DESIGN OF RESONANT CIRCUITS BASED EMBEDDED CONTROLLER FOR POWER SUPPLY OF LCD TV AND MONITOR

A thesis submitted in partial fulfillment of the requirements for the degree of

BACHELOR OF TECHNOLOGY

IN

ELECTRONICS AND INSTRUMENTATION ENGINEERING

By

PARUL PRADHAN

108EI002

Under the guidance of

Prof. K. K. Mahapatra

Department of Electronics and Communication Engineering

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CERTIFICATE

This is to certify that the thesis entitled "Design of resonant circuits based Embedded Controller for power supply of LCD TV and Monitor" submitted by Parul Pradhan (108EI002) in partial fulfilment of the requirements for the award of Bachelor of Technology in Electronics and Instrumentation Engineering at National Institute of Technology Rourkela is an authentic work under my supervision and guidance. To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other University/Institute for the award of any degree or diploma.

Date: 14.05.2012

Place: Rourkela

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I am indebted to all the people in the Embedded System lab. Their constant support and help during difficulties made my work easier.

I would also like to thank my friends who made this journey of completion of thesis a memorable one. Last but not the least; I would like to thank my parents for being there for me always, and my younger sister, whose fun-filled words were a constant source of motivation for moving ahead.

PARUL PRADHAN

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ABSTRACT

Miniaturization of electronic gadgets and rapid development of technology have placed novel challenges in front of power design engineers for an efficient delivery of power at high power density. Next generation microprocessors will require a reductionin power consumption which will result in lower supply voltages for these microprocessors. Thus, power conversion will be guided by objectives such as low voltage, high power density, and high current and high efficiency. To fulfil the requirement of smaller size units as a result of technology scaling, high operating frequencies is the need of the hour. But such high frequencies bring forth the problem of increased switching losses.In this work, a simple buck converter with soft switching ZCS topology in full wave mode which includes a resonance circuit of inductor and a capacitor is proposed to optimize efficiency and reduce switching loss at a very high operating frequency. As high frequency operation is commanded, the size and weight of the power supply unit practically gets reduced and thus it becomes a better candidate for portable electronics equipment and personal digital assistants (PDAs). Also extended battery life which is a must for such handheld gadgets is directly dependent on the efficiency of the power conversion. Hence, a high efficiency circuit is expected to meet the ends.The system analysis for ZCS full wave mode is presented. Its advantage over the traditional hard switched PWM converter is well shown. The mathematical modeling of the configuration along with its modes of operation is described extensively. The feasibility of this circuit is supported by simulation results.

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ABBREVIATIONS

VLSI	-Very Large Scale Integration
PWM	- Pulse Width Modulation
PDA	- Personal Digital Assistant
SMPS	- Switched Mode Power Supply
IC	- Integrated Circuit
NASA	- National Aeronautics and Space Administration
BJT	- Bipolar Junction Transistor
MOSFET	- Metal-Oxide-Semiconductor Field-Effect-Transistor
FET	- Field Effect Transistor
IGBT	-Insulated Gate Bipolar Transistor
ZVT	-Zero Voltage Transition
ZVS	-Zero Voltage Switching
ZCS	- Zero Current Switching

CHAPTER 1

INTRODUCTION

Literature Review

Motivation

Objective

CHAPTER 1INTRODUCTION

1.1 LITERATURE REVIEW

The concept of power supply comes under the discipline of 'Power Electronics' and it finds its applications in varied fields starting from space shuttle power supplies, arc and industrial furnaces to battery chargers and power supplies in consumer electronics. The coverage is gigantic. We are now going to look at various generations of power supplies module starting with the simple rectifier circuit to the revolutionary 'Resonant Mode Power Supply (RMPS)' and what was the reason behind its inception.

With the strict necessity for power supplies for handheld electronic equipment under various power ratings power management faces stiff challenges. The automation in every aspect of our livescompelsus to go for power conversion from ac to fixed dc and vice versa. Power conversion is nowadays guided by objectives such as high current, low voltage, high efficiency and high power density. These motives create new standards for management of power and distribution. Attaining these objectives becomes even more challenging when low operating voltages are to be achieved [2].

Achieving low power consumption and quality performance in digital cameras, palmtops, MP3 players, personal digital assistants (PDAs) and other portable consumer gadgets has long been a challenge for power supply developers. Consequently, battery life is of utmost priority in portable battery-powered products, making efficiency the prime aim in the design of thepower system. Also the necessity of small sized devices calls for increase in frequency of operation. Thus, we have to look for options which support such high frequencies with minimal losses. With the advent of technology scaling with each generation of microprocessors, the supply voltage has seen a decreasing trend. Microprocessors, with reduced power supply voltages and increased power consumption need greater amounts of current from external power supplies, thereby posing a dire challenge on power generation and distribution problem in today's generation (both on chip and off-chip) .

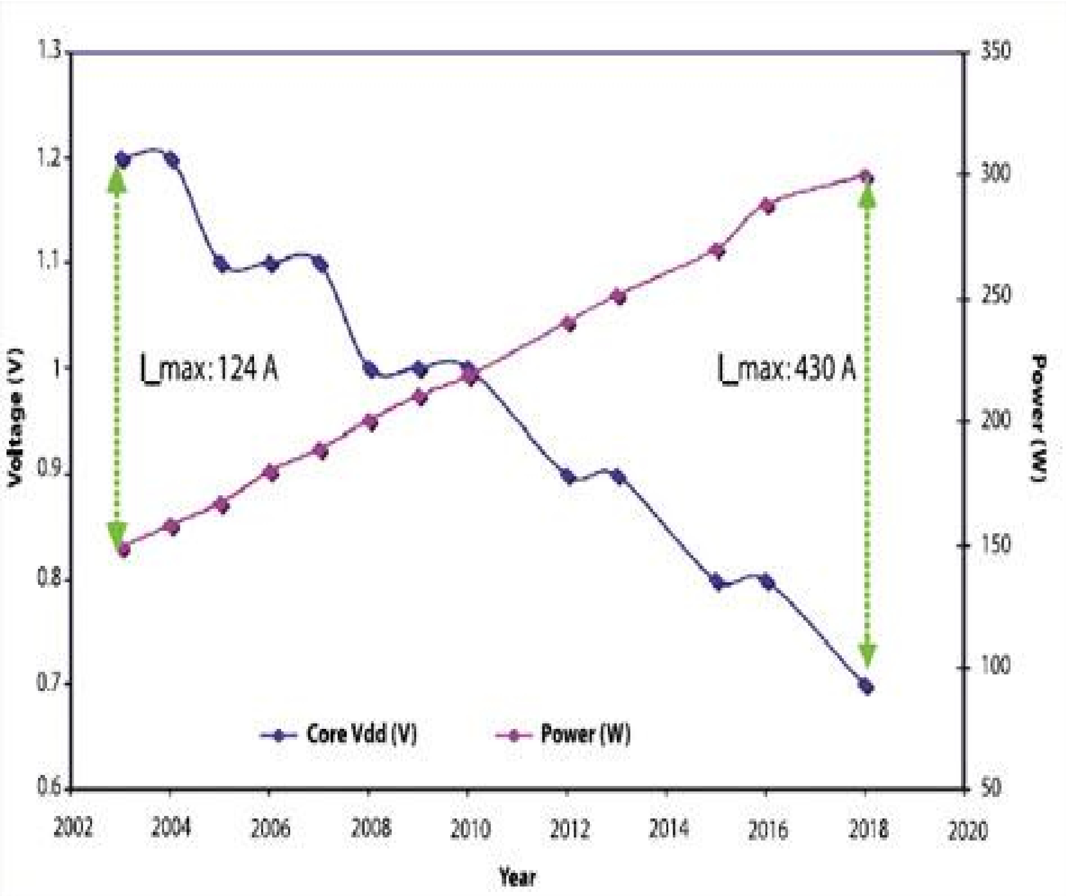
1.2 MOTIVATION

The need for fixed dc power supply has been there since ages and a controlled one of course. Previously, controlled dc supply could be obtained from phase controlled rectifiers. An ac to dc rectifier operates at supply frequency of 50 (or 60) Hz. In order to obtain almost negligible ripple in the dc output voltage, physical size of the filter circuits required is quite large. This makes dc power supply inefficient, bulky, and weighty. Moreover, an efficiency of nearly 40% was not satisfying at all whatsoever may be the size.

All these gave way to the birth of SMPS (Switched Mode Power Supply). With the advances in electronics circuitry and with the advent of VLSI technology, need for fixed dc power supplies for use in ICs and digital circuits has increased manifold. For such electronic circuits, NASA was the first one to develop a light-weight and compact switched mode power supply in the 1960's for use in its space vehicles. Since then Switched mode power supplies have been the leader in the market of power supplies and have been widely used in contemporary industrial applications and products to supply stable dc output voltage. At present, annual production of SMPSscount for 70 to 80 % of the total number of power supplies produced. The sole reason behind its success was its high efficiency of around 80%. For clarity, SMPS are used as substitutes for the linear regulators when higher efficiency, smaller size and light weight are required.

For many years never was the dominance of SMPS questioned mostly because of its high efficiency. But in past few years its disadvantages started showing up which prompted people to look for methods beyond the SMPS. Disadvantages include the generation of high amplitude, high frequency energy that the low pass filter must block to prevent electromagnetic interference (EMI) and a ripple voltage at the switching frequency and the harmonic frequencies thereof. The switching currents can cause electrical noise problem also if not carefully suppressed. Another major problem is that the switching devices in SMPS's are made to turn-on and turn-off the entire load at high current across the device. The devices handling high current through them also face high voltage stresses across them. Due to these two effects there are increased power losses in the switching devices. In case size and weight of the converter components is to be reduced, switching frequencies are increased. At these high frequencies, switching losses and high voltage stresses are further aggravated. The shortcomings enunciated above were the motivations to come up with a better design where in a converter are turned on/off when the voltage across it and/or current through it is zero at the switching instant. It is otherwise known as '**soft switching'.**The converter circuits which employ zero voltage and/or zero current switching are called 'resonant converters'.

Intel founder Gordon Moore stated that the numbers of transistors per square inch in ICs willdouble every year.This law is undeniably true even in today's billion transistors era.The trend has been towards lower operating voltage without reducing the power consumption.Current requirements for processors have increased exponentially over the last 4-5 years and will soon be crossing 400 A in a few decades a number of processor applications [2].



<u>Fig. 1.1 Current and voltage demands in processors in different generations of technology</u>

To achieve this high power density with high rate of increase in the number of transistors, increased switching frequency is required.But high switching frequency results in high switching losses in SMPS.This motivates to look for methods which promise reduction in switching losses at such high frequencies and improve power density and efficiency of the power supply.

1.3 OBJECTIVE

To develop a resonant mode power supply for LCD Monitor or LCD TV using a soft switching technique that can optimize efficiency and switching loss at a very high operating frequency . With this scheme there will also be a reduction in the size of filter components as well as the overall size of the unit. The topology used will be a buck converter wherein a soft switching technique like ZCS will be incorporated. This will lead to greater performance at high frequencies as well as reduce current stresses across the switch.

CHAPTER 2

TRENDS IN POWER SUPPLIES

INTRODUCTION

POWER SUPPLY AND ITS TYPES

LINEAR VOLTAGE REGULATOR

SWTICHED MODE REGULATOR

CHAPTER 2 TRENDS IN POWER SUPPLIES

2.1 INTRODUCTION

As costs of electronics decline, the power supply cost contributes a lot to the total costof system and design effort Thus, new technology developments in power supplies are critically important. In the past, heavy linear power supplies were used with transformers and rectifiers from the ac line frequency to provide low-level dc voltages for electronic circuits. Late in the 1960s, use of dc sources in aerospace applications led to the development of power electronic dc-dc conversion circuits for power supplies. In a typical power electronics arrangement today, an ac source from a wall outlet is rectified without any transformation; the resulting high dc voltage is converted through a dc-dc circuit to the 5V, 12 V, or other level required. These switched-mode power supplies are rapidly substitutinglinear supplies across the whole dimension of circuit applications.The bulk and weight of linear supplies make them infeasible for hand-held communication devices, calculators, palmtops,mobile phones, and other such equipment. Switched-mode supplies often take advantage of MOSFET semiconductor technology [10].

2.2 POWER SUPPLY AND ITS TYPES

By definition, a power supply module is a device that converts the output from an ac power line to a steady dc output or multiple numbers of outputs. The ac voltage is first rectified to provide a pulsating dc, and then filtered to produce a smooth voltage. Finally, the voltage is regulated to produce a constant output level despite variations in the ac line voltage or circuit loading. These steps are shown if Fig.1.

Here, in this dissertation we will be concerned about the regulator part which can be either of the two types:

- Linear Voltage Regulator
- Switching Regulator

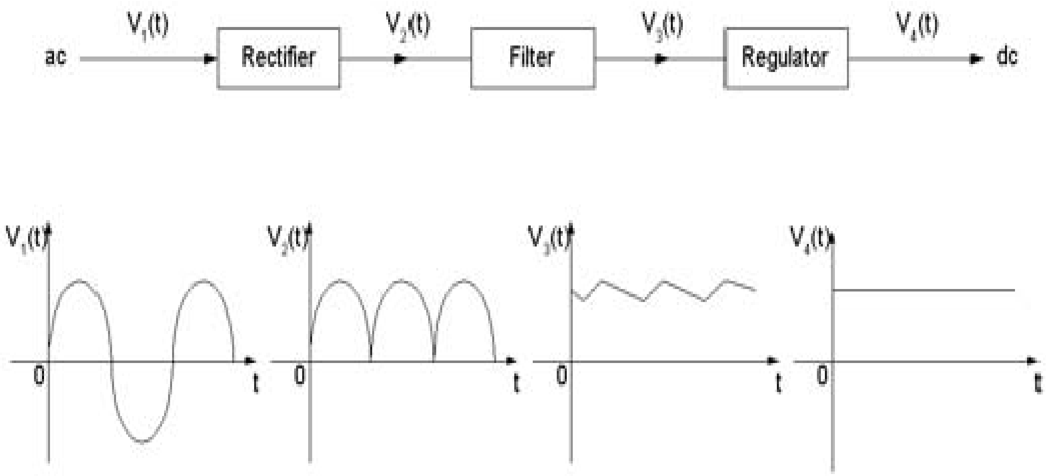


Fig.2.1 Block diagram of a power supply module

2.3 LINEAR VOLATGE REGULATOR

A linear voltage regulator is a kind of regulator which uses either an active device (such as a BJT, FET or vacuum tube) operating in its linear region (in exchange of the saturation and cut-off region, which are the principle operating regions in a switching regulator) or passive devices like the zener diodes. The regulating device is made to behave like a variable resistor connected across a current divider or voltage divider configuration, constantly altering the divider circuit to maintain a steady constant output voltage. Two types are possible-series and shunt [11].

It is a very inefficient method as it shed the difference in voltage by dissipating heat. Its efficiency basically lies in the range of 20-60 %. Their application is limited to output voltages smaller than the input voltage, and their power density is also low as they require low frequency (50 or 60 Hz) line transformers and filters. However, a very high-quality output voltage is obtained from linear voltage regulators. Their main area of usage is at lower power levels [10].

2.4 SWITCHED MODE REGULATOR

A Switched Mode Power Supply includes a switching regulator (which works within fully on and fully off states) in order to efficiently convert electrical power from the source side to load side. Unlike a linear regulator, the transistor in a SMPS supply switches very quickly (typically in the range of 60 kHz to 1MHz) between its two states. As a result, wastage of energy is diminished to a large extent. By changing the duty cycle or the ratio of on time to off time; voltage regulation is achieved. Whenever there is a need for higher efficiency, lighter weight and smaller size, switching regulators are preferred over linear regulators [11].

Either output voltage or current is regulated in a switched mode power supply by switching ideal storage elements like inductors and capacitors into and out of certain electrical modes of operations. Converters can operate with 100% efficiency theoretically as ideal switching elements, when ‘closed’, have no resistance across them and carry no current when ‘open’.

The comparison between linear regulated and unregulated AC-to-DC supplies with switching regulators in general is done in the table below.

TABLE 2.1

Difference between Linear Power Supply and Switched Mode Supply.

	Linear Power Supply	**Switched mode supply**
Efficiency	In the range of 20-60%	Lies between 80-90%
Area of operation	Only as step-down regulator	Used as both step up as well as step down.
Frequency of operation	In the ac mains frequency range of 50(or 60) Hz	In the high frequency range of several kHz to MHz
Size and weight	Requires mains frequency transformer. Hence, heavy and bulky	Utilises high frequency transformer. Therefore, small in size.
Electrical noise at output	Little or no electrical noise	Generate considerable noise if not properly designed.
Power level	Suitable for < 20W applications	More suitable for large power operations

CHAPTER 3

SWITCHED MODE POWER SUPPLY:

OPERATION AND SIMULATION

GENERAL PRINCIPLES

THEORY OF OPERATION

SIMULATION AND RESULTS

CHAPTER 3 SWITCHED MODE POWER SUPPLY

3.1 GENERAL PRINCIPLES:

In the design of power supplies, the cost and performance of the regulator is guiding factor for choosing the type of regulator that should be used in a specific design. In order to do this selection of an apt regulator in the designing phase, it is necessary to understand the requirements of the application and then finalise on the selection. Advantages and disadvantages of both types of regulators have already been jotted down in the previous chapter. That will make this work of selection much more hassle free.

The switched mode power supply uses a switch (circuit element) to generate a regulated dc output voltage from an unregulated one. The switch employed is turned 'ON' and 'OFF' (referred as switching) at a high frequency.When the switch is in 'ON' mode,it is in saturation mode with negligible voltage drop across the collector and emitter terminals of the switch In contrast, while in 'OFF' mode,it is in cut-off mode with negligible current through the collector and emitter terminals.The ON and OFF durations are suitably controlled such that the average dc voltage applied to the output circuit equals the desired magnitude of output voltage. This is the basic chopper principle on which SMPS is based.

To understand this better consider the following scheme. A dc voltage source, V_s is connected as input in series with a switch S and a load resistance, R. The switch is considered to have unidirectional voltage- blocking capabilities and unidirectional current conduction capabilities. If, however, an anti-parallel diode is connected across the switch, we get bi-directional properties. Fig. 2 depicts the schematic of this simple step down dc chopper.

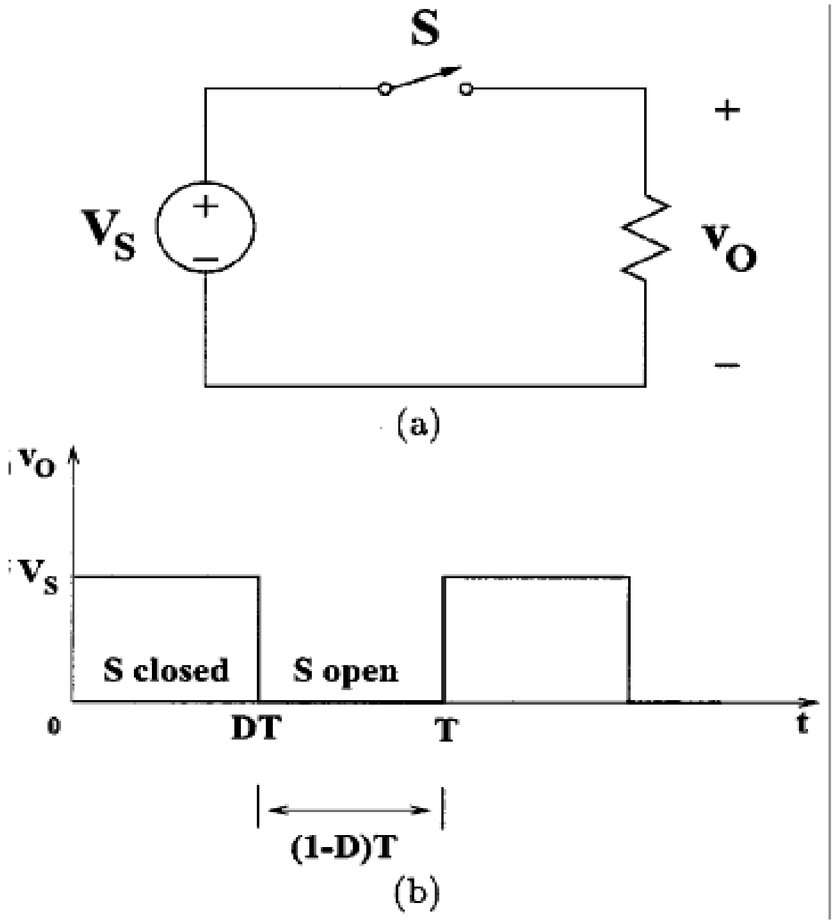


Fig. 3.1 DC chopper with resistive load (a) circuit diagram (b) output voltage waveform

The switch is being operated at a duty ratio, D which is defined as the ratio of 'ON' time to the sum of the 'OFF' time and 'ON' time i.e.

$$D \equiv \frac{ton}{ton+toff} = \frac{ton}{T}$$

Where, T is the time period of the switching pulse [10]. For constant frequency of operation, T= 1/f.The output voltage so obtained is given as

$$V_o = \frac{ton}{ton+toff} \times V_s = DV_s$$

3.2 THEORY OF OPERATION

The basic block diagram of a SMPS module is shown below following which there is a detailed description of the various blocks used in it.

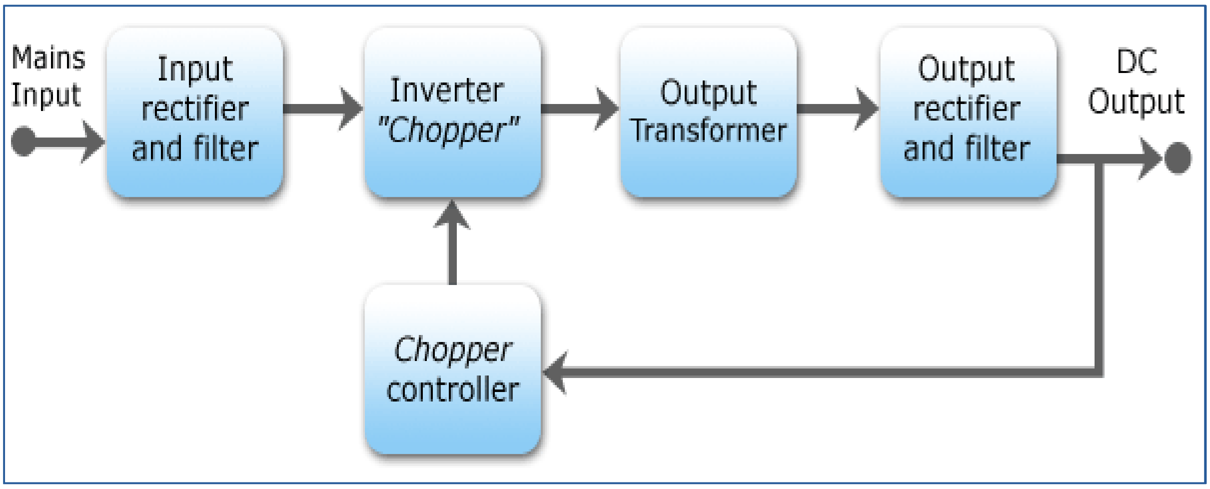


Fig. 3.2 BLOCK DIAGRAM OF A MAINS OPERATED SMPS MODULE

3.2.1 INPUT RECTIFIER AND FILTER STAGE

This stage is required only when the input supply is from ac mains. If input is itself in DC then there is no need of this stage. When input is ac in nature, the first thing that is done is conversion from ac to dc voltage. This step is known as rectification. The rectifier generates an unregulated DC voltage which is then sent for filtering with a filter capacitor of nominal value. As the DC passes through the rectifier stage unchanged, an SMPS designed for AC mains input can often be used for a DC supply. However, this kind of use may prove to be detrimental for the rectifier stage as this configuration in full load condition will only use half of diodes in the rectifier. As a result, it may lead to overheating of these components, and cause premature failure of the components. For correcting the power factor, the designer should employ special control techniques to force the average input current to follow the AC input sinusoidal voltage [11].

3.2.2 INVERTER CHOPPER STAGE

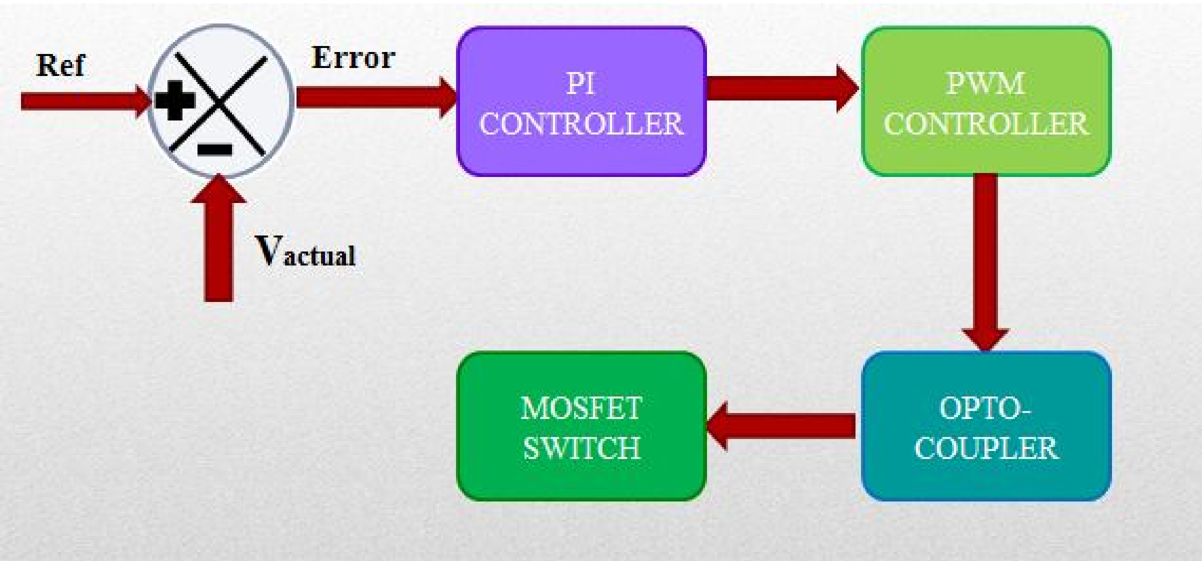
This stage converts the DC voltage fed to it, either directly from the input supply or from the rectifier and filter stage, to an AC voltage by passing in through a switch like MOSFET, IGBT. MOSFETs have high current handling capacity and have low on resistance. The switch is regulated at a very high frequency range of several kHz. This gives the added advantage of making it inaudible for human perception.The pulses for switching this stage comes from a PWM controller which gives output pulses depending on the feedback obtained from output voltage. Thus, the scheme is tightly controlled with the inclusion of feedback loop. More on the feedback loop will be discussed later. Due to the high frequency of application, the output transformer so used will be a high frequency type and will have small size. This transformer is used when it is required that the output be isolated from the input, which is the usual case.

3.2.3 OUTPUT VOLTAGE RECTIFIER AND FILTER:

If Dc output is required at the output end, the voltagefrom the chopper stage needs to be rectified. The diodes used here will not be the normal diodes used in the previous rectifier circuit used at the input. Here, the diodes that shall be used should be suitable for high frequency operation. Thus, we use fast switching diodes. Also, silicon diodes are used for high voltage of 10V or above. For lower voltages schottky diodes are used. The rectified output is then passed through filters consisting of inductors and capacitors to give smooth output. The values and size of these filter elements will be small as a result. Non-isolated types are even simpler as they consist of inductors instead of transformer.

3.2.4CHOPPER CONTROLLER:

The chopper controller basically controls the chopping frequency of the inverter stage based on the output voltage sensed by it. The feedback loop provides a closed loop condition, thereby, yielding a regulated output voltage at the output stage. We use a PI controller to respond to error signal produced, as result of difference between the measured output and expected output, which will generate control signal for PWM controller. As result of this, the width of the pulse energizing the chopper will vary and desired output pattern will be obtained. Hence, voltage regulation will be achieved. The exact scheme used in this work for feedback control is shown below.



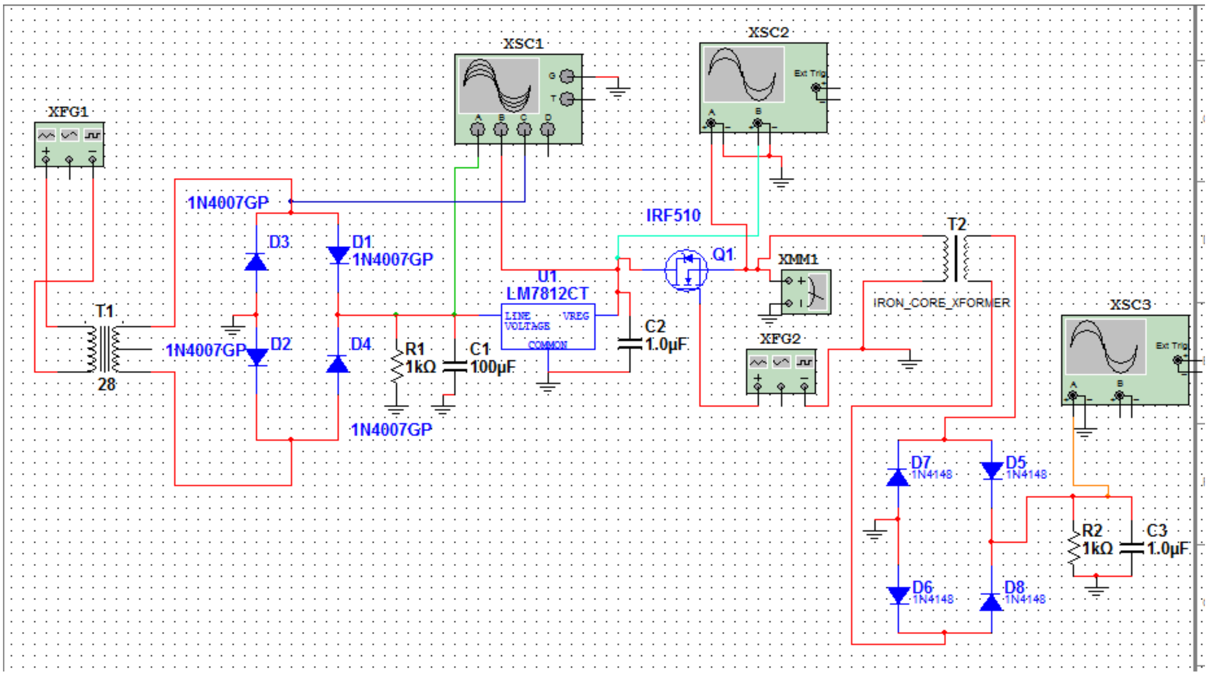
<u>Fig.3.3 Feedback scheme used to obtain regulation</u>

3.3 SIMULATION AND RESULTS

Here, in this project we first try to design the first part i.e. a switched mode power supply with hard switching and then incorporate within it a soft switching methodology possibly a ZCS(Zero Current Switching) scheme to result in highly efficient resonant mode power supply.We use MULTISIM simulation software provided by NI Circuit design Suite product line. MULTISIM is the schematic capture and simulation program designed for schematic entry, simulation and feeding to downward steps such as PCB layout. It also includes mixed analog/digital simulation capability.

In the first half of the project we design a basic SMPS isolated buck converter topology and check for its operation as a voltage regulator. In this method, switching of the MOSFET is done with the help of PWM controller. As a result, the circuit undergoes hard switching. There are a lot of advantages of using PWM converters such as less component count, constant frequency operation, high efficiency,commercial availability of integrated circuit controllers, comparatively simple control and ability to achieve high conversion ratios for both step upand step-down applications. However, a major disadvantage of PWM converters is that rectangular voltage and current waveforms of the PWM cause switching losses (or turn-on and turn-off losses) in semiconductor devices. Unfortunately this practicallylimitsthe operating frequency range of the converter to hundreds of kilohertz. Additionally, rectangular waveforms also generate EMI.

We disintegrate the entire circuit into parts and do designing in an organised manner to make the debugging easier. First, we construct the forward part i.e. without any feedback. Obtain an output, vary the load from our specified min to max range and observe the output. This variation in output will then be used to give reference signal in the error amplifier used thereafter. Next we do the feedback loop for which we first design out PI controller and examine its proper operation. Then we incorporate it within the feedback loop and see if PWM regulation is obtained properly or not. On getting satisfactory results we club the entire circuit together and look for the results. The results so obtained are shown below.



<u>Fig.3.4 SCHEMATIC FOR THE FORWARD PATH OF POWER SUPPLY BLOCK</u>

Next we design the feedback loop part and finally present the complete circuit schematic. The components used and their values are given in the Table 3.1.

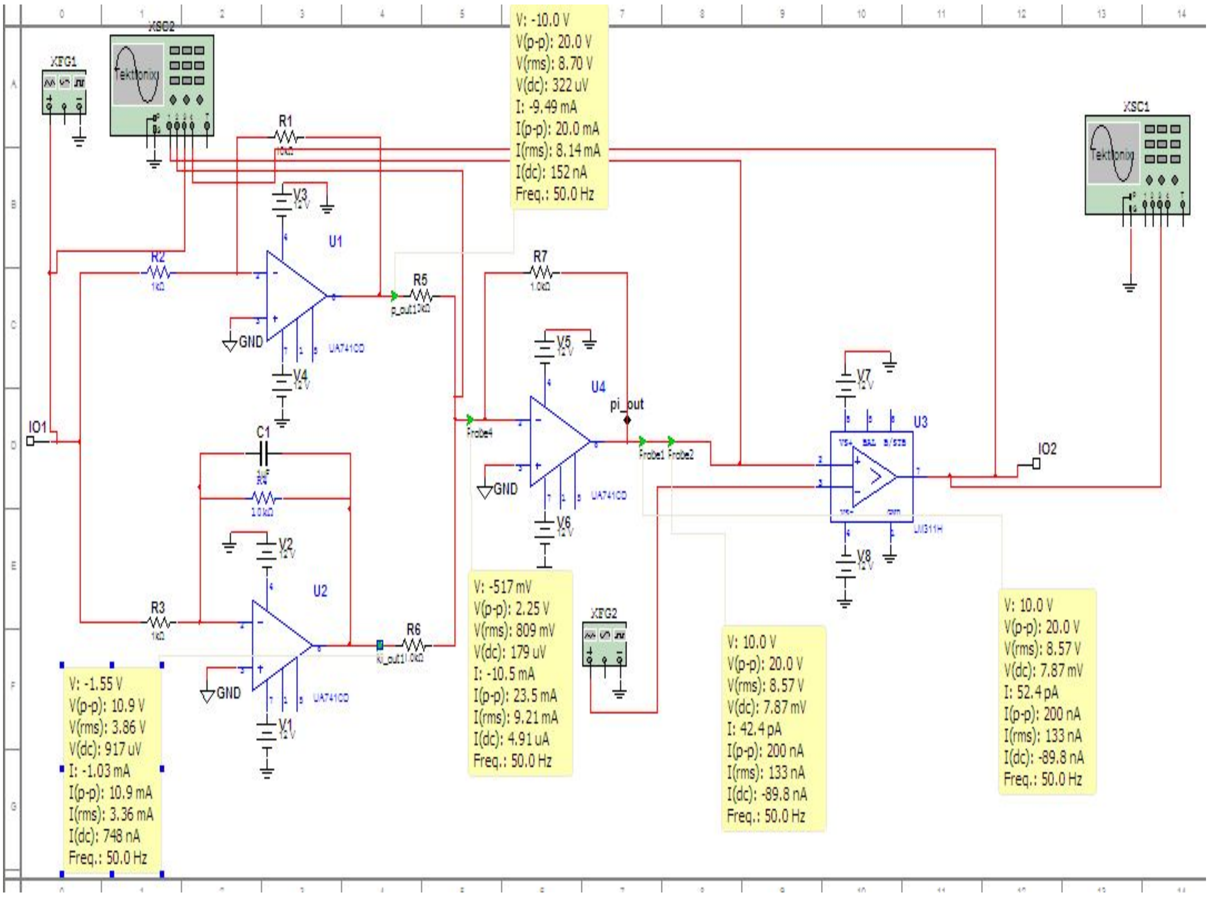


Fig. 3.5 SCHEMATIC OF THE FEEDBACK LOOP

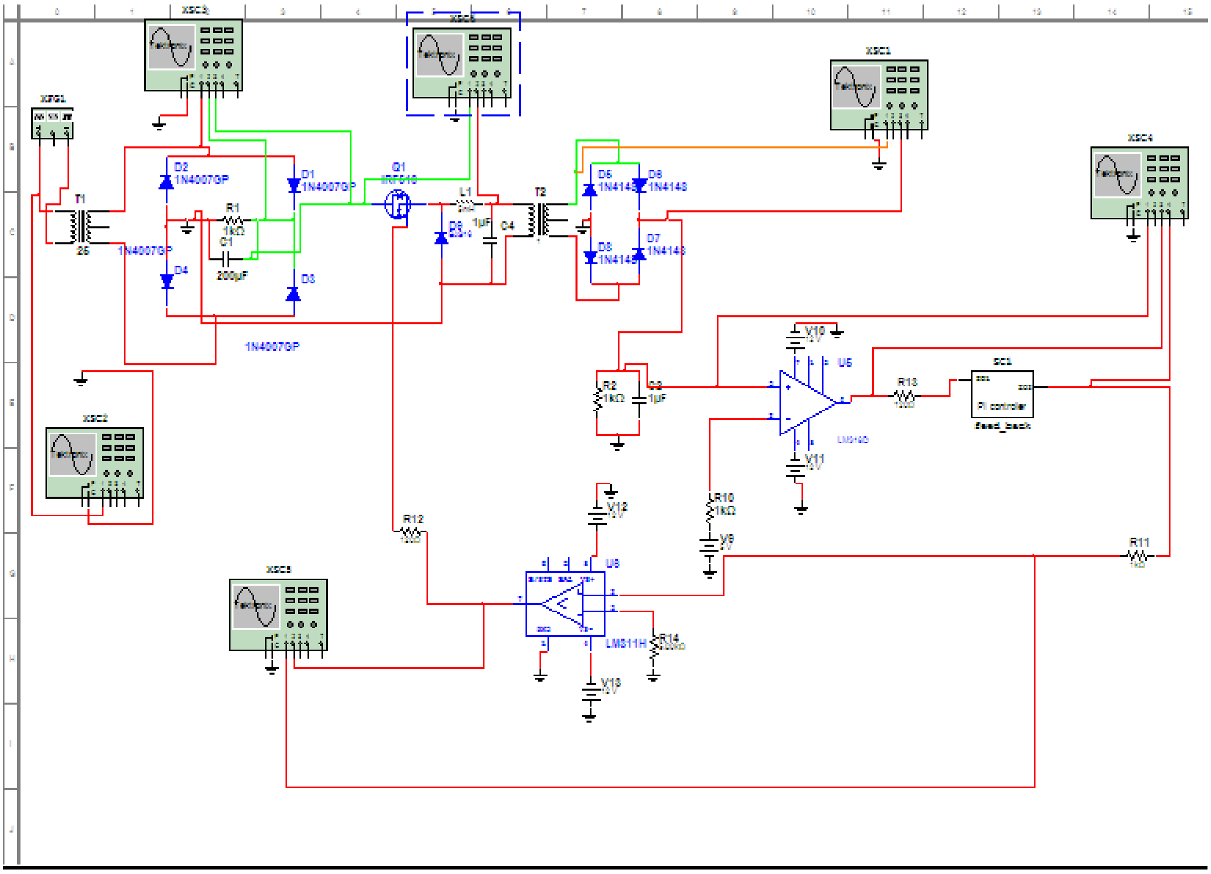


Fig. 3.6 COMEPLTE SCHEMATIC FOR SWITCHED MODE POWER SUPPLY INCORPORATING THE FEEDBACK LOOP

TABLE 3.1 COMPONENTS USED IN THE CONVERTER

COMPONENT	VALUE
Mains Transformer,T1	50Hz, 1 Amp , TS_vitual 9-0-9V
Rectifier Diode; D1,D2,D3,D4	IN4007
Filter Capacitor,C1	100uF
Load resistance, R1	1kΩ
MOSFET Switch, Q1	IRF510
High Frequency Transformer,T2	Iron core Xformer
Switching Diodes,D5,D6,D7,D8	IN4148
High frequency Capacitor	1uF
Error amplifier,U1	UA741CD
Differential Amplifier,U2,U3,U4	UA741CD
PWM Comparator, U4	LM311H

SIMULATION RESULTS:

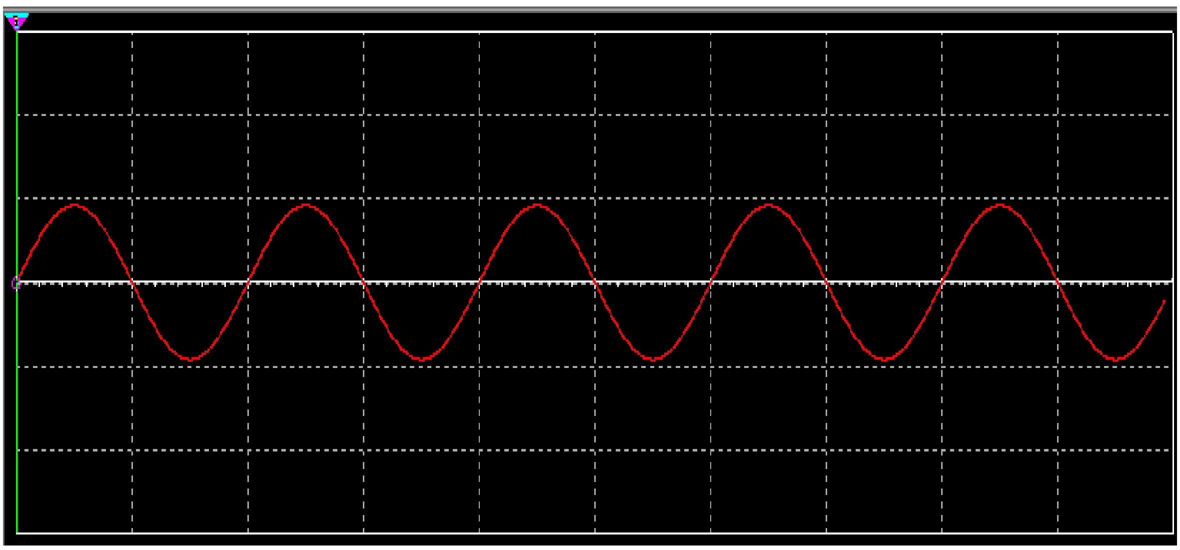


Fig. 3.7 AC MAINS SUPPLY INPUT

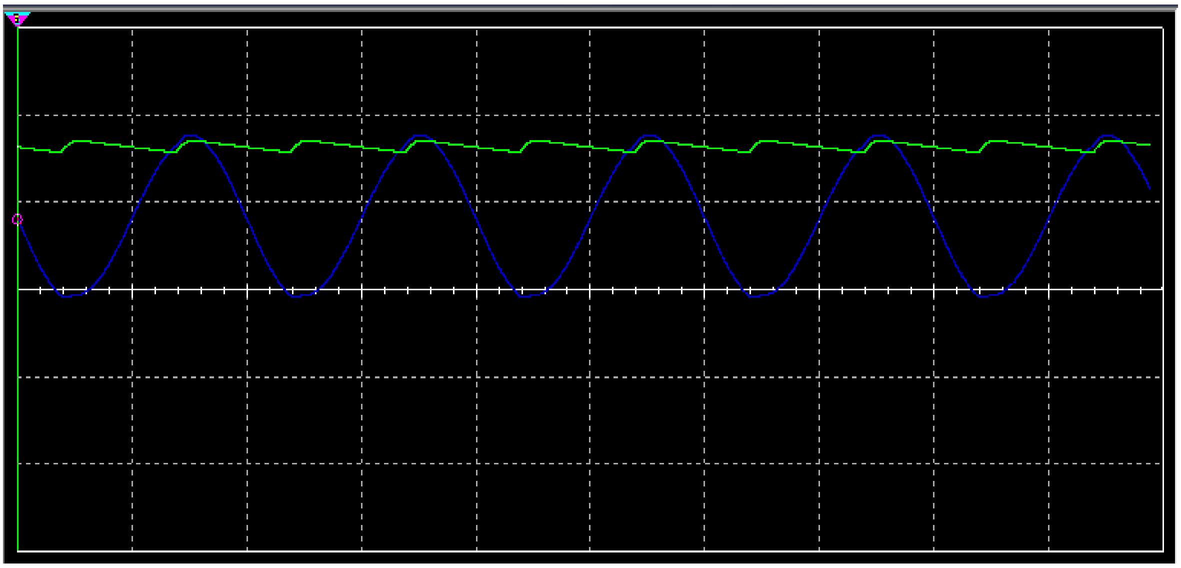


Fig. 3.8 RECTIFIED OUTPUT(BLUE) AND FILTERED OUTPUT(GREEN)

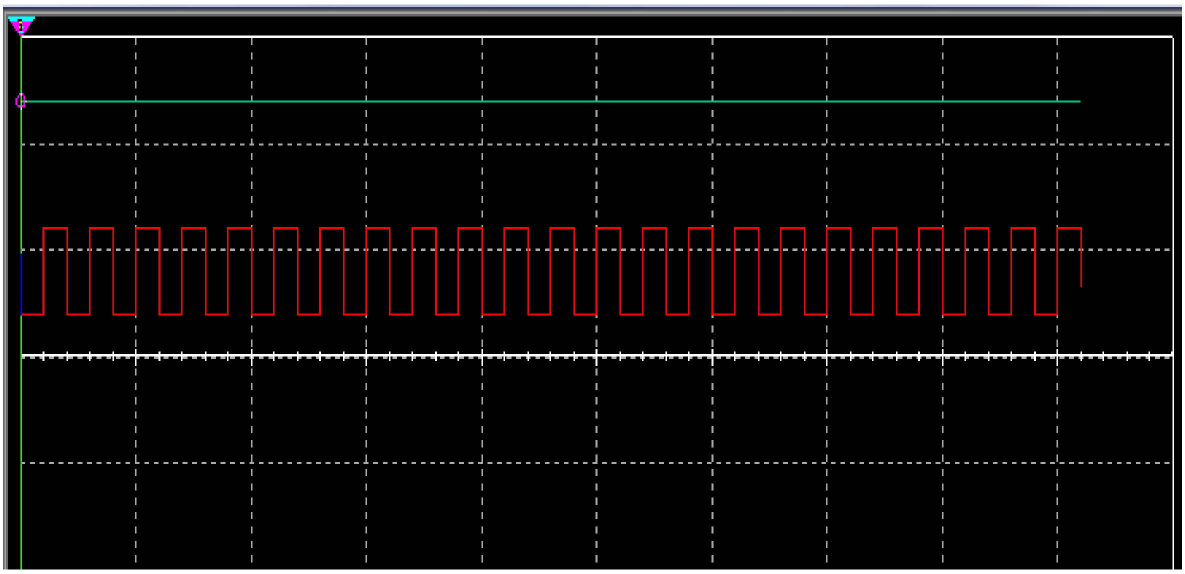


Fig. 3.9 INPUT AND OUTPUT (RED) OF THE MOSFETINVERTER STAGE

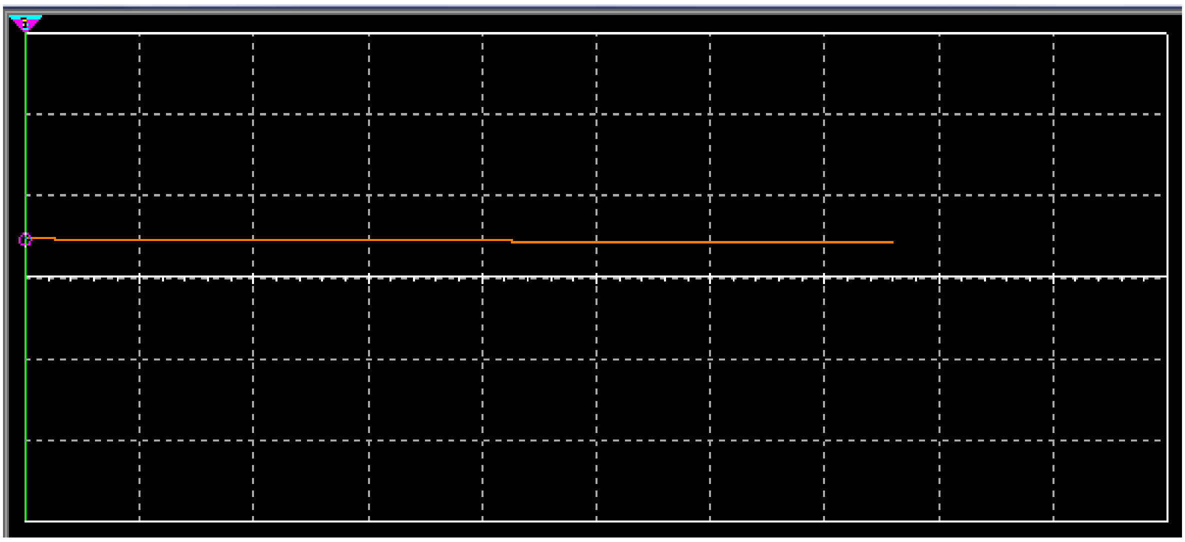


Fig. 3.10 VOLTAGE AT OUTPUT STAGE

After looking in the results of the forward path simulations, we observe that on varying the load at the output, voltage levels at the corresponding points change. We calculate the extremes of this voltage variation and take an average of that to feed into the inverting end of the error amplifier. The non-inverting end is coming from the output voltage directly. The error signal is fed to the PI controller which tries to integrate the errors till it becomes zero and gives an output rectifying voltage which is used to vary the width of the pulses of the PWM generator to be fed to the MOSFET switch. If the output voltage level falls below the desired limit then an error signal will be generated that will be given to the PI controller to produce the rectified signal. This signal is then the basis of generation of proper width of the pulse. Thus, the width of the pulses in increased to meet the desired output of increasing the output voltage levels. In this way, regulation of voltage is achieved. The schematic showing how the PWM controller varies the width as per the magnitude and sign of the error signal is as shown in Fig. 3.9. The PWM function is obtained using LM 311H where the carrier signal is a triangular waveform of 50 kHz frequency.

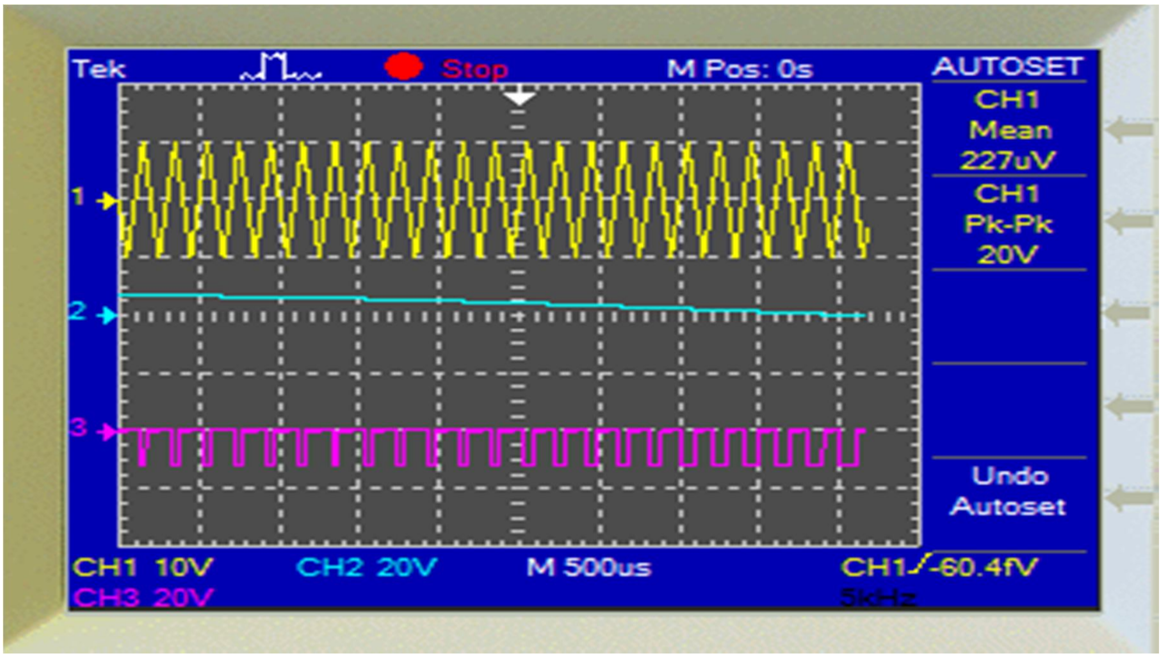


Fig. 3.11 Pulse width modulation controller output

The PWM function is obtained using LM 311H where the carrier signal is a triangular waveform of 50 kHz frequency. The inverting end of the comparator is fed with this carrier signal whose magnitude is much larger than the input signal to be fed at the non-inverting end of the comparator. As can be seen from the pink sketch in the schematic, the pulse width is gradually decreasing as the error signal traverses from positive voltage towards negative side.

Thus, proper voltage regulation is done using isolated SMPS converter topology.

CHAPTER 4

SWITCHING LOSSES AND TECHNIQUES TO MINIMIZE THEM

Losses across a switch

Concept of Hard Switching and Soft Switching

CHAPTER 4 SWITCHING LOSSES AND TECHNIQUES TO MINIMIZE THEM

Switching mode power supplies (SMPS) have been widely used in contemporary industry products to provide regulated dc output voltage. The traditional SMPS with hard switching techniques has eminent large switching losses in the power switches. As such the overall circuit efficiency is not satisfactory. To achieve a high efficiency circuit configuration, zero voltage switching (ZVS) or zero current switching (ZCS) techniques based on resonant circuits have been proposed over 10 years[1].

4.1 Losses across a switch:

A converter as in the SMPS consists of two types of elements: some controlled elements and some uncontrolled ones like the diodes.While the controlled device is forced to turn-on or off, the other device mainly functions as a slave to the controlled device. Power loss in the converter, which directly affects the efficiency, is due to a combination of losses in these devices. The losses due to each of these devices contribute individually to the rise in temperature of the integrated converter module. Thus, in our circuit shown in the previous chapter, MOSFET and the diode cause the maximum power loss in the configuration [12].

There are two kinds of losses that primarily are seen in these devices:

- Conduction loss
- Switching loss

We will discuss these two losses from the point of view of MOSFET and diode.

CONDUCTION LOSS:

The MOSFET and the diode behave as switches that channel current through the circuit during each switching interval. Conduction loss is generated across these devices when they are conducting current or when they are in ‘ON’ state. Thus, conduction loss occurs across a MOSFET due to its ‘ON’ resistance, R_{DSon} and across a diode due to its forward voltage drop.

MOSFET conduction loss ($P_{conduction\ (MOSFET)}$)over the switch on-period can be approximated as the product of $R_{DS\ (ON)}$),the average MOSFET current ($I_{MOS\ (AV)}$)and the

Duty cycle (D).

$$P_{conduction\ (MOSFET)} = I_{MOS\ (AV)} \times R_{DS\ (ON)} \times D$$

Diode conduction loss is dependent on forward voltage (VF) whose value is large. As a result, diodes’ conduction loss is more than that of MOSFETs. Diode loss is proportional to V_F, forward current, and conduction time (1-D) as the diode conducts when the MOSFET is off. Therefore, diode conduction loss ($P_{conduction(DIODE)}$) is given approximately as:

$$P_{conduction\ (DIODE)} = I_{DIODE\ (ON)} \times V_F \times (1 - D)$$

Thus, the longer the ‘ON’ period, higher are the conduction losses in the devices.

SWITCHING LOSSES:

Switching losses occurs in a device during its transition between ‘ON’ state and ‘OFF’ state. Since some time is required for changing of states in the devices, there is an inevitable overlap between voltage and current waveforms which eventually leads to power losses in the respective devices. These losses appear as power spikes in the power waveform. This is depicted in the following figure.

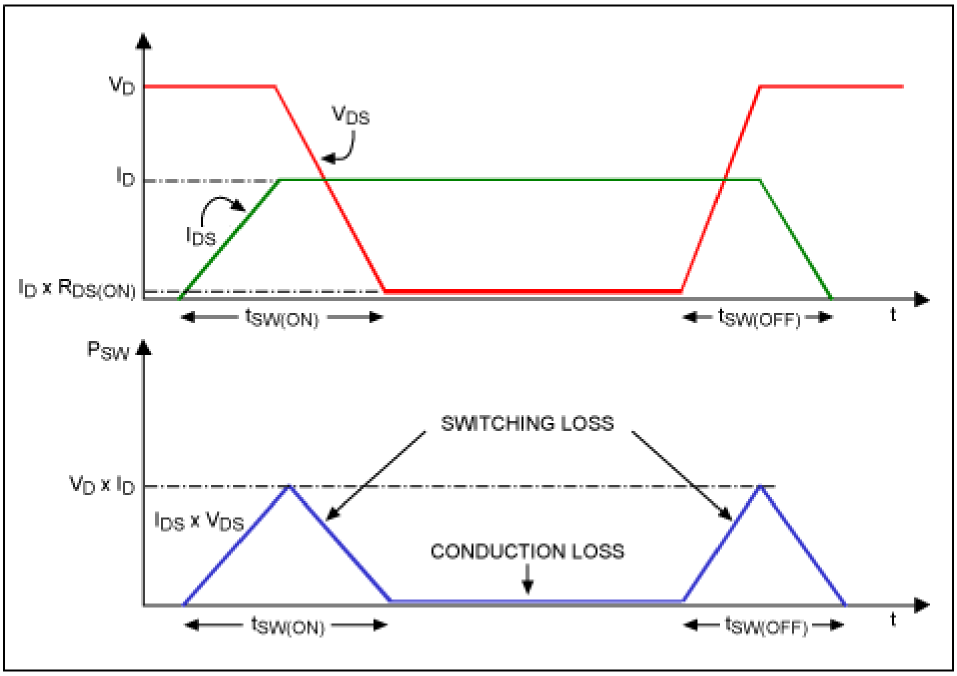


Fig. 4.1 Switching losses across a MOSFET during its transition between on and off states

In early days of power electronics, conduction losses were the main source of headache for the power supply designer. But with the advent of technology, fast converters with smaller size were the order of the day. Naturally, all these called for high switching frequencies which resulted in higher switching losses as the switching loss is directly proportional to switching frequency. As a result, in this present scenario, switching loss become dominant and cause rise in the device junction temperature.Novel techniques are entertained to obtain clear turn-on and turn-off of these devices. We will next look into the methods for controlling these losses so as to cool down the circuit to some extent.

4.2 Concept of Hard Switching and SoftSwitching

Hard switching refers to stressful switching behaviour of power electronic devices [10]. It is a standard SMPS switching methodology where the current and voltage waveforms are in same phase thereby, resulting in large switching losses.

Soft switching, on the other hand, includes complex circuit and control method which guarantees either current or voltage becomes zero while switching. It, consequently, results in near zero switching losses. This difference becomes clear from the following diagram.

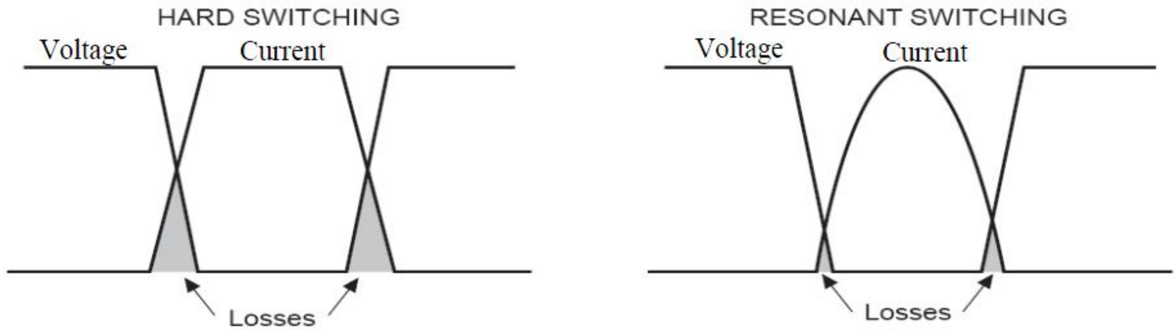


Fig.4.2 Inevitable switching losses in conventional and resonant converters

Historically, SMPS systems were considered so competent relative to the traditional linear power supplies that no one ever questioned about their switching losses. But now, as we are transitioning towards frequencies in the Megahertz range, the issue of switching losses becomes fresh ground of debate. These switching losses limit the maximum switching frequencies in hard switched systems.

DEVELOPMENT TOWARDS SOFT SWITCHING:

In the 1970's, traditional PWM converters were employed in a switched mode operation[10]. Power switches had to turn on and turn off under hard switching conditions. Power device had to undergo high voltage and high current concurrently leading to high switching losses and stress.The switching trajectory of a hard-switched device and that of a soft switched one is shown in Fig.4.2

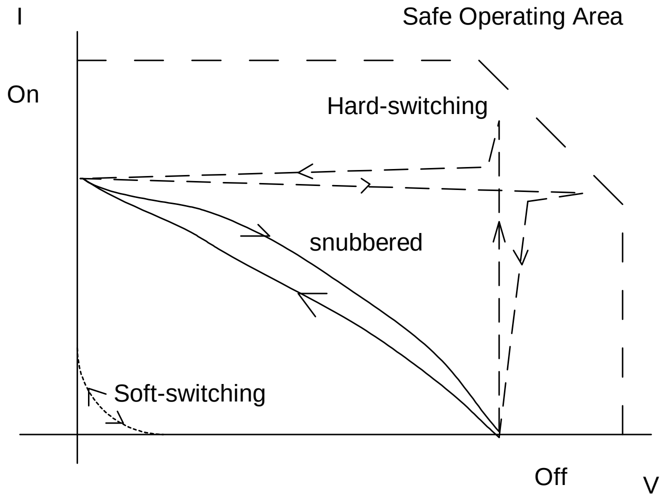


Fig. 4.2 switching trajectory of hard switched and soft switched circuit

Hence, in the next decade, quite an amount of research was done towards the promising areas of resonant converters. The main idea was to implement resonant tank circuits in the SMPS converter configuration to create sinusoidal current or voltage waveforms. As a consequence, Zero Current Switching (ZCS) and Zero Voltage Switching (ZVS) condition can be created for power supplies. The reduction of switching loss and the continualrefinement of power switches allow the switching frequency of resonant converters to reach hundreds of kHz (typically 100kHz to 500kHz). Eventually the sizes of the circuit magnetics as well as that of the capacitors decrease.Resonance is allowed to occur just before and during the turn-on and turn-off processes so as to create ZVS and ZCS conditions. Other than that, they behave just like conventional PWM converters.

CHAPTER 5

RESONANT CONVERTER TOPOLOGIES

INTRODUCTION

CONVERTER TOPOLOGIES

CHAPTER 5 RESONANT CONVERTER TOPOLOGIES

5.1 Introduction

Electronic power conversion technology has matured around two fundamentally different circuit configurations: duty cycle variation, commonly known as Pulse-Width Modulation (PWM), and resonance. The PWM technique processes power by interceding the power flow and manipulatingthe duty cycle, thereby, resulting in continuously pulsating current and voltage waveforms. The resonant technique processes power in a sinusoidal form.Due to simplicity in circuit and ease of control, the PWM technique has been used substantially in today's power electronics industry, especially, in low-power applications [4]. Resonant converters, in contrast, have not been a preferred choice in the low power dc to dc converters simply because of its circuit complexity.To improvise the switching behaviour of semiconductor devices in power converting circuits, two techniques were put forth. The first one is known as the zero-current-switching (ZCS) technique.By integrating an LC resonant tank circuit, the current waveform of the switching device is guided to oscillate in a quasi-sinusoidal manner. As a result, during both turn on and turn off process, zero-current-switching conditions are generated.This new family of circuits can be viewed as a hybrid of PWM and resonant converters.This LC tank circuit is placed near the power switch and is used for shaping the current and voltage waveforms of the power switch as well as storing and transferring energy from the input side to the output sidejust as in conventional resonant converters.

The second technique thus developed is known as zero-voltage switching (ZVS). Here, by utilising a resonant tank LC circuit, the voltage waveform is altered so that zero voltage condition exists across the switch during its turn on and turn off process. Thus, switching losses are avoided. Practically switching frequencies of several Megahertz is possible with this generation of quasi-resonant converters.

5.2 CONVERTER TOPOLOGIES:

There is on-going research to bring out innovative converter topologies. In today's scenario, converters with three different topologies:resonant, quasi-resonant and ZVT techniques are used [2].

A resonant switch consists of a sub circuit constituting of semiconductor switch $S_{1,}$ and resonant circuit elements L_r, and C_r. For a ZC resonant switch, inductor L_r, is in series with switch S, toachieve zero-current switching; as shown in Fig. 5.1(a). In a ZV resonant switch, as shown in Fig. 5.1(b), capacitor C_r, is in parallel with switch $S_{1,}$ to achieve the configuration of zero-voltage switching[4].

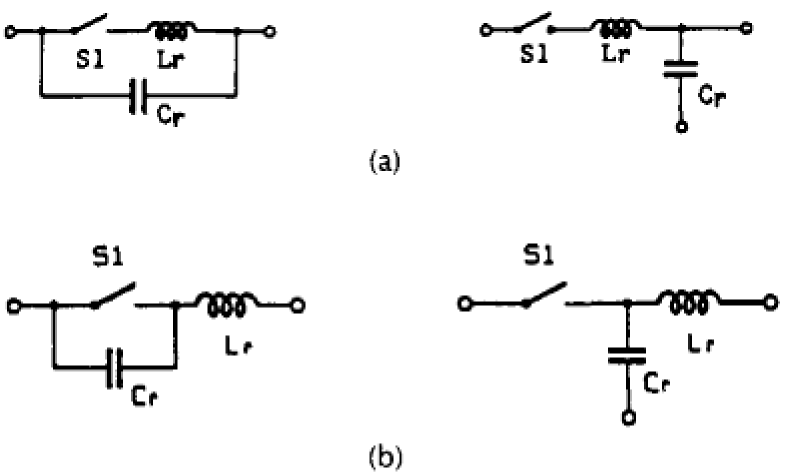


Fig. 5.1 (a) ZC resonant switches (b) ZV resonant switches

If the ideal switch S_1 is incorporated as a unidirectional switch in Fig.5.2 (a); the switch current is permitted to resonate only in the positive half cycle. This resonant switch is,thus, configured to operate in a half-wave mode.In contrast to this, if diode D, is connected in antiparallel manner with Q1,theswitchcurrent can flow in bidirectional way and the resonantswitch is said to operate in full-wave mode as shown in Fig. 5.2 (b).

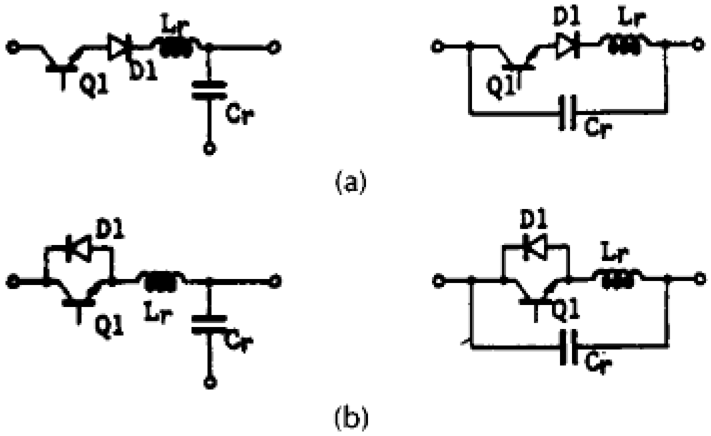


Fig. 5.2 (a) Half-wave mode (b) Full wave mode

In a resonant switch converter, switch network containing resonant elements is used to substitute the switch network of a PWM converter. The resulting upgraded converter merges the properties ofthe parent PWM converter and the resonant switch network. Inclusion of resonant tank elements, Lr and Cr, provides resonating condition to the conventional PWM converter to experiencezero-current-switching (ZCS) and zero-voltage-switching (ZVS). When aresonant tank consists of more than one energy storing element like an inductor or a capacitor, then it results in a multi-resonant converter. With the combination of different location of resonant elements, other resonant converter topologies can be designed.

In certain applications, the resonating condition is inevitable such as in high power applications, where the transformer leakage inductance and the MOSFET switch’s junction capacitance undergo resonance condition at certain load condition. However, it should be noted here that resonance is obtained only at a specific load and it fails to happen at various load conditions or where there is variation in line supply. The switching frequency variation is a means to control the resonant converter circuit.

CHAPTER 6

BUCK CONVERTER TOPOLOGY WITH RESONANT CONFIGURATION

CIRCUIT CONFIGURATION

SYSTEM ANALYSIS

SIMULATION RESULTS

CHAPTER 6BUCK CONVERTER TOPOLOGY WITH RESONANT CONFIGURATION

6.1 Circuit Configuration:

A buck converter is modified to a quasi-resonant converter incorporating Zero Current Switching (ZCS) configuration to result in a topology as shown in Fig.6.1. A switch Q1 is operated along with a resonant tank circuit, consisting of elements L1 and C1, to achieve zero current switching so as to minimize switching losses and achieve high efficiency. This converter will be a part of the buck converter used in the circuit shown in Fig. 3.6. The regular circuit elements of a buck converter are also present as shown with the filter elements, inductor, L2 and capacitor, C2. The state space equations for various modes are found out by taking into account the boundary conditions. For modelling the system with the help of MATLAB, we design the state space matrix equations for each of the modes and thereby, use it to solve for the system output variables.

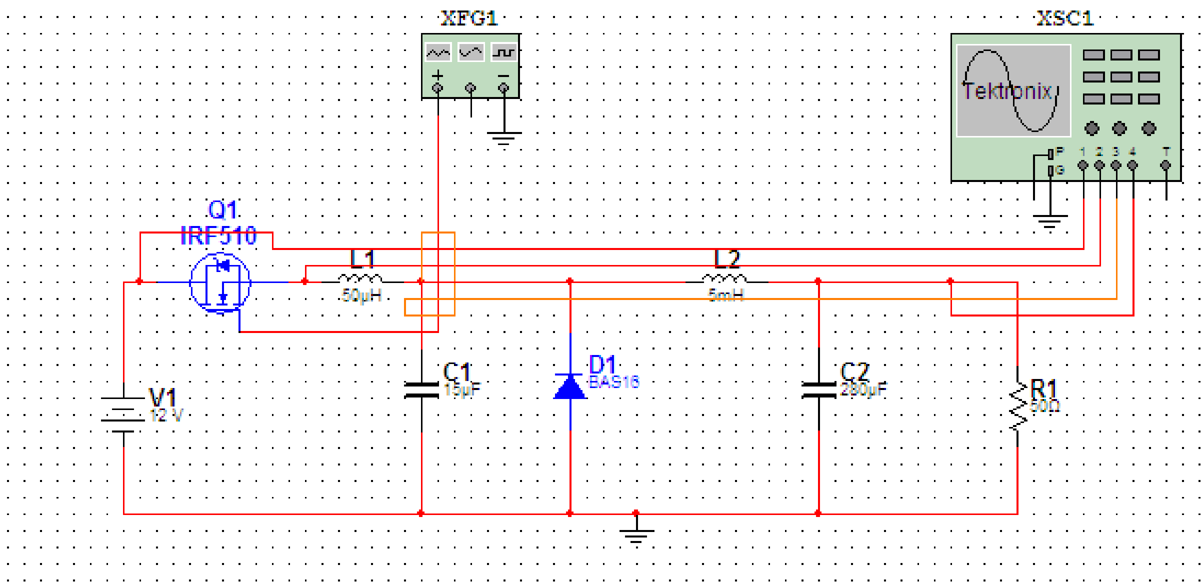


Fig. 6.1 Quasi resonant buck converter using ZCS configuration

6.2 System Analysis:

Before analysing the steady state behaviour of the circuit, we make the following assumptions.

- The filter inductor, L2 is having much larger value than the resonant inductor, L1.
- Filter components at the output side, L2 and C2 along with the load resistance, R1; are treated as a constant current sink together.
- MOSFET switch and diode are assumed to be ideal. Thus, there is no forward voltage drop in the conducting stage, neither is there any leakage current in the blocking stage. Also, it is assumed that there is no time delay between the transitions from on state to off state.

The following variables are defined for system analysis:

- Resonant angular frequency, $\acute{\omega} = 1 / \sqrt{(L1 * C1)}$
- Resonant frequency, $f = \acute{\omega} / 2\pi$
- System impedance, $Zo = \sqrt{(L1 / C1)}$

The entire cycle of operations can be divided into four stages or modes. These stages are described below along with the supporting mathematical modelling:

We suppose that before switch Q1 isswitched on, diode D1 carries the output load current, Io and let theresonant capacitor voltage is Vcrwhich clamped at zero. At the commencing of the switching cycle, t = To, S1 is turned on.

Mode 1:-[T0-T1]

Input current, I_L increases linearly and is given by the state equation

$$L1\left(\frac{dI1}{dt}\right) = V1$$

Where, V1 is the rms value of voltage at the input side.

The span of this interval, Td1, is found out using the boundary condition given as

$I_L(0) = 0;$

$$I_L(Td1) = Io;$$

And, $Td1 = T1 - T0 = {L1 * Io}/{V1};$

Mode 2: [T1, T2]

At time T1, when input current I1 reaches a level of Io, D1 is turned off. As a result, the amount of current called [i_1 (t)- Io] is utilised in charging Vcr. The state equations are:

$$C1\left(\frac{dVcr}{dt}\right) = i_1(t);$$

$$L1\left(\frac{dI1}{dt}\right) = V1 - Vcr(t);$$

Subject to boundary conditions

Vcr(0) = 0;

I1(0) = Io;

Therefore,

$$i_1(t) = Io + (V1/Zo) \sin\acute{\omega}t;$$

$$Vcr(t) = V1(1 - \cos\acute{\omega}t);$$

Now, depending upon whether we are using half- wave mode or full wave mode, two cases occur. Here, in our topology we use the full wave mode as full wave modes are less load sensitive.If a full-wave resonant switch is used, current in the circuit $i_1(t)$will continuetooscillateand feed energy back to input V1 through the situated antiparallel diode.

Span of this mode of operation is solved as given:

$$Td2 = \acute{\alpha} / \acute{\omega};$$

Where ά lies in the range; $3\pi/2 \leq \acute{\alpha} \leq 2\pi$

At time T2, Vcr can be obtained as

$$Vcr\ (Td2) = Vcb = V1(1- \cos\acute{\alpha});$$

Mode 3: [T2, T3]

Switch Q1 is turned off at time instant T2. As a result, capacitor begins to discharge through the output sink. Consequently, Vcr decreases linearly to zero. The state equation for this mode of operation is given as:

$$C1\left(\frac{dVcr}{dt}\right) = Io;$$

The span of this stage is solved as Td3 with the boundary conditions;

$$Vcr\ (0) = Vcb;$$

$$Td3 = \frac{C1*V1\ (1-\cos\acute{\alpha})}{Io};$$

Mode 4: [T3, T4]

Here, the capacitor is in off state. So, diode D1 is left. Output current flows through this diode. The duration of this mode of operation is given as Td4:

$$Td4 = T4\text{-}T3;$$

$$Td4 = Ts\text{-}Td1\text{-}Td2\text{-}Td3;$$

Where, Ts= Switching cycle period.

6.3 Simulation Result:

We use MATLAB to generate the output waveforms for current and voltage across the switch for this zero current switching topology. For doing this, we convert the state equations described above into state space matrix of the format:

$$\mathbf{\dot{x} = Ax + Bu;}$$

$$\mathbf{Y = Cx + Du;}$$

Here, our state vector and output vector turns out to be same making it easier for calculations. This vector is x= $[I1, Vcr]^T$. Now, we solve the equations for each stage and find out the value of system matrix vector A and input matrix vector B to solve the equation.

Mode 1:

$$A1 = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix};\ B1 = \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & 0 \end{bmatrix};$$

Mode 2:

$$A2 = \begin{bmatrix} 0 & \frac{-1}{L} \\ \frac{1}{C} & 0 \end{bmatrix}; \; B2 = \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & \frac{-1}{C} \end{bmatrix};$$

Mode 3;

$$A3 = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}; \; B3 = \begin{bmatrix} 0 & 0 \\ 0 & \frac{1}{C} \end{bmatrix};$$

Mode 4:

A4= 0; B4= 0;

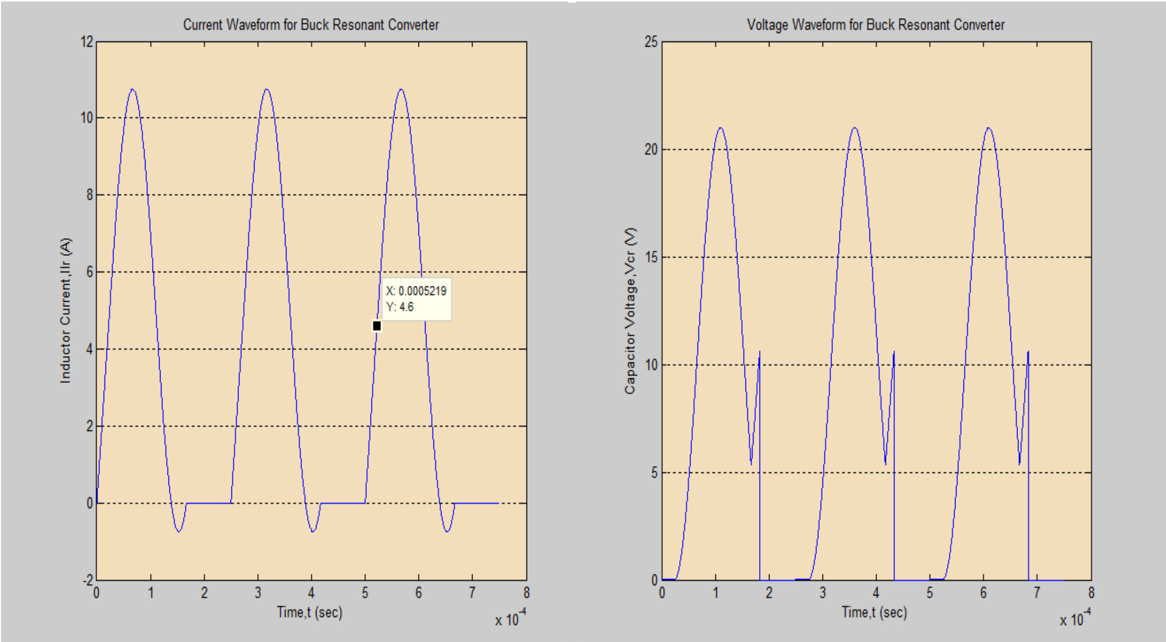
The circuit parameters so used is given in TABLE 6.1 below.

TABLE 6.1

Values of circuit parameters used

COMPONENT	TYPE
MOSFET SWITCH, Q1	IRF510
RESONANT INDUCTOR,L1	50uH
RESONANT CAPACITOR,C1	15uF
SWITCHING DIODE,D1	BA918
FILTER INDUCTOR,L2	5mH
FILTER CAPACITOR,C2	280uF
LOAD RESISTANCE,R1	50Ω

The voltage and current waveforms for full wave mode zero current switching quasi resonant convertersare given in Fig. 6.2.



(a) (b)

Fig. 6.2 (a) current waveform and (b) voltage waveform for zero current switching resonant converter

Thus, we see from the current waveform of the above circuit that current across the switch becomes zero during the time interval from T2 to T4. As a result, when in these modes, we can forcedly turn the switch on and off without incurring any sort of losses across the switch. Thus, zero current switching is obtained which results in enhanced efficiency. Thus, paradigm change in the efficiency is observed in soft-switched switches as compared with hard switched ones.

CHAPTER 7

SUMMARY AND FUTURE WORK

SUMMARY

FUTURE WORK

CHAPTER 7 SUMMARY AND FUTURE WORK

The dawn of the new era in the field of consumer electronics has put forth a herculean task before the power supply designers where the objectives of high efficiency, high power density, low voltage and high current have become the guiding principles. High efficiency dc to dc converters are highly essential for optimised working of various areas such as industries, communication systems, power transmission etc. Miniaturisation in all aspects of automotive industries requires smaller sized modules which mandatethe high operating frequencies. But managing the switching losses at such high frequencies becomes the critical issues nowadays which every power designer has to face. So here, in our work, we concentrate upon methods to diminish these switching losses.

7.1 Summary

This dissertation was committed to find out solutions for step down converters operating in high frequency region. The conventional PWM switched buck converter faces problems in the area of switching losses when high frequencies and small size equipment is required at the delivery side. It, therefore, abases the system efficiency and hinders with the power quality. To attain high power density, it is mandatory that switching frequency be increased. Increase in switching frequency results in increased switching losses. Thus, this loss reduction is the prime aim of our work which will be achieved with the help of soft switching techniques. The precise goal of this study can be summarised as: a step down buck converter topology with quasi-resonant switching is done to minimize switching losses across the device, lower the current and voltage stresses formed across it and diminish the overall size of the device with enhanced efficiency so as to be suitable for use in high frequency circuits. Under this scheme, the switch is turned on and off under zero resonant switching (ZCS) condition where current across it is zero during transition between its two states. Therefore, it becomes very efficient. These qualities of the converter are validated by experimental results provided in the chapters concerned which certify that zero current is present across the switch while it's turned on. The circuit configuration is also simple. Moreover, it employs a controlled feedback loop which promises accurate regulation of output voltage. Thus, soft switching technique comes to our rescue when high frequency demand is presented by today's ultra-advanced electronics circuitry.

7.2 Future work

This dissertation has looked into some substantial and excellent methods in the management of power. But a lot of future research work still needs to be done. A great area for such research lies in the parasitic effects found in the circuit elements. Parasitic capacitances are inevitable and undesirable effects that occur within the parts of electronic circuits simply because of their proximity to one another. Also, at low frequencies these capacitances generally don't make their presence felt, but when it comes to high frequency applications, they are a real headache. Parasitic capacitance in a MOSFET can instigate conduction without any pulse applied to its gate. Therefore, excellent design parameters are to be maintained to avoid this issue. The other interesting area is that of viability of the power supply module in terms of its compatibility with the portable electronic equipment to which it is attached. Thus, the supreme challenge is that of system integration for such power supply module.

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