Department of Electrical & Electronic Engineering

EEE 447 – Power Electronics

PROJECT

Design and Simulation of a Buck Converter.

Course Instructor : Dr Ratil Hasnat

Group – 3

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OBJECTIVE

To design and simulate a DC-DC Buc Converter that steps down an input voltage to a specified output voltage and analyze its performance under varying load conditions.

THEORY

A buck converter, also known as a step-down converter, is a DC-DC power converter that reduces the input voltage to a lower, regulated output voltage while maintaining energy efficiency. It works by switching a semiconductor device (like a MOSFET or transistor) at high frequency, transferring energy through an inductor to the load. The inductor and capacitor in the circuit act as energy storage elements, smoothing out the output voltage and current. The basic operation relies on Pulse Width Modulation (PWM) to control the duty cycle, which directly determines the output voltage:

$$Vout = D \times Vin$$

Where D is the duty cycle (ratio of the ON time to the total switching period). The key advantages of buck converter are high efficiency, compact size and adaptability for various applications in power supplies and battery-operated devices.

EQUIPMENT LIST

1) MOSFET (IRFZ44N)

2) Capacitor (10uF)

3) Inductor (30uH)

4) Resistor (1k Ω)

5)Signal generator

6) Oscilloscope

7) DC voltage source

THEORITICAL ANALYSIS

Given specification for design

- $Input\ Voltage: Vin = 24\ V$
- $Output\ Voltage: Vout = 12\ V$
- $Load\ Resistance: R = 10\ \Omega$
- $Switching\ Frequency: fs = 50\ kHz$

$$Duty\ cycle, D\ = \frac{Vout}{Vin} = \frac{12\ V}{24\ V} = 0.5$$

$$Time\ period, T\ = \frac{1}{fs} = \frac{1}{(50 * 10^3)} = 20\mu s$$

$$D\ = \frac{ton}{T}$$

$$ton\ = D * T$$

$$T\ = ton + toff$$

$$toff\ = T - ton$$

$$= T - D * T$$

$$= T * (1 - D)$$

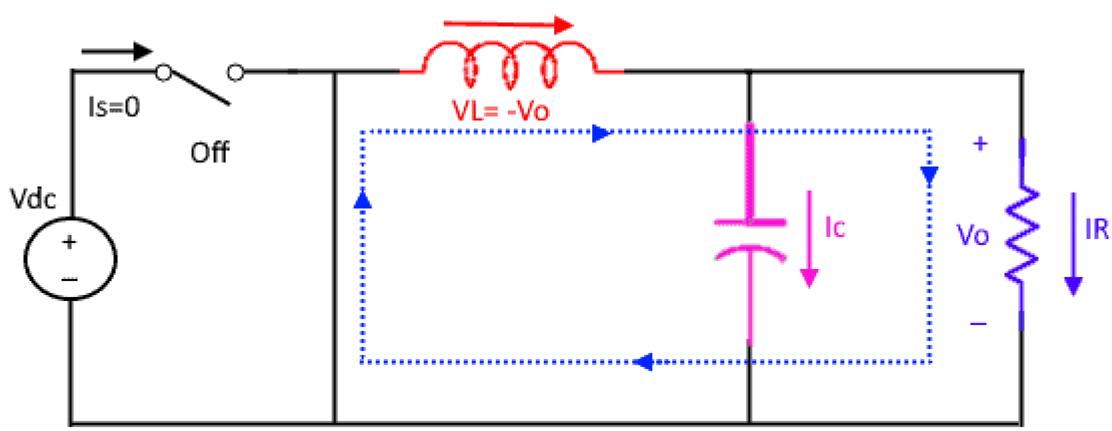

Fig 1: Buck converter when switch is open

$Here,$

$$V_L = -Vo$$

$$V_L\ = L * \frac{di}{dt}$$

$\frac{di}{dt} = \frac{\mathrm{VL}}{L}$

The change in current during off period ($\Delta Ioff$) is; $[\Delta ioff = Imax - Imin]$

$\Delta Ioff = (VL/L) * toff$

$\Delta Ioff = (-Vo/L) * (1 - D)T$

$\Delta Ioff = (Vo/L) * (1 - D)T$

$Imax - Imin = (Vo/L) * (1 - D)T$ ----------(i)

$Here,$

$Io = Vo/RL$

$= (Imax + Imin)/2$

$Imax + Imin = 2Io = 2 * Vo/RL$ ----------(ii)

$After\ (ii - i)\ we\ get,$

$2Imin = 2Vo/RL - Vo/L * (1 - D)T$

$Imin = Vo/RL - Vo/2L * (1 - D)T$

$For\ BCM,$

$Imin = 0$

$So,$

$Vo/RL - Vo/2Lc * (1 - D)T = 0$

$Lc = (RL/2) * (1 - D)T$

$= (RL/2fs) * (1 - D)$

$= (10'\Omega/2 * 50 * 10\text{^}3) * (1 - 0.5)$

$= 50\mu H$

$As\ for\ CCM$

$L > Lc$

$We\ are\ taking\ L = \mathbf{100\mu H}$

$Combining\ (i + ii)\ we\ get,$

$2Imax\ =\ 2Vo/Rl\ +\ Vo/L\ * (1 - D)T$

$Imax\ =\ Vo * [1/RL\ +\ (1 - D)/2 * L * fs]$

$=\ 12\ *\ [1/10Ω\ +\ (1 - 0.5)/2 *\ 100 * 10^{\wedge} - 6\ *\ 50 * 10^{\wedge}3]$

$=\ \mathbf{1.8A}$

$Imin\ =\ Vo/RL – Vo/2L\ *\ (1 - D)T$

$=\ (12/10) – (12/2 * 100 * 10^{\wedge} - 6)\ *\ (1 - 0.5) * 20 * 10^{\wedge} - 6$

$=\ \mathbf{0.6A}$

$IL\ =\ Imax\ +\ Imin\ /\ 2$

$=\ 1.8\ +\ 0.6\ /2$

$=\ \mathbf{1.2A}$

$Inductor\ ripple\ current, ΔIL\ =\ 1 - D/L * fs$

$=\ 1 - 0.5/(100 * 10^{\wedge} - 6) * (50 * 10^{\wedge}3)$

$=\ \mathbf{0.1A}$

$\boldsymbol{Switch}\ (MOSFET)\ rating\ [when\ closed]$

$Vswitch\_max\ =\ Vinmax\ +\ Diode's\ Forward\ Biased\ voltage\ drop$

$=\ 24\ +\ 0.7V$

$=\ 24.7V\ (rating\ should\ be\ 20\%\ higher)$

$Vswitch\_max\_rating\ =\ (24.7\ +\ 24.7 * 0.2)\ =\ 29.64V\ \approx\ \mathbf{30V}$

$Iswitch\_max\ =\ IL\ *\ D$

$=\ 1.2\ *\ 0.5$

$=\ \mathbf{0.6A}$

$\boldsymbol{Diode}\ rating\ [when\ switch\ is\ open]$

$VRRM\ =\ Vinmax\ +\ VSW$

$=\ 24\ +\ 0.7$

$=\ 24.7V\ (rating\ should\ be\ 20\%\ higher)$

$VPRM\_rating\ =\ (24.7\ +\ 24.7 * 0.2)\ =\ 29.64V\ \approx\ \mathbf{30V}$

$Idiode\_max = IL * (1 - D)$

$= 1.2 * (1 - 0.5)$

$= \mathbf{0.6A}$

Electrolytic DC ***capacitor*** *selection*

Let's assume that

$Ripple\ percentage, \Delta Vo/Vo = \mathbf{2}\%$

Here,

$\Delta Q = ½ * (I/2) * (\Delta I/2)$

$= (1/2) * (I/2) * (1/2) * ((Vin - Vo)/L) * D * T$

$= (1/2) * (I/2) * (1/2) * ((\Delta Vo)/L) * (1 - D) * T$

$\Delta Q = (1/8) * T\text{^}2 * (Vo/L) * (1 - D)$

$\Delta Vo * C = (1/8) * T\text{^}2 * (Vo/L) * (1 - D)$

$C = Vo * (1 - D)/8 * L * fs * \text{^}2 * \Delta Vo$

$= (1 - D)/8 * L * fs\text{^}2 * (\Delta Vo/V)$

$= (1 - 0.5)/8 * (100 * 10\text{^} - 6) * (50 * 10\text{^}3)\text{^}2 * 0.02$

$= \mathbf{12.5\mu F}$

$Ripple\ voltage, \Delta Vo = 0.02 * 12$

$= \mathbf{0.04V}$

$Voltage\ rating\ for\ capacitor, Vcmax = Vo + (\Delta Vo/2)$

$= 12 + (0.04/2)$

$= 12.02V\ (rating\ should\ be\ 20\%\ higher)$

$Vcmax\_rating = Vcmax + Vcmax * 0.2)$

$= 12.02 + 12.02 * 0.2$

$= 14.424V \approx \mathbf{15V}$

SIMULATION PART

Circuit diagram designed on LTSPICE

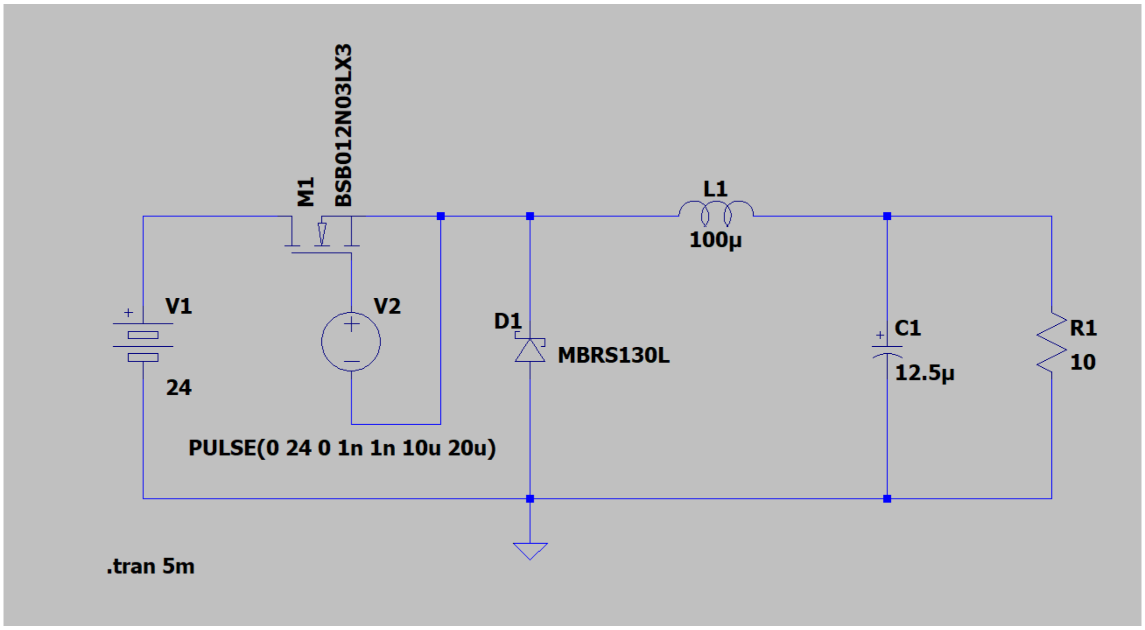

Fig 2: Circuit diagram of the buck converter

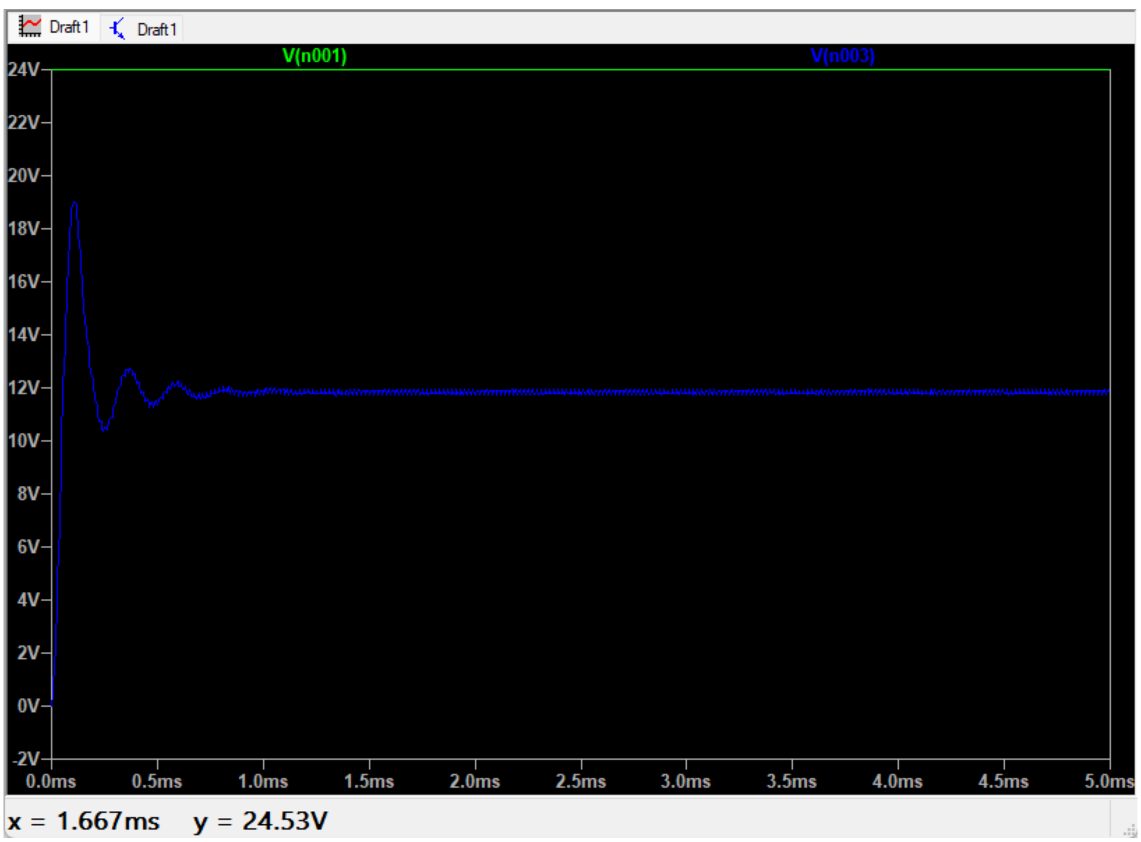

Fig 3: Input (24V) and output (12) voltage waveforms

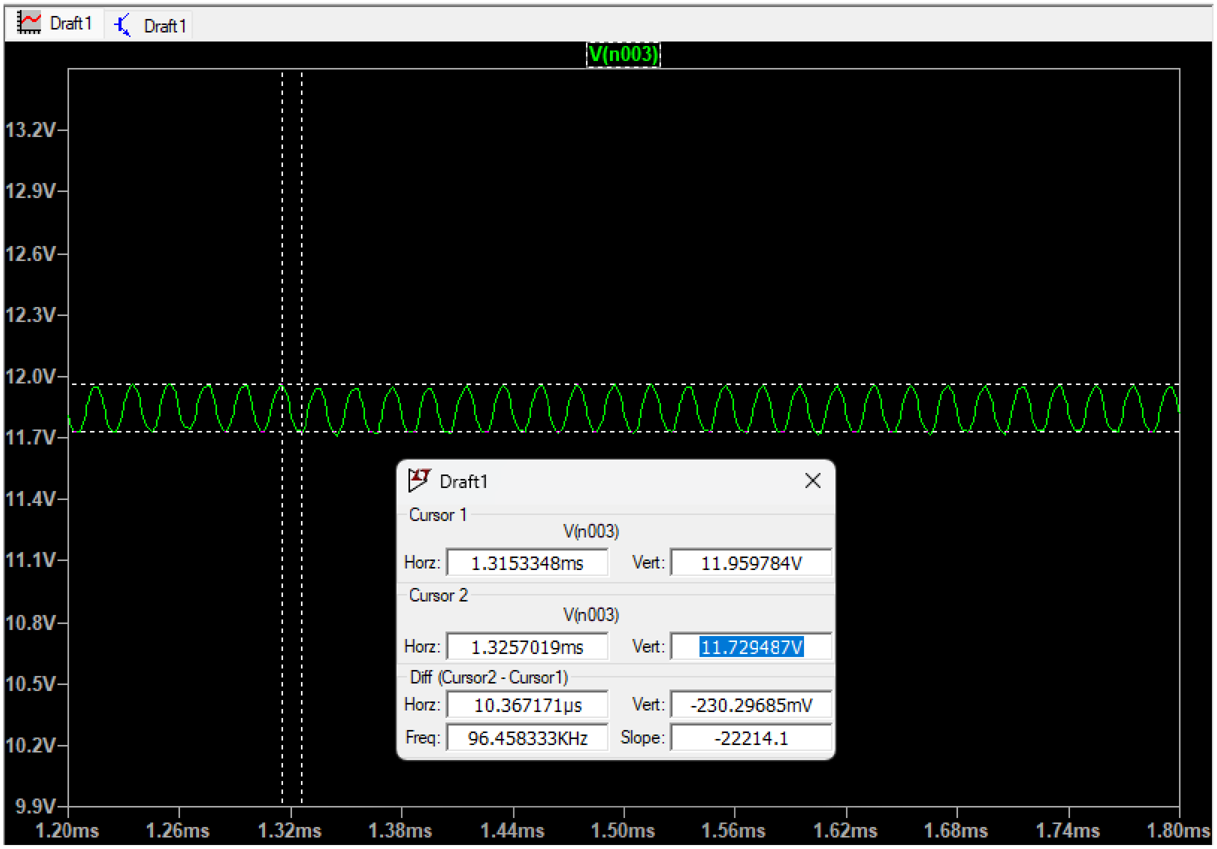

Fig 4: Output voltage waveform

From the graph we can find the ripple voltage, $\Delta Vo \; = \; (11.959 - 11.729)V$

$$= \; \mathbf{0.23}\boldsymbol{V}$$

So the ripple percentage we get, $\Delta Vo/Vo \; = \; (0.23/11.959) \, * \, 100$

$$= \; \mathbf{1.92}\%$$

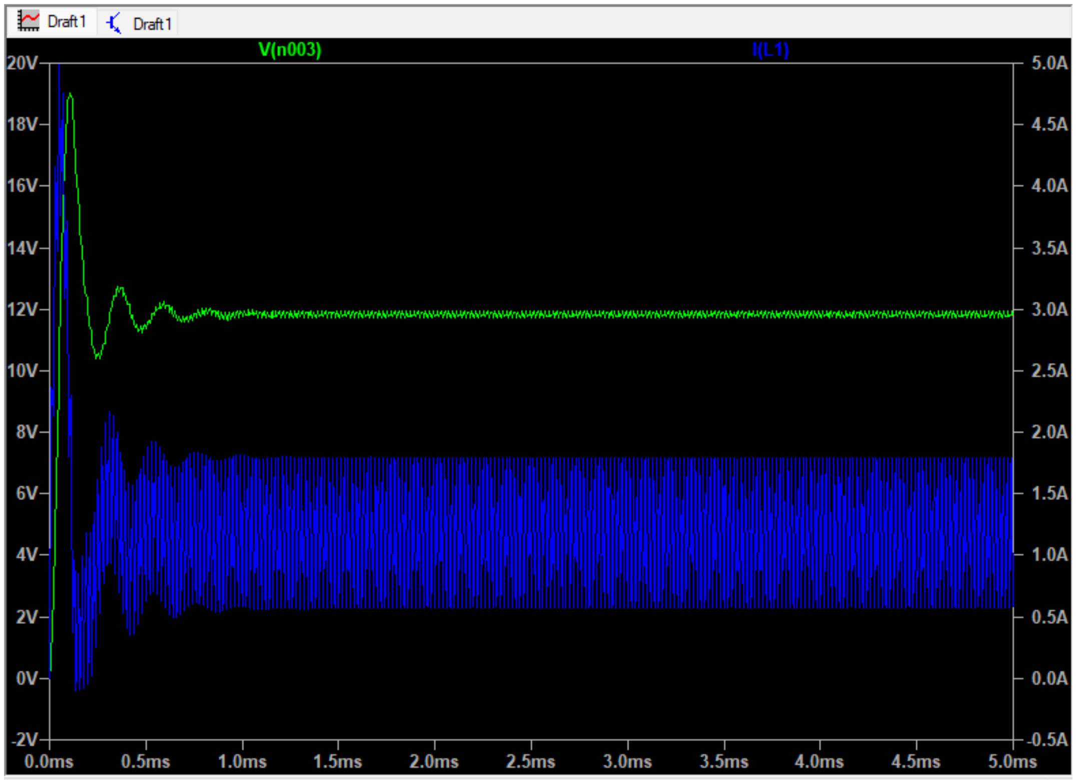

Fig 5: Voltage ripple vs Inductor current waveform

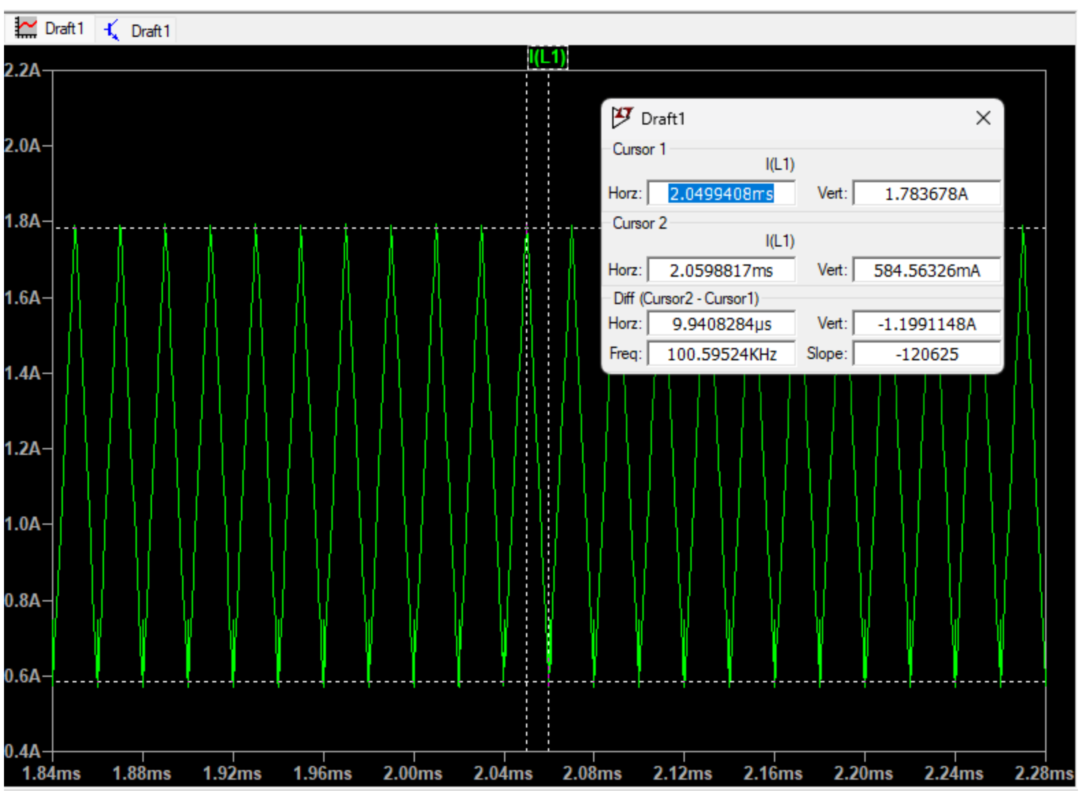

Fig 6: Inductor current waveform

From the graph we can find the inductor current, $IL \;=\; (1.783678 + 0.5845632)/2A$

$$= \mathbf{1.184}A$$

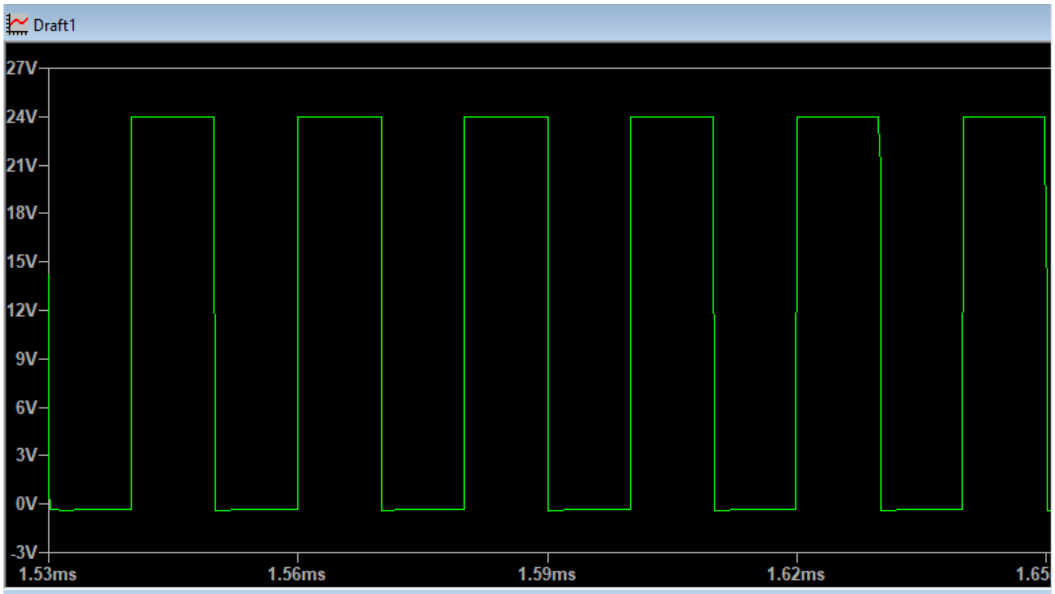

Fig 7: Voltage across the switching device and diode

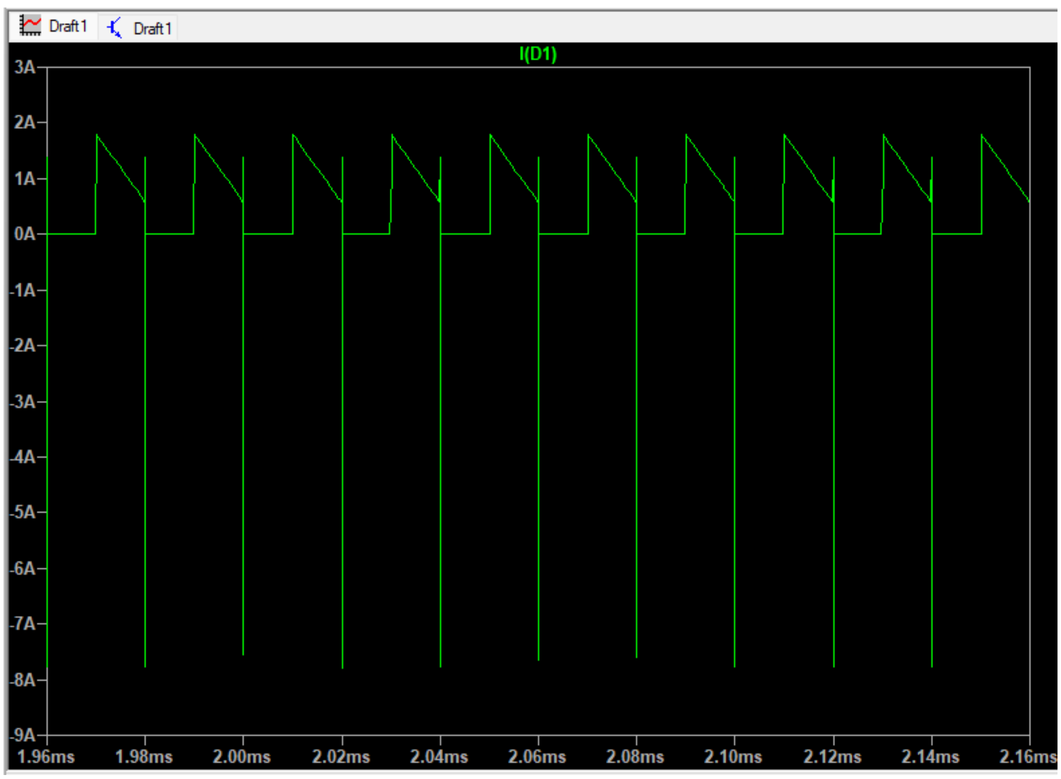

Fig 8: Current waveform across diode

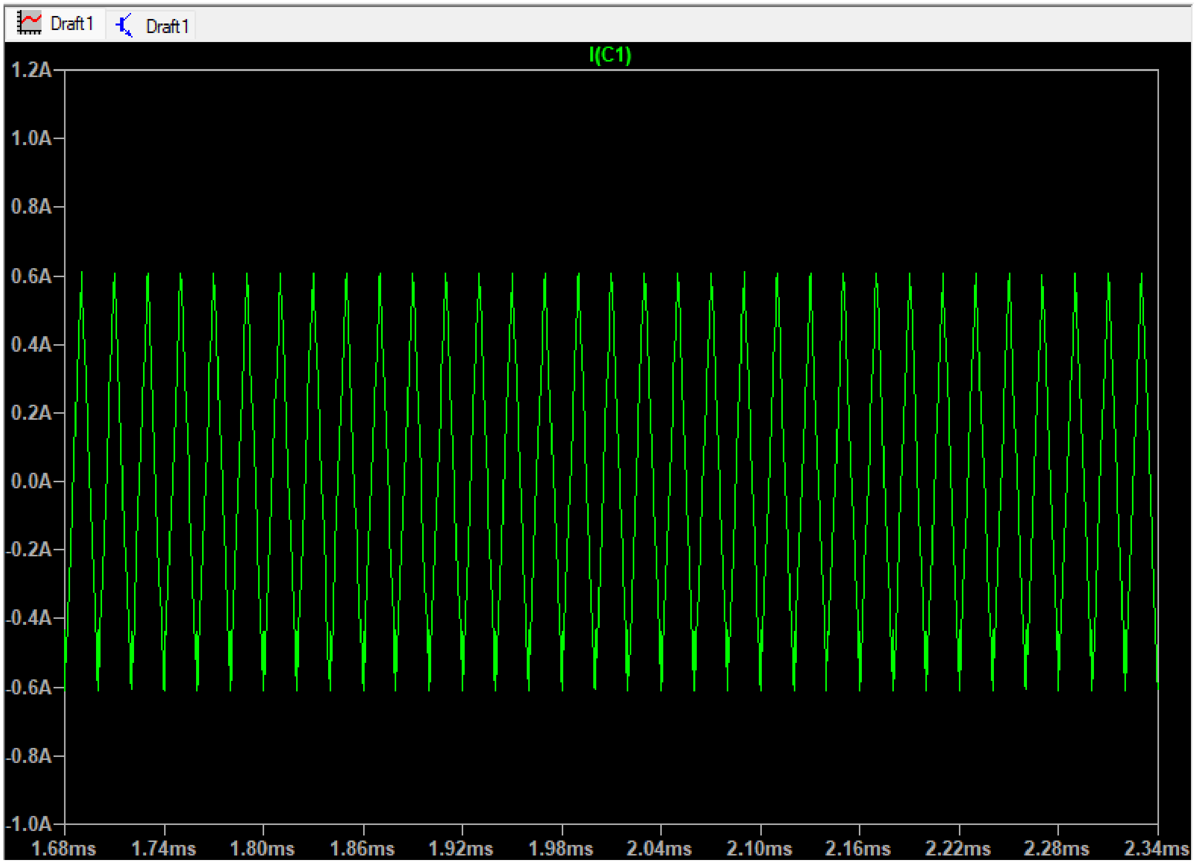

Fig 9: Current waveform across the capacitor

Efficiency of converter =12/24=0.50=50%

PRACTICAL ANALYSIS (Done in Lab)

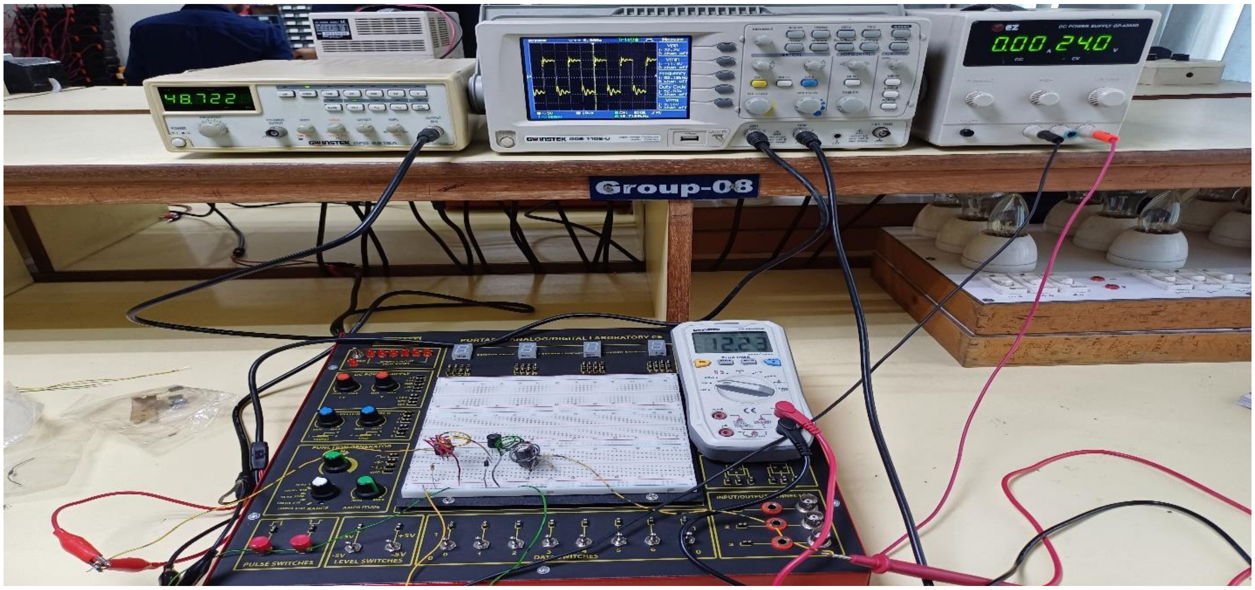

Fig 10: Vin= 24.0 V and Vout =12.23 V

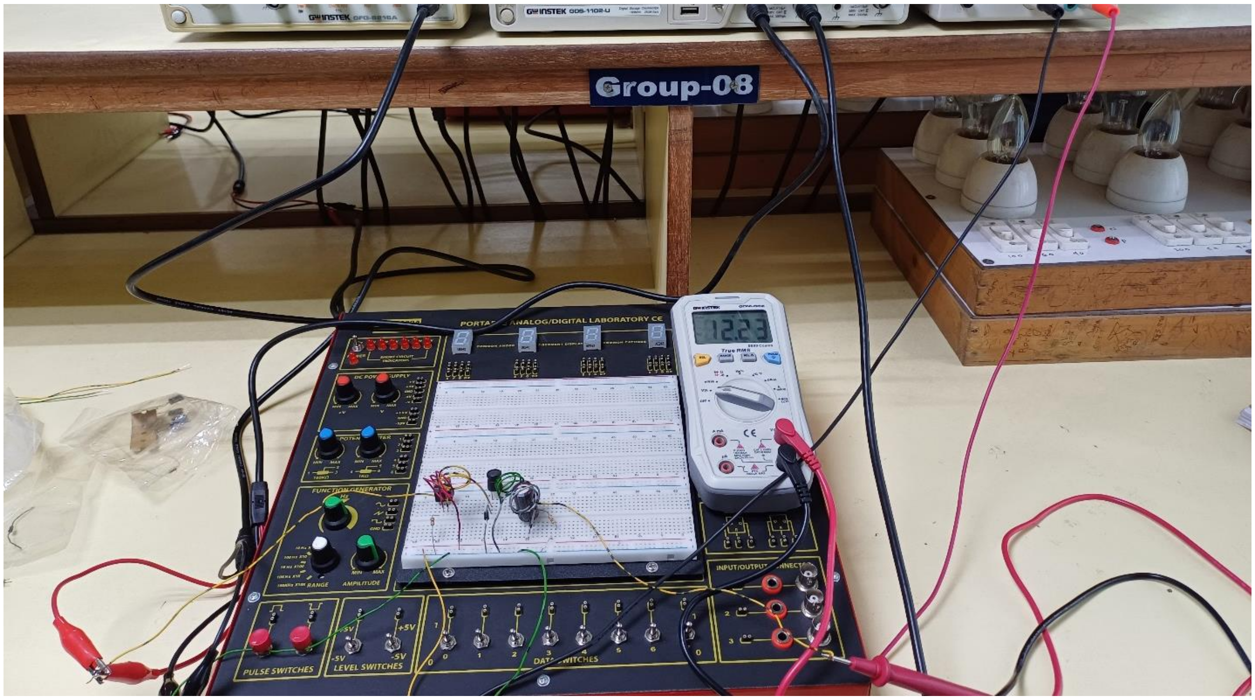

Fig 11: Buck Converter Circuit

Fig 12: Switching frequency and duty cycle

Here,

Input voltage, Vin = 24.0V

Output voltage, Vout =12.23 V

Frequency of switching = 48.722 kHz

Duty cycle = 52.83% (From oscilloscope)

Efficiency =1-(12.23/24)=0.49=49%

Comparizon between Simulated values and practical results:

	Simulated values	Practical result	Error %
Vin	24 V	24 V	0
Vout	12 V	12.23 V	1.92
Switching frequency	50 kHz	48.722 Hz	2.56
Duty cycle	50%	52.83%	5.64
Efficiency	50%	49%	2%
Ripple voltage	0.23 V	0.2 V	13.04%
Ripple percentage	1.92%	1.64%	14.58%

Comment: Here we can see some difference between simulated and practical values.It happened because there is a difference in switching frequency. We could not find 10Ω 50W resistor. That is why we used 1k Ω resistor and made necessary change in inductor value (30 uH)

Discussion:

In this project we made a buck converter. We can observe there are some differences in simulated values and practical values. The reasons are given below:

1)The equipment we used were not ideal case. Those equipment has some erors

2) The used frequency generator, oscilloscope and multimeter also have errors

3) We could no find any 10Ω 50W resistor in the market.So, we used 1k Ω resistor and used a 30uH inductor instead 100uH

Video link of the project

https://drive.google.com/file/d/1A6YVaiPHam7MV-TO0s1GLhCnoP3sUD95/view?usp=drive_link