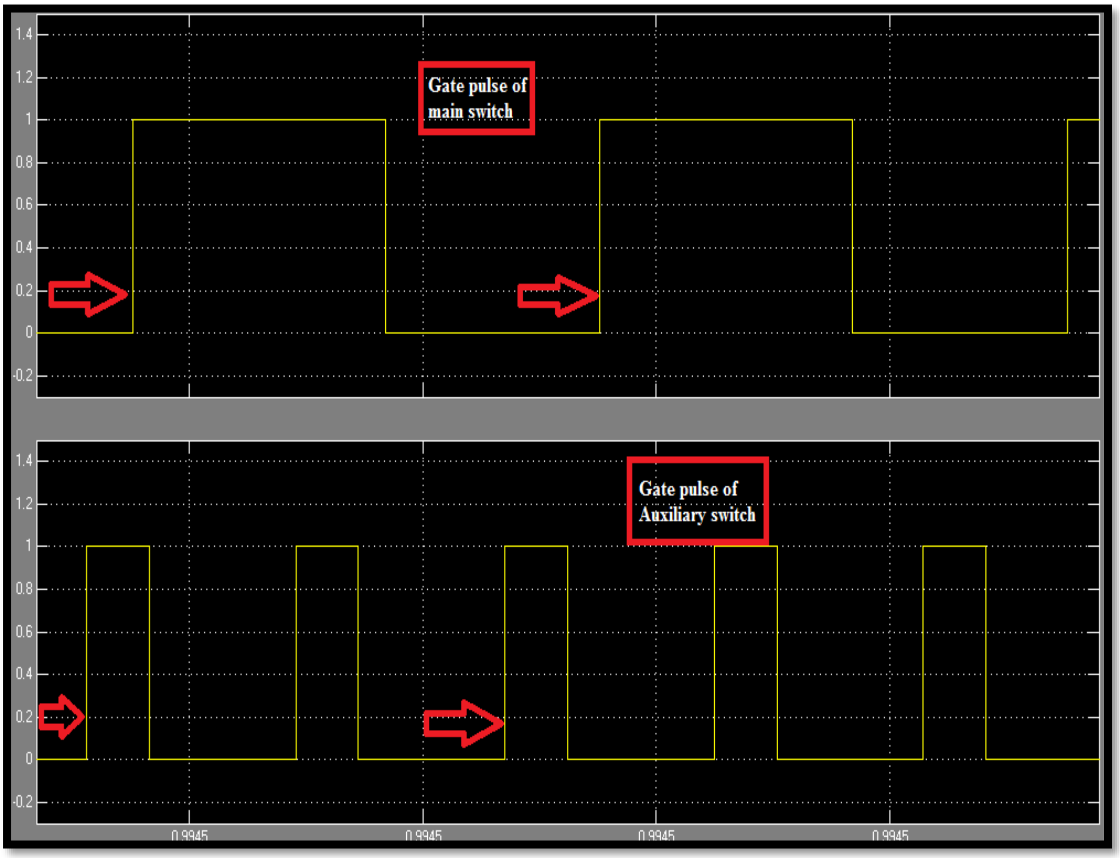


Fig 4.5 Gate Pulse for the main switch and for the auxiliary switch.

From the figure 4.5, triggering or gate pulses of the main and the auxiliary switch are shown, the upper one is the main switch gate pulse and the bottom is auxiliary switch gate pulse. With the help of this waveform, we easily understand the gate pulse sequence of both the switches, the width or ON time of the main and auxiliary switch, delay time of both the switches and also off time of both the switches so simply that graph shows the Duty cycle of both the switches.

4.6 Waveform of input, output voltage and output current

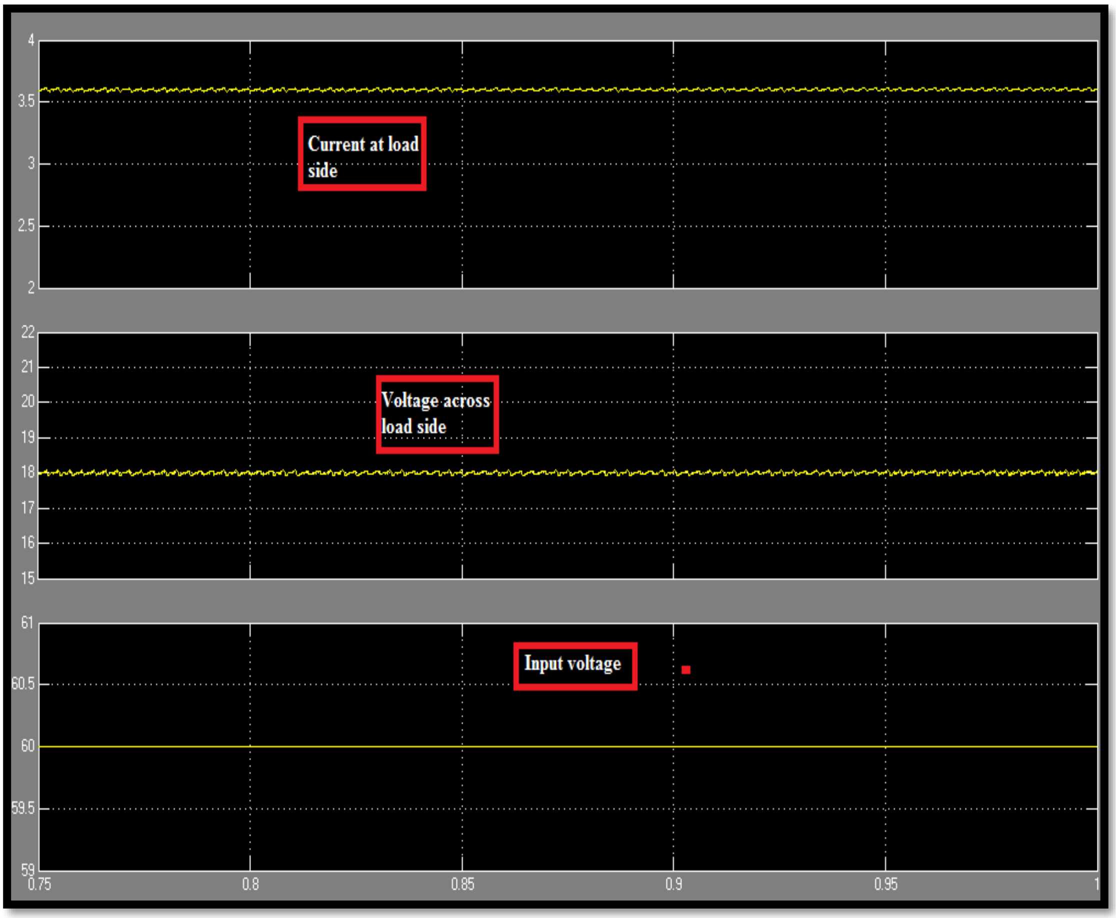


Fig 4.6 Output voltage and current waveform of the proposed buck converter.

This figure shows the output waveform of the voltage and current and also input voltage waveform of the converter. Top one is the output current and the Middle one is output voltage and lower one is input voltage of the buck converter.

From the figure 4.6, easily conclude that our proposed output voltage and current has very low ripple or is pulsesating DC, so we can say our output has very less disturbance, this will gain full for further use of this output voltage and current signals.

4.7 Output power of the simulated converter

The output power of the converter circuit for a particular load is given by:

$$P_{out} = V_{out} * I_{out} \tag{33}$$

Where,

V_{out} = Output Voltage.

I_{out} = Output Current.

The load connected across the output terminal of load is RL type having resistance of 5Ω and inductance of 50μH.

Then from equation no (31);

Vout = 18 Volt

Iout = 3.5 Amp

$$P_{out} = 18 * 3.5$$

$$= 63\text{Watt}$$

The power output is in expected range and hence satisfies the operation of converter circuit.

Chapter 5

Application of the proposed converter

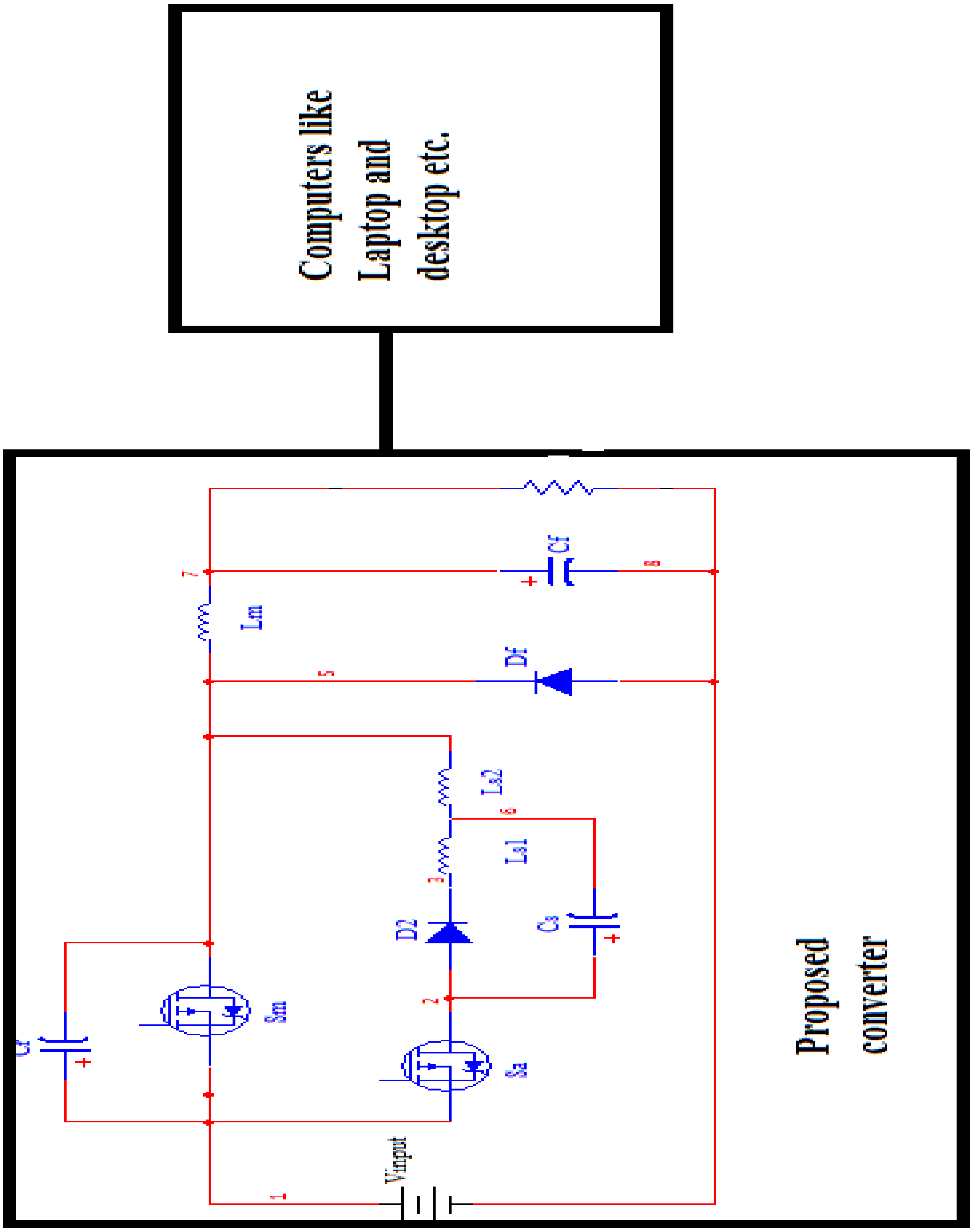


Fig 5.1 Block diagram

The above figure shows the application of the proposed converter circuit. In which computer device is fed from the soft switching buck converter with snubber cell.

By this when it takes input from that proposed converter circuit it takes smooth, harmonics distortion free power supply of 18Volt and 3.5Amp current and the losses and the stresses on the power electronics devices will also be least. Conduction loss reduces and the heating problem by electrical loss will also be checked by ZVS and ZCS because it reduces the conduction mode losses.

<u>Where It Can Be Used?</u>

It can be used anywhere because in every part of life we need computer added machine like in offices, labs, or in the hospitals. It can do several operations at a time. It can also be used in the railway reservation system, in banking system where we need sharp and fast calculation.

These are the practical daily life benefits from these proposed converter circuit.

Chapter 6

Conclusion and Future work

6.1 Future work

As we know "Need is the Mother of Invention". Whenever the new thing is introduced several need are located behind that invention. The aim of to propose this circuit was to introduce an open loop soft switching buck converter with snubber cell. In this work module there are some things that can be do in future and that are:

1. Hardware implementation

The proposed soft switching buck Converter would be fabricated physically and the simulation and experimental results would be matched. So that the net increased output can be achieved and utilized in feeding the machine. The hardware design can be further used in many projects for different machinery and problem of high supply voltage can be eliminated. The designed circuit is loss free hence the efficiency of hardware also increases and can be used where efficiency plays a wide role in operation.

The stability and efficiency can be further improved. The response of the buck converter can also be improved.

2. Design and implement of AC-DC rectifier with buck circuit

Next work that can be done in this work module is to design and implement a such circuit which converter Ac-power to DC power also with step down the input power using soft switching technique.

6.2 Conclusion

In this thesis, a new soft-switching open loop buck converter using a snubber cell circuit has been discussed which uses an auxiliary switch with resonant circuit. The soft switching under the zero-voltage and zero current condition is performed by main and auxiliary switch using a resonant capacitor and inductor, as does the auxiliary switch. This thesis has proposed a new ZVT–ZCT quasi-resonant buck converter circuit. A newly proposed active snubber cell provides ZVT turn-ON and ZCT turn-OFF together for the switches of the converter.

In this thesis the schematic diagram of the converter and every mode of operation are discussed. Every mode of operation is analyzed by using MULTISIM 8 software. This circuit combines the most desirable features of the circuits which are presented previously and also overcomes most drawbacks of these circuits by only using one auxiliary switch with some other components Practically it is clear that the main switch and both of the auxiliary switches operate for the soft switching. The switching losses are minimized by soft switching and efficiency of the buck converter is improved because the auxiliary and main switch is turned ON and OFF by the zero voltage (ZVS) and zero current (ZCS) switching.

The operation principles and theoretical analysis of the proposed buck converter have been confirmed by simulation. The results are found to agree with the theoretical analysis presented in this thesis.

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