Simulation of DC-DC Converters

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ABSTRACT—*Thisresearchpaperfocusesespeciallythe design and simulation of dc-dc converters. It contains the theoretical derivations and parameters equations with design and examples. Simulation results for buck, boost and buck-boost converters are shown with the chance of different input parameters. In this work we have analyzed the equation of a buck, boost and buck- boost converters and proposed the design components and simulation of these converters. Changing the input parameters like inductance, capacitance and switching frequency in order to observe the changes in output voltage has been added with simulation graph. These parameters and their equations should be well understood before designing buck or boost or buck- boost converters. Simulation procedures in Orcadare also added in this paper. We have achieved performance parameter equations for these three regulators. It was completed the design and investigation of these three converters through mathematical examples and have generated the circuits for simulating buck, boost and buck boost converters. And also have attained different output voltage curve with the change of input parameters. The outputgraphsforalltheconvertersarewellfitted.*
Key Words: Converters, Simulation, Orcad, PSpice, Power Regulator, Switching Matrix.

I.   INTRODUCTION

For   the   control   of   electric   power   or   power   conditioning, theconversionofelectricpowerfromoneformtoanother   isnecessaryandtheswitchingcharacteristicsofthepower devices permit these conversions [1]. The static power converters perform these functions of power conversions [2].Aconvertermaybeconsideredasaswitchingmatrix.

As the portable electronics industry progressed over the years, different requirements evolved such as increased thebatterylifetime,smallandcheapsystems,brighter,full color displays and a demand for increased talk time in cellular phones. A continually increasing demand from power systems has placed power consumption at a premium.Tocarryonwiththesedemandsengineershave worked towards developing efficient conversion techniques and also have resulted in the subsequent formal growth of an interdisciplinary field of Power Electronics.Howeveritcomesasnosurprisethatthisnew field has offered challenges owing to the unique combination of two major disciplines of electrical engineering: electronics andpower.
Commonly speaking the use of a swift or switches for the rationaleofpowerconversioncanberegardedasanSMPS (Switch Mode Power Supply). A dc-dc converter can be considered as dc equivalent to an ac transformer with a continuously variable turn's ratio[3].

1.1 Application of DC-DCConverters

Inmanyindustrialapplications,itisrequiredtoconverta   fixed-voltagedcsourceintoavariable-voltagedcsource.A   dc-dc   converter   converts   directly   from   dc   to   dc   and   is simplyknownasadcconverter[4].Adcconvertercanbe considered as dc equivalent to an ac transformer with a continuouslyturnsratio.Likeatransformer,itcanbeused tostepdownorstepupadcvoltagesource.

The dc-dc converters are widely used for traction motor control in electronic automobiles, trolley cars, marine hoists, forklift trucks, and mine haulers. They provide smooth acceleration control, high efficiency, and fast dynamic response. DC-DC converters can be used in regenerative braking of dc motors to return energy back intothesupply,thanthisfeatureresultsinenergysavings for transportation systems with frequent stops [5]. DC converters are used in dc voltage regulators and also are used in conjunction with an inductor, to generate a dc current source, especially for the current source inverter.

1.2 DifferentTopologies

The dc converters can be used as switching mode regulatorstoconvertadcvoltage,usuallyunregulated,to a regulated dc output voltage. The regulation is normally achieved by PWM at a fixed frequency and the switching driverisnormallyBJT,MOSFET,orIGBT.
The power regulator can be inductor based, switch-mode power converter, a switch capacitor charge

pump or a linear regulator. Each regulator has its own advantages and disadvantages, but it is the particular application requirements that determine which type of power regulator is best suited.

There are four topologies of switching-mode regulators:

- Buckregulator
- Boostregulator
- Buck-boostregulator
- Cukregulator

This thesis paper focuses especially on buck, boost and buck-boost regulator topologies. The boost is one of the fundamental switch-mode power topologies. The other beingisthebuckregulator.Fromthesetwotopologies,all other topologies switch-mode power supply topologies arederived.

II. THEORETICALBACKGROUND

1.3 BuckConverter

A buck converter is a step down dc-dc converter consisting primarily of inductor and two switches (generally a transistor switch and diode) for controlling inductor.Itfluctuatesbetweenconnectionofinductionto source voltage to mount up energy in inductor and then dischargingtheinductor'senergytotheload[6].
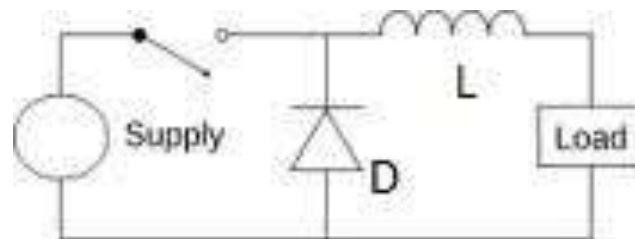
Figure 1: Basic buck circuit.

When the switch pictured above is closed (i.e., On-state), the voltage across the inductor is $V_L = V_i - V_O$. The current flowingthroughinductorlinearlyrises.Thediodedoesn't allow current to flow through it, since it is reverse-biased byvoltage.

For Off case (i.e., when switch pictured above is opened), diode is forward biased and voltage is $V_L = -V_O$(neglecting drop across diode) across inductor. The inductor current which was rising in ON case now decreases.

2.1.1 Ideal circuit analysis

In a buck converter, the average output $V_a$is less thanthe input voltage, V_S. The circuit diagram of a buck regulator hasshownbelowandthisislikeastep-downconverter.
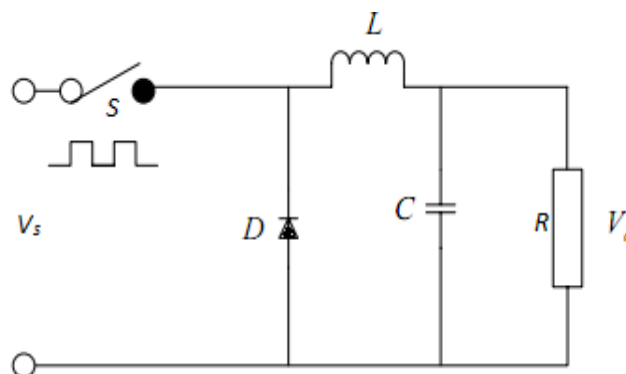

Figure 2: Circuit diagram of an ideal buck regulator.

The freewheeling diode D conducts due to energy stored intheinductor; andtheinductor currentcontinuestoflow through inductor (L), capacitor (C), load and diode (D). TheinductorcurrentfallsuntiltransistorSisswitchedon again in the nextcycle.

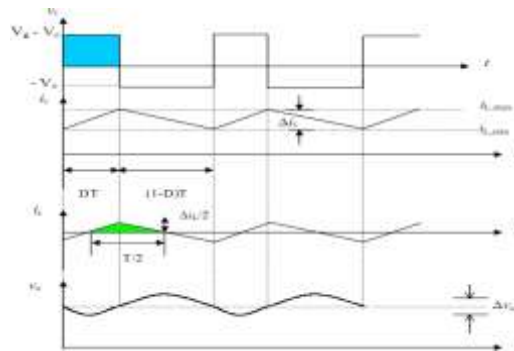**Figure3:**Waveformsofvoltageandcurrentofbuck converter.

The waveforms for voltage and current are shown in for continuousloadcurrentassumingthatthecurrentrisesor fallslinearly.

ForaconstantcurrentflowintheinductorL,itisassumed that the current rises and falls linearly. In practical circuits, the switch has a finite, nonlinear resistance. Its effect can generally be negligible in themost applications depending on the switching frequency, filter inductance, and capacitance, the inductor current could be discontinuous.

1.4 BoostConverter

Aboostconverter(step-upconverter),asitsnamesuggest stepuptheinputDCvoltagevalueandprovidesatoutput. This converter contains mostly a diode, a transistor as switches and at least one energy storage element. Capacitors are usually added to output so as to perform the function of removing output voltage ripple and sometimesinductorsarealsocombinedwith[7].
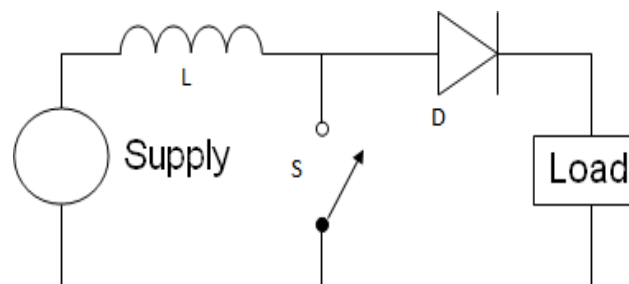

Figure 4: Basic boost circuit.

Its operation is generally of two separate states,
- During the ON period, switch is made to closeits contacts which results in increase of inductor current.
- During the OFF period, switch is made to open and thus the only path for inductor current to flow through the fly-back diode 'D' and the parallel combination of capacitor and load. This enables capacitor to transfer energy gained by it during ONperiod.

2.2.1 Ideal Circuit Analysis

In a boost regulator the output voltage is larger than the input voltage hence the name 'boost'. A boost regulator using a power MOSFET is shown in figure.
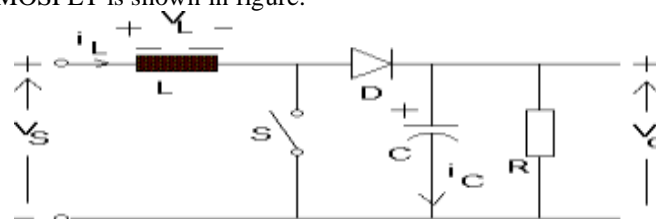

Figure 5: Circuit diagram of an ideal boost regulator.

1.5 Buck-boostConverter

A buck-boost converter provides an output voltage that may be less than or greater than the input voltage hence the name "buck-boost"; the output voltage polarity is oppositetothatoftheinputvoltage.Thisconverterisalso knownasinvertingregulator[8].Thecircuitarrangement ofabuck-boostconverterisshownisfigure6.

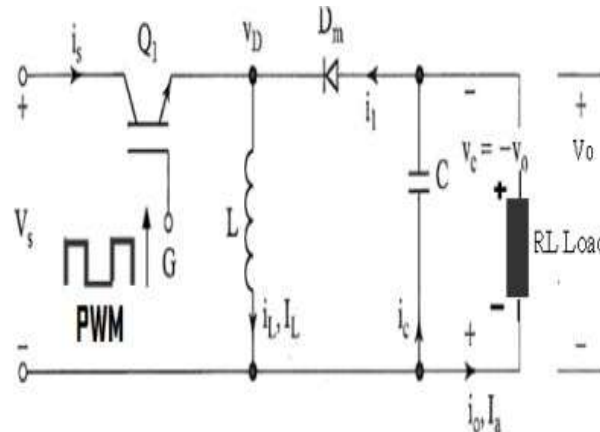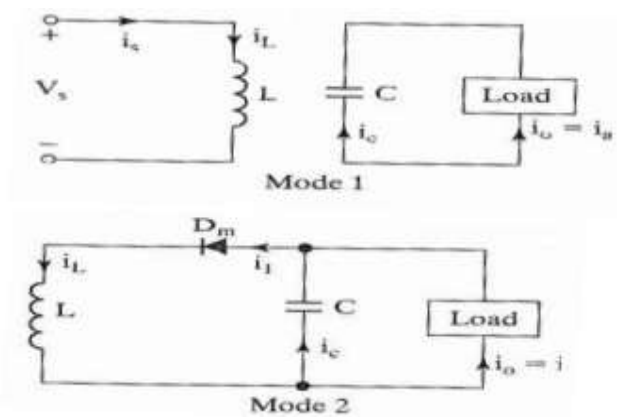**Figure 6:** Circuit diagram of buck-boost converter.

Figure 7: Equivalent circuit of buck-boost converter.

The circuit operation divided into two modes. During mode 1, transistor Q_1 is turned on and the diodeD_m is reversed biased. The input current, which rises, flows through inductor L and transistor Q_1. During mode 2, transistor Q_1 is switched off and the current, which was flowing through inductor L, would flow through L, C, D_m, and the load. The energy stored in inductor L would be transferred to the load and inductor current would fall until transistor Q_1 is switched on again in the next cycle. The equivalent circuits for the modes are shown in figure7.Thewaveformsforsteady-statevoltagesandcurrentsof the buck-boost regulator are shown in figure 8 for a continuous loadcurrent.
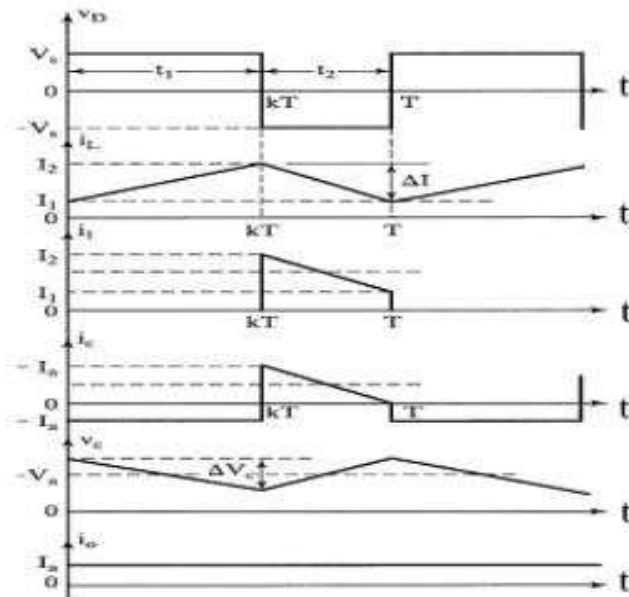
Figure 8: Waveforms of buck-boost converter.

III.   DESIGN ANALYSIS OF DC-DCCONVERTERS
3.1   PerformanceParameters
There are quantities of vital performance parameters which decide the output characteristics of the dc-dc converters. These parameters should be well understood before designing an ideal dc-dc converter.

3.1.1   Operatingfrequency
The operating frequency determines the performance of the switch. Switching frequency selection is normally determined by efficiency requirements. There is now a rising trend in research work and new power supply designs in increasing the switching frequencies. The higheristheswitchingfrequency,thesmallerthephysical size and componentvalue.AthigherfrequenciestheswitchinglossesintheMOSFET increase,andthereforereducetheoverallefficiencyofthe circuit.Atlowerfrequenciestherequiredoutputcapacitanceand inductor size increases, and the volumetric efficiency of the supplydegrades.
The trade-off between size and efficiency has to be evaluated very carefully.

3.1.2   InductorSelection
The role of the inductor is to limit the current slew rate (limitthecurrentinrush)throughthepowerswitchwhen thecircuitisON.Thecurrentthroughtheinductorcannot change abruptly. When the current through an inductor trendstofall,ittendstosustainthecurrentbyactingasa source. This

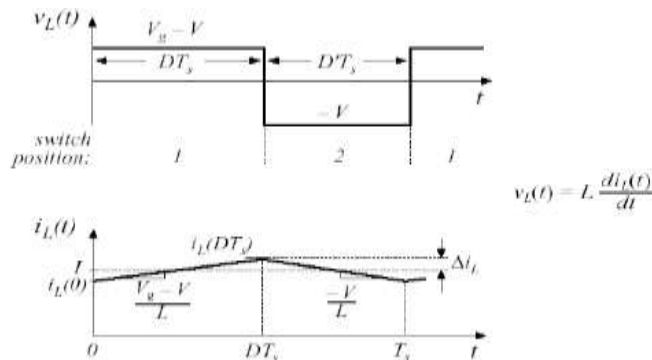**Figure 9:** The waveform of the inductor current.

limits the otherwise high peak current that wouldbelimitedbytheresistancealone.

The key advantage is when the inductor is used to drop voltage, it stores energy. Also the inductor controls the percent of the ripple and determines whether or not the circuit is operating in the continuous mode. A smaller inductor value enables a faster transient response; it also results in larger current ripple, which causes higher conductor losses in the switches, inductor, and parasitic resistances. The smaller inductor also requires a larger filter capacitor to decrease the output voltage ripple.
Critical value of inductor L_C, for buck converter

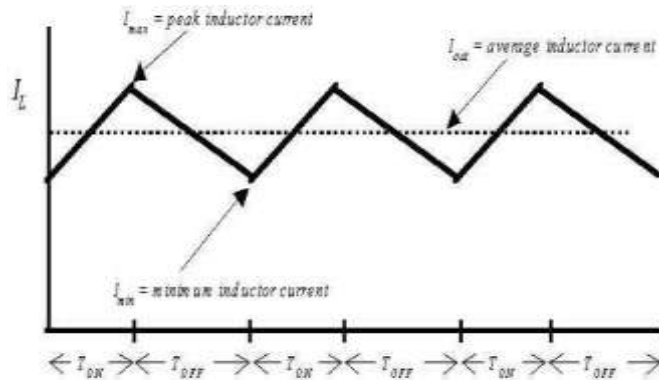$$L_C = L = \frac{(1-k)R}{2f} \qquad (3.1)$$

Figure 10: Continuous mode of operation.

$$\text{For Boost converter } L_C = L = \frac{k(1-k)^2 R}{2f} \qquad (3.2)$$

Critical inductance L_C is the minimum value of the inductor for a given k, f and R before the converter enter the discontinuous conduction mode (dcm) of operation.
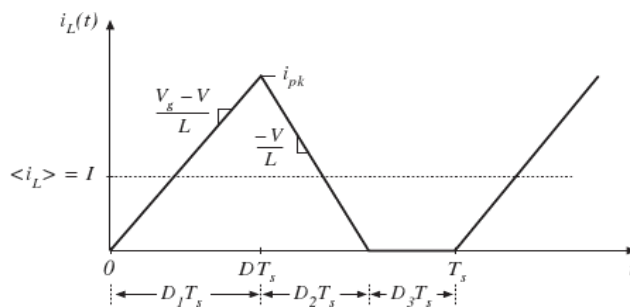
3.1.3 Capacitor Selection

Figure 11: Discontinuous mode of operation.

Peak current through the inductor determines the inductor's required saturation current rating, which is turn dictates the approximate size of the inductor. The primary criterion for selecting the output filter capacitor is its capacitance and equivalent series resistance, ESR. Since the capacitor's ESR affects the efficiency, low ESR capacitors will be used for best performance.
For reducing ESR, it is also possible to connect few capacitors in parallel. The output filter capacitors are chosen to meet an output voltage ripple specifications,as well as the ability to handle the required ripple current stress.
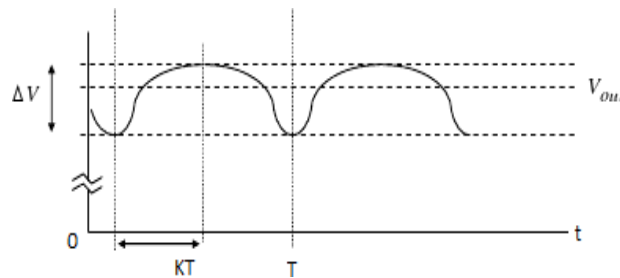
For Buck converter the peak-to-peak ripple voltage is,
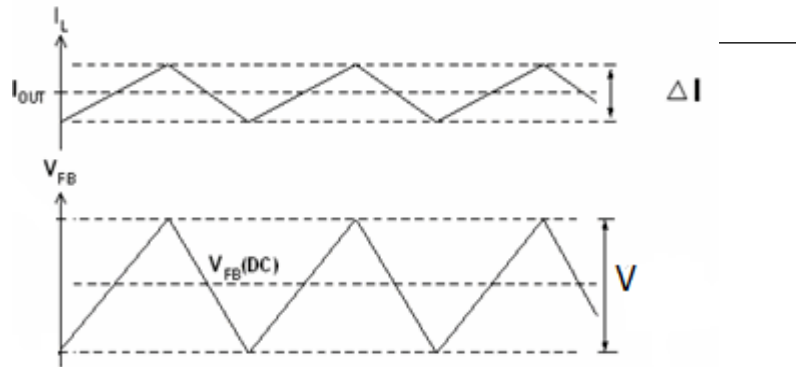
Figure 12: Output voltage ripple of inductor.

$$\Delta V_C$$
$$\frac{V_s\,k(1-k)}{8LCf^2}$$

(3.3)

Saturating the inductor core decreases the converter efficiency, while increasing the temperature of the inductor, the MOSFET and diode. The size of inductor and capacitor can be reduced by the implementation of high switching frequency, multi-phase interleaved topology, and a fast hysteric controller.

Figure 13: Ripple voltage in buck capacitor.

For Boost converter the peak-to-peak ripple voltage is,

ΔV_Cple voltage in boost capac
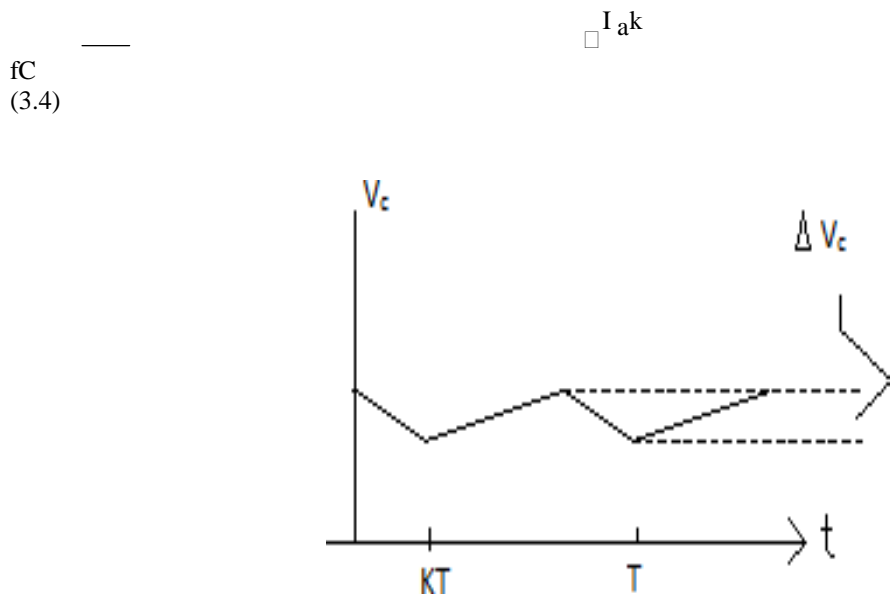
$$\_\_\_\_ \quad \Box I_a k$$

fC
(3.4)
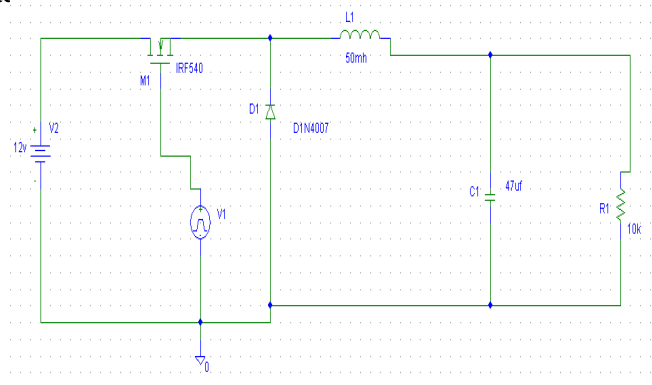
Figure 15: Circuit for the simulation of buck converter.
- 5VoltgatepulseappliedtotheMOSFETIRF 540
- Circuit operating at continuous conduction mode, $L_1 \Box \Box l_c$

IV.   SIMULATION RESULTS OF DC-DCCONVERTERS
3.2 Introduction toPSpice
The SPICE, the acronym for a Simulation Program with Integrated Circuit Emphasis, was developed at the University of California Berkeley, USA. PSpice is a commercialversion,developedbyMicrosimCorporation. In 1997 PSpicewas bought by Orcad, Inc., then in 1998 Cadence bought Orcad. There are two schematic editors areavailable:a)Captureandb)Schematic.

TheCaptureisinheritedfromOrcad,whilsttheSchematic is inherited from Microsim. The Schematic Editor of Microsim is still available now and for the next few years until the PSpice users become more familiar with the Orcadcapture.

3.3 General Procedure to use PSpiceOrcad Capture
ThecircuitsimulationinPSpiceisafoursteppedprocess:

1.   Open and draw a circuit file under Orcad Capture
2.   Simulate
3.   Plot results usingprobe
4.   Analyze theresults

3.4 BuckConverter
Table 1: Input parameters for buck converter.

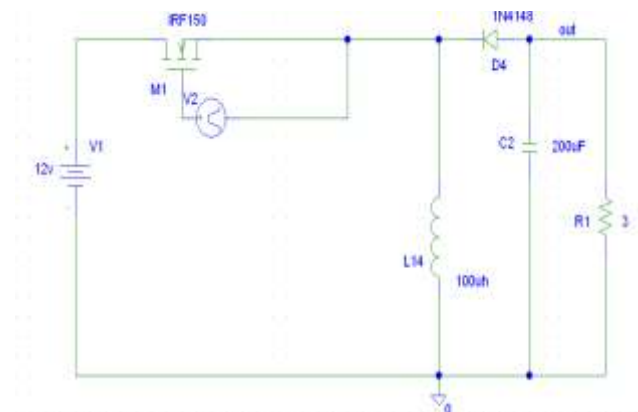| Frequency	Period	On Period T_{on}	Duty Cycle	Inductance	Capacitance	Input Voltage	Load Resistance
25 kHz	40 μs	18 μs	0.45	50 mH	47 μf	12V	10 $k\Omega$
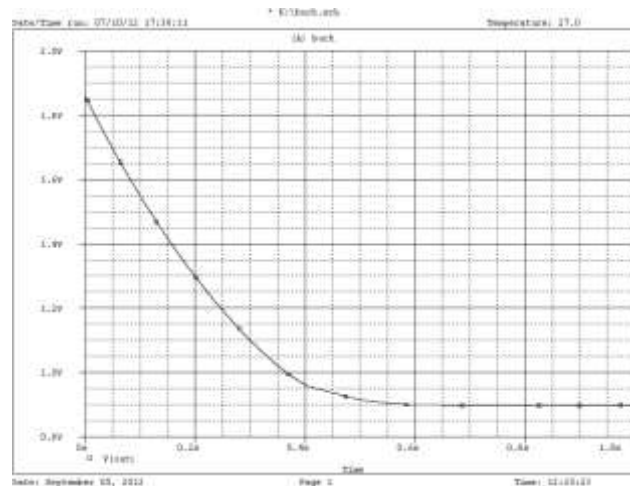
Figure 16: Output voltage of buck converter.

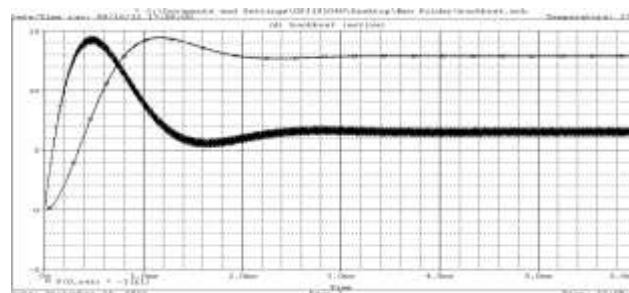- Simulationhastakenupto1.0s.
- Outputvoltagebecomessteadyatalmost600 ms.

3.5 Buck-BoostConverter

Figure17: Circuitforthesimulationofbuck-boost converter

Table 2: Input parameters for the buck-boost converter.

Frequency	Period	On Period T_{on}	Duty Cycle	Inductance	Capacitance	Input Voltage	Load Resistance
25 kHz	40 μs	18 μs	0.45	100 μ H	200 μf	12V	3Ω

Figure18: Outputcurrentandvoltagewaveformofbuck- boostconverter.

- Simulationhastakenupto6.0ms.
- Outputvoltagebecomespeakat1.1msandat

14.4   volts.
- Outputcurrentbecomespeakat0.5msandat

14.5   volts.
- Currentandvoltagedon'treachfromzerotothe peak during sametime.
- Insteadystatepositionsthecurrentfallsmore than thevoltage.
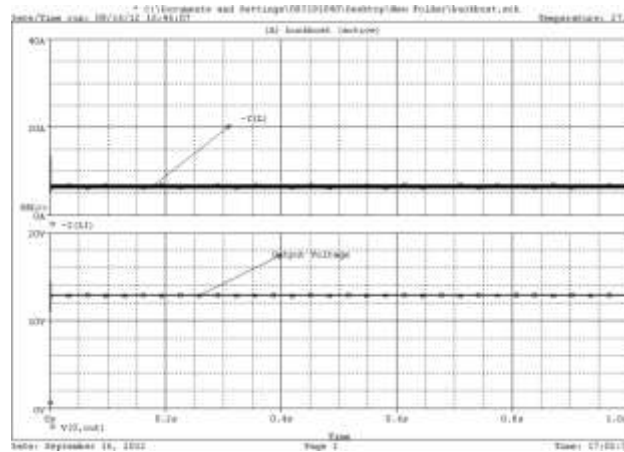- Bettertheripplecurrentbettertheperformance which depends on circuitparameters.

Figure19: Outputcurrentandvoltagewaveformofbuck- boostconverter.

- Simulationhastakenupto1.0s.
- Outputvoltagebecomespeakat1.1msandat
14.4   volts.
- Outputcurrentbecomespeakat0.5msandat
14.5   volts.
- Currentandvoltagedon'treachfromzerotothe peak during sametime.
- Insteadystatepositionsthecurrentfallsmore than thevoltage.
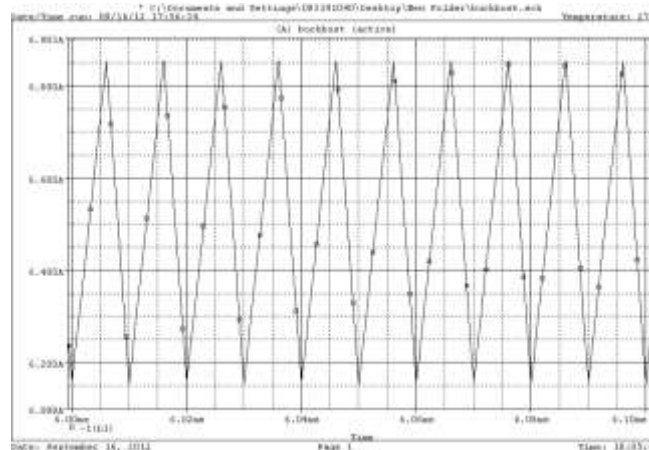- Bettertheripplecurrentbettertheperformance which depends on circuitparameters.

Figure20: Outputripplecurrentwaveformofbuck-boost converter.

- Thispartofthewaveformhastakenfromthe outputcurrent.
- Simulationhastakenfrom6.00msto6.10ms.
- Minimuminductorcurrentis6.140Aandthe maximum is6.850A.

- $\Box I \Box_2^{} \Box I_1$ isthepeaktopeakripplecurrentof inductor which depends on input voltage, inductance andtime.
- Bettertheripplecurrentbettertheperformance.
- Ripplecurrentcanbereducedbydecreasingthe inputvoltageorincreasingtheinductance.

V. CONCLUSIONS

From the simulation results it is found that in case of the buck,boostandbuck-boostconverters,thedesiredoutput voltages can be obtained by selecting proper values of inductor, capacitor and switching frequency. All of these individual theories were difficult for anyone to grasp primarily and putting them collectively in the simulator which was extremely puzzling. But it has been done most excellenttoformulateanoutstandingschemedissertation withaffluentinitscontest.Ateachstage,targetswereset to acquire the necessary skills to meet the criteria of the research and design the circuits for implementation into the software simulation. This research gives the opportunity to study new skills and raise valuable knowledgeincircuitdesigningandproblemsolvingskills whichhasgreatlyenrichedknowledgeandunderstanding throughtheeruditionroutewhichmayhelponeinforthe furtherprogression.

ACKNOWLEDGEMENT

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